NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON STORAGE NEWSLETTER

ANNUAL INDEX

FISCAL YEAR (FY) 2019

October 2018 – September 2019

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ANNUAL INDEX – FY 2019

This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters (CSN) published from October 2018 to September 2019. The CSN is produced by NETL to provide information on activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news. Outdated information (e.g., conference dates, paper submittals, etc.) and duplicative stories have been removed.

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

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

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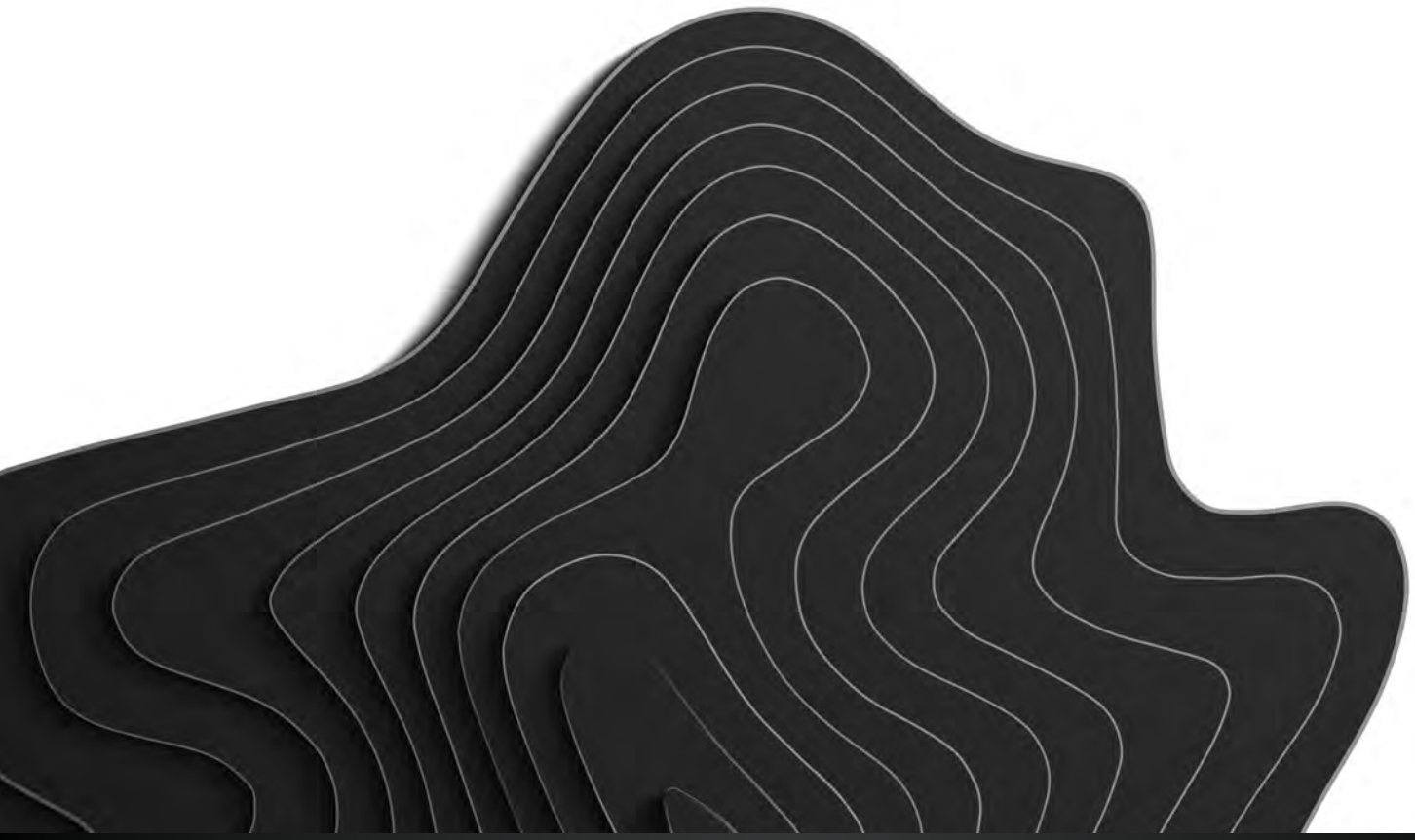

DOE/NETL HIGHLIGHTS

OCTOBER 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.

NOVEMBER 2018

Energy Department Seeks Information on Transformational Sensing for the Subsurface.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) *issued a Request for Information (RFI)* on the development of transformational sensing capabilities for monitoring parameters associated with subsurface carbon dioxide (CO_2) storage. The objective of the RFI is to assess relevant state-of-the-art sensor technologies and determine future needs associated with CO_2 injection, including requirements of the future storage industry for cost-effective monitoring, the priority of technology opportunities for developing transformational sensor capabilities for monitoring parameters, and ways to improve how technology can be effectively measured at minimum cost. Stakeholder responses to the RFI are due to the National Energy Technology Laboratory (NETL) by December 3, 2018. From *energy.gov* on November 5, 2018.

DECEMBER 2018

DOE Issues RFP to Advance Coal Plants.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) issued a Request for Proposal (RFP) seeking conceptual designs for coal-based power plants of the future. In addition, the RFP includes an option to conduct preliminary front-end engineering design (Pre-FEED) studies. The RFP is in support of the *Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative*, which looks to develop coal plants that provide secure, stable, and reliable power. From *energy.gov* on December 7, 2018.

JANUARY 2019

DOE Issues Notice of Intent for Carbon Storage Funding.

The U.S. Department of Energy (DOE) *issued a Notice of Intent (NOI)* to provide federal funding for research and development (R&D) projects that contribute to the development of transformational sensing capabilities for monitoring parameters associated with subsurface carbon dioxide (CO_2) storage. The National Energy Technology Laboratory (NETL) will manage the projects selected under the Funding Opportunity Announcement (FOA), "Transformational Sensing Capabilities for Monitoring the Subsurface," which will be issued in fiscal year (FY) 2019. The objective of the FOA is to competitively solicit and award R&D projects that improve existing technologies to reduce uncertainty and enable real-time decision-making associated with subsurface CO_2 storage. From *energy.gov* on January 3, 2019.

FEBRUARY 2019

There were no new DOE/NETL Highlights printed in the February 2019 CSN.

MARCH 2019

Eight Projects Selected to Receive Federal Funding.

Eight projects have been selected to receive federal funding for cost-shared research and development (R&D) for "Novel and Enabling Carbon Capture Transformational Technologies." The scope of the projects aligns with the U.S. Department of Energy's (DOE) ministerial-level Mission Innovation report, titled "*Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage.*" The projects are funded by the Office of Fossil Energy's (FE) *Carbon Capture Program* and will be managed by the National Energy Technology Laboratory (NETL). From *energy.gov* on February 28, 2019.

APRIL 2019

DOE Announces Funding to Accelerate CCUS.

The U.S. Department of Energy (DOE) announced federal funding for cooperative agreements that will help accelerate the deployment of carbon capture, utilization, and storage (CCUS). Through *this Funding Opportunity Announcement (FOA)*, DOE will look to award cooperative agreements to research and development (R&D) projects that will help identify and address regional storage and transport challenges currently facing the development of CCUS. Specifically, this FOA seeks to preserve, share, and advance existing R&D by addressing key technical challenges; facilitating data collection, sharing, and analysis; evaluating regional infrastructure; and promoting regional technology transfer. The selected projects will support the Office of Fossil Energy's (FE) *Carbon Storage Program*. From *energy.gov* on April 1, 2019.

DOE Selects Carbon Storage Project for Funding.

DOE selected a carbon capture project and a carbon storage project to receive federal funding. The associated geologic storage project was selected under the FOA "Developing Technologies for Advancement of Associated Geologic Storage for Basinal Geo-Laboratories." Supported by FE's Carbon Storage Program and managed by the National Energy Technology Laboratory (NETL), the University of Wyoming project plans to establish the technical and economic viability of associated carbon dioxide (CO_2) storage and oil recovery in the greenfield residual oil zones of the Powder River Basin of Wyoming and Montana (USA). It joins *two other associated geologic storage projects* announced to receive funding in August 2018. From *energy.gov* on March 29, 2019.

DOE Announces Funding for FEED Studies.

DOE announced federal funding for cost-shared R&D for front-end engineering design (FEED) studies for CO_2 capture. Supporting FEED studies for commercial CO_2 capture systems helps to understand the costs associated with CCUS. The projects will be funded by FE's Carbon Capture Program. From *energy.gov* on March 14, 2019.

MAY 2019

DOE Announces Funding for Coal R&D Projects.

The U.S. Department of Energy (DOE) announced federal funding for cost-shared research and development (R&D) projects for advanced coal technologies and research. The projects for coal-fueled power plants and technologies will fall under five separate Funding Opportunity Announcements (FOAs). One of the FOAs, *Transformational Sensing Systems for Monitoring the Deep Subsurface*, supported by the Office of Fossil Energy (FE) Carbon Storage Program, seeks to reduce uncertainty and enable real-time decision making associated with subsurface carbon dioxide (CO_2) storage. All of the selected projects will be managed by DOE's National Energy Technology Laboratory (NETL). From *energy.gov* on April 10, 2019.

JUNE 2019

NETL Signs Partnership with ExxonMobil and NREL.

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) signed a research and development (R&D) partnership with ExxonMobil and the *National Renewable Energy Laboratory (NREL)*. Per the *cooperative research and development agreement (CRADA)*, ExxonMobil is investing up to $100 million over 10 years for the R&D of advanced lower-emissions technologies. The agreement will support research and collaboration in bringing biofuels and carbon capture and storage (CCS) to commercial scale. In addition to developing technologies related to energy efficiency and greenhouse gas (GHG) mitigation, the joint research will also focus on reducing emissions from fuel and petrochemicals production; stimulate collaborative projects among ExxonMobil, NREL, and NETL; and facilitate work with other national laboratories, such as the Idaho National Laboratory. From *National Energy Technology Laboratory* on May 8, 2019.

JULY 2019

There were no new DOE/NETL Highlights printed in the July 2019 CSN.

AUGUST 2019

DOE Invests in Large-Scale Fossil Fuel Pilot Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) selected six projects to receive federal funding to support future design and construction of the next generation of coal-fired power plants that are flexible, resilient, economical, and emit near-zero emissions, including carbon dioxide (CO_2). The projects were selected under Phase II of the "*Fossil Fuel Large-Scale Pilots*" Funding Opportunity Announcement (FOA), which was issued in August 2017 and includes three phases, with competitive down-selections made between each phase. All of the selected projects will be managed by the National Energy Technology Laboratory (NETL). From *energy.gov* on July 9, 2019.

SEPTEMBER 2019

NETL Hosts Inaugural Comprehensive Annual Project Review Meeting.

The National Energy Technology Laboratory (NETL) hosted the inaugural Carbon Capture, Utilization, Storage, and Oil & Gas Technologies Integrated Project Review Meeting, showcasing research aimed at developing novel technological solutions to the nation's energy challenges. "Addressing the Nation's Energy Needs Through Technology Innovation" combined four Office of Fossil Energy (FE) research programs, offering attendees an opportunity to share in the knowledge and insights gained from more than 200 research projects sponsored by the U.S. Department of Energy's (DOE) *Carbon Capture*, *Utilization* and *Storage*, and *Oil and Natural Gas Programs*. From *energy.gov* on August 30, 2019.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2018

Application Submitted for CO_2 Storage Project.

Partners in the Northern Lights project have submitted an application for an exploration permit for a subsea reservoir for CO_2 injection and storage on the Norwegian Continental Shelf (NCS). The project, which is part of Norwegian authorities' efforts to develop full-scale CCS in Norway, will capture CO_2 from the onshore industrial facilities in eastern Norway and transport it, via ship, to an onshore receiving plant located on the west coast of Norway. From there, the CO_2 will be sent by pipeline on the seabed to injection wells east of the Troll field on the NCS. The first phase of the project has the potential to reach a capacity of approximately 1.5 million tons of CO_2 per year. From *Offshore Energy Today* on September 10, 2018.

Climeworks Launches Third Direct Air CO_2 Capture Plant.

Climeworks launched its third Direct Air Capture (DAC) demonstration plant, which removes CO_2 from the atmosphere. Located in southern Italy, DAC-3 will be in operation for 4,000 hours over the next 17 months. Climeworks also has DAC plants in Switzerland and Iceland; the latter of which annually injects 50 metric tons of CO_2 underground. From *Business Green* on October 1, 2018.

NOVEMBER 2018

Ground Broken on STEP Pilot Power Plant.

A groundbreaking ceremony was held for a *Supercritical Transformational Electric Power (STEP) pilot plant* in San Antonio, Texas, USA. Project partners include DOE, Southwest Research Institute (SwRI), the Gas Technology Institute (GTI), and GE Global Research. The 10-megawatt (MW) supercritical carbon dioxide (sCO_2) facility will demonstrate the next generation of higher-efficiency, lower-cost electric power technology. Current power plants use water as a thermal medium in power cycles; replacing it with sCO_2 increases efficiency by as much as 10 percent. Because of the efficiency of sCO_2 as a thermal medium, STEP turbomachinery can be one-tenth the size of conventional power plant components. From *SwRI Press Release* on October 15, 2018.

Companies Sign MOU to Support CCS.

Technology Centre Mongstad (TCM) (Norway) and DNV GL signed a Memorandum of Understanding (MOU) to form a global advisory partnership to support carbon capture technologies. The partnership will build on current carbon capture and storage (CCS) efforts and deliver advisory and verification services for CO_2 capture technology. Technology companies currently conduct advanced testing of their carbon capture technologies at TCM; integration of technology verification is expected to expedite new solutions to the market. From *Carbon Capture Journal* on October 28, 2018.

EOR Pipeline Proposed.

A Texas (USA) company is proposing a 110-mile CO_2 pipeline in Montana (USA) that has the potential to release as many as 400 million barrels of oil through enhanced oil recovery (EOR). Subsidiaries of Denbury Resources, Inc. proposed the Cedar Creek Anticline CO_2 pipeline, which would deliver CO_2 from Bell Creek oil field in southwest Montana to the Cedar Creek Anticline fields in eastern Montana near the North Dakota border over several decades. If approved, Denbury plans to begin construction on the pipeline in 2019. From *Great Falls Tribune* on October 9, 2019.

DECEMBER 2018

DOE Awards Grant for CCS Research.

A DOE grant for CCS research will allow the University of Kentucky Center for Applied Energy Research (CAER) to develop new technologies to lower the cost of capturing CO_2. CAER's project, titled "Advancing Post-Combustion CO_2 Capture through Increased Mass Transfer and Lower Degradation," proposes to "advance deployment of CO_2 capture through enabling technologies that increase CO_2 mass transfer and reduce solvent loss." CAER and partner Lawrence Livermore National Laboratory (LLNL) will develop and fabricate customized dynamic packing and an electrochemical cell, both of which will be tested on CAER's bench-scale CO_2 capture unit. From *Carbon Capture Journal* on November 18, 2018.

BECCS Pilot Plant Underway in Europe.

The commissioning of a bio-energy with carbon capture and storage (BECCS) pilot plant at Drax Power Station has been initiated. If successful, the project will capture 1 metric ton of CO_2 per day at Drax, located near Selby in North Yorkshire, United Kingdom (UK). According to estimates by the Royal Academy and Royal Society of Engineers, BECCS technology has the potential to lead to the capture of approximately 50 million metric tons of CO_2 per year by 2050. From *Drax Press Release* on November 26, 2018.

UK Government Announces Plan for CCUS Project.

At a summit of international leaders, UK government officials announced plans for a CCUS project, which could be operational beginning in the mid-2020s. As part of the UK's *Industrial Strategy*, the government action plan will commit the UK to begin identifying opportunities to enable the CCUS facility, invest in supporting construction of CCUS technologies at industrial sites across the UK, and invest in the decarbonizing industry. From *UK Government Press Release* on November 28, 2018.

Agreement Reached on CO_2 Storage Infrastructure.

Crown Estate Scotland announced the signing of a lease option for CO_2 storage with the Acorn CCS project, based at the St. Fergus Gas Terminal on the Aberdeenshire coast. The project is designed to utilize existing oil and gas assets to deliver large-scale, cost-effective CO_2 transport and storage infrastructure in the Central North Sea. When combined with CCUS infrastructure, Scotland's geology below the Central North Sea has the potential to store approximately 75 percent of the UK's capacity of CO_2 emissions, helping to meet UK and Scottish targets. From *Crown Estate Scotland Media Release* on November 27, 2018.

JANUARY 2019

CCS Test Started at Japanese Cement Plant.

In conjunction with the government of Japan's Ministry of Environment, Taiheiyo Cement started a CCS test at its Fujiwara plant in Inabe, Japan. The company is testing a chemical absorption method, with further installations on the project planned in early 2019. From *Global Cement* on January 2, 2019.

CCS License Awarded.

The Oil and Gas Authority (OGA), the licensing authority of offshore CO_2 storage in the United Kingdom (UK), awarded a CO_2 appraisal and storage license to Pale Blue Dot Energy for the Acorn CCS project, which seeks to reuse existing oil and gas infrastructure for transporting and storing CO_2. In addition, the Acorn CCS project will also repurpose or rebuild an existing CO_2 capture facility based at the St. Fergus Gas Terminal, located on the Aberdeenshire coast. Together with the *lease option awarded by Crown Estate Scotland*, these documents allow Pale Blue Dot to undertake the characterization work required for a full lease and storage permit to permanently store CO_2 at the Acorn CO_2 storage site. From *Oil and Gas Authority* on December 6, 2018.

Zero-Emission Cement Plant Takes Shape in Norway.

A cement plant in Brevik, Norway, is moving towards becoming carbon free. According to officials at the Norcem plant, the first stage of CCS installation is expected to capture approximately half of the plant's CO_2 emissions. A final feasibility study will be published in August 2019 in order to inform a Norwegian government proposal to invest in building the full-scale CCS facility. According to officials, if the proposal is approved by Parliament, the project will enter a three-year construction phase. From *EURACTIV.com* on December 17, 2018.

CCS Projects Selected for EU Funding.

Twelve near-zero emissions projects were awarded European Union (EU) Horizon 2020 funding under the *Competitive Low-Carbon Energy* calls for proposals. *The selected projects* are expected to develop technologies for capturing, storing, and converting CO_2. Project areas include advanced CO_2 capture technologies, conversion of captured CO_2, strategic planning for CCUS development, and modeling in support of the transition to a low-carbon energy system in Europe. The projects are expected to be launched in spring 2019. From *Carbon Capture Journal* on December 21, 2018.

FEBRUARY 2019

Large-Scale CO_2 Storage Field Trials Planned.

Very Large Scale Decarbonization Partners (VLS Decarb) is planning field trails in several U.S. shale basins, with the potential to further develop the trials into fully functioning CO_2 storage facilities. VLS Decarb is in the process of securing Precedent Agreements for long-term carbon storage contracts. From *Carbon Capture Journal* on February 4, 2019.

Permit Awarded for Carbon Storage Project.

The government of Norway awarded a permit for a CO_2 storage project on the Norwegian Continental Shelf (NCS). Oil firm Equinor was awarded the permit for its "Northern Lights" project, which aligns with the government of Norway's goal to develop and export new technologies for CCS. First announced in July 2018, the Equinor project is currently performing FEED studies, which will provide cost estimates. From *The Maritime Executive* on January 11, 2019.

Technology Development May Lead to EOR Operations.

The development of Carbon Engineering's "Air to Fuels" technology may enable captured CO_2 to be used for enhanced oil recovery (EOR) operations. Direct air capture (DAC) plants are not location-dependent, meaning they could be sited near an oil field to enable the CO_2 to be used for EOR operations. Carbon Engineering has been capturing 1 ton/day of atmospheric CO_2 at a pilot plant in Squamish, British Columbia (Canada), since 2015. The "Air to Fuels" technology produces synthetic fuel by combining the captured CO_2 with hydrogen generated from electrolysis using renewable energy. From *The Chemical Engineer* on January 15, 2019.

DOE Collaboration May Help Identify, Design New CCS Materials.

A computational modeling method may help to fast-track the identification and design of new CCS materials for use by coal-fired power plants. Developed at the University of Pittsburgh's Swanson School of Engineering, in collaboration with DOE/NETL scientists, the hypothetical mixed matrix membranes would provide an economical solution, with a predicted cost of less than $50/ton of CO_2 removed. The research findings were *published in the Royal Society of Chemistry journal Energy & Environmental Science*. From *University of Pittsburgh's Swanson School of Engineering* on January 8, 2019.

MARCH 2019

DOE Research Grant Awarded for CO_2 Storage Monitoring.

As part of a new project awarded by DOE, GroundMetrics Inc. will use proprietary sensor systems and machine learning to monitor CO_2 in the subsurface. In partnership with DOE, Lawrence Berkeley National Laboratory (LBNL), and Expero Inc., GroundMetrics will develop a continuous monitoring system to measure resistivity changes in the subsurface, enabling CO_2 saturation to be monitored and providing insight into how the CO_2 is distributed underground. From *Business Insider* on February 21, 2019.

CCS Project Publishes Findings.

The ACT Acorn project announced findings of its research into the feasibility of establishing a carbon capture and storage (CCS) facility in the North Sea. Geologists involved in the international research project analyzed sandstone and caprock samples at two potential storage sites in the North Sea to determine if they were suitable for the injection and long-term storage of CO_2. The *key findings from the ACT Acorn project* evaluated the potential value of the United Kingdom's (U.K.) existing North Sea oil and gas transport infrastructure coupled with a natural CO_2 geologic storage resource. From *Phys.Org* on February 20, 2019.

BECCS Pilot Plant Operations Underway.

The BECCS demonstration plant at Drax Power Station, near Shelby in North Yorkshire, U.K., has begun operations to capture one metric ton of CO_2 per day. Data being obtained during the pilot will be analyzed to understand the utilized technology's potential to be scaled-up and to identify and develop methods to store the captured CO_2. From *Drax Press Release* on February 7, 2019.

Project Looks to Store CO_2 in Salt Caverns.

Research conducted at the Research Center for Gas Innovation (RCGI) has shown the potential to store CO_2 in salt caverns. According to RCGI, an Engineering Research Center (ERC) funded by São Paulo (Brazil) Research Foundation, the first "pilot cavern" may be ready by 2022. The site of the pilot has not yet been determined. From *Phys.Org* on February 14, 2019.

APRIL 2019

Aker Solutions Selected for CCUS Work.

The Swedish fuel company Preem selected Aker Solutions to perform CCUS work at a Scandinavian oil refinery in Lysekil on the Swedish west coast. Aker Solutions will conduct a feasibility study of the technological and economic impact of implementing CO_2 capture at Preemraff Lysekil, Scandinavia's largest refinery. The scope of work also includes pilot testing of CO_2 capture from the oil refinery flue gas under industrial conditions. According to Aker Solutions officials, the refinery in Lysekil is a potential candidate for carbon capture and storage (CCS). From *Aker Solutions News* on February 27, 2019.

Oil and Gas Authority to Research Renewable Energy.

The U.K.'s Oil and Gas Authority (OGA) research into powering the North Sea oil and gas assets with renewable energy sources is assessing CCS technology. *According to an OGA press release*, OGA will publish a policy position as well as a strategy that will cover CO_2-EOR. From *Energy Voice* on March 21, 2019.

MAY 2019

Drilling Begins on Carbon Storage Test.

As part of a DOE-funded project, drilling on a test well in Gillette, Wyoming (USA) was initiated as part of a storage complex feasibility study. The project is from *DOE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative*, and the drilling will take place near Basin Electric Power Cooperative's Dry Fork Station. The Dry Fork Station was selected to develop integrated carbon capture and storage (CCS) complexes that will be constructed and permitted for operation around 2025. From *University of Wyoming News* on April 12, 2019.

Ethanol Plant Moving Forward with CCS Project.

Red Trail Energy completed a geophysical survey on a North Dakota (USA) ethanol plant in which they propose to capture CO_2 and store it underground. The data from the survey is expected to help scientists from the University of North Dakota Energy and Environmental Research Center gain a better understanding of the subsurface geology of the Brook Creek formation. The project would involve the injection of approximately 160,000 metric tons of CO_2 per year into the Brook Creek formation. From *Williston Herald* on April 15, 2019.

JUNE 2019

Quest CCS Facility Reaches Milestone.

Shell's Quest CCS facility in Alberta, Canada, has captured and stored 4 million metric tons of CO_2, according to officials. The designs, certain intellectual property, and data from Quest were made publicly available in order to benefit future CCS projects. The Quest CCS facility captures and stores approximately one-third of the CO_2 emissions from the Shell-operated Scotford Upgrader near Fort Saskatchewan, Alberta. The CO_2 is transported through a pipeline and stored underground. From *Shell News Release* on May 23, 2019.

CCS Project Gains Funding.

A CCS venture in Indiana (USA) secured funding to develop a CCS project capable of storing up to 1.75 million metric tons of CO_2. The Wabash Valley Resources (WVR) project is expected to capture nearly 100% of the plant's CO_2 and store it in the Mount Simon Sandstone approximately 7,000 feet underground. According to WVR officials, the company will utilize the investment from the Oil and Gas Climate Initiative to produce ammonia with a near-zero carbon footprint. From *Gasworld* on May 21, 2019.

Engineering Begins on DAC and Storage Plant.

An international oil and gas exploration and production company and a Canadian-based clean energy company will begin engineering and design of a direct-air capture (DAC) and storage facility. Oxy Low Carbon Ventures, LLC (OLCV) and Carbon Engineering Ltd. (CE) are evaluating a facility, to be located in the Permian Basin, that will be capable of capturing 500 metric kilotons of atmospheric CO_2 per year for use in enhanced oil recovery operations. Construction is expected to begin in 2021 pending initial approval by OLCV and CE, with the plant becoming operational within approximately two years. From *Occidental News Release* on May 21, 2019.

North Sea Gas Fields To Be Used for CO_2 Storage.

The Rotterdam, Antwerp, and Ghent ports in Europe will be used to capture and store approximately 10 million metric tons of CO_2 emissions under the North Sea. According to the Dutch government, the ports will be used in the transport of the CO_2 into a porous reservoir of sandstone approximately two miles below the seabed. Plans call to begin construction of the CO_2 network by 2026, with the project to be completed by 2030. A further expansion is expected after 2030. From *The Guardian* on May 9, 2019.

China Implements CCS Project.

China implemented a CCS demonstration project in saline aquifers in Ordos, North China's Inner Mongolia Autonomous Region. The demonstration project was launched in 2010 and had completed carbon capture, purification, pressurization, and drilling work by the end of that year. Carbon dioxide produced by coal liquefaction will be liquefied after it is captured and transported to the operation area by special tankers, where it will be injected into saline aquifers at depths ranging from approximately 4,900 to 8,200 feet underground for storage. From *Chinanews.com* on May 9, 2019.

Consortium Launches Industrial-Scale CCS Project.

A consortium of European stakeholders launched a project to demonstrate CO_2 capture from industrial activities as part of a study dedicated to the development of the future European Dunkirk North Sea CCS cluster. The project is part of Horizon 2020, the European Union's (EU) research and innovation project. The Dunkirk North Sea cluster, which is expected to be capable of capturing, packing, transporting, and storing 10 million metric tons of CO_2 per year, is expected to be operational by 2035. From *Oil & Gas Journal* on May 28, 2019.

Partnership to Demonstrate CCUS.

Inventys *announced a partnership* to develop and demonstrate a full-cycle solution to capture and reuse CO_2 from a cement plant. Project CO2MENT, being conducted in partnership with Lafarge Canada Inc., LafargeHolcim, and Total, will evaluate the potential for a new business model for supplying post-combustion CO_2 to the existing CO_2 market, as well as assessing the economic feasibility of newly developed CO_2 utilization technologies. From *Carbon Capture Journal* on May 29, 2019.

JULY 2019

Equinor to Publish Offshore Carbon Storage Data.

Equinor and its partners will publish a dataset from the Sleipner CCS project located in the North Sea region of Norway. The Sleipner field has been used for CCS since 1996, and Equinor has been sharing data with the research community for the past 15 years. The data will now be made openly available, published via the DOE-supported and SINTEF-led CO_2 Data Share Consortium, which is an open international network for data and knowledge exchange. The digital platform for the data sharing is scheduled to be online in 2019. From *The Maritime Executive* on June 12, 2019.

Third Phase of CCS Project Announced.

Australian CCS research organization CO2CRC announced a $31.3 million investment for the third phase of the Otway CCS project located in southwest Victoria. The third phase (Otway Stage 3 Monitoring and Verification Project) follows the finalization of all project-related technical and scientific work programs, operational arrangements, regulatory approvals, and funding. According to CO2CRC officials, this phase of the project will be to develop subsurface storage technologies for long-term CO_2 storage monitoring. From *Gas World* on June 12, 2019.

CCUS Pilot Project Unveiled.

Drax and Deep Branch Biotechnology are collaborating on a CCUS pilot project to be executed within the CCUS Incubation Area at Drax's power station in Yorkshire, United Kingdom (U.K.). *According to officials*, the objective of the project is to explore how captured CO_2 can be used to make sustainable animal feed. The pilot project, expected to begin later this year, will capture CO_2 from the energy generation process and feed it to microbes, which will use it to make single-cell proteins that could replace soy and fishmeal in fish and livestock feeds. From *BusinessGreen* on June 18, 2019.

AUGUST 2019

China Energy to Build New CCS Plant.

China Energy Group announced plans to launch a CCS project in northwest China in 2020. Officials also announced that the company would add more than 6 gigawatts (GW) of ultra-low emission, coal-fired capacity, as well as build another 5 GW of low-emissions capacity in 2020. From *Reuters* on July 18, 2019.

Work Starts at CCS Research Facility.

Work has begun at CO2CRC's Otway National CCS Research Facility—located at Nirranda South in southwest Victoria (Canada)—with the drilling of four monitoring wells, equipped with fiber-optic sensing and subsurface gauges, approximately 1 mile underground. Part of CO2CRC's Otway Stage 3 Project, the effort will develop subsurface carbon storage technologies that reduce the cost and carbon footprint of long-term CO_2 storage monitoring for CCS projects. From *CO2CRC News* on July 17, 2019.

Project Stores CO_2 in Mine Waste.

Technology developed by the University of British Columbia (UBC) will be used to store CO_2 in two Canadian mines. The project, a collaboration among UBC, the University of Alberta, Trent University, INRS (a Canadian university focused on fundamental and applied research), and three mining companies, will store the CO_2 in mine tailings, which is the waste left over from ore mining. The project received funding from Natural Resources Canada's *Clean Growth Program*. From *UCB News* on July 23, 2019.

SEPTEMBER 2019

Companies Collaborate for Forest Carbon Storage Opportunities.

Two Canadian companies—AurCrest Gold Inc. and Blue Source Canada ULC—signed a Carbon Development and Marketing Agreement (CDMA) to develop forest carbon storage opportunities. Under the CDMA, Lac Seul First Nation (Canada) will also collaborate with the companies to assess the potential of forests to capture and store CO_2 within First Nation's traditional territory for the development of GHG offsets and other potential environmental attributes. Blue Source prepared an initial carbon assessment. From *StreetInsider* on August 19, 2019.

Australian CCS Project Begins Operation.

The CO_2 injection system at the Gorgon natural gas facility on Barrow Island off the coast of Western Australia has begun operations. Once fully operational, the system will reduce Gorgon's GHG emissions by approximately 40 percent (more than 100 million metric tons over the life of the project). The Australian government contributed to the capital cost of the Chevron Australia and Gorgon Joint Venture project as part of the Low-Emissions Technology Demonstration Fund. From *Carbon Capture Journal* on August 9, 2019.

Carbon Farming Incentive Offered in Australia.

A soil carbon farming developer in Australia announced a cash prize for carbon farming within the country. According to AgriProve, their 20/20 Olsen Prize for Soil Carbon Farming is designed to spur innovation in regenerative agriculture, encourage farmers to register projects under the Australian Emissions Reduction Fund (ERF), and build an evidence base for soil carbon farming. The prize will be awarded to the first farmer under an ERF project that achieves 20 metric tons of dry matter yield plus an additional 20 metric tons of soil carbon abatement per hectare (~2.5 acres) in a 12-month period. The Australian Broadcasting Commission highlighted the carbon farming incentive in an *audio segment*. From *AgriProve* on August 5, 2019.

LEGISLATION and POLICY

OCTOBER 2018

California Aims for Carbon Neutrality.

An executive order was issued in California (USA), seeking carbon neutrality in the state by 2045. In addition, Senate Bill 100 was also signed, establishing mandatory renewable energy targets of 33 percent by 2020, 50 percent by 2026, and 60 percent by 2030, before implementing a zero-carbon electricity grid by 2045. To achieve its goals, California will reduce carbon emissions; increase carbon storage in forests, soils, and other natural landscapes; and implement programs to improve air quality and public health. From *International Institute for Sustainable Development* on September 20, 2018.

Revised Tax Credit Role on CCUS Commercial Viability.

Research conducted by the Computational Earth Science group at Los Alamos National Laboratory (LANL) (USA) has shown that using CO_2 for CCUS can be commercially viable under the revised 45Q tax regulation. Until recently, there was a limit on the 45Q tax credit, which creates incentives for capturing and storing CO_2; the 2018 revision eliminated the cap. From *Albuquerque Journal* on August 31, 2018.

CARB-Approved Changes Establish CCS Protocol.

The California Air Resources Board (CARB) approved several amendments to their Low-Carbon Fuel Standard (LCFS) Program, one of which establishes a regulatory protocol to set requirements for CCS. In addition, the amendments set a new carbon-intensity target within the state. The LCFS currently requires a 10 percent reduction in California's transportation fuels by 2020; the amendments will require a 20 percent reduction by 2030. From *Ethanol Producer Magazine* on October 1, 2018.

NOVEMBER 2018

Norway to Increase CCS Efforts.

The Norwegian government's *national budget for 2019* proposes to allocate approximately $80 million for CCS, representing an increase of nearly $19 million compared to the final budget for 2018. The proposal includes funds for continuing the work on a new, full-scale CCS project in Norway, as well as increased funding for TCM. Knowledge and experience gained from TCM is expected to be used for planning the full-scale CCS project. From *Carbon Capture Journal* on October 15, 2018.

North Carolina Sets GHG Reduction Goal.

The Governor of North Carolina (USA) *signed an executive order* to reduce the state's greenhouse gas (GHG) emissions by 40 percent by 2025. In addition, the order creates a committee that will work with the state's Department of Environmental Quality to develop a report on how the state's government can use more renewable energy sources. From *The News & Observer* on October 29, 2018.

Saskatchewan Introduces Legislation.

The Saskatchewan (Canada) environment minister introduced legislation to implement industry performance standards. "*The Management and Reduction of Greenhouse Gases Amendment Act, Bill 132*," will also provide regulatory framework for emitters contributing to a green technology fund or purchasing performance credits and carbon offset credits. Under the bill, those emitting more than 10,000 metric tons of CO_2 annually will be required to track their emissions, while those with emissions exceeding 25,000 metric tons will be required to comply with performance standards. From *Global News* on October 30, 2018.

DECEMBER 2018

Carbon Tax Bill Introduced.

A carbon tax bill was introduced into the U.S. House of Representatives. The new bill is considered a "testing ground for a carbon-fee-and-dividend model" that distributes the revenue in the form of a monthly rebate to American households. Under the bill, a $15/ton of CO_2 tax would be imposed in 2019, increasing by $10 every year, rising to nearly $100/ton by 2030. In addition, the bill would create a border carbon adjustment, which would require exporting countries to pay a fee on CO_2-emitting products that come into the United States. According to the bill's authors, the legislation has the potential to reduce U.S. CO_2 emissions 45 percent by 2030 compared to 2015 levels, and 80 to 90 percent by 2050. From *Washington Examiner* on November 27, 2018.

JANUARY 2019

Carbon Tax Legislation Introduced. [Link no longer active.]

Two U.S. senators introduced carbon tax legislation that would place a price on CO_2 and other greenhouse gas (GHG) emissions. S. 3791, "*The Energy Innovation and Carbon Dividend Act*," is designed to address potential climate change and encourage market-driven innovation in clean energy technologies. A one-pager on the bill is *available online*. From *U.S. Senator Jeff Flake Press Release* on December 20, 2018.

Canada Carbon Pricing Act Takes Effect.

Canada's *Greenhouse Gas Polluting Pricing Act* went into effect on January 1, 2019, instituting a fee on carbon emissions beyond a certain threshold for larger industrial facilities. The act is reserved for the provinces that did not adopt the carbon pricing system or did not develop their own plan. From *Kitchener Today* on January 1, 2019.

FEBRUARY 2019

Draft Carbon Emissions Bill Released in Oregon.

A draft bill set to reduce CO_2 emissions in Oregon (USA) has been released. The measure would establish a Carbon Policy Office and modify greenhouse gas (GHG) emissions reduction goals and market-based mechanisms for covered entities to demonstrate compliance. From *The Register-Guard* on February 1, 2019.

California CCS Protocol Takes Effect.

The California Air Resources Board's (CARB) decision to include a CCS protocol in its Low-Carbon Fuel Standard (LCFS) has taken effect. The protocol allows transportation fuels whose lifecycle emissions have been reduced through CCS to become eligible for credits under the LCFS. Credits are *currently trading at approximately $180 per ton*, and can be combined with the federal tax credit (45Q) for CCS projects; 45Q provides $50 per ton for CO_2 stored geologically and $35 per ton for CO_2 stored permanently via EOR. From *Carbon Capture Journal* on January 20, 2019.

Carbon Legislation Introduced.

Legislation to help reduce U.S. CO_2 emissions by up to 45 percent by 2030, with a more than 90 percent reduction target by 2050 (compared to 2016 levels), was introduced in the U.S. House of Representatives. *The Energy Innovation and Carbon Dividend Act (EICDA)* will price CO_2 at $15 per metric ton of CO_2e and increasing the price by $10 every year. From *U.S. Congressman Ted Deutch Press Release* on January 24, 2019.

Massachusetts Carbon Tax Analyzed.

According to analysis by researchers from the Harvard T.H. Chan School of Public Health (USA), a carbon tax based on several proposals in the Massachusetts legislature has the potential to reduce CO_2 emissions by 33 million metric tons. Published in the journal *Environmental Research Letters (ERL)*, the findings were based on models of how a potential carbon fee-and-rebate bill would affect CO_2 emissions in the 2017 through 2040 timeframe. From *Physics World* on January 24, 2019.

MARCH 2019

Bill to Support CCS Introduced in US Senate.

A bill that would address a tax credit to better support CCS for coal power plants was introduced in the U.S. Senate. The "*Carbon Capture Modernization Act*" updates the tax credit system for coal producers and incentivizes the usage of modern technology for underground CO_2 storage. From *U.S. Senator Tina Smith Press Release* on February 11, 2019.

South African Parliament Approves Carbon Tax Bill.

South Africa's parliament approved a carbon tax bill that establishes a state tax of 120 rand (approximately $8.50) per metric ton of carbon dioxide equivalent (CO_2e). South Africa pledged to reduce CO_2 emissions by almost half by 2030. From *Nasdaq.com* on February 19, 2019.

APRIL 2019

CO_2 Storage Bill Passes House.

Indiana (USA) legislation that would create a pilot program to store CO_2 underground passed the House and is returning to the state Senate. The bill would create a pilot program that allows one company to store CO_2 underground by taking ownership of the land, if approved by the Indiana Department of Natural Resources. From *Indiana Public Media* on March 26, 2019.

Nevada Introduces Carbon-Free Bill.

Nevada (USA) legislators introduced a bill that would require 100 percent carbon-free emissions by 2050. In addition, SB 358 would double Nevada's renewable portfolio standard to 50 percent by 2030. From *Utility Dive* on March 20, 2019.

Flemish Government Approves CO_2 Package.

The executive branch of the Flemish Region of Belgium approved a plan to manage CO_2 emissions over the next 20 years and become carbon-neutral by 2050. As part of the plan, the Flemish government will focus on carbon capture and use projects. From *Brussels Times* on March 24, 2019.

South Africa Parliament to Consider Carbon Tax Legislation.

The National Council of Provinces of the Parliament of South Africa is considering carbon tax legislation. The Carbon Tax Bill would create a mechanism that puts a price on carbon emissions in South Africa. From *Eyewitness News* on March 25, 2019.

MAY 2019

Bill with Carbon Storage Focus Introduced.

A group of U.S. Senators introduced a bill to increase federal funding for developing carbon capture technology. The *Enhancing Fossil Fuel Energy Carbon Technology (EFFECT) Act* would also establish four new research programs within DOE FE: Carbon Storage, Carbon Utilization, Carbon Removal, and Coal and Natural Gas Technology. From *The Hill* on April 11, 2019.

U.S. Senate Environment Panel Approves Bill.

The U.S. Senate Environment Panel approved a bill that would support collaboration to construct and develop CCUS facilities and CO_2 pipelines. *The Utilizing Significant Emissions with Innovative Technologies (USE IT) Act* would, among other actions, clarify that CCUS projects and CO_2 pipelines are eligible for permitting review processes as well as direct the Council on Environmental Quality to establish guidance to assist project developers and operators of CCUS facilities and CO_2 pipelines. From *Carbon Capture Journal* on April 10, 2019.

Norwegian Government Proposes Funding of CCS Exploration Well.

The Norwegian government, as part of the Norwegian full-scale CCS project, will propose funding for an exploration well for CO_2 storage on the Norwegian Continental Shelf. The exploration well is expected to provide Parliament with information on the quality and capacity of the reservoir, which will influence the decision on whether to proceed with the CCS project. The Norwegian government will present their proposal to Parliament in connection with the revised national budget for 2019. From *Royal Norwegian Ministry of Petroleum and Energy Press Release* on April 11, 2019.

JUNE 2019

Newly Introduced Legislation Promotes Carbon Storage.

Two U.S. senators introduced legislation that promotes more carbon storage. In addition, *the bill* allows for the use of biomass from certain federal lands needing ecological restoration to develop renewable fuels to promote "healthier forests" and "cleaner transportation fuels." A one-pager of the bill is *available online*. From *U.S. Senator Ron Wyden Press Release* on May 22, 2019.

South Africa Carbon Tax Signed into Law.

The South African President signed a carbon tax into law, effectively adopting a carbon-pricing program for the country. The tax will be introduced in phases: Phase I will begin in December 2022, taxing carbon at an approximate rate of $8.35/per ton of CO_2 equivalent. The South African government will assess the impact of the tax and the nation's progress toward emissions goals before the second phase of the policy, which will start in 2023 and end in 2030. From *National Public Radio* on May 26, 2019.

JULY 2019

Bill Seeks CO_2 Reduction Through CCS Projects.

A bill reintroduced in the U.S. Senate would allow businesses to use governmental private activity bonds for CCS projects. If the *Carbon Capture Improvement Act* is passed, a project could be financed entirely if more than 65% of the CO_2 emissions at the facility are captured and stored underground (projects that achieve lower percentages could be permitted on a pro-rated basis). From *Daily Energy Insider* on June 13, 2019.

Canada Unveils CO_2 Reduction Plan.

Canadian officials unveiled a CO_2 reduction plan that encourages companies to make emissions reduction part of their business models. Under the plan, companies that release GHG emissions above set standards would be required to pay into a fund for investment in government-certified clean tech companies. According to officials, the plan has the potential to lower Canada's baseline emissions by as much as 101 metric megatons by 2030. From *CBC News* on June 19, 2019.

AUGUST 2019

Energy Research Legislation Reintroduced.

A bill that reauthorizes DOE FE research activities and sets priorities for the next generation of clean energy technologies passed through the Committee on Science, Space, and Technology's Subcommittee on Energy. The Fossil Energy Research and Development Act of 2019 is expected to be considered by the full committee next. The reintroduced legislation focuses on CCUS and CO_2 removal, among other areas. From *U.S. Congressman Marc Veasey Press Release* on July 10, 2019.

EU Clarifies Intent to Support CCS Technology.

The European Commission clarified its intent to support CCS. According to officials, future European Union (EU) funding for CCS will likely focus on transport infrastructure, such as CO_2 pipelines. While the prior focus was on CCS demonstration plants, the Commission will now concentrate on supporting carbon storage and utilization value chains. From *EURACTIVE* on July 10, 2019.

SEPTEMBER 2019

Low-Carbon Fuel Policy Boosts CCS Opportunities.

A *new amendment to California's Low-Carbon Fuel Standard* has created an incentive for the bioethanol industry to utilize CCS technology for the production of low-emissions bioethanol. Due to its *highly concentrated CO_2 waste stream*, bioethanol production presents an opportunity for near-term CCS deployment; applying CCS to the fermentation and distillation process in the biorefinery has the potential to *reduce the fuel's carbon intensity*. From *Global CCS Institute* on August 7, 2019.

New Zealand Government Announces Climate Action Plan.

The New Zealand government *released their Climate Action Plan* in response to the New Zealand Productivity Commission's inquiry into the low-emissions economy. In 2017, the Productivity Commission was asked to identify options for New Zealand to reduce its GHG emissions, taking into account the country's intention to set emissions-reduction goals through the Zero-Carbon Bill. From *New Zealand Government Press Release* on August 3, 2019.

Report Reviews Global Storage Regulations.

A report published by the *CO_2 Capture Project* analyzed recent developments in regulations for CO_2 storage projects globally, finding an increase in confidence for CCS policy and growth in regulatory regimes for CO_2 storage worldwide. The "Survey of CO_2 Storage Regulations" report examined key developments, issues, and gaps that may affect the commercial success of CCS. From *Carbon Capture Journal* on August 28, 2019.

EMISSIONS TRADING

OCTOBER 2018

Report on RGGI Investments.

The Regional Greenhouse Gas Initiative (RGGI)-participating states released a report on the investments of proceeds generated from RGGI's regional CO_2 allowance auctions in 2016. According to the report, in 2016 more than $436.4 million in RGGI proceeds were invested in programs such as energy efficiency, clean and renewable energy, GHG abatement, and direct bill assistance. More details, such as state-specific success stories and program highlights, as well as information on both the 2016 and cumulative investments of RGGI, are available in the full report, titled "*Investment of RGGI Proceeds in 2016.*" From *RGGI News Release* on September 19, 2018.

EU, California Strengthen Carbon Market Cooperation.

The European Union (EU) and California (USA) announced intentions to strengthen their bilateral cooperation on carbon markets. According to the announcement, made at the Global Action Summit held in San Francisco, California, in September 2018, officials from the EU and California will focus on sending near- and long-term investment signals for transformative technologies, addressing economic competitiveness, and maximizing public benefits of use of program revenues. In addition, the collaboration will work through the existing "Florence Process" – a workshop that seeks to bring together emissions trading scheme (ETS) experts. From *Clean Technica* on September 21, 2018.

Zero Carbon Project Set to Launch. [Link no longer active.]

The U.K.'s Zero Carbon Project announced it will launch in October 2018 in the U.K. and in early 2019 in Australia. The project is designed to mitigate potential climate change through blockchain technology and international carbon credits. From *Market Journal* on September 23, 2018.

NOVEMBER 2018

RGGI Releases Auction 42 Notice.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the *Auction Notice* and *application materials* for their 42nd quarterly CO_2 allowance auction, to be held December 5, 2018. The Auction Notice provides potential participants with the information needed to indicate their intent to bid on Auction 42. As indicated in the Auction Notice, Auction 42 will offer for sale 13,360,649 CO_2 allowances at a minimum reserve price of $2.20. In addition, there will also be a 10 million CO_2 allowance cost containment reserve (CCR) made available for the auction, which will be accessed if the interim clearing price exceeds the CCR trigger price of $10.25. From *RGGI News Release* on October 9, 2019.

New Carbon Investment Fund to Be Launched.

A New Zealand investment company announced plans to launch a carbon fund that will be listed on the New Zealand Stock Exchange (NZX). Salt Funds Management will manage the fund, with the intent to purchase carbon credits in emissions trading schemes from New Zealand and offshore. According to Salt Fund officials, the fund would provide individuals and organizations an opportunity to invest in or offset carbon. From *NZ Herald* on October 15, 2018.

Hexindai to Support Emissions Reduction.

Hexindai Inc., based in Beijing, China, reached an agreement with Shell Energy (China) Limited to support China's national emissions trading scheme (ETS). Under the agreement, Hexindai will provide price hedging of National Carbon Allowances (NCAs) for three years, to begin when the cement sector is enrolled in China's ETS and the Chinese carbon offsets can be used for compliance purposes. An NCA unit is equal to one ton of CO_2 equivalent. From *Hexindai Press Release* on October 16, 2018.

DECEMBER 2018

RGGI States Release Results of 42nd Auction.

The RGGI-participating states released the results of their 42nd auction of CO_2 allowances, in which 13,360,649 CO_2 allowances were sold at a clearing price of $5.35. Bids ranged from $2.20 to $7.50 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 42 generated $71.5 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement. From *RGGI News Release* on December 7, 2018.

Cap-and-Trade Auction Held.

California (USA) and Québec (Canada) held a joint cap-and-trade auction in which all of the current and future vintage GHG emissions allowances were sold. Organized by the California Air Resources Board (CARB) and Québec's Ministry of the Environment and Climate Change (MELCC), a total of 78.8 million current allowances and 9.4 million advance allowances were sold, generating approximately $813 million for a GHG reduction fund. The auction, which included current allowances for 2016, 2017, and 2018, as well as vintage 2021 credits, was the seventh consecutive CARB auction to sell out, with bids coming in both U.S. and Canadian dollars. From *Natural Gas Intelligence* on November 27, 2018.

China's Carbon Trading Valued.

China's carbon trading saw transaction values exceed approximately $860 million since June 2013, with traded emission quotas exceeding 270 million metric tons, according to officials. China's government has committed to reducing its carbon emissions per unit of GDP by 60 to 65 percent by 2030 from the 2005 level. From *Xinhuanet* on November 26, 2018.

JANUARY 2019

RGGI Releases 2016 Annual Electricity Monitoring Report.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "*CO_2 Emissions from Electricity Generation and Imports in the Regional Greenhouse Gas Initiative: 2016 Monitoring Report*." The eighth in a *series of annual monitoring reports*, this report summarized data for the period from 2005 through 2016 for electricity generation, net electricity imports, and related CO_2 emissions for the states participating in RGGI's third control period. From *RGGI News Release* on December 13, 2018.

RGGI Releases Statement, Revision.

The RGGI-participating states *released a statement* on the New Jersey Department of Environmental Protection's *draft proposed regulation* to reduce GHG emissions (which will be open for public comment through February 15, 2019). In addition, the RGGI-participating states also *issued a revision* to the *2017 Model Rule*, which was developed to provide guidance to states as they implement the RGGI program. From *RGGI News Releases* on December 14 and 17, 2018.

FEBRUARY 2019

RGGI States Initiate Auction Process for Auction 43.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for their 43rd quarterly CO_2 allowance auction, to be held on March 13, 2019. The Auction Notice provides potential participants with the information needed to submit a Qualification Application and indicate their intent to bid. Auction 43 will offer for sale 12,883,436 CO_2 allowances at a minimum reserve price of $2.26. A 10 million CO_2 allowance cost containment reserve (CCR) will also be made available (the CCR will be accessed if the interim clearing price exceeds the CCR trigger price of $10.51). From *RGGI News Release* on January 15, 2019.

Report Analyzes Value of Global CO_2 Markets.

The value of traded global markets for CO_2 allowances rose 250 percent in 2018, according to a new report. According to analysts at Refinitiv, a global provider of financial markets and infrastructure, the overall value of traded global markets in 2018 was $164 billion (144 billion euros). A total of 9 billion carbon permits were traded globally in 2018, up 45 percent from 2017. The European market accounted for 90 percent of the total value of globally traded carbon permits, with North American trading schemes making up 9 percent. From *Reuters* on January 16, 2019.

MARCH 2019

California's New Underground Injection Rules to go into Effect.

California's (USA) underground injection requirements will go into effect on April 1, 2019. According to the states' Department of Conservation, approximately 55,000 underground injection control wells will be affected under the new regulations, elements of which include (but are not limited to) testing requirements to identify potential leaks, continuous well-pressure monitoring, and monitoring for seismic activity. From *Oil & Gas Journal* on February 21, 2019.

UK Working on Carbon Trading System.

The U.K. is working to establish a domestic carbon emissions trading system (ETS). According to the energy minister, the U.K. will look to link to the existing European Union (EU) ETS beginning in January 2021. The U.K. government plans to launch a consultation on its plans in April 2019. From *Reuters* on February 27, 2019.

APRIL 2019

Dutch Government to Introduce CO_2 Tax.

The Dutch government intends to introduce a tax on CO_2 emissions for companies, according to the Prime Minister. The plan would be in addition to the European Union's (EU) current Emissions Trading System. From *Reuters* on March 13, 2019.

RGGI Announces Auction Results.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the results of their 43rd auction of CO_2 allowances. The first auction of 2019 (Auction 43) saw 12,883,436 CO_2 allowances sold at a clearing price of $5.27, with bids ranging from $2.26 to $7.12 per allowance. The auction generated $67.9 million for reinvestment in strategic programs, including energy efficiency, renewable energy, direct bill assistance, and greenhouse gas abatement programs. More information is available in the *Market Monitor Report for Auction 43*. From *RGGI News Release* on March 15, 2019.

MAY 2019

RGGI 2019 Interim Compliance Materials Available.

The states participating in RGGI made materials regarding the 2019 interim control period compliance available. RGGI's fourth three-year control period is from January 1, 2018, through December 31, 2020; the 2019 interim control period began on January 1, 2019, and ends December 31, 2019. Each CO_2 budget source must hold allowances available for compliance deduction equal to 50% of their emissions by March 2, 2020. Market participants can acquire allowances through CO_2 allowance auctions or secondary markets. The next CO_2 allowance auction (*Auction 44*) will be held on June 5, 2019. From *RGGI News Release* on April 8, 2019.

Virginia Approves Regulation to Reduce GHGs.

Virginia (USA) officials approved a regulation to establish a market-based program to reduce GHGs by 30% by 2030. The regulations align with the RGGI Model Rule and *guidelines set forth by RGGI*. Virginia's GHG reductions are set to begin in 2020. From *Daily Press* on April 22, 2019.

JUNE 2019

Oregon Legislature Approves Cap-and-Trade Bill.

Oregon (USA) Legislature's Joint Carbon Reduction Committee approved a cap-and-trade bill that could put a progressively declining cap on GHGs across the state. Under the proposal (H.B. 2020), Oregon's largest emitters would be required to purchase carbon credits for each ton of emissions they release annually. Before becoming law, the bill goes to the Oregon Joint Ways and Means Committee before heading to the House floor for a vote. From *Statesman Journal* on May 17, 2019.

RGGI Secondary Market Report Made Available.

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 2019*" addresses the period from January through March 2019. The report is part of Potomac's ongoing monitoring of the RGGI auctions and the secondary markets where CO_2 allowances are traded, and is based on data reported to the U.S. Commodity Futures Trading Commission and the Intercontinental Exchange, as well as other data. From *RGGI News Release* on May 9, 2019.

JULY 2019

New Jersey Finalizes CO_2 Regulation, Joins RGGI.

New Jersey (USA) *finalized a regulation* to establish a market-based program to reduce GHG emissions and, as a result, will join the Regional Greenhouse Gas Initiative (RGGI) as a participating state starting on January 1, 2020. The decision was made after an extensive public process, as well as an RGGI ruling that New Jersey's starting CO_2 allowance budget and emissions reduction trajectory demonstrates a stringency comparable to the existing RGGI program. From *RGGI News Release* on June 17, 2019.

RGGI Releases Results of 44th Auction of CO_2 Allowances.

The RGGI-participating states released the results of their 44th auction of CO_2 allowances. Auction 44 saw 13,221,453 CO_2 allowances sold at a clearing price of $5.62, with bids ranging from $2.26 to $10.01 per allowance. None of the 10 million cost containment reserve (CCR) allowances made available were sold (CCR is a fixed additional supply of allowances only available for sale if CO_2 allowance prices exceed certain price levels [$10.51 in 2019]). More information is available in the *Market Monitor Report for Auction 44*. From *RGGI News Release* on June 7, 2019.

Emissions Trading Scheme Unveiled in India.

Government officials in Gujarat, the westernmost Indian state, announced the launch of an emissions trading scheme (ETS). Under the ETS, an environmental governing body would set a limit on the amount of emissions that can be released with or without permits. From *Business Standard* on June 4, 2019.

Carbon Trading Market Launched.

Universal Solar Technology announced a joint venture to launch the Entrex Carbon Market, which utilized a blockchain-enabled technology platform to trade carbon credits and carbon offsets. The platform allows credits, offsets, and other products to be found, researched, tracked, managed, and traded via regulated entities through a compliant platform. From *Yahoo! Finance* on June 17, 2019.

AUGUST 2019

RGGI Releases Notice and Materials for Auction 45.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for the 45th quarterly CO_2 allowance auction, scheduled for September 4, 2019. The *Auction Notice for CO_2 Allowance Auction 45* provides the information needed to submit a *Qualification Application* for Auction 45, in which the RGGI states will offer 13,116,447 CO_2 allowances for sale at a minimum reserve price of $2.26. A 10 million CO_2 allowance cost containment reserve (CCR) will also be made available (the CCR will be accessed if the interim clearing price exceeds the CCR trigger price of $10.51). From *RGGI News Release* on July 9, 2019.

Carbon Trading Initiative Launched.

An initiative to trade carbon credits from mangrove conservation and restoration on the Kenyan coast was launched. Under the Vanga Blue Forests Project, the Kenya Forest Service and the Community Forest Association will co-manage the mangroves while the Kenya Marine and Fisheries Research Institute will provide technical support to the community. The United Nations (UN) Environment Program also helped to develop the management plan, which includes the sale of carbon credits on the voluntary carbon market, verified by the *Plan Vivo carbon trading standard*. From *UN Environment Program* on July 24, 2019.

SEPTEMBER 2019

RGGI Secondary Market Report Made Available.

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 2019*" addresses the period from April through June 2019. The report is part of Potomac's ongoing monitoring of the RGGI auctions and the secondary markets in which CO_2 allowances are traded, and is based on data reported to the U.S. Commodity Futures Trading Commission and the Intercontinental Exchange, as well as other data. From *RGGI News Release* on August 21, 2019.

RGGI Releases Results of 45th Auction of CO_2 Allowances.

The RGGI-participating states released the results of their 45th auction of CO_2 allowances. Auction 45 saw 13,116,447 CO_2 allowances sold at a clearing price of $5.20, with bids ranging from $2.26 to $8.00 per allowance. None of the 10 million cost containment reserve (CCR) allowances made available were sold. (CCR is a fixed additional supply of allowances only available for sale if CO_2 allowance prices exceed certain price levels [$10.51 in 2019].) More information is available in the *Market Monitor Report for Auction 45*. From *RGGI News Release* on September 6, 2019.

SCIENCE NEWS

OCTOBER 2018

Plant's Ability to Store CO_2 Studied.

Scientists from the University of Washington (USA) have found that higher levels of atmospheric CO_2 may lead to plants storing less carbon. When CO_2 levels in the atmosphere rise, plants thicken their leaves as a result. The research found that plants with thicker leaves may be less efficient in storing atmospheric CO_2, which models had not considered. In their study, which appeared in the journal *Global Biogeochemical Cycles*, the researchers reported that when this data was incorporated into global models under potentially high CO_2 levels, the global "carbon sink" contributed by plants was less productive, leaving approximately 6.39 million tons of CO_2 in the atmosphere per year. From *Science Daily* on October 1, 2018.

Researchers Develop Battery to Capture, Store CO_2.

Researchers from Massachusetts Institute of Technology (MIT) (USA) have developed a new type of battery that could capture and store CO_2 as a solid carbonate mineral. The lithium-based battery could be made partly from CO_2 capture from power plants; instead of converting the CO_2 to specialized chemicals using metal catalysts, the battery could continuously convert it into a solid mineral carbonate as it discharges. The findings were published in the journal *Joule*, in an article titled "*Tailoring the Discharge Reaction in Li-CO_2 Batteries through Incorporation of CO_2 Capture Chemistry.*" From *Carbon Capture Journal* on September 23, 2018.

Study Looks into CO_2 Storage Potential in the United States.

According to a new study, the United States has the potential to double the amount of CO_2 emissions currently captured and stored worldwide within the next six years. The study, conducted by Princeton University (USA), proposed a pipeline network that would transfer CO_2 from ethanol refineries in the American Midwest to oilfields in West Texas, where it would be used for EOR activities. *According to the study, which was published in the Proceedings of the National Academy of Sciences*, the CCS network could prevent up to 30 million metric tons of CO_2 per year from entering the atmosphere. From *Phys.Org* on September 25, 2019.

NOVEMBER 2018

New Report on Negative Emissions Technologies and Carbon Storage.

A new report from the National Academies of Sciences, Engineering, and Medicine provides a research agenda for technologies that capture and store atmospheric CO_2. The report, titled "*Negative Emissions Technologies and Reliable Sequestration*," discusses the role negative emissions technologies (NETs) can have on achieving goals and reducing emissions. NETs remove CO_2 directly from the atmosphere and enhance natural carbon sinks. The report concluded that the NETs available today could be scaled up, but that a research effort is needed to address potential constraints. From *The National Academies of Sciences, Engineering, and Medicine Press Release* on October 24, 2018.

Article Analyzes Impact of CCS on Marine Ecosystems.

Implementing CCS at the point of CO_2 generation is a possible solution to reduce GHGs and their impact on marine ecosystems, according to a recently published article, titled "*Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems*." Researchers assessed 13 ocean-based measures to reduce potential climate change and its impacts on marine ecosystems and ecosystem services. Other possible solutions include shifting from fossil fuels to renewable energy, improving energy efficiency, and protecting and enhancing natural carbon sinks. From *International Institute for Sustainable Development* on October 16, 2018.

DECEMBER 2018

Researchers Turn CO_2 Into Useful Product.

A WVU-led research team is focusing on converting CO_2 in power plant flue gas into commercial-quality sodium bicarbonate (baking soda). Current techniques can increase costs on a clean, coal-fired ultrasupercritical power plant by more than 50 percent, according to data collected by the National Renewable Energy Laboratory. Potential product sales of the converted baking soda would be used to lower the cost of CCS technology. From *West Virginia University Energy Institute* on November 15, 2018.

Researchers Locate Carbon Reserve.

Researchers from Washington State University (USA) conducted a survey to understand the role potential climate change could have on soil's ability to store carbon. By analyzing climate data and soil samples from 65 different dig sites across the world, researchers created a global map of soil-based carbon storage, detailing the way carbon physically and chemically binds to minerals in soil. The data showed that while minimal amounts of carbon are stored in the sediments of deserts and dry forests, an abundance of carbon bound to reactive minerals is stored beneath the surfaces of wet forests. According to the research, *published in the journal Nature Climate Change*, potential climate change won't impact the carbon stored beneath the surface of wet forests, but it may alter the pathway by which new carbon is stored. From *UPI.com* on November 26, 2018.

Researchers Study Arctic Carbon Balance.

New research shows that damage to arctic vegetation can impact its ability to absorb CO_2. In a study *published in the journal Global Change Biology*, a team of researchers from the UK, Norway, and Italy discovered a decline in the amount of CO_2 absorbed by plants affected by an extreme climatic event. The study focused on the Lofoten archipelago in northern Norway. From *Physics World* on November 26, 2018.

JANUARY 2019

Scientists Identify New Minerals for Carbon Capture and Storage.

University of Alberta (Canada) geologists have identified new minerals that are capturing and storing CO_2. Members of the hydrotalcite group, the minerals are the first outside of the carbonate family to naturally capture CO_2 in mine waste. The research, which was *published in the International Journal of Greenhouse Gas Control*, highlights the potential for improving carbon capture one to two meters beneath the surface of mining wastes, where most carbon storage usually occurs. According to researchers, findings of the study, which was conducted at the Woodsreef Asbestos Mine in New South Wales, Australia, point to the potential of mineral waste from mines to more effectively store CO_2. From *ScienceDaily* on December 12, 2018.

New Soil Management Portal Helps Track Carbon Storage.

An Agri-Tech company has launched a Nutrient Management System that has the potential to quantify carbon storage in soil, according to company officials. Farmeye's NMP Portal is an online, map-based system for soil nutrient management and a tool to help manage and monitor fertilizer usage on farms. From *Agri-Land* on December 31, 2018.

Global-Scale Evaluation of Role of Soil Minerals in Carbon Storage.

Scientists from University of California, Santa Barbara, and Washington State University (USA) have found that minerals in soil can store a significant amount of atmospheric CO_2. The researchers conducted a global-scale evaluation of the role soil plays in producing dissolved organic matter and storing it in minerals by consulting soil profiles from the National Ecological Observatory Network (NEON). The results showed that wetter climates are more conducive to the formation of minerals that are more effective at storing CO_2, while more arid climates store less CO_2, thus suggesting that a change in water balance could drive carbon storage. From *ScienceDaily* on January 2, 2019.

Study Shows Organic Particles Effect on Carbon Cycling.

A *new study* analyzed how carbon degraded in different aquatic habitats in Sweden's boreal forests, where CO_2 is often stored in conifers. Conducting the study to better understand carbon transformation and the role of particulate organic carbon (POC) in boreal waters, the researchers found that across all aquatic ecosystems, the degradation rates of POC were approximately 15 times higher than those of dissolved organic carbon (DOC). According to researchers, the results imply that particulate organic matter may play a role in aquatic CO_2 emissions. From *Eos.org* on January 2, 2019.

FEBRUARY 2019

Pair of Studies Detail Accelerated Antarctica Ice Melt.

According to a pair of studies, Antarctica's ice sheet has been melting at an accelerated rate over the past four decades, potentially due to elevated levels of CO_2. Published in the *Proceedings of the National Academy of Sciences, a new study* led by the University of California at Irvine (USA) found that the rate of ice loss in Antarctica has increased from 40 gigatons per year from 1979 through 1990 to 252 gigatons per year from 2009 through 2017 (a six-fold increase). *Another study*, published in the journal *Nature Geoscience* and led by New Zealand's GNS Science, Victoria University of Wellington, and the University of Wisconsin-Madison, found that elevated atmospheric CO_2 levels could be playing a role in the instability of the Antarctica ice sheet. From *CNN* on January 14, 2019.

Research Team Finds Potential CCS Opportunities.

Japanese scientists found a way to separate carbon monoxide (CO) and CO_2, allowing for potential CCS opportunities. The study, conducted by Kanazawa University, used a hollow, spherical cluster of vanadate molecules to separate the molecules. The results found that vanadium in V12 form has the potential to be an ideal solution in CO_2 capture and CO_2 storage. From *Kanazawa University* on January 7, 2019.

Small Trees Impact on CO_2 Storage.

According to a study led by the Royal Museum for Central Africa, small trees can store CO_2 for a longer period of time compared to larger trees due to smaller trees growing slower and living longer. The research, *published in the online journal Nature Plants*, found that small trees have the potential to store CO_2 for an average of 74 years, whereas larger trees can store it for an average of 54 to 57 years. From *Phys.Org* on January 29, 2019.

Consortium Receives Grant to Research CO_2 Storage.

A consortium led by the University of California, Davis, and the UC Working Lands Innovation Center (USA) *received a grant* from California's Strategic Growth Council to research scalable methods of using soil amendments to store GHGs such as CO_2. The consortium will oversee 29 treatment and control sites across California to find out if adding pulverized rock, compost, and biochar to different types of crops and rangelands can store CO_2. The studies are expected to assess whether soil amendments can bring additional co-benefits, such as improved crop and rangeland productivity and soil health, to California growers and ranchers across diverse regions. After three years, the consortium plans to deliver the most promising soil amendment strategies. From *UC Davis News* on January 16, 2019.

MARCH 2019

Seismic Waves Reveal CO_2 Storage Plume in NETL-Supported Research.

Researchers from Penn State University and LBNL are using seismic waves to track CO_2 plumes underground. Supported by NETL, the research found that coda waves, which come after P and S waves following an earthquake or explosion, have the potential to reveal where CO_2 is stored underground. Researchers believe that using permanent seismic sources and coda wave analysis will enable more frequent monitoring than the current standard of intervals. From *Penn State University News* on February 26, 2019.

Scientists Study Long-Term Storage Capability of Peatlands.

An international group of scientists conducted a study of global peatland and carbon storage over the last 130,000 years to gauge peatlands' effectiveness as a long-term carbon storage mechanism over a long timescale. Peatlands, which are a type of wetland formed by incompletely decomposed organic matter and water, comprise approximately three percent of the Earth's land area, but contain approximately one-third of the global soil carbon, according to the study. From *EurekAlert!* on February 25, 2019.

APRIL 2019

Researchers Study Mineral Trapping for CO_2 Storage.

A computational study conducted by a Japanese-led group of international researchers showed the potential for "mineral trapping" to be used for CO_2 storage. Researchers from Kyushu University ran computer simulations of CO_2 reacting with rock surfaces to show how trapped CO_2 can be converted into minerals. The results of the simulations were *published in The Journal of Physical Chemistry C*. From *EurekAlert!* on March 8, 2019.

Bamboo May Have Carbon Storage Potential.

Farmers in the Philippines' province of Antique are being asked to plant more bamboo to mitigate potential CO_2 emissions. According to speakers at the "Change Adaptation and Mitigation Summit of the Provincial Disaster Risk and Reduction and Management Council," bamboo is a potential resource for carbon storage. From *Panay News* on March 24, 2019.

Scientists Turn CO_2 Into Solid Carbon for Storage.

Research conducted by RMIT University, Melbourne, Australia, has led to the development of a new CO_2 capture process that converts CO_2 gas into solid carbon, making it easier to store. Researchers used a liquid metal electrocatalyst to convert the CO_2 at room temperature; previously developed electrocatalysts were only able to convert CO_2 to solid carbon at temperatures above 600°C. Results of the study were *published in the journal Nature Communications*. From *The Chemical Engineer* on March 25, 2019.

Scientists Measure Ocean Sink for CO_2 Emissions.

An international team of scientists studied the amount of manmade CO_2 emissions stored in the ocean from 1994 to 2007. According to their research, *published in the journal Science*, the ocean stored as much as 34 gigatons of manmade atmospheric CO_2 during the 13-year span (31 percent of all anthropogenic CO_2 emitted during that time). From *chemeurope.com* on March 18, 2019.

Technique Could Lead to CO_2 Reductions.

A team of researchers from Washington State University is working to develop ways to capture, store, and use the CO_2 emitted during energy production. In their research, *published in the journal ACS Applied Materials and Interfaces*, the team developed a way to create hollow, nanorod-shaped porous materials to separate the CO_2 in a way that is applicable to real-life conditions. From *Washington State University News* on February 26, 2019.

MAY 2019

Researchers Develop Mechanical Trees to Capture, Store CO_2.

Researchers from Arizona State University (USA) have developed a cluster of "mechanical trees" capable of capturing CO_2 and storing it for industrial or agricultural use. A cluster of 12 trees has the potential to remove one metric ton of CO_2 from the atmosphere per day. The technology will be deployed in a pilot CO_2 farm targeting 100 metric tons of CO_2 capture per day; according to researchers, full-scale CO_2 farms using the mechanical trees should be capable of removing 3.8 million metric tons of CO_2 per year. From *The Engineer* on April 29, 2019.

Study Explains How Oceans Store CO_2.

Research led by the University of California, Santa Barbara (USA) was performed to study mechanisms of ocean carbon storage to improve understanding of how CO_2 moves in the ocean. *The study, which appears in the journal Nature*, discusses "particle injection pumps," which represent a multidimensional approach to account for carbon movement in the deep ocean. From *UC Santa Barbara News* on April 10, 2019.

Plastic Eaten by Plankton May Impair Ocean's Ability to Store CO_2.

According to a study conducted by Irish researchers, the consumption of microplastics by plankton has the potential to reduce the efficiency of the ocean's ability to store CO_2 on the seafloor. Marine scientists from the Ryan Institute at the National University of Ireland in Galway found that microscopic fragments of waste plastic might be interfering with the marine food chain, altering the density of faecal pellets and reducing the speed at which they sink to the seafloor. According to the research, published in the journal *Environmental Science and Technology*, the longer the faecal pellets remain at the sea surface, the greater their potential to be broken down as CO_2 and released into the ocean and atmosphere. From *The Irish Times* on April 30, 2019.

JUNE 2019

Scientists Study Seaweed's Ability to Store CO_2.

New research measured the importance of the coastal ocean as a potential global carbon sink and the relevance of macroalgae (seaweed) in storing CO_2. Led by scientists from the U.K.'s Plymouth Marine Laboratory, the study assessed how much of the organic macroalgal CO_2 was stored in the sediment. In addition, the study, which was part of the Natural Environmental Research Council and the U.K.'s Department for the Environment, Food, and Rural Affairs-funded Marine Ecosystems Research Programme, highlighted the importance of macroalgae in supporting seabed organisms through the winter months when other food resources were low, as well as how they contribute to carbon storage. From *Plymouth Marine Laboratory* on May 23, 2019.

New Process Converts CO_2 Into Useful Products.

Researchers from the University of Toronto (U of T) engineering department developed a new electrochemical path to convert CO_2 into valuable products. Currently, implementing DAC technology to convert CO_2 requires temperatures above 900°C; the U of T's alternative process applies an electrolyzer to drive chemical reactions, skipping the heating step. From *Carbon Capture Journal* on June 3, 2019.

Patent Awarded to Store CO_2 During Crop Harvesting.

A Newton, Kansas (USA) company received a patent from the U.S. Patent Office for a system that will enable farmers to permanently store CO_2 in the soil. The new TRIBINE Harvester system will be used during grain harvesting and, according to officials, has the potential to store up to 1.4 tons of CO_2 per acre in the soil when combined with other crop practices. From *High Plains Journal* on May 29, 2019.

JULY 2019

Researchers Study Ice Age CO_2 Levels.

New research conducted by scientists at Oregon State University claims that the lower atmospheric CO_2 levels during the ice age could be attributed in part to seawater temperature variation. According to the study, which was *published in the journal Science Advances*, the difference in ocean surface temperatures between the high latitudes and the mid latitudes was significant during the warm phases of the ice age. As the warmer water moved toward Antarctica and began to cool, the lost heat went into the atmosphere, increasing the ocean's potential to store CO_2. From *Oregon State University Press Release* on June 12, 2019.

Company Launches Initiative to Capture, Store CO_2.

A Boston, Massachusetts (USA) company launched an initiative to accelerate carbon storage. According to Indigo Agriculture officials, *the Terraton Initiative* seeks to utilize the potential of agricultural soils to remove 1 trillion tons of atmospheric CO_2. From *Indigo Agriculture Press Release* on June 12, 2019.

Researchers Develop Organisms to Convert CO_2.

Researchers from the University of Colorado Boulder's Department of Chemical and Biological Engineering developed organisms capable of using CO_2 to produce a variety of plastics and fuels. By using light-activated quantum dots to fire particular enzymes within microbial cells, the researchers were able to create nanobio-hybrid organisms that "eat" CO_2 and convert it into useful products such as biodegradable plastic, gasoline, ammonia, and biodiesel. Findings of the study, which were published in the *Journal of the American Chemical Society*, are expected to help researchers develop low-cost carbon storage. From *University of Colorado Boulder* on June 11, 2019.

Tropical Soil Disturbance Could Be Source of CO_2.

According to a new study, CO_2 that had previously been stored in the Earth for millennia could now be re-entering the carbon cycle. Researchers from Florida State University studied 19 sites in the eastern Democratic Republic of the Congo and discovered that thousand-year-old tropical soil unearthed by deforestation and agriculture land use could be releasing CO_2 into the atmosphere. The study was *published in the journal Nature Geoscience*. From *Phys.org* on June 24, 2019.

Researchers Convert CO_2 into Liquefiable Fuels.

Researchers from the University of Illinois developed an artificial photosynthesis process that converts CO_2 into fuels. In the study, *published in the journal Nature Communications*, the researchers developed a process that uses the same green light portion of the visible light spectrum during natural photosynthesis to convert CO_2 and water into fuel, in conjunction with electron-rich gold nanoparticles that serve as a catalyst. From *University of Illinois News Bureau* on June 24, 2019.

AUGUST 2019

Scientists Engineering Plants to Store CO_2.

Researchers at Salk Institute's Harnessing Plants Initiative (USA) discovered a gene with the potential to optimize a plant's natural ability to capture and store CO_2. The deeper a plant's root system, the better the plant's ability to store CO_2; the gene discovered by Salk researchers, called EXOCYST70A3, has the ability to determine how deep a plant's roots grow in soil. According to the study, *published in the journal Cell*, the EXOCYST70A3 gene can be altered, enabling the plant's root system to grow more deeply. From *Science Alert* on July 15, 2019.

Forest Elephant Extinction Linked to Carbon Storage.

Biologists from Saint Louis University (USA) conducted a study of the effect of potential elephant extinction on forest composition. According to their findings, forest elephants prefer to browse on fast-growing trees, enabling slow-growing trees, which are capable of storing more CO_2, to be more dominant. Therefore, the extinction of forest elephants, *according to the study published in the journal Nature Geoscience*, could potentially cause an increase in the fast-growing trees at the expense of the slow-growing trees, thus reducing the forest's ability to store CO_2. From *Newswise* on July 24, 2019.

SEPTEMBER 2019

Study Identifies Way to Enhance Soil Sustainability.

Scientists from the University of Plymouth (United Kingdom) demonstrated that adding biochar (a product of biomass) to soils constructed from waste materials has the potential to improve manufactured soil sustainability by enhancing conditions suitable to sustain plant growth, such as carbon storage capacity. The study was *published in the journal Science of the Total Environment*. From *University of Plymouth News* on August 2, 2019.

Refitted Oil Rigs Could Store CO_2.

A research study found that North Sea oil and gas rigs could be modified to pump CO_2 emissions into formations below the seabed. Researchers from the University of Edinburgh used a computer model to analyze data from the Beatrice oil field (located 15 miles off the north east coast of Scotland), and found that making modifications to existing platforms is potentially less costly than decommissioning the oil field. The study was *published in the International Journal of Greenhouse Gas Control*. From *University of Edinburgh School of Geosciences* on August 9, 2019.

Structurally Complex Forests Better at Carbon Storage.

According to a study *published in the journal Ecology*, a forest's structural complexity is a better predictor of its carbon storage potential than tree species diversity. The study, conducted by researchers from Virginia Commonwealth University (USA), found that forests in the Eastern United States with highly varied arrangements of vegetation have the potential to store more carbon. The study suggests that using light detection and ranging to map forest structure could predict the potential of forests to store carbon in biomass better than conventional approaches. From *Phys.Org* on August 12, 2019.

Study Looks Into Plants' CO_2 Storage Potential.

A team of international researchers mapped the potential of today's plants and trees to store extra CO_2 by the end of the century. By analyzing 138 experiments, the researchers found that trees and plants have the potential to increase their biomass (organic material) by 12% when exposed to concentrations of CO_2 predicted for the year 2100. According to the results, *published in the journal Nature Climate Change*, the extra growth could draw enough CO_2 from the atmosphere to remove several years of current emissions. From *Imperial College London* on August 12, 2019.

JOURNAL ARTICLES

OCTOBER 2018

A novel experimental system for the exploration of CO_2-water-rock interactions under conditions relevant to CO_2 geological storage.

The following is the abstract of this article: "This paper describes the design and experimental validation of a novel flow-through reactor system conceived for experimental studies to determine the kinetics and thermodynamics of mineral precipitation and dissolution in environmental conditions relevant to CO_2 geological storage. The experimental system was designed to work under a confining pressure of up to 150 bar, temperature up to 150°C and corrosive conditions. The unique design allows the injection of precise amounts of liquid CO_2 into the reactor while avoiding the formation of multiple CO_2 phases. The modular design enables the in-situ measurement of pH using a pressure resistant in-line probe and electronic gauges which record pressure and temperature at multiple points. The system enables the user to withdraw liquid samples without disturbing the experimental conditions in the reactor. Customized computer software was developed and connected to the system to provide automatic data-logging capabilities, remote process control and the ability to partially shut-down the system in case of safety issues." **Pedro M. Rendel, Domenik Wolff-Boenisch, Ittai Gavrieli, and Jiwchar Ganor,** *Chemical Engineering Journal.* (Subscription may be required.)

Natural enhancement and mobility of oil reservoirs by supercritical CO_2 and implication for vertical multi-trap CO_2 geological storage.

The following is the abstract of this article: "The accumulation and production of both deep mantle-derived CO_2 and light oil were discovered in the Huangqiao reservoir, which is located in the Subei Basin, East China. The Huangqiao reservoir shows that both CO_2 and oil are entrapped in and produced from vertical multi-traps. The effects of deep CO_2 on the accumulation and production of oil under natural conditions and the implications for CO_2 geological storage are investigated in detail. The fluid inclusions in quartz or calcite veins from the Silurian Fentou Formation ($S_{2\text{-}3}f$), Permian Longtan Formation (P_2l) and Triassic Qinglong Formation (T_1q) have homogenization temperatures (Ths) that display peak ranges of 180°C–190 °C, 170°C–180 °C and 150°C–160 °C, respectively. The Ths are higher than the formation temperatures. The calcite veins have light carbon and oxygen isotope compositions and have high $^{87}Sr/^{86}Sr$ ratios and positive Eu anomalies. These characteristics reveal the activities of deep CO_2-rich hydrothermal fluids in the basin strata. The feldspar in the $S_{2\text{-}3}f$ and P_2l sandstone reservoirs underwent significant dissolution because of the presence of CO_2-rich fluids, forming of a large amount of secondary pores in the sandstone reservoirs and enhancing the reservoirs' physical properties. The measured porosity reaches 12.3%. CO_2 in a supercritical state extracted or dissolved light petroleum components out of sedimentary rocks and then carried them towards reservoirs. Thus, CO_2 and oil co-accumulated in the enhanced reservoirs, e.g. $S_{2\text{-}3}f$, P_2l and T_1q. During drilling development, this supercritical CO_2 naturally increased the mobility of oil, resulting in the co-production of highly pure CO_2 and light oil. Based on the unique features of the Huangqiao CO_2-oil reservoir, [the authors] propose a new CO_2 geological storage model, namely, a vertical multi-trap geological storage model, which can either entrap large volumes of CO_2 or lower the risk of long-term storage." **Dongya Zhu, Qingqiang Meng, Quanyou Liu, Bing Zhou, Zhijun Jin, and Wenxuan Hu,** *Journal of Petroleum Science and Engineering.* (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.)

Policy Insights from the EMF 32 Study on U.S. Carbon Tax Scenarios.

The following is the abstract of this article: "The Stanford Energy Modeling Forum exercise 32 (EMF 32) used 11 different models to assess emissions, energy, and economic outcomes from a plausible range of economy-wide carbon price policies to reduce CO_2 emissions in the United States. Here [the authors] discuss the most policy-relevant results of the study, mindful of the strengths and weaknesses of current models. Across all models, carbon prices lead to significant reductions in CO_2 emissions and conventional pollutants, with the vast majority of the reductions occurring in the electricity sector. Importantly, emissions reductions do not significantly depend on the rebate or tax cut used to return revenues to the economy. Expected economic costs, as modeled by either GDP or welfare, are modest, but vary across models. These costs are offset by benefits from avoided climate damages and health benefits from reductions in conventional air pollution. Using revenues to reduce preexisting capital or labor taxes reduces costs in most models relative to lump-sum rebates, but the size of the cost reductions varies significantly. Devoting at least some revenue to household rebates can significantly reduce adverse impacts on low income households. Carbon prices at $25/ton or even lower levels cause significant shifts away from coal as an energy source with responses of other energy sources highly dependent upon technology cost assumptions. Beyond 2030, [the authors] conclude that model uncertainties are too large to make quantitative results useful for near-term policy design. [The authors] close by describing recommendations for policymakers on interacting with model results in the future." **Alexander R. Barron, Allen A. Fawcett, Marc A. C. Hafstead, James R. McFarland, and Adele C. Morris,** *Climate Change Economics.* (Subscription may be required.)

Tech-economic assessment of second-generation CCS: Chemical looping combustion.

The following is the abstract of this article: "Chemical looping combustion (CLC) is regarded as the most promising technology for CO_2 capture to mitigate [GHG] effect. In this work, a technical and economic performance of [methane (CH4)]-feed CLC power plant by means of utilizing promising nickel-, copper-, and ilmenite-based oxygen carriers is studied. Nickel-based CLC power plant has the highest net power efficiency of 50.14%, followed by 48.02% for ilmenite-based case and 45.59% for copper-based case. By contrast nickel-based case has a specific CO_2 emission of 1.44 kg/MW h, which is dramatically lower than the referenced [natural gas combined cycle (NGCC)] with CCS system (40.10 kg/MW h). The economic [analyses] reveal nickel-based case is most economic-benefits due to the lowest cost of electricity (COE) of 71.66€/MW h, approximately 0.32 €/MW h and 13.06 €/MW h COE reduction benefits have been increased in comparison with ilmenite-based and copper-based case, respectively. The natural gas price has an important influence on COE, as approximately 49.73%, 48.60% and 56.30% of COE enhancement is expected with the natural gas price ranging in 4–8 €/GJ for nickel-based, copper-based, and ilmenite-based case, respectively. Finally a comparison between [natural gas combined cycle (NGCC)] and CLC-related power system in terms of economic performance further demonstrates the feasibility of the latter system." **Lin Zhu, Yangdong He, Luling Li, and Pengbin Wu,** *Energy.* (Subscription may be required.)

Mass flow measurement of gas-liquid two-phase CO_2 in CCS transportation pipelines using Coriolis flowmeters.

The following is the abstract of this article: "CCS is a promising technology that stops the release of CO_2 from industrial processes such as electrical power generation. Accurate measurement of CO_2 flows in a CCS system where CO_2 flow is a gas, liquid, or gas-liquid two-phase mixture is essential for the fiscal purpose and potential leakage detection. This paper presents a novel method based on Coriolis mass flowmeters in conjunction with least squares support vector machine (LSSVM) models to measure gas-liquid two-phase CO_2 flow under CCS conditions. The method uses a classifier to identify the flow pattern and individual LSSVM models for the metering of CO_2 mass flowrate and prediction of gas volume fraction of CO_2, respectively. Experimental work was undertaken on a multiphase CO_2 flow test facility. Performance comparisons between the general LSSVM and flow pattern based LSSVM models are conducted. Results demonstrate that Coriolis mass flowmeters with the LSSVM model incorporating flow pattern identification algorithms perform significantly better than those using the general LSSVM model. The mass flowrate measurement of gas-liquid CO_2 is found to yield errors less than ±2% on the horizontal pipeline and ±1.5% on the vertical pipeline, respectively, over flowrates from 250 kg/h to 3200 kg/h. The error in the estimation of CO_2 gas volume fraction is within ±10% over the same range of flow rates." **Lijuan Wang, Yong Yan, Xue Wang, Tao Wang, Quansheng Duan, and Wenbiao Zhang,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

How China's current carbon trading policy affects carbon price? An investigation of the Shanghai Emission Trading Scheme pilot.

The following is the abstract of this article: "To better establish a unified carbon market in China, this study evaluates the effect of current carbon trading policy and further investigates the relationship between such policy that is published during the second phase of Shanghai Environment and Energy Exchange (SEEE) and Shanghai Emission Allowance (SHEA) price. [The authors] aim to analyze whether these policies can improve the operation efficiency of current carbon market. By the Mean Reversion Test, Cox-Ingersoll-Ross (CIR) Model, and Event Study Method, [the authors] first analyze the potential price discovery function of SHEA products, thereby describing the transmission channel of current policy to SHEA price. Then [the authors] examine the effect of carbon policies published in different periods on their corresponding SHEA price. By the Auto-correlation Test and CIR simulation, [the authors] find that 3/4 of all auto-correlation values are less than 0 after Apr. 2017, and the minimum cumulative error is 31.3792 under the supply and demand channel. These findings imply that SHEA price has the discovery function at the middle and end of trading period, and the current policy affects SHEA price through its effect on the fundamentals of supply and demand. Further, more than 60% of all r-values (r-value that reflects the response of price to policy) are less than 1, which implies that the published policy will improves future SHEA price. Accordingly, [the authors] argue that SEEE belongs to a policy-oriented market, and the change of carbon price is closely related to emission allocation policies. In this case, China's government should further push forward the smooth operation of current carbon market by the aid of incentive policy in the coming period." **Yazhi Song, Dapeng Liang, Tiansen Liu, and Xiaoqiu Song,** *Journal of Cleaner Production.* (Subscription may be required.)

Carbon pricing and system linking: Lessons from the New Zealand Emissions Trading Scheme.

The following is the abstract of this article: "Textbook theory of linking carbon systems suggests linking reduces marginal abatement costs. Contrasting theoretical work and policy analyses suggests that linking, or at least unfettered linking, may not always be beneficial. The New Zealand Emissions Trading Scheme (NZ ETS) is unique in that, until 2013, it allowed unlimited use of Kyoto allowances. NZ ETS, thus provides an ideal context to explore the effect of linking and linking restrictions on carbon pricing of small systems. Using data on importation and exportation of allowances, [the authors] provide the first empirical analysis of the determinants of allowance prices in the early phase of the NZ ETS. [The authors'] results indicate that imports of offsets rather than fundamentals have been the major price determinant. Moreover, the pricing of New Zealand units (NZUs) can be placed into three distinct periods, delineated by two structural breaks. In the first period, the system is largely autarkic; in the second period, as international offset prices drop below the NZU price, the system becomes a 'price taker'; in the final period, following policy interventions, the system regains some independence. The case of the NZ ETS shows that small trading systems need to impose, or have the option to impose, quantitative import restriction so as to reap the benefits (lower abatement cost), but not the drawbacks ('importation' of distortions and market integrity issues), of linking." **Ivan Diaz-Rainey and Daniel J. Tulloch,** *Energy Economics.* (Subscription may be required.)

NOVEMBER 2018

Enhanced safety of geologic CO_2 storage with nanoparticles.

The following is the abstract of this article: "Some methods have been developed to detect leakage of CO_2 from its desired storage domain, but that is not sufficient to prevent and mitigate a leak. Two techniques have been proposed to prevent the migration of buoyant CO_2 from the storage domain by expediting mixing of CO_2 with the brine and mitigate risk of its leakage risk. These two methods are injection of CO_2 pre-mixed with brine, and injection of CO_2 with nanoparticles (NPs). The former has been studied to some extent, however, understanding of the latter is very limited. Unlike the application of NPs in hydrocarbon recovery, its use to enhance safety of CO_2 storage is a fairly unexplored topic that can have important benefits for the safety of the storage process. Also, the use of NPs for subsurface application in general is compromised for its cost. [The authors] investigate how NPs produced from low-level nuclear waste can be added with injected CO_2 to enhance the mixing of CO_2 with brine, which can mitigate leakage risk of CO_2. [The authors] numerically investigate the effect of adding NPs from nuclear waste with the CO_2 and show that it enhances the mixing of CO_2 with in-situ brine in saline aquifers that mitigates the risk related to buoyancy and high mobility of CO_2. Additionally, [the authors] examine the effect of reservoir heterogeneity on mixing of CO_2 in reservoir brine when it is injected with NPs. The results show that: (i) addition of NPs to CO_2 leads to higher mixing, (ii) the discrete shape of CO_2 concentration in brine tends to diffuse and become smooth as the heterogeneity of the medium increases, and (iii) the impact of heterogeneity is more pronounced than the fraction of NPs on mixing." **Harpreet Singh and Akand Islam,** *International Journal of Heat and Mass Transfer.* (Subscription may be required.)

Pricing forest carbon: Implications of asymmetry in climate policy.

The following is the abstract of this article: "Using an integrated assessment model, [the authors] examine the implications of climate policies that do not fully recognize forest carbon. Specifically, [the authors] first investigate the impact of an asymmetric policy that recognizes carbon emissions from fossil fuels while fully ignoring forest carbon. Next, [the authors] investigate the relative importance of not recognizing emissions from a reduction in the stock of forest biomass compared to not recognizing sequestration from the growth of forest biomass. [The authors] show that asymmetric carbon policies lead to lower levels of welfare, as well as higher emissions and carbon prices. This occurs because the forest resource will be allocated inefficiently under these carbon policies. Broadly, [the authors] find that when the social planner does not account for emissions or sequestration from the forest, the planner will set bioenergy levels that are too high and afforestation and avoided deforestation levels that are too low. [The authors'] results further reveal that not recognizing forest emissions leads to larger welfare losses than not recognizing sequestration." **Mathilda Eriksson, Runar Brännlund, and Tommy Lundgren,** *Journal of Forest Economics.* (Subscription may be required.)

The impact of gradational contact at the reservoir-seal interface on geological CO_2 storage capacity and security.

The following is the abstract of this article: "The implementation of CO_2 storage in sub-surface sedimentary formations can involve decision making using relevant numerical modelling. These models are often represented by 2D or 3D grids that show an abrupt boundary between the reservoir and the seal lithologies. However, in an actual geological formation, an abrupt contact does not always exist at the interface between distinct clastic lithologies such as sandstone and shale. This article presents a numerical investigation of the effect of sediment-size variation on CO_2 transport processes in saline aquifers. Using the Triassic Bunter Sandstone Formation (BSF) of the Southern North Sea (SNS), this study investigates the impact a gradation change at the reservoir-seal interface on CO_2 sequestration. This is of great interest due to the importance of enhanced geological detail in reservoir models used to predict CO_2 plume migration and the integrity of trapping mechanisms within the storage formation. The simplified strategy was to apply the Van Genutchen formulation to establish constitutive relationships for pore geometric properties, which include capillary pressure (Pc) and relative permeability (kr), as a function of brine saturation in the porous media. The results show that the existence of sediment gradation at the reservoir-seal interface and within the reservoir has an important effect on CO_2 migration and pressure diffusion in the formation. The modelling exercise shows that these features can lead to an increase in residual gas trapping in the reservoir and [localized] pore pressures at the caprock's injection point." **Michael U. Onoja and Seyed M. Shariatipour,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

[Decarbonization] of the Industrial Sector by means of Fuel Switching, Electrification and CCS.

The following is the abstract of this article: "The industrial sector will have to undergo major changes in order to reduce its emissions with the goal of climate change mitigation. In this context, the iron and steel subsector accounts for the highest CO_2 emissions share. This work uses a simulation model of the global energy system and quantifies the impacts of different measures for CO_2 reduction (such as fuel switching, electrification and Carbon Capture and Storage - CCS) on investment and operation decisions. The reported scenarios consider the implementation of a CO_2 price as a policy instrument to [decarbonize] the industrial sector. The selected case study covers steel production in the USA up to the year 2050. The results show that single measures such as fuel switching, electrification and CCS adoption alone have a limited impact on the [decarbonization] of the iron and steel sector and should be rather implemented all together in an integrated approach towards climate change mitigation." **Sandro Luh, Sara Budinis, Thomas J. Schmidt, and Adam Hawkes,** *Computer Aided Chemical Engineering.* (Subscription may be required.)

A meta-frontier DEA approach to efficiency comparison of carbon reduction technologies on project level.

The following is the abstract of this article: "Carbon reduction technologies such as renewable energy, nuclear energy and CCS technology for the power industry play a significant role in achieving low-carbon development goals. This research employed a meta-frontier DEA approach to evaluate carbon reduction efficiency of technologies on project level. The sample consists of several groups of projects such as nuclear energy, hydro-electric energy, wind energy, solar energy and biomass energy and CCS technology in power plants. The comparison study takes consideration the carbon reduction efficiency gap and management level of different technologies for the power industry. The results reveal that 1) Biomass energy power plants and conventional power plants installed with CCS have the highest efficiency in carbon reduction efficiency, with potential improvement in management. 2) Nuclear power plants show a high efficiency in carbon reduction while facing some constraints from safety and stability issues. 3) Although wind power, hydro-electric power and solar power have been exploited in power generation for a long time, they still have low efficiency in reducing carbon emission from the power industry. Suggestions are provided for policy makers to choose appropriate low-carbon development route of the power industry." **Nannan Wang, Ji Chen, Shengnan Yao, and Yen-Chiang Chang,** *Renewable and Sustainable Energy Reviews.* (Subscriptions may be required.)

An integrated measurement of household carbon emissions from a trading-oriented perspective: A case study of urban families in Xuzhou, China.

The following is the abstract of this article: "The measurement of household carbon emissions from a trading-oriented perspective has become increasingly important and urgently required due to the growing attention to personal carbon trading. From a trading-oriented perspective, this study established an integrated measurement system of household carbon emissions that consists of four modules: direct carbon emissions produced by energy use and private transport, and indirect carbon emissions produced by the consumption of a portion of non-energy goods and services and waste disposal. The emissions coefficient method and input–output model were then adopted to systematically calculate the carbon emissions coefficients of 31 items related to household activities. Furthermore, this study developed an integrated measurement scale of household carbon emissions that includes 23 questions based on the integrated measurement system. Additionally, the carbon emissions of three urban families in Xuzhou were measured and analyzed using the integrated measurement scale, which exhibits the simple, clear, and calculable characteristics of the integrated measurement system and integrated measurement scale. This study provides new perspectives for the measurement of household carbon emissions and valuable references for the research and implementation of personal carbon trading scheme, and then contributes to the reduction of households' carbon emissions." **Daoyan Guo, Hong Chen, Ruyin Long, and Yingzhe Ni,** *Journal of Cleaner Production.* (Subscription may be required.)

A general equilibrium analysis on the impacts of regional and sectoral emission allowance allocation at carbon trading market.

The following is the abstract of this article: "It is critical to adapt to climate change and reduce the overall carbon emissions. China announced its Nationally Determined Contributions (NDC) at the Paris climate conference in 2015. The carbon cap-and-trade scheme, which plays a key role in carbon emissions abatement, is an effective policy for China to achieve its NDC. This study focuses on the allocation of regional and sectoral initial carbon emission allowances in Shanghai. An impact evaluation on the macro-economy, carbon trading markets and participating sectors for the year 2030 was conducted by applying a computable general equilibrium (CGE) model. The results show that the carbon cap-and-trade scheme would cause a 3.4% GDP loss and an 8.9% welfare loss in 2030. The carbon price would be 161.2 USD/t and 147.2 USD/t under the two representative scenarios. The allocation of initial allowances would have a significant impact on both carbon market scale and sectoral trading behaviors. The power generation sector and the petrol oil sector would undertake the greatest output loss, while the metal smelting sector

would become the main seller. Furthermore, the initial allowances allocation under a certain abatement target would hardly affect sectoral production but remarkably affect trade behaviors at the carbon trading markets." **Zhongjue Yu, Yong Geng, Hancheng Dai, Rui Wu, Zhiqing Liu, Xu Tian, and Raimund Bleischwitz,** *Journal of Cleaner Production*. (Subscription may be required.)

DECEMBER 2018

Probabilistic evaluation of multi-fluid-phase carbon dioxide storage capacities of saline formations in the Pohang Basin, Korea using three-dimensional geologic modeling and grid-based Monte Carlo simulation.

The following is the abstract of this article: "A series of probabilistic evaluation is performed sequentially using three-dimensional geologic modeling and grid-based Monte Carlo simulation as a linked methodology to estimate multi-fluid-phase (i.e., individual gas-, liquid-, supercritical-, and whole fluid-phase) CO_2 storage capacities of the target clastic saline formations in the Pohang Basin, Korea. The Pohang Basin is subdivided into the six geologic formations including the two clastic saline formations, which are the sandstone-dominant Fluvial Conglomerate and Sandstone (FCSS) and Shallow Marine Sandstone (SMSS) in ascending order. The results of the three-dimensional geologic modeling show that the six geologic formations are distributed very complicatedly both onshore and offshore with irregular depths and thicknesses, and they are partly dissected and offset by the eight major faults. The two clastic saline formations FCSS and SMSS are deep and thick at the three prospective areas such as Areas 1, 2, and 3 in the modeling domain. The results of the grid-based Monte Carlo simulation show the following three main contents. First, in the two clastic saline formations SMSS and FCSS, CO_2 exists as gas, liquid, and supercritical phases with the corresponding distinctive density ranges depending on the pressure and temperature with depth. Second, the theoretical multi-fluid-phase CO_2 storage capacities of the SMSS and FCSS all show asymmetric normal distributions. On the other hand, the effective multi-fluid-phase CO_2 storage capacities of the saline formations all show log-normal distributions, and their values are much lower than the values of the theoretical multi-fluid-phase CO_2 storage capacities. The mean theoretical fluid-phase CO_2 storage capacities of the SMSS and FCSS are equal to 2,511.60 Mton and 1,370.91 Mton, respectively. The mean effective fluid-phase CO_2 storage capacities of the SMSS and FCSS are equal to 64.19 Mton and 35.32 Mton, respectively. Third, in the SMSS, the grid-wise (elemental) median theoretical and effective multi-fluid-phase CO_2 storage capacities are probabilistically higher at Area 1 (mainly as supercritical and liquid phases), intermediate at Area 2 (mainly as liquid and gas phases), and lower at Area 3 (mainly as a gas phase). However, in the FCSS, the grid-wise median theoretical and effective multi-fluid-phase CO_2 storage capacities are probabilistically higher at Area 2 (mainly as supercritical and liquid phases), intermediate at Area 1 (mainly as a supercritical phase), and lower at Area 3 (mainly as a gas phase). Finally, four key criteria (parameters) for selecting or ranking the optimal CO_2 storage locations are decided by summarizing and analyzing the results of the three-dimensional geologic modeling and grid-based Monte Carlo simulation. On the basis of the four key criteria (parameters), the overall suitability ranks of Areas 1, 2, and 3 for geologic CO_2 storage are determined to be the first, second, and third, respectively." **Jai-Yong Park, Sungho Lee, Jung-Hwi Kihm, Jun-Mo Kim, and Yong Il Lee,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Cost-efficient climate policies for interdependent carbon pools.

The following is the abstract of this article: "The purpose of this paper is to investigate cost-effective climate policy instruments for bioenergy and timber, adapted to the impacts on interdependent forest carbon pools, and applied in the [European Union (EU)] climate policy to 2050. [The authors] develop a discrete time dynamic model including forest carbon pools in biomass, soil, and products, as well as fossil fuel consumption. The analytical results show that the optimal taxes on forest products depend on the growth in the respective carbon pool. The application to the EU 2050 climate policy for emission trading shows that total costs for target achievement can be reduced by 33 percent if all carbon pools are included, and the carbon tax on fossil fuel can be reduced by 50 percent. Optimal taxes on forest products differ among countries and over time depending on the potential for increased carbon sequestration over the planning period." **Katarina Elofsson and Ing-Marie Gren,** *Environmental Modelling & Software*. (Subscription may be required.)

Reducing emissions in transportation and inventory management: (R, Q) Policy with considerations of carbon reduction.

The following is the abstract of this article: "In this study, [the authors] examine three approaches on the effects of controlling carbon emissions in transportation and inventory management. A Business-As-Usual Scenario Model (BAUSM), which delineates how carbon footprints from inventory storage and related transportation are captured, is firstly developed as the benchmark model. Based on BAUSM, [the authors] then develop three models with different carbon reduction approaches. The first one is constructed by adding a constraint to represent the percentage target of emission reduction. The second one integrates carbon taxes (or cap-and-trade scheme) into inventory management, and the last one takes both reduction target and carbon offset opportunities into account. [The authors'] work provides new analytical models, which integrate cost and emissions in transportation and storage under the framework of continuous inventory review (R, Q) policy for stochastic demand. Optimization algorithms are developed for solving models and related properties are investigated to examine the effects of carbon reduction and associated costs of three models. The policy implications of the models are examined and discussed to provide insights for reference of the practitioners and the policy makers." **Tang, Shaolong; Wang, Wenjie; Cho, Stella; and Yan, Hong,** *European Journal of Operational Research*. (Subscription may be required.)

Residual trapping of carbon dioxide during geological storage —Insight gained through a pore-network modeling approach.

The following is the abstract of this article: "To reduce emissions of the [GHG] CO_2 to the atmosphere, sequestration in deep saline aquifers is a viable strategy. Residual trapping is a key containment process important to the success of CO_2 storage operations. While residual trapping affects CO_2 migration over large scales, it is inherently a pore-scale process. Pore-network models (PNMs), capturing such processes, are useful for… understanding of residual trapping, and for upscaling trapping parameters for larger scale models. A PNM for simulation of quasi-static two-phase flow; CO_2 intrusion (drainage) followed by water flooding (imbibition) was developed. It accounts for pore-scale displacement mechanisms, and was used to investigate residual CO_2 trapping. The sensitivity of the residual CO_2 saturation to several parameters was studied, to validate a trapping behavior in agreement with earlier studies. Then the PNM was calibrated to core sample data and used to simulate drainage-imbibition scenarios with different turning point saturations. From these the initial-residual saturation curves of CO_2 in Heletz sandstone were estimated, essential for future macroscopic-scale simulations. Further, the occurrence of different pore-scale mechanisms were quantified and the size distribution of the residual clusters was shown to exhibit a bimodal appearance. The findings improve the understanding of residual trapping in Heletz sandstone." **K. Rasmusson, M. Rasmusson, Y. Tsang, S. Benson, F. Hingerl, F. Fagerlund, and A. Niemi,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

On the variability of CO_2 feed flows into CCS transportation and storage networks.

The following is the abstract of this article: "The flexible operation of CO_2 injection wells presents significant challenges. To avoid premature degradation of wells or loss of integrity it is imperative to understand the feed flow patterns that future CO_2 transportation and storage networks will face. [The authors] use a unit commitment economic dispatch (UCED) model to study CCS operating regimes in low carbon energy systems scenarios that are [characterized] by high shares of weather dependent renewable power generation. Using the case study of Great Britain, [the authors] determine the extent to which flexible operation of CCS plants is required, resulting in variable CO_2 flows that need to be accommodated by future CO_2 transportation and storage networks. [The authors] find that around 21% and 12% of the net flow rate changes over 6h-periods in the core scenario have greater amplitudes than 30% and 50% of nominal flow, respectively. When changes are averaged over two consecutive blocks of 6 h, representing the smoothing effect achievable via line-packing over a pipeline of reasonable length and diameter, around 9% of the net changes have greater amplitudes than 40% of nominal flow. Given the high and frequent fluctuations in feed flows across all considered scenarios, further research is urgently required on the capability of transportation and storage networks to accommodate variable CO_2 flow rates." **T. Spitz, V. Avagyan, F. Ascui, A.R.W. Bruce, H. Chalmers, and M. Lucquiaud,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

The role of CCS and biomass-based processes in the refinery sector for different carbon scenarios.

The following is the abstract of this article: "This paper studies technological pathways in the refinery sector, such as fuel switching, CCS, energy efficiency as well as retrofit decisions (i.e. upgrading, scaling-up, and equipment [modernization]) with the aim of [decarbonization]. A global refinery outlook is presented for a 2.5°C and 2°C climate target scenario from 2010 through to 2050. The results highlight that a full portfolio of technologies (non-conventional processes, gas-/coal-based, with/without CCS, and biomass-based process) is necessary. Among the conventional refineries, only the most efficient ones or those investing in CCS to increase competitiveness and reducing emissions, can stay in the market." **Julia Sachs, Sukma Hidayat, Sara Giarola, and Adam Hawkes,** *Computer Aided Chemical Engineering*. (Subscription may be required.)

Analysis of the contribution of CCS to achieve the objectives of Mexico to reduce GHG emissions.

The following is the abstract of this article: "Mexico has a strong commitment to reduce its GHG emissions. The electrical and the industrial sectors have been the second and third largest contributors to GHG emissions–excluding fugitive emissions-. This paper analyzes the potential contributions of CCS systems on the electrical sector, as well as the participation of the cement, metal and chemical industries. This study was carried out using a computational mathematical model, the MEM70, which is a partial equilibrium model that represents the Mexican energy system. It was found that, even considering energy efficiency measures, a high penetration of electric vehicles and the electrical sector with high participation of low carbon emission technologies such as renewable and nuclear sources. Further, it is necessary to implement CCS to achieve the goal for reducing national greenhouse gas emissions." **David Castrejón, Alan M. Zavala, Jesús A. Flores, Marco Polo Flores, and Diana Barrón,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Tracking carbon transfers embodied in Chinese municipalities' domestic and foreign trade.

The following is the abstract of this article: "Cities are the major contributors to global [CO_2] emissions; however, the carbon transfers embodied in cities' domestic and foreign trade have not been fully discussed. As carbon emissions from different domestic and foreign trade partners have not been distinguished, and since China's four municipalities (Beijing, Tianjin, Shanghai and Chongqing) carry an increasingly significant responsibility for carbon reduction in China, a multi-scale and multi-regional carbon emission assessment is applied to identify their emission transfers to and from 26 domestic provinces and 184 foreign economies. The results show that the intensities of the four municipalities are mainly above the international standard (0.14 kg/CNY) but beneath the Chinese average (0.24 kg/CNY). 71.72%, 55.35%, 65.34% and 33.65% of their emissions are imported from other regions. Generally, the four municipalities are net recipients of domestic carbon transfers and suppliers of foreign carbon transfers. Carbon transfers from Hebei to Beijing and Tianjin, Zhejiang to Shanghai, and Sichuan to Chongqing as well as from Beijing and Tianjin to Japan and South Korea and from Shanghai and Chongqing to the United States and Germany are identified in domestic and foreign supply chains. The multi-scale and multi-regional simulation and assessment in this work allows [the authors] to identify the carbon emissions not only within a city's boundaries but also via inter- and intra-national trade, providing a solid foundation for the carbon emission assessments of Chinese mega cities from an embodied perspective." **Y.L. Li, Bin Chen, M.Y. Han, Michael Dunford, Weidong Liu, and Zhi Li,** *Journal of Cleaner Production*. (Subscription may be required.)

Can carbon cap and trade mechanism be beneficial for remanufacturing?

The following is the abstract of this article: "Remanufacturing is an environmentally friendly and profitable way to conduct production operations. For environmental protection, carbon cap and trade mechanism, which is conventionally considered a burden for manufacturers, is a viable approach to reduce carbon emissions. This paper explores the possibility of a monopolistic manufacturer involved in both manufacturing and remanufacturing to profit under carbon cap and trade mechanism in a single period. [The authors] develop a model to derive the [favorable] conditions under which carbon cap and trade is beneficial for the manufacturer in ordinary markets and green markets and obtain the manufacturer's optimal decisions. Furthermore, [the authors analyze] the influence of carbon emissions-related parameters on the manufacturer's optimal decisions and carbon trading quantity. The results show that carbon cap and trade can be valuable for remanufacturing in both the ordinary market and the green market. Policy makers should focus on carbon trading prices to reduce carbon emissions and improve the manufacturers' profits in both markets. In addition, the low carbon emissions characteristics of remanufactured products allow for better profits for manufacturers under carbon cap and trade, and their investments in low carbon production technology should be expanded. Finally, the proportion of green consumers has important performance implications for remanufacturing in green markets. Specifically, excessive green consumers in a monopolistic market are not always a blessing when the carbon trading price is high." **Qiangfei Chai, Zhongdong Xiao, Kee-hung Lai, and Guanghui Zhou,** *International Journal of Production Economics*. (Subscription may be required.)

JANUARY 2019

CO_2-SCREEN tool: Application to the Oriskany sandstone to estimate prospective CO_2 storage resource.

The following is the abstract of this article: "The ability to accurately predict the CO_2 storage resource in saline formations is important to make high-level, energy-related government policy and business decisions. CO_2-SCREEN (Storage prospeCtive Resource Estimation Excel aNalysis) is a tool developed by DOE-NETL to screen saline formations for prospective CO_2 storage resources. CO_2-SCREEN uses DOE methods and equations to serve as a consistent mechanism for calculating prospective CO_2 storage resources. CO_2-SCREEN is comprised of two files: an Excel file used for inputs and outputs and a GoldSim Player file used to run Monte Carlo simulations. CO_2-SCREEN requires input of physical geologic parameters (i.e. thickness, porosity) as well as efficiency factor ranges (i.e. net-to-gross thickness) to calculate a mass storage estimate. An application of CO_2-SCREEN is demonstrated here using well log data from the Oriskany Sandstone portion in Pennsylvania. The Oriskany Sandstone is divided into 20 km x 20 km grid cells in which 151 cells contain well log data. CO_2-SCREEN calculates prospective CO_2 storage resource for each grid cell based on the well log data and uses lithology and depositional environment information for efficiency factor ranges. The Oriskany Sandstone CO_2 storage resource estimate for Pennsylvania, calculated by CO_2-

SCREEN, ranges from 0.07 to 1.28 gigatons (Gt) with a P50 value of 0.32 Gt. This resource assessment analysis is done to demonstrate the use of CO_2-SCREEN and results are comparable to previous studies which encourages the application of CO_2-SCREEN to other saline formations and warrants exploring the expansion of this tool to assess the CO_2 storage resource in other formations such as shale and depleted oil and gas reservoirs." **Sean Sanguinito, Angela L. Goodman, and James I. Sams III,** *International Journal of Greenhouse Gas Contro*l. (Subscription may be required.)

Immediate and long-run impacts of a forest carbon policy—A market-level assessment with heterogeneous forest owners.

The following is the abstract of this article: "Sequestering carbon in forests and wood products is an inexpensive way to reduce the atmospheric carbon concentration. However, its full potential is not utilized in present climate policies. Optimizing sequestration, while continuing to harvest wood for materials and energy, could reduce the economic burden of mitigation efforts. Optimal sequestration can be incentivized by subsidizing carbon storage according to its social value. [The authors] analyze the dynamic market-level impacts of implementing a forest carbon policy by using the Finnish Forest and Energy Policy model (FinFEP). [The authors] find that sizeable and immediate increases in carbon sinks can be obtained, even with low carbon prices. High carbon payments strongly increase the carbon sink in the short run, but this impact diminishes over time. Low payments have a milder but longer-lasting impact. Forest owners' valuations of forest amenities also affect the magnitude and dynamics of harvest and carbon sequestration results. Thus, a realistic description of forest owner behavior is needed to assess the impacts of forest carbon policies. Moreover, [the authors] show that a market-level model is necessary for assessing the regional carbon sequestration impacts and costs. Relying on stand-level models with fixed timber prices may yield overly optimistic results." **Johanna Pohjola, Jani Laturi, Jussi Lintunen, and Jussi Uusivuori**, *Journal of Forest Economics.* (Subscription may be required.)

A dynamic assessment of instrument interaction and timing alternatives in the EU low-carbon policy mix design.

The following is the abstract of this article: "The European Union low-carbon strategy includes a range of complementary policies. Potential interactions between instruments and different timing of their implementation can influence the cost and likelihood of achieving the targets. [The authors] test the interactions between the three main pillars of the European Union strategy through a dynamic Computable General Equilibrium model (GDynEP) with a time horizon of 2050. Main results are: i) going for the unilateral European Union carbon mitigation target without any complementary technological policy will produce large economic losses; ii) by investing in clean energy technologies (energy efficiency and renewable energy) with a carbon tax revenue recycling mechanism, these losses will decrease substantially; iii) when complementary clean energy technology policies are implemented, the optimal timing of binding targets changes; iv) the higher the public support to clean energy technologies, the larger the economic gains in early adoption of challenging abatement targets." **Massimiliano Corradini, Valeria Costantini, Anil Markandya, Elena Paglialunga, and Giorgia Sforna**, *Energy Policy.* (Subscription may be required.)

Economic [optimization] of European supply chains for CO_2 capture, transport and sequestration, including societal risk analysis and risk mitigation measures.

The following is the abstract of this article: "European large stationary sources are currently emitting more than 1.4 Gt of CO_2 every year. A significant decrease in [GHG] emissions cannot be achieved without CCS technologies. However, although being practiced for over 30 years, CO_2 transportation is intrinsically [characterized] by the risk of leakage. This study proposes to assess and tackle this issue within the CCS design problem, by proposing a spatially explicit mixed integer linear programming approach for the economic [optimization] of a European supply chain for carbon capture, transport and geological storage, where societal risk assessment is formally incorporated within the modelling framework. Post-combustion, oxy-fuel combustion and pre-combustion are considered as technological options for CO_2 capture, whereas both pipelines (inshore and offshore) and ships are taken into account as transport means. Both inland-inshore and offshore injection options are available for carbon geological sequestration. Risk mitigation measures are considered in the design of the transport network. The overall supply chain is economically [optimized] for different minimum carbon reduction scenarios. Results demonstrate that accounting for societal risk may impact the overall carbon sequestration capacity, and that the proposed approach may represent a valuable tool to support policy makers in their strategic decisions." **Federico d'Amore, Paolo Mocellin, Chiara Vianello, Giuseppe Maschio, and Fabrizio Bezzo,** *Applied Energy*. (Subscription may be required.)

Carbon Capture and Sustainable Utilization by Algal Polyacrylonitrile Fiber Production: Process Design, Techno-Economic Analysis, and Climate Related Aspects.

The following is the abstract of this Article: "Carbon capture and sustainable utilization (CCU) is essential to accomplishing the targets of 2015's Paris Agreement. A promising option consists of algal based CO_2 conversion into lipid rich biomass with further processing into polyacrylonitrile (PAN) fiber, the major precursor for carbon fiber production. A first feasibility analysis was carried out under multiple constraints for price, byproduct yield, and consumption of land, CO_2, and energy. Several process-route alternatives were composed, modeled, and compared in terms of mass and energy flows, resource needs, and cost. To quantify risks from market and modeling uncertainties, [the authors] conducted a primary techno-economic analysis (TEA) with variable process pathways in a dynamic economic model of a related project company (SPV), embedded in a Monte Carlo simulation. First results indicate that process combinations with algal biodiesel-production and biomass-liquefaction (BtL) components come close to meeting the multiple constraints and justify progressing to extended research and development activities." **Uwe Arnold, Thomas Brück, Andreas De Palmenaer, and Kolja Kuse,** *Industrial & Engineering Chemistry Research.* (Subscription may be required.)

Practical deployment of pipelines for the CCS network in critical conditions using MINLP modelling and optimization: A case study of South Korea.

The following is the abstract of this article: "In applying CCS technology, pipelines are an economic choice for transporting CO_2. However, it is difficult to plan the pipeline network in detail since various factors, such as mountain regions and high population density increase the cost of pipeline installation. Also, uncertainty of the reservoir capacity and national policies is important factors in practical pipeline deployment, especially in critical conditions mentioned above. In this study, the development of an optimal CCS pipeline network in critical conditions, and the effect of practical design conditions on the network, are studied using mixed-integer nonlinear programming (MINLP) modeling and optimization. South Korea is selected as a case study and optimal CCS networks are obtained according to four scenarios developed with regard to reservoir capacity and policy options. A rigorous cost model was developed, and subdivided penalty factors were applied to consider the drastic change in geographical conditions. The four scenarios were evaluated and the effect of the considered factors on the timely development of the CCS network was analyzed." **Changsoo Kim, Kyeongsu Kim, Jeongnam Kim, Usama Ahmed, and Chonghun Han,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Shelf space allocation problem under carbon tax and emission trading policies.

The following is the abstract of this article: "This study formulates a mixed integer nonlinear programming (MINLP) model for the shelf space allocation problem (SSAP) under two common environmental policies: the Carbon Tax System and the Emission Trading System. For each system, the impact on profitability and the opportunities for emission cuts are presented. Via numerical experiments [the authors] specifically explore the impact of a fixed carbon tax, emission allowances, and emission price on two of the most important in-store management decisions in retail: shelf space capacity and product allocation decisions. Real-life retail data of four product categories are tested and solved to optimality using COUENNE. Then, [the authors] analyze optimal solutions to gain important insights for the benefit of both retailers and governmental decision makers." **Vincent F. Yu, Renan Maglasang, and Yu-Chung Tsao,** *Journal of Cleaner Production.* (Subscription may be required.)

Regional impacts of launching national carbon emissions trading market: A case study of Shanghai.

The following is the abstract of this article: "This study investigates the impacts of launching a national carbon trade market through the IMED|CGE (Integrated Model of Energy, Environment and Economy for Sustainable Development|Computable General Equilibrium) model, between Shanghai and the Rest of China (ROC). Five scenarios are established by considering China's Nationally Determined Contributions (NDC) targets, including a baseline scenario (BaU scenario), a carbon cap on ETS participating sectors scenario (CAPsec scenario), a carbon cap on Shanghai and ROC regions scenario (CAPreg scenario), a carbon cap scenario with local carbon emissions trading among ETS participating sectors (ETsec scenario) and a carbon cap scenario with inter-regional carbon emissions trading (ETreg scenario). The results under the ETreg scenario predict a carbon price of 164.64 USD/tCO_2 and a total carbon trade volume of 189.91 Mt by 2030. The metal smelting sector will be the largest seller of emissions quotas in Shanghai, whereas the power generation sector will be the largest buyer. Due to its higher carbon mitigation cost and increasing autonomous carbon intensity, the aviation sector will face more challenges to reduce emissions among ETS participating sectors in Shanghai. The results indicate that launching a national carbon trade market could generate both economic and environmental benefits and help China achieve its NDC targets." **Zhiqing Liu, Yong Geng, Hancheng Dai, Jeffrey Wilson, Yang Xie, Rui Wu, We You, and Zhongjue Yu,** *Applied Energy.* (Subscription may be required.)

FEBRUARY 2019

Tracking CO_2 Plumes in Clay-Rich Rock by Distributed Fiber Optic Strain Sensing (DFOSS): A Laboratory Demonstration.

The following is the abstract of this article: "Monitoring the migration of pore pressure, deformation, and saturation plumes with effective tools is important for the storage and utilization of fluids in underground reservoirs, such as geological stores of CO_2 and natural gas. Such tools would also verify the security of the fluid contained reservoir-caprock system. Utilizing the swelling strain attributed to pressure buildup and the adsorption of supercritical CO_2 on clay minerals, [the authors] tracked the fluid plume in a natural clay-rich Tako sandstone at the laboratory core scale. The strain was measured by a high-resolution distributed fiber optic strain sensing (DFOSS) tool. The strain changes induced by CO_2 adsorptions on clay minerals were significantly greater than those caused by pore pressure alone. The distribution of the swelling strain signals effectively captured the dynamic breakthrough of the CO_2 plume from the high- to low-permeability regions in the Tako sandstone. Besides revealing the in situ deformation state, the measured strain changes can track the movement of the CO_2 plume as it enters the clay-rich critical regions in the reservoir-caprock system. The present findings and potential future applications of DFOSS in the field are expected to enhance the monitoring and management of underground fluid reservoirs." **Yi Zhang, Ziqiu Xue, Hyuck Park, Ji-Quan Shi, Tamotsu Kiyama, Xinglin Lei, Yankun Sun, and Yunfeng Liang,** *Water Resources Research.* (Subscription may be required.)

The U.S. power sector decarbonization: Investigating technology options with MARKAL nine-region model.

The following is the abstract of this article: "The U.S. economy decarbonization over the next 35 years requires a large transformation of the energy system. The main finding of this study is that it is technically feasible to achieve 80% GHG emissions reduction below the 2005 levels by 2050 through deployment of existing or near-commercially available technologies. GHG reductions are primarily achieved through high levels of electricity sector decarbonization, electrification of end uses, and exchange of the remaining end-uses to lower carbon fuels such as natural gas. However, deep decarbonization by 2050 triggers very high marginal CO_2 reduction costs, unless significant cost reductions of zero and near-zero carbon technologies occur. The results show that CO_2 reduction policies accelerate the deployment of renewables and CCS only in the scenarios where the decarbonization policies are more stringent than those in the Clean Power Plan (CPP). Electricity generation mixes in the reference scenarios are largely dependent on the price of natural gas, but also show significant sensitivity to cost reductions in CCS. When increased CCS learning rates are incorporated into the model runs, more CCS is optimal in the medium-term and long-term future in the scenarios with CO_2 constraints. An 80% reduction scenario also prompts electrification in end-use demand sectors, creating even more dependence on CO_2 management in the electricity generation sector." **Nadejda Victor, Christopher Nichols, and Charles Zelek,** *Energy Economics.* (Subscription may be required.)

Econometric supply-and-demand models to analyze carbon pricing policies.

The following is the abstract of this article: "In this paper, the introduction of a carbon pricing policy in air transport industry is investigated. The impact on ticket prices, airlines' market shares and resulting network-wide carbon emissions is studied via a methodology which includes a supply and demand model and a method for estimating carbon emissions costs by airline and itinerary. The application of the carbon pricing policy at the U.S. domestic aviation network revealed that the policy could have some significant effects on ticket prices, air travel demand and resulting CO_2 emissions for high carbon price. But, to achieve the aviation industry ambitious goal to reduce net aviation CO_2 emissions by 50% until 2050, this paper suggests that airlines and policy makers need to adopt a multi-faceted approach with carbon pricing policies, technological, operational and infrastructure improvements to ensure economic and environmental sustainability." **Ioanna Pagoni and Paraskevi Psaraki-Kalouptsidi,** *International Journal of Transportation Science and Technology.* (Subscription may be required.)

Exploring the impacts of a low-carbon policy instrument: A case of carbon tax on transportation in China.

The following is the abstract of this article: "The rapid growth of energy consumption and CO_2 emission in transportation has brought great challenges to China's energy demand and environmental issues. Carbon tax, considered as an efficient low-carbon policy instrument, can effectively reduce the use of fossil fuels and improve energy efficiency. This study aims to explore the impacts of a transportation carbon tax on transport sectors, macroeconomy and social welfare by developing a computable general equilibrium (CGE) model. Meanwhile, to achieve fiscal revenue neutrality, two schemes are employed for revenue recycling. One is that all of the carbon tax revenue is recycled to subsidize households through lump-sum transfer; the other one is that carbon tax revenue is used to reduce the income tax of households and enterprises. The simulation results show that the appropriate carbon tax rate is 50 Chinese Yuan (RMB)/ton-CO_2. At this level of taxation, energy demand and carbon reduction have fewer negative impacts on the macro-economy and transport sectors. [The authors] also find that the appropriate carbon tax rates among different transport sectors and different energy categories are different. The appropriate carbon tax rates for airlines, railway, urban transport and water transport are same (50 RMB/ton-CO_2), while the appropriate carbon tax rate for road transport sector is 60 RMB/ton-CO_2. The recycling of carbon tax revenue to households and enterprises should be implemented to realize the 'weak double dividend' effect of the carbon tax." **Yinxiang Zhou, Wenshi Fang, Mengjuan Li, and Weili Liu,** *Resources, Conservation and Recycling.* (Subscription may be required.)

Optimum storage depths for structural CO_2 trapping.

The following is the abstract of this article: "Structural trapping is the primary CO_2 geo-storage mechanism, and it has historically been quantified by CO_2 column heights, which can be permanently immobilized beneath a caprock, using a buoyancy force-capillary force balance. However, the high dependence of CO_2-wettability (a key parameter in the above analysis) on pressure and temperature – and thus storage depth – has not been taken into account. Importantly, rock can be CO_2-wet at high pressure, and this wettability reversal results in zero structural trapping below a certain storage depth (~2400 m maximum caprock depth for a most likely scenario is estimated here). Furthermore, more relevant than the CO_2 column height is the actual mass of CO_2 which can be stored by structural trapping (mCO_2). This aspect has now been quantified here, and importantly, mCO_2 goes through a maximum at ~1300 m depth, thus there exists an optimal storage depth at around 1300 m depth." **Stefan Iglauer,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Postcombustion CO_2 Capture from Wet Flue Gas by Temperature Swing Adsorption.

The following is the abstract of this article: "[The authors] present an analysis of a novel temperature swing adsorption (TSA) process with condensers capable of treating wet flue gas reaching 90% CO_2 recovery and 95% purity (on a dry basis). In the first part, the characterization of the binary CO_2/water vapor adsorption equilibrium on zeolite 13X is presented, quantifying residual CO_2 adsorption at different levels of water adsorption. On this basis, [the authors] propose an empirical and analytical isotherm model able to capture the competition between CO_2 and water vapor. In the second part, the isotherm model is used in a process simulator to assess the performance of the proposed TSA process in detail. The strict specifications on the CO_2 product could be reached by employing a layered-bed configuration, where a portion of the zeolite 13X bed is replaced by activated alumina. Further, the process is optimized by parametric analysis with respect to productivity and energy consumption while using the specifications as constraints. It is shown that reasonable performance can be obtained, comparable to the scenario where a drying step precedes the cyclic adsorption process but achieving this in a single process step. Moreover, the critical effect of the significant mass transfer resistance of water vapor on zeolite 13X is quantified. Due to a spread of reported mass transfer coefficients of water vapor on zeolite 13X, the process is assessed for three representative values, showing that comparable performance can be obtained for all cases considered by varying the length of the guard layer. The robustness of the process is further underlined by the reasonable performance for varying concentrations of water vapor in the feed." **Max Hefti and Marco Mazzotti,** *Industrial & Engineering Chemistry Research.* (Subscription may be required.)

The impact on electric power industry under the implementation of national carbon trading market in China: A dynamic CGE analysis.

The following is the abstract of this article: "As the largest carbon emissions source sector, electric power industry is undoubtedly a principal part of the carbon trading market in China. Aimed at researching the impact on power industry beyond establishing the national carbon trading market, a dynamic computable general equilibrium (CGE) model embedded with carbon trading block is introduced in this paper. Subsequently, [the authors] design 8 scenarios of which illustrate corresponding industry carbon emissions baselines and free quotas ratios. The main simulation results are as follows. The implementation of carbon emissions trading would bring a certain negative impact on the overall economy. Real GDP will be reduced by about 0.08%–0.52% in 2030. Though low free quotas ratio will cause a relatively high loss of GDP, this negative impact would be eliminated in the long run. In addition, carbon emissions trading would also promote the clean production of electricity. Indeed, the electric power industry would reach carbon emissions peak around 2020. Relative to scenarios without carbon trading, carbon emissions would reduce more than 1000 million tons in 2030 when industry carbon emissions baseline declines at an annual rate of 2%. Consequently, the carbon market can achieve a more significant reduction in carbon emissions with the influencing of quotas fully auctioned scenario." **Wei Li, Yan-Wu Zhang, and Can Lu,** *Journal of Cleaner Production.* (Subscription may be required.)

Impact of carbon allowance allocation on power industry in China's carbon trading market: Computable general equilibrium based analysis.

The following is the abstract of this article: "Global warming has necessitated the quest for CO_2 mitigation globally. Emission Trading Scheme (ETS) is a market-oriented strategy which may be effective for CO_2 mitigation. This study establishes a Computable General Equilibrium (CGE) model to analyze the impact of different ETS quota allocation scheme on the electricity industry and determine the best choice of quota allocation scheme for the electricity industry in China. The research on China's carbon trading market may provide an important case for the global carbon trading market. The results show that different quota allocation schemes have impacts on electricity price, and there are some spillover effects to other industries. Higher Annual Decline Factor (ADF) will reduce carbon rights than lower ones. Changes in the quota allocation schemes of a single industry (electricity) can hardly affect aggregate GDP and CO_2 emissions. Moreover, ETS quota allocation scheme in the electricity sector based on historical emission intensity could have better performance in commodity price, electricity supply, ETS price, GDP and social welfare. Thus, this paper suggests that the best choice of ETS quota allocation scheme in the electricity sector is the scheme that is based on historical emission intensity which ADF is 0." **Lirong Zhang, Yakun Li, and Zhijie Jia,** *Applied Energy.* (Subscription may be required.)

MARCH 2019

Carbon sequestration in biogenic magnesite and other magnesium carbonate minerals.

The following is the abstract of this article: "The stability and longevity of carbonate minerals make them an ideal sink for surplus atmospheric [CO_2]. Biogenic magnesium carbonate mineral precipitation from the magnesium-rich tailings generated by many mining operations could offset net mining greenhouse gas emissions, while simultaneously giving value to mine waste products. In this investigation, cyanobacteria in a wetland bioreactor enabled the precipitation of magnesite (MgCO3), hydromagnesite [$Mg5(CO3)_4(OH)_2{\cdot}4H_2O$], and dypingite [$Mg5(CO3)_4(OH)_2{\cdot}5H_2O$] from a synthetic wastewater comparable in chemistry to what is produced by acid leaching of ultramafic mine tailings. These precipitates occurred as micrometer-scale mineral grains and microcrystalline carbonate coatings that entombed filamentous cyanobacteria. This provides the first laboratory demonstration of low temperature, biogenic magnesite precipitation for carbon sequestration purposes. These findings demonstrate the importance of extracellular polymeric substances in microbially enabled carbonate mineral nucleation. Fluid composition was monitored to determine carbon sequestration rates. The results demonstrate that up to 238 t of CO_2 could be stored per hectare of wetland/year if this method of [CO_2] sequestration was implemented at an ultramafic mine tailing storage facility. The abundance of tailings available for carbonation and the anticipated global implementation of carbon pricing make this method of mineral carbonation worth further investigation." **Jenine McCutcheon, Ian M. Power, Jeremiah Shuster, Anna Lee Harrison, Gregory Dipple, and Gordon Southam,** *Environmental Science & Technology.* (Subscription may be required.)

Integrated assessment for solar-assisted carbon capture and storage power plant by adopting resilience thinking on energy system.

The following is the abstract of this article: "Integrating solar-thermal energy into the power plant with post-combustion [CCS] can reduce the energy penalty derived from solvent regeneration. However, few metrics exist to evaluate the trade-off associated with technic, economic and ecological perspectives for different integration schemes of the three subsystems, namely the solar field, power plant and carbon capture system. This paper analysis five configurations of coal-fired power plant with and without solar field as well as CCS technology based on the resilience concept. Still at the budding stage, the status of resilience definitions and evaluation methods related to energy system is reviewed. The resilience level for five configurations of coal-fired power plant both with and without solar-field, together with the CCS system is measured, which takes into consideration five critical characteristics towards resilience: fossil fuel depletion potential (CADP), global warming potential (GWP), levelized cost of energy (LCOE), solar to electricity fraction and spare

capacity. Results indicate that among all the configurations, the solar-assisted power generation CCS power plant with 90% capture rate shows the highest resilience level. However, the scheme which utilizes solar energy to assisted solvent regeneration, shows limited advantage in terms of resilience level due to high CADP and LCOE." **Junyao Wang, Jun Zhao, Shuai Deng, Taiwei Sun, Yanping Du, Kaixiang Li, and Yaofeng Xu,** *Journal of Cleaner Production*. (Subscription may be required.)

Retrofitting carbon capture and storage to natural gas-fired power plants: A real-options approach.

The following is the abstract of this article: "This paper presents a real-options approach to assess the value of retrofitting [CCS] technology to an existing natural gas-fired base-load power plant. Operating in a deregulated electricity market, a power plant owner seeks to decide whether to retrofit and at what techno-economic conditions to retrofit [CCS]. The value of the plant is determined based on clean spark spread options. Two alternative [CCS] technologies, post-combustion and oxy-fuel combustion, are evaluated. Price uncertainties of electricity and natural gas are modeled as mean-reverting processes. The plant is abided by the emission reduction policy of carbon tax or price. Results show that a plant owner would opt for retrofitting post-combustion technology to an existing power plant if the carbon price hits to at least 140 dollars per ton of [CO_2], and would select oxy-fuel combustion technology if the carbon price moves further to 185 dollars per ton of [CO_2] or above. Since parameters of [CCS] vary widely across the literature, sensitivity tests of the expected values to different costs, prices, and volatility parameters are also presented for an insightful comparative view of which [CCS] technology to adopt at what techno-economic conditions." **R.S. Elias, M.I.M. Wahab, and L. Fang,** *Journal of Cleaner Production*. (Subscription may be required.)

Carbon dioxide sequestration and methane production promotion by wollastonite in sludge anaerobic digestion.

The following is the abstract of this article: "This study investigated the feasibility and performance of simultaneous in-situ CO_2 sequestration and [methane (CH4)] production promotion by wollastonite addition in sludge AD. A maximum CH4 yield increment of 30.8% and maximum methane production rate increment of 64.9% with wollastonite addition at dosage of 16.25 g/L were achieved. CO_2 was efficient sequestered by wollastonite addition and resulted in a higher CH4 content of 81.7%–82.4%. The mechanism of CO_2 sequestration by wollastonite was confirmed as Ca^{2+} release and subsequently carbonation based on cation and precipitates analysis. The results demonstrated that wollastonite could be applied as an effective additive for simultaneous in-situ CO_2 sequestration and CH4 production promotion of sludge AD." **Yan Zhang, Lihui Zhang, He Liu, Linlin Gong, Qianqian Jiang, Hongbo Liu, and Bo Fu,** *Bioresource Technology*. (Subscription may be required.)

Geologic CO_2 sequestration monitoring design: A machine learning and uncertainty quantification based approach.

The following is the abstract of this article: "Monitoring is a crucial aspect of geologic CO_2 sequestration risk management. Effective monitoring is critical to ensure CO_2 is safely and permanently stored throughout the life-cycle of a geologic CO_2 sequestration project. Effective monitoring involves deciding: (i) where is the optimal location to place the monitoring well(s), and (ii) what type of data (pressure, temperature, CO_2 saturation, etc.) should be measured taking into consideration the uncertainties at geologic sequestration sites. [The authors] have developed a filtering-based data assimilation procedure to design effective monitoring approaches. To reduce the computational cost of the filtering-based data assimilation process, a machine-learning algorithm: Multivariate Adaptive Regression Splines is used to derive computationally efficient reduced order models from results of full-physics numerical simulations of CO_2 injection in saline aquifer and subsequent multi-phase fluid flow. [The authors] use example scenarios of CO_2 leakage through legacy wellbore and demonstrate a monitoring strategy can be selected with the aim of reducing uncertainty in metrics related to CO_2 leakage. [The authors] demonstrate the proposed framework with two synthetic examples: a simple validation case and a more complicated case including multiple monitoring wells. The examples demonstrate that the proposed approach can be effective in developing monitoring approaches that take into consideration uncertainties." **Bailian Chen, Dylan R. Harp, Youzuo Lin, Elizabeth H. Keating, and Rajesh J. Pawar,** *Applied Energy*. (Subscription may be required.)

Effects of N_2 and H_2S binary impurities on CO_2 geological storage in stratified formation – A sensitivity study.

The following is the abstract of this article: "Impurities are unavoidable during CO_2 geological storage, and they would potentially affect the plume spread as well as storage capacity and/or efficiency of CO_2. The current study numerically investigated the effects of binary impurities comprising typical components [nitrogen (N_2)] and [hydrogen sulfide (H_2S)] on CO_2 geological storage in stratified formations. For a fixed total content of the binary impurities, increasing ratio of N_2/H_2S resulted in larger plume spread which meant a higher dissolution trapping efficiency. Because of the backflow of formation brine during the post-injection period, the residual trapping efficiency decreased while the dissolution trapping efficiency increased. This tendency was reinforced with increasing ratio of N_2/H_2S. Besides, this work examined the effects of the ratio of vertical permeability (*kv*) to horizontal permeability (*kh*) and the addition of an injection point in the stratified formation. It was found that lower *kv/kh* shrunk the plume spread and intensified the maximum pressure build-up. However, in the case of two injection points, the plume in the vertical direction was elongated and the maximum pressure build-up was lessened. The results should be taken into consideration to determine the types and concentrations of impurities allowed in the injected CO_2 stream as well as the site selection and injection design for impure CO_2 geological storage in stratified formation." **Didi Li, Hongcheng Zhang, Yang Li, Wenbin Xu, and Xi Jiang,** *Applied Energy*. (Subscription may be required.)

Drivers of tree carbon storage in subtropical forests.

The following is the abstract of this document: "Tropical and subtropical forest ecosystems play an important role in the global carbon regulation. Despite increasing evidence for effects of biodiversity (species diversity, functional diversity and functional dominance), stand structural attributes, stand age and environmental conditions (climate and topography) on tree carbon storage, the relative importance of these drivers at large scale is poorly understood. It is also still unclear whether biodiversity effects on tree carbon storage work through niche complementarity (i.e. increased tree carbon storage due to interspecific resource partitioning) or through the mass-ratio effect (tree carbon storage regulated by dominant traits within communities). Here [the authors] analyze tree carbon storage and its drivers using data of 480 plots sampled across subtropical forests in China. [The authors] use multiple regression models to test the relative effects of biodiversity, stand structural attributes, stand age and environmental conditions on tree carbon storage, and use a partial least squares path model to test how these variables directly and/or indirectly affect tree carbon storage. [The authors'] results show that tree carbon storage is most strongly affected by stand age, followed by climate, biodiversity and stand structural attributes. Stand age and climate had both direct and indirect (through species diversity, functional dominance and stand structural attributes) effects. [The authors] find that tree carbon storage correlates with both species diversity and functional dominance after stand age and environmental drivers are accounted for. [The authors'] results suggest that niche complementarity and the mass-ratio effect, not necessarily mutually exclusive, both play a role in maintaining ecosystem functioning. [The authors'] results further indicate that biodiversity conservation might be an effective way for enhancing tree carbon storage in natural, species-rich forest ecosystems." **Yin Li, Weikai Bao, Frans Bongers, Bin Chen, Guoke Chen, Ke Guo, Mingxi Jiang, Jiangshan Lai, Dunmei Lin, Chunjiang Liu, Xiaojuan Liu, Yi Liu, Xiangcheng Mi, Xingjun Tian, Xihua Wang, Wubing Xu, Junhua Yan, Bo Yang, Yuanrun Zheng, and Keping Ma,** *Science of The Total Environment*. (Subscription may be required.)

Full-infinite interval two-stage credibility constrained programming for electric power system management by considering carbon emission trading.

The following is the abstract of this article: "In this study, a full-infinite interval two-stage credibility constrained programming (FITCP) method is developed for optimizing electric power system (EPS) by considering CO_2 mitigation and air pollutant emission control. Through integrating full-infinite programming (FIP), interval two-stage programming (ITSP) and credibility constrained programming (CCP) within a general framework, the developed FITCP method can tackle multiple uncertainties in terms of interval values (both crisp and functional interval values), probabilistic and possibilistic distributions. Then, a FITCP-based electric power system (FITCP-EPS) model has been formulated for EPS planning where carbon emission trading (CET) scheme and air pollutant emission limitation are introduced to cope with the problem of carbon and air pollutant mitigation. Scenarios in response to diverse carbon mitigation levels, different trading schemes and different environmental policies are generated. Moreover, sensitive analysis and value of information analysis are conducted to help decision makers to have a clear view of the effects of data variation and uncertainty data collection. Results reveal that (i) CET scheme can bring more economic benefits for power plants especially when mitigation level is high; (ii) whether the CET is carried out or not, a corresponding construction of [CCS] infrastructure should be implemented to achieve the mitigation target; (iii) the expected system benefit would increase [0, 2.17] % by resolving the uncertainty of CO_2 emission levels. The results also indicate that FITCP-EPS model can not only provide an effective linkage between the pre-regulated generation targets and environmental policies, but also generate more decision options under different credibility levels and CO_2 emission levels, which are useful for helping decision makers to make appropriate generation targets, plan electricity generation mix, as well as gain in-depth insight into the effects of carbon emission trading and pollutant control on EPS." **J.W. Gong, Y.P. Li, and C. Suo,** *International Journal of Electrical Power & Energy Systems*. (Subscription may be required).

APRIL 2019

Effect of thermal stress on wellbore integrity during CO_2 injection.

The following is the abstract of this article: "Wellbore integrity is a critical component of long-term carbon storage. Depleted reservoirs that are potential CO_2 storage sites, typically contain several wells. Due to years of operations and abandonment, these wells can have cracks in the cement, cement-casing interface, and/or cement-formation interface. During CO_2 injection, changes in temperature may result in stress variations that can further damage the well, threatening its integrity. The temperature difference between the cold injected CO_2 and warm reservoir, and different thermal properties for the wellbore casing, cement, and the lithology, will stress the near wellbore environment, potentially extending pre-existing defects creating leakage pathways from the storage reservoir to the overlying strata. [The authors] have conducted a systematic numerical study to explore the role of CO_2 injection temperature, downhole effective in-situ horizontal stress, and the thermo-mechanical properties by coupling a linear elastic stress model with heat conduction. [The authors] consider conditions in non-perforated casing above the injection zone where conductive heating is dominant. The injection temperatures considered covers current industrial practice as well as sub-zero temperatures. The latter represents direct injection following ship transport, without pre-heating. In this study, [the authors] consider the connection between damage risk and the temperature difference between the injected CO_2 and the formation and downhole effective in-situ horizontal stress. The study found that the negative impacts of thermal stress in the wellbore environment are mitigated by the presence of effective in-situ horizontal stresses. Stresses normal to the well have the potential to reduce the tensile stress and stress intensity factor. In the absence of sufficient effective in-situ horizontal stress, thermal stress may cause the fracture to propagate due to high stress concentration near the fracture edges. In general, formations with large effective in-situ horizontal stress can prevent leakage paths from growing even when large temperature difference exists between the formation and the injected CO_2. [The authors'] simulations suggest that CO_2 can be injected at sub-zero temperatures, suitable for ship transport, when the downhole effective in-situ horizontal stress is greater than 10 or 12 MPa, depending on the location of the pre-existing cracks. For onshore transportation, injection of liquid CO_2 results in minimal damage, provided there is ample in-situ horizontal stress." **Pratanu Roy, Joseph P. Morris, Stuart D.C. Walsh, Jaisree Iyer, and Susan Carroll,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Best practices and recent advances in CCS cost engineering and economic analysis.

The following is the abstract of this article: "Cost engineering and economic analysis are key elements of the performance assessment of carbon capture and storage (CCS) technology. The CCS field has seen noticeable advances in the transparency and rigor of costing studies, but there is still significant room for improvement in three major areas: the more rigorous application of good cost engineering practices; the inclusion (and progression) of recent methodological advances; and adaptation to changing policy focus. Here, [the authors] discuss each of these three areas, bringing diverse information sources together into one paper, and [summarizing] important advances made in recent years, with the goal of strengthening CCS cost engineering and economic analysis in general. The first part of the paper discusses equipment design and sizing; cost indices and location factors; process and project contingency costs; CO_2 transport and storage costs; and uncertainty analysis and validation. The second part discusses new insights and advances in capture plant integration costs; the costs of steam supply; flexible dispatch of power plants with CCS; a hybrid method for the costing of advanced CCS technologies; qualitative uncertainty analysis methods; and calculation methods for CO_2 avoidance costs in non-power industries. The third part highlights several recent changes in the policy environments and how they affect the requirements of CCS costing studies. [The authors] close the paper by echoing earlier calls for the transparent reporting of assumptions and input variables underlying costing studies and by [prioritizing] three CCS costing issues for further methods and guideline development." **Mijndert van der Spek, Simon Roussanaly, and Edward S. Rubin,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Low carbon unit commitment (LCUC) with post carbon capture and storage (CCS) technology considering resource sensitivity.

The following is the abstract of this article: "This paper proposes a new methodology for scheduling of thermal generation plants equipped with Amine based post combustion carbon capture technology. The methodology develops a generic and simplified model for operational planning of thermal generators through unit commitment. The performance indices developed in this paper can accommodate the resource sensitivity of the fuel used for combustion. The proposed performance indices are coupled to unit commitment procedure through intelligent scheduling methodology considering both economic and environmental concerns of the system. The proposed models can be readily integrated into the unit commitment algorithm using the test system data and fuel composition. The same provides a simple and near appropriate model to consider resource sensitivity as compared to detailed (or) dedicated modeling carried out in Aspen, APEA, promax etc. The impact of resource sensitivity and scheduling strategy has been illustrated using a 10 unit thermal generation test system with amine based post combustion carbon capture technology. The resource sensitivity of the model has been demonstrated using three different compositions of fuel/coal viz. sub-bituminous, bituminous and lignite coals. The simulation results of resource sensitivity at various capture efficiencies are presented and discussed in detail with respect to various performance indices developed. The models developed in this paper can be integrated to wide range of thermal generation plants with wide range of coal type (or) fuel compositions across the globe." **Srikanth ReddyK, Lokesh Panwar, B.K. Panigrahi, and Rajesh Kumar,** *Journal of Cleaner Production*. (Subscription may be required.)

Quantities versus prices for best social welfare in carbon reduction: A literature review.

The following is the abstract of this article: "Weitzman's price-quantity analysis framework has been widely used, and in the field of climate economy it is applied to choose proper emissions reduction instruments for best welfare under uncertainty. This article summarizes the principle and method of selecting carbon emission reduction instruments by price versus quantities decision criterion. The probability of uncontrollable outcomes under uncertainty is reduced by comparing marginal abatement costs with marginal abatement benefits. On this basis, the following outreach research are summarized on some key issues such as dynamic analysis, assumptions improvements, elements expansion and hybrid policies. This topic drives a lot of research but no review has been conducted. [The authors] sum up the time-correlated cost and multi-period policy research to extend the static framework to dynamic analysis. There are also many studies that relax the strong assumptions of original framework including correlated uncertainty between cost and benefit, stock effect of carbon, nonlinear marginal cost and benefit, distributional inefficiency and extension of partial equilibrium. In addition, more elements around emissions control have been included and specified such as uncertainty, incomplete enforcement, technology innovation and multiple pollutants. [The authors] also summarize the researches of hybrid policy which combines quantity and price control to be a new regulation method and dual regulation which suggest applying both quantity and price control in different departments. It is found that early researches favor carbon tax while quantity regulation has gradually become popular. Finally, this article puts forward some research directions worth more exploring at both theory and application level." **Bao-Jun Tang, Xiang-Yu Wang, and Yi-Ming Wei,** *Applied Energy.* (Subscription may be required.)

Carbon leakage from geological storage sites: Implications for carbon trading.

The following is the abstract of this article: "A number of studies show that large-scale deployment of Carbon Capture and Storage (CCS) is necessary to limit the increase in global average temperature to less than 2°C by 2100. However, some experts and citizens worry about the integrity of [CO_2] storage sites due to the possibility of future leakage. [The authors] introduce a two-period model where two emission mitigation technologies are available to society in the first period: CCS, with a risk of [CO_2] leakage in the second period, and a riskless mitigation alternative, such as renewable energy. [The authors] first solve the model assuming that society does not know what the future rate of leakage will be. [The authors] then solve the model assuming that society will eventually learn the actual leakage rate. [The authors] find that, in a trading market in period one, reductions of CO_2 emissions through CCS should generate a less than proportional amount of CO_2 allowances. Estimates from simulations, using a coarse range of parameters, indicate that the discount factor of CCS allowances lies in the range (0.72, 1). Site-specific data is required to determine site-specific risks of leakage and discount factors." **Jorge H. García and Asbjørn Torvanger**, *Energy Policy*. (Subscription may be required.)

MAY 2019

Feasibility of CO_2 migration detection using pressure and CO_2 saturation monitoring above an imperfect primary seal of a geologic CO_2 storage formation: a numerical investigation.

The following is the abstract of this article: "A numerical model was developed to investigate the potential to detect fluid migration in a (homogeneous, isotropic, with constant pressure lateral boundaries) porous and permeable interval overlying an imperfect primary seal of a geologic CO_2 storage formation. The seal imperfection was modeled as a single higher-permeability zone in an otherwise low-permeability seal, with the center of that zone offset from the CO_2 injection well by 1400 m. Pressure response resulting from fluid migration through the high-permeability zone was detectable up to 1650 m from the centroid of that zone at the base of the monitored interval after 30 years of CO_2 injection (detection limit = 0.1 MPa pressure increase); no pressure response was detectable at the top of the monitored interval at the same point in time. CO_2 saturation response could be up to 774 m from the center of the high-permeability zone at the bottom of the monitored interval, and 1103 m at the top (saturation detection limit = 0.01). More than 6% of the injected CO_2, by mass, migrated out of primary containment after 130 years of site performance (including 30 years of active injection) in the case where the zone of seal imperfection had a moderately high permeability (10^{-17} m^2 or 0.01 mD). Free-phase CO_2 saturation monitoring at the top of the overlying interval provides favorable spatial coverage for detecting fluid migration across the primary seal. Improved sensitivity of detection for pressure perturbation will benefit time of detection above an imperfect seal." **Robert Dilmore, Argha Namhata, and Grant Bromhal,** *Computational Geosciences*. (Subscription may be required.)

Application of Blockchain in Carbon Trading.

The following is the abstract of this article: "This paper introduces the similarity between the mechanism of carbon trading and blockchain, then it elaborates on the application of blockchain in carbon trading. In corporate carbon trading, blockchain technology can record and transfer information flow reliably, realize point-to-point transactions between suppliers and demanders to achieve 'decentralization,' help to reduce the entry threshold for the carbon trading market. At the same time, an analysis of social environment for blockchain-based carbon trading on person is made. Finally, the paper confirms the value of 'blockchain + carbon trading' and looks forward to the future." **Yuting Pan, Xiaosong Zhang, Yi Wang, Junhui Yan, Shuonv Zhou, Guanghua Li, and Jiexiong Bao,** *Energy Procedia*. (Subscription may be required.)

Analysis of the Impact of China's Emissions Trading Scheme on Reducing Carbon Emissions.

The following is the abstract of this article: "By referring to the methods provided by Inter-governmental Panel on Climate Change (IPCC) and National Development and Reform Committee (NDRC), [the authors] first calculate the carbon emissions and carbon intensity (measured by emissions per output) of 39 sectors in 24 provinces from 2005 to 2015. Then using the panel data calculated, [the authors] apply difference-in-difference (DID) two-way fixed effects models to evaluate the causal impact of China's Emissions Trading Scheme (ETS) on the reduction of carbon emissions. Empirical results indicate that ETS sectors significantly decreased their emissions relative to non-ETS sectors after the start of ETS, while no obvious impact on carbon intensity was identified after ETS started. The results suggest that there is still room for policy makers to improve the ETS design to achieve declines not only in carbon emissions but also in carbon intensity in national ETS." **Zhang Haijun, Duan Maosheng, and Zhang Peng,** *Energy Procedia*. (Subscription may be required.)

The CCS hub in Norway: some insights from 22 years of saline aquifer storage.

The following is the abstract of this article: "The development of industrial-scale CCS in Norway, starting with the Sleipner project in 1996, gives a uniquely long track record of experience with CCS and provides valuable insights for the projected global growth in CCS. By the end of 2017, the Sleipner and Snøhvit CCS projects had captured and stored 22 Mt of CO_2 in saline aquifers offshore Norway. CO_2 plume monitoring observations at Sleipner can be used to indicate an overall storage efficiency of around 5% of the pore volume, with approximately one tenth of this volume dissolved in the brine phase. These estimates are consistent with the fluid dynamics of CO_2 injection in which a gravity dominated processes are expected to give efficiencies in the range of 1-6%. Future projects may be able to find ways of improving these efficiencies." **Philip S. Ringrose,** *Energy Procedia*. (Subscription may be required.)

Offshore power generation with carbon capture and storage to decarbonise mainland electricity and offshore oil and gas installations: A techno-economic analysis.

The following is the abstract of this article: "This study investigates the techno-economic potential of offshore power generation from natural gas with carbon capture and storage to reduce the climate impact of mainland electricity and the offshore oil and gas industry. This potential is assessed through techno-economic assessments over two relevant cases ('floating' and 'shallow water' cases) including comparison with relevant reference concepts. In the base case evaluation, the offshore power plant concept toward decarbonising mainland electricity results in high costs (178 and 258 $/MWh respectively for the floating and shallow water cases) compared to a reference onshore power plant with carbon capture and storage (around 95 $/MWh). However, a stronger potential is identified for the concept toward decarbonising offshore oil and gas platforms as the concept results in costs more comparable with the reference electrification concept (137 compared to 133 $/MWh in the floating case and 207 compared to 166 $/MWh in the shallow water case). Although the base cases show a limited potential for the offshore concept, the results show that with technological improvements (advanced capture technology, reuse of infrastructure…) and more suited case characteristics (development based on associated gas…), the offshore concept offers a significant potential for cost-efficiently decarbonising the offshore oil and gas industry, while a more moderate potential is foreseen for the decarbonisation of mainland electricity." **S. Roussanaly, A. Aasen, R. Anantharaman, B. Danielsen, J. Jakobsen, L. Heme-De-Lacotte, G. Neji, A. Sødal, P.E. Wahl, T.K. Vrana and R. Dreuxd,** *Applied Energy*. (Subscription may be required.)

Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise.

The following is the abstract of this article: "Salt marshes respond to sea-level rise through a series of complex and dynamic bio-physical feedbacks. In this study, [the authors] found that sea-level rise triggered salt marsh habitat restructuring, with the associated vegetation changes enhancing salt marsh elevation resilience. A continuous record of marsh elevation relative to sea level that includes reconstruction of high-resolution, sub-decadal, marsh elevation over the past century, coupled with a lower-resolution 1500-year record, revealed that relative sea-level rose 1.5±0.4 m, following local glacial isostatic adjustment (1.2 mm/yr). As sea-level rise has rapidly accelerated, the high marsh zone dropped 11 cm within the tidal frame since 1932, leading to greater inundation and a shift to flood- and salt-tolerant low marsh species. Once the marsh platform fell to the elevation favored by low-marsh Spartina alterniflora, the elevation stabilized relative to sea level. Currently low marsh accretion keeps pace with sea-level rise, while present day high marsh zones that have not transitioned to low marsh have a vertical accretion deficit. Greater biomass productivity, and an expanding subsurface accommodation space favorable for salt marsh organic matter preservation, provide a positive feedback between sea-level rise and marsh platform elevation. Carbon storage was 46±28 g C/m2/yr from 550 to 1800 CE, increasing to 129±50 g C/m2/yr in the last decade…" **Meagan Eagle Gonneea, Christopher V. Maio, Kevin D. Kroeger, Andrea D. Hawkes, Jordan Mora, Richard Sullivan, Stephanie Madsen, Richard M. Buzard, Niamh Cahill, and Jeffrey P. Donnelly,** *Estuarine, Coastal and Shelf Science*. (Subscription may be required.)

Uncovering attitudes towards carbon capture storage and utilization technologies in Germany: Insights into affective-cognitive evaluations of benefits and risks.

The following is the abstract of this article: "Carbon capture and storage (CCS) and carbon capture and utilization (CCU) are technologies which aim at mitigating climate change and saving fossil resources: CO_2 emissions from industrial plants are captured and stored underground (CCS) or used for the manufacturing of products (CCU). In contrast to CCS, CCU is less about the reduction of CO_2 emissions, since the global demand for feedstock CO_2 to be used for CCU products is considerably lower than the CO_2 emissions produced worldwide. Moreover, the CO_2 is only temporarily stored until the disposal of the CCU products. Instead, a reduction of fossil resources in product manufacturing is the primary goal for CCU. The successful roll-out of CCS and CCU is not solely determined by technical feasibility but also depends on public acceptance. Research has shown that acceptance of energy technologies is impacted by laypersons' attitudes. So far, little is known about differences in affective and cognitive evaluations of CCU in comparison to CCS. To address this research gap, an online survey was conducted in Germany (n = 449), in which affective and cognitive evaluation profiles for CCS and CCU were compared. Also, it was explored whether attitudes towards CCS are predictive of CCU acceptance. Results revealed basically similar evaluation profiles for CCS and CCU but CCU was rated significantly more positively. Comparing results for CCS supporters and opponents, it was found that CCS supporters rated CCU similarly positive whereas CCS opponents evaluated CCU significantly better than CCS. The findings can be used for communication concepts tailored to laypeople's requirements and concerns and yield implications for industrial policy-making." **Anika Linzenich, Katrin Arning, Julia Offerman-van Heek, and Martina Ziefle,** *Energy Research & Social Science*. (Subscription may be required.)

JUNE 2019

420,000 year assessment of fault leakage rates shows geological carbon storage is secure.

The following is from the abstract of this article: "… CCS can directly reduce industrial CO_2 emissions and is essential for the retention of CO_2 extracted from the atmosphere. To be effective… CO_2 must be securely retained for 10,000 years (10 ka) with a leakage rate of below 0.01% per year of the total amount of CO_2 injected. Migration of CO_2 back to the atmosphere via leakage through geological faults is a potential high impact risk to CO_2 storage integrity. Here, [the authors] calculate for the first time natural leakage rates from a 420 ka paleo-record of CO_2 leakage above a naturally occurring, faulted, CO_2 reservoir in Arizona, USA. Surface travertine (CaCO3) deposits provide evidence of vertical CO_2 leakage linked to known faults. U-Th dating of travertine deposits shows leakage varies along a single fault and that individual seeps have lifespans of up to 200 ka. Whilst the total volumes of CO_2 required to form the travertine deposits are high, time-averaged leakage equates to a linear rate of less than 0.01%/yr. Hence, even this natural geological storage site, which would be deemed to be of too high risk to be selected for engineered geologic storage, is adequate to store CO_2 for climate mitigation purposes." **Johannes M. Miocic, Stuart M. V. Gilfillan, Norbert Frank, Andrea Schroeder-Ritzrau, Neil M. Burnside, and R. Stuart Haszeldine,** *Scientific Reports*. (Subscription may be required.)

Establishing rates of carbon sequestration in mangroves from an earthquake uplift event.

The following is the abstract of this article: "[The authors] assessed the carbon stocks (CS) in mangroves that developed after a magnitude 7.1 earthquake in Silonay, Oriental Mindoro, south Luzon, The Philippines in November 1994. The earthquake resulted in a 50 cm uplift of sediment that provided new habitat within the upper intertidal zone which mangroves colonized (from less than 2 ha pre-earthquake to the current 45 ha, 23 years post-earthquake). The site provided an opportunity for a novel assessment of the rate of carbon sequestration in recently established mangroves. The carbon stock was measured in above-ground, below-ground and sediment compartments over a seaward to landward transect. Results showed a mean carbon stock of 549 ± 30 Mg C ha^{-1} (of which 13% was from the above-ground biomass, 5% from the below-ground biomass and 82% from the sediments). There was high carbon sequestration at a 40 cm depth that can be inferred attributable to the developed mangroves. The calculated rate of C sequestration (over 23 years post-earthquake) was 10.2 ± 0.7 Mg C ha^{-1} yr^{-1} and is comparable to rates reported from mangroves recovering from forest clearing. The rates [the authors] present here from newly developed mangroves contributes to calibrating estimates of total CS from restored mangroves (of different developmental stages) and in mangroves that are affected by disturbances." **Severino G. Salmo, Vanessa Malapit, Maria Carmela A. Garcia, and Homer M. Pagkalinawan,** *Biology Letters*. (Subscription may be required.)

Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany.

The following is from the abstract of this article: "…This research takes a social science perspective and investigates the awareness, general perception and acceptance of CCS in comparison to [carbon capture and utilization (CCU)] by applying an online survey in Germany (2017, n = 509). In addition, the risk perception of single steps in the CCU/CCS process chains was explored (CCS: CO_2-capturing, CO_2-transport, CO_2-storage; CCU: CO_2-capturing, CO_2-transport, temporary CO_2-storage, production, product usage, product disposal). Significant differences were found for the perception and acceptance of CCS and CCU: while both technologies were generally accepted, CCU was perceived significantly more positively than CCS. CCS-acceptance was negatively influenced by storage and transport risks; for CCU, disposal and product risks decreased acceptance. [The authors'] results contribute to the development of communication concepts for a successful implementation of CO_2-based technologies by considering public concerns." **K. Arning, J. Offermann-van Heek, A. Linzenich, A. Kaetelhoen, A. Sternberg, A. Bardow, and M. Ziefle,** *Energy Policy.* (Subscription may be required.)

A Review on Public Understanding of Carbon Dioxide Capture and Storage (CCS) in South Korea.

The following is the abstract of this article: "Since the Paris Agreement, member countries have set national goals clearly stated in the 'Intended Nationally Determined Contributions' (INDC) to reduce the intended amount of carbon dioxide. In many other countries, the government has invested in national R&D to promote cleaner energy and Carbon Capture and Storage (CCS) projects that is considered as one of the most pragmatic means to achieve the set mitigation target in a national scale. In some country, the control and management of CO_2 has been implemented in new technical systems called CO_2 smart grids. However, along with continual CCS R&D, laws and regulatory interventions supporting its technical pillars should mutually encompass its development. Without public understanding, technological development cannot be fully implemented by the involved public and private entities permitting to attain the set mitigation targets. In previous research, only few studies on public understanding have linked its policies to the actual valid legislation. This article therefore aims to review the overall public understanding conditions on CCS in Korea and to systematically outline public understanding in actual Acts as well as in the Draft of Korean integrated CCS Act. Finally, this research tried to imply regulatory intervention guidelines on public understanding of CCS along with possible improvement for the next revision of the Korean CCS Act." **Moonhyun Koh, Bola Ju, and Woongchan Seo,** *Energy Procedia.* (Subscription may be required.)

The economics of CCS: Why have CCS technologies not had an international breakthrough?

The following is the abstract of this article: "Eleven years on since the United Nations' Intergovernmental Panel on Climate Change was awarded the Nobel Peace Prize in recognition of its efforts in combating climate change, fossil fuels remain the most dominant global energy source. As the total replacement of fossil fuel energy is not expected to take place immediately in the near future, the International Energy Agency has repeatedly declared carbon capture and sequestration (CCS) as a key technology for mitigating climate change. However, CCS lacks the scale required for substantial reduction in carbon dioxide emissions from fossil fuel power generation. Even though CCS is one of the key technologies for mitigating climate change, why has this technology not had an international breakthrough? To shed light on this question, this paper employs a simple model of energy generation, scrutinizes the economic drivers of CCS based on the analytical results, and discusses the possible obstacles that can prevent a widespread rollout of the technology. This is followed by a state-of-the-art in literature pertaining to the economics of CCS, and a discussion that points to a dichotomy between the economic theory and reality. The study concludes with some policy suggestions and directions for future research." **Tunç Durmaz,** *Renewable and Sustainable Energy Reviews.* (Subscription may be required.)

CO_2-enhanced oil recovery and CO_2 capture and storage: An environmental economic trade-off analysis.

The following is the abstract of this article: "CO_2 enhanced oil recovery can play a significant role in stimulating carbon capture and storage because of additional oil revenues generated. However, it also leads to additional greenhouse gas emissions. [The authors] estimate the global warming potential of different CO_2 capture scenarios with and without enhanced oil recovery. During a 10 year period in which oil and electricity are produced without CO_2 being captured, the global warming potential is 11 $MtCO_2$ equivalents. [The authors] show that if CO_2 is captured and used for 15 years of enhanced oil recovery, the global warming potential decreases to 3.4 $MtCO_2$ equivalents. This level is 100% higher compared to the scenario in which the captured CO_2 would be stored in an offshore aquifer instead. If the capture of CO_2 is stopped when the oil reservoir is depleted, the global warming potential resulting from 10 years electricity production is 6 $MtCO_2$ equivalents. However, if CO_2 is stored in the depleted reservoir, the global warming potential is six times lower during that period. Electricity production and oil refining are the main contributors to the global warming potential. The net present value analysis indicates that for CO_2 prices lower than or equal to 15 €/t and oil prices greater than or equal to 115 €/t, it is most profitable to capture CO_2 for enhanced oil recovery only. Because of the low CO_2 price considered, large incomes from oil production are required to stimulate CO_2 capture. The environmental economic trade-off analysis shows that if CO_2-enhanced oil recovery is followed by CO_2 capture and storage, costs increase, but the net present value remains positive and the global warming potential is reduced. Authorities could use these outcomes to support the development of economic mechanisms for shared investments in CO_2 capture installations and to mandate both oil producer and large CO_2 emitting firms to store CO_2 in depleted oil fields." **Pieter Roefs, Michele Moretti, Kris Welkenhuysen, Kris Piessens, and Tine Compernolle,** *Journal of Environmental Management.* (Subscription may be required.)

Anatomy of Emissions Trading Systems: What is the EU ETS?

The following is the abstract of this article: "An anatomy identifies four main components of actual or proposed Emissions Trading Systems (ETS): (1) Pursued policy goals with the ETS instrument; (2) Public authority allocations of permits to the regulated participants; (3) Carbon emissions price levels; and (4) Participants' abatement expenses dependent on the ready availability of affordable abatement techniques or of low-carbon innovation opportunities. These components cover a range of options. A different assemblage of options delivers different ETS exemplars. Two main exemplars are identified. The actual EU ETS is highly successful in meeting the goal of low financial burdens on EU industry, thereby precluding carbon leakage. The other exemplar opts for high carbon emissions prices in the EU to induce industrial innovations towards a low-carbon economy. Incumbent industrial interests oppose this exemplar. Contrary to current policy discourse and to wishful proposals, both ETS exemplars cannot co-exist. ETS anatomy offers insight and structure for thorough analysis and evaluation of existing ETS, resulting in context–specific and appropriate designs of the carbon trading systems." **Aviel Verbruggen, Erik Laes, and Edwin Woerdman,** *Environmental Science & Policy.* (Subscription may be required.)

Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures.

The following is the abstract of this article: "Considering the cap-and-trade regulation and manufacturer's two types of strategies: adopting green technology (GT) and purchasing carbon credits (PC), [the authors] develop game models to investigate the manufacturer's production and emission abatement decisions as well as the governmental emission cap regulation in a supply chain with three power structures (Manufacturer Stackelberg (MS), Retail Stackelberg (RS) and Vertical Nash (VN)), and analyze how a manufacturer's low carbon strategy changes with the various governmental cap under the three supply chain power structures. The main conclusions are as follows. If the manufacturer adopts green technology strategy, supply chain power structure will not affect social welfare. High consumer's low-carbon preference is more beneficial to the social welfare, the government should advocate the consumer's preference for low carbon product. If the manufacturer purchases

carbon credits, the government under the power structure of VN will gain the most social welfare." **Suyong Zhang, Chuanxu Wang, Chao Yu, and Yangjun Ren,** *Computers & Industrial Engineering.* (Subscription may be required.)

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High-resolution 3D marine seismic acquisition in the overburden at the Tomakomai CO_2 storage project, offshore Hokkaido, Japan.

The following is the abstract of this article: "Monitoring injected CO_2 is an important part of assuring permanence of long term storage to mitigate atmospheric emissions. Three-dimensional (3D) seismic has been shown to be an effective technology for visualizing and quantifying subsurface geology and fluids. In this study, [the authors] demonstrate the successful acquisition, processing, and initial interpretation of a first-of-its-kind high-resolution 3D (HR3D) marine seismic survey above an active CO_2 injection site offshore Tomakomai, Japan. An initial sensitivity study indicated generally favorable subsurface conditions for imaging subsurface pore fluid changes. A unique processing workflow incorporating multiple data processing software packages has been tailored to the short-offset and low-fold HR3D acquisition. The final 3D volume shows generally flat and laterally-continuous stratigraphy in the overburden above the injection zone without identifiable faults, indicating coherent overburden above the CO_2 injection site and low associated risk of vertical CO_2 migration. The successful deployment of this novel marine seismic monitoring technology in the overburden at a small-scale (100 kt/yr) demonstration project suggests HR3D will also be a useful characterization and monitoring tool for larger demonstration and commercial-scale (~10 MT) offshore CCS sites." **T.A. Meckel, Y.E. Feng, R.H. Treviño, and D. Sava,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Application of the Aquifer Impact Model to support decisions at a CO_2 sequestration site.

The following is the abstract of this article: "The National Risk Assessment Partnership (NRAP) has developed a suite of tools to assess and manage risk at CO_2 sequestration sites. The NRAP tool suite includes the Aquifer Impact Model (AIM), which evaluates the potential for groundwater impacts from leaks of CO_2 and brine through abandoned wellbores. There are two aquifer reduced-order models (ROMs) included with the AIM tool, a confined alluvium aquifer, and an unconfined carbonate aquifer. The models accept aquifer parameters as a range of variable inputs so they may have broad applicability. The generic aquifer models may be used at the early stages of site selection, when site-specific data is not available. Guidelines have been developed for determining when the generic ROMs might be applicable to a new site. This paper considers the application of the AIM to predicting the impact of CO_2 or brine leakage were it to occur at the Illinois Basin Decatur Project (IBDP). Results of the model sensitivity analysis can help guide characterization efforts; the hydraulic parameters and leakage source term magnitude are more sensitive than clay fraction or cation exchange capacity. Sand permeability was the only hydraulic parameter measured at the IBDP site. More information on the other hydraulic parameters could reduce uncertainty in risk estimates. Some non-adjustable parameters are significantly different for the ROM than for the observations at the IBDP site. The generic ROMs could be made more useful to a wider range of sites if the initial conditions and no-impact threshold values were adjustable parameters." **Diana Holford Bacon, Randall A. Locke II, Elizabeth Keating, Susan Carroll, Abbas Iranmanesh, Kayyum Mansoor, Bracken Wimmer, Liange Zheng, Hongbo Shao, and Sallie E. Greenberg,** *Greenhouse Gases: Science and Technology.* (Subscription may be required.)

Researching candidate sites for a carbon storage complex in the Central Appalachian Basin, USA.

The following is the abstract of this article: "The purpose of the Central Appalachian Basin-Carbon Storage Assurance Facility Enterprise Integrated Prefeasibility Project was to identify candidate sites in eastern Ohio for a storage complex capable of storing 50 million [metric tons]. Carbon capture and storage (CCS) will be essential in the Appalachian Basin, which includes coal-fired power plants, natural gas processing, refineries, chemical plants, and natural gas power. The project team investigated Cambrian-Ordovician Age sandstones and carbonates collocated near depleted oilfields, where enhanced oil recovery could provide a stepping stone for developing a storage hub. Feasible routes for linking sources to sinks via regional pipelines were assessed. The sub-basinal analysis demonstrated significant potential storage capacity in both deep saline reservoirs and depleted oil and gas fields. The project definition analysis revealed the project footprint would be reasonable and only two wells would be needed for injection of CO_2. Project economics illustrated a need for both government and private investment in the absence of a regulatory mandate. Ohio also lacks a comprehensive policy for long-term liability and subsurface storage rights, which could be addressed during pilot testing. Developing qualified sites within two selected areas for large-scale deployment of CCS appears feasible and the study helped to define future research needs." **Lydia Cumming, Jared Hawkins, Joel Sminchak, Manoj Valluri, and Neeraj Gupta,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Carbon pricing, technology transition, and skill-based development.

The following is the abstract of this article: "[The authors] analyze the impact of carbon prices on human capital accumulation, sectoral change, and economic growth. In [the authors'] framework output is produced with dirty and/or clean technologies using skilled and unskilled labor as inputs. Carbon policy affects technology selection which transmits incentives for human capital formation. [The authors] show that a temporary policy may be sufficient for a transition to a clean economy and that such a policy also stimulates economic growth. Moreover, in the presence of inter-country knowledge spillovers, a carbon policy in the North helps human capital formation in the South and induces South's transition to the clean steady state." **Kirill Borissov, Alexandra Brausmann, and Lucas Bretschger,** *European Economic Review.* (Subscription may be required.)

On the role of spatially correlated heterogeneity in determining mudrock sealing capacity for CO_2 sequestration.

The following is the abstract of this article: "Storing CO_2 in depleted hydrocarbon reservoirs is a common practice world-wide. Mudrocks often serve as seals above these reservoirs due to their small pore throats and low permeability, but they can fail if the buoyant pressure of the trapped fluid overcomes the threshold pressure of the seal. Mudrocks are primarily made of silt-sized and clay-sized particles, and sufficiently high silt concentrations can create situations where the silt grains create a connected stress chain through the rock matrix, which preserves the large pore throats under compaction. This phenomenon, termed silt bridging, can reduce the threshold pressure of the mudrock, causing seal failure. [The authors] used grain-scale modeling to create computer-generated grain packs with and without the effect of gravity to understand the effects of deposition and compaction on the petrophysical properties like capillary pressure, tortuosity, permeability, capillary drainage curves, and spatial correlation of heterogeneities. [The authors] found that, when the fraction of silt-sized grains exceeded 40%, the percolation length (the length of the first path of the non-wetting fluid through a medium) and the tortuosity suddenly decreased. This was supported by the results from the throat size variograms, where the same type of correlations between throats were observed at greater lag distances, signifying increased intergranular distances. [The authors'] work provides an insight into the role of different grain sizes, concentrations and spatial distributions on the flow properties and sealing capacity of mudrocks." **Abhishek Bihani and Hugh Daigle,** *Marine and Petroleum Geology.* (Subscription may be required.)

Carbon capture and storage (CCS) experts' attitudes to and experience with public engagement.

The following is from the abstract of this article: "…Public engagement with CCS is important for a range of reasons, but previous work has not explored the perceived rationales for, or benefits of, public engagement amongst CCS experts (including those who engage the public themselves). Here, [the authors] present mixed-methods research (comprising expert interviews and an online survey) to elucidate these rationales, and expose CCS expert views of public engagement. [The authors'] findings indicate some differences in perceptions of public engagement with CCS (and of the risks and benefits of CCS) between those who engage directly with the public and those who do not: the former tend to have a more nuanced view of engagement, and are also more enthusiastic about the benefits of CCS, than the latter. Overall, CCS experts recognise the importance of public engagement for the roll-out of CCS for both substantive and instrumental rationales, and are largely aware of the range of factors (knowledge, values, trust, etc.) influencing public engagement. Nevertheless, the relatively low salience of early and substantive engagement amongst CCS experts suggests there is room for improving the flow of learning from the public engagement research literature to those charged with delivering it." **Dimitrios Xenias and Lorraine Whitmarsh,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Can a carbon emission trading scheme generate the Porter effect? Evidence from pilot areas in China.

The following is the abstract of this article: "'…Since 2013 China implemented carbon emission trading scheme (ETS) in seven provinces or cities. The purpose of this paper is to investigate whether the implementation of ETS can result in the Porter effect. Based on the Porter hypothesis theory, this study employs the difference-in-difference (DID) method and the improved DEA model to analyze whether ETS can bring economic dividend and environmental dividend. The empirical results specify that in the short term, ETS can significantly reduce carbon emissions in the pilot provinces, but fail to increase GDP. Therefore, ETS does not realize the Porter effect in the short term. Nevertheless, in terms of the empirical results [the authors] can find ETS plays a significant role in emission reduction. In the long term, ETS can stimulate sustainable economic dividend and environmental dividend, and achieve the Porter effect. From the test results, [the authors] can find ETS has good economic and emission reduction functions. ETS achieves the Porter effect in the long term but not in the short term. In order to achieve the Porter effect from ETS successfully, a sound carbon emission trading scheme must be established to ensure efficient carbon emission trading market." **Feng Dong, Yuanju Dai, Shengnan Zhang, Xiaoyun, Zhang, and Ruyin Long,** *Science of The Total Environment.* (Subscription may be required.)

China's roadmap to low-carbon electricity and water: Disentangling greenhouse gas (GHG) emissions from electricity-water nexus via renewable wind and solar power generation, and carbon capture and storage.

The following is from the abstract of this article: "Electricity and water form an intricate nexus, in that water is crucial for power generation, and electricity (or other primary forms of energy) is the key enabler for water purification and waste-water treatment. Nonetheless, both energy conversion and water purification result in substantial amounts of greenhouse gas (GHG) emissions. These negative interactions with potential 'snowball' effect, can be decoupled via the deployment of renewable power generation, and carbon capture from fossil-[fueled] technologies. However, such retrofits pose new challenges as wind and solar energy exhibit intermittent generation patterns. In addition, integrating thermal power plants with carbon capture and storage (CCS) imposes energy penalties and increases water requirements. In the present research, an optimization framework is developed which enables systematic decision-making for the retrofit of existing power and water infrastructure as well as investment in renewable and green technologies. A key aspect of the applied framework is the simultaneous optimization of design and operational decisions in the presence of uncertainties in the water demand, electricity demand, as well as wind and solar power availability. The proposed methodology is demonstrated for the case of the water-electricity nexus in China, and provides in-depth insights into regional characteristics of low carbon electricity generation, and their implications for water purification and wastewater treatment, demonstrating a roadmap towards sustainable energy and electricity." **Mahdi Sharifzadeh, Raymond Khoo Teck Hien, and Nilay Shah,** *Applied Energy.* (Subscription may be required.)

AUGUST 2019

Modeling of time-lapse seismic monitoring using CO_2 leakage simulations for a model CO_2 storage site with realistic geology: Application in assessment of early leak-detection capabilities.

The following is from the abstract of this article: "Time-lapse surface seismic surveys have been widely used at carbon sequestration sites for site characterization, monitoring subsurface CO_2 plume migration, and detecting potential CO_2 leakage from a storage reservoir. Monitoring in the first permeable unit directly above the primary seal is important for early detection of CO_2 leakage. Forward modeling of time-lapse seismic data can be used to assess the utility of the seismic method for CO_2 leakage detection. [The authors] develop a workflow for forward modeling of time-lapse seismic data, including constructing seismic velocity models using flow simulation outputs, modeling of pre-stack and post-stack synthetic seismic data following seismic data processing sequence and analysis of processed synthetic time-lapse seismic data. [The authors] apply the forward modeling and analysis workflow to assessing the detectability and the earliest detection time of seismic monitoring using the hypothetical CO_2 leakage scenarios for a model geologic storage site with realistic geology. [The authors] derive the detection thresholds using the simulated normalized root-mean-square (NRMS) differences for the no-leakage case at a range of signal-to-noise ratios, representing the background noise levels in seismic data. [The authors] then compare NRMS differences triggered by the CO_2 leakage to the detection thresholds at each time step to quantify the detectability and the earliest detection time of seismic monitoring. [The authors] analyze the effects of the acquisition parameters and elastic parameters on the produced synthetic seismic data and earliest detection time. [The authors'] modeling results indicate that high signal-to-noise ratio is needed to detect the CO_2 leakage at the model site. Minimizing the background noise in seismic data is crucial for improving the detectability of the seismic method. Increasing the shot density or increasing the dominant frequency of the source wavelet is likely to increase the possibility of the leakage detection and reduce the time needed for the detection. The elastic parameters used in the rock physics modeling have significant effects on the resultant seismic velocity models and synthetic seismic data, highlighting their critical roles in understanding and interpreting time-lapse seismic reflection data associated with CO_2 monitoring, verification and accounting activities." **Zan Wang, William P. Harbert, Robert M. Dilmore, and Lianjie Huang,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Boundary Dam or Petra Nova – Which is a better model for CCS energy supply?

The following is from the abstract of this article: "SaskPower's Boundary Dam plant (Canada) and NRG's Petra Nova plant (USA) are the only two commercial-scale coal-fired power plants currently operational in the world that use CCS technology. While both CCS installations are retrofit projects that employ a post-combustion CO_2 capture system using advanced amines, the two plants differ significantly in their approach to providing the steam and electrical energy requirements of the capture system. This paper presents a comparative techno-economic evaluation of pulverized coal (PC) power plants equipped with the different CCS system configurations used in these two demonstration plants, as well as two additional design configurations that may be of interest. The results presented in this paper illustrate the conditions which favor one approach over the other, and thus provide insights for planning new large-scale CCS projects." **Hari C. Mantripragada, Haibo Zhai, and Edward S. Rubin,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Efficient pathways to reduce carbon emissions in the electric sector.

The following is from the abstract of this article: "The study develops a 2-dimensional map of the feasible design space for an electric generation system. Cost and CO_2 emissions contours are plotted across the map. The principles of constrained optimization are used to identify the efficient pathways eliminating emissions and the technology drivers that determine them. The CO_2 intensity of the baseload is shown to be the primary driver. Further, the need for large, seasonal storage depends strongly on the level of baseload deployed." **Alan D. Lamont,** *The Electricity Journal.* (Subscription may be required.)

Impacts of a carbon tax across US household income groups: What are the equity-efficiency trade-offs?

The following is from the abstract of this article: "This paper assesses the impacts across U.S. household income groups of carbon taxes of various designs. [The authors] consider both the source-side impacts (reflecting how policies affect wage, capital, and transfer incomes) as well as the use-side impacts (reflecting how policies alter the prices of goods and services purchased by households). [The authors] apply an integrated general equilibrium framework with extended measures of the source- and use-side impacts that add up to the overall welfare impact. [The authors'] results indicate that the distributional impacts depend importantly on the nature of revenue-recycling and the treatment of transfer income. In the absence of targeted compensation to achieve distributional objectives, the use-side impacts tend to be regressive while the source-side impacts are progressive, and the progressive source-side impacts tend to offset fully the regressive use-side impacts. Both impacts are considerably larger when one employs the more comprehensive welfare measures introduced in this study. The efficiency costs of targeted compensation to achieve distributional objectives depend critically on the recycling method and compensation target. These costs are an order of magnitude higher when the remaining revenues after compensation are used for corporate income tax cuts, compared with costs when remaining revenues are used other ways. Efficiency costs also rise dramatically when targeted compensation extends beyond the lowest income quintiles." **Lawrence H. Goulder, Marc A.C. Hafstead, GyuRim Kim, and Xianling Long,** *Journal of Public Economics.* (Subscription may be required.)

The economic effects of carbon tax on China's provinces.

The following is from the abstract of this article: "The responsibility for carbon emissions tends to be different under different emission accounting principles. By applying the latest 2012 Chinese multi-regional input–output table, this study evaluated the impacts of carbon tax on tax burdens and sectoral competitiveness in Chinese provinces when considering either production-based or consumption-based emissions. [The authors'] results indicated that, in the scenario of cutting production tax for carbon tax, the developed provinces, such as Beijing, Shanghai, Zhejiang, and Jiangsu, who are much bigger payers of production tax, are net beneficiaries of carbon tax. In contrast, recycling the tax revenues to low-income households makes the less-developed provinces in the central and western China become net revenue receivers. Furthermore, for competitiveness effects, the emission intensive sectors, such as Electricity and hot water production and supply, Petroleum and gas, and Metal products, are impacted vitally under both accounting principles in all provinces. Nevertheless, compared with the production-based principle, a consumption-based carbon tax could reduce the unfavorable competitiveness effects of most affected sectors in the less-developed provinces, while slightly increasing those effects in the developed provinces. [The authors'] results provide new information on the regional impacts of carbon tax based two different accounting principles with different tax revenue recycling scenarios." **Kun Zhang, Mei-Mei Xue, Kuishuang Feng, and Qiao-Mei Liang,** *Journal of Policy Modeling.* (Subscription may be required.)

Recovery in soil carbon stock but reduction in carbon stabilization after 56-year forest restoration in degraded tropical lands.

The following is from the abstract of this article: "Afforestation is considered as an effective method for alleviating the rising of atmospheric CO_2 concentration through the accumulation and long-term storage of carbon (C) in the vegetation and soil. However, it is still unknown whether soil C accumulation in the restored forests could eventually recover to the equivalent level of the undisturbed forests and much less is known about how afforestation will affect C stabilization. Here [the authors] conducted a field study in degraded tropical forests of south China. The aim was to evaluate the recovery of soil C stock following afforestation by comparing different C fractions in soils (0–10 cm and 10–20 cm) in two reforested forests [a restored secondary forest (RSF) and a managed *Eucalyptus* plantation (MEP)] to those in a bare land (BL) and a nearby undisturbed forest (UF). Results showed that after 56-year afforestation at the bare lands, C stocks in both soil layers were significantly increased with an increase greater in the RSF than the MEP, while C recalcitrant indices (RI) were reduced. Soil C stock in the RSF recovered to a similar level to the UF, but soil RI in the RSF was still lower than the UF particularly in the 10–20 cm layer. The calculated capacity of soil C sequestration with the product of soil C stock and its RI followed the order of UF > RSF > MEP > BL. [The authors'] results demonstrate that afforestation on degraded tropical lands could recover soil C stock within a few decades, but C stabilization would be reduced." **Huiling Zhang, Qi Deng, Dafeng Hui, Jianping Wu, Xin Xiong, Jianqi Zhao, Mengdi Zhao, Guowei Chu, Guoyi Zhou, and Deqiang Zhang,** *Forest Ecology and Management.* (Subscription may be required.)

The initial three years of carbon dioxide exchange between the atmosphere and a reclaimed oil sand wetland.

The following is from the abstract of this article: "Northern peatlands contain up to 20% of the ~3000 Pg of global soil organic carbon. Carbon-rich peatlands cover upwards of 65% of the landscape in northern Canada where resource extraction activities disturb both the carbon pools and the future carbon sequestration capacity of the landscape. Previous estimates of the carbon losses from this disturbance predict a complete loss of the region's peatland carbon pool. Mining industries operating in these sensitive environments have recently begun constructing closure landscapes which are intended to develop carbon cycle processes similar to undisturbed northern peatlands. This study investigates eddy covariance fluxes of CO_2 at one of Canada's first fully constructed boreal plains watersheds, the Sandhill Fen Watershed. During the first three years since inception, only the lowland region had an annual net ecosystem exchange of CO_2 (NEE) indicative of increasing CO_2 sink potential. The lowland region was characterized by saturated salvaged peat soils, standing water, thriving communities of *Typha* and *Carex* spp. and was a net CO_2 sink of $77 gCm^{-2}$ in the third year. At the same time the upland and the midland regions characterized by moist salvaged peat soils and a mix of herbaceous, shrub and planted *Picea glauca* and *Pinus banksiana* remained net sources of CO_2. Despite similar rates of gross primary production, ecosystem and plot-level respiration rates in the lowland were significantly lower than in the midland region, likely due to very low reduction potentials within the lowland's saturated soils. With no other significant outflows of carbon, the lowland of the Sandhill Fen Watershed may be in the early stages of organic matter accumulation. Due to limited oxidation of the salvaged peat substrate in the lowland region, wetland reclamation employing these techniques may reduce the disturbance loss of the carbon pool in the boreal plains." **M. Graham Clark, Elyn Humphreys, and Sean K. Carey,** *Ecological Engineering.* (Subscription may be required.)

Carbon and nitrogen storage of constructed and natural freshwater wetlands in Southern California.

The following is from the abstract of this article: "Artificial wetlands are often constructed to replace degraded natural wetlands; however, it is unclear whether constructed wetlands can become functionally equivalent to natural wetlands. [The authors] used measurements of soil and plant nitrogen (N) and carbon (C) storage as indicators of initial function in an artificial wetland in southern California, and compared them to the C and N stocks of local naturally occurring wetlands. [The authors] hypothesized that C and N stocks would be significantly lower in the constructed wetland. Soil and vegetation C and N stocks of the constructed wetland increased rapidly but plateaued after 6 years, and soil C and N stocks of the constructed wetland were higher than, or comparable to, local natural wetlands. Limited comparisons between constructed and natural freshwater wetlands reported in the literature illustrated high variability in ecosystem C and N storage, but soil C and N stocks in artificial wetlands were significantly lower than in natural wetlands. Southern California wetlands had lower soil C and N storage compared to other temperate zone wetlands, which may be due to the highly variable rainfall and flow regimes of semi-arid wetlands in southern California." **Jacob Maziarz, George L Vourlitis, and William Kristan,** *Ecological Engineering*. (Subscription may be required.)

Feasibility study for carbon capture utilization and storage (CCUS) in the Danish North Sea.

The following is from the abstract of this article: "An innovative addition to the conventional oil and gas extraction by introducing enhanced oil recovery (EOR) techniques in the Danish North Sea is something which has been sought for long time. Combining the offshore EOR technology with the CCS is considered to be a possibly attractive solution as the associated benefit is twofold: (1) increased oil recovery through miscible displacement via CO_2 pushing the hydrocarbons out of the reservoir and (2) the disposal of a greenhouse gas such as the CO_2. A feasibility study for implementing a CCUS project is presented in the scope of this study, in a North Sea Chalk Field which is the oldest and one of the largest oilfields in the Danish sector, both for the technical and the economic merit, by means of using a commercial reservoir simulation package. The capital (CAPEX) and operational (OPEX) expenditures associated with such a long term development project is estimated. Results suggest that around 100 million barrels of additional oil reserves can be unlocked via CO_2 injection, while 40 million [metric tons] of CO_2 is being trapped in the reservoir." **Vural Sander Suicmez,** *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

SEPTEMBER 2019

Quest carbon capture and storage offset project: Findings and learnings from 1st reporting period.

The following is from the abstract of this article: "Quest is a fully integrated CCS project that started CO_2 injection in August of 2015. The Quest CCS Project is located near Fort Saskatchewan, Alberta, Canada. It includes a capture facility which uses a Shell amine technology, a pipeline of about 65 km length, and three injection well pads. Each injection well pad has an injection well, a deep monitoring well, and shallow groundwater wells. The storage complex is geologically defined by the injection reservoir, a deep saline aquifer called the Basal Cambrian Sand (BCS) (about 45 m thick) and several seals, including the Middle Cambrian Shale (about 50 m thick) and Lotsberg Salts (about 120 m thick). As of August 2018, over three million [metric tons] of CO_2 have been safely injected and permanently stored in the BCS. The Alberta Carbon Competitiveness Incentive Regulation (CCIR) requires the use of standard methods of quantification for reporting GHG emissions for facilities with over 100,000 [metric tons] of carbon dioxide equivalent (CO_2e) per year. An emission offset project is required to comply with CCIR, associated standards and protocols, to demonstrate a reduction in the specified gas emissions and, in the case of Quest, geological sequestration. Quest is the first CCS project to implement an offset project in the context of commercial scale on-shore CO_2 geological sequestration within a saline aquifer. Quest uses the Quantification Protocol for CO_2 Capture and Permanent Storage in Deep Saline Aquifers, from Alberta Environment and Parks. An offset project must develop an offset project plan (OPP) which demonstrates how the project meets the requirement of the protocol, describes how GHG emissions reductions are achieved, identifies risks associated with the quantification of emission reduction benefits, and describes methodologies used to quantify sources and sinks. Subsequent to completing the OPP, an offset project will put together offset project reports (OPR) to report on the net reductions of GHG emissions for a specific period. The intent of this paper is a) to provide an overview of the OPP and OPR for the Quest CCS project, and b) to discuss learnings from the initial compilation and submission of offset project reports. The key learning at this time is associated to the equipment improvements to the injection gas online analyzer." **Celina Duong. Charles Bower, Ken Hume, Luc Rock, and Stephen Tessarolo,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Possibilities of CO_2 purification coming from oxy-combustion for enhanced oil recovery and storage purposes by adsorption method on activated carbon.

The following is the abstract of this article: "The results of laboratory and numerical investigations of oxy-combustion flue gas purification for enhanced oil recovery (EOR) as well as storage purposes using the adsorption method were presented. The experimental investigations provided results of purification process and allowed to determine the correction factors for validation and calibration of the elaborated numerical model. In turn, the numerical simulations were used to extensive research on the purification process at different thermodynamic conditions and process configurations, other than applied at laboratory tests. Neither experimental research nor numerical simulations confirmed the possibility of enrichment the oxy-combustion flue gas to meet the conceptual design purity limits of oxygen at the level of 10ppmv (recommended by NETL) for EOR and storage purposes, but the purity of the product was met in the case of higher ones, described in the literature. The conducted analysis of the energy demand shows that the one-stage vacuum-pressure swing adsorption (VPSA) purification process requires about 57 kWh/t_{CO2} at recovery of 73.58% and product purity of 97.78% when the product is at the ambient pressure, 128 kWh/t_{CO2} when the product is at 18 bar and 161 kWh/t_{CO2} at the pressure equals 120 bar. Obtained results were also compared with the literature data." **Dariusz Wawrzyńczak, Marcin Panowski, and Izabela Majchrzak-Kucęba,** *Energy*. (Subscription may be required.)

Managing the invasion of guava trees to enhance carbon storage in tropical forests.

The following is the abstract of this article: "Tropical forests account for a substantial percentage of the world's carbon stocks, but the consequences to carbon storage of the rapid invasiveness of the guava tree in these forests is not known. Two different forest management strategies are practiced in a tropical forest in western Kenya: (1) a protection strategy where human entry is prohibited except for minimalistic human presence (e.g., research activities); and (2) a conservation strategy where human access to the forest and its resources are permitted. [The authors] assessed the effects of these management strategies and different levels of disturbance caused by the legacy effects of legal logging activities and the contemporary effects of unauthorized harvesting of forest products on the abundance of guava and non-guava trees and carbon storage in both plant biomass and soil in this forest. [The authors] found that guava trees were less likely to thrive and carbon storage in plants and soils was similar in sites with minimal disturbance under both the protection and conservation strategies. However, as disturbance increased, whether by the historical or contemporary effects of human activities, guava trees were more likely to thrive and carbon storage in plants shifted from non-guava trees to guava trees, but without an effect on more stable soil carbon. [The authors] conclude that regulations should be strictly enforced to prevent all logging activity, but the conservation strategy would provide similar effects on both forest plant and soil carbon to the protection strategy, while providing benefits to the surrounding community who rely on the forest for cultural and spiritual nourishment." **Rael Adhiambo, Francis Muyekho, Irena F. Creed, Eric Enanga, William Shivoga, Charles G. Trick, and John Obiri,** *Forest Ecology and Management*. (Subscription may be required.)

Soil organic matter priming and carbon balance after straw addition is regulated by long-term fertilization.

The following is from the abstract of this article: "Straw incorporation is crucial to soil organic carbon (SOC) sequestration… The fate of straw C and the associated net SOC balance remain largely unexplored, particularly in soils subjected to long-term mineral and organic fertilization. To address this, soil ($\delta^{13}C$: –19‰) that had been continuously cropped with maize for 31 years and subjected to five long-term fertilization regimes, including (i) control (Unfertilized), (ii) mineral fertilizer (NPK) application, (iii) 200% NPK (2×NPK) application, (iv) manure (M) application, and (v) NPK plus manure (NPKM) application, was incubated with or without addition of rice straw ($\delta^{13}C$: –29‰) for 70 days. Straw addition largely primed SOC mineralization. The priming effect (PE) was considerably higher in 2 × NPK (+122% of CO_2 from soil without straw addition) but lower in M (+43%) relative to the unfertilized soil (+82%), highlighting the importance of fertilization in controlling PE intensity. Fertilization increased the straw-derived microbial biomass C by 90–577% and straw-derived SOC by 34–68% compared to the unfertilized soil, primarily due to the increased abundance of Gram-negative bacteria and cellobiohydrolase activity. Straw-derived SOC was strongly positively correlated with straw-derived microbial biomass C, suggesting that dead microbial biomass (necromass) was a dominant precursor of SOC formation. Consequently, fertilization facilitated microbial utilization of straw C and its retention in soil, particularly in the M and NPKM fertilized soils. The amounts of straw-derived SOC overcompensated for the SOC losses by mineralization, resulting in net C sequestration which was highest in the NPK fertilized soil. [The authors'] study emphasizes that NPK fertilization decreases the intensity of the PE induced by straw addition and increases straw C incorporation into SOC, thus facilitating C sequestration in agricultural soils." **Lei Wu, Wenju Zhang, Wenjuan Wei, Zhilong He, Yakov Kuzyakov, Roland Bol, and Ronggui Hu,** *Soil Biology and Biochemistry*. (Subscription may be required.)

Study of convective-diffusive flow during CO_2 sequestration in fractured heterogeneous saline aquifers.

The following is the abstract of this article: "CO_2 sequestration in naturally fractured saline aquifers is important to be studied. This paper investigates the convective-diffusive flow to study CO_2 sequestration by dissolution in single and multi-fractured heterogeneous saline aquifers. The effect of fractures density, orientation, permeability, aperture and surface roughness on CO_2 dissolution and propagation of density-driven fingers are investigated. The results indicate that a single fracture causes the growing density fingers to deviate towards the high permeability path of the fracture. Additionally, the higher vertical fracture orientation, aperture and permeability will lead to a higher CO_2 storage. In the multiple fracture systems, matrix permeability has a dominant and positive effect on CO_2 storage. Nevertheless, the effect of fractures properties such as fracture density, spacing, permeability, aperture and surface roughness on the CO_2 storage are dependent on the fractures orientation. For instance, having fractures with rough surface can cause CO_2 dissolution retardation in the aquifers with only vertical fractures. This study provides more insights into dissolution trapping of CO_2 in fractured heterogeneous saline aquifers." **Mohamed Gamal Rezk and Jalal Foroozesh,** *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

Incentive model for enterprises based on carbon emission intensity.

The following is the abstract of this article: "A pilot scheme for a carbon emissions trading market has been launched in China. Some problems within the market include insufficient incentives, inefficient emissions reduction, and inequitable distribution. While previous studies adopted a state or provincial level perspective to examine such issues, little research has focused on enterprises at a business level. This article proposes a new incentive model that aims to resolve these problems. This model was developed while considering the carbon emission intensity of enterprises and cooperative game theory. According to the advanced value and average value of carbon emission intensity, the model classifies enterprises into three regions. The quota in the second year is related to its own emission intensity and the number of enterprises located in the region, which not only stimulates the enthusiasm of the enterprise to reduce emissions, but also serves to encourage more enterprises to participate in emission reductions. This article presents a study of 16 textile enterprises in Shandong Province. Depending on the model's calculation, the quota can be redistributed. Different emission intensity brings different emission reduction costs, which can intuitively show different responsibilities. The result is fairer and more reasonable than distributions that are based on a historical emissions quota." **Kai Wang, Linyu Xu, and Johannes Kals,** *Journal of Cleaner Production*. (Subscription may be required.)

Estimation of CO_2 sequestration potential by afforestation in the arid rangelands of Western Australia based on long-term empirical data.

The following is from the abstract of this article: "In this study (1999–2015), in an arid area near Leonora, Western Australia (annual rainfall: 220 mm $year^{-1}$; pan evaporation: 3400 mm $year^{-1}$), carbon sequestration was assessed in above and below ground biomass in Eucalyptus camaldulensis under ambient conditions and with active site amelioration (combination of water harvesting with large mounds and hardpan blasting). The carbon sequestration rate was estimated at 7.92 Mg-CO_2-e ha^{-1} $year^{-1}$ for a total carbon sink of 230 Mg-CO_2-e ha^{-1}. Carbon mitigation may thus be a viable option in arid regions, not only in Western Australia but globally, and can be enhanced with active site engineering." **Hideki Suganuma, Shin-ichi Aikawa, Yuji Sakai, Hiroyuki Hamano, Nobuhide Takahashi, Kiyotaka Tahara, Satoko Kawarasaki, Hajime Utsugi, Yasuyuki Egashira, Takuya Kawanishi, Richard J. Harper, Hiroyuki Tanouchi, Toshinori Kojima, Yukuo Abe, Masahiro Saito, Shigeru Kato, John Law, and Koichi Yamada,** *Ecological Engineering*. (Subscription may be required.)

Acorn: Developing full-chain industrial carbon capture and storage in a resource- and infrastructure-rich hydrocarbon province.

The following is from the abstract of this article: "Through assessment of Acorn's publicly-available outputs, [the authors] identify strategies which may help to enhance the viability of early-stage CCS projects. Initial capital costs can be minimised by infrastructure re-use, particularly pipelines, and by re-use of data describing the subsurface acquired during oil and gas exploration activity. Also, development of the project in separate stages of activity (e.g. different phases of infrastructure re-use and investment into new infrastructure) enables cost reduction for future build-out phases. Additionally, engagement of regional-level policy makers may help to build stakeholder support by situating CCS within regional decarbonisation narratives. [The authors] argue that these insights may be translated to general objectives for any CCS project sharing similar characteristics such as legacy infrastructure, industrial clusters and an involved stakeholder-base that is engaged with the fossil fuel industry." **Juan Alcalde, Niklas Heinemann, Leslie Mabon, Richard H. Worden, Heleen de Coninck, Hazel Robertson, Marko Maver, Saeed Ghanbari, Floris Swennenhuis, Indira Mann, Tiana Walker, Sam Gomersal, Clare E. Bond, Michael J. Allen, R. Stuart Haszeldine, Alan James, Eric J. Mackay, Peter A. Brownsort, Daniel R. Faulkner, and Steve Murphy,** *Journal of Cleaner Production*. (Subscription may be required.)

Carbon policy in developing countries: Giving priority to non-price instruments.

The following is the abstract of this article: "Carbon pricing might not be appropriate as the main element of the carbon policy package in emerging and developing countries (DCs), because the political economy constraints are greater than in developed countries. Non-price instruments and policies such as efficiency standards, market-oriented regulation, subsidies for clean technologies and public programs involving low carbon infrastructure should be preferentially developed to deal with market and regulatory failures, which are more widespread than in developed countries. These approaches are most effective in orientating technology and infrastructure, the principal means to achieving the mitigation imperative in DCs. Moreover, even if, in theory, policy packages using non-price instruments are less socially efficient than those focused on carbon pricing, they allow governments to circumvent political economy constraints, because their costs to consumers and citizens are not generalized and tend to be much less visible, while their redistributive effects are, if appropriately designed, generally not too regressive. In the end, developing a carbon policy that emphasizes non-price instruments and measures will pave the way to leverage carbon pricing as the main pillar of their future carbon policy in long term." Dominique Finon, *Energy Policy*. (Subscription may be required.)

Carbon tax incidence on household demand: Effects on welfare, income inequality and poverty incidence in Thailand.

The following is the abstract of this article: "Studying the impact of a carbon tax on household demand can be relevant in terms of securing public acceptance of a carbon tax and clarifying the implications for policy design. This paper aims to fill a gap in the academic literature by simulating carbon tax scenarios and estimating distributional effects of the tax on household welfare, income inequality, and poverty rates based on household consumption in Thailand. The study employs a microsimulation model incorporating the economy-wide effects of the tax on prices and consumers' behavioral responses to changes in prices. The results indicate that a carbon tax is progressive in Thailand under revenue-recycling scenarios by expanding social transfer programs. When carbon tax revenues are recycled through pensions for elderly people, the carbon tax could reduce the poverty rate and improve the welfare of households in the lowest quintile. The results imply that the distributional impacts of environmental taxes could result in favorable outcomes for income inequality and poverty reduction in developing countries." Supawan Saelim, *Journal of Cleaner Production*. (Subscription may be required.)

REPORTS and PUBLICATIONS

OCTOBER 2018

ADVANCED FOSSIL ENERGY: Information on DOE-Provided Funding for Research and Development Projects Started from Fiscal Years 2010 through 2017.

The following is from the highlights of this U.S. Government Accountability Office (GAO) document: "DOE provided $2.66 billion in funding, or obligations, for 794 R&D projects started from fiscal years 2010 through 2017 to develop advanced fossil energy technologies. Such technologies include processes for converting coal into synthesis gas composed primarily of carbon monoxide and hydrogen, and recovering methane from gas hydrates. Of the $2.66 billion, DOE provided $1.12 billion in funding for 9 later-stage, large demonstration projects, which were to assess the readiness for commercial viability of CCS technologies. CCS involves capturing man-made [CO_2] at its source and storing it permanently underground. DOE provided the remaining $1.54 billion in funding for 785 other projects in amounts that were relatively small—over half were for less than $1 million. Six demonstration projects researched CCS technologies using coal, while three used other fuels. The nine demonstration projects received funding ranging from $13 million to $284 million."

Estimating Carbon Storage Resources in Offshore Geologic Environments.

The following is the Executive Summary of this NETL document: "Long-term carbon storage in geologic reservoirs is a leading technique for removing excess CO_2 that would otherwise be emitted to the atmosphere as a result of anthropogenic activities. Effective carbon storage requires both safety and permanence. One underutilized national storage scenario involves carbon storage in offshore geologic formations, similar to those that hold oil, gas, or brine. This scenario has been tested in other countries on a small-scale, but is yet unproven in the United States. A major advantage of offshore storage is that the risk of CO_2 leakage into fresh groundwater resources is decreased, and the effect of that leakage on human population centers is minimized. However, as with onshore storage scenarios, there are many uncertainties surrounding offshore storage. These include issues related to both safety and permanence. After an extensive literature review of the current storage methodologies for onshore carbon storage in saline formations, comparing and contrasting the offshore and onshore characteristics of reservoirs, this study makes recommendations about future work to support offshore storage estimates and research. This report concludes with the suggestion that despite important differences between onshore and offshore systems, carbon can be stored safely and permanently in offshore saline geologic formations. This research proposes using the [DOE/NETL's] saline storage methodology with an integration of spatial-statistical tools to adjust for uncertainties."

Technology Roadmap – Low-Carbon Transition in the Cement Industry.

The following is a summary of this International Energy Agency (IEA) document: "The cement sector is the third-largest industrial energy consumer and the second-largest industrial CO_2 emitter globally. Rising global population and [urbanization] patterns, coupled with infrastructure development needs, drive up the demand for cement and concrete and increase pressure to accelerate action in reducing the carbon footprint of cement production. Under a scenario that considers announced carbon mitigation commitments and energy efficiency targets by countries, the cement sector would increase its direct CO_2 emissions just 4% globally by 2050, for an expected growth of 12% in cement production over the same period. However, more ambitious action would be needed to achieve global climate goals. This Technology Roadmap builds on the long-standing collaboration of the IEA with the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD). It provides an update of the Cement Technology Roadmap 2009: Carbon Emissions Reductions up to 2050, and sets a strategy for the cement sector to achieve the decoupling of cement production growth from related direct CO_2 emissions through improving energy efficiency, switching to fuels that are less carbon intensive, reducing the clinker to cement ratio, and implementing emerging and innovative technologies such as carbon capture. The report therefore outlines a detailed action plan for specific stakeholders to 2050 as a reference and a source of inspiration for international and national policy makers to support evidence-based decisions and regulations."

NOVEMBER 2018

A Multisensor Plume Monitoring Schema for Carbon Sequestration Sites in Subsurface Engineered-Natural Systems.

The following is from the Introduction of this NETL document: "The National Carbon Sequestration (NATCARB) Monitoring, Verification, and Accounting (MVA) program is tasked with monitoring CO_2 storage sites for compliance with the U.S. Environmental Protection Agency's (EPA) Underground Injection Control (UIC) Program to ensure that potable groundwater sources and sensitive ecosystems are protected. The major monitoring technology areas are atmospheric, remote sensing and near surface, subsurface, and intelligent monitoring networks and protocols. The primary objective of the NETL-led National Risk Assessment Partnership (NRAP) is to develop simulation-based risk assessment tools needed for safe, permanent geologic CO_2 storage, as well as monitoring and mitigation protocols to reduce uncertainty in the predicted long-term behavior of a storage site. This multi-sensor monitoring assessment project addresses three technology focus areas within the NATCARB MVA program: [1]. Remote sensing and near surface - (surface deformation, near surface electric resistivity structure) using ground and satellite interferometric radar, airborne transient electromagnetic (TEM), ground-based audiofrequency/radiofrequency natural and controlled source audio magnetotelluric/radiofrequency magnetotelluric(CSAMT/RFMT) methods [2] Subsurface - (surface deformation, electrical resistivity structure from 100–15,000 ft below ground level) using ground and satellite interferometric radar, audiofrequency magnetotelluric (AMT) and controlled source electromagnetic (CSEM) methods [3] Intelligent monitoring networks and protocols - (the optimized multi-sensor deployment and data acquisition schema), as well as the monitoring protocols focus area of the NRAP program "

Reducing UK emissions: 2018 Progress Report to Parliament.

The following is from the Executive Summary of this UK Committee on Climate Change document: "This is the Committee on Climate Change's (CCC) tenth statutory Progress Report to Parliament – an important moment to reflect on the UK's achievements in tackling climate change to date. 2018 also marks the tenth year since the Climate Change Act came into force and, with it, the creation of the CCC as an independent statutory adviser. [Decarbonizing] electricity generation is the clear achievement of the last decade - a notable success, in line with the Committee's early recommendations, which will underpin a strategy of shifting progressively from fossil fuels to low-carbon electricity. But progress in the power sector masks a marked failure to [decarbonize] other sectors. In the last five years, this failure has become more acute, as emissions reductions in these sectors have stalled. Offshore wind deployment exemplifies how clear goals, an ambitious strategy and well-designed mechanisms, can encourage and enable the market to reduce cost and help to build wider economic co-benefits. These lessons should be applied more broadly - to meet the challenges [the authors] highlight in this report in transport, industry, buildings and agriculture. It is in the consumer interest to act early and avoid the need for more costly interventions later. There is also potential for economic advantage, in line with the Government's aim to develop industrial and commercial advantage from emissions reduction. [The UK] now [enters] a new decade of action to address climate change. So far, the governance framework under the Climate Change Act has worked to deliver overall UK emissions reduction, but a much tougher challenge is presented by the fourth and fifth carbon budgets. The formal request from the UK Government to provide advice on the implications of the Paris Agreement on the UK's long-term emissions targets, announced for later this year, will mark the next phase of the UK's climate leadership."

DECEMBER 2018

Delivering Clean Growth: CCUS Cost Challenge Taskforce Report.

The following is the Executive Summary of this independent report to the UK government: "The Clean Growth Strategy reaffirms the UK Government's commitment to lead the way to a low carbon future and underlines the enormous opportunity for the UK that is emerging from the global transition to a low carbon economy. The Clean Growth Strategy sets out the Government's new approach to carbon capture usage and storage ('CCUS'), and [recognizes] the potential importance of CCUS to support the [decarbonization] of the UK's economy. The CCUS Cost Challenge Taskforce was established in January 2018 with the remit of informing and proposing a strategic plan to Government for supporting the development of CCUS in the UK, in order to meet Government's stated ambition of 'having the option to deploy CCUS at scale during the 2030s, subject to costs coming down sufficiently.' In this report, the Taskforce proposes a range of measures and actions to inform a new approach to CCUS deployment that will enable cost reductions to be secured. By demonstrating that CCUS can deliver [decarbonization] across industry, power, and provide solutions for heat and transport, the report focuses on building a long term, commercially sustainable and cost-effective [decarbonization] service industry for the UK. This, in turn, can bring new industrial opportunities, secure long-term jobs, deliver new economic development across industrial heartlands and secure international competitiveness through new [decarbonized] products and services. [The authors] have identified viable business models, funding mechanisms, and an innovation pathway, as well as suggesting options to support the lowest cost delivery of a potentially transformative technology, underpinned by a series of short, medium and longer term recommendations."

The Carbon Capture and Storage Readiness Index 2018: Is the world really ready for carbon capture and storage?

The following is from this Global CCS Institute document: "The 2018 edition of the Global CCS Institute's (the Institute) CCS Readiness Index (CCS-RI) identifies those nations which are leaders in the creation of an enabling environment for the commercial deployment of CCS. However, no nation, including the leaders, have yet established the conditions necessary to drive deployment at the rate required to meet ambition climate targets. It is clear that more must be done. The Institute actively monitors the progress of CCS deployment, through a series of targeted 'indicators', which consider a country's: Inherent CCS interest; Policy developments; Legal and regulatory frameworks; [and] Geological CO_2 storage development. Collectively, these indicators establish the CCS-RI. The 2018 CCS-RI examines over 50 countries using 70 discrete criteria and enables a comparative assessment of countries globally."

JANUARY 2019

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 abstract of this NETL 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. A reactive-transport finite element model was developed for the numerical investigation of the deterioration of Class H cement that was exposed to brines with different compositions and sequestration scenarios (e.g. CO_2 and CO_2-O_2 exposures) at wellbore temperatures and pressures. The modeling study also included the simulation of the hydration processes of cement. The high temperature/pressure conditions required the modeling of a two-phase flow problem due to the presence of supercritical CO_2. The modeling framework involved the integration of reactive-transport processes (modeled using a commercial finite element modeling software) with thermodynamic processes of species in cement and brine (modeled using a geochemical modeling open source software)."

Estimating Carbon Storage Resources in Offshore Geologic Environments.

The following is from the Executive Summary of this NETL document: "Long-term carbon storage in geologic reservoirs is a leading technique for removing excess CO_2 that would otherwise be emitted to the atmosphere as a result of anthropogenic activities. Effective carbon storage requires both safety and permanence. One underutilized national storage scenario involves carbon storage in offshore geologic formations, similar to those that hold oil, gas, or brine. This scenario has been tested in other countries on a small-scale, but is yet unproven in the United States. A major advantage of offshore storage is that the risk of CO_2 leakage into fresh groundwater resources is decreased, and the effect of that leakage on human population centers is minimized. However, as with onshore storage scenarios, there are many uncertainties surrounding offshore storage. These include issues related to both safety and permanence. After an extensive literature review of the current storage methodologies for onshore carbon storage in saline formations, comparing and contrasting the offshore and onshore characteristics of reservoirs, this study makes recommendations about future work to support offshore storage estimates and research. This report concludes with the suggestion that despite important differences between onshore and offshore systems, carbon can be stored safely and permanently in offshore saline geologic formations. This research proposes using DOE, NETL saline storage methodology with an integration of spatial-statistical tools to adjust for uncertainties."

FEBRUARY 2019

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 µD. 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 µD. Porosity of the parallel sample group ranges from 0.54% to 1.32% and permeability readings from 0.02 to 1.12 µD. 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."

Industrial Carbon Capture Business Models.

The following is the Executive Summary of this UK Department of Business, Energy, and Industrial Strategy (BEIS) document: "Deep [decarbonization] of all sectors of energy use is required to meet the UK's long-term emissions reductions goals. Whilst progress has been made in the power sector, energy intensive industry (EII) presents a particular challenge, both technically due to lack of alternative processes, and economically, due to the internationally traded nature of many products. Carbon Capture [Utilization] and Storage (CCUS) has been [recognized], both internationally and in the UK, as a key technology in reducing CO_2 emissions in industry. In the last 15 years, the annual global CO_2 storage rate doubled to a 2017 value of around 37 $MtCO_2$/year, with most operational projects being industrial CCUS. Importantly, [Industrial carbon capture (ICC)] presents many opportunities for the UK, including protecting existing industry from exposure to climate regulations (e.g. CO_2 pricing), attracting foreign direct investment in UK manufacturing and supporting [decarbonization] of the heat sector. The International Energy Agency estimates there will be a global CCUS market worth over £100 bn, and even a modest share of this could increase UK [gross value added (GVA)] by between £5 bn and £9 bn per year by 2030. To unlock the potential for CCUS deployment at scale in the UK during the 2030s, BEIS committed in the Clean Growth Strategy (CGS) to review viable delivery and investment models. As the previous full-chain CCS projects in the UK involved complex risk sharing arrangements, it is important to explore whether 'part chain' business models for ICC are more investable. Element Energy and its partners were commissioned by BEIS to identify the range of business models that could [incentivize] cost-effective deployment and operation of ICC technology in the UK. Consideration is given to the key barriers currently hindering the deployment of ICC as well as business models used in other sectors and countries that have potential to address these challenges and drive cost reductions."

MARCH 2019

DOE/NETL Capture Program R&D: Compendium of Carbon Capture Technology.

The following is from the Overview of this DOE/NETL document: "The DOE Fossil Energy Program has adopted a comprehensive, multi-pronged approach to the research and development (R&D) of advanced CO_2 capture technologies for today's coal power platforms as well as for future platforms. NETL is implementing the Carbon Capture R&D program to develop the next generation of advanced CO_2 capture concepts. The success of this research will enable cost-effective implementation of CCS technologies throughout the power generation sector and ensure the United States will continue to have access to safe, reliable, and affordable energy from fossil fuels. DOE's CCS R&D effort is conducted as part of the CCS and Power Systems program under the overarching Clean Coal and Carbon Management Research Program (CCCMRP). The CCCMRP is implemented by NETL through contracted research activities and on-site research at NETL. Research projects are carried out under various award mechanisms — including partnerships, cooperative agreements, and financial assistance grants — with corporations, small businesses, universities, nonprofit organizations, and other national laboratories and government agencies. The Carbon Capture program consists of two core research areas, Post-Combustion Capture and Pre-Combustion Capture, composed of projects with technology readiness levels (TRL) ranging from conceptual engineering and materials design (i.e., TRL 2) to 25 MW-electrical (MWe) equivalent pilot testing (i.e., TRL 5-7). These two core areas are focused on creating technological improvements providing a step-change in both cost and performance as compared to current state-of-the-art solvent-based capture systems. Post-combustion systems separate CO_2 from the flue gas stream produced by conventional pulverized coal power plants after fuel combustion in air. In this approach, CO_2 is separated from nitrogen (N_2), the primary constituent of the flue gas. Pre-combustion systems are designed to separate CO_2 and hydrogen (H_2) from the syngas stream produced by the gasifier in integrated gasification combined cycle (IGCC) power plants. In both cases, R&D is underway to develop solvent-, sorbent-, and membrane-based capture technologies, as well as novel technologies. This Technology Compendium provides a technical summary of DOE/NETL's Carbon Capture program, assembling CO_2 capture technology R&D descriptions for 91 projects in a single document. As of September 1, 2017, there were 47 active projects and 44 completed projects."

Computed Tomography Scanning and Geophysical Measurements of the Salina Formation from the #36 Brine Well.

The following is the abstract of this DOE/NETL document: "The computed tomography (CT) facilities and the Multi-Sensor Core Logger (MSCL) at NETL in Morgantown, West Virginia were used to characterize core of the Salina Formation from a vertical well (Brine Well #36) from Marshall County, West Virginia at a depth of 6,555.6 to 6,719.5 ft. The primary impetus of this work is a collaboration between West Virginia Geological and Economic Survey (WVGES) and NETL to characterize core from multiple wells to better understand the key formations in West Virginia. As part of this effort, bulk scans of core were obtained from the Brine Well #36, provided by the WVGES. This report, and the associated scans generated, provide detailed datasets not typically available for researchers to analyze. The resultant datasets are presented in this report, and can be accessed from NETL's Energy Data eXchange (EDX) online system using the following link: *https://edx.netl.doe.gov/dataset/salina-well*. All equipment and techniques used were non-destructive, enabling future examinations and analyses to be performed on the cores. Low-resolution CT images with the NETL medical CT scanner were obtained for the entire core and high-resolution CT images with the NETL industrial CT scanner were obtained for sections of the core. Qualitative analysis of the medical CT images coupled with X-ray fluorescence (XRF) measurements from the MSCL were useful in identifying zones of interest for more detailed analysis. The ability to quickly identify key areas for more detailed study with higher resolution will save time and resources in future studies. The combination of methods used provides a multi-scale analysis of this core and descriptions of the core that are relevant for many subsurface examinations that have traditionally been performed at NETL."

The Shand CCS Feasibility Study: Public Report.

The following is from this International CCS Knowledge Centre document: "The Canadian province of Saskatchewan is a world-leader in CCS. Saskatchewan and its provincial utility, SaskPower, pioneered the way for full-scale carbon capture facilities around the world with their fully-integrated [CCS] demonstration project on Unit 3 of the Boundary Dam coal-fired power plant (BD3). Operations at BD3 have steadily improved since initial startup. The facility has addressed safety issues and has recently started to demonstrate a level of reliability that is consistent with a thermal-generating facility, although still at below design CO_2 production levels. Once stable operation of the facility is achieved, it will allow the plant operations and support staff to focus on improving the efficiency and cost effectiveness of the operation. As with any world-first project, many lessons were learned through the design, construction and operations of the facility. These lessons have resulted in novel optimizations, operating methods and overall learnings for the facility and its role as a power generator in the power utility. While ongoing improvements are anticipated, second-generation CCS will undoubtedly realize many improvements over the first generation – which this report will highlight…"

APRIL 2019

Dynamic reduced order modelling (ROM) of chemical and mechanical processes in CO_2-cement systems.

The following is from the abstract of this National Risk Assessment Partnership (NRAP) Technical Report: "Damaged wells pose a significant risk of leakage of reservoir fluids stored in a geological CO_2 storage site. The leaking CO_2 can react with well cement and alter its chemical, mechanical, and hydraulic properties. Recently, [the authors] have developed an experimentally-calibrated model that couples two-phase flow, reactive transport of brine, cement geochemistry, and geomechanics to predict the leakage of reservoir fluids through a fractured pathway in a cemented well (Iyer, et al. 2018, Iyer, et al. 2017, Walsh, et al. 2013, Walsh, et al. 2014, Walsh, et al. 2014). [The authors] are developing a reduced order model (ROM) to rapidly assess the evolution of leakage flux from a well for a wide range of CO_2 storage sites scenarios, because the coupled numerical model is computationally very expensive. The coupled numerical model was used to run simulations needed to train the ROM by applying quasi-Monte Carlo sampling of seven inputs parameters, with some physical restrictions, to ensure efficient and additive sampling. The ROM uses the reservoir overpressure and saturation, the fracture aperture, length, and width, the normal stress acting on the fracture, and the reservoir depth as inputs. To ensure a sensitive response the input variables and the output leakage rate were post-processed using a logarithmic transformation followed by normalization. The coupled model solves several partial differential equations that describe the spatial and temporal evolution of pressure, velocity, concentrations, and extent of reaction. As a result, the solution at any time depends on the solution at previous times. To preserve this notion of memory the ROM was developed such that the leakage rate at any given time depends not only on the input parameters like pressure, saturation, etc., but also on the predicted leakage rate in the previous time steps. This process was found to perform significantly better than any approach that ignored this notion of memory…"

MAY 2019

Carbon Capture & Storage in The United States Power Sector: The Impact of 45Q Federal Tax Credits.

The following is from the summary of this Clean Air Task Force (CATF) document: "In February 2018, the United States (U.S.) Congress passed the Bipartisan Budget Act of 2018, expanding the corporate income tax credit for carbon capture and storage (CCS). This tax credit, known as 45Q, was adopted to enable additional deployment of CCS projects in the U.S. – both to achieve economic goals such as meeting energy needs and supporting jobs as well as carbon emission reductions. CCS is an essential technology in the climate solution toolbox but has not yet been deployed widely enough to meet its full potential. CATF advocated for the expansion of 45Q for several years as a way to provide a performance-based financial incentive to increase deployment of the technology. In June 2018, after the adoption of the expanded 45Q tax credits, CATF retained Charles River Associates (CRA) to perform a modeling analysis, based on assumptions developed in conjunction with CATF, that estimates the impact of this new incentive on CCS deployment in the U.S. power sector by 2030. The modeling results show that 45Q leads to significant deployment of CCS, capturing and storing approximately 49 million [metric tons] of CO_2 annually in 2030. The estimated CO_2 that will be captured and stored is equivalent to removing roughly 7 million cars from U.S. roads. For perspective, this is greater than the number of new cars sold in the U.S. in all of 2017. Importantly, the modeling results show that the power sector carbon reductions due to 45Q-induced deployment of CCS are additive to those achieved through renewable sources of electricity generation. That is, the modeling shows that carbon capture-controlled electricity generation replaces uncontrolled fossil-fired power, not new or existing renewable energy. Electricity generation and corresponding emission reductions from renewables remain unaffected by the availability of 45Q."

JUNE 2019

The LCFS and CCS Protocol: An Overview for Policymakers and Project Developers.

The following is from the Introduction of this Global CCS Institute document: "This report provides a summary of the CCS Protocol of the California Low Carbon Fuel Standard ('LCFS') and how it compares to other significant regulations and policies in the US associated with the injection and geologic sequestration of CO_2. The other regulations and policies covered include the Underground Injection Control ('UIC') Program, GHG Reporting Program and 45Q tax credits…The report was written to inform policymakers and CCS project developers interested in understanding the main elements of the regulations and the requirements a CCS project would need to fulfill to generate LCFS credits. The report necessarily simplifies the regulatory text and interested readers are encouraged to read the LCFS Regulation Order and CCS Protocol in full to get a better understanding of the detailed requirements of the regulations."

Building a low carbon economy: A roadmap for a sustainable Ireland in 2050.

The following is from the Executive Summary of this Irish Business and Employers Confederation (Ibec) document: "…This report sets out an Ibec vision for a competitive low carbon economy in the year 2050 and a roadmap for Ireland to achieve this ambition that safeguards [the country's] energy security and competitiveness. The report has been developed in consultation with Ibec member companies and with guidance from the SFI MaREI Centre's Energy Policy and Modelling team at UCC. Ibec has also considered the findings and recommendations of the 2019 International Energy Agency's (IEA) review of Irish energy policy and the Joint Oireachtas Committee on Climate Action's 2019 report 'Climate Change: A Cross-Party Consensus for Action.'"

JULY 2019

The Potential for CCS and CCU in Europe.

The following is from the Executive Summary of this International Association of Oil & Gas Producers (IOGP) document: "…Estimates have shown that the sum of European jobs linked directly and indirectly to the emergence of a market for CCS may approach 150,000 in 2050. There are 18 commercial projects in operation globally today with a total capture capacity of some 40 Mtpa CO_2. In Europe, CCS technologies and projects are currently more advanced than CCU projects, with Norway in particular having deployed CCS at Sleipner since 1996 and at Snøhvit since 2007. CCU covers a range of technologies at differing levels of maturity, cost and market size. Ultimately CCS and CCU are mutually supportive solutions, since both require access to capture facilities and to gas infrastructure and transportation services. They should both be seen as technology options to cost-effectively meet the EU's climate targets for 2030 and 2050. Europe is well placed to benefit from CCS and CCU due to its extensive pipeline infrastructure which can be used to transport CO_2, hydrogen and synthetic methane, and other renewable and decarbonised gases. Europe also has extensive geological CO_2 storage capacity and subsea expertise, with countries such as Norway and the UK willing to enable shared access to their offshore storage facilities for CO_2 from EU industry. Today, the largest CCS facilities are in the United States where Enhanced Oil Recovery (EOR) has been an important economic driver. In Europe, EOR applications are more limited and the current ETS price does not sufficiently support the CCS or CCU business case. Appropriate and timely policies coupled with regulatory and financial support are needed for CCS and CCU, as in many cases infrastructure must be put in place in advance of a mature market for decarbonised products and services. Support for CO_2 transportation and storage infrastructure will in particular be important, to help de-risk the early development of the CCS and CCU value chains. Large source emission clusters in Europe provide good opportunities to create economies of scale, by establishing shared CO_2 transportation infrastructure with third party access and efficient use of this infrastructure by multiple parties. Existing EU and national funding schemes should continue to apply to CCS and CCU, and these technologies should be recognised in the national energy and climate plans…"

Global Carbon Capture and Storage (CCS) Market Size, Status and Forecast 2019-2025.

The following is from a description of this document: "Carbon capture and storage (CCS) (or carbon capture and sequestration or carbon control and sequestration) is the process of capturing waste carbon dioxide (CO_2) from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere, normally an underground geological formation. The aim is to prevent the release of large quantities of CO_2 into the atmosphere (from fossil fuel use in power generation and other industries)… Although CO_2 has been injected into geological formations for several decades for various purposes, including enhanced oil recovery, the long term storage of CO_2 is a relatively new concept. In the coming years there is an increasing demand for [CCS] in the regions of United States and Europe that is expected to drive the market for more advanced Carbon Capture and Storage. Growth in government budgets in the principal countries, increasing of power generation fields expenditures, more-intense competition, launches in introducing new products, retrofitting and renovation of old technology, increasing adoption of [CCS] will drive growth in United States and Europe markets. In 2018, the global [CCS] market size was [$3,300 million] and it is expected to reach [$4,980 million] by the end of 2025, with a [compound annual growth rate (CAGR)] of 6.1% during 2019-2025. This report focuses on the global [CCS] status, future forecast, growth opportunity, key market and key players. The study objectives are to present the [CCS] development in United States, Europe and China."

AUGUST 2019

Computed Tomography Scanning and Geophysical Measurements of the FutureGen FGA-1 Core.

The following is from the abstract of this DOE/NETL document: "The computed tomography (CT) facilities at the NETL Morgantown, West Virginia site were used to characterize multiple cores collected during the FutureGen project. The core from the FutureGen Industrial Alliance, Inc., Battelle, FGA-1 well was drilled through 4,813 ft (1,467 m) of the Eau Claire (Lombard and Elmhurst members), the Mount Simon (Upper and Lower), and the basement. Core from the FGA-1 was collected in four sections to obtain samples from these formations: Eau Claire (3,772 to 3,919.5 ft), Eau Claire to Mount Simon transition (3,924 to 3,954 ft), lower Mount Simon (4,400 to 4,426 ft), and the basement (4,434 to 4,442 ft). The primary impetus of this work is to further characterize the FutureGen 2.0 core currently stored in the NETL core repository. As part of this effort, bulk scans of core were obtained from the FGA-1 well. This report, and the associated scans, provide detailed datasets not typically available for analysis. The resultant datasets are presented in this report and can be accessed from NETL's Energy Data eXchange (EDX) online system. All equipment and techniques used were non-destructive, enabling future examinations to be performed on these cores. Low resolution CT imagery with the NETL medical CT scanner was performed on the entire core. Qualitative analysis of the medical CT images, coupled with dual energy density scans and X-ray fluorescence (XRF) were useful in identifying zones of interest for more detailed analysis. The ability to quickly identify key areas for more detailed study at higher resolution will save time and resources in future studies. The combination of methods used provided a multi-scale analysis of this core and provides both a macro and micro description of the core that is relevant for many subsurface energy-related examinations that have traditionally been performed at NETL."

Foamed Cement: Correlation of Foam Quality with Mechanical and Physical Properties.

The following is from the abstract of this DOE/NETL document: "The primary functions of oil well cement include providing casing support and zonal isolation for the life of a well. Foam cement systems are often used to achieve these objectives. Industry standards and practices require careful assessment of various cement properties to ensure the integrity of the primary cement job. This report presents a series of studies focused on the mechanical (compressive strength, Young's modulus, and Poisson's ratio) and physical (density, permeability, and porosity) properties of foamed cement typically used for cementing deep offshore wells in the Gulf of Mexico. Cements with various amounts of entrained air were prepared in the lab according to American Petroleum Institute, API RP 10B- 4 using Class H cement and industry standard foaming agents. Permeability, porosity, compressive strength, Young's modulus, and Poisson's ratio were measured across a range of foam qualities and compared to 'baseline' or 'control sample' of a neat cement system. Additional studies include cement evolution with curing time and the effect of temperature variations on this evolution. Bubble sizes and interconnection in the foamed cement systems were also briefly discussed. All the cements investigated in this study were produced at atmospheric pressure, which is the current industry practice for testing foam cement systems. Nevertheless, there is some caution to the end users, as the curing pressures in this document differ from the 'bottomhole' conditions. The data obtained in this study are useful for comparative purposes and may serve as a baseline for future evaluation of foam cement systems under representative 'bottomhole' conditions. These data are also complementary to the CT image analysis of foamed cements performed at NETL."

Carbon Capture, Storage and Utilization to the Rescue of Coal? Global Perspectives and Focus on China and the United States.

The following is from the Executive Summary of this document: "…There is increasing policy support for CCS projects around the world. This renewed interest comes with different focuses than policies at the beginning of the 2000s, which had coal power plants as a focal point. Today, there is a growing focus on CCS in industrial and manufacturing applications. There is also a growing interest in hydrogen production combined with CCS in several countries. The focus is not only on capture and storage but also on utilization of the carbon (CCUS) for applications like increasing output from oil wells (enhanced oil recovery or EOR) or as an input for creating useful products. However, outside EOR, the uses of CO_2 are limited... Currently, there are 23 large-scale CCS/CCUS [projects] in operation and construction in the world, with a capture capacity of 40 million tons per annum (Mtpa) of CO_2. Most of these projects come from processes with highly concentrated CO_2 streams, such as natural gas processing and chemical production facilities, and 70% of the capture capacity is in North America. Only two coal power units in the world have been retrofitted with carbon capture, one in Canada and one in the United States (US). In addition, among the 20 projects under development in the world, six projects (4 in China and 2 in South Korea) involve coal power plants. There is also one project under feasibility study in Canada. Altogether, CCS/CCUS projects based on coal power plants have a CO_2 capture capacity of 12.4 Mtpa and involve some 4 GW of coal capacity. The challenge to scale up the technology is enormous..."

SEPTEMBER 2019

Bioenergy with Carbon Capture and Storage: Using Natural Resources for Sustainable Development.

The following is from a description of this book: "Bioenergy with Carbon Capture and Storage: Using Natural Resources for Sustainable Development presents the technologies associated with bioenergy and CCS and its applicability as an emissions reduction tool… Sections offer an overview of several routes to use biomass and produce bioenergy through processes with low or even negative CO_2 emissions. Associated technology and the results of recent research studies to improve the sustainability of the processes are described, pointing out future trends and needs. This book can be used by bioenergy engineering researchers in industry and academia and by professionals and researchers in carbon capture and storage."

Policy Priorities to [Incentivize] Large Scale Deployment of CCS.

The following is from the Executive Summary of this Global CCS Institute document: "CCS prevents CO_2 from being released into the atmosphere. The technology involves capturing CO_2 produced by large industrial plants, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored… It is the only feasible technology that can deliver deep emissions reductions in many industrial processes that are vital to the global economy, such as steel, cement and chemicals production. In combination with bioenergy used for power generation or biofuel production, it provides one of the few technologies that can deliver negative emissions at scale; unambiguously required to limit temperature rises to no more than 2°C. CCS can also be applied to coal and gas fired power plants, providing dispatchable generation capacity to complement the increased deployment of intermittent renewables, and in the production of low emissions hydrogen for heat and transport. While the critical role of CCS has been demonstrated in many reports, the policies in place today are insufficient to ensure CCS deployment scales up at the rate required. This paper seeks to address the current policy gap by describing priorities for policymakers to support the transition from current to future rates of deployment of CCS. It starts by reviewing the barriers to investment in CCS and how these have been overcome for the eighteen large scale facilities currently in operation and five under construction. It then develops a framework to support the scaling up of CCS deployment. It concludes with recommendations for policymakers..."

ANNOUNCEMENTS

OCTOBER 2018

NETL Issues RFI.

DOE's FE issued a Request for Information (RFI) on the development of transformational sensing capabilities for monitoring parameters associated with subsurface carbon dioxide (CO_2) storage. The objective of the RFI is to assess relevant state-of-the-art sensor technologies and determine future needs associated with CO_2 injection. Stakeholder responses to the 16-question RFI may help DOE develop technical objectives for future FOAs. Responses are due to the National Energy Technology Laboratory (NETL) by December 3, 2018.

DOE/NETL Conference Proceedings Available Online.

Proceedings from the "2018 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 13-16, 2018, are available online. Included are posters and presentations from the meeting.

FY 2018 Carbon Storage Newsletter Annual Index Available.

The Fiscal Year (FY) 2018 Carbon Storage Newsletter Annual Index is available online. The document is a compilation of NETL's Carbon Storage Newsletters published over the October 2017 through September 2018 timeframe, organized by section. Outdated information (e.g., conference dates, paper submittals, expired FOAs) have been removed.

DOE Announces FOA for Transformational Carbon Capture Technologies.

DOE has made available up to $30 million in federal funding for cost-shared R&D under the second closing of FE's "*Novel and Enabling Carbon Capture Transformational Technologies*" FOA. Selected projects must address one area of interest, "Development of Novel Transformational Materials and Processes." The R&D requested in this FOA aligns with the scientific challenges and knowledge gaps identified in the DOE ministerial-level Mission Innovation report, titled "*Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage.*" NETL will manage the projects.

NETL Presents at USAEE Conference.

NETL gave four presentations at a recent conference, including one titled "Assessing Key Drivers Impacting the Cost to Deploy Integrated CO_2 Capture, Utilization, Transportation, and Storage (CCUS)." Held in September 2018, the "36th U.S. Association for Energy Economics/International Association for Energy Economics (USAEE/IAEE) North American Conference: Evolving Energy Realities: Adapting to What's Next" highlighted contemporary energy themes at the intersection of economics, public policy, and politics.

Report Addresses Role of CCS in Energy Transition.

A report by the CO_2 Capture Project provides projections for the role of carbon capture and storage (CCS) in the energy sector. The "*Role of CCS in the Energy Transition*" report (subscription may be required) reviewed five leading energy transition scenarios with CCS, estimating the technologies contribution to achieving greenhouse gas (GHG) emissions-reduction goals.

Report Outlines GHG Removal and Storage Methods.

In partnership with the Royal Academy of Engineering, the Royal Society (an independent academy of the United Kingdom [U.K.] and the Commonwealth) produced a *report* and associated *summary* outlining methods of GHG removal, their storage, and how their deployment may be affected. The report also discusses how these methods may be utilized to meet potential goals.

RGGI Compliance Webinar Available.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) made available a webinar on guiding CO_2 budget sources through the interim control compliance process. The 2018 interim control period began on January 1, 2018, and extends through December 31, 2018.

CCS Facility Back Online.

The CCS facility at Unit 3 at the Boundary Dam Power Station (located near Estevan, Saskatchewan, Canada) started operating again after being offline for nearly three months due to a severe thunderstorm. Start-up of the CO_2 compressor began in September 2018 and the CO_2 is now being delivered to Whitecap Resources in western Canada for enhanced oil recovery (EOR).

NOVEMBER 2018

Director Appointed to DOE's NETL.

Steven Winberg, DOE's Assistant Secretary for Fossil Energy, appointed Brian J. Anderson, Ph.D. as the new director of DOE's NETL. Dr. Anderson previously served as director of West Virginia University's (WVU) Energy Institute. As part of the move, NETL's Acting Director, Sean Plasynski, Ph.D., will transition into his new role as NETL's Deputy Director and Chief Operating Officer.

DOE Announces Intent to Fund R&D to Advance Coal Technologies.

DOE's FE announced its intent to fund competitive research and development (R&D) that will advance first-of-a-kind coal generation technologies. The effort, referred to as the Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative, will look to develop the coal plant of the future while also reducing emissions.

DOE Invests to Develop Products from CO_2.

DOE's FE selected 17 projects to receive federal funding for cost-shared R&D to develop technologies to generate novel, marketable products using CO_2 or coal as a feedstock. The projects are supported through DE-FOA-0001849, titled "Novel Methods for Making Products from Carbon Dioxide or Coal."

US Cities Awarded Resources, Technical Support to Reduce Carbon Emissions.

Four U.S. cities (Pittsburgh, Philadelphia, Boston, and Washington, D.C.) were selected to receive resources and technical support from The Bloomberg American Cities Climate Challenge. Under the program, which is part of Bloomberg's American Cities Initiative, the four cities will be accepted into a two-year acceleration program that will provide them with resources to help meet or beat their near-term carbon-reduction goals. A total of 20 U.S. cities will be awarded under the program.

IPCC Releases Report.

The Intergovernmental Panel on Climate Change (IPCC) *released* a special report and *Summary for Policy Makers* on the impacts of potential climate change. A total of 91 authors and editors from 40 countries prepared the report, which was developed in response to an invitation from the United Nations Framework Convention on Climate Change (UNFCC).

New Report on CO_2 Utilization Technologies.

A new report by the National Academies of Sciences, Engineering, and Medicine identifies R&D to improve the commercial viability of carbon utilization technologies. The report offers an agenda for research to advance these technologies, including R&D to improve utilization methods. The report, titled "*Gaseous Carbon Waste Streams Utilization*," was sponsored by DOE.

DECEMBER 2018

DOE Issues NOI for Carbon Storage FOA.

DOE issued a Notice of Intent (NOI) to provide federal funding for innovative research and development (R&D) projects that develop transformational sensing capabilities to reduce uncertainty and enable real-time decision-making for subsurface carbon dioxide (CO_2) storage. The Funding Opportunity Announcement (FOA), "Transformational Sensing Capabilities for Monitoring the Subsurface," will be issued in the second quarter of fiscal year 2019.

Conference Discusses Reducing CO_2 Emissions.

An international group of researchers and policymakers met in Australia to discuss global CO_2 emissions. Topics discussed included boosting the carbon stores of soils, carbon storage in coastal wetlands, and the potential of bioenergy carbon capture and storage (BECCS).

European Commission Strategy Paper on CCS.

The European Commission released a strategy paper detailing the role of carbon capture and storage (CCS) in emissions reduction. According to the Commission, CCS will be needed for the European Union (EU) to achieve its greenhouse gas (GHG) emissions goal by 2050.

ADNOC to Expand its CCUS for EOR.

The Abu Dhabi National Oil Company (ADNOC) announced plans to expand carbon capture, utilization, and storage (CCUS) operations and boost enhanced oil recovery (EOR) from reservoirs. The CO_2 will be captured from either the Habshan-Bab gas processing facilities or the Shah gas plant (both located in the United Arab Emirates [UAE]).

Large-Scale CCS Facilities Added to Database.

New large-scale CCS facilities have been added to the Global CCS Institute's CCS database. According to the database, there are now 18 large-scale CCS facilities in operation, as well as 5 under construction globally. Combined, these facilities have the potential to remove 40 million metric tons of CO_2 per year from the atmosphere.

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: Third Quarter 2018" addresses the period from July through September 2018.

JANUARY 2019

DOE Issues NOI for Crosscutting Technologies.

NETL issued an NOI for an FOA for cost-shared R&D projects to enhance the performance and economics of the existing and future coal fleet. The objective of the FOA is to competitively solicit and award R&D projects to develop innovative technologies that can improve operational performance, reduce costs at existing coal power plants, and enhance future facilities. "*Crosscutting Research for Coal-Fueled Power Plants*" is expected to be available in FY 2019.

NARUC Publishes Study of CCUS Technology and Policy.

NETL contributed to a report from the National Association of Regulatory Utility Commissioners (NARUC) that examines the state of national carbon issues. The report, titled "*Carbon Capture, Utilization, and Storage: Technology and Policy Status and Opportunities*," assists state regulators in their understanding of current carbon capture, utilization, and storage (CCUS) policy and technology. Developed by NARUC's Center for Partnerships and Innovation, the report is part of the NARUC/DOE Carbon Capture, Storage, and Utilization Partnership.

NASA Instrument Maps Carbon Storage in 3D.

Led by the University of Maryland in collaboration with the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center, the Global Ecosystem Dynamics Investigation (GEDI) telescope will provide a three-dimensional map of forest canopies and carbon storage. The instrument is capable of revealing the makeup of remote forest ecosystems around the world.

Award Launched for Best CO_2 Utilization.

Innovative technologies and products in the carbon capture and utilization area will be eligible to win a new award for "Best CO_2 Utilization." The award will allow innovators to market their CO_2 capture or conversion technology, CO_2-based material, or a corresponding product launched to the market in 2018 or 2019. The award will be presented at the "*7th Conference on Carbon Dioxide as Feedstock for Fuels, Chemistry, and Polymers*," which will take place March 20-21, 2019, in Cologne, Germany.

Report on CCS Released.

The Global CCS Institute released a report, titled "*Global Status of CCS: 2018*," at the United Nation's (UN) 24th Conference of the Parties (COP24) in Katowice, Poland. The report depicts the importance of deploying carbon capture and storage (CCS) technologies.

CCUS Lessons-Learned Workshop Held.

Emissions Reduction Alberta (ERA) held a CCUS lessons-learned workshop in Calgary, Canada. Technology developers, industry insiders, investors, government employees, and regulatory officials attended the workshop, at which topics covered included the business case for carbon capture and use, the market potential of current and future technologies, knowledge sharing of the operation of commercial facilities, and implementing CCUS projects.

FEBRUARY 2019

DOE Issues Notice of Intent.

DOE's Office of Fossil Energy (FE) issued an NOI for an FOA with the objective of competitively soliciting and awarding R&D projects for front-end engineering and design (FEED) studies to retrofit a domestic coal-fired power plant and for a coal or natural gas plant that generates CO_2 suitable for utilization or storage. The FOA, titled "Front-End Engineering and Design Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants," will support FE's *Carbon Capture Program*.

DOE Announces Federal Funding.

DOE's FE announced federal funding for cost-shared R&D under an FOA, titled "Maximizing the Coal Value Chain," to develop innovative uses of domestic coal to create new market opportunities. These projects will support FE's *Advanced Energy System Program*. DOE also *made available federal funding* for cost-shared R&D projects, under the FOA "Improving Efficiency, Reliability, and Flexibility of Existing Coal-Based Power Plants," that will enhance technologies that improve overall performance, reliability, and flexibility of the nation's existing coal-fired power plant. Projects will support DOE's *Transformative Power Generation Program* and *Crosscutting Research Program*.

Nordic Countries Commit to Further Develop CCS.

Finland, Sweden, Norway, Denmark, and Iceland signed a declaration committing to work towards carbon neutrality, including further developing and deploying carbon capture and storage (CCS) and bioenergy with CCS (BECCS) technologies. In the "Declaration on Nordic Carbon Neutrality," the countries also agreed to enhance their Nationally Determined Contributions (NDCs), which represent a country's efforts to reduce national emissions.

"Ideal" CCS Transport Site Named.

A report has named Peterhead Port as the "ideal" hub across the United Kingdom (UK) to facilitate CCS in the north of Scotland. The Acorn CCS project study highlighted 16 UK plots deemed "suitable" for CCS, singling out Peterhead's deepwater water port as the key location for the transfer of 15 million metric tons of CO_2 due to its proximity to existing North Sea pipelines and infrastructure.

Company Commits to Reduce CO_2 Emissions, Achieve Net Zero by 2050.

Baker Hughes, a GE Company (BHGE), announced its commitment to reduce its CO_2 equivalent (CO_2e) emissions by 2030, achieving net-zero CO_2e emissions by 2050. BHGE also launched a Carbon Management Practice that offers quantitative assessment of carbon intensity, evaluation of carbon solutions, and the accreditation of emission reductions.

MARCH 2019

NETL Director Delivers Lecture.

NETL Director Brian Anderson, Ph.D., gave an in-depth description of NETL's fossil energy research priorities, activities, and capabilities at the 2019 Carnegie Mellon University Wilton E. Scott Institute for Energy Innovation Distinguished Lecture Series in Pittsburgh, Pennsylvania (USA). Highlighted NETL fossil energy priorities included reducing the cost of carbon capture, utilization, and storage (CCUS).

DOE's Office of Science Graduate Student Research Program Accepting Applications.

DOE's Office of Science Graduate Student Research (SCGSR) Program is now accepting applications for the 2019 Solicitation. The SCSGR Program provides supplemental awards to U.S. graduate students to pursue part of their graduate thesis research at a DOE laboratory/facility. Priority Research Areas for 2019 Solicitation 1 include Biological and Environmental Research (BER), which contains improving carbon storage capabilities. Applications are due May 9, 2019.

CO_2 Storage ISO Standard Published.

The first edition of an International Organization for Standardization (ISO) standard that applies to quantifying and documenting the total carbon dioxide (CO_2) stored in association with CO_2 enhanced oil recovery (EOR) was published. Members of NETL's Regional Carbon Sequestration Partnership Initiative participated in the ISO working group that drafted ISO-27916, which is titled "Carbon dioxide capture, transportation and geological storage – Carbon dioxide storage using enhanced oil recovery (CO_2-EOR)."

RGGI States Submit Comments on Re-Proposed Virginia Regulation.

The U.S. states participating in the Regional Greenhouse Gas Initiative (RGGI) *submitted comments* to Virginia regarding the state's re-proposed regulation with the existing RGGI 2017 Model Rule.

RGGI Releases Two Reports.

The independent market monitor for 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 2018*" addresses the period from October through December 2018. In addition, RGGI also made available the "*2018 Interim Compliance Summary Report*," which contains data regarding CO_2 allowances provided by CO_2 budget sources to meet their 2018 interim control period compliance obligation. RGGI's fourth three-year control period took effect on January 1, 2018, and extends through December 31, 2020.

Advisory Council Updates Analysis on CCS Policy.

The European Academies' Science Advisory Council *released a statement* updating their previous analysis on the role of bioenergy with carbon capture and storage (BECCS). The new analysis factors in recent peer-reviewed papers and international reviews.

APRIL 2019

DOE/NETL Announces Funding Opportunity.

DOE/NETL announced a funding opportunity to develop and validate innovative transformational sensor systems. Research and Design will need to improve the ability to characterize and predict movement of fluids in the subsurface, and will include field-laboratory validation of the proposed component sensor system. Concept Papers for FOA 1998 are due on May 8, 2019, and full applications are due on June 21, 2019 (Concept Paper submission is required for applicants to be permitted to submit a full application).

DOE/NETL Studies Focus on Geologic Storage of CO_2.

DOE/NETL developed three studies that evaluated industrial analogs to CO_2 geologic storage. The three analogs studied (*underground natural gas storage*, *deep well waste disposal*, and *CO_2 enhanced oil recovery [EOR]*) were selected because of their commonalities with CO_2 geologic storage. The studies aim to draw insights and lessons learned from the history of other commercially prominent analogous industries and to help address technical and policy-related questions concerning captured CO_2 geologic storage moving forward.

DOE Issues Request for Information.

DOE's FE and NETL *issued a Request for Information (RFI)* for strategies for improving or creating emission-reduction or utilization technologies for hazardous substances resulting from coal combustion. FE funds research, development, and demonstration (RD&D) projects to reduce the risk and cost of advanced carbon technologies and further the sustainable use of the nation's fossil resources.

USGS Conducts Review of Carbon Mineralization.

The U.S. Geological Survey (USGS) published a review of potential carbon storage in igneous and metamorphic rocks through carbon mineralization. The report, titled "*Carbon Dioxide Mineralization Feasibility in the United States*," explores the feasibility of CO_2 storage through carbon mineralization, which is the process by which CO_2 becomes a solid mineral.

Grants Awarded to Enhance Carbon Storage.

The California Department of Forestry and Fire Protection (USA) announced grants to 16 projects that promote healthy forests to help enhance carbon storage.

Workshop Explores Potential for Carbon Storage Economy.

Cornell University's Atkinson Center for a Sustainable Future (USA) hosted a workshop to outline a research agenda to support a carbon storage economy. The workshop, which drew participants from academia, non-governmental organizations, businesses, and government, emphasized the human and societal dimensions of CO_2 removal.

CCUS Investments Day.

The Oil and Gas Climate Initiative (OGCI) is holding a CCUS investment day in Chicago, Illinois (USA), in September 2019. OGCI member companies, selected financial firms, business partners, and policy makers will be in attendance to hear presentations seeking investment for commercial projects that result in the utilization or storage of CO_2, or technologies that can lower the cost of CO_2 capture or create products that utilize CO_2.

CCUS Advisory Group Launched.

A government- and industry-backed CCUS advisory group was launched in the United Kingdom (U.K.). In addition to providing advice on potential incentives and regulations for the CCUS market in Britain, the group will also advise on potential challenges of the technology and support the review of delivery and investment framework.

MAY 2019

DOE/NETL's Carbon Capture, Utilization, Storage, and Oil and Natural Gas Programs Annual Meeting.

Registration is currently open for DOE/NETL's "Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting," to be held August 26–30, 2019, at the David L. Lawrence Convention Center in Pittsburgh, Pennsylvania, USA.

DOE Announces Funding to Accelerate CCUS.

DOE announced federal funding for cooperative agreements that will help accelerate the deployment of carbon capture, utilization, and storage (CCUS). Through *this FOA*, DOE will seek to award cooperative agreements to R&D projects that will help identify and address regional storage and transport challenges. Specifically, this FOA will seek to preserve, share, and advance existing R&D by addressing key technical challenges; facilitating data collection, sharing, and analysis; evaluating regional infrastructure; and promoting regional technology transfer. The selected projects will support FE's *Carbon Storage Program*.

DOE Selects Carbon Storage Project for Funding.

The associated geologic storage project was selected under the FOA "Developing Technologies for Advancement of Associated Geologic Storage for Basinal Geo-Laboratories." Supported by the FE Carbon Storage Program and managed by NETL, the University of Wyoming project aims to establish the technical and economic viability of associated CO_2 storage and oil recovery in the greenfield residual oil zones of the Powder River Basin of Wyoming and Montana (USA).

DOE Announces Investments in Coal FIRST.

DOE announced investments to help develop coal plants of the future that will provide secure, stable, and reliable power with near-zero emissions. DOE FE issued a Notice of Intent for an FOA, titled "Critical Components for Coal FIRST Power Plants of the Future," that will make federal funding available for cost-shared R&D projects that focus on developing components required by Coal FIRST (Flexible, Innovative, Resilient, Small, and Transformative) systems.

RGGI Releases Notice and Materials for Auction 44.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice and application materials for the 44th quarterly CO_2 allowance auction scheduled for June 5, 2019. The *Auction Notice for CO_2 Allowance Auction 44* provides the information needed to submit a Qualification Application for Auction 44 in which the RGGI states will offer 13,221,453 CO_2 allowances for sale at a minimum reserve price of $2.26. A 10 million CO_2 allowance cost containment reserve (CCR) will also be made available. (The CCR will be accessed if the interim clearing price exceeds the CCR trigger price of $10.51.)

2018 RGGI Market Monitoring Report Available.

Potomac Economics, the independent market monitor for the RGGI CO_2 allowance market, released the *Annual Report on the Market for RGGI CO_2 Allowances: 2018*. The report evaluates market activity for RGGI CO_2 allowances, focusing on allowance prices, trading and acquisition of allowances in the auctions and secondary market, participation in the market by individual firms, and market monitoring.

Status Report on Role of CCS Technologies.

The International Energy Agency released the 2018 "*Global Energy & CO_2 Status Report.*" The second annual online report provides an overview of recent global trends and developments in energy and CO_2 emissions in 2018.

New Zealand Releases GHG Inventory Report.

New Zealand's GHG Inventory report represents an annual estimate of greenhouse gas (GHG) emissions and removals that occurred in New Zealand from 1990 through 2017. The inventory also contains emissions trends and methodologies used for estimating emissions and removals.

Europe Relaunches CCUS Knowledge Exchange Network.

The European Commission announced funding for a knowledge-sharing network to develop CCUS projects throughout Europe. The European CCUS Projects Network will connect industry partners involved in current CCUS projects and provide them with opportunities for knowledge sharing, best practices, and guidance on increasing public awareness and acceptance of CCUS technologies.

JUNE 2019

EU Plans Satellite Fleet to Monitor CO_2.

The European Space Agency announced plans to launch a fleet of satellites to create a global observation system capable of monitoring carbon dioxide (CO_2) emissions. The fleet is expected to launch in 2025, and the data will be used to inform the United Nation's *global stocktake* of GHGs three years later.

New International System for Classifying CO_2 Storage Resources.

The Society of Petroleum Engineers adopted and approved the *CO_2 Storage Resources Management System (SRMS)*, which uses common terminology, instinctive criteria, and clear definitions to classify storage resources. The full guidelines of the CO_2 SRMS are scheduled for publication later this year.

Energy Companies Sign MOU to Explore CCUS.

Drax Group, Equinor, and National Grid Ventures signed a Memorandum of Understanding (MOU) that includes collaboration on the potential construction of a large-scale carbon capture, utilization, and storage (CCUS) network in the United Kingdom (U.K.) Humber region in the mid-2020s. In addition, work under the MOU will explore the opportunity to scale-up the bioenergy CCS pilot project at the Drax Power Station.

CCS Facility Back Online After Scheduled Maintenance.

Unit 3 of the CCS facility at the Boundary Dam Power Station (located near Estevan, Saskatchewan, Canada) is back online after a scheduled two-month shutdown. In addition to calibration testing of the sensors, the boilers were inspected and work on auxiliary equipment was performed.

Report Studies Role of CCUS in California.

The Energy Futures Initiative published the findings of a study that assessed the impact of CCUS on California's (USA) economy. The study, titled "*Optionality, Flexibility, & Innovation: Pathways for Deep Decarbonization in California*," identified policies and technologies that currently contribute to the state's ability to meet its low-carbon energy goals.

JULY 2019

NETL Participates in Conference on Coal Technologies.

NETL participated in the 2019 *Clearwater Clean Energy Conference*, which provided an overview of emerging, evolving, innovative technologies, fuels, and/or equipment in the power generation industry. The agenda included an NETL-led technical session focused on carbon dioxide (CO_2) capture, storage, and reuse.

NETL Infographics Highlight Carbon Capture Work.

NETL is releasing a series of eight infographics that explain the structure of its *Carbon Capture Program*, illustrating its impact and highlighting achievements and notable projects. *Infographics that have been released to date are currently available online*, with the rest scheduled for release at a later date.

World Bank Releases Report on Carbon Pricing.

The World Bank released the annual "State and Trends of Carbon Pricing" report, which presents the latest worldwide developments regarding carbon pricing. According to the report, 57 carbon pricing initiatives have been implemented or are scheduled for implementation globally (up from 51 in April 2018).

EERC Established as Energy Research Center of North Dakota.

The North Dakota State House of Representatives approved a bill to establish the Energy & Environmental Research Center at the University of North Dakota (EERC) as the state's energy research center. The Energy Research Center of North Dakota will focus on areas related to the state's energy industry as well as pipeline safety and increasing oil recovery.

Personal CO_2 Subscription Service Launched.

Climeworks launched a new program allowing individuals to purchase a CO_2 removal service to offset their emissions. Once captured, the CO_2 is stored underground in Iceland via *Climeworks' CarbFix process*.

Workshop Discusses CCS.

Representatives from industry, government, academia, and the private sector convened at the Global CCS Institute's workshop at the Innovate4Climate Conference to discuss CCS technologies. Held in Singapore in June 2019, the workshop covered topics such as the significance of CCS as an emissions reduction technology; the cost of CCS technology; and opportunities for carbon capture, utilization, and storage (CCUS) technologies present for the South East Asia region.

Study Launched on Decarbonizing Europe.

Industry, regional experts, academics, and European Union (EU) officials held a public meeting of the research study group "Infrastructure needs of an EU industrial transformation towards deep decarbonization." The workshop highlighted the potential of individual regions specializing more in CCS.

AUGUST 2019

DOE Director Testifies Before US Senate Energy and Natural Resources Committee.

NETL Director Brian Anderson, Ph.D., appeared before the U.S. Senate Energy and Natural Resources Committee to discuss how NETL effectively develops innovative energy technologies that promote economic growth and competitiveness. To highlight the technology advances, the Director submitted *NETL's 2018 Science and Technology Accomplishments publication* for the hearing record. An archived webcast of the hearing *is available online*.

Report Summarizes Subsurface Workshop.

A team led by NETL and Carnegie Mellon University's Wilton E. Scott Institute for Energy Innovation *released a report summarizing the "Real-Time Decision-Making for the Subsurface" workshop* held in July 2018 in Pittsburgh, Pennsylvania, USA. The two-day workshop was attended by technical experts from DOE, industry, universities, and national laboratories discussing the current state of technology capable of enabling autonomous monitoring and subsurface control for unconventional oil and gas recovery and carbon storage.

Paper Looks to Inspire Strategies for Early-Stage CCS.

Pale Blue Dot Energy released a paper outlining research findings of its *ACT Acorn carbon capture and storage (CCS) project* in northeast Scotland. The paper, *published in the Journal of Cleaner Production*, follows recent funding from the United Kingdom government's carbon capture, utilization, and storage (CCUS) Innovation fund to carry out a detailed design and move the project closer to realization by 2023. The paper assesses Acorn's publicly available outputs to identify strategies that could enhance the viability of early-stage CCS projects.

Partnership to Develop Business Case for CCUS.

Dutch energy transition firm DAREL and Carbon Clean Solutions are partnering to enable development of a value chain for cost-effective carbon management for large industrial emitters. The partnership will seek to develop a business case for CCUS for large-scale decarbonization.

UCSB Grant Program Funds Carbon Storage Study.

A program at University of California Santa Barbara (UCSB) *awarded a grant* for a carbon storage study project at its North Campus Open Space. The project will assess the potential of carbon storage and provide hands-on research experience in "carbon farming."

Conference Notes Importance of CCS.

The Westminster Energy, Environment, and Transport Forum held a policy conference titled "The UK Gas Network: Infrastructure, Decarbonization and Energy Security." During the event, leaders stated that large-scale CCS would be needed to reach net-zero goals.

Database to Monitor CO_2 Emissions.

The *World Input-Output Database*, launched by the Joint Research Center, will monitor the industrial and energy use of residents in more than 40 countries, as well as their corresponding CO_2 emissions, from 2000 through 2016. Primarily targeting policy makers and researchers, the database covers global energy consumption, efficiency, energy splits and trends, and CO_2 emissions generated.

SEPTEMBER 2019

DOE Invests in Large-Scale Fossil Fuel Pilot Projects.

DOE's FE selected six projects to receive federal funding to support future design and construction of the next generation of coal-fired power plants that are flexible, resilient, economical, and emit near-zero emissions, including carbon dioxide (CO_2). The projects were selected under Phase II of the "*Fossil Fuel Large-Scale Pilots*" Funding Opportunity Announcement (FOA), which was issued in August 2017 and includes three phases, with competitive down-selections made between each phase. All of the selected projects will be managed by NETL.

NETL Releases Additional Infographics Highlighting Carbon Capture Work.

NETL is releasing a series of eight infographics that explain the structure of its Carbon Capture Program, illustrating its impact and highlighting achievements and notable research and development (R&D) projects that are reducing costs to ensure the availability of clean, reliable, and affordable energy from America's abundant domestic resources. Infographics that have been released to date are *available on the NETL website*.

DOE's NCCC Welcomes New Member.

The French energy company Total has joined DOE's National Carbon Capture Center (NCCC), becoming the second oil and gas producer to sponsor NCCC. According to NCCC, the addition of Total reflects the center's focus on carbon capture, utilization, and storage (CCUS) solutions for natural gas-based power generation. NCCC serves as a research facility to advance technologies that reduce greenhouse gas (GHG) emissions from fossil-based power plants.

Agreement Reached to Explore CCS.

ExxonMobil announced it would explore carbon capture and storage (CCS) for industrial uses at scale through an agreement with chemical and engineering firm Mosaic Materials. This announcement follows *ExxonMobil announcing an agreement with DOE's NETL and National Renewable Energy Laboratory* to research and develop advanced lower-emissions technologies.

Event Highlights Potential for Hydrogen Production with CCS.

An event at Federation University Australia, Gippsland Campus, highlighted the potential for hydrogen production with CCS in Australia's Gippsland region. *Hydrogen Forum: A pathway to environmental & regional prosperity – Where to for Gippsland?* covered the pathways to hydrogen production, including those from fossil fuels with CCS.

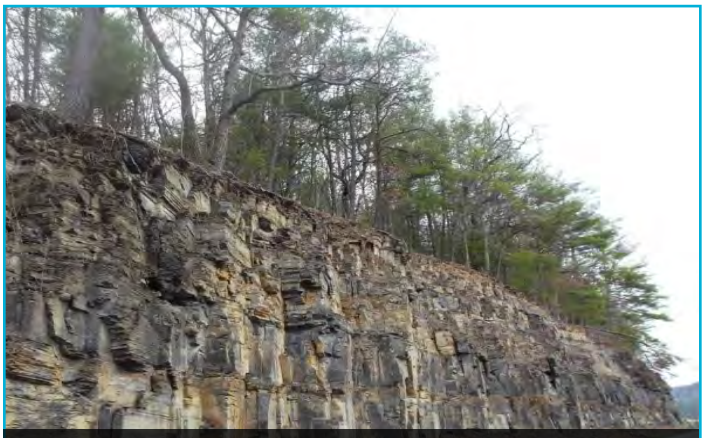
ABOUT DOE'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** at the National Energy Technology Laboratory (NETL) is focused on developing and advancing technologies to enable safe, cost-effective, permanent geologic storage of CO_2, both onshore and offshore, in different depositional environments. The technologies being developed will benefit both industrial and power sector facilities that will need to mitigate future CO_2 emissions. The program also serves to increase the understanding of the effectiveness of advanced technologies in different geologic reservoirs appropriate for CO_2 storage—including saline formations, oil reservoirs, natural gas reservoirs, unmineable coal, basalt formations, and organic-rich shale basins—and to improve the understanding of how CO_2 behaves in the subsurface. These objectives are key to increasing confidence in safe, effective, and permanent geologic 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 information related to the Carbon Storage Program is available on *DOE's Energy Data eXchange (EDX) website*.



Parallel, vertical, orthogonal natural fracture faces (joint sets) in an outcrop of organic-rich Millboro Shale (Marcellus equivalent), Clover Creek, VA. Photo by Dan Soeder, 2014.

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 (note that all links were active at the time of publication).

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1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Program staff are also located in
Houston, Texas and **Anchorage, Alaska**.

CUSTOMER SERVICE: 1-800-553-7681

www.netl.doe.gov

Contact

Traci Rodosta
304-285-1345
traci.rodosta@netl.doe.gov

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