NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON STORAGE NEWSLETTER

ANNUAL INDEX

FISCAL YEAR (FY) 2020

October 2019 – September 2020

NETL'S CARBON STORAGE NEWSLETTER
ANNUAL INDEX – FY 2020

This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters (CSN) published from October 2019 to September 2020. 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 Outdated information (e.g., conference dates, paper submittals, etc.)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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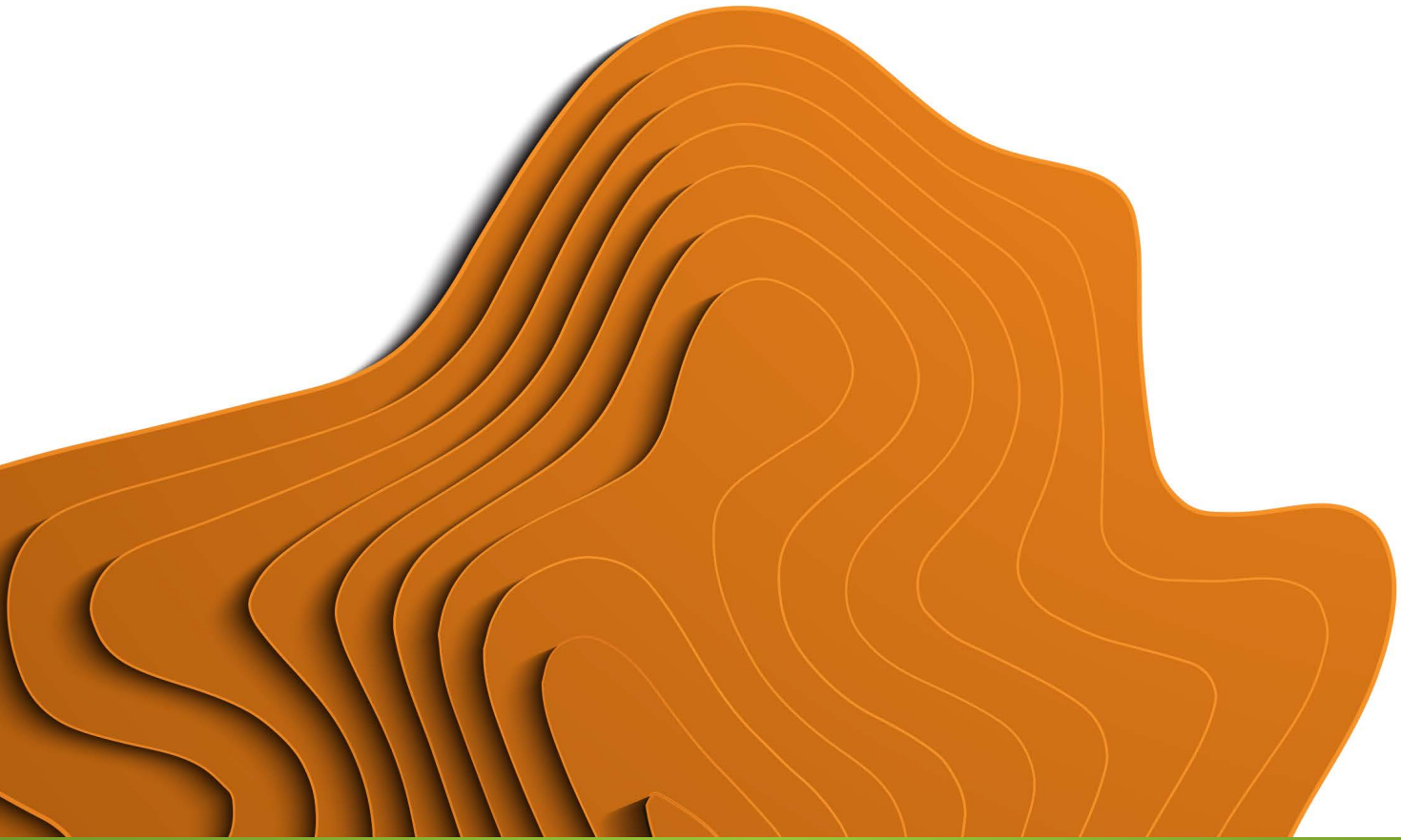

DOE/NETL HIGHLIGHTS

OCTOBER 2019

DOE Announces Funding for CCUS Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) announced federal funding for cost-shared research and development (R&D) projects under three Funding Opportunity Announcements (FOAs). The projects will build upon DOE's large-scale carbon capture, utilization, and storage (CCUS) pilot and demonstration projects to test, mature, and prove CCUS technologies at commercial scale. Two of the FOAs were announced earlier this fiscal year (FY); the new FOA, DE-FOA-0001999 "*Carbon Storage Assurance Facility Enterprise (CarbonSAFE)*," is seeking R&D projects that accelerate wide-scale deployment of CCUS through assessing and verifying safe and cost-effective anthropogenic carbon dioxide (CO_2) commercial-scale storage sites and carbon capture and/or purification technologies (responses are due by January 15, 2020). DOE's National Energy Technology Laboratory (NETL) will manage the projects. From *energy.gov* on September 13, 2019.

NOVEMBER 2019

DOE Announces Funding to Collaborate Internationally and Accelerate CCUS.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) announced federal funding for national laboratories to collaborate with international partners to accelerate and mature carbon capture, utilization, and storage (CCUS) projects. The collaboration will be on seven of the *12 projects that were selected* as part of the *Accelerating Carbon Capture and Storage Technologies (ACT) Initiative*. The ACT Initiative is a consortium of 10 European countries (France, Germany, Greece, the Netherlands, Norway, Romania, Spain, Switzerland, Turkey, the United Kingdom) and the United States. From *energy.gov* on November 1, 2019.

DOE Ranked Global Leader in CCS Research.

DOE was described as a global leader in carbon capture and storage (CCS) research in a *report* issued by the peer-reviewed journal *Science of the Total Environment*. DOE ranked first in number of publications and "h-index," which measures the productivity and citation impact of a scientist. Notable advances include the development of the Regional Carbon Sequestration Partnerships (RCSPs), which has helped DOE characterize the carbon storage resource potential throughout the United States, verifying the major resources available to store carbon dioxide (CO_2). Through the work of the RCSPs, six large-scale projects have cumulatively injected more than 10 million tons of CO_2. In addition, DOE has prepared a series of carbon storage *Best Practice Manuals* that disseminate lessons learned from the projects to the public. *Click here for more information on DOE's carbon storage research*. From *energy.gov* on October 15, 2019.

DECEMBER 2019

DOE Announces Funding to Develop CCS Technology.

The U.S. Department of Energy's (DOE) *Advanced Research Projects Agency-Energy (ARPA-E)* announced funding to develop carbon capture and storage (CCS) technologies that enable power generators to respond to grid conditions in a high variable renewable energy (VRE) penetration environment. The FLExible Carbon Capture and Storage (FLECCS) Program, which seeks to develop technologies capable of addressing difficulties in decarbonization of electricity systems and focuses specifically on complications in CCS design, operations, and commercialization, will have two phases. Phase I will focus on designing and optimizing CCS processes that enable flexibility on a high-VRE grid. Phase II will focus on building components, unit operations, and small prototype systems to reduce the technical risks and costs associated with CCS systems. From *energy.gov* on November 14, 2019.

JANUARY 2020

NETL Develops Flexible CCUS Analysis Tools and Resources.

National Energy Technology Laboratory (NETL) researchers developed a first-of-its-kind suite of tools that enables better decision-making regarding the economic challenges of carbon capture, utilization, and storage (CCUS). The publicly available tools and resources can evaluate CCUS costs during each step in the value chain. NETL researchers are also developing techno-economic models for offshore carbon dioxide (CO_2) saline storage, onshore CO_2 enhanced oil recovery (EOR), and offshore CO_2 EOR. The flexibility and adaptability of NETL's CCUS tools and resources are critical for addressing challenges and acclimating to the changing factors that influence CCUS implementation. More information is available on *NETL's Energy Analysis page*. NETL's work supports the U.S. Department of Energy's (DOE) mission to advance the national, economic, and energy security of the United States. From *NETL Press Release* on December 19, 2019.

FEBRUARY 2020

NETL Project Validates CO_2 Storage.

The National Energy Technology Laboratory (NETL) and research partners pioneered technology with the potential to reduce industrial carbon emissions. The Plains CO_2 Reduction (PCOR) Partnership, one of the U.S. Department of Energy's (DOE) seven *Regional Carbon Sequestration Partnerships (RCSPs)*, completed work across the Great Plains and into portions of Canada that demonstrates the ability to reduce carbon dioxide (CO_2) emissions and enhance the efficiency of oil production. Supported by NETL, RCSP activities have included assessments of geologic and terrestrial storage potential in each region, followed by small-scale validation projects and six large-scale (greater than 1 million metric tons) geologic storage projects. From *NETL News Release* on January 10, 2020.

MARCH 2020

NETL Celebrates 2019 Achievements.

The National Energy Technology Laboratory (NETL) welcomed congressional guests and university partners to the *Science and Technology (S&T) Accomplishments Session*, celebrating more than 30 notable 2019 S&T accomplishments that focused on key research priorities that promote safe, reliable, and affordable energy nationwide. The interactive poster session, held at NETL's Pittsburgh, Pennsylvania (USA) site, featured a broad range of NETL researchers sharing work that showcased NETL's facilities and core science and engineering capabilities. From *NETL Press Release* on February 20, 2020.

FY 2021 Congressional Budget Request Released.

The President's FY 2021 Congressional Budget Request seeks $930.7 million to fund the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE). The Budget Request includes funding for the Fossil Energy Research and Development (R&D) Program, which includes R&D programs in carbon capture, utilization, and storage (CCUS). The FY 2021 Budget Request focuses on early-stage R&D and reflects an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies. From *energy.gov* on February 11, 2020.

APRIL 2020

NETL's Decarbonization Work Highlighted at Meeting.

The National Energy Technology Laboratory (NETL) Director, Brian Anderson, shared information on NETL's decarbonization work while speaking at a Massachusetts Institute of Technology (MIT) Energy Initiative meeting. NETL's advancements in cost-effective implementation of carbon capture, utilization, and storage (CCUS) technologies were highlighted, as was NETL's Carbon Storage Program. Video of the Director's presentation is *available online*. From *NETL News Release*. March 2020.

MAY 2020

DOE Announces Funding for CCUS Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) announced funding for carbon capture, utilization, and storage (CCUS) projects. The Funding Opportunity Announcement (FOA), titled "*Engineering-Scale Testing from Coal- and Natural-Gas-Based Flue Gas and Initial Engineering Design for Industrial Sources*," will support cost-shared research and development (R&D) projects that capture and store carbon dioxide (CO_2) emissions from industrial sources. Responses are due by June 5, 2020. In addition, DOE/FE also announced the *selection of five projects* under the "Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Site Characterization and CO_2 Capture Assessment" FOA. The projects selected under this FOA will (1) assess and verify safe and cost-effective commercial-scale geologic storage sites for anthropogenic CO_2 emissions, and (2) assess the technical and economic viability of carbon capture or purification technologies for sources that will supply CO_2 to the storage sites. From *energy.gov*. April 2020.

Document Highlights DOE's CCS R&D.

A document released by DOE's National Energy Technology Laboratory (NETL) highlights 20 years of DOE/NETL carbon capture and storage (CCS) R&D. The document, titled "*Safe Geologic Storage of Captured Carbon Dioxide: Two Decades of DOE's Carbon Storage R&D Program in Review*," details the role played by DOE's *Regional Carbon Sequestration Partnership (RCSPs) Initiative*, as well as the CarbonSAFE Initiative. An excerpt from the Executive Summary can be found in the Publications section of this newsletter. From *energy.gov*. April 2020.

JUNE 2020

NETL Software Helps Estimate CO_2 Storage Potential.

A new iteration of a National Energy Technology Laboratory (NETL) software application enables researchers to more accurately estimate carbon dioxide (CO_2) storage potential. The *CO_2-SCREEN* (Storage prospeCtive Resource Estimation Excel aNalysis) tool applies methods and equations for estimating prospective CO_2 storage resources in residual oil zones (ROZs), which can be used for large-scale carbon capture, utilization, and storage (CCUS) projects. ROZs have the potential to boost economic activity through energy production while also storing CO_2. From *NETL Press Release*. May 2020.

JULY 2020

NETL-Led NRAP Expanding Toolset, Collaborations.

Led by the National Energy Technology Laboratory (NETL), the National Risk Assessment Partnership (NRAP) has worked to accelerate the commercial deployment of large-scale carbon storage for the past 10 years. Now into Phase II, NRAP is expanding its *award-winning toolset* and creating new collaborations to continue improving the ability to address risk management for carbon storage sites. NRAP researchers are engaging with new partnerships, such as the U.S. Department of Energy's (DOE) Regional Initiatives, industry, state and federal regulators, and academia. Technical objectives and capability developments continue to be realized in NRAP's Phase II efforts, which began in 2017 and are expected to be completed in 2022. From *NETL News Release*. May 2020.

AUGUST 2020

DOE Invests in Coal FIRST Initiative.

The U.S. Department of Energy (DOE) announced federal funding to support the Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative. Seven projects will receive funding under the Funding Opportunity Announcement (FOA), "*Critical Components for Coal FIRST Power Plants of the Future*," for cost-shared research and development. In addition, DOE is releasing a new FOA, "*Design Development and System Integration Design Studies for Coal FIRST Concepts*," in which projects must incorporate carbon capture and storage (CCS) or carbon capture, utilization, and storage (CCUS) technologies. From *energy.gov*. July 2020.

DOE Announces Funding for FLECCS Program.

DOE announced funding for 12 projects under Phase I of the *Advanced Research Projects Agency-Energy's (ARPA-E)* FLExible Carbon Capture and Storage (FLECCS) Program. FLECCS Phase I project teams will design, model, and optimize CCS processes that enable flexibility on a high-variable renewable energy grid. At the conclusion of Phase I, teams will be downselected to Phase II to receive additional funding to further develop their technologies. The list of FLECCS projects is *available online*. From *energy.gov*. July 2020.

SEPTEMBER 2020

DOE/NETL 2020 Virtual Integrated Project Review Meeting Underway.

A series of free virtual sessions organized by the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) commenced with a three-day conference on carbon capture, utilization, and storage (CCUS) on August 17, 2020. Over a 12-week period, the 2020 Virtual Integrated Project Review Meeting will feature projects from several DOE Office of Fossil Energy (FE) portfolios, including Carbon Capture, Carbon Storage, and Carbon Utilization. Sessions focus on how DOE/FE-sponsored research and development (R&D) activities are advancing transformative science and technologies to support efficient and environmentally sound use of fossil fuels. A comprehensive schedule of the integrated virtual meeting, which will run through November 2020, is *available online*. From *NETL News Release*. August 2020.

DOE Offers Prize to Design Subsurface Visualization Tool.

DOE/FE will award up to $1.5 million to winning innovators in a prize challenge to support their SMART (Science-informed Machine Learning to Accelerate Real-Time Decisions in the Subsurface) Initiative. The SMART Visualization Platform (VP) Challenge prize competition seeks competitors with software development expertise to create a new visualization platform that will assist in making subsurface insights accessible to a wider range of users and stakeholders. *SMART* leverages the expertise of seven national laboratories, as well as industry partners, universities, unconventional field laboratories, and carbon storage regional initiatives, to realize breakthroughs in understanding the subsurface environment through machine learning. Registration information can found on the *SMART VP Challenge website*. The registration deadline is January 22, 2021. From *NETL News Release*. September 2020.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2019

European Companies Sign MOU on CCS.

Equinor signed a Memorandum of Understanding (MOU) with seven European companies to develop value chains in CCS. In cooperation with its partners in the Northern Light project, which includes the transport, reception, and storage of CO_2 in a reservoir in the northern part of the North Sea, Equinor is studying the possibilities for developing CO_2 storage on the Norwegian continental shelf. Under the MOU, the companies will evaluate solutions for CO_2 delivery and transport, develop a timeline for possible final investment decisions and start of operations, and cooperate on the CCS dialogue with national authorities and the EU. From *Equinor* on September 5, 2019.

Drilling Operations for CCS Project Begin.

Easternwell commenced drilling operations for CO2CRC's Otway Stage 3 project in southwestern Victoria, Australia. The *Otway research facility* demonstrates the geologic storage of CO_2; the Stage 3 project aims to demonstrate the implementation of solutions for monitoring CO_2, providing alternative monitoring techniques and enabling faster monitoring. From *Easternwell News* on September 20, 2019.

Memorandum of Cooperation Explores CO_2 Reuse.

Officials from Australia and Japan signed a Memorandum of Cooperation to explore the potential use of CO_2 to manufacture high-value products. The Minister for Resources and Northern Australia and the Japanese Minister for Economy, Trade, and Industry signed the memorandum to spur research into developing technologies that can capture, store, and utilize CO_2 by turning it into an ingredient for the manufacture of products such as carbon fiber, which has the potential for use in the construction and agricultural sectors. From *Manufacturers' Monthly* on September 30, 2019.

CO_2 Emissions Reduction Target Revised.

American Electric Power (AEP) revised its 2030 emissions reduction target to a 70% reduction from 2000 levels; AEP's previous target was a 60% reduction from 2000 levels by 2030. According to AEP, they will achieve future CO_2 emissions reductions through investments in renewable generation and transmission and distribution technologies to enhance efficiency, as well as expanded demand response and energy efficiency programs. Since 2000, AEP has reduced its CO_2 emissions by 59%. From *AEP News Release* on September 10, 2019.

OCGI and CEM CCUS Initiative Members Commit to CCUS.

Members of the *Oil and Gas Climate Initiative (OGCI)* and the *Clean Energy Ministerial (CEM) CCUS Initiative* released joint statements reaffirming their support for a worldwide CCUS industry. OGCI member companies and CEM CCUS Initiative countries intend to explore opportunities to support the commercial development of CCUS through sustained dialogue on policy and regulatory frameworks. The joint declaration builds upon OGCI's "Kickstarter" initiative, which is designed to unlock large-scale commercial investment in CCUS by enabling multiple low-carbon industrial hubs. From *Carbon Capture Journal* on September 23, 2019.

NOVEMBER 2019

Qatar to Build CCS Plant.

Qatar officials announced the commissioning of a CCS facility to be located in Ras Laffan, Qatar, with a planned capacity of 2.1 million tons of CO_2 per year. According to officials, Qatar also plans to use CO_2 for EOR operations. From *Oil Price* on October 8, 2019.

Companies Sign MOU to Advance CCS.

Organizations from Japan and Saskatchewan agreed to collaborate on accelerating the use and understanding of CCS/CCUS. The Memorandum of Understanding (MOU) between Japan CCS Co., Ltd. (based in Tokyo, Japan) and the International CCS Knowledge Centre (based in Regina, Saskatchewan, Canada) represents a path forward to collaborate in the development, demonstration, and deployment of CCS/CCUS. The companies will exchange information and knowledge of CCS/CCUS acquired through the conduct of their respective projects (the Tomakomai CCS Demonstration Project and SaskPower's Boundary Dam 3 CCS Facility). From *International CCS Knowledge Centre Media Release* on October 8, 2019.

Agreement Reached for Carbon Capture/Biomass-to-Fuels Project.

Velocys, Inc., and Oxy Low Carbon Ventures, LLC (OLCV) signed an agreement to capture CO_2 from a planned biomass-to-fuels project in Natchez, Mississippi (USA) and store it underground. As part of the agreement, OLCV will transport and store the CO_2 captured from the planned Bayou Fuels facility (once it is completed), enabling the production of transportation fuels that have a net-negative carbon intensity. The Bayou Fuels project is expected to convert woody biomass into transportation fuels using Velocys' Fischer-Tropsch process. From *Velocys News* on October 10, 2019.

MITEI, Founding Members Renew Research Collaboration.

Energy company Eni *renewed its collaboration* with the Massachusetts Institute of Technology (MIT) by extending its tenure as a founding member of the MIT Energy Initiative (MITEI). Eni will also continue its membership in MITEI's Low-Carbon Energy Center for CCUS. The collaboration, which has been extended through 2023, began in 2008. In addition, ExxonMobil *renewed its status* as a founding member of MITEI for another five years. From *Carbon Capture Journal* on October 20, 2019.

Aker Solutions Unveils Low-Carbon Strategy.

Aker Solutions unveiled an updated strategy focused on low-carbon and renewable energy. The "20/25/30 strategy" sets the path for Aker Solutions to derive 20% of its revenue from renewable energy and 25% from low-carbon solutions by 2030. The low-carbon segment of the strategy is a portfolio of existing Aker Solutions offerings, which includes CCUS. From *Aker Solutions News Release* on October 23, 2019.

DECEMBER 2019

Joint-Development Agreement May Lead to CO_2 Storage.

ExxonMobil and FuelCell Energy signed a joint-development agreement (JDA) for the purpose of capturing CO_2 from industrial sources. FuelCell Energy's proprietary technology uses carbonate fuel cells to efficiently capture and concentrate CO_2 streams from large, industrial sources. Combustion exhaust is directed to the fuel cell, which produces power while capturing and concentrating CO_2 for storage. The modular design enables the technology to be deployed at a wide range of locations. From *Carbon Capture Journal* on November 7, 2019.

CCS Facility Captures 3 Million Metric Tons of CO_2.

According to company officials, SaskPower's CCS facility near Estevan, Saskatchewan, Canada, has captured more than 3 million metric tons of CO_2. SaskPower has committed to reducing its GHG emissions by at least 40% below 2005 levels by 2030 through increased use of renewable energy, as well as by continuing to utilize CCS technology. From *Carbon Capture Journal* on November 8, 2019.

Drilling Operations Begin for CO_2 Storage Project.

Drilling operations at a CO_2 storage project in southern Australia have begun. Easternwell will drill four wells for its project with *CO_2CRC's Otway* in Victoria, Australia, using their Rig 103, which is capable of drilling production and core extraction wells 2,400 meters deep. The objective of the project is to demonstrate the efficiency of implementing solutions for monitoring CO_2. From *Ferrovial Newsroom* on November 11, 2019.

Demonstration Plant Reaches CO_2 Injection Target.

Japan CCS (JCCS) achieved its target of 300,000 metric tons of CO_2 injection at the Tomakomai CCS Demonstration Project in Tomakomai City, Hokkaido Prefecture, Japan. JCCS was selected by the Ministry of Economy, Trade, and Industry of Japan to demonstrate CO_2 reduction technologies. The CCS demonstration project at Tomakomai commenced in FY 2012; in November 2019, the cumulative CO_2 injection reached the 300,000 metric ton target. A monitoring operation will be conducted at the project site. From *JCCS Media Release* on November 25, 2019.

JANUARY 2020

North Dakota Company Advances Carbon Storage Project.

A North Dakota (USA) ethanol company is preparing to store its CO_2 emissions underground. Red Trail Energy plans to drill a test well on its property to examine the geology in which it intends to store its CO_2. The North Dakota Industrial Commission approved the CCS project in 2019. If tests confirm the practicality of CCS operations, Red Tail Energy could begin injection in 2021. From *Casper Star Tribune* on December 11, 2019.

Companies Commit to CCS.

ExxonMobil, Shell, Air Liquide, and Air Products signed an agreement with Porthos, a CCS project organization, to commit to work in parallel on preparations for the capture, transport, and storage of CO_2 from their refineries and hydrogen production facilities in Rotterdam, Netherlands. Porthos has begun technical preparations for transporting and storing CO_2 beneath the North Sea. From *Carbon Capture Journal* on December 9, 2019.

Seismic Data to Be Used in CCS Project.

The CCUS Net Zero Teesside project planned for North East of England purchased seismic datasets to verify the suitability for CO_2 storage in offshore reservoirs located in the Permian Gas Basin in the southern North Sea. The seismic datasets were purchased from TGS-NOPEC Geophysical Company (TGS), which provides geoscience data to oil and gas companies. From *TGS Press Release* on December 5, 2019.

Proposals Sought for CCS Pilot.

The University of Wyoming (UW) Energy Resources Council is seeking proposals for a coal-based pilot project for capturing at least 75% of CO_2 from coal power plants. The call for proposals was posted by *UW's School of Energy Resources (SER)* on behalf of the Wyoming State Legislature. The Wyoming State Legislature appropriated $5 million for the program during its 2019 session; final submissions of proposals are due February 14, 2020. From *Carbon Capture Journal* on December 15, 2019.

FEBRUARY 2020

Oxy, Total Team Up for Carbon Storage Project.

Occidental Petroleum (Oxy) and Total announced a consortium to assess the viability of a commercial-scale carbon capture facility. The joint study will evaluate the cost of capturing 725,000 metric tons of CO_2 per year from a cement plant in Florence, Colorado (USA); emissions will be separated utilizing a solid adsorbent nanomaterial developed by the Canadian-based company Svante, and stored underground by Oxy. From *Journal of Petroleum Technology* on January 7, 2020.

Oil Company to Expand CCUS Capacity.

The state oil company of the United Arab Emirates announced plans to expand its CCUS capacity six-fold, reducing its greenhouse gas (GHG) emissions by 25% by 2030. Abu Dhabi National Oil Company's (Adnoc) sustainability plan is to expand the capacity of the region's commercial-scale CCUS facility from its current rate of 800,000 metric tons of CO_2 captured per year to 5 million metric tons per year by 2030. In addition, Adnoc will plant 10 million mangrove seedlings in Abu Dhabi in order to capture and store additional CO_2. From *Kallanish Energy News* on January 14, 2020.

Companies Sign MOU on CCUS R&D.

Adnoc and Eni—Italy's energy company—signed a Memorandum of Understanding (MOU) to explore potential CCUS collaboration opportunities. According to the terms of the MOU, the two companies will explore geomechanical and geochemical workflows for CCUS programs. From *Adnoc Press Release* on January 20, 2020.

MARCH 2020

Study to Map UK Offshore CO_2 Storage Potential.

A study conducted by Heriot-Watt University (Edinburgh, Scotland) will produce a roadmap for CO_2 storage in the United Kingdom (UK) by identifying sites with CO_2 storage potential. Funded by the Oil and Gas Technology Centre and supported by the UK regulator Oil and Gas Authority, the study will focus on mapping the geological features of the gas fields of the southern North Sea. The sites with the most CO_2 storage potential, as well as those with any potential release points, will be identified, and the overburden will be mapped to develop mitigation strategies and warning systems for any possible CO_2 release. From *Carbon Capture Journal* on February 5, 2020.

ExxonMobil to Expand Carbon Capture Facility, EOR Operations.

ExxonMobil filed a permit application to expand its carbon capture facility in LaBarge, Wyoming (USA) and construct a pipeline and CO_2 injection well. In addition, ExxonMobil plans to add compressors to capture approximately 50% more CO_2 from natural gas streams than existing infrastructure allows; the CO_2 will then likely be used for EOR. The company plans to begin construction later this year and complete the project by 2020. From *Billings Gazette* on February 10, 2020.

Monitoring Work Completed for North Sea CCS Project.

Ashtead Technology completed subsea installation monitoring work to support the Northern Lights carbon capture and storage (CCS) project in the North Sea. Ashtead Technology monitored the installation of an Integrated Satellite Structure with their Deflection Monitoring System and equipment, which monitored and analyzed parameters in real-time, reducing the risk of structural damage by enabling any potential issues to be acted upon quickly. Developed by Equinor in partnership with Shell and Total, the Northern Lights CCS project seeks to capture and transport CO_2 from onshore sources and store it under the seabed. From *Oilfield Technology* on February 13, 2020.

Pre-FEED Carbon Capture Study Commissioned.

Chevron Technology Ventures commissioned a pre-front end engineering design (FEED) study to explore the potential for testing technology by Svante Inc. (formerly Inventys Inc.). The pre-FEED study will evaluate the feasibility and design of a CO_2 capture unit in one of Chevron's California (USA) facilities and is expected to be complete in the first half of 2020. From *Hydrocarbon Engineering* on February 12, 2020.

Drax Announces New CCUS Projects.

Drax Group announced new partnerships with cleantech company Econic Technologies and Deep Branch Biotechnology that may lead to projects using CCUS technology. In addition, Drax is working with multiple businesses to deliver *a zero-carbon industrial cluster* by 2040, in which CO_2 from industry across the region (North of England) could be captured, transported, and stored under the North Sea. From *Drax Press Release* on January 30, 2020.

Partnership Receives Grant to Incorporate Carbon Storage.

A partnership consisting of towns and non-profit organizations in Massachusetts (USA) received a grant from the state that may be used to incorporate carbon storage practices. The Mohawk Trail Woodlands Partnership plans to utilize the grant to conduct a regional feasibility study to explore forestry management practices that incorporate carbon storage. The Mohawk Trail Woodlands Partnership works to increase natural resource-based economic development, support forest conservation on private land and use of sustainable forestry practices, and improve the fiscal sustainability of towns and cities. From *Greenfield Recorder* on February 12, 2020.

APRIL 2020

NETL-Funded Research Project to Study Geologic CO_2 Storage.

Scientists at Virginia Polytechnic Institute and State University (USA) are researching geologic CO_2 storage through two projects, one of which is funded by DOE/NETL's University Coalition for Fossil Energy Research Program. This project aims to develop a machine-learning-based, scale-bridging, data assimilation framework with applications to geologic CO_2 storage. The other project is funded by the National Science Foundation to study the fundamentals of miscible density-driven convection in porous media, which is encountered in geologic carbon storage. From *Carbon Capture Journal.* March 2020.

ADNOC Expands CCUS Program.

The Abu Dhabi National Oil Company (ADNOC) announced plans to expand its CCUS program. According to officials, ADNOC plans to expand the capacity of the program by more 500%, with a goal of reaching 5 million metric tons of CO_2 per year. ADNOC's Al Reyadah facility in the emirate of Abu Dhabi currently has the capacity to capture 800,000 metric tons of CO_2 annually. From *Gasworld*. February 2020.

Drilling Project Confirms Carbon Storage Site.

Results from drilling at the *Northern Lights project* were released and, according to the Norwegian Ministry of Energy and Petroleum, the respective area on the Norwegian Continental Shelf could be suitable for CO_2 storage. Part of Norway's full-scale CO_2 capture and return project, the Northern Light project will capture CO_2 from a cement plant in Brevik and a waste-to-energy plant in Klemetsrud, eventually transporting it via pipeline offshore to a storage location below the seabed in the North Sea. From *The Maritime Executive*. March 2020.

CCS Assessment Atlas Completed in Canada.

TGS, a provider of geoscience data for exploration and production companies, announced the completion of a CCS assessment atlas, which provides an understanding of geologic carbon storage locations (onshore and offshore) throughout British Columbia. Collaborating with Canadian Discovery Limited, TGS created a framework for carbon storage assessment and an atlas for potential storage locations. From *TGS Press Release*. March 2020.

Energy Companies Join Forces on CCS.

Energy companies Santos and BP entered into an agreement to store up to 20 million metric tons of CO_2 per year in the Moomba gas fields in Australia. While the initial proposal is to store 1 million metric tons per year, the Cooper Basin (located mainly in the southwest part of Queensland, Australia) has the capacity to store up to 20 million metric tons per year for 50 years. The companies will next seek Australian government support in the form of carbon credits. From *Australian Financial Review*. March 2020.

UK CCS Project Progresses.

Costain, an infrastructure solutions company, was selected to provide technical consultancy services to the Acorn CCS project. The Pale Blue Dot Energy project is a CCS scheme with the objective to enable the capture and storage of current CO_2 emissions from the onshore gas facilities at the St. Fergus terminal in Scotland. Acorn will take advantage of existing oil and gas infrastructure and a well-understood offshore CO_2 storage site, which has a UK CO_2 appraisal and storage license awarded by the UK Oil and Gas Authority. From *Costain News Release*. March 2020.

CCS Consortium to Develop Teesside Project.

The Oil and Gas Climate Initiative investment fund announced the formation of a consortium to accelerate the development of the Net Zero Teesside project, which plans to build a transportation and storage system to capture industrial CO_2 and store it under the North Sea. In addition, Net Zero Teesside plans to sign three MOUs with existing industrial partners to evaluate technical and commercial cases for CCS. From *Net Zero Teesside*. February 2020.

Research Project Delivers Insights into the Monitoring of Stored CO_2.

CO2CRC's Otway Stage 2C research project provided findings regarding the monitoring of CO_2 stored underground that were used for a larger project: CO2CRC's Otway Stage 3. Work on Otway Stage 3 began in 2019 with the expansion of the Otway National Research Facility by drilling four monitoring wells. Equipped with fiber-optics sensing and subsurface gauges, Otway Stage 3 is expected to demonstrate subsurface monitoring technologies and improve CO_2 storage monitoring. From *CO2CRC Media Release*. February 2020.

MAY 2020

Partners Investigate Second Phase Under DOE's CarbonSAFE Initiative.

The Kansas Geological Survey, along with private and public partners, is characterizing a site as one of DOE's CarbonSAFE projects. The joint effort—the Integrated Midcontinent Stack Carbon Storage Hub—is the second phase of the effort, with the objective of investigating the subsurface geology at sites in southwest Kansas and southwest Nebraska (USA) to verify the viability of CO_2 storage. *The CarbonSAFE Initiative aims to reduce technical risk, uncertainty, and costs of commercial-scale storage projects*. From *Phys.org*. April 2020.

CCS Facility Provides Updated Capture Totals.

The CCS facility at SaskPower's Boundary Dam Power Station in Saskatchewan, Canada, reported a total of 61,801 metric tons of CO_2 captured in March 2020 (approximately 62% of capacity). The average for the previous 12 months at the CCS facility was 55,328 metric tons of CO_2 captured. The facility captured 178,520 metric tons of CO_2 in the first quarter of 2020 and has captured more than 3.2 million metric tons of CO_2 since it went online in October 2014. From *Pipeline News*. April 2020.

Agreement Signed to Study CCS in Malaysia.

JOGMEC, JX Nippon Oil & Gas Exploration, and PETRONAS signed a joint agreement to study the use of CCS technology to develop gas fields in Malaysia that produce a mixture of methane and CO_2. In the study, CO_2 produced from the fields will be separated, captured, and injected into suitable storage reservoirs. From *Carbon Capture Journal*. March 2020.

Large-Scale Capture, EOR Project Announced.

Agreements to develop a large-scale CO_2 capture facility that will include CO_2-enhanced oil recovery (EOR) operations in an existing oil field were finalized. Starwood Energy and Oil and Gas Climate initiatives (OGCI) Climate Investments announced the agreements for the facility, which will be integrated with a natural gas power plant. Jointly developed by Starwood and Elysian Ventures, LLC, the project will use commercially available CO_2 capture technology and aims to capture 90% of the CO_2 emissions from an existing power facility for use in EOR operations. From *Starwood Energy Group Press Release*. April 2020.

CCUS Study Awarded.

The *Athos consortium*, which manages the *Athos CCUS* project in the Noordzeekanaal region of the Netherlands, awarded a concept select study to *io consulting* to support the review of options for CO_2 transportation and storage from the region's industrial CO_2 emitters. io consulting will support an evaluation of the transportation infrastructure required to capture CO_2 and transport it offshore to depleted hydrocarbon reservoirs in the Dutch sector of the North Sea. From *Carbon Capture Journal*. April 2020.

Multi-Year CCUS Collaboration Announced.

Cambridge Quantum Computing (CQC) and Total S.A. announced a partnership to develop algorithms and quantum computing solutions for advanced CCUS technologies. The collaboration will apply CQC's quantum computing and quantum chemistry experience to Total's CCUS R&D efforts. From *Cambridge Quantum Computing News Release*. April 2020.

CCUS Projects Awarded Funding in UK.

United Kingdom Research and Innovation (UKRI) announced funding for a range of decarbonization projects for the first phases of the UK government's Deployment and Roadmap Program strategies for decarbonization. The projects aim to help the UK achieve net-zero emissions by 2050 as part of the UK government's Clean Growth Strategy. From *Carbon Capture Journal.* April 2020.

JUNE 2020

Technology Approved for Full-Scale Demo Project.

DNV GL, an international accredited registrar and classification society headquartered in Høvik, Norway, has approved technology for a full-scale demonstration project to remove CO_2 emissions from a cement plant in Norway. The project, which was initiated by Gassnova (the Norwegian state's agency for implementation of CCS projects), will apply carbon capture technology developed by Aker Solutions at Norcem's Brevik, Norway, cement plant. The plant is part of Europe's industrial demonstration of CCUS; the captured CO_2 is expected to be transported to and injected into a CO_2 storage site offshore of Norway. From *DNV GL News Release*. April 2020.

Feasibility Study to Assess CCS Options.

KBR was awarded a feasibility study to assess options for CCS in South East Asia. As part of the study, awarded by JX Nippon Oil & Gas Corporation, KBR will provide technical consultancy services for developing concepts and technology recommendations for CO_2 capture and reinjection. KBR is a global provider of professional services and technologies within the government, technology, and energy solution sectors. From *KBR Press Release*. May 2020.

Investment in CCS Project Announced.

Equinor, Shell, and Total announced their intent to establish a joint venture company to invest in Norway's Northern Lights project, part of the Norwegian full-scale CCS project. The investment decision concludes the study phase of the project during which the companies conducted engineering studies and project planning, drilled a confirmation well, and developed the necessary agreements. Phase I of the project includes capacity to transport, inject, and store up to 1.5 million metric tons of CO_2 per year. If approved by the Norwegian government, Phase I is expected to be operational in 2024. From *Total News Release*. May 2020.

Partnership to Capture, Store CO_2.

LafargeHolcim, a Swiss building material company, is partnering with Solidia Technologies, a U.S.-based cement and concrete technology company, to reduce CO_2 across its value chain. Combined, the two companies' solutions capture and store CO_2 and emit up to 30% less CO_2 during cement production, leading to 70% reduced-carbon concrete. From *World Cement*. May 2020.

JULY 2020

Alberta CCS Project Fully Operational.

The Alberta Carbon Trunk Line (ACTL) CCUS system—an approximately 150-mile pipeline that transports CO_2 for geologic storage via enhanced oil recovery (EOR)—was announced as fully operational. The ACTL utilizes and stores CO_2 captured at a refinery and a fertilizer plant located in Alberta, Canada. Combined, the refinery and fertilizer plant connected to the ACTL system have a storage capacity of approximately 1.6 million metric tons of CO_2 per year. From *Gasworld*. June 2020.

Contract Awarded for CCUS Project in Netherlands.

MAN Energy Solutions was awarded an engineering contract for the Port of Rotterdam CO_2 Transport Hub and Offshore Storage (Porthos) project in the Netherlands. The Porthos project plans to store approximately 2.5 million tons of CO_2 per year under the North Sea. As part of the contract, MAN Energy Solutions will engineer three RG compressor trains, with an order for three additional units anticipated at a later stage. From *MAN Energy Solutions Press Release*. May 2020.

CCS Research Grant Issued.

The Energy and Environmental Research Center (EERC) received a grant from the North Dakota Industrial Commission to continue research into CCS at ethanol plants. Red Trail Energy, located near Richardton, North Dakota (USA), will be used as a case study, with the grant enabling EERC to complete a CO_2 storage facility permitting guidance document. From *The Bismarck Tribune*. June 2020.

Consortium to Develop Shared CO_2 Storage and Transport Infrastructure.

A consortium of chemical and energy companies aims to build CO_2 infrastructure to support future CCUS applications at the Belgian port of Antwerp, including a shared CO_2 liquefaction plant, storage facilities, and CO_2 transport infrastructure. From *Energy Live News*. June 2020.

CCS Plant Launched in Sweden.

A CCS plant has begun operations at a refinery in Lysekil, Sweden. Within the Preem CCS pilot project, the entire value chain (e.g., CO_2 capture at the refinery, local storage, transport to storage location off the Norwegian west coast) will be evaluated. According to the Swedish fuel company Preem, the goal is for the tests to form the basis for a full-scale CCS plant that can be operational by 2025. The pilot project is a collaboration among Preem, Aker Solutions, Chalmers University of Technology (Sweden), Equinor, and the Norwegian research institute SINTEF. From *Preem Press Release*. May 2020.

Consortium to Investigate Feasibility of CCUS.

A consortium of Belgian and Dutch companies will investigate the feasibility of CCUS. The Carbon Connect Delta Project will research the technical, economic, and legal aspects of the technology; the infrastructure needed for CO_2 transport; financing options; commercial feasibility; and permit procedures. The consortium expects to conclude the feasibility study by the end of 2020, after which the project will be further developed to completion. From *Smart Delta Resources*. May 2020.

CCS Pilot Phase Successfully Completed.

A waste-to-energy plant in Oslo, Norway, successfully validated its CCS pilot phase. One of two sites being evaluated as part of Norway's plan for a full-scale, full-chain CCS project, Fortum Oslo Varme's Klemetsrud site started the pilot phase in March 2019. Captured CO_2 from the plant will be transported to an onshore storage area in western Norway before transport via pipeline to an offshore storage reservoir. From *The Chemical Engineer*. May 2020.

Contract Awarded for CCS Project.

Wood, an Aberdeen-based engineering company, was awarded a contract to provide design services for the *Humber Zero project*, a CCS project located in the Humber region of England. Work will involve capturing CO_2 emissions from three industrial sites in the area for CO_2 storage in depleted North Sea reservoirs. From *The Herald*. June 2020.

AUGUST 2020

Offshore CO_2 Storage Consortium Formed.

A CO_2 storage consortium, comprised of Maersk Drilling, INEOS Oil & Gas Denmark, and Wintershall Dea, will target the development of CO_2 storage capacity offshore Denmark based on reusing discontinued offshore oil and gas fields for CO_2 storage. The first phase of the CCS project will be a feasibility study to validate reservoir compatibility, followed by a CO_2 injection pilot test. The long-term goal of the project is to develop the capacity to store approximately 3.5 million tons of CO_2 per year by 2030. From *Maersk Drilling Press Release*. June 2020.

Research Project Commenced at Otway.

A team of engineers began a research project at the Otway National Research Facility (located in south-western Victoria, Australia) that focuses on reducing the long-term cost of CO_2 storage monitoring. A water tracer technology team from Deakin University will seek to develop new ways to track variations in water quality in groundwater above rock that acts as a natural barrier to saline formations and stored CO_2. The *Otway National Research Facility* was established in 2008 to demonstrate that CO_2 could be safely captured, transported, and injected and stored in different geologic formations. From *Carbon Capture Journal*. July 2020.

Project Uses CCS to Produce Hydrogen from Natural Gas.

A project to produce hydrogen from natural gas in combination with CCS is being developed in the United Kingdom (UK). The initial phase of the Hydrogen to Humber Saltend (H2H Saltend) project comprises a 600-megawatt auto thermal reformer with CO_2 capture to convert natural gas to hydrogen. Later phases can serve other industrial users, enabling a large-scale network for transporting and storing captured CO_2 emissions. The H2H Saltend project supports the UK government's aim to establish at least one low-carbon industrial cluster by 2030 and a net-zero cluster by 2040. From *Equinor News Release*. July 2020.

CCS Systems Used at Cement Plant.

Carbon8 Systems signed a commercial agreement to deploy its CCUS systems at a cement plant in France. Carbon8's CO_2ntainer system will be integrated into the existing industrial processes onsite at the cement plant and will capture CO_2 from the plant's flue gas emissions. The CO_2 will then be used to convert cement bypass dust into construction aggregates. The aggregates can then be repurposed in various commercial applications, such as lightweight concrete blocks. From *Carbon Capture Journal*. July 2020.

CCS Project Receives Grant.

The North Dakota Industrial Commission awarded a grant to Midwest AgEnergy Group to advance the development of a potential CCS system at the Blue Flint facility located near Underwood, North Dakota (USA). The research will include drilling a stratigraphic well to examine the geology of the surrounding area and collecting core samples that will be analyzed for suitability to store CO_2 in saline formations. If the project is successful, the Blue Flint facility anticipates storing approximately 200,000 tons per year. From *Ethanol Producer Magazine*. June 2020.

Collaboration to Use CCS to Transport Liquefied CO_2.

Preem signed a collaborative agreement with industry and government stakeholders to create a joint infrastructure for transporting liquefied CO_2 extracted using CCS technology. The CinfraCap project will identify an industry-scale logistics system required to support CCS, eventually presenting proposals for an optimized infrastructure that links to other CCS projects. From *Preem Press Release*. June 2020.

Full-Scale Demo Project Approved by Norwegian State Agency for CCS.

Gassnova, the Norwegian state agency for CCS projects, is supporting a full-scale carbon capture demonstration project at a waste-to-energy plant in Oslo, Norway. The project, which tested Shell's CANSOLV CO_2 carbon capture technology at Fortum Oslo Varme's Waste-to-Energy plant at Klemetsrud in Oslo, is expected to contribute to Norway's emission goals. A pilot initiated at Klemetsrud in 2018 captured more than 90% of all flue gas; according to officials, going full-scale with CCS will improve the plant's environmental performance by helping it achieve net-negative emissions. From *DNV GL Media Release*. July 2020.

SEPTEMBER 2020

CO_2 Conversion Projects Receive DOE Funding.

In June 2020, DOE/FE and NETL selected 11 projects to receive funding through the *Carbon Utilization Program*. The University of California, Los Angeles (UCLA) will *develop a process capable of converting CO_2 emissions into construction materials*. The technology captures CO_2 emitted from power plants, cement plants, and other CO_2 producers, using it to make a form of concrete known as *CO_2Concrete*, which is expected to have a carbon footprint 50 to 70% lower than that of regular concrete. In addition, the University of Louisiana at Lafayette *will develop a way to convert CO_2 into ethylene* with low pulses of electricity; by comparison, current methods of producing the chemical emit 200% more CO_2. From *UCLA News Release*, July 2020; and *The University of Louisiana at Lafayette*, August 2020.

KGS Joins DOE-Funded Project.

The Kansas Geological Survey (KGS) is *partnering with the Carbon Utilization and Storage Partnership (CUSP) to research CO_2 storage. CUSP*, made up of 15 other entities, is led by the Petroleum Recovery Research Center at the New Mexico Institute of Mining and Technology, which was awarded funding for the project by DOE. KGS will also work with CUSP members on methods to analyze data that may provide a better understanding of infrastructure development potential, infrastructure costs, and ways to optimize future project development. From *The University of Kansas*. August 2020.

DOE-Funded FEED Contract Awarded for CCS Project.

A front-end engineering and design (FEED) contract was awarded to Fluor Corporation for a CCS project in Tupman, California (USA). Flour will use its carbon capture technology to provide engineering services for the licensed process unit and required utility systems at the 550-megawatt, natural gas-powered Elk Hills Power Plant. The project is a collaboration between the Electric Power Resource Institute (EPRI), California Resources Corporation, and Flour. The FEED is funded by DOE through collaboration with EPRI as part of a larger initiative to advance carbon capture technology development. From *Business Wire*. July 2020.

Geologic Carbon Storage Project Progresses.

The Wales-based Flexible Integrated Energy Systems (FLEXIS) Project is collaborating with Polish and German entities to establish an underground research observatory to study European coal reserves for carbon storage. The three-year ROCCS project (establishing a Research Observatory to unlock European Coal seams for Carbon dioxide Storage) will conduct in-situ tests at the Experimental Mine Barbara in Mikołów, Poland, where a horizontal well system will be installed for CO_2 injection. A large-scale commercial site will be selected and analyzed for CO_2 storage. From *Gasworld*. July 2020.

Australian CCUS Study Announced.

National Energy Resources Australia (NERA) and CO_2CRC announced a study into CCUS to assist the Australian energy resources sector in reducing CO_2 emissions. The two-phase study will first rank oil and gas basins in Australia for their potential use of CO_2-EOR. The second phase will provide industry and government stakeholders with insight into potential CO_2-EOR opportunities at the field level in Australian onshore basins. In addition, the study will evaluate policies, incentives, and regulations with the potential to help Australia adopt CO_2-EOR and CO_2 storage. From *CO_2CRC Media Release*. July 2020.

Carbon Storage Company Acquired.

Oil and gas company Shell Australia is acquiring a carbon management firm as part of its net-zero emissions strategy. Shell will acquire the Australian-based Select Carbon for its Nature-Based Solutions business, which specializes in CO_2 storage in forests, grasslands, wetlands, and other natural ecosystems. From *Kallanish Energy*. August 2020.

Companies to Collaborate on CCS.

Petrofac, an international service provider to the energy industry, signed a Memorandum of Understanding (MOU) with Storegga Geotechnologies, an independent supporter of CCS, to build new energy capability and capacity in the United Kingdom. Under the MOU, the companies will collaborate on potential business development and project initiatives in CCS and other low-carbon projects. From *Petrofac Press Release*. August 2020.

JDA Signed to Develop CCUS Projects.

Carbon Clean Solutions Limited (CCSL) *signed a Joint Development Agreement (JDA)* with Marubeni Corporation, a Japanese integrated trading and investment company, to develop and invest in CCUS projects. The JDA builds on an existing relationship between the two companies; Marubeni previously invested in CCSL to help it deliver its CO_2 capture technology for CCUS projects across the steel, cement, waste management, and refining and petrochemicals sectors. From *Carbon Capture Journal*. August 2020.

LEGISLATION and POLICY

OCTOBER 2019

Businesses Call for Long-Term, Stable Carbon Pricing Policies.

A report by the High-Level Commission on Carbon Pricing and Competitiveness focuses on the benefits of adopting carbon pricing policies. According to the report, carbon pricing combined with other policies, such as increased investment in low-carbon technologies, can help drive innovation in industries, foster continuous process improvement, and facilitate the transition to a low-carbon economy. The High-Level Commission on Carbon Pricing and Competitiveness includes private sector leaders and senior government officials that explore the evidence base, business concerns, and lessons learned from carbon pricing systems across the world. From *Carbon Pricing Leadership Coalition* on September 21, 2019.

EU Officials Discuss CCS Funding.

European Union agriculture ministers agreed that increasing carbon storage in soil to reduce greenhouse gasses (GHGs) would require funding. The EU farming officials gathered at an informal meeting in Helsinki, Finland, hosted by the current Finnish presidency. In addition to discussing how best to support carbon capture through the post-2020 Common Agricultural Policy, the ministers discussed the need for more flexibility in meeting target measures for CCS. From *EURACTIV* on September 26, 2019.

NOVEMBER 2019

Legislation to Invest in Carbon Capture, Storage Introduced.

Legislation to establish a program leading to the construction of transportation infrastructure for anthropogenic CO_2 was introduced in the U.S. House of Representatives. Under the "Investing in Energy Systems for the Transport of CO_2 (INVEST CO_2) Act," CO_2 captured at industrial sources would be transported via pipeline for storage or for beneficial use. From *Congresswoman Cheri Bustos Press Release* on October 29, 2019.

Amendment Allows for Transboundary CCS Projects.

Parties to the *London Protocol* agreed that transboundary export of CO_2 for the purpose of CCS could now be provisionally allowed under certain circumstances. The International Maritime Organization (IMO) resolution will allow for subsea CCS projects to be shared across national boundaries. Since 2006, the London Protocol has provided the basis in international environmental law for governments to allow CCS under the seabed. According to IMO officials, adoption of the resolution is expected to limit barriers for countries looking to pursue CCS under such scenarios. From *The Maritime Executive* on October 14, 2019.

Germany Approves Legislation to Reduce CO_2 Emissions.

The German cabinet approved legislation aimed at reducing CO_2 emissions by 55% in 2030. The legislation includes annual targets for CO_2 emissions specific for each sector. A monitoring commission will assess the annual targets every year, triggering additional measures if they are not met. From *S&P Global* on October 9, 2019.

DECEMBER 2019

EU Countries Increase Funding for Low-Carbon Investment.

Five European Union (EU) member states increased funding to the Modernization Fund, which is a pool of carbon allowances that will be auctioned after 2020 to finance low-carbon investments in Europe. According to the European Commission, the increase in funding is expected to amount to more than 350 additional EU carbon allowances, which will be sold on the common EU auctioning platform in equal shares for each year from 2021 to 2030. The Modernization Fund supports low-carbon investments in the energy systems of 10 EU member states (Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia). From *S&P Global* on November 11, 2019.

New Program Promotes CO_2 Storage.

The U.S. Department of Agriculture's Natural Resources Conservation Service and the Nature Conservancy have partnered on a program to support sustainable forests and carbon market development in targeted areas in Virginia, Tennessee, and Kentucky (USA). The *Healthy Forest Reserve Program* will offer financial assistance for specific conservation actions on private forests and tribal lands. Landowners who develop a carbon forest project will also get assistance with carbon credit development. From *CBS19 News* on November 13, 2019.

JANUARY 2020

Coal-to-Products Bill Introduced to Establish Program Within DOE.

U.S. Senators introduced legislation to establish a dedicated program within DOE that focuses on advancing the research and promotion of coal-derived carbon products. Enactment of *the Creating Opportunities and Leveraging Technologies for Coal Carbon Act (COAL TeCC Act)* is expected to enhance ongoing work at DOE, being carried out through NETL, to utilize coal as a precursor for value-added products. The COAL TeCC Act also directs DOE to establish a pilot and demonstration program in Appalachia to help coal-derived carbon products reach the commercialization phase. From *U.S. Senator Shelley Moore Capito Press Release* on December 13, 2019.

Drax to Use BECCS to Become Carbon-Negative.

British electrical power generation company Drax announced plans to become carbon-negative by 2030 through the use of BECCS technology. Drax is planning to scale-up the use of CO_2 capture technologies in its power plant in Yorkshire, England, to remove more CO_2 from the atmosphere than it produces in advance of CCS-related government policy and investment framework. From *Business Green* on December 10, 2019.

US Senators Introduce Legislation with Potential to Increase CO_2 Storage

A group of U.S. Senators introduced legislation that addresses reforestation, which could potentially increase the natural storage of CO_2 emissions. The Reforestation Act of 2019 provides funding to the U.S. Forest Service to carry out projects in forests affected by events such as wildfires, insect infestations, and disease. Among other activities, reforestation includes the replanting of forests, which is expected to increase natural carbon storage. From *U.S. Senator Tom Udall Press Release* on December 19, 2019.

FEBRUARY 2020

Norway Proposes to Invest in CCS.

The Norwegian government proposed to invest in the development of CCS projects in 2020, including support for a full-scale CO_2 capture, transport, and storage project. The government's budget proposal for 2020 would provide funds for operating the *Technology Centre at Mongstad* (a test center for developing CO_2 capture technologies) and the research program *CLIMIT* (a program focusing on the research, development, and demonstration [RD&D] of CCS technologies). From *Energy Live News* on January 8, 2020.

Wyoming Budget Proposal Looks to Accelerate CCS.

The Governor of Wyoming revealed a list of budget priorities that included accelerating the commercial development of CCS technologies. The budget proposal includes the establishment of an Energy Commercialization Program that would focus on advancing coal and CCS research. From *Natural Gas Intelligence* on January 15, 2020.

Massachusetts Senate Bills Could Reduce GHG Emissions.

The Massachusetts Senate unveiled bills that include a package that sets a statewide "net-zero" emissions GHG limit for 2050. To reach the proposed GHG reduction goals, the legislation requires the state to realize its near-term CO_2 limits every five years, beginning in 2025. From *The Hour* on January 23, 2020.

MARCH 2020

CCUS Legislation Proposed.

Legislation that promotes R&D for carbon capture technology and researches solutions for CO_2 utilization was introduced in the U.S. House of Representatives. The *New Energy Frontiers Through Carbon Innovation Act* directs existing DOE funds for research, development, and deployment of carbon capture technology for natural gas-generated power, and also establishes a "Carbon Innovation Hub" that will examine solutions to CO_2 utilization. From *U.S. Congressman Dan Crenshaw Press Release* on February 12, 2020.

US Representative Introduces Legislation Incentivizing Carbon Storage.

Legislation that incentivizes the use of wood products as carbon storage devices by planting 1 trillion trees globally by 2050 was introduced in the U.S. House of Representatives. The *Trillion Trees Act* is based on a 2019 Swiss report featured by the American Academy for the Advancement of Science that concluded planting 1 trillion trees throughout the world could store 205 gigatonnes of CO_2. The act has three parts: (1) plant more trees in urban areas, (2) grow more wood in existing forests, and (3) store more CO_2 by incentivizing innovative building practices. From *U.S. Congressman Bruce Westerman Press Release* on February 12, 2020.

Bill Seeks Net-Zero CO_2 Emissions in US by 2050.

A group of U.S. senators introduced a bill that would require the United States to become "net-zero" by 2050. *The Clean Economy Act* would require the U.S. Environmental Protection Agency (EPA) to develop a plan to reduce greenhouse gas (GHG) emissions by 2025, 2030, and 2040, before reaching net-zero emissions by 2050. From *The Hill* on February 11, 2020.

Legislation Looks to Expand Carbon Storage Tax Credit.

Legislation to expand the 45Q carbon storage tax credit and make it permanent in the federal tax code was introduced in the U.S. House of Representatives. Section 45Q provides a tiered tax credit for projects that permanently store CO_2, with the current law requiring that projects begin before 2024 in order to qualify. In addition to making the credit permanent, *the legislation* would enhance the value of the credit by 25% for both tiers and reduce the minimum amount of CO_2 that must be stored for a direct air capture project to qualify from 100,000 tons to 50,000 tons. From *Ethanol Producer Magazine* on February 13, 2020.

APRIL 2020

Executive Order Directs Oregon Agencies to Reduce Emissions.

Oregon's Governor signed an *executive order* directing state agencies in Oregon (USA) to adopt a series of measures to reduce the state's overall greenhouse gas (GHG) emissions. Under the order, the state will enforce a standard to lower the carbon impacts of transportation fuels and cap emissions from industrial processes, transportation fuels, and natural gas. According to a *Governor's Office press release*, the order updates the state's existing carbon emissions goals, setting a standard of 45% reduction from 1990 levels by 2035, and an 80% reduction from 1990 levels by 2050. From *The Register-Guard*. March 2020.

Vermont House Approves Bill.

The Vermont House approved legislation that would legally mandate the state to meet carbon emissions reduction targets. Under the legislation, Vermont (USA) would be required to develop a plan to reduce GHG emissions to 26% below 2005 levels by 2025. Emissions would also need to be 40% below 1990 levels by 2030, and 80% below by 2050. From *VTDigger*. February 2020.

EU Unveils Industrial Strategy to be Carbon-Neutral by 2050.

The European Commission presented a new industrial strategy to help Europe become carbon-neutral by 2050. Included in the strategy are measures intended to strengthen current carbon release tools and secure a supply of low-carbon energy, as well as the development of an alliance of low-carbon industries. The *government also announced* that CCS will be established in at least two sites in the United Kingdom, one by the mid-2020s and a second by 2030. From *ReNews.biz*. March 2020.

MAY 2020

Virginia Governor Signs Clean Energy Legislation.

The governor of Virginia (USA) signed the Virginia Clean Economy Act into law, requiring Virginia state electricity providers to become carbon free by 2050. Under the new laws, Virginia plans to join the *Regional Greenhouse Gas Initiative (RGGI)*. From *Virginia Business*. April 2020.

Shell Aims to Be Net-Zero by 2050.

Officials from Royal Dutch Shell laid out a strategy to reduce the company's greenhouse gas emissions to net-zero by 2050. The company previously had long-term intensity-based targets rather than goals based on absolute emissions reductions. From *Reuters*. April 2020.

JUNE 2020

Policy Design to Finance CCUS Projects in US.

Columbia University's Center on Global Energy Policy released a report on CCUS policy configurations. The report found that additional policies would benefit and incentivize the deployment of CCUS in the commercial power market. The authors analyzed which policy configurations would incentivize the widespread deployment of CCUS in the U.S. electric generation industry. The results focused on the effect of ownership structure, the 45Q tax credit, capital cost incentives, and revenue enhancement incentives. More information, including the full report, a presentation, and a data-sharing portal, is *available online*. From *Carbon Capture Journal*. April 2020.

Roadmap Examines CO_2 Emissions Reductions Through Technologies.

CEMBUREAU (the European Cement Association) *published its Carbon Neutrality Roadmap (CNR)*, examining how the European cement industry can reach net-zero CO_2 emissions by 2050 and align with the European Green Deal. *According to the roadmap*, achieving net-zero emissions by 2050 will require the deployment of existing and new technologies, such as CCUS. The CNR also details the role these technologies could play in reducing CO_2 emissions at each stage of the cement and concrete value chain and provides both technical and policy recommendations. From *CemNet.com*. May 2020.

Australia's Technology Investment Roadmap Considers CCS Technologies.

Australia's federal government released its technology investment roadmap for reducing CO_2 emissions over the next 30 years. CCS was among the technologies under consideration to meet the nation's emissions goals, for which the Australian government recommended long-term investment. From *ABC.net*. May 2020.

UK Draft Accord Sets Path for Future UK-EU CO_2 Trading.

In a draft technical energy accord released on its website, the UK set out the basis for potentially linking UK-European Union (EU) CO_2 emissions trading systems (ETSs). The carbon pricing section of the draft accord states that the UK is open to linking to the EU ETS, which could potentially include enabling CO_2 allowances from either entity to be used in either system. From *S&P Global*. May 2020.

JULY 2020

US Treasury Unveils Rules for CO_2 Tax Credit Program.

The U.S. Department of Treasury *released proposed regulations* for implementing the 45Q federal tax code, which is designed to increase investment in CCS projects. The rules aim to provide clear guidelines to ensure investors and developers are capturing and storing the correct amount of CO_2 required to receive the credits ($50 per metric ton of CO_2 for storage projects and $35 per metric ton for CO_2-EOR projects). Among the new measures in the proposed rule are monitoring requirements for projects to demonstrate safe, underground geologic CO_2 storage and standards for measuring CO_2 utilization. From *Reuters*. May 2020.

Switzerland to Extend CO_2 Act Measures.

Switzerland's Federal Department of the Environment, Transport, Energy, and Communication launched a consultation process for a partial revision of the CO_2 Act. The amendments will extend certain measures until the end of 2021, as recently required by Parliament, and are subject to consultation until August 2020. Under the current CO_2 Act, certain measures, such as CO_2 tax exemptions guidelines, were set to expire at the end of 2020. From *Lexology.* June 2020.

Scottish Support Package Includes Funding for CCS Project.

A support package *announced by the Scottish government* to help fund the energy sector due to impacts of COVID-19 includes funding for the *Acorn CCS project*. The Energy Transition Fund will support businesses in the oil, gas, and energy sectors over the next five years. From *Carbon Capture Journal*. June 2020.

Bill Aims to Help Farmers Sell CO_2 Credits.

Legislation was introduced in the U.S. Congress that would allow the agricultural industry to participate in a carbon credit market. The legislation tasks the U.S. Department of Agriculture with creating a certification program to assist farmers and forest landowners who use sustainable practices in implementing the protocols. From *The Hill*. June 2020.

AUGUST 2020

Examining Impact of Legal Framework on CCS.

Research examining the impact of legal framework for CCS projects in Canada and Mexico was *published in the U.K.'s Environmental Liability: Law, Policy, and Practice*. The paper was prompted by an agreement between Mexico and the University of Calgary's Global Research Initiative to share expertise. From *Haskayne School of Business News*. June 2020.

Consortium to Advise UK Government on CCS.

The UK Department for Business, Energy, and Industrial Strategy appointed a consortium to provide engineering and technical advice for advancing CCUS development in the UK. The consortium will support the design of a CCUS work program to enable the deployment of various projects during the 2020s and advise on the engineering and technical implications for CCUS business models, associated policy development, and CCUS cluster engagement. The consortium is part of the UK government's goal to have the option to deploy CCUS at scale during the 2030s. From *New Civil Engineer*. July 2020.

White Paper Identifies Near-Term CCS Opportunities.

The Great Plains Institute and the University of Wyoming (USA) *released a white paper* presenting the results of modeling efforts to identify regional-scale CO_2 transport infrastructure that would serve existing facilities and enable participation by new capture projects and facilities in the near future. The white paper identifies near-term CCS opportunities, designing and planning the regional transport infrastructure required to maximize CO_2 reductions while minimizing cost and land use impacts throughout the Midwest, Rockies, Plains, Gulf Coast, and Texas. From *Enhanced Oil Recovery Institute*. July 2020.

SEPTEMBER 2020

CO_2 Management Bill Proposed.

A proposed bill would establish a Committee on Large-Scale Carbon Management in the National Science and Technology Council and a Federal Carbon Removal Initiative, according to the U.S. congressional record bill summary. If enacted, *S. 4341* would create a large-scale CO_2 management program co-chaired by officials from DOE, as well as other institutions and U.S. departments, that would establish four working groups to pursue a Carbon Dioxide Removal (CDR) initiative. Using both natural and technological approaches, the working groups would focus on CDR in the oceans, atmosphere, and land. From *The Ripon Advance*. August 2020.

VA Governor Signs Legislation for Carbon-Free Future.

The Governor of Virginia (USA) signed legislation addressing the state's carbon-free transition. The *Virginia Clean Economy Act* establishes a renewable portfolio standard to achieve 30% renewable energy by 2030, an energy efficiency resource standard, and a path to a carbon-free electric grid by 2045. From *Governor Ralph Northam News Release*. August 2020.

EMISSIONS TRADING

OCTOBER 2019

Global Carbon Index Launched.

IHS Markit launched its Global Carbon Index, a benchmark for the global price of carbon credits. The *IHS Global Carbon Index* tracks the performance of tradable carbon markets, such as the EU Emissions Trading System, the California Cap-and-Trade Program, and the Regional Greenhouse Gas Initiative. According to the index, the global weighted average price of carbon credits is $23.65, with the data showing the total return potentially gained by investors in global carbon since the beginning of 2018 is 132%. From *IHS Markit Press Release* on September 25, 2019.

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

California (USA) and Québec (Canada) *released results of the 20th joint cap-and-trade auction of CO_2 allowances*. All 66,289,515 current vintage allowances (2016, 2017, and 2019) offered were sold at a settlement price of $17.16. All 9,038,000 advance vintage allowances (2022) were sold at a settlement price of $16.85. The *21st Joint Auction* will be held on November 19, 2019. From *California Air Resources Board* on August 27, 2019.

NOVEMBER 2019

Governor Signs Executive Order to Begin Process of Joining RGGI.

Pennsylvania's Governor signed an executive order to begin the process of joining RGGI, a market-based program that focuses on reducing greenhouse gas (GHG) emissions in the United States. The executive order directs the Pennsylvania Department of Environmental Protection to begin drafting a set of regulations to govern the state's entry into the program. From *PennLive* on October 3, 2019.

RGGI States Initiate Auction Process for Auction 46.

The states participating in RGGI released the *Auction Notice* and application materials for their 46th quarterly CO_2 allowance auction, to be held December 4, 2019. The Auction Notice provides potential participants with the information needed to submit a Qualification Application and indicate their intent to bid. Auction 46 will offer 13,116,444 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). Auction 46 will be the last quarterly auction in which states will offer CO_2 allowances for purchase to meet CO_2 interim compliance obligations for the 2019 interim control period, which began on January 1, 2019. From *RGGI* on October 8, 2019.

Indonesia Starts Fund for Carbon Trading.

According to government officials, Indonesia is planning to develop a carbon trading market under a new agency formed to reduce GHG emissions. The Environment Fund Agency, which will be supervised by the Indonesian finance ministry, will also fund various carbon-reduction programs and seek multiple sources of financing. From *Bloomberg* on October 9, 2019.

New Digital Exchange Allows Trading of Carbon Credits.

A global blockchain-based carbon exchange for the transportation industry was launched, providing a marketplace for stakeholders to trade carbon emissions. The AirCarbon Exchange will provide a supply of carbon credits, known as eligible emission units, for buyers to acquire CO_2 offsets. From *The Business Times* on October 30, 2019.

DECEMBER 2019

RGGI States Release Reports.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the 2017 Annual Electricity Monitoring Report. The "*CO_2 Emissions from Electricity Generation and Imports in the Regional Greenhouse Gas Initiative: 2017 Monitoring Report*," the ninth such annual monitoring report released by the RGGI states, summarizes data for electricity generation, electricity imports, and related CO_2 emissions for the RGGI states. In addition, 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: Third Quarter 2019*" addresses the period from July through September 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 Releases* on November 8 and 14, 2019.

Full Compliance Requirements Met for California Cap-and-Trade Program.

The California (USA) Air Resources Board (CARB) announced that all businesses covered by the state's cap-and-trade program have fully met their compliance obligations for 2018. In addition, CARB released data from the Mandatory Reporting Regulation (MRR), which shows that emissions remained below 1990 levels in 2018. The *MRR data* also indicates that California is on track to meet the GHG reduction target of 2020 under *Assembly Bill 32*. From *California Air Resources Board News Release* on November 4, 2019.

JANUARY 2020

Results of 46th RGGI Auction Released.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of their 46th auction of CO_2 allowances. A total of 13,116,444 CO_2 allowances were sold at a clearing price of $5.61, with bids ranging from $2.26 to $8.00 per allowance. In addition, none of the 10 million cost containment reserve (CCR) allowances made available were sold. (The CCR is a fixed additional supply of allowances made available if CO_2 allowance prices exceed certain price levels [$10.51 in 2019].) Auction 46 generated $73.6 million for states to reinvest in strategic programs, including energy efficiency and greenhouse gas (GHG) abatement programs. Additional details are available in the *Market Monitor Report for Auction 46.* From *RGGI News Release* on December 6, 2019.

Switzerland, EU Link Emissions Trading Systems.

Switzerland formally linked its GHG emissions trading system with the European Union Emissions Trading System in January 2020. The agreement to link cap-and-trade systems has the potential to increase the availability of reduction opportunities and enhance the cost efficiency of emissions trading. From *Council of the EU Press Release* on December 9, 2019.

FEBRUARY 2020

RGGI States Initiate Auction Process for Auction 47.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) initiated the auction process for their 47th quarterly CO_2 auction scheduled for March 11, 2020. Auction 47 will offer 16,208,347 CO_2 allowances for sale at a minimum reserve price of $2.32. An 11.8 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 $10.77). From *RGGI* on January 14, 2020.

Fund to Help Industries in EU ETS Reduce CO_2 Emissions.

The European Commission proposed a European Union (EU) Just Transition Fund to help heavy industries reduce their CO_2 emissions. Only plants in the EU's Emissions Trading Scheme (ETS) and located in EU regions with carbon emissions at least twice the EU average would receive support through the proposed fund, which is part of a wider plan to keep the EU on the path to becoming carbon-neutral by 2050. From *S&P Global* on January 14, 2020.

Indonesia Plans to Start Carbon Trading in 2020.

Indonesian government officials announced plans to start carbon trading later this year. The draft regulation, anticipated to be submitted for approval in 2020, is expected to allow different carbon trading schemes, with the rules stipulating how carbon credits will be priced (e.g., credits from forest preservation and credits from industrial emissions reductions will be priced differently). From *Reuters* on January 16, 2020.

MARCH 2020

Virginia House Legislation Includes Cap-and-Trade Language.

The Virginia House of Delegates passed legislation that includes language to add the state to the Regional Greenhouse Gas Initiative (RGGI) program. From *WHSV* on February 11, 2020.

RGGI Secondary Market Report Made Available.

The independent market monitor for the 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 2019*" addresses the period from October through December 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 February 13, 2020.

IRS Issues Guidance on Carbon Capture Credits.

The U.S. Government Internal Revenue Service (IRS) issued guidance to help businesses understand legislation on claiming carbon capture credits. The IRS also announced plans for future guidance on the secure geologic storage of CO_2. *Notice 2020-12* provides guidance to help businesses determine when construction has begun on a qualified facility or on carbon capture equipment that may be eligible for the carbon capture credit. *Revenue Procedure 2020-12* creates a safe harbor that simplifies the application of carbon capture credit rules to partnerships able to claim the credit. From *IRS News Release* on February 19, 2020.

Partnership to Sell Carbon Offsets.

Spanish renewable energy company Acciona SA and Valencia-based Climate Blockchain Initiatives have partnered to support the global expansion of a carbon credits trading platform. The *ClimateTrade platform* uses blockchain technology to make commercial transactions of carbon offsets more efficient. From *Renewables Now* on February 19, 2020.

APRIL 2020

S&P Dow Jones Launches EU Carbon Allowance Index.

S&P Dow Jones Indices launched an index to track European Union carbon allowance prices. According to a *press release*, the new index provides investors with a publicly available investment performance benchmark for European Carbon Emission Allowances and is an expansion of the single-commodity series of indices based on the *S&P GSCI*. From *Carbon Pulse*. March 2020.

Results of 47th RGGI Auction Released.

The RGGI-participating states announced the results of their 47th auction of CO_2 allowances. A total of 16,208,347 CO_2 allowances were sold at a clearing price of $5.65, with bids ranging from $2.32 to $6.75 per allowance. In addition, none of the 11.8 million cost containment reserve (CCR) allowances made available were sold. (The CCR is a fixed additional supply of allowances made available if CO_2 allowance prices exceed certain price levels [$10.77 in 2020].) Auction 47 generated $91.6 million for states to reinvest in strategic programs, including energy efficiency and GHG abatement programs. Additional details are available in the *Market Monitor Report for Auction 47*. From *RGGI News Release*. March 2020.

MAY 2020

RGGI States Initiate Auction Process for Auction 48, Release CO_2 Budget Source Compliance Materials.

The states participating in RGGI's 2020 auctions initiated the auction process for their 48th quarterly CO_2 auction, scheduled for June 3, 2020. Auction 48 will offer 16,336,298 CO_2 allowances for sale at a minimum reserve price of $2.32. An 11.8 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 $10.77.) In addition, the RGGI states *released materials* for CO_2 budget source compliance for their fourth three-year control period, which is from January 1, 2018, through December 31, 2020. From *RGGI*. April 2020.

Canadian Government Releases Notice of Intent to Amend Pricing Regulations.

The Canadian government announced an intent to amend carbon pricing regulations amid the coronavirus pandemic. The Canadian Minister of Environment and Climate Change intends to develop regulations for the country's *Output-Based Pricing System* that would amend reporting requirements within Canadian provinces. From *JD Supra*. April 2020.

JUNE 2020

Regional Greenhouse Gas Initiative Reports Made Available.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released two reports. The *Annual Report on the Market for RGGI CO_2 Allowances: 2019* 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. More details on 2019 allowance prices, holdings, and market participation are available on RGGI's *Market Monitor Reports webpage*. In addition, the *Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2020* addresses the period from January through March 2020 and contains information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. From *RGGI News Releases*. May 2020.

EU, Swiss Carbon Trading Link Postponed.

The EU Commission announced that it had postponed the launch of a provisional mechanism for transferring carbon permits between Switzerland and the EU ETS. The EU and Switzerland linking agreement entered into force in January 2020; however, for the linking to happen, a provisional mechanism for the transfer of permits had to be in place by May 2020. The EU Commission said this transfer has been postponed until September 2020 due to the COVID-19 outbreak. From *Today Online*. May 2020.

Europe Carbon Trading Volumes Rise.

According to Germany's emissions trading authority (DEHSt), trading volumes in Europe's carbon trading market rose in the first quarter of 2020 by 8% year-on-year. More than 1 billion allowances were traded in March 2020, which was the largest volume in a single month since October 2018. From *Montel News*. May 2020.

German Bank Forecasts Global Carbon Offset Market.

The value of the global market for CO_2 emissions offsets could increase from $0.6 billion (2019) to $200 billion by 2050, according to the German bank Berenberg. The bank states that as countries hit the limits of decarbonization, they will have to rely on offsetting projects to balance carbon emissions. Carbon offsets can include land-use projects that absorb CO_2 (such as forest and marshland development programs) or changes to cleaner energy of industrial technologies that would otherwise be uneconomical. From *S&P Global*. May 2020.

JULY 2020

UK Plans Emissions Trading System.

The United Kingdom (UK) unveiled an Emissions Trading System (ETS) to replace the EU ETS; the UK will leave the EU ETS at the end of 2020. As part of the UK's plan to reach net-zero CO_2 emissions by 2050, its ETS includes plans to reduce the emissions cap by 5%, *according to the UK government*. In addition, the UK ETS would include a fixed auction reserve price ($18.78 per metric ton of CO_2) as well as a cost containment mechanism to prevent price spikes. From *Reuters*. June 2020.

New Zealand Bill to Reform ETS.

A series of annual carbon budgets was included in a bill by the New Zealand government to reform its ETS. A proposed cap on emissions included in the bill would lower the country's GHG emissions by approximately 3% next year. From *Stuff*. June 2020.

AUGUST 2020

Virginia to Join RGGI.

The state of Virginia (USA) *finalized its regulation* to establish a market-based program to reduce greenhouse gases (GHGs) and will join the Regional Greenhouse Gas Initiative (RGGI) as a participant. Beginning on January 1, 2021, Virginia will be able to take part in the quarterly CO_2 auctions and will be a part of the RGGI program review process. From *RGGI Press Release*. July 2020.

RGGI States Initiate Auction Process for Auction 49.

The states currently participating in RGGI initiated the auction process for their 49th quarterly CO_2 auction scheduled for September 2, 2020. Auction 49 will offer 16,192,785 CO_2 allowances for sale at a minimum reserve price of $2.32. An 11.8 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 $10.77). From *RGGI*. July 2020.

SEPTEMBER 2020

RGGI States Release Investment Report.

The RGGI-participating states *released a report* tracking the investment of proceeds from their 2018 regional CO_2 allowance auctions. The report, which provides state-specific data and highlights, found that in 2018, $248 million in proceeds generated in RGGI auctions were invested in programs such energy efficiency, clean and renewable energy, and greenhouse gas (GHG) abatement. Over their lifetime, the investments are projected to help reduce 4.6 million short tons of CO_2 emissions. From *RGGI News Release*. July 2020.

EU, Switzerland to Link ETS.

The European Commission announced the merger of European Union (EU) and Swiss carbon markets. Originally scheduled for May 2020, the launch was delayed until September 2020 due to the COVID-19 global pandemic. Allowance transactions traded between the two markets will be transferred on 10 separate one-day windows. The full calendar of transfer dates for 2021 will be released later in 2020. From *Reuters*. August 2020.

SCIENCE NEWS

OCTOBER 2019

Concrete Program Piloted.

Hawaii's Department of Transportation initiated a pilot program to test the use of a carbon-storing form of concrete in road construction. CarbonCure's concrete manufacturing process injects CO_2 from an industrial emitter into a concrete mix, creating a chemical reaction that converts the CO_2 into solid calcium carbonate. The resulting concrete mix is incorporated with other ingredients to form carbon-infused concrete. Honolulu's City Council passed a resolution requesting that all new city infrastructure projects consider using carbon-infused concrete. From *ZME Science* on September 11, 2019.

Company Developing Personal Carbon Storage Device.

Hyper Industries, an artificial intelligence-focused tech company, is developing a personal-sized bioreactor that uses algae to capture and store CO_2. According to the company, the Eos Bioreactor has the potential to store as much CO_2 as an acre of trees. Currently a prototype, the closed system works indoors and connects with an HVAC system to reduce the CO_2 levels. From *Fast Company* on September 17, 2019.

Researchers Study Peatlands Carbon Storage Potential.

French researchers studied the effects of climate on the survival of peatlands, which store one-third of the soil carbon trapped in soils globally. The scientists came to their conclusions by studying the carbon uptake by the two main species of moss in Eastern France. The results of the study were published in the journal *Global Change Biology*. From *Phys.org* on September 16, 2019.

NOVEMBER 2019

Researchers Develop New CO_2 Capture, Conversion Material.

A team of researchers developed a material that can selectively capture CO_2 and convert it into useful organic materials. Researchers at Kyoto University, the University of Tokyo, and Jiangsu University in China collaborated on designing the material, which is a porous coordination polymer (PCP) that consists of zinc metal ions. Testing revealed that the material can selectively capture CO_2 molecules with 10 times more efficiency than other PCPs. After capturing the carbon, the converted material can be used to make polyurethane, a material with a wide variety of applications, including clothing, domestic appliances, and packaging. The research was published in the journal *Nature Communications*. From *Kyoto University Institute for Integrated Cell-Material Sciences* on October 11, 2019.

Report Shows Glacial Rivers Absorb CO_2 Faster than Rainforests.

University of British Columbia researchers found that the glaciers of Canada's high Arctic absorb CO_2 at a faster rate than the Amazon rainforest. The team of researchers collected meltwater samples on Ellesmere Island (Canada), where several glaciers flow into Lake Hazen; the team also gathered samples in the Rocky Mountains and Greenland. After analysis, the findings, *published in the Proceedings of the National Academy of Sciences*, showed that during high-melt periods, glacial river water absorbs 40 times as much CO_2 as the Amazon rainforest. From *The Guardian* on October 25, 2019.

Study Highlights CO_2 Storage Potential of Antarctic Krill.

According to a study *published in Nature Communications*, Antarctic krill can increase the ocean's carbon storage potential through their feces. The small, shrimp-like creatures fertilize oceans and help store carbon by releasing essential nutrients that can be used by tiny ocean plants to photosynthesize and grow. Krill waste influences the carbon cycle by sinking to the deep ocean where it remains for many years, storing carbon in the process. From *Phys.Org* on October 21, 2019.

DECEMBER 2019

Engineers Develop New Way to Remove CO_2.

Researchers from the Massachusetts Institute of Technology (MIT) are researching a new way of removing CO_2 from the air that could potentially work at any concentration level. According to the researchers, the new method is also less energy-intensive and less expensive compared to other methods, which require higher concentrations of the gas. The technique is described in an article published in the journal *Energy and Environmental Science*. From *MIT News* on October 24, 2019.

Tool Estimates Carbon Storage Potential.

A new tool enables farmers in New Zealand to estimate how much CO_2 their tree blocks are capable of storing. The carbon stock tool adds to an existing GHG emissions analysis tool by using data from the Ministry for Primary Industries' *Carbon Look-Up Tables* to estimate the carbon storage potential for existing and future tree blocks on farms (Carbon Look-Up Tables are a series of pre-calculated values of forest carbon stocks, by age, for a given forest type). From *New Zealand Herald* on November 2, 2019.

Researchers Study Business Potential of CCUS.

Researchers from UCLA, the University of Oxford, and five other institutions analyzed 10 different ways to use CO_2, focusing on the potential of turning the captured CO_2 into commercial products such as fuels or construction materials. *Published in the journal Nature*, the research presents a comprehensive study of the potential future scale and cost of utilizing CO_2. From *UCLA Samueli School of Engineering* on November 6, 2019.

JANUARY 2020

Geologic Capacity Exists to Store Large Quantities of CO_2.

A study *published in Nature Scientific Reports* indicates the existence of geologic formations on Earth suitable for storing enough CO_2 to provide a 13% reduction of worldwide emissions by 2050. The study states that drilling approximately 12,000 carbon storage wells has the potential to store 6 to 7 billion tons of CO_2 a year by 2050. Conducted by researchers from the Norwegian Institute of Science and Technology and the University of Texas, the study identified locations worldwide that could store CO_2. From *Yale Environment 360* on December 26, 2019.

Scientists Develop New Material for Absorbing CO_2.

Swedish scientists developed a new material for capturing CO_2 that may enhance CCUS technologies. The new material is a bio-based hybrid foam infused with CO_2 zeolites, which has an elevated ability to absorb CO_2. Results of the Swedish joint research study, conducted by scientists from Chalmers University of Technology and Stockholm University, were *published in the journal ACS Applied Materials & Interfaces*. From *Chalmers University of Technology* on December 9, 2019.

Study Identifies Carbon Storage Potential of Western US Forests.

Oregon State University researchers identified forests in the western United States that have carbon storage potential. The five-year study, which was supported by the U.S. Department of Agriculture, identified and targeted forests with high carbon storage potential; low vulnerability to drought, fire, and beetles; and high biodiversity value. The findings of the study were *published in the journal Ecological Applications*. From *Oregon State University Newsroom* on December 9, 2019.

FEBRUARY 2020

Military Researching Utilization of CO_2 for Fuel.

The *National Defense Authorization Act*, passed in December 2019, included a provision directing the Pentagon to work with DOE and Homeland Security to research methods by which CO_2 from ocean water and ambient air could be converted to fuel. According to a spokesperson, the U.S. Department of Defense is researching ways to use carbon capture technology "to address energy security for the military," including capturing carbon for conversion to military transportation fuel and "alternative fuels or products" to be used at military installations. From *Bloomberg Environment* on January 15, 2020.

Testing Looks to Eliminate Some CCS Barriers.

The International CCS Knowledge Centre is developing a portable testing apparatus for post-combustion amine-based capture. The testing apparatus will seek to eliminate barriers to widespread deployment of CCS and further advance the technology. A design feature will allow the apparatus to connect to a variety of CO_2-containing gas streams beyond coal-fired plants, creating the potential for advancement of CCS across industry sectors. From *Carbon Capture Journal* on January 13, 2020.

Study: Wildfires Could Transform Amazon From Carbon Sink to Carbon Source.

A study led by U.S. and Brazilian researchers has found that Amazon wildfires have the potential to convert the Amazon region from a carbon sink to a carbon source. The study used a model to examine different scenarios with various levels of deforestation, with the model predicting the behavior and spread of wildfires, as well as the way forest ecosystems would respond. The results, *published in the journal Science Advances*, also suggested that remaining Amazon trees, as a result of the wildfires, may store less CO_2 as they grow. From *Scientific American* on January 14, 2020.

MARCH 2020

Nitrogen-Fixing Trees Help Forests Store More CO_2.

According to a study *published in the journal Nature Communications*, the ability of tropical forests to store CO_2 depends upon the trees' capacity to fix nitrogen from the atmosphere. The study modeled how the mix of tree species growing in a tropical forest following a disturbance, such as clearcutting, can affect the forest's ability to store CO_2. The results showed that the presence of trees that fix nitrogen have the potential to double the amount of CO_2 a forest stores in its first 30 years of growth. Furthermore, the researchers found that at maturity, forests with nitrogen fixation stored 10% more CO_2 than those without. From *Phys.org* on February 13, 2020.

Oceans: Particle Fragmentation Plays a Role in Carbon Storage.

A team of French and British researchers analyzed a process that regulates the capacity of oceans to store CO_2. Photosynthesis performed by phytoplankton on the ocean's surface converts atmospheric CO_2 into organic particles, some of which sink to its depths, and are stored as oceanic carbon. By using a fleet of robots deployed in different oceans, scientists were able to study the particle flux and carbon storage potential. The results were *published in the online journal Science*. From *EurekAlert!* On February 13, 2020.

APRIL 2020

Scientists Use AI to Store CO_2.

MIT scientists *developed* a machine learning system that uses artificial intelligence (AI) to map underground structures for storing CO_2. The research team studied "hidden correlations" in components of high-frequency data from simulated earthquakes to spot low-frequency waves that would best help map the subterranean landscape. The AI learned how to find patterns that could be used to infer low frequencies, creating an algorithmic system that has the potential to estimate low frequencies and map the underground with greater accuracy. From *Engadget*. March 2020.

New Method Converts CO_2 to Methane at Low Temperatures.

Scientists from Waseda University in Tokyo, Japan, developed a new method that converts CO_2 to valuable chemicals for use in carbon capture and utilization. *Reported in the journal Chemical Letters*, the method has the potential to convert CO_2 into methane more efficiently and quickly than previous methods. According to the research, the method could produce methane from atmospheric CO_2, possibly enabling an unlimited amount of methane production by recycling CO_2 released from factories. From *Waseda University News*. February 2020.

MAY 2020

Researchers Use 3D Printing to Predict Rock Fractures, Aid Carbon Storage.

Researchers are 3D-printing minerals to help better predict fracture formation, which could be used to improve understanding of carbon storage. Working with their university's Rock Physics Research Group, researchers from Purdue University (USA) used a 3D printer to create synthetic rock samples, enabling the team to use a computer program to control the quality of the synthetic rock. The research, which was supported by DOE's SC and Sandia National Laboratories, was *published in the journal Scientific Reports*. From *Purdue News*. April 2020.

Long-Living Tropical Trees Play Role in CO_2 Storage.

A team of scientists found that a group of fast-growing, long-lived, slow-to-reproduce trees in some tropical rainforests play a large role in CO_2 storage. The study of the trees, which are referred to as "long-lived pioneers," provides insight into the roles of different species of trees in CO_2 storage. The research, led by the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, was *published in the journal Science*. From *ScienceDaily*. April 2020.

Conversion Test Facility Being Built.

A test facility to convert CO_2 from air into solid carbon is being built at Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany. The NEgative Carbon diOxide to Carbon (NECOC) research project's test facility will aim to actively reduce CO_2 emissions by capturing CO_2 from ambient air and, together with renewable hydrogen, convert it into methane, which will serve as a "carbon carrier." More information on the process can be found in KIT's *press release*. From *KIT Press Release*. March 2020.

Study Explores Oceans' Ability to Store CO_2.

A study found that the world's oceans have the potential to capture and store twice as much CO_2 from the atmosphere as previously thought. Scientists from the Woods Hole Oceanographic Institution (WHOI) came to their conclusions by recalculating the section of upper ocean layer that sunlight can penetrate, referred to as the euphotic zone. WHOI scientists then used data gathered from chlorophyll sensors to help reveal the true edges of the euphotic zone, finding that the depths of the boundary vary throughout the world. The study concluded that the world's oceans may have the potential to absorb approximately twice as much CO_2 each year than original data projected. From *New Atlas*. April 2020.

Research Examines Mature Forests' Ability to Store CO_2.

Researchers from the State University of New York (SUNY) College of Environmental Science and Forestry (ESF) and Western Sydney University found evidence that mature forests have a limited ability to store CO_2. ESF's Department of Sustainable Resources Management (USA) collaborated with Western Sydney University's (Australia) *Eucalyptus Free Air CO_2 Enrichment* research facility to study a 90-year-old eucalyptus woodland in Western Sydney's Cumberland Plain exposed to elevated CO_2 levels. The study found that extra CO_2 absorbed by the trees was cycled through the soil and returned to the atmosphere. Previous models predicted that mature forests would store more CO_2 by acting as carbon sinks; the findings of this study, *published in the journal Nature*, suggest those sinks may be weaker or absent for mature forests. From *ScienceDaily*. April 2020.

JUNE 2020

Research Examines Water Sustainability During CCS Implementation.

Research conducted by scientists from University of California, Berkeley (USA) examined how CCS technology can be sustainably implemented without compromising water resources. The study, *published in the online journal Nature Sustainability*, also examined how emerging CCS technologies could mitigate the demand current CCS practices place on water consumption. From *University of California, Berkeley, News Release*. May 2020.

Scientists Develop Artificial Photosynthesis for Carbon Storage.

New developments may allow scientists to recreate and control artificial photosynthesis for carbon storage. Using spinach membranes and oil droplets filled with enzymes, European researchers were able to mimic natural plant pathways and transform CO_2 into useful compounds. According to the study, *published in the journal Science*, this artificial photosynthesis may be more efficient than its natural counterpart in the future since the researchers are able to carefully control how photosynthesis takes place. From *Inverse*. May 2020.

Scientists Develop CO_2-Separating Membrane.

Newcastle University (UK) scientists developed a self-assembling silver membrane with the potential to capture CO_2 emissions and possibly be utilized in certain CCS applications. According to the researchers, silver could be an effective material for some CCS applications. In the study, *published in the journal Energy & Environmental Science*, the research team found a way to gain the benefits of using silver in the CO_2 separation process without needing a lot of the element itself. From *ScienceAlert*. May 2020.

JULY 2020

Researchers Develop Technology for CCS Use.

Australian researchers used a metal organic framework (MOF) nanocomposite to develop sponge-like technology capable of capturing CO_2 from several sources. In the study, published in Cell Reports Physical Science, researchers from Australia's Monash University and the Australian federal government's Commonwealth Scientific and Industrial Research Organization designed a material that delivered an energy cost 45% below that of commercially deployed materials. From *Phys.Org*. June 2020.

Study Uses Sunlight to Convert CO_2.

Researchers at Linköping University in Sweden are attempting to convert CO_2 into fuel using energy from sunlight. *Published in the journal ACS Nano*, the results show that the technique has the potential to produce methane, carbon monoxide, or formic acid from CO_2 and water. The method is at a research stage, with a long-term objective of converting solar energy to fuel. From *Science Magazine*. June 2020.

Researchers Study Oceans' Ability to Store CO_2.

Scientists at Columbia University's Lamont-Doherty Earth Observatory (USA) studied the variability of the ocean as a carbon sink over the last 30 years. According to the findings, *published in the journal AGU Advances*, decreasing global fuel consumption may lead to the ocean absorbing less CO_2 in 2020 than in 2019. The results of the study are expected to enable more accurate measurements and projections of how much oceans can offset CO_2 emissions. From *Phys.Org*. June 2020.

AUGUST 2020

DOE Lab Demonstrates Novel, Affordable CO_2 Removal Method.

Researchers from DOE's Oak Ridge National Laboratory conducted a study to expand technology options for reducing industrial CO_2 emissions. Results of the study, *published in the journal Chem*, expand the limited library of options for carbon capture membranes. The research was supported by *DOE's Office of Science*. The researchers will next investigate the mechanisms by which fluorinated membranes absorb and transport CO_2. From *Oak Ridge National Laboratory News*. July 2020.

Study Identifies Optimal BECCS Facility in UK.

Researchers studied six potential locations for bioenergy with carbon capture and storage (BECCS) power plants across the UK, finding the Drax power station in North Yorkshire (UK) to be an optimal site. Led by the University of Southampton, the study assessed each site based on several criteria, including proximity to CO_2 storage sites, costs of transportation, potential for geologic storage, and flood mitigation. *A video explaining the study is available online*. From *University of Southampton News*. June 2020.

Researchers Convert CO_2 into Formic Acid.

Researchers at Oslo University (Norway) developed a process to convert waste CO_2 through artificial photosynthesis. The researchers show that under the right circumstances, FDH enzymes can "grab" a CO_2 molecule and convert it into formic acid, a substance used by industry in multiple forms. From *Carbon Capture Journal*. July 2020.

Researchers Study CO_2 Removal Ability of Rock Dust.

According to a study *published in the journal Nature*, spreading rock dust on farmland has the potential to remove approximately half of the atmospheric CO_2 produced by Europe. The "enhanced rock weathering" process involves layering crushed rock onto soil; when silicate or carbonate materials in the dust dissolve in rain water, CO_2 is drawn into the solution to form bicarbonate ions, which are eventually washed into the ocean where they form carbonate minerals, storing their CO_2 indefinitely. From *The Washington Post*. July 2020.

SEPTEMBER 2020

DOE Researchers Develop CO_2 Conversion Method.

Researchers at DOE's Argonne National Laboratory (ANL) developed a method that converts CO_2 and water into ethanol with high energy efficiency and high selectivity for the desired final product. The electrocatalytic selectivity of this process is more than 90%, which is higher than currently reported. *DOE's Office of Science* and *Office of Basic Energy* helped fund the research, which was conducted using two DOE Office of Science User Facilities located at ANL: the Advanced Photon Source and the *Center for Nanoscale Materials*. The results were *published in the journal Nature Energy*. From *Argonne National Laboratory Press Release*. August 2020.

Study Shows Amazon Gold Mining's Impact on CO_2 Storage.

A study focusing on the impacts of Amazon gold mining in Guyana (South America) found that forests remain barren at the abandoned goldmines three to four years after the conclusion of the mining, impacting the rainforest's ability to store CO_2. Published in the *Journal of Applied Ecology*, the research shows that the deforestation and recovery rates resulting from depleted nitrogen levels have the potential to reduce CO_2 storage across Amazonian secondary forests. From *Mongabay*. August 2020.

Study Provides Insight into CO_2 Storage.

Scientists from Scotland and Malaysia conducted a review of past, recent, and ongoing developments in CO_2 storage in saline formations. The results, highlighting the role of saline formations in the storage of CO_2, *were published in the Journal of Natural Gas Science & Engineering*. The scientists studied the different ways CO_2 can be trapped within the pore space of rocks. The findings are expected to improve understanding of different CO_2 trapping methods to maximize the storage potential of a CO_2 storage site, enabling further development of CCS projects. From *Carbon Capture Journal*. July 2020.

Scientists Study Trees' CO_2 Storage Ability.

A study conducted at the Harvard Forest Long-Term Ecological Research site found that the rate at which CO_2 is captured from the atmosphere at Harvard Forest nearly doubled from 1992 to 2015. Scientists attribute the forest's increase in CO_2 storage capacity to, among other things, the growth of 100-year-old oak trees, timber harvest, and a longer growing season. The study took CO_2 measurements from air, soil, water, and trees to document the flow of CO_2 through the forest. Results of the study were *published in the journal Ecological Monographs*. From *The Harvard Gazette*. August 2020.

Researchers Study CO_2 Release in Tropical Soils.

According to a study conducted by researchers from the University of Edinburgh, tropical soils have the potential to release more CO_2 into the atmosphere than previously thought. The research team conducted a large-scale field experiment in a tropical forest in Panama, finding that soil carbon emissions may increase by 55% due to potential climate change. The results, *published in the journal Nature*, showed that from every hectare of tropical forest, up to eight extra tons of soil carbon would be released in the form of CO_2 each year in a potentially warming climate. From *Earth.com*. August 2020.

PUBLICATIONS

OCTOBER 2019

Reconsidering CCS in the US fossil-fuel fired electricity industry under section 45Q tax credits.

The following is the abstract of this article: "CO_2 capture and storage (CCS) can be an important feature of a decarbonization strategy involving electricity generation. According to the recently revised Section 45Q tax credits, said credits will be provided for implementing CCS, which is motivating some United States (US) electricity generation companies to revisit their business strategies for CCS. This paper discusses alternative business models being considered by companies for undertaking CCS, including providing a 'template' for evaluating the cost-effectiveness of CCS with Section 45Q tax credits and storage in saline reservoirs. Using stylized illustrative examples, the paper indicates how use of Section 45Q tax credits should be expected to change dispatch at an electricity generating unit. For situations similar to the examples, the paper suggests that Section 45Q tax credits may need to be modified to achieve its intended impact. Modifications can include extending the time period of tax credit availability beyond the current 12 years. In addition, continued R&D investments in CCS and specific support for first-of-a-kind CCS demonstrations would be valuable complements for the deployment of the Section 45Q tax credit." **Richard A. Esposito, Vello A. Kuuskraa, Charles G. Rossman, and Michele M. Corser,** *Greenhouse Gases Science and Technology*. (Subscription may be required.)

The North Dakota integrated carbon storage complex feasibility study.

The following is the abstract of this article: "The Energy & Environmental Research Center is investigating the feasibility of safely, permanently, and economically storing 50 million tonnes of CO_2 in central North Dakota, United States, over a 25-year operational period, should a business case for CO_2 storage emerge. The study is part of the U.S. Department of Energy (DOE) National Energy Technology Laboratory CarbonSAFE initiative and addresses the technical and nontechnical challenges of commercially deploying a CO_2 storage project. Evaluation of cores from two stratigraphic test wells demonstrate that the Broom Creek Formation (sandstone) is an excellent candidate for the geologic storage of CO_2 and the overlying Opeche Formation a competent cap rock." **Wesley D. Peck, Scott C. Ayash, Ryan J. Klapperich, and Charles D. Gorecki,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Analysis of carbon tax efficiency in energy industries of selected EU countries.

The following is from the abstract of this article: "A carbon tax is one of economic policy instruments of environmental protection supposed to contribute to the reduction of greenhouse gas (GHG) emissions. A functional carbon tax aims at incorporating costs for elimination of environmental harm into the pricing decisions…. the carbon tax is usually imposed on the production, distribution or consumption of carbon-content fossil fuels. The main aim of the study is to evaluate the carbon tax environmental effectiveness in the energy industries of selected EU countries, namely Sweden, Finland, Denmark, Ireland and Slovenia. To achieve the principal research objective, the multiple panel regression method for the selected variables was used, the synergy of other environmental policy tools being taken into account. Control variables employed were emission allowance price, household final consumption expenditure, corporate investments, solid fuel consumption and renewable energy consumption. The analysis results suggest that the carbon tax in the energy industry is environmentally efficient, an increased tax rate allowing to reduce GHG production, which is statistically significantly affected by the consumption of fossil fuels. Based on the estimated partial regression coefficient (–0.01158), raising the carbon tax by one euro per tonne can cut annual per capita emissions by 11.58 kg." **Miroslav Hájek, Jarmila Zimmermannová, Karel Helman, and Ladislav Rozenský,** *Energy Policy*. (Subscription may be required.)

Understanding gas-phase breakout with high H_2 content in CCS pipeline gathering networks.

The following is the abstract of this article: "An accurate understanding of the behaviour of impure carbon dioxide (CO_2) during pipeline transport stage is required for commercial scale deployment of Carbon Capture and Storage (CCS) networks. Impurities in the CO_2 stream modify phase behaviour and change the thermophysical and transport properties of the stream. CO_2 streams containing hydrogen (H_2) are a particular challenge due to the unique physical properties of H_2. In a CCS gathering network where CO_2 is sourced from processes such as pre-combustion capture or hydrogen production, H_2 with a concentration of 2% mol can be expected to be present in the mixture. This paper describes foreseeable operating scenarios where gas breakout in single-phase CCS gathering networks might occur, leading to pockets of gas with high H_2 concentration. Multiphase flow modelling of a CCS gathering network with impure CO_2 containing H_2 has been performed, demonstrating these operating scenarios and providing a basis for design. The H_2 content of the gas breakout is shown to be >20% mol when the conditions are close to bubble point. High concentrations of H_2 due to gas breakout must be considered as part of a single-phase CCS gathering network design, whenever H_2 is present. This paper provides practical guidelines for understanding, quantifying and, managing the worst design cases for H_2 exposure due to gas breakout. Specific recommendations for what must be included in the project design basis are presented. Potential mitigating factors and engineering measures that can be taken to manage high H_2 concentration in a CCS system are also discussed." **Matthew Healey, Ketan Mistry, Thomas Jones, and Eduardo Luna-Ortiz,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Bioenergy and full carbon dioxide sinking in sugarcane-biorefinery with post-combustion capture and storage: Techno-economic feasibility.

The following is the abstract of this article: "Sugarcane plantations promote impressive drainage of atmospheric carbon dioxide reaching 781 t/h for a 1000 t/h sugarcane-biorefinery. For first-generation bioethanol sugarcane-biorefineries, only 10% of sugarcane carbon dioxide equivalent leaves as hydrous-ethanol, while 90% return to atmosphere through bagasse-fired power cogeneration in steam-Rankine cycles. Thus, a sugarcane-biorefinery exports two bioenergy flows – electricity and hydrous-ethanol – and its impressive Bioenergy Carbon Capture and Storage potential is wasted. Capture of fermentation carbon dioxide merely means 5% of Bioenergy Carbon Capture and Storage efficiency. This work assesses a new sugarcane-biorefinery concept dramatically raising the Bioenergy Carbon Capture and Storage efficiency. With fermentation carbon dioxide already captured, it is advocated to implement 90% post-combustion capture of flue-gas carbon dioxide. Then, captured carbon dioxide is compressed and traded as Enhanced Oil Recovery agent transported to deep-water offshore oil fields via high-pressure pipelines counting on topographic gravitational effects to lower compression power. Aggregating pipeline/compression investment to the biorefinery, it is shown that such new Plantation-Biorefinery-Post-Combustion-Pipeline-Oil-Recovery enterprise is technically feasible for 5.22 $MtCO_2$/y of Bioenergy Carbon Capture and Storage capacity and is economically feasible under certain conditions: (i) idle pipeline capacity rental to fossil carbon emitters at 10–20 USD/tCO_2; (ii) recovered oil revenues traded at 1–2 bbl/tCO_2 and 50–80 USD/bbl; (iii) carbon-taxation at 40–80 USD/tCO_2; and (iv) carbon Cap-and-Trade at 30–70 USD/tCO_2. Under such conditions the Plantation-Biorefinery-Post-Combustion-Pipeline-Oil-Recovery can attain 7 MMMUSD net value and 6 years payback-time." **Hudson Bolsoni Carminati, Raquel de Freitas D. Milão, José Luiz de Medeiros, and Ofélia de Queiroz F. Araújo,** *Applied Energy*. (Subscription may be required.)

Feasibility of carbon dioxide storage in post-burn underground coal gasification cavities.

The following is the abstract of this article: "Supplementary to the prospect of carbon storage in the geological formations for carbon emission mitigation, the deep post-burn underground coal gasification (UCG) cavities are proposed to be good venues for carbon dioxide storage, albeit without substantial validation in any form. Using a modelling methodology, this paper intends to bridge that knowledge gap by exploring the feasibility of storing CO_2 in the post-UCG venues. A 3D post-burn UCG cavity model was constructed taking into account of the various char walls and rubble floor. To better utilize the subsurface space, the migration of CO_2 in a supercritical state was modelled for a span of 10,000 days. The modelling results show that it is possible to inject CO_2 into UCG cavities for storage. Insight was achieved concerning the transport pattern of CO_2 plume in the UCG cavity under various effects, e.g. CO_2 buoyant flow, diffusion and adsorption are coupling behaviours, and coal adsorption and swelling have a complex effect on CO_2 transport." **Liangliang Jiang, Zhangxin Chen, and S.M. Farouq Ali,** *Applied Energy*. (Subscription may be required.)

Profiting from CCS innovations: A study to measure potential value creation from CCS research and development.

The following is the abstract of this article: "Globally, large private and public funds are invested into CO_2 capture and storage (CCS) research to provide the knowledge and technology required to mitigate CO_2 emissions below a sustainable level. A pertinent question to ask is whether this is the best way of spending limited resources. This paper presents a study aiming to quantify the potential economic gains from selected CCS innovations created in the international research centre BIGCCS and its successor NCCS. Development of CCS technology is currently driven by technology push and the lack of a market makes it hard to predict future potentials for increased revenue. Consequently, the study investigates potential cost reductions from implementing the innovations in full-scale industry projects based on qualified assumptions. The results show that even with limited deployment of CCS the potential cost savings from implementation of the innovations by far exceed the research investment. Additional value not considered is in this work is expected from commercialisation of the technologies for the technology providers, improved competitive edge for providers of CO_2 free products and enhanced safety for people, equipment and environment. By developing illustrative examples from technology innovations, the study aims to contribute to a broader public CCS debate addressing also potential gains and commercial opportunities in addition to the current focus on costs and safety." **Sigmund Ø. Størset, Grethe Tangen, David Berstad, Peder Eliasson, Karl Anders Hoff, Øyvind Langørgen, Svend Tollak Munkejord, Simon Roussanaly, and Malin Torsæter,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Game analysis of carbon emission verification: A case study from Shenzhen's cap-and-trade system in China.

The following is the abstract of this article: "Carbon emission verification is one of the key factors required for proper implementation of a cap-and-trade (C&T) system. However, to obtain more revenue, emission generating companies (GCs) may collude with third-party verifiers (3 PVs) and conceal real carbon emission data. Based on actual practice of Shenzhen's C&T system, a three-player game model has been devised in this paper to analyze the behaviors among GCs, 3 PVs and government. Given the government's current piecewise linear re-verification policy, the optimal reported carbon intensity for GCs has been provided. [The authors'] research reveals that if the actual carbon intensity is larger than historical carbon intensity GCs may report less carbon intensity and conceal actual carbon emission. To deal with this issue, a new exponential re-verification policy is proposed. Based on authentic data from Shenzhen's C&T system, the experimental results show that the government should devote more attention to GCs with a decreasing industrial product output value-added (IVA) than to those with high carbon emissions when selecting GCs for re-verification. [The authors'] experiments also illustrate that the new policy outperforms the current one on both total concealed amount of carbon emission and total re-verification cost if the initial re-verification probability is set within a specific range." **Yanchun Pan, Wen Yang, Nan Ma, Zhimin Chen, Ming Zhou, and Yi Xiong,** *Energy Policy*. (Subscription may be required.)

Financing BECCS in developing countries.

The following is from the Introduction of this document: "BECCS is a promising class of technologies for carbon dioxide (CO_2) removal and consists of the capture and permanent geological storage of CO_2 stemming from biomass transformation or combustion. Several industrial sectors can implement this technology, including the biofuel sector which is predominantly made up of bioethanol production. Bioethanol is one of the few renewable alternatives to oil and gas-based liquid fuel, with which it can be easily blended to be used as a transportation fuel. As countries seek to decarbonise transport, demand for bioethanol is set to grow globally. By integrating CCS into the production process for bioethanol, negative emissions can be created. It is forecast that a significant proportion of the world's bioethanol production will come from developing countries. This paper focuses on how the production of bioethanol with CCS can be supported by climate finance providers, and the pivotal role Brazil can play in facilitating this process."

Lessons and Perceptions: Adopting a Commercial Approach to CCS Liability.

The following is a description of this document: "Liability has long been raised as a significant barrier to the wide scale deployment of carbon capture and storage (CCS). Despite regulatory developments, the topic of liability continues to be considered by some CCS project developers, policy-makers and regulators as a critical issue and potential 'show-stopper' for the technology's deployment. This report, through policy and regulatory analysis as well as interviews with policy makers, regulators, lawyers, project proponents and representative from the insurance sector, seeks to challenge these views and make the case for a more commercially-minded view of liability. The report's findings reveal that many of the liabilities borne under CCS-specific models are both familiar and eminently manageable. Furthermore, the report demonstrates proposed solutions and examples available in addressing liability for those seeking to invest in or operate CCS projects. The report also examines the meaning of liability throughout the CCS lifecycle and the unique challenges presented by greenhouse emissions/climate liabilities. The critical role of government and the private sector in allocating and managing risks across the CCS project lifecycle, as well as the essential requirement for further engagement of the insurance sector to assist operators manage liabilities are also topics addressed through this timely report. The report will be of particular interest to government policy makers, regulatory bodies, CCS project proponents, investors and those in the insurance sector wishing to further understand the topic of liability, the reasons why it is perceived as a barrier to CCS deployment and gain insights into how these barriers have been - and may continue to be - managed and overcome."

NOVEMBER 2019

Thermo-hydrological numerical evaluation of carbon dioxide injection efficiency for its geologic storage using a coupled reservoir-well simulation scheme.

The following is the abstract of this article: "A coupled reservoir-well simulation scheme is established to analyze quantitatively multi-phase fluid flow and heat transport due to carbon dioxide (CO_2) injection in a reservoir rock-injection well system and to evaluate rigorously the CO_2 injection efficiency in terms of the CO_2 injection rate and injectivity. Two different cases of the CO_2 injection pressure and temperature at the well head are then simulated using the coupled reservoir-well simulation scheme within a multi-phase thermo-hydrological numerical model. The results of the numerical simulations show that the fluid pressure and temperature and the CO_2 injection rate and injectivity in the reservoir rock-injection well system can be quantitatively evaluated using the coupled reservoir-well simulation scheme. The fluid pressure and temperature in the injection well including the well head and bottom can also be simply predicted with assumptions of the hydrostatic fluid pressure transition and the adiabatic fluid temperature transition from the well head to the well bottom using the thermodynamic equation of state (EOS) data of CO_2. In addition, the CO_2 injection rate and injectivity have very close relationships with the fluid pressure and temperature at the well bottom, respectively, which determine the fluid pressure difference between the injection well bottom and the far-field reservoir rock and the kinematic viscosity of CO_2 at the well bottom. The

CO_2 injection rate increases almost linearly with the fluid pressure difference, whereas the CO_2 injectivity varies unsystematically with it. Instead, the CO_2 injectivity has an excellent linear relationship with the reciprocal of the kinematic viscosity (i.e., kinematic fluidity) of CO_2. These results can be utilized as practical guidelines to determine optimal injection operation schemes for sustainable, safe, and efficient geologic storage of CO_2." **Jung-Hwi Kihm, Jai-Yong Park, Sungho Lee, Jun-Mo Kim, and Byoung-Woo Yum,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

The Role of Capillary Hysteresis and Pore-Scale Heterogeneity in Limiting the Migration of Buoyant Immiscible Fluids in Porous Media.

The following is the abstract of this article: "Understanding the main mechanisms affecting long-term migration and redistribution of injected CO_2 in geological carbon storage is needed for developing predictive models to assess environmental risks and designing monitoring schemes. Preparation of a postinjection site care plan is required for CO_2 injection wells, including monitoring of pressure changes and injected CO_2 plume. Knowledge gaps exist regarding assessment of postinjection monitoring timeframes for the CO_2 plume because the processes driving long-term CO_2 plume migration and trapping are not fully understood. In the postinjection stage of geological carbon storage, redistribution of CO_2 occurs mainly due to buoyancy and capillary forces. This work presents experimental and modeling studies to investigate processes contributing to postinjection plume distribution and stabilization. [The authors] conducted a flow cell experiments (0.5 m × 0.05 m × 0.01 m) with two immiscible fluid phases in a glass bead porous medium to study postinjection plume behavior. [The authors] employed a hysteretic macroscopic two-phase flow model to interpret the experimental results and to understand main processes leading to plume stabilization. [The authors'] findings show that capillary pressure hysteresis explains the experimentally observed plume shape and redistribution at early postinjection stages; however, the long-term plume migration and eventual plume stabilization can only be represented when in addition microscale heterogeneity is accounted for. Results also show that plume stabilization can be extremely slow and that the migration of the plume front can occur through multiple intermittent bursts over long times. Further studies are needed to understand implications of the results for more realistic porous media and large-scale storage reservoirs." **Abdullah Cihan, Shibo Wang, Tetsu K. Tokunaga, and Jens T. Birkholzer,** *Water Resources Research*. (Subscription may be required.)

Reframing the Value Case for Carbon Capture and Storage.

The following is the abstract of this article: "In meeting long term climate ambitions at regional and national levels, there is a need to retain and ultimately grow high value jobs and production activity across the economy. This is reflected in the 'Just Transition' element of the 2015 Paris Agreement and will always be a preferable outcome to job offshoring/GDP loss and not meeting targets in the short and long term (UNFCCC, 2015, p4). The inevitable consideration of how best to value alternative approaches to deliver against these ambitions requires a broadening of focus from project cost metrics to a political economy and ultimately wider societal perspective. A key conclusion of the current study is that the most useful and easily communicated way of measuring a broader economic impact of Carbon Capture, Utilisation and Storage (CCUS) investments and associated government support is in terms of the expenditures required to sustain existing and/or create new jobs and/or other outcomes valued by society. Such a focus is likely to be particularly important in the UK context of the 2019 HM Treasury Spending Review, where all investment projects are likely to be judged on the basis of contributing to prosperity going forward and value delivered per pound spent. This is an important context for the CCUS Delivery and Investment Frameworks planned for 2019 in the UK Government's CCUS Action Plan Economic multiplier methods enable a transparent and rigorous initial assessment of how many direct, indirect and induced supply chain jobs may be sustained and/or created where a solution like CCUS is introduced to allow industries to decarbonise and continue to grow in key regional locations." **Karen Turner, Oluwafisayo Alabi, Ragne Low, and Julia Race,** *University of Strathclyde's Centre for Energy Policy*. (Subscription may be required.)

Targeted carbon tax reforms.

The following is the abstract of this article: "In the presence of intersectoral linkages, sector-specific carbon tax changes can have complex general equilibrium effects. In particular, a carbon tax on the emissions of a sector can lead to an increase in aggregate emissions. [The authors] analytically characterise how incremental taxes on the emissions of any set of sectors affect aggregate emissions. [The authors] show that carbon tax reforms that target sectors based on their position in the production network can achieve a greater reduction in aggregate emissions than reforms that target sectors based on their direct emissions alone. [The authors] illustrate the effects of carbon tax reforms by calibrating [the authors'] intersectoral network model to the economies of two countries." **Maia King, Bassel Tarbush, and Alexander Teytelboym,** *European Economic Review.* (Subscription may be required.)

Prediction of the lifespan of cement at a specific depth based on the coupling of geomechanical and geochemical processes for CO_2 storage.

The following is the abstract of this article: "The injection of carbon dioxide (CO_2) captured from combustion-based processes into underground formations is one of a number of plausible methods to reduce its release into the atmosphere and consequential greenhouse gas warming. Once the gas has been captured efficiently and effectively, depleted oil and gas reservoirs are seen as high potential candidates for carbon storage projects. However, legacy issues associated with a high number of oil and gas wells abandoned during the last few decades put the carbon capture and storage projects (CCS) at risk. These include any defects within the cement surrounding the well casing or for capping an abandoned well that can become unwanted CO_2 leakage pathways. To predict the lifespan of these cements due to exposure to CO_2-bearing fluids at the conditions found underground, the geochemical processes need to be coupled with the geomechanical changes within the cement matrix. In a viable CCS project for sequestering CO_2, the cement matrix should be capable of withstanding acidic environments formed by dissolution of CO_2 in brine for more than ten thousand years. This work aims at providing a framework to predict the behaviour of cement due to CO_2 exposure under reservoir conditions. The results show that the chemical reactions and geomechanical changes within the cement matrix can result either in its radial cracking or radial compaction. Both of these behaviours are investigated as possible phenomena which may affect the CO_2 leakage, and therefore the viability of the site for long term carbon storage." **Mohammadreza Bagheri, Seyed M. Shariatipour, and Eshmaiel Ganjian,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

SimCCS: An open-source tool for optimizing CO_2 capture, transport, and storage infrastructure.

The following is the abstract of this article: "Commercial-scale carbon capture and storage (CCS) technology will involve deploying infrastructure on a massive and costly scale. This effort will require careful and comprehensive planning to ensure that capture locations, storage sites, and the dedicated CO_2 distribution pipelines are selected in a robust and cost-effective manner. Introduced in 2009, *Sim*CCS is an optimization model for integrated system design that enables researchers, stakeholders, and policy makers to design CCS infrastructure networks. *Sim*CCS$^{2.0}$ is a complete, ground-up redesign that is now a portable software package, useable and shareable by the CCS research, industrial, policy, and public communities. *Sim*CCS$^{2.0}$ integrates multiple new capabilities including a refined optimization model, novel candidate network generation techniques, and optional integration with high-performance computing platforms. Accessing user-provided CO_2 source, sink, and transportation data, *Sim*CCS$^{2.0}$ creates candidate transportation routes and formalizes an optimization problem that determines the most cost-effective CCS system design. This optimization problem is then solved either through a high-performance computing interface, or through third-party software on a local desktop computing platform. Finally, *Sim*CCS$^{2.0}$ employs an open-access geographic information system framework to enable analysis and visualization capabilities. *Sim*CCS$^{2.0}$ is written in Java and is publicly available via GitHub to encourage collaboration, modification, and community development." **Richard S. Middleton, Sean P. Yaw, Brendan A. Hoover, and Kevin M. Ellett,** *Environmental Modelling & Software*. (Subscription may be required.)

A novel analysis of carbon capture and storage (CCS) technology adoption: An evolutionary game model between stakeholders.

The following is the abstract of this article: "Carbon capture and storage (CCS) plays a vital role in achieving carbon dioxide (CO_2) emission reduction for the power sector. It is meaningful to explore how to promote widespread adoption of CCS technology by power plants more smoothly. Distinguished from previous literature, this paper firstly established a government-enterprise evolutionary game framework to study issues of CCS adoption at the micro level. By expounding the conflict of interests on CCS adoption between governments and coal-fired power plants in China, an evolutionary game model was built to analyze the evolutionary stability and discuss the systematic dynamic evolutionary processes. Based on the simulation method, the theoretical consequences were verified, and the effects of critical parameters on the evolution trajectories were analyzed. This study found that: (i) for impelling the system to tend towards the optimal evolutionary stable strategy (ESS), it was essential to strengthen governmental supervision and improve the enthusiasm of power plants to adopt CCS technology. (ii) the initial willingness of stakeholders would affect the evolutionary trajectories. (iii) it was significant to increase governments' political achievements and reduce its supervisory cost, improve policy support for power enterprises deploying CCS and its low-carbon power generation revenue, and decrease their CCS adoption cost." **Tian Zhao and Zhixin Liu,** *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 carbon dioxide 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 carbon dioxide 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.)

The importance of lithofacies control on fluid migration in heterogeneous aeolian formations for geological CO_2 storage: Lessons from observational evidence and modelling of bleached palaeoreservoirs at Salt Wash Graben, Utah.

The following is the abstract of this article: "Exhumed bleached palaeoreservoirs provide a means of understanding fluid flow processes in geological media because the former movement of fluids is preserved as visible geochemical changes (grey bleaching of continental red-beds). The bleached palaeoreservoirs of the Jurassic Entrada Sandstone occur in a region (Utah) where there are high fluxes of naturally-occurring CO_2 and form outcrop analogues for processes related to geological storage of CO_2. In this paper a bleached palaeoreservoir now exposed at outcrop is used to test the importance of geological heterogeneity on fluid flow. The bleached palaeoreservoir is developed in 'wet aeolian' lithofacies composed of alternating layers of sandstone and cemented muddy sandstone that range across three or more orders of magnitude in permeability. Despite these permeability contrasts the bleaching shows a remarkably uniform distribution within the palaeoreservoir that crosses lithofacies boundaries. Evidence from bleaching therefore suggests that geological heterogeneity within the range $1–10^3$ millidarcies should not greatly impede the relatively uniform distribution of low-viscosity CO_2 charged fluids throughout a reservoir: a conclusion that has been substantiated here by flow modelling. Residence time is an important factor and where flows are transient the distribution of bleaching and modelling shows that flows are confined to high-permeability lithofacies." **Andrew J. Newell, Azadeh Pourmalek, Andrew S. Butcher, and Seyed M. Shariatipour,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Technologies and practice of CO_2 flooding and sequestration in China.

The following is the abstract of this article: "The latest advancement of CO_2 flooding and sequestration theory and technology in China is systematically described, and the future development direction is put forward. Based on the geological characteristics of continental reservoirs, five theories and key technologies have been developed: (1) Enriched the understandings about the mass transfer characteristics of components between CO_2 and crude oil in continental reservoirs, micro-flooding mechanism and sequestration mechanism of different geological bodies. (2) Established the design method of reservoir engineering parameters, injection-production control technology and development effect evaluation technology of CO_2 flooding, etc. (3) Developed a series of production engineering technologies such as separated layer CO_2 injection technology, high efficiency lifting technology, on-line wellbore corrosion monitoring and protection technology. (4) Innovated a series of surface engineering technology including CO_2 capture technology, pipeline CO_2 transportation, CO_2 surface injection, and production gas circulation injection, etc. (5) Formed a series of supporting technologies including monitoring, and safety and environmental protection evaluation of CO_2 flooding reservoir. On this basis, the technological development directions in the future have been put forward: (1) Breakthrough in low-cost CO_2 capture technology to provide cheap CO_2 gas source; (2) Improve the miscibility technology between CO_2 and crude oil to enhance oil displacement efficiency; (3) Improve CO_2 sweeping volume; (4) Develop more effective lifting tools and technologies; (5) Strengthen the research of basic theory and key technology of CO_2 storage monitoring. CO_2 flooding and sequestration in the Jilin Oilfield shows that this technology has broad application prospects in China." **Yongle Hu, Mingqiang Hao, Guoli Chen, Ruiyan Sun, and Shi Li,** *Petroleum Exploration and Development*. (Subscription may be required.)

CarbonTech: A Primer on Carbon Capture, Conversion, Utilization and Storage Technologies.

The following is from the "Purpose of the Study" of this CMC Research Institutes and Canadian Business for Social Responsibility document: "Carbon Capture, Utilization and Storage (CCUS) technologies can play a significant role in meeting national and international greenhouse gas (GHG) emission reduction targets. With research, development and scale-up infrastructure in place, along with many decades of experience in developing full-scale CCUS facilities, Canada has an opportunity to become a global leader and exporter of CCUS knowledge and technology. This report seeks to provide an overview of the risks and opportunities for development, testing, implementation, and export of CCUS in Canada. By identifying barriers to national growth of CCUS, stakeholders can determine effective ways to build a national and international market for CCUS. This report is intended to serve as a primer, and will: [1] Provide an overview of the CCUS marketplace and recent CCUS technology developments (both in Canada and globally). [2] Identify who is developing innovative, commercially viable CCUS technology. [3] Highlight the challenges and opportunities to convert industrial CO_2 emissions into feedstock for value-added products."

Industrial Transformation 2050: Pathways to Net-Zero Emission from EU Heavy Industry.

The following is from the Executive Summary of this document: "This study explores multiple ways to achieve net-zero emissions from EU steel, plastics, ammonia and cement production while keeping that production in the EU. It quantifies the potential impact of different solutions and finds that emissions from those industries can be reduced to net zero by 2050, confirming the findings of the pathways presented in the Commission's *A Clean Planet for All*. Many new solutions are emerging, thanks to a more circular economy with greater materials efficiency and extensive recycling of plastics and steel, as well as innovative industrial processes and carbon capture and storage.

Many different industrial strategies and pathways can be combined to achieve net-zero emissions. The analysis finds that the impact on end-user/consumer costs will be less than 1% regardless of the path pursued – but all pathways require new production processes that are considerably costlier to industry, as well as significant near-term capital investment equivalent to a 25–60% increase on today's rates. Keeping EU companies competitive as they pursue deep cuts to emissions will thus require a new net-zero CO_2 industrial strategy and policy agenda. There is a need to accelerate innovation, enable early investment, support costlier low-CO_2 production, overcome barriers to circular economy solutions, and ensure that companies can access the large amounts of clean electricity and other new inputs and infrastructure they need. Time is short, with 2050 only one investment cycle away, and any further delays will hugely complicate the transition. As the EU ponders its industrial future, this transformation should be a clear priority."

DECEMBER 2019

Maturing global CO_2 storage resources on offshore continental margins to achieve 2DS emissions reductions.

The following is from the abstract of this article: "Most studies on CO_2 emissions reduction strategies that address the 'two-degree scenario' (2DS) recognize a significant role for CCS. For CCS to be effective, it must be deployed globally on both existing and emerging energy systems. For nations with large-scale emissions, offshore geologic CO_2 storage provides an attractive and efficient long-term strategy. While some nations are already developing CCS projects using offshore CO_2 storage resources, most geographic regions have yet to begin. This paper demonstrates the geologic significance of global continental margins for providing broadly-equitable, geographically-relevant, and high-quality CO_2 storage resources. [The authors] then use principles of pore-space utilization and subsurface pressure constraints together with analogs of historic industry well deployment rates to demonstrate how the required storage capacity can be developed as a function of time and technical maturity to enable the global deployment of offshore storage for facilitating 2DS. [The authors'] analysis indicates that 10–14 thousand CO_2 injection wells will be needed globally by 2050 to achieve this goal." **P. S. Ringrose and T. A. Meckel,** *Scientific Reports*. (Subscription may be required.)

Enhanced safety of geologic CO_2 storage with nanoparticles.

The following is from 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.)

Green tax reforms with promotion of renewable energy sources and carbon capture and sequestration: Comparison of different alternatives.

The following is from the abstract of this article: "The need to decarbonize economic production processes is undeniable and has been considered by most countries worldwide. Renewable Energy Sources (RES) and Carbon Capture and Sequestration (CCS) technologies appear among the most promising routes to the decarbonization process. [The authors] propose an equilibrium model where final-goods production uses labor and energy, and energy is generated using non-polluting RES and polluting fossil fuels. The government implements a Green Tax Reform (GTR), where it imposes a tax on emissions and uses revenues to finance subsidies to RES and support to CCS technologies. [The authors] test how results change according to the priority given to RES or to CCS support. [The authors'] results show that prioritizing RES support achieves better economic results and potentially also better environmental results. Overall, [the authors'] empirical simulation demonstrates that resource substitution has a stronger benefit than decarbonizing fossil fuels." **Susana Silva, Isabel Soares, and Carlos Pinho,** *Energy Reports*. (Subscription may be required.)

Is it worth to invest? -An evaluation of CTL-CCS project in China based on real options.

The following is from the abstract of this article: "China's consumption of liquid fuels as well as the dependence on foreign oil has increased considerably in recent years. Alternative liquid fuel technologies such as coal to liquid (CTL) are attracting attentions. However, facing uncertainties of energy price and carbon price as well as policy fluctuations and potential CO_2 utilizations, evaluations of CTL project becomes a complex question. In this context, [the authors] develop a sequential investment real options decision model of a typical CTL-CCS project in China with the flexibility in investment timing and operation. As an application, the model is used to evaluate Shenhua direct coal liquefaction (DCL) project with CCS retrofits option. Four scenarios and sensitivities of key parameters are discussed. The results show that under current market and policy conditions the CTL project is economically infeasible but the option to delay is of huge value. A high level of carbon price or carbon tax is necessary to make the CCS retrofit economically feasible despite relatively lower capture costs, while the captured CO_2 could be better utilized for Enhanced Oil Recovery (EOR). [The authors] suggest the government to exempt fuel tax for enhancing the economic viability of CTL companies, especially in the current condition of low oil price." **Xing Yao, Ying Fan, Yuan Xu, Xian Zhang, Lei Zhu, and Lianyong Feng,** *Energy*. (Subscription may be required.)

Reaction of pseudowollastonite with carbonate-bearing fluids: Implications for CO_2 mineral sequestration.

The following is from the abstract of this article: "The kinetics of silicate carbonation in aqueous solutions are typically sluggish, especially at neutral to alkaline conditions. This hampers the complete understanding of the mechanisms and parameters that control mineral carbonation during carbon capture and storage (CCS). Here [the authors] study the hydrothermal dissolution and carbonation of pseudowollastonite (psw; α-CaSiO3), one of the most reactive silicates known, under a range of geochemical conditions ranging from acidic to strongly alkaline pH, presence/absence of different background alkali metal ions and carbonate sources (K_2CO3 and Na_2CO3, pH ~13, or NaHCO3 and KHCO3, pH ~9). [The authors] show that in addition to amorphous silica precipitation, the formation of secondary Na+Ca- or K+Ca-silicates in the presence of Na^+ and K^+ background ions, respectively, fosters the progress of psw carbonation. However, the formation of Ca-containing secondary crystalline silicates and Ca-containing amorphous silica is shown to be a strong handicap for a fully effective carbonation. In all cases a higher conversion into CaCO3 (up to ~70 mol%) is achieved when using bicarbonate salts (i.e., lower initial pH). By using a reactor with a pressurized CO_2-solution, with and without Na^+ or K^+ background ions, rapid and nearly complete conversion of psw with a CaCO3 yield ~92 mol% is achieved because, in addition to the initial low pH (~3.7) that favored α-CaSiO3 dissolution, abundant Ca-free non-passivating amorphous silica formed along with calcite. These results imply that the presence (e.g., use of sea water during CO_2 injection or mixing with saline formation solutions)

or the release of different alkali metal ions (e.g., after feldspar and/or basaltic glass dissolution) in combination with a reaction-induced pH increase during in situ CCS scenarios may strongly limit carbonation due to the capture of alkaline-earth metals in secondary silicates and a reduction in reaction rates. In turn, [the authors'] results show that the high conversion achieved in pure CO_2-aqueous systems, while relevant for ex situ CCS, may not reflect the actual conversion in multicomponent natural systems following reactive transport during in situ CCS. Moreover, the precipitation of secondary silicate and calcium carbonate phases have a direct cementing effect, which could be detrimental for in situ CCS, as it would likely reduce host rock permeability, but would be relevant and beneficial for the setting of novel CaSiO3-based non-hydraulic cements with reduced CO_2 footprint." **Luis Monasterio-Guillot, Fulvio Di Lorenzo, Encarnacion Ruiz-Agudo, and Carlos Rodriguez-Navarro,** *Chemical Geology.* (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 from 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. Dreux,** *Applied Energy*. (Subscription may be required.)

Pressure management via brine extraction in geological CO_2 storage: Adaptive optimization strategies under poorly characterized reservoir conditions.

The following is from the abstract of this article: "Industrial-scale injection of CO_2 into the subsurface increases the fluid pressure in the reservoir, which if not properly controlled can potentially lead to geomechanical damage (i.e., fracturing of the caprock or reactivation of faults) and subsequent CO_2 leakage. Brine extraction is one approach for managing formation pressure, effective stress, and plume movement in response to CO_2 injection. The management of the extracted brine can be expensive (i.e., due to transportation, treatment, disposal, or re-injection), with added cost to the carbon capture and sequestration (CCS); thus, minimizing the volume of extraction brine is of great importance to ensure that the economics of CCS are favorable. The main objective of this study is to demonstrate the use of adaptive optimization methods in the planning of brine extraction and to investigate how the quality of initial site characterization data and the use of newly acquired monitoring data (e.g. pressure at observation wells) impact the optimization performance. [The authors] apply an adaptive management approach that integrates monitoring, calibration, and optimization of brine extraction rates to achieve pre-defined pressure constraints. [The authors'] results show that reservoir pressure management can be extremely benefited by early and high frequency pressure monitoring during early injection times, especially for poor initial reservoir characterization. Low frequencies of model calibration and optimization with monitoring data may lead to optimization problems because either pressure buildup constraints are violated or excessively high extraction rates are proposed. The adaptive pressure management approach may constitute an effective tool to manage pressure buildup under uncertain reservoir conditions by minimizing the volumes of extracted brine while controlling pressure buildup." **Ana González-Nicolás, Abdullah Cihan, Robin Petrusak, Quanlin Zhou, Robert Trautz, David Riestenberg, Michael Godec, and Jens T. Birkholzer,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Modeling oil saturation evolution in residual oil zones: Implications for CO_2 EOR and sequestration.

The following is from the abstract of this article: "Residual oil zones (ROZs) are extensively developed in carbonate formations in the Permian Basin, West Texas. These ROZs have the potential both for economically-viable CO_2 enhanced oil recovery (CO_2-EOR) and for significant volumes of associated CO_2 sequestration. The accepted model for ROZ formation is based on the hydrodynamic effects of tectonically-controlled increased water flow in aquifers at the base of oil fields. The nature of this process is modelled using a commercial reservoir simulator in this work. These simulations explore the effects of strength of aquifer flow, flow direction, and capillary pressure on the nature and distribution of oil saturations in ROZs. A special emphasis was on understanding the impact of heterogeneity of capillary pressures in ROZ reservoirs. These factors determine the thickness of ROZs, the magnitude of oil saturation, and the slope of water-oil contacts. Understanding the magnitude of oil saturation and how it varies within ROZs is important in determining reserves, and evaluating both EOR and sequestration potential. The geometry of ROZs are established slowly, especially for small regional water fluxes, however oil saturations achieve almost steady states in relatively short time scales. The simulated oil saturation profiles found in this study are in reasonable agreement with the measured profile published for the San Andres Seminole Unit's ROZ. The results support the plausibility of the hydrodynamic model, but do not rule out other models for the origin of ROZs." **Bo Ren and Ian Duncan,** *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

Achieving carbon-neutral iron and steelmaking in Europe through the deployment of bioenergy with carbon capture and storage.

The following is from the abstract of this article: "The 30 integrated steel plants operating in the European Union (EU) are among the largest single-point CO_2 emitters in the region. The deployment of bioenergy with carbon capture and storage (bio-CCS) could significantly reduce their emission intensities. In detail, the results demonstrate that CO_2 emission reduction targets of up to 20% can be met entirely by biomass deployment. A slow CCS technology introduction on top of biomass deployment is expected, as the requirement for emission reduction increases further. Bio-CCS could then be a key technology, particularly in terms of meeting targets above 50%, with CO_2 avoidance costs ranging between €60 and €100 t_{CO2}^{-1} at full-scale deployment. The future of bio-CCS and its utilisation on a larger scale would therefore only be viable if such CO_2 avoidance cost were to become economically appealing. Small and medium plants in particular, would economically benefit from sharing CO_2 pipeline networks. CO_2 transport, however, makes a relatively small contribution to the total CO_2 avoidance cost. In the future, the role of bio-CCS in the European iron and steelmaking industry will also be influenced by non-economic conditions, such as regulations, public acceptance, realistic CO_2 storage capacity, and the progress of other mitigation technologies." **Hana Mandova, Piera Patrizio, Sylvain Leduc, Jan Kjärstad, Chuan Wang, Elisabeth Wetterlund, Florian Kraxner, and William Gale,** *Journal of Cleaner Production*. (Subscription may be required.)

Comparing carbon accumulation in restored and natural wetland soils of coastal Louisiana.

The following is from the abstract of this article: "Louisiana's chronic wetland deterioration has resulted in massive soil organic matter loss and subsequent carbon release through oxidation. To combat these losses, and reestablish ecosystem function, goods, and services, many restoration projects have been constructed or planned throughout coastal Louisiana. There are significant data gaps and conflicting results regarding wetland contributions […] especially

related to carbon sequestration in restored wetlands. An exceptionally large data set was used to derive carbon accumulation rates from key soil characteristics and processes. Assessments and comparisons of bulk density, organic matter, total carbon, vertical accretion (short- and longer-term), and carbon accumulation rates were made across time (chronosequence) and space (i.e., coastwide, watershed basins, and vegetation zones). Carbon accumulation rates in the Louisiana coastal zone were generally correlated to hydrogeomorphology, with higher rates occurring in zones of high river connectivity or in swamp or higher salinity tolerant marsh. On average, naturally occurring wetlands had higher carbon accumulation rates than restoration sites. Although some restoration measures were higher, and most showed increasing carbon accumulation rates over time […]" **Glenn M. Suir, Charles E. Sasser, Ronald D. DeLaune, and Elizabeth O. Murray,** *International Journal of Sediment Research*. (Subscription may be required.)

Carbon Capture Innovation Challenge: Report of the Carbon Capture, Utilization and Storage Experts' Workshop.

The following is from the Preface of this Mission Innovation Report: "… The Mission Innovation Carbon Capture Challenge aims to provide a platform for advancing broad international collaboration in CCUS research and development that could significantly reduce CO_2 emissions. This report presents the outcome of the Mission Innovation CCUS Experts workshop held in Trondheim, Norway in June 2019, in which attendees worked to identify research gaps, opportunities, and priorities in CCUS. The workshop addressed six different topics, and the report presents summaries and recommendations for all six topics, in short-, medium-, and long-term perspectives."

Scaling Up Action: Aiming for net zero emissions.

The following is from the Foreword of this Oil and Gas Climate Initiative (OGCI) report: "A key focus for OGCI this year has been carbon capture, use and storage (CCUS). [OCGI is] delighted to be launching CCUS KickStarter, a major new initiative designed to facilitate large-scale commercial investment in CCUS, by enabling multiple low-carbon industrial hubs. These hubs capture carbon dioxide from several industrial companies and bring economies of scale by sharing transport and storage infrastructure. [OCGI aims] to work with governments and other industries to facilitate the necessary market conditions for investment in CCUS hubs and projects by OGCI member companies, OGCI Climate Investments, governments and other investors. To this end [OCGI has] developed a strategic cooperation with the Clean Energy Ministerial CCUS Initiative to facilitate the market conditions for commercial scale investment in CCUS around the world."

JANUARY 2020

Estimating the pressure-limited dynamic capacity and costs of basin-scale CO_2 storage in a saline formation.

The following is from the abstract of this article: "Deployment of carbon capture and storage (CCS) could be necessary to be able to satisfy baseload electricity demand, maintain diversity in the energy mix, and achieve mitigation of carbon dioxide (CO_2) emissions at lowest cost (IPCC, 2015; U.S. DOE, 2016). If basin-, regional- or national-scale deployment of CCS is needed, it may be possible to store only a small fraction of the captured CO_2 in oil and natural gas reservoirs. The vast majority would likely have to be stored in saline formations. Pressure buildup as a result of injecting CO_2 into such reservoirs is expected to be an important source of risk associated with CO_2 storage, and could constrain dynamic storage capacities (maximum injection rates) to be far below estimates based on access to theoretical storage resources. Estimates of CO_2 storage costs based on an assumption of practical availability of the theoretical storage resource could lead to underestimation of the costs of CO_2 storage. In this study, simulation results suggest that the pressure-limited dynamic CO_2 storage capacity of the Mount Simon Sandstone could be less than 4% of the theoretical storage resource in this saline formation, and storage costs could be an order of magnitude higher than recent estimates. However, consideration of the geologic heterogeneity in this deep saline formation allowed definition of a high injectivity zone, and estimated costs of CO_2 storage in this 'sweet spot' of the reservoir approached recent estimates that did not include costs for pressure management." **Steven T. Anderson and Hossein Jahediesfanjani,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Characterization of local capillary trap clusters in storage aquifers.

The following is from the abstract of this article: "Local capillary trapping occurs when buoyant CO_2 moves upward in a saline aquifer during geologic carbon sequestration. The volumetric capacity of local capillary traps (LCTs) is controlled by reservoir geological heterogeneity. These traps are thus intrinsic to heterogeneous storage aquifers; their volumetric capacities are however largely unknown. To address this issue, this work employs an easily calculated criterion that requires only a static geologic model to estimate the properties of LCT clusters, including size, frequency, and extent. Specifically, this work quantitatively analyzes: i) the properties of the largest LCT cluster; and ii) the impact of reservoir heterogeneity on cluster properties. The key finding of this work is that spatially-correlated reservoir heterogeneity in the horizontal direction causes the largest LCT cluster to laterally span across a given domain even when the horizontal correlation length is small (only 1/25th) compared to the domain width. The overall work sheds useful insights of the dependence of LCT clusters on reservoir heterogeneity and its implication for CO_2 trapping quantification." **Bo Ren and Luca Trevisan,** *Energy*. (Subscription may be required.)

Modeling of ex-situ dissolution for geologic sequestration of carbon dioxide in aquifers.

The following is from the abstract of this article: "Underground carbon dioxide (CO_2) sequestration is considered to be one of the main methods to mitigate greenhouse gas (GHG) emissions. In this technology, pure CO_2 is injected into an underground geological formation and since it is less dense than residual fluids, there is always a risk of leakage to the surface. To increase security of underground CO_2 disposal, ex-situ dissolution can be implemented. When CO_2 is dissolved in brine before injection, it significantly reduces the risks of leakage. In this approach, pure CO_2 is dissolved on the surface before injection. Surface dissolution could be achieved in a pipeline operating under the pressure of a target aquifer into which the CO_2 is injected. In a pipeline, CO_2 droplets are dissolved being dispersed in a brine turbulent flow. In this paper, a comprehensive model of droplet dissolution along a pipeline is presented. The model accounts for droplet breakup and coalescence processes and is validated against available experimental data." **Federico Cao, Dmitry Eskin, and Yuri Leonenko,** *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

Prediction leakage channels of CO_2 injection wells.

The following is from the abstract of this article: "During CO_2 injection, a microannulus will be generated, leading to the transmission of gas through the cement behind the casing or before the formation when thermal stress exceeds bond strength. In this work, leakage channel prediction model was developed to predict the leakage channel of CO_2 injection wells. The prediction results indicate that the thermal stresses first decreased and then increased with increasing well depth; decreased with increasing radial distance; and increased with increasing injection time. The cement sheath of a production casing is more likely to form a leakage channel than other cement sheaths during long-duration CO_2 injection." **Bin Yuan, Yongqing Wang, Shuqiang Shi, and Yibo Feng,** *Energy Procedia*. (Subscription may be required.)

Nanosilica-latex reduction carbonation-induced degradation in cement of CO_2 geological storage wells.

The following is from the abstract of this article: "Carbon capture and storage (CCS) is a promising solution for reducing carbon dioxide concentration in the atmosphere. Wellbore integrity (in particular, the durability of the cement) is critical for ensuring the long-term viability and safety of CCS projects. The ordinary Portland cement (OPC) currently used in CCS wells has been shown to be unstable in CO_2-rich environments. Therefore, this study investigated amorphous-nanosilica-latex (ANL) modified oil well cement and studied its carbonation-induced degradation resistance properties. [The authors] observed that the modified cement had lower original permeability, higher

compressive strength, and smaller penetration depth than existing OPC, even after carbonation degradation. For example, the initial permeability of 6 wt % for the ANL-modified cement was seven times smaller than that of OPC, while after 90 days of carbonation degradation, the carbonation penetration depth was more than 15.7 times smaller than OPC. ANL also reacted with hydroxide ($Ca(OH)_2$) to generate products with low calcium silicon ratios (such as tobermorite) and reduced the pH of the cement. ANL-modified cement showed superior degradation resistance due to (i) a decrease in permeability because of film formation effect of latex and filling effect of nano-particles, and (ii) the reacted with $Ca(OH)_2$ to generate longer chains of calcium silicate hydrate." **Bihua Xu, Bin Yuan, Yongqing Wang, Shunpeng Zeng, and Yuhao Yang,** *Journal of Natural Gas Science and Engineering.* (Subscription may be required.)

The impact of environmental innovation on carbon dioxide emissions.

The following is from the abstract of this article: "This paper examines the effects of environmental innovation on carbon dioxide emissions in the EU-27 countries between 1992 and 2014. [The authors] utilize the Generalized Method of Moments in a dynamic panel setting. Patent counts of environmental patent applications are used as indicator for environmental innovation. [The authors] find that environmental innovation did contribute to reductions of carbon dioxide emissions, while general innovative activity does not cause decreases in emissions. However, this effect is found to be comparatively small to the effects of increased economic activity. Further, [the authors] find the effect of innovation to differ across countries, with less developed economies showing a higher level of heterogeneity." **Daniel Töbelmann and Tobias Wendler,** *Journal of Cleaner Production.* (Subscription may be required.)

Knowledge spillover efficiency of carbon capture, utilization, and storage technology: A comparison among countries.

The following is from the abstract of this article: "This study examines the carbon capture, utilization, and storage research performance of 31 countries from the knowledge spillover perspective. Knowledge spillover efficiency—operationally defined as the level of academic and practical influence of research and development outputs—is measured using the output-oriented constant return to scale, variable returns to scale, and super efficiency models using data envelopment analysis. [The authors] consider the number of patents and research articles from 2000 to 2016 as input variables, while the number of research article citations, patent citations, and registration of triadic patent families as of 2017 are the three output variables. The samples for measuring efficiency were obtained by collecting patents and research articles using Wintelips and Scopus database, respectively. The results of the super-efficiency data envelopment analysis were used to examine each country's position in terms of knowledge spillover. More specifically, the US, European countries, Japan, Australia, and New Zealand showed relatively high efficiency, which might be characteristic of their R&D policies and environmental factors. Moreover, the returns to scale analysis provide implications for R&D resource allocation as to whether to encourage the quantitative or qualitative expansion of R&D outputs to improve efficiency. This study can provide meaningful information to policymakers to identify ex post R&D activities and planning." **Junhee Bae, Yanghon Chung, Jaewook Lee, and Hangyeol Seo,** *Journal of Cleaner Production.* (Subscription may be required.)

Impacts of China's emissions trading schemes on deployment of power generation with carbon capture and storage.

The following is from the abstract of this article: "The establishment of an emissions trading scheme (ETS) in China creates the potential for a 'least cost' solution for achieving the greenhouse gas (GHG) emissions reductions required for China to meet its Paris Agreement pledges. China has pledged to reduce CO_2 intensity by 60–65% in 2030 relative to 2005 and to stop the increase in absolute CO_2 emissions around 2030. In this series of studies, [the authors] enhance the MIT Economic Projection and Policy Analysis (EPPA) model to include the latest assessments of the costs of power generation technologies in China to evaluate the impacts of different potential ETS pathways on deployment of carbon capture and storage (CCS) technology. This paper reports the results from baseline scenarios where power generation prices are assumed to be homogeneous across the country for a given mode of generation. [The authors] find that there are different pathways where CCS might play an important role in reducing the emission intensity in China's electricity sector, especially for low carbon intensity targets consistent with the ultimate goals of the Paris Agreement. Uncertainty about the exact technology mix suggests that decision makers should be wary of picking winning technologies, and should instead seek to provide incentives for emission reductions. While it will be challenging to meet the CO_2 intensity target of 550 g/kWh for the electric power sector by 2020, multiple pathways exist for achieving lower targets over a longer timeframe. [The authors'] initial analysis shows that carbon prices of 35–40$/$tCO_2$ make CCS technologies on coal-based generation cost-competitive against other modes of generation and that carbon prices higher than 100$/$tCO_2$ favor a major expansion of CCS. The next step is to confirm these initial results with more detailed modeling that takes into account granularity across China's energy sector at the provincial level." **Jennifer Morris, Sergey Paltsev, and Anthony Y. Ku,** *Energy Economics.* (Subscription may be required.)

ELEGANCY: The Interdisciplinary Approach of the German Case Study to Enable a Low Carbon Economy by Hydrogen and CCS.

The following is from the abstract of this article: "The goal of the multinational ACT project ELEGANCY is to accelerate the decarbonisation of the European energy system by exploiting synergies between carbon capture and storage (CCS) and hydrogen (H_2). The introduction of CCS is delayed due to lack of business models, the widespread use of H_2 is hindered by the cost and availability of large quantities of clean hydrogen. The five participating countries Norway, England, Netherlands, Switzerland and Germany want to investigate and evaluate the combination of a hydrogen infrastructure with CCS in case studies and develop a planning tool. The Ruhr-University Bochum is working interdisciplinarily with five institutes within the framework of the Research Department Closed Carbon Cycle Economy (RD-CCCE). Thus, in addition to the technical part, social, macroeconomic and legal aspects are considered in the German case study. This interdisciplinary approach is presented in this paper, describing the practices of the different disciplines." **Stefan Flamme, Daniel Benrath, Sabrina Glanz, Franziska Hoffart, Christian Pielow, Michael Roos, Roland Span, Hermann-Josef Wagner, and Anna-Lena Schönauer,** *Energy Procedia.* (Subscription may be required.)

Soil organic matter decomposition and carbon sequestration in temperate coniferous forest soils affected by soluble and insoluble spruce needle fractions.

The following is from the abstract of this article: "Temperate forest soils are important carbon (C) sinks, where the C-stock is largely determined by the balance of leaf inputs and losses through respiration. However, studies dealing with leaf inputs to coniferous forest soils are limited although coniferous forests are widespread through the Northern temperate zone. In this study, [the authors] focused on the effects of soluble, insoluble and whole-tissue coniferous needle fractions on soil organic matter (SOM) decomposition and C storage in soil fractions. In addition, the effect of future increased C input was tested by applying a doubled amount of the soluble fraction (whole-tissue + soluble fraction). ^{13}C-labelled needles were produced from spruce seedlings in growth chambers and needle fractions were added to the coniferous forest soil in laboratory microcosms. CO_2 respired during incubation from the microcosms was partitioned into needle- and SOM-derived components. After seven months, soils were destructively harvested and analyzed for C content in soil fractions and microbial community composition…" **Veronika Jílková, Kateřina Jandová, Allan Sim, Barry Thornton, and Eric Paterson,** *Soil Biology and Biochemistry.* (Subscription may be required.)

Computed Tomography Scanning and Geophysical Measurements of Core from the State Charlton #4-30 Well.

The following is from the abstract of this DOE/NETL document: "The computed tomography (CT) facilities and the Multi-Sensor Core Logger (MSCL) at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia were used to characterize core of the Bass Island, Bois Blanc, and Amherstburg Formations from a vertical well (State Charlton #4-30) from Otsego County, Michigan at depths 3,030.0 to 3,090.0 ft and 3,400.0 to 3,520.5 ft.

The primary impetus of this work is a collaboration between the Michigan Geological Survey (MGS) and NETL to characterize core to better understand the potential of carbon dioxide (CO_2) sequestration within formations in the Michigan Basin. As part of this effort, bulk CT scans of core were obtained from the State Charlton #4-30 well, provided by the MGS. This report, and the associated scans generated, provide detailed datasets not typically available for researchers to analyze. The resulting 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 and analyses to be performed on the cores. Low-resolution CT images obtained with the NETL medical CT scanner were obtained for the entire core and high-resolution CT images acquired with the NETL industrial CT scanner were obtained for selected 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."

Carbon Dioxide Enhanced Oil Recovery Life Cycle (CELiC) Model.

The following is the description of this DOE/NETL product: "The Carbon Dioxide (CO_2) Enhanced Oil Recovery (EOR) Life Cycle (CELiC) Model calculates life cycle greenhouse gas (GHG) emissions for a CO_2-EOR system, where the user can select one of three sources of the injected CO_2: (1) extracted from a natural dome, (2) captured from a coal-fired power plant, or (3) captured from a natural gas power plant. The model has several parameters and options to allow the assessment of the system for a wide-array of products—electricity, pipeline CO_2, crude oil, and refined fuels. The model is also capable of deterministic (i.e., point estimate) and stochastic (i.e., probabilistic) analyses and finally a deterministic time-series analysis that shows the changing GHG emissions for the CO_2-EOR system over time."

FE/NETL CO_2 Transport Cost Model.

The following is the description of this DOE/NETL product: "The FE/NETL CO_2 Transport Cost Model is a spreadsheet-based tool that calculates the net present value for a project that transports liquid CO_2 by pipeline. The model includes the capital costs, operating costs, financing costs and revenues for the project. The model can calculate the break-even first year price (or cost) for transporting a tonne of CO_2 by finding the price that yields a net present value of zero for the project. The user provides a variety of inputs including the annual mass of CO_2 to be transported, the pipeline length, the years of operation and financial parameters."

FEBRUARY 2020

Comparative Analysis of Transport and Storage Options from a CO_2 Source Perspective.

The following is the description of this DOE/NETL product: "This analysis evaluated integrated CCS costs (i.e., capture, transport, and storage) from the perspective of a CO_2 source. Capture costs for sources with annual CO_2 capture rates from 0.65 to 3.90 Mt were based on two NETL reports. Transportation costs from source to storage reservoir were modeled for two pipelines systems (dedicated and trunkline) using the FE/NETL CO_2 Transport Cost Model. Storage costs were modeled in dome and regional dip structural settings for two reservoirs in the Rose Run Formation, three within the Mt. Simon, one in the Lower Tuscaloosa, and one in the Frio using the FE/NETL CO_2 Saline Storage Cost Model. A paper with the same name and information as well as additional details on this analysis was published in The International Journal of Greenhouse Gas Control along with a supplementary document that provides additional material (i.e., key parameters used in the models for obtaining transport and storage costs and CCS cost and pipeline results)."

NETL Baseline Studies for Fossil Energy Plants.

The following is the overview of these NETL studies: "The NETL Baseline Studies for Fossil Energy Plants establish estimates for the cost and performance of combustion- and gasification-based power plants, as well as options for co-generating synthetic natural gas and fuels - all with and without carbon dioxide capture and storage - for several ranks of coal. These studies are considered to be the most comprehensive set of public data available for state-of-the-art technologies. The primary value of these studies lies not in the absolute accuracy of estimates for the individual cases, but in the fact that all cases are evaluated using a common methodology with an internally-consistent set of technical and economic assumptions. This consistency allows for meaningful comparisons of relative costs among the cases and with advanced technology cases build upon the same case assumptions." The four volume set consists of the following: *Volume 1: Bituminous Coal and Natural Gas to Electricity*; *Volume 2: Coal to Synthetic Natural Gas and Ammonia (Various Coal Ranks)*; *Volume 3: Low-Rank Coal to Electricity*; and *Volume 4: Bituminous Coal to Liquid Fuels with Carbon Capture*.

Feasibility of limestone reservoirs as a carbon dioxide storage site: An experimental study.

The following is from the abstract of this article: "Carbon capture and storage technology is a means to permanently store carbon dioxide (CO_2) in suitable geologic formations, such as depleted oil and gas reservoirs and saline aquifers. The potential of depleted carbonates reservoirs for being a secure storage site has been assessed in several studies based on the key storage aspects. However, minor attention has been given to rock type and the potential compaction of carbonates at different injection rates when geochemical interactions posed by supercritical CO_2 reduces their elastic properties and strength. In this study, limestone samples were tested to investigate changes in their physical and mechanical characteristics once flooded by CO_2 at a very low injection rate. The results obtained indicate that an excessive pressure drop might be experienced even under a very low injection rate because of continuous dissolution of carbonates in the presence of CO_2 and brine. Creation of wormholes and the dissolution of the matrix were also observed through scanning electron microscope, computerized tomography scan, and nuclear magnetic resonance tests. It was also observed that the elastic parameters and the strength of the limestone samples may significantly decrease after CO_2 flooding, which might be linked to calcite dissolution and weakening of the solid skeleton." **Arshad Raza, Raoof Gholami, and Mohammad Sarmadivaleh,** *AAPG Bulleting*. (Subscription may be required.)

Numerical assessment of fault impact on caprock seals during CO_2 sequestration.

The following is from the abstract of this article: "Coupled fluid-flow and geomechanical analysis of caprock integrity has gained a lot of attention among scientists and researchers investigating the long-term performance of geologic carbon storage systems. Reactivation of pre-existing fractures within the caprock or re-opening of faults can create permeable pathways which can influence the seal integrity. Stability of the caprock during and after injection of super-critical CO_2, and the impact of pre-existing fractures in the presence or absence of one or multiple faults have been investigated in this study. The impact of the wellbore orientation and the injection rate are among other key factors in understanding the structural trapping mechanisms within such geological formations. In this study, [the authors] numerically investigated the impact of each of these factors. This study revealed the interplay between joints and faults and how different leakage pathways are formed and under which scenario they play a dominant role in terms of CO_2 leakage. This study also highlights the role of one versus multiple faults in the domain and the importance of the fault hydrological property in forming leakage pathway." **P. Newell and M.J. Martinez,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Experimental study on natural gas hydrate exploitation: Optimization of methane recovery, carbon dioxide storage and deposit structure preservation.

The following is from the abstract of this article: "Aim of this work is locating how CO_2 replacement into methane hydrate deposits may be performed, in order to increase both methane recovered and carbon dioxide stored quantities. The experimental section deals with the study of natural gas hydrate formation process and replacement of methane, contained into water cages, with carbon dioxide. In particular, the formation of methane hydrate is analyzed to understand the parameters that most influence the replacement process. A total of 10 tests were carried out in a laboratory scale reactor. Test 1–8 were performed adopting thermal stimulation as replacement technique, while in Test 9 and Test 10 depressurization was used. Results obtained have led to the conclusion that the rate of methane hydrate formation positively influences the percentage of CO_2 stored, while the initial saturation of the sand pores has a negative effect. The presence of hydrate agglomerates hinders the gas transition preventing the replacement process. Finally, a greater quantity of CO_2 hydrate, both via replacement process and via new hydrate formation, is related to a higher deposit structure preservation. As emerges from the experimental tests, the adopted replacement strategy influences the experimental relationships." **Alberto Maria Gambelli, Beatrice Castellani, Andrea Nicolini, and Federico Rossi,** *Journal of Petroleum Science and Engineering.* (Subscription may be required.)

Bringing value to the chemical industry from capture, storage and use of CO_2: A dynamic LCA of formic acid production.

The following is from the abstract of this article: "Low carbon options for the chemical industry include switching from fossil to renewable energy, adopting new low-carbon production processes, along with retrofitting current plants with carbon capture for ulterior use (CCU technologies) or storage (CCS). In this paper, [the authors] combine a dynamic Life Cycle Assessment (d-LCA) with economic analysis to explore a potential transition to low-carbon manufacture of formic acid. [The authors] propose new methods to enable early technical, environmental and economic assessment of formic acid manufacture by electrochemical reduction of CO_2 (CCU), and compare this production route to the conventional synthesis pathways and to storing CO_2 in geological storage (CCS). Both CCU and CCS reduce carbon emissions in particular scenarios, although the uncertainty in results suggests that further research and scale-up validation are needed to clarify the relative emission reduction compared to conventional process pathways. There are trade-offs between resource security, cost and emissions between CCU and CCS systems. As expected, the CCS technology yields greater reductions in CO_2 emissions than the CCU scenarios and the conventional processes. However, compared to CCS systems, CCU has better economic potential and lower fossil consumption, especially when powered by renewable electricity. The integration of renewable energy in the chemical industry has an important climate mitigation role, especially for processes with high electrical and thermal energy demands." **Rubén Aldaco, Isabela Butnar, María Margallo, Jara Laso, Marta Rumayor, Antonio Dominguez-Ramos, Angel Irabien, and Paul E. Dodds,** *Science of The Total Environment.* (Subscription may be required.)

A carbon price prediction model based on secondary decomposition algorithm and optimized back propagation neural network.

The following is from the abstract of this article: "Carbon trading is one of the important mechanisms used to reduce carbon dioxide emissions. The increasing interest in the carbon trading market has heightened the need to decrease the prediction error of the carbon price. In this paper, a new hybrid model for carbon price forecasting is proposed, and the secondary decomposition algorithm is innovatively introduced into carbon price forecasting. First, time series data were decomposed into several intrinsic modal functions by empirical mode decomposition (EMD). Second, the first intrinsic mode function (IMF1) was further decomposed by variational mode decomposition (VMD). Then, the model input was determined by partial autocorrelation analysis (PACF). Finally, the back propagation (BP) neural network model optimized by genetic algorithm (GA) was utilized for prediction. In the empirical analysis of the Hubei market, the proposed model outperforms other comparative models. The mean absolute percentage error (MAPE), goodness of fit (R^2) and root mean square error (RMSE) of the model are 1.7577%, 0.9929 and 0.5441, respectively. In the complementary cases of the Beijing and Shanghai carbon markets, the model also performs best. The results suggest that the proposed model is effective and robust and could predict carbon prices more accurately." **Wei Sun and Chenchen Huang,** *Journal of Cleaner Production.* (Subscription may be required.)

CO_2 leakage environmental damage cost – A CCS project in South Korea.

The following is from the abstract of this article: "The safety of CCS, namely the prevention of CO_2 leakage, is one of the most sensitive issues in the CCS project. In order to solve this issue efficiently, the knowledge of environmental damage cost of CO_2 leakage, in advance of CCS project, is indispensable. Therefore, this study estimates this cost by employing a contingent valuation (CV) method with data collected from a nationwide survey in South Korea. In addition, numerous zero willingness to pay (WTP) responses were dealt thorough the spike model in setting one-and-one-half-bound dichotomous choice data (OOHBDC). The estimate of the annual mean WTP was 2645.9 Korean won (USD 2.4), while the annual mean WTP is 3489.8 Korean won (USD 3.2) for those supporting the introduction of CCS technology in South Korea. The environmental damage cost of CO_2 leakage was 49.5 billion Korean won (USD 45.0 million) annually." **Joo Suk Lee and Eun Chul Choi,** *Renewable and Sustainable Energy Reviews.* (Subscription may be required.)

Carbon reduction in a supply chain via dynamic carbon emission quotas.

The following is from the abstract of this article: "… governments have issued a series of policies to control carbon emissions. A carbon quota policy is one of them. This study aimed to verify the effectiveness of the policy by examining its impact on supply chain members. This paper investigates emissions reduction in a supply chain under different carbon emission quotas in two stages. This paper constructs a supply chain model in three modes: (i) no carbon emission quota policy, (ii) the government implements the first stage of a carbon quota policy, and (iii) the government offers lower carbon quotas in the second stage. The analysis reveals that when the initial carbon quota allocated by the government meets certain conditions, the emission reduction rate in the first stage of the carbon quota policy is greater than that without the carbon quota policy; and an interesting finding is that the reduction rate further increases when the government reduces carbon quotas in the second stage. In addition to the reduction rate, the manufacturer's and the retailer's profits increase with consumers' preference for low-carbon products. With an increase of the decline parameter of free allocated carbon emission rights, the profits of both the manufacturer and the retailer decrease, but the profit of the manufacturer in the second stage is always lower than that in the first stage, whereas the retailer's profit is higher in the second stage than in the first stage." **Wenbin Wang, Changya Zhou, Xingyue Li,** *Journal of Cleaner Production.* (Subscription may be required.)

Impacts of horizontal integration on social welfare under the interaction of carbon tax and green subsidies.

The following is from the abstract of this article: "Both a carbon tax and green subsidies are efficient approaches to limit greenhouse gas emission. However, interactions between these two policies remain a critical gap area. In this paper [the authors] consider a channel structure originally consisted of two manufacturers and two retailers each of whom sells only one manufacturer's product exclusively. The products produced by the two manufacturers are substitutable. The government subsidizes consumers who buy low carbon products but imposes a carbon tax on the manufacturer producing high carbon products. [The authors] analyze tripartite games among manufacturers, retailers, and the government when horizontal integration between manufacturers or retailers is presented. It is a common belief that horizontal integration reduces competition and thus causes a loss in social welfare. However, [the authors] find that, with government intervention, neither type of horizontal integration has an effect on social welfare. Although horizon integration may change the optimal subsidy and carbon tax levels, it has no

effect on the equilibrium demands for both products. [The authors] also show that the integration of manufacturers does not affect retailers' profits, but the integration of retailers hurts both manufacturers due to the direct head-to-head competition." **Changyan Xu, Chuanxu Wang, and Rongbing Huang,** *International Journal of Production Economics.* (Subscription may be required.)

Assessment of the carbon emissions reduction potential of China's iron and steel industry based on a simulation analysis.

The following is from the abstract of this article: "This study provides a feasible approach for decreasing the carbon emissions of China's iron and steel industry (ISI) by 2030 using the environmental-economic simulation model. The ISI and its upstream industries are optimized by introducing both technological upgrades and environmental policies. Six scenarios are designed, including business-as-usual (BaU), industrial upgrades (*tec*), carbon tax (*tax*), carbon trading (*tra*), and combination *(cob) 1* and *cob2*, which combine the *tec*, *tax* and *tra* scenarios. The results show that the *tec* scenario can effectively curb carbon emissions. The *tax* scenario significantly promotes low emissions technologies. The *cob2* scenario has the most stringent carbon emissions control effect and helps the ISI meet the Intended Nationally Determined Contributions (INDCs) target of China. Moreover, the rates of carbon emissions increase under the *tec*, *cob1*, and *cob2* scenarios will decrease after 2027, indicating that it is highly possible that carbon emissions will peak in 2030. The decrease in crude steel production and electricity demand is also essential for the carbon emissions reduction of the ISI. This research comprehensively analyzes the factors influencing carbon emissions from the Chinese ISI. Analyzing this issue from the industrial chain perspective provides a new research scope for future simulation model studies." **Zhaoling Li, Hancheng Dai, Junnian Song, Lu Sun, Yong Geng, Keyu Lu, and Tatsuya Hanaoka,** *Energy.* (Subscription may be required.)

Trends in global research in forest carbon sequestration: A bibliometric analysis.

The following is from the abstract of this article: "Based on the Web of Science Core Collection databases from 1990 to 2018, a scientometric analysis of 1,284 academic works related to forest carbon sequestration is carried out to characterize the intellectual landscape by identifying and revealing the basic characteristics, research power, intellectual base and research hotspots in this field. The results of this work show that: [1] the number of publications in forest carbon sequestration research has increased rapidly and the research in this field is in its 'growth stage'; Forest Ecology and Management is the most productive journal and Forestry is the most popular subject category; [2] the most productive authors and institutions in this subject area are in the USA, China and Canada, with the Chinese Academy of Sciences being the key institution performing such research; [3] in the sample, 9 papers have played a key role in the evolution of the field and laid a solid foundation for future research; [4] Keyword clustering analysis showed that the main research topics in the domain of forest carbon sequestration could be summarized as: (a) temperate forest; (b) forest management; (c) uncertainty analysis; (d) forest floor; (e) REDD; (f) net primary productivity…" **Li Huang, Mi Zhou, Jie Lv, and Ke Chen,** *Journal of Cleaner Production.* (Subscription may be required.)

Quantifying the soil organic carbon sequestration performance and carbon emissions offset potential of the City of Calgary's Willow Biomass and Marginal Land Reclamation Demonstration Project.

The following is from the abstract of this article: "The primary objective of this study was to measure the soil organic carbon (SOC) sequestration performance of The City of Calgary Dewatered Biosolids Land Application Program – Willow Biomass and Marginal Land Reclamation Demonstration Project (hereafter, 'the demonstration Project') after five years of operation. The second objective was to assess the demonstration Project's potential to earn soil-based carbon offset revenue through the Alberta Emissions Offset System in the future. To accomplish the first objective, SOC stocks were measured at three sampling locations subject to different combinations of recommended management practices (RMP) for SOC sequestration by the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21)." **Chelsey Greene**, *UWSpace.* (Subscription may be required.

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Pulverized Coal Carbon Capture Retrofit Database.

The following is a description of this DOE/NETL product: "This tool provides a high level analysis on the incremental costs for retrofitting point sources with CO_2 capture and compression systems. Options are available to include cost of other technological improvements that would be required to comply with various regulations and new source performance standard when installing CO_2 capture technology."

Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies.

The following is a description of this DOE/NETL product: "The costs to be used in energy system studies sponsored by the National Energy Technology Laboratory (NETL) for estimating the cost of carbon dioxide (CO_2) pipeline transport and storage (T&S) (rounded to the nearest whole, real dollar in 2018 dollars per metric ton [2018$/tonne])."

The fossil fuel industry's framing of carbon capture and storage: Faith in innovation, value instrumentalization, and status quo maintenance.

The following is from the abstract of this article: "Drawing from the critical theory of Herbert Marcuse, [the authors] expect that the fossil fuel industry will support carbon capture and storage (CCS) because it can further and prolong profitability in the industry. Through a qualitative analysis of fossil fuel company and trade organization framings of CCS, three frames are identified: (1) faith in innovation, or, the belief that any barrier that fetters technological solutions to environmental problems can be overcome; (2) value instrumentalization, or, the predominance of instrumental values when justifying or explaining the benefits of technological solutions; and (3) status quo maintenance, or, the application or anticipated application of technological solutions in order to reproduce the most fundamental processes and social structures that characterize modern societies. Frames tend to omit the following issues and concerns relevant to CCS: (4) potential social and environmental risks (risk minimization); (5) non-instrumental values (value restriction); and (6) possible future scenarios that are qualitatively different than a growing economy powered by increased energy throughput (possibility blindness). The potential climate and energy policy implications of these framings are analyzed and assessed." **Ryan Gunderson, Diana Stuart, and Brian Peterson,** *Journal of Cleaner Production.* (Subscription may be required).

Gas hydrate exploitation and carbon dioxide sequestration under maintaining the stiffness of hydrate-bearing sediments.

The following is from the abstract of this article: "To improve the stratum mechanical properties and prevent the geological disaster, [the authors] present a new approach by executing CH4 hydrate exploitation and CO_2 sequestration below the freezing point of water to maintain the stratum stiffness during and after hydrate exploitation. An experimental method to clearly show the evolution of the stratum mechanical properties was built and a series of experiments were conducted to simulate the CH4 exploitation and CO_2 sequestration process below and above the freezing point of water. The stratum stiffness was found to be maintained during the whole hydrate exploitation process when below the freezing point. Moreover, the presence of ice improves the stratum stiffness due to cementing the sandy grain. The CO_2 injection into the hydrate-bearing sediments would further enhance the mechanical properties and realize a CO_2 geological sequestration. Compared with hydrate exploitation above the freezing point, the CH4 recovery efficiency is a little lower when under below the freezing point and it decreased with the increased hydrate saturation due to the CH4 hydrate being surrounded by the generation of ice from hydrate dissociation. This phenomenon could be modified by injecting CO_2, from which the CH4 recovery efficiency obviously improved for hydrate exploitation below the freezing point." **Liang-Liang Ren, Min Jiang, Ling-Ban Wang, Yi-Jian Zhu, Zhi Li, Chang-Yu Sun, and Guang-Jin Chen,** *Energy.* (Subscription may be required.)

Silicate mediated simultaneous in-situ CO_2 sequestration and nutrients removal in anaerobic digestion.

The following is from the abstract of this article: "This study investigated the reactions among $CO3^{2-}$, $PO4^{3-}$, $NH4^{+}$, Mg^{2+}, and Ca^{2+}, under different $CO3^{2-}$ concentration and Mg^{2+}/Ca^{2+} ratio, and conducted sludge anaerobic digestion (AD) with silicate addition to achieve in-situ CO_2 sequestration and nutrients removal. High $CO3^{2-}$ concentration facilitated the formation of MgNH4PO4, and Mg^{2+}/Ca^{2+} ratio of 1:1 achieved best $CO3^{2-}$, $PO4^{3-}$, and $NH4^{+}$ removal in simulated anaerobic digestate. Supplementation of 40 g/L magnesium silicate combined with 20 g/L wollastonite decreased CO_2 content in biogas from 28.2% to 19.0%, and removed $PO4^{3-}$ and $NH4^{+}$ by 61.8% and 21.2%, respectively, in AD. Simultaneous in-situ CO_2 sequestration and nutrients removal was achieved by directed precipitation of $PO4^{3-}$, $NH4^{+}$, and CO_2 with silicate released Mg^{2+} and Ca^{2+}, to form MgNH4PO4 and CaCO3. Meanwhile, methane production was improved by 51.2% with silicate supplementation. This study provides an attractive measure for CO_2 and nutrients removal as well as methane production enhancement of sludge AD." **He Liu, Linlin Gong, Yan Zhang, Qianqian Jiang, Minhua Cui, Jie Zhang, Bo Fu, and Hongbo Liu,** *Bioresource Technology.* (Subscription may be required.)

Mechanism of the CO_2 storage and in situ hydrogenation to CH4. Temperature and adsorbent loading effects over Ru-CaO/Al2O3 and Ru-Na2CO3/Al2O3 catalysts.

The following is from the abstract of this article: "The use of fossil fuels to satisfy the growing energy demand results in the emission of a huge amount of CO_2 to the atmosphere. One alternative to overcome this environmental issue is the CO_2 valorization through the storage and in situ hydrogenation to CH4. In this work, Ru-CaO/Al2O3 and Ru-Na_2CO3/Al2O3 dual function materials are synthesized with different adsorbent loadings, namely 5, 10 and 15 wt.%. The prepared catalysts are characterized in terms of surface area by N_2 adsorption and desorption, crystallinity by XRD, Ru dispersion by H_2-chemisorption and TEM, basicity by CO_2-TPD and reducibility and oxidation state of the noble metal by H_2-TPR and XPS. Temperature programmed surface reaction experiments with H_2 on samples with pre-adsorbed CO_2 reveal that the decomposition of surface carbonates and the subsequent hydrogenation occurs at lower temperatures for catalysts containing Na_2CO3 than CaO. A complete reaction scheme describing the CO_2 adsorption and hydrogenation process has been proposed based on the temporal evolution of reactants and products. Oxides (CaO or Na_2O) and hydrated oxides ($Ca(OH)_2$ or NaOH) have been identified as CO_2 storage sites, the former oxides being more reactive towards the CO_2 adsorption. CH4, H_2O and minor amounts of CO are detected during the hydrogenation step. The CO_2 storage and hydrogenation to CH4 is promoted with increasing the adsorbent loading. Maximum CH4 production of 414 $\mu molg^{-1}$ is observed for Ru15%CaO/Al2O3 at 400°C. High temperature is needed to efficiently decompose the highly stable carbonates formed onto CaO. On the other hand, the higher Ru dispersion along with a lower stability of carbonates in Ru10%Na_2CO3/Al2O3 promotes CH4 formation (383 $\mu molg^{-1}$) at notably lower temperature, i.e. 310°C. Thus, Ru10%Na_2CO3/Al2O3 is regarded as a suitable catalyst for the CO_2 storage and in situ hydrogenation to CH4." **A. Bermejo-López, B. Pereda-Ayo, J.A. González-Marcos, and J.R. González-Velasco,** *Applied Catalysis B: Environmental.* (Subscription may be required.)

Determinants of Soil Organic Carbon Sequestration and Its Contribution to Ecosystem Carbon Sinks of Planted Forests.

The following is from the abstract of this article: "The area of forest established through afforestation/reforestation has been increasing on a global scale, which is particularly important as these planted forests attenuate climate change by sequestering carbon. However, the determinants of soil organic carbon sequestration and their contribution to the ecosystem carbon sink of planted forests remains uncertain. By using globally distributed data extracted from 154 peer-reviewed publications and a total of 355 sampling points, [the authors] investigated above-ground biomass carbon (ABC) sequestration and soil organic carbon (SOC) sequestration across three different climatic zones (tropical, warm temperate, and cold temperate) through correlation analysis, regression models, and structural equation modeling (SEM). [The authors] found that the proportion of SOC sequestration in the ecosystem C sequestration averaged 14.1% globally, being the highest (27.0%) in the warm temperate and the lowest (10.7%) in the tropical climatic zones. The proportion was mainly affected by latitude. The sink rate of ABC (R_{ABC}) in tropical climates (2.48 Mg C ha−1 yr−1) and the sink rate of SOC (R_{SOC}) in warm temperate climates (0.96 Mg C ha−1 yr−1) were higher than other climatic zones. The main determinants of R_{SOC} were the number of frost-free days, latitude, mean annual precipitation (MAP), and soil organic carbon density (SOCD) at the initial observation; however, these variables depended on the climatic zone. According to the SEM, frost-free period MAT, and MAP are the dominant driving factors affecting R_{SOC} in Chinese plantations. MAT has an positive effect on R_{SOC}, and global warming may increase R_{SOC} of temperate plantations in China. [The authors'] findings highlight the determinants of SOC sequestration and quantitatively reveal the substantial global contribution of SOC sequestration to ecosystem carbon sink provided by planted forests. [The authors'] results help managers identify and control key factors to increase carbon sequestration in forest ecosystems." **Shiqiang Wang and Yao Huang,** *Global Change Biology.* (Subscription may be required.)

Projected trends of soil organic carbon stocks in Meghalaya state of Northeast Himalayas, India. Implications for a policy perspective.

The following is from the abstract of this article: "Agricultural and forestry activities can affect soil organic carbon (SOC) levels and CO_2 emissions from terrestrial ecosystems due to land use changes. In Northeast Himalayas, studies on the effects of forest conversion to temporary agricultural lands (*jhum*) on the loss of SOC and soil quality degradation have received the attention of policy makers and scientific research. Presently, local communities are now oriented towards the settled plantations systems with modern cash crops such as tea and rubber, that could act as potential SOC sinks. However, no information on SOC dynamics and simulation studies after land-use change from temporary agricultural lands (*jhum*) to settled cultivations and under climate change (CC) conditions are available for the Meghalaya state. Applying the RothC model, [the authors] focused on four different scenarios including the conversion from *jhum* to settled cultivation (rubber plantations and tea gardens), as well as continuous *jhum* cultivation and *jhum* to *jhum* with a period of secondary succession. Simulations under CC conditions indicated that SOC stocks significantly increased by 1.20 t C ha−1 yr−1 in tea gardens compared to rubber and *jhum* scenarios. Conversely, SOC stocks slightly decreased by 0.07 t C ha−1 yr−1 in rubber plantations, while the regrowth of a natural vegetation cover as secondary succession following the abandonment of the *jhum* fields, showed a lower SOC decrease (0.18 t C ha−1 yr−1) compared to the continuous *jhum* cultivation (0.24 t C ha−1 yr−1). Thus, for CC mitigation in a policy perspective, tea gardens could represent the best land use to store increasing amounts of SOC in the long-term perspective and optimize farmers' incomes, while in rubber plantations SOC storage is limited in time. *Jhum* cultivation can benefit in terms of productivity and profitability by extending the duration of the secondary succession period." **Gaurav Mishra, Krishna Giri, Abhishek Jangir, and Rosa Francaviglia,** *Science of The Total Environment.* (Subscription may be required.)

Ten-year long-term organic fertilization enhances carbon sequestration and calcium-mediated stabilization of aggregate-associated organic carbon in a reclaimed Cambisol.

The following is from the abstract of this article: "Soils play a vital role in the global carbon (C) cycle, yet little is known about the calcium (Ca)-mediated stabilization of soil organic carbon (SOC) in calcareous soils. With wet sieving, density fractionation and an incubation experiment from field soils, [the authors] investigated the effects of long-term fertilization on the Ca-mediated stabilization of aggregate-associated organic C and on the SOC stock at a soil depth of 0–20 cm in a reclaimed Cambisol on the Loess Plateau of China. Compared to the initial soil, after ten years the SOC stock increased by 50%, 76%, 94% and 110% in soils amended with no fertilizer (control), 100% chemical fertilizer, 50% chemical fertilizer plus 50% chicken manure compost and 100% chicken manure compost, respectively. The specific C mineralization rate (SCMR, rate per unit SOC) decreased as silt and clay > macroaggregate > microaggregate, indicating that SOC in microaggregates was more stable than in macroaggregates and the silt and clay fraction. The exchangeable Ca

in the bulk soil ($P < 0.001$) and soil aggregates ($P < 0.001$) were positively correlated with the SOC, whereas the Ca carbonate (CaCO3) was negatively correlated with the SCMR ($P < 0.001$). The application of compost not only increased the exogenous C inputs but also promoted the transformation of CaCO3 to exchangeable Ca compared with the sole chemical fertilization. Furthermore, organic fertilization significantly increased the organic C in the heavy fraction (> 2.0 g cm^{-3}) compared with the sole chemical fertilization, which was positively correlated with the mass proportion of macroaggregates ($P < 0.001$). These results indicate that organic fertilization can enhance the availability of Ca for C binding possibly by forming organo-Ca complexes, which in turn improve soil aggregation, and thus contribute to a long-term SOC sequestration in reclaimed soils of the Loess Plateau of China." **Xiaolei Huang, Zhixin Jia, Junjie Guo, Tingliang Li, Dasheng Sun, Huisheng Meng, Guanghui Yu, Xinhua, He, Wei Ran, Shusheng Zhang, Jianping Hong, and Qirong Shen,** *Geoderma*. (Subscription may be required.)

Effects of the EU Emission Trading Scheme on the international competitiveness of pulp-and-paper industry.

The following is from the abstract of this article: "[The authors] designed an interactive item between the EU ETS dummy and the number of patent applications to represent the EU ETS's indirect effect. Then, based on the panel data of 42 countries' pulp-and-paper industry from 1998 to 2013, [the authors] conducted the test by using the system generalized method of moments to address the endogeneity problem. The results show that the EU ETS's direct effect is insignificant, while its indirect effect is significantly positive. That is, the EU ETS can bring positive effect by stimulating the pulp-and-paper making enterprises toward technological innovation. [The authors'] analysis further finds that this indirect effect changes from being insignificant in Phase I to be significantly positive in Phase II and Phase III as well as gradually become larger, suggesting that the ETS-induced innovation gradually became more prominent. The above findings provide convincing new evidence that the ETS's 'innovative compensation effect' is greater than its cost-effect." **Weiming Lin, Jianling Chen, Yi Zheng, and Yongwu Dai,** *Forest Policy and Economics*. (Subscription may be required.)

Competitive strategies for original equipment manufacturers considering carbon cap and trade.

The following is from the abstract of this article: "This paper considers an original equipment manufacturer (OEM) faces competition from an independent remanufacturer (IR) and they both are regulated by carbon cap and trade policy (CTP). [The authors] develop models to explore the OEM's optimal competitive strategy in the face of IR's competition and environmental regulation. [The authors] first investigate the impact of CTP on the OEM and IR. Then, [the authors] analyze three competitive strategies that the OEM may choose: remanufacturing, fixed-fee licensing, and royalty licensing. [The authors] investigate their optimal decisions under each strategy and identify the conditions under which these strategies can coordinate the OEM and IR. Finally, [the authors] explore conditions under which [their] strategy is superior to another. The results show that the OEM is worse off when competing with the IR under CTP if the carbon cap allocated to the OEM is small. Fixed-fee licensing and royalty licensing can coordinate the OEM and IR not only from an economic perspective but also from an environmental perspective. The OEM's optimal competitive strategy is determined by thresholds of three critical parameters: the fixed cost of setting up a remanufacturing system, the fixed-fee, and the per-unit royalty. [The authors] provide specific guidance on strategy selection for the OEM." **Qiangfei Chai, Zhongdong Xiao, and Guanghui Zhou,** *Transportation Research Part D: Transport and Environment*. (Subscription may be required.)

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Natural Gas Combined Cycle Carbon Capture Retrofit Database.

The following is a description of this DOE/NETL document: "This tool provides high-level analysis on the incremental costs for retrofitting point sources with carbon dioxide (CO_2) capture and/or compression systems. Options are available to include costs of other technological improvements that would be required to comply with various regulations and New Source Performance Standards when installing CO_2 scrubbing technology."

Innovating to Net Zero.

The following is from the Executive Summary of this Energy Systems Catapult document: "Meeting the UK's Net Zero target will require unprecedented innovation across the economy. Innovation not just in new technologies, but in new ways of deploying existing technologies, new business models, new consumer offerings, and, crucially, new policy, regulation and market design. Unleashing innovation at the pace and scale needed requires a deep understanding of how the different parts of the energy system interact; in short, taking a whole system approach. This report updates Energy Systems Catapult's national Energy System Modelling Environment (ESME) to consider the potential pathways to 2050, and to help identify the technologies, products and services which are most important to meeting Net Zero. It recommends what needs to happen during this Parliament to deliver Net Zero levels of investment, infrastructure and innovation. While the challenge is daunting, the commercial opportunity for those companies able to deliver the innovations needed is huge. This analysis will help identify those opportunities, and what may be needed to unlock them."

Leveraging operational information from wastewater injection wells to evaluate CO_2 injection performance for carbon storage applications in the Appalachian Basin.

The following is from the abstract of this article: "Geologic parameters, geophysical logging, injection testing, and operational metrics from wastewater injection wells were integrated to develop a preliminary design of a carbon storage facility in the Appalachian Basin. A scattered group of 10–20 commercial wastewater injection wells dispose off produced water from oil and gas wells in the region, utilizing a sequence of stacked deep saline formations for injection zones. These wastewater injection wells provide practical benchmarks for understanding the feasibility of carbon dioxide (CO_2) storage. Geologic models were developed based on characterization data from the wastewater injection wells. Reservoir simulations were calibrated according to injection testing and operational data from the wastewater injection wells. Long-term operational data on injection flow rates and pressures measured in the wastewater injection wells were especially useful to evaluate the performance of carbon storage applications. The simulations were used to estimate injection pressures, radius of CO_2 saturation, and pressure response for industrial scale CO_2 storage applications. Results were also used to provide a design basis in terms of number of injection wells, well spacing, area of review, injection system components, monitoring plan, and CO_2 pipeline distribution system. The analysis demonstrates that there is sufficient injectivity in the deep saline formations in the west-central Appalachian Basin to store commercial volumes of anthropogenic CO_2. The geologic system appears suitable for supporting CO_2 injection rates of 0.5–1.0 million metric tons per year at injection pressures below formation fracture pressure in a single well. The long-term operational data of wastewater injection wells within the study area suggested a lower permeability-thickness values than indicated by initial reservoir tests. A workflow for developing realistic permeability values for input into reservoir simulations is presented." **Manoj Valluri, Joel Sminchak, Lydia Cumming, Joel Main, and Glenn Larsen,** *Greenhouse Gases: Science and Technology*. (Subscription may be required.)

Large CO_2 Storage Volumes Result in Net Negative Emissions for Greenhouse Gas Life Cycle Analysis Based on Records from 22 Years of CO_2-Enhanced Oil Recovery Operations.

The following is from the abstract of this article: "Emissions were documented in a greenhouse gas emission life cycle analysis of 22 years of CO_2-enhanced oil recovery (CO_2-EOR) operations for a site in the Northern Michigan Basin, U.S. At the site, CO_2 was cycled through a series of 10 carbonate reef structures 1500–2000 m deep in the subsurface. The CO_2 mobilized oil in the reefs, and the operator produced [294,321 metric tons (2,290,000 barrels)] of oil with CO_2-EOR at the site from 1996 to 2017. In the process, a total of [2,089,000] metric tons of CO_2 were stored in the deep rock formations, which is a very large volume for CO_2-EOR applications of this scale. The life cycle analysis accounted for greenhouse gas emissions related to CO_2 capture, compression, pipeline transport, CO_2 injection, oil processing, CO_2 recycle, dehydration, fugitive emissions, construction, land use, well drilling, oil transport, oil refining, hydrocarbon product combustion, and other processes. The analysis was based on site-specific operational records such as natural gas usage, drilling records, and system flow metering. Altogether, the upstream CO_2 capture, 'gate-to-gate' CO_2-EOR operations, and downstream fuel product refining/combustion had total emissions of [1,929,443] metric tons of CO_2 equivalent. Thus, the life cycle analysis showed [–159,907] metric tons of CO_2 equivalent net balance for the CO_2-EOR system for 1996–2017. The CO_2-EOR system obtains CO_2 from a gas processing facility that separates CO_2 from natural gas produced in the area, and the CO_2 would be otherwise vented to the atmosphere. A ready source of CO_2 that allowed a large volume of associated CO_2 storage, compressors that run on natural gas, a small pipeline distribution network, highly contained reservoirs, and government incentives to encourage CO_2 storage also contributed to the lower CO_2 emission balance when compared to other CO_2-EOR life cycle studies. While this site had many favorable factors to result in net negative emissions, it provides an example of managing CO_2-EOR operations and optimizing associated CO_2 storage to reduce net greenhouse gas emissions." **Joel R. Sminchak, Sanjay Mawalkar, and Neeraj Gupta,** *Energy & Fuels.* (Subscription may be required.)

Comparing the explicit and implicit attitudes of energy stakeholders and the public towards carbon capture and storage.

The following is from the abstract of this article: "Research on the attitudes of energy stakeholders and the general public towards Carbon Capture and Storage is a necessary starting point for the industry to understand the development trajectory of the technology. However, previous studies have only used explicit approaches, such as self-report questionnaires, to measure attitudes. Some researchers have argued that explicit measures are not able to reflect participants' true thoughts. To investigate the potential gap between the results of explicit tests and the true attitudes of participants, this study uses the implicit association test, to detect the attitudes towards environmental technology for the first time (to [the authors'] knowledge), by comparing the explicit and implicit attitudes of energy stakeholders and the public towards carbon capture and storage. The results indicate that energy stakeholders hold favorable attitudes, whereas public vary across the two tests. Public show supportive attitudes in the explicit test, but present their concerns about the risk of carbon capture and storage in the implicit test. The inconsistencies between the explicit and implicit test results among the public indicate that researchers need to be very cautious about the method they use to understand attitudes towards carbon capture and storage as well as other environmental technologies. Further, [the authors] suggested that implicit association test would be an effective and easy-to-use approach to complement traditional explicit tests to discover participants' real attitudes towards environmental technologies in the future research." **Yan Sun, Yang Li, Bo-feng Cai, and Qi Li,** *Journal of Cleaner Production.* (Subscription may be required.)

The permitting procedure for CO_2 geological storage for research purposes in a deep saline aquifer in Spain.

The following is from the abstract of this article: "Most European Member States that transposed the *EU Directive 2009/31/CE* on geological storage of carbon dioxide to each national legislation have not yet developed a regulatory framework to govern the permitting process of this industrial activity. This scenario does not help the deployment of Carbon Capture and Storage (CCS) technologies, as regulators, administrations, operators and general public do not handle a clear compendium of rules and standards to follow. This lack of regulation affects even more to the on-shore sites, which are usually surrounded by communities, industries, farms and other environmental elements that require the compliance of regulations to assure safe and controlled industrial processes. This article describes and analyses the workflow followed for granting the storage permit of Hontomín Technology Development Plant (TDP) in Spain. Hontomín is today the only onshore CO_2 injection site in Europe, recognized by the European Parliament as a key test facility for CCS technology development. The authors aim to show the experience gained from this real case as a guideline for regulators, operators and administrations to facilitate the grant of storage permits for supporting the development of industrial scale projects." **J. Carlos de Dios and Roberto Martínez,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

An economic-environmental asset planning in electric distribution networks considering carbon emission trading and demand response.

The following is from the abstract of this article: "Initiatives such as government programs and investment in low-carbon technologies have been adopted to mitigate the carbon emissions in the electricity sector. These initiatives have resulted in new challenges in the power sector, and to address them adequately, innovative frameworks are required in the electric distribution network (EDN) expansion planning and operation problems. Therefore, this work proposes an environmentally committed asset planning approach to remedy the existing issues to some extent. The proposed strategy investigates the benefits of the simultaneous allocation of several assets such as capacitor banks (CBs), distributed generation (DG) units based on renewable energy sources, and energy storage systems (ESSs). Moreover, an innovative carbon emission trading scheme is formulated in the planning stage to mitigate the CO_2 emissions while a demand response program is applied to modify the consumption behavior. The proposed approach is formulated as a two-stage robust mixed-integer programming model, which considers uncertainties associated with the electricity demand and renewable-based DG. To cope with the difficulties of this complex model, utilizing an efficient decomposition algorithm, such as the C&CG decomposition algorithm, is essential. The potential of the proposed approach is studied under different operating conditions and via several test cases on a 137-node EDN. In addition, to validate the performance of the proposed carbon emission scheme, a multi-region 54-node distribution network is adequately evaluated. Results show that by considering simultaneously multiple planning alternatives, carbon emission trading scheme, and the demand response program, the total CO_2 emissions are reduced by up to 15%." **Ozy D. Melgar-Dominguez, Mahdi Pourakbari-Kasmaei, Matti Lehtonen, and José R. Sanches Mantovani,** *Electric Power Systems Research.* (Subscription may be required.)

Price dynamics in the European Union Emissions Trading System and evaluation of its ability to boost emission-related investment decisions.

The following is from the abstract of this article: "The price of permits in the European Union Emissions Trading System (EU ETS) has historically been highly sensitive and prone to jumps. [The authors] consider different stochastic processes to model the price of permits, and show that the Variance Gamma (VG) model provides the best fit for the price distribution, among a selection of infinite activity processes. Using this result as a starting point, [the authors] assess the effects of the EU ETS in delivering low-carbon investments at the firm level, by modeling a price taker electricity producer subject to the EU ETS jurisdiction. [The authors] compute, via Least Squares Monte Carlo, the value of the real option the greenhouse gas emitter has, consisting in the opportunity to switch from its current high-carbon technology to a cleaner one. [The authors] use a VG specification for carbon prices, and a mean-reverting (Brennan–Schwartz) process for the price of fuel. Moreover, [the authors] further analyze the investment decision problem, in case of a CO_2 price stabilization mechanism in the form of a price floor, by explicitly computing the expected value of the investment project by means of Fourier methods. [The authors'] results show that the introduction of the price stabilization mechanism significantly affects the timing of the investment decision, and supports emission-related investments." **Maria Flora and Tiziano Vargiolu,** *European Journal of Operational Research.* (Subscription may be required.)

Flexible Carbon Capture and Utilization technologies in future energy systems and the utilization pathways of captured CO_2.

The following is from the abstract of this article: "Future 100% renewable energy systems will have to integrate different sectors, including provision of power, heating, cooling and transport. Such energy systems will be needed to mitigate the negative impacts of economic development based on the use of fossil fuels, but will rely on variable renewable energy resources. As two-thirds of global greenhouse gas emissions can be attributed to fossil fuel combustion, decarbonization of energy systems is imperative for combating the climate change. Integrating future energy systems with CO_2 capture and utilization technologies can contribute to deep decarbonization. As these technologies can be operated flexibly, they can be used to balance the grid to allow for high levels of variable renewable energy in the power mix. The captured CO_2 can be either utilized as a feedstock for various value-added applications in the chemical industry and related sectors such as the food and beverage industries. This paper reviews the state-of-the-art literature on CO_2 capture and utilization technologies, with an emphasis on their potential integration into a low-carbon, high-renewables penetration grid. The potential market size for CO_2 as raw material is also elaborated and discussed. The review paper provides an insight to the development and the technological needs of different energy system sectors, as well the limitations, challenges and research gaps to the integration of the variable renewable energy sources and flexible carbon capture and utilization technologies." **Hrvoje Mikulčić, Iva Ridjan Skov, Dominik Franjo Dominković, Sharifah Rafidah Wan Alwi, Zainuddin Abdul Manan, Raymond Tan, Neven Duić, Siti Nur Hidayah Mohamad, and Xuebin Wang,** *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

Improved Vinegar & Wellington calibration for estimation of fluid saturation and porosity from CT images for a core flooding test under geologic carbon storage conditions.

The following is from the abstract of this article: "X-ray computed tomography (CT) of fluid flow in formation rocks is an important characterization technique in geologic carbon sequestration research to provide insight into the migration and capillary trapping of CO_2 under reservoir conditions. An improved calibration method adapted from traditional Vinegar & Wellington calibration is proposed to map the 3D pore and fluid distributions from the CT images of CO_2/brine displacement flooding. Similar to Vinegar & Wellington calibration, the proposed method adopts the linear scaling law of CT number transformation to mass density. However, different from Vinegar & Wellington calibration that uses a 100% brine-saturated core image and a 100% CO_2-saturated core image as references to calculate CO_2 and brine saturations at all time steps, the proposed method uses the CT numbers of CO_2 and brine to calculate the incremental of CO_2 and brine saturations from time step i to time step i +1. The method is intended for cases in which the two 100% brine saturation and 100% CO_2 saturation images can not be successfully obtained. Overall, the improved calibration proposed by this study presents more reasonable results of CO_2 and brine distribution in a Berea sandstone core, as compared to traditional Vinegar & Wellington calibration. The reconstructed porosity image agrees with the laminated structure of the Berea sandstone core, and the average porosity evaluated over the entire core (0.176) is comparable to the physical porosity (0.165). Furthermore, the reconstructed saturation images using the improved calibration reveal a flat piston-like flooding front from a homogeneous longitudinal-section of the 3D orthogonal view and preferential fingerings from another non-homogeneous longitudinal-section, which are not present in the reconstructed saturation images using traditional Vinegar & Wellington calibration. Concerns and causes with respect to the uncertainty of linear CT number calibration are also explained, and approaches to alleviate the uncertainty are suggested." Xiuxiu Miao, Yan Wang, Liwei Zhang, Ning Wei, and Xiaochun Li, *Micron*. (Subscription may be required.)

Towards carbon sequestration using stainless steel slag via phase modification and co-extraction of calcium and magnesium.

The following is the abstract of this article: "Iron– and steelmaking processes produce a large quantities of greenhouse gas and metallurgical slag. Using Ca/Mg–rich phases in the slag to capture and bind the CO_2 via mineral carbonation is a promising approach to reduction of emissions and solid wastes to be landfilled. However, Cr–bearing stainless steel slag (SSS) cannot straightforwardly be employed for carbon capture and storage (CCS) or rather carbon capture and utilization (CCU). For the dual–purpose of chromium immobilization and co–extraction of calcium and magnesium, a slag modification using added MnO is performed followed by an acid leaching treatment. Results show that the MnO content has a significant influence on the phase composition and element distribution of SSS. A Box–Behnken design (BBD) based acid leaching treatment of SSS is investigated and optimized. Second-order polynomial regression models that reveal a functional relationship between processing parameters and leaching yields of calcium and magnesium are established and verified by the analysis of variance (ANOVA). Model calculation results show a good agreement with the experimental data. The direct (linear) and cross-correlated effects of the processing parameters on the leaching yields are illustrated by three-dimensional (3D) response surfaces. The maximum leaching yields of calcium and magnesium obtained in this work are 65 % and 55 %, respectively, while for chromium the leached amounts are well below legislative limits." Qing Zhao, Kun Liu, Lifeng Sun, Chengjun Liu, Maofa Jiang, Henrik Saxén, and Ron Zevenhoven, *Process Safety and Environmental Protection*. (Subscription may be required.)

Understanding public support for carbon capture and storage policy: The roles of social capital, stakeholder perceptions, and perceived risk/benefit of technology.

The following is from the abstract of this article: "As climate change mitigation technologies emerge, there is an increased need to understand public support for the technology and the policies that will shape or thwart its evolution. Of particular importance are the communities most directly impacted. The current study focuses on a random sample of 970 adults in eight counties within the oil and gas industry-reliant region of southeast Texas in order to explore support for carbon capture and storage (CCS), which is a climate change mitigation technology that has seen a great deal of investment in that area. Results of ordinary least squares (OLS) regression analysis and general linear modeling (GLM) suggest that policy support – individual support and perceived community support – is dependent on perceived risks and benefits of CCS, community-focused perceptions (including Bourdieu's social capital), and perceptions about stakeholders (trustworthiness and expected role in CCS policy making). One key takeaway is that social capital was both a predictor and moderator in community-level CCS support and helped explain the hidden effects of risk perception of CCS and CCS knowledge on community-level CCS support. Implications for public policy and stakeholder relations are discussed." Won-Ki Moon, Lee Ann Kahlor, and Hilary Clement Olson, *Energy Policy*. (Subscription may be required.)

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Safe Geologic Storage of Captured Carbon Dioxide: Two Decades of DOE's Carbon Storage R&D Program in Review.

The following is from the Executive Summary of this DOE/NETL document: "Carbon capture, utilization, and storage (CCUS) is widely regarded as a necessary component in the global effort to reduce carbon dioxide (CO_2) emissions to the atmosphere in a cost-effective way. A key question about the viability of CCUS with respect to protection of human health and the environment is how to ensure that CO_2 injected in deep geologic reservoirs is securely stored. Geological storage of CO_2 has been a natural process in the Earth's upper crust for hundreds of millions of years. While this provides supporting evidence that CO_2 can be securely and safely contained in the deep subsurface, it is vitally important that the technical means exist to identify suitable sites and monitor stored CO_2 to verify secure containment. The U.S. Department of Energy (DOE) has invested more than $1 billion during the past two decades through its Carbon Storage Research and Development (R&D) Program to develop the technologies and capabilities for widespread commercial deployment of geologic storage. This investment has made DOE a leader in this worldwide effort. CCUS projects supported by DOE and other organizations around the world, which in 2019 injected more than 25 million metric tons of CO_2, have shown no adverse impacts to human health or the environment. And no DOE supported project has observed migration of CO_2 outside of the intended storage reservoir or confining cap rock. Increasing years of experience and a preponderance of successful projects will promote even further confidence in secure storage for operators, regulators, insurers, financial institutions, environmental groups, and the public."

Industrial Sources Carbon Capture Retrofit Database.

The following is a description of this DOE/NETL database: "This tool provides high-level analysis on the incremental costs for retrofitting point sources with carbon dioxide (CO_2) capture and/or compression systems applied to various high purity industrial CO_2 sources. Options are available to include costs of other technological improvements that would be required to comply with various regulations and New Source Performance Standards when installing CO_2 scrubbing technology."

Assessment of CO_2-enhanced oil recovery and associated geologic storage potential in the Michigan Northern Pinnacle Reef Trend.

The following is from the abstract of this article: "This paper provides an improved estimate of CO_2-EOR (where CO_2 is carbon dioxide and EOR is enhanced oil recovery) and CO_2 storage potential for depleted oil fields in Michigan's northern pinnacle reef trend (NPRT). [The authors'] methodology is based on capturing data on reservoir performance from reefs currently undergoing CO_2-EOR operations in the NPRT (referred to as 'monitored reefs'), and then applying them to other reefs within the NPRT (referred to as 'catalog reefs'). For each monitored reef, [the authors] calculate fractional primary recovery, fractional incremental EOR recovery, net utilization ratio, and storage efficiency factor. The corresponding incremental oil recovery from EOR, storage capacity until end of EOR, and total CO_2 injection needs are then estimated for each catalog reef and combined (over all monitored reefs) using a weighted averaging procedure. These weights are related to a statistical similarity measure that is calculated between each monitored reef and each catalog reef based on a number of variables related to production data, formation type, or descriptive geologic attributes. For the entire NPRT catalog of 383 reefs as used in this study, [the authors'] results indicate 118 million (MM) stock tank barrels (STB) (1.88×10^7 Sm3) of incremental oil from EOR operations, corresponding to 49 MM metric tons (MT) of CO_2 storage and 266 MM MT of total CO_2 injection. However, approximately one-third of the reefs provide two-thirds of the potential for CO_2-EOR and geologic storage, assuming an economic threshold of 0.5 MM STB (80 000 Sm3) of incremental oil from EOR." **Srikanta Mishra, Autumn Haagsma, Manoj Valluri, and Neeraj Gupta,** *Greenhouse Gases: Science and Technology.* (Subscription may be required.)

Carbon dioxide storage resource assessment of Cretaceous- and Jurassic-age sandstones in the Atlantic offshore region of the northeastern United States.

The following is from the abstract of this article: "Carbon capture and storage is a critical technology for ensuring a range of clean energy options are available to meet future energy demand in the United States and abroad. A total of 1079 industrial CO_2 emission sources are located in the northeastern United States, where challenging surface and subsurface conditions limit onshore CO_2 storage potential. A systematic resource assessment was conducted using industry-standard resource classification methods established by the Society of Petroleum Engineers' Storage Resources Management System to characterize CO_2 storage resources in the middle–northern Atlantic offshore region along the eastern United States. Storable CO_2 quantities and storage efficiencies were estimated for Cretaceous- and Jurassic-age sandstone sequences. Regional data integration and analysis were conducted to estimate storable quantities and storage efficiencies using probabilistic methods with static volumetric calculations and dynamic simulations. Offshore storage efficiencies range from 1% to 13%, with regional-scale estimates of 37–403 billion t (Gt) of CO_2 classified as prospective storage resources. Dynamic CO_2 injection simulation in a middle Cretaceous sequence on the eastern flank of the Great Stone Dome suggests 30–51 million t of CO_2 can be stored and contained within the time and pressure constraints assumed for a commercial storage project. The regional Cretaceous and Jurassic plays identified in the offshore study region have prospective storage resources sufficient for long-term storage of CO_2 from nearby industrial sources onshore. Continued resource discovery efforts are recommended to assess the development and commerciality of the potential storage identified near the Great Stone Dome." **Isis Fukai, Laura Keister, Priya Ravi Ganesh, Lydia Cumming, Will Fortin, and Neeraj Gupta,** *Environmental Geosciences.* (Subscription may be required.)

An analysis of research hotspots and modeling techniques on carbon capture and storage.

The following is from the abstract of this article: "With the significant role that carbon capture and storage (CCS) could play in limiting the future temperature increase to below 2°C higher than pre-industrialization levels, a growing research interest of CCS is attracted to the environmental, economic, and social field. However, a bibliometric analysis-based comprehensive review of CCS which covers mainly all industry sectors and all regions of the globe has not been made yet. To provide deeper insight into the research trends, this study employs a bibliometric analysis to examine the basic features of the literature from 1997 to 2017 and identifies the key research hotspots and modeling techniques by reviewing the current status and new efforts. Based on the analysis of the temporal and spatial trends, disciplines and journals distribution, institutions, authors, and citations, the publications relating to the environmental, economic and social aspects of CCS are assessed. The results indicate that the total number of publications has rapidly increased since 2006 and entered a stable stage. The most productive country, journal, institute, and author are the USA, International Journal of Greenhouse Gas Control, United State Department of Energy, and Rubin E S, respectively. Based on the co-occurrence analysis of keywords, five hot research topics in CCS are recognized, including tackling climate change, CCS technology prospects, cost estimates, sectoral applications, and social attitudes. In addition, three main methodologies including life cycle analysis, optimization methods, and real options methods used in quantifying the social, economic, and environmental impacts of CCS are thoroughly refined based on selection, limitation, and improvement. Finally, the recommendations for CCS future work concerning environmental, economic, and social aspects are proposed." **Hui Li, Hong-Dian Jiang, Bo Yang, and Hua Liao,** *Science of the Total Environment.* (Subscription may be required.)

Time-lapse gravity monitoring of CO_2 migration based on numerical modeling of a faulted storage complex.

The following is from the abstract of this article: "In this study, the performance of both surface and borehole time-lapse gravity monitoring to detect CO_2 leakage from a carbon storage site is evaluated. Several hypothetical scenarios of CO_2 migration in a leaky fault, and thief zones at different depths at the Kimberlina site (California, USA) constitute the basis of the approach. The CO_2 displacement is simulated using the TOUGH$_2$ simulator applied to a detailed geological model of the site. The gravity responses to these CO_2 plumes are simulated using forward modeling with sensors at ground surface and in vertical boreholes. Results of inversion on one scenario are also presented. The surface-based gravity responses obtained for the different leakage scenarios demonstrate that leakage can be detected at the surface in all the scenarios but the time to detection is highly variable (10–40 years) and dependent on the detection threshold considered. Borehole measurements of the vertical component of gravity provide excellent constraints in depth when they are located in proximity of the density anomaly associated with the presence of CO_2, thus discriminating multiple leaks in different thief zones. Joint inversion of surface and borehole data can bring valuable information of the occurrence of leakages and their importance by providing a reasonable estimate of mass of displaced fluids. This study demonstrates the importance of combining multiphase flow simulations with gravity modeling in order to define if and when gravity monitoring would be applicable at a given storage site." **Delphine Appriou, Alain Bonneville, Quanlin Zhou, and Erika Gasperikova,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Possibilities for CCUS in medium temperature geothermal reservoir.

The following is from the abstract of this article: "Based on the hypothetical structure, a 3D numerical simulation model was created to examine the flow characteristics of a geothermal field. According to the known dimensions, assumption of existing fault and petrophysical properties, the model can relate to the properties of Velika Ciglena geothermal reservoir, and thus the simulation results of heat flow (reservoir cooling due to reinjection of cooled water), wellbore injectivity and productivity are comparable with previously published data related to the same field. This simulation model for a geothermal reservoir of such structure has been made for the first time and was complemented by an analysis of possible CO_2 injection. It has been established that the effect of CO_2 storage is significant until CO_2 reaches the production well (first two years). The effect of pressure relief on the CO_2 injection well has been achieved because of simultaneous injection and production and due to an increase in CO_2 saturation which had consequently induced an increase of the effective permeability for CO_2. The effect of reservoir cooling is shown, which is significant only when the water is injected, while in the case of injection and production of CO_2, this effect does not reflect on the temperature of the produced fluid." **Domagoj Vulin, Lejla Muhasilović, and Maja Arnaut**, *Energy*. (Subscription may be required.)

A study on the thermal-hydrodynamical-coupled CO_2 flow process in the Ordos CCS-geological-formation.

The following is from the abstract of this article: "Non-isothermal flow in wellbores and geological formations is an important process associated with geologic storage of CO_2. Technically, simulation of it is a highly challenging task as it often encounters phase transition problems for the fluids involved, which may greatly influence the profiles of pressure, temperature, and flowrate along the wellbore and consequently changes the injectivity of the relevant gas injection. In this paper [the authors] present a coupled non-isothermal wellbore/reservoir model for simulating the relevant flow behaviors, in which the non-isothermal wellbore flow model CO_2Well and the reservoir simulator TOUGH$_2$/ECO$_2$N are combined to form a novel coupled flow model. The model developed is compared and verified by the existing wellbore-reservoir simulator T2Well with two CO_2 injection examples. These examples demonstrate that the present method has considerable computational advantages in simulating wellbore flows when phase transition occurs. [The authors] then apply this model to the Ordos CCS demonstration project in China, and investigate the sophisticated, thermal-hydrodynamically-coupled flow processes observed there owning to injection of the condensed, cold CO_2 that was directly captured from a nearby coal liquefaction plant. The results obtained by the simulation, along with the relevant field observations, provide in-depth insights into the CO_2 flow behaviors in both the wellbore and the geological formation. For example, the simulation revealed that, in the wellbore, the heat exchange between the injected CO_2 and the surrounding rock plays a critical role for the temperature distribution. It was also observed that phase transition occurred in the transferred period between the injection time and the shut-in time. In addition, both the simulation and field observation showed that most CO_2 injected entered the topmost layer due to the high transmissivity of the rock. The simulation also showed that the temperature-change zone travelled slower than the CO_2 plume. For example, the CO_2 plume extended to 430 m away from the injection site after 31 months of CO_2 injection, while the temperature-change zone extended merely about 90 m away, much smaller than that of the CO_2 plume. The simulation suggests that the injectivity at this site is about 0.83 kg/(MPa·s). The simulation also suggests that the injection temperature should be relatively high (e.g., above –3°C if the injection rate is more than 9.45 kg/s) to avoid formation of CO_2 hydrate in the subsurface." **Hongwu Lei, Yuna Cai, Meng Lu, Xiaochun Li, and Luke Daulton Connell,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Materials and logistics for carbon dioxide capture, storage and utilization.

The following is from the abstract of this article: "The efforts to curtail carbon dioxide presence in the atmosphere are a strong function of the available technologies to capture, store and usefully utilize it. Materials with adequate CO_2 sorption kinetics that are both effective and economical are of prime importance for the whole capture system to be built around. This work identifies such materials that are currently used in CO_2 adsorption beds/columns at different global locations, along with their vital operational parameters, logistics and costs. Three main classes of materials currently in use to that end are discussed in detail here, namely solid sorbents, advanced solvents membrane systems. These materials are then compared in terms of their potential CO_2 uptake, operating parameters and ease of use and implementation of the respective technology. Tabular data are appended to each technology covered with the most relevant advantages and disadvantages. With such comprehensive survey of the recent state-of-the-art materials, recommendations are also made to facilitate the selection of systems based on their CO_2 yield, price and suitability to the geographical location." **Abdul Hai Alami, Abdullah Abu Hawili, Muhammad Tawalbeh, Rita Hasan, Lana Al Mahmoud, Sara Chibib, Anfal Mahmood, Kamilia Aokal, and Pawarin Rattanapanya,** *Science of The Total Environment*. (Subscription may be required.)

The flow of embodied carbon through the economies of China, the European Union, and the United States.

The following is from the abstract of this article: "Indirect CO_2 emissions are gaining increasing interests in addition to direct CO_2 emissions, as policy makers become more aware of the possibilities for structural and technical change, sometimes resulting from policies, to move CO_2 emissions along supply chains. An analysis of the composition of emissions and carbon efficiency of production and their development over time may inform the formulation of demand-side and supply-side solutions for emission reduction over the entire life-cycle. In addition, understanding of emissions embodied in trade (EET) at intermediate and final stages is crucial for allocation of emission responsibilities in a fair manner. Hence, [the authors] account for global direct and indirect intermediate and final CO_2 emissions using the global, multiregional input-output model EXIOBASE 3.3. [The authors] present results for the flow of embodied carbon through the economies of 49 countries and regions using an interactive visualization and provide a comparative analysis of China, the US, and the EU. It shows that China has undergone rapid, continuous increase in both intermediate and final indirect CO_2 emissions compared to the other two economies from 1995 to 2015, to 26.1 Pg and 11.0 Pg respectively. Emission intensities in China are on average 3.7 times of the US and 2.4 times of the EU in the year 2015, implying the possibility of further reducing emission by efficiency improvement and fuel switching. CO_2 EETs of intermediate production by sectors in the three economies are also reported." **Kehan He and Edgar G. Hertwich,** *Resources, Conservation and Recycling*. (Subscription may be required.)

Inventory management in supply chains with consideration of Logistics, green investment and different carbon emissions policies.

The following is from the abstract of this article: "This study investigates the effects that carbon policies and green technologies may have on the integrated inventory of a two-echelon supply chain with consideration of carbon emissions during the processes of product production, transportation, and storage. The three carbon emissions policies: limited total carbon emissions, carbon taxation, and cap-and-trade, are considered in the study. The proposed model can assist firms in determining their corresponding optimal production quantity, delivery quantity, and green investment amount with an aim of minimizing the costs under different carbon emissions policies. Moreover, this study also provides practical implications for the government to make appropriate policies and regulations in balancing the trade-off between environmental protection and economic growth. Finally, the results indicate that firms adopting the carbon tax policy would prefer to invest in a relatively efficient green technology. With regard to the sources of carbon emissions, the effects of unit carbon emissions during production and unit distance of transportation are the most dramatic, and the cap limit has greater effects than the carbon emissions reduction factor of the green technology. Besides, the government should set the limit of carbon emissions within a reasonable range under the cap-and-trade policy to avoid suppliers overly trading their quotas of carbon emissions." **Yeu-Shiang Huang, Chih-Chiang Fang, and Ying-An Lin,** *Computers & Industrial Engineering*. (Subscription may be required.)

Proglacial freshwaters are significant and previously unrecognized sinks of atmospheric CO_2.

The following is from the abstract of this article: "Carbon dioxide (CO_2) emissions from freshwater ecosystems are almost universally predicted to increase with climate warming. Glacier-fed rivers and lakes, however, differ critically from those in nonglacierized catchments in that they receive little terrestrial input of organic matter for decomposition and CO_2 production, and transport large quantities of easily mobilized comminuted sediments available for carbonate and silicate weathering reactions that can consume atmospheric CO_2. [The authors] used a whole-watershed approach, integrating concepts from glaciology and limnology, to conclusively show that certain glacier-fed freshwater ecosystems are important and previously overlooked annual CO_2 sinks due to the overwhelming influence of these weathering reactions. Using the glacierized Lake Hazen watershed (Nunavut, Canada, 82°N) as a model system, [the authors] found that weathering reactions in the glacial rivers actively consumed CO_2 up to 42 km downstream of glaciers, and cumulatively transformed the High Arctic's most voluminous lake into an important CO_2 sink. In conjunction with data collected at other proglacial freshwater sites in Greenland and the Canadian Rockies, [the authors] suggest that CO_2 consumption in proglacial freshwaters due to glacial melt-enhanced weathering is likely a globally relevant phenomenon, with potentially important implications for regional annual carbon budgets in glacierized watershed." **Kyra A. St. Pierre, Vincent L. St. Louis, Sherry L. Schiff, Igor Lehnherr, Paul G. Dainard, Alex S. Gardner, Pieter J. K. Aukes, and Martin J. Sharp**, *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required.)

JUNE 2020

Computed Tomography Scanning and Geophysical Measurements of the T.R. McMillen #2 Core.

The following is from the abstract of this DOE/NETL document: "The computed tomography (CT) facilities and the Multi-Sensor Core Logger (MSCL) at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia were used to characterize core from the Carbon Safe Christian County project, T.R. McMillen #2 well (API 1202125650). The primary impetus of this work is a collaboration between the U.S. Department of Energy (DOE) and the Illinois State Geologic Survey at the University of Illinois, Urbana-Champaign. 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/carbonsafe-tr-mcmillen-2*. […] Imaging with the NETL medical CT scanner was performed on the entire core. Qualitative analysis of the medical CT images, coupled with X-ray fluorescence (XRF), P-wave, and magnetic susceptibility 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 the core; the resulting macro and micro descriptions are relevant to many subsurface energy related examinations traditionally performed at NETL."

U.S. DOE/NETL large pilot-scale testing of advanced carbon capture technologies.

The following is from the abstract of this article: "The mission of the United States (U.S.) Department of Energy/National Energy Technology Laboratory (DOE/NETL) Carbon Capture Program is to develop the next generation of advanced CO_2 capture concepts for the power-generation sector. The Carbon Capture Program employs a down-selection process that graduates technologies from a large portfolio of laboratory/bench-scale projects to a smaller set of small-scale pilot projects and eventually to an even smaller group of large-scale pilot projects. At every scale, computer simulation plays a significant role in guiding experimental efforts and accelerating the overall pace of technology development. This down-selection process serves to de-risk industrial investment, given that there is insufficient information generated at the laboratory/bench scale to confidently predict eventual commercial success. The Carbon Capture Program is currently engaged in efforts to advance the next generation of capture technologies to large pilot scale. Three capture technologies have been awarded Phase I projects in a competition to build large-scale pilots for advanced energy and post combustion capture systems. In addition, six capture technologies are working toward large-scale pilot testing at Technology Center Mongstad in Norway. Advances along three innovation pathways—materials, processes, and equipment—have been critical in preparing these technologies for large pilot-scale testing. This paper describes the approach that is being followed by the Carbon Capture Program to advance the technologies and provides brief descriptions of the technical innovations that have prepared individual technologies for large pilot-scale testing." **Lynn Brickett, Ron Munson, and John Litynski,** *Fuel*. (Subscription may be required.)

A comparison of carbon dioxide storage resource estimate methodologies for a regional assessment of the Northern Niagaran Pinnacle Reef Trend in the Michigan Basin.

The following is from the abstract of this article: "The Northern Niagaran Pinnacle Reef Trend has more than 800 identified Silurian-aged pinnacle reefs in the Michigan Basin. The reefs have a long history of oil and gas production, gas storage, and more recently successful CO_2-enhanced oil recovery (EOR) operations. These fields provide an excellent opportunity to evaluate the geologic variability in complex carbonate reservoirs and its impact on carbon capture, utilization, and storage feasibility. A comprehensive database was built that identifies reefs and links key reservoir attributes to each field. Novel methodologies and techniques were developed to analyze hundreds of fields for CO_2 storage and EOR options. This included a regional static earth model to compute volumetric-based resource estimates, fluid substitution to estimate storage resources from oil and gas production, and proximity analysis–based weighting of reefs to predict reservoir performance metrics and estimate EOR. Lastly, an enhanced storage scenario of maximizing a reef's storage potential at the end of a CO_2-EOR life cycle was evaluated." **Autumn Haagsma, Joel Main, Ashwin Pasumarti, Manoj Valluri, Mackenzie Scharenberg, Glenn Larsen, Wayne Goodman, Amber Conner, Zachary Cotter, Laura Keister, William Harrison, Srikanta Mishra, Rick Pardini, and Neeraj Gupta,** *Environmental Geosciences*. (Subscription may be required.)

Development and application of a machine learning based multi-objective optimization workflow for CO_2-EOR projects.

The following is from the abstract of this article: "Carbon dioxide-Enhanced Oil Recovery (CO_2-EOR) is known as one of techniques for hydrocarbon production improvement as wells as an important candidate to reduce greenhouse gas emissions. Thus, an ideal development strategy for a CO_2-EOR project would consider multiple objectives including to maximize oil recovery, CO_2 storage volume and project economic outcomes. This work proposes a robust computational framework that couples artificial neural network (ANN) and multi-objective optimizers to optimize the aforementioned objectives in CO_2-EOR processes simultaneously. Expert ANN systems are trained and employed as surrogate models of the high-fidelity compositional simulator in the optimization workflow. The robustness of the development optimization protocol is confirmed via a synthetic injection-pattern-base case study. Afterward a field implementation to Morrow-B formation to optimize the tertiary recovery stage of the field development is discussed. This work compares the optimum solution found using an aggregate objective function and the solution repository (Pareto front) generated by the multi-objective optimization process. The comparison indicates the existence of potential multi-solutions satisfying certain criteria in a CO_2-EOR project designing, which cannot be found using traditional weighted sum method. The optimization results provide significant insight into the decision-making process of CO_2-EOR project when multiple objective functions are considered." **Junyu You, William Ampomah, and Qian Sun,** *Fuel*. (Subscription may be required.)

Application of bioelectrochemical systems for carbon dioxide sequestration and concomitant valuable recovery: A review.

The following is from the abstract of this article: "The rise in global atmospheric temperature due to increase in the atmospheric carbon dioxide concentration needs to be tackled immediately before it reaches the point of no return. The application of innovative technologies based on the concepts of bioelectrochemical systems (BESs) can contribute in this direction by simultaneously sequestrating CO_2 and producing value-added products in the process. Wastewater treatment with simultaneous bioenergy and biofuel recovery is also one of the added [advantages] of employing BESs for CO_2 fixation. This review focuses on the potential of employing BES-based technologies like microbial carbon capture, plant-microbial fuel cell and microbial electrosynthesis cell for the concomitant production of valuables and CO_2 sequestration. Also, various parameters affecting performance of BES that need to be optimized for the proper field-scale demonstration of these technologies are discussed." **Sovik Das, Swati Das, Indrasis Das, and M.M. Ghangrekar,** *Materials Science for Energy Technologies*. (Subscription may be required.)

Mitigation of carbon dioxide by accelerated sequestration in concrete debris.

The following is from the abstract of this article: "Carbon capture and storage is becoming increasingly feasible. This study provides a novel quantitative analysis of the global CO_2 mitigation potential through accelerated carbon sequestration in concrete debris separated from construction and demolition waste. [The authors] consider the economic and environmental tradeoff. Based on data collection from 14 large regions and countries, [the authors] created a method to estimate and project the generation of concrete debris, recycling and carbonation rates, and cost. The overall concrete debris generation was more than 3.0 (0.6) billion tonnes (Bt) in 2017 worldwide, mainly from emerging countries such as China and India. This debris has the potential to mitigate 62.5 (8.9) million tonnes (Mt) CO_2 under optimal carbonation conditions determined by pressure, temperature, humidity, time, CO_2 concentration, and debris size. [The authors'] scenario analysis reveals that the global cumulative carbonation of concrete debris could be as high as 3.0 Bt CO_2 between 2018 and 2035, which equals approximately one third of the total CO_2 emissions from fuel combustion of China in 2016. In our scenarios, the economic benefits of storing CO_2 by concrete debris are mainly from recycled concrete aggregate rather than carbon sequestration, but also consider the current carbon price in major carbon markets. These findings highlight an effective and practical approach to reuse concrete debris as well as enhancing economic benefits. This approach could be helpful to better manage the fast-growing concrete debris and need for carbon mitigation as well as bridging the gap of CO_2 sequestration by concrete debris between research and application." **Ning Zhang, Huabo Duan, Travis R. Miller, Vivian W.Y. Tam, Gang Liu, and Jian Zuo,** *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

When Is Blockchain Worth It? A Case Study of Carbon Trading.

The following is from the abstract of this article: "Blockchain, as an emerging technology and a disruptive innovation, has attracted attention from both academia and industry. However, there are many potential risks associated with it, such as the technical risk, the legal risk and the privacy risk. A comprehensive risk analysis is crucial for cost-effective deployment of blockchain technology. Important adoption decisions, including when to deploy blockchain, how to plan the investment, how to transfer current businesses onto blockchain, and how to price the blockchain service depend on this risk analysis. Yet very little study exists concerning the blockchain adoption planning with risks analysis. This research presents a cost-and-risk analysis framework and an adoption planning method for the case of blockchain application in carbon trading. Design requirements implied by the analysis are inferred and the architecture of a novel hybrid blockchain system is proposed. The system leverages the advantages of blockchain technology and incorporates institutional risk control framework. The optimal adoption strategy of this system is derived through modelling of users' and the organizer's behavior." **Fangyuan Zhao and Wai Kin (Victor) Chan,** *Energies*. (Subscription may be required.)

Evaluating the efficiency of carbon emissions policies in a large emitting developing country.

The following is from the abstract of this article: "Using the energy-environmental version of the Global Trade Analysis Project, this study compares the effects of three carbon emissions mitigation strategies – a carbon tax, a fuel tax and an emissions trading scheme (ETS) to combat the intended emissions target for Indonesia, a large emitting developing country. Although the fuel tax was found to raise economic growth by 0.29% in 2030, the carbon tax and ETS which reduce economic growth by about 0.11% have less adverse effects on inflation, welfare loss, wage decline, and employment loss. Unlike the fuel tax, the carbon tax and ETS are also likely to promote substitution towards renewable energy given the massive increase in the price of coal of over 100% due to the carbon tax and ETS. To meet Indonesia's emissions target, a carbon tax of US$36/ton of CO_2 is needed. The carbon tax which is simpler and more swiftly implementable is the more practical choice compared to the ETS in the short to medium term for developing countries with political economy constraints in their energy and transportation sectors." **Sumali Dissanayake, Renuka Mahadevan, John Asafu-Adjaye,** *Energy Policy*. (Subscription may be required.)

Pricing decisions in a socially responsible supply chain under carbon cap-and-trade regulation.

The following is from the abstract of this article: "This article investigates a socially responsible supply chain under the cap-and-trade mechanism. Stylized centralized and decentralized models are established to characterize corporate social responsibility (CSR) in this supply chain. Analytical results reveal that the centralized case always achieves a higher socially responsible channel profit than the two decentralized models, but whether the centralized case achieves a higher pure channel profit than the decentralized scenarios depends on how heavier the weight is placed on CSR: when the weight is modest, the centralized model attains a higher pure channel profit, while a heavier weight on CSR leads to a higher pure channel profit for the two decentralized cases. [The authors] further examine how the CSR concern level and a government-set carbon cap-and-trade policy affect the operations of this socially responsible supply chain." **Zhi-chao Zhang, Kevin W. Li, Zhi Liu, and Jun Huang,** *IFAC-PapersOnLine*. (Subscription may be required.)

Carbon Taxes and CO_2 Emissions: Sweden as a Case Study.

The following is from the abstract of this article: "This quasi-experimental study is the first to find a significant causal effect of carbon taxes on emissions, empirically analyzing the implementation of a carbon tax and a value-added tax on transport fuel in Sweden. After implementation, carbon dioxide emissions from transport declined almost 11 percent, with the largest share due to the carbon tax alone, relative to a synthetic control unit constructed from a comparable group of OECD countries. Furthermore, the carbon tax elasticity of demand for gasoline is three times larger than the price elasticity. Policy evaluations of carbon taxes, using price elasticities to simulate emission reductions, may thus significantly underestimate their true effect." **Julius J. Andersson,** *American Economic Journal: Economic Policy*. (Subscription may be required.)

JULY 2020

Conceptual and Mathematical Foundation for the FE/NETL CO_2 Prophet Model for Simulating CO_2 Enhanced Oil Recovery.

The following is a description of this FE/NETL product: "This document provides the mathematical basis for the FE/NETL CO_2 Prophet Model. The FE/NETL CO_2 Prophet Model is a streamline/stream tube reservoir simulator for modeling CO_2 EOR. It is comprised of two Fortran programs, StrmtbGen (generates streamlines and stream tubes) and StrmtbFlow (solves the multiphase flow equations within stream tubes). StrmtbGen and StrmtbFlow along with their user's manuals are available on NETL's website under the Collection Name: FE/NETL CO_2 Prophet Model."

Net Zero and Beyond: What Role for Bioenergy with Carbon Capture and Storage?

The following is from the Introduction of this Chatham House research paper: "In the context of seeking to reduce greenhouse gas emissions to net zero, policymakers are beginning to pay more attention to options for removing carbon dioxide from the atmosphere – a process referred to as CDR ('carbon dioxide removal'). Without the rapid scale-up of such measures, achieving Paris Agreement temperature targets will be increasingly challenging: current emissions abatement efforts are not progressing quickly enough to prevent the world from overshooting global emissions targets. In theory, CDR measures may permit the total costs of a climate mitigation strategy to be reduced in absolute terms (or amortized over a longer period); enable ambitious targets (such as limiting global warming to 1.5°C) to become more feasible; or delay the point when peak emissions are reached, retroactively compensating for overshooting the cumulative carbon budget. A wide range of potential CDR measures are currently being discussed. Alongside afforestation and reforestation, the main option featuring in integrated assessment models (IAMs) is bioenergy with carbon capture and storage (BECCS). BECCS refers to a set of technologies and processes through which the carbon emissions from burning biomass for energy are captured before release into the atmosphere, and then stored in underground reservoirs. If this biomass energy is assumed to be carbon-neutral, BECCS should theoretically result in net negative emissions, as the accompanying carbon sequestered by biomass is permanently stored. The prominence of BECCS in the models does not, however, represent a prescriptive judgment about its merits relative to other negative emissions options. Nor does it necessarily validate the current, highly constrained, development trajectory of BECCS technology. It is, rather, a reflection mainly of the fact that BECCS is based on well-understood biology, so it is easier to make assumptions about and model the impacts on emissions at various carbon prices. In contrast, evaluating the potential of newer and more speculative negative emissions technologies is more challenging. In reality, there are many reasons to question the reliance on BECCS assumed in the models – including the carbon balances achievable, the substantial demand for land, water and other inputs that is associated with BECCS solutions, and the underlying assumption that technically and economically viable carbon capture and storage (CCS) technologies will be available 'off the shelf' in the near term, which is not being borne out in practice."

Active surface and borehole seismic monitoring of a small supercritical CO_2 injection into the subsurface: experience from the CO_2CRC Otway Project.

The following is from the abstract of this article: "Time-lapse (TL) (4D) seismic monitoring of injected CO_2 in geological formations is being increasingly employed as the principal method for ensuring containment of CO_2 and testing conformance of predicted plume behavior. However, to bring further confidence in this method, the CO_2 volume detection limit in the seismic monitoring and key factors controlling it need to be quantitatively understood. The CO_2CRC Otway Project attempts to improve this understanding by exploring the capability of seismic reflection method to detect and monitor a 15-kt injection of supercritical CO_2/CH4 mixture in a saline aquifer at a depth of 1500 m. The monitoring program consists of TL 3D seismic surveys using a buried geophone array, TL 3D vertical seismic profiling (VSP), and offset VSP. Seismic acquisition was carried out at injection intervals of 5, 10, and 15 kt over a 5-month period and also, 9 and 23 months after the end of injection. The TL seismic images clearly show the distribution and evolution of the stored CO_2/CH4 plume. The results demonstrate the potential of TL reflection seismic to provide key information to both operators and regulators for confirming the security and behavior of stored CO_2 at very small volumes." **Roman Pevzner, Milovan Urosevic, Konstantin Tertyshnikov, Hussain AlNasser, Eva Caspari, Julia Correa, Tom Daley, Tess Dance, Barry Freifeld, Stanislav Glubokovskikh, Andrew Greenwood, Anton Kepic, Dmitry Popik, Sofya Popik, Matthias Raab, Michelle Robertson, Valeriya Shulakova, Rajindar Singh… Boris Gurevich,** *Active Geophysical Monitoring* (Second Edition). (Subscription may be required.)

Imine-linked polymer/silica composites for CO_2 sequestration.

The following is from the abstract of this article: "The silica supported imine polymers are synthesized using a facile single step Schiff-base condensation. The formation of imine linkage on silica support is confirmed using FT-IR and solid state ^{13}C NMR. The crystallinity and surface morphology of the materials are examined by PXRD and SEM analyses. The thermal stability of the materials is confirmed from TGA analysis. N_2 sorption isotherms for Si-TPA-1 and Si-TPA-2 exhibit surface area of 105.8 m2/g and 404.5 m2/g respectively. The adsorption isotherms exhibit meso- and microporous environments of Si-TPAs. The CO_2 uptake capacity of Si-TPAs are around 38.86 mg/g - 121. 85 mg/g. The experimental adsorption data is fitted with Langmuir and Freundlich adsorption isotherm models. The thermodynamic parameters emphasis that the adsorption process is spontaneous and exothermic physisorption. Isosteric heats of adsorption for Si-TPAs are around 38.5–32.5 kJ/mol. The high selectivity of CO_2 over N_2 is obtained for both Si-TPAs at 273 K and also high selectivity of CO_2 over CH4 is achieved at 298 K." **Marimuthu Senthilkumaran, Lakshmanan Eswaran, Chokalingam Saravanan, Pillaiyar Puthiaraj, Perumal Rameshkumar, and Paulpandian Muthu Mareeswaran,** *Materials Chemistry and Physics.* (Subscription may be required)

Evaluating the efficiency of carbon emissions policies in a large emitting developing country.

The following is from the abstract of this article: "Using the energy-environmental version of the Global Trade Analysis Project, this study compares the effects of three carbon emissions mitigation strategies – a carbon tax, a fuel tax and an emissions trading scheme (ETS) to combat the intended emissions target for Indonesia, a large emitting developing country. Although the fuel tax was found to raise economic growth by 0.29% in 2030, the carbon tax and ETS which reduce economic growth by about 0.11% have less adverse effects on inflation, welfare loss, wage decline, and employment loss. Unlike the fuel tax, the carbon tax and ETS are also likely to promote substitution towards renewable energy given the massive increase in the price of coal of over 100% due to the carbon tax and ETS. To meet Indonesia's emissions target, a carbon tax of US$36/ton of CO_2 is needed. The carbon tax which is simpler and more swiftly implementable is the more practical choice compared to the ETS in the short to medium term for developing countries with political economy constraints in their energy and transportation sectors." **Sumali Dissanayake, Renuka Mahadevan, and John Asafu-Adjaye,** *Energy Policy*. (Subscription may be required.)

Methane production via syngas fermentation within the bio-CCS concept: A techno-economic assessment.

The following is from the abstract of this article: "The study provides a comprehensive approach on assessing the feasibility of a novel process configuration that couples synthetic natural gas (SNG) production via syngas fermentation with carbon capture and storage (CCS). The present research constitutes the first endeavour to examine the techno-economic performance of this sophisticated hybrid SNG+CCS infrastructure. For this purpose, a flowsheet analysis within the Aspen Plus environment served to quantify the material and energy flows and then based on the simulations technical and economic indicators were estimated. A plant processing 6.25 dt/h of virgin biomass yields 1.32 t/h of SNG, achieves 51.2% energy efficiency and stores 2.97 t/h of CO_2. The threshold SNG price (NPV=0) for the project to become economically viable is 92.14 £/MWh. A combination of existing policy schemes and the establishment of new instruments that will reward negative emissions has the potential to generate profits. A thorough cost breakdown along with a sensitivity analysis revealed that the process is CAPEX and feedstock intensive while larger plants can reduce the SNG price by about 15%. A stochastic Monte Carlo analysis indicated that even if the project shows promising techno-economic potential without the establishment of a consistent and robust legislation framework there is no realistic prospect for the proposed bio-CCS plant to compete with fossil natural gas." **Stavros Michailos, Oluchi Emenike, Derek Ingham, Kevin J. Hughes, and Mohamed Pourkashanian,** *Biochemical Engineering Journal*. (Subscription may be required.)

Modified mineral carbonation of phosphogypsum for CO_2 sequestration.

The following is from the abstract of this article: "A modified phosphogypsum carbonation was systematically investigated, and ammonium acetate was used to separate Ca^{2+} and concentrate impurity ions from PG. The effect of technological conditions on salt-leaching and carbonation results were discussed. The calcium leaching rate was 98.1%, and the only crystal phase of salt-leaching product was quartz with granular morphology and some pores in the surface. The carbonation ratio (η) was 98.32%, and 1000 kg of phosphogypsum produced 510 kg of high-purity CaCO3 and sequestered 224 kg of CO_2 under the optimized conditions. The spherical vaterite carbonation product met the recommended Chinese standard (HG/T 2226-2010). The carbonation filtrate can be reused for salt-leaching experiments. Various polymorph and morphology of CaCO3 were achieved by adjusting the carbonation temperature and ammonia dosage. The mechanism of phosphogpysum carbonation was studied by using thermodynamics research. All of this indicated that the whole procedure setup of phosphogypsum carbonation showed potential application for phosphogypsum utilization and CO_2 sequestration." **Wenjin Ding, Qiuju Chen, Hongjuan Sun, and Tongjiang Peng,** *Journal of CO_2 Utilization*. (Subscription may be required.)

Exploring the potential of carbon capture and storage-enhanced oil recovery as a mitigation strategy in the Colombian oil industry.

The following is from the abstract of this article: "The use of CO_2 for enhanced oil recovery (CO_2-EOR) is a promising alternative for reducing the cost of carbon capture and storage (CCS). In this study the techno-economic potential of integrated CCS-EOR projects for reducing greenhouse gas (GHG) emissions in the Colombian oil industry is estimated. For this purpose, a source-sink matching process is carried out, including CO_2 capture potentials in sources from the petroleum, cement, power generation, and bioethanol industries, as well as from the CO_2 storage in suitable oil fields for EOR. The results indicate that a total of 142 million tons of carbon dioxide ($MtCO_2$) could be stored, while delivering 465 MMbbl through five CCS-EOR projects in four clusters identified around the country. The levelised cost for capture ranged between 12–209 €/tCO_2, followed by the cost of CO_2 during EOR operations with a variation of 24–59 €/tCO_2, and finally the CO_2 transport, from 1 €/tCO_2 to 23 €/tCO_2. The CO_2 mitigation potential of CCS-EOR represents 25% of the forecasted oil industry emissions in Colombia for the period of 2025–2040. As compared to the intended nationally determined contribution (INDC) target set by the Colombian government, CCS-EOR projects could contribute 7% of the total accumulated emissions reductions by 2040." **Edgar Yáñez, Andrea Ramírez, Vanessa Núñez-López, Edgar Castillo, and André Faaij,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Impact of deadwood decomposition on soil organic carbon sequestration in Estonian and Polish forests.

The following is from the abstract of this article: "The deadwood of different tree species with different decomposition rates affects soil organic carbon sequestration in Estonian and Polish forests. In warmer conditions (Poland), the deadwood decomposition process had a higher rate than in cooler Estonian forests. Soil organic matter fractions analysis can be used to assess the stability and turnover of organic carbon between deadwood and soil in different experimental localities." **Ewa Błońska, Jarosław Lasota, Arvo Tullus, Reimo Lutter, and Ivika Ostonen,** *Annals of Forest Science*. (Subscription may be required.)

Challenges and potentials for soil organic carbon sequestration in forage and grazing systems.

The following is from the abstract of this article: "Forage and grazing (FG) systems can store a substantial amount of soil organic carbon (SOC) under appropriate land use management and reduce atmospheric CO_2 concentrations. Increasing SOC levels along with many interlinked ecosystem services are essential for increased productivity and sustainability of FG lands (FGLs). Although adoption of improved management practices (MPs) that support SOC sequestration (SOCq) is necessary, clear understandings of challenges and opportunities which are sometimes unique to individual FGLs, are also important for implementation of MPs. The objective of this forum paper is to explore the latest scientific knowledge on opportunities to address major challenges for increasing SOCq in FGLs. In intensively managed FGLs where the goal is often to maximize yields, lands are heavily fertilized and thus, usually drive towards SOC loss. Diversifications of both forage and grazing species along with strategic grazing plans have been proven as effective MPs for increasing SOCq. However, challenge of maintaining productivity levels still remains. Implementing improved grazing for nutrient cycling and integrating forage diversification for increased biodiversity are found to improve soil health attributes, which are critical for SOCq. However, to achieve this, [the authors] also need to consider site- and soil- specific factors. Extreme climatic events often lead to a decline in soil fertility status, SOCq and overall productivity of FGL systems. To address these challenges, uses of models to simulate the FGL systems and have definite choices of suitable MPs are helpful. However, [the authors] must be able to access a wide range of datasets to develop system-level adaption strategies that are effective in mitigating these adverse effects. Ultimately, participatory research with novel views and improved perceptions based on the value of SOCq and long-term benefits of the implementation of the best MPs and developing education and outreach materials to enrich the producers' knowledge gaps are helpful for climate-resilient FGL systems." **Reshmi Sarkar, Vanessa Corriher-Olson, Charles Long, and Anil Somenahally,** *Rangeland Ecology & Management*. (Subscription may be required.)

AUGUST 2020

The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update.

The following is from the Introduction of this Global CCS Institute brief: "This brief is intended for carbon capture and storage (CCS), climate and clean energy advocates, policymakers and projects developers globally and focuses on the latest developments with regards to the 45Q tax credit for carbon oxide sequestration in the US, including a summary of the guidance released so far. The US has a long history of providing energy tax credits to a variety of fuels and production methods. In the context of clean energy deployment, tax credits have become the preferred incentive structure by the federal government to spur the deployment of and unlock investment in clean energy. Examples include tax credits for energy efficiency investments, the federal Investment Tax Credit (ITC) for solar energy and the Production Tax Credit (PTC) for wind, all of which have delivered large amounts of renewable energy capacity. With the ability to claim tax credits depending on a clean energy developer's being profitable enough to owe taxes, a market for financing clean energy

has developed through these tax credits. Such tax equity partnerships allow a developer who is unable to claim the credits to secure financing by partnering with an investor – a tax equity investor."

A New Era for CCUS Driven by Contrasted Policies and Business Models: US and European Approaches.

The following is a summary of this CEDIGAZ document: "[…] There are currently 20 new, large-scale, CCUS projects planned around the world, nine of them in Europe. While projects developed in the middle of the 2000s mainly targeted coal-fired power plants and stored the captured carbon, the focus of the new projects is different as they tend to concentrate on industrial and manufacturing processes and on carbon utilization rather than just storage. Several projects involve production of clean hydrogen from natural gas, a cheaper option than hydrolysis using renewable power. New business models aim at reducing costs by dis-integrating the CCUS value chain into its three components of capture, transport and storage, and by addressing clusters of industrial facilities to achieve economies of scale. The US is the most advanced globally in terms of CCUS supporting policies. In February 2018, the US Congress passed substantial tax credits to encourage private investment in the deployment of CCUS. In addition, in September 2018, California amended its Low Carbon Fuel Standard (LCFS) program with a CCS Protocol. While insufficient to incentivize CCUS in existing facilities (retrofitting) or in the largest US emitting sectors like power plants or cement and steel production, they should help deploy CCUS on the 'low hanging fruits' which could lead to cost reduction for further projects through the learning curve and the deployment of shared infrastructure. As Europe's new energy strategy aims at a carbon neutral economy by 2050, large-scale deployment of CCUS appears necessary. The EC is supporting CCUS through a range of policy initiatives and has pledged to invest €10 billion in CCUS and other low-carbon technologies. Nine projects are currently under development, making Europe the leader in the renewed global effort to promote CCUS. They focus on energy intensive industries and those with inherent process emissions of CO_2 (e.g. cement). Gas-fired power plants are also targeted and several [projects] involve clean hydrogen production from natural gas. The business model of European CCUS projects is to develop multi-user 'hub and cluster' facilities in industrial regions, tied-in to shared transport and storage infrastructure. With different policy approaches and different incentives, the US and Europe both look to achieve global leadership in CCUS technologies and both recognize the crucial role of carbon management and CCUS in the future."

Assessment of CO_2 trapping mechanisms in partially depleted oil-bearing sands.

The following is from the abstract of this article: "The objective of this work is to evaluate various CO_2 sequestration mechanisms occurring in the Morrow B Sandstone in the Farnsworth Unit. A history-matched numerical simulation model was created using extensive geological, petrophysical, and operational data collected from the field. The numerical model is competent to investigate the impact of residual, structural-stratigraphic, solubility, and mineral trapping mechanisms on the fluid transportation dynamics and petrophysical property variations. The model forecasts the field response of 20 years of WAG injections. Afterward, all wells were shut-in, and the reservoir was allowed to evolve for 1000 years to investigate the fate of injected CO_2. In this paper, [the authors] assess the impacts of various trapping mechanisms on oil recovery and CO_2 storage efficacy. By analyzing the results reported from the numerical simulation model, the in-situ fluid composition and mineralogy changes are also investigated. More importantly, [the authors] seek to confirm the petrophysical property variations due to the CO_2 injection with observations from laboratory measurements. The experiences gained from this study provide valuable insights regarding physiochemical storage induced by the CO_2 injection activities and serve as a benchmark case for future CO_2 enhanced oil recovery (EOR) projects involving reactive solute transport." **Qian Sun, William Ampomah, Eusebius Junior Kutsienyo, Martin Appold, Benjamin Adu-Gyamfi, Zhenxue Dai, and Mohamed Reza Soltanian,** *Fuel*. (Subscription may be required.)

Mobilization of trace metals from caprock and formation rocks at the Illinois Basin – Decatur Project demonstration site under geological carbon dioxide sequestration conditions.

The following is from the abstract of this article: "One concern for geologic CO_2 sequestration is the potential leakage of CO_2 or CO_2-saturated brine containing trace metals into overlying aquifers, which poses the risk of adversely affecting underground sources of drinking water. In this work, rock and brine samples collected in the Illinois Basin – Decatur Project (IBDP), a large-scale geological CO_2 sequestration demonstration project in Decatur, Illinois, USA, as well as synthetic brine samples were used to understand the mobilization of trace metals as a result of CO_2–rock–brine interactions under IBDP-specific conditions (50°C and 20.6 MPa). Rock sample characterization indicated that, at the IBDP site, trace metal concentrations were greatest in cap rock samples from the Eau Claire Formation, compared with those from formations above and below this Formation. The natural brine samples collected from the Mt. Simon Sandstone reservoir were highly reducing and saline, with trace metal concentrations up to 680 times greater than the U.S. Environmental Protection Agency-prescribed drinking water standards. Batch leaching experiments indicated that both trace metal mobilization from rock and immobilization from the brine occurred when high-pressure CO_2 was introduced into the rock-brine system. The amounts of metals mobilized from the rock generally accounted for <5% of the total metals in the rock, but for some metals, including Ni, Pb, and Tl, up to 63% of the metals in the rock were mobilized to the brine. Leaching of trace metals into synthetic brines was different from that into the natural brine. The results of this study provided current information on the trace element sources and will help in risk simulations and experimental design to further evaluate potential impact of leakage on groundwater quality, which is important for future GCS projects to consider for monitoring and containment assurance purposes." **Hongbo Shao, Jared T. Freiburg, Peter M. Berger, Alexander H. Taylor, Hanna F. Cohen, and Randall A. Locke II,** *Chemical Geology.* (Subscription may be required.)

Can bioenergy carbon capture and storage aggravate global water crisis?

The following is from the abstract of this article: "Bioenergy carbon capture and storage (BECCS) is an effective option for mitigation of greenhouse gas (GHG) emissions. Nevertheless, there is barely serious debate about whether its implementation can possibly jeopardize the global water resources security. Here, [the authors] provided an assessment of biomass-based Substitute Natural Gas (BioSNG) production combined with CCS, a promising BECCS technology, in terms of global water resources security, with a focus on the growth of two typical second-generation bioenergy crops: *switchgrass* and *miscanthus*. A bottom-up analysis approach was applied in this paper to calculating water consumption for BECCS and estimating water quality deterioration caused by increasing fertilizer and pesticide application. The results indicated that water usage of BECCS was equal to adding 12.86%–16.64% (*switchgrass*) and 17.59%–26.06% (*miscanthus*) additional water stress on global available water resources at 2100. Additional N fertilizer application in 2100 would be equal to over 84%, 55% and 42% for both *switchgrass* and *miscanthus* under three CCS capture efficiency scenarios, respectively, comparing to such global scale in 2012. Additional phosphate fertilizer adding to global annual available water at 2100 were 0.004–0.008 mg L−1 (*switchgrass*) and 0.003–0.006 mg L−1 (*miscanthus*), respectively. The secondary environmental hazards, such as N_2O emission, would offset GHG emission mitigation by BECCS. Meanwhile, the enrichment and leaching of pesticide residues increased the risk of groundwater contamination. This study revealed water consumption and contamination issues caused by BECCS cannot be neglected. Thus, additional studies of accurate land-use models in global scale and advanced technology for biofuel extraction are needed in the future." **Bin Hu, Yilun Zhang, Yi Li, Yanguo Teng, and Weifeng Yue,** *Science of The Total Environment*. (Subscription may be required.)

Technical economic analysis of an intensified Integrated Gasification Combined Cycle (IGCC) power plant featuring a sequence of membrane reactors.

The following is from the abstract of this article: "In this work, a technical economic analysis (TEA) is carried-out for the design of an Integrated Gasification Combined Cycle (IGCC) power plant featuring a sequence of hydrogen-permeable ceramic membrane reactors (MRs). The proposed design features membrane reactors that generate hydrogen of higher purity than conventional reactor-separator systems used in IGCC plants, and enable over 90% carbon capture in the Dual-Stage Selexol unit. A multi-scale model is used to simulate the proposed MR sequence, and a commercial process flowsheet simulator is used to create the proposed intensified MR IGCC plant flowsheet, which is subsequently heat integrated. The TEA developed for the MR IGCC power plant allows for the economic characteristics of its design to be compared with those of a traditional IGCC plant equipped with carbon capture storage (CCS) technology." **Patricia A. Pichardo, Seçgin Karagöz, Theodore Tsotsis, Richard Ciora, and Vasilios I. Manousiouthakis,** *Journal of Membrane Science*. (Subscription may be required.)

CO_2 storage and CaCO3 production using seawater and an alkali industrial by-product.

The following is from the abstract of this article: "Indirect carbonation is one of the typical carbon capture, utilization, and storage technologies. It is well known, however, that the technology is very difficult to achieve economic feasibility because expensive chemical solvents used account for most of the cost. To overcome this limitation, [the authors] performed an experimental study to secure the economic feasibility of the technology by replacing such chemical solvents with nearly costless seawater. For the study, [the authors] used cement kiln dust (CKD), which is an alkali industrial by-product, together with seawater. In this paper, [the authors] attained CO_2 storage and CaCO3 yield despite the use of seawater, which is comparable in both quantitative and qualitative respects to the existing studies using chemical reagents. The CO_2 storage and CaCO3 yield were 185kg-CO_2/ton-CKD and 419kg-CaCO3/ton-CKD, respectively. With the addition of Mg into the seawater, moreover, the amounts could significantly increase to reach 271kg-CO_2/ton-CKD and 615kg-CaCO3/ton-CKD, respectively. Despite using CKD and seawater containing many impurities, the purity of CaCO3 produced was as high as 99.4%. It was also found that Mg is one component, which can elute Ca from CKD, dissolved in seawater. The solid to liquid ratio was the most influential factor for the Ca elution efficiency, while the CO_2 flow rate and NaOH dosage had significant effects on the carbonation efficiency." **Junhyeok Jeon and Myoung-Jin Kim,** *Chemical Engineering Journal*. (Subscription may be required)

Carbon sequestration and soil restoration potential of grazing lands under exclosure management in a semi-arid environment of northern Ethiopia.

The following is from the abstract of this article: "Exclosures are used to regenerate native vegetation as a way to reduce soil erosion, increase rain water infiltration and provide fodder and woody biomass in degraded grazing lands. Therefore, this study assessed the impact of grazing exclosure on carbon sequestration and soil nutrients under 5 and 10 years of grazing exclosures and freely grazed areas in Tigray, northern Ethiopia. Carbon stocks and soil nutrients increased with increasing grazing exclusion. However, open grazing lands and 5 years of grazing exclosure did not differ in above- and belowground carbon stocks. Moreover, 10 years of grazing exclosure had a higher ($p < 0.01$) grass, herb and litter carbon stocks compared to 5 years exclosure and open grazing lands. The total carbon stock was higher for 10 years exclosure (75.65 t C ha^{-1}) than the 5 years exclosure (55.06 t C ha^{-1}) and in open grazing areas (51.98 t C ha^{-1}). Grazing lands closed for 10 years had a higher SOC, organic matter, total N, available P, and exchangeable K + and Na + compared to 5 year's exclosure and open grazing lands. Therefore, establishment of grazing exclosures had a positive effect in restoring degraded grazing lands, thus improving carbon sequestration potentials and soil nutrients." **Tsegay Gebregergs, Zewdu K. Tessema, Negasi Solomon, and Emiru Birhane,** *Ecology and Evolution*. (Subscription may be required.)

Geomechanical and petrographic assessment of a CO_2 storage site: Application to the Acorn CO_2 Storage Site, offshore United Kingdom.

The following is from the abstract of this article: "Extraction or injection of fluids within the subsurface causes fluctuations of fluid pressures and thus stress conditions. It is paramount to have knowledge of the geomechanical strength of a system's lithologies, and the factors that control it, in order to maintain optimal conditions during extraction/injection. If the yield strengths of the reservoir or caprock are overcome, particularly in the near-wellbore region where stress is amplified, these fluctuations could potentially compromise the system, through compactional or dilatational failure. Here [the authors] have used a novel combination of methods to determine the geomechanical and petrographic properties of the reservoir and caprock lithologies to assess suitability of the proposed Acorn CO_2 Storage Site, offshore north-east Scotland, for long-term injection and storage of CO_2. The Acorn CO_2 Storage Site has a highly porous and transmissible sandstone reservoir, with bulk mineralogy that will be stable under CO_2-rich conditions, making it ideal for receiving at least 152 MT CO_2 injected over ~20 years and storage of >1000 years post-injection, as part of the ACT-Acorn Development Plan. However, due to the high porosity and low cementation of the sandstone reservoir, it has low yield strength and is vulnerable to disaggregation and porosity-reduction if injection rates are too high and stress/pressure conditions exceed their yield strength. The results presented here provide quantitative constraints on the porosity reduction expected should yield occur and place limits on CO_2 injection rates. The shale caprock, with a high swelling clay content and very low permeability, present ideal Carbon Capture and Storage seal properties." **Michael J. Allen, Daniel R. Faulkner, Richard H. Worden, Elliot Rice-Birchall, Nikolaos Katirtsidis, and James E.P. Utley,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

CO_2 mitigation policy for Indian thermal power sector: Potential gains from emission trading.

The following is from the abstract of this article: "This study shows potential cost savings by adoption of emission trading in India. At the Paris Agreement, India pledged to reduce CO_2 emissions intensity by about 30–35% by 2030 relative to 2005. Applying joint production function of electricity and CO_2 emissions, [the authors] find that India could have saved about US$ 5 to 8 billion, if she had constituted an emission trading system, with the provision of banking and borrowing over the study period of 5 years. To [the authors'] knowledge, this is the first study measuring foregone gains due to absence of a nationwide carbon emission-trading program in coal fired thermal power sector, using an ex-post analysis." **Surender Kumar, Shunsuke Managi, and Rakesh Kumar Jain,** *Energy Economics*. (Subscription may be required.)

SEPTEMBER 2020

Carbon Capture and Storage (CCS) Market Size 2020 – Competitive Landscape and Growth Opportunity, Industry Status and Forecast to 2025.

The following is a description of this Market Research report: "[This report] offers a thorough investigation of Carbon Capture and Storage (CCS) Market, SWOT examination of the most prominent players right now. Alongside an industrial chain, market measurements regarding revenue, sales, value, capacity, regional market examination, section insightful information, and market forecast are offered in the full investigation, and so forth… Some of the major objectives of this report: [1] To provide a detailed investigation of the market structure alongside conjecture of the different sections and sub-portions of the worldwide Carbon Capture and Storage (CCS) Market. [2] To provide bits of knowledge about factors influencing market development. To examine the Carbon Capture and Storage (CCS) Market dependent on different variables value examination, store network investigation, porter five power investigation and so on. [3] To provide authentically and estimate the income of the Carbon Capture and Storage (CCS) Market portions and sub-fragments concerning four principle geographies and their nations North America, Europe, Asia, and the Rest of the World. [4] Nation level examination of the market regarding the present market size and future prospective. [5] To provide a national level examination of the market for section by Component, Technology, Application, End-Use, And Region. [6] To provide key profiling of key players in the market, thoroughly investigating their center capabilities, and drawing a serious scene for the market. [7] Track and break down serious advancements, for example, joint endeavors, key coalitions, mergers and acquisitions, new item improvements, and research and improvements in the worldwide Carbon Capture and Storage (CCS) Market."

Raising Ambition Through Fossil Fuel Subsidy Reform: Greenhouse gas emissions results modelling from 26 countries.

The following is a description of this International Institute for Sustainable Development (IISD) report: "This working paper models the impact of the removal of fossil fuel subsidies on greenhouse gas (GHG) emission reductions for the following countries: Algeria, Bangladesh, Brazil, China, Egypt, Germany, Ghana, India, Indonesia, Iran, Iraq, Mexico, Morocco, Myanmar, Nigeria, Pakistan, Russia, Saudi Arabia, South Africa, Sri Lanka, Tunisia, United Arab Emirates, the United States, Venezuela, Vietnam and Zambia. The research found simple country average GHG emission reductions of 6 per cent from 2018 until 2025, compared to business as usual. With an additional 10 per cent energy tax from 2025 until 2030 and a shift of 30 per cent of the savings from reforms and of revenues from taxation into investments in renewable energy and energy efficiency (i.e., a swap), GHG emission reductions improve to an average of 13.2 per cent by 2030. Cumulative fiscal savings from fossil fuel subsidy reform (FFSR) alone by 2030 total USD 2.56 trillion across the countries analyzed, with total cumulative GHG emissions abated from FFSR of 4.8 $GtCO_2e$ by 2030. For every tonne of CO_2e removed through FFSR, governments save an average of USD 93. This study also includes a literature review of 60 pieces of research on global GHG emission reductions stemming from negative and positive carbon pricing. [The authors] reviewed 40 papers concerned with FFSR and 20 papers focused on fossil fuel energy or carbon taxation. [The authors'] review found that global studies of fossil fuel subsidy removal result in emission reductions of between 1 and 10 per cent by 2030 and between 6.4 and 8.2 per cent by 2050. Removing fossil fuel subsidies and applying appropriate taxation could reduce emissions by a much larger 28 per cent globally. Fossil fuel subsidies act as a negative carbon price and could also be considered along with carbon pricing discussions. Furthermore, governments could consider the co-benefits of GHG emission reductions from FFSR and taxation, and include these policies within second-generation Nationally Determined Contributions."

CSIRO In-Situ Lab: A multi-pronged approach to surface gas and groundwater monitoring at geological CO_2 storage sites.

The following is from the abstract of this article: "In February 2019, at the CSIRO In-Situ Laboratory CCS project, a test was conducted where 38 t of gaseous CO_2 were injected over 5 days into a fault zone at a depth of approximately 340 m. As a release test, this project enabled the testing and validation of surface and shallow well monitoring strategies at intermediate depths (i.e. depths much deeper than previous release projects and shallower than reservoirs used for CO_2 storage). One of the aims of this project is to understand how CO_2 would behave at intermediate depths if it did migrate from deeper depths (i.e. from a storage reservoir); the CO_2 was not intended to migrate to the shallow subsurface or to surface/atmosphere. To verify that the injected CO_2 remained in the subsurface, and to comply with environmental performance requirements on site, a comprehensive surface gas and groundwater monitoring program was conducted. The monitoring strategy was designed such that any leakage(s) to the surface of injected CO_2 would be detected, mapped and, ultimately, quantified. The surface air monitoring program was comprised of three different but complementary approaches allowing data to be efficiently collected over different spatial and temporal scales. These approaches included continuous soil-gas chamber measurements at fixed locations, periodic soil-gas chamber measurements on gridded locations and near-surface atmospheric measurements on a mobile platform. The surface air monitoring approaches gave self-consistent results and reduced the risk of 'false negative' test results. The only anomalous CO_2 detected at the surface flowed from the observation well and could be directly attributed to a breach in the well casing at the injection depth providing a conduit for CO_2/water to rise to the surface. Groundwater monitoring program revealed no impact on the groundwater resources attributable to the carbon injection project. Based on this work, [the authors] demonstrate that this multi-pronged monitoring strategy can be utilized to minimize the overall resources devoted to monitoring by increasing the number of monitoring approaches and diminishing the resources devoted to each technique. By maximizing the effectiveness of each element of the monitoring program, a cost-efficient and robust monitoring strategy capable of early leak detection and attribution of any leaking CO_2 can be achieved." **Matthew Myers, Cameron White, Bobby Pejcic, Andrew Feitz, Jennifer Roberts, Yun-Yeong Oh, Liang Xu, Ludovic Ricard, Karsten Michael, Arsham Avijegon, Praveen Kumar Rachakonda, Martijn Woltering, Alf Larcher, Linda Stalker, and Allison Hortle,** *Chemical Geology.* (Subscription may be required.)

Optimization-based approach for CO_2 utilization in carbon capture, utilization and storage supply chain.

The following is from the abstract of this article: "Carbon dioxide (CO_2) is one of the primary anthropogenic greenhouse gases (GHGs), and its increasing emission has drawn wide attention from the international community. Among the strategies for CO_2 diminishment, carbon capture, utilization and storage (CCUS) is considered as the key option. The objective of this work is to develop an optimization-based assessment framework that aims to incorporate CO_2 storage and CO_2 utilization into an integrated framework. To achieve this goal, a superstructure network including all the sections of CCUS supply chain is proposed, which includes CO_2 capture, transportation, storage and utilization with 15 candidate conversion process paths. Based on this superstructure, a mathematical model for the optimal design of a supply chain of CCUS is developed. CO_2 would be stored underground and/or utilized to produce chemical products through candidate conversion paths. Finally, a case with real data of large emission sources in Northeast China is studied. Three different scenarios are investigated, according to key constraints on CCUS network: CO_2 emission source, raw material limits and products demands limits. Results show that adsorption is the preferred capture technology at relative high flue gas flow rate and high CO_2 concentration. Storing CO_2 is the recommended approach compared with utilization from the point of economy, however, carbon utilization could be a more sustainable option and may generate a carbon-neutral cycle. With the increase of CO_2 utilization, the cost of CCUS supply chain also increase (Scenario A: 2.49 billion $/y, Scenario B: 2.76 billion $/y, Scenario C: 2.85 billion $/y)." **Shuai Zhang, Yu Zhuang, Linlin Liu, Lei Zhang, and Jian Du,** *Computers & Chemical Engineering.* (Subscription may be required.)

Moisture-Driven CO_2 Sorbents.

The following is a summary of this article: "Moving the energy infrastructure away from fossil fuels to renewable energies to stop global warming is a challenging task. In the transition, CO_2 capture and storage (CCS) from point sources could reduce CO_2 emission. However, the objective of stabilizing atmospheric CO_2 at 450 ppm cannot be achieved by CCS alone. Here, the urgency of the development of CO_2 capture from ambient air, or 'direct air capture' (DAC) is demonstrated. A successful sorbent for DAC must (1) have fast reaction kinetics, (2) be low in cost, and (3) be able to regenerate with a low energy barrier to complete the whole CO_2 capture-release cycle. Most CO_2 sorbents failed in the third category as they had to overcome a large energy barrier to regenerate. This study presents an energy-saving sorbent to capture CO_2 simply by controlling the water quantities on it. [The authors] report the effects of parameters of the sorbents on CO_2 capture efficiency. The study can lead the way toward the optimization of sorbents for DAC. An energy-saving system containing ion-exchange or nanoporous materials and carbonate ions is proposed, which is capable of capturing CO_2 from ambient air simply by controlling the amount of water (moisture) in contact with the sorbent. The system binds CO_2 from the air when the surrounding is dry, whereas it desorbs CO_2 when it is wet. A design of such CO_2 sorption and desorption systems is investigated using quantum mechanics simulations and is verified by experiments. Its working mechanism is revealed as the free energy change of the chemical reaction of the carbonate ions and water molecules; the free energy change decreases when the number of water molecules in the materials decreases. The influence of pore size, spacing of cations, and surface hydrophobicity of the sorbents on CO_2 capture efficiency are elucidated. The study sheds light on ways to optimize an efficient direct air capture system and therefore contributes to the development of 'negative emission technologies.'" **Xiaoyang Shi, Hang Xiao, Kohei Kanamori, Akio Yonezu, Klaus S. Lackner, and Xi Chen,** *Joule*. (Subscription may be required.)

Modified phosphogypsum sequestrating CO_2 and characteristics of the carbonation product.

The following is from the abstract of this article: "A method of PG carbonation to produce polymorphs of high-purity CaCO3 was proposed. The effect of experimental conditions on transformation process from PG to calcium carbonate was systematically discussed. PG transformed into granular portlandite and fibrous quartz under the action of caustic soda at room temperature for 10min. The carbonation ratio (η) was 98.57%, and 1000kg of PG could produce 519kg of high-purity CaCO3 and sequestrated 228kg of CO_2. The spherical vaterite carbonation product met the relevant standards for the industrial precipitated calcium carbonate. A reaction mechanism of PG carbonation was also proposed by thermodynamic research of the gas-liquid-solid reaction. The products with a single vaterite structure, or a vaterite and calcite mixing structure or a vaterite, aragonite and calcite mixing structure were all successfully prepared. All of these indicated that the whole procedure setup of PG carbonation showed potential application for PG utilization and CO_2 sequestration." **Wenjin Ding, Qiuju Chen, Hongjuan Sun, and Tongjiang Peng**, *Energy*. (Subscription may be required.)

Application of a dual tubing CO_2 injection-water production horizontal well pattern for improving the CO_2 storage capacity and reducing the CAPEX: A case study in Pohang basin, Korea.

The following is from the abstract of this article: "Water production is an efficient way of relieving pressure build-up and improving the CO_2 storage capacity (CSC) in the carbon capture and storage process. The additional offshore platforms, production wells, pipelines, and pumps required for water production, however, increase the capital expenditure (CAPEX) of the project. Therefore, a CO_2 injection method that can both improve the CSC and reduce the CAPEX is needed. This paper proposes a dual-tubing CO_2 injection-water production horizontal well (DTHW) pattern for improving the CSC, in which CO_2 is injected at the heel of the horizontal well while water is produced at the toe. The CSC and CAPEX of the proposed DTHW pattern were then compared to those of other cases in a saline aquifer in the Pohang basin, offshore Korea. The CCSPerformance (CSC to CAPEX ratio) of the proposed DTHW pattern was larger than that of a typical CO_2 injection with a water production pattern for the all CO_2 injection-water production rate cases. The proposed DTHW pattern showed promising results in that the maximum CSC was improved by 98.2% compared to a single vertical CO_2 injection well pattern and the CAPEX was reduced by 37.1% compared to the typical CO_2 injection with a water production pattern. More CAPEX might be saved if a DTHW pattern is used in an onshore platform near a power plant because an additional offshore platform and pipeline are not required." **Min Kim and Hyundon Shin,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Effects of land use and forest management on soil carbon in the ecoregions of Maryland.

The following is from the abstract of this article: "The impacts of forest-related land use and management on soil organic carbon (SOC) stocks have been investigated through years of primary research and review articles. This attention is justified given the importance of land use and management to greenhouse gas mitigation, soil and forest productivity, and other ecosystem services. However, there is a gap of scale and scope between site-level studies that control for sources of variation, producing high-confidence results for limited locations, and the broad reviews that offer more general conclusions. The present analysis is intended to fill that gap. Here, [the authors] focus on six ecoregions of the eastern United States, and integrate meta-analysis of published literature with synthesis of geo-referenced soil observations to: (1) test whether common land use and management practices quantitatively impact SOC; (2) identify key sources of variation in these effects; (3) assess how sources of variation translate to decisions about land use and management at ecoregional to landscape levels. Results corroborate general trends, such as O horizon SOC losses with harvesting and fire and SOC gains during reforestation, but provide greater detail about the influence of specific practices and site-level controls on SOC stocks and change in the study region. Results also show that: (1) harvest impacts depend upon landform and soil taxonomy; (2) harvesting forests that are recovering on previously cultivated lands decreases SOC; (3) tree biomass and SOC recovery increase concurrently during reforestation; (4) specific harvest, site preparation, and fire management practices affect the magnitude and variability of changes in SOC. Perhaps more importantly, ecoregional classification and soil taxonomy provide spatial frameworks for placing quantitative estimates of SOC stocks and changes in the geographic context of the study region, providing greater detail and specificity for individuals and institutions concerned with SOC management at more localized levels." **L.E. Nave, K. DeLyser, P.R. Butler-Leopold, E. Sprague, J. Daley, and C.W. Swanston,** *Forest Ecology and Management*. (Subscription may be required.)

Evolution of soil organic carbon in a carbonaceous glacial till as an effect of crop and fertility management over 50 years in a field experiment.

The following is from the abstract of this article: "Changes in soil organic carbon (SOC) content depending on different factors are extensively investigated when the soil is in steady-state equilibrium between formation and decomposition of soil organic matter. However, studies of SOC formation and dynamics in [initially] organic matter free soil are rare. Evolution of soil organic carbon was studied in a field experiment established in 1964 on a carbonaceous glacial till soil with very low initial SOC content (1.28g kg–1). The effects on SOC content changes of bare fallow, barley and different perennial fodder crops such as grasses, clover-grass mixture, galega, hybrid lucerne and a turfgrass mixture, with or without mineral N and PK fertilisation and manure, were studied. There were 19 treatments in total and most had unchanged plant cover composition throughout the experiment. During 1964–2014, SOC stock increased in all treatments, by 0.11Mg ha–1 y–1 in bare fallow and by at most 0.50Mg ha–1 y–1 in the treatment with hybrid lucerne and manure. Average SOC sequestration rate was 0.35±0.11Mg ha–1 y–1. SOC changes were highly correlated with estimated C inputs and were therefore higher in treatments with perennials than with an annual barley crop. C retention efficiency for total crop-derived C inputs and for organic amendments was 6.1% and 22%, respectively. Water-soluble C measured in 2014 increased linearly with SOC, indicating that the quality of recently formed SOC was not strongly affected by the treatments. However, water-soluble C as a fraction of SOC was significantly lower in treatments with legumes than in treatments with bare fallow or a barley or grass crop. These results demonstrate that the quantity and quality of C inputs were both main drivers for observed changes in SOC. However, C retention efficiency of C inputs was relatively low. This may be related to soil texture with high sand proportion, suggesting that SOC sequestration rates in light-textured soils may be lower than expected even in case of low initial SOC content." **Karin Kauer, Alar Astover, Rein Viiralt, Henn Raave, and Thomas Kätterer,** *Agriculture, Ecosystems & Environment.* (Subscription may be required.)

Vulnerability of seagrass blue carbon to microbial attack following exposure to warming and oxygen.

The following is from the abstract of this article: "Seagrass meadows store globally-significant quantities of organic 'blue' carbon. These blue carbon stocks are potentially vulnerable to anthropogenic stressors. Here, [the authors] tested the impact of oxygen exposure and warming (major consequences of human disturbance) on rates of microbial carbon break-down in seagrass sediments. Active microbes occurred throughout seagrass sediment profiles, but deep, ancient sediments (~5000 yrs. old) contained only 3% of the abundance of active microbes as young, surface sediments (<2 yrs. old). Metagenomic analysis revealed that microbial community structure and function changed with depth, with a shift from proteobacteria and high levels of genes involved in sulfur cycling in the near surface samples, to a higher proportion of firmicutes and euraracheota and genes involved in methanogenesis at depth. Ancient carbon consisted almost entirely (97%) of carbon considered 'thermally recalcitrant', and therefore presumably inaccessible to microbial attack. Experimental warming had little impact on carbon; however, exposure of ancient sediments to oxygen increased microbial abundance, carbon uptake and sediment carbon turnover (34–38 fold). Overall, this study provides detailed characterization of seagrass blue carbon (chemical stability, age, associated microbes) and suggests that environmental disturbances that expose coastal sediments to oxygen (e.g. dredging) have the capacity to diminish seagrass sediment carbon stocks by facilitating microbial remineralisation." **P.I. Macreadie, T.B. Atwood, J.R. Seymour, M.L. Schmitz Fontes, J. Sanderman, D.A. Nielsen, and R.M. Connolly,** *Science of The Total Environment.* (Subscription may be required.)

ANNOUNCEMENTS

OCTOBER 2019

US Representatives Visit NETL.

U.S. Representative Conor Lamb (Chairman of the House Science, Space, and Technology Energy Subcommittee) and U.S. Representative Marcy Kaptur (Chairwoman of the House Appropriations Energy and Water Development Subcommittee) visited NETL-Pittsburgh (Pennsylvania, USA) for briefings and to tour research laboratories. The discussions and tours focused on effective resource development, efficient energy conversion, and environmental sustainability.

DOE Invests in Offshore Projects in Support of EOR.

DOE's FE selected three projects to receive federal funding for cost-shared R&D in support of enhanced oil recovery (EOR). Under DE-FOA-0002005 "*Advanced Subsea System Technologies to Improve Efficiency and Capabilities for Enhanced Oil Recovery (EOR) in Offshore Wells*," the projects will enhance the potential for EOR in offshore settings by advancing promising proof-of-concept technologies to reduce subsea facility complexity, increase control and monitoring, and enable greater tieback distances to production facilities. NETL will manage the projects.

DOE Invests in Coal Technology Projects.

DOE announced award recipients of federal funding for cost-shared R&D projects for advanced coal technologies and research under six separate FOAs. The projects cover a range of topics, including CCUS, rare earth element recovery, coal-to-products, crosscutting coal R&D, steam turbine efficiency, and advanced materials. NETL will manage the selected *projects*.

NETL Hosts Inaugural Comprehensive Annual Project Review Meeting.

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 FE research programs, offering attendees an opportunity to share in the knowledge and insights gained from more than 200 research projects sponsored by DOE's *Carbon Capture*, *Utilization*, *Storage*, and *Oil and Natural Gas* Programs. The *conference proceedings* are available.

FY 2019 Carbon Storage Newsletter Annual Index Available.

The FY 2019 Carbon Storage Newsletter Annual Index is available. The document is a compilation of NETL's Carbon Storage Newsletters published from October 2018 through September 2019, organized by section.

Report Forecasts Role of CCS in Energy Transition.

DNV GL forecasts the role of carbon capture and storage (CCS) in securing a rapid energy transition in a new report. According to the "*2019 Energy Transition Outlook*," integrated hydrocarbon and renewable energy technologies, with support from CCS, have the potential to help achieve global policy goals.

EU Officials Discuss Reducing Emissions with CCS.

The European Climate Commissioner presented the "Long-Term Strategy to 2050" at the European High-Level Conference on CCS in Oslo, Norway. The plan discusses the role CCS can have in the European Union's (EU) plans to reduce CO_2 emissions.

Germany Industry Seeks CCS Opportunities.

German industrial companies are seeking opportunities for CCS in light of the German government unveiling policies to meet its emissions reduction targets, including carbon storage and use. The German government *agreed to a climate action plan in September 2019*, which includes a measure to put a price on the emissions of CO_2 beginning in 2021.

NOVEMBER 2019

NETL Director Delivers Keynote Address.

National Energy Technology Laboratory (NETL) Director Brian Anderson, Ph.D., delivered a keynote address at the Lignite Energy Council Fall Conference in Bismarck, North Dakota (USA). His presentation focused on state-of-the-art energy research and development (R&D) and scientific and technological initiatives related to fossil energy that bring together multidisciplinary teams to meet some of the nation's energy challenges. Prior to the conference, NETL hosted a program review workshop that covered coal-related topics, including carbon storage.

NETL-Developed Model Helps Evaluate CO_2 Storage Potential.

FE/NETL developed the CO_2 Prophet Model, which is an oil reservoir simulator that calculates CO_2 retention and oil production for enhanced oil recovery (EOR) projects. The CO_2 Prophet Model is available online, along with supporting documentation, and provides key input to the FE/NETL Onshore CO_2-EOR Cost Model (currently in beta-testing). Integrated, these models enable rapid evaluation of the economics and CO_2 storage potential of multiple oil field and residual oil zone units.

NETL-Developed Tool Used in Carbon Storage Study.

NETL's advanced carbon storage estimation tool, the CO_2 Storage prospeCtive Resource Estimation Excel aNalysis (CO_2-SCREEN), was used to assess the feasibility of a commercial-scale CO_2 storage complex in the Northern Michigan Basin (USA). CO_2-SCREEN provides researchers and decision makers with a mechanism to calculate CO_2 storage resources to help assess a site. Use of the tool was documented in a *study* published in the *International Journal of Greenhouse Gas Control*.

Conference Proceedings Available for NETL's Project Review Meeting.

Conference proceedings are available for the NETL-hosted Carbon Capture, Utilization, Storage, and Oil & Gas Technologies Integrated Project Review Meeting held in August 2019. The inaugural "*Addressing the Nation's Energy Needs Through Technology Innovation*" meeting combined four FE research programs, offering attendees an opportunity to share in the knowledge and insights gained from more than 200 research projects sponsored by DOE's *Carbon Capture*, *Utilization*, *Storage*, and *Oil and Natural Gas* Programs.

DOE Invests in Projects to Advance Coal Power Generation.

DOE's FE selected seven Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) conceptual designs to proceed with preliminary front-end engineering design studies. The Coal FIRST Initiative seeks to advance coal power generation beyond current state-of-the-art capabilities and make coal-fired power plants better adapted to the evolving electrical grid.

Report Released on Investment of RGGI Proceeds.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released a report tracking the *investment of proceeds* in 2017 generated by their CO_2 allowance auctions. "*The Investment of RGGI Proceeds in 2017*" also provides state-specific success stories and program highlights. According to the report, $315.6 million in RGGI proceeds were invested in energy programs in 2017.

DECEMBER 2019

US Senate Confirms New Secretary of Energy.

The U.S. Senate confirmed former Deputy Secretary of Energy Dan Brouillette to be the 15th U.S. Secretary of Energy. The official swearing in will occur at a later date.

Conference Highlights CCUS.

The Carbon Capture and Storage Association hosted "CCUS 2019: Capturing the clean growth opportunities," which brought together stakeholders from the CCUS sector, including industry providers, potential customers, policymakers, investors, and researchers. Presentations from the conference are *available online*.

CO_2 Utilization Summit to be Held in February.

Active Communication International's (ACI) 15th Carbon Dioxide Utilization Summit is scheduled for February 26–27, 2020, in Orlando, Florida, USA. Focusing on the reuse of greenhouse gases (GHGs) and their conversion into sustainable materials, the conference brings together senior experts from various industries to discuss the sustainable, technological, and commercial aspects of CO_2 utilization.

Report Highlights CCUS Potential in North Sea.

A new report claims the North Sea has the potential to become a leader in energy transition through the deployment of CCUS technology. The report, titled "*Turning the tide: The transformation of the North Sea*," is a collaboration between PricewaterhouseCoopers and Oil and Gas UK.

Program Looks at Experimental CO_2 Storage Methods.

A Canadian group was awarded a grant for an initiative to turn forest waste into biochar and store it in soil as a potential and experimental means of removing CO_2 through carbon storage.

JANUARY 2020

Report Documents CCS Milestones.

The Global CCS Institute released a report that documents milestones for carbon capture and storage (CCS) over the past 12 months. The 2019 Global Status of CCS report provides detailed information and analysis of the global CCS facility pipeline, policy, CO_2 storage, and the legal and regulatory environment.

CCUS-Supporting Project Launches.

A European Union (EU)-funded project to accelerate the widespread deployment of CCUS *unveiled its new website*. Building on international collaboration and work already undertaken, LAUNCH, an international consortium of academic and industry partners, will investigate barriers to implementing CCUS.

Study Shows World Has Sufficient CO_2 Storage Capacity.

According to a study conducted by the University of Texas at Austin, there is enough storage capacity in the world's nearshore continental margins to meet CO_2 storage goals. The study, *published in Nature Scientific Reports*, shows the role CCS has in reaching targets.

Indonesia Drafting Regulations for Sale of Carbon Credits.

Indonesia is drafting regulations for the sale of carbon credits for carbon reserves stored in peatlands, rain forests, and mangroves. Officials expect the sales to generate up to $100 billion a year, which could be used to help Indonesia preserve its rain forests, mangrove forests, and peatlands.

Report Highlights Roles of CCS, BECCS in UK.

According to a report *published in Petroleum Geoscience*, advances and investment in CCS and bioenergy with carbon capture and storage (BECCS) can play a key role in helping the United Kingdom advance towards its emission targets.

FEBRUARY 2020

Office of Fossil Energy's Year in Review.

DOE's Office of Fossil Energy (FE) shared highlights of work conducted in 2019 that helped to maximize the use of the nation's energy resources. Among the accomplishments noted was accelerated research and development (R&D) on direct air capture of CO_2 through carbon capture, utilization, and storage (CCUS) R&D.

NETL-Supported CCUS Demonstration Project Celebrates Sustainable Operation.

Petra Nova, an operating post-combustion CO_2 capture project supported by DOE's FE, *celebrated its third anniversary in January 2020*. Administered by NETL, the project is demonstrating how CCUS technologies can economically support the flexibility and sustainability of fossil fuels at commercial scale. Located in Texas (USA), the Petra Nova project addresses capture and beneficial reuse of CO_2 from coal-based electricity production.

DOE Selects Projects to Create New Market Opportunities for Coal.

DOE's FE announced the selection of three projects to receive federal funding for cost-shared R&D to create new market opportunities for coal. Supported through the Funding Opportunity Announcement (FOA) "Maximizing the Coal Value Chain," the projects will develop innovative uses of domestic coal for upgraded coal-based feedstocks used to produce power and make steel and high-value products. NETL will manage the projects, which will support FE's *Advanced Energy Systems Program*.

Digital Portal for Sharing CCS Projects Datasets Opens.

The international CO_2 Storage Data Consortium launched an open, web-based digital portal for sharing reference datasets from CO_2 storage projects. *The CO_2 DataShare online portal* will attempt to improve understanding, reduce costs, and minimize uncertainties associated with CO_2 storage projects by making curated and well-documented datasets available to interested stakeholders.

CCS Facility Provides Capture Totals for 2019.

The carbon capture and storage (CCS) facility at SaskPower's Boundary Dam Power Station located in Saskatchewan, Canada, reported a total of more than 616,000 metric tons of CO_2 captured in 2019. Since the facility came online in October 2014, it has captured more than 3 million metric tons of CO_2.

Report Indicates Market Opportunities for Carbon Capture.

A *newly released report* projects the potential worldwide market opportunities for carbon capture, including long-term storage. The Thunderbird School of Global Management (of the Arizona State University Knowledge Enterprise) report projected the broader economic, social, and environmental benefits per year by 2030.

Institute to Help Canada Become Net-Zero by 2050.

The Canadian Institute for Climate Choices was created to help Canada transition to a net-zero emissions economy by 2050. The Ottawa-funded institute will also provide options to help Canada reach its emissions reduction target of 30% below 2005 levels by 2030.

Report Highlights Need for CCS in UK.

A report calls for the United Kingdom (UK) to increase investment in CCS to meet its net-zero emissions target for 2050. According to Atkins Global's "*Engineering Net Zero*" report, the UK will need to facilitate a four-fold increase in low-carbon energy, including CCS, nuclear, wind, and hydrogen energy generation.

Study Evaluates China's CO_2 Emissions Pricing System.

A study, titled "*China's Unconventional Nationwide CO_2 Emissions Trading System: The Wide-Ranging Impacts of an Implicit Output Subsidy*," assesses the overall costs and distributional impacts of China's planned nationwide emissions trading system for CO_2 emissions reductions. The study also describes how China's tradable performance standard mechanism differs from other cap-and-trade programs.

MARCH 2020

Podcast Features NETL, Carbon Storage.

DOE/NETL was featured on a recent edition of the Energy Cast podcast, in which the focus was carbon storage. The episode covered the 45Q tax credit, enhanced oil recovery (EOR), and the RCSPs, among other topics.

DOE Announces Funding for Components of Coal FIRST Power Plants.

DOE/NETL announced federal funding for cost-shared R&D projects under the Funding Opportunity Announcement (FOA) "*Critical Components for Coal FIRST Power Plants of the Future*." DOE's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative seeks to develop the coal plant of the future needed to provide secure and reliable power to the U.S. grid. DOE anticipates selecting up to 14 cost-shared projects focused on developing the critical components required by Coal FIRST and transformational coal-fired systems. Responses are due March 30, 2020.

Report: US Energy-Related CO_2 Emissions Reduced in 2019.

An *International Energy Agency (IEA) report* claims that energy-related CO_2 emissions in the United States fell 2.9% in 2019. According to the report, U.S. emissions have decreased nearly 1 metric gigaton since 2000.

Saudi Arabia Hosts International Conference on CCUS.

More than 800 participants attended the International Carbon Capture, Utilization, and Storage Conference (*iCCUS 2020*) in Riyadh, Saudi Arabia. Organized by the National Oil and Gas Authority, the conference focused on the role of CCUS technologies in empowering the global carbon economy.

LLNL Develops Program for a Carbon-Neutral California.

The Lawrence Livermore National Laboratory (LLNL) released a report outlining ways to make California (USA) carbon neutral by 2045. "*Getting to Neutral: Options for Negative Carbon Emissions in California*" offers a three-pronged strategy for removing CO_2 emissions across the state, leading to the potential storage of 125 million metric tons of CO_2 underground each year.

Reforestation Initiative Reaches Milestone.

The Hawaiian Legacy Reforestation Initiative planted its 500,000th tree in Hawaii (USA), increasing carbon storage on the island. To date, more than 1,200 acres of former pastureland on Oahu and Hawaii Island have been reclaimed and returned to native forest.

APRIL 2020

NETL Releases New Infographic.

NETL released an infographic highlighting the role of advanced manufacturing in reducing costs associated with carbon capture. The "Advanced Manufacturing to Drive Down Capture Costs" infographic is part of a *series of infographics* published by NETL in support of the *Carbon Capture Program*.

RGGI Releases Interim Compliance Report.

Regional Greenhouse Gas Initiative (RGGI) carbon dioxide (CO_2) budget sources participating in the 2019 interim control period were *required* to provide allowances equal to 50% of their 2019 emissions. The 2019 Interim Compliance Summary Report contains data regarding CO_2 allowances provided by CO_2 budget sources to meet their 2019 interim control period obligation.

MOU Includes CCS.

Fortum Corporation, a Finnish clean-energy company, and Kvaerner, a Norwegian engineering, procurement, and construction company, signed a Memorandum of Understanding (MOU) to identify projects and opportunities for technical or commercial operation, which may include plants with carbon capture and storage (CCS) technology.

World Carbon Fund Launched.

A London-based environmental asset management firm launched the *World Carbon Fund*, which ties a percentage of fund investment to carbon storage. Carbon Cap Management's fund also invests in and trades liquid carbon allowance certificates, carbon futures, and carbon options.

CCS Policy Forum Convened.

CO2CRC convened the inaugural CO2CRC CCS Policy Forum to develop an industry view on practical CCS policy framework that will stimulate CCS project investment in Australia.

CCS Forum Held in Washington, DC.

The Global CCS Institute hosted the ninth annual forum on CCS in Washington, DC (USA). Experts discussed key areas to advance CCS in North America, including enabling access to geologic storage hubs and solutions across the CCUS value chain.

MAY 2020

DOE Announces Funding for CO_2 Capture Research.

DOE announced funding for research aimed at advancing CO_2 capture technology. The initiative encompasses two concurrent FOAs: one by DOE's Office of Science (SC) and another by DOE's FE. *The SC FOA* invites DOE's national laboratories to submit proposals for research in materials and chemical sciences. *The FE FOA* focuses on applied development of new materials and the field testing of prototypes.

Get to Know NETL.

NETL *released a series of "Get to Know NETL" videos* highlighting work being conducted at NETL facilities. The series includes an overview of NETL as well as videos about NETL sites in *Albany, Oregon*; *Morgantown, West Virginia*; and *Pittsburgh, Pennsylvania*.

Global CCS Institute Hosts CCS Webinar.

The Global CCS Institute conducted a webinar explaining how CO_2 storage works and addressing myths and misconceptions. *Presentation slides* and *video* of the webinar, titled "CCS Talks: All you need to know about CO_2 storage," are available.

Pandemic's Impact on CO_2 Emissions.

According to *data released by the U.S. Energy Information Administration (EIA)*, energy-related CO_2 emissions in the United States could potentially decline by 7.5% in 2020 as a result of stay-at-home restrictions due to the coronavirus. Similar measures enacted by European Union (EU) member states have led to the EU experiencing a 58% reduction in daily CO_2 emissions, according to consultants.

CCUS Project Launches Wiki Page.

The ALIGN-CCUS project *launched a Wiki page* to communicate the project's activities to non-experts. Integrated into the project's website, the Wiki provides user-friendly access to the project objectives and outputs. The web-based platform will be continually updated through the conclusion of the project.

JUNE 2020

DOE Announces Intent to Commit Funding for Coal FIRST Initiative.

DOE's Office of Fossil Energy announced its intention to commit federal funding for cost-shared R&D projects through the release of the draft Funding Opportunity Announcement (FOA), *Design Development and System Integration Design Studies for Coal FIRST Concepts*. (The draft FOA was issued to make interested parties aware of DOE's intention to issue the finalized FOA later this summer.) Projects resulting from the finalized FOA will support DOE's Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative.

National Carbon Capture Center Expands Testing.

The National Carbon Capture Center (NCCC) announced expanded testing in its future scope of work for DOE/NETL. NCCC is now expected to include testing of CO_2 utilization and direct air capture technologies. In addition, NCCC will broaden its testing and evaluation of CO_2 capture technologies for natural gas power generation through a new addition to the center.

CCUS Finance Workshop Report Available.

CMC Research Institutes released a summary report of a workshop exploring CCUS investment opportunities. Workshop attendees discussed challenges that technology developers, industry, and investors may face and potential solutions that may be realized while advancing CCUS technologies from early-stage research to commercialization.

Report Assesses Value, Benefits of CCS.

The Global CCS Institute released a report analyzing the benefits of large-scale investment and deployment of CCS. *The report discusses* the evidence related to the value of CCS under two themes: CCS as an essential technology to economically meet long-term goals, and CCS as a driver of economic growth and employment.

UK CCC Pens Letter in Support of CCS.

The United Kingdom (UK) Committee on Climate Change (CCC) wrote letters to *the UK* and *Scottish governments* providing advice on (1) strengthening the economy through actions such as redeploying workforces in low-carbon industries, including CCS, and (2) targeted funding for science and innovation in low-carbon technologies.

Podcast Discusses Carbon Cycle, Carbon Storage.

The "No-Till Farmer Influencers & Innovators" podcast released an episode discussing the carbon cycle and why it is more complicated than the common perception of carbon storage. In addition, the episode covered the role carbon cycling can play in today's carbon credits program.

JULY 2020

DOE Invests in Carbon Utilization Projects.

DOE's Office of Fossil Energy (FE) and NETL selected 11 carbon utilization projects to receive federal funding for cost-shared research and development (R&D). The NETL-managed projects will develop and test technologies that can utilize CO_2 from power systems or other industrial sources as the primary feedstock. DOE's *Carbon Utilization Program* aims to reduce emissions and transform carbon streams into value-added products.

DOE Infographics Highlight Achievements in Carbon Capture Program.

NETL is developing a *series of infographics* to help convey highlights and achievements of the *Carbon Capture Program*. New infographics on second-generation technologies that have reached engineering-scale testing have been published.

DOE-Funded FEED Contract Awarded for CCUS Project.

A DOE-funded front-end engineering design (FEED) study contract was awarded for a CCUS retrofit project in North Dakota (USA). Under the contract, Fluor will use its proprietary carbon capture technology on the Minnkota Power Cooperative's Project Tundra at the Milton R. Young Station in Center, North Dakota.

Global CCS Institute Releases Briefs.

The Global CCS Institute released two briefs. "*CCS Development in Southeast Asia*" focuses on why Southeast Asia needs carbon capture and storage (CCS)/CCUS. "*Is CCS Expensive? Decarbonisation costs in the net-zero context*" demonstrates the business-case support needed for large-scale CCS deployment.

CCS Facilities Added to Global Database.

The Global CCS Institute added 10 CCS facilities to its global database. The *CO_2RE database* now contains 59 CCS facilities (21 in operation, three under construction, 35 in various stages of development) with a combined CO_2 capture capacity of more than 127 million metric tons per year.

Report Outlines Role of CCS in European Clean Hydrogen Market.

The Zero Emissions Platform, supported by the European Union (EU), released a report providing input on how the European Commission can enable a European clean hydrogen market with clean hydrogen from natural gas with CCS. The overview of the outline is *available online*.

RGGI Releases Results of CO_2 Auction.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced results of their 48th auction of CO_2 allowances. Auction 48 saw 16,336,298 CO_2 allowances sold at a clearing price of $5.75, with bids ranging from $2.32 to $8.00 per allowance. The auction generated $93.9 million for reinvestment in strategic programs, including energy efficiency and greenhouse gas (GHG) abatement programs. Additional details are available in the *Market Monitor Report for Auction 48*.

AUGUST 2020

CO_2 Storage Resource Catalogue Launched.

The Oil and Gas Climate Initiative, Global CCS Institute, and Pale Blue Dot Energy launched a worldwide evaluation of geologic carbon dioxide (CO_2) storage resource assessments. The *CO_2 Storage Resource Catalogue*, to be updated annually, aims to become a global repository for all future storage resource assessments.

CCS Project Reaches Milestone.

Shell's Quest CCS project has captured and stored 5 million metric tons of CO_2 since its startup in November 2015. Originally designed to capture and store approximately 1 million metric tons of CO_2 per year, the Quest CCS facility exceeded the target at a cost approximately 35% lower than that forecasted in 2015.

CCS Collaboration Renewed.

ExxonMobil and Princeton University's (USA) Andlinger Center for Energy and the Environment renewed their collaboration to better understand underground storage capacity for future CO_2 storage projects.

Fact Sheet on Pilot Test at NCCC.

The CO_2 Capture Project *released a fact sheet* detailing the results of pilot testing conducted at the DOE-sponsored National Carbon Capture Center (NCCC) in Wilsonville, Alabama (USA). The pilot tested piperazine with advanced stripper technology for capturing CO_2 from low-CO_2 flue gas (representative of flue gas from natural gas combined cycle power plants).

Companies Invest in CCUS Projects.

Carbon Clean Solutions Limited (CCSL) finalized an investment to deliver its CO_2 capture technology for CCUS projects across the steel, cement, waste management, and refining and petrochemicals sectors. Additional information on the investment is available on the *CCSL website*.

ZEP, European Commission Discuss CCS.

A meeting between the Zero Emissions Platform (ZEP) and the European Commission focused on the role of CCS projects, CO_2 infrastructure, and clean hydrogen in Europe. ZEP presented a *set of recommendations* for how the European Union (EU) can use CCS.

15 Years of CCS Research at SCCS.

Scottish Carbon Capture and Storage (SCCS) is celebrating its 15th year researching CCS technologies. Since inception in 2005, the SCCS team broadened its reach to a range of international projects exploring, developing, and defining the use of CCS technology across sectors, from industrial processes and power generation to hydrogen production, waste-to-energy, and refineries.

Report Studies Need for CCS.

A new study examines the importance of CCS in achieving carbon neutrality in the EU. Eurogas' study, "*A Pathway to a Carbon Neutral 2050: The Role of Gas*," investigates different scenarios to help the EU reach its goals.

SEPTEMBER 2020

NETL Posts Offshore Oil Field Case Studies.

NETL released three case studies regarding offshore carbon dioxide (CO_2) enhanced oil recovery (EOR). The studies (*Horn Mountain Oil Field Case Study*, *Cognac Offshore Oil Field Case Study*, and *Petronius Offshore Oil Field Case Study*) provide perspective into the challenges of evaluating offshore CO_2-EOR and CO_2 storage potential, and demonstrate the performance of the CO_2 Prophet Model EOR reservoir simulator. These studies, as well as other relevant documents, can be found on *NETL's Search Energy Analysis website* by searching "offshore EOR."

Carbon Storage Study Update.

Giga Metals Corporation provided an update on its carbon storage research program at the *Turnagain Nickel Project*, located in British Columbia, Canada. The research is being conducted in conjunction with the University of British Columbia.

Study Shows CCS Role in Decarbonizing Electricity Grids.

Economists from the Brattle Group conducted a study assessing the cost-effectiveness of CCS for utilities in meeting decarbonization goals. *The study* found that opportunities to retrofit coal-fired power plants with CCS at low net costs exist, and that due in part to recent tax credits, CCS can be developed at a minimal incremental net cost.

Report Covers COVID-19 Impact Analysis on CCS Market.

Fortune Business Insights released a report analyzing the CCS market and the impact of the COVID-19 global pandemic. The report covers market trends and key industry developments by end use (e.g., EOR, CO_2 capture source, and geography). According to the report, the global CCS market size in 2019 was approximately $1.6 billion and is projected to reach approximately $6.1 billion by 2027.

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 2020" addresses the period from April through June 2020. The report is part of Potomac's ongoing monitoring of the RGGI auctions and secondary markets.

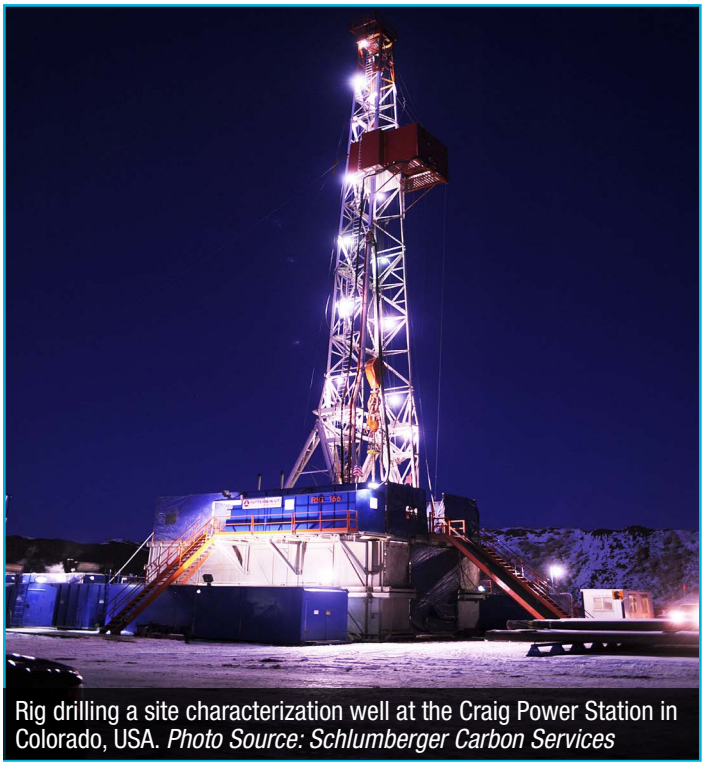
ABOUT DOE'S CARBON STORAGE PROGRAM

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*.



Rig drilling a site characterization well at the Craig Power Station in Colorado, USA. *Photo Source: Schlumberger Carbon Services*

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

Mark McKoy
304-285-4426
Mark.McKoy@netl.doe.gov

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