NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON STORAGE NEWSLETTER

ANNUAL INDEX

FISCAL YEAR (FY) 2021

October 2020 – September 2021

NETL'S CARBON STORAGE NEWSLETTER
ANNUAL INDEX – FY 2021

This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Storage Newsletters (CSN) published from October 2020 to September 2021. 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 Outdated information (e.g., conference dates, paper submittals, etc.)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 links were active at the time of publication.

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

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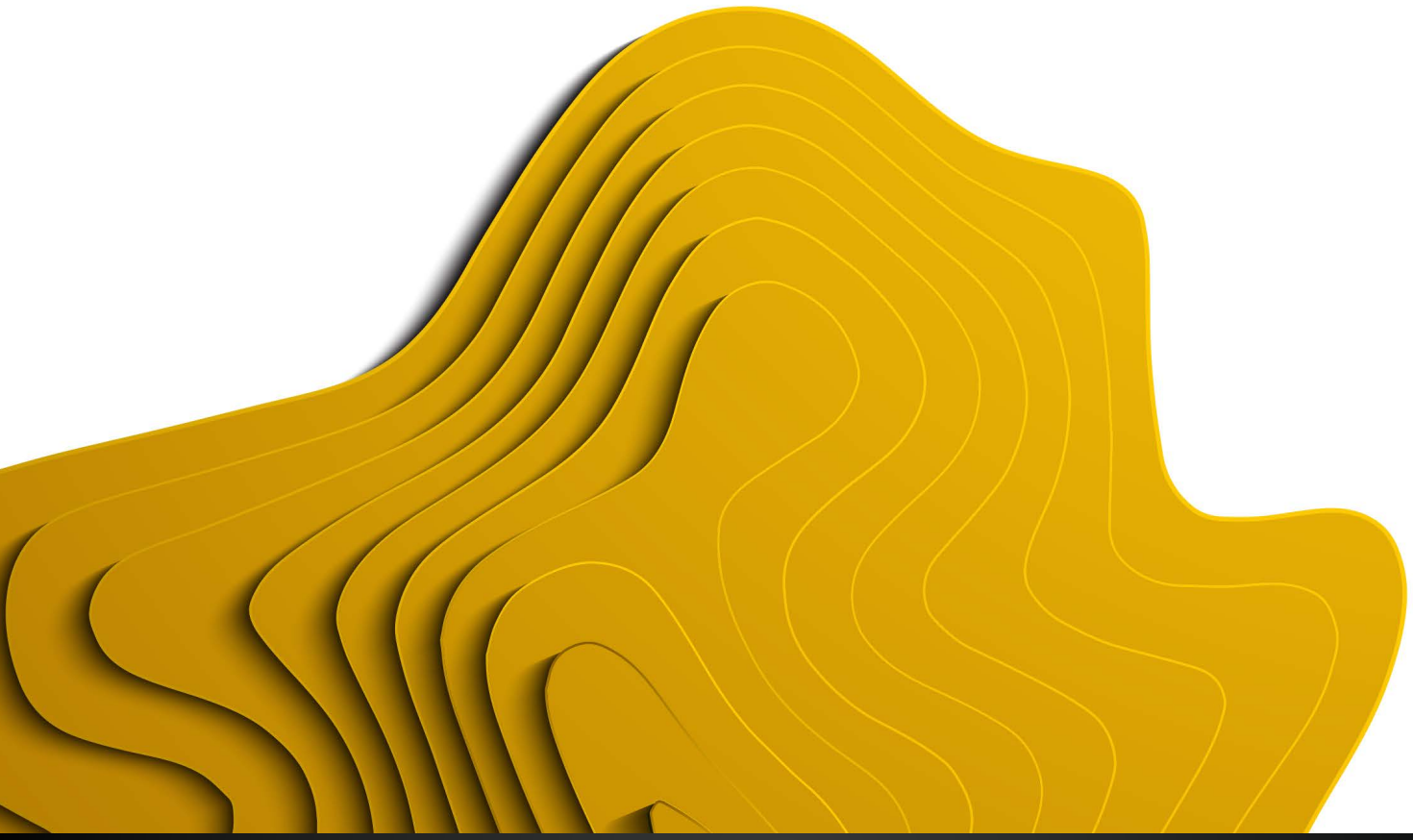

DOE/NETL HIGHLIGHTS

OCTOBER 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 in August 2020 with sessions on carbon capture, utilization, and storage (CCUS). In September 2020, the virtual meeting *featured four days of carbon storage topics*, including an overview of the Regional Initiatives, updates on *Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative* Phase II projects, and results from recent efforts of *DOE's Regional Carbon Sequestration Partnerships (RCSPs)*. In addition, the virtual meeting included discussions on carbon storage technologies, wellbore integrity, plume detection, intelligent monitoring systems, and offshore opportunities. The 2020 Virtual Integrated Project Review Meeting, which will run into November 2020, features sessions focused on how DOE/Office of Fossil Energy (FE)-sponsored research and development (R&D) activities advance transformative science and technologies to support efficient and environmentally sound use of fossil fuels. A comprehensive schedule of the virtual meeting is *available online*. From *NETL News Releases*. August and September 2020.

NOVEMBER 2020

DOE Issues NOI for Carbon Storage FOA.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) *issued a notice of intent (NOI)* for a Funding Opportunity Announcement (FOA) in support of the goals of the *Advanced Storage research and development (R&D)* technology area of *DOE's Carbon Storage Program*. The "Emerging CO_2 Storage Technologies: Optimizing Performance Through Minimization of Seismicity Risks and Monitoring Caprock Integrity" FOA would seek projects to develop tools and methods designed to optimize safe, secure, and verifiable carbon dioxide (CO_2) storage. The FOA intends to achieve three goals: facilitating the development of novel or advanced tools and methods to improve detection and characterization of faults during the site characterization phase; assessing seismic risk associated with large-scale CO_2 injection; and identifying, locating, and quantifying unpredicted CO_2/native fluid migration through the main caprock layer(s) overlying an injection reservoir. From *Office of Fossil Energy Press Release.* November 2020.

NETL Renews Partnership with NCCC.

DOE/FE and the National Energy Technology Laboratory (NETL) renewed their agreement with Southern Company to operate the *National Carbon Capture Center (NCCC)*—a DOE-sponsored research facility focused on next-generation carbon capture technologies. Under the agreement, Southern Company will continue to manage and operate NCCC, which is located in Wilsonville, Alabama (USA), for an additional five years, setting the stage for the facility to expand into new areas of research and to advance CO_2 utilization and direct air capture (DAC) solutions. From *NETL Press Release*. October 2020.

DECEMBER 2020

DOE Issues NOI for Carbon Storage FOA.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) *issued a notice of intent (NOI)* for a Funding Opportunity Announcement (FOA) in support of the goals of the *Advanced Storage research and development (R&D)* technology area of *DOE's Carbon Storage Program*. The "Emerging CO_2 Storage Technologies: Optimizing Performance Through Minimization of Seismicity Risks and Monitoring Caprock Integrity" FOA would seek projects to develop tools and methods designed to optimize safe, secure, and verifiable carbon dioxide (CO_2) storage. The FOA intends to achieve three goals: facilitating the development of novel or advanced tools and methods to improve detection and characterization of faults during the site characterization phase; assessing seismic risk associated with large-scale CO_2 injection; and identifying, locating, and quantifying unpredicted CO_2/native fluid migration through the main caprock layer(s) overlying an injection reservoir. From *Office of Fossil Energy Press Release*. November 2020.

NETL Explores Expanded Use for CO_2-EOR.

A project utilizing National Energy Technology Laboratory (NETL) expertise in CO_2-enhanced oil recovery (EOR) is underway in southern Michigan (USA). *The project* aims to unlock access to significant resources in the Trenton/Black River play by injecting CO_2 in the subsurface to improve the flow of oil to production wells. NETL's industry partners are drilling an approximately 3,900-foot well near Ann Arbor, Michigan, to collect data and for later use as a recovery/production well. A second well will be drilled nearby to collect additional data and for use as the injection well. The goals of the project are to help the United States maintain its energy independence and economically use captured CO_2 while reducing emissions and maximizing the lifetime utility of existing infrastructure and wells in mature fields. From *NETL Press Release*. November 2020.

JANUARY 2021

DOE Announces Funding for Carbon Storage Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) made available federal funding for cost-shared research and development (R&D) to develop tools and methods designed to optimize safe, secure, and verifiable carbon dioxide (CO_2) storage. The "Emerging CO_2 Storage Technologies: Optimizing Performance Through Minimization of Seismicity Risks and Monitoring Caprock Integrity" Funding Opportunity Announcement (FOA) supports the *Advanced Storage R&D* technology area of DOE's *Carbon Storage Program*. From *energy.gov*. December 2020.

FEBRUARY 2021

DOE/FE Funding to Include CCUS.

The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) announced the availability of financial assistance for cost-shared research and development (R&D) projects under a *Funding Opportunity Announcement (FOA)* that supports the initial engineering and design of carbon capture, utilization, and storage (CCUS) projects. Projects selected under the CCUS-focused Area of Interest (AOI) for this FOA will support the completion of an initial design of a commercial-scale CCUS-direct air capture system that separates, stores, or utilizes a minimum of 1,000 metric tons of carbon dioxide (CO_2) per year from the air. The National Energy Technology Laboratory (NETL) will manage the projects, which will support DOE's *Carbon Capture Program*. Responses are due by March 5, 2021. From *energy.gov*. January 2021.

MARCH 2021

NRAP Releases Draft Recommended Practices for Geologic Carbon Storage Sites.

Researchers from the U.S. Department of Energy's (DOE) National Risk Assessment Partnership (NRAP) released two draft reports providing recommendations to support quantitative assessment and management of subsurface environmental and induced seismicity risks at geologic carbon storage sites. The draft reports—"*NRAP Recommended Practices for Containment Assurance and Leakage Risk Quantification*" and "*NRAP Recommended Practices for Managing Induced Seismicity Risk Associated with Geologic Carbon Storage*"—are available through the National Energy Technology Laboratory's (NETL) Energy Data eXchange (EDX). Public comment is sought through May 7, 2021. The reports are organized as a set of conceptual workflows that progress through the various stages of the geologic carbon storage project lifecycle. Recommendations are intended to

support stakeholder decision-making related to site characterization, area of review, post-injection site care, and monitoring intensity and duration. NRAP is a collaboration of five U.S. national laboratories focused on quantifying and managing subsurface environmental risks to support implementation of safe and secure large-scale geologic carbon storage.

NRAP Releases Dataset and Tools.

DOE's *NRAP released FutureGen 2.0 data* to the public on NETL's EDX. Stemming from a federally funded research and multi-year preservation effort, the release makes this dataset available to the carbon storage community for model simulation development and validation and for future machine learning/artificial intelligence applications in carbon storage analysis. In addition, NRAP *released the Passive Seismic Monitoring Tool*, which is used for optimal design of passive seismic monitoring networks using surface or borehole geophones.

DOE's SMART Initiative Generates Dataset for CO_2 Injection Site and Develops an LIP Framework.

DOE's National Energy Technology Laboratory's (NETL) Science-Informed Machine Learning for Accelerating Real-Time Decisions in Subsurface Applications (SMART) Team *generated a comprehensive synthetic dataset for a realistic carbon dioxide (CO_2) injection site*. In addition, the SMART Real-Time Forecasting Team is *developing a learning-based inversion-free prediction (LIP) framework* that has the potential to produce real-time forecasting with uncertainty quantification informed by streaming observation data through parallel forward simulations. Funded by DOE's *Carbon Storage* and Upstream Oil and Gas Programs, the SMART Initiative is a 10-year, multi-organizational effort with the goal of transforming data analysis and predictive capabilities for subsurface applications and significantly improving efficiency and effectiveness of carbon storage and unconventional oil and gas field operations.

APRIL 2021

DOE Briefs State Lawmakers on CO_2 Management, Mitigation Technologies.

National Energy Technology Laboratory (NETL) Director Brian Anderson, Ph.D., addressed the Pennsylvania Senate Environmental Resources and Energy Committee, highlighting NETL-supported projects that reduce carbon dioxide (CO_2) emissions, technologies that safely capture and store CO_2, and processes that make value-added products from the carbon waste stream. The *information briefing* focused on the deployment and utilization of CO_2 management technologies in Pennsylvania (USA). NETL conducts research and development (R&D) for the U.S. Department of Energy's (DOE) *Carbon Storage Program* to advance technologies that enable safe, cost-effective, permanent geologic storage of CO_2. DOE's *Carbon Utilization Program* is developing technologies to transform CO_2 and other carbon byproducts and wastes into valuable products in an efficient, economical, and environmentally friendly manner. From *NETL News Release*. March 2021.

MAY 2021

DOE Announces Funding to Enhance Safety, Security of CO_2 Storage.

The U.S. Department of Energy (DOE) announced funding for four research and development (R&D) projects to enhance the safety and security of carbon dioxide (CO_2) storage. The selected projects will look to address challenges related to long-term, commercial-scale storage of CO_2, working to improve the tools to monitor the seal integrity of caprocks used in CO_2 storage complexes and identify and reduce the risk of potential seismic activity. The projects will be managed by DOE's Office of Fossil Energy and Carbon Management's (FECM) National Energy Technology Laboratory (NETL) and will support the goals of the *Advanced Storage R&D* technology development area in *DOE's Carbon Storage Program*. From *DOE's Office of Fossil Energy and Carbon Management*. May 2021.

DOE Announces Funding Focused on CCS for Power Generation.

DOE's FECM announced federal funding for cost-shared R&D projects under a Funding Opportunity Announcement (FOA) titled "*Carbon Capture R&D for Natural Gas and Industrial Sources and Front-End Engineering Design Studies for Carbon Capture Systems at Industrial Facilities and Natural Gas Plants.*" The funding is focused on carbon capture and storage (CCS) for power generation and industrial applications, with a goal of commercial deployment by 2030. NETL will manage the projects, which will support *DOE's Carbon Capture Program*. From *DOE's Office of Fossil Energy and Carbon Management*. April 2021.

JUNE 2021

DOE Leads International Forum to Develop Net-Zero Emissions Strategies.

The U.S. Department of Energy (DOE) is leading the creation of a new international forum dedicated to developing long-term strategies, such as carbon capture and storage (CCS), to reach global net-zero emissions. The Net-Zero Producers Forum includes Canada, Norway, Qatar, Saudi Arabia, and the United States, which collectively represent 40% of global oil and gas production. DOE, along with other governments, also *announced several other initiatives* to expand international cooperation in addressing potential climate issues and enhance clean energy innovation. The efforts were coordinated by DOE's Office of International Affairs in support of *President Biden's Leaders Summit on Climate*. From *DOE's Office of Fossil Energy and Carbon Management*. April 2021.

JULY 2021

DOE-Sponsored, Battelle-Led CCUS Partnership Completed.

The final reports for the Midwest Regional Carbon Sequestration Partnership (MRCSP) have been completed and approved by the U.S. Department of Energy (DOE), *marking the completion of the MRCSP Program* after 17 years of carbon capture, utilization, and storage (CCUS) research and development (R&D). MRCSP's work was funded mainly by DOE's Office of Fossil Energy and Carbon Management (FECM). Battelle led the MRCSP in phases, starting with the Characterization Phase in 2003, moving to multiple small-scale pilot tests in the Validation Phase in 2005, and culminating in the large-scale Development Phase in 2008. The focus now shifts to commercialization of CCUS, with Battelle continuing its leadership role, jointly with the Illinois State Geological Survey, of the *Midwest Regional Carbon Initiative (MRCI)*. From *DOE's Office of Fossil Energy and Carbon Management*. June 2021.

DOE Announces Funding for DAC Technology.

DOE announced federal funding for six R&D projects that advance direct air capture (DAC) technology—a carbon dioxide (CO_2) removal approach that extracts CO_2 from the atmosphere. One of the selected projects will develop preliminary designs for large-scale DAC and work with partners on the designs to permanently store CO_2 in underground facilities in Wyoming, Louisiana, and California. The projects will be managed by DOE's FECM and the National Energy Technology Laboratory (NETL). From *DOE's Office of Fossil Energy and Carbon Management*. June 2021.

AUGUST 2021

DOE-Sponsored, SSEB-Managed CCUS Partnership Completed.

The Southeast Regional Carbon Sequestration Partnership (SECARB), one of the U.S. Department of Energy's (DOE) *Regional Carbon Sequestration Partnerships (RCSPs)*, has concluded after nearly 20 years of collaboration and research. Established in 2003 and managed by the Southern States Energy Board (SSEB), SECARB set out to identify major sources of carbon dioxide (CO_2) emissions, characterize the geology of a 13-state region, determine the most promising options for commercial deployment of CO_2 storage technologies in their region, and validate the technology options. Phase III of SECARB consisted of two large-scale injection tests (the "Early Test" at Cranfield oilfield near Natchez, Mississippi, and the "Anthropogenic Test" at the Citronelle injection site in Alabama) that helped lay the foundation for future carbon capture, utilization, and storage (CCUS) projects. The conclusion of SECARB follows that of another National Energy Technology Laboratory (NETL)-funded RCSP, *the Midwest Regional Carbon Sequestration Partnership (MRCSP)*. From *NETL News Release*. July 2021.

SEPTEMBER 2021

DOE Names Phase I Winners of FECM Initiative.

The U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) announced the winners in Phase I of the SMART (Science-informed Machine Learning to Accelerate Real-Time Decisions in the Subsurface) Initiative. SMART leverages the expertise of seven national laboratories, as well as industry partners, universities, field laboratories, and carbon storage regional initiatives, to advance the understanding of the subsurface environment through machine learning. The four winners in Phase I of the *SMART Visualization Platform Prize Challenge* designed prototype platforms and/or mockups that demonstrate a user-friendly visualization platform. The platform concept is intended to transform how scientists, engineers, regulators, and the public interact with subsurface data. The winners will develop the prototypes provided by the SMART Initiative technical team. From *FECM SMART*. August 2021.

NRAP Publishes Integrated Assessment Model Journal Article.

DOE's National Risk Assessment Partnership (NRAP) developed an open-source integrated assessment model (NRAP-Open-IAM) to help address questions about a potential geologic carbon storage site's ability to effectively contain injected carbon dioxide (CO_2) and protect groundwater and other overlying environmentally sensitive receptors. The model's basic components, important features and capabilities, and functionality are highlighted in a *journal article published by Environmental Modelling & Software*. NRAP-Open-IAM is available for download on *GitLab* and the National Energy Technology Laboratory's (NETL) *Energy Data eXchange (EDX)*. NRAP is a collaboration of five U.S. national laboratories focused on quantifying and managing subsurface environmental risks to support implementation of safe and secure large-scale geologic carbon storage. From *NRAP*. July 2021.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2020

CCS Study Moves to Geophysical Survey Stage.

The University of Wyoming, Basin Electric Power Cooperative, and other partners are working to develop a site capable of storing more than 50 million metric tons of CO_2 underground as part of a DOE CarbonSAFE Initiative project. A geophysical survey has begun, covering approximately nine square miles around the Dry Fork Station power plant in Gillette, Wyoming (USA). Over the next three years, the project partners will conduct commercial-scale surface and subsurface testing, data assessment, and modeling; prepare and file construction permits with Wyoming's Department of Environmental Quality; integrate the project with a separate CO_2 capture study; and conduct the required National Environmental Policy Act analyses. From *University of Wyoming*. August 2020.

CCS Feasibility Study Set to Begin.

A study to determine the feasibility of constructing a full-scale CCS facility project at a cement plant in Edmonton, Canada, is set to begin. The study will focus on the feasibility of capturing the majority (90 to 95%) of CO_2 from the flue gas of the Lehigh cement plant. The International CCS Knowledge Centre is a partner on the project. From *Journal of Commerce*. August 2020.

Agreement Reached on Scaled-Up CO_2 Removal, Storage.

Climeworks, ON Power, and CarbFix will collaborate to build facilities to capture CO_2 using DAC technology and store the CO_2 via natural underground mineralization. The facilities will be built within ON Power's Geothermal Park in Iceland, and the CO_2 will be stored in basalt formations. From *Carbon Capture Journal*. September 2020.

Funding Awarded to CO_2 Storage Project.

MIT Energy Initiative's Carbon Capture, Utilization, and Storage Center awarded funding to a research project seeking to expand understanding of new processes for storing CO_2 in basalt formations by converting it from an aqueous solution into carbonate minerals. The plan for the project, titled "High-fidelity monitoring for carbon sequestration: integrated geophysical and geochemical investigation of field and laboratory data," is to conduct a comprehensive study to better understand the coupled chemo-mechanical processes that accompany CO_2 storage in basalt formations. From *MIT News. August* 2020.

Marine-Based CO_2 Capture System Has EOR Potential.

Mitsubishi Heavy Industries and partners will conduct test operations and measurements of a small-scale, ship-based CO_2 capture demonstration plant to verify the plant equipment's use as a marine-based CO_2 capture system. Carbon dioxide captured as a result of the "Carbon Capture on the Ocean" (CC-Ocean) project has the potential to be recycled for use in EOR operations. The project is expected to last two years; following further operational tests, the plant is expected to be installed onboard a coal carrier. From *Mitsubishi Heavy Industries*. August 2020.

NOVEMBER 2020

US States to Establish Regional CO_2 Transport, Storage Infrastructure Plan.

Seven U.S. states signed a Memorandum of Understanding (MOU) to establish a regional carbon transport plan by 2021. Under the MOU, the states will commit to the development of safe CO_2 transport and storage. A state coordination group will be facilitated by the Great Plains Institute and informed by ongoing work by the Regional Carbon Capture Deployment Initiative—a network of 25 U.S. states working to ensure near-term deployment of CO_2 capture projects. More information is *available online*. From *Beaver County Times Online*. October 2020.

Japanese Firms to Demonstrate CO_2 Storage.

Two Japanese firms will conduct a demonstration project to store CO_2 in Indonesia. Electric Power Development Co. and Japan NUS Co., with cooperation of the Indonesian government, will execute the four-year plan at Gundih gas field in Central Java Province. A gas pipeline will connect the gas field to the CO_2 storage site. From *Kyodo News*. September 2020.

CCS Project Awarded in North Yorkshire.

Worley, an Australian engineering company, was selected to provide the early front-end engineering and design (pre-FEED) for two carbon capture units at Drax Group's power station in North Yorkshire. The capture units will integrate bioenergy with carbon capture and storage (BECCS) technology. Once operational, the capture units have the potential to capture approximately 4 million metric tons of CO_2 annually. From *Energy Live News*. September 2020.

Norway to Build CCS Project.

The Norwegian government proposed a funding package to enable large-scale implementation of CCS in Norway. The "Longship" funding package seeks to implement a full-scale CCS project that will capture CO_2 emissions from the NORCEM Heidelberg cement plant in Brevik, near Oslo, and transport and store it under the North Sea. The full-scale CCS chain includes CO_2 storage nearly 10,000 feet under the ocean at the Northern Lights project, a collaboration among Equinor, Shell, and Total. Initially able to handle 1.5 million tons of CO_2 per year, the site aims to be able to receive, inject, and store up to 5 million tons of CO_2 per year when fully realized. From *Forbes*. September 2020.

Organizations Sign CCS MOU.

Three international organizations signed an MOU to further develop CCS technologies. Through the MOU, Technology Centre Mongstad, DNV GL, and SINTEF aim to help advance CCS technology from pilot demonstration to wide-scale commercial deployment. From *TCM News*. October 2020.

Carbon Storage License Awarded in UK.

The UK's Oil and Gas Authority awarded a CO_2 appraisal and storage license to Eni UK Limited. Under the license, which will cover an area within the Liverpool Bay area of the east Irish Sea, Eni plans to reuse and repurpose depleted hydrocarbon reservoirs and associated infrastructure to store CO_2 captured in northwest England and northern Wales. From *ENI Press Release*. October 2020.

DECEMBER 2020

Wyoming CarbonSAFE Project Enters Phase III.

The University of Wyoming launched Phase III of their Carbon Storage Assurance Facility Enterprise (CarbonSAFE) project. Phase III of the Wyoming CarbonSAFE project includes finalizing site characterization, completing Class VI permitting, and conducting National Environmental Policy Act (NEPA) analyses. From *University of Wyoming News*. November 2020.

CCS Project Proposed in Denmark.

Plans for a CCS project in Copenhagen, Denmark, were unveiled. The project—a collaboration between Amager Resource Center (ARC) and Copenhagen Malmö Port—will have the potential to capture approximately 500,000 metric tons of CO_2 from ARC. Once captured, the CO_2 will be transported for storage in underground oil reservoirs. From *Gasworld*. November 2020.

Moomba CCS Injection Trial Conducted.

Approximately 100 metric tons of CO_2 were injected underground in depleted gas reservoirs as part of the final field trial for the Moomba CCS Project. The injection occurred in the Strzelecki field in the Cooper Basin in South Australia. According to Santos, an Australian gas supplier, the Moomba CCS Project has the potential to store up to 20 million metric tons of CO_2 per year. From *Santos*. October 2020.

CO_2 Storage License Application Submitted.

Chrysaor, a North Sea oil and gas producer, submitted a license application and will submit an application for a storage lease to store CO_2 in a depleted gas reservoir. The applications support the V Net Zero Project, which seeks to store and transport CO_2 from the Immingham cluster on Humberside. From *Chrysaor News Release*. November 2020.

MOU for Bio-CCS Projects Signed.

Vattenfall (Sweden) and Aker Carbon Capture (Norway) signed a Memorandum of Understanding (MOU) to accelerate the evaluation of future carbon capture sites in Sweden and Northern Europe. According to Vattenfall, the companies will collaborate to develop solutions for large-scale, commercial bio-CCS plants. The MOU has a two-year timeline. From *Chemical Engineering*. October 2020.

Large-Scale CCUS Plant to be Developed.

A large-scale CCUS plant will be developed in Almeria, Spain. Carbon Clean, LafargeHolcim, ECCO$_2$, and Sistemas de Calor agreed to develop the project, which aims to capture CO_2 emitted through the cement production process and recycle it for agricultural use for accelerated crop production. By accelerating the photosynthesis process, this technique has the potential to increase farm efficiency. According to the companies, the commercial applicability of this process has the potential to leverage 700,000 metric tons of CO_2 and achieve 100% decarbonization at the plant. From *Carbon Capture Journal*. October 2020.

Partnership to Develop Offshore CO_2 Transport, Storage in UK.

A partnership to develop offshore CO_2 transport and storage infrastructure in the North Sea was formed. The Northern Endurance Partnership (NEP)—comprising BP, Eni, Equinor, National Grid, Shell, and Total—will serve the proposed Net Zero Teesside and Zero Carbon Humber projects that aim to establish decarbonized industrial clusters in Teesside and Humberside, respectively. NEP submitted a bid for funding through the United Kingdom (UK) government's Industrial Decarbonisation Challenge. From *Equinor*. October 2020.

JANUARY 2021

CO_2 Injection Begins at Otway Stage 3 Project.

Australian CCUS research organization CO2CRC announced the commencement of CO_2 injection operations at their *Otway Stage 3 project* in southwestern Victoria, Australia. The project aims to develop monitoring and verification technologies for field applications that have a lower surface environmental footprint, can be operated and monitored remotely, and are more cost-effective and reliable than traditional CO_2 monitoring methods. From *CO2CRC Media Release*. December 2020.

Project Certified for CO_2 Storage.

Carbon dioxide storage beneath the Danish North Sea as part of Project Greensand was confirmed to be feasible by independent certification. The project completed the first phase of validation with the certification of feasibility to DNV GL's (Det Norske Veritas Germanischer Lloyd) CCS certification regime and the international standard. DNV GL confirmed that the Nini West field in Denmark is conceptually suitable for injecting 0.45 million metric tons of CO_2 per year, per well, for a 10-year period. Project Greensand is aiming to have the first well from the Nini platform ready for injection in 2025, with the long-term goal of developing the capacity to store approximately 3.5 million metric tons of CO_2 per year before 2030. From *Oil and Gas Republic*. November 2020.

Construction Begins at Storage Plant.

Construction began at *Climeworks' Ocra plant* (Iceland), which combines direct air capture technology with CO_2 storage. The construction involves two phases—Phase I began in October 2020 and included the infrastructure and foundation; in Phase II, the plant and machinery will be installed. Once complete, Ocra is expected to remove more than 4,000 tons of CO_2 from the atmosphere per year. From *Carbon Capture Journal*. December 2020.

Feasibility Study to be Conducted for Large-Scale CCS Project.

Neptune Energy will conduct a feasibility study for a large-scale CCS project in the Dutch North Sea. The project could achieve more than 50% of the CO_2 reduction targeted by the Dutch industrial sector. From *Offshore Magazine*. December 2020.

Companies Collaborate on CCS Compression.

Aker Carbon Capture and MAN Energy Solutions signed a technology-cooperation agreement to develop more energy-efficient compression solutions for CCS applications with heat recovery. The agreement will form the basis for project deliveries to carbon capture plants. From *Carbon Capture Journal*. December 2020.

Australian and Japanese Companies to Study CCS.

Australian and Japanese companies are reviewing plans to capture CO_2 and store it under the ocean floor off the coast of Australia. The companies are working on proposals to ship industrial emissions across the Asia-Pacific region and store it under the seabed. From *Japan Times*. December 2020.

CCUS Pilot Project Underway.

Cambridge Carbon Capture (CCC) won the first phase of a United Kingdom (UK) Research and Innovation competition to pilot CO_2LOC—its carbon capture and utilization technology. *CCC's CO_2LOC technology* enables CO_2 storage through a two-stage mineralization process that stores CO_2 in rock form and that can be utilized across a range of industries. From *Cambridge Independent*. December 2020.

MOU Signed to Collaborate on CCUS in Italy.

Italian companies Eni and Saipem signed a Memorandum of Understanding (MOU) to cooperate on potential CCUS opportunities in Italian industrial districts. The objective of the MOU is to contribute toward the decarbonization process of entire production chains to help achieve CO_2 emissions reduction goals. From *Eni Press Release*. December 2020.

FEBRUARY 2021

Full-Scale CCS Facility to Be Installed in Norway.

A full-scale carbon capture and storage (CCS) facility will be installed at a cement plant in Brevik, Norway. The HeidelbergCement Norcem project is expected to capture and store 400,000 tons of CO_2 per year. Work on the facility is projected to begin in 2021, with the goal of beginning CO_2 separation from the cement process in later years. The outcome is expected to be a 50% reduction of emissions produced at the plant. From *The Baltic Course*. December 2020.

MOU Signed to Further Develop CCUS Value Chain.

Equinor Energy and Mitsubishi Heavy Industries signed a Memorandum of Understanding (MOU) for a low-carbon technology collaboration. Under the MOU, both companies will develop and use technology to reduce the CO_2 footprint of oil and gas operations. The companies will look to further develop the hydrogen and CCUS value chains. From *Mitsubishi Heavy Industries News Release*. December 2020.

Norwegian CO_2 Storage, Transport Project to Proceed.

The Norwegian government has voted to fund the Northern Lights CO_2 transport and storage project, enabling it to proceed. *The Northern Lights project* will be an open and available infrastructure that enables the transport of CO_2 from industrial capture sites to a terminal in Øygarden for intermediate storage before being transported by pipeline for permanent storage in an underground reservoir. The project is the transport and storage component of *Longship*, the Norwegian government's full-scale CCS project. From *Carbon Capture Journal*. December 2020.

Companies to Collaborate on CCUS Projects in India.

Carbon Clean and *Veolia* announced a joint venture to develop two CCUS projects in India. The newly established company, Veolia Carbon Clean, will finance, design, build, and operate the projects, as well as research the opportunity for other projects in India. From *Carbon Clean*. December 2020.

Locations Being Investigated for Storage, Liquefaction of CO_2 in Sweden.

Five energy companies in Sweden will collaborate in a pre-study to investigate infrastructure for capturing and storing CO_2. One location being studied by representatives of the Carbon Infrastructure Capture (CinfraCap) project is the Energy Terminal at the Port of Gothenburg (Sweden), where they are looking to identify a suitable location for intermediate storage and possible liquefaction of CO_2. From *Port of Gothenburg News Release*. December 2020.

Carbon Storage Consulting Services Contract Awarded.

Oxy Low Carbon Ventures was awarded a contract to provide carbon storage consulting services for Minnkota Power Cooperative's Project Tundra. Oxy Low Carbon Ventures, a carbon management company, will advise Minnkota on the design and overall requirements of the project's carbon storage facility. Minnkota is currently conducting front-end engineering and design studies. From *Yahoo!* December 2020.

UK Government to Fund CO_2 Reduction Projects.

Six projects across the United Kingdom (UK) were awarded funding from the UK government to form a "net-zero industrial zone." Among the projects is the Humber Industrial Cluster Plan, which will examine how hydrogen and CCS technology can be scaled up to help achieve net-zero emissions by 2040. From *Energy Live News*. January 2021.

MARCH 2021

Companies to Explore CCS Solutions.

LafargeHolcim and Schlumberger New Energy announced a partnership to explore the development of CCS solutions. The two companies will study the feasibility of capturing CO_2 from two LafargeHolcim cement plants—based in North America and Europe—using Schlumberger's carbon storage technology. From *The Maritime Executive*. February 2021.

ExxonMobil to Invest in CCS.

ExxonMobil announced the creation of a business to commercialize its low-carbon technology portfolio, with an initial focus on CCS technologies. According to the company's press release, ExxonMobil Low Carbon Solutions will advance plans for more than 20 new CCS opportunities worldwide to enable large-scale emissions reductions. ExxonMobil also plans to invest in lower-emissions energy solutions. From *ExxonMobil News Release*. February 2021.

EOR Pipeline Project Approved.

The Bureau of Land Management (USA) approved the Wyoming Pipeline Corridor Initiative, designating approximately 1,100 miles of federal land for potential future pipeline development. The proposal identifies routes across Wyoming that could be utilized for enhanced oil recovery (EOR). From *Wyoming Tribune News*.
January 2021.

Chevron Invests in CCUS Startup.

Chevron plans to invest in Blue Planet, a startup that uses captured CO_2 to produce carbonate aggregates that can be used for building materials. The two companies signed a letter of intent to collaborate on potential pilot projects and commercial opportunities. Blue Planet's CO_2 capture process does not require that CO_2 be purified and enriched before use, which has the potential to reduce energy and cost compared to other CO_2 utilization technologies. The technology could also be used to store CO_2 in building materials at a significant scale. From *The Chemical Engineer*. January 2021.

Feasibility Study Underway for India CCUS Project.

Datsur, Air Liquide, and the Bureau of Economic Geology at the University of Texas at Austin (USA) have been selected to conduct a feasibility study for a carbon capture, utilization, and storage (CCUS) project in India. The project will be conducted at Indian Oil Corporation Ltd.'s Koyali refinery near Vadodara, Gujarat, which has the potential to capture more than 5,000 tons of CO_2 per day for large-scale EOR. The project will examine the technical viability, economic cost, and feasibility of capturing CO_2; develop technical specifications, designs, and plans; review and identify necessary approvals and permits required; and analyze the environmental benefits of the CCUS project. From *Chemical Engineering*. January 2021.

CCS Project Awards Contract.

Subsea 7—a subsea company servicing the offshore energy industry—and Aibel—a service company within the oil, gas, and offshore wind industries—were awarded contracts for the *Northern Lights Project*, which is part of the Norwegian full-scale CCS project. Through an engineering, procurement, construction, and installation (EPCI) contract, Subsea 7 will lay the pipeline that will transport CO_2 from the intermediate storage site to the injection well in the North Sea. Aibel was awarded an EPCI contract for the Northern Lights subsea control system. The scope of work includes upgrades to the platform to operate the system that will connect it to the Northern Lights subsea facilities. From *Carbon Capture Journal*. February 2021.

Companies Sign MOU to Develop Integrated CO_2 Capture Solution.

Chart Industries and Svante signed a Memorandum of Understanding (MOU) to develop an integrated CO_2 capture and storage solution to make high-purity CO_2 products from industrial flue gas streams. The facilities will employ Svante's solid-sorbent technology to capture CO_2 directly from post-combustion flue gases to produce pipeline-grade CO_2 for transportation and storage. From Gasworld. February 2021.

APRIL 2021

Engineering and Design Contract Awarded for Large-Scale CCS Project.

Audubon Companies—a services company that supports the energy, infrastructure, and industrial markets—was awarded an engineering and design contract for a large-scale carbon capture and storage (CCS) project that has the potential to capture and store approximately 1.5 million metric tons of CO_2 annually from processing facilities. The captured CO_2 will be transported via pipeline to produce a high-purity CO_2 product, then used for enhanced oil recovery (EOR) operations. From *Audubon Companies Press Release*. March 2021.

Collaboration to Develop BECCS Plant in California.

Schlumberger, Chevron, and Microsoft announced a collaboration to develop a bioenergy plant with carbon capture and storage (BECCS) in Mendota, California (USA) designed to produce carbon-negative power. The BECCS plant will convert agricultural waste biomass into renewable synthesis gas that will be mixed with oxygen in a combustor to generate electricity. More than 99% of carbon from the BECCS process is expected to be captured and stored in nearby geologic formations. From *Carbon Capture Journal*. March 2021.

Proposal to Store CO_2 in North Dakota.

Summit Carbon Solutions is proposing a project to capture CO_2 from at least 17 midwestern ethanol plants and pipe it to North Dakota for storage. The project, which is planned to be operational by 2024, has the potential to capture and store up to 10 million tons of CO_2 per year. Summit's plan involves adding equipment at participating ethanol plants to capture CO_2 and compress it into liquid form, where it would then travel through feeder pipelines to a larger pipeline that extends across the Upper Midwest (USA) into North Dakota for eventual storage, or potentially for EOR. From *The Bismarck Tribune*. March 2021.

Large-Scale CCS Project Announced.

Valero Energy Corp., the BlackRock Global Energy & Power Infrastructure Fund, and Navigator Energy Services are partnering to develop a large-scale CCS project. The initial phase of the project includes capturing CO_2 and transporting it though a pipeline spanning five midwestern states, with the potential to store up to 5 million metric tons of CO_2 per year. Operations are expected to begin in late 2024. From *Business & Industry Connection Magazine*. March 2021.

Partnership to Explore DAC and CO_2 Storage in Norway.

Climeworks and Northern Lights have agreed to explore a full-chain CO_2 removal project in Norway. Climeworks will combine their DAC technology, which has the potential to reach a net-CO_2 removal efficiency of more than 90%, with the Northern Lights' infrastructure. The project includes the capture of CO_2 from industrial stationary sources in the Oslo-fjord region; shipping it to an onshore terminal on the Norwegian west coast; and transferring it, in liquid form, to an offshore storage location below the North Sea. From *Climeworks News Release*. March 2021.

Drax to Build BECCS Power Station.

Drax will begin the planning process for its proposal to build and deploy BECCS in the United Kingdom (UK). The company plans to first secure a Development Consent Order from the UK government. If the application is successful, work to build Drax's first two BECCS units could begin in 2024. From *Carbon Capture Journal*. March 2021.

Marine CCS Project Underway.

A Finnish company is conducting a pilot project to explore how CCS can be developed and scaled in maritime applications. Wärtsilä, which manufactures and services power sources and other equipment in the marine and energy markets, is installing a 1-megawatt (MW) pilot plant at its test facility in Moss, Norway, which will allow the company to test its CCS technologies in a range of scenarios and conditions. From *Diesel & Gas Turbine Worldwide*. March 2021.

Study Assesses Feasibility of Establishing CCS.

Elkem, an advanced materials supplier, is conducting a feasibility study to establish CCS at Norwegian smelters. The study will assess the technical and economic feasibility of installing CCS technology at Elkem's Norwegian plants. As part of the effort, Elkem is partnering with Aker Carbon Capture and Saipem to evaluate various designs of carbon capture facilities and liquefaction facilities, as well as evaluate uploading CO_2 from the Northern Lights project to transport ships. From *Elkem News Release*. February 2021.

Norway CCUS Project Signs Agreement with Technical Advisors.

AGR signed a two-year framework agreement with the Norwegian state-owned Gassnova for the Longship CCUS project. *Under the agreement*, AGR (a CCUS solutions technical advising company) will act as technical advisors by offering technical expertise across the geoscience, reservoir, drilling, and well engineering disciplines, in addition to facilities and cost engineering. From *Carbon Capture Journal*. February 2021.

MOU Includes CO_2 Storage.

ENGIE and Equinor signed a Memorandum of Understanding (MOU) to investigate the development of low-carbon value chains in Belgium, the Netherlands, and France. Specifically, the MOU will be to investigate the production and market potential for hydrogen from natural gas, whereby the CO_2 will be captured and stored offshore. From *Equinor News Release*. February 2021.

Proposal Submitted for CCS Facility in Greece.

Energean, an exploration and production company, submitted a proposal to the Greek government to build a CO_2 storage facility near its Prinos oil field in northern Greece. From *JWNEnergy*. February 2021.

MAY 2021

Company Focuses Artificial Intelligence on Characterizing Subsurface Stresses.

Petrolern—a technology company working on subsurface solutions for carbon storage, geothermal, and oil and gas projects—will use a DOE grant to develop and commercialize artificial intelligence-based technology for estimating Earth stresses. A better understanding of the Earth's stress field at a project site can improve subsurface operations, such as enhanced oil recovery (EOR) and carbon storage. Petrolern's technology can also be used in geothermal energy applications and in both conventional and unconventional oil and gas resource development. From *Journal of Petroleum Technology*. April 2021.

Partnership to Develop Industrial CCS Pipeline System.

Valero—a U.S.-based renewable fuel producer—joined a partnership to build an industrial-scale CO_2 pipeline system to support CCS in the Midwest United States. Teaming with BlackRock Global Energy & Power Infrastructure Fund and Navigator Energy Services, Valero will be an "anchor shipper" on the CCS pipeline system. The first phase is expected to have more than 1,200 miles of CO_2-gathering pipelines across five Midwest states (Nebraska, Iowa, South Dakota, Minnesota, and Illinois) with the potential to store up to 5 million metric tons of CO_2 per year. Startup is planned in 2024. From *S&P Global*. March 2021.

LNG Company Proposes CCS Project.

NextDecade Corp.—a U.S. liquified natural gas (LNG) company—is looking to develop a CCS project at its proposed Rio Grande LNG export plant in Texas (USA). According to NextDecade, the CCS project would have the potential to reduce CO_2 emissions at Rio Grande by more than 90%. From *Reuters*. March 2021.

MOU to Explore Carbon Capture, Transport, and Storage Project.

Baker Hughes and Horisont Energi signed a Memorandum of Understanding (MOU) for the Polaris carbon storage project in Norway. Under the MOU, the companies will explore the development and integration of technologies to minimize the cost and delivery time of carbon capture, transport, and storage. Horisont's Polaris offshore carbon storage project is part of its "*Barents Blue*" project, which has the potential to store more than 100 million tons of CO_2. In addition, the companies will collaborate on new processes and technologies across the carbon capture, transport, and storage value chain. From *Horisont Energi Press Release*. March 2021.

Companies to Develop CCS Plant.

Equinor and SSE announced they will develop two low-carbon United Kingdom (UK) power stations, one of which would be equipped with CCS technology. Under the cooperative agreement, Equinor—a Norwegian state-owned energy company—and SSE—an energy company headquartered in Scotland—will help support the UK's transition to net-zero. Keadby 3, the planned plant with CCS, would be a 900-megawatt (MW) power station fueled by natural gas and fitted with carbon capture technology; the captured CO_2 would be transported via pipeline for storage under the southern North Sea. From *S&P Global*. April 2021.

Testing Initiated at CO_2 Circulation Plant.

DENSO began testing a demonstration facility designed to capture and recycle CO_2 at its Anjo Plant's Electrification Innovation Center. The *CO_2 circulation plant* is designed to capture CO_2 generated by the plant and recycle it as an energy source for the facility. From *After Market News*. April 2021.

Company Introduces CCUS Technology.

A South Korea-based chemical company is using gas separation membranes to increase the purity of CO_2 and change it to industry materials. Lotte Chemical installed a demonstration facility in the southern industrial port of Yeosu, where they plan to operate a commercial facility by 2023. According to the company, the facility would capture more than 60,000 tons of CO_2 per year and use it to produce dry ice and semiconductor cleaning liquid. From *Aju Business Daily*. April 2021.

Large-Scale CCS Project Selects Technologies.

Wabash Valley Resources selected a range of Honeywell UOP technologies to capture and store up to 1.65 million tons of CO_2 annually from a repurposed gasification plant in West Terre Haute, Indiana (USA). UOP will provide technology licenses, basic engineering, and specialty equipment to store CO_2 and process synthesis gas from the gasification unit. From *Oil & Gas 360*. April 2021.

JUNE 2021

DOE-Funded Project Completed.

The University of Illinois announced the completion of the Illinois Basin—Decatur Project (IBDP). Primarily funded through DOE/NETL's Midwest Geological Sequestration Consortium (MGSC), IBDP was designed to evaluate and test CCS technology at commercial scale, with the goal of confirming the ability of the Mt. Simon Sandstone to store 1 million metric tons of CO_2 over three years. The Illinois State Geological Survey designed, implemented, and monitored the project, which was hosted and operated by ADM. From *ADM News Release*. May 2021.

Companies Seek CCUS Opportunities.

A Memorandum of Understanding (MOU) between Italian oil company Eni and Australian energy company Santos could lead to the development of carbon capture, utilization, and storage (CCUS) facilities. Under the MOU, the companies plan to look at potential optimizations, synergies, and sharing of infrastructure; the potential expansion of a liquified natural gas field; and possibly developing CCUS facilities. From *Offshore Engineer*. May 2021.

Dutch Government Grants Subsidies for CCS Project.

The Dutch government granted subsidies to a consortium for the Port of Rotterdam CCS project. The project aims to capture CO_2 in the Rotterdam port area and store it in gas fields in the North Sea. The CCS subsidies are a means to cover the cost(s) of capturing CO_2 by the consortium, which includes Royal Dutch Shell, ExxonMobil, Air Liquide, and Air Products. The project is expected to be operational by 2024. From *Reuters*. May 2021.

Companies Further Collaboration on CCS.

Aker Carbon Capture and SINTEF entered into an MOU to advance CCS solutions. The two companies have collaborated on CCS development for more than a decade, and currently collaborate on several R&D projects. The MOU is intended to advance ongoing and future work in the CCS field. From *Business Insider*. May 2021.

Australian University Announces CCS Partnership.

Researchers at the University of Newcastle (Australia) announced a partnership to further their work on capturing CO_2 for either storage or utilization. The university's Global Innovation Centre for Advanced Nanomaterials will explore the conversion of halloysite nanotubes into advanced nanomaterials that can be utilized as novel adsorbent systems and catalysts for CO_2 capture and conversion processes. From *University of New Castle*. April 2021.

Additional Locations for CCS Project Announced.

Green Plains Inc.—a biorefining company based in Omaha, Nebraska (USA)—and Summit Carbon Solutions (SCS)—an affiliate of Summit Agricultural Group—entered into a long-term carbon offtake agreement as part of a pipeline expansion of SCS's CCS project. The project expansion allows for the development of infrastructure to capture and transport CO_2 for long-term storage. From *Green Plains Press Release*. April 2021.

CCUS Research Project Completes Injection Phase.

Australian CCUS research organization CO2CRC announced the completion of CO_2 injection beneath the Otway International Test Center (OITC) in Nirranda South, Victoria. The injection marks the end of field operations for the Otway Stage 3 Project, which is developing next-generation subsurface CO_2 monitoring and verification technologies for application in commercial CCS projects. More than 95,000 metric tons of CO_2 have been stored at OITC since operations began in 2007. From *CO2CRC News Release*. April 2021.

Carbfix to Build CO_2 Storage Hub.

Iceland startup Carbfix announced that preparations to build an onshore CO_2 mineral storage facility are underway. Based in the bay of Straumsvik in southwestern Iceland, the CO_2 Mineral Storage Terminal would receive CO_2 emissions from industries in Northern Europe by ship; Carbfix would then inject the CO_2 into basaltic bedrock. According to company officials, the preparation phase will begin later this year with the engineering and permitting processes. Drilling of the first wells is planned for 2022, with the aim of starting operations in 2025 and reaching full-scale operations by 2030. From *High North News*. April 2021.

MOU to Explore Feasibility of CCS Solutions.

Borg CO_2—a joint project between 18 industry partners and the port of Borg—and Northern Lights—a Norwegian transport and storage company—signed an MOU to explore the feasibility of CO_2 capture, transport, and storage solutions for industrial partners in the Fredrikstad region. Under the MOU, captured CO_2 would be transported to a CO_2 loading terminal hosted by Borg CO_2, where it would then be loaded onboard a Northern Lights-operated ship for transport to Øygarden on the Norwegian west coast for underground injection. From *Carbon Capture Journal*. April 2021.

Deal Struck in Acorn CCS Project.

Oil and gas firms Shell and Harbour Energy reached a deal with clean energy firm Storegga on the Aberdeenshire Acorn CCS project. The "Acorn Development Agreement" formalizes their relationship and helps to guide the firms through a final investment decision, construction, and operation. The project is expected to be operational in the mid-2020s. From *Energy Voice*. April 2021.

MOU Signed on Australian CCUS Project.

China Huaneng Group—an energy and technology company—and Glencore—a natural resource company—signed an MOU to cooperate on CCUS technology, beginning with the CTSCo Project at Millmerran power station in Australia. Glencore's CTSCo Project is an onshore CCUS project that aims to demonstrate CCUS at industrial scale. From *Carbon Capture Journal*. April 2021.

JULY 2021

Company Launches CCS Project.

Pending regulatory approvals, Venture Global LNG plans to launch a CCS project at its Calcasieu Pass and Plaquemines liquid natural gas (LNG) facilities, located in the southwestern and southeastern corners of Louisiana, respectively. In addition to capturing and storing approximately 500,000 tons of CO_2 per year from both sites, the company also plans to use similar infrastructure to capture and store an additional 500,000 tons of CO_2 from the CP2 facility (once permitted) located in Cameron Parish, Louisiana. From *Renewable Energy Magazine*. May 2021.

CCS Joint Venture Formed.

Talos Energy and Storegga Geotechnologies agreed to jointly assess and develop CCS opportunities on the U.S. Gulf Coast and in the Gulf of Mexico. The two companies will also explore cooperation with others across the CCS value chain. Under the joint venture framework, the companies plan to originate and mature CCS ventures, combining Talos' offshore operations and subsurface experience with Storegga's CCS project experience. From *Offshore Magazine*. June 2021.

CCS Projects Chosen for UK's GHG Removal Program.

The UK government selected projects for *Phase I of its DAC and GHG removal program*. Among the winning projects are a bio-hydrogen with CCS project; a carbon capture and hydrogen production from biomass project that will separate and store CO_2 streams; a carbon-negative community energy project that will produce biochar for carbon storage; a project that will combine biochar production, combined heat and power generation, and CCUS; and a bioenergy with carbon capture and storage (BECCS) project. From *Bioenergy Insight*. May 2021.

Companies Agree to Advance CCS Project.

Equinor and Horisont Energi agreed to advance a CCS project in the Barents Sea, off the coast of northern Norway. The two Norwegian companies entered into the joint development agreement for the Polaris project, which is expected to have the potential to store more than 100 million metric tons of CO_2. After the feasibility phase, Polaris will enter the concept phase, with startup anticipated in 2025. From *Upstream*. May 2021.

Companies Partner on BECCS Project.

Drax Group and Mitsubishi Heavy Industries (MHI) agreed to collaborate on a BECCS project at Drax's power station in North Yorkshire, England. The power station has been converted to use sustainable biomass instead of coal, reducing its CO_2 emissions by more than 85%. By using MHI's carbon capture solvent and deploying BECCS technology, Drax aims to have their first BECCS unit operational as soon as 2027, capturing and storing at least 8 million metric tons of CO_2 a year by 2030. From *Power Engineering International*. June 2021.

UK to Invest in Large-Scale GHG Removal Projects.

UKRI will invest in projects to investigate the viability of five methods of large-scale GHG removal, with a goal of helping the UK reach its net-zero target by 2050. One of the research areas includes afforestation and assessing effective locations for carbon storage. The five interdisciplinary projects will conduct research over 4.5 years to better understand the effectiveness, cost, and limitations of the methods at scale. From *UKRI*. May 2021.

AUGUST 2021

Partnership to Develop CO_2 Storage, Transport System.

Two Canadian companies (Pembina Pipeline Corporation and TC Energy Corporation) announced a partnership to jointly develop a carbon transport and storage system. The Alberta Carbon Grid (ACG) will have the potential to transport more than 20 million metric tons of CO_2 annually, according to the companies. Designed to be an open-access system, the ACG will support the CCUS industry in Alberta, Canada. From *TC Energy News Release*. June 2021.

Shell to be Technical Developer of CCS Project.

Shell will be the Technical Developer for the Acorn CCS Project in Scotland, the oil and gas company announced. In that role, Shell will be responsible for the technical planning and execution of CO_2 capture, transport, and storage. Based at the St. Fergus gas terminal in Northeast Scotland, the Acorn CCS Project plans to repurpose existing gas pipelines to take CO_2 directly to a storage site located approximately 60 miles offshore from St. Fergus. In addition, the Acorn CCS *Project signed an MOU with a group of companies* to advance a CCS system linking Scotland's industrial heartland to the Acorn CO_2 transport and storage system in Northeast Scotland by 2027. From *Offshore Engineer*. June 2021.

Partnership to Explore CCS in France.

A group of companies signed an MOU to explore the development of CCS infrastructure in the industrial basin in the Normandy region of France. The objective of the MOU—among Air Liquide, Borealis, Esso S.A.F., TotalEnergies, and Yara International ASA—is to reduce CO_2 emissions by up to 3 million tons per year by 2030. The companies will assess the technical and economic feasibility of implementing an industrial CCS chain from their industrial facilities for storage in the North Sea. From *Air Liquide News Release*. July 2021.

Carbon Storage Project Announced.

Green Carbon Technologies, Texas Forest Services, and Texas Parks and Wildlife will collaborate on new carbon storage and forestation efforts, the companies announced. The new company, Green Carbon Technologies LLC, projects their efforts will result in storage of an average of 7 tons of CO_2 per year, per acre, over their lifespan, with initial project sites estimated to be up to 250,000 acres in size. From *Digital Journal*. June 2021.

Companies Offer Full Value Chain CCS.

Companies in Norway and Iceland will combine their technologies to offer the full CCS value chain. Aker Carbon Capture and Carbfix signed an MOU to collaborate on CCS solutions to accelerate carbon removal. The agreement also covers opportunities to evaluate strategic options on future storage projects and collaboration. In addition, *Aker Carbon Capture signed another MOU*—with Carbfix and Elkem Iceland—to reduce CO_2 emissions at Elkem Iceland's ferrosilicon plant through CCS in basalt structures. From *Aker Carbon Capture*. July 2021.

CCUS Partnership Announced.

Blue Planet and Sulzer will partner to further develop and optimize Blue Planet's carbon mineralization process for CCUS. The U.S.-based Blue Planet is developing a sustainable CCUS system that captures CO_2 from a variety of emissions sources, mineralizing the CO_2 to form synthetic limestone aggregates by storing the CO_2 in a solid form to be incorporated in concrete. From *Carbon Capture Journal*. June 2021.

SEPTEMBER 2021

UK Research Center Funds CCS Projects.

The United Kingdom Carbon Capture and Storage Research Centre (UKCCSRC) announced the funding of 10 CCS projects to help the UK achieve net-zero emissions targets. The projects will research CO_2 capture from industrial sources and directly from air, as well as research environmental protection and CO_2 monitoring. The UKCCSRC's mission is to ensure CCS plays an effective role in reducing net-CO_2 emissions while securing affordable and controllable electricity supplies, providing low carbon heat, and maintaining competitive industries for the UK. From *Energy Voice*. July 2021.

Companies Collaborate on Seismic for CCUS.

PGS, a marine geophysics company, and *CGG*, a geoscience technology company, signed an MOU to combine their seismic products and technical capabilities applied to the CCUS industry. The companies plan to explore, conceptualize, and create new data products using existing seismic data to facilitate screening and evaluating carbon storage sites. From *Carbon Capture Journal*. July 2021.

Companies Plan to Collaborate to Advance CCS Project.

A group of companies will collaborate with Navigator CO_2 Ventures to advance a carbon storage project across five Midwestern U.S. states. Tenaska, Advanced Resources International (ARI), and Chabina Energy Partners will help advance a CO_2 storage pipeline: the Heartland Greenway System. Tenaska and ARI will lead the overall development of the initial CCS site in Illinois, with Chabina helping to promote the commercial outreach and contracting structure. From *Natural Gas Intelligence*. July 2021.

Large-Scale CCS Facility Proposed in Canada.

Shell announced a proposal to build a large-scale CCS project in Alberta, Canada. The proposed Polaris CCS project would capture CO_2 from the Shell-owned Scotford refinery and chemicals plant located near Edmonton. The initial phase of the project is projected to be operational by the middle of the decade, with the potential to capture and store approximately 750,000 metric tons of CO_2 a year. From *Shell News Release*. July 2021.

Project Makes CO_2 Storage Recommendations.

The Subsurface Evaluation of CCS and Unconventional Risks (SECURe) project developed several monitoring and remediation techniques to help raise the carbon storage readiness levels of potential storage sites. The British Geological Survey-led project also provided guidance on communicating with stakeholders and communities to develop public acceptance of CCS. Knowledge gained through *the SECURe project* can be used to show the potential of CO_2 storage as a safe, efficient, and viable option for advancing decarbonization of industrial and energy emitters. From *Carbon Capture Journal*. August 2021.

Carbon Storage to be Tested in North Dakota.

With funding from the North Dakota Industrial Commission, Midwest AgEnergy will study the feasibility of storing CO_2 in a rock formation underground. Midwest AgEnergy will use seismography to study the Deadwood Formation approximately 3,000 feet below the surface in North Dakota. According to Midwest AgEnergy, if the study shows the formation is capable of holding the CO_2, it could reduce or eliminate 200,000 tons of CO_2. From *The Jamestown Sun*. July 2021.

CO_2 Capture Plant Installed on Ship.

A project led by Japan's Kawasaki Kisen Kaisha ("K" LINE) completed the installation of an operational CO_2 capture plant aboard an ocean-going vessel, and is now advancing to the commissioning and testing phase. The project is being conducted with support from the Maritime Bureau of Japan's Ministry of Land, Infrastructure, Transport, and Tourism, and involves converting the design of an existing CO_2 capture system for onshore power plants to a marine environment. The CO_2 captured from the vessel is expected to be recycled as a new CO_2 source for enhanced oil recovery (EOR) or as a raw material in synthetic fuel through methanization. From *The Maritime Executive*. August 2021.

LEGISLATION and POLICY

OCTOBER 2020

Reports Highlight Carbon Pricing, CCUS.

A pair of reports released in September 2020 discuss the potential policies that could impact energy transition scenarios. In an Energy Outlook released by the United Kingdom (UK)-based BP, the role of future carbon prices was highlighted. In addition, a report titled "Delivering on America's Pledge," released by the U.S.-based sustainability research organization Rocky Mountain Institute, discussed the role of CCUS in power generation. From *S&P Global*. September 2020.

UK Publishes CCUS Policy Documents.

The UK's Department of Business, Energy and Industrial Strategy (BEIS) published new policy documents that focus on CCUS. The policy documents are BEIS's follow-up to previous consultation on CCUS and hydrogen policy. The documents establish "Expert Working Groups" and discuss topics such as preferred business models; the future of CCUS clusters supported by a CCS Infrastructure Fund and a consumer-funded, gas-fired CCS power station; decarbonization; CCUS chain links; and export opportunities within CO_2 storage. From *Lexology* (subscription may be required). September 2020.

European Commission to Propose CO_2 Emissions Reduction.

The European Commission (EC) will propose updated 2030 European Union (EU) CO_2 reduction targets, with the goal of making the EU climate-neutral by 2050, according to officials. The current reduction target, agreed upon in 2018, was to reduce CO_2 emissions to 40% of 1990 levels. The new target will be proposed as an amendment to the EC's draft EU climate law proposed earlier in 2020. From *S&P Global*. September 2020.

New Zealand Risk Reporting for Financial Institutions.

New Zealand officials announced new legislation mandating climate risk reporting for large financial institutions. Under the legislation, the financial institutions would be required to report annually on governance, risk management, and mitigation strategies for potential climate change. The disclosure requirements, which are based on the Task Force on Climate-Related Disclosure framework, would apply to approximately 200 institutions throughout New Zealand. From *Financial Review* (subscription may be required). September 2020.

NOVEMBER 2020

Company Files to Obtain US EPA Permit for CCS Project.

Gulf Coast Sequestration initiated the process for obtaining a *Class VI Underground Injection Control* permit from the U.S. Environmental Protection Agency (EPA). The Louisiana (USA)-based company plans to build and operate a CO_2 storage project with the potential to store more than 80 million tons of CO_2 in geologic formations. From *Gulf Coast Sequestration*. October 2020.

Carbon Dioxide Removal Law Database Launched.

Researchers at Columbia University (USA) launched a database of CO_2 removal laws that provides an annotated bibliography of legal materials related to CO_2 removal and carbon storage and use. *Publicly available online*, the database has more than 500 resources on legal issues related to CO_2 removal, including techniques such as BECCS and soil carbon storage, as well as more than 230 legal resources on CO_2 storage, utilization, and transportation. From *Phys.org*. October 2020.

EU Invests in CCS Projects.

European Union (EU) member states *agreed* with the *European Commission's (EC) proposal to invest in European infrastructure projects*, including several CCS projects. Funding will be awarded to the Porthos CO_2 transport network project, which aims to develop an open-access, cross-border network to transport CO_2 from industrial sources in Europe's main ports to offshore storage locations in the North Sea. The funding will come from the EU's financial mechanism for trans-European infrastructure, the Connecting Europe Facility (CEF) Program. *The full list of projects selected under the CEF Energy Call for Proposals is available*. From *Carbon Capture Journal*. October 2020.

Alberta Invests in CCUS.

The government of Alberta (Canada) is investing in a CCUS grant program to help industries reduce emissions, increase competitiveness, and lower carbon compliance costs. The *Industrial Energy Efficiency and Carbon Capture Utilization and Storage (IEE CCUS) Grant Program* is part of a larger investment of the *Technology Innovation and Emissions Reduction (TIER) fund*, and targets improvements at facilities that are regulated, or eligible to be regulated, by the *TIER Regulation*. From *Carbon Capture Journal*. October 2020.

DECEMBER 2020

Legislation to Develop CO_2-Removal Technology Introduced.

Legislation was introduced in the U.S. House of Representatives that would authorize an approach to research, develop, and demonstrate CO_2-removal technology. The *Carbon Removal, Efficient Agencies, Technology Expertise (CREATE) Act* would direct federal agencies to include the development of CO_2-removal technology as part of their annual budget requests and ensure that the work is coordinated across the federal government. From *U.S. Congresswoman Ann McLane Kuster Press Release*. October 2020.

Net-Zero Initiative Launched.

University of Oxford (Oxfordshire, England) researchers launched the Oxford Net Zero initiative to help address global CO_2 emissions. *Oxford Net Zero* is a collaboration of research and tools to support policy interventions and address questions such as how CO_2 will be distributed among the atmosphere, oceans, biosphere, and lithosphere, and where the CO_2 will be stored. From *Environmental Leader*. November 2020.

JANUARY 2021

CCUS Bills Introduced to Extend 45Q.

The Accelerating Carbon Capture and Extending Secure Storage Through 45Q (ACCESS 45Q) Act was introduced in the U.S. House of Representatives. The bill aims to extend the date for projects to begin construction to claim the 45Q tax credit for carbon oxide storage by 10 years and would also provide a direct pay elective for the full value of the tax credits. In addition, *the 45Q CCUS Tax Credits Amendment Act of 2020 was introduced in the U.S. Senate*. The bill looks to extend 45Q's start of construction date by five years to counter delays in finalizing regulator guidance. From *Biomass Magazine*. December 2020.

US Legislation Introduced to Support Natural Carbon Storage.

Two U.S. Senators introduced legislation to support the reduction of atmospheric CO_2 through the restoration and conservation of forests, grasslands, wetlands, and coastal habitats. The *Trillion Trees and Natural Carbon Storage Act* amends existing international conservation programs to include carbon storage among the list of approved technical assistance categories. From *U.S. Senator Mike Braun Press Release*. December 2020.

UK Government Plan Includes CCUS Commitment.

The UK government *outlined a 10-point plan* that includes a commitment to CCUS. The plan sets a target to capture 10 million metric tons of CO_2 by 2030 and includes new investment to spur CCUS technologies. From *Carbon Capture Journal*. November 2020.

FEBRUARY 2021

Bill Introduced to Support CO_2 Storage.

A bill was *introduced* in the U.S. House of Representatives that supports the buildout of the infrastructure necessary to transport CO_2 from where it is captured to where it could be stored. The *Storing CO_2 and Lowering Emissions (SCALE) Act* would also authorize DOE to provide grants for procuring carbon utilization products for infrastructure projects, as well as build upon *DOE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE)* projects. Under the bill, increased funding would also enable the U.S. Environmental Protection Agency to review permit applications for Class VI CO_2 storage wells in a timely manner and provide grants for states to establish and operate their own Class VI permitting programs. From *Ethanol Producer.* December 2020.

IRS Finalizes Carbon Capture Tax Credits.

The U.S. Internal Revenue Service (IRS) and the U.S. Treasury Department *released final regulations* for businesses seeking to claim carbon capture tax credits under section 45Q. The final rules aim to help businesses understand how the tax credit for qualified carbon oxide storage can benefit companies claiming carbon capture credits. From *Accounting Today*. January 2021.

New York State Establishes GHG Emissions Cap.

New York State adopted a regulation that requires statewide greenhouse gas (GHG) emissions limits. Under the New York Climate Leadership and Community Protection Act, emissions limits in the state are required to reflect a 40% reduction in statewide GHG emissions by 2030 and an 85% reduction by 2050 (both based on 1990 levels). From *Lexology*. December 2020.

Agreement on Bill to Reduce CO_2 Emissions Reached.

Agreement was reached on a Massachusetts bill to reduce the state's CO_2 emissions by at least 85% below 1990 levels by 2050. The bill (*S. 2995*) would establish a net-zero GHG emissions limit for 2050, as well as statewide emissions limits every five years over the next three decades. From *Milford Daily News*. January 2021.

Researchers Produce CCUS Study.

Researchers from the University of Wyoming, the West Virginia University School of Law, and the U.S. Energy Association published a study identifying regulatory shortcomings that may impact the deployment of CCUS technologies in the United States. The study identified legal and regulatory obstacles to CCUS deployment, such as land, mineral, pore space, or water rights; eminent domain; or pipeline or CO_2 storage regulations. The U.S. Energy Association *conducted a webinar* outlining the results of the study. From *Casper Star-Tribune*. December 2020.

UK Oil and Gas Strategy Includes Support for CCS Projects.

The UK Oil and Gas Authority submitted a *revised strategy* in the UK Parliament that supports the government's net-zero targets. Under the revised strategy, industry is encouraged to collaborate with the supply chain and actively support CCS projects. From *Carbon Capture Journal*. December 2020.

UK Energy White Paper Builds on CCS Development.

The UK government released an Energy White Paper that outlines plans to support a transition to net-zero. The white paper builds on the *Ten-Point Plan*, which includes funding for the *development of four CCS hubs and clusters*. From *Global CCS Institute*. December 2020.

MARCH 2021

Carbon Market Bill Passes State Senate Natural Resources Committee.

A bill to establish a voluntary carbon market in Indiana (USA) passed the Indiana Senate Natural Resources Committee. *Senate Bill 373* would establish a carbon market program that facilitates carbon market trading in Indiana, as well as a "Climate-Friendly Farming and Forestry Registration Program" that registers technical advisers and creates an advisory council. The bill will next head to the full Senate for consideration. From *Indiana Environmental Reporter*. February 2021.

Bill Aims for Tax Exemption to Support CO_2 Storage.

Legislation to create a tax exemption for storage of CO_2 was passed in the North Dakota (USA) Senate. North Dakota already exempts CO_2 used for EOR from sales and use tax; the legislation, *Senate Bill 2152*, provides clarification that the same tax treatment can be extended to CO_2 used for geologic storage. The bill will next go to the North Dakota House. From *Ethanol Producer Magazine*. January 2021.

New Mexico Emissions Reduction Bill Passes First Step.

Legislation focused on reducing greenhouse gas (GHG) emissions in New Mexico (USA) passed the House Energy and Natural Resources Committee. House Bill 9, "The Climate Solutions Act," would establish carbon emissions reduction targets and incentivize businesses to find solutions to meet the targets. A key element of the bill includes the establishment of statewide GHG emissions standards, with goals of reaching a 50% reduction in GHGs by 2030 and net-zero emissions by 2050. The bill will be heard next by the New Mexico House State Government, Elections, and Indian Affairs Committee. From *Los Alamos Reporter.* February 2021.

APRIL 2021

Bill Funds Tax Credit, Could Benefit CCS Projects.

A pair of U.S. Senators *unveiled* a bill that *would provide tax credits* for energy manufacturers to spur reinvestment in rural areas. *The American Jobs in Energy Manufacturing Act of 2021* would, among other actions, build new or retrofit existing manufacturing and industrial facilities to produce or recycle products that capture, remove, use, or store CO_2. From *Biomass Magazine*. March 2021.

Legislation to Modernize Tax Credit for CCUS Retrofit Projects.

Legislation to modernize tax credits to better support the use of CCUS technology was reintroduced in the U.S. House of Representatives. The *Carbon Capture Modernization Act* would update the Section 48A tax credit's performance efficiency standards to reflect the capabilities of existing technology, which is expected to help promote the adoption of CCUS technology. The Section 48A tax credit was established in 2005, with certain CO_2 capture projects made eligible in 2008. From *MSN*. March 2021.

Carbon Storage Tax Exemption Bill Passes Legislature.

The North Dakota Legislature passed a bill exempting CO_2 stored underground from sales tax. A similar tax exemption is already in place for CO_2 injected into old oil fields for EOR. *Senate Bill 2152* will advance to the governor of North Dakota. From *The Bismarck Tribune*. March 2021.

Australian Government Opened CCUS Development Fund.

The Australian government opened their CCUS Development Fund, which provides businesses with grants for pilot projects or pre-commercial projects aimed at reducing CO_2 emissions. The fund aims to attract private sector investment. Projects that applied for the grants had to be located in Australia and be completed by June 2025. *More information on the fund and grants is available online*. From *Global CCS Institute*. March 2021.

Malaysia Unveils CCS Opportunities.

Petronas Malaysia Petroleum Management unveiled potential CCS opportunities, including deploying CCS technology at the Kasawari development. The first injection is planned for 2025. A total of 46 trillion cubic feet of storage volume has been identified. From *Energy Voice*. February 2021.

MAY 2021

Lawmakers Introduce Legislation to Plant Trees, Store CO_2.

A group of U.S. Senators and U.S. Representatives introduced the *Repairing Existing Public Land by Adding Necessary Trees Act (REPLANT Act)* in the U.S. Senate. The bill would help reforest 4.1 million acres by planting 1.2 billion trees over the next 10 years, which has the potential to store 758 million metric tons of CO_2 over the trees' lifetime. A summary of the bill is *available online*. From *U.S. Senate Committee on Agriculture, Nutrition, and Forestry Press Release*. March 2021.

Climate Bill Passes Washington State Senate.

The Washington State Senate passed a bill that would institute a decreasing cap on CO_2 emissions. In addition, the *Climate Commitment Act (CCA)* would include investments in new infrastructure, transit, agriculture, forestry, and shipbuilding projects to spur job growth. CCA also includes provisions to prioritize historically overburdened communities, including the establishment of an Environmental Justice and Equity Advisory Panel. From *PR Newswire.* April 2021.

JUNE 2021

Roadmap Aims to Maximize CCUS Potential in UK Through Government, Industry Collaboration.

The UK's Department for Business, Energy & Industrial Strategy released a roadmap that outlines how the UK government and industry can collaborate to create an industrialized UK CCUS supply chain. "*CCUS Supply Chains: a roadmap to maximise the UK's potential*" is organized across four crosscutting activities: supply chain mapping, capability development, skills and innovation, and finance and trade. From *Carbon Capture Journal*. May 2021.

JULY 2021

U.S. Senators' Coalition Seeks Update on CCUS Legislation.

A coalition of U.S. Senators signed a letter to the White House Council on Environmental Quality seeking an update on the implementation of the Utilizing Significant Emissions with Innovative Technologies (USE IT) Act. *Introduced in 2019*, the USE IT Act was signed into law as part of the *Consolidated Appropriations Act of 2021* to support the development of CCUS projects. From *U.S. Senator Kevin Cramer Press Release*. May 2021.

U.S. Senators Introduce Bill to Help CCUS Projects.

U.S. Senators introduced legislation that would help support domestic energy production, create new economic opportunities, and reduce CO_2 emissions. *The Carbon Capture Improvement Act* would make it easier for power plants and industrial facilities to finance the purchase and installation of CCUS equipment using private activity bonds (PABs), which are tax-exempt. Under the bill, if more than 65% of CO_2 emissions from a facility are captured and stored underground, then 100% of the eligible equipment can be financed with PABs. The bill would also allow facilities to utilize the existing 45Q tax credit for carbon storage for industrial emissions. From *U.S. Senator Rob Portman Press Release*. May 2021.

Legislation Incentivizes Carbon Storage.

Legislation was introduced in the U.S. Senate to incentivize investment in climate-forward forestry practices, such as carbon storage. In addition to encouraging forest landowners to adopt voluntary practices to capture CO_2, the *Rural Forest Markets Act* would establish an investment program at USDA to offer guaranteed loans for companies to help small and family foresters create and sell forest credits for storing CO_2. From *Congresswoman Elise Stefanick Press Release*. June 2021.

EU To Unveil Policy Measures.

The European Commission announced plans to unveil a range of new policy measures to help the European Union (EU) reach its target of 55% emissions reductions (compared to 1990 levels) by 2030. The Commission's "*Fit for 55*" package includes a new carbon border adjustment mechanism and, according to officials, could help to strengthen the EU Emissions Trading System (ETS). From *Recharge News*. May 2021.

AUGUST 2021

Legislation Aims to Reduce CO_2 Emissions.

The U.S. House of Representatives introduced legislation that would create a national renewable energy standard with a goal of reducing CO_2 emissions. The *American Renewable Energy Act of 2021* would require U.S. energy producers to meet goals for renewable energy generation, resulting in a net decrease in emissions of criteria air pollutants in impacted communities. From *U.S. Congressman Peter Welch Press Release*. June 2021.

Legislation Helping to Standardize Carbon Market Passes U.S. Senate.

Legislation that may help agricultural activities qualify for carbon market credits passed the U.S. Senate. The *Growing Climate Solutions Act* aims to help private landowners find the right carbon market for their operations by addressing the uncertainties and variabilities surrounding practices, such as no-till farming or planting cover crops, and standardizing best practices. From *Williston Herald*. June 2021.

SEPTEMBER 2021

UK Government Opens Consultation on CCUS Policy.

The UK's Department for Business, Energy, and Industrial Strategy sought views on proposed duties, powers, functions, and objectives of an economic regulator for CO_2 transport and storage networks. The purpose of *the consultation* was to inform the continued development of CCUS policy and legislative proposals. The responses will be used to help the UK government continue to develop policy and consider alternatives, as appropriate. A response to the consultation will include a summary of the responses received. From *GOV.UK*. August 2021.

EMISSIONS TRADING

OCTOBER 2020

RGGI Release Results of Auction 49.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced results of their 49th auction of CO_2 allowances, during which 16,192,785 CO_2 allowances were sold at a clearing price of $6.82. None of the 11.8 million cost containment reserve (CCR) allowances made available were sold; CCR is a fixed supply of allowances made available if prices exceed certain levels ($10.77 in 2020). The auction generated $110.4 million for reinvestment in strategic programs such as energy efficiency, renewable energy, and greenhouse gas (GHG) abatement programs. Additional information on RGGI auctions is *available online*. From *RGGI Press Release*. September 2020.

EC to Adjust EU ETS Regulations.

According to EU executives, the EC will adjust the EU emission trading system (ETS) to be included in the bloc's carbon border adjustment mechanism. The new carbon border tax is expected to provide an alternative to providing free CO_2 allowances. From *Euractiv*. September 2020.

NOVEMBER 2020

RGGI States Initiate Auction Process for Auction 50.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the Auction Notice for their 50th quarterly CO_2 allowance auction, to be held December 2, 2020. Auction 50 will offer 16,237,495 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.) Auction 50 will be the last quarterly auction in which states will offer CO_2 allowances for purchase to meet CO_2 compliance obligations for the fourth control period, which began on January 1, 2018, and extends through December 31, 2020. Market participants can continue to obtain CO_2 allowances through various secondary markets. From *RGGI News Release*. October 2020.

Carbon Market Partnership Launched.

Two companies formed a pilot project to create a voluntary CO_2 removal marketplace. The pilot program, formed by Truterra, LLC and Nori, will focus on using blockchain technology to translate existing farm data that capture the CO_2 removal impact of on-farm conservation practices into potential carbon credits. The pilot is expected to provide farmers with a better understanding of the carbon market potential. From *Successful Farming*. October 2020.

DECEMBER 2020

EU Commission Reports on CO_2 Emissions.

The European Commission released a report detailing the European Union's (EU) output of greenhouse gas (GHG) emissions under Europe's carbon market. According to the report, EU carbon market emissions fell by 9.1% in 2019 from 2018. Approximately 45% of EU's GHG emissions are regulated by the EU Emissions Trading System (EU ETS). Under the EU ETS, businesses can buy permits through auctions held on behalf of EU member states. From *Reuters*. November 2020.

JANUARY 2021

Results of 50th RGGI Auction Released.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of their 50th auction of CO_2 allowances. A total of 16,237,495 CO_2 allowances were sold at a clearing price of $7.41, with bids ranging from $2.32 to $15.00 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 50 generated more than $120.3 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 50*. From *RGGI News Release*. December 2020.

FEBRUARY 2021

RGGI States Initiative Auction Process for Auction 51.

The RGGI-participating states initiated the auction process for their 51st quarterly CO_2 auction, scheduled for March 3, 2021. Auction 51 will offer 23,467,261 CO_2 allowances for sale at a minimum reserve price of $2.38. An 11,976,778 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 $13.00). From *RGGI News Release*. January 2021.

Daily Carbon Credit Assessment Launched.

IHS Markit launched a daily pricing suite for global voluntary carbon offset credits. According to the company, IHS Markit's OPIS Global Carbon Offset Report encompasses daily price assessments in response to demand for benchmark pricing for voluntary carbon credits. From *Nasdaq*. December 2020.

MARCH 2021

RGGI to Conduct Program Review.

The RGGI-participating states intend to initiate a program review in 2021, as stated in their *Principles to Accompany Model Rule Amendments*. To date, two program reviews have been conducted, which considered program design and outcomes, as well as potential changes or new program elements. The RGGI-participating states intend to publish a preliminary program review schedule later in 2021, including a public engagement plan to solicit input to inform the review process. From *RGGI News Release*. February 2021.

EU Carbon Auction Clears at Record High Price.

A February 2021 CO_2 carbon allowance auction under the European Union (EU) Emissions Trading System (ETS) cleared at the highest auction price since the EU ETS launched in 2005, according to auction host European Energy Exchange. From *S&P Global*. February 2021.

ICE to Move EU Carbon Trading to Netherlands.

The Intercontinental Exchange (ICE), which provides price transparency within energy markets, announced that it will move its trading of European carbon futures and options from London to its Netherlands-based exchange in Amsterdam. The date of the move has not been announced, but it is expected to take place later in 2021. From *Nasdaq*. February 2021.

APRIL 2021

Adjustment to RGGI Cap Announced.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the third adjustment to the RGGI cap to account for banked allowances. Each of the RGGI states revised its CO_2 Budget Trading Program to be consistent with the *updated RGGI Model Rule*, which was released in 2017. The updated Model Rule addressed the private bank of CO_2 allowances through a Third Adjustment for for Banked Allowances (TABA), which is a reduction to the states' CO_2 allowance base budgets that are equivalent to the private bank of CO_2 allowances (allocation years 2009–2020). The TABA is made over the five-year period 2021–2025. From *RGGI News Release*. March 2021.

European Parliament Adopts Cross-Border CO_2 Tax.

The European Parliament adopted a resolution to reduce GHG emissions in the European Union (EU) by implementing a carbon tax on imports and commodities covered by the EU's Emissions Trading Systems (ETS). According to the European Parliament, the Carbon Border Adjustment Mechanism (CBAM) must be compatible with the World Trade Organization, and revenues generated should be used to support the *European Green Deal*. The European Commission is expected to present a legislative proposal for the CBAM in the second quarter of 2021. From *Balkan Green Energy News*. March 2021.

MAY 2021

RGGI States Initiate Auction Process for Auction 52.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) initiated the auction process for their 52nd quarterly CO_2 auction, scheduled for June 2, 2021. Auction 52 will offer 22,987,719 CO_2 allowances for sale at a minimum reserve price of $2.38. An 11,976,778 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 $13.00). From *RGGI News Release*. April 2021.

RGGI Releases Compliance Report.

The RGGI-participating states released the *Compliance Summary Report* for RGGI's fourth three-year control period (January 1, 2018–December 31, 2020). The report found that 198 of the 203 power plants (97.5%) subject to RGGI requirements met their compliance obligations. The RGGI program requires fossil fuel power plants 25 MWs or larger to purchase and hold one CO_2 allowance for each ton of CO_2 released during the control period. From *RGGI News Release*. April 2021.

German Government Adopts Carbon Release Rules.

The German government adopted a Carbon Leakage Ordinance aimed at providing relief for companies impacted by the German national carbon emissions trading system. Implemented in 2021, the German national carbon emissions trading system complements the European Union emissions trading system (EU ETS). While the EU ETS applies to large industrial facilities, Germany created a similar cap-and-trade system for the heating and transportation sectors. From *Lexology*. April 2021.

Companies to Sell Emissions Credits Under MOU.

A U.S. Agricultural company and a Japanese trading house entered into an MOU to utilize agricultural land to store CO_2. By using organic fertilizers and improving soil, Indigo Ag and Sumitomo Corp. will increase the amount of CO_2 that can be absorbed into the ground and then sell the amount that has been reduced from the atmosphere as an emissions allowance. Joint research will also be conducted on CO_2 storage in paddy fields. From *Nikkei Asia*. April 2021.

Carbon Trading Desk Launched.

Trafigura—a global commodities trading firm—launched a carbon trading desk. The Geneva-based firm will be involved in voluntary offsets, as well as regulated carbon markets in the United States and the EU. From *Yahoo! Finance*. April 2021.

JUNE 2021

Australia Seeks Partners to Help Develop Carbon Exchange.

Australia's Clean Energy Regulator *sought partner(s)* to facilitate the development of a domestic exchange market for carbon offset units. According to officials, the carbon exchange would complement the current Australian over-the-counter market and accelerate Australia's emissions reduction. From *Regulation Asia*. May 2021.

JULY 2021

RGGI States Release Market Reports.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the *Annual Report on the Market for RGGI CO_2 Allowances: 2020* and the *Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2021*. The annual market report for 2020 reviewed four auctions in 2020 and found no evidence of anti-competitive conduct. The report for the first quarter of 2021 also found no evidence of anti-competitive conduct. From *RGGI News*. May 2021.

Results of 52nd RGGI Auction Released.

The RGGI-participating states announced the results of their 52nd auction of CO_2 allowances. A total of 22,987,719 CO_2 allowances were sold at a clearing price of $7.97, with bids ranging from $2.38 to $12.51 per allowance. In addition, none of the 11.98 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 [$13.00 in 2021].) None of the 11.31 million emissions containment reserve (ECR) allowances made available were sold. (The ECR is a designated quantity of allowances to be withheld if an auction's interim clearing price is below an established price level [$6.00 in 2021]). Auction 52 generated $183,212,120 for states to reinvest in strategic programs, including energy efficiency, renewable energy, and GHG abatement programs. Additional details are available in the *Market Monitor Report for Auction 52*. From *RGGI News Release*. June 2021.

UK Hosts First CO_2 Emission Auction.

The Intercontinental Exchange, Inc. (ICE) hosted the UK's first emissions trading scheme (UK ETS). In addition to providing continuity from the EU ETS, the scheme also focuses efforts to reach the UK's goal of reaching net-zero GHG emissions by 2050. From *mondaq*. May 2021.

AUGUST 2021

RGGI Report Details Investment of 2019 Auction Proceeds.

The RGGI-participating states released a report tracking the investment of proceeds generated from their regional CO_2 allowance auctions. *The report* tracks investments of RGGI proceeds in 2019, providing state-specific success stories and program highlights. In 2019, according to the report, $217 million in RGGI proceeds were invested in programs such as energy efficiency, clean and renewable energy, greenhouse gas (GHG) abatement, and direct bill assistance. From *RGGI Press Release*. June 2021.

SEPTEMBER 2021

Nationwide Carbon Market Opens in China.

A nationwide carbon market opened in China. In 2011, the country launched a pilot carbon trading scheme in Beijing, Tianjin, Shanghai, Chongqing, Shenzhen, Hubei Province, and Guandong Province. In September 2020, China announced its goal to have carbon emissions peak by 2030 and to achieve carbon neutrality by 2060. From *Pinsent Masons*. August 2021.

Britain ETS Update.

According to Intercontinental Exchange®, Britain auctioned 2,594,000 UK emissions permits at 47.25 pounds ($65.49) per metric ton at its auction held in August 2021. Britain's Emissions Trading Scheme (ETS) started trading in May 2021 to replace the European Union's (EU) ETS. Since the launch, more than 38 million CO_2 permits have been traded. From *Reuters*. August 2021.

SCIENCE

OCTOBER 2020

Monitoring System to Track CO_2 Storage in Soil.

A monitoring system designed to track soil carbon storage on dairy farms is being developed in the Netherlands. Researchers from Wageningen University and Research (WUR) and FrieslandCampina, a Dutch dairy company, partnered to develop the monitoring system to better inform farmers on how soil carbon storage affects their dairy farms. For example, an increase in soil organic matter could lead to improved soil carbon storage, thus lowering a farms' "carbon footprint." The research, titled "Possibilities for Monitoring CO_2 Sequestration & Decomposition of Soil Organic Matter on Dairy Farms," is *available on the WUR website*.

Researchers Study Ability of Forests to Store CO_2.

University of Leeds (UK) researchers conducted a study on the long-term CO_2 storage capacity of forests. The study, *published in the journal Nature Communications*, analyzed the relationship between tree growth and tree lifespan by examining more than 200,000 tree-ring records from 82 tree species from sites across the world. The results showed that accelerated tree growth results in shorter tree lifespans, thus leading researchers to question the previously assumed future net carbon uptake of forests this century. From *University of Leeds*. September 2020.

Impact of Animal-Sourced Food Production on CO_2 Emissions Studied.

According to a study, reduced meat production could result in storing up to 16 years of CO_2 emissions by 2050. The study, conducted by scientists from New York University (USA), found that shifting global food production to plant-based diets by 2050 has the potential to store 332 to 547 gigatons of CO_2. *Published in the journal Nature Sustainability*, the study concluded that lowering the demand for meat production and regrowing vegetation in areas where native vegetation has been compromised to make space for animal foods has the potential to help store between 9 and 16 years' worth of CO_2 emissions by 2050. From *Plant Based News*. September 2020.

NOVEMBER 2020

Increasing CO_2 Storage Capacity in US Forests.

According to an analysis by the U.S. Department of Agriculture (USDA) Forest Service, fully stocking non-stocked and poorly stocked forests may lead to a 20% increase in the amount of CO_2 that forests can store. The USDA study was based on publicly available data from more than 130,000 forested plots in the *Forest Service's Forest Inventory and Analysis Program*. The study was *published in the journal Proceedings of the National Academy of Sciences*. From *USDA News Release*. September 2020.

Scientists Discover "Natural Laboratory" to Test Carbon Storage Theory.

Geoscientists at the University of Sydney found the Tweed River valley in northeastern New South Wales to be a "natural laboratory" to test the viability of rock weathering to store CO_2. According to the study, *published in the journal Frontiers in Earth Science*, when common rocks break down, they absorb CO_2 to form carbonates that can then be washed into the oceans, essentially allowing river valleys like the Tweed to act as carbon sinks. Scientists believe this act of common rock weathering has the potential to absorb millions of metric tons of CO_2 from the atmosphere; however, it has never been tested at scale. Scientists believe the Tweed catchment area will enable these claims to be tested. From *The University of Sydney News*. October 2020.

DECEMBER 2020

Wooden Buildings Could Store CO_2.

A study found that wooden buildings have the potential to store approximately half of the cement industry's CO_2 emissions. In collaboration with the Finnish Environment Institute, researchers from Aalto University in Helsinki, Finland, conducted the study, which estimated the CO_2 storage potential of using wood to construct residential buildings in Europe. According to the analysis, if 80% of new homes were made of wood, the buildings could store 55 million tons of CO_2 a year (equivalent to 47% of the cement industry's annual emissions across Europe). From *Earth.com*. November 2020.

Study to Investigate Potential for CO_2 Storage Testbed.

The British Geological Survey (BGS) will conduct a study using preliminary technical and permitting evidence to identify a range of location and design options for a CO_2 storage testbed. Conducted on behalf of the Natural Environment Research Council (NERC), the project aims to define future investment options in CO_2 storage research, outline the CCS landscape for future investment decisions, gather technical and business case evidence to de-risk further investment, and help define the required capabilities and scientific objectives of a testbed. From *BGS News*. October 2020.

JANUARY 2021

Monitoring System for CCS Operations Launched.

Silixa launched a distributed acoustic sensing-based system for CCS monitoring. According to the company's news release, the fiber-optic monitoring system, referred to as Carina® CarbonSecure™, includes continuous and microseismic monitoring throughout the lifetime of a CO_2 storage facility to ensure safety over the stages of CCS. In addition, the company claims the system is a reservoir management tool that can be deployed to assess the viability of geologic formations for CO_2 storage during site characterization; monitor well and storage integrity, as well as microseismic activity, during CO_2 injection; and provide 4D monitoring of the CO_2 plume migration throughout the lifetime of the facility. From *Silixa News Release*. November 2020.

Researchers Study Red Sea Carbon Storage System.

A team of researchers from King Abdullah University of Science and Technology (Saudi Arabia) used an underwater robot to investigate the carbon storage potential of the Red Sea, factoring in water temperature and oxygen depletion. By studying the fate of organic carbon at different depths, the researchers hope to better predict how oceans absorb and store atmospheric CO_2 in the future. From *Phys.org*. December 2020.

Deep Tillage of Soil Can Improve Carbon Storage: Study.

Researchers conducted a meta-analysis of 43 separate studies to further understand the relationship between deep tillage and soil organic carbon (SOC). According to their results, *published in Renewable and Sustainable Energy Reviews*, deep tillage can enhance SOC and increase storage of CO_2 by approximately 8%. From *Concordia University*. December 2020.

Marine Scrubber Technology to Include CCS.

A Norwegian company developed an emissions capture system that helps promote compliance with regulations and is equipped with CCS capabilities. Developed by TECO 2030, "Future Funnel" could help the shipping industry reduce emissions and address the International Maritime Organization's GHG targets while permitting existing ships to operate. From *The Maritime Executive*. December 2020.

FEBRUARY 2021

Research Partnership to Use CCUS Technology.

A research partnership to use CCUS technology to produce plastic was formed. Braskem, a polyolefins producer, and the University of Illinois Chicago (UIC) (USA) will develop a new method for producing ethylene—a raw material used to make thermoplastic resins—that will utilize CCUS technology. The project will use the CCUS technology under development at UIC to connect the capture and conversion of waste CO_2 streams with the production of sustainable feedstock for making plastic. Braskem will assist with scale-up of the technology and help validate the theoretical and experimental studies produced by UIC. From *Braskem News Release*. December 2020.

Scientific Development Could Improve CO_2 Capture.

Researchers from Swansea University (UK) developed a new way of producing carbon spheres that has the potential to improve carbon capture technologies. According to scientists, carbon spheres play an important role in gas adsorption and storage. The Swansea team adapted an existing method of creating carbon spheres (chemical vapor deposition) by using pyromellitic acid as both a carbon and oxygen source and applied the method at different temperatures. From *Swansea University Press Release*. December 2020.

Scientists Convert CO_2 into Jet Fuel.

Scientists from Oxford University successfully converted CO_2 into jet fuel using a technique that reverses the process of burning fuel by relying on the organic combustion method. By heating a mix of citric acid, hydrogen, and an iron-manganese-potassium catalyst, the team was able to convert CO_2 into a liquid fuel capable of powering jet aircraft. According to the scientists, the technique has the potential to make conventionally powered aircrafts with net-zero CO_2 emissions. From *Yahoo!* December 2020.

MARCH 2021

New Carbon Storage Studies Launched.

Agronomic research trials and field demonstrations are being conducted to help farmers add carbon storage to their operations. AGCO—an agricultural machinery and solutions company—will conduct research trials in Africa, Switzerland, Denmark, and the United States, focusing on best practices to maximize carbon stores. From *No-Till Farmer*. February 2021.

New Method Could Boost CO_2 Storage Rates.

Researchers from the Massachusetts Institute of Technology (MIT; USA) developed a method that could boost the performance of systems that use catalytic surfaces to enhance the rates of carbon-storing electrochemical reactions. In such catalytic systems, the movement of a stream of gas containing CO_2 is typically sluggish, slowing down the rate of CO_2 conversion. Results of the study, *published in the journal Cell Reports Physical Science*, show that the new design ensures the CO_2 stream stays concentrated, nearly doubling the performance of the system. From *Carbon Capture Journal*. January 2021.

APRIL 2021

Amazon Rainforest May Release More CO_2 than it Stores—Study.

According to research *supported by National Geographic*, the Amazon rainforest might be releasing more GHGs into the atmosphere than it can absorb. The report, *published in the journal Frontiers in Forests and Global Change*, found that GHGs (e.g., methane and nitrous oxide) being released in the Amazon basin offset and may potentially exceed the region's ability to store CO_2. From *The Weather Channel*. March 2021.

Engineers Developing Concrete with Increased CO_2 Storage Capability.

Research conducted by Purdue University (USA) engineers led to the discovery of a way to potentially double the carbon storage potential of concrete. The study, which *appeared in the scientific journal Construction and Building Materials*, showed that by adding small amounts of nano-titanium dioxide to the cement mix to make concrete, it became more efficient at absorbing CO_2 than other cement pastes. The addition also accelerated the rate of carbon absorption and increased the total volume of CO_2 the cement could absorb. Purdue University also *released a video based on their work*. From *Carbon Capture Journal*. February 2021.

MAY 2021

Concrete Reduces CO_2 Emissions.

A California (USA)-based company developed a process for injecting concrete with CO_2 emissions from power plants or other industrial facilities. CarbonBuilt Inc.'s approach uses hydrated lime as a base material for the manufacture of concrete, then injects the CO_2 emissions to cure the concrete into usable form. As a result, the CO_2 is stored in the concrete, reducing emissions from the concrete manufacturing process by 50 to 70%, according to the company. CarbonBuilt completed two pilot projects that demonstrated the technology and is one of several teams that qualified for the final round of the *XPrize competition*, which supports the development of technologies that convert CO_2 into usable products. From *Los Angeles Business Journal*. April 2021.

Report: Carbon Storage Key to Net-Zero Farming.

According to a report by the Scottish Suckler Beef Climate Change Group, the beef industry could play a major role in making farming a net-zero business by focusing on carbon storage practices. *The report* found that the Scottish Suckler-based beef industry has the potential to reduce greenhouse gas emissions by 24 to 39% by increasing soil carbon storage where possible. From *The Scottish Farmer*. April 2021.

JUNE 2021

Startup Uses Kelp to Store CO_2.

A company based in Maine (USA) is farming kelp to capture and store CO_2 beneath the ocean floor. Running Tide Technologies grows the kelp in a hatchery and then moves it to biodegradable buoys once matured. According to the scientists, kelp—a type of seaweed—captures CO_2 at one of the fastest rates of any species in the world. As the plant grows, it eventually sinks to the bottom of the ocean floor. Running Tide is working with scientists and universities to collect data to monitor the CCS potential. From *CNN*. May 2021.

Company to Store CO_2 as Ocean Bicarbonate.

The UK-based company Cquestr8 secured funding to develop carbon capture technology using natural processes to store CO_2 as stable ocean bicarbonate. The *Cquestr8* process will store CO_2 while also providing ocean ecosystem co-benefits through the deployment of marine bicarbonate. Cquestr8 targets decarbonization of the cement, lime, and steel production sectors. From *Carbon Capture Journal*. April 2021.

Startup Unveils CCS Technology.

High Hopes launched a CCS technology that uses high-flying balloons to capture CO_2 emissions at high altitudes. The captured CO_2 is then brought down to the ground for either underground storage or re-use. According to the company, low temperatures and constant winds save most of the energy required for the process. From *Power Engineering International*. April 2021.

Mangrove Loss Could Create CO_2 Hotspots—Study.

A study led by Australia's Griffith University identified six mangrove-rich regions that could become future "hotspots" of CO_2 emissions due to the potential loss of mangroves. The study, *published in the journal Global Change Biology*, integrated global datasets for carbon stocks, mangrove distribution, deforestation rates, and land-use change drivers into a predictive model of mangrove CO_2 emissions, allowing the researchers to project CO_2 emissions and soil carbon storage potential. According to the study, mangroves have high carbon densities and can store large amounts of CO_2 for long periods. From *Scroll.in*. May 2021.

JULY 2021

Canadian Project Uses Seeds to Store CO_2.

A project based in British Columbia, Canada, will use seeds to regenerate large swathes of land to store CO_2. Seed the North will collect seeds, combine them in biodiverse seedpods, and use drone technology to drop them over target areas disturbed by natural events and industry for forest regeneration. From *Crosscut*. May 2021.

Companies to Collaborate on CCS Monitoring Research.

Geoscience technology companies *CGG* and *Geopic* signed an R&D agreement to jointly research and assess a novel borehole solution for monitoring CO_2 in underground storage sites. The collaboration is focused on delivering a new, continuous, long-term underground monitoring solution that will reduce the risks associated with potential CO_2 release and enhance the safety of CO_2 storage projects. From *Carbon Capture Journal*. June 2021.

Champagne-Inspired Technology Captures, Stores CO_2.

Scientists from the University of Exeter developed a CO_2 capture technology that mirrors the way CO_2 bubbles can be captured from a fizzy drink. Their solution uses natural-based processes and renewable energy to remove carbon from seawater that can then be returned to capture more CO_2. The technology makes the seawater temporarily more acidic, allowing the CO_2 to "bubble out." While the CO_2 is stored, the carbon-depleted water is released back to the ocean. Initial plans are for the research team to design a pilot plant capable of capturing at least 100 metric tons of CO_2 a year. The project was awarded a grant from the *Net-Zero Innovation Portfolio*, which is run by the UK Department for Business, Energy, and Industrial Strategy. From *Energy Live News*. May 2021.

AUGUST 2021

Study to Investigate Reduced BECCS Costs.

A study by Phoenix BioPower and Drax will investigate how turbine technology could reduce the costs of BECCS plants. The feasibility study will look at how energy-efficient gas turbines could make new-build BECCS projects more cost-effective by generating 50% more power with the same amount of fuel. Results from Phoenix's test facilities in Sweden and Germany will inform the study. From *Carbon Capture Journal*. June 2021.

Researchers Study Barriers to CCUS.

Researchers from the University of Wyoming and the University of Texas–Austin will study the economic and political barriers related to CCUS technology. The study will explore questions about CCUS costs, barriers to investment and implementation, and tradeoffs relative to other climate mitigation approaches and policies. The study includes a look at CO_2 sources and users, geologic storage sites, and pipelines and other CCUS infrastructure. From *Carbon Capture Journal*. June 2021.

Scientists Freeze CO_2 for Storage.

Scientists are testing a method to reduce emissions by freezing CO_2 combusted from energy production and storing the solid form underground or using it for beneficial use. A team of scientists at King Abdullah University of Science and Technology (Saudi Arabia) is testing a technology developed by Sustainable Energy Solutions (based in Utah) that can capture approximately 1 ton of CO_2 per day; within two years, the scientists hope to capture up to 25 tons per day. If the project is successful, it could lead to the creation of a unit capable of storing approximately 1,000 tons of CO_2 per day. From *Bloomberg*. June 2021.

Study Shows Potential of Storing CO_2 in Old Oil Fields.

In a case study of the Delaware Basin (USA), Stanford University geophysicists found that the influence of past oil drilling changes stresses on faults that make the injection of fluids less likely to induce earthquakes. According to the researchers, targeting these sites of past oil production, with their lower earthquake risk, could be a good approach for carbon storage. From *Science Daily*. June 2021.

SEPTEMBER 2021

Amine Technology Capable of 99% CO_2 Capture.

Scientists from Imperial College London's Department of Chemical Engineering and the Centre for Environmental Policy found that post-combustion capture of CO_2 using amine absorption—a liquid-based CCS technology—can capture up to 99% of CO_2 from emission sources. Using computational models to demonstrate that amine-based CCS could cost-effectively capture high levels of CO_2 across a wide range of applications in power and industry, the researchers highlighted the areas with the highest potential for cost reduction. The study was published in the journal *Environmental Science & Technology*. From *Carbon Capture Journal*. August 2021.

Study Explores Feasibility of Blue Hydrogen and CCS.

A new study will explore the feasibility of blue hydrogen and CCS in Australia. The feasibility study, to be conducted by Pilot Energy, is designed to assess blue hydrogen and CCS projects that can integrate with existing assets and infrastructure to deliver clean energy. The objective of the study is to assess the CCUS potential of the Cliff Head oil project and additional reservoirs across the broader Perth Basin. The projects identified will form the basis for future FEED studies, and may include a CO_2 pipeline and injection facility, blue hydrogen plants, and CCS sites. From *H2 View*. August 2021.

PUBLICATIONS

OCTOBER 2020

Review of Federal, State, and Regional Tax Strategies and Opportunities for CO_2-EOR-Storage and the CCUS Value Chain.

The following is from the Introduction of this document: "In 2018, the United States emitted 6.7 billion metric tons of GHG emissions. Almost half of these emissions (49 percent) came from the power and industrial sectors… GHG emissions in the power sector have decreased by 28 percent since 2005 due to fuel mix changes and the penetration of renewables. GHG reductions in other sectors, however, have remained stagnant. CCUS presents an opportunity to lessen the tension between meeting the nation's energy needs and reducing its greenhouse gas emissions. It can help reduce GHG emissions not only in the power sector but also in the industrial sector through direct capture and utilization and in the transportation sector at ethanol facilities and through EOR, for example. CCUS is a demonstrated, commercially proven technology path for making deep GHG reductions. In North America, the most recent CCUS examples in the power sector include the 110-MW coal-fired retrofit of Boundary Dam Unit 3 in Saskatchewan, Canada, and the 240 MW retrofit of W.A. Parish Unit 8 in Texas ('Petra Nova') that is used for enhanced oil recovery. Both the Boundary Dam and Petra Nova projects are post-combustion capture projects where CO_2 is removed after combustion in the boiler stack. Pre-combustion capture through hydrogen production (e.g., coal gasification) and oxyfuel combustion where a fossil fuel is combusted with pure oxygen are other forms of carbon capture for power generation. In the industrial sector, where CO_2 can often be captured within existing processes, recent CCUS examples include the Air Products Steam Methane Reformer CO_2 capture project in Texas and the ADM Illinois Industrial CCS project. To help describe and, in some ways, enable the deployment of CCUS, DOE and USEA engaged FTI and Orrick to provide a guide to the current federal, state, and regional tax strategies and opportunities for CO_2 for EOR and storage. This report identifies federal and state incentives and regulatory regimes that are applicable to CCUS in the United States. It then illustrates several deal structures for application of these incentives. In addition, the report describes the various stakeholders that are critical for CCUS deployment, the roadblocks stakeholders face, and potential solutions that would increase the likelihood of the successful progress of CCUS programs as well as [Corporate Social Responsibility (CSR) and Environmental, Societal Governance (ESG)] implications. The goal of this report is to provide interested parties with an overview of the current landscape, the problems that current stakeholders face, and a preview into the developments that are expected in the coming years."

Carbon Pricing as a Policy Instrument to Decarbonize Economies.

The following is from the Summary of Findings of this Earth Institute's Research Program on Sustainability Policy and Management document: "This study analyzes the jurisdictional characteristics of economies where carbon pricing mechanisms (both carbon taxes and cap-and-trade schemes) have been implemented or proposed as a means to support decarbonization. Firstly, [the authors] compare certain average economic and emission-related characteristics of 37 countries, which have implemented or are considering implementing carbon pricing with the global average to derive a set of stylistic facts that appear to be correlated with the adoption of carbon pricing. [The authors] differentiate between carbon tax (CT) and emissions-trading (ETS) jurisdictions where possible. Secondly, [the authors] review the historical experience of 11 national and 2 sub-national jurisdictions, which either implemented carbon pricing or attempted to do so in vain. Finally, [the authors] perform an in-depth review of two case study countries (Chile and Colombia) which are in the process of implementing carbon pricing policies, to identify the key drivers of adoption as well as any barriers that may impact successful policy implementation or effectiveness. Throughout [the authors'] analyses, [the authors] review ETS and carbon tax impacts on five policy choice criteria: (1) effectiveness in delivering environmental outcomes; (2) regulatory stability; (3) costs and distributional effects; (4) the coherence and interaction with other environmental and tax policies; and (5) an evaluation of the impact of global trade."

Community compensation in the context of Carbon Capture and Storage: Current debates and practices.

The following is from the abstract of this article: "Societal opposition has the potential to slow down the implementation of Carbon Capture and Storage (CCS). One of the difficulties is that the perceived benefits associated with a CCS facility for local communities tend to be low compared to its perceived burdens. As is the case for other low carbon technologies, community compensation (or community benefits) has been suggested as a way to restore this perceived imbalance. A diverse literature has looked into the role of community compensation across various land uses and research fields. Synthesis is limited, while at the same time, the provision of community compensation in practice is moving from an ad hoc to a more institutionalized approach. Therefore, it is important to take stock of the literature. This paper provides a review of the community compensation literature in the form of four debates, drawing together environmental social science research on different low carbon technologies (e.g. CCS, renewable energy). In addition, current practices in community compensation for four European countries are discussed. The two parts of this paper are brought together in a set of lessons for the provision of community compensation for future CCS projects; in turn, suggestions for further research are made to address remaining knowledge gaps." **Christine Boomsma, Emma ter Mors, Corin Jack, Kevin Broecks, Corina Buzoianu, Diana M. Cismaru, Ruben Peuchen, Pim Piek, Diana Schumann, Simon Shackley, and Jasmin Werker,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Optimization of CCUS supply chains in the UK: A strategic role for emissions reduction.

The following is from the abstract of this article: "The UK is the second largest emitter of carbon dioxide in Europe. It aims to take urgent actions to achieve the 2030 target for CO_2 emissions reduction imposed by EU environmental policies. Three different carbon capture utilization and storage (CCUS) supply chains are developed giving economic indicators for CO_2 utilization routes not implying carbon dioxide hydrogenation (i.e. with high TRL). The study presents an innovative proposal to reduce CO_2 impact in the UK, a country rich in coal, which requires reduction of carbon dioxide emissions from flue gases as the easiest and best performing solution. Bunter Sandstone, Scottish offshore and Ormskirk Sandstone are the storage sites considered, while several attractive potential utilization options are considered. Through minimization of total costs, the CCUS supply chain with Bunter Sandstone as storage site results in the most economically profitable solution due to the highest value of net present value (€ 0.554 trillion) and lowest value of pay back period (2.85 years). Only carbon tax is considered. The total cost is € 1.04 billion/year. Across the supply chain, 6.4 Mton/year of carbon dioxide emissions are avoided, to be either stored or used for calcium carbonate production. Future work should consider uncertainty, dynamics of market demand and social aspects." **Grazia Leonzio, David Bogle, Pier Ugo Foscolo, and Edwin Zondervan,** *Chemical Engineering Research and Design*. (Subscription may be required.)

CO_2 sequestration on cement.

The following is from the abstract of this article: "The manufacturing of cement is associated with large amount of CO_2 emissions. Carbon capture and storage (CCS) or carbon sequestration is identified as one of the solutions to mitigate high level of CO_2.…Mineral carbonation of metal oxides present in cement can allow sequestering of CO_2 in cement in the form of stable silica gel and carbonates. Sequestration of CO_2 in cement and cement-based products such as mortar, paste, and concrete is accomplished by accelerated carbonation curing (ACC). This chapter discusses in detail possibility of CO_2 sequestration by cement-based materials through accelerated carbonation curing. Reaction mechanisms, laboratory processes, and resulting performance of carbonation curing have been comprehensively discussed and reviewed based on available literature. The chapter also discusses challenges faced by ACC for industrial implementation and future scope of research on carbonation curing." **Shweta Goyal and Devender Sharma,** *Start-Up Creation*. (Subscription may be required.)

Relationship between oil production and CO_2 storage during low-salinity carbonate water injection in acid carbonate reservoirs.

The following is from the abstract of this article: "This study investigates enhanced oil recovery (EOR) and CO_2 storage efficiencies during low-salinity carbonate waterflooding (LSCWF) in carbonate reservoirs containing 'acid' formation water. In order to identify the detailed geochemical reactions for acidic condition during LSCWF, simulational analysis was performed with 'CMG-GEM'. After core-scaled model was constructed through history-matching processes based on the coreflooding experimental results, primary mechanisms during LSCWF were analyzed for various levels of injection water salinity. From the results of this study, CO_2 dissolved in injected carbonate water yielded CaCO3 precipitation in acidic reservoirs, decreasing permeability significantly compared to in neutral reservoirs. In terms of wettability alteration and oil swelling by CO_2 mass transfer, their effects were almost similar regardless of the salinity for both acid and neutral reservoirs. In the aspects of EOR and CO_2 storage efficiencies, they strongly depend on the salinity for both acidic and neutral conditions. In the results of EOR–CO_2 storage relationship, enhanced oil was smaller in acidic condition, while CO_2 storage efficiency was not greatly related to acidity of the reservoir. The findings of this study can help for better understanding of smart water injection design into acid carbonate reservoir for the optimal EOR and CO_2 storage efficiencies." **Yeonkyeong Lee, Sooyeon Kim, Jihoon Wang, and Wonmo Sung,** *Journal of Industrial and Engineering Chemistry*. (Subscription may be required.)

Application of ITM to improve the efficiency of SOFC/GTCC triple combined cycle with carbon capture.

The following is from the abstract of this article: "Carbon capture and storage processes are being researched to reduce carbon dioxide emissions from power plants. This paper proposes a new system that applies an ion transport membrane (ITM) to a triple combined cycle, which includes the gas turbine combined cycle and a solid oxide fuel cell. Two systems which differ in the method of utilization of the fluid that is separated by the ion transport membrane were compared. Then, the better system was determined, and its performance characteristics were analyzed in detail. The operating temperature of the fuel cell and the pressure ratio of the compressor were varied within the operating conditions of the ITM as the main design variables. The performance of the proposed system was compared with that of a post-combustion system and other oxy-fuel combustion capture systems. The proposed system had 1.70% and 4.0%p higher power and efficiency than the post-combustion capture system, respectively. Furthermore, the purity of the carbon dioxide captured from the proposed system was 97.4%, which is 9.1%p higher than that of the semi-closed cycle oxy-fuel combustion system, while the efficiency was 7.8%p higher." **Ji Hun Jeong, Ji Ho Ahn, and Tong Seop Kim,** *Energy*. (Subscription may be required.)

An empirical investigation between CO_2 emission, energy consumption, trade liberalization and economic growth: A case of Kuwait.

The following is from the abstract of this article: "The purpose of the present study is to investigate the link among CO_2 emissions, energy consumption, gross domestic product, and trade liberalization as related to Kuwait. The study used annual data, starting from 1971 to 2017, which was obtained from a world development indicator of the World Bank. For the empirical analysis, the study adopted Augmented Dicky Fuller and Phillips-Perron methods to review stationarity among the data sets. Their results explained a mixed trend, some variables followed the I (1) process, and few are I (0). Based on the findings, a well-defined Autoregressive Distributed Lag Model was applied to the data sets and the outcome was in support of the long and short-run relationship between variables. Carbon dioxide and energy consumption accelerate economic growth; an increase in CO_2 emission also plays a significant role in increasing energy consumption. Furthermore, the Granger Causality test shows evidence of bi-directional causality existing between CO_2 emissions and energy consumption. A unidirectional causality is running from the gross domestic product to CO_2 emissions and energy consumption to trade liberalization." **Syed Khurram Arslan Wasti and Shumaila Waqar Zaidi,** *Journal of Building Engineering*. (Subscription may be required.)

Optimization of well placement and operating conditions for various well patterns in CO_2 sequestration in the Pohang Basin, Korea.

The following is from the abstract of this article: "The aquifer consists of multi-layers and has pre-existing faults and heterogeneous reservoir properties that restrict CO_2 injection to a certain amount. To store large amounts of CO_2 and maintain storage security, it is important to define the optimal injection well pattern, placement, and operating conditions. This study applied various well patterns and optimized their locations and fluid injection rates with monitoring the pressure build-up in the aquifer to improve the storage capacity. Four well patterns in this study were employed: (1) a single vertical injection well (SVI), (2) two vertical injection wells (TVI), (3) a single horizontal injection well (SHI), and (4) two vertical wells for brine extraction and CO_2 injection (TVEI). The results showed TVEI at the optimal location and fluid rate that allowed an almost eight times larger volume of CO_2 to be stored compared to the base case (simulation result of SVI drilled for the CO_2 storage pilot project in the Pohang basin, Korea), and maintained the pressure within the boundary for security. When using a single well (SVI and SHI), SVI injected 126 kton of CO_2, which is larger than that of SHI, but storage security of SHI is better than that of SVI due to the difference in CO_2 migration. Through this research, the effects of various well patterns in CO_2 geological storage in the Pohang Basin can be forecasted and the optimal well pattern and conditions for the largest storage capacity can be determined." **Changhyeok Jun, Min Kim, and Hyundon Shin,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

New soil carbon sequestration with nitrogen enrichment: a meta-analysis.

The following is from the abstract of this article: "Through agriculture and industry, humans are increasing the deposition and availability of nitrogen (N) in ecosystems worldwide. Carbon (C) isotope tracers provide useful insights into soil C dynamics, as they allow to study soil C pools of different ages. [The authors] evaluated to what extent N enrichment affects soil C dynamics in experiments that applied C isotope tracers. Using meta-analysis, [the authors] synthesized data from 35 published papers. [The authors] made a distinction between 'new C' and 'old' stocks, i.e., soil C derived from plant C input since the start of the isotopic enrichment, or unlabeled, pre-existing soil C. Averaged across studies, N addition increased new soil C stocks (+30.3%), total soil C stocks (+6.1%) and soil C input proxies (+30.7%). Although N addition had no overall, average, effect on old soil C stocks and old soil C respiration, old soil C stocks increased with the amount of N added and respiration of old soil C declined. Nitrogen-induced effects on new soil C and soil C input both decreased with the amount of extraneous N added in control treatments. Although [the authors'] findings require additional confirmation from long-term field experiments, [the authors'] analysis provides isotopic evidence that N addition stimulates soil C storage both by increasing soil C input and (at high N rates) by decreasing decomposition of old soil C. Furthermore, [the authors] demonstrate that the widely reported saturating response of plant growth to N enrichment also applies to new soil C storage." **Xiaomin Huang, César Terrer, Feike A. Dijkstra, Bruce A. Hungate, Weijian Zhang, and Kees Jan van Groenigen,** *Plant and Soil*. (Subscription may be required.)

The role of soil carbon in natural climate solutions.

The following is from the abstract of this article: "Here [the authors] quantify the role of soil carbon in natural (land-based) climate solutions and review some of the project design mechanisms available to tap into the potential. [The authors] show that soil carbon represents 25% of the potential of natural climate solutions (total potential, 23.8 Gt of CO_2-equivalent per year), of which 40% is protection of existing soil carbon and 60% is rebuilding depleted stocks. Soil carbon comprises 9% of the mitigation potential of forests, 72% for wetlands and 47% for agriculture and grasslands. Soil carbon is important to land-based efforts to prevent carbon emissions, remove atmospheric carbon dioxide and deliver ecosystem services in addition to climate mitigation." **D. A. Bossio, S. C. Cook-Patton, P. W. Ellis, J. Fargione, J. Sanderman, P. Smith, S. Wood, R. J. Zomer, M. von Unger, I. M. Emmer, and B. W. Griscom,** *Nature Sustainability*. (Subscription may be required.)

NOVEMBER 2020

Net-Zero and Geospheric Return: Actions Today for 2030 and Beyond.

The following is from the Executive Summary of this Global CCS Institute document: "The case for rapid and profound decarbonization has never been more obvious or more urgent, and immediate action must match growing global ambition and need. An important new component of this discussion is the necessity of achieving net-zero global greenhouse gas emissions for any climate stabilization target. Until net-zero emissions are achieved, greenhouse gas will accumulate in the atmosphere and oceans, and concentrations will grow, even with deep and profound emissions reduction, mitigation, and adaptation measures. This places a severe constraint on human enterprise: any carbon removed from the earth must be returned to the earth. To manage this aspect of the global carbon budget, carbon capture and storage (CCS) must play a central role. In particular, CCS will be important in two major roles: [1] To manage emissions from existing, long-lived capital stock. This is especially true for rapid emissions reduction from three kinds of facilities: heavy industrial sector (i.e., cement, steel, and chemicals); production of near–zero-C hydrogen in abundance; and recently built power plants, in particular coal and gas facilities in Asia. [2] To enable large-scale rapid carbon dioxide (CO_2) removal through engineered systems. This will include approaches like direct-air capture with storage (DACS), bioenergy with CCS (BECCS), and carbon mineralization."

Carbon Capture and Storage (CCS) Market Sales Outlook.

The following is a description of this report: "The Carbon Capture and Storage (CCS) report provides an independent information about the Carbon Capture and Storage (CCS) industry supported by extensive research on factors such as industry segments size & trends, inhibitors, dynamics, drivers, opportunities & challenges, environment & policy, cost overview, porter's five force analysis, and key companies. In this report, [the authors offer] 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."

Start-up and Shut-down times of power CCUS facilities.

The following is from the Executive Summary of this UK Department for Business, Energy and Industrial Strategy document: "The Department for Business, Energy and Industrial Strategy (BEIS) has commissioned AECOM to investigate potential improvements to the start-up and shut-down times of gas-fired power Carbon Capture, Utilisation and Storage (power CCUS) facilities. This report summarises the outputs of the study, including process modelling to demonstrate the performance of a range of configuration variants and inputs to the BEIS Dynamic Dispatch Model. A reference or 'standard' configuration case was identified to achieve 95% capture of normal carbon dioxide emissions from a modern H-Class Combined Cycle Gas Turbine power plant. The standard configuration was developed from open literature, project history and AECOM experience of carbon capture processes and is recorded in the Basis of Design, which is appended to this report. Results of the literature review are also provided in an appendix to this report."

Experimental study on the fracture behavior of sandstone after $ScCO_2$–water–rock interaction.

The following is from the abstract of this article: "Geological sequestration of carbon dioxide is one way of offsetting carbon emissions. During geological CO_2 sequestration, any effects that CO_2 may have on the physical and mechanical properties of the caprock can potentially affect the stability of its storage. This paper investigates the fracturing behavior of sandstone immersed in water dissoluted with supercritical carbon dioxide ($ScCO_2$). For this purpose, the fracture toughness of sandstone was tested after different durations of immersion in water with $ScCO_2$ (10 days, 20 days and 30 days). Furthermore, the surface and fracture characteristics of the sandstone were evaluated with X-ray diffraction (XRD), X-ray fluorescence (XRF), and scanning electron microscopy (SEM). The results show that: (1) The mode I fracture toughness (KIC) of sandstone reduced by up to 23.91%, 20.43%, and 31.92% after immersion in water with $ScCO_2$ for 10 days, 20 days and 30 days, respectively, indicating clear temporal heterogeneity in the damage caused to sandstone by $ScCO_2$ and water. (2) Similar variation occurs in the maximum deviation distance of sandstone failure cracks with an increase in saturation time as in fracture toughness (KIC); that is, the maximum deviation distance increases in parallel with fracture toughness. (3) $ScCO_2$–water–rock interactions change the mineral composition of sandstone. As a result, many pores and cracks appear in the sandstone, especially after 30-day saturation, seriously damaging its structure; this is the direct cause of the decrease in the ability of the sandstone to resist fracture. The results of this study provide a significant theoretical reference for evaluating the long-term stability of geological CO_2 sequestration under caprock." **Ze-dong Sun, Xuan-min Song, Gan Feng, Yu-ming Huo, Shao-qi Kong, and De-fu Zhu,** *Journal of Natural Gas Science and Engineering.* (Subscription may be required.)

Modeling CO_2 wettability behavior at the interface of brine/CO_2/mineral: Application to CO_2 geo-sequestration.

The following is from the abstract of this article: "Carbon capture and storage (CCS) has been introduced as an effective method for reduction of CO_2 emissions to the atmosphere. While different aspects and controlling parameters of geological CO_2 sequestration process are well understood, there is still large uncertainty regarding brine/CO_2/rock wettability and no model has yet been presented for characterizing the contact angle of brine/CO_2/rock system at different environmental conditions. In this study, various intelligent models have been developed for accurate estimation of brine/CO_2/rock contact angles. Results demonstrated that the proposed models have the ability to accurately simulate the brine/CO_2 wettability behavior for quartz, calcite, feldspar, and mica minerals at different pressures, temperatures and salinities. Additionally, results revealed that adaptive neuro-fuzzy interference system has the best performance compared with the other models and its superiority is shown through statistical and graphical analyses. Afterward, the most effective input parameters on brine/CO_2/rock wettability were investigated by employing Monte-Carlo algorithm, which showed that mineral type, salinity and pressure are the most sensitive variables for this process. As wettability can highly affect the residual and structural trapping mechanisms during carbon geo-sequestration, presenting reliable models for estimating brine/CO_2/rock wettability is crucial. Therefore, the outcomes of this study can be useful for accurate estimation of these mechanisms capacity." **Amin Daryasafar, Amin Keykhosravi, and Khalil Shahbazi,** *Journal of Cleaner Production.* (Subscription may be required.)

Can carbon emission trading scheme achieve energy conservation and emission reduction? Evidence from the industrial sector in China.

The following is from the abstract of this article: "Whether the emission trading scheme (ETS) can achieve energy conservation and emission reduction in developing countries is crucial for these countries to achieve sustainable economic and environmental development. This study investigates the energy conservation and emission reduction effects of China's carbon dioxide (CO_2) ETS pilot policy implemented in 2011. Based on panel data of the two-digit industry at province level from 2005 to 2015, [the authors] adopt the difference-in-differences (DID) model to examine the effects of the CO_2 ETS on energy conservation and emission reduction. The results show that the CO_2 ETS decreases the energy consumption of the regulated industries in pilot areas by 22.8% and the CO_2 emissions by 15.5% compared to those in nonpilot areas. Further analysis indicates that the policy effects are mainly driven by improving technical efficiency and adjusting industrial structure. In addition, [the authors] find that the CO_2 ETS performs better in areas with high levels of environmental enforcement and marketization. Overall, [the authors'] findings suggest that the CO_2 ETS has achieved energy conservation and emission reduction effects in developing countries." **Yucai Hu, Shenggang Ren, Yangjie Wang, and Xiaohong Chen,** *Energy Economics.* (Subscription may be required.)

A near-term to net zero alternative to the social cost of carbon for setting carbon prices.

The following is from the abstract of this article: "The social cost of carbon (SCC) is commonly described and used as the optimal CO_2 price. However, the wide range of SCC estimates provides limited practical assistance to policymakers setting specific CO_2 prices. Here [the authors] describe an alternate near-term to net zero (NT2NZ) approach, estimating CO_2 prices needed in the near term for consistency with a net-zero CO_2 emissions target. This approach dovetails with the emissions-target-focused approach that frames climate policy discussions around the world, avoids uncertainties in estimates of climate damages and long-term decarbonization costs, offers transparency about sensitivities and enables the consideration of CO_2 prices alongside a portfolio of policies. [The authors] estimate illustrative NT2NZ CO_2 prices for the United States; for a 2050 net-zero CO_2 emission target, prices are US$34 to US$64 per metric ton in 2025 and US$77 to US$124 in 2030. These results are most influenced by assumptions about complementary policies and oil prices." **Noah Kaufman, Alexander R. Barron, Wojciech Krawczyk, Peter Marsters, and Haewon McJeon,** *Nature Climate Change*. (Subscription may be required.)

A meta-analysis of global cropland soil carbon changes due to cover cropping.

The following is from the abstract of this article: "Including cover crops within agricultural rotations may increase soil organic carbon (SOC). However, contradictory findings generated by on-site experiments make it necessary to perform a comprehensive assessment of interactions between cover crops, environmental and management factors, and changes in SOC. In this study, [the authors] collected data from studies that compared agricultural production with and without cover crops, and then analyzed those data using meta-analysis and regression. [The authors'] results showed that including cover crops into rotations significantly increased SOC, with an overall mean change of 15.5% (95% confidence interval of 13.8%–17.3%). Whereas medium-textured soils had highest SOC stocks (overall means of 39 Mg ha−1 with and 37 Mg ha−1 without cover crops), fine-textured soils showed the greatest increase in SOC after the inclusion of cover crops (mean change of 39.5%). Coarse-textured (11.4%) and medium-textured soils (10.3%) had comparatively smaller changes in SOC, while soils in temperate climates had greater changes (18.7%) than those in tropical climates (7.2%). Cover crop mixtures resulted in greater increases in SOC compared to mono-species cover crops, and using legumes caused greater SOC increases than grass species. Cover crop biomass positively affected SOC changes while carbon:nitrogen ratio of cover crop biomass was negatively correlated with SOC changes. Cover cropping was associated with significant SOC increases in shallow soils (≤30 cm), but not in subsurface soils (>30 cm). The regression analysis revealed that SOC changes from cover cropping correlated with improvements in soil quality, specifically decreased runoff and erosion and increased mineralizable carbon, mineralizable nitrogen, and soil nitrogen. Soil carbon change was also affected by annual temperature, number of years after start of cover crop usage, latitude, and initial SOC concentrations. Finally, the mean rate of carbon sequestration from cover cropping across all studies was 0.56 Mg ha−1 yr−1. If 15% of current global cropland were to adopt cover crops, this value would translate to 0.16 ± 0.06 Pg of carbon sequestered per year, which is ~1–2% of current fossil fuels emissions. Altogether, these results indicated that the inclusion of cover crops into agricultural rotations can enhance soil carbon concentrations, improve many soil quality parameters, and serve as a potential sink for atmosphere CO_2." **Jinshi Jian, Xuan Du, Mark S. Reiter, and Ryan D. Stewart,** *Soil Biology and Biochemistry*. (Subscription may be required.)

Efficient sequestration of terrigenous organic carbon in the New Britain Trench.

The following is from the abstract of this article: "The fate of terrigenous organic carbon (OC_{terr}) in the ocean remains an enigma for four decades. Hadal trenches, the deepest ocean realm (6–11 km deep), were recently proposed to be OC depocenters, but whether and how much OC_{terr} was sequestrated there remain elusive. Here [the authors] conducted comprehensive analyses for four sediment cores from the New Britain Trench (NBT) close to Papua New Guinea to assess source, translocation and burial of OC. The bulk and molecular radiocarbon data suggest that the NBT landward slope and axis sediments mainly receive young and biogenic rather than petrogenic OC. The three-endmember mixing model based on $\Delta^{14}C$, δ13C and OC contents reveals that sediments of the NBT axis (8225 m) comprise relatively high OC contents (0.66 ± 0.08%), of which biogenic OC_{terr} accounts for 62 ± 10%. The high proportion of biogenic OC_{terr} was attributed to the selective translocation of OC_{terr}-enriched coarse particles and rapid delivery of sediments supported by unique V-shape feature of the trench. In contrast, the sediment OC at the oceanward slope is primarily of a marine origin, suggesting that OC_{terr} was efficiently trapped in the trench bottom. It is estimated that the burial rate is 2.75 ± 0.32 g C m−2 yr−1 for OC and 1.69 ± 0.41 g C m−2 yr−1 for OC_{terr} in the NBT. Given a fact that many trenches are close to the landmasses, [the authors] propose that the hadal trenches may contribute significantly to the burial of OC_{terr} in the ocean." **Wenjie Xiao, Yunping Xu, Negar Haghipour, Daniel B. Montluçon, Binbin Pan, Zehua Jia, Huangmin Ge, Peng Yao, and Timothy I. Eglinton,** *Chemical Geology*. (Subscription may be required.)

Effects of soil texture and nitrogen on ability of carbon sequestration in different organs of two Tamarix species as a good choice for carbon stock in dry lands.

The following is from the abstract of this article: "The present study was conducted to examine how different organs of plants (leaf, stem and root) of *Tamarix aphylla* and *Tamarix kotschyi* could affect carbon sequestration in soil depths ranging from 0 to 15 cm and 15 to 30 cm. This study was carried out in the Ahoochar region, 25 km north of Shiraz, during 2015–2017. This study was carried out in two separate factorial experiment arranged in a randomized complete design. The first factor was the type of plant species in both experiments. The second factor was the plant organs in experiment I and different soil depths in experiment II. The results showed that there was a higher degree of carbon sequestration in depths that ranged from 0–15 cm, compared to soil at 15–30 cm depth. The results of correlation coefficients showed that the percentage of clay was the strongest parameter that contributed to carbon sequestration. Furthermore, *Tamarix aphylla* and *T. kotschyi* showed similar amounts of organic carbon stored in their tissues. Stems had higher amounts of stored organic carbon compared to the leaves. In general, it was observed that carbon sequestration reached its highest level (54.15 t/ha) in soil with *T. kotschyi* at 0–15 cm depth. The stem of both plants had a higher ability for carbon sequestration." **Mahbobeh Iranmanesh and Hossein Sadeghi,** *Ecological Engineering*. (Subscription may be required.)

Tree layer carbon stock quantification in a temperate food forest: A peri-urban polyculture case study.

The following is from the abstract of this article: "Food forests offer a number of potential benefits and one of those is the ability to sequester carbon and increase terrestrial carbon stocks on urban, peri-urban and rural land. There is little research on the carbon storage capabilities within agroforestry systems let alone food forests and it is considered an underexploited option for carbon storage. This case study quantified the carbon stored within the above and below ground components of all tree layer woody biomass above 2 m in height and greater than 2 cm diameter at breast height (DBH) in the Agroforestry Research Trust's peri-urban food forest in Devon, UK. The study formed a population census, which measured all 528 trees across 68 species within the 0.64 ha food forest. Twenty-three allometric equations were used to estimate above ground biomass (AGB) while the below ground biomass (BGB) was calculated using a root to shoot ratio of 0.18:1. The stored carbon content was calculated as 50% of the total biomass. The temperate food forest case study site was estimated to store 39.53 ± 4.05 Mg C ha−1 in above and below ground living biomass. This result highlights the potential for a food forest stand to store a considerable amount of carbon that is at least within a similar range to other literature sourced urban and peri urban land uses. Thus, a purposely selected food forest assemblage whose primary focus is food production can also be a valuable carbon sink The results offer a promising initial study into the carbon storage potential within a food forest, which is only made more valuable given the other prospective benefits of food forests." **Luke J. Schafer, Marin Lysák, Christian B. Henriksen,** *Urban Forestry & Urban Greening*. (Subscription may be required.)

DECEMBER 2020

Using Geophysical Technologies Deployed in Inexpensive Monitoring Wells to Monitor the Evolution of a CO_2 Plume: Potential Benefits and R&D Needs.

The following is from the Executive Summary of this DOE/NETL document: "Capturing carbon dioxide (CO_2) from coal-fired power plants, natural gas-fired power plants and industrial CO_2 sources, and storing this captured CO_2 in deep saline formations is one method for reducing the emissions of CO_2 to the atmosphere. Often referred to as carbon capture, utilization and storage (CCUS), large quantities of CO_2 can be stored using two processes. The first process, known as saline storage of CO_2, involves injecting CO_2 into deep saline formations. The second process is CO_2 enhanced oil recovery (EOR). This study focuses on saline storage of CO_2. This technology is regulated by the United States (U.S.) Environmental Protection Agency (EPA) and each CO_2 injection well needs a Class VI permit to comply with the Underground Injection Control Program. As part of the Class VI permit, the operator of a CO_2 injection well must prepare and execute a Testing and Monitoring Plan and this plan must include monitoring the evolution of the injected CO_2 plume over time…This study was completed by the National Energy Technology Laboratory (NETL) which is part of Fossil Energy (FE) within the U.S. Department of Energy (DOE). This study compares the costs of 4-D seismic surveys and [vertical seismic profiling (VSP) using distributing acoustic sensing (DAS) with surface orbital vibrators (SOVs)]. An example CO_2 storage project was developed for the cost analysis. The example project involves the injection and storage of 4.33 million metric tons of CO_2 per year for 30 operating years and 50 years of post-injection site care (PISC). The example project is assumed to inject CO_2 into the Mount Simon formation in Illinois which is a good formation for storing CO_2. A six injection well pattern was devised, and the area that is needed to monitor the evolution of the CO_2 plume was calculated using the FE/NETL CO_2 Saline Storage Cost Model."

Energy Technology Perspective 2020.

The following is a description of this International Energy Agency (IEA) publication: "*Energy Technology Perspectives 2020* is a major new IEA publication focused on the technology needs and opportunities for reaching international climate and sustainable energy goals. This flagship report offers vital analysis and advice on the clean energy technologies the world needs to meet net-zero emissions objectives. The report's comprehensive analysis maps out the technologies needed to tackle emissions in all parts of the energy sector, including areas where technology progress is still lacking such as long-distance transport and heavy industries. It shows the amount of emissions reductions that are required from electrification, hydrogen, bioenergy and carbon capture, utilisation and storage. It also provides an assessment of emissions from existing infrastructure and what can be done to address them." (Subscription may be required.)

Probabilistic risk-based Area of Review (AoR) determination for a deep-saline carbon storage site.

The following is from the abstract of this article: "Regulatory oversight of a geologic carbon sequestration (GCS) project relies on iterative estimations, throughout the project lifetime, of the area where increased risks to underground sources of drinking water (USDWs) may occur due to injection of CO_2. This area, referred to as Area of Review (AoR), is typically delineated by predicting the migration of fluid between the reservoir and the lowermost USDW via an open wellbore using predictions from physics-based reservoir simulators. The inherent uncertainty in input parameters used in reservoir modeling therefore affects the accuracy of determining the AoR for a project. Furthermore, the standard analytical approaches for calculating a critical pressure to delineate the risk area yield an infinite AoR for cases where the injection reservoir is overpressured relative to the USDW. A methodology is presented here to better characterize the risk to USDWs while accounting for the uncertainty in reservoir modeling, with an application to a permitted GCS project with an overpressured injection formation, FutureGen 2.0. The methodology is demonstrated using the National Risk Assessment Partnership's open-source integrated assessment model (NRAP-Open-IAM) to develop a probabilistic estimate of impact risk to USDW quality. CO_2 and pressure predictions from the reservoir modeling conducted using the STOMP-CO_2 simulator for the FutureGen 2.0 site are used in a NRAP-Open-IAM model with reservoir, wellbore, and aquifer components to: (1) assess the extent of potential leakage into the USDW for the predicted reservoir pressure conditions; (2) evaluate the extent of potential impact using 'no-net-degradation' thresholds; and (3) account for uncertainty in reservoir permeabilities." **Diana H. Bacon, Deniz I. Demirkanli, Singe K. White,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Carbon dioxide management via exergy-based sustainability assessment: Carbon Capture and Storage versus conversion to methanol.

The following is the abstract of this article: "Carbon Capture and Storage and Carbon Capture and Utilization refer to carbon dioxide management technologies for its removal from flue-gases, followed by carbon recycling or storage, aiming at limiting global warming. For large-scale deployment, geological storage is the most promising alternative but imposes an economic penalty to the emitting process, while the utilization monetizes carbon dioxide contributing to compensate for the large capture costs. The exergy concept builds a suitable framework to measure useful power according to the Second Law of Thermodynamics, such that maximizing exergy efficiency necessarily promotes sustainability. This work applies a novel framework for exergy assessment of processes with chemical reactions, which is employed to evaluate the performance of two methanol production routes from carbon dioxide from power plant flue-gas: the direct hydrogenation and the indirect conversion through natural gas bi-reforming for synthesis gas production. Exergy efficiency of the direct route is about 66.3%, against 55.8% for the indirect one, indicating the lower sustainability of the latter. Carbon capture and storage had the worst Exergy efficiency, even lower than the emission scenario, accounting for 44.8% against 53.5%. Exergy metrics pinpoint low scalability as the main drawback of the utilization technologies, despite high exergy and capture efficiency." **Igor Lapenda Wiesberg, George Victor Brigagão, Ofélia de Queiroz F. Araújo, and José Luiz de Medeiros,** *Renewable and Sustainable Energy Reviews.* (Subscription may be required.)

Comparative evaluation of two biomass direct-fired power plants with carbon capture and sequestration.

The following is from the abstract of this article: "The biomass direct-fired power plant with carbon capture and sequestration is promising to remove CO_2 from air whilst generate electricity. However, the efficiencies of such power plants are usually low, and the life cycle CO_2 emission of such power plants is seldom determined. To solve these issues, a novel chemical looping oxy-fired power plant with carbon capture and sequestration is proposed in this work. The proposed system is then modeled and compared with the conventional biomass air-fired plant in terms of thermodynamics and economics. All the sub-unit models of the two power plants are validated by reported data in literature. Sensitivity analyses are then implemented to investigate the effects of different key operation parameters on the system essential performance indicators. Under the optimum conditions, the power generation efficiency, the levelized cost of electricity, the CO_2 capture rate, the annual power generation and the annual CO_2 mitigation of the proposed system (or the conventional system) are 35.7% (31.5%), 0.0522$/kWh (0.0601$/kWh), 100% (98%), 1443.7 × 109 kWh/year (1241.81 × 109 kWh/year) and 1.191 × 109 t/year (1.159 × 109 t/year), respectively. The key findings of this work are of reference value for the construction, operation and optimization of the biomass direct-fired power plants with carbon capture and sequestration." **Linbo Yan, Ziqi Wang, Yang Cao, and Boshu He,** *Renewable Energy.* (Subscription may be required.)

A first look at social factors driving CCS perception in Brazil: A case study in the Recôncavo Basin.

The following is from the abstract of this article: "Carbon Capture and Storage (CCS) is a promising technology to help greenhouse gas emission mitigation. However, one of the greatest challenges for this technology implementation is the opposition from the population living near the potential sites. Despite

the Brazilian geological potential for carbon dioxide injection, research investigating social site characterization or CCS public perception is almost non-existent in Brazil. Thus, this research aims to address this gap and analyze social factors driving CCS perception of the population living near potential sites in the Recôncavo Basin, state of Bahia, this being one of the first steps for social site characterization. Fifty-seven interviews were carried out near 10 CCS potential injection fields, focusing on questions about climate change knowledge, people's previous relationship with oil exploration, trust in public and private stakeholders, belief in citizens' influence and CCS perception. The results showed that the previous history of the community with oil companies is an important factor influencing people's perception of private companies in general and CCS projects in particular. Another relevant social factor is the sense of empowerment in some communities that may respond with riots and obstruction of the project if they feel harmed by the companies. The results also suggest that communication can be a relevant factor for CCS perception, correcting some wrong assumptions about the technology. It is important to educate people not only about CCS but also about climate change and other environmental issues and, ethically, address all aspects, positive and negative, of CCS implementation." **Anna Luisa Abreu Netto, George Câmara, Expedito Rocha, Aldo Luiz Silva, José Célio Silveira Andrade, Drielli Peyerl, and Paulo Rocha,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Parametric study and geomechanical design of Ultra-deep-water Offshore Salt Caverns for Carbon Capture and Storage in Brazil.

The following is from the abstract of this article: "This article describes a new concept to reduce carbon dioxide emissions of offshore oil production of high gas-to-oil ratio reservoirs and high content of CO_2, denominated Offshore Salt Cavern Ultra-deep Water CCS (Carbon Capture and Storage) System. This hybrid system is intended for natural gas storage, the gravitational separation between CO_2/CH4, and CO_2 confinement for final destination. This development emerged from a current demand of some Brazilian pre-salt reservoirs to destinate a gas stream with high CO_2 contamination, produced during the oil extraction. These reservoirs have a continuous salt rock layer of 2000 m as caprock making the construction possible of salt caverns by leaching using seawater. In the first stage of technology development, the system will only store a gas stream contaminated with a high concentration of CO_2. In the second stage of its development, it will allow not only the separation of natural gas from the CO_2 but also its storage and the monetization of CH4. This paper presents the conceptual design of this technology, showing the steps from the parametric study to select the best relation between flowrate, leaching time, structural stability, and the volume of gas with the high content of CO_2 storage, up to the final geomechanical design using the set of parameters selected." **Pedro Vassalo Maia da Costa, Alvaro Maia da Costa, Julio R. Meneghini, Kazuo Nishimoto, Claudio M. Sampaio, Gustavo Assi, Edgard Malta, Mariana B.R. Goulart, Andre Bergsten, Okhiria D. Udebhulu, Ricardo Cabral Azevedo, Sérgio M. de Eston, Giorgio de Tomi, Nelson F.F. Ebecken, Luiz Pinguelli Rosa, Antonio C.O. Miranda, Camila Brandão, and Alexandre Breda,** *International Journal of Rock Mechanics and Mining Sciences*. (Subscription may be required.)

The impact of energy trade patterns on CO_2 emissions: An emergy and network analysis.

The following is from the abstract of this article: "Fossil fuel is considered to be the major cause of CO_2 emissions, and it flows across countries through the international energy trade. In this paper, [the authors] analyse the impact of energy trade patterns on CO_2 emissions for a global sample from 2000 to 2014. [The authors] construct an international fossil fuel trade network based on emergy theory and calculate some corresponding structural parameters. Then, [the authors] systematically evaluate the impact of energy trade on CO_2 emissions from the trade volume and trade relationships perspectives. [The authors] obtain the following results: (1) Trade strength mainly affects CO_2 emissions through the scale effect, composition effect and technique effect. (2) Trade security and trade-centre status of one country will significantly affect CO_2 emissions. (3) For high economic-level (HE) countries, concentrating the trade volume on several finite countries will destroy the environment; low economic-level (LE) countries that are proximal to the important countries of the energy market will experience an increase in pollution. This research also discusses some implications for policy makers." **Hongwei Zhang, Ying Wang, Xuehong Zhu, and Yaoqi Guo,** *Energy Economics*. (Subscription may be required.)

CO_2 storage potential in sedimentary basins of Kazakhstan.

The following is from the abstract of this article: "The terms of the Paris Agreement oblige Kazakhstan to decrease its Greenhouse Gas (GHG) emissions by 2030. Annual GHG emissions of the country already went beyond the limit set by the Paris agreement in 2014 and this number is expected to increase with a growing economy showing that current measures of GHG mitigation in the country are insufficient. Despite the energy sector of the country being heavily dependent on its coal and substantial land resources, CCS was not featured in the 'Green Economy' plan of the country. To investigate the applicability of this technology, six selected Kazakhstan sedimentary basins (the Precaspian, Mangyshlak, South-Torgay, Ustyurt, Chu-Sarysu, and Zaysan basins) were evaluated and ranked for geologic CO_2 storage deployment in terms of containment, capacity, and feasibility. The effective CO_2 storage capacities in oil reservoirs, gas reservoirs, and saline aquifers were estimated for each basin using the Carbon Sequestration Leadership Forum (CSLF) and USDOE methods. The evaluations revealed that the Precaspian Basin is the most suitable for geological CO_2 storage, followed by the Mangyshlak, South Torgay, and Ustyurt basins. The total effective CO_2 storage capacity of the country is estimated to be ~583 Gt, of which ~539 Gt corresponds to the abovementioned four suitable basins where most of injected CO_2 is expected to be stored in the hydrodynamic traps. The results suggest that four sedimentary basins identified in this study have prospectivity to reduce GHG emissions of Kazakhstan significantly and thus enable the decarbonization of national economy to achieve the goals set by the Paris Agreement." **Yerdaulet Abuov, Nurlan Seisenbayev, and Woojin Lee,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

JANUARY 2021

A Four-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin.

The following is from the Introduction of this DOE/NETL report: "This report addresses the four-county San Andres Residual Oil Zone (ROZ) 'fairway' within the West Texas portion of the Permian Basin—Gaines, Yoakum, Terry, and Dawson counties. In this report, the term 'ROZ fairway' refers to the portion of the ROZ where there is no overlying oil field. The ROZ under a conventional oil field is not included in the assessment. This four-county San Andres ROZ fairway resource assessment has been undertaken to address five fundamental questions: [1.] What is the size and distribution of the in-place San Andres ROZ fairway oil resource favorable for CO_2-enhanced oil recovery (EOR)? [2.] How much of this in-place San Andres ROZ fairway oil resource can be mobilized and technically produced using CO_2 EOR? [3.] How much CO_2 can be stored by developing the San Andres ROZ fairway resource in this four-county area? [4.] What portion of the San Andres ROZ fairway resource can be economically developed while providing by-product storage of CO_2? [5.] What value could the uneconomic portion of the San Andres ROZ fairway resource provide?"

Start up and shutdown times of power carbon capture, usage and storage (CCUS) facilities.

The following is from the Executive Summary of this UK Department for Business, Energy, and Industrial Strategy (BEIS) document: "The Department for Business, Energy and Industrial Strategy (BEIS) has commissioned AECOM to investigate potential improvements to the start-up and shut-down times of gas-fired power Carbon Capture, Utilisation and Storage (power CCUS) facilities. This report summarises the outputs of the study, including process modelling to demonstrate the performance of a range of configuration variants and inputs to the BEIS Dynamic Dispatch Model. A reference or 'standard' configuration case was identified to achieve 95% capture of normal carbon dioxide emissions from a modern H-Class Combined Cycle Gas Turbine power plant. The standard configuration was developed from open literature, project history and AECOM experience of carbon capture processes and is recorded in

the Basis of Design, which is appended to this report. Results of the literature review are also provided in an appendix to this report. A concept design was developed for the power CCUS facility, using Thermoflow 29 for the power cycle and ProMax 5.0 for the carbon capture process. Results of the simulation work are presented in the report, including concept material balances and estimated electrical and heat consumption of a 95% post-combustion capture plant. 35% MEA (no other solvent) was the solvent chosen for this study as an open-art, technology-neutral solvent."

Could congressionally mandated incentives lead to deployment of large-scale CO_2 capture, facilities for enhanced oil recovery CO_2 markets and geologic CO_2 storage?

The following is from the abstract of this article: "In passing the Bipartisan Budget Act of 2018, Congress reformed and strengthened a section of the tax code, 45Q, which provides tax credits of up to $35/ton CO_2 for the capture and utilization of CO_2 in qualifying applications such as enhanced oil recovery (EOR) and up to $50/ton CO_2 for CO_2 that is captured and permanently stored in a geologic repository. Earlier versions of the tax credit with lower credit values generated limited interest. This change to the tax code could potentially alter U.S. energy systems. This paper examines the effect of the increased 45Q credits on CO_2 capture, utilization and storage (CCUS) deployment in the United States and on petroleum and power production. A range of potential outcomes is explored using five modeling tools. The paper goes on to explore the potential impact of possible modifications of the current tax credit including extension of its availability in time, the period over which 45Q tax credits can be utilized for any given asset and increases in the value of the credit as well as interactions with technology availability and carbon taxation. The paper concludes that 45Q tax credits could stimulate additional CCUS beyond that which is already underway." **James Edmonds, Christopher Nichols, Misha Adamantiades, John Bistline, Jonathan Huster, Gokul Iyer, Nils Johnson, Pralit Patel, Sharon Showalter, Nadja Victor, Stephanie Waldhoff, Marshall Wise, and Frances Wood,** *Energy Policy.* (Subscription may be required.)

Major role of particle fragmentation in regulating biological sequestration of CO_2 by the oceans.

The following is the abstract of this article: "A critical driver of the ocean carbon cycle is the downward flux of sinking organic particles, which acts to lower the atmospheric carbon dioxide concentration. This downward flux is reduced by more than 70% in the mesopelagic zone (100 to 1000 meters of depth), but this loss cannot be fully accounted for by current measurements. For decades, it has been hypothesized that the missing loss could be explained by the fragmentation of large aggregates into small particles, although data to test this hypothesis have been lacking. In this work, using robotic observations, [the authors] quantified total mesopelagic fragmentation during 34 high-flux events across multiple ocean regions and found that fragmentation accounted for 49 ± 22% of the observed flux loss. Therefore, fragmentation may be the primary process controlling the sequestration of sinking organic carbon." **Nathan Briggs, Giorgio Dall'Olmo, and Hervé Claustre,** *Science.* (Subscription may be required.)

The Value of Bioenergy with CO_2 Capture and Storage in an Electrified UK Heat Sector.

The following is from the abstract of this article: "The electrification of heat in the UK offers an alternative to a heating system dominated by natural gas, but poses significant challenges for the current energy supply, both in terms of meeting peak heat demand, and in decommissioning existing infrastructure. The UK's recent adoption of a net zero target by 2050 signals an increase in ambition in heat decarbonisation targets. On the other hand, negative emissions from the power sector, in the form of bioelectricity with carbon capture and storage (BECCS), could provide both low-carbon firm power and CO_2 removal, to assist in this transition. [The authors'] study explores the role of CO_2 removal in least cost electrification pathways to net zero, using a spatially explicit hourly unit operation and capacity expansion optimisation model of the UK heat and power sectors. [The authors] model the full biomass and CCS value chains to account for potential geo-physical, sustainability and financial constraints to BECCS deployment at the regional level. [The authors'] contribution introduces the methodology to derive the biomass supply curve and CO_2 storage capacity and injectivity cost curves for the UK." **Mathilde Fajardy, Vasileios Charitopoulos, and David Reiner,** *Computer Aided Chemical Engineering.* (Subscription may be required.)

Amazon forest response to CO_2 fertilization dependent on plant phosphorus acquisition.

The following is from the abstract of this article: "Global terrestrial models currently predict that the Amazon rainforest will continue to act as a carbon sink in the future, primarily owing to the rising atmospheric carbon dioxide (CO_2) concentration. Soil phosphorus impoverishment in parts of the Amazon basin largely controls its functioning, but the role of phosphorus availability has not been considered in global model ensembles—for example, during the Fifth Climate Model Intercomparison Project. Here [the authors] simulate the planned free-air CO_2 enrichment experiment AmazonFACE with an ensemble of 14 terrestrial ecosystem models. [The authors] show that phosphorus availability reduces the projected CO_2-induced biomass carbon growth by about 50% to $79 \pm 63\,g\,C\,m^{-2}\,yr^{-1}$ over 15 years compared to estimates from carbon and carbon–nitrogen models. [The authors'] results suggest that the resilience of the region to climate change may be much less than previously assumed. Variation in the biomass carbon response among the phosphorus-enabled models is considerable, ranging from 5 to $140\,g\,C\,m^{-2}\,yr^{-1}$, owing to the contrasting plant phosphorus use and acquisition strategies considered among the models. The Amazon forest response thus depends on the interactions and relative contributions of the phosphorus acquisition and use strategies across individuals, and to what extent these processes can be upregulated under elevated CO_2."**Katrin Fleischer, Anja Rammig, Martin G. De Kauwe, Anthony P. Walker, Tomas F. Domingues, Lucia Fuchslueger, Sabrina Garcia, Daniel S. Goll, Adriana Grandis, Mingkai Jiang, Vanessa Haverd, Florian Hofhansl, Jennifer A. Holm, Bart Kruijt, Felix Leung, Belinda E. Medlyn, Lina M. Mercado, Richard J. Norby, Bernard Pak, Celso von Randow, Carlos A. Quesada, Karst J. Schaap, Oscar J. Valverde-Barrantes, Ying-Ping Wang, Xiaojuan Yang, Sönke Zaehle, Qing Zhu, and David M. Lapola,** *Nature Geoscience.* (Subscription may be required.)

The current status of high temperature electrochemistry-based CO_2 transport membranes and reactors for direct CO_2 capture and conversion.

The following is from the abstract of this article: "The concept of direct CO_2 capture and conversion has attracted significant interest from industries and academia in recent decades due to its potential to address the current grand challenge of global warming/climate change, rapid depletion of fossil fuels and realization of a future carbon neutral ecosystem. The incumbent benchmark technology for CO_2 capture is the post-combustion flue-gas 'amine washing', which is energy intensive and costly for large-scale commercial implementation. The CO_2 conversion technologies, on the other hand, are still at their infancy with many technical challenges to overcome, but primarily being explored in laboratory-scale, low-temperature, solution-based and high-temperature, solid-oxide-based electrochemical cells with renewable electricity perceived as the energy input. In this article, [the authors] provide a comprehensive overview on an emergent class of high-temperature electrochemical CO_2 transport membranes that can capture and convert CO_2 into valuable chemicals in single catalytic reactor fashion. The review starts with the chemistry and transport theory of three basic types of membranes purposely designed for different CO_2 feedstocks and downstream conversions. A range of key functional materials used in these membranes and their microstructural/electrochemical properties important to the CO_2 transport are then thoroughly discussed in conjunction with the effects of surface modifications and operating conditions. Several types of combined CO_2 capture and conversion catalytic reactors based on these membranes are also assessed with a focus on their working principles, system configurations and performance demonstrations. Finally, challenges and prospective of these electrochemical CO_2 transport membranes and their associated conversion reactors are candidly discussed for future development." **Peng Zhang, Jingjing Tong, Kevin Huangm Xuefeng Zhu, and Weishen Yang,** *Progress in Energy and Combustion Science.* (Subscription may be required.)

Post-combustion CO_2 capture from a natural gas combined cycle power plant using activated carbon adsorption.

The following is from the abstract of this article: "As fossil fuel power plants have emitted significant quantity of carbon dioxide (CO_2) into the atmosphere which aggravates climate change, capturing and storing such emissions is key to mitigate the issue. An adsorption system based on a physical adsorbent i.e. activated carbon is first assessed to capture CO_2 emissions from a natural gas combined cycle. Then a subcritical sequential supplementary firing combined cycle with CO_2 capture is used to analyse the effect of CO_2 concentration. Analyses are carried out in terms of power loss and thermal efficiency. To evaluate the advantages of post-combustion CO_2 capture using activated carbon, results are compared with systems using a commercial absorbent, i.e. monoethanolamine and a chemical adsorbent i.e. polyethyleneimine/silica. The net efficiency of natural gas combined cycle using activated carbon increases slightly from 50.8% to 51.1% due to the lower regeneration temperature at 358 K. The performance of the system using PEI/silica is almost the same as that using activated carbon at 368 K. Although the thermal energy required to regenerate the activated carbon is relatively high, a significant improvement of net efficiency is observed with increased partial pressure. Economic analysis indicates that the systems using activated carbon is a competitive alternative for CO_2 capture. It is concluded activated carbon is relatively more advantageous than monoethanolamine in terms of efficiency and cost, which could be further improved with enhanced heat and mass recovery." **L. Jiang, A. Gonzalez-Diaz, J. Ling-Chin, A.P. Roskilly, and A.J. Smallbone,** *Applied Energy*. (Subscription may be required.)

A comprehensive review of value-added CO_2 sequestration in subsurface saline aquifers.

The following is from the abstract of this article: "This paper comprehensively reviews CO_2 sequestration process in saline aquifers. The storage mechanisms including structural, residual, solubility, and mineral trappings are assessed along with a discussion of their relative contributions, and their key parameters and optimisations. In view of storage security and capacity, effects of rock and fluid properties and reservoir conditions together with injection strategies are discussed. Furthermore, CO_2 storage site selection is investigated followed by an evaluation of the different measurement, monitoring and verification methods to mitigate the risk of leakage. Field examples with key learnings are also presented to help engineers with sustainable development of storage projects." **Sunil Kumar, Jalal Foroozesh, Katriona Edlmann, Mohamed Gamal Rezk, and Chun Yan Lim,** *Journal of Natural Gas Science and Engineering*. (Subscription may be required.)

FEBRUARY 2021

CCS deployment at dispersed industrial sites.

The following is from the Executive Summary of this UK Department for Business, Energy & Industrial Strategy (BEIS) research paper: "The Department for Business Energy and Industrial Strategy commissioned Element Energy in 2019 to identify and assess the range of high-level deployment options for Industrial Carbon Capture (ICC) technology on sites isolated from CO_2 transport and storage infrastructure in the United Kingdom. This area is of particular relevance because most of the existing Carbon Capture and Storage (CCS) reports in the UK focus on how shoreline CCS clusters can be developed. Isolated or inland emitters and clusters are generally excluded in these reports, or high-level onshore pipelines routes are presented in the longer term once the shoreline hubs are developed; the level of thinking and evidence are therefore limited in this area. In this work [the authors] identify key dispersed sites in the UK as well as their unique challenges and barriers to CCS deployment. Next, [the authors] appraise a range of high-level options for CCS deployment and the risks associated with each challenge and finally [the authors] assess the most promising options based on their cost, risk and emission reduction potential. [The authors] also include a comparison of CCS against alternatives such as carbon utilisation and hydrogen fuel switching based on the same metrics. This work has been supported by a period of stakeholder engagement during which organisations involved across a wide range of the CCS value chain were consulted."

Scaling Up the CCS Market to Deliver Net-Zero Emissions.

The following is from the Executive Summary of this Global CCS Institute report: "Understanding how the carbon capture and storage (CCS) market is likely to develop over the coming years is of interest to a wide range of stakeholders. It can help inform the timing and design of policies introduced by governments, the scale of the market for potential investors, and the challenges associated with meeting long-term climate targets. This report aims to inform the discussion on these topics by providing an overview of the near-term and longer-term developments in the CCS market. It reviews the current CCS facility pipeline, and how that could change in the next few years given project lead-in times. It then considers how this compares to projections of the number of CCS facilities needed to meet long-term climate goals. Throughout the report the number of CCS facilities deployed is used as a proxy for the size of the CCS market. The current CCS facility pipeline provides a relatively robust indicator of the CCS market in the next few years, particularly given it takes around 6-8 years for projects to progress through the full development cycle. There are currently 51 large-scale CCS facilities in the CCS facility pipeline, with 19 in operation, 4 under construction, 10 in advanced development and 18 in early development. Most of the large-scale facilities in operation are in North America, with the remainder in Norway, China, Brazil, Saudi Arabia, Australia and the UAE. The projects tend to be concentrated in industries where the unit cost of capturing CO_2 is low, such as natural gas processing, fertiliser and ethanol production."

A knowledge-data framework and geospatial fuzzy logic-based approach to model and predict structural complexity.

The following is from the abstract of this article: "Prediction of structural complexity for geohazard and subsurface resource applications requires constraining and interpreting data that are often ambiguous or lack key information. Moreover, structural complexity is a subjective term, requiring context for quantification. Recognizing this, a new knowledge-data framework and a geospatial fuzzy logic method is developed to represent and predict structural complexity in the subsurface. A conceptual model for known structural complexity serves as a basis for associating geospatial representations with types of damage zones. A second conceptual model for zones of structural complexity facilitates its prediction, notably in areas with limited explicit structural data. For each conceptual model, a fuzzy logic inference model is developed to incorporate geospatial data and estimate structural complexity potential. This approach is demonstrated using several public geospatial datasets within the state of Oklahoma. Explicit fault and earthquake location data were integrated using a fuzzy model of known structural complexity to train topographic, lithologic, and geophysical proxy datasets, applied to a fuzzy model to predict structural complexity, and evaluated with Receiver Operating Characteristic analyses and error classification. The final model output, displayed in maps and cross sections, offers comparison with interpreted structural data for validation. Together, these results demonstrate the effectiveness and limitations of the new approach as a screening tool for predicting structurally complex areas." **Devin Justman, C. Gabriel Creason, Kelly Rose, and Jennifer Bauer,** *Journal of Structural Geology*. (Subscription may be required.)

A European Optimisation Tool for Carbon Capture and Storage, Accounting for Delays in Public Procurement.

The following is from the abstract of this article: "The global anthropogenic generation of greenhouse gasses experienced an exponential increase compared to pre-industrial levels and, among these, CO_2 is the most abundant, with an emission that rose globally from 2 Gt/year in 1850 to over 35 Gt/year in 2010. Carbon capture and storage has been highlighted among the most promising options to decarbonise the energy sector, especially considering the European context which heavily relies on fossil fuels. When dealing with the strategic design and planning of an international carbon capture and storage infrastructure, the necessity of taking into account the differential behaviour among the European countries in terms of public procurement and assignation delays emerges as a key requirement for attaining an effective implementation of the network. This contribution proposes a mixed integer linear programming modelling framework for the economic optimisation of a multinational European carbon capture and storage supply chain, including the effects of

countrywide delays in public procurement. Assignation lags are implemented as an additional cost for the installation of the network. Results show that only minor modifications in the supply chain design should be taken into account with respect to an equivalent non-delayed scenario, with a consequent just moderate increase in transport costs (+ 3 %). Moreover, it is shown that capture and sequestration stages are barely not affected by the introduction of assignation lags among countries." **Federico d'Amore, Leonardo Lovisotto, and Fabrizio Bezzo,** *Computer Aided Chemical Engineering.* (Subscription may be required.)

Coal phase-outs and carbon prices: Interactions between EU emission trading and national carbon mitigation policies.

The following is from the abstract of this article: "The European Union Emission Trading System (EU ETS) constitutes the core instrument of the European Union climate protection policy. It limits greenhouse gas emissions of its member states and aims at facilitating an efficient allocation of emission reduction across national borders. Accompanying this policy at the European level, individual member states have introduced national mitigation policies, including renewable energy (RES) expansion measures or coal phase-outs. This study examines to what extent national policies affect the effectiveness of the EU ETS and to what degree the impact is reflected in prices for European Union Allowances (EUA). To investigate this question, a fundamental optimization model of the European electricity markets is deployed and model endogenous EUA prices are derived with a set of future market scenarios. Overall findings indicate that fundamental market forces strongly affect EUA prices. Furthermore, national policies play a critical role: The expansion of RES does not affect the capacity of the EU ETS to provide sufficient price signals for the desired level of decarbonization but a coal phase-out has a strong price-suppressing effect. A withdrawal of certificates can re-establish the effectiveness of the EU ETS but prices can rise drastically when overestimating the necessary amount." **Carl-Philipp Anke, Hannes Hobbie, Steffi Schreiber, and Dominik Möst,** *Energy Policy.* (Subscription may be required.)

Machine learning based co-optimization of carbon dioxide sequestration and oil recovery in CO_2-EOR project.

The following is from the abstract of this article: "This paper presents a machine learning assisted computational workflow to optimize a CO_2-WAG project considering both hydrocarbon recovery and CO_2 sequestration efficacies. A compositional field-scaled numerical simulation model is structured to investigate the fluid flow dynamics of an on-going CO_2-EOR project in the Farnsworth Unit (Texas, US). Artificial-neural-network (ANN) based proxy models are trained to predict time-series project responses including hydrocarbon production, CO_2 storage and reservoir pressure data. The outputs of the proxy model not only serve for evaluating the objective function but also provide significant physical and economic constraints to the optimization processes. In this work, the objective function considers both the oil recovery and CO_2 sequestration volume. Moreover, the project net present values (NPV) and reservoir pressure are employed to screen the optimum solutions. The proposed optimization workflow couples the Particle Swarm Optimization (PSO) algorithm and the ANN proxies to maximize the prescribed objective function. The results of this work indicate that the presented workflow is a more robust approach to co-optimize the CO_2-EOR projects. Results show that the optimized case can store about 94% of the purchased CO_2 within Farnsworth Unit. Comparing to the baseline case, the CO_2 storage amount of the found optimal case increases by 21.69%, and the oil production improves 8.74%. More importantly, the improvements in CO_2 storage and hydrocarbon recovery lead to 8.74% greater project NPV and 19.79% higher overall objective function value, which confirms the success of the developed co-optimization approach for CO_2 sequestration and oil recovery. The lessons and experiences earned from this work provides significant insights into the decision-making process of similar CO_2-EOR cases." **Junyu You, William Ampomah, Qian Sun, Eusebius Junior Kutsienyo, Robert Scott Balch, Zhenxue Dai, Martha Cather, and Xiaoying Zhang,** *Journal of Cleaner Production.* (Subscription may be required.)

Carbon sequestration and vegetation properties across the age of community managed exclosures in Northern Ethiopia.

The following is from the abstract of this article: "Exclosure management is becoming a common approach to rehabilitate and increase net biomass productivity of extremely degraded areas in Northern Ethiopia. However, the effect of age of exclosures on vegetation and soil property of communal lands is not yet well studied. In this study, the effect of land exclusion and age of exclosure on plant species richness, diversity, density and dominance, herbaceous standing biomass, woody biomass, woody biomass carbon, soil organic carbon (SOC) and other soil properties were assessed. To study the above listed variables, exclosures in three age classes (5–7, 12–15 and >20 years) and adjacent free grazing areas were selected. [The authors] replicate each age class three times considering agroecological similarity. From each exclosure and free grazing area, six larger plots (10m × 20m) each having five small quadrats were taken. Totally, 72 larger plots and 360 small quadrats were sampled. The result of this study indicates that exclusion of communal lands significantly improved species richness, diversity, biomass, woody biomass carbon, SOC, total nitrogen (TN) and total potassium (TK). Similarly, the density of perennial species and the density of grass species were found increased with the age of exclosure. Herbaceous species richness, diversity and annual species density were higher in the young-aged exclosures than in the older exclosures. Woody species richness, diversity, density, biomass, and woody biomass carbon were highest in the older exclosures. Besides, age of exclosure increases the content of SOC, TN and TK. Furthermore, it was found that the old-aged exclosures stored more biomass carbon (267 %) and SOC (37.66 %) than the young-aged exclosures. The study indicates the benefits of land exclosure for permanent carbon storage, which is vital to reduce atmospheric greenhouse gas concentration." **Gebrehaweria Kidane Reda, Teame Gebrehiwot Kebede, Shishay Tekklay Kahsay, and Berhane Hagos Gebrehiwot,** *Journal for Nature Conservation.* (Subscription may be required.)

Carbon dioxide wettability of South West Hub sandstone, Western Australia: Implications for carbon geo-storage.

The following is from the abstract of this article: "CO_2-rock wettability is a key factor which determines the fluid dynamics and CO_2 geo-storage capacity. However, the full understanding of real reservoir CO_2-wettability is yet to be gained. [The authors] thus systematically analysed the wettability of CO_2/brine/South West Hub sandstones at various pressures (0.1 MPa, 5 MPa, 10 MPa, 15 MPa, and 20 MPa) at 334 K. A new procedure based on organic carbon isotope tracking ($\delta^{13}C_{org}$) was proposed to eliminate the effect of artificial organic matter introduced by drilling mud penetration. The results indicate that the advancing (Θ_a) and receding (Θ_r) water contact angles for the CO_2/brine/South West Hub sandstone system increase with increase in pressure (ranging from 71° to 118° and 66° to 111°). It can thus be suggested that the system is weakly water-wet to intermediate-wet. When the samples were treated with dichloromethane, a slight decline in organic content was observed leading to slight decrease in water contact angles (i.e. TOC decreased from 0.019% to 0.003% for core C, and the corresponding Θ_a and Θ_r decreased from 118° and 111° to 110° and 104°, respectively, at 20 MPa and 334 K). This wettability analysis demonstrates that (a) of the contact angle is very sensitive to the amount of organic matter and therefore care should be taken to remove artificial organic matter from the sample, and that (b) this condition prevails in a real proposed CO_2-storage site. This analysis thus has important implications for assessing the feasibility of long-term CO_2 storage and enabling large-scale industrial carbon geological storage projects." **Cut Aja Fauziah, Ahmed Z. Al-Yaseri, Nilesh Kumar Jha, Christopher Lagat, Hamid Roshan, Ahmed Barifcani, and Stefan Iglauer,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Sustainable utilization and storage of carbon dioxide: Analysis and design of an innovative supply chain.

The following is from the abstract of this article: "A mixed integer linear programming model is developed for the optimal design of carbon capture utilization and storage supply chain in Germany. A sensitivity analysis shows that for the optimal supply chain the total costs are 97.9 billion €/year with a NPV of 675 billion € and a PB of 2.71 years: the economic profitability is

ensured only due to the use carbon tax. Also, 160 MtonCO_2 year are captured to produce methanol, concrete, wheat, lignin, polyurethane, calcium carbonate, urea and concrete by red mud. It is found that the selection of capture material/ technology depends on CO_2 composition, flue gas flow rate and CO_2 final use The high flow rate of flue gasses with a CO_2 composition between 13 mol% and 22 mol%, is most effectively captured by absorption technology. A Monte Carlo simulation is carried out to evaluate the uncertainties regarding the selling price and national demand of compounds." **Grazia Leonzio, Pier Ugo Foscolo, and Edwin Zondervan,** *Computers & Chemical Engineering*. (Subscription may be required.)

Zeolite and fly ash in the composition of oil well cement: Evaluation of degradation by CO_2 under geological storage condition.

The following is from the abstract of this article: "The performance of cement class G used in cementation of oilfield wellbores with addition of pozzolans was evaluated under geological carbon storage conditions. Two commercial synthetic zeolites types (4A-1 and 4A-2) and fly ash from a coal-fired plant were used as pozzolanic materials in amounts of 5 and 10% in weight replacing the cement. After curing, the cement samples were submitted to degradation tests in CO_2-saturated water at 15 MPa and 90°C for 7 and 14 days. The cement chemical degradation by CO_2 was investigated using scanning electron microscopy (SEM), X-ray diffraction (XRD) and compressive strength tests. The chemically altered layer thickness was averaged 3.46 mm for standard cement after 14 days of exposure to CO_2. On the other hand, cement systems with 10% wt. of pozzolanic material varied from 1.70 to 5.50 mm depending on the type of pozzolan and level of cementitious matrix porosity related to pozzolanic particle clustering. In general, 4A-1 zeolite presented better performance in terms of resistance to CO_2 attack and higher compressive strength after 14 days when compared to 4A-2 zeolite. The results showed that the addition of fly ash improved the compressive strength of the samples but increased the chemically altered layer due to CO_2 diffusion. SEM and XRD analyses showed that the portlandite was consumed and carbonation occurred in the chemical modified layer due to cement reaction with aqueous CO_2. Most cement systems with and without pozzolanic material exhibited no expressive loss on compressive strength after being exposed to CO_2-rich environment up to 14 days. On the contrary, some cement systems with 4-A1 zeolite and fly ash exhibited a mechanical resistance increase due to the carbonation process." **Roger Braun Ledesma, Natália Feijó Lopes, Katryanne Georg Bacca, Martimiano Krusciel de Moraes, Giovanni dos Santos Batista, Marçal Rodrigues Pires, and Eleani Maria da Costa,** *Journal of Petroleum Science and Engineering*. (Subscription may be required.)

MARCH 2021

Energy transition: Measurement needs for carbon, capture, usage and storage.

The following is from the Introduction of this United Kingdom (UK) National Physical Laboratory (NPL) document: "In 2019, the UK became the first major economy to pass legislation that committed to a target of net zero greenhouse gas (GHG) emissions by the year 2050, and by 2045 in Scotland… As of September 2020, the global average CO_2 content in the atmosphere was around 411 parts per million (ppm), which is 'higher than at any point in at least the past 800,000 years'. However, there are uncertainties in the scale, timeline and geographical nature of the impacts of climate change on society and hence in the relative value of differing mitigation strategies. These uncertainties mean that the consequences for society, in both action and inaction, are dramatic and far-reaching. CCUS provides an effective transitionary tool to deal with these uncertainties and to enable progress towards net zero whilst allowing the economy to time to adapt."

Carbon Capture and Storage Market: Technology Innovations and Analysis Till 2030.

The following are key highlights of this Prophecy Market Insights report: "The global carbon capture and storage market accounted for US$ 1.4 billion in 2018 and is projected to register a moderate CAGR of 9.30% over the forecast period. The market report has been segmented on the [capture] technology, end-user industry, and region. By technology, pre-combustion is dominating the segment, due to increased energy generation, newly developed advanced amine systems. By end-user industry, the oil and gas industry is dominating the segment, as carbon capture and storage (CCS), is aiding the oil and gas industry to mitigate greenhouse gases out of the atmosphere. By region, North America is projected to lead the global carbon capture and storage market and is expected to remain dominant during the forecast period, owing to the growing demand for clean technology."

Recent advances in carbon dioxide utilization.

The following is from the abstract of this article: "Carbon dioxide (CO_2) is the major contributor to greenhouse gas (GHG) emissions and the main driver of climate change. Currently, CO_2 utilization is increasingly attracting interest in processes like enhanced oil recovery and coal bed methane and it has the potential to be used in hydraulic fracturing processes, among others. In this review, the latest developments in CO_2 capture, utilization, conversion, and sequestration are examined through a multi-scale perspective. The diverse range of CO_2 utilization applications, including mineralization, biological utilization, food and beverages, energy storage media, and chemicals, is comprehensively presented. We also discuss the worldwide research and development of CO_2 utilization projects. Lastly, we examine the key challenges and issues that must be faced for pilot-scale and industrial applications in the future. This study demonstrates that CO_2 utilization can be a driver for the future development of carbon capture and utilization technologies. However, considering the amount of CO_2 produced globally, even if it can be reduced in the near-to mid-term future, carbon capture and storage will remain the primary strategy and, so, complementary strategies are desirable. Currently, the main CO_2 utilization industry is enhanced oil and gas recovery, but considering the carbon life cycle, these processes still add CO_2 to the atmosphere. In order to implement other CO_2 utilization technologies at a large scale, in addition to their current technical feasibility, their economic and societal viability is critical. Therefore, future efforts should be directed toward reduction of energy penalties and costs, and the introduction of policies and regulation encouraging carbon capture, utilization and storage, and increasing the public acceptance of the strategies in a complementary manner." **Zhien Zhang, Shu-Yuan Pan, Hao Li, Jianchao Cai, Abdul Ghani Olabi, Edward John Anthony, and Vasilije Manovic,** *Renewable and Sustainable Energy Reviews*. (Subscription may be required.)

Evolution patterns of bioenergy with carbon capture and storage (BECCS) from a science mapping perspective.

The following is from the abstract of this article: "Negative emissions technologies (NETs), which remove and isolate carbon dioxide from the atmosphere, are expected to play a significant role in mitigating climate change. As one of the most promising NETs, bioenergy with carbon capture and storage (BECCS) methods, which captures carbon dioxide (CO_2) emissions from bioenergy plants and then stores them in geological reservoirs, are being widely used in climate change scenarios. With the increased focus on mitigating solutions, several concerns have been raised regarding the deployment of BECCS. As no science mapping analyses of evolutionary BECCS patterns have yet been made, this study sought to determine these evolution patterns using a systematic analysis approach based on science mapping and visualization analyses. Under a longitudinal framework, the conceptual BECCS evolutionary track was determined using SciMAT to elucidate the structure and dynamic aspects of the associated scientific research. The co-word network and thematic evolutionary analysis revealed five main BECCS related themes. While this study provides a systematic study of BECCS research and development, further research should continue to focus on techno-economic analyses and the ecological and environmental impacts (land-use, water, diversity, and bioenergy crops) of BECCS. An increased research focus on the emerging biochar and hydrogen production themes is expected." **Meihui Li, Yi Lu, and Mengjiao Huang,** *Science of The Total Environment*. (Subscription may be required.)

The value of hydrogen and carbon capture, storage and utilisation in decarbonising energy: Insights from integrated value chain optimisation.

The following is from the abstract of this article: "There is increasing interest in carbon capture, utilisation and storage (CCUS) and hydrogen-based technologies for decarbonising energy systems and providing flexibility. However, the overall value of these technologies is vigorously debated. Value chain optimisation can determine how carbon dioxide and hydrogen technologies will fit into existing value chains in the energy and chemicals sectors and how effectively they can assist in meeting climate change targets. This is the first study to model and optimise the integrated value chains for carbon dioxide and hydrogen, providing a whole-system assessment of the role of CCUS and hydrogen technologies within the energy system. The results show that there are opportunities for CCUS to decarbonise existing power generation capacity but long-term decarbonisation and flexibility can be achieved at lower cost through renewables and hydrogen storage. Methanol produced from carbon capture and utilisation (CCU) becomes profitable at a price range of £72–102/MWh, compared to a current market price of about £52/MWh. However, this remains well below existing prices for transport fuels, so there is an opportunity to displace existing fuel demands with CCU products. Nonetheless, the scope for decarbonisation from these CCU pathways is small. For investment in carbon capture and storage to become attractive, additional drivers such as decarbonisation of industry and negative emissions policies are required. The model and the insights presented in this paper will be valuable to policymakers and investors for assessing the potential value of the technologies considered and the policies required to incentivise their uptake." **Christopher J. Quarton and Sheila Samsatli,** *Applied Energy*. (Subscription may be required).

Freight consolidation and containerization strategy under business as usual scenario & carbon tax regulation.

The following is from the abstract of this article: "With the increase of greenhouse gasses and climate change, international regulators faced a challenging task in determining carbon footprint regulations. With global greenhouse gas emissions from maritime logistics accounts for about 2.5%, this study would take to account for shipment containerization strategies under carbon tax regulation to explore the influence of carbon tax regulation on maritime logistics carbon emission reduction. The motivation of this study comes from a real case example of freight consolidation and containerization problem (FCCP) in Indonesia. This study tries to model an actual problem faced by a third-party logistics provider in consolidating goods into various sizes of containers while keeping the total transportation costs as low as possible. The most significant contributions of this study are to incorporate environmental factors into the FCCP model and to illustrate the impacts of various carbon footprints schemes on both cost and carbon emissions. Therefore, shipment containerization strategies under various carbon footprints schemes are formulated to minimize the transportation costs, as well as to lower the amount of carbon emission from maritime and land transport modes. The methodology used is a case-based approach; it depicts product delivery activities from one origin hub in Kaohsiung, Taiwan, to the biggest retailer stores in Jakarta, Indonesia. The aim is to incorporate environmental factors and illustrate how the proposed policy balances both cost and carbon emissions. Under the proposed policy, a new mixed-integer programming model is introduced considering the freight consolidation and containerization problem. Based on the different groups of numerical results, [the authors] found that the shipment containerization strategy under carbon tax regulation gives a better outcome in terms of total transportation cost and total carbon emissions compared with the business as usual policy." **Sunil Tiwari, Hui Ming Wee, Yanjie Zhou, and Leonardo Tjoeng,** *Journal of Cleaner Production*. (Subscription may be required.)

Ex-post investigation of cost pass-through in the EU ETS – an analysis for six industry sectors.

The following is from the abstract of this article: "In the discussion on the potential risk of carbon leakage related to the EU ETS and the effect of safeguard measures, the scope for passing through carbon costs into final product prices is considered a key issue. This study investigates whether and to what extent ETS-related carbon costs have been passed through into product prices by EU industry. Literature on the issue of carbon cost pass-through in industry, other than electric power generation, is relatively sparse and [the authors] therefore aim to add to the knowledge gathered in this area so far. [The authors] investigate a number of products in six industry sectors in several European countries and regions and provide estimates for carbon cost pass-through for more than 50 product/country pairs. In line with the literature, [the authors'] econometric results imply significant cost pass-through for a number of products, with results being most conclusive for the cement, iron and steel, and refineries sectors. The extent of the estimated pass-through rates diverges between products and countries/regions. These findings are aimed at informing discussions about carbon leakage protection for industries covered by the EU ETS." **Johanna Cludius, Sander de Bruyn, Katja Schumacher, and Robert Vergeer,** *Energy Economics*. (Subscription may be required.)

No-tillage did not increase organic carbon storage but stimulated N_2O emissions in an intensively cultivated sandy loam soil: A negative climate effect.

The following is from the abstract of this article: "Although numerous studies have been conducted on the effects of no-tillage on carbon (C) sequestration in agricultural systems, there is still no consensus on the balance between the potential of C sequestration and nitrous oxide (N_2O) or nitric oxide (NO) emissions. A no-tillage field experiment in the North China Plain was established in 2006 and the influence of no-tillage on N_2O and NO emissions was monitored under an annual wheat-maize cropping system. The study included four treatments: no-tillage (NT) and conventional tillage (CT) soils amended with N fertilizer at a rate of 225 kg N ha^{-1} for wheat and 195 kg N ha^{-1} for maize (NTN and CTN) and without N fertilizer (NT0 and CT0). Three years of no-tillage significantly ($p < 0.05$) increased soil organic C (SOC) content by 12.2% in the 0–5 cm soil layer, possibly due to the surface aggregation of organic C derived from crop roots and exudates, but did not alter SOC pool in the 0–30 cm profile. Annual N_2O emissions in the NT0 and CT0 treatments were 0.53 and 0.57 kg N_2O-N ha^{-1}, respectively, and were significantly ($p < 0.05$) increased to 0.96 kg N_2O-N ha^{-1} in CTN and to 1.23 kg N_2O-N ha^{-1} in NTN. Remarkable differences in N_2O emissions between CTN and NTN were observed during the maize growing season. In contrast, NO emissions were not affected by the tillage regimes regardless of N fertilization. The mean ratios of NO/N_2O fluxes in N-unfertilized plots were 0.26–0.29 and 1.79–2.11 for the maize and wheat season, respectively, indicating that both NO and N_2O were primarily derived from denitrification during the maize growing season and from nitrification under wheat cultivation. Under N-fertilized plots, the ratios increased to 1.44–2.02 and 5.00–6.03 for the maize and wheat season, respectively, with significantly ($p < 0.05$) lower values in NTN plots than in CTN plots. The N_2O emission factors for N applied in the wheat-maize rotation system were 0.16% and 0.09% for NTN and CTN, respectively, which was far lower than the IPCC Tier 1 default value (1.0%), primarily due to the absence of irrigation after fertilization in maize season and low temperature in wheat season. The results suggest that the 3-year no-tillage regime with residue removal did not substantially increase C storage in the 0–30 cm profile, but stimulated N_2O emissions primarily by increasing denitrification." **Yuhui Niu, Yanjiang Cai, Zengming Chen, Jiafa Luo, Hong J Di, Hongyan Yu, Anning Zhu, and Weixin Ding,** *Soil and Tillage Research*. (Subscription may be required.)

First report on carbon storage in a warm-temperate mangrove forest in South Africa.

The following is from the abstract of this article: "Carbon (C) storage by vegetated coastal habitats (mangroves, salt marshes and seagrasses) is globally recognized as a critical ecosystem service. Research efforts have therefore focused on quantifying C stored in these 'blue carbon' ecosystems but a notable knowledge gap still exists for certain geographical regions. This study aimed to provide the first comprehensive assessment of C storage in South African warm temperate mangroves by quantifying the C storage in aboveground biomass and soil C pools associated with the mangrove forest at the Nxaxo Estuary. C storage variability was also related to mangrove forest structure and soil environmental variables. C storage was quantified using standardized protocols for aboveground (live trees, leaf litter, pneumatophores)

and soil C pools at five *Avicennia marina* sites. The results showed soil C storage to be spatially variable while aboveground C pools were similar between intertidal zones within the sites. The soil C pool made the largest contribution to total C storage at each site and ranged from 176.91 ± 4.5MgC.ha–1 to 262.53 ± 18.8 MgC.ha–1. Of the aboveground carbon pools, live trees made the largest contribution and ranged from 2.25 ± 1.0 MgC.ha–1 to 9.56 ± 3.6 MgC.ha–1. Across all sites, average C storage for all pools was 234.9 ± 39.16 MgC.ha–1, which falls within the range reported for mangroves at other southern hemisphere range limits. Variability in soil C was linearly related to soil organic matter but this relationship was inconsistent between different soil depth intervals that were sampled. Total C storage was inversely related to mangrove tree density. This study confirms the need for more blue carbon studies to quantify C storage in under-represented geographical areas and to investigate factors that drive variability in C storage at different spatial scales." **Jaime L. Johnson, Jacqueline L. Raw, and Janine B. Adams,** *Estuarine, Coastal and Shelf Science*. (Subscription may be required.)

APRIL 2021

Accelerating Decarbonization of the U.S. Energy System.

The following is from a description of this National Academies of Sciences, Engineering, and Medicine report: "The world is transforming its energy system from one dominated by fossil fuel combustion to one with net-zero emissions of carbon dioxide (CO_2), the primary anthropogenic greenhouse gas. This energy transition is critical to mitigating climate change, protecting human health, and revitalizing the U.S. economy. To help policymakers, businesses, communities, and the public better understand what a net-zero transition would mean for the United States, the National Academies of Sciences, Engineering and Medicine convened a committee of experts to investigate how the U.S. could best decarbonize its transportation, electricity, buildings, and industrial sectors. This report, *Accelerating Decarbonization of the United States Energy System*, identifies key technological and socio-economic goals that must be achieved to put the United States on the path to reach net-zero carbon emissions by 2050. The report presents a policy blueprint outlining critical near-term actions for the first decade (2021-2030) of this 30-year effort, including ways to support communities that will be most impacted by the transition." (Purchase may be required.)

Taskforce on Scaling Voluntary Carbon Markets: Final Report.

The following is from the Executive Summary of this Institute of International Finance (IFF) report: "… Achieving a global net-zero goal is critical for the health of the planet, the stability of ecosystems, and to ensure safe conditions for future generations. To achieve this goal, deep, broad-ranging, and rapid action to reduce emissions must begin immediately across all sectors of the economy. In support, an increasing number of firms are making commitments to achieve their own net-zero targets, by reducing their own emissions, emissions associated with supply chains, and the use of their products. Firms setting such targets will be expected to demonstrate how net-zero emissions goals will be achieved. Carbon credits, purchased voluntarily, enable organizations to compensate or neutralize emissions not yet eliminated by financing the avoidance/reduction of emissions from other sources, or the removal of greenhouse gases from the atmosphere and thus meaningfully contribute in the transition to global net-zero. The projects generating these carbon credits can be broadly grouped into two categories: i) GHG avoidance/reduction projects, such as renewable energy or avoided deforestation and ii) GHG removal/sequestration projects, such as reforestation or technology-based removal. In addition to climate mitigation, many projects can also generate broader environmental, social, and economic benefits, ranging from increased biodiversity, job creation, support for local communities, and health benefits from avoided pollution. Similarly, credits supporting emerging climate technologies can help scale down cost curves, bringing these technologies to market earlier and decreasing their 'green premiums' against carbon-intensive alternatives. Furthermore, as a significant share of potential projects are located in the Global South, carbon credits can generate flows of private capital to these economies."

Biomass-based integrated gasification combined cycle with post-combustion CO_2 recovery by potassium carbonate: Techno-economic and environmental analysis.

The following is from the abstract of this article: "In this study, a thermodynamic model depicting integrated bioenergy with carbon capture and storage (BECCS) system is developed using Aspen Plus under thermodynamic equilibrium for the power generation segment, and a rate-based model for the carbon capture segment representing CO_2 recovery from the exhaust flue of a biomass based integrated gasification combined cycle (BIGCC). A thorough techno-economic analysis is conducted for the integrated system to evaluate system-wide environmental impacts and economic costs. The carbon capture is modeled using post combustion technology with chemical absorption by means of Piperazine promoted potassium carbonate to absorb the CO_2 from the exhaust stream of the gas turbine. The results demonstrate that the proposed system with 80% carbon capture has negative emissions of -0.31 kg/kWh of CO_2-e, when assuming neutral emissions from the BIGCC. For a production of 419 kW of net electricity, the overall energy and exergy efficiencies are 43.8% and 57.2%, respectively." **Ikhlas Ghiat, Ahmed AlNouss, Gordon McKay, and Tareq Al-Ansari**, *Computers & Chemical Engineering*. (Subscription may be required.)

Techno-economic analysis for the integration of a power to fuel system with a CCS coal power plant.

The following is from the abstract of this article: "In this paper, an analysis of the integration of a carbon capture unit and a power to fuel system for methanol synthesis with a coal power plant is presented from the energetic, environmental and economic standpoints. The study is carried out in three different sections. In the first part, the impact of the integration of a carbon capture system (CCS) and of a power to fuel plant (PtF) for methanol production is investigated in terms of plant average efficiency, fuel consumption, CO_2 emissions. In the second part, the annual fixed and variable costs of the power plant, and the annual cost of electricity (COE) are assessed for different plant configurations. Additionally, future scenarios are analyzed considering the impact of European policies on the CO_2 emission's cost, defined by the European Emission Trading System (ETS). Finally, an economic feasibility analysis of the power to fuel plant is performed and the methanol production is evaluated. Moreover, a sensitivity analysis is carried out to evaluate the impact of the most affecting parameters (electrical energy cost, the methanol selling price and the capital cost of the electrolyzer) in terms of Internal Rate of Return (IRR)." **D. Bellotti, A. Source, M. Rivarolo, and L. Magistri,** *Journal of CO_2 Utilization*. (Subscription may be required.)

Assessing the viability of soil successive straw biochar amendment based on a five-year column trial with six different soils: Views from crop production, carbon sequestration and net ecosystem economic benefits.

The following is from the abstract of this article: "Converting straw to biochar (BC) followed by successive application to soil has been increasingly suggested as a multi-win approach for soil fertility improvement, carbon (C) sequestration and efficient disposal of straw residues in intensive cropping agroecosystems. However, different soil types response differently in terms of crop growth and non-CO_2 greenhouse gas (GHG) emissions after BC application. Furthermore, few studies have comprehensively evaluated the net global warming potential (GWP) and net ecosystem economic benefits (NEEB) after long-term BC incorporation across representative soil types in China. A five-year outdoor column experiment was conducted using three rice-wheat rotated paddy soils and three millet-wheat rotated upland soils developed from different parent materials. Rice straw BC application rates of 0, 2.25 and 11.3 Mg ha–1 were used in each crop season with identical doses of NPK fertilizers. Compared with the no BC controls, BC significantly boosted crop growth, enhanced C sequestration, and decreased cumulative N_2O and CH4 emissions in all six soils over five rotation cycles. The response of the upland soils to BC was better in terms of crop growth and N_2O mitigation, whereas the soil organic carbon (SOC) increment and CH4 mitigation were less effective compared with the paddy soils. Net GWP decreased 0.6–19 fold after BC application; however, given the low trade price of CO_2 (0.21×10^3 CNY Mg–1), only a

small contribution was made in terms of C costs to the NEEB. The BC-induced NEEB was mainly dependent on grain yield gains and BC costs. These findings highlight that widespread adoption of successive straw BC application to farmland requires an increase in crop yield and substantial lowering of the BC cost regardless of the soil type. From the standpoints of agronomics, environment and economics, acid upland soil shows most potential in terms of BC application." **Yucui Bi, Siyuan Cai, Yu Wang, Yongqiu Xia, Xu Zhao, Shenqiang Wang, and Guangxi Xing,** *Journal of Environmental Management*. (Subscription may be required.)

The volatility spillover effect of the European Union (EU) carbon financial market.

The following is from the abstract of this article: "This paper modifies the BEKK-GARCH model based on the empirical results of the VAR model to analyze the dynamic volatility spillover effect between the European Union allowance (EUA) and certified emissions reduction (CER) markets during the second and third phases of the European Union Emission Trading System (EU ETS). The empirical results show that (1) an asymmetric volatility spillover effect exists between the EUA and CER markets and that the EUA market has a more significant volatility spillover effect on the CER market, and (2) the volatility spillover effect between the EUA and CER becomes weaker in phase III since the European Commission has limited the substitution of CER for EUA more strictly and the global carbon reduction requirements have become less demanding. [The authors'] study can help investors and managers of carbon market to have a more comprehensive understanding of the information and risk transmission mechanism between the EUA and CER markets, thus, providing them with a basis to make investment decisions and formulate policies." **Shihong Zeng, Jingmin Jia, Bin Su, Chunxia Jiang, and Guowang Zeng,** *Journal of Cleaner Production*. (Subscription may be required.)

Investigating the competitiveness of Carbon Capture and Storage in Italian power plants under different investment scenarios.

The following is from the abstract of this article: "This paper explores the viability of Carbon Capture and Storage (CCS) in Italy by examining two different scenarios. The first scenario evaluates the investments on traditional power generation technologies, i.e. USC (Ultra Super Critical), NGCC (Natural Gas Combined Cycle) and IGCC (Integrated Gas Combined Cycle), with and without CCS, and on wind farms; the second scenario studies the convenience of retrofitting existing Italian power plants with respect to the construction of new capture-ready plants. To the scope, a techno-economic analysis based on the calculation of the LCOE (Levelised Cost Of Electricity), the CCAV (cost of CO_2 avoided) and the CCAP (cost of CO_2 captured) is assessed. Beyond these measures, the analysis in both scenarios accounts for the calculation of the so-called LACE (Levelised Avoided Cost of Electricity) in order to evaluate the profitability of CCS systems and, therefore, to properly orient CCS investment decision in Italy." **Alberto Fichera and Rosaria Volpe,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Technology readiness assessment of ultra-deep salt caverns for carbon capture and storage in Brazil.

The following is from the abstract of this article: "This article presents a Technology Readiness Assessment (TRA) of a new concept called the Salt Cavern Hybrid Subsea Carbon Capture and Storage (CCS) System, which performs all the offshore natural gas and CO_2 separation process with subsequent storage in offshore underground salt caverns. Currently there is a demand for CCS of large quantities of CO_2 associated with CH4 in the pre-salt offshore oil fields in Brazil. The pre-salt reservoirs have as caprock 2000 m of continuous rock salt. This hybrid system is expected to perform, at the same time, the separation between the natural gas and CO_2, and Carbon Capture and Storage of CO_2, allowing the monetization of the separated natural gas. The Technology Readiness Levels (TRL) approach is discussed in this paper for estimating the maturity of the CCS System. The TRL analysis concluded that no technological gaps were identified that would made the project unfeasible and the TRL level enables the project to advance to the field test stage within a reasonably short time horizon. Once implemented it could be one of the largest CCS projects in the world. Also, this paper describes the conceptual design of this hybrid system and presents the results of a TRA showing the methodology that was employed in the process, the technology critical items that were analyzed and the results obtained for each of them and the design of a salt cavern for the storage of 1 billion Sm3 (Standard cubic meter) of a natural gas stream with high CO_2 content." **Mariana Barbero Ribeiro Goulart, Pedro Vassalo Maia da Costa, Alvaro Maia da Costa, Antonio C.O. Miranda, Andre Bergsten Mendes, Nelson F.F. Ebecken, Julio R. Meneghini, Kazuo Nishimoto, and Gustavo R.S. Assi,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Towards a clean environment: The potential application of eco-friendly magnesia-silicate cement in CO_2 sequestration.

The following is from the abstract of this article: "The key point of this study is the fabrication of magnesia-based cement with promising mechanical properties and high efficiency of CO_2-capture. The naturally occurring volcanic ashes (white & red ashes) and reactive magnesium oxide are the main materials used in the synthesis of eco-friendly CO_2-capture materials. Volcanic ashes were individually mixed with reactive magnesium oxide at ash to magnesium oxide ratio of 25:75 wt %. The dry blends can react with water to yield hardened materials (at ambient temperature) with compressive strength depends on the type of volcanic ash. A considerable change in the features of the hardened samples was recorded when the fabricated materials exposed to 100% CO_2 gas for 28-days. This change is mainly due to CO_2-capture by magnesium hydroxide $Mg(OH)_2$ within the fabricated materials, resulting in the formation of Nesquehonite minerals $MgCO3.3H_2O$ as proved by X-ray diffraction, thermo-gravimetric, and infra-red instrumental techniques. The thermo-gravimetric analysis demonstrates that, the fabricated sample containing low amorphous red ashes has higher CO_2-capture capacity (~260 kg/ton) compared to that having high amorphous white volcanic ashes (~220 kg/ton) at 28-days of CO_2-exposure. Accordingly, the fabricated magnesia-based cement is not only used as cementitious material with outstanding mechanical properties, but also used as a super CO_2-absorbent precursor. This can strongly contribute in the mitigation of global warming potential caused by different industrial activities." **Hamdy A. Abdel-Gawwad, Hassan Soltan Hassan, S.R. Vásquez-García, Isabel Israde-Alcántara, Yung-Chin Ding, Marco Antonio Martinez-Cinco, S. Abd El-Aleem, Hesham M. Khater, Taher A. Tawfik, and Ibrahim M. El-Kattan,** *Journal of Cleaner Production*. (Subscription may be required.)

Anthropogenic alteration of nutrient supply increases the global freshwater carbon sink.

The following is from the abstract of this article: "Lakes have a disproportionate effect on the global carbon (C) cycle relative to their area, mediating C transfer from land to atmosphere, and burying organic-C in their sediments. The magnitude and temporal variability of C burial is, however, poorly constrained, and the degree to which humans have influenced lake C cycling through landscape alteration has not been systematically assessed. Here, [the authors] report global and biome specific trajectories of lake C sequestration based on 516 lakes and show that some lake C burial rates (i.e., those in tropical forest and grassland biomes) have quadrupled over the last 100 years. Global lake C-sequestration (~0.12 Pg year−1) has increased by ~72 Tg year−1 since 1900, offsetting 20% of annual CO_2 freshwater emissions rising to ~30% if reservoirs are included and contributing to the residual continental C sink. Nutrient availability explains ~70% of the observed increase, while rising temperatures have a minimal effect." **N.J. Anderson, A.J. Heathcote, D.R. Engstrom, and Globocarb data contributors,** *Science Advances*. (Subscription may be required.)

MAY 2021

A Review of International Field Experience with Well Integrity at Carbon Utilization and Storage Sites.

The following is the description of this DOE-funded report: "This report details findings from a survey of well integrity experiences elicited from operators of geologic carbon storage (GCS) and carbon dioxide enhanced oil recovery (CO_2-EOR) sites around the world. The survey consisted of 41 questions organized in four sections and its goal was to obtain information about site characteristics and operator experiences with well integrity, monitoring methods, and risk assessment of legacy wells. Current literature relevant to the survey questions was also reviewed and summarized to provide context for survey responses and identify areas where field experiences with well integrity do and do not align with the current state of research."

Geochemical Variation of Produced Waters and Overlying Groundwaters at an Active CO_2 Enhanced Oil Recovery Field in the Permian Basin Central Platform.

The following is a description of this DOE-funded report: "This report discusses the results of baseline geochemical data from a carbon dioxide (CO_2) enhanced oil recovery (EOR) field in the Permian Basin's Central Basin Platform. This report focuses on understanding the variability in geochemistry during normal oil field practices, including the transition from water flooding to a water-alternating-gas (WAG) technique. The primary objectives of this study were to focus on 1) determining the best general geochemical parameters to identify produced water intrusion into overlying groundwaters, 2) observing if there was any intrusion during the sampling period, and 3) identifying changes in produced water following CO_2 injection."

Carbon Capture, Utilization, and Storage Game Changers in Asia: 2020 Compendium of Technologies and Enablers.

The following is from the Overview of this Asian Development Bank publication: "This compendium deals with four interesting carbon dioxide capture technologies, five carbon dioxide utilization technologies, one utilization storage technology, and one enabler concept. The technologies presented are in various stages, ranging from research and development to commercial deployment. The enabler concept introduced in this compendium is an initiative to accelerate collaboration and deployment of CCUS. The technologies and enablers included in this compendium were furnished by CCUS technology providers and enablers through their responses to an e-mail questionnaire prepared by the consultant team of the Asian Development Bank (ADB) through regional technical assistance, Integrated High Impact Innovation in Sustainable Energy Technology (Subproject 2): Prefeasibility Analysis for Carbon Capture, Utilization, and Storage. ADB would like to clarify that the compendium is not exhaustive. Other ideas are available and may also be added to this but—because of time constraints—they are not added here. ADB looks forward to other opportunities to add to this collection of ideas on CCUS, which could help ADB developing member countries achieve low-carbon growth." (Purchase may be required.)

Carbon Capture and Storage Market to Make Great Impact in Forecast Period 2021-2026.

The following is from a description of this document: "This study is a perfect blend of qualitative and quantifiable information highlighting key market developments, industry and competitors' challenges in gap analysis, and new opportunities and maybe trending in the Global Carbon Capture and Storage Market. This report encloses a comprehensive analysis of the market and is assessed through volume and value data validated on approaches including top companies' revenues. It concludes with precise and authentic market estimations considering all the parameters and market dynamics. Every crucial and decisive detail for the development and restriction of the market is mentioned in fine points with solutions and suggestions that may affect the market in near future. Segmentation of the market is studied specifically to give profound knowledge for supplementary market investments. Competition intensity of the global Carbon Capture and Storage Market is also an integral report section that allows readers and manufacturers to gauge into the stiffening competition augmented by novice entrants, besides other versatile market veterans peaking competition with their unique business delivery models, growth strategies, regional investments, as well as technological milestones and pipeline projects. All profiled market participants have been subject to tremendous assessment based on advanced evaluation techniques, aligning with the report objective of the unbiased evaluation… Global Carbon Capture and Storage market also specifically underpins end-use application scope and their improvements based on technological developments and consumer preferences." (Purchase may be required.)

Evaluation of multiple time carbon capture and storage network with capital-carbon trade-off.

The following is from the abstract of this article: "The carbon dioxide emission from the industrial sector and the power plant contribute significantly to global climate change for several decades. The carbon capture and storage technology is the primary solution to reach the reduction target of carbon dioxide emissions. The carbon capture and storage activities involve CO_2 capturing, transporting, and storing in geological storage, requires number planning. The process integration approach by pinch analysis method can be used for the carbon capture and storage planning problem and to develop the carbon capture and storage network design. However, the applicability of the method needs to be evaluated when some constraints in carbon capture and storage network design are applied. This paper proposes an improved pinch analysis based method for carbon capture and storage target and network design. The method begins with targeting the maximum carbon exchange in the carbon capture and storage system, which is followed by designing the carbon capture and storage network. Next, the capital-carbon trade-off is introduced as a new strategy for assessing carbon capture and storage network design to show the economic feasibility of the design. Four case studies demonstrate the applicability of the proposed method to the carbon capture and storage systems in the central and western part of Indonesia. The application of this new strategy in the western part of Indonesia as a single region system revealed that the flat minimum of the total annual cost is obtained at a five year time difference with the amount of up to US$ 149.3 million." **Annasit Mualim, Hairul Huda, Ali Altway, Juwari Purwo Sutikno, and Renanto Handogo,** *Journal of Cleaner Production*. (Subscription may be required.)

The effects of renewable energy, spatial spillover of CO_2 emissions and economic freedom on CO_2 emissions in the EU.

The following is from the abstract of this article: "Renewable energy is a variable influencing CO_2 emission. Previous studies investigated its effects on CO_2 emission in the European Union (EU) countries using classical econometrics method. However, if there was a spatial dependence between CO_2 emissions of the EU countries, the results of previous studies may have been biased. Another gap in the literature is nonlinear effects of economic freedom on CO_2 emissions. To fill these gaps, the present study explored the aforementioned issues in the framework of environmental Kuznets curve in the EU countries for period 2000 to 2017 using a spatial dynamic panel data model. The results showed that the renewable energy consumption had a negative effect on CO_2 emissions, and the relationship between economic freedom and CO_2 emissions was U-shaped. Finally, a significant positive spatial lag coefficient was found for CO_2 emissions, indicating that the CO_2 emissions of a country were positively correlated with those of its neighbors." **Rouhollah Shahnazi and Zahra Dehghan Shabani,** *Renewable Energy*. (Subscription may be required.)

Effect of nanofluid on CO_2-wettability reversal of sandstone formation; implications for CO_2 geo-storage.

The following is from the abstract of this article: "Hypothesis—Nanofluid treatment is a promising technique which can be used for wettability reversal of CO_2-brine-mineral systems towards a further favourable less CO_2-wet state in the existence of organic acids. However, literature requires more information and study with respect to organic acids and nanoparticles' effect at reservoir (high pressure and high temperature) conditions. Experiments—Therefore, [the authors] have measured in this study that what influence small amounts

of organic acids exposed to quartz for aging time of (7 days and 1 year) have on their wettability and how this impact can be reduced by using different concentrations of nanoparticles at reservoir conditions. Precisely, [the authors] have tested lignoceric acid (C_{24}), stearic acid (C_{18}), lauric acid (C_{12}) and hexanoic acid (C_6) at 10–2 Molarity, as well as, [the authors] have also used different concentrations (0.75 wt%, 0.25 wt%, 0.1 wt%, 0.05 wt%) of silica nanoparticles at realistic storage conditions. Findings—The quartz surface turned significantly hydrophobic when exposed to organic acids for longer aging time of 1 year, and significantly hydrophilic after nanofluid treatment at optimum concentration of 0.1 wt%. It was observed that most nanoparticles were mechanistically irreversibly adsorbed on the surface of quartz sample. This wettability shift thus may increase CO_2 storage capacities and containment security." **Muhammad Ali, Muhammad Faraz Sahito, Nilesh Kumar Jha, Zain-Ul-Abedin Arain, Shoaib Memon, Alireza Keshavarz, Stefan Iglauer, Ali Saeedi, and Mohammad Sarmadivaleh,** *Journal of Colloid and Interface Science.* (Subscription may be required.)

Life cycle environmental impact assessment of coupled underground coal gasification and CO_2 capture and storage: Alternative end uses for the UCG product gases.

The following is from the abstract of this article: "Underground coal gasification (UCG) has the potential to provide a source of energy or chemical feedstock derived from coal seams, where traditional mining methods are not suitable or are uneconomical. This paper presents the life cycle inventory models developed for the UCG processes and three alternative syngas utilisation options with and without CO_2 capture and storage. The paper compares the life cycle carbon footprint of two different conventional above ground coal fired power generation options with UCG Integrated Gasification Combined Cycle power generation with/without CCS for two different lignites and one bituminous coal. One of the lignites is then used to compare the life cycle performance of different syngas utilisation options: power generation, ammonia production with power generation, and methanol production with power generation. It was found that the life cycle carbon footprint of conventional above ground coal fired power generation is very much dependent on the in-situ methane content of the coal used, and methane emissions experienced during mining and accompanying upstream processes, whereas the same for UCG-IGCC power depends more on the process dependent syngas composition. UCG methanol production with associated power and CCS is shown to release more life cycle CO_2-eq emissions per tonne of lignite consumed than that of UCG ammonia production with associated power and CCS and UCG CCGT power generation with CCS. Furthermore, when chemicals production from UCG is considered as the main objective, the most substantial improvements in comparison to conventional methods are associated with UCG ammonia process per tonne of chemical produced." **Anna Korre, Sevket Durucan, and Zhenggang Nie,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

The impact of the global stock and energy market on EU ETS: A structural equation modelling approach.

The following is from the abstract of this article: "The industrial revolution has brought about great development in the economy, but it has also increased the dependence on fossil energy. The emissions of CO_2 and other greenhouse gases have contradicted economic development and the ecological environment. The establishment of the EU Emission Trading System (EU ETS) has improved the global carbon emission price mechanism, but as a new commodity, its price trend will affect buyers' risk evaluation. Therefore, it is influential to master the driving factors behind carbon emission prices and make effective predictions. First, the paper points out that the driving factors are divided into macroeconomic risk factors and energy factors. Second, the Bayesian Network is used to select variables and make prediction of carbon prices. The results show that its accuracy exceeds other machine learning algorithms. Third, a structural equation model is used to study the impact of the selected markets on the carbon market. Finally, from the perspective of global carbon emission reduction, the relationship between driving factors and the carbon futures market is explained. The empirical results show that Cotation Assistée en Continu 40, natural gas and Brent crude oil will directly affect the yield of European Union Allowances and Certified Emission Reduction futures, and the Standard Poor 500 and Global Clean Energy Index will indirectly affect the yield of European Union Allowances and Certified Emission Reduction futures. The energy market will affect the carbon market through the intermediary effect of the stock market, in which the clean energy index is the most relevant factor. From the perspective of how to improve the carbon trading system, this paper proposes suggestions for the sustainable development of the world to promote the virtuous cycle of the global carbon emission market and the high-quality development of the global economy." **Zi-Jie Wang and Lu-Tao Zhao,** *Journal of Cleaner Production.* (Subscription may be required.)

Structural controls on the location and distribution of CO_2 emission at a natural CO_2 spring in Daylesford, Australia.

The following is from the abstract of this article: "Secure storage of CO_2 is imperative for carbon capture and storage technology, and relies on a thorough understanding of the mechanisms of CO_2 retention and leakage. Observations at CO_2 seeps around the world find that geological structures at a local and regional scale control the location, distribution and style of CO_2 emission. Bedrock-hosted natural CO_2 seepage is found in the Daylesford region in Victoria, Australia, where many natural springs contain high concentrations of dissolved CO_2. Within a few meters of the natural Tipperary Mineral Spring, small CO_2 bubble streams are emitted from bedrock into an ephemeral creek. [The authors] examine the relationship between structures in the exposed adjacent outcropping rocks and characteristics of CO_2 gas leakage in the stream, including CO_2 flux and the distribution of gas emissions. [The authors] find that degassing is clustered within ~1 m of a shale-sandstone geological contact. CO_2 emission points are localised along bedding and fracture planes, and concentrated where these features intersect. The bubble streams were intermittent, which posed difficulties in quantifying total emitted CO_2. Counterintuitively, the number of bubble streams and CO_2 flux was greatest from shale dominated rather than the sandstone dominated features, which forms the regional aquifer. Shallow processes must be increasing the shale permeability, thus influencing the CO_2 flow pathway and emission locations. CO_2 seepage is not limited to the pool; leakage was detected in subaerial rock exposures, at the intersection of bedding and orthogonal fractures. These insights show the range of spatial scales of the geological features that control CO_2 flow. Microscale features and near surface processes can have significant effect on the style and location and rates of CO_2 leakage. The intermittency of the bubble streams highlights challenges around characterising and monitoring CO_2 stores where seepage is spatially and temporally variable. CCS monitoring programmes must therefore be informed by understanding of shallow crustal processes and not simply the processes and pathways governing CO_2 fluid flow at depth. Understanding how the CO_2 fluids leaked by deep pathways might be affected by shallow processes will inform the design of appropriate monitoring tools and monitoring locations." **Jennifer J. Roberts, Aero Leplastrier, Andrew J. Feitz, Zoe K. Shipton, Andrew F. Bell, and Rūta Karolytė,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

JUNE 2021

A Survey of U.S. CO_2 Enhanced Oil Recovery Projects.

The following is description of this Advanced Resources International survey: "The purpose of this survey is to provide a comprehensive status report of active CO_2 EOR projects in the U.S., as of end-of-year 2019. This survey provides the first update of CO_2 EOR project data since the final publication of the Oil & Gas Journal (OGJ) EOR Survey in 2014. The 2019 U.S CO_2 EOR survey shows that incremental oil recovery from CO_2 EOR in the U.S. has held steady at approximately 300,000 barrels of oil per day. A total of 3.0 Bcf per day of CO_2 is purchased for CO_2 EOR, including 1.0 Bcf per day from 'industrial' sources, which represents an increase of 30% over the last seven years. Carbon management, in the form of CO_2 capture and storage, is the most viable pathway to meeting significant carbon emission reduction targets over the next several decades. This survey demonstrates the value and potential of CO_2 EOR to the overall carbon management strategy in the U.S."

Financing CCS in Developing Countries.

The following is a description of this Global CCS Institute publication: "For CCS to fulfill its potential in reducing significant global emissions, this technology must be deployed in all parts of the world. Yet there are currently very few CCS projects in developing countries. This report was commissioned by ClearPath and Southern Company to examine the role of climate finance in supporting CCS project development in developing countries. It investigates: The support afforded to existing CCS facilities; Reasons for the lack of deployment in developing countries; How to overcome CCS investment risks; and Relevant global climate finance mechanisms to support the deployment of more facilities. It was found that while there is a very high need for CCS in several developing countries, their level of readiness for CCS deployment is low. Climate finance has an important role to play in both, improving their level of readiness as well as closing the funding gap in developing CCS projects."

Application of three-dimensional fault stress models for assessment of fault stability for CO_2 storage sites.

The following is from the abstract of this article: "Carbon Capture and Storage (CCS) is a key technology for a low-carbon energy future and will have an important role on the economic future of the UK Continental Shelf (UKCS). The East Irish Sea Basin (EISB) is a prospective area for CCS in the western UKCS. 3D seismic from the EISB were used in this study to characterise the fault network and potential fault reactivation risks associated with CO_2 injection. Two main structural domains are present: a Northern domain with NW-SE faults, and a Southern domain with faults following a N-S orientation. The main storage sites consist of structural closures in Triassic strata of the Sherwood Sandstone Formation (SSF), overlain by alternations of mudstones and evaporites of the Triassic Mercia Mudstone Group (MMG). The closures occur predominantly at fault-bounded horsts, with adjacent grabens filled by thick sequences of the Triassic Mercia Mudstone Group (MMG). The fault framework was used to test, in 3D, the stress model published for the EISB and assess the fault reactivation risk associated with CO_2 storage. Slip tendency values were predominantly below 0.6, suggesting the presence of stable structures in the EISB. Under the tested conditions, faults are capable of withstanding pressure increases between 3 MPa and 10 MPa before the onset of slip. The limited fault reactivation risk suggests CCS operations are suitable prospects for the EISB. This work demonstrates the additional value gained from integration of accurately constrained fault geometries in 3D stress models." **Davide Gamboa, John D.O. Williams, Michelle Bentham, David I. Schofield, and Andrew C. Mitchell,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Utilization of CO_2 to reduce environmental impact of diluted bitumen transportation and improve economics of CCS operations.

The following is from the abstract of this article: "Environmental impact and economics of Carbon Dioxide (CO_2) and bitumen transportation are among the major challenges of oil sands operations. [The authors] propose and assess a new approach to address these important challenges by using diluted bitumen (DilBit) as a carrier for large-scale CO_2 transportation. The proposed approach provides a unique prospect to significantly reduce the cost of CO_2 transportation from the carbon capture and storage (CCS) value chain, facilitate more efficient detection of DilBit spills from pipelines, utilize CO_2, and improve public perception of both oil sands and CCS operations. These opportunities will offer the possibility of sustaining access to oil resources while reducing environmental impact and improving the economics of CCS and oil sands operations. Through experimental measurements, [the authors] have shown that 80–200 kg of CO_2 per m3 of DilBit can be dissolved and transported. [The authors] also report simulation results from the simultaneous transportation of DilBit and CO_2 and DilBit spill detection through monitoring concentration of leaked CO_2." **Ali Zirahi, Ali Haddadnia, Mohammadjavad Mohammadi, Bahareh Azinfar, Mohsen Zirrahi, Hassan Hassanzadeh, and Jalal Abedi,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Effects of grazing management on spatio-temporal heterogeneity of soil carbon and greenhouse gas emissions of grasslands and rangelands: Monitoring, assessment and scaling-up.

The following is the from the abstract of this article: "Grazing lands provide many goods and ecosystem services, such as forage, livestock, soil carbon (C) storage, biodiversity, and recreational opportunities. Ensuring the long-term sustainability of grazing lands requires optimal management to simultaneously balance livestock productivity for sustaining human food and nutritional demands while reducing environmental impacts, such as greenhouse gases (GHG) emissions and soil degradation. In this paper, [the authors] revisit grazing management in grazing lands exposed to different grazing systems […] review parameterization and multi-faceted goals for sustainability of grazing systems considering broader sustainability from economic to environmental aspects […] discuss the inconsistencies between grazing researchers and ranchers' practices […] review the separate experimental data to examine the impacts of multi-paddock rotational grazing on soil carbon, nutrient and GHGs [and] present status and upcoming challenges in monitoring and upscaling of grazing ecosystem research and management. In [this paper], new concepts of multiple source monitoring networks are presented that enable the analysis of scale-dependent processes. Finally, [this paper points] out future directions for monitoring and assessment of managing soil C and GHG emissions from grazing lands. The results show that the inconsistences are essentially due to (1) effects of spatiotemporal scales on both economic and ecological outcomes, and (2) simplistic representations of multi-faceted grazing systems and sustainability. The development of multi-faceted monitoring systems needs to be further parametrized and standardized to make consistent for meaningful and comparable assessment of grazing management impacts on SOC and GHGs." **Junye Wang, Yumei Li, Edward W. Bork, Goetz M. Richter, Changchun Chen, Syed Hamid Hussain Shah, and Symon Mezbahuddin,** *Journal of Cleaner Production*. (Subscription may be required.)

Impacts of wetland dieback on carbon dynamics: A comparison between intact and degraded mangroves.

The following is from the abstract of this article: "Mangroves are effective blue carbon sinks and are the most carbon rich ecosystems on earth. However, their areal extent has declined by over one-third in recent decades. Degraded mangrove forests result in reduced carbon captured and lead to release of stored carbon into the atmosphere by CO_2 emission. The aim of this study was to assess changes in carbon dynamics in a gradually degrading mangrove forest on Bonaire, Dutch Caribbean. Remote sensing techniques were applied to estimate the distribution of intact and degraded mangroves. Forest structure, sediment carbon storage, sediment CO_2 effluxes and dissolved organic and inorganic carbon in pore and surface waters across intact and degraded parts were assessed. On average intact mangroves showed 31% sediment organic carbon in the upper 30 cm compared to 20% in degraded mangrove areas. A loss of 1.51 $MgCO_2$ ha–1 yr–1 for degraded sites was calculated. Water samples showed a hypersaline environment in the degraded mangrove area averaging 93 which may have caused mangrove dieback. Sediment CO_2 efflux within degraded sites was lower than values from other studies where degradation was caused by clearing or cutting, giving new insights into carbon dynamics in slowly degrading mangrove systems. Results of water samples agreed with previous studies where inorganic carbon outwelled from mangroves might enhance ecosystem connectivity by potentially buffering ocean acidification locally. Wetlands will be impacted by a variety of stressors resulting from a changing climate. Results from this study could inform scientists and stakeholders on how combined stresses, such as climate change with salinity intrusion may impact mangrove's blue carbon sink potential and highlight the need of future comparative studies of intact versus degraded mangrove stands." **D.F. Senger, D.A. Saavedra Hortua, S. Engel, M. Schnurawa, N. Moosdorf, and L.G. Gillis,** *Science of The Total Environment*. (Subscription may be required.)

On the theoretical carbon storage and carbon sequestration potential of hempcrete.

The following is from the abstract of this article: "Hempcrete is a natural insulation material that is well known for exhibiting favorable thermal properties and low manufacturing emissions. Hempcrete is a biocomposite, consisting of hemp shiv and a lime-based binder composed of hydrated lime and either a hydraulic (*e.g.*, natural hydraulic lime and ordinary portland cement) or pozzolanic binder (*e.g.*, metakaolin). While long-term biogenic carbon storage can be achieved via utilization of hemp shiv in hempcrete, additional carbon storage can be achieved via carbonation of the binder. This study advances previous carbonation modeling approaches by deriving a theoretical model based on the fundamentals of cement hydration and carbonation chemistry to quantify the total theoretical *in situ* CO_2e sequestration potential of hempcrete binders. To estimate the percentage of manufacturing CO_2e emissions that can be recovered through *in situ* binder carbonation, the model is implemented in life cycle assessments of 36 hempcrete formulations of various binder contents and densities using an equivalent functional unit (FU) of a 1 m2 wall assembly with a U-value of 0.27 W/(m2K). [The authors'] model estimates between 18.5% and 38.4% of initial carbon emissions associated with binder production can be sequestered through *in situ* carbonation. Considering biogenic carbon storage, [the authors] predict that the total life cycle CO_2e emissions of hempcrete can be negative, with a minimum of –16.0 kg CO_2e/FU for the hempcrete mixture formulations considered herein. However, [the authors] estimate that some hempcrete formulations can exhibit net-positive emissions, especially high-density mixes (>300 kg/m3) containing portland cement, thereby illustrating the importance of materials selection and proportioning in designing carbon-storing hempcrete." **Jay H. Arehart, William S. Nelson, and Wil V. Srubar III,** *Journal of Cleaner Production*. (Subscription may be required.)

Dynamic interactive effect and co-design of SO_2 emission tax and CO_2 emission trading scheme.

The following is from the abstract of this article: "To solve the different environmental problems caused by the over-use of fossil fuels, multiple environmental policies currently coexist. How these environmental policies interact with each other and how to optimise them are a few issues that need to be resolved urgently in practice. [The authors] established an environmental dynamic stochastic general equilibrium model (E-DSGE) to analyse the dynamic interactive effects of the SO_2 emission tax and CO_2 emission trading in China and the optimal design of these two environmental policies. [The authors] have calibrated the model based on China's actual data. The results indicate that synergistic emission reduction effects have led to an overlap between the two policies, because both SO_2 and CO_2 emissions share a common root—fossil fuels. Currently there is no obvious conflict between them. When the SO_2 emission tax is levied at 12.6 CNY/kg, the CO_2 emission cap should be lower than 76.1%. Second, the synergistic emission reduction effect between CO_2 emission trading and the SO_2 emission tax can enhance the automatic stabilisation function of both. Third, [the authors] suggest to optimise both policies pro-cyclically. However, if either of these two policies is ineffective, the optimal SO_2 emission tax will be counter-rather than pro-cyclical." **Bowen Xiao, Ying Fan, and Xiaodan Guo,** *Energy Policy*. (Subscription may be required.)

Assessing the potential of soil carbonation and enhanced weathering through Life Cycle Assessment: A case study for Sao Paulo State, Brazil.

The following is from the abstract of this article: "Enhanced silicate rock weathering for long-term carbon dioxide sequestration has considerable potential, but depends on the availability of suitable rocks coupled with proximity to suitable locations for field application. In this paper, [the authors] investigate the established mining industry that extracts basaltic rocks for construction from the Paraná Basin, Sao Paulo State, Brazil. Through a Life Cycle Assessment, [the authors] determine the balance of carbon dioxide emissions involved in the use of this material, the relative contribution of soil carbonation and enhanced weathering, and the potential carbon dioxide removal of Sao Paulo agricultural land through enhanced weathering of basalt rock. [The authors'] results show that enhanced weathering and carbonation respectively emit around 75 and 135 kg carbon dioxide equivalent per tonne of carbon dioxide equivalent removed (considering a quarry to field distance of 65 km). [The authors] underline transportation as the principal process negatively affecting the practice and uncover a limiting road travel distance from the quarry to the field of 540 ± 65 km for carbonation and 990 ± 116 km for enhanced weathering, above which the emissions offset the potential capture. Regarding Sao Paulo State, the application of crushed basalt at 1 t/ha to all of the State's 12 million hectares of agricultural land could capture around 1.3 to 2.4 Mt carbon dioxide equivalent through carbonation and enhanced weathering, respectively. This study suggests a lower sequestration estimate than previous studies and emphasizes the need to consider all process stages through a Life Cycle Assessment methodology, to provide more reliable estimates of the sequestration potential of greenhouse gas removal technologies." **David Lefebvre, Pietro Goglio, Adrian Williams, David A.C. Manning, Antonio Carlos de Azevedo, Magda Bergmann, Jeroen Meersmans, and Pete Smith,** *Journal of Cleaner Production*. (Subscription may be required.)

JULY 2021

Developing and validating pressure management and plume control strategies.

The following is from the abstract of this DOE/NETL publication: "The U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) plays a key role in advancing transformative and innovative Carbon Capture Utilization and Storage (CCUS) technologies. In its efforts to ensure safe and secure storage of carbon dioxide (CO_2) in a variety of geologic depositional environments, FE is investing in the development of systems for reservoir pressure management in terms of optimizing storage safety and performance. DOE supports a unique set of projects that are exploring brine extraction strategies as an approach to manage reservoir pressure and storage efficiency for CO_2 storage sites that may call for such measures. These Brine Extraction Storage Test (BEST) projects have followed a two-phased research approach. Five Phase I projects (completed) carried out modeling and other analyses to support development of pressure management strategies for potential field projects, focusing on five areas/formations representing important potential geologic storage opportunities in the United States. The modeling studies showed how the reservoir characteristics of the various potential storage formations would impact pressure reduction achieved for various injection/extraction scenarios. Life cycle analysis (LCA) studies performed by the projects highlighted the likelihood of encountering very high total dissolved solids (TDS) brines in many saline formation storage projects, as well as the challenges of handling these brines. Two projects have advanced to Phase II (ongoing) to validate brine extraction strategies through injection/extraction of brine and monitoring of differential pressures at active wastewater disposal facilities. Both Phase II projects also host facilities for testing emerging enhanced water recovery (EWR) technologies." **Andrea McNemar, Larry Myer, Darin Damiani, Mark McKoy, and Grant Bromhal,** *Proceedings of the 15th Greenhouse Gas Control Technologies Conference.*

Putting a Price on Carbon: Evaluating A Carbon Price and Complementary Policies for a 1.5° World.

The following is from the Executive Summary of this World Resources Institute report: "The increasing effects of climate change highlight the need to rapidly transform the global economy to achieve the Paris Agreement goals and limit global warming this century to well below 2°C, while aiming for 1.5°C. Deeply decarbonizing the U.S. energy system by 2050 will require rapidly increasing energy efficiency, decarbonizing electricity supply, and electrifying energy end uses, including buildings, transportation, and industry. A carbon price is needed to incorporate climate change costs into economic decision-making to significantly reduce U.S. greenhouse gas emissions, particularly in the electricity sector; however, a price is not a silver bullet for addressing climate change. Policies and programs that address externalities other than the cost of climate change and that provide incentives to develop and deploy long lead time mitigation options are needed in addition to a price on carbon so that deep emission reductions can be achieved in the longer term. Measures are needed to bend the cost curve and remove the market barriers that hinder long-term emission reductions. Such measures should be evaluated based on their ability to minimize the cost of achieving long-term emission targets rather than on their cost in achieving near-term emission reductions."

Does CCS reduce power generation flexibility? A dynamic study of combined cycles with post-combustion CO_2 capture.

The following is from the abstract of this article: "To date, the deployment, integration, and utilization of intermittent renewable energy sources, such as wind and solar power, in the global energy system has been the cornerstone of efforts to combat climate change. At the same time, it is recognized that renewable power represents only one element of the portfolio of technologies that will be required to deliver a technically feasible and financially viable energy system. In this context, carbon capture and storage (CCS) is understood to play a uniquely important role, providing significant value through flexible operation. It is therefore of vital importance that CCS technology can operate synergistically with intermittent renewable power sources, and consequently ensuring that CCS does not inhibit the flexible and dispatchable nature of thermal power plants. This work analyses the intrinsic dynamic performance of the power and CO_2 capture plants independently and as an integrated system. Since the power plant represents the fast dynamics of the system and the steam extraction is the main point of integration between the CO_2 capture and power plants, disturbances with fast dynamics are imposed on the steam extraction valve during steady state and dynamic operation of a natural gas combined cycle (NGCC) to study the effects of the integration on power generation capacity. The results demonstrate that the integration of liquid-absorbent based post-combustion CO_2 capture has negligible impact on the power generation dynamics of the NGCC." **Jairo Rúa, Mai Bui, Lars O. Nord, and Niall Mac Dowell,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Deploying gas power with CCS: The role of operational flexibility, merit order and the future energy system.

The following is the abstract of this article: "Combined cycle gas turbine (CCGT) power plants are an important part of many electricity systems. By fitting them with carbon capture their CO_2 emissions could be virtually eliminated. [The authors] evaluate CCGT plants with different variations of post combustion capture using amine solvents, covering a range of options, including solvent storage, partial capture and shifting the energy penalty in time. The analysis is based on the UK electricity system in 2025. The behaviour of individual CCGT plants is governed by the plant's place in the merit order and to a lesser extent by CO_2 reduction targets for the electricity system. In the UK, CCGT plants built from 2016 onwards will emit ~90% of the CO_2 emissions of the whole CCGT fleet in 2025. The typical 'base case' CCGT plant with capture is designed to capture 90% of the CO_2 emissions and to operate dynamically with the power plant. Downsizing the capture facility could be attractive for low-merit plants, i.e. plants with high short-run marginal costs. Solvent storage enables electricity generation to be decoupled in time from the energy penalty associated with carbon capture. Beyond a few minutes of solvent storage, substantial tanks would be needed. If solvent storage is to play an important role, it will require definitions of 'capture ready' to be expanded to ensure sufficient land is available." **Matthias A. Schnellmann, Chi Kong Chyong, David M. Reiner, and Stuart A. Scott,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Is aquatic bioenergy with carbon capture and storage a sustainable negative emission technology? Insights from a spatially explicit environmental life-cycle assessment.

The following is from the abstract of this article: "It is anticipated that achievement of the Paris Climate Agreement goals will require widespread deployment of negative emission technologies (NETs). The most prominent NET is bioenergy with carbon capture and storage (BECCS), which is typically envisioned to use terrestrial crops as feedstock. Several recent studies have focused on aquatic BECCS (A-BECCS), making use of microalgae or macroalgae as feedstock, as possible means of reducing water and land use. However, the high logistical complexity of the A-BECCS supply chain makes it likely that regional biophysical and socio-technical factors will strongly influence its overall favorability. Therefore, this study applies life-cycle assessment (LCA) incorporating a geographic information system (GIS) framework to estimate the environmental impacts of A-BECCS over all stages of its life-cycle. Three candidate locations in the USA are evaluated based on seemingly good proximity to coastal regions and CO_2 storage; namely, East Coast, West Coast, and the Gulf of Mexico. Monte Carlo simulation is used to characterize distributions of model outputs, including energy return on investment (EROI) and net global warming potential (GWP). Results reveal that only the Gulf of Mexico configuration has any likelihood of achieving both net energy production (probability of EROI > 1 = 29%) and net CO_2 sequestration (probability of GWP < 0 = 6%), but the probability of achieving both together is very low (5%). The other two locations exhibit net positive energy production (EROI > 1), but not net negative carbon sequestration. These results call into question the feasibility of the modeled A-BECCS system as an energy-producing NET and offer insights into possible system reconfiguration. For example, anaerobic digestion offers very low EROI and creates multiple carbon-bearing waste streams, which strongly undercuts overall net CO_2 sequestration. Finally, it is observed that enhanced oil recovery (EOR) strongly contributes to net-energy production (EROI > 1) in the modeled A-BECCS system, but also strongly undercuts net CO_2 sequestration, which is arguably the main goal of any NET. This analysis showcases how geographically-explicit analysis can advance our understanding of biomass-based NETs." **A. Jasmin Melara, Udayan Singh, and Lisa M. Colosi,** *Energy Conversion and Management.* (Subscription may be required.)

Carbon storage potential of mangrove forests from Northeastern Vietnam.

The following is from the abstract of this article: "Quantifying the C storage in mangrove forests is important to understand their ecological roles in climate change mitigation. The present study aims to determine the whole ecosystem C storage and to examine factors influencing on the sedimentary C stocks in Dong Rui mangrove forests (DRM), northeastern Vietnam. The mean above- and below-ground C stock was 48.6 ± 11.7 and 554.8 ± 112.2 MgC ha–1, respectively. In which, the sediment C pool contributed >80% proportion to the C storage. The covarying C/N ratios, δ13 C and sediment compositions suggested that sedimentary OC were mainly originated from in situ productions. Results emphasized that the DRM has an important role in C sequestration and offsetting atmospheric CO_2 concentration and should be included in the climate change mitigation programs." **Nguyen Tai Tue, Nguyen Dinh Thai, and Mai Trong Nhuan,** *Regional Studies in Marine Science.* (Subscription may be required.)

Introducing BECCS through HPC to the research agenda: The case of combined heat and power in Stockholm.

The following is from the abstract of this article: "In the years since COP21 in Paris, awareness of the need for carbon sinks has grown rapidly. However, policy instruments supporting a path to this target are still lacking. Bioenergy carbon capture and storage (BECCS) may provide a way to rapidly reduce global warming. In the Nordics, much of the basic infrastructure for successful BECCS implementation is already in place. So why is not more happening? This study provides insights to barriers and policy implications in relation to successful BECCS implementation. Though implementation could support economic growth and welfare development, the cost is relatively high for individual utilities. In the deregulated competitive heating market in the case of Stockholm, cost transfer to customers is prohibited, effectively impeding implementation. Moreover, while present national or EU-based support schemes could cover investments, the operating cost is high, so other economic policy approaches are required. Lastly, this paper shows that BECCS on combined heat and power plants has a potential, but requires much more research. Thus it is suggested that negative emission technologies in energy systems are brought into research agendas such as the future of combined heat and power and urban multi energy systems." **Fabian Levihn, Linus Linde, Kåre Gustafsson, and Erik Dahlen,** *Energy Reports.* (Subscription may be required.)

AUGUST 2021

Wyoming CarbonSAFE: Advancing Commercialization of Low-Carbon Energy Technologies in Fossil-Rich Wyoming.

The following is from the abstract of this report: "Wyoming's Powder River Basin (PRB) is the most prolific coal producer and exporter in the United States and the State of Wyoming's largest oil-producing basin. In addition to being a leading energy producer, the PRB is the site of research programs whose aim is to develop and integrate low-carbon technologies into existing fossil fuel energy industries. Much of the PRB's low-carbon research is focused around Dry Fork Station (DFS), which is the newest coal-fired power station in the western US. Currently, DFS hosts five carbon capture projects, including pilot-scale capture projects that utilize different capture technologies and a full front-end engineering and design (FEED) study, a commercial CO_2 pipeline for nearby CO_2-enhanced oil recovery industry, and is also co-located with the Wyoming Integrated Test Center, which is a host facility for unconventional carbon utilization research (i.e. flue gas carbon-to-products innovations). DFS is also the host site for the Wyoming CarbonSAFE project. Wyoming CarbonSAFE, funded by the Department of Energy/National Energy Technology Laboratory, is a multi-phased program (currently in Phase II) whose core objective is developing and validating storage sites within a complex capable of storing 50 million metric tonnes of CO_2 over a 30 year project period using carbon capture, utilization and storage (CCUS). This paper will provide an overview of the project to-date, showing that CarbonSAFE goals are achievable with respect to geologic, environmental, regulatory, CO_2 source and economic conditions, and why the State of Wyoming offers one of the more favorable environments to advance the commercialization studies."

Carbon capture, utilization, and storage hub development on the Gulf Coast.

The following is from the abstract of this article: "The Gulf Coast of the United States hosts diverse power generation, refining, and petrochemical processing facilities, resulting in the nation's largest volumetric concentration of industrial CO_2 emissions, rivaled only by the Ohio River Valley. These emissions sources are concentrated in specific industrial clusters that allow combining emissions streams to achieve economies of scale. The region is currently undergoing globally significant industrial expansion and investment as a result of abundant and inexpensive regional unconventional natural gas availability, and is a growing exporter of liquefied natural gas (LNG). Opportunities to integrate CO_2 emission management within the diverse energy chains in the region are volumetrically significant and include both concentrated and dilute sources. Significant examples of capture, transport, and storage exist. Offshore storage is particularly attractive, as it provides simplified land leasing models (single governmental land owner), proven reservoir quality, and presents fewer risks to both protected groundwater and populated areas. Projects can now take advantage of recently expanded opportunities under section 45Q of the Internal Revenue Service tax code. The region continues to evolve as an active carbon-handling hub, and is uniquely suited to justify additional investment in carbon capture, utilization, and storage (CCUS) technologies via a large-scale integrated project development. Continued development of integrated projects will allow the region to continue to grow economically within its strong fossil-fuel handling competence focus while advancing low-carbon energy technologies that maintain globally competitiveness." **T.A. Meckel, A.P. Bump, S.D. Hovorka, and R.H. Trevino,** *Greenhouse Gases: Science and Technology.* (Subscription may be required.)

Energy storage system based on transcritical CO_2 cycles and geological storage.

The following is from the abstract of this article: "The use of CO_2 as a working fluid in power generation and storage applications has experienced a significant boost in recent years, based on its high-performance characteristics in power generation or heat pumps. This work proposes a novel combined use of transcritical CO_2 cycles as an energy storage system and carbon dioxide storage inside geological formations. In this work, the layouts for concept integration were developed. They were adapted to operate under different scenarios and operation modes based on storing energy from renewable sources or storing energy to capture CO_2. The preliminary results show these cycles as promising energy storage technologies, with a high potential to compete in terms of electric to electric storage efficiencies (42–56%) and costs (70–120 USD/MWh). Besides, results show that more than 1 Mton/year of CO_2 could be additionally stored with this renewable energy storage concept depending on the conditions. These results show the opportunity for the concept as an energy storage system, with special interest when combined with carbon-intensive industries as cement or chemicals." **A. Carro, R. Chacartegui, C. Ortiz, J. Carneiro, and J.A. Becerra,** *Applied Energy Engineering.* (Subscription may be required.)

An empirical analysis of the non-linear effects of natural gas, nuclear energy, renewable energy and ICT-Trade in leading CO_2 emitter countries: Policy towards CO_2 mitigation and economic sustainability.

The following is from the abstract of this article: "Achieving reliable energy supply and environment sustainability whereby mitigating CO_2 emissions and promoting sustainable development has become a global effort. Thus, the current study intends to verify the non-linear influence effects of natural gas, nuclear energy, renewable energy and information and communication technology trade on economic growth and carbon dioxide emission in ten leading CO_2 emitter countries from [2000–2016]. The panel regression, such as pooled regression, model fixed effect, random effects, robust least squares and panel causation procedures are applied for panel data appraisal. The regression analysis results mention that nuclear energy, renewable energy, and Information and communication technology (ICT-trade) stimulate economic growth, whereas environmental results illustrate that renewable energy and ICT-trade contribute to eliminating CO_2 emissions. The causality findings indicate that renewable energy consumption and ICT trade cause economic growth as well as CO_2 emissions. Therefore, policymakers should invigorate to exploit renewable energy and achieve the benefits from the significant influence of economic growth and a clean environment through the potential of green ICT-trade." **Anam Azam, Muhammad Rafiq, Muhammad Shafiqu, and Jiahai Yuan,** *Journal of Environmental Management.* (Subscription may be required.)

Evaluation of the carbon tax effects on the structure of Finnish industries: A computable general equilibrium analysis.

The following is from the abstract of this article: "Limitations and environmental effects of fossil fuels have encouraged decision-makers to create and implement different energy policies, in which carbon tax is one of the most important financial policies. Governments are considering the implementation of the carbon tax to achieve lower greenhouse gas emission, higher national incomes and tax systems, deployments of renewable energy sources, and increasing the efficiency of the energy systems. Therefore, understanding the effects and consequences of the carbon tax policy on different economic, social welfare, and industries is imperative due to its impact on the costs of productions, inflation, and competitiveness of the industries. This research is to evaluate the impact of the carbon tax on the structure of the Finland industry as one of the high energy-intensive consumption countries. [The authors] use a computable general equilibrium model to create a connection between the effects of the carbon tax and economic indicators, production, and consumption sector. In this research, the effect of the carbon tax on the macro-economic and industry sector is studied. The results of this research indicate that the application of carbon tax policies leads to adverse effects on gross domestic production (GDP). By studying the fluctuations of the trade balance, export and import level, production price, and energy consumption level in the industry sector, considerable results have been achieved. For instance, considering the specific coverage of industries in Finland, they have higher competitiveness in general." **Mojtaba Khastar, Alireza Aslani, Mehdi Nejati, Kaveh Bekhrad, and Marja Naaranoja,** *Sustainable Energy Technologies and Assessments*. (Subscription may be required.)

Authority–enterprise equilibrium based mixed subsidy mechanism for carbon reduction and energy utilization in the coalbed methane industry.

The following is from the Abstract of this article: "As coalbed methane, the natural gas adsorbed in coal seams, is a greenhouse gas that is 21 times stronger than CO_2, coalbed methane extraction significantly influences carbon reduction and energy conservation efforts. While the injection of CO_2 into coal seams is known to effectively enhance coalbed methane recovery, this process has been limited because of high investment and production costs. Therefore, to promote the application of CO_2 injection techniques in coalbed methane industry, this paper proposes an authority–enterprise equilibrium based mixed subsidy mechanism which combines direct subsidies with indirect tax-incentives. Specifically, a multi-objective bi-level programming model is established under uncertainty to assign a practical constraint and achieve a trade-off between the local authority and the coalbed methane plants. A practical case validates the feasibility and efficiency of the proposed method, proving that an authority–enterprise equilibrium based mixed subsidy mechanism is able to achieve carbon emissions reductions and conserve energy. Further analysis indicated that the marginal energy efficiency gains were greater than the authority costs under a strict energy utilization policy and that the environmental protection target had larger impacts on the coalbed methane plant performances." **Lurong Fan and Jiuping Xu,** *Energy Policy*. (Subscription may be required.)

Criteria for selecting sites for integrated CO_2 storage and geothermal energy recovery.

The following is from the abstract of this article: "One of the currently considered methods of reducing carbon dioxide emissions is the simultaneous storage of carbon dioxide (CCS) and production of geothermal energy accumulated in porous rocks (hydrothermal systems). The exploitation of geothermal heat and the storage of carbon dioxide are carried out in rock formations containing groundwater and lying at sufficient large depth. The selection of sites for combined heat recovery and CCS is a complex issue, conditioned by many different criteria […] The paper proposes the criteria for selecting geological structures in aquifer for the simultaneous recovery of geothermal energy and the storage of carbon dioxide (main goal). A set of 12 geological criteria was developed for this purpose. Based on the Analytical Hierarchy Process method, the importance of individual criteria was assessed. This assessment was made by pairwise comparison based on expert opinion of 10 decision makers. On this basis, the influence of individual factors on the main goal is estimated and an analysis of the order of occurrence of individual criteria in the aggregated ranking is made." **Barbara Uliasz-Misiak, Joanna Lewandowska-Śmierzchalska, and Rafał Matuła,** *Journal of Cleaner Production*. (Subscription may be required.)

Passive acoustic monitoring of a natural CO_2 seep site – Implications for carbon capture and storage.

The following is from the abstract of this article: "Estimating the range at which an acoustic receiver can detect greenhouse gas (e.g., CO_2) leakage from the sub-seabed is essential for determining whether passive acoustic techniques can be an effective environmental monitoring tool above marine carbon storage sites. Here [the authors] report results from a shallow water experiment completed offshore the island of Panarea, Sicily, at a natural CO_2 vent site, where the ability of passive acoustics to detect and quantify gas flux was determined at different distances. Cross-correlation methods determined the time of arrival for different travel paths which were confirmed by acoustic modelling. [The authors] develop an approach to quantify vent bubble size and gas flux. Inversion of the acoustic data was completed using the modelled impulse response to provide equivalent propagation ranges rather than physical ranges. The results show that [the authors'] approach is capable of detecting a CO_2 bubble plume with a gas flux rate of 2.3 L/min at ranges of up to 8 m, and determining gas flux and bubble size accurately at ranges of up to 4 m in shallow water, where the bubble sound pressure is 10 dB above that of the ambient noise." **Jianghui Li, Ben Roche, Jonathan M. Bull, Paul R. White, John W. Davis, Michele Deponte, Emiliano Gordini, and Diego Cotterle,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Development and surrogate-based calibration of a CO_2 reservoir model.

The following is from the abstract of this article: "Simulation-optimization framework is a widely used approach for numerical model calibrations, though its primary difficulty is its high-demand of computational efforts. In this study, Bagging MARS (BMARS) adapted from Multivariate Adaptive Regression Splines (MARS) algorithm, is used to construct the surrogate of a three-dimensional CO_2 reservoir model, which is developed to simulate CO_2 injection and migration in a fault-compartmentalized underground reservoir. The BMARS surrogate model is then used in model calibration to estimate specified reservoir model input parameters efficiently. The results demonstrate that the BMARS model can improve fitting stability and predictive accuracy against the ordinary MARS model. Parameter sensitivity analysis, which is efficiently conducted using the BMARS model, suggest that permeability of Fault#10 and caprock dominate the pressure buildup in this fault-compartmentalized reservoir. Hence priority should be given to investment in estimating these two reservoir properties. Overpressure propagation and CO_2 migration in the reservoir responding to three years of CO_2 injection are also analyzed using the calibrated model. The calibrated water-CO_2 flow model could be a useful tool to evaluate the future operation and risk assessment of the reservoir. The results comparison and sensitivity analysis demonstrated the proposed BMARS-based simulation–optimization framework is an efficient and accurate model calibration approach." **Mingjie Chen, Osman A. Abdalla, Azizallah Izady, Mohammad Reza Nikoo, and Ali Al-Maktoumi,** *Journal of Hydrology*. (Subscription may be required.)

SEPTEMBER 2021

Supply Chain Excellence for CCUS.

The following is from the Executive Summary of this Carbon Capture and Storage Association (CCSA) document: "The CCSA estimates that expenditure on Net Zero CCUS (including hydrogen and greenhouse gas removals) projects could reach c.£41bn by 2035. Investment and ongoing expenditure of this size will deliver a huge boost to the economies of the industrial clusters on which most of these projects will be built. This report demonstrates that not only will CCUS be vital for achieving the UK's Net Zero goal, but also the significant role CCUS will play in boosting the UK's prosperity and delivering the government's levelling-up agenda by supporting jobs and growth in the UK's industrial heartlands. [The authors] set out recommendations to maximise this impact by developing supply chain strategies to deliver long-term benefit to the UK and its domestic projects, and to ramp up the export opportunities created though international deployment of CCUS. A successful Net Zero rollout will involve intensive project work all the way through to 2050 – a long-term prospect for industry. Current onshore major energy projects in the UK are themselves targeting a 50–60% UK content and offshore projects in the North Sea are targeting a 30% UK technology spend. If these levels of UK content persist, half of the estimated project expenditure could be spent outside the UK. A focused and effective approach to supporting UK supply chains could displace imports and capture a larger portion of the growth opportunity, providing domestic jobs and business, as well as securing export opportunities for the UK as other countries seek to develop CCUS."

Engineered greenhouse gas removals.

The following is from the Executive Summary of this UK National Infrastructure Commission document: "Engineered greenhouse gas removals capture carbon dioxide directly from the atmosphere and permanently store it. They will become a major new infrastructure sector for the UK over the coming decades, helping the UK meet its climate targets in the 2030s and beyond by offsetting residual emissions. Government needs to make a clear commitment to deploy engineered removals at scale no later than 2030. In total this commitment to the first engineered removals plants should deliver 5-10 $MtCO_2e$ of removals a year no later than 2030. The biggest barrier to deploying engineered removals is a lack of demand for negative emissions. There are currently no obligations on some of the UK's most carbon intensive industries to reduce their emissions. Government has set ambitious targets to reduce the UK's emissions to net zero. Given some sectors are hard to abate fully, this will not be possible without engineered removals. Engineered removals are expensive, although the costs will be phased in over time. By 2030, revenues of around £2 billion per year could be required to support a sector capable of delivering the necessary engineered removals. Polluting industries, not taxpayers, should bear these costs. But government should support the initial deployment of a portfolio of engineered removals, and, in time, the transition to a competitive market, which will be the most efficient solution. This new sector will need to be independently monitored to provide confidence to the public and investors. Government, regulators and infrastructure operators will need to plan for the enabling infrastructure, including carbon transport and storage networks. All this needs to happen alongside, not instead of, action to reduce and prevent emissions."

Improving the Business Case for CCS in the Electric Power Generation Industry.

The following is from the abstract of this paper: "Supporting new, high impact energy and environmentally friendly initiatives has been a regular and important component of US tax policy. A production tax credit (PTC) of up to 2.3 cents per kWh (now reduced) was available for electricity generated by wind. Solar photovoltaic projects receive a 30% investment tax credit (ITC). These tax credits, along with state-level renewable performance standards, have significantly increased investments in renewables and supported their growth in the electricity generation sector. A similar opportunity now exists for supporting accelerated installation of large-scale Carbon Capture and Storage (CCS) in the US electric power generation industry. Section 45Q of the US tax code represents a first, but still insufficient, step for covering the costs of using CCS with electric power generation. It provides a $50 per metric ton (mt) tax credit for captured CO_2 stored in geological formations and a $35 per mt tax credit for captured CO_2 used and stored with enhanced oil recovery. However, the 45Q tax credits contain limitations, including-- a rapidly approaching "commence construction" deadline, limited years for claiming the tax credit, a tax credit level insufficient for economically viable installation of CCS by natural gas-fueled power plants, and little support for first-of-a-kind (FOAK), higher CO_2 capture rate facilities. In a previous paper (Esposito, et al., 2019), the authors illustrated the basic arithmetic for assessing the economic viability of CCS in the electric power generation industry with availability of the Section 45Q tax credits, including an extensive look at the business case for installing CCS by coal-fueled power plants. This paper discusses a series of modifications to the Section 45Q tax credit, as well as additional steps, that would improve the business case for installing CCS on natural gas-fueled power plants." **Richard Esposito, Vello Kuuskraa, Charles Rossmann, and Michele M. Corser,** *Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021.* (Subscription may be required.)

A Computationally Efficient Method for Field-Scale Reservoir Simulation of CCS in Basalt Formations.

The following is from the abstract of this paper: "Unlike sedimentary formations, flood basalts have the potential for relatively rapid mineral trapping when used as an injection target for CO_2 storage. While CO_2 storage in basalt and its underlying geochemistry have been studied in various ways, including two successful small-scale pilot projects, there are still open questions surrounding the viability of large-scale CO_2 storage in basalt, including how the properties of the target formation will be altered after decades of geochemical activity. Field-scale numerical models can play a part in answering these questions. In this work, [the authors] present an overview and initial results of [their] recent development of a flexible, computationally efficient reactive transport model for CO_2 mineral trapping in basalt. The model combines a fully customizable geochemistry solver with a vertically integrated description of two-phase flow in porous media. It provides a platform for extensive field-scale numerical modeling studies of large-scale CO_2 storage in basalt, which in turn can help address some of the current barriers to its implementation in the field." **Tom Postma, Karl W. Bandilla, and Michael Celia,** *Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021.* (Subscription may be required.)

Storage Readiness Levels: communicating the maturity of site technical understanding, permitting and planning needed for storage operations using CO_2.

The following is from the abstract of this article: "A framework of Storage Readiness Levels (SRLs) is presented to communicate the entirety of technical appraisal, permitting and planning activities achieved at a potential CO_2 storage site and what remains to be completed for CO_2 storage operations. The schema, based on learning gained from the experience of researchers, regulators and industry from the 1990s, is described and assessed by application to 742 saline formation and hydrocarbon field sites, offshore the UK, Norway and The Netherlands. The framework is flexible to accommodate national differences in procedures and practise and the unique character of each site. It is applicable regardless of the time-scale of appraisal or scale of assessment. The framework is consistent with and extends the industry commercial project development classification to include categories for sites with a lesser level of data and evaluation. Application to the phases of appraisal of three sites illustrates that investigations may advance understanding by different pathways and rates. The standardised framework enables comparison of the experience of permitting and planning activities completed within different jurisdictions, the level of investment and the duration required to achieve permitted or permit-ready sites. It is intended that the framework of SRLs should be widely applied." **Maxine Akhurst, Karen Kirk, Filip Neele, Alv-Arne Grimstad, Michelle Bentham, and Per Bergmo,** *International Journal of Greenhouse Gas Control.* (Subscription may be required.)

Multiscale design and analysis of CO_2 networks.

The following is from the abstract of this article: "Carbon Capture and Storage (CCS) is an essential technology for CO_2 emissions reductions, which will allow us to continue consuming fossil fuels in the short to medium term. In this work, [the authors] developed a multiscale modeling and optimization approach that links detailed models of the capture plant, compression train and pipelines with the CO_2 supply-chain network model. This was used to find the cost-optimal CO_2 network considering a case-study of meeting a national reduction target in the United Arab Emirates that supplies CO_2 for EOR activities. The main decision variables were the optimal location and operating conditions of each CO_2 capture and compression plant in addition to the topology and sizing of the pipelines while considering the whole-system behaviour. A key result of [the authors'] study was that the cost-optimal degree of capture should be included as a degree of freedom in the design of CO_2 networks and it is a function of several site-specific factors, including exhaust gas characteristics, proximity to transportation networks and adequate geological storage capacity. This conclusion serves to underscore the need to comprehend the science governing the physical behaviour at different scales and the importance of a whole-system analysis of potential CO_2 networks." **Ahmed Alhajaj and Nilay Shah,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Storage of hydrogen, natural gas, and carbon dioxide – Geological and legal conditions.

The following is from the abstract of this article: "The analysis of geological and reservoir conditions of the underground storage of hydrogen, methane, and carbon dioxide, that are important when choosing rock formations for the storage of gas, was presented. Physico-chemical properties of the discussed gases, affecting underground storage, were taken into account. Aquifers, hydrocarbon reservoirs, and caverns leached in salt rocks were analyzed. Legal aspects of underground gas storage were indicated. The physico-chemical conditions of the gases considered (especially molecular mass, and dynamic viscosity) are important for the selection of geological structures for their storage. The reservoir tightness is one of the most important geological and reservoir conditions when taking the appropriate porosity and permeability of rocks building underground storage sites into account. Salt caverns should be mainly used for hydrogen storage due to the tightness of rock salt. Geochemical and microbiological interactions affecting the operation of the underground storage site and its tightness are especially important and should be taken into account. The size of the underground storage site, while not as crucial in the case of H_2 storage, is important for CO_2 storage. When it comes to reservoir conditions, the amount of cushion gas and storage efficiency are important. The legal status of gas storage sites is highly variable. While there are existing regulations regarding natural gas storage, CO_2 storage requires further legislation. In the case of H_2 storage legal regulations need to be developed based on the experience of storage of other gases. The potential competition from other entities focused on the use of underground space for gas storage should be taken into account." **Radosław Tarkowski, Barbara Uliasz-Misiak, and Piotr Tarkowski,** *International Journal of Hydrogen Energy*. (Subscription may be required.)

Assessing the influence of injection temperature on CO_2 storage efficiency and capacity in the sloping formation with fault.

The following is from the abstract of this article: "Complex factors can affect carbon dioxide (CO_2) geological storage efficiency and capacity. In this paper, a three-dimensional (3D) conceptual model of the Shiqianfeng formation in the Ordos basin was established (a total of 16 sets of schemes) to study the influence of injection temperature on CO_2 storage efficiency and migration safety in the sloping formation with a fault. In addition, storage capacity is investigated for CO_2 storage site selection. The results show that injection temperature and formation slope have a significant effect on CO_2 storage efficiency. Faulting provides a possible channel for CO_2 leakage. High injection temperature is more likely to cause CO_2 leakage in the sloping formation. When the injection temperatures are 11, 31.5, 51 and 71 °C in the 15° slope formation, the time points of CO_2 leakage are 200, 170, 150 and 140 years, respectively. The lower injection temperature results in a higher CO_2 concentration near the injection well and a closer migration distance of dissolved CO_2. The larger the formation slope is, the farther the dissolved CO_2 migration distance will be. The higher injection temperature results in a greater gas phase, dissolved phase, and total CO_2 storage amount in the whole formation. The larger the formation slope is, the smaller the CO_2 storage capacity will be for CO_2 injected over 20 years. However, the larger formation slope resulted in a smaller gas phase and larger storage amount of the dissolved phase CO_2 for CO_2 migration after 140 years. The influence of the formation slope on the dissolved CO_2 migration safety is more obvious than that of injection temperature. However, the influence of the injection temperature on CO_2 storage capacity is more obvious than that of the formation slope." **Jing Jing, Yanlin Yang, and Zhonghua Tang,** *Energy*. (Subscription may be required.)

Efficient marine environmental characterisation to support monitoring of geological CO_2 storage.

The following is from the abstract of this article: "Carbon capture and storage is key for mitigating greenhouse gas emissions, and offshore geological formations provide vast CO_2 storage potential. Monitoring of sub-seabed CO_2 storage sites requires that anomalies signifying a loss of containment be detected, and if attributed to storage, quantified and their impact assessed. However, monitoring at or above the seabed is only useful if one can reliably differentiate abnormal signals from natural variability. Baseline acquisition is the default option for describing the natural state, however we argue that a comprehensive baseline assessment is likely expensive and time-bound, given the multi-decadal nature of CCS operations and the dynamic heterogeneity of the marine environment. [The authors] present an outline of the elements comprising an efficient marine environmental baseline to support offshore monitoring. [The authors] demonstrate that many of these elements can be derived from pre-existing and ongoing sources, not necessarily related to CCS project development. [The authors] argue that a sufficient baseline can be achieved by identifying key emergent properties of the system rather than assembling an extensive description of the physical, chemical and biological states. Further, that contemporary comparisons between impacted and non-impacted sites are likely to be as valuable as before and after comparisons. However, as these emergent properties may be nuanced between sites and seasons and comparative studies need to be validated by the careful choice of reference site, a site-specific understanding of the scales of heterogeneity will be an invaluable component of a baseline." **Jerry Blackford, Katherine Romanak, Veerle A.I. Huvenne, Anna Lichtschlag, James Asa Strong, Guttorm Alendal, Sigrid Eskeland Schütz, Anna Oleynik, and Dorothy J. Dankel,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Modeling trade-offs across carbon sequestration, biodiversity conservation, and equity in the distribution of global REDD+ funds.

The following is from the abstract of this article: "The program on Reducing Emissions from Deforestation and Forest Degradation (REDD+) is one of the major attempts to tackle climate change mitigation in developing countries. REDD+ seeks to provide result-based incentives to promote emission reductions and increase carbon sinks in forest land while promoting other cobenefits, such as the conservation of biodiversity. [The authors] model different scenarios of international REDD+ funds distribution toward potential recipient countries using 2 carbon emission reduction targets (20% and 50% compared to the baseline scenario, i.e., deforestation and forest degradation without REDD+) by 2030. The model combines the prioritization of environmental outcomes in terms of carbon sequestration and biodiversity conservation and social equity, accounting for the equitable distribution of international REDD+ funds. Results highlight the synergy between carbon sequestration and biodiversity conservation under alternative fund allocation criteria, especially for scenarios of low carbon emission reduction. Trade-offs increase when distributional equity is considered as an additional criterion, especially under higher equity requirements. The analysis helps to better understand the inherent trade-offs between enhancing distributional equity and meeting environmental targets under alternative REDD+ fund allocation options." **Ignacio Palomo, Yann Dujardin, Estelle Midler, Manon Robin, María J. Sanz, and Unai Pascual,** *Proceedings of the National Academy of Sciences of the United States of America*. (Subscription may be required.

Effects of Temporal Variation in Long-Term Cultivation on Organic Carbon Sequestration in Calcareous Soils: Nile Delta, Egypt.

The following is from the abstract of this article: "Soil carbon sequestration is a riskier long-term strategy for climate mitigation than direct emissions reduction, but it plays a main role in closing carbon emission gaps. Effects of long-term cultivation on soil carbon sequestration were studied at the western edge of the Nile Delta near Alexandria, Egypt. Seven agricultural fields of different ages (0–50 years in use) were selected and compared with the surrounding desert (virgin soil) and desert shrub-land. Samples were taken at three horizons, 0–30, 30–60, and 60–90 cm, and tested for differences in physical and chemical properties. The results of long-term cultivation reveal that the European Commission (EC) value was 11.77 dS/m in virgin soil, while the EC values decreased to 5.82, 4.23, 3.74, 2.40, and 2.26 dS/m after 5, 10, 20, 30, and 50 years of cultivation, respectively. The calcareous rock fraction smaller than 50 µm in size revealed another phenomenon, where active calcium carbonate content increased with cultivation practices from 1.15% (virgin soil) to 5.42%, 6.47%, 8.38%, and 10.13% after 5, 10, 20, and 30 years of cultivation, respectively, while shrub-land also showed a low amount of active CaCO3 with 1.38%. In fifty years of cultivation, soil bulk density decreased significantly from 1.67 to 1.11 g/cm3, and it decreased to 1.65, 1.44, 1.40, and 1.25 g/cm3 after 5, 10, 20, and 30 years, respectively. These results reveal that the increase in soil carbon stock in the upper 90 cm amounted to 41.02 t C/ha after five years of cultivation, compared to virgin soil with 13.47 t C/ha. Soil carbon levels increased steeply during the five years of cultivation, with an average rate of 8.20 t C/ha per year in the upper 90 cm. After the first five years of cultivation, the carbon sequestration rate slowed, reaching 4.68, 3.77, 2.58, and 1.93 t C/ha per year after 10, 20, 30, and 50 years, respectively, resulting in sequestration-potential values of 46.78, 75.63, 77.43, and 96.45 t C/ha. These results indicate that potential soil carbon sequestration resembles a logarithmic curve until the equilibrium state between carbon application and decomposition by microorganisms is reached." **Manal Alnaimy, Martina Zelenakova, Zuzana Vranayova, and Mohamed Abu-Hashim,** *Sustainability.* (Subscription may be required.)

ANNOUNCEMENTS

OCTOBER 2020

Wyoming Granted Primacy to Regulate CO_2 Storage Wells.

The U.S. Environmental Protection Agency (EPA) granted the Wyoming Department of Environmental Quality primacy to monitor underground injection wells used to store carbon dioxide (CO_2). In addition, Wyoming state regulators will have the authority to craft and enforce regulations to protect drinking water sources during construction and use of the wells, as required under the *Safe Drinking Water Act*. Wyoming joins North Dakota as U.S. states permitted to implement their own regulations on *Class VI injection wells*.

DOE/NETL Launches Carbon Capture Newsletter.

DOE/NETL announced the launch of a Carbon Capture Newsletter. The monthly newsletter provides information on recent activities and publications related to carbon capture and *NETL's Carbon Capture Program*. Sections include Interagency News and Updates, Upcoming U.S. and International Conferences, Business and Industry News, and Publications. *Click here for subscription information.*

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.

NETL Releases ROZ Appraisals Featuring FE/NETL Onshore CO_2-EOR Cost Model.

NETL released CO_2-enhanced oil recovery (EOR) appraisal reports for two regions of the San Andres residual oil zone (ROZ) fairway in the Permian Basin (USA). The two reports (*An Eight-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin* and *A Four-County Appraisal of the San Andres Residual Oil Zone (ROZ) "Fairway" of the Permian Basin*) use reservoir simulator outputs and economic viability considerations to estimate the oil that can be produced and the CO_2 that can be stored in these fairway regions. The FE/NETL CO_2 Prophet Model and the *FE/NETL Onshore CO_2-EOR Cost Model* were used to determine results of these studies. The reports, cost model, and other relevant documents can be found on NETL's *Search Energy Analysis* website by searching under the Collection Names "Eight-County San Andres ROZ Appraisal," "Four-County San Andres ROZ Appraisal," and "FE/NETL Onshore CO_2-EOR Cost Model."

NETL Releases Offshore Oil Field Case Studies.

NETL released three case studies on offshore CO_2-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."

DOE Invests in Carbon Capture Technologies.

DOE announced federal funding to support the development and advancement of CO_2 capture technologies under two Funding Opportunity Announcements (FOAs). The funding will support nine projects for coal and natural gas power and industrial sources and 18 projects that remove CO_2 through direct air capture (DAC) technology. Descriptions of the projects are *available on the NETL website*.

NETL Releases 2020 Compendium of Carbon Capture Technology.

NETL's 2020 Compendium of Carbon Capture Technology, which is now *available on the NETL website*, provides stakeholders with a summary of NETL's Carbon Capture Program. The document contains CO_2 capture technology R&D descriptions for more than 130 active and completed projects.

Field Hearing Held on CCS.

The U.S. Senate Committee on Environment and Public Works held a field hearing on carbon capture and storage (CCS) near the Dry Fork Station power plant in Wyoming, USA. The hearing was held at the *Integrated Test Center (ITC)*, a utility-scale carbon capture laboratory attached directly to a coal facility.

CCS Facility Announces Monthly Totals.

The CCS facility located at SaskPower's Boundary Dam Power Station captured more than 75,000 metric tons of CO_2 in July 2020, marking the facility's highest single month total since July 2019. More than 390,000 metric tons of CO_2 have been captured through CCS at the facility in 2020; nearly 3.48 million metric tons of CO_2 have been captured since the facility went online in 2014.

Report Reviews CO_2 Storage Regulations.

The CO_2 Capture Project published a report reviewing global CCS regulations. The "*Survey of CO_2 Storage Regulations*" report (subscription may be required to view) analyzes recent developments in CO_2 storage project regulations worldwide, emphasizing key developments, outstanding issues, and gaps that may impact the commercial success of CCS.

White Paper Outlines Case for CO_2 Storage.

The American Forest Foundation released a white paper outlining the case for how family-owned forests can store CO_2. "*Family-owned Forests: How to Unlock the Carbon Potential in America's Backyard*" details financial mechanisms that could enable family landowners to overcome cost barriers for implementing practices that would increase the health and CO_2 storage ability of their trees.

NOVEMBER 2020

DOE Announces Project Selections Under COAL FIRST Initiative.

DOE/FE selected *four projects* for cost-shared R&D through the *Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) Initiative*. DOE's early-stage research for the Coal FIRST Initiative supports the development of 21st century electricity and hydrogen energy plants that have net-zero carbon emissions. These plants will be fueled by coal, natural gas, biomass, and waste plastics and incorporate carbon capture, utilization, and storage (CCUS) technologies.

DOE/NETL 2020 Virtual Integrated Project Review Meeting Proceedings.

Proceedings from the DOE/NETL Integrated Project Review Meeting are *available on the NETL website*. The virtual integrated review meeting consisted of a series of free virtual sessions organized by DOE/NETL that featured projects from several DOE/FE portfolios, including *Carbon Capture* and *Carbon Storage*.

IEA Report Focuses on Impact of CCUS.

A report from the International Energy Agency (IEA) examines the impact of CCUS technology on reducing CO_2 emissions. The report, "*CCUS in Clean Energy Transitions*," also includes geospatial analysis of power and industrial emissions in key regions and their proximity to potential geologic storage sites.

Study Highlights CO_2 Capture, Storage Potential.

A study funded by the United Kingdom's (UK) Department for Transport found that CO_2 capture could achieve marine decarbonization at 50% of a comparable cost for zero-carbon fuels. *According the study*, vessel stability could be maintained without other modifications, and the captured CO_2 could be delivered to arrival ports in liquid form for geologic storage.

Analysis on CCS Spending in Europe.

An analysis conducted by Rystad Energy found that carbon capture and storage (CCS) technology development in Europe has reached a stage in which large-scale developments could lead to as much as 75 million metric tons of CO_2 captured and stored by 2035.

DNV GL's Energy Transition Outlook 2020.

The scaling of CCS technology has the potential to be a catalyst to decarbonize the oil and gas value chain after 2035, according to *DNV GL's Energy Transition Outlook 2020*. The report provides an independent forecast of developments in the world energy mix to 2050, and presents the demand, supply, and investment forecast to 2050. According to DNV GL's report, 13% of natural gas will be decarbonized in 2050, with 12% of world energy emissions captured through CCS technology.

DECEMBER 2020

DOE Releases Coal R&D Fact Sheets.

DOE's *Office of Clean Coal and Carbon Management* posted nine coal R&D fact sheets. The Office of Clean Coal and Carbon Management R&D efforts advance transformative science and innovative technologies that enable the reliable, efficient, affordable, and environmentally sound use of fossil fuels.

Open-Access CO_2 Storage Simulator Released.

Lawrence Livermore National Laboratory (LLNL), Total, and Stanford University released an open-source, high-performance simulator for large-scale geologic CO_2 storage. The GEOSX simulator provides researchers with an open framework to accelerate the development of carbon capture, utilization, and storage (CCUS) technologies by using field data to predict the behavior and impact of CO_2 stored in geologic sources.

CCS Project Briefing.

The Bellona Foundation released a *briefing* on Norway's Longship Carbon Capture and Storage (CCS) Project. The briefing provides an overview of the project and the stages of its CCS chain, an analysis of the financial risks and estimated project costs, and a calculation of cost per metric ton of avoided CO_2.

White Paper on Incentivizing Large-Scale CCS in Canada.

RSM Canada and the International CCS Knowledge Centre released a white paper identifying opportunities within the Canadian tax and grant systems to incentivize large-scale CCS technology. The white paper examines the economic impact related to the development of CCS projects in Canada and recommends policy options for Canadian incentive scenarios.

Companies to Partner on CCUS R&D.

ADNOC and Total signed a strategic framework agreement to explore joint research, development, and deployment partnership opportunities in the areas of CO_2 emissions reduction and CCUS. In the area of CCUS, the companies will further develop joint research into new technologies covering CCS solutions and EOR projects based on CO_2 usage.

JANUARY 2021

NETL Explores Expanded Use for CO_2-EOR.

A project utilizing National Energy Technology Laboratory (NETL) expertise in CO_2-enhanced oil recovery (EOR) is underway in southern Michigan (USA). *The project* aims to access significant resources in the Trenton/Black River play by injecting CO_2 in the subsurface to improve the flow of oil to production wells. The goals of the project are to help the United States maintain its energy independence and economically use captured CO_2 while reducing emissions and maximizing the lifetime utility of existing infrastructure and wells in mature fields.

NETL-Funded Project Supports Carbon Utilization Program.

More than 1,200 hours of field testing was completed at the *Wyoming Integrated Test Center*. The demonstration of a process to create concrete blocks using CO_2 from power plant flue gas support DOE's *Carbon Utilization Program*.

DOE Released Hydrogen Program Plan.

DOE released its *Hydrogen Program Plan* to provide a strategic framework for its hydrogen research, development, and demonstration activities. The plan involves participation from FE, as well as the DOE Offices of Energy Efficiency and Renewable Energy, Nuclear Energy, Electricity, Science, and the Advanced Research Projects Agency–Energy.

DOE Announces Selections for FOA.

DOE/FE selected 14 projects to receive federal funding for cost-shared R&D to help foster new uses for domestic coal resources. The projects will be managed by NETL and support the *Advanced Coal Processing Technologies Program*, which focuses on improving coal feedstock, producing high-value products from coal, and alternative technologies to produce high-performance carbon material from coal.

CCUS Stakeholder Workshops Held.

STRATEGY CCUS—a European Union funded project—conducted workshops to support the development and deployment of carbon capture, utilization, and storage (CCUS) in Southern and Eastern Europe. Participants included local and national government officials, community representatives, industry members, CCUS project developers and researchers, environmental groups, and support organizations.

Report on Global Status of CCS.

The *Global Status of CCS Report 2020* (purchase may be required) demonstrates the role carbon capture and storage (CCS) technologies can play in reducing emissions to net-zero by 2050. In addition, the Global CCS Institute report also documents the current status of CCS technology, as well as the milestones it has achieved in 2020.

FEBRUARY 2021

DOE Announces FOA in Support of CO_2 Utilization.

DOE/FE will make available federal funding for cost-shared research, development, and testing of technologies that can utilize CO_2 from power systems for bio-mediated uptake by algal systems to create valuable products and services. *The FOA*, which supports DOE's *Carbon Utilization Program*, will seek applications that aim to perform engineering-scale testing and validation of algae-based technologies and bioproducts. Responses are due March 2, 2021.

DOE Announces Funding to Help Decarbonize Energy and Commodity Production.

DOE/FE announced that federal funding is available for cost-shared R&D to help recalibrate the nation's fossil fuel and power infrastructure for decarbonized energy and commodity production. The funding is aimed at developing technologies for the production, transport, storage, and utilization of fossil-based hydrogen, with progress toward net-zero emissions. Projects selected under the *FOA* will be managed by NETL. Responses are due March 1, 2021.

RGGI Secondary Market Report Made Available.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report 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 2020" addresses the period from July through September 2020. The report is part of Potomac's ongoing monitoring of the RGGI auctions and secondary markets.

Industry Research Report on CO_2-EOR Market Released.

A research report on the global CO_2-enhanced oil recovery (EOR) market was released by a research and consulting services company. The report offers qualitative and quantifiable information on factors affecting or influencing market dynamics and market growth, including sections on global CO_2-EOR market growth drivers, market trends, and market opportunities. (Purchase may be required.)

Report Outlines Potential Approaches to Reduce CO_2 Emissions.

University of Colorado's (Boulder) Renewable and Sustainable Energy Institute (USA) released a report outlining steps the United States can take to reduce CO_2 emissions. "Accelerating the U.S. Clean Energy Transition: Challenges and Solutions by Sector" describes low- and zero-carbon solutions across a variety of sectors, laying out policy options for each. The report also provides an overview of technologies that have the potential to reduce CO_2 levels.

MARCH 2021

NETL-Supported Project to be Field-Tested.

An NETL-supported project to develop a transformational CO_2 capture technology will be field-tested at Norway's Technology Centre Mongstad (TCM). The Non-Aqueous Solvent technology is being developed by RTI International with support from DOE's Office of Fossil Energy (FE) and NETL.

DOE Announces Funding for Clean Energy Research.

DOE announced funding for transformative clean energy research and development (R&D) via the Advanced Research Projects Agency-Energy (ARPA-E). DOE will also participate in the National Climate Task Force's Climate Innovation Working Group, which will coordinate federal efforts to help achieve net-zero economy-wide emissions by 2050.

Report Examines CCS Potential to Address CO_2 Emissions.

Rystad Energy's monthly "Energy Transition Report" found that carbon capture and storage (CCS) technology has the potential to address approximately 62% of global CO_2 emissions. The assessment adds that direct air capture (DAC) and bioenergy carbon capture and storage (BECCS) technology will also be needed to reach this level.

Database to Support North Sea CCS Operators.

Applied Petroleum Technology compiled a new database of CO_2 properties at various pressures and temperatures for the North Sea to support operators considering offshore CO_2 storage. The database includes more than 950 data points.

CCS Project Update.

Porthos, a CCS project in Rotterdam, Netherlands, *announced* it is on schedule to store approximately 2.5 million metric tons of CO_2 per year in gas fields beneath the North Sea.

IEA to Produce Net-Zero Roadmap.

The International Energy Agency (IEA) will produce a report that details the steps governments, companies, investors, and citizens can take for the energy sector to reach net-zero emissions by 2050. "The World's Roadmap to Net Zero by 2050" is expected to be released in 2021.

APRIL 2021

MGSC Transitions to MRCI.

The Midwest Geological Sequestration Consortium (MGSC), one of DOE's Regional Carbon Sequestration Partnerships (RCSPs), has transitioned to the Midwest Regional Carbon Initiative (MRCI). Led by Battelle Memorial Institute and the Illinois State Geological Survey, MRCI aims to advance carbon capture, utilization, and storage (CCUS) research by addressing key technical challenges, obtaining and sharing data to support CCUS, facilitating regional infrastructure planning, and performing regional technology transfer. Presentations from MRCI's February 2021 virtual partners meeting are *available*.

USDA Requests Information on Climate Policy.

The U.S. Department of Agriculture (USDA) published a Federal Register Notice requesting public input on the climate-smart agriculture and forestry strategy. The Notice, which was available for public input through April 30, 2021, followed an *Executive Order*.

Report Highlights CCUS Importance.

The United Nations Economic Commission for Europe released *a report* highlighting the importance of CCUS technology for meeting carbon-reduction targets. The technology brief provides an overview of existing CCUS projects in Europe and North America and addresses the requirements and potential costs for large-scale CCUS deployment.

CO_2CRC Launches CCUS Technical Advisory and Consultancy.

CO2CRC launched CO2Tech—a technical advisory and consultancy services company. According to the CO2CRC, which specializes in CCUS research, CO2Tech will have access to the Otway International Test Centre and CO2CRC's knowledge via commercial agreements.

Tool to Measure Carbon Storage in Forests.

ICLEI—Local Governments for Sustainability developed the *Land Emissions and Removals Navigator (LEARN) Tool* to better understand and measure greenhouse gas (GHG) emissions and storage potential of forests. The LEARN Tool provides preliminary analysis on emissions and removals that may be used to inform and be integrated into nature-based solutions in climate action planning.

Carbon Dioxide Removal Service Launched.

Carbon Engineering (CE) launched a CO_2 removal service enabling the purchase of CO_2 removal units (each represents one metric ton) through CE's direct air capture (DAC) technology. The CO_2 removal will be performed by 1PointFive in the United States and Pale Blue Dot Energy in the United Kingdom.

MAY 2021

White House Report Outlines Revitalization in Coal, Power Plant Communities.

The White House Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization *released a report of recommendations* to the President to catalyze robust economic activity and support workers in America's energy sector. NETL supported the drafting of the report for the *Interagency Working Group*, of which NETL Director Brian Anderson, Ph.D., has been *named Executive Director*. The Interagency Working Group was formed in response to President Biden's Executive Order 14008, "*Tackling the Climate Crisis at Home and Abroad*."

Project Tundra Informational Video Available.

Minnkota Power Cooperative, with research support from the University of North Dakota's Energy and Environmental Research Center's (EERC), is implementing *Project Tundra*, which is a carbon capture, utilization, and storage (CCUS) retrofit project for Minnkota Power's Milton R. Young station located in North Dakota, USA. The project is in part funded by DOE's *Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative*, which builds on work done by the Regional Carbon Sequestration Partnerships (RCSPs) to fund and develop projects that focus on developing commercial-scale carbon storage complexes that will be ready for integrated CCUS system deployment in the 2025–2035 timeframe.

CO_2 Pipeline Guidance Published.

DNV published guidance for transporting CO_2 via pipelines and strengthening the development of CCS projects. The procedures were published based on results from a joint industry project between Energy Pipelines CRC and DNV, which involved two large-scale CO_2 "crack arrest tests" to better understand CO_2 releases.

Carbon and Ecosystems Services Portfolio Launched.

Corteva Agriscience—an American agricultural chemical and seed company—created a "Carbon and Ecosystems Services" portfolio to help enable the development of carbon storage and ease access to carbon credits. In addition, the company created the 2021 Climate Positive Leaders Program, which is a nomination-based program to recognize those in the agricultural community who have successfully implemented "climate-positive" agricultural practices.

CCS Facility Reaches Milestone.

SaskPower's Boundary Dam 3 CCS facility has captured and prevented 4 million metric tons of CO_2 from entering the atmosphere according to the International CCS Knowledge Centre. Experience gained through the design, construction, and operation of the facility has led to two studies—the *Shand CCS Feasibility Study* and the *Lehigh CCS Feasibility Study*.

Global CCS Institute Gets New Member.

An energy commodity trader has joined the *Global CCS Institute*. Gunvor Group—whose main trading offices are located in Geneva, Singapore, Houston, and London—has shifted approximately half of its trading to "transitional commodities," according to EU Taxonomy. One part of their Energy Transition strategy includes CCS. The Global CCS Institute's mission is to accelerate the deployment of CCS, and its international membership includes governments, global corporations, private companies, research bodies, and non-governmental organizations.

JUNE 2021

DOE Announces Funding to Enhance Safety, Security of CO_2 Storage.

DOE announced funding for four research and development (R&D) projects to enhance the safety and security of carbon dioxide (CO_2) storage. The selected projects will look to address challenges related to long-term, commercial-scale storage of CO_2, working to improve the tools to monitor the seal integrity of caprocks used in CO_2 storage complexes and identify and reduce the risk of potential seismic activity. The projects will be managed by DOE's Office of Fossil Energy and Carbon Management's (FECM) National Energy Technology Laboratory (NETL) and will support the goals of the *Advanced Storage R&D* technology development area in *DOE's Carbon Storage Program*.

NETL FY 2020 Science and Technology Accomplishments Book Available.

NETL's FY 2020 Science & Technology Accomplishments book is available. These demonstrated accomplishments, which represent a selection of NETL researchers' achievements, characterize NETL's six Core Competencies: Computational Science and Engineering, Energy Conversion Engineering, Geological and Environmental Sciences, Materials Engineering and Manufacturing, Program Execution and Integration, and Systems Engineering and Analysis.

In Case You Missed It, Office of Fossil Energy and Carbon Management.

DOE's FECM reported on highlights from the first quarter of 2021, including Principal Deputy Assistant Secretary Jennifer Wilcox—who is also Acting Assistant Secretary for Fossil Energy—speaking about the importance of CCS and direct air capture technologies at several virtual events.

NETL-Supported Technology Wins Global Competition.

An NETL-supported technology won a global competition for the development of an eco-friendly process that infuses concrete with CO_2 emissions directly captured from industrial facilities. The University of California, Los Angeles (UCLA) CarbonBuilt Team won the grand prize in the NRG COSTIA Carbon XPRIZE global competition's track for technologies related to coal-fired power generation. The project was supported by *DOE's Carbon Utilization Program*.

Partnership Formed to Accelerate CCUS.

Battelle and Catahoula Resources will jointly develop solutions for the capture, transport, and storage of CO_2 produced at ethanol facilities in Nebraska (USA). The companies, paired with private investment firm The Energy and Minerals Group, plan to design and build multiple low-cost storage options either onsite or close to existing ethanol plants where the geology proves to be favorable.

Report on BECCS Potential at Drax.

Energy consultancy Baringa released a report evaluating the impact of deploying bioenergy with carbon capture and storage (BECCS) technology at the Drax Power Station in North Yorkshire, England. Commissioned by the Drax Group, *the report* also found that with investment from the United Kingdom (UK) government, work to build two BECCS units could begin in 2024.

Carbontech Initiative Announces First Participants.

The Carbon to Value Initiative (C2V Initiative)—a program aimed at commercializing technologies that capture, convert, and store CO_2—announced the selection of 10 companies for the first cohort of the program. The startups will participate in a program with members from the C2V Initiative's Carbontech Leadership Council.

International Consortium to Develop Electricity-Based CCS.

An international consortium plans to investigate the potential of CCS technology to reduce CO_2 industrial emissions. "ConsenCUS – CarbOn Neutral cluSters through Electricity-based iNnovations in Capture, Utilisation and Storage" aims to scale up technological innovations and conduct socio-economic research to investigate electrochemical CO_2 emissions reduction.

Pre-Study of CCS Project Complete.

The Carbon Infrastructure Capture Project (CinfraCap) in western Sweden completed a pre-study, which included proposals for optimizing CCS and identifying potential risks. *CinfraCap*—a collaboration project among Göteborg Energi, Nordion Energi, Preem, St1, Renova, and the Gothenburg Port Authority—is focused on the transport of captured CO_2.

Brief Surveys U.S. Federal CCS Policy Landscape.

The Global CCS Institute released a brief detailing the CCS-related bills introduced in the U.S. House of Representatives and the U.S. Senate in 2021. The brief examines the CCS policies that support the advancement of the technology in the United States and provides a history of CCS policy.

JULY 2021

DOE Leads International Forum to Develop Net-Zero Emissions Strategies.

DOE is leading the creation of a new international forum dedicated to developing long-term strategies, such as carbon capture and storage (CCS), to reach global net-zero emissions. The Net-Zero Producers Forum includes Canada, Norway, Qatar, Saudi Arabia, and the United States, which collectively represent 40% of global oil and gas production. DOE, along with other governments, also *announced several other initiatives* to expand international cooperation in addressing potential climate issues and enhance clean energy innovation.

NETL-Supported Paper Published as "Feature Paper."

An NETL-supported paper evaluating the influences that market and policy changes could have on the economics of CCS facilities was published as a "Feature Paper in a *Special Issue of Alternative Energy Policy*. The paper, titled "*Comparative Analysis of Carbon Capture and Storage Finance Gaps and the Social Cost of Carbon*," used data provided from modified versions of models and resources created and managed by NETL.

FECM Chief of Staff Participates in CCS Webinar.

FECM Chief of Staff Shuchi Talati provided *opening remarks* at the final installment of a three-part Global CCS Institute webinar, discussing DOE's role in implementing CCS technologies to meet the Administration's emissions targets. *The Carbon Capture and Storage 101 Webinars: CCS Policy for a Net-Zero Future* focused on global CCS policies.

NETL Director Delivers Keynote Address at Carbon Forum.

NETL Director Brian Anderson delivered the keynote address at "The Value of Carbon and Coal in West Virginia's Energy Future" virtual forum. U.S. Secretary of Energy Jennifer Granholm also spoke at the virtual forum, highlighting the importance of CCUS and CO_2 removal technologies. The virtual forum discussed West Virginia's role in reducing the nation's CO_2 emissions.

DOE Funds Carbon-Based Building Materials.

DOE's FECM announced the selection of three projects to receive federal funding for cost-shared R&D to explore carbon-based building materials. The selected projects will investigate opportunities to develop construction materials that offer lower life cycle CO_2 emissions and other improved properties.

U.S. Launches Decarbonization Initiative.

U.S. Secretary of Energy Jennifer Granholm launched the G7 Industrial Decarbonization Agenda (IDA) Initiative to address potential climate change and reduce greenhouse gas (GHG) emissions from heavy industry. IDA challenges G7 members to leverage their innovation to develop robust, durable, and impactful common approaches to net-zero outcomes while spurring clean market growth.

USDA Initiative to Quantify CCS Evaluation Tools.

The U.S. Department of Agriculture (USDA) announced an initiative to quantify the climate benefits of Conservation Reserve Program contracts to improve existing models and tools (e.g., *COMET-Farm* and *COMET-Planner*). These tools enable producers to evaluate potential carbon storage and GHG emissions reductions based on specific management scenarios. *Offshore CCS Report Released.*

Offshore CCS Report Released.

Columbia World Projects (CWP) released a report identifying key opportunities and challenges in offshore CCS. "*Accelerating Offshore Carbon Capture and Storage: Opportunities and Challenges for CO_2 Removal*" is based on a workshop held by CWP in 2020, and the findings aim to help the development of policy framework, technical needs, and future large-scale infrastructure investments needed to capture and store CO_2 at scale.

UK Announces Funding for CCUS.

The UK's Carbon Capture and Storage Association announced the funding of 14 projects, three of which relate to CCUS. In addition, the UK government also announced funding for the *CCUS Innovation 2.0 Competition*, which supports projects that are developing novel technologies that reduce CCUS technology deployment costs.

White Paper on CCS Cost Guidelines Developed.

A consortium developed a white paper explaining cost guidelines for CCS. The *white paper* aims to help properly estimate costs involved in CCS projects to better inform investment and policy decisions.

UKRI Launches Research and Innovation Center.

UK Research and Innovation (UKRI) launched the Industrial Decarbonisation Research and Innovation Centre (IDRIC), which will be tasked with identifying and researching opportunities to reduce costs, risks, timescales, and carbon emissions. In addition, IDRIC will analyze ways to help decarbonization plans work more effectively to meet net-zero and economic targets in the UK.

AUGUST 2021

The New Vision of the Office of Fossil Energy.

DOE's Office of Fossil Energy officially changed its name to the Office of Fossil Energy and Carbon Management (FECM), aligning itself with the climate goals set forth by the Biden-Harris Administration. FECM is a key part of DOE's leadership role in the new Administration's all-of-government approach to addressing climate issues. *Click here* to learn more about work conducted by FECM.

2021 DOE/NETL Carbon Management and Oil and Gas Research Project Review Meeting Agenda Available.

The DOE/NETL *2021 Carbon Management and Oil and Gas Research Project Review Meeting* was held in August 2021 through a series of virtual meetings. The project review meeting allowed researchers to present results from more than 250 projects funded through a variety of program areas, including carbon storage and utilization. Conference proceedings *are available*.

FECM Acting Assistant Secretary Speaks at CCUS Forum.

DOE's Acting Assistant Secretary for FECM, Dr. Jennifer Wilcox, *spoke* at the *First Asia CCUS Network Forum*. The event focused on global goals and expectations for CCUS and how advances in technology can help address potential climate concerns.

Australia Explores Offshore CO_2 Storage.

The Australian government sought nominations from companies for offshore acreage to explore locations for CO_2 storage as part of a government initiative to promote carbon capture and storage (CCS). Companies nominated areas for potential storage locations in Australian federal waters, which start three nautical miles offshore. The nominations were collected in July 2021 and will be open for bidding in December 2021.

CCS Service Launched.

Aker Carbon Capture launched a service designed to accelerate deployment of CCS across industries. As part of *Carbon Capture as a Service; Carbon capture made easy™*, Aker Carbon Capture will deliver and operate the carbon capture facilities; transport and storage will be included through strategic partnerships.

Companies to Develop CCS Solutions on Ships.

The Norwegian company TECO 2030 and American manufacturer Chart Industries signed a Memorandum of Understanding (MOU) to jointly develop technology solutions to capture and store CO_2 emitted by ships. The MOU involves the development of onboard carbon capture solutions for ships using *Cryogenic Carbon Capture™ technology*.

RGGI States Initiate Auction Process.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the *Auction Notice for CO_2 Allowance Auction 53*, to be held September 8, 2021. According to the notice, the states will offer 22,911,423 CO_2 allowances for sale using a minimum reserve price of $2.38 in 2021. Auction 53 will also make available a cost containment reserve (CCR) of 11,976,778 CO_2 allowances, which will be accessed if the interim clearing price exceeds the CCR trigger price of $13.00, as well as an emissions containment reserve (ECR) of 11,307,333 allowances, which are available to be withheld if the interim clearing price is less than the ECR trigger price of $6.00.

JBIC to Support Exports from CCS Power Plants.

The Japan Bank for International Cooperation (JBIC) will provide support for exports from coal power plants if they are equipped with CCS, according to officials. Under a new three-year plan, the bank will help transition finance to support CCUS.

Report on Large-Scale Emissions Reduction.

According to a new study by the Coalition for Negative Emissions, technologies such as bioenergy with carbon capture and storage (BECCS), direct air capture and storage (DACS), and natural climate solutions are needed to help meet global climate targets. A summary of *The Case for Negative Emissions: A Call for Immediate Action* findings is also *available*.

Report Presents U.S. Policy Blueprint for CO_2 Transport and Storage.

The Energy Futures Initiative released a report that presents a policy roadmap to build out CO_2 infrastructure while supporting the development of jobs, infrastructure, and pathways to net-zero emissions by mid-century. *Building to Net-Zero: A U.S. Policy Blueprint for Gigaton-Scale CO_2 Transport and Storage Infrastructure* is also available as a *webinar presentation* and a *webinar recording.*

SEPTEMBER 2021

CCS Explained.

DOE's FECM released an instructional video titled "Carbon Capture and Storage Explained." In the video, *Secretary of Energy Jennifer Granholm* breaks down how carbon capture and storage (CCS) works and its role in addressing potential climate change.

DOE-Sponsored Partnerships Conclude Work.

The *Southeast Regional Carbon Sequestration Partnership (SECARB)* and the *Midwest Regional Carbon Sequestration Partnership (MRCSP)* concluded their work in support of DOE's *Regional Carbon Sequestration Partnerships (RCSPs)*.

DOE Announces Additional DAC Funding.

DOE's FECM announced the selection of four additional direct air capture (DAC)-focused research and development (R&D) projects to receive federal funding, which add to the six DAC projects *announced in June 2021*. The awards are funded under Funding Opportunity Announcement (FOA) DE-FOA-0002402, Carbon Capture R&D: Bench-Scale Testing of Direct Air Capture Components *(Technology Readiness Level [TRL] 3) and Initial Engineering Design for Carbon Capture, Utilization and Storage Systems from Air (TRL 6)*. A detailed list of the selected projects and their associated areas of interest is *available*.

DOE Issues NOI.

DOE's FECM issued a *Notice of Intent (NOI)* for an FOA expected to support front-end engineering design (FEED) studies of DAC combined with dedicated storage and coupled to existing low-carbon energy. The NOI is in collaboration with the Office of Nuclear Energy and the Office of Energy Efficiency and Renewable Energy's Geothermal Technology Office. If issued, the FOA will support the advancement of DAC technologies that remove CO_2 directly from the atmosphere.

CCUS Report Released.

The National Association of State Energy Officials (NASEO) released a report outlining state energy planning and policy considerations to support carbon capture, utilization, and storage (CCUS). The report, "*Carbon Capture, Utilization, and Storage: Overview and Considerations for State Planning*," also includes an overview of CO_2 source sectors, CCUS activities, CO_2 capture technologies, and the potential utilization of CO_2.

MOU Promotes Collaborative Research.

The state of Wyoming and the Japan Coal Energy Center *signed a Memorandum of Understanding (MOU)* to continue collaborative research into CCUS at the *Wyoming Integrated Test Center* in Gillette, Wyoming. The agreement extends the initial MOU signed in 2016.

CCUS Capacity Studied.

According to GlobalData—a data and analytics company—additional CCUS capacity is needed in reference to the net-zero emissions by 2050 scenario by the International Energy Agency (IEA).

Data Management Platform Designed for Carbon Storage Projects.

Compass Carbon introduced a *new technology platform* designed for large-scale and complex carbon storage projects. The fully automated data management, monitoring, and analysis technology is designed to replace the manual processing methods used in the industry.

Report Outlines G-20 Progress.

A new report outlines the progress each G-20 member country has made toward moving to a low-carbon economy. The *Climate Policy Factbook* was released to increase transparency and inform climate policy priorities.

ABOUT DOE/NETL'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** at the U.S. Department of Energy's (DOE) 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 *DOE/NETL 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.

DOE/NETL Carbon Storage Program Resources

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more information related to the DOE/NETL 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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