NETL'S CARBON TRANSPORT AND STORAGE NEWSLETTER

ANNUAL INDEX

FISCAL YEAR (FY) 2022

October 2021 – September 2022

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL'S CARBON TRANSPORT AND STORAGE NEWSLETTER

ANNUAL INDEX – FY 2022

This Annual Index is a compilation of the National Energy Technology Laboratory's (NETL) monthly Carbon Transport and Storage Newsletters (CTSNs; formerly known as the Carbon Storage Newsletters) published from October 2021 to September 2022. The CTSN is produced by NETL to provide information on activities and publications related to carbon transport and 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 Outdated information (e.g., conference dates, paper submittals, etc.)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. Content is included as-published from the respective monthly newsletter.

Note that links were active at the time of publication.

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

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DOE/FECM/NETL HIGHLIGHTS

OCTOBER 2021

DOE Funding to Support Carbon Management Technologies.

The U.S. Department of Energy's (DOE) *Office of Fossil Energy and Carbon Management (FECM)* announced funding for four national public power associations to help increase regional- and state-level engagement in carbon management. In one award, the National Association of Regulatory Utility Commissioners will promote learning and discussion among its members on topics such as carbon capture, utilization, and storage (CCUS). In another award, the National Association of State Energy Officials will research, analyze, and develop educational information on topics such as new developments in carbon management, including CCUS. DOE's National Energy Technology Laboratory (NETL) will serve as the contracting authority for the cooperative agreements issued with the awards.

From *FECM*. September 2021.

NOVEMBER 2021

DOE Announces Intent to Fund Carbon Storage Projects.

The U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) released a *Notice of Intent (NOI)* to fund cost-shared research and development (R&D) projects looking to accelerate wide-scale deployment of carbon capture and storage (CCS) and carbon dioxide removal (CDR). The potential projects will be selected under DOE's *Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative*, which focuses on developing geologic storage sites with capacities to store at least 50 million metric tons of carbon dioxide (CO_2).

From *energy.gov*. November 2021.

DOE Announces Funding to Deploy CCUS.

DOE announced funding for an initiative focused on accelerating the regional deployment of carbon capture, utilization, and storage (CCUS). The *Regional Initiative to Accelerate CCUS Deployment* is designed to identify and address regional storage and transportation challenges facing the commercial deployment of CCUS. The four Regional Initiatives, representing four regions of the United States, are partnerships with academia, non-governmental organizations, industry leaders, and local and state governments. The initiatives identify and promote carbon storage and transport projects by addressing key technical challenges; facilitating data collection, sharing, and analysis; evaluating regional storage and transport infrastructure; and promoting regional technology transfer. The Regional Initiatives continue the work of predecessors funded under *DOE's Regional Carbon Sequestration Partnership (RCSP) Initiative*, supporting efforts to validate geologic storage technologies and support the commercialization of carbon capture and storage (CCS).

From *energy.gov*. October 2021.

DOE Invests to Decarbonize Using CCS.

DOE announced funding for 12 projects to advance point-source CCS technologies that can capture at least 95% of CO_2 emissions generated from natural gas power and industrial facilities. The projects were selected by *DOE's FECM* and will be managed by the National Energy Technology Laboratory (NETL). The 12 front-end engineering design studies are part of DOE's efforts to help achieve the administration's goals of net-zero carbon emissions by 2050 and a 100% clean electricity sector by 2035.

From *energy.gov*. October 2021.

DECEMBER 2021

DOE Releases RFI on Deployment-Ready CO_2 Reduction, Removal Tech.

The U.S. Department of Energy (DOE) *released a Request for Information (RFI)* on demonstration-ready technologies that can reduce emissions and remove carbon dioxide (CO_2) from the atmosphere. The RFI seeks feedback from industry, investors, developers, academia, research laboratories, government agencies, non-governmental organizations (NGOs), and potentially affected communities (including environmental justice, tribal, energy transition, and other communities). Information provided through the RFI, which follows the enactment of the Bipartisan Infrastructure Law, is expected to inform the design of successful projects as well as the effective, just, and sustainable deployment of technologies that will enable a safe climate future, with particular attention to including historically marginalized communities in the decision-making process. Responses are due by January 24, 2022.

From *energy.gov*. December 2021.

DOE Funding to Support DAC and Carbon Storage.

DOE announced funding to leverage existing low-carbon energy to scale-up direct air capture (DAC) technology combined with carbon storage. DAC, a CO_2-removal (CDR) approach, separates CO_2 from ambient air for either underground storage or conversion into products. The *Funding Opportunity Announcement (FOA)* will facilitate engineering studies of advanced DAC systems capable of removing 5,000 metric tons of CO_2 per year from the air. The studies will provide detailed information on the operation of these systems and potential investment costs that will enable DOE to accelerate research and development (R&D) for existing DAC technologies co-located with domestic low-carbon thermal energy sources, such as nuclear power plants, geothermal resources, and industrial plants. This FOA is a collaborative effort among DOE's Office of Fossil Energy and Carbon Management (FECM), Office of Nuclear Energy, and Office of Energy Efficiency and Renewable Energy's Geothermal Technologies Office.

From *energy.gov*. October 2021.

JANUARY 2022

DOE, USGS to Explore CCS.

The U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management (FECM) and the U.S. Department of Interior's (DOI) U.S. Geological Survey (USGS) announced a partnership to explore global, regional, and national resources for the geologic storage of carbon dioxide (CO_2). Under the *Memorandum of Understanding (MOU)*, the agencies will collaborate with international governments, geologic surveys, and other organizations to provide technical assistance through a series of discussions, meetings, workshops, and research activities. The information will be used by government, academia, industry, research organizations, and other stakeholders to help identify potential investment opportunities for research, development, demonstration, and deployment to advance carbon capture and storage (CCS) technologies for application in power and industrial sectors.

From *energy.gov*. December 2021.

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From *energy.gov*. December 2021.

FEBRUARY 2022

DOE Announces Funding for CO_2 Utilization.

The U.S. Department of Energy's (DOE) *Bioenergy Technologies Office (BETO)* in the Office of Energy Efficiency and Renewable Energy (EERE) and the Office of Fossil Energy and Carbon Management's (FECM) Carbon Utilization Program announced the availability of federal funding for the advancement of technologies that utilize waste carbon to reduce greenhouse gas (GHG) emissions and produce reliable feedstocks for biotechnologies. The Funding Opportunity Announcement (FOA), titled "*Carbon Utilization Technology: Improving Efficient Systems for Algae*," specifically aims to increase the capability of algal systems to capture carbon dioxide (CO_2) and put it to productive use. Concept papers for the FOA are due March 18, 2022; applications are due May 27, 2022.

From *energy.gov*. February 2022.

FECM's 2021 Year in Review.

Dr. Jennifer Wilcox, the Acting Assistant Secretary for DOE's FECM, shared highlights of FECM's 2021. Achievements included adding "Carbon Management" to the office's name; updating the mission to focus on minimizing impacts of fossil fuels to help the nation achieve net-zero GHG emissions; providing funding to 40 research projects to advance carbon management approaches (such as carbon capture and storage [CCS] and CO_2 removal); and launching key carbon management initiatives. To keep up to date with future FECM announcements, blogs, and more, sign up for FECM's *news alerts*.

From *energy.gov*. December 2021.

MARCH 2022

NETL Releases Report on CCS.

A report authored by the National Energy Technology Laboratory (NETL) analyzed the buildout of America's carbon capture and storage (CCS) technologies in terms of job growth potential and supply chain risks. NETL researchers conducted a supply chain risk analysis by comparing raw material estimates against domestic and global production to search for opportunities and vulnerabilities. The report, titled "*Carbon Capture, Transport, and Storage, Supply Chain Review*," found that a major reason for the low risk to the supply chain is because CCS infrastructure can be supplied by components made in the United States. The report also concluded that a CCS industry buildout could create up to 1.8 million jobs through construction, operation, and maintenance of capture, pipeline, and storage sites.

From *NETL News*. February 2022.

DOE's FOA to Develop Carbon-Free Fuel.

DOE's FECM announced federal funding for research and development (R&D) and front-end engineering design (FEED) projects that will advance clean hydrogen as a carbon-free fuel. The FOA, titled "*Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions*," will leverage innovative approaches to produce clean hydrogen at lower costs from materials that include municipal solid waste, legacy coal waste, waste plastics, and biomass with CCS. These next-generation hydrogen technologies are expected to play a significant role in decarbonizing the U.S. economy and advancing the Biden-Harris administration's goal of net-zero GHG emissions by 2050. Responses are due March 23, 2022.

From *energy.gov*. February 2022.

APRIL 2022

DOE Announces Funding to Support CCUS.

The U.S. Department of Energy (DOE) announced two funding opportunities for student training and research on remediating legacy pollution from coal-based electricity generation and using carbon capture, utilization, and storage (CCUS) to generate low-carbon power. The *University Training and Research for Fossil Energy and Carbon Management—UCR* Funding Opportunity Announcement (FOA) will support DOE's University Coal Research (UCR) Program by providing research and development (R&D) grants to educate and train the next generation of engineers and scientists by supporting novel, early-stage research at U.S. colleges and universities. The *University Training and Research for Fossil Energy and Carbon Management—Minority Serving Institutions (MSIs)* FOA will support the Historically Black Colleges and Universities and Other Minority Institutions (HBCU-OMI) Program by providing R&D grants to educate and train the next generation of engineers and scientists by supporting novel, early-stage research at MSIs in the United States. Combined, the two FOAs will support approximately 20 student engineers and scientists working two to three years on research projects related to advancing the Biden-Harris administration's goals of net-zero greenhouse gas (GHG) emissions by 2050.

From *energy.gov*. February 2022.

MAY 2022

DOE Announces BIL Effort to Establish DAC Hubs.

The U.S. Department of Energy (DOE) released *a Notice of Intent (NOI)* to fund the Bipartisan Infrastructure Law's (BIL) program to capture and store atmospheric carbon dioxide (CO_2) emissions. The Regional Direct Air Capture (DAC) Hubs Program will support four large-scale, regional DAC hubs that each comprise a network of carbon dioxide removal (CDR) projects to help address potential impacts of climate change while creating good-paying jobs and prioritizing community engagement and environmental justice. The widespread deployment of DAC technologies and CO_2 transport and storage infrastructure plays a significant role in delivering on the Biden-Harris Administration's goal of achieving an equitable transition to a net-zero economy by 2050. Each of the projects selected will demonstrate the delivery and storage or end-use of removed atmospheric CO_2. The hubs will have the capacity to capture and store at least 1 million metric tons of CO_2 from the atmosphere annually, either from a single unit or from multiple interconnected units. In the development and deployment of the four regional DAC hubs, DOE will also emphasize environmental justice, community engagement, consent-based siting, equity and workforce development, and domestic supply chains and manufacturing.

From *energy.gov*. May 2022.

FECM Releases Strategic Vision.

DOE's FECM released its strategic vision, "*The Role of Fossil Energy and Carbon Management in Achieving Net-Zero Greenhouse Gas Emissions*." FECM's Strategic Vision will enable DOE to make strategic carbon management decisions and prioritize approaches that minimize the environmental impacts of fossil fuels and carbon-based feedstocks and help the nation achieve net-zero greenhouse gas (GHG) emissions. Three strategic directions were outlined to help the U.S. government achieve a fully decarbonized power sector by 2035 and net-zero emissions by 2050: Advancing Justice, Labor, and Engagement; Advancing Carbon Management Approaches Toward Deep Decarbonization; and Advancing Technologies that Lead to Sustainable Energy Resources. More information on FECM's Strategic Vision is available via *infographic*.

From *energy.gov*. April 2022.

NETL Report Compares Cost and Performances of Hydrogen Plants With/Without CCS.

The National Energy Technology Laboratory (NETL) released a report that depicts the levelized cost of hydrogen, in real 2018 dollars, as well as the CO_2-equivalent life cycle emissions of select hydrogen production plants. "*Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies*" compares the cost, performance, and emissions profiles of hydrogen production plants that were selected to reflect the capabilities of current, commercial technologies within industrial-scale plant configurations, providing critical prospective for researchers, regulators, and policymakers. The report includes analyses of three natural gas reforming configurations: (1) natural gas steam methane reforming without carbon capture and storage (CCS), (2) natural gas steam methane reforming with CCS, and (3) autothermal reforming with CCS. The NETL team also analyzed three gasification configurations: (1) coal gasification without carbon capture, (2) coal gasification with carbon capture, and (3) coal plus biomass co-gasification with carbon capture. The full report is *available on the NETL website*.

From *energy.gov*. April 2022.

DOE Invests in DAC and Storage Technology.

DOE announced the award of federal funding for five front-end engineering design (FEED) studies that will leverage existing zero- or low-carbon energy to supply DAC projects, combined with dedicated and reliable carbon storage. *The studies* aim to provide a better understanding of system costs, performance, and business case options for existing DAC technologies coupled to durable storage that are capable of removing a minimum of 5,000 metric tons per year net CO_2 from the air, and which are co-located with domestic zero- or low-carbon thermal energy sourced from geothermal or nuclear power plants and low-grade heat from industrial facilities. The funding opportunity was a collaborative effort among DOE's FECM, Office of Nuclear Energy, and Office of Energy Efficiency and Renewable Energy's (EERE) Geothermal Technologies Office. The selected projects will be managed by NETL and support FECM's *Carbon Dioxide Removal* and *Conversion* Programs.

From *energy.gov*. April 2022.

JUNE 2022

DOE Investments to Accelerate CO_2 Storage Projects and Increase CO_2 Storage Sites.

DOE announced two Funding Opportunity Announcements (FOAs) and one NOI to advance carbon storage projects that reduce CO_2 emissions, address potential impacts of climate change, and create good-paying jobs while prioritizing community engagement and environmental justice. DOE first issued an FOA for "*Carbon Management*" to advance a variety of carbon management technologies, including assessments of rock and material resources for CO_2 mineralization. DOE then issued an FOA for "*CarbonSAFE: Phase II - Storage Complex Feasibility*" to increase the number of available CO_2 storage sites in the early developmental levels. The next investment has been announced through an NOI for "*Bipartisan Infrastructure Law: Storage Validation and Testing (Section 40305): Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative: Phases III, III.5, and IV*," which would be funded through the BIL to accelerate commercial-scale geologic carbon storage projects toward operational readiness. CarbonSAFE projects must be capable of storing at least 50 million metric tons of CO_2 within a 30-year operational period. Projects funded under these three opportunities will be managed by DOE's Office of Fossil Energy and Carbon Management (FECM).

From *energy.gov*. May 2022.

JULY 2022

DOE Announces NOIs, Launches Online Resources.

The Biden-Harris Administration, through DOE, issued NOIs to fund two programs that will advance carbon capture demonstration projects and expand regional pipeline networks to transport CO_2 for geologic storage or conversion. Funded by the BIL, the *Carbon Capture Demonstration Projects Program* and the *Carbon Dioxide Transport/Front-End Engineering Design (FEED) Program* help to advance the administration's goal of a net-zero greenhouse gas (GHG) emissions economy by 2050. In addition, DOE's Office of Fossil Energy and Carbon Management (FECM) launched two new interactive tools to assist with advancing carbon management technologies and infrastructure in the United States. The *Carbon Matchmaker Tool* is an online information resource designed to increase awareness of carbon management funding opportunities; support private sector development of carbon capture, storage, and transportation infrastructure and CDR pathways; and facilitate regional business development opportunities and education. The *Carbon Management Interactive Diagram* is an online tool that highlights carbon management programs in the BIL and through other DOE funding opportunities, as well as educates users about resources that fall under each program.

From *energy.gov*. July 2022.

AUGUST 2022

NETL, Partners Release Resource on Computational Tools to Complete CO_2 Storage Permit Applications.

The National Energy Technology Laboratory (NETL) collaborated with the U.S. Environmental Protection Agency (EPA), other contributing national laboratories, and the U.S. Department of Energy's (DOE) Regional Initiatives to Accelerate Carbon Capture, Utilization, and Storage (CCUS) on a report that identifies computational tools useful for addressing aspects of the dedicated carbon storage (Class VI) well permit application under EPA's Underground Injection Control (UIC) Program. "*Rules and Tools Crosswalk: A Compendium of Computational Tools to Support Geologic Carbon Storage Environmentally Protective UIC Class VI Permitting*" is intended to serve as a resource for industry, regulatory, academic, and public stakeholders. The report will be periodically updated as new information on relevant computational tools becomes available.

From *National Energy Technology Laboratory*. July 2022.

SEPTEMBER 2022

DOE Announces Set of FOAs to Manage and Store CO_2.

The U.S. Department of Energy (DOE) announced a nearly $4.9 billion set of funding opportunities to bolster investments in the carbon management industry and to significantly reduce carbon dioxide (CO_2) emissions released into the atmosphere through power generation and industrial operations. The three Funding Opportunity Announcements (FOAs) will be supported by Bipartisan Infrastructure Law (BIL) funding to help drive the demonstration and deployment of carbon capture systems, along with carbon transport and storage infrastructure. The *Carbon Storage Validation and Testing* FOA supports the *Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative*, managed by DOE's Office of Fossil Energy and Carbon Management (FECM), and provides up to $2.25 billion to support the development of new and expanded large-scale, commercial carbon storage projects with capacities to store 50 or more million metric tons of CO_2, along with associated CO_2 transport infrastructure. The *Carbon Capture Demonstration Projects Program* FOA provides up to $2.54 billion to develop six integrated carbon capture, transport, and storage demonstration projects that can be readily replicated and deployed at fossil energy power plants and major industrial sources of CO_2 and certain types of chemical production facilities. The *Carbon Dioxide Transport Engineering and Design* FOA provides up to $100 million to design regional CO_2 pipeline networks to safely transport captured CO_2 from key sources to centralized locations.

From *energy.gov*. September 2022.

PROJECT and BUSINESS DEVELOPMENTS

OCTOBER 2021

CCS Drilling Study Investigates Feasibility of Storing CO_2.

A carbon capture and storage (CCS) drilling study concluded that more than 2 million metric tons of CO_2 per year can be stored underground at two ethanol plants in California. Commissioned by Aemetis Inc. (a renewable natural gas and renewable fuels company) and conducted by Baker Hughes (a global energy services company), the study estimated that 1 million metric tons of CO_2 per year can be stored in saline formations located at or near the Aemetis Keyes ethanol plant site, and that up to 1.4 million metric tons of CO_2 per year could be injectable at or near the Aemetis Riverbank ethanol plant site.

From *Yahoo! Finance*. August 2021.

Initial Phase of Carbon Storage and Soil Health Pilot Program Completed.

A group of U.S. farmers completed the initial benchmarking phase of a carbon storage and soil health pilot program. Rabo AgriFinance is facilitating the pilot program, which will see participating farmers receive compensation for implementing regenerative agricultural practices that enrich their fields' soils while capturing CO_2 from the air. Participants receive compensation based on the amount of carbon stored, measured, and monitored over time. The initial stage of the pilot is focused on learning which practices result in the best soil health and carbon capture in a variety of conditions and crops.

From *Business Wire*. August 2021.

Companies Collaborate on CCS Project.

TGS, a global subsurface data company, and Magseis Renewables, a subsidiary of the surveying services company Magseis Fairfield, agreed to collaborate on a CCS pilot project in Norway. The project will employ high-resolution 3D seismic acquisition offshore Norway at a potential carbon storage area to demonstrate detailed imaging of the full section, from the seabed to the target storage reservoir. The imaging software and high-resolution acquisition configurations will be combined to determine the resolution needed by CCS developers.

From *Offshore Magazine*. August 2021.

CO_2 Storage Project Planned in South Africa.

Geologic mapping at a CCS site in South Africa has begun, according to the Council for Geoscience (a National Science Council of South Africa). The project will be based around the town of Leandra, Mpumalanga province, in South Africa's northeast. The project plans to link a pipeline transporting compressed CO_2 from emitting sources to the injection point. According to researchers, South Africa has approximately 150 metric gigatons of potential storage capacity.

From *Reuters*. August 2021.

Companies Sign Purchase Agreement for DAC and Storage of CO_2.

Swiss Re, a reinsurance provider, and Climeworks, a CO_2 air capture specialist, signed a partnership for a purchase agreement for direct air capture (DAC) and CO_2 storage. The agreement also includes collaboration on developing risk management knowledge and risk transfer solutions.

From *Swiss Re News Release*. August 2021.

Offshore CCS Project Launched in South China Sea.

The China National Offshore Oil Corporation (CNOOC) launched an offshore CCS project. According to CNOOC, the project is expected to store more than 1.46 million metric tons of CO_2. Located in the Pearl River Mouth basin of the South China Sea, the project is designed to reinject up to 300,000 metric tons of CO_2 per year into seabed reservoirs.

From *Reuters*. August 2021.

NOVEMBER 2021

Consortium to Evaluate, Develop CCS Projects on US Gulf Coast.

Carbon-Zero US LLC and international multi-energy company Repsol signed an agreement to evaluate opportunities to develop innovative CCS projects on the U.S. Gulf Coast. The consortium will share technical knowledge and resources to evaluate potential projects that would combine the offshore experience and operations of Cox Oil with Repsol's technical knowledge and global experience with CCS projects.

From *GlobeNewswire*. November 2021.

CCUS Project Proposed at Synfuels Plant in North Dakota.

Basin Electric Power Cooperative and the Dakota Gasification Company announced a proposed CCUS project at the Great Plains Synfuels Plant near Beulah, North Dakota. The proposed project is expected to enable the facility to capture up to 3.5 million tons of CO_2 per year and be part of a CCUS project that utilizes both enhanced oil recovery (EOR) and carbon storage. The Great Plains Synfuels Plant currently captures approximately 2 million tons of the plant's CO_2 emissions, which are piped to Saskatchewan, Canada, for EOR operations.

From *Devils Lake Journal*. September 2021.

CCS Project Receives Funding.

The U.S. Department of Agriculture (USDA) awarded funding to Red Tail Energy to build a carbon capture processing and storage facility at an existing ethanol manufacturing plant in Richardton, North Dakota. Funded through *USDA's Rural Development Program*, the CO_2 storage project would store the CO_2 in the Broom Creek rock formation.

From *Williston Herald*. September 2021.

CCS Project Launched in Iceland.

Climeworks, a Swiss carbon capture company, announced the launch of Orca—a direct air capture (DAC) and storage plant in Iceland with the capacity to capture and store approximately 4,000 tons of CO_2 per year. *Carbfix* will mix the air-captured CO_2 with water and store it underground through a natural mineralization process that takes less than two years.

From *Power Engineering International*. September 2021.

Carbon Storage Project Announced in Québec.

Questerre Energy Corporation completed the engineering and work program to test a carbon storage reservoir in Québec, Canada. The operation will include an injectivity test to estimate the optimal injection rate for CO_2 into the storage reservoir and the volume that can be stored in the reservoir at a depth of approximately 3,280 feet below the surface in the Potsdam (a Cambrian age sandstone formation).

From *Carbon Capture Journal*. September 2021.

Energy Companies Collaborate on Large-Scale CCS Project.

Energy companies Air Liquide and TotalEnergies announced a collaboration on a large-scale CCS project in Normandy, France. Air Liquide will use its carbon capture technology to help reduce the CO_2 released by TotalEnergies' hydrogen production unit, and TotalEnergies will manage the transportation and storage process through projects such Norway's Northern Lights and the Dutch Aramis CCS project. Air Liquide's technology has the potential to reduce CO_2 emissions from the unit's hydrogen production by approximately 650,000 metric tons per year by 2050.

From *gasworld*. September 2021.

DECEMBER 2021

North Dakota Approves CCS Project.

The North Dakota Industrial Commission approved a CCS project, marking the first time a CCS project in the United States has fallen under the authority of a state rather than the U.S. Environmental Protection Agency. North Dakota received primacy of Class VI wells in 2018, giving the state primary regulatory authority over the use of wells for underground CO_2 injection. The project involves Red Trail Energy capturing CO_2 from its ethanol facility near Richardton, North Dakota, with the intent to inject and store approximately 180,000 metric tons of CO_2 per year.

From *Upstream*. October 2021.

Clean Energy Complex to Feature CCS.

Air Products plans to build, own, and operate a project that will produce more than 750 million standard cubic feet per day of blue hydrogen in Louisiana (USA). The "blue" products at the clean energy complex will be produced utilizing hydrocarbons as a feedstock, with the CO_2 in the production process captured for storage.

From *Air Products*. October 2021.

Partnership to Accelerate CCUS Technology.

Aker Carbon Capture and U.K. waste management company Viridor announced plans for a partnership for next-generation modular CCUS technology. Viridor plans to explore the installation of modular CCS plants on five of its waste-to-energy sites across the U.K. The modular plants enable the CCUS technology to be deployed more quickly following planning and permitting.

From *Aker Carbon Capture*. October 2021.

Consortium to Explore CCS Opportunities in Australia.

Woodside, BP, and Japan Australia LNG formed a consortium to advance feasibility studies for a CCS project near Karratha in Western Australia. The consortium will assess the technical, regulatory, and commercial feasibility of capturing CO_2 released by multiple industries located near Karratha on the Burrup Peninsula and storing it in offshore reservoirs in the Northern Carnarvon Basin.

From *Rigzone*. November 2021.

Companies Agree on Full-Scale Pilot Retrofit of CCS System.

Wärtsilä Exhaust Treatment and Solvang ASA, a Norwegian shipping company, agreed on a full-scale pilot retrofit installation of a CCS system on one of Solvang's ethylene carriers. Wärtsilä will design the retrofitted unit while it also completes a land-based, 1-megawatt (MW) test system. The land-based unit is planned for completion in 2021, and the companies project completion of the retrofit pilot system by 2023.

From *The Maritime Executive*. October 2021.

Large-Scale Facility to Convert CO_2 to Fuel.

Preliminary engineering and design has begun on a large-scale, commercial facility in British Columbia, Canada, that will capture CO_2 and convert it to clean fuels. Clean energy company Huron Clean Energy will partner with The Upper Nicola Band, Oxy Low Carbon Ventures, and Carbon Engineering (CE) on the facility, which will combine atmospheric CO_2 with hydrogen to produce fuels. The proposed facility is being designed to utilize CE's technologies to capture atmospheric CO_2 and deliver up to 100 million liters of carbon fuel each year.

From *Carbon Engineering*. October 2021.

JANUARY 2022

Partnership to Explore CCS Opportunities.

Malaysia state energy firm Petronas and ExxonMobil announced a partnership to explore opportunities in CCS technologies. According to the MOU, both companies plan to assess the viability of potential CCS projects in select locations offshore Peninsular Malaysia and identify suitable technology for potential application. In addition, the companies will share subsurface technical data to enable CO_2 storage assessment and characterization.

From *Reuters*. November 2021.

Companies Plan CCS Project on US Gulf Coast.

U.S.-based companies Talos Energy and Freeport LNG Development signed an LOI to develop a CCS project on the U.S. Gulf Coast. The Freeport LNG CCS project will be built next to Freeport LNG's natural gas pre-treatment facilities near Freeport, Texas, which is within 25 miles of an industrial cluster that could provide up to 15 million metric tons per year of additional CO_2. Talos will manage and operate the project with partner Storegga Geotechnologies, which *signed an MOU with Talos* earlier in 2021 to explore CCS opportunities in the Gulf region.

From *Upstream*. November 2021.

MOU to Explore CO_2 Liquefaction, Storage Facility.

Singapore LNG Corporation Pte Ltd and Linde Gas Singapore Pte Ltd signed an MOU to explore the feasibility and development of a CO_2 liquefaction and storage facility in Singapore. The project will initially target the liquefaction, storage, and transport of CO_2 for the project partners, but could potentially be scaled-up to handle CO_2 from more sources, with an open-access, multi-user concept.

From *Singapore LNG Press Release*. November 2021.

Project to Test Subsea Pipelines for CO_2 Transport.

DNV, Wintershall Noordzee, and the OTH Regensburg University of Applied Sciences are exploring how existing natural gas pipelines in the southern North Sea can be used for the future transport of CO_2. The large-scale CO_2 pipeline testing includes a comparison of the pipe in a submerged (water) condition versus the pipe in open air. The aim of the tests is to better define the model parameters used for different backfill types. The large-scale testing of the CO_2 pipelines will take place at DNV's Testing and Research Facility at Spadeadam in the United Kingdom (UK).

From *DNV News*. November 2021.

Summit Carbon Solutions Begins Test Well Drilling.

Summit Carbon Solutions has begun testing the potential for CO_2 storage at a carbon storage hub in North Dakota, USA. In addition to drilling stratigraphic test wells, Summit received state and local permits to collect 3D seismic data on approximately 200 square miles of land in western North Dakota. The company will use the resulting data to create a 3D model that will provide the basis for simulation, design, and permitting of CO_2 storage facilities.

From *Carbon Capture Journal*. December 2021.

Companies Agree to Provide CO_2 Transport, Storage Services.

Navigator CO_2 Ventures will provide CO_2 transportation and storage services to OCI's Iowa Fertilizer Company facility under an agreement for up to 1,130,000 metric tons of CO_2 per year. The project will have two phases; start of operations for the first phase is projected for 2024.

From *Business Wire*. December 2021.

Danish Energy Agency Funds CCS Project.

The Danish Energy Agency will fund a CCS project in the North Sea. Project Greensand will transport CO_2 by ship to the Nini West reservoir off Denmark and inject it via the offshore wellhead platform. The CO_2 will be stored in depleted oil and gas sandstone reservoirs beneath the seabed, and existing infrastructure will be repurposed from oil and gas production to CO_2 injection.

From *Offshore Engineer*. December 2021.

FEBRUARY 2022

CarbonSAFE Project Drills Second Exploratory Well.

DOE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Wyoming team began drilling a second characterization test well near Basin Electric Power Cooperative's Dry Fork Station (near Gillette, Wyoming). Adjacent to the first well (completed in 2019), the second well will allow researchers to gather data and more fully characterize the geologic layers of the subsurface site. *CarbonSAFE Initiative* projects focus on the development of geologic storage sites for the storage of 50+ million metric tons of CO_2 from industrial sources. The Wyoming CarbonSAFE team is led by the University of Wyoming School of Energy Resources (SER).

From *University of Wyoming News Release*. January 2022.

Dutch Energy Companies Sign Contract for CCUS Project.

Air Liquide, Air Products, ExxonMobil, and Shell signed contracts with the Port of Rotterdam CO_2 Transport Hub and Offshore Storage (Porthos) project, which will store 2.5 million metric tons of CO_2 as of 2024. The Porthos project will transport the CO_2 to a depleted gas field approximately 12 miles off the coast; it will then be stored under the North Sea seabed.

From *Offshore Energy*. December 2021.

Denmark Awards Grant to CCS Project.

The Danish Energy Agency awarded a grant to a consortium backing the Greensand CCS project in the North Sea. Greensand is located off the coast of Denmark and has a storage potential of up to 1.5 million metric tons of CO_2 per year from 2025, increasing to 8 million metric tons per year by 2030.

From *Reuters*. December 2021.

CCS Project Supported with New Platforms.

Neptune Energy will develop new "digital twins" of two drilling and production platforms in support of its offshore CCS project. The global exploration and production company will use digitized versions of the area to reduce costs and environmental impacts by enabling engineers to work onshore. The digitized versions will allow engineers to conduct work from onshore locations and advance the CCS facilities.

From *Gas World*. December 2021.

Partnership to Explore CCS in Malaysia.

Malaysia's state oil firm Petronas and Royal Dutch Shell signed an agreement to collaborate on CCS in Malaysia. Under the agreement, Petronas and Shell will perform an integrated CCS development plan study at several locations offshore Sarawak. The scope of the agreement includes exploring the provision of decarbonization services to Shell's local and cross-border facilities, as well as to other potential regional customers.

From *Reuters*. January 2022.

EPA Approves CCS Project in Permian Basin.

The U.S. Environmental Protection Agency (EPA) approved Lucid Energy Group's monitoring, reporting, and verification (MRV) plan to store CO_2 in the Permian Basin. The MRV plan documents Lucid's means of safely ensuring the capture and storage of CO_2 from its Red Hills gas processing complex in Lea County, New Mexico (USA). *Lucid Energy Group* is a privately held natural gas processor in the Permian Basin servicing New Mexico and West Texas.

From *Lucid Energy Group News*. January 2022.

ADM Signs CO_2 Capture, Transport Deal.

Archer Daniels Midland (ADM) signed an LOI with Wolf Carbon Solutions to build a pipeline that would capture and transport CO_2 from ADM's ethanol facilities in Iowa (USA) to a storage site in Decatur, Illinois, USA. The 350-mile steel pipeline is expected to be capable of transporting 12 million metric tons of CO_2 per year, according to ADM.

From *Reuters*. January 2022.

Summit Carbon Solutions, Northern Plains Nitrogen, Partner on CCS Project.

Summit Carbon Solutions and *Northern Plains Nitrogen (NPN)* will partner on a CCS project focused on decarbonizing the agriculture and biofuels industries. NPN will capture 500,000 tons of CO_2 emissions per year at a blue ammonia plant under development near Grand Forks, North Dakota, that will supply low-carbon nitrogen-based fertilizer in the northern United States and Canada. Summit Carbon Solutions will transport and store the CO_2 in central North Dakota.

From *Summit Carbon Solutions News*. January 2022.

MARCH 2022

CCS Project Releases Finalized Datasets.

Complete datasets from the Illinois Basin–Decatur Project (IBDP), which concluded in 2021, are available through *DOE's Energy Data eXchange (EDX)*. Over three years, through this CCS R&D project, approximately 1 million metric tons of CO_2 captured from the Archer Daniels Midland (ADM) ethanol production facility in Decatur, Illinois, were injected into the Mount Simon Sandstone in the Illinois Basin. The DOE/NETL project was carried out by the Midwest Geological Sequestration Consortium (MGSC). The Illinois State Geological Survey (ISGS) at the University of Illinois was the principal investigator for and manager of the IBDP, with partners including Indiana Geological Survey (now the Indiana Geological and Water Survey), the Kentucky Geological Survey, ADM, Trimeric Corporation, and Schlumberger. Curated datasets are also being released through *CO_2DataShare*, an international open-access portal managed by SINTEF.

From *The University of Illinois Prairie Research Institute*. March 2022.

CO_2 Storage Hub Planned.

Denbury Carbon Solutions and a subsidiary of Natural Resource Partners (NRP) executed a CO_2 storage agreement for the evaluation and potential development of a CO_2 storage site located on Alabama's Gulf Coast. Under the agreement, Denbury will look to develop a CO_2 storage site on approximately 75,000 acres of pore space controlled by NRP near Mobile, Alabama, USA. According to Denbury, the total CO_2 storage potential of the site is estimated to be more than 300 million metric tons.

From *Denbury Press Release*. February 2022.

Indigenous Communities and Energy Infrastructure Company Advance CO_2 Storage.

Energy infrastructure company Enbridge Inc. and the First National Capital Investment Partnership (FNCIP) reached an agreement to advance the proposed Open Access Wabamun Carbon Hub west of Edmonton, Alberta, Canada. The hub is being developed as a combination of CO_2 transport and storage solutions. The FNCIP was formed by four *Treaty 6 Nations* (Alexander First Nation, Alexis Nakota Sioux Nation, Enoch Cree Nation, and Paul First Nation) to pursue ownership in infrastructure projects with commercial partners who share Indigenous values.

From *Enbridge News Release*. February 2022.

Australian LNG Company Secures CO_2 Storage Reservoirs.

Australian gas producer Santos *secured a network* of depleted gas reservoirs that has the potential to store approximately 100 million metric tons of CO_2, according to the company. The onshore storage reservoirs, located in northeastern South Australia, previously held natural gas, but have been repurposed for CO_2, which Santos plans to capture in its future Moomba CCS project. The booking of storage resources was in accordance with the *SPE CO_2 Storage Resource Management System (SRMS)*. DOE/NETL's foundational *Site Characterization Best Practices Manual* included a similar classification system.

From *Financial Times*. February 2022.

Wyoming Energy Authority Awards Grant for CCS Project.

The Wyoming Energy Authority (WEA) awarded a grant to Tallgrass Energy to fund the development of a commercial-scale CO_2 storage hub in the Denver-Julesburg Basin in eastern Wyoming, USA. The Eastern Wyoming Sequestration Hub project is designed to provide a means of capturing, transporting, and storing CO_2 across multiple states. Tallgrass Energy expects to utilize the WEA grant this year to fund development activities and drill a characterization well in connection with its anticipated Class VI permit filing for the hub.

From *Journal of Petroleum Technology*. January 2022.

Rig to Drill Carbon Storage Well.

The semisubmersible rig "Transocean Enabler" will drill a new carbon injection well for the Northern Lights carbon storage project in the Norwegian North Sea. Northern Lights is the transport and storage component of a larger Norwegian project, Longship, for storing industrial CO_2 emissions. The captured CO_2 will be shipped from industrial capture sites to a terminal in Øygarden, Norway, for intermediate storage before being transported by pipeline for storage.

From *The Maritime Executive*. January 2022.

Norwegian CCS Project to Expand.

The European Union (EU) approved funding for an expansion of the Norwegian CCS project Northern Lights. According to the Northern Lights joint venture (owned by Equinor, TotalEnergies, and Shell), the funding is planned for FEED studies on the expansion of the project's CO_2 transport and storage capacity, including subsea facilities and capacity increase of the onshore receiving terminal in Øygarden, Norway; a second jetty to cater for additional volumes of imported CO_2 from larger ships; additional intermediate storage for CO_2 with additional volume; and additional CO_2 export pumps.

From Offshore Engineer. January 2022.

Carbon Storage Project Being Considered Off Australian Coast.

Mitsubishi Corp. and Mitsui & Co. are studying the feasibility of commercializing a CCS project on the seabed off the coast of Australia. According to reports, the two Japanese companies will likely carry out the project, which is expected to take place off Western Australia, in cooperation with other resources companies.

From *Japan Today*. January 2022.

Liquified CO_2 Transport and Storage Company to be Developed.

Two shipping companies will collaborate on the development of a global liquified CO_2 marine transportation and storage business. NYK (Japan) and Knutsen (Norway) formed the joint venture company *Knutsen NYK Carbon Carriers*, which will utilize Knutsen's patented technology that enables transport of liquified CO_2 at ambient temperatures. The liquified CO_2 loading and offloading, both onshore and offshore, will be conducted through the company's Knutsen NYK Offshore Tankers.

From *gasworld*. January 2022.

APRIL 2022

Companies to Develop CO_2 Capture, Transport, and Storage Service.

Talos Energy signed a Memorandum of Understanding (MOU) with EnLink Midstream to jointly develop an industrial-scale CO_2 capture, transport, and storage service in Louisiana (USA). Portions of EnLink's existing regional pipeline infrastructure will be used, as will Talos' River Bend CCS site, which includes more than 26,000 acres of pore space and provides more than 500 million metric tons of CO_2 storage capacity.

From *Journal of Petroleum Technology*. February 2022.

CCS Projects to Be Developed in Australia.

Santos, SK E&S, K-CCUS Association, CO_2CRC, and Korea Trade Insurance Corporation signed an MOU to support and collaborate on the development of CO_2 storage facilities in the Australia region. CCS at Bayu-Undan has the potential capacity to store approximately 10 million metric tons of CO_2 per year. In addition, Santos *also announced* the beginning of the FEED phase of a proposed Bayu-Undan CCS project.

From *Santos Media Release*. February 2022.

Collaboration to Accelerate CCS Projects Across Europe.

Aker Carbon Capture and Northern Lights JV—a CO_2 reduction project developer—signed an MOU to collaborate on the acceleration of CCS projects in Norway and across Europe. The MOU builds on lessons learned from the Longship project—a Norwegian government effort to develop technology for full-scale CCS in Norway. Operations are expected to begin in 2024.

From *gasworld*. February 2022.

Exxon Announces Plans for CCS Project.

ExxonMobil announced plans for a CCS project at its Baytown refinery near Houston, Texas (USA). Along with a planned hydrogen production plant, the complex would be part of the company's effort to create a CCS zone along the Houston Ship Channel. A final investment decision is pending regulatory permits and engineering studies. In addition, Exxon also announced plans to *expand CCS at its LaBarge, Wyoming, facility*. The expansion project is expected to capture up to an additional 1.2 million metric tons of CO_2 per year (approximately 6–7 million metric tons are currently captured at LaBarge each year).

From *Reuters*. March 2022.

Companies to Develop Flexible CO_2 Transportation Solutions.

Aker Carbon Capture and Dan-Unity CO_2—a Danish CCS-specific shipping entity—will collaborate on the development of CO_2 transport solutions with the aim of establishing a full CCUS value chain. The companies will explore the development potential of future CCS value chains by collaborating on market analysis and insight and utilizing their industry expertise to identify technical and commercial risks across the CCS value chain, including capture and liquefaction technology, loading and offloading operations, offshore offloading, intermediate storage, and subsurface storage.

From *Aker Carbon Capture Press Release*. February 2022.

MAY 2022

Equinor Awarded CO_2 Licenses.

The Royal Norwegian Ministry of Petroleum and Energy awarded Equinor two licenses to develop CO_2 storage in the North Sea and in the Barents Sea. The two licenses—referred to by Equinor as "Smeaheia" and "Polaris"—are considered building blocks for developing the Norwegian continental shelf. Through these two projects, Equinor aims to contribute to CO_2 reductions equivalent to half of Norway's annual emissions.

From *Equinor News*. April 2022.

LOI to Develop Australia's Offshore Carbon Storage.

Marine geophysics firm PGS ASA (PGS) and CCS project developer deepC Store (DCS) signed a Letter of Intent (LOI) to develop offshore carbon storage in Australia. As part of the collaboration, PGS will provide geologic and geophysics advice on projects developed and operated by DCS.

From *gasworld*. March 2022.

Carbon Storage Licenses Awarded in Southern North Sea.

Britain's North Sea Transition Authority (NSTA) awarded energy firms Equinor and BP two carbon storage licenses on the United Kingdom Continental Shelf off the coast of Humberside. Combined with existing nearby licenses held by the Northern Endurance Partnership (which includes Equinor and BP), the licenses have the potential to enable the storage of up to 23 million metric tons of CO_2 per year, *according to NSTA*.

From *Reuters*. May 2022.

CCS Venture Proposed for Texas Gulf Coast.

BP and industrial gas supplier Linde launched a CCS venture proposed for the Texas Gulf Coast. The offshore facility aims to collect up to 100 million metric tons of CO_2 annually. The project, which targets a 2026 startup, will begin storing CO_2 from Linde's hydrogen gas plants. BP will develop and permit the venture's subterranean sites, and Linde will provide gas compression technology.

From *Reuters*. May 2022.

JUNE 2022

Companies Announce Partnership to Develop CCS Project.

Lapis Energy—an infrastructure investment firm—and LBS Industries—a chemical product manufacturer for the agricultural, mining, and industrial markets—entered into an agreement to develop a CCS project at LSB Industries' El Dorado, Arkansas, facility (USA). Subject to the approval of a U.S. Environmental Protection Agency (EPA) Class VI permit, the project is projected to be completed by 2025, at which time CO_2 injections would begin. Once operational, the project would have the potential to initially capture and store more than 450,000 metric tons of CO_2 per year, with the potential to increase that amount, according to the companies.

From *Business Wire*. April 2022.

Chevron Signs on to Joint Venture to Develop CCS Hub.

U.S. oil company Chevron signed a Memorandum of Understanding (MOU) with U.S. oil company Talos and CCS project development and finance company Carbonvert to join their joint venture to develop an offshore CCS hub. The Bayou Bend CCS project—a *2021 joint venture* between Talos and Carbonvert—encompasses more than 40,000 acres and, according to the preliminary estimates, has the potential to store 225–275 million metric tons of CO_2 from industrial sources in the area (offshore Beaumont and Port Arthur, Texas).

From *Offshore Engineer*. May 2022.

FEED Contract Awarded for CCS Project.

A FEED contract for a Malaysian CCS project was awarded to a consortium led by the National Petroleum Construction Company (NPCC). Per the terms of the contract, consortium member Technip Energies—a provider of consulting, engineering services, and technologies for the low-carbon energy market—will provide project management and technological capabilities, while NPCC will utilize its offshore installation experience and fabrication capabilities. The Kasawari CCS project is located off the coast of Sarawak, Malaysia, and is expected to average 3.7 million metric tons of CO_2 annually.

From *Construction Review Online*. April 2022.

Summit Carbon Solutions Joins CO_2 Storage Project.

Summit Carbon Solutions, an Iowa (USA) pipeline builder, announced plans to collaborate with Minnkota Power Cooperative to develop a CO_2 storage facility. The project would include capturing and storing CO_2 from Minnkota's Milton R. Young Station near Center, North Dakota (USA). Summit has also proposed a pipeline across five states, including Iowa, that would capture CO_2 at ethanol, fertilizer, and other industrial agriculture facilities, liquefy it under pressure, and then transport it via the pipeline to North Dakota for storage.

From *Des Moines Register*. April 2022.

JULY 2022

Red Trail Energy Begins CCS Operations.

Red Trail Energy LLC (RTE) announced the start of CCS operations at its ethanol facility located near Richardton, North Dakota (USA). According to RTE officials, it is the first CCS project allowed under state primacy in the United States. In October 2021, the North Dakota Industrial Commission approved the EPA Class VI injection well and the reservoir space RTE needed to operate the facility. The RTE ethanol plant releases an average of 180,000 metric tons of CO_2 per year from the fermentation process during ethanol production. With CCS, RTE will capture 100% of their CO_2 emissions from the fermentation process and inject approximately 500 metric tons of CO_2 per day. The CO_2 will then be stored below the surface in the Broom Creek formation.

From *Ethanol Producer Magazine*. July 2022.

Companies Reach Agreement to Transport, Store CO_2.

Denbury Carbon Solutions and PCS Nitrogen Fertilizer (a subsidiary of Nutrien Ltd.) reached a term sheet agreement under which Denbury would transport and store CO_2 captured from a potential clean ammonia project in Geismar, Louisiana. Nutrien is evaluating its ammonia facilities in the area as a potential site for the project, which is expected to capture approximately 1.8 million metric tons per year of CO_2. Under the agreement, Denbury would transport and store the CO_2 in Denbury's storage sites.

From *Business Wire*. May 2022.

Companies to Develop Louisiana Carbon Storage Project.

TotalEnergies, Mitsui, Mitsubishi, and Sempra Infrastructure signed a participation agreement to develop the proposed Hackberry Carbon Sequestration (HCS) project in Southwest Louisiana (USA). Under the agreement, the combined Cameron Liquefied Natural Gas (LNG) Phase I and proposed Phase II export projects would potentially serve as the source for the capture and storage of CO_2 by the HCS project. Last year, the HCS project applied for a Class VI Injection well permit from EPA for storage of up to 2 million metric tons of CO_2 per year.

From *Carbon Capture Journal*. May 2022.

Energy Companies to Study CCUS in Oman.

Two development companies signed an agreement to study the potential for CCUS in Oman. Shell Development Oman and Petroleum Development Oman will explore key factors (i.e., technical matters, project time frame and cost, and support for a regulatory and fiscal framework) for CCUS in the country, with the aim of scaling-up Oman's CCUS industry while also working toward net-zero emissions.

From *Gas World*. May 2022.

Loan Approved for Project Tundra.

Minnkota Power Cooperative received approval for a $100 million loan to help advance Project Tundra—an effort at the Milton R. Young Station in North Dakota (USA) to capture and store more than 90% of the CO_2 emissions produced by the coal-based plant. Authorized by the North Dakota Industrial Commission, the loan was made available through the state's Clean Sustainable Energy Authority. Project Tundra is in an advanced stage of development, which includes having a fully permitted CO_2 storage facility and an EPA-approved monitoring, reporting, and verification (MRV) plan for CO_2 storage.

From *Carbon Capture Magazine*. May 2022.

Japanese Companies to Join CCS Project.

Three Japanese energy companies plan to join a CCS project in Australia. JERA, Tokyo Gas, and Inpex will look to transport, by sea, CO_2 released during the production of LNG in Japan to Australia for storage. The CCS plant, led by oil and gas company Santos, could have the potential to store up to 10 million tons of CO_2 per year. Planned for northern Australia, the plant is expected to be operational around 2025.

From *Nikkei Asia*. June 2022.

Ethanol Plant to Transport CO_2 to Wyoming for Storage.

An ethanol plant in Eastern Nebraska has agreed to transport its CO_2 to a future storage plant in Wyoming (USA). According to company officials from Tallgrass, the system will be capable of capturing 10 million tons of CO_2 annually from an Archer Daniels Midland (ADM) plant in Columbus, Nebraska. The CO_2 will be transported through a former 400-mile natural gas pipeline to a storage hub in eastern Wyoming.

From *Brownfield Ag News*. May 2022.

Energy Producer Plans CCS Project.

Columbian energy producer Ecopetrol announced plans to start a pilot CCS project in 2023. According to company officials, the pilot aims to capture 1 million metric tons of CO_2 from its refineries and store it in a gas-depleted reservoir.

From *Reuters*. May 2022.

Thai Company Looking to Develop CCS Project.

Thailand's national oil and gas company PTT Exploration and Production (PTTEP) announced plans to develop the country's first CCS project, as well as the initiation of CCS feasibility studies in other areas of Thailand. PTTEP concluded the feasibility study of its Pioneer CCS Project at the Arthit gas field, which covered the preliminary assessment of the carbon storage capacity of targeted geologic storage formations and a conceptual development plan. According to the company, the project is undergoing a pre-FEED study and is expected to start CCS operations by 2026. PTTEP *signed a Memorandum of Understanding (MOU)* with JGC Holdings and Inpex in April 2022 to study the potential development of CCS solutions to help industries reduce their CO_2 emissions.

From *Offshore Energy*. June 2022.

AUGUST 2022

Shell to Build Ships to Carry More CO_2 for CCS Hubs.

Shell announced plans to build larger vessels that can carry more CO_2 over longer distances to offshore CCS hubs. As part of the Northern Lights project in Norway, Shell has a joint venture with Equinor and TotalEnergies to build two ships capable of carrying 7,500 cubic meters of CO_2. Shell is leading the design and construction of the vessels, which will be powered by liquefied natural gas. The ships are expected to be ready for delivery in 2024.

From *Reuters*. June 2022.

C-Capture Awarded CCUS Innovation 2.0 Program Funding.

CDR firm C-Capture was awarded funding from the UK Department for Business, Energy, and Industrial Sector (BEIS) as part of the CCUS Innovation 2.0 Program aimed at accelerating the deployment of next-generation CCUS technology in the UK. C-Capture's project, called XLR8 CCS, uses a class of capture solvents that are free of amine and nitrogen and can be manufactured on a large scale. C-Capture also recently secured a grant from the UK government to advance its bioenergy and carbon capture and storage (BECCS) project at Drax Power Station in North Yorkshire, England.

From *The Chemical Engineer*. June 2022.

Climeworks to Launch DAC Plant.

Swiss climate tech firm Climeworks broke ground on a large-scale direct air capture (DAC) plant in Iceland. The DAC facility, called "Mammoth," will have the potential to capture 36,000 tons of CO_2 per year when fully operational. Carbon storage firm CarbFix will store the CO_2 and ON Power will supply the plant and the CO_2 injection sites with renewable energy to run the DAC and storage process. Construction is expected to last 18–24 months.

From *Reuters*. June 2022.

Canadian CCUS Plant Announced.

Teck Resources Limited announced a CCUS pilot project at its Trail Operations metallurgical complex in southern British Columbia, Canada. The plant will capture CO_2 from the acid plant flue gas at Trail Operations at a rate of 3 metric tons per day. Expected to begin operation in 2023, the pilot project will also evaluate options for the utilization and/or storage of the captured CO_2. If successful, the project could be scaled up to an industrial CCUS plant with the potential to capture more than 100,000 metric tons of CO_2 per year at Trail Operations.

From *Teck News Release*. June 2022.

Lease Agreement for CCS Project in Louisiana Announced.

1PointFive, a CCUS platform and subsidiary of Occidental's Low Carbon Ventures business, and Manulife Investment Management entered into a lease agreement for a CCS project in Louisiana, USA. The agreement provides 1PointFive with access to subsurface pore space and surface rights to develop and operate a carbon storage hub on approximately 27,000 acres of timberland in western Louisiana. Two EPA Class VI injection permits have been filed for the site. The companies are also exploring other locations and projects with the potential to add additional acreage for CO_2 removal and storage.

From *GlobeNewswire*. June 2022.

Collaborative Agrees to Progress CCS Project.

Neptune Energy, Rosewood Exploration Ltd, EBN Capital BV, and ExxonMobil subsidiary XTO Netherlands Ltd. signed a cooperation agreement to progress a large-scale, offshore CCS project in the Dutch North Sea. The agreement intends to have the project FEED-ready by the end of 2022, followed by a storage license application. This CCS project has the potential to store 4–5 million tons of anthropogenic CO_2 annually in the exhausted gas fields located in Neptune-operated L10-A, B, and E areas. The L10 area would be the first step in the development of CO_2 storage.

From *Pipeline Technology Journal*. June 2022.

Companies to Evaluate Potential CCS Hub in China.

ExxonMobil, Shell, China National Offshore Oil Corporation (CNOOC), and Guangdong Provincial Development & Reform Commission initiated a joint study to identify CCS opportunities. The companies and local authorities signed a Memorandum of Understanding (MOU) to evaluate a potential CCS hub project at the Dayawan Petrochemical Industrial Park in Huizhou, Guangdong Province, China. As part of the agreement, the companies will also evaluate the carbon policy systems in China and propose policies for consideration that would support the deployment of CCS in Dayawan Petrochemical Industrial Park.

From *Offshore Energy*. June 2022.

SEPTEMBER 2022

Denbury Adds CCS Site in Louisiana.

Energy company Denbury announced the expansion of its CO_2 storage portfolio with an additional storage site in Louisiana (USA). Denbury signed an agreement with a landowner to lease approximately 18,000 acres of land near Donaldsonville, Louisiana, for future CO_2 storage. The site is located less than five miles from Denbury's existing CO_2 Green Pipeline and in close proximity to the Louisiana Industrial Corridor. Denbury estimates more than 50 million metric tons per year of existing stationary CO_2 emissions are located within 30 miles of the site.

From *Denbury Press Release*. July 2022.

CCUS MOU Signed in Midwest United States.

Chart Industries and Wolf Carbon Solutions signed a Memorandum of Understanding (MOU) focused on CCUS in the Midwest United States. The MOU will support refineries, cement, steel, and petrochemical companies to capture, transport, and store CO_2 emissions from industrial facilities. Chart's Sustainable Energy Solutions technology will be deployed at a number of host sites, where CO_2 emissions will be captured and stored in Wolf Carbon Solutions' Mt. Simon Hub pipeline (which will run from Cedar Rapids, Iowa, to central Illinois).

From *gasworld*. July 2022.

Companies Collaborate to Reduce CCS Costs.

Global technology company ABB and CCS solutions company Captimise are collaborating to assist industrial CO_2 emitters with incorporating CCS into their operations. The companies will work with operators to assess alternative technologies and plant configurations available to achieve CCS.

From *Industry and Energy*. July 2022.

Japanese Companies to Explore CCS in Malaysia.

A trio of Japanese energy companies agreed to explore the viability of CCS technology in Malaysia. Japan Petroleum Co. Ltd. (JAPEX), JGC Corporation, and Kawasaki Kisen Kaisha Ltd. agreed to investigate suitable sites for CO_2 storage and methods to capture and transport the CO_2 from the Petronas liquified natural gas complex in Malaysia, in addition to the possibility of transporting it from outside the country.

From *gasworld*. August 2022.

CCS Project to Be Developed in Thailand.

PTT Exploration and Production (PTTEP) announced plans to develop a CCS project at the Arthit offshore gas field in Thailand. Currently in the pre-FEED phase, the project is expected to store 1 million metric tons of CO_2. A final investment decision is expected in 2023, with the CCS facility projected to be operating by 2026. PTTEP plans to carry out more feasibility studies for CCS projects in Thailand and is also collaborating to establish a Thailand CCUS consortium for the adoption of CCUS in the country's industrial sector.

From *Energy Voice*. August 2022.

California Carbon Management Projects Net Investment.

A Canadian-based asset management firm agreed to invest in California Resources Corporation's (CRC) plans to develop carbon management projects in California (USA). CRC's joint venture, with a fund run by Brookfield Asset Management Inc., will provide $10 per metric ton of CO_2 injected into a geologic formation in the Elk Hills oil field (proposing up to 5 million tons of CO_2 per year).

From *The Bakersfield Californian*. August 2022.

LEGISLATION and POLICY

OCTOBER 2021

Canada to Review Calls for CCUS Studies.

Natural Resources Canada sought *expressions of interest* to support CCUS across Canada. Funded under Canada's Energy Innovation Program, the call supported front-end engineering and design studies that have the potential to reduce the impact of carbon emissions. Following the review process, successful applicants will be invited to submit full project proposals later this year. As part of their 2021 budget, the Canadian federal government is investing in research, development, and demonstrations to advance the commercial viability of CCUS technologies. From *Natural Resources Canada News Release*. August 2021.

Australian Government to Fund Carbon Storage Projects.

The Australian government plans to fund carbon storage activities in the southwest land division of Western Australia. The Western Australian Carbon Farming and Land Restoration Program will provide funding to projects that utilize agriculture's potential to store carbon in the landscape and contribute to the growth of the Western Australian carbon farming market. Funding amounts will be determined after assessing the expressions of interest, which were accepted through September 2021. From *business.gov.au*. September 2021.

NOVEMBER 2021

Bill Contains Historic CCS Infrastructure Investment.

The U.S. House of Representatives passed *the Infrastructure Investment and Jobs Act*, which contains the largest appropriation of money for CCS in the history of the technology. The bill contains major provisions for CCS, including $2.5 billion appropriated for CCS demonstration projects, $1 billion for large-scale CCS pilot projects, and $3.5 billion for regional DAC hubs over the next five years. The bill also contains the *Storing CO_2 And Lowering Emissions (SCALE) Act* in its entirety, which will direct nearly $5 billion to support the development and financing of CO_2 transport and storage infrastructure and sites. From *Global CCS Institute*. November 2021.

California to Set CO_2 Storage Goals on State Lands.

Legislation intended to boost CO_2 storage efforts on California state lands was signed into law. *SB 27* will require the state Natural Resources Agency to (1) establish carbon storage goals for natural and working lands by July 2023 and (2) create a registry of projects for public and private investment and track the carbon benefits of each project. Under the bill, the California Air Resources Board (CARB) must establish a specific CO_2 removal target for the state's natural and working lands for 2030 and beyond. CARB will also establish the Natural and Working Lands Climate Smart Strategy to serve as a framework to advance the state's goals. From *Argus Media*. September 2021.

Bill Aims to Store CO_2.

A bill was introduced in the U.S. Senate that aims to increase the natural carbon storage capacity of forests and rangelands. The America's Revegetation and Carbon Sequestration Act directs the U.S. Forest Service and Natural Forest Foundation to develop a carbon credit program for non-federal buyers. Under the current plan, revenue from the carbon market would be used to fund additional carbon storage and emissions mitigation efforts on U.S. Forest Service land. From *Casper Star-Tribune*. September 2021.

Australian Government Invests in CCUS Hubs.

The Australian government announced a program to increase the development of commercial-scale CCUS projects and hubs across the country. *The CCUS Hubs and Technologies Program* will operate across two streams: (1) supporting the design and construction of carbon capture hubs and shared infrastructure and (2) supporting the research and commercialization of carbon capture technologies and the identification of viable storage sites. From *Carbon Capture Journal*. September 2021.

DECEMBER 2021

Australia Announces CCUS Initiatives.

The Australian government announced initiatives encouraging CCUS efforts. Among the initiatives is the CCUS Hubs and Technologies Program, which aims to deploy CCUS at scale by encouraging domestic and international research collaborations and lowering the cost of technology adoption. From *The Chemical Engineer*. October 2021.

Potential Tax Incentives Include CCS Modifications.

The U.S. House Ways and Means Committee released legislation that includes "Green Energy Provisions" that would incentivize cleaner, more efficient operations that focus on reducing emissions. In addition, the provisions contain several modifications to the development of the CCUS market. From *Financial Executives International*. October 2021.

Iowa Task Force to Review Carbon Storage Policy Recommendations.

The Iowa Carbon Sequestration Task Force (USA) *met to discuss policy recommendations* for lawmakers within the state. *Announced in July 2021*, the Carbon Sequestration Task Force is supported by two working groups: the Agriculture Working Group and the Energy Working Group. From *Radio Iowa*. October 2021.

UK Plan Includes CCS Funding.

The U.K. government unveiled its *Net-Zero Strategy*, which includes the funding of two CCS hubs. The East Coast Cluster project will look to develop offshore infrastructure to transport and store CO_2 in the U.K.'s North Sea. The Hynet project plans to produce clean hydrogen and capture and store CO_2 from industry. From *Bloomberg*. October 2021.

North Carolina Bill Calls for CO_2 Reductions.

The Governor of North Carolina (USA) signed a bipartisan energy measure aimed at reducing the state's greenhouse gas emissions in the coming decades. *HB 951* requires the North Carolina Utilities Commission to take steps needed to achieve the goal of reducing energy producers' CO_2 emissions by 70% by 2030 and to reach carbon neutrality by 2050. From *Watauga Democrat*. October 2021.

JANUARY 2022

US Government Establishes Goal to Achieve Net-Zero Carbon Emissions by 2050.

The President of the United States *signed an Executive Order (EO)* directing the U.S. federal government to achieve a goal of net-zero carbon emissions by 2050. In addition, the EO calls for the federal government to use 100% carbon-free electricity and to reduce its CO_2 emissions by 65%, both by 2030. From *The Hill*. December 2021.

FEBRUARY 2022

UK Government Launches BECCS Program.

The United Kingdom (UK) government launched a program to support the development of technologies to produce hydrogen generated from biomass with carbon capture and storage (BECCS). Applicants can bid for a share of government funding under Phase I of the Hydrogen BECCS Innovation Programme to help develop their project plans and demonstrate feasibility. A second phase will follow, providing more funding to the most promising Phase I projects. The program is funded through the UK Department for Business, Energy, and Industrial Strategy.

From *Renewable Energy Magazine*. January 2022.

MARCH 2022

North Dakota Commission Approves Carbon Storage Plans.

The North Dakota Industrial Commission approved storage plans for the Project Tundra carbon capture effort northwest of Bismarck, North Dakota. The project would capture emissions from the Milton R. Young Station power plant operated by Minnkota Power Cooperative. If the project moves forward, construction could start in 2022 and be completed by 2026.

From *The Bismarck Tribune*. January 2022.

Indiana Lawmakers Advance CCS Bills.

The Indiana House Committee on Natural Resources (USA) passed a pair of CCS bills. *House Bill 1249* gives a Vigo County CCS project special liability protections; *House Bill 1209* sets the foundation for a state permitting process for CCS projects. Both bills will next be considered by the full House of Representatives.

From *Indiana Environmental Reporter*. January 2022.

Clean Fuel Standards Act Passes New Mexico Senate.

A bill that would require decreased carbon intensity requirements for transportation fuels in New Mexico, USA, as well as create a carbon credit market to help businesses achieve the requirements, passed the New Mexico Senate. If passed, the Clean Fuel Standards Act has the potential to reduce emissions by approximately 18.5 million metric tons of CO_2, according to the a *press release*. *Senate Bill 14* next goes to the House of Representatives.

From *NM Political Report*. January 2022.

APRIL 2022

West Virginia Legislature Approves Carbon Storage Bills.

Committees in both chambers of the West Virginia (USA) Legislature approved bills that would set up a regulatory program for the underground storage of CO_2. Under *House Bill (HB) 4491* and *Senate Bill (SB) 622*, the state Department of Environmental Protection would be responsible for setting rules for developing and approving underground CO_2 storage facilities. In addition, the bills would require the storage operator to assess the migration of CO_2 injected for storage. HB 622 was referred to the full Senate by the Senate Energy, Industry, and Mining Commission, and HB 4491 was referred to the House Judiciary Committee by the House Energy and Manufacturing Committee.

From *Charleston Gazette-Mail*. February 2022.

Wyoming Looks to Expand CO_2 Storage Network.

Wyoming (USA) lawmakers have created two bills to expand the state's legal and regulatory framework for advancing underground carbon storage and encouraging CCUS at existing coal-fired power plants. *Senate File (SF) 47—Carbon Storage and Sequestration Liability* establishes a process for the state to assume ownership and liability for CO_2 injected into geologic formations. *SF 64—Carbon Capture and Sequestration* addresses regulated utilities and retiring coal-fired power plants in favor of either retrofitting the plants with CCUS technology or selling them (to an owner who will install CCUS technology).

From *WyoFile*. February 2022.

MAY 2022

PUK Government Invests in CCUS.

The UK government announced financial support for CCUS research. The investment follows the announcement of the "*British energy security strategy*," which, according to the Carbon Capture and Storage Association, reaffirms the UK government's commitment to deliver four CCUS clusters by 2030. The new investment includes funding for an international initiative among 14 countries aimed at accelerating CCUS technologies through funding research innovation projects.

From *Carbon Capture Journal*. April 2022.

Legislation Would Create Regulations for CCS Projects.

The Pennsylvania Geologic Storage of Carbon Dioxide Act would establish legislative intent to facilitate carbon capture in the state; designate property rights around storage sites in geologic formations; assign state regulatory authority to CCS facilities in the state; specify the regulatory and permitting process within the existing federal structure; and create a cash fund for sustaining regulatory operations. The U.S. Environmental Protection Agency currently holds the regulatory authority over CCS projects; a Pennsylvania-specific statute will allow the state to facilitate CCS feasibility studies within its own borders. The legislation will next be introduced into the state Senate.

From *Pennsylvania Business Report*. March 2022.

Canadian Budget Proposes CCUS Tax Credit.

The *2022 Canadian Federal Budget* released in April 2022 proposed a refundable investment tax credit for CCUS projects. Under the proposal, from 2022 through 2030, the investment tax credit rates would be set at 60% for investment in equipment for DAC projects; 50% for equipment in other carbon capture projects; and 37.5% for transportation, storage, and use. These rates will be halved for the period from 2031 through 2040.

From *Bloomberg*. April 2022.

JUNE 2022

Legislative Changes to Carbon Storage Projects Proposed in Canada.

The Canadian Ministry of Northern Development, Mines, Natural Resources, and Forestry (NDMNRF) filed a proposal on the Environmental Registry of Ontario website to gather input from stakeholders on possible legislative changes related to carbon storage projects. The proposal aims to narrow prohibitions under the *Oil, Gas, and Salt Resources Act* and the *Mining Act* that relate to CO_2 storage. Possible changes to the regulatory structure also include (1) allowing proponents to voluntarily enter into agreements with NDMNRF to use wells to explore, test, pilot, or demonstrate new technology, such as carbon storage, in areas where oil, gas, and salt resources are typically found; (2) enhancing protections by allowing the issuance of orders related to public or environmental risks; and (3) changing the Mining Act framework to allow the NDMNRF to grant authorizations to use Crown land for carbon storage activities.

From *Mondaq*. April 2022.

Japan Plans Legal CCS Framework.

Japan's industry ministry plans to create a legal framework for CCS to enable companies to begin storing CO_2 underground or under the seabed by 2030. According to the ministry, Japan expects to store approximately 120–240 million metric tons of CO_2 per year in 2050. The Japanese government plans to submit (1) a draft bill to establish a new right to store CO_2 in Japan and limit liability, and (2) a scheme in the legal framework to transport CO_2 released in Japan to other countries for storage.

From *Reuters*. April 2022.

Ohio Legislation Seeks Primacy of Carbon Storage Injection Wells.

Legislation has been signed into law in Ohio (USA) that seeks primacy over EPA Class VI injection wells for carbon storage. *House Bill 175* includes a provision that requires the Ohio Department of Natural Resources to begin the process of seeking primacy over Class VI injection wells for carbon storage from EPA no later than 90 days after the effective date of the bill (the legislation takes effect on July 19, 2022).

From *JD Supra*. April 2022.

JULY 2022

Legislation to Accelerate CDR Introduced.

Legislation to reduce emissions by accelerating CDR technologies was introduced in the U.S. Senate. The *Federal Carbon Dioxide Removal Leadership Act* would leverage federal procurement to create a market for CDR by removing an increasing amount of CO_2 using DAC or other technology-based removal solutions; setting aside 20% of funds for promoting newer, innovative technologies; and prioritizing the creation of jobs domestically, supporting American competitiveness in developing climate solutions, and maximizing the efficacy of CDR techniques. The full bill text is *available for download*.

From *U.S. Senator Sheldon Whitehouse News Release*. May 2022.

AUGUST 2022

US BLM Issues Carbon Storage Policy for Public Lands.

The U.S. Department of Interior's (DOI) Bureau of Land Management (BLM) issued a new policy related to geologic storage of CO_2 on public lands. The new instruction memorandum provides a path for geologic carbon storage projects on BLM-managed lands by providing direction for authorizing rights-of-way (ROWs) for site characterization, transportation, injection, capture, and storage of CO_2 at appropriately classified injection well locations. The *instruction memorandum* ensures consistent processing of ROW applications for carbon storage projects across BLM-managed lands.

From *BLM Press Release*. June 2022.

California (USA) Releases Draft Blueprint to Achieve Carbon Neutrality by 2045.

The California Air Resources Board (CARB) released a proposed plan for the state to achieve carbon neutrality by 2045. The draft 2022 Scoping Plan Update, developed after more than 15 public workshops and meetings, also assesses progress toward meeting the interim statutory mandate of reducing GHG emissions by at least 40% below 1990 levels by 2030. This is the third update to CARB's original 2008 Scoping Plan, which was the original blueprint for achieving the goals of the *California Global Warming Solutions Act of 2006 (Assembly Bill 32)*.

From *Reuters*. June 2022.

Government of Canada Enacts Offset Regulations.

The government of Canada enacted offset regulations that will enable projects governed by the Canadian federal Output-Based Pricing System (OBPS) to generate and sell carbon credits. The carbon credits can be used by facilities covered by the federal OBPS to meet GHG emissions compliance obligations. Requirements for projects registered under the *Canadian Greenhouse Gas Offset Credit System Regulations* are further set out in applicable Canadian federal offset protocols, which describe the approach for quantifying GHG reductions or removals for a given type of project.

From *Lexology*. June 2022.

SEPTEMBER 2022

New Bill on EPA CO_2 Regulations.

A new bill introduced in the U.S. House of Representatives would require EPA to enforce new fuel carbon-intensity standards for ships—specifically commercial voyages, international and domestic, involving any "U.S ports of call." *The Clean Shipping Act of 2022* is modeled on the *European Union's (EU) Fit for 55* regulatory framework for shipping. Under the proposed bill, the GHG intensity would be reduced by 20% in 2027, 45% in 2030, 80% in 2035, and 100% in 2040.

From *The Maritime Executive*. July 2022.

Government of Alberta Investing in CCUS.

The Government of Alberta (Canada), through non-profit *Emissions Reduction Alberta (ERA)*, is investing in 11 projects focused on advancing CCUS in the province. If successful, the projects could lead to the reduction of approximately 24 million metric tons of CO_2 emissions annually. The projects selected under the Carbon Capture Kickstart: Design and Engineering funding opportunity represent industrial sectors such as power generation, cement, fertilizer, forest products, and oil and gas. Projects are expected to be operational by 2030.

From *Emissions Reduction Alberta*. July 2022.

EMISSIONS TRADING

OCTOBER 2021

Québec and California Hold Joint GHG Auction.

Québec (Canada) and California held the 28th joint auction of greenhouse gas (GHG) emission units. In total, 71,261,536 current vintage emission units were sold at $23.30 and 8,306,250 2024 vintage emission units were sold at $23.69. The summary of the auction results is available on the *Québec Ministry website*. The next auction is scheduled for November 17, 2021.

From *Newswire*. August 2021.

Carbon Credits Program Established on State Forest Land.

Michigan's Department of Natural Resources and DTE Energy agreed to establish a carbon credits program on state forest land, leveraging the carbon storage capacity of their trees. The *Bluesource/Michigan DNR Big Wild Forest Carbon Project* offers a portfolio of carbon offset credits generated from sustainable forest management activities on more than 100,000 acres of the Pigeon River Country State Forest in the northern Lower Peninsula.

From *Midland Daily News*. August 2021.

Six Carbon Credit Indices Launched.

S&P Global Platts, an information provider for the commodities and energy markets, announced the launching of six carbon credit indices with environmental technology company Viridios AI. The CARBEX™ carbon credit indices reflect the value of different types of voluntary carbon credits.

From *PR Newswire*. August 2021.

NOVEMBER 2021

Results of 53rd RGGI Auction Released.

The RGGI-participating states announced the results of their 53rd auction of CO_2 allowances. A total of 22,911,423 CO_2 allowances were sold at a clearing price of $9.30, 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 53 generated $213 million for states to reinvest in strategic programs, including energy efficiency, renewable energy, and greenhouse gas abatement programs. Additional details are available in the *Market Monitor Report for Auction 53*.

From *RGGI News Release*. September 2021.

Australia to Issue Credits for CCS.

The Australian government set rules to issue carbon credits for projects to capture and store CO_2. Under the rules, CCS projects will earn one Australian Carbon Credit Unit (ACCU) for each metric ton of carbon emissions avoided. ACCUs can either be sold by auction to the Australian government's Emissions Reduction Fund or on the private market.

From *Reuters*. October 2021.

DECEMBER 2021

Western Australia Legislation to Enable Carbon Trading by Forest Products Commission.

The Western Australia Forestry Minister introduced a bill that would allow the state's Forest Products Commission (FPC) to own and trade carbon assets. The bill would amend the Forest Products Act 2000, under which the FPC was limited to dealing with "forest products." (Forest products are defined to mean trees, parts of trees, and similar products.) The amendments would also allow the FPC to obtain and trade Australian Carbon Credit Units.

From *Government of Western Australia*. October 2021.

JANUARY 2022

Results of 54th RGGI Auction Released.

The RGGI-participating states announced the results of their 54th auction of CO_2 allowances. A total of 27,041,000 CO_2 allowances were sold at a clearing price of $13.00, with bids ranging from $2.38 to $17.00 per allowance. The emissions sold included the initial offering of 23,121,518 allowances, as well as 3,919,482 of the 11.98 million cost containment reserve (CCR) allowances available for sale. (The CCR is a fixed additional supply of allowances that is made available for sale if an auction's interim clearing price exceeds a certain price level [$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 54 generated $351 million 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 54*.

From *RGGI News Release*. December 2021.

FEBRUARY 2022

Vietnam to Pilot Carbon Trade Exchange.

Vietnam plans to set up and pilot a carbon trade exchange beginning in 2025, according to a government decree on GHG emissions. From now until the end of 2027, according to the document, the country will put forward regulations on the management of carbon credits, the exchange of GHG emissions quotas and carbon credits, and the operation of a carbon credit exchange. The carbon trade exchange is expected to be put into official operation in 2028.

From *The Star*. January 2022.

Carbon Permit Trades Up in 2021.

The Intercontinental Exchange (ICE) saw a record number of carbon allowance trades in 2021, up almost 30% from the previous year, according to the company. A total of 18.3 billion tons of carbon allowances were traded on the exchange in 2021 (up from 14.3 billion in 2020). Approximately 15.2 billion tons were trades of European Union allowances (up from 12.17 in 2020); 2.4 billion were California carbon allowances (up from 1.87 billion in 2020); 255 million were from Britain's emission trading system, which launched in 2021; and approximately 346 million were RGGI allowances (up from 231.5 in 2020).

From *Reuters*. January 2022.

Global Carbon Emissions Reduction Contract to Launch.

Net Zero Markets, through signed agreements with the European Energy Exchange (EEX) and AirCarbon Exchange (ACX), will launch Global Emission Reduction (GER)®, a product that will address potential issues in the Voluntary Carbon Market (VCM). Net Zero expects the GER to be progressively listed on the exchanges and commence trading in early 2022.

From *Yahoo! Finance*. January 2022.

MARCH 2022

Europe's Carbon Price Rises.

The price of permits in the EU's carbon market closed at a record high in February 2022, ending the day (February 4, 2022) at 96.43 euros ($109.40 USD), which is the highest closing price since the carbon market launched in 2005. The EU Emissions Trading System requires companies to pay for each metric ton of CO_2 released, providing a financial incentive to reduce emissions and invest in green technologies.

From *Reuters*. February 2022.

APRIL 2022

Results of RGGI Auction Announced.

The 11 states participating in the Regional Greenhouse Gas Initiative (RGGI) announced the results of their 55th auction of CO_2 allowances, during which 21,761269 CO_2 allowances were sold at a clearing price of $13.50. According to the "*Market Monitor Report for Auction 55*," the auction generated $294 million for states to reinvest in strategic programs, including those focused on energy efficiency, renewable energy, and GHG abatement.

From *RGGI News Release*. March 2022.

RGGI Reports Made Available.

The independent market monitor for 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: Fourth Quarter 2021*" addressed the period from October through December 2021. In addition, RGGI's "*2021 Interim Compliance Summary Report*" was also made available; the report contains data regarding CO_2 allowances provided by CO_2 budget sources to meet their 2021 interim control period compliance obligation. (RGGI's fifth three-year control period took effect on January 1, 2021, and extends through December 31, 2023.)

From *RGGI News Release*. February 2022.

MAY 2022

Report on EU Carbon Market.

The European Securities and Markets Authority (ESMA) published its "*Final Report on the European Union Carbon Market*." Based on key findings and in-depth analysis, the report also formulated policy recommendations to improve transparency and monitoring; identified courses of action for consideration by the European Commission (EC); and provided next steps for the EC, Council of the European Union (EU), and the European Parliament to consider to further regulate the carbon market.

From *ESMA*. March 2022.

JUNE 2022

EU Proposal Aims to Unify Carbon Removal Processes.

The European Commission plans to present a proposal to unify the European Union's (EU) carbon-removal measurement, reporting, and verification processes by the end of 2022, according to EU officials. The proposal aims to regulate the bloc's carbon-removal market and will be based on existing verification and certification schemes. The commission's proposal will apply to carbon credits generated in the EU and not to international credits.

From *EURACTIV*. May 2022.

JULY 2022

RGGI Report Tracks Investment of Auction Proceeds.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released a report tracking the investment of proceeds generated from their regional CO_2 allowance auctions in 2020. According to *Investment of RGGI Proceeds in 2020*, which also provides state-specific success stories and program highlights, $196 million in RGGI proceeds were invested in 2020 in programs such as energy efficiency, clean and renewable energy, and GHG abatement. Over their lifetime, these 2020 investments are projected to help households and businesses avoid the emissions of approximately 6.6 million short tons of CO_2.

From *RGGI Press Release*. May 2022.

Indian State to Set Up Carbon Market.

The Gujarat government signed an MOU with the Energy Policy Institute, the University of Chicago, and JPal of South Asia to set up a carbon market. The MOU is in line with the government's commitment to achieving net-zero emissions by 2070.

From *India Today*. May 2022.

Results of 56th RGGI Auction Released.

The RGGI-participating states announced the results of their 56th auction of CO_2 allowances. A total of 22,280,473 CO_2 allowances were sold at a clearing price of $13.90, with bids ranging from $2.44 to $27.00 per allowance. None of the 11.61 million cost containment reserve (CCR) allowances made available were sold, and none of the 10.96 million emissions containment reserve (ECR) allowances made available for withholding were withheld. (The CCR is a fixed additional supply of allowances made available for sale if the auction's interim clearing price exceeds $13.91. The ECR is a designated quantity of allowances to be withheld if the auction's interim clearing price is below $6.42.) Auction 56 generated $309.7 million 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 56*.

From *RGGI Press Release*. June 2022.

AUGUST 2022

Parliament Groups Reach Compromise on EU ETS Reform.

The European Parliament reached a deal on the reform of the European Union's (EU) emissions trading scheme (ETS). The main elements of the agreement include the following: emissions reductions from industries covered by the ETS, which will reach 63% by 2030 compared to 2005 levels; a phase-out of free ETS allowances for industry from 2027 to 2032; initiation of the EU's new carbon border adjustment mechanism in 2033; the Linear Reduction Factor, which defines the annual cap on CO_2 allowances available for auction, will reach 4.6% by 2029 (it will be reduced by 4.4% annually from 2024 to 2026 and by 4.5% from 2026 to 2029); and an agreement on a gradual "rebasing" of the overall level of allowances.

From *EUROACTIV*. June 2022.

EU Votes to Expand Carbon Market.

EU government ministers voted on an expansion of the EU's carbon market to include shipping and road transport. Shipping emitters will have to pay for CO_2 produced when sailing within the EU and 50% of voyages outside the bloc until 2027. After 2027, the scope of the carbon market will be automatically extended to 100% of ships entering and leaving European ports. EU ministers also agreed to a carbon market for road transport and heating (proposed for these emissions to be regulated from 2027).

From *European Federation for Transport and Environment*. June 2022.

SEPTEMBER 2022

International Soil Carbon Credit Issued in UK.

BCarbon, a Houston-based (USA) carbon credit registry, issued an international soil credit to Future Food Solutions in the UK, which created the Futures Carbon Bank to sell credits on the voluntary carbon market. Under the carbon bank program, farmers are encouraged to grow cover crops that store atmospheric CO_2 in the soil while employing no-till practices.

From *British Consulate General Houston*. July 2022.

Cambodia Successfully Sells Carbon Credits.

According to a state official, Cambodia sold carbon credits in the voluntary carbon market, earning ~$11 million from 2016–2020. The kingdom sold three carbon credit projects at the Keo Seima Wildlife Sanctuary in Mondulkiri province, the REDD+ Project at the Southern Cardamom National Park in Koh Kong province, and the Prey Lang Wildlife Sanctuary in Stung Treng province.

From *The Manila Times*. July 2022.

SCIENCE

OCTOBER 2021

DOT Partnering with Port of San Diego in Carbon Storage Study.

The U.S. Department of Transportation (DOT) and the Port of San Diego announced a partnership to study bay wide eelgrass carbon storage. According to the port and DOT's Maritime Administration (MARAD), eelgrass can capture and store large amounts of CO_2 in the plants and soils. MARAD awarded the port a cooperative agreement for a study to assess how much CO_2 is stored in San Diego Bay's eelgrass, as well as how much CO_2 eelgrass could continue to capture in the future.

From *Times of San Diego*. August 2021.

Researchers to Study Feasibility of Using Quantum Gravity Sensors to Monitor CCS Sites.

A research project will consider the feasibility of using quantum gravity sensors to monitor CCS sites. With funding from the UKCCSRC, researchers at the *Quantum Technology* Hub will research how the sensors can contribute to detecting and monitoring CO_2. The project will model the gravity gradient signals of the CO_2 to determine the ability of the cold atom sensors to detect and monitor its migration. The work will investigate how an existing portable cold atom gravity gradiometer could be used to monitor a planned injection of CO_2 at the GeoEnergy Test Bed at the University of Nottingham's Sutton Bonington campus, a facility with multi-sensor technology for CO_2 monitoring research.

From *Carbon Capture Journal*. August 2021.

Study Finds Volcanoes Play Role in Atmospheric CO_2.

Using machine learning (ML) to model Earth's systems, scientists studied the role of volcanoes in the Earth's carbon life cycle. Researchers from the University of Southampton, the University of Sydney, Australian National University, the University of Ottawa, and the University of Leeds used ML algorithms and plate tectonic reconstructions to model interactions within the Earth and how they may have changed over time. Their findings, published in the journal *Nature Geoscience*, found that when fragments of these volcanoes break off and reach the oceans, they trap CO_2 in the atmosphere. According to their research, this means that volcanoes play a balancing act between emitting large amounts of CO_2 while also removing CO_2 through erosion processes.

From *Siliconrepublic.com*. August 2021.

Researchers Develop Fuel Tank to Capture, Store CO_2 on Ships.

Researchers from Northwestern University developed a CO_2-capturing solid oxide fuel cell that captures traditional carbon-based fuels for storage or recycling into renewable hydrocarbon fuel. To store and reuse this CO_2, the researchers invented a patent-pending dual-chamber storage tank. After the carbon emissions are captured by the tank, they would then be offloaded as carbon to be stored at each destination port.

From *Interesting Engineering*. August 2021.

NOVEMBER 2021

Shell Collaborating on Technology for CCS Applications.

Shell and BASF are collaborating to evaluate and deploy BASF's Sorbead® Adsorption Technology for pre- and post-combustion CCS applications. The technology is used to dehydrate CO_2 gas after it has been captured by Shell's carbon capture technologies. According to the companies, the technology treats the CO_2 gas to meet pipeline and underground storage specifications.

From *BASF News Release*. September 2021.

Researchers Find Catalyst to Convert CO_2 to Fuel.

Researchers used a supercomputer to identify a group of "single-atom" catalysts that has the potential to convert CO_2 into fuel. Led by Queensland University of Technology's Centre for Materials Science in Australia, the researchers used theoretical modeling to identify six metals that would be effective in a reaction that can convert CO_2 into sustainable and clean energy sources. The study was published in the journal *Nature Communications*.

From *ScienceDaily*. October 2021.

Study Measures Reaction of Trees to Elevated Levels of CO_2.

Researchers from the University of Birmingham found that mature oak trees have the potential to increase their rate of photosynthesis by up to one-third. The results, published in the journal *Tree Physiology*, are derived from an outdoor experiment in which an old oak forest was exposed to elevated levels of CO_2. The researchers found, through the first three years of the 10-year project, that the 175-year-old oak trees consistently increased their rate of photosynthesis. The researchers will next measure leaves, wood, roots, and soil to determine where and for how long the extra carbon captured is stored.

From *ScienceDaily*. October 2021.

DECEMBER 2021

New Research Findings Could Help Inform How Zeolites Used in CCS.

Researchers from Northwestern University analyzed ancient zeolite specimens collected from the edges of East Iceland and discovered that zeolites separate calcium isotopes differently than previously thought. The findings could help quantify temperatures in both modern and ancient geologic systems, as well as inform CCS efforts. The results of the study were published in the journal *Communications Earth and Environment*.

From *Science Daily*. October 2021.

Researchers Study Effects of Antibiotics, Temperature on Carbon Sinks.

Ecologists from Cary Institute of Ecosystem Studies (New York, USA) investigated the effects of rising temperatures and a common livestock antibiotic on soil microbes. The research team found that heat and antibiotics disrupt soil microbial communities—degrading soil microbe efficiency, resilience to future stress, and ability to store CO_2. The study, published in the journal *Soil Biology and Biochemistry*, found that rising temperatures alone increased soil respiration and dissolved organic carbon, which could reduce long-term carbon storage capacity.

From *Science Daily.* November 2021.

JANUARY 2022

Researchers Use Physics to Assess CO_2 Storage Sites.

A team of researchers used physics-informed deep learning to study hypothetical CO_2 storage sites. The work was completed as part of DOE's *Science-informed Machine learning to Accelerate Real-Time (SMART)* Decisions for Carbon Storage Initiative. Led by Penn State University (PSU), the research team combined artificial intelligence and physics to develop a predictive modeling approach that avoided the cost and time commitment required with normal numerical simulations. In the study, published in the *Journal of Contaminant Hydrology*, the team trained deep-learning algorithms to make accurate predictions across a variety of scenarios. By simulating CO_2 in a 7,500-foot-deep reservoir, the algorithms were able to predict how CO_2 saturation and pressure would behave in new simulated systems.

From *PSU News*. November 2021.

Study Examines Behavior of Salty Water Under Different Conditions.

Researchers from the University of Bath (UK) studied the way salty water acts in deep geologic formations, paving the way for future research into the CO_2 storage potential beneath the seabed. In the study, published in the *Journal of Chemical Physics*, the researchers observed saline solutions under conditions of pressure and temperatures that mimic the conditions found in the deep geologic formations. Using a technique that allowed them to examine saline solutions in extreme conditions, they studied different versions of sodium chloride, providing new insight into the way salty water behaves under different sets of pressure and temperature conditions.

From *Carbon Capture Journal*. December 2021.

Report Assess Ocean-Based Carbon Storage.

A *report* from the National Academies of Sciences, Engineering, and Medicine assessed the potential risks and benefits of using ocean-based approaches to store CO_2. Six specific approaches were studied, each evaluated for their efficacy, durability, scalability, potential environmental risks, and social considerations, among other factors. The results led the report committee to recommend the United States undertake a research program to learn more about how these methods could be utilized.

From *National Academy of Sciences, Engineering, and Medicine News Release*. December 2021.

FEBRUARY 2022

Company Tests CO_2 Monitoring Technology.

Carbon Management Canada (CMC) and UK-based TenzorGEO Ltd. are testing the use of passive seismic data to monitor CO_2 storage at CMC's Field Research Station (FRS) in Alberta, Canada. According to TenzorGEO, their technology can continuously monitor reservoir integrity while tracking fluid velocity-related changes when it comes to CCS. TenzorGEO's partnership with CMC allows them to test their technology by utilizing already acquired passive seismic data from the FRS and deploying the technology at the FRS to further validate its capability.

From *Carbon Capture Journal*. December 2021.

Researchers Study CO_2 Conversions, Failures.

Researchers from the *Massachusetts Institute of Technology (MIT)* studied potential reasons for failure(s) in CO_2 conversion, identifying possible solutions in the process. The study identified, quantified, and modeled CO_2 conversion systems, finding that a local depletion of the CO_2 gas next to the electrodes being used to catalyze the conversion could lead to potential poor performance. According to the findings, *published in the journal Langmuir*, a potential solution resides in pulsing the current off and on at specific intervals, allowing time for the gas to build back up to the needed levels next to the electrode.

From *Science Daily*. January 2022.

Ecologists Study Carbon Cycles.

Ecologists from Colorado State University (CSU) are studying how co-occurring droughts and deluges impact carbon cycling. The CSU researchers are combining field experiments and computer modeling to assess the impact on carbon cycling across the vast grasslands of the continental United States. The region of interest will be a 174,000-mi^2, semi-arid shortgrass steppe located at the western edge of the U.S. Great Plains; however, the research will be conducted within the Central Plains Experimental Range, a 15,500-acre area managed by the U.S. Department of Agriculture's Agricultural Research Service.

From *Colorado State University College of Natural Sciences*. January 2022.

MARCH 2022

Researchers Study Brine Concentration for CO_2 Storage.

A study published in the journal *Sustainability* analyzes the influence of four varieties of brine at varying salt concentrations on CO_2 storage. The study investigates a broad array of brine contents for various salt varieties to obtain the optimum saline percentage for CO_2 storage.

From *AZo Materials*. January 2022.

Scientists Study Cultivation Methods for Improving Soil's CO_2 Storage Capacity.

Scientists studied the conversion of savannas into oil palm plantations as a deforestation-free way of growing the plantations, which has the potential to enhance the net-carbon balance. By measuring how methods used to cultivate oil palms affect soil carbon levels, the team of scientists from Switzerland public research university EPFL and Switzerland's WSL Research Institute found that cultivation methods can improve soil's capacity for carbon storage.

From *Phys.org*. January 2022.

"Mechanical Trees" Could Help Store CO_2.

According to experts, the production of "mechanical trees" might be a viable method of storing CO_2. The mechanical tree is a vertical column of discs coated with a chemical resin. Carbon dioxide is absorbed by the discs' surfaces when the air passes over them. After approximately 20 minutes, the discs fill up and begin to sink into a barrel below, where the CO_2 is released into a sealed environment by using water and steam.

From *Nature World News*. January 2022.

APRIL 2022

Researchers Identify CCS Factors.

A researcher from the University of Texas at Austin's Bureau of Economic Geology used supercomputers to understand how CO_2 storage works within the micrometer-wide pores in rock, as well as to determine the characteristics and factors that can help optimize the amount of CO_2 that can be stored. The study, *published in the International Journal of Greenhouse Gas Control*, explored the trapping efficiency of CO_2 through dissolving the gas into the resident brine in saline aquifers. The results showed that two factors improve the amount of CO_2 that could be stored in the spaces within rocks: wettability and injection rate.

From *Phys.Org*. February 2022.

Scientists Study CO_2 Storage Potential of Deep-Ocean Creatures.

According to a study published in the journal *Science Advances*, scientists have learned that seafloor sediments are home to vast populations of previously unknown organisms that may have an impact on carbon storage. By analyzing DNA sequences detected in ocean floor sediments, researchers were able to determine that the biodiversity of tiny marine organisms in seabed sediments was at least three times greater than in the ocean above. Their conclusions were reached by generating a database of DNA sequences from 418 samples of deep ocean sediments collected from 2010 to 2016. Those sequences were then compared to DNA taken from organisms residing at different ocean depths, allowing the scientists to determine which organisms live in seafloor sediments and which had come to rest there after descending from upper zones of the ocean.

From *The Japan Times*. February 2022.

MAY 2022

Carbon Storage Using Green Hybrid Concrete.

Scientists from Colorado State University's Systems Engineering Department investigated the use of sustainable concrete with the ability store CO_2. The study, "Toward Carbon-Neutral Concrete through Biochar-Cement-Calcium Carbonate Composites: A Critical Review," focuses on the interaction between biochar and calcium carbonate in sustainable concrete and high-density CO_2 storage possibilities. The paper, *published in the journal Sustainability*, provides a review of current literature and identifies and explains new research opportunities that will help identify the amounts of these additives and amendments for cement.

From *AZoMaterials*. April 2022.

JUNE 2022

Researchers Study Subsurface CO_2 Storage Monitoring System.

Researchers from Texas A&M University are studying machine-learning methods to analyze sensor-gathered data from geologic carbon storage sites to rapidly depict underground CO_2 plume locations and movements over time. The research, which looks to help reduce the risk of an unregistered release of CO_2, was published in the journal *Expert Systems with Applications*.

From *Texas A&M Today*. April 2022.

Researchers Study Carbon-Storing Microbes in Ocean.

Two recent studies examined the impact of ocean temperatures and the ocean's ability to store CO_2. The first study, published in *Nature Communications* and conducted by researchers at Bigelow Laboratory for Ocean Sciences in Maine (USA), analyzed 30 years of data and found that phytoplankton, which live on the surface of the ocean and store atmospheric CO_2, may become more efficient as the ocean warms. In the second study, also published in *Nature Communications*, oceanographers from the University of Technology Sydney in Australia reported the discovery of a new, widely distributed ocean microbe species that also has the potential to store CO_2.

From *Eos*. May 2022.

JULY 2022

Battery-Like Device Could Help Power CCS Technologies.

Researchers from the University of Cambridge designed a battery-like device that could help power CCS technologies. The supercapacitor device is about the size of a coin and consists of two electrodes of positive and negative charge. By alternating from a negative to a positive voltage to extend the charging time from previous experiments, the research team found they could capture twice the amount of CO_2. The results were *published in the journal Nanoscale*.

From *SciTechDaily*. May 2022.

Study: Thinning Forests Improve CO_2 Storage Potential.

According to a study conducted by scientists from the Agricultural and Forestry Systems Evaluation and Restoration (ERSAF) group at the University of Córdoba (Andalusia, Spain), decreasing the number of trees in a forest helps to increase the forest's CO_2 storage potential. ESRAF scientists coordinated a global study by performing forest "thinning" trials, with the help of *Silvadapt project's Adaptive Silviculture Plot Network*, during which both light and heavy reforestations of three Mediterranean pine species were performed. By gathering measurements such as soil organic carbon data and biomass, the researchers found that plots subject to a larger reduction in forest thickness stored more carbon. The results were *published in the journal Forests*.

From *AZoCleantech*. June 2022.

CCS Project to be Developed in Egypt.

The Egyptian government and the Italian oil and gas company Eni will develop a multi-phased CCS project in the Melehia field in northern Egypt. In the first phase, algae oil will be extracted for biofuel production, leading to the reduction of up to 1.2 million tons of CO_2 per year. In the second phase, 75,000 tons of biodegradable plastics will be produced, targeting the reduction of 45,000 tons of CO_2 annually. The third and final phase will focus on converting plastic waste into oil to be used as raw material in polyethylene production, aiming to reduce 63,000 tons of CO_2 annually.

From *Energy Capital and Power*. May 2022.

AUGUST 2022

Paper Shows Potential of Offshore Storage.

Scientists conducted an experiment in the North Sea, northeast of Aberdeen, Scotland, where they simulated a release of CO_2 below the seabed over a period of 12 days to test whether new technologies were able to detect releases of CO_2. The pilot study, led by the *National Oceanography Centre (NOC)*, demonstrated that the releases were detectable and quantifiable through new technologies. NOC is a marine science research and technology institution based in the UK.

From *KeyFacts Energy*. June 2022.

Companies to Develop Forest Management Model Incorporating Carbon Storage.

TotalEnergies is partnering with Compagnie des Bois du Gabon (CBG) to develop a forest management model that combines long-term storage, sustainable harvesting, and biodiversity conservation. The forest management model will make it possible to develop a balance between the harvesting and processing of wood combined with carbon storage and the production of related carbon credits.

From *TotalEnergies Press Release*. June 2022.

Researchers Look to Engineer Crops that Absorb CO_2 Faster, Longer.

The Innovation Genomics Institute (IGI) is researching genetically engineering plants to absorb more atmospheric CO_2 and hold on to it longer. The IGI research project relies on a gene-editing tool called CRISPR to give plants and soil microbes traits that improve their ability to capture and store CO_2. The project will be carried out by three research groups that will study commercial crops: the first group will focus on rice crops, the photosynthesis process, and root development to encourage carbon storage; the second group will study a biomass crop for genome-editing techniques that spur CDR; and the third group will develop ways of tracing the captured CO_2 and study the soil microbial communities that help CO_2 storage.

From *S&P Global*. June 2022.

Researchers Use Remote Sensing to Track Carbon Storage in Mangroves.

Researchers from the Institute of Industrial Science at the University of Tokyo developed a model that uses remote sensing of environmental conditions to determine how much carbon is stored in mangrove forests. Published in *Scientific Reports*, the study used satellite data to develop a productivity model appropriate for mangroves. The researchers developed a model that considered the effects of tidal inundation and then combined the model with satellite data on photosynthetically active radiation to estimate the productivity of mangrove forests along the coastline of China.

From *Phys.org*. June 2022.

SEPTEMBER 2022

Researchers Study Plankton's Ability to Store CO_2.

According to researchers at the University of Bristol and the National Oceanography Centre, the amount of CO_2 stored by microscopic plankton may increase in the coming century. *Published in the journal Proceedings of the National Academy of Sciences*, the researchers' findings suggest the "biological pump"—a process where phytoplankton take up carbon and then die and sink into the deep ocean where carbon is stored for hundreds of years—may account for 5–17% of the total increase in carbon uptake by the oceans by 2100.

From *Phys.org*. July 2022.

LLNL Leads Research on Soil Carbon Storage Capacity.

A team of researchers led by Lawrence Livermore National Laboratory (LLNL) studied the potential of carbon storage in soils. *Published in the journal Nature Communications*, the study found that regions under agricultural management and having deeper soil layers contain the largest undersaturation of mineral-associated carbon; the degree of undersaturation can help inform storage efficiency over years to decades. The team showed that across 103 carbon accrual measurements spanning management interventions globally, soils furthest from their mineralogical capacity are more effective at accruing carbon. Storage rates average three times higher in soils at one-tenth of their capacity compared to soils at one-half of their capacity.

From *LLNL News*. July 2022.

Data Shows UK Forests Not Storing as Much CO_2.

According to data collected by researchers, the amount of CO_2 captured and stored annually by trees in the UK peaked in 2009, and has fallen every year since. Official projections, which are based on the forestry stocks and policies in place in 2019, forecast the carbon they absorb will fall by 25% a year by 2025. In the absence of any further forests being planted, that could fall by half by 2038, the forecasts show.

From *The Guardian*. July 2022.

Lab Chip Developed to Accelerate Carbon Storage Efforts.

Scientists at Stanford University (USA) developed a device that enables assessments of sites for underground storage of CO_2, hydrogen, and industrial waste. To demonstrate the microfluidics device, the researchers used eight rock samples from the Marcellus shale in West Virginia and the Wolfcamp shale in Texas. They then cut and polished the slivers of rock to bits no bigger than a few grains of sand, with each one containing varying amounts and arrangements of reactive carbonate minerals. The researchers placed the samples into a polymer chamber sealed in glass, with two tiny inlets left open for injections of acid solutions. High-speed cameras and microscopes enabled them to study how chemical reactions caused individual mineral grains in the samples to dissolve and rearrange.

From *Stanford News*. August 2022.

PUBLICATIONS

OCTOBER 2021

Technoeconomic and Life Cycle Analysis of Bio-Energy with Carbon Capture and Storage (BECCS) Baseline.

The following is from the product description of this NETL document: "Bio-Energy with Carbon Capture and Storage (BECCS) is an attractive option from an environmental standpoint, as biomass regrowth removes CO_2 from the atmosphere, which offsets the emissions produced by burning the biomass. When combined with carbon capture, this produces a system that is capable of zero or even negative greenhouse gas (GHG) emissions. This study examines the performance, environmental impact, and economics of co-firing biomass in pulverized coal (PC) power plants. The analysis is based on various plant configurations (with and without carbon dioxide [CO_2] capture) using hybrid poplar biomass at three levels of co-fire (20, 35, and 49 weight percent) with Illinois No. 6 coal. This study is an analysis of the overall performance and economics of the plant, which was used to determine the levelized cost of electricity (LCOE) and to perform a full environmental life cycle analysis (LCA) of greenfield PC plants co-firing biomass."

Global Carbon Capture and Storage Market 2021–2025.

The following is from a summary of this market research: "The analyst has been monitoring the carbon capture and storage market and it is poised to grow by 64.05 mn tons during 2021-2025, progressing at a CAGR of almost 21% during the forecast period. [The authors'] report on the carbon capture and storage market provides a holistic analysis, market size and forecast, trends, growth drivers, and challenges, as well as vendor analysis covering around 25 vendors. The report offers an up-to-date analysis regarding the current global market scenario, latest trends and drivers, and the overall market environment. The market is driven by the dependence on fossil fuels for generation of electricity and the need to adhere to stringent environmental regulations. In addition, the dependence on fossil fuels for generation of electricity is anticipated to boost the growth of the market as well. The carbon capture and storage market analysis includes application, technology, and end-user segments and geographic landscape."

Risk-based monitoring designs for detecting CO_2 leakage through abandoned wellbores: An application of NRAP's WLAT and DREAM tools.

The following is from abstract of this article: "As geologic CO_2 storage (GCS) moves towards industrial-scale deployment, strategies must be developed to ensure long-term environmental risks related to potential leakage are managed. One approach to is to perform risk-based subsurface monitoring targeting early leak detection. Early detection is particularly important to address the risk associated with leakage along legacy wells. The challenge in risk-based monitoring is that leakage impacts are expected to be small in comparison with the footprint of the stored CO_2 plume and could occur over considerable depths, ranging from the storage formation up to surficial aquifers. Here [the authors] demonstrate the application workflow of two of the National Risk Assessment Partnership's (NRAP) computational tools, WLAT (Wellbore Leakage Analysis Tool) and DREAM (Designs for Risk Evaluation and Management), to a hypothetical CO_2 storage site based on a study area in the Midwestern United States. By incorporating site specific wellbore integrity analyses, results show how fluid leakage may be estimated, evaluated, and monitored in terms of risk. For the selected site, three monitoring wells were ultimately needed to detect all possible CO_2 leaks and six monitoring wells were needed to minimize time to leak detection. Such analyses inform stakeholders about long-term liability and monitoring costs of GCS projects."

C. Yonkofski, G. Tartakovskly, N. Huerta, and A. Wentworth, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

A comprehensive thermodynamic performance assessment of CO_2 liquefaction and pressurization system using a heat pump for carbon capture and storage (CCS) process.

The following is from the abstract of this article: "CO_2 compression process significantly contributes to the overall efficiency penalty resulting from carbon capture and storage (CCS) process. In this study, heat-pump (HP)-assisted CO_2 compression configurations are examined using first and second laws of thermodynamics to reduce power consumption during CO_2 compression. The performance is quantified in terms of net electric power consumption and compared with the conventional multi-stage compression. The input boundary conditions required for the proposed configurations modeling such as captured CO_2 pressure, CO_2 required pressure, the number of stages or the pressure ratio during CO_2 compression, and cooling temperature depend on the plant configuration, location, and compression chain characteristics. This study emphasizes that the variability in boundary conditions can significantly impact the optimum thermodynamic route of CO_2 pressurization. A thorough parametric investigation is thus performed to clarify the impact of these parameters on the overall power consumption. CO_2 pumping or compression near the critical point was shown to play a key role in optimizing CO_2 pressurization routes. Additionally, a high CO_2 captured pressure and a low target pressure, number of stages, and cooling temperature were shown to enhance system performance. Furthermore, the second law analysis illustrated that the point of minimum net power consumption corresponds to the minimum exergy destruction. Finally, the optimization of the proposed system using a genetic algorithm allowed for a 7.77% electric power saving and 68.02% exergetic efficiency using the proposed system."

Hafiz Ali Muhammad, Chulwoo Roh, Jongjae Cho, Zabdur Rehman, Haider Sultan, Young-Jin Baik, and Beomjoon Lee, *Energy Conversion and Management. (Subscription may be required.)*

Modeling and economic evaluation of carbon capture and storage technologies integrated into synthetic natural gas and power-to-gas plants.

The following is from the abstract of this article: "The production of synthetic natural gas from coal and biomass gasification made it possible to obtain a product that can be used to replace easily the standard natural gas in the existing infrastructures. This paper follows and presents a study that was conducted on a synthetic natural gas plant integrated with carbon capture and storage technologies. The recent growth in the use of energy coming from renewable sources requires that balancing measures be taken for electricity grids, which, as can be easily imagined, is best accomplished by using multiple energy storage technologies. In particular, the power-to-gas technology allows renewable electrical energy to be transformed into methane via electrolysis and subsequent methanation. Moreover, the production of synthetic natural gas can be enhanced by using concentrated CO_2 emitted by synthetic natural gas plants, coupling the coal gasification and methanation processes within the same plant. This paper compares and evaluates two distinct process configurations and their implementation with power-to-gas technology in Aspen Plus v.8. During the study, it was analyzed how the introduction of carbon capture and storage technologies affect the overall energy balance, as well as the individual performances of each configuration. The two cases proved to have similar efficiency; it was also observed that the integration of and carbon capture and storage technologies resulted in a negligible reduction in the efficiency of the system (approximately 1%). The integration of power-to-gas technologies led to a decrease in the efficiency of the system up to 30%. Based on the current emission allowances specified in the rules of the regulated market of CO_2, it was also assessed how such technologies would be sustainable in terms of costs derived from the production of gas. An analysis was in fact performed to estimate the costs associated with this type of plant and the results showed that the introduction of carbon capture and storage technologies in synthetic natural gas plants had a lower impact on the

costs related to both the plant and the synthetic natural gas. In this respect, a sensitivity analysis of the most influent factors was performed as well. The results showed that, when it comes to the production of gas in in the power-to-gas process, the specific cost strongly depends on the price of electricity and the operating hours."

Claudia Bassano, Paolo Deiana, Giorgio Vilardi, and Nicola Verdone, *Applied Energy. (Subscription may be required.)*

Geomechanical properties will constrain CO_2 injection into the lower Ordovician Rose Run sandstone deep saline reservoir, Appalachian Basin, Kentucky, USA.

The following is from the abstract of this article: "The Kentucky Geological Survey (KGS) 1 Hanson Aggregates stratigraphic research well, Carter County, Kentucky, USA, was drilled to a total depth of 1474 m as a field-scale test of potential CO_2 storage reservoir properties in the Central Appalachian Basin. Geomechanical properties of the Rose Run sandstone (upper Ordovician Knox group) were tested for its suitability as a storage reservoir. A 9.8-m thick section of the Rose Run was penetrated at 1000 m drilled depth and a whole-diameter core and rotary sidewall cores were taken. Average porosity and permeability measured in core plugs were 9.1% and 44.6 mD, respectively. Maximum vertical stress gradient calculated in the wellbore was 26 MPa/km. Wellbore fractures in dolomites underlying and overlying the Rose Run follow the contemporary N53°E Appalachian Basin stress field. The Rose Run elastic geomechanical properties were calibrated to values measured in core plugs to evaluate its fracturing risk as a CO_2 storage reservoir. Mean Young's modulus and Poisson's ratio values of the Rose Run were 45 GPa and 0.23, respectively, whereas Young's modulus and Poisson's ratio values were 77.1 GPa and 0.28, respectively, in the overlying Beekmantown dolomite, suggesting the Rose Run may fracture if overpressured during CO_2 injection but be confined by the Beekmantown. Triaxial compressive strength measured in core plugs found the Rose Run and Beekmantown fractured at mean axial stresses of 156.5 MPa and 282.2 MPa, respectively, confirming the Beekmantown as suitable for confining CO_2 injected into the Rose Run. A step-rate test was conducted in a mechanically-isolated 18.6-m interval bracketing the Rose Run. Static Rose Run reservoir pressure was 9.3 MPa, and fracture gradient under injection was 13.6 MPa/km, suggesting step-rate testing before CO_2 injection, and subsequent pressure monitoring to ensure confinement. As the region around the KGS 1 Hanson Aggregates well is underpressured and adjacent to faulted Precambrian basement, further research is needed to evaluate its induced seismicity risk during CO_2 injection."

John Richard Bowersox, Stephen F. Greb, Junfeng Zhu, and David C. Harris, *Journal of Rock Mechanics and Geotechnical Engineering. (Subscription may be required.)*

A coupled thermo-hydro-mechanical model for simulating leakoff-dominated hydraulic fracturing with application to geologic carbon storage.

The following is from the abstract of this article: "A potential risk of injecting CO_2 into storage reservoirs with marginal permeability ($\lesssim$ 10 mD (1 mD = $10–1^5$ m2)) is that commercial injection rates could induce fracturing of the reservoir and/or the caprock. Such fracturing is essentially fluid-driven fracturing in the leakoff-dominated regime. Recent studies suggested that fracturing, if contained within the lower portion of the caprock complex, could substantially improve the injectivity without compromising the overall seal integrity. Modeling this phenomenon entails complex coupled interactions among the fluids, the fracture, the reservoir, and the caprock. [The authors] develop a simple method to capture all these interplays in high fidelity by sequentially coupling a hydraulic fracturing module with a coupled thermal-hydrological-mechanical (THM) model for nonisothermal multiphase flow. The model was made numerically tractable by taking advantage of self-stabilizing features of leakoff-dominated fracturing. The model is validated against the PKN solution in the leakoff-dominated regime. Moreover, [the authors] employ the model to study thermo-poromechanical responses of a fluid-driven fracture in a field-scale carbon storage reservoir that is loosely based on the In Salah project's Krechba reservoir. The model reveals complex yet intriguing behaviors of the reservoir-caprock-fluid system with fracturing induced by cold CO_2 injection. [The authors] also study the effects of the in situ stress contrast between the reservoir and caprock and thermal contraction on the vertical containment of the fracture. The proposed model proves effective in simulating practical problems on length and time scales relevant to geological carbon storage."

Xin Ju, Pengcheng Fu, Randolph R. Settegast, and Joseph P. Morris, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

A hard-to-keep promise: Vegetation use and aboveground carbon storage in silvopastures of the Dry Chaco.

The following is from the abstract of this article: "In dry woodland regions, silvopastures have emerged as a promising option to balance cattle production, carbon storage and biodiversity. However, one of the major challenges in these systems, particularly when implemented in a matrix of natural vegetation, is the preservation of tree populations in the face of management actions implemented by ranchers to control woody encroachment. Here, [the authors] investigate the extent of that tradeoff by analyzing the impact of woody encroachment control practices on carbon storage in silvopastures of the Argentine Dry Chaco. First, [the authors] analyze tree density and carbon storage in aboveground woody biomass for silvopastures and woodlands at 24 sites in five properties across the Argentine Dry Chaco. Then, [the authors] characterize vegetation management goals and actions of ranchers who have adopted silvopastures in that same region, combining field assessments, high-resolution imagery analysis, characterization of site history, and surveys. [The authors] find that woody biomass in silvopastures retains an average of 64 % of the carbon present in aboveground biomass in intact woodlands (28.8 Mg C ha−1). However, [the authors] also find that this storage capacity decreases by 12 % with each woody encroachment control intervention, due to these interventions' negative effects on tree density. Ranchers expressed concern about tree mortality, but also indicated low profitability of wood products and highlighted woody encroachment as a major issue for livestock production. Therefore, ranchers feel they have no choice but to continue preventing woody encroachment, even if this implies the gradual depletion of tree populations. Understanding how ranchers manage silvopastures, and how that management affects the provision of ecosystem services, is essential and will require more careful long-term monitoring and evaluation. This is particularly true in agricultural frontiers such as the Argentine Dry Chaco, where silvopastoral systems have the potential to mitigate the seemingly irremediable conflict between commodity production and nature conservation."

Pedro D. Fernández, Yann le Polain de Waroux, Estéban G.Jobbágy, Dante E. Loto, and N. Ignacio Gasparri, *Agriculture, Ecosystems $ Environment. (Subscription may be required.)*

Application of computed tomography (CT) in geologic CO_2 utilization and storage research: A critical review.

The following is from the abstract of this article: "Computed tomography (CT) is a useful sample characterization and analysis technique to better understand complicated reactive transport processes in geologic CO_2 utilization and storage (GCUS) conditions. According to previous studies, [the authors] have identified four major challenges that hinder the application of CT scanning in GCUS-related sample characterization: (1) lack of registration, segmentation, noise/artifact-reducing and model selection algorithms; (2) great uncertainty in mineral composition characterization; (3) low resolution to characterize caprock with nanopores, and (4) limited real-time CT imaging capacity. To tackle these challenges, future R&D directions regarding CT applications in GCUS research are proposed."

Manguang Gan, Liwei Zhang, Xiuxiu Miao, Sergey Oladyshkin, Xiaowei Cheng, Yan Wang, Yutong Shu, Xuebin Su, and Xiaochun Li, *Journal of Natural Gas Science and Engineering. (Subscription may be required.)*

NOVEMBER 2021

Carbon Capture and Storage - Global Market Trajectory & Analytics.

The following is from the abstract of this market study published by Global Industry Analysts Inc.: "Amid the COVID-19 crisis, the global market for Carbon Capture and Storage estimated at US$2.8 Billion in the year 2020, is projected to reach a revised size of US$4.9 Billion by 2026, growing at a CAGR of 9.9% over the analysis period. Pre-Combustion, one of the segments analyzed in the report, is projected to grow at a 10.1% CAGR to reach US$4.1 Billion by the end of the analysis period. After a thorough analysis of the business implications of the pandemic and its induced economic crisis, growth in the Post Combustion segment is readjusted to a revised 11.2% CAGR for the next 7-year period. This segment currently accounts for a 11.3% share of the global Carbon Capture and Storage market. Post-combustion capture process involves extraction of carbon dioxide from low-pressure flue gases at conventional power plants and other large point sources after the combustion of fossil fuels or other carbonaceous materials such as biomass. This technology has been widely used for capturing carbon dioxide in the food and beverage sector. Pre-combustion capture technology is more beneficial than post-combustion technology as separating carbon dioxide from hydrogen is much easier than from flue gas due to the fact that the partial pressure and concentration of carbon dioxide is much higher than in flue gases. The technology expands options for various gas separation methodologies, which previously were not possible in post-combustion capture processes."

Influence of capillary threshold pressure and injection well location on the dynamic CO_2 and H_2 storage capacity for the deep geological structure.

The following is from the abstract of this article: "The subject of this study is the analysis of influence of capillary threshold pressure and injection well location on the dynamic CO_2 and H_2 storage capacity for the Lower Jurassic reservoir of the Sierpc structure from central Poland. The results of injection modeling allowed [the authors] to compare the amount of CO_2 and H_2 that the considered structure can store safely over a given time interval. The modeling was performed using a single well for 30 different locations, considering that the minimum capillary pressure of the cap rock and the fracturing pressure should not be exceeded for each gas separately. Other values of capillary threshold pressure for CO_2 and H_2 significantly affect the amount of a given gas that can be injected into the reservoir. The structure under consideration can store approximately 1 Mt CO_2 in 31 years, while in the case of H_2 it is slightly above 4000 tons. The determined CO_2 storage capacity is limited; the structure seems to be more prospective for underground H_2 storage. The CO_2 and H_2 dynamic storage capacity maps are an important element of the analysis of the use of gas storage structures. A much higher fingering effect was observed for H_2 than for CO_2, which may affect the withdrawal of hydrogen. It is recommended to determine the optimum storage depth, particularly for hydrogen. The presented results, important for the assessment of the capacity of geological structures, also relate to the safety of use of CO_2 and H_2 underground storage space."

Katarzyna Luboń and Radosław Tarkowski, *International Journal of Hydrogen Energy. (Subscription may be required.)*

Recovery of calcium and magnesium bearing phases from iron– and steelmaking slag for CO_2 sequestration.

The following is from the abstract of this article: "Large amounts of iron– and steelmaking slag and greenhouse gas are annually produced by the steel industry worldwide. Using Ca/Mg in the slag to capture and store the CO_2 via mineral carbonation is a promising approach to the reduction of waste emissions. Since iron– and steelmaking slags are a mixture of numerous types of minerals, understanding the dissolution behavior of various phases in solution system is of critical importance for Ca/Mg recovery. In this work, seven Ca/Mg–bearing phases and four typical solutions were prepared and studied. Theoretical results indicated that the order of mineral solubility in aqueous solution is as follows: (CaO and Ca_2SiO4) > ($Ca_3MgSi2O8$, $Ca_2MgSi_2O_7$, and MgO) > $Ca_2Al2SiO7$ > $MgCr_2O4$. A batch of leaching tests was conducted at room temperature, and the recovery yield of Ca/Mg was investigated. It was found that minerals show different dissolution behavior in various systems, and the metallic oxide phases exhibited a relatively higher solubility than silicate phases. The solubility of minerals in various systems was illustrated by radar plots. Moreover, leaching tests for silicate briquettes were performed to investigate the transformation mechanism. On the basis of the results, it was proposed that a silicic acid layer generated on the surface of briquettes in the leaching process, and could transform into porous silica phase via dehydration process. The formed Si–rich layer obstructed the dissolution of inner mineral leading to a low recovery efficiency of Ca/Mg."

Qing Zhao, Jingyu Li, Kaiwen You, and Chengjun Liu, *Process Safety and Environmental Protection. (Subscription may be required.)*

Is hydrothermal treatment coupled with carbon capture and storage an energy-producing negative emissions technology?

The following is from the abstract of this article: "This paper evaluates the feasibility of hydrothermal treatment (HTT) with carbon capture and storage (CCS) as an energy producing negative emissions technology (NET) and compares such system with a conventional bioenergy with carbon capture and sequestration (BECCS) system. Machine learning models were developed to predict product yields and characteristics from HTT of various feedstocks. The model results were then integrated into a life cycle assessment (LCA) model to compute two metrics: energy return on investment (EROI) and net global warming potential (GWP). Results showed random forest models had better prediction accuracy than regression tree and multiple linear regression to model HTT of feedstocks (e.g., microalgae, crops/forest residues, energy crops, and biodegradable organic wastes) and predicted the mass yields of multiple products (biocrude, hydrochar, gas, and aqueous co product) as well as the energy and carbon contents of biocrude and hydrochar. LCA results revealed that the proposed HTT-CCS system constituted a net-energy producing NET for some combinations of feedstock characteristics and reaction conditions. Best overall energy and GWP performance was achieved for HTT-CCS of lignocellulosic biomass at low temperature. Compared with the conventional BECCS system, HTT-CCS generally exhibited higher EROI but higher net GWP, depending on processing conditions and the feedstock types."

Fangwei Cheng, Michael D. Porter, and Lisa M. Colosi, *Energy Conversion and Management. (Subscription may be required.)*

Chitosan-based zeolite-Y and ZSM-5 porous biocomposites for H_2 and CO_2 storage.

The following is from the abstract of this article: "Sustainable energy is the most valuable clean and renewable energy for the future. A simple, robust, and inexpensive ecofriendly method has been developed here to prepare chitosan-based zeolite porous biocomposites via solvent exchange followed by calcination. The resulting chitosan-based zeolite biocomposites were characterized using advanced technologies including attenuated total reflection-infrared (ATR-IR) spectroscopy, X-ray powder diffraction (XRD) analysis, thermogravimetric analysis (TGA), high-resolution field-emission scanning electron microscopy (HR-FE-SEM), high-resolution transmission electron microscopy (HR-TEM), and nitrogen adsorption-desorption isotherms. The Brunauer-Emmett-Teller (BET) surface area of the ZeY@CS composite (795 m2 g−1) was greater than those of ZSM-5@CS (444 m2 g−1), pure chitosan, pure zeolite Y, and ZSM-5. The chitosan-based zeolite biocomposites show enhanced gas storage for small molecule like CO_2 and hydrogen. Therefore, chitosan-based zeolite biocomposites should be suitable for energy storage, carbon capture, and sequestration (CCS) applications."

Santosh Kumar, Ranajit Bera, Neeladri Das, and Joonseok Koh, *Carbohydrate Polymers. (Subscription may be required.)*

3D grid based screening process for large-scale CO_2 geological storage in Gunsan Basin, Yellow Sea, Korea.

The following is from the abstract of this article: "This study presents an approach to screen sedimentary basins for their CO_2 geological storage potential based on a 3D grid with geological data. The 3D grid-based screening was applied to the Gunsan Basin, offshore Korea, for selecting potential sub-basins. Six sub-basins were recognized and prioritized using a set of quantifiable criteria, reflecting storage capacity, geological risk, and socio-economic aspects. Nine criteria were defined and weighed to reflect local priority and geological characteristics. Every grid cell was populated with geological and geometrical properties, scored and ranked for each criterion. Typically, the storage capacity is used for evaluating the storage potential of a basin, which, however, was not estimated here due to the low quantity of available data. Instead, the capacity potential was quantified by combining the pore volume and Gravitational Number for each grid cell. Mean score values for each sub-basin indicate that the East Sub-basin is the most promising region, containing a suitable aquifer with an estimated storage capacity of a few hundreds of $MtCO_2$. Therefore, [the authors] suggest that the Gunsan Basin is suitable for implementing a CCS program with an injection rate of 4 $MtCO_2$/year for 30 years. Moreover, [the authors] suggest that the 3D grid-based screening process could be used to quickly screen different sub-basins or potential aquifers by depth."

Young Jae Shinn, Hyun Suk Lee, Youngmin Lee, Insun Song, and Myong-HoPark, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

A carbon price floor in the reformed EU ETS: Design matters!

The following is from the abstract of this article: "Despite the reform of the European Emissions Trading System (EU ETS), discussions about complementing it with a carbon price floor (CPF) are ongoing. This paper analyzes the effect of a European CPF in the reformed EU ETS using a Hotelling model of the EU ETS, amended by the market stability reserve (MSR), and the cancellation mechanism. Two CPF designs are compared: (1) a buyback program and (2) a top-up tax. The buyback program sets a minimum price for the allowances from the implementation year onwards. After the announcement, firms anticipate the CPF, which immediately increases the carbon price to the discounted CPF level. Therefore, firms emit less and bank more allowances, leading to more intake into the MSR, and more cancellation of allowances. The top-up tax imposes a tax on emissions, which enhances the market price of allowances to the CPF level from the implementation year onwards. Firms increase their short-run emissions in anticipation of the upcoming tax. Only after the implementation year firms start to lower their emissions. Thus, the effect on aggregate cancellation is ambiguous. Despite being equivalent in a static setting, the design choice for the CPF matters in a dynamic context, such as the EU ETS."

Martin Hintermayer, *Energy Policy. (Subscription may be required.)*

Evaluation of the carbon sequestration capacity of arid mangroves along nutrient availability and salinity gradients along the Red Sea coastline of Saudi Arabia.

The following is from the abstract of this article: "In the present work, [the authors] assessed the carbon sequestration capacity of mangrove forests (Avicennia marina) in relation to nutrient availability and salinity gradients along the Red Sea coast of Saudi Arabia. This was achieved through estimating the sediment bulk density (SBD), sediment organic carbon (SOC) concentration, SOC density, SOC pool, carbon sequestration rate (CSR) and carbon sequestration potential (CSP). The present study was conducted at 3 locations (northern, middle and southern), using 7 sites and 21 stands of mangrove forests (A. marina) along ~1134 km of the Red Sea coastline of Saudi Arabia (from Duba in the north to Jazan in the south), all of which are in an arid climate. The correlation coefficients between the water characteristics and the first two Canonical Correspondence Analysis (CCA) axes indicated that the separation of the sediment parameters along the first axis were positively influenced by TDS (total dissolved solids) and EC (electric conductivity) and were negatively influenced by total N and total P. On the other hand, the second axis was negatively correlated with total N, total P, EC and TDS. The SOC pools at the northern (10.5 kg C m–2) and southern locations (10.4 kg C m–2) were significantly higher than the SOC pool at the middle location (6.7 kg C m–2). In addition, the average CSR of the northern (5.9 g C m–2 yr–1) and southern locations (6.0 g C m–2 yr–1) were significantly higher than they were in the middle location (5.0 g C m–2 yr–1)."

Kamal H. Shaltout, Mohamed T. Ahmed, Sulaiman A. Alrumman, Dalia A. Ahmed, and Ebrahem M. Eid, *Oceanologia. (Subscription may be required.)*

Performance evaluation and carbon assessment of IGCC power plant with coal quality.

The following is from the abstract of this article: "Techno-economic and environmental impacts of coal type were evaluated using a 500 MW-class integrated coal gasification combined cycle (IGCC), including reheat combined cycle process with three-pressure level based on higher than 99.9% sulfur removal and 90% carbon capture. Efficiency and cost of electricity (COE) of four different coals in the IGCC power plant were compared: two bituminous and two sub-bituminous coals. As coal with higher heating value per unit weight was fed into a gasifier, higher cold gas efficiency of the gasifier and greater net overall plant efficiency was achieved. The highest overall plant efficiency of 31.62% could be achieved by using bituminous. Raw water consumption was also affected by the moisture content of the as-received coal. The as-received coal with the highest moisture content consumed the least amount of water. The exergy flow and destruction were presented in Grassmann diagrams to provide more detailed information on main units. However, according to the sensitivity test, the COE was mainly influenced by fuel prices and costs of CO_2 transport and storage. If the price difference between bituminous coals and sub-bituminous coals is reduced, the utilization of bituminous coals becomes more competitive in terms of COE and capital cost."

Hyun-Taek Oh, Woo-Sung Lee, Youngsan Ju, and Chang-Ha Lee, *Energy. (Subscription may be required.)*

Research trends in carbon capture and storage: A comparison of China with Canada.

The following is from the abstract of this article: "In order to effectively address climate change, academia and industry have paid much attention to the development trend of Carbon Capture and Storage (CCS). However, there is no mature CCS research trend monitoring system. China is likely to be the largest market for CCS technology in the future, while Canada is the first country to start the research and development of CCS. Existing studies have discussed the CCS research trends at the global level, in China, Canada, and in other countries. However, few comparative studies have been carried out in key countries. In this study, an integrated method of bibliometrics and S-Curve is proposed with the purpose of comparing CCS research trends between China and Canada. Firstly, the bibliometrics method was used to compare the conceptual structure and research route of CCS research in China and in Canada. Secondly, the key collaborators were [identified] through the comparison of collaboration relationships. Finally, the S-Curve model was employed to forecast the CCS research output trend in China and Canada. This study found that China's CCS research had the advantage of pre-combustion carbon capture, while Canada's advantage lied in the ecosystem carbon sequestration. It was also shown that Canada's CCS cumulative publication may reach saturation 15 years later than that in China. This paper provides insight into the CCS research and development optimization for China, Canada and globally. The CCS research trends comparison tools proposed in this study can benefit to monitor the CCS research by governments and enterprises."

Jin-Wei Wang, Jia-Ning Kang, Lan-Cui Liu, Ioan Nistor, and Yi-Ming Wei, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

DECEMBER 2021

Financing CCS in Developing Countries.

The following is from the Introduction of this Global CCS Institute report: "CCS is vital to solving the climate crisis, which experts believe will require the world's emissions to reach net-zero by 2050. To this, the IEA's Sustainable Development Scenario (SDS) estimates that ±9% of the world's emissions reductions must come as a result of deployment of CCS across numerous sectors. It is one of the few technologies that can substantially reduce emissions from hard-to-abate sectors as well as in decarbonising fossil fuel powered electricity generation. It is also one of the few technologies that can be used to create negative emissions through bioenergy with CCS or Direct Air Capture (DAC). To ensure that CCS can meet the SDS' requisites, its deployment must occur in all parts of the world where opportunities exist for its application. This means that CCS must be deployed in both developed and developing countries. Given the long lead times associated with developing CCS projects, the steps taken between now and 2030 will determine whether CCS technology will be deployed at the scale necessary to meet net-zero emissions by 2050. It must, therefore, be the case that between 2030 and 2050 the rate of deployment of CCS must increase by more than a factor of 100. This implies that a rapidly growing demand for CCS projects emerges from debt and capital markets by 2030, and for this to happen, investments in CCS must be significantly derisked during the intervening years. Some parts of the world will lend themselves better to the challenge of early deployment than others, specifically the difference in levels of deployment in developed countries versus developing countries. Developing countries represent high-risk environments for investments in CCS, which create funding gaps for CCS projects. This in turn poses a significant risk to the timely deployment of this vital technology. It is the role of climate finance to help close such funding gaps. This report examines how CCS projects can be structured so as to avail themselves to the different climate finance options currently available to support their deployment around the world."

Waste Incineration and Carbon Capture and Storage.

The following is a segment of this Bellona Europa Position Paper: "In 2019, the European Union (EU) generated 224 Mt of municipal waste. Out of these 224 Mt, 53 Mt were landfilled, 60 Mt incinerated and 107 Mt recycled. Export of hazardous and non-hazardous waste had tripled between 2001 and 2020, growing from 6.3 million tonnes to 32.7 million tonnes respectively. With a 3% share of EU greenhouse gas emissions in 2017, the municipal waste sector is the fourth largest contributor to emissions in the EU. In 2017, the emissions registered for the waste sector amounted to approximately 138 million tonnes of greenhouse gases. That number grows even larger when emissions from waste to energy plants, currently covered by emission accounting in the power sector, are included. Emissions from waste incineration in Europe grew from 5,373kt[3] CO_2 in 1990 to 95,628kt of CO_2 and are now approximately equivalent to emissions coming from landfills. Other than its impact on the climate, waste disposal has significant impacts on biodiversity and public health. Reducing waste, retaining the value of resources and minimising the overall impact of the products we use and dispose of is essential to reduce the environmental pressures created by the growing amount of waste we create. To do so, we need to establish a set of integrated waste reduction and management measures. Waste management conditions vary from region to region; due to these differences, waste management measures must be tailored to local waste management systems. Within the EU the amount of generated waste per capita varies from 280 kg in Romania to 844 kg in Denmark (per person, per year)."

Achieving negative emissions through oceanic sequestration of vegetation carbon as Black Pellets.

The following is from the abstract of this article: "Natural processes and human activities produce vast amounts of dead vegetation which return CO_2 to the atmosphere through decay and combustion. If such vegetation could be converted into biocoal and sequestered on the ocean floor, it could reduce the accumulation of atmospheric CO_2 without involving sequestration in the form of CO_2. Given that raw vegetation is unsuitable for large-scale energy applications, a process was developed to convert raw vegetation into a form of biocoal, termed Black Pellets, that solves the logistical and energy conversion problems of using raw vegetation for power generation. Seemingly overlooked is that properties of Black Pellets—higher density than seawater and resistance to microbial decay—may offer an environmentally safe way of sequestering vegetation carbon on the sea floor. Sequestering vegetation carbon by depositing biocoal as Black Pellets in the deep ocean (oceanic sequestration of biocoal—OSB) would be a means of achieving long-lasting negative emissions. Sacrificing the energy content of the deposited pellets would require substituting energy from other sources. If the substitute energy could be from lower-carbon natural gas or carbon-free sources, the effects would be less accumulation of atmospheric CO_2 compared to using the pellets for energy and a nearly 60 to 100% reduction in the need for geologic sequestration compared to bioenergy carbon capture and storage (BECCS). If confirmed by research, OSB would be an addition to the sparse toolbox of negative emission technologies (NETs) which would give humankind more flexibility in meeting the goals of the Paris Agreement."

Leonard A. Miller and Philip M. Orton, *Climatic Change. (Subscription may be required.)*

A real options approach to production and injection timing under uncertainty for CO_2 sequestration in depleted shale gas reservoirs.

The following is from the abstract of this article: "Depleted shale gas reservoirs may be candidates for conversion to injection wells for the long-term geologic storage of CO_2, but the decision to transition from production to injection depends on economic and policy factors that may be uncertain. This paper aims to comprehend the uncertainty inherent to the underlying assumptions of CO_2 sequestration and their impact on the injection decision. [The authors] view and analyze the production to injection transition decision as a kind of options problem, where the owner of a producing well can choose to exercise the option to stop producing natural gas and start injecting CO_2. [The authors'] approach integrates a detailed reservoir model for shale-gas production and CO_2 injection in the Marcellus shale formation with a multi-period decision problem under uncertainty in future prices for CO_2 and produced natural gas. With no uncertainty, the modeling framework is able to identify the optimal timing of the transition to CO_2 injection as a function of natural gas prices and a hypothetical CO_2 price. [The authors] find that a CO_2 price of approximately $15 per tonne to be needed in order to incentivize a producer to transition to CO_2 injection earlier. If these prices are uncertain, [the authors] find that the option to delay CO_2 injection has value even when CO_2 prices are relatively high and natural gas prices are low, although the option value is highly sensitive to the choice of discount rate and the option value to delay injection is generally very low when CO_2 prices are $20/tonne or higher. [The authors'] modeling suggests that commitment in carbon pricing regimes is of equal importance to the choice of the price level."

Farid Tayari and Seth Blumsack, *Applied 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.)*

A guideline for appropriate application of vertically-integrated modeling approaches for geologic carbon storage modeling.

The following is from the abstract of this article: "Mathematical modeling is an essential tool for answering questions related to geologic carbon storage (GCS). The choice of modeling approach depends on the type of questions being asked. In this paper [the authors] discuss a series of approaches with a hierarchical complexity including vertically-integrated single-phase flow approaches, vertically-integrated multi-phase flow approaches (with and without vertical equilibrium assumption), three-dimensional multi-phase flow approaches, and fully-coupled multi-phase flow approaches that couple flow with geochemistry and/or geomechanics. Three spatial scales are used to categorize the questions to be addressed by modeling: regional scale (encompasses CO_2 plume extent and majority of area of pressure impact of one or more injection operations), site scale (includes the CO_2 plume extent and some of the area impacted by the pressure increase of a single injection site), and well scale (the immediate vicinity of an injection well). A set of guidelines is developed to help modelers choose the most appropriate modeling approach, and show when simpler modeling approaches may be the better choice. Vertically-integrated single-phase flow models are the most appropriate choice at both the site and regional scales, if the pressure impact outside of the CO_2 plume is of interest. Vertically-integrated multi-phase flow models should be chosen at the regional scale, if the locations of CO_2 plumes are of interest, and at the site scale if vertical segregation of CO_2 and brine is fast or vertical heterogeneity in properties can be presented by distinct, continuous layers. Three-dimensional multi-phase flow models are the appropriate choice at the well and site scales for cases with significant vertical flow components of CO_2 and brine. Fully-coupled multi-phase flow models should only be chosen if pore-space alteration through geochemistry or geomechanics feeds back to fluid flow."

Karl W. Bandilla, Bo Guo, and Michael A. Celia, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Co-optimizing water-alternating-carbon dioxide injection projects using a machine learning assisted computational framework.

The following is from the abstract of this article: "In this article, a robust machine-learning-based computational framework that couples multi-layer neural network (MLNN) proxies and a multi-objective particle swarm optimizer (MOPSO) to design water-alternating-carbon dioxide injection (CO_2-WAG) projects is presented. The proposed optimization protocol considers various objectives, including oil recovery and CO_2 storage volume. Expert MLNN systems are trained and employed as surrogate models of the high-fidelity compositional simulator in the optimization workflow. When multiple objective functions are considered, two approaches are employed to treat the objectives: the weighted sum method and the Pareto-front-based scheme. A field-scale implementation focusing on tertiary recovery in the Morrow B formation at Farnsworth Unit (FWU) is presented. The developed Pareto-optimal solutions indicate the maximal available oil production can be 1.64 × 107 barrels and maximal carbon storage can achieve 2.35 × 107 tons. Trade-offs factor is defined to divide the constructed Pareto front into 4 sections with the trade-off factors' value ranges from 0.35 to 49.9. This work also compares the optimum solution found by the aggregative objective function and the solution repository covered by the Pareto front that considers the physical and operational constraints and reduces uncertainties involved by the multi-objective optimization process. [The authors'] comparison indicates multiple solutions exist to satisfy the objective criteria of the WAG design, and these results cannot be found using the traditional weighted sum method. The Pareto front solution can provide more options for project designers, but decisions regarding necessary trade-offs must be made using the solution repository to balance the project economics and CO_2 storage amount."

Junyu You, William Ampomah, and Qian Sun, *Applied Energy. (Subscription may be required.)*

Using socio-technical analogues as an additional experience horizon for nuclear waste management A comparison of wind farms, fracking, carbon capture and storage (CCS) with a deep-geological nuclear waste disposal (DGD).

The following is from the abstract of this article: "Energy technologies can be described as socio-technical ensembles, in which social, political, economic and technical dimensions are embedded. Based on this concept as well as other theoretical approaches dealing with the deployment and development of technologies (e.g. the multi-level perspective of Geels (2002)) this contribution investigates the dynamics and interactions that can occur within the socio-technical ensemble of a deep geological disposal (DGD) for high-level radioactive waste (HLRW). [The authors] compare socio-technical analogues and relate findings of three energy technologies with large-scale infrastructures to a DGD. The analysis is based on a systematic literature review and aims to gain indirect knowledge for nuclear waste management (NWM) deduced from the dynamics within the socio-technical ensembles of wind farms, fracking and carbon dioxide capture and storage (CCS). The analysis is based on a systematic literature review along four central dimensions with eight respective criteria e.g. public participation, conflicts, role of science, etc."

DörteThemann and Achim Brunnengräber, *Utilities Policy. (Subscription may be required.)*

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

The following is from the abstract of this article: "Monitoring injected CO_2 is an important part of assuring permanence of long term storage to mitigate atmospheric emissions. Three-dimensional (3D) seismic has been shown to be an effective technology for visualizing and quantifying subsurface geology and fluids. In this study, [the authors] demonstrate the successful acquisition, processing, and initial interpretation of a first-of-its-kind high-resolution 3D (HR3D) marine seismic survey above an active CO_2 injection site offshore Tomakomai, Japan. An initial sensitivity study indicated generally favorable subsurface conditions for imaging subsurface pore fluid changes. A unique processing workflow incorporating multiple data processing software packages has been tailored to the short-offset and low-fold HR3D acquisition.

The final 3D volume shows generally flat and laterally-continuous stratigraphy in the overburden above the injection zone without identifiable faults, indicating coherent overburden above the CO_2 injection site and low associated risk of vertical CO_2 migration. The successful deployment of this novel marine seismic monitoring technology in the overburden at a small-scale (100 kt/yr) demonstration project suggests HR3D will also be a useful characterization and monitoring tool for larger demonstration and commercial-scale (~10 MT) offshore Carbon Capture and Storage (CCS) sites."

T.A. Meckel, Y.E. Feng, R.H. Treviño, and D. Sava, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

JANUARY 2022

Digital Monitoring of CO_2 Storage Projects (Digimon).

The following is from the abstract of this article: "With an overall objective to 'accelerate the implementation of CCS by developing and demonstrating an affordable, flexible, societally embedded and smart Digital Monitoring early-warning system', the DigiMon project aims to combine different technologies for monitoring CO_2 storage into a uniform system. The project includes qualification of critical system components, integration of the components and embedding the system in a societal context."

Arvid Nøttvedt, Kirsti Midttømme, Martha Lien, Hanneke Puts, and Anna Stork, *Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021. (Subscription may be required.)*

Application of Active Reservoir Management to Enable Geologic CO_2 Storage.

The following is from the abstract of this article: "Active reservoir management (ARM) can enhance geologic CO_2 storage activities via strategic extraction of formation water and can provide site operators with a means of managing risks and costs associated with carbon capture, utilization, and storage (CCUS) projects. Implementation of ARM strategies for CCUS can provide several advantages to a project, including 1) reducing stress on sealing formations and separating pressure from the CO_2 footprint; 2) geosteering of injected fluids away from hazards or permitted storage facility boundaries; 3) reducing area of review (AOR) and/or amalgamated lease area; and 4) improving injectivity, capacity, and storage efficiency to reduce infrastructure and operating requirements. The Energy & Environmental Research Center (EERC) is conducting field tests of ARM strategies for CCUS at a commercial saltwater disposal facility in western North Dakota, USA. Ongoing commercial injection of oilfield produced brine serves as a proxy for CO_2 injection at the site. Initial interference testing has substantiated connectivity between project wells and that extraction response should be observable in the injection wells. A water treatment development and test facility has also been established at the North Dakota Brine Extraction and Storage Test (BEST) site to enable the development and demonstration of new and emerging water treatment technologies on produced or extracted waters. The test bed facility enables pilot testing, demonstration, and performance monitoring of novel water treatment technologies capable of treating high-salinity (average of 180,000 mg/L total dissolved solids [TDS]) fluids associated with CO_2 storage in deep saline formations (DSFs)."

John Hamling, Ryan J. Klapperich, Marc D. Kurz, Tao Jiang, Agustinus Zandy, and Lonny Jacobson, *Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021. (Subscription may be required.)*

What Does It Take to Go Net-zero-CO_2? A Life Cycle Assessment on Long-term Storage of Intermittent Renewables With Chemical Energy Carriers.

The following is from the abstract of this article: "The concept of net-zero-CO_2 power systems has gained increased attention by the EU goal to be a climate neutral continent by 2050. As potential pathways towards a net-zero-power system, this work analyzes future power systems based on intermittent renewable electricity with long-term storage through chemical energy carriers, so called Power-to-Fuel-to-Power systems, and a system based on the combustion of natural gas with 100% carbon capture and storage. The chemical energy carriers selected for electricity storage are hydrogen, methane and ammonia. Using life cycle assessment, [the authors] determine and compare the environmental impacts of 1 kWh of dispatchable electricity produced by the two pathways on seven impact categories. There was not one single pathway that had the most environmental benefits on all seven impact categories. Of the Power-to-Fuel-to-Power systems assessed the use of hydrogen for storage has the lowest environmental impact in all categories. Additionally, all the Power-to-Fuel-to-Power systems have a lower environmental impact on climate change, photochemical ozone formation and fossil resource depletion compared with the natural gas with carbon capture and storage system. The natural gas with carbon capture and storage system has a lower environmental impact on particulate matter formation, marine eutrophication and mineral resource scarcity. [The authors'] work is complemented by an analysis of pathways from a net-zero-direct-CO_2 to a life-cycle net-zero-CO_2-equivalent power system which is actually climate neutral, achieved by direct air capture of the residual CO_2 from the atmosphere. However, this leads to an increase in all other impact categories of 11% for the Power-to-Fuel-to-Power systems and 21% in the natural gas combustion with carbon capture and storage system. A system sizing study also highlights the very low capacity factors of the capital employed for electricity storage, raising the point of economic feasibility."

Jan Bernard Wevers, Li Shen, and Mijndert Van der Spek, *Proceedings of the 15th Greenhouse Gas Control Technologies Conference 15-18 March 2021. (Subscription may be required.)*

The spatial spillover effect of fossil fuel energy trade on CO_2 emissions.

The following is from the abstract of this article: "[The authors] diagnose CO_2 emission changes and determine the driving mechanisms and spatial spillover effect worldwide using spatial econometric techniques embedded within energy trade in the period 2000–2014. [The authors] focus on fossil fuel import, taking it as the medium through which to examine the spatial spillover effect on CO_2 emissions, and compare the spatial influence between developed and developing countries. [The authors] propose different hypotheses considering the magnitude of spatial influence through fossil fuel trade between developed countries, between developing countries, and between developed and developing countries. These hypotheses are manifested in the multiple spatial econometric model. Results revealed general heterogeneity of CO_2 emissions among different countries alongside fluctuations and wavy increments in the analyzed groups of countries. However, the convergence of emissions was predictable because the growth rate of CO_2 emissions was low in countries with high levels of CO_2 emission and converged rapidly with that of developed countries. The spatial autocorrelation phenomenon and spatial spillover effects generated from energy trade have previously only been verified worldwide rather than solely in developed countries or developing countries. Urbanization, industrial development, deforestation and GDP growth all drive the increase in CO_2 emissions whereas renewable energy options can help to mitigate emission increases."

Chen Zeng, Lindsay C. Stringer, and Tianyu Lv, *Energy. (Subscription may be required.)*

Zero-energy penalty carbon capture and utilization for liquid fuel and power cogeneration with chemical looping combustion.

The following is from the abstract of this article: "The utilization of captured CO_2 for fuel, chemicals and materials is currently a focus of significant research effort as a method that can simultaneously mitigate greenhouse gas effect while reduce fossil fuel depletion. In this work, CO_2 source is provided by a desirable three-stage Fe-based chemical looping combustion power system that can achieve zero-energy-penalty CO_2 capture while simultaneously obtain pure H_2 source. The aim of this study is to present this designed process for the first time with demonstrating it as an energy-efficient and environmental-friendly CO_2-to-liquid fuel pathway. Within this context, the liquid fuels energy output and carbon emissions are compared with different CO_2 utilization ratios to the thermodynamic assessment, intending to disclose the insufficiency location within system. With conceivable improvements in an optimum condition, the fuel energy saving ratio and CO_2 emission ratio of this process are projected to be 12.19% and 98.46%, respectively in relative to separate production system. The maximal exergy destruction, though projected to be located in chemical looping hydrogen generation unit (as represented by 37.56% of total exergy destruction), still has opportunities to reduce in some extent by elevating oxygen carries high-temperature resistance along with future research needs. Finally the sensitivity analysis is also projected to assess the strong influencing parameters that affect the system performance."

Yangdong He, Lin Zhu, Luling Li, and Ling Sun, *Journal of Cleaner Production. (Subscription may be required.)*

Energy, exergy, economic and environmental (4E) analysis of an integrated process combining CO_2 capture and storage, an organic Rankine cycle and an absorption refrigeration cycle.

The following is from the abstract of this article: "In order to reduce the cost of CO_2 capture and storage, and promote the application of this technology in the coal chemical industry, [the authors] propose an integrated process combining an organic Rankine cycle, an absorption refrigeration cycle, and the purification of syngas from coal. Its purpose is to make efficient use of the waste heat produced in the manufacture of natural gas from coal, converting it into available energy, such as electric energy and cold energy, so as to save energy and reduce emissions. At the same time, the integration process can effectively improve the efficiency of energy use. Based on an accurate model, a simulation of the entire process is established, and the process is then analyzed from the aspects of energy, exergy, economy, and the environment. The thermal efficiency of the organic Rankine cycle, and the coefficient of performance of the absorption refrigeration cycle, are 0.148 and 0.1058, respectively. The result of an exergy analysis shows that the exergy efficiency of the waste heat utilization system is 42.88%. The integration process can greatly reduce the operational cost of CO_2 capture and storage, making it 81% lower than that of the basic process. The results of a life-cycle assessment show that the integration process has good environmental benefits, with a total equivalent CO_2 emission of 2.03 kg CO_2-eq/t. The integration process is of great significance for CO_2 capture and storage in the coal chemical industry, and for the optimization and improvement of other processes by making use of low grade waste heat."

Xiaobin Liu, Xiao Yang, Mengxiao Yu, Wanxiang Zhang, Yinglong Wang, Peizhe Cui, Zhaoyou Zhu, Yixin Ma, and Jun Gao, *Energy Conversion and Management. (Subscription may be required.)*

A Hybrid Optimization Methodology Identifying Optimal Operating Conditions for Carbon Dioxide Injection in Geologic Carbon Sequestration.

The following is from the abstract of this article: "Prior to determining the optimal operating parameters for CO_2 injection, conditions for both injection wellbore and storage formation should be evaluated; the build-up pressure induced by the CO_2 injection could promote fractures in the storage formation, even collapsing the wellbore. In this study, a hybrid optimization methodology, which combined the proxy modeling and multi-objective optimization, was engaged in searching appropriate operating conditions for CO_2 injection. The study utilized a fully coupled wellbore-reservoir (WR) model to simulate the CO_2 injection scenarios. Three responses, such as pressure, temperature, and CO_2 mass flow rate at the bottom-hole of injection wellbore, were investigated. To reduce the computational cost, the statistical proxy models were developed for approximating three responses. The developed fine-tuned proxy models revealed four influential factors; wellhead pressure, injected CO_2 temperature, wellbore diameter, and permeability of a storage formation were significant in predicting three responses. Among these four influential factors, permeability was treated to be an uncertainty factor, while the other three factors were treated as tuning factors. According to acquired optimal solution sets, the optimum values for wellhead pressure and injected CO_2 temperature were distributed around 10.0 MPa and 35°C, respectively. For the wellbore diameter, its mean of optimal solutions was 0.1 m, and more solutions were concentrated at this mean value with a decrease in permeability."

Jize Piao, Weon Shik Han, Peter K. Kang, Baehyun Min, Kue-Young Kim, Gidon Han, and Jong Gil Park, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

The determinants of CO_2 prices in the EU emission trading system.

The following is from the abstract of this article: "In 2005, the European Union launched its Emissions Trading System (ETS), the first and one of the largest international carbon markets aimed at reducing member states' CO_2 emissions. Policymakers tend to use the carbon price as an indicator of the 'health' and effectiveness of the ETS mechanism, although this measure is influenced by many other energy and climate policies, energy market fundamentals, and speculative shocks. This paper develops a model that links the energy sector (oil, natural gas, coal, electricity prices, and the share of fossil fuels in electricity generation), economic activity, and the carbon price. The model can be used as a monitoring tool for carbon price dynamics. [The authors] represent the model empirically through a Structural Vector Autoregression and use frequency-domain analysis to distinguish the effects of changes in fundamental factors from shocks to market microstructure. [The authors'] empirical results show that up to 90% (65% on average) of the fluctuations in the carbon price, adjusted for supply effects, are explained by fluctuations in fundamental market variables; however, the individual contributions are not stable. Overall, [the authors'] results suggest that the ETS has started to work well."

Yuliya Lovcha, Alejandro Perez-Laborda, and Iryna Sikora, *Applied Energy. (Subscription may be required.)*

FEBRUARY 2022

A Trans-European CO_2 Transportation Infrastructure for CCUS: Opportunities & Challenges.

The following is from a description of this Zero Emissions Platform report: "This report looks at the challenges and opportunities for CO_2 transport in Europe, including pipelines and other modes of transport. It provides an overview of CO_2 transportation, particularly in industrial clusters, and highlights the importance of developing dedicated business models, as well as enabling policy framework, for CO_2 transportation. This report is particularly relevant in the context of the European Green Deal, as CO_2 infrastructure is crucial to deliver large-scale decarbonisation across industry and energy sectors, which will be necessary to achieve climate-neutrality."

The $2 Trillion Transition: Canada's Road to Net Zero.

The following is from the Executive Summary of this report: "To get on a more serious path to Net Zero, the [Canadian] federal government committed to getting Canada back to around 500 million tonnes by the end of this decade—and eliminating or offsetting the rest by 2050, using new technologies like electric vehicles, new heat sources for homes, and new processes to capture and store some of the emissions that [continue to be produced to power the planet]. This report aims to map out some of those pathways, as well as the investments and policies needed to achieve Net Zero. [The authors] use a range of established modelling on the emissions of major sectors, and the potential of breakthrough technologies, behavioural changes and improvements in industrial and agriculture processes. [The authors'] research aims to project out, over 30 years, what the estimated long-term costs and benefits could be, understanding that many uncertainties exist around climate, technology and behavioural trends and such forecasts will continue to evolve."

Bio-energy with carbon capture and storage via alkaline thermal Treatment: Production of high purity H_2 from wet wheat straw grass with CO_2 capture.

The following is from the abstract of this article: "Biomass has a unique potential for "negative emissions" of CO_2 if carbon capture and storage are integrated into the biomass conversion. While a large body of research has explored biomass conversion, challenges such as low energy density and high moisture content persist. This study proposes and investigates a novel single-step reaction scheme called Alkaline Thermal Treatment (ATT) to convert a real biomass feedstock (e.g. wet wheat straw grass) into high purity H_2 in the presence of alkali (e.g., NaOH) at a moderate temperature of 500°C and ambient pressure. Importantly, negligible CO and a very low percentage of CO_2 (0.3%) were detected in the product gas stream, thus rendering gas products from the ATT reaction usable in various applications including fuel cells without further gas purification steps. The solid residue contained a very high percentage of carbonate, confirming the in-situ carbon capture effect."

Hui Zhou and Ah-Hyung Alissa Park, *Applied Energy. (Subscription may be required.)*

The CO_2 cost pass-through and environmental effectiveness in emission trading schemes.

The following is from the abstract of this article: "In this paper, [the authors] theoretically investigate the issues of CO_2 cost pass-through and environmental effectiveness in emission trading schemes by virtue of a Stackelberg equilibrium. [The authors] characterize the equilibrium output and price of energy product, and construct analytical derivations of CO_2 cost pass-through rates. [The authors'] findings indicate that after the introduction of emission trading scheme, CO_2 costs of energy firms are not over-shifted to energy consumers, energy supplies and demands are not excessive distortion as well. Compared to some known results, [The authors] prove that the environment effectiveness of emission trading scheme can be improved by the Stackelberg equilibrium under mild conditions. [The authors'] main results add to the theory of emission trading scheme by developing a framework where [the authors] allow for multi-stage games with observed actions, and present an optimal competition mechanism to optimize CO_2 costs and CO_2 emissions in emission trading schemes as well. More importantly, the optimal competition mechanism provides regulators and policy makers important information that can be used to design efficient and effective energy policies to trad off energy production, consumption and environmental objectives in emission trading schemes."

Shiyong Yu, Yuke Chen, Linchang Pu, and Zhe Chen, *Energy. (Subscription may be required.)*

Integration of hydrothermal liquefaction and carbon capture and storage for the production of advanced liquid biofuels with negative CO_2 emissions.

The following is from the abstract of this article: "The technical and economic feasibility to deliver sustainable liquid biocrude through hydrothermal liquefaction (HTL) while enabling negative carbon dioxide emissions is evaluated in this paper, looking into the potential of the process in the context of negative emission technologies (NETs) for climate change mitigation. In the HTL process, a gas phase consisting mainly of carbon dioxide is obtained as a side product driving a potential for the implementation of carbon capture and storage in the process (BECCS) that has not been explored yet in the existing literature and is undertaken in this study. To this end, the process is divided in a 'standard' HTL base and a carbon capture add-on, having forestry residues as feedstock. The Selexol™ technology is adapted in a novel scheme to simultaneously separate the CO_2 from the HTL gas and recover the excess hydrogen for biocrude upgrading. The cost evaluation indicates that the additional cost of the carbon capture can be compensated by revenues from the excess process heat and the European carbon allowance market. The impact in the MFSP of the HTL base case ranges from –7% to 3%, with –15% in the most favorable scenario, with a GHG emissions reduction potential of 102–113% compared to the fossil baseline. These results show that the implementation of CCS in the HTL process is a promising alternative from technical, economic and environmental perspective in future scenarios in which advanced liquid biofuels and NETs are expected to play a role in the decarbonization of the energy system."

E.M. Lozano, T.H. Pedersen, and L.A. Rosendahl, *Applied Energy. (Subscription may be required.)*

Operating flexibility of natural gas combined cycle power plant integrated with post-combustion capture.

The following is from the abstract of this article: "Highly flexible, low-carbon electricity generation with gas-fired power stations with CO_2 capture addresses the challenges of balancing variable renewable electricity supply in low carbon electricity systems. This detailed technical assessment of flexible CO_2 capture plant operation at natural gas combined cycle power stations with post-combustion CO_2 capture examines the operating strategies of capture plant by-pass and interim solvent storage. [The authors] show that solvent storage allows expanding the operating envelope of gas fired CCS power stations by +/-10%. Further [the authors] demonstrate that electricity and CO_2 output can be decoupled for up to 3 h with approx. 6000 m3 of additional solvent inventory for the purpose of reducing the CO_2 flow variability in downstream transportation and storage systems, mitigating potentially deleterious injection well effects. 1 h of solvent storage operation at full load can be regenerated in as fast as 2.1 h during continuous operation of the CCS power plant by choosing a controlled steam extraction strategy from the combined cycle and thus throttling the low pressure turbine. The electricity output penalty associated with the delayed regeneration of solvent ranges from 420–450 kWh/tCO_2 with this strategy, which compares to 380 kWh/tCO_2 for immediate regeneration at full load design conditions. By deploying a novel variable speed drive integrally geared compressor model, [the authors] find that, unlike previously thought, an uncontrolled steam extraction strategy, referred as a floating steam extraction strategy, can lead to choking of the CO_2 compressor during additional solvent regeneration. A pre-compression stage would be necessary under this extraction strategy to restore feasible operation of the main CO_2 compressor, and makes this strategy more complex to implement. When decreasing the desorber pressure at part-load care must, therefore, be taken to respect the operating limits of the compressor. To assist with the use of rigorous plant performance data in wider electricity system models, correlations for key performance parameters of NGCC-CCS power plants at varying load, with capture by-pass and additional solvent regeneration are provided."

Thomas Spitz, Abigail González Díaz, Hannah Chalmers, and Mathieu Lucquiaud, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Impact of formation slope and fault on CO_2 storage efficiency and containment at the Shenhua CO_2 geological storage site in the Ordos Basin, China.

The following is from the abstract of this article: "Carbon dioxide (CO_2) storage security is a key issue in CO_2 geological storage (CGS). A three-dimensional (3D) conceptual reservoir model of the Shenhua CO_2 geological storage site in the Ordos Basin has been used to investigate the impact of reservoir formation dip and the influence of enhanced permeability fault zones on CO_2 storage and migration security. A total of 8 simulations were carried out using the TOUGH$_2$ integral finite difference modelling code with the ECO2N fluid property module. The simulation results showed that the dip of the reservoir formation and fault had a significant impact on CO_2 migration and storage security. Increasing the dip of the reservoir increased CO_2 migration distance, decreased the total volume of CO_2 safely stored in the formation and resulted in increased maximum gas saturation and liquid mass fraction of dissolved CO_2. The presence of fault provided a channel for CO_2 leakage and caused an irregular distribution of formation pressure. The onset time of leakage through the fault proved to be a function of formation dip, occurring at 465, 230, and 160 years following commencement of CO_2 injection for dips of 5°, 10°, and 15° respectively. The lateral extent of both the high saturation CO_2 plume and the plume of dissolved CO_2 was greater in the steeply dipping faulted reservoir model, suggesting that gently dipping un-faulted reservoir formations should be selected for future CGS projects in the Ordos Basin."

Jing Jing, Zhonghua Tang, Yanlin Yang, and Liangzhe Ma, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Estimating in-use wood-based materials carbon stocks in Indonesia: Towards a contribution to the national climate mitigation effort.

The following is from the abstract of this article: "The carbon sequestered in harvested wood products (HWP) can contribute to climate change mitigation. As a fast-growing country with abundant forest resources, Indonesia potentially has vast HWP carbon stocks that need to be accurately assessed as a first step towards understanding the extent of their potential contribution in climate change mitigation. In this study, a dynamic materials stock and flow analysis for carbon in wood-based products in Indonesia was conducted, covering six end-use sectors. In general, only around 30.3% of the harvested wood (carbon mass) was converted into end-use materials in 2014, indicating a significantly low harvested wood conversion rate in Indonesia. There was a significant increase of wood-based products' carbon stocks in Indonesia from 1961 to 2016. There were 72 (-17/+15) Mt-C of wood stocks in Indonesian society in 2016, or equivalent to 0.28 t-C/capita. Buildings (42%) and infrastructure (31%) were the largest contributors to in-use carbon stocks. The product lifetime uncertainty had a significant influence on the estimate of total society's wood-based carbon stock. Indonesia's in-use stock of wood-based products in 2008 was below its stock level of steel (1.2 times smaller) and cement (5.3 times smaller). Both wood-steel and wood-cement stock ratios showed declining trends, indicating a shifting trend to non-renewable materials use over the past decades. This is the first study that accounts for the in-use wood-based carbon stocks in a developing country. Its results can facilitate further quantitative environmental assessments of non-renewable materials substitution and could help framing materials use policies for climate change mitigation."

Rio Aryapratama and Stefan Pauliuk, *Resources, Conservation and Recycling. (Subscription may be required.)*

The effects of environmental innovations on CO_2 emissions: Empirical evidence from Europe.

The following is from the abstract of this article: "Environmental innovations are key enablers of transition towards greener economies. Despite their importance, empirical studies examining the effect of green technologies on CO_2 emissions are still limited. Using an autoregressive distributed-lag model (ARDL), [the authors] analyze the impact of environmental innovations, the consumption of renewable energies, GDP per capita, and degree of economic openness on CO_2 emissions for 15 European countries over 23 years. [The authors'] results indicate that, in the long-term, environmental innovations tend to lower CO_2 emissions, whereas in the short-term the observed effect is the opposite, suggesting the existence of a rebound effect. This study recommends introducing new policies that combine tools of environmental economics with those of ecological economy to integrate economic incentives with regulatory changes and encourage individuals to consume differently by favouring products and/or services with a less negative impact on the environment."

Michelle Mongo, Fateh Belaïd, and Boumediene Ramdani, *Environmental Science & Policy. (Subscription may be required.)*

MARCH 2022

Computed Tomography Scanning and Petrophysical Measurements of the Wellington KGS 2-32 Core.

The following is from the abstract of this DOE/NETL report: "The computed tomography (CT) facilities and the Multi-Sensor Core Logger (MSCL) at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia were used to characterize core from the Wellington KGS 2-32 well (API 15-191-22770). Core from the well was obtained as part of the Small-Scale Field Test Demonstrating Carbon Dioxide (CO_2) Sequestration in Arbuckle Saline Aquifer and by CO_2-Enhanced Oil Recovery at Wellington Field, Sumner County, Kansas (DE-FE0006821). The primary impetus of this work was to capture [a detailed digital representation] of the core from the Wellington KGS 2-32 well (Sumner County, Kansas). The collaboration between the U.S. Department of Energy's (DOE) NETL and the Kansas Geological Survey (KGS) at the University of Kansas enables other research entities to access information about this potential carbon storage location and formations. The resultant datasets are presented in this report and can be accessed from NETL's Energy Data eXchange (EDX) *online system*."

Innovative method for CO_2 fixation and storage.

The following is from the abstract of this article: "The concentration of CO_2 in Earth's atmosphere has been gradually increasing since the Industrial Revolution, primarily as a result of the use of fossil fuels as energy sources. Although coal and oil have been vital to the development of modern civilization, it is now recognized that atmospheric CO_2 levels must be reduced to avoid the serious effects of climate change, including natural disasters. Consequently, there is currently significant interest in developing suitable methods for the fixation of CO_2 in the air and in exhaust gases. The present work demonstrates a simple yet innovative approach to the chemical fixation of extremely low and very high CO_2 concentrations in air, such as might result from industrial sources. This process is based on the use of aqueous solutions of the water-soluble compounds NaOH and CaCl2, which react with CO_2 to produce the harmless solids CaCO3 (limestone) and NaCl (salt) via intermediates such as NaHCO3 and Na_2CO3. The NaCl generated in this process can be converted back to NaOH via electrolysis, during which H_2 (which can be used as a clean energy source) and Cl2 are produced simultaneously. Additionally, sea water contains both NaCl and CaCl2 and so could provide a ready supply of these two compounds. This system provides a safe, inexpensive approach to simultaneous CO_2 fixation and storage."

Kenji Sorimachi, *Scientific Reports. (Subscription may be required.)*

Integration of hydrothermal liquefaction and carbon capture and storage for the production of advanced liquid biofuels with negative CO_2 emissions.

The following is from the abstract of this article: "The technical and economic feasibility to deliver sustainable liquid biocrude through hydrothermal liquefaction (HTL) while enabling negative carbon dioxide emissions is evaluated in this paper, looking into the potential of the process in the context of negative emission technologies (NETs) for climate change mitigation. In the HTL process, a gas phase consisting mainly of carbon dioxide is obtained as a side product driving a potential for the implementation of carbon capture and storage in the process (BECCS) that has not been explored yet in the existing literature and is undertaken in this study. To this end, the process is divided in a 'standard' HTL base and a carbon capture add-on, having forestry residues as feedstock. The Selexol™ technology is adapted in a novel scheme to simultaneously separate the CO_2 from the HTL gas and recover the excess hydrogen for biocrude upgrading. The cost evaluation indicates that the additional cost of the carbon capture can be compensated by revenues from the excess process heat and the European carbon allowance market. The impact in the MFSP of the HTL base case ranges from –7% to 3%, with –15% in the most favorable scenario, with a GHG emissions reduction potential of 102–113% compared to the fossil baseline. These results show that the implementation of CCS in the HTL process is a promising alternative from technical, economic and environmental perspective in future scenarios in which advanced liquid biofuels and NETs are expected to play a role in the decarbonization of the energy system."

E.M. Lozano, T.H. Pedersen, and L.A. Rosendahl, *Applied Energy. (Subscription may be required.)*

Basalt powder as a supplementary cementitious material in cement paste for CCS wells: chemical and mechanical resistance of cement formulations for CO_2 geological storage sites.

The following is from the abstract of this article: "This study proposes the application of basalt powder (BP) as a supplementary cementitious material (SCM) in cement formulations for Carbon Capture and Storage (CCS) wells. From experimental results, [the authors] identified that the BP can be characterized as a filled-pozzolanic SCM, presenting low pozzolanic activity, large inert fraction, and particle size significantly smaller than class G cement. Formulations with low basalt powder (≤ 0.5 wt.%) content presented the greatest potential for application in CCS wells since they are more resistant to CO_2 degradation, showing low porosity and suitable mechanical properties, as evidenced in carbonation tests. Due to basalt powder characteristics, [the authors] conclude that the increase in the chemical resistance of the cement formulation with low BP content is due to the reduction of both the porosity and permeability as a result of filling of empty spaces and the refinement of the porous cement network, allied to the low reduction of the alkaline reserve of portlandite. The combination of these features increases the material's resistance to fluid intrusion, reduces the progress of the CO_2 degradation front, and preserves the cement matrix's ability to delay the reaction of acid gases."

Gabriela Gonçalves Dias Ponzi, Victor Hugo Jacks Mendes dos Santos, Renan Bordulis Martel, Darlan Pontin, Amanda Sofia de Guimarães e Stepanha, Marta Kerber Schütz, Sonia C. Menezes, Sandra M.O. Einloft, and Felipe Dalla Vecchia, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Gas adsorption characteristics changes in shale after supercritical CO_2-water exposure at different pressures and temperatures.

The following is from the abstract of this article: "The supercritical CO_2 ($ScCO_2$)-water-shale interaction and its influence on adsorption characteristics of shale have significant impact on the estimation of the CO_2 storage capacity. In this study, the influence of $ScCO_2$-water exposure pressures and temperatures (P = 0, 10, 15, 20 MPa, T = 308, 323, 338, 353 K) on shale CH4 and CO_2 adsorption characteristics were investigated. CH4 and CO_2 adsorption tests, X-ray diffraction analysis, low-pressure N_2 adsorption measurement were carried out on the shale samples before and after exposure. The results shown that after $ScCO_2$-water exposure, the CH4 and CO_2 adsorption capacity were decreased gradually with the increase of exposure pressure and the decrease of exposure temperature, due to the alterations of mineral composition and pore structure in shale. After $ScCO_2$-water exposure, the contents of shale clay minerals, organic matter and carbonate were decreased, resulting in the decrease of specific surface area and micropore volume. With the increase of exposure pressure and the decrease of exposure temperature, the solubility and extraction ability of $ScCO_2$-water were increased, then more significant mineral composition and pore structure alterations, as well as more significant changes on the gas adsorption capacities of shale were expected. The selectivity factor of CO_2 to CH4 of shale shown a gradually decreased trend with the increase of exposure pressure and the decrease of exposure temperature, respectively, and were all greater than 1 for both the untreated and $ScCO_2$-water treated shale samples at different exposure conditions, indicating that CO_2 enhanced shale gas recovery and sequestration is feasible even after $ScCO_2$-water exposure. To predict the CO_2 storage capacity in shale gas reservoirs, the combined effects of exposure pressure and temperature on the adsorption characteristics of shale should be considered at the reservoir conditions."

Kang Yang, Junping Zhou, Xuefu Xian, Yongdong Jiang, Chengpeng Zhang, Zhaohui Lu, and Hong Yin, *Fuel. (Subscription may be required.)*

Optimization of dynamic incentive for the deployment of carbon dioxide removal technology: A nonlinear dynamic approach combined with real options.

The following is from the abstract of this article: "Due to the high adoption cost, large uncertainty, and ignorance of the positive externalities for private entities, additional incentives are needed for the development of carbon dioxide removal (CDR) technology. And there is a trade-off between the government and investors on how to ensure the effectiveness of the incentive policy and optimally allocate subsidized capital. This paper proposes a nonlinear dynamic programming model that combines real options method to study the optimization of dynamic subsidies for CDR technology. Using the endogenous learning effect, technological advance, and technology applicability, [the authors] modeled the investor decisions under uncertainty, as well as the government's effective use of incentive policies. [The authors'] model is available for deriving the development path of CDR technology with optimized subsidies and research and development (R&D) input across multiple periods. [The authors] use China's carbon capture and storage (CCS) development as a case study. The results show that, unlike other kinds of low-carbon technology such as renewable energy, the subsidy level of CCS may not decrease in the future because of rising trend of fuel costs and worse technology applicability in large-scale deployment. The achievement of large-scale CCS development will rely more on second-generation CCS. The levelized policy cost of incentivizing CCS technology in China can be high, and thus the target should be prudently set based on an evaluation of its socioeconomic burden. A supplementary measure that caps the CCS installation in each period is recommended to prevent excessive development."

Xing Yao, Ying Fan, Lei Zhu, and Xian Zhang, *Energy Economics. (Subscription may be required.)*

From CO_2 sources to sinks: Regulatory challenges for trans-boundary trade, shipment and storage.

The following is from the abstract of this article: "Carbon Capture and Storage (CCS) technologies have been hailed as a solution to climate change with capacity not only to reduce atmospheric carbon dioxide (CO_2) but also to achieve net-zero emission by the mid-21st century. CO_2 captured (either directly from the atmosphere or from large point sources), is compressed and transported to storage sites, either via pipelines or through shipping. Often, the CCS projects are deployed nationally where capture, transport and storage take place within the jurisdiction of one State. However, wide scale deployment of CCS projects is imperative for global matching of CO_2 sources to sinks. To that end, the outreach of CCS technology needs to go beyond the developed world. Studies have indicated that developing countries have vast storage resource potential. Internationalization of CCS projects where CO_2 is captured in one State and is then transported to another State for storage raises a number of challenges particularly in terms of trans-boundary transport and storage. This paper explores some of these challenges particularly in terms of international trade law, liability framework for shipping and storage and potential of insurance to act as a stop-gap arrangement until a regulatory regime is in place. It examines questions such as: whether CO_2 and CCS technologies are environmental goods and services under trade law; are there any regulatory frameworks in place to ensure liability against long-term health and safety as well environmental risks and what role can insurance industry play in promoting global deployment of CCS projects?"

Swati Gola and Kyriaki Noussia, *Resources, Conservation and Recycling. (Subscription may be required.)*

The role of storage technologies throughout the decarbonisation of the sector-coupled European energy system.

The following is from the abstract of this article: "[The authors] use an open, hourly-resolved, networked model of the European energy system to investigate the storage requirements under decreasing CO_2 emissions targets and several sector-coupling scenarios. For the power system, significant storage capacities only emerge for CO_2 reductions higher than 80% of 1990 level in that sector. For 95% CO_2 reductions, the optimal system includes electric batteries and hydrogen storage energy capacities equivalent to 1.4 and 19.4 times the average hourly electricity demand. Coupling heating and transport sectors enables deeper global CO_2 reductions before the required storage capacities become significant, which highlights the importance of sector coupling strategies in the transition to low carbon energy systems. A binary selection of storage technologies is consistently found, i.e., electric batteries act as short-term storage to counterbalance solar photovoltaic generation while hydrogen storage smooths wind fluctuations. Flexibility from the electric vehicle batteries provided by coupling the transport sector avoid the need for additional stationary batteries and reduce the usage of pumped hydro storage. Coupling the heating sector brings to the system large capacities of thermal energy storage to compensate for the significant seasonal variation in heating demand."

Marta Victoria, Kun Zhu, Tom Brown, Gorm B. Andresen, and Martin Greiner, *Energy Conversion and Management. (Subscription may be required.)*

Terrestrial organic carbon storage modes based on relationship between soil and lake carbon, China.

The following is from the abstract of this article: "Terrestrial ecosystems have received considerable attention as a significant sink for organic carbon at regional to global scales. Previous studies were focused on assessment and quantification of carbon sinks for one ecotype, and few have worked on the interconnection of terrestrial sinks. In this paper, [the authors] synthesized the data from China's second national soil survey and direct measurements from 54 lakes. Meanwhile, [the authors] investigated the controlling factors of carbon accumulation dynamics in soils and lakes. Results showed varied spatial distribution of soil and lake organic carbon in different regions, and three storage modes were found. The storage mode of watershed collection was observed in the region of the Qinghai-Tibetan Plateau, while the northeast China and Yunnan-Guizhou Plateau revealed another storage mode of autochthonous deposition, and the mode of human activities affection was represented by the East Plain and Mongolia-Xinjiang Plateau. The spatial difference throughout China was regulated by various climate patterns, geological conditions and anthropogenic interference. [The authors'] results provide insights into carbon storage modes in various regions, and also inform strategies for enhancing global carbon sequestration and future mitigation policies towards global climate change."

Lingmei Xu, Yu Li, Wangting Ye, and Xinzhong Zhang, *Journal of Environmental Management. (Subscription may be required.)*

A carbon-sink in a sacred forest: Biologically-driven calcite formation in highly weathered soils in Northern Togo (West Africa).

The following is from the abstract of this article: "…In the OM rich soils under forest, bio-calcification takes place in the form of CaCO3 needles, micrite hypocoatings around biopores and calcified cells. Oribatid excrements are associated with calcite and organic matter in the sacred forest soil, indicating that litter recycling has played an important role in the formation of calcite. [The authors] hypothesize that the high biological activity releasing CO_2, formation of $HCO3^-$ and precipitation of CaCO3 due to the $Ca2^+$ released by the recycled organic matter and weathering of plagioclases, lead to different forms of secondary calcium carbonate in the sacred forest soils. The high oxalate content of the vegetation in the sacred forest suggests that calcium carbonate formation, possibly via the oxalate-carbonate pathway, may also have played a role in calcite precipitation in these in organic matter rich soils. The parent material of these soils is not calcareous, meaning that these are not lithogenic carbonates, thus making them an important carbon sink. The soil characteristics indicate a high potential for development of the soils of the area in both agricultural yields and in potential carbon sequestration relevant to global change policies."

Hafeez Ur Rehman, Rosa M. Poch, Fabio Scarciglia, and Michele L. Francis, *CATENA. (Subscription may be required.)*

African Continental Free Trade Area treaty and CO_2: A volatility-driven CO_2 mitigation pathways model for ratified countries.

The following is from the abstract of this article: "The African Continental Free Trade Area (AfCFTA) agreement is expected to boost continental trade volume, but the effects of the expected increase in trade volumes on carbon dioxide (CO_2) emissions has not been explored. In addition, although attempts are being made towards providing a reliable CO_2 forecasting and mitigation values, existing mitigation pathways have been found to be illusory, misleading, and largely irrelevant due to their inability to inculcate observed volatilities in the core modeling. This study considers 25 countries that have ratified the AfCFTA agreement investigates their CO_2 determinants, and proposes relevant and representative mitigation roadmaps for each country. A novel model that considers growth, maximum and minimum volatilities for all the variables is constructed to propose these roadmaps. The empirical results on causal relationships find that whiles trade openness, urbanization, and economic activities are positive determinants of CO_2, renewable energy, human capital, and financial development are negative drivers. Among the factors examined, trade openness has been identified as the most significant long-term driver of CO_2 within AfCFTA countries. The results from [the authors'] prediction model show that the 25 ratified countries will collectively increase their emissions by 17% relative to their 2015 emissions level if no measures are taken. However, if these countries follow our proposed radical roadmaps, they will collectively emit zero carbon emissions by 2028. In order to achieve a massive reduction in CO_2 emissions, policymakers within the AfCFTA should adopt radical mitigation roadmaps as proposed. Future studies should focus on developing models to identify the cost and highlight the feasibility of our strategy."

Evans Opoku-Mensah, Yuming Yin, Amos Oppong, Peter Adjei Darko, Rockson Sai, and PriscillaTuffour, *Journal of Cleaner Production. (Subscription may be required.)*

APRIL 2022

User's Manual for Seal_Flux: A Seal Barrier Reduced-Order Model.

The following is from the Executive Summary of this National Risk Assessment Partnership (NRAP) report: "This report provides a brief description on the use of the *Seal_Flux* computer program developed as part of the effort to quantify the risk of geologic storage of carbon dioxide (CO_2) under the U.S. Department of Energy's (DOE) National Risk Assessment Partnership (NRAP). The *Seal_Flux* code simulates the flow of CO_2 through a low permeability rock horizon or seal formation overlying the storage reservoir into which CO_2 is injected. A two-phase, relative permeability approach with Darcy's law is used for one-dimensional (1D) flow computations of CO_2 through the horizon in the vertical direction. The code also allows the simulation of time-dependent processes that can influence such flow. However, as part of its design, *Seal_Flux* is what can be termed a 'reduced-order model' (ROM) and is not intended as a full-functioning flow code. The theory and simulation in the code is stream-lined and directed towards the implementation of Monte Carlo risk analyses of CO_2 transport or as termed in this context as 'leakage.' While presented in this report as a stand-alone tool, the *Seal_Flux* code is intended to function in the future as one of several models as part of an integrated, systems-level model of CO_2 storage performance. Finally, the code is written in Python 3.8 to provide an open framework for further development by others and to assist in linking the code with other modules in an integrated assessment model."

Distilling data to drive carbon storage insights.

The following is from the abstract of this article: "Wide-spread implementation of carbon capture and storage has the potential to decrease carbon emissions and aid in meeting global climate change mitigation goals. Data availability is one of the biggest challenges faced by the carbon capture and storage (CCS) community for modeling risks associated with CCS, necessary for wide-spread implementation in coming years. Collecting, integrating, and intuitively managing data is a time-consuming process, but one which is fundamental to establishing necessary access to carbon storage data. The US Department of Energy (US DOE) has been a major supporter of energy research in the US, including significant investment into carbon capture and storage research and technology development over the last ten years. The US DOE investments into the Regional Carbon Sequestration Partnerships, the National Risk Assessment Partnership, and other CCS related research has resulted in a large volume of data, of which much has been made public through the National Energy Technology Laboratories data repository, the Energy Data eXchange (EDX). Researchers at the National Energy Technology Laboratory have developed workflows, tools, and other methods that leverage EDX, open-source software, machine learning, and natural language processing to discover, curate, label, organize and visualize available data. This paper describes the available data on EDX for carbon storage applications, describes the results of a spatial and temporal analysis of the data, describes where it is most geographically available, makes a general assessment of the quality of the available data, and discusses visualization tools and natural language processing tools developed for understanding, discovering and reusing the data."

Paige Morkner, Jennifer Bauer, C. Gabriel Creason, Michael Sabbatino, Patrick Wingo, Randall Greenburg, Samuel Walker, David Yeates, and Kelly Rose, *Computers & Geosciences. (Subscription may be required.) [Click here to access NETL's EDX.]*

Numerical analysis of fracture deformation and instability during CO_2 geological sequestration using a THM-XFEM coupled model.

The following is from the abstract of this article: "Fracture deformation and instability during long-term CO_2 geological sequestration in abandon reservoirs is simulated with a thermal-hydro-mechanical model. The two-phase in non-isothermal condition is used both in matrix and fracture, and thermoelastic and poroelastic deformation are all taken into account. The extended finite element method is employed to solve the strong discontinuity problem involving thermal-hydro-mechanical coupling. The S-W equation of state and transport equation are chosen to characterize CO_2 phase change. CO_2 geological sequestration in abandoned-fractured reservoir with high water-cut is discussed with a two-dimensional model. The analysis of fracture deformation shows that CO_2 geological sequestration has a great effect on fracture deformation and instability. Fracture aperture, deformation and the effective fluid pressure in fracture are highly affected by the water residual saturation and injected temperature difference. The analysis of fracture instability presents that mode I mainly appears in the fracture propagation, and propagation prefers to occur in fracture near the injection wellbore. The higher CO_2 phase pressure when cold CO_2 injection into reservoirs with low water residual saturation can promote fracture propagation 1–2 years in advance. Fracture aperture is enhanced but fracture instability time would be delayed due to the thermal stress."

Long Cheng, Zhifeng Luo, Liqiang Zhao, and Yaozeng Xie, *Computers and Geotechnics. (Subscription may be required.)*

Analytical and numerical modeling for the assessment of CO_2 storage in the Pariñas geological formation - Talara, Peru.

The following is from the abstract of this article: "This research evaluates the CO_2 storage capacity of the Pariñas Formation belonging to the Talara basin in Peru through analytical modeling based on mass balance equations and numerical modeling using IMEX CMG. Pariñas Formation has several depleted hydrocarbon reservoirs that presents favorable conditions for CO_2 geological storage. It has an average porosity of 17.6% and a permeability of 640 mD in the horizontal direction consisting of sandstones with interspersed lutites layers. The study evaluates the depleted Bellavista oil deposits involving CO_2 storage capacity estimation with CO_2 and reservoir fluid (oil and water) interaction. It involves numerical modeling based on the reservoirs properties and CO_2 injection simulation not exceeding the fracture pressure of the reservoir rock. This approach is the first one carried out in Peru and provides the chance to evaluate the CO_2 storage capacity in a hydrocarbon reservoir in this part of the world, as a strategy to mitigate future global change impacts. The results indicate a storage capacity of 35.37 million tons of CO_2, approximately. Besides, the sandstone reservoir of the Pariñas geological formation has adequate characteristics to serve as a CO_2 storage reservoir. C_{30+} pseudo component shows greater sensitivity in its properties (temperature and critical pressure) adjusting the fluid properties with the experimental data (saturation pressure, viscosity and minimum miscibility pressure)."

Rafu Pomar-Castromonte, Eusebio Ingol-Blanco, Jose Santos, and Sandra Santa-Cruz, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Effects of long-term (70 years) nitrogen fertilization and liming on carbon storage in water-stable aggregates of a semi-arid grassland soil.

The following is from the abstract of this article: "Grasslands cover up to 40.5% of the world's landmass and store 30% terrestrial carbon (C). Various practices, including mineral fertilization and liming, are used to manage these ecosystems with potential long-term effects on the size and distribution of soil aggregates and inevitably carbon dynamics. The objective of this study was to examine the long-term effects of nitrogen fertilization and liming on soil carbon storage and its dynamics in water-stable aggregates of a semi-arid grassland. Soil samples (0–10 cm) were collected from Ukulinga long-term grassland trial in Pietermaritzburg, South Africa where nitrogen fertilizers have been applied annually and lime every five years for 70 years. Ten treatments were studied: the control (0 kgN/ha and unlimited), lime at 2250 kg/ha (L), ammonium sulphate at 70 kg/ha (AS70) and 211 kg/ha (AS211); ammonium nitrate at 70 kg/ha (AN70) and 211 kg/ha (AN211); AS70 + lime (AS70L); AS211 + lime (AS211L); AN70 + lime (AN70L) and AN211 + lime (AN211L) …"

Kwenama Buthelezi and Nkosinomusa Buthelezi-Dube, *Heliyon. (Subscription may be required.)*

Dynamics of plantation forest development and ecosystem carbon storage change in coastal Bangladesh.

The following is from the abstract of this article: "Plantation forest has an immense potential for significantly contributing to the global carbon cycle for regulating climate change. Assessing the spatio-temporal distribution of plantation forest vegetation by analyzing Landsat land use/land cover (LULC) data can provide a logical basis for developing ecological and environmental policies to effectively manage ecosystem carbon storage in the future. The study aimed at assessing and predicting dynamics of plantation forest development and ecosystem carbon storage change in coastal Bangladesh over 1988–2041 under three future land management scenarios: business-as-usual (BAU), economic development (ED), and ecological protection-afforestation (EPA) by linking CA-Markov and InVEST models. Findings from LULC change analysis revealed that during 1988–2018, plantation forest increased by 984.9 km2 (68.34%) leading to an overall increase in regional carbon storage, of 3.30 Tg C. Over 2018–2041, plantation forest land could be increased by 249.90, 361.24, and 472.14 km2 under the BAU, ED, and EPA scenarios, respectively, that may potentially increase future carbon storage by 0.64 Tg C, 0.91 Tg C, and 3.77 Tg C, respectively. However, the three future land management scenarios may lead to shortages of regional food supply, of 5.96%, 13.69%, and 11.06% respectively. The suitability maps of different LULC types created in this study could be useful to find out the potential areas of plantation forest development in the future and would provide a scientific basis for further discussion by policymakers on future land use planning, to minimize the trade-offs between food security and climate change adaptation."

Muhammad Ziaul Hoque, Shenghui Cui, Imranul Islam, Lilai Xu, and Shengping Ding, *Ecological Indicators. (Subscription may be required.)*

Analysis of the effect of environmental protected areas on land-use and carbon storage in a megalopolis.

The following is from the abstract of this article: "Carbon storage in terrestrial ecosystems plays a vital role in climate control. However, urban expansion and damage to natural areas, especially the rise of megalopolises, have affected carbon storage. To mitigate this damage, various policies have been established by international, domestic, and local governments. This study focuses on the establishment and management of environmental protection areas and analyzes their impact on carbon storage. The study targets the cities of Gyeonggi-do province, South Korea, which make up a representative megalopolis, and the effectiveness of protected areas was analyzed by typifying the cities based on the proportion of available development areas and environmentally protected areas. In this study, the SLEUTH (Slope, Land-use, Excluded Area, Urban, Transportation, Hillshade) land-use change model was used to predict future land-use changes, and carbon storage was estimated using the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) Carbon model. When operating the model, [the authors] tested a control group scenario that only preserves the water zone, a scenario that preserves the legally protected areas, and a scenario that protects the areas with high environmental value. There are two significant effects of setting up protected areas: First, the 'development inhibition effect' of reducing the development area itself. Second, the 'development replacement effect' of moving development to relatively low environmental value areas. These two effects differ depending on the availability of development areas, with 'development replacement effects' prominent in areas with high development availability and 'development inhibition effects' predominant in areas with low development availability. Future policies for setting up and managing protected areas can be used in megalopolis in conjunction with policies focusing on securing the area of carbon sinks."

Jinhoo Hwang, Yuyoung Choi, Yoonji Kim, Lim No Ol, Young-Jae Yoo, Hyo Jin Cho, Zhemin Sun, and Seongwoo Jeon, *Ecological Indicators. (Subscription may be required.)*

Spatial distribution characteristics of carbon storage density in typical mixed fir and broadleaf forests.

The following is from the abstract of this article: "In order to further improve the vegetation utilization rate of typical Chinese fir and broad-leaved mixed forest, increase the carbon storage in the ecological environment, protect and improve the ecological environment, the spatial distribution characteristics of carbon storage in typical Chinese fir broad-leaved mixed forest were analyzed. The weight set of subjective estimation of carbon storage density of vegetation carbon storage factor was modified, and the fuzzy evaluation matrix of vegetation carbon storage was obtained. The evaluation vector of the matrix was calculated to evaluate the carbon storage density, and the spatial distribution characteristics of carbon storage density of typical mixed fir and broad-leaved forest were obtained. The carbon content in tree layer, shrub layer, herb layer and litter layer was detected through the sample investigation in Ganzhou City, Ji'an City, Jiujiang City, Yichun City and Shangrao City of Jiangxi Province under the same climate environment. At the same time, the soil samples of each layer were collected for analysis. The results showed that under the same age, density and site conditions, there were significant differences in the carbon storage of vegetation layer and litter layer between Chinese fir mixed forest and Chinese fir pure forest, and the carbon fixation capacity of Chinese fir mixed forest was greater than that of Chinese fir pure forest. In order to enhance the carbon storage in the ecological environment, [the authors] can consider a variety of Chinese fir mixed forest, which is of great significance to the maintenance of the ecosystem environment."

Tianyao Lan, Jiancai Gu, and Zhehua Wen, *Energy Reports. (Subscription may be required.)*

MAY 2022

Dimensionally Reduced Model for Rapid and Accurate Prediction of Gas Saturation, Pressure, and Brine Production in a CO_2 Storage Application: Case Study Using the SACROC Field as Part of SMART Task 5.

The following is from the description of this product developed by the Strategic Systems Analysis and Engineering (SSAE) group at NETL for Task 5 of SMART Phase 1: "This study involved the development of deep learning models for CO_2 geologic storage that are capable of accurate prediction of spatio-temporal outputs of CO_2 saturation, pressure, and brine production in three dimensional space over a storage operation's injection and post-injection timeframes. The model framework involves [assembling] multi-layer encoder networks that provide [dimensionality] reduction of geologic inputs with fully connected long short-term memory (LSTM) neural networks that generate time-series prediction This approach offers a means to maximize training time efficiency, reduce computational memory burden, and minimize prediction turnaround."

Geophysical Monitoring for Geologic Carbon Storage.

The following is from the description of this book: "Storing carbon dioxide in underground geological formations is emerging as a promising technology to reduce carbon dioxide emissions in the atmosphere. A range of geophysical techniques can be deployed to remotely track carbon dioxide plumes and monitor changes in the subsurface, which is critical for ensuring for safe, long-term storage. Geophysical Monitoring for Geologic Carbon Storage provides a comprehensive review of different geophysical techniques currently in use and being developed, assessing their advantages and limitations. Volume highlights include: Geodetic and surface monitoring techniques; Subsurface monitoring using seismic techniques; Subsurface monitoring using non-seismic techniques; Case studies of geophysical monitoring at different geologic carbon storage sites." (Purchase may be required.)

Policy Brief: EU ETS Directive Review: A focus on the Article 29a.

The following is from a summary of this European Roundtable on Climate Change and Sustainable Transition policy brief: "The EU ETS Directive, as currently designed, provides two instruments to act when EUA prices fall outside what is perceived as acceptable boundaries: the Market Stability Reserve (MSR), and the Art 29 of the EU ETS Directive addressing price imbalances. So far these instruments are not interlinked, being different from other jurisdictions under ETS regime. Before any modifications to the current rules are implemented, the role of the EU policy maker is to understand the reasons why some sectors of the society are concerned about the current carbon price escalation. Being able to answer fundamental questions about the role of carbon prices, the right definition of market abuse, when intervention in the carbon market is justified, and the role of financial institutions in the carbon market and its impact on contributing or destroying decarbonisation value are a must if we are to come up with the best fit-for purpose design."

Potential for hydrogen production from sustainable biomass with carbon capture and storage.

The following is from the abstract of this article: "Low-carbon hydrogen is an essential element in the transition to net-zero emissions by 2050. Hydrogen production from biomass is a promising bio-energy with carbon capture and storage (BECCS) scheme that could produce low-carbon hydrogen and generate the carbon dioxide removal (CDR) envisioned to be required to offset hard-to-abate emissions. Here, [the authors] design a BECCS supply chain for hydrogen production from biomass with carbon capture and storage and quantify, at high spatial resolution, the technical potential for hydrogen production and CDR in Europe. [The authors] consider sustainable biomass feedstocks that have minimal impacts on food security and biodiversity, namely agricultural residues and waste. [The authors] find that this BECCS supply chain can produce up to 12.5 [million tons (Mtons)] of H_2 per year (currently ~10 Mtons of H_2 per year are used in Europe) and remove up to 133 Mtons CO_2 per year from the atmosphere (or 3% of European total greenhouse gas emissions). [The authors] then perform a geospatial analysis to quantify transportation distances between where biomass feedstocks are located and potential hydrogen users, and find that 20% of hydrogen potential is located within 25 km from hard-to-electrify industries. [The authors] conclude that BECCS supply chains for hydrogen production from biomass represent an overlooked near-term opportunity to generate carbon dioxide removal and low-carbon hydrogen."

Lorenzo Rosa and Marco Mazzotti, *Renewable and Sustainable Energy Reviews. (Subscription may be required.)*

The importance of biogenic carbon storage in the greenhouse gas footprint of medium density fiberboard from poplar wood and bagasse.

The following is from the abstract of this article: "Carbon storage in long-lived bio-based products is typically ignored or accounted for in a simplistic way in greenhouse gas (GHG) footprint calculations. [The authors] quantified the GHG footprint of medium density fiberboard (MDF) in Iran from poplar wood and bagasse, a by-product from sugarcane production. Inventory data was collected from sugarcane and poplar wood plantations and MDF factories in Iran during 2017–2019 to calculate cradle-to-grave footprints for 1 m3 of MDF. [The authors] quantify the effect of carbon storage, which depends on the crop rotation time and the economic lifetime of the product, with shorter rotation times and longer storage periods leading to lower footprints. Cradle-to-grave GHG footprints of poplar and bagasse-based MDF without accounting for biogenic carbon storage are 6.8·102 kg CO_2-eq/m3 and 8.5·102 kg CO_2-eq/m3, respectively. Footprints are higher for bagasse-based MDF than for poplar-based MDF because of a higher electricity use, higher resin use and larger transport distances in Iran. Taking into account carbon storage periods of 10–60 years decreases the footprints to 345–655 kg CO_2-eq/m3 for poplar-based MDF and 292–771 kg CO_2-eq/m3 for bagasse-based MDF. These results emphasize the importance of appropriately accounting for biogenic carbon storage in GHG footprint calculations of long-lived bio based products."

Seyedeh Masoumeh Hafezi, Hamid Zarea-Hosseinabadi, Mark A.J. Huijbregts, and Zoran J.N. Steinmann, *Cleaner Environmental Systems. (Subscription may be required.)*

Analyzing how forest-based amenity values and carbon storage benefits affect spatial targeting for conservation investment.

The following is from the abstract of this article: "[The authors] analyze how two different ecosystem services: forest-based amenity values and carbon storage benefits, affect spatial targeting for conservation investment for protected area acquisition using selected forest clusters in Knox County, Tennessee in the United States. [The authors] determine return-on-investment (ROI) for these two different forest-based ecosystem services by estimating amenity values and carbon storage amounts using hedonic price model and dynamic Terrestrial Ecosystem Model (TEM), respectively, and corresponding acquisition costs at the forest cluster level. [The authors'] findings of the optimal protected area acquisition in the form of forest clusters serve as an empirically informed knowledge base to help both the conservation and planning agencies in prioritizing acquisition of potential protected areas depending on their preferences. By using carbon and amenity ROIs in spatial targeting of forest clusters within the multi-objective optimization set up, [the authors] not only addressed the spatial heterogeneity in the carbon storage benefits and amenity values but also the spatial heterogeneity in cluster acquisition costs. [The authors] also found that selection decisions were dictated by the weakly negative correlation (–0.16) between the carbon and amenity ROIs instead of weakly positive correlation (0.14) between carbon storage benefits and amenity values. Since the spatial distribution of carbon and amenity ROIs were weakly negatively correlated, there were apparent conflicts between the objectives of maximizing forest carbon storage and amenity value. This resulted in concave frontiers with tradeoffs between the objectives implying variation in spatial distribution of the selected forest clusters letting the conservation and planning agencies decide combination of strategies which best fit their preferences."

Bijay P. Sharma and Seong-Hoon Cho, *Forest Policy and Economics. (Subscription may be required.)*

What is different about different net-zero carbon electricity systems?

The following is from the abstract of the article: "In deeply decarbonized electricity systems with significant shares of variable renewable energy, the additional availability of at least one firm electricity generating technology can overcome reliability challenges and substantially reduce electricity costs. Firm resources can operate at any time of the year and for as long as needed to maintain electricity system reliability. Low- and zero-carbon firm technologies include flexible resources with high variable and low capital costs, such as biogas or hydrogen combustion, capital-intensive resources with low or zero variable cost, including nuclear and geothermal, as well as intermediate resources such as natural gas plants with carbon capture and sequestration (CCS). This paper explains the distinct roles of nuclear, CCS, and combustion of zero-carbon fuels in decarbonized electricity systems as examples of each class of firm resources. [The authors] analyze and compare results from three long-term electricity system capacity expansion models for California and the U.S. Western Interconnection, demonstrating robustness of [the authors'] conclusions to different model assumptions and domains. Individually, each firm technology delivers substantial cost reductions relative to portfolios restricted to wind, solar, and energy storage alone. Additionally, because each technology occupies a distinctive functional niche in the electricity system, having all of these technologies available optimizes the utilization rate of each resource and reduces system costs by up to 10% relative to cases with just one class of firm resource. The analysis highlights the benefits of an expansive range of technology options to meet emissions reductions goals for the power sector while maintaining operational reliability and affordability."

Ejeong Baik, Kiran P. Chawla, Jesse D. Jenkins, Clea Kolster, Neha S. Patankar, Arne Olson, Sally M. Benson, and Jane C.S. Long, *Energy and Climate Change. (Subscription may be required.)*

Filter Cake Removal during the Cementing and Completion Stages in CO_2 Storage Wells: Current Developments, Challenges, and Prospects.

The following is from the abstract of this article: "Carbon capture and storage (CCS) technology has become one of the most cost-effective and promising ways to achieve global climate change mitigation goals. The CO_2 storage capacity in depleted oil and gas reservoirs is currently the safest and most economical option. The long-term sealing of the cement–formation interface in CO_2 storage wells (CSW) is essential to avoid CO_2 leakage. The filter cake easily affects the interfacial sealing ability, which is a thin impermeable layer formed by drilling fluid residue or solid particles remaining on the borehole wall due to permeable formation. Filter cake removal is essential for favorable cementation and production efficiency. This study highlights the current developments and the main challenges for oil- and water-based mud filter cake removal during the cementing and completion process. Moreover, research ideas and recommendations for various types of filter cake removal are proposed to provide a reference for future work. This information helps deepen understanding with respect to the different filter cake removal options available in the CCS industry and provides a knowledge base that can facilitate the improvement of the cementing quality and production efficiency of existing systems to combat battle CSW safety and production efficiency problems."

Jin Li, Sheng Huang, Zao-Yuan Li, Jian Liu, Xu-Ning Wu, Dong-Hua Su, and Wei-Tao Song, *Energy Technology*. (Subscription may be required.)

An Advanced Discrete Fracture Methodology for Fast, Robust, and Accurate Simulation of Energy Production from Complex Fracture Networks.

The following is from the abstract of this article: "Fracture networks are abundant in subsurface applications (e.g., geothermal energy production, CO_2 sequestration). Fractured reservoirs often have a very complex structure, making modeling flow and transport in such networks slow and unstable. Consequently, this limits [the] ability to perform uncertainty quantification and increases development costs and environmental risks. This study provides an advanced methodology for simulation based on Discrete Fracture Model (DFM) approach. The preprocessing framework results in a fully conformal, uniformly distributed grid for realistic 2D fracture networks at a required level of precision. The simplified geometry and topology of the resulting network are compared with input (i.e., unchanged) data to evaluate the preprocessing influence. The resulting mesh-related parameters, such as volume distributions and orthogonality of control volume connections, are analyzed. Furthermore, changes in fluid-flow response related to preprocessing are evaluated using a high-enthalpy two-phase flow geothermal simulator. The simplified topology directly improves meshing results and, consequently, the accuracy and efficiency of numerical simulation. The main novelty of this work is the introduction of an automatic preprocessing framework allowing [the authors] to simplify the fracture network down to required level of complexity and addition of a fracture aperture correction capable of handling heterogeneous aperture distributions, low connectivity fracture networks, and sealing fractures. The graph-based framework is fully open-source and explicitly resolves small-angle intersections within the fracture network. A rigorous analysis of changes in the static and dynamic impact of the preprocessing algorithm demonstrates that explicit fracture representation can be computationally efficient, enabling their use in large-scale uncertainty quantification studies."

S. de Hoop, D. V. Voskov, G. Bertotti, and A. Barnhoorn, *Water Resources Research*. (Subscription may be required.)

JUNE 2022

Computed Tomography Scanning and Geophysical Measurements of Core from the Boggess 17H Well.

The following is from the abstract of this DOE/NETL report: "The computed tomography (CT) facilities and the Multi-Sensor Core Logger (MSCL) at the National Energy Technology Laboratory (NETL) in Morgantown, West Virginia were used to characterize the Marcellus Shale and underlying formations. The core is from a vertical pilot well (Boggess 17H) drilled in western Monongalia County near Core, West Virginia by Northeast Natural Energy for the second Marcellus Shale Energy and Environmental Laboratory (MSEEL). MSEEL is a joint venture between NETL, Northeast Natural Energy, and West Virginia University. The primary impetus for this report is to characterize the core to better understand the structure and variation of the Marcellus Shale and surrounding formations. This report, and the associated scans, provide detailed datasets not typically available from unconventional shales for analysis. The resultant datasets are presented as part of this report and can be accessed from NETL's Energy Data eXchange (EDX) online system using the following link: *https://edx.netl.doe.gov/dataset/boggess-17h-well*. All equipment and techniques used were non-destructive, enabling future examinations to be performed on these cores. None of the equipment used was suitable for direct visualization of the shale pore space, although fractures and discontinuities were detectable with the methods tested. CT imagery with the NETL medical CT scanner was performed on the entire core. Qualitative analysis of the medical CT images, coupled with X-ray fluorescence (XRF), P-wave, and magnetic susceptibility measurements from the MSCL were useful in identifying zones of interest for more detailed analysis and locating fractured zones. The ability to quickly identify key areas for more detailed study with higher resolution will save time and resources in future studies. The combination of all methods used provides a multi-scale analysis of the core; the resulting macro and micro descriptions of the core are relevant for many subsurface energy related examinations of core that have traditionally been performed at NETL." [*Click here to access NETL's EDX*.]

State of the Art: CCS Technologies 2022.

The following is from the Foreword of this Global CCS Institute technical report: "Carbon Capture and Storage (CCS) has emerged as an indispensable tool in humanity's efforts to combat climate change and reach its goal of net-zero emissions. Industries as diverse as cement, iron and steel, chemicals, natural gas and electricity generation can benefit from the ability of CCS to cut industrial CO_2 emissions deeply. CCS is also moving into carbon dioxide removal (CDR) in applications such as Direct Air Capture (DAC) and Bioenergy with CCS (BECCS), drawing down historical CO_2 emissions from the atmosphere. The CCS sector has been growing at an unprecedented rate in recent years, and that growth is only accelerating. The increased dependence of global plans for net-zero on CCS means that the economic performance of CCS is becoming increasingly important. Technology development will be a significant driver of improved economics for CCS. Higher energy efficiency, reduced variable operating costs, capital cost reductions, and plant performance improvements, enabled by new technologies, are meeting the demand for improved CO_2 capture system performance, transport system costs, and CO_2 storage options. CCS is happening now, and the technology is ready to purchase today. This inaugural Technology Compendium is intended to showcase the breadth and depth of commercially-available CCS technologies worldwide."

Policy Brief: Unlocking the governance challenges of Just Transition in the EU.

The following is from a summary of this European Roundtable on Climate Change and Sustainable Transition (ERCST) Policy Brief: "This brief looks into the European Just Transition process, with a specific focus on the Just Transition Fund (JTF) and its underpinning Territorial Just Transition Plans (TJTPs). It examines the governance challenges identified from the consultations and literature review and injects some ideas for strengthening the Just Transition governance process both at EU and Member State level. [Key messages:] While in certain Member States and regions of the EU [the ERCST] see strong Just Transition governance frameworks in place, in some others accountability, clarity on implementation plans, inclusive dialogue and transparency are lacking. Establishing a long-term vision and a detailed transition plan will prove crucial for the socio-economic success of regions in transition in the following decades. Looking beyond the JTF and the TJTPs, in the longer term, political and economic decisions will have to be made in this context and [the ERCST] believe that the basic principle to be followed should be to make Just Transition self-sustainable and cost-efficient beyond grant-based instruments as the JTF. One example would be to strengthen the InvestEU component of the JTM. Social and environmental objectives throughout the EU decarbonisation process will only be reached by a well-proportioned mix of market approaches, standards, and regulations in conjunction with a strong political vision."

Immediate and long-term effects of tillage practices with crop residue on soil water and organic carbon storage changes under a wheat-maize cropping system.

The following is from the abstract of this article: "Reasonable tillage management benefits soil structure optimization and agricultural sustainability. However, the differences of immediate (i.e. changes between post- and pre-tillage) and long-term effects (i.e. changes between treatments after certain years) under different tillage practices is often neglected. This study involved a 16-year field experiment including three tillage practices (plow tillage, PT; subsoiling tillage, ST and rotary tillage, RT) and two crop residue management practices (no residue return and all residue return). Those immediate and long-term effects on soil physical properties and soil organic carbon were investigated. For the immediate effects after tillage, the soil water storage under PT, ST, and RT decreased by 5.8%, 4.0%, and 3.2%, respectively; while those under residue return and no residue return decreased by 3.9% and 4.6%, respectively. Under the same conditions, ST was more beneficial to reduce soil penetration resistance. The soil bulk density post-tillage was significantly lower than that pre-tillage at 0–10 cm soil depth, meanwhile the soil bulk density at 10–40 cm soil depth was generally decreased after tillage practice under ST treatment. For the long-term effects, the penetration resistance at 10–50 cm soil depth and the soil bulk density at 10–30 cm soil depth were lower under the ST treatment than those under PT and RT treatments. Additionally, residue return was beneficial for soil water storage, soil bulk density, and soil organic carbon storage. Overall, both for the immediate and long-term effects, subsoiling tillage with residue return significantly increased soil water storage, total porosity, soil organic carbon storage and crop yields, while decreased soil bulk density and penetration resistance."

Hongxiang Zhao, Jihao Qin, Tianping Gao, Mengkun Zhang, Hongchang Sun, Shuwei Zhu, Cailong Xu, and Tangyuan Ning, *Soil and Tillage Research. (Subscription may be required.)*

A storage-driven CO_2 EOR for a net-zero emission target.

The following is from the abstract of this article: "Stabilizing global climate change to within 1.5°C requires a reduction in greenhouse gas emissions, with a primary focus on carbon dioxide (CO_2) emissions. CO_2 flooding in oilfields has recently been recognized as an important way to reduce CO_2 emissions by storing CO_2 in oil reservoirs. This work proposes an advanced CO_2 enhanced oil recovery (EOR) method—namely, storage-driven CO_2 EOR—whose main target is to realize net-zero or even negative CO_2 emissions by sequestrating the maximum possible amount of CO_2 in oil reservoirs while accomplishing the maximum possible oil recovery. Here, dimethyl ether (DME) is employed as an efficient agent in assisting conventional CO_2 EOR for oil recovery while enhancing CO_2 sequestration in reservoirs. The results show that DME improves the solubility of CO_2 in in situ oil, which is beneficial for the solubility trapping of CO_2 storage; furthermore, the presence of DME inhibits the 'escape' of lighter hydrocarbons from crude oil due to the CO_2 extraction effect, which is critical for sustainable oil recovery. Storage-driven CO_2 EOR is superior to conventional CO_2 EOR in improving sweeping efficiency, especially during the late oil production period. This work demonstrates that storage-driven CO_2 EOR exhibits higher oil-in-place (OIP) recovery than conventional CO_2 EOR. Moreover, the amount of sequestrated CO_2 in storage-driven CO_2 EOR exceeds the amount of emissions from burning the produced oil; that is, the sequestrated CO_2 offsets not only current emissions but also past CO_2 emissions. By altering developing scenarios, such as water alternating storage-driven CO_2 EOR, more CO_2 sequestration and higher oil recovery can be achieved. This work demonstrates the potential utilization of DME as an efficient additive to CO_2 for enhancing oil recovery while improving CO_2 storage in oil reservoirs."

Yueliang Liu and Zhenhua Rui, *Engineering. (Subscription may be required.)*

Carbon capture: Prospects and policy agenda for CO_2-neutral power generation.

The following is from the abstract of this article: "By mid-century, global mean temperature increase from pre-industrial levels must remain below 1.5°C to resist the forces of climate chaos. Recent studies emphasize the central role that the electricity system must play in achieving 100% carbon-free generation, particularly through greater reliance on zero-carbon, firm output. Major firm power options that emit little or no carbon include hydro, nuclear, geothermal, and carbon capture and storage (CCS). This article examines the status of CCS, now applied at coal-fired power plants and under consideration at natural gas plants in North America and certain European nations. [The authors] identify key developments: (i) CCS can eliminate and permanently store virtually all fossil-fired CO_2 emissions from power plants; (ii) following targeted policies, doing so would be cost-competitive with other strategies to generate zero-carbon, firm electricity; and (iii) combining aggressive upstream greenhouse gas emissions mitigation with near-100% carbon capture at the power plant can create significant benefits on par with the lifecycle emissions of other renewable and clean generation resources. Finally, [the authors] examine the policy pathways, infrastructure, and jurisdictions central to CCS expansion—particularly in the U.S. and its subdivisions. Also discussed is the critical need to export CCS technology to all parts of the globe, especially areas like China and Southeast Asia that are likely to depend on fossil electricity for decades."

Deepika Nagabhushan, R.H. Russell, Kurt Waltzer, John Thompson, Lee Beck, and Marc Jaruzel, *The Electricity Journal. (Subscription may be required.)*

What are the potential paths for carbon capture and storage in Sweden? A multi-level assessment of historical and current developments.

The following is from the abstract of this article: "Carbon capture and storage (CCS), including bioenergy with carbon capture and storage (BECCS), could contribute to climate change mitigation strategies. However, the 2020s is not the first time that CCS is high on the agenda. This study explores the differences between the past and current developments of CCS and discusses how incumbent actors' experiences can inform the understanding of potential future energy system transitions in Sweden. For this purpose, a multi-level perspective (MLP) analysis was conducted based on documents, interviews and focus groups with key actors. Since the 2000s, increased urgency of climate change has further pushed policy makers into action. In addition, there is a new framing of CCS that underscores the potential of BECCS to provide negative carbon dioxide (CO_2) emissions, as well as prospects for offshore storage of CO_2 in Norway and other territories. As such, this study shows that Sweden could be on a transformation pathway towards implementing CCS alongside other mitigation measure."

Adrian Lefvert, Emily Rodriguez, Mathias Fridahl, Stefan Grönkvist, Simon Haikola, and Anders Hansson, *Energy Research & Social Science. (Subscription may be required.)*

Bamboo construction materials: Carbon storage and potential to reduce associated CO_2 emissions.

The following is from the abstract of this article: "The construction industry is one of the largest contributors of CO_2 emissions. To achieve the goal of carbon peaking by 2030 and carbon neutrality by 2060, China needs to develop carbon reduction pathways for the construction industry. Bamboo is believed to be one of the most appropriate candidates for afforestation to reduce CO_2 concentration and alleviate the effects of climate change. It is also an ideal building material with high tensile and compressive strengths. However, the carbon emissions and storage of bamboo building materials have not been well understood. This study aims to quantify the CO_2 emissions and carbon storage of bamboo building materials and to analyse the potential to reduce these carbon emissions. Results show that the planting phase contributes the largest amount of carbon uptake whilst the production phase contributes the largest amount of carbon emissions. 'Carbonisation' is found to be the production process with the highest carbon emissions, followed by 'antimould, anticorrosion and drying treatment' and 'glue application'. Three strategies that are useful in reducing carbon emissions are proposed and validated. After the implementation of the proposed strategies, the average and median amount of carbon emissions changed from 1291.63 and 1290.75 kg to 1088.36 and 1090.29 kg. Taking all phases into account, one cubic meter of bamboo assembled components can reduce 249.92 kg CO_2 from the atmosphere. Compared to dimensioned lumber, engineered lumber, cement, steel, timber, hempcrete, bamboo building materials have the highest CO_2 emissions and carbon storage. The carbon storage of bamboo assembled components per tonne is around 140 kg more than that of timber per tonne. This study is expected to assist not only researchers in understanding the carbon reduction potential of bamboo building materials but also practitioners in promoting bamboo building-based carbon reduction pathways."

Xiaoxiao Xu, Peiyu Xu, Jianjun Zhu, Haitao Li, and Zhenhua Xiong, *Science of The Total Environment. (Subscription may be required.)*

Technical Perspective of Carbon Capture, Utilization, and Storage.

The following is from the abstract of this article: "Carbon dioxide (CO_2) is the primary greenhouse gas contributing to anthropogenic climate change which is associated with human activities. The majority of CO_2 emissions are results of the burning of fossil fuels for energy, as well as industrial processes such as steel and cement production. Carbon capture, utilization, and storage (CCUS) is a sustainable technology promising in terms of reducing CO_2 emissions that would otherwise contribute to climate change. From this perspective, the discussion on carbon capture focuses on chemical absorption technology, primarily due to its commercialization potential. The CO_2 absorptive capacity and absorption rate of various chemical solvents have been summarized. The carbon utilization focuses on electrochemical conversion routes converting CO_2 into potentially valuable chemicals which have received particular attention in recent years. The Faradaic conversion efficiencies for various CO_2 reduction products are used to describe efficiency improvements. For carbon storage, successful deployment relies on a better understanding of fluid mechanics, geomechanics, and reactive transport, which are discussed in details."

Qingyang Lin , Xiao Zhang, Tao Wang, Chenghang Zheng, and Xiang Gao, *Engineering. (Subscription may be required.)*

Temporal dynamics of carbon storage in a Mediterranean mountain scrubland managed by prescribed fire.

The following is from the abstract of this article: "Farmland abandonment and reduction of grazing activity, mainly in mountain areas with remote access and ageing population, have been contributing to shrub encroachment in such territories and, consequently, to increase fuel load available for triggering wildfires. Accordingly, it is necessary to use vegetation management practices in order to reduce wildfire risk, prescribed fire being one of the most common techniques used in the Mediterranean region. This research focused in the effects of a prescribed fire (PF) applied in Montesinho Natural Park (PNM), NE Portugal, on the temporal dynamics of carbon storage in mineral soil, litter layer (organic horizon), and shrub biomass. Before PF and thirty-six months after PF, aboveground shrub biomass was collected in areas of 1 m2 in 11 plots randomly distributed in the experimental shrub area. Also, in the same plots, litter thickness was measured and soil samples were collected before, two, six and thirty-six months after PF, in order to assess carbon concentration, bulk density and coarse elements content. Despite low to moderate fire intensity, carbon storage changes were observed in all compartments evaluated. Thirty-six months after PF, carbon storage in aboveground biomass of shrub species (7.4 Mg C ha–1) was roughly two-thirds of that recorded prior to PF, and in litter layer (1.6 Mg C ha–1) it was about half of that in the original situation (before PF). In contrast, the mineral soil showed a 10% carbon increase (6.4 Mg C ha–1). Based on the balance between losses (shrub species and litter layer) and gains (mineral soil), at the end of the monitoring period (36 months), there was an annual positive rate of carbon storage, equivalent to 0.2 Mg C ha–1 year–1. Even after anthropogenic disturbances, such as prescribed fire, shrub communities constitute important terrestrial carbon pools; hence, these ecosystems might play an important role in mitigating climate change."

Felícia Fonseca, Diego Silva, Paulo Bueno, Zulimar Hernández, Ana Caroline Royer, and Tomás de Figueiredo, *CATENA. (Subscription may be required.)*

JULY 2022

Cost Impacts of Risk-Based Methods for Defining AoR and PISC Duration of a CO_2 Storage Project Using NRAP Tools and FE/NETL CO_2 Saline Storage Cost Model.

The following is from the Executive Summary of this DOE/NETL report: "The purpose of this analysis is to assess the fiscal impact of using risk-based methods to define the area of review (AoR) and post-injection site care (PISC) duration for a geologic carbon dioxide (CO_2) storage project. The Office of Fossil Energy (FE)/National Energy Technology Laboratory (NETL) CO_2 Saline Storage Cost Model ("cost model") was utilized to evaluate CO_2 storage economics in this study. The cost model is a widely used tool for evaluating CO_2 storage costs in geologic settings. It estimates costs for storage operations conducted under compliance to the United States Environmental Protection Agency (EPA) Underground Injection Control (UIC) Class VI regulations. This analysis evaluates and compares the costs of storage (on a first-year break-even dollar per tonne [2018$] basis) at the proposed FutureGen 2.0 site as a case-study storage location by implementing different approaches to determine AoR and PISC given the prevailing geologic conditions and injection volume and duration considerations. The approaches include the use of 1) risk-based methods to define AoR and PISC duration, 2) an EPA-approved AoR and PISC documented in the FutureGen 2.0 UIC Class VI permit applications, and 3) cost model default settings that utilize uncertainty multipliers to estimate CO_2 plume and pressure front extent as part of AoR determination, as well as a 50-year PISC default. From all three sources, the AoR and PISC specified in the Class VI permit applications for FutureGen 2.0 were the largest and longest relative to the other two sources…"

Treatments of Exports in the EU CBAM.

The following from a description of this European Roundtable on Climate Change and Sustainable Transition (ERCST) report: "This new report examines one of the most critical issues in the current political debate on the EU's Carbon Border Adjustment Mechanism (CBAM): the treatment of exports. Exports are currently not covered by the European Commission's CBAM proposal. However, there are concerns that the exclusion of exports will open-up an export-related carbon leakage channel, thereby harming EU competitiveness and climate ambition. In this report, ERCST presents its recommendations on how to address exports in the EU CBAM."

Basin Management of Geologic CO_2 Storage: Effect of Well Spacing on CO_2 Plume and Pressure Interference.

The following is from the abstract of this paper: "Large-scale deployment of carbon capture and storage (CCS) is a key decarbonization approach to achieve drastic reductions in greenhouse gas emission levels. The United States Department of Energy's National Energy Technology Laboratory, through the Carbon Storage Assurance Facility Enterprise Initiative projects, defines a commercial-scale CO_2 saline storage project as one in which at least 50 million tonnes of CO_2 are injected over the course of 20 to 30 years. Large-scale decarbonization through CCS may likely involve many commercial-scale CO_2 storage projects located in close proximity. Nearby injection operations may result in CO_2 plume commingling and create pressure buildup over time, which could cause pressure interference and may require preventative strategies to avoid exceedance of fracture pressure threshold. This study employs numerical modeling to analyze the evolution of the extent of CO_2 and pressure plumes in which the commercial-scale CO_2 storage projects inject simultaneously into a common storage formation from multiple projects located in proximity. Injection operations target an extensive saline formation with formation top of 1 km below ground surface, thickness of 200 m, horizontal and vertical permeabilities of 50 and 15 mD, porosity of 10%, and all external boundaries closed to fluid flow (i.e., top, bottom and all sides). The injection occurs at 1 million tonnes/year per well for 30 years, followed by a 50-year post-injection period (PISC). The effect of well spacing and resulting pressure buildup and CO_2 plume migration is explicitly evaluated…"

Nur Wijaya, Derek Vikara, David Morgan, Timothy Grant, and Donald Remson, *SPE Western Regional Meeting (April 26–28, 2022; Bakersfield, California, USA). (Subscription may be required.)*

A bacteria-based carbon sequestration and waste recycling system.

The following is from the abstract of this article: "Achieving carbon neutrality requires a variety of technological approaches. In the present study, [the authors] confirmed the applicability of a carbon cycle system in several industrial fields using sulphur-oxidising bacteria. This system produces a nitrogen fertiliser, which decreases carbon emissions by recycling H_2S and NH_3 pollutants discharged into the atmosphere or wastewater. It should be considered in industrial fields as a carbon reduction strategy."

Yeon Hwa La, Ki-Sung Lee, Tae-Wan Kim, and Jae Yang Song, *Nature. (Subscription may be required.)*

A multi-criteria CCUS screening evaluation of the Gulf of Mexico, USA.

The following is from the abstract of this article: "Continued research into reservoir characterization along with offshore carbon dioxide (CO_2) transportation and infrastructure assets is needed to facilitate development of safe and successful carbon capture, utilization, and storage (CCUS) projects. This paper outlines a multi-criteria evaluation methodology that incorporates disparate sets of quantitative, spatially variable data into a decision-making framework for screening the Gulf of Mexico (GOM) outer continental shelf (OCS) for potentially viable CO_2 storage and enhanced oil recovery (EOR) sites. Criteria categories include favorable geologic characteristics, logistics, and potential risks. Data compiled for 14 criteria from several publicly available geographic information system (GIS) layers was aggregated over 2559 spatially balanced points across the study area using the National Energy Technology Laboratory (NETL)-developed Cumulative Spatial Impact Layers™ (CSIL) GIS tool. Criteria are weighted by qualitative expert opinion relative to their perceived importance to given scenarios— the output of combined criteria values and weights enables regional CO_2 storage suitability differentiation. The methodology considers both technical and non-technical factors impacting CCUS decision-making. The flexible methodology enables a systematic approach to regional ranking at high spatial resolution over a large study domain. Additionally, the framework enables high-grading of priority sites that warrant further characterization and follow-on analysis. Areas along the Louisiana coast and Mississippi River Delta consistently rank high for all scenarios largely a result of the favorable geology with the potential for stacked storage, as well as the density of existing pipelines and platforms, and proximity to several onshore CO_2 sources. High-graded regions for the CO_2 EOR-related scenarios are typically located further offshore towards the middle and edge of the OCS compared to higher priority regions for the geologic storage scenarios which fall closer to the Louisiana coastline."

Anna Wendt, Alana Sheriff, Chung Yan Shih, Derek Vikara, and Tim Grant, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Thermodynamic loss analysis of a liquid-sorbent direct air carbon capture plant.

The following is from the abstract of this article: "Direct air capture of CO_2 is often presented as a promising technology to help mitigate climate change, although proposed processes are highly energy intensive. [The authors] analyze Carbon Engineering's 1 Mt-CO_2/year natural-gas-powered direct air capture (DAC) process, which requires 273.2 MW per plant, where [they] find that 252 MW are irreversibly lost, corresponding to a second-law efficiency of 7.8%. [The authors'] component-level analysis details the mechanisms by which these losses of thermodynamic work potential occur in the most energy-intensive plant segments. Here, [the authors] emphasize the effects of chemical exergy dissipation in the air contactor, where stored chemical exergy is released as low-grade heat into the environment. Other major losses occur in the calciner and its preheat cyclones due to the high temperature demanded by its internal chemical reaction, as well as in the water knockout system, CO_2 compression system, and power island. Finally, [the authors] illustrate the issues arising from the use of natural gas as a feedstock for heat and power, and suggest directions to pursue for further analysis and process improvements, which [the authors] consider imperative to make this DAC process a viable option for large-scale CO_2 removal toward IPCC targets."

Ryan Long-Innes and Henning Struchtrup, *Cell Report Physical Science. (Subscription may be required.)*

More sustainable vegetable oil: Balancing productivity with carbon storage opportunities.

The following is from the abstract of this article: "Intensive cultivation and post-harvest vegetable oil production stages are major sources of greenhouse gas (GHG) emissions. Variation between production systems and reporting disparity have resulted in discordance in previous emissions estimates. The aim of this study was to assess global systems-wide variation in GHG emissions resulting from palm, soybean, rapeseed and sunflower oil production. Such an analysis is critical to understand the implications of meeting increasing edible oil demand. To achieve this, [the authors] performed a unified re-analysis of life cycle input data from diverse palm, soybean, rapeseed, and sunflower oil production systems, from a saturating search of published literature. The resulting dataset reflects almost 6000 producers in 38 countries, and is representative of over 71% of global vegetable oil production. Across all oil crop systems, median GHG emissions were 3.81 kg CO_2e per kg refined oil. Crop specific median emissions ranged from 2.49 kg CO_2e for rapeseed oil to 4.25 kg CO_2e for soybean oil per kg refined oil. Determination of the carbon cost of agricultural land occupation revealed that carbon storage potential in native compared to agricultural land cover drives variation in production GHG emissions, and indicates that expansion of production in low carbon storage potential land, whilst reforesting areas of high carbon storage potential, could reduce net GHG emissions whilst boosting productivity. Nevertheless, there remains considerable scope to improve sustainability within current production systems, including through increasing yields whilst limiting application of inputs with high carbon footprints, and in the case of palm oil through more widespread adoption of methane capture technologies in processing stages."

Thomas D. Alcock, David E. Salt, Paul Wilson, and Stephen J. Ramsden, *Science of The Total Environment. (Subscription may be required.)*

Carbon storage potential of Avicennia marina as influenced by soil factors in National Park Nayband, South Coast of Iran.

The following is from the abstract of this article: "The carbon storage potential varies according to plant species, locations, and soil parameters. This study conducted to calculate amounts of carbon storage and effects of soil factors on C storage *Avicennia marina* in the coastal area of Bradkhon-Mal Gonzeh in National Park Nayband, of Bushehr province. To conduct research, aboveground and belowground biomass, and a distance of 1.5 m in two depths (0–60 and 60–100 cm) in 5 sample plots in the habitat zone and control site in March 2019, samples of biomass and soil were taken. The aboveground and belowground biomass were estimated using the allometric equation. The soil factors in each sample point were done by laboratory methods. The relations between soil factors and C storage in above and below-ground biomass were determined using cluster analysis. The result showed that the amount of C storage in above and belowground biomass is 12.7 ± 1.08 and 5.7 ± 0.4 g/m2, respectively. The amount of carbon stored at the first depth of the soil was more than the second depth, this is due to the expansion of roots on the surface of the soil. The most important parameters influencing soil carbon storage is electrical conductivity (EC), total neutralizing value (TNV), percentage of sand, silt and clay, organic matter and nitrogen."

Fazel Amiri, *Acta Ecologica Sinica. (Subscription may be required.)*

Assessing the effects of ecological engineering on spatiotemporal dynamics of carbon storage from 2000 to 2016 in the Loess Plateau area using the InVEST model: A case study in Huining County, China.

The following is from the abstract of this article: "Implementation of the Grain for Green program (GGP) resulted in great changes in land use and cover in northwest China, and presumably in the region's carbon. However, accurate assessment of the effects of the GGP on carbon storage remains a challenge. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model can map and evaluate natural goods and services that sustain life and quantify their impact from the changes in the ecosystem. Taking Huining County in China's Loess Plateau region as a case, the land use and land cover changes (LUCC) following the GGP were quantified, and their effects on carbon storage between 2000 and 2016 were evaluated using the InVEST model. The results showed that, a total area of about 3996.13 km2 underwent changes following the GGP in Huining County during the study period, accounting roughly for 74% of the county. The total carbon storage increased from 6470.72 Gg in 2000 to 7335.07 Gg in 2016. Spatially, carbon density in the south of this county was greater than the northern part. Directly induced by the GGP (conversions of farmlands to forests and grasslands), the carbon storage increased by 786.84 Gg in total, with a rate of 46.28 Gg per year, the majority of which occurred during the first stage of the study period (from 2000 to 2008). The increase of carbon storage was mostly attributable to the increases in vegetation pool and the carbon density showed a strong spatial correlation with the growing season Normalized Difference Vegetation Index (NDVI). The similarities between carbon density and NDVI spatial patterns during the study period may have been shaped by the county's climate patterns, but not to any significant extent by climate change during the study period. This county-scale study allows for a deeper understanding of the links between LUCC induced by environmental restoration programs and carbon storage changes, and contributes to a greater accuracy in the estimation of carbon storage at the provincial (or larger) scale."

Kongming Li, Jianjun Cao, Jan F. Adamowski, Asim Biswas, Junju Zhou, Yujia Liu, Yongkai Zhang, Chunfang Liu, Xiaogang Dong, and Yuli Qin, *Environmental Development. (Subscription may be required.)*

Experiment study on CO_2 adsorption performance of thermal treated coal: Inspiration for CO_2 storage after underground coal thermal treatment.

The following is from the abstract of this article: "Underground coal thermal treatment is a clean method of coal utilisation. Pyrolytic semi-coke provides a good storage vehicle for CO_2 geological storage, but there are few studies on the CO_2 adsorption capacity of pyrolytic semi-coke. To investigate the CO_2 storage potential of thermal treated coals, scanning electron microscopy, low temperature nitrogen adsorption, low-field nuclear magnetic resonance and thermogravimetric analysis were used in this paper to analyze the differences and the influence mechanisms of different thermal treated coals for CO_2 adsorption. The results showed the CO_2 maximum adsorption amount of different thermal treated coals decreased and then increased as the thermal treatment temperature increased, reaching a minimum at 773.15 K. Although the maximum adsorption amount of 773.15 K thermal treated raw coal was disadvantageous, the gas pressure <4.49 MPa showed superior adsorption advantage over the 303.15 K thermal treated coal. However, the KCl-impregnated coal showed an overall low adsorption capacity attributed to crystal blocking effects and catalysis. Although the adsorption pores of the high temperature thermal treated coals were substantially reduced, their ability to adsorb CO_2 was significantly higher than that of the low temperature thermal treated coals. Furthermore, the number of adsorption pores was closely related to CO_2 adsorption."

Qingmin Shi, Shidong Cui, Shuangming Wang, Yichen Mi, Qiang Sun, Shengquan Wang, Chenyu Shi, and Jizhou Yu, *Energy. (Subscription may be required.)*

AUGUST 2022

Benefit Analysis of CO_2 Delivery Options for Offshore Storage or Enhanced Oil Recovery.

The following is a description of this DOE/NETL product: "The analysis presented in this report evaluates the benefits of CO_2 offshore transport via pipeline or ship within the [Gulf of Mexico (GOM)]. It takes a top-down framework to estimate the costs. First, this analysis designed a reduced-order model (ROM) based on the cash flows in the FECM/NETL CO_2 Transport Cost Model (also known as CO2_T_COM). The ROM takes capital expenses (CAPEX) and operating expenses (OPEX) to calculate the CO_2 breakeven price based on the cash flows. Second, this analysis developed regression models utilizing published data from other analyses to estimate CAPEX and OPEX. Since the ROM is a simplified cash flow calculation, it is easy to exchange the core regression models to estimate various costs. The ROM and regression models provided a framework that can be easily used by other researchers, decision-makers, operators, and regulators. The objective of this analysis is to assess the CO_2 breakeven cost range for pipeline and ship transport of captured CO_2 given the CO_2 source and storage reservoir located in the GOM."

Role of heterogeneous surface wettability on dynamic immiscible displacement, capillary pressure, and relative permeability in a CO_2-water-rock system.

The following is from the abstract of this article: "Surface wettability is one of the major factors that regulate immiscible fluid displacement in porous media. However, the role of pore-scale wettability heterogeneity on dynamic immiscible displacement is rarely investigated. This study investigated the impact of pore-scale wettability heterogeneity on immiscible two-fluid displacement and the resulting macroscopic constitutive relations, including the capillary pressure-water saturation (*Pc-Sw*) and relative permeability curves. A digital Bentheimer sandstone model was obtained from X-ray micro-computed tomography (micro-CT) scanning and the rock surface wettability fields were generated based on in-situ measurements of contact angles. A graphics processing unit-accelerated lattice Boltzmann model was employed to simulate the immiscible displacement processes through the primary drainage, imbibition, and second drainage stages in a CO_2-water-rock system. [The authors] found that pore-scale surface wettability heterogeneity caused noticeable local supercritical CO_2 ($scCO_2$) and water redistribution under less water-wet conditions. At the continuum scale, the *Pc-Sw* curves under the heterogeneous wetting condition were overall similar to those under the homogeneous wetting condition. This is because the impact of local wettability heterogeneity on the large-scale *Pc-Sw* curve was statistically averaged out at the entire-sample scale. The only difference was that heterogeneous wettability led to a negative entry pressure at the primary drainage stage under the intermediate-wet condition, which was caused by local, $scCO_2$-wet surfaces. The impact of pore-scale wettability heterogeneity was more noticeable on the relative permeability curves. Particularly, the variation of the $scCO_2$ relative permeability curve in the heterogeneous wettability scenario was more significant than that in the

homogenous wettability scenario. This suggests that pore-scale wettability heterogeneity enhances the coalescence and snap-off behaviors of $scCO_2$ blobs. This is the first study that systematically investigated the role of pore-scale wettability heterogeneity on dynamic immiscible displacement and associated *Pc-Sw* curves in complicated, three-dimensional porous media."

Ruichang Guo, Laura Dalton, Dustin Crandall, James McClure, Hongsheng Wang, Zhe Li, and Cheng Chen, *Advances in Water Resources. (Subscription may be required.)*

Screening for Geologic Sequestration of CO_2: A Comparison Between SCO_2TPRO and the FE/NETL CO_2 Saline Storage Cost Model.

The following is from the abstract of this article: "Meeting greenhouse gas emission reduction targets will likely require identifying and assessing subsurface storage space for sequestering billions of tonnes of CO_2 each year. Accomplishing this feat could include estimating the cost and capacity for thousands to hundreds-of-thousands of potential geologic CO_2 storage sites with CO_2 storage screening tools. In this study, [the authors] introduce a screening tool, SCO_2T^{PRO}, and compare and contrast it to the FE/NETL CO_2 Saline Storage Cost model (CSSC) using publicly available databases of saline reservoir properties in the United States. [The authors] find that the two tools use different methodologies to execute site-screening: SCO_2T^{PRO} calculates dynamic CO_2 injection rates and plume evolution that are used to estimate operationally-realistic well spacing designs and CO_2 storage capacities, whereas CSSC combines a volumetric storage estimation approach with geology-engineering well injectivity equations that can lead to an unrealistically high number of wells. These methodological differences translate into CSSC cost estimates that are several times higher than the SCO_2T^{PRO} estimates and around double for the capacity estimates. SCO_2T^{PRO} can also screen thousands of potential storage sites in seconds, which is thousands of times faster than CSSC. Lastly, [the authors] also find there is no single publicly available dataset of saline formation properties that can be used for screening across the United States."

Jonathan D. Ogland-Hand, Ryan M. Kammer, Jeffrey A. Bennett, Kevin M. Ellett, and Richard S. Middleton, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

The role of carbon capture, utilization, and storage for economic pathways that limit global warming to below 1.5°C.

The following is from the abstract of this article: "The 2021 Intergovernmental Panel on Climate Change (IPCC) report, for the first time, stated that CO_2 removal will be necessary to meet […] climate goals. However, there is a cost to accomplish CO_2 removal or mitigation that varies by source. Accordingly, a sensible strategy to prevent climate change begins by mitigating emission sources requiring the least energy and capital investment per ton of CO_2, such as new emitters and long-term stationary sources. The production of CO_2-derived products should also start by favoring processes that bring to market high-value products with sufficient margin to tolerate a higher cost of goods."

Jenny G. Vitillo, Matthew D. Eisaman, Edda S.P. Aradóttir, Fabrizio Passarini, Tao Wang, and Stafford W. Sheehan, *iScience. (Subscription may be required.)*

Carbon mineralization and geological storage of CO_2 in basalt: Mechanisms and technical challenges.

The following is from the abstract of this article: "Climate change is taking place due to significant emissions of greenhouse gases into the atmosphere. CO_2 storage in geological formations is a promising approach that can help to reduce greenhouse gas emissions from large emitters such as the steel and cement industries. However, effective storage in underground formations requires active trapping mechanisms to reduce the likelihood of leakage. Carbon mineralization is a trapping technique that can permanently store CO_2 in reactive rocks such as basalt. Although this method has been known for a long time, only two pilot projects in Iceland and the USA practiced CO_2 injection into basalts. This could be mainly due to the complexity of the interactions, the rapid carbon mineralization, and the difficulty to estimate the storage capacity in the long term. In this paper, [the authors] discuss different mechanisms and technical challenges of CO_2 storage in igneous rocks and propose a selection criterion based on laboratory and field-scale experience. It appears that basalt is a suitable rock for rapid carbon mineralization given its worldwide distribution, vesicular texture, and favourable mineral composition, but the lack of effective monitoring techniques and the amount of water required for injection are two major challenges that need to be addressed."

Arshad Raza, Guenther Glatz, Raoof Gholami, Mohamed Mahmoud, and Saad Alafnan, *Earth-Science Reviews. (Subscription may be required.)*

Characterisation of UK Industrial Clusters and Techno-Economic Cost Assessment for Carbon Dioxide Transport and Storage Implementation.

The following is from the abstract of this article: "The UK Government and British industries are making important efforts for the development and implementation of carbon capture, transport and storage (CCTS). Critical to this will be an understanding of the composition and characteristics of the industrial clusters and of the costs for the CCTS systems. However, the available literature presents a wide range of cost values and many of the studies do not tend to consider all of the carbon transport and storage elements together. Moreover, there are a very limited number of UK specific analyses and in some cases the studies are considered to be too historical. In this paper, [the authors] present a review and characterisation of the main UK industrial clusters, in terms of geographical limits, available infrastructure, industries present and level of emissions. [The authors] then provide a brief review of carbon transport and storage (T&S) cost models and costing information before conducting a techno-economic assessment of the potential T&S system costs for the UK industrial clusters. To the best of [the authors'] knowledge, this integrated analysis has not been conducted for the UK context, and this is key for policy development and to assess the wider economic impacts of CCTS. From [the authors'] cluster characterisation and techno-economic analysis, [they] found that there is important potential for CCTS for industrial decarbonisation in the UK. Also, the creation of a CO_2 shipping industry will allow for industrial clusters that do not have an adequate storage sites nearby to use the CCTS infrastructure in other sites. The development of a CO_2 shipping infrastructure also enables carbon management and storage services to be exported to polluters overseas, potentially creating and maintaining jobs and economic growth."

Christian Calvillo, Julia Race, Enrong Chang, Karen Turner, and Antonios Katris, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

3D micro-structural changes of an artificial flow channel in wellbore cement under geologic CO_2 storage conditions: Combined effect of effective stress and flow.

The following is from the abstract of this article: "Understanding CO_2-induced micro-structural changes at the imperfections in wellbore cement is vital for assessing the risk of CO_2 leakage through wellbore cement under geologic CO_2 storage (GCS) conditions. To investigate the evolution of a flow channel width in cement under GCS conditions and the influence of effective stress and flow on the micro-structural changes of the flow channel in cement, [the authors] carried out a set of experiments in which the flow condition (flow-through v.s. static) and the effective stress (3 MPa effective stress v.s. no effective stress) were varied. Micro-structural changes of an artificial flow channel were investigated by X-ray micro-computed tomography (CT). CT images revealed a clear micro-structural change of the flow channel and distributions of $Ca(OH)_2$/C-S-H dissolution and calcite precipitation zones near the channel after reacting with CO_2-saturated brine. CT results showed that a flow rate of 0.01 mL/min through the channel turned channel self-sealing (as observed in the static scenario) into channel opening. Effective stress accelerated the dominant chemical reaction, i.e., enhancement of $Ca(OH)_2$/C-S-H dissolution around the channel in a flow-through scenario and enhancement of calcite precipitation around the channel in a static scenario. It seems that effective stress and flow have a combined contribution to micro-structural change of the flow channel in hydrated Portland cement, which may increase the risk of CO_2 leakage through wellbore cement when exposed to high concentration CO_2."

Manguang Gan, Liwei Zhang, Yan Wang, Kaiyuan Mei, Xiaojuan Fu, Xiaowei Cheng, Mingxing Bai, Hejuan Liu, and Xiaochun Li, *Construction and Building Materials. (Subscription may be required.)*

From CO_2 sources to sinks: Regulatory challenges for trans-boundary trade, shipment and storage.

The following is from the abstract of this article: "Carbon Capture and Storage (CCS) technologies have been hailed as a solution to climate change with capacity not only to reduce atmospheric carbon di-oxide (CO_2) but also to achieve net-zero emission by the mid-21st century. CO_2 captured (either directly from the atmosphere or from large point sources), is compressed and transported to storage sites, either via pipelines or through shipping. Often, the CCS projects are deployed nationally where capture, transport and storage take place within the jurisdiction of one State. However, wide scale deployment of CCS projects is imperative for global matching of CO_2 sources to sinks. To that end, the outreach of CCS technology needs to go beyond the developed world. Studies have indicated that developing countries have vast storage resource potential. Internationalization of CCS projects where CO_2 is captured in one State and is then transported to another State for storage raises a number of challenges particularly in terms of trans-boundary transport and storage. This paper explores some of these challenges particularly in terms of international trade law, liability framework for shipping and storage and potential of insurance to act as a stop-gap arrangement until a regulatory regime is in place. It examines questions such as: whether CO_2 and CCS technologies are environmental goods and services under trade law; are there any regulatory frameworks in place to ensure liability against long-term health and safety as well environmental risks, and; what role can insurance industry play in promoting global deployment of CCS projects?"

Swati Gola and Kyriaki Noussia, *Resources, Conservation and Recycling. (Subscription may be required.)*

SEPTEMBER 2022

Best Practices for Life Cycle Assessment (LCA) of Direct Air Capture with Storage (DACS).

The following is from the Executive Summary of this DOE report: "As the one of the performance elements of the Carbon Negative Shot, robust life cycle greenhouse gas (GHG) accounting is a critical element for Carbon Dioxide Removal (CDR). Life Cycle Analysis/Assessment (LCA) is an existing framework that is well suited to evaluate the environmental implications of CDR. By design, LCA provides a holistic perspective of the potential environmental impacts of a product or process across the different life cycle phases. Not only can LCA be used to help determine the net CO_2e removal of a CDR approach, but it can also help with the assessment of potential tradeoffs with other environmental impacts. Even though the approaches for LCA are codified in the ISO 14040/14044 standards, [the authors] recognize the need to establish specific best practices for the subjective elements in those standards to harmonize data and methods to allow for consistent assessments of CDR approaches…"

A scoping study for a deep geological carbon dioxide storage research facility.

The following is from a description of this British Geological Survey (BGS) report: "A new report from a carbon storage scoping study demonstrates the importance of community engagement to define the research agenda to achieve the UK national climate change targets. Carbon capture and storage is 'a necessity, not an option, in meeting net-zero', according to the UK Committee on Climate Change. A NERC-funded carbon storage scoping study, commissioned in October 2020, identifies a strategic need for a national research infrastructure in carbon dioxide (CO_2) storage and developed the key research and innovation challenges it could address…"

Dawsonite as a Temporary but Effective Sink for Geological Carbon Storage.

The following is from the abstract of this article: "The possibility of using dawsonite mineral trapping as a carbon capture and storage (CCS) strategy intrigues many. In this study, [the authors] used a dawsonite-rich (~10%) CO_2 gas reservoir in the Hailar basin in northern China as a natural analogue of a CO_2 storage site, along with numerical modeling, to demonstrate that a large amount of dawsonite can be generated in sandstone formations, provided sufficient Na-rich feldspar and CO_2 gas are available. While precipitated dawsonite can be preserved only in a hydrodynamically-closed system in the long term under high CO_2 fugacity and $\log((Na^+)/(H^+))$ activities in solution, short-term trapping of CO_2 in dawsonite (on the order of 10 kyr) is possible and lowers CO_2 pressure, which mitigates the risk of CO_2 leakage to the ground surface or overlying drinking water aquifers. The re-dissolution of dawsonite after a few thousand years facilitates progressive dissipation of the gas phase CO_2 over time. Consideration of reservoirs or saline aquifers with minerals or formation water that can provide a high abundance of dissolved sodium, significantly increases the number of potential CCS sites globally. Furthermore, alternating water-and-gas injection regimens could enhance the precipitation of dawsonite in Na-rich aquifers. Future editions of the Carbon Storage Atlas should consider aquifer geochemistry in the site selection for secure long-term carbon storage in addition to the volumetric considerations for short-term operation."

Peng Lu, Guanru Zhang, Yi Huang, John Apps, and Chen Zhu, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Effects of Hydrogeological Heterogeneity on CO_2 Migration and Mineral Trapping: 3D Reactive Transport Modeling of Geological CO_2 Storage in the Mt. Simon Sandstone, Indiana, USA.

The following is from the abstract of this article: "[The authors] used three-dimensional (3D), high-resolution simulations facilitated by parallel computation to assess the effect of hydrogeological heterogeneity in the Mt. Simon Sandstone on CO_2 plume evolution and storage and geochemical reactions in a portion of the Illinois Basin, Indiana. Two scenarios were selected to investigate the effects of the hydrogeological heterogeneity in 3D reactive transport simulations: a heterogeneous case with variable porosity and permeability, and a homogenous case with constant porosity and permeability. The initial pressure, temperature, and mineralogical distributions are consistently applied in both the heterogeneous case and the homogeneous case. Results indicate that including hydrogeological heterogeneity in 3D reservoir simulations for geological CO_2 storage significantly impacts modeling results for plume migration patterns, CO_2-water-mineral interaction, reservoir quality, and CO_2 plume containment. In particular, results indicate that (1) the CO_2 plume reached the top of the Mt. Simon Sandstone in the homogeneous case, but was restrained to the lower third of the formation when hydrogeologic heterogeneity was considered; (2) the dominant trapping mechanism in the heterogeneous case was mineral trapping (43%), while it was solubility trapping (47%) in the homogeneous case (at 10,000 years); (3) incorporating reservoir heterogeneity in the model leads to a higher likelihood of long-term containment."

Babak Shabani, Peng Lu, Ryan Krammer, and Chen Zhu, *Energies. (Subscription may be required.)*

Assessment of chemo-mechanical impacts of CO_2 sequestration on the caprock formation in Farnsworth oil field, Texas.

The following is from the abstract of this article: "This study evaluates the chemo-mechanical influence of injected CO_2 on the Morrow B sandstone reservoir and the upper Morrow shale caprock utilizing data from the inverted 5-spot pattern centered on Well 13-10A within the Farnsworth unit (FWU). This study also seeks to evaluate the integrity of the caprock and the long-term CO_2 storage capability of the FWU. The inverted 5-spot pattern was extracted from the field-scale model and tuned with the available field observed data before the modeling work. Two coupled numerical simulation models were utilized to continue the study. First, a coupled hydro-geochemical model was constructed to simulate the dissolution and precipitation of formation minerals by modeling three intra-aqueous and six mineral reactions. In addition, a coupled hydro-geomechanical model was constructed and employed to study the effects of stress changes on the caprock's porosity, permeability, and ground displacement. The Mohr–Coulomb circle and failure envelope were used to determine caprock failure. In this work, the CO_2-WAG injection is followed by the historical field-observed strategy. During the forecasting period, a Water Alternating Gas (WAG) injection ratio of 1:3 was utilized with a baseline bottom-hole pressure constraint of 5500 psi for 20 years. A post-injection period of 1000 years was simulated to monitor the CO_2 plume and its effects on the CO_2 storage reservoir and caprock integrity. The simulation results indicated that the impacts of the geochemical reactions on the porosity of the caprock were insignificant as it experienced a decrease of about 0.0003% at the end of the 1000-year post-injection monitoring. On the other hand, the maximum stress-induced porosity change was about a 1.4% increase, resulting in about 4% in permeability change. It was estimated that about 3.3% of the sequestered CO_2 in the formation interacted with the caprock. Despite these petrophysical property alterations and CO_2 interactions in the caprock, the caprock still maintained its elastic properties and was determined to be far from its failure."

Benjamin Adu-Gyamfi, William Ampomah, Jiawei Tu, Qian Sun, Samuel Erzuah, and Samuel Acheampong, *Scientific Reports. (Subscription may be required.)*

Cost–benefit analysis of Gencos market trading with carbon-tax and cap-and-trade policies.

The following is from the abstract of this article: "Environmental issues have made reducing carbon emissions a consensus among all countries. The electricity market provides a competitive environment and at the same time makes it possible to reduce the carbon emissions of the electricity system through market-oriented means. Firstly, this paper focuses on carbon-tax and cap-and-trade market policies and introduces the quotation models of power generation companies with the two market policies. Then, in a specific market scenario, the bidding strategies, cost-benefit changes, and the carbon emission changes of the power system are analyzed when the Gencos are affected by carbon-tax policies with different tax rates or cap-and-trade policies with different carbon quota allocation methods. The results show that with the increase of the carbon-tax rate, the market-clearing price rises; except for the coal-fired power plants with high carbon emissions, the profits of other Gencos increase, and the carbon emissions in the system decrease significantly. Using the baseline method, historical emission method, and carbon emission reduction intensity method to allocate carbon allowances among Gencos can all achieve carbon emission reduction effects, and the carbon emission reduction intensity method has the best effect. Finally, the trading strategy of coal-fired Gencos with the cap-and-trade policy is proposed to increase their profits."

Jingrong Guo and Yue Xiang, *Energy Reports. (Subscription may be required.)*

Dynamic estimates of extreme-case CO_2 storage capacity for basin-scale heterogeneous systems under geological uncertainty.

The following is from the abstract of this article: "Geological CO_2 storage is expected to grow dramatically in the coming decades to meet global climate targets. Assessment of worldwide storage resources using static methods indicates significant theoretical potential for large-scale deployment. Dynamic capacity estimates are needed at the basin-scale that fully capture the impact of geological uncertainty and account for regional limits on pressure buildup. Accurate quantification of the risk of low or critically low capacity under extreme occurrences of heterogeneity will be increasingly important. There are significant challenges associated with efficient computation of low probability capacity within Monte Carlo frameworks at these scales. In this paper, [the authors] propose a workflow for uncertainty quantification that is able to efficiently estimate increasingly outer percentiles of dynamic capacity such as P1, P0.1, or even lower probability events. [The authors'] approach is based on the rare-event methodology that uses a subset simulation approach to concentrate sampling of the parameter space in the tail regions of the capacity distributions. This approach greatly speeds up uncertainty quantification for very small probabilities compared to standard Monte Carlo. [The authors] demonstrate the method by introducing a correlated heterogeneity field to a highly prospective basin-scale system that can support regional injection rates of 100 million tons annually. [The authors] find that the outer quantiles are more sensitive to the underlying geostatistical model compared to the median P50 capacity. This implies that for large-scale systems, well characterized heterogeneity is essential to identify the likelihood of very rare yet still relevant dynamic estimates of storage capacity."

Per Pettersson, Svenn Tveit, and Sarah E. Gasda, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

Carbon capture penetration in Mexico's 2050 horizon: A sustainability assessment of Mexican CCS policy.

The following is from the abstract of this article: "Mexico is expected to become the 6th largest economy in 2050. According to EDGAR database, in 2019 it was the largest polluting country in Latin America and the 13th in the world, regarding Greenhouse Gas (GHG) emissions. Lately, the new Administration has shifted its energy strategy from a renewable path into the reinforcement of conventional energy sources. In this context, new policies have to be deployed to meet the Paris Agreement goals. In such scenario, carbon capture and storage (CCS) technology may contribute reducing CO_2 emissions as a way to transform Mexico into a low-carbon economy in the long term. However, the construction and operation and maintenance phases will embody environmental impacts that should be considered. This paper assesses the carbon capture investments required for the expected increasing capacity of natural gas power plants up to 2050 and their impact on production, value added, employment, climate change, acidification, water consumption and human health effects. An environmentally extended multi-regional the input-output analysis (EMRIO) is used to address Mexican policies for the period 2020–2050. Results show that the investment in capture technologies in Mexico allows a net reduction of the carbon emissions in Mexico that is pursued at a low cost (33 EUR/tCO_2). This mitigation policy has important additional co-benefits in terms of domestic value added and employment creation of medium and high qualification. As for the environmental impacts, most of them are produced in the power plant due to the burning of the natural gas consumed."

Santacruz Banacloche, Yolanda Lechon, and Antonio Rodríguez-Martínez, *International Journal of Greenhouse Gas Control. (Subscription may be required.)*

ANNOUNCEMENTS

OCTOBER 2021

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

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

Consortium Backs CO_2 Storage Project.

The Greensand carbon dioxide (CO_2) storage project will continue to Phase II of the pilot project. A grant application will be filed with Denmark's Energy Technology Development and Demonstration Program; if the application is successful, work on the project could begin as soon as late-2021, with the offshore injection pilot starting in late-2022.

Publication Highlights CCUS in Wyoming.

The Enhanced Oil Recovery Institute published a StoryMap highlighting CCUS in Wyoming. "*Wyoming is CCUS Ready!*" highlights the state's infrastructure, geology, and tax incentives as they relate to CCUS, as well as the financial and environmental benefits.

RGGI Releases Report on Secondary Market.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "Report on the Secondary Market for RGGI CO_2 Allowances: Second Quarter 2021." Prepared by independent market monitor Potomac Economics, the report found no evidence of anticompetitive conduct in the RGGI CO_2 allowance secondary market.

NASA's CO_2 Conversion Challenge Winners Announced.

The National Aeronautics and Space Administration (NASA) *CO_2 Conversion Challenge* sought the development of novel synthesis technologies that use CO_2 as the sole carbon source to generate molecules that can be used to manufacture a variety of products for use in microbial bioreactors. The three teams that received awards demonstrated prototype systems capable of converting CO_2 from the air into glucose and other useful sugars.

NOVEMBER 2021

DOE Funding to Support Carbon Management Technologies.

DOE's FECM announced funding for four national public power associations to help increase regional- and state-level engagement in carbon management. In one award, the National Association of Regulatory Utility Commissioners will promote learning and discussion of CCUS among its members. In another award, the National Association of State Energy Officials will research, analyze, and develop educational information on new developments in carbon management, including CCUS.

FY 2021 Carbon Storage Newsletter Annual Index Available.

The FY 2021 Carbon Storage Newsletter Annual Index is available. The document is a compilation of NETL's Carbon Storage Newsletters published from October 2020 through September 2021.

MRCI Virtual Stakeholder Meeting.

The Midwest Regional Carbon Initiative (MRCI) held their *Fall 2021 MRCI Virtual Stakeholder Meeting* on November 9, 2021. MRCI is one of four individual *Regional Initiatives* that support FECM and build upon advancements made by the RCSP Initiative by identifying and addressing challenges to the widespread, commercial deployment of CCUS.

Partnership Launched to Study CCS.

Louisville Gas and Electric Company, Kentucky Utilities, and the University of Kentucky Center for Applied Energy Research (CAER) launched a partnership to study CCS for gas-powered systems. The partnership will look to develop a flexible, net-negative CO_2 emissions technology that will be applicable to natural gas combined cycle power plants while minimizing the associated capital costs of installation.

CO_2 Capture Collaboration Includes Bio-CCS.

Petrofac and CO_2 Capsol signed an agreement to collaborate on carbon capture projects. The companies are currently collaborating on a bio-energy carbon capture and storage (Bio-CCS) plant in Europe.

FECM Infographic Available.

DOE's FECM released an infographic providing facts and information on its vision and goals. "*10 Things You Should Know About FECM*" is available for download.

CCS to be Studied in Western Australia.

Mitsui and Metals National Corporation will conduct a joint feasibility study on CCS in Western Australia. In addition, Mitsui and Wesfarmers Chemicals, Energy, and Fertilisers Limited will jointly study the viability of building a low-carbon ammonia production plant with CCS in Western Australia.

Companies Sign MOU on CCS in Australia.

Santos, an Australian natural gas supplier, signed a Memorandum of Understanding (MOU) to advance CCS at the Bayu-Undan shallow-water field in the Timor Sea. The MOU details the areas in which the Bayu-Undan Joint Venture (operated by Santos) and Autoridade Nacional do Petróleo e Minerais (ANPM; the Timor-Leste regulator) will collaborate to test the viability of repurposing the existing Bayu-Undan facilities and use the Bayu-Undan reservoir for CCS.

Companies Agree to Collaborate on Carbon Management.

Equinor and Rosneft signed an agreement to share experiences and explore low-carbon opportunities to reduce CO_2 emissions from joint projects. The companies will also evaluate potential cooperation opportunities regarding CCUS.

DECEMBER 2021

DOE Announces Intent to Fund Carbon Storage Projects.

DOE's FECM released a *Notice of Intent (NOI)* to fund cost-shared R&D projects to accelerate wide-scale deployment of carbon capture and storage (CCS) and CDR. CDR technologies remove CO_2 directly from the atmosphere, and CCS technologies reduce CO_2 emissions from power plants and industrial facilities by capturing the CO_2 they produce. The potential projects will be selected under DOE's *Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative*, which focuses on developing geologic storage sites with capacities to store at least 50 million metric tons of CO_2.

DOE Announces New CO_2 Removal, Storage Goal.

U.S. Secretary of Energy Jennifer M. Granholm announced DOE's new goal to remove gigatons of CO_2 from the atmosphere and store it for less than $100/ton of net CO_2-equivalent. The "Carbon Negative Shot," the third target within *DOE's Energy Earthshots Initiative*, is a call for innovation in the expanding field of CDR. CDR is defined as a wide array of approaches that capture CO_2 directly from the atmosphere and durably store it in geological, bio-based, and ocean reservoirs or in value-added products to create negative emissions.

DOE Releases Joint Mission Statement on Carbon Dioxide Removal Mission.

The *Carbon Dioxide Removal Mission* will seek to enable CDR technologies to achieve net reduction of 100 million metric tons of CO_2 per year globally by 2030. The focus of the mission is to enhance the systems that lead to negative emissions through an emphasis on secure CO_2 storage and conversion into long-lived products. Co-leads of the mission include DOE, the Ministry of Energy (Kingdom of Saudi Arabia), and Natural Resources Canada.

DOE Announces Funding to Deploy CCUS.

DOE announced funding for an initiative focused on accelerating the regional deployment of carbon capture, utilization, and storage (CCUS). The *Regional Initiative to Accelerate CCUS Deployment* is designed to identify and address regional storage and transportation challenges facing the commercial deployment of CCUS. The four Regional Initiatives, which represent four regions of the United States, continue the work of predecessor projects funded under *DOE's Regional Carbon Sequestration Partnership (RCSP) Initiative*, supporting efforts to validate geologic storage technologies and support the commercialization of CCS.

DOE Invests to Decarbonize Using CCS.

DOE announced funding for 12 projects to advance point-source CCS technologies that can capture at least 95% of CO_2 emissions generated from natural gas power and industrial facilities. The projects were selected by *DOE's FECM* and will be managed by the National Energy Technology Laboratory (NETL). The 12 R&D front-end engineering design and engineering-scale projects are part of DOE's efforts to help achieve the administration's goals of net-zero carbon emissions by 2050 and a 100% clean electricity sector by 2035.

SMART Team Develops Reservoir Models for Depositional Environments.

The Science-informed Machine Learning for Accelerating Real-Time Decisions in Subsurface Applications (SMART) Team has developed machine learning-based predictive models for geologic CO_2 storage. The SMART Initiative is funded by *DOE/NETL's Carbon Storage* and *Upstream Oil and Gas Programs*.

Alliance to Develop Technical, Commercial Solutions to CCS Projects.

Technology provider *TechnipFMC* and offshore energy company *Talos Energy* entered into a partnership to develop technical and commercial solutions for CCS projects along the U.S. Gulf Coast. The companies will collaborate to advance CCS opportunities through the full life cycle.

UK Awards CO_2 Storage License.

The United Kingdom's (U.K.) Oil and Gas Authority awarded a CO_2 appraisal and storage license to Harbour Energy, who proposes to reuse depleted gas fields to store CO_2. Injection is targeted in 2026.

Carbon Zero Grand Challenge Seeks CCUS Solutions.

Singapore's *national water agency* launched the Carbon Zero Grand Challenge, seeking CCUS and removal solutions for its water treatment facilities to achieve net-zero emissions by 2050. Proposals are being accepted through February 2022.

Canada Co-Op Plans CCS Facilities.

Canada's Federated Co-Operatives signed a Memorandum of Understanding with Whitecap Resources Inc. to store 500,000 metric tons of CO_2 equivalent annually at Whitecap's Weyburn, Saskatchewan, carbon storage site.

UK Government Issues Response to Climate Change Committee Report.

The U.K. government released its response to a *Climate Change Committee* report on the progress made in adapting to climate change and recommendations moving forward. The U.K. government's *Net-Zero Strategy is available*.

JANUARY 2022

DOE to Fund Decarbonization Projects.

In December 2021, DOE's FECM announced intent to fund projects through its University Training and Research Program, which is comprised of the University Coal Research (UCR) and the Historically Black Colleges and Universities and Other Minority Institutions (HBCU-OMI) Programs. The projects would be funded to conduct early-stage R&D of decarbonization approaches, such as exploring biomass feedstocks blended with waste coal and coupled with CCS to advance net-zero energy production.

RGGI Releases Report on Secondary Market.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the "*Report on the Secondary Market for RGGI CO_2 Allowances: Third Quarter 2021*." Prepared by independent market monitor Potomac Economics, the report found no evidence of anticompetitive conduct in the RGGI CO_2 allowance secondary market.

Companies to Develop Roadmap to Decarbonize.

Emirates Global Aluminum (EGA) and *GE* signed an MOU to develop a roadmap to reduce greenhouse gas (GHG) emissions by exploring hydrogen as a fuel and carbon capture, utilization, and storage (CCUS). The decarbonization roadmap will explore the potential to integrate CCUS into EGA's power plants and implement changes to the auxiliary and balance of plant systems.

ARI Releases Report on CO_2-EOR.

Advanced Resources International (ARI) *released a report* updating enhanced oil recovery (EOR) and CO_2 supplies for CO_2-EOR projects for the end of the year 2020. The report found a decrease in oil production from CO_2-EOR in 2020, which was comparable to the overall decline in U.S. crude production.

Australian Govt Releases GHG Storage Acreage.

The Australian Minister for Resources and Water announced the availability of five new areas in Australian Commonwealth waters for the exploration of GHG storage opportunities. Maps for the 2021 Offshore Greenhouse Gas Acreage Release, public consultation comments, and information on the bidding process are available on *the Australian Government's Department of Industry, Science, Energy, and Resources website*.

Canadian Company Signs LOI, MOU for CCS.

$SpectrumH_2$ signed a Letter of Intent (LOI) to assess the feasibility of a large-scale carbon capture facility and associated CO_2 storage project in Alberta, Canada. The company also announced an MOU with an intermediate natural gas producer to help establish the production, marketing, and distribution of zero-emission blue hydrogen with associated CCS at a hydrogen production plant in Alberta.

Cooperative Agreement to Explore CCS.

The United Arab Emirates' (UAE) Abu Dhabi National Oil Corporation (ADNOC) signed an agreement with French company TotalEnergies to explore collaboration in CCS. ADNOC currently has the capacity to capture 800,000 tons of CO_2 annually and plans to expand the capacity sixfold, with the aim of reaching 5 million tons of CO_2 captured each year by 2030.

Midwest Regional Carbon Initiative Newsletter.

The MRCInfo Newsletter is available via *mailing list* to share updates on events and progress on various projects and their impact to the region and overall environment. The *Midwest Regional Carbon Initiative (MRCI)* is led by the Battelle Memorial Institute and Illinois Geologic Survey and aims to advance CCUS research by addressing key technical challenges, obtaining and sharing data to support CCUS, facilitating regional infrastructure planning, and performing regional technology transfer. Additional information on FECM's Regional Initiatives is available via the *NETL website*.

MHI CO_2 Capture System Ordered for Use in Commercial Plant.

Mitsubishi Heavy Industries Engineering—a subsidiary of Mitsubishi Heavy Industries (MHI)—will incorporate its CO_2 capture system into a biomass power plant within Hiroshima City, Japan, for Taihei Dengyo Kaisha, Ltd, a provider of plant construction, maintenance, and auxiliary services.

FEBRUARY 2022

DOE, USGS to Explore CCS.

DOE's FECM and the U.S. Department of Interior's U.S. Geological Survey (USGS) announced a partnership to explore global, regional, and national resources for the geologic storage of CO_2. Under the *Memorandum of Understanding (MOU)*, the agencies will collaborate with international governments, geologic surveys, and other organizations to provide technical assistance through a series of discussions, meetings, workshops, and research activities. The information will be used by government, academia, industry, research organizations, and other stakeholders to help identify potential investment opportunities for research, development, demonstration, and deployment to advance CCS technologies for application in power and industrial sectors.

Fossil Energy and Carbon Management Legislation Digest Available.

The Southern States Energy Board released a publication focused on fossil energy and carbon management legislation in the United States. The *Fossil Energy and Carbon Management Legislative Digest* covers regulatory measures affecting fossil energy generation; carbon capture, utilization, and storage (CCUS); and decarbonization bills.

PCOR Partnership Atlas Available.

The *Plains CO_2 Reduction (PCOR) Partnership Initiative*, one of four FECM Regional Initiative projects, released the *PCOR Partnership Atlas, 6th Edition*. The atlas provides a regional profile of CO_2 sources and potential storage locations across the PCOR Partnership region (approximately 2.4 million square miles from Missouri to Alaska, including 10 U.S. states and four Canadian provinces).

NRAP Report Recommends Practices for Carbon Storage Induced Seismicity Risk Management.

Researchers collaborating through DOE's National Risk Assessment Partnership (NRAP) released a technical report that presents a framework and steps to systemically evaluate, manage, communicate, and mitigate the risk of induced seismicity at geologic carbon storage sites. "*Recommended Practices for Managing Induced Seismicity Risk Associated with Geologic Carbon Storage*" builds on earlier work from DOE's Geothermal Technologies Office, incorporating new insights, and is adapted to cover a carbon storage project's life cycle.

Honeywell, University of Texas at Austin, to Develop CCS Technology.

Honeywell announced an agreement with the University of Texas at Austin (UT Austin) that will enable the capture of CO_2 emissions from power plants and industry. Under the licensing agreement, Honeywell will leverage UT Austin's proprietary advanced solvent technology to provide heavy industrial plants an additional tool to help meet regulatory requirements and sustainability goals.

CCUS-Focused Magazine Launched.

BBI International, a producer of bioenergy trade magazines, announced the launch of *Carbon Capture Magazine*. There will be one print issue in 2022, as well as a carbon capture industry directory and a map of storage and capture facilities. The magazine will also produce weekly online stories and distribute a bi-weekly newsletter.

Companies Seek to Develop CO_2 Storage Off Norway.

Five companies applied to develop CO_2 storage technology on the Norwegian continental shelf. The Norwegian government is seeking to promote the development of CCS technology to help reach climate goals. The country's oil and energy ministry said plans call for the allocation of the offshore acreage for CO_2 storage in 2022.

CCUS Partnership to Implement Roadmap.

The Technical University of Denmark entered a CCUS partnership with representatives from universities, public sector research, industry, and approved technological service institutes. The partnership, INNO-CCUS, will implement a Danish CCUS roadmap focused on short-term, medium-term, and long-term climate solutions.

Company Signs LOI for CCUS Deployment.

McDermott—a U.S. offshore engineering and construction company—and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) signed a Letter of Intent (LOI) to evaluate technical and commercial opportunities for the deployment of CSIRO's carbon capture technologies for energy and heavy industry applications.

MARCH 2022

NETL FY 2021 S&T Accomplishments Book Available.

NETL's FY 2021 Science and Technology (S&T) Accomplishments book is available online. The document contains nearly 40 poster presentations that showcase significant accomplishments made by NETL, industries, academia, and other entities, with many projects making progress to meet the Biden administration's clean energy goals calling for a net-zero carbon emissions electricity sector by 2035 and economy-wide net-zero emissions by 2050. Accomplishments in the document include efforts to increase the efficiency and lower the cost to capture CO_2 for permanent storage in the subsurface. A significant portion of the NETL research portfolio includes collaborative efforts conducted through partnerships, cooperative research and development agreements, financial assistance, and contractual arrangements with universities, research organizations, the private sector, and other national laboratories. Together, coupled with NETL's research, these efforts serve to focus the nation's wealth of scientific and engineering talent to create commercially viable solutions to help solve national and global energy and environmental challenges.

White House Issues CCUS Guidance.

The White House Council on Environmental Quality (CEQ) delivered new guidance to federal agencies to help ensure that the advancement of carbon capture, utilization, and storage (CCUS) technologies is done responsibly, incorporates community input, and reflects the best available science. The guidance builds on CEQ's *June 2021 CCUS report* and identifies measures to facilitate sound and transparent environmental reviews for CCUS projects. *CEQ extended* the public comment period in the *Federal Register* through April 18, 2022.

APRIL 2022

DOE Announces Funding to Advance Carbon Capture Technologies.

DOE's FECM announced the availability of federal funding for projects that will develop point-source carbon capture technologies for natural gas power plant and industrial applications capable of capturing at least 95% of CO_2 emissions generated. FECM's support for advancing carbon capture technology for coal-fired power plants has led to more than 20 successful pilot-scale projects, as well as a demonstration-scale project capable of capturing and storing approximately 1 million metric tons of CO_2 per year.

PCOR Partnership Highlights Reports.

The Plains CO_2 Reduction (PCOR) Partnership, one of four Regional Initiative Projects established through DOE's FECM, highlighted 2021 work products, including the *PCOR Partnership Atlas (6th Edition)*; *CCUS Business Models in the PCOR Partnership Region*; *Technical Approaches to Stacked Storage*; and *Risk-Based Area of Review (AoR) Estimation to Support Injection Well Storage Facility Permit Requirements for CO_2 Storage Projects*.

Explaining DAC Technology.

An Arizona State University professor discussed direct air capture (DAC) technology, CO_2 removal, and carbon storage in an interview.

Developments from NETL's SMART Initiative.

NETL's Science-informed Machine Learning for Accelerating Real-Time Decisions in Subsurface Applications (SMART) Initiative released two updates: *Development of a data-driven reduced order model to estimate the stimulated reservoir volume (SRV) from microseismic data in near real time* and *Multi-level Fracture Analysis and Visualization Workflow Improves Unconventional Reservoir Management*. Funded by DOE's Carbon Storage and Upstream Oil and Gas Programs, the SMART Initiative is a multi-organizational effort to transform understanding of the subsurface through real-time visualization, forecasting, and virtual learning.

Climate Research Initiative Launched.

The Massachusetts Institute of Technology Energy Initiative launched a research consortium to address potential climate issues. The Future Energy Systems Center will provide insights into the complex multi-sectorial transformations needed to alter energy-consuming sectors of the economy in conjunction with decarbonization-enabling technologies.

Survey for Offshore CCS Project Awarded.

PGS, a marine geophysics company, was awarded a survey contract from Equinor on behalf of the Northern Lights joint venture project offshore Norway. The survey is set to start in 2022.

Italian Company Signs Agreements to Capture, Store CO_2.

Italian energy group Eni signed a total of 19 agreements with companies to capture and store their CO_2 emissions as part of its *HyNet North West project* in the United Kingdom. HyNet North West is an industrial decarbonization project aimed at reducing CO_2 emissions and providing low-carbon power for industry.

Companies Sign CCUS MOU.

Lehigh Cement and energy infrastructure company Enbridge signed a Memorandum of Understanding (MOU) to collaborate on a carbon solution for Lehigh's cement manufacturing facility in Edmonton, Alberta, Canada. Lehigh is developing a full-scale CCUS solution for the cement industry at its Edmonton plant, with the captured emissions being transported via pipeline and stored by Enbridge.

MOU Part of CCUS Value Chain.

Malaysian energy company Petronas and shipping company Misui O.S.K. Lines signed an MOU to explore opportunities for liquified CO_2 transport as part of the CCUS value chain in the Asia Pacific and Oceania regions.

NETL Releases CCS Report.

A report authored by the National Energy Technology Laboratory (NETL) analyzed the buildout of America's carbon capture and storage (CCS) technologies in terms of job growth potential and supply chain risks. NETL researchers conducted a supply chain risk analysis by comparing raw material estimates against domestic and global production to search for opportunities and vulnerabilities. The report, titled "*Carbon Capture, Transport, and Storage, Supply Chain Review*," found that one reason for the low risk to the supply chain is because CCS infrastructure can be supplied by components made in the United States. The report also concluded that a CCS industry buildout could create up to 1.8 million jobs through construction, operation, and maintenance of capture, pipeline, and storage sites.

DOE FOA to Develop Carbon-Free Fuel.

DOE's Office of Fossil Energy and Carbon Management (FECM) announced federal funding for R&D and front-end engineering design (FEED) projects that will advance clean hydrogen as a carbon-free fuel. The FOA, titled "*Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions*," will leverage innovative approaches to produce clean hydrogen at lower costs from materials that include municipal solid waste, legacy coal waste, waste plastics, and biomass with CCS.

FECM/NETL Releases New Version of CCUS Model.

A new, updated version of a CCUS model developed by FECM/NETL has been released. The FECM/NETL CO_2 Transport Cost Model (also known as CO_2_T_COM) is an Excel-based tool that estimates revenues, capital, and operating and financing costs, as well as calculates the break-even cost (in $/tonne) for transporting liquid-phase CO_2 by pipeline. A *user's manual* and *overview presentation* were also released. Model updates include real (and nominal) dollar cost estimate capability, an update to the CO_2 equation of state, and a refined booster pump determination algorithm. The CO_2_T_COM can help evaluate integrated CCUS networks (i.e., connecting a CO_2 source to a storage site) and costs of large-diameter trunklines or shorter, smaller pipelines (e.g., gathering/distribution).

An Atlas of Carbon and Hydrogen Hubs.

The Great Plains Institute *published an atlas* of carbon and hydrogen hubs based on analysis of U.S. industrial activity, emissions, and fuel combustion. The atlas considers geologic storage potential, current hydrogen production, industrial concentration, and other factors that provide opportunities for siting CO_2 removal, as well as carbon capture retrofit and zero-carbon hydrogen production.

An Analysis of Government, Corporate CCS Investment.

Economic and financial analysts at *ING's THINK* discussed how governments are shaping CCS support mechanisms for corporate investment. Included in their analysis is a breakdown of CCS tax credits in the United States and how, globally, CCS has the potential to become a $200 billion market annually.

Public Offset Registry for Engineered CO_2 Removals Launched.

Puro.earth, a business-to-business marketplace focused on carbon removal, launched Puro Registry, a public registry dedicated to carbon removal and CO_2 Removal Certificates (CORCs). Puro Registry enables beneficiaries of CORCs to make their retirements public. According to Puro.earth, the registry is designed to meet industry comments from the 2021 United Nations Climate Change Conference (COP26) and is intended to align with the *Paris Agreement's Article 6 rules on corresponding adjustments*.

IPCC Releases New Report.

The Intergovernmental Panel on *Climate Change (IPCC) released "Climate Change 2022: Impacts, Adaptation and Vulnerability*," the second installment of its *Sixth Assessment Report (AR6)*. IPCC is producing AR6 with contributions by its three Working Groups, as well as a Synthesis Report, three Special Reports, and a refinement to its latest Methodology Report. The Working Group I contribution, "*Climate Change 2021: The Physical Science Basis*," was released in August 2021; the Working Group III contribution, as well as the Synthesis Report, are expected to be released later this year.

MAY 2022

DOE's Supply Chain Assessments.

DOE's report "*America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition*" includes 13 deep-dive supply chain assessments, including the "*Carbon Capture, Transport, and Storage Supply Chain Deep Dive Assessment*." The assessment found that developing CCS can support the U.S. government in achieving its net-zero goals.

Midwest Regional Carbon Initiative Newsletter Released.

The *Midwest Regional Carbon Initiative (MRCI)* released the latest edition of the *MRCInfo newsletter*, which focuses on news in the field of CCUS. MRCI, led by the Battelle Memorial Institute and Illinois Geologic Survey, is one of four individual *Regional Initiatives* that support FECM by identifying and addressing challenges to the widespread, commercial deployment of CCUS.

Report: CCS Spending Could Quadruple Through 2025.

According to energy research company Rystad Energy, service sector spending on CCS developments has the potential to quadruple from 2022 to 2025. The research found that there are 56 commercial CCS projects in operation globally. Based on already announced projects, nearly 140 CCS plants could be operational by 2025, capturing at least 150 million metric tons of CO_2 per year if the projects move ahead as scheduled. These projects are currently in various stages of development, including feasibility, concept, and construction.

CarbonCure Enters Carbon Credit Agreement.

CarbonCure Technologies signed a 10-year carbon credit purchase agreement supported by its process of mineralizing and storing CO_2 in concrete. CarbonCure measures and tracks CO_2 from the point of capture to mineralization, allowing credit buyers to trace deployment dates and points of the CO_2 they pay to store.

JUNE 2022

DOE Funding to Develop Hydrogen Turbines and Production with CCS.

DOE announced funding for *six research and development projects* to develop technologies for more efficient hydrogen turbines and production with carbon capture and storage (CCS). DOE's National Energy Technology Laboratory (NETL), under the purview of FECM, will manage the projects.

DOE Invests in DAC and Storage Technology.

DOE announced the award of federal funding for five front-end engineering design (FEED) studies that will leverage existing zero- or low-carbon energy to supply DAC projects, combined with dedicated and reliable carbon storage. *The studies* aim to provide a better understanding of system costs, performance, and business case options for existing DAC technologies coupled with durable storage that can remove a minimum of 5,000 metric tons per year of net CO_2 from the air, and which are co-located with domestic zero- or low-carbon thermal energy sourced from geothermal or nuclear power plants and low-grade heat from industrial facilities.

DOE Welcomes DOT's CO_2 Pipeline Safety Measures.

DOE released a statement welcoming the *CO_2 pipeline safety measures announced* by the U.S. Department of Transportation's (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA). The new guidance will be incorporated into DOE's research, development, demonstration, and deployment portfolio to ensure safe operations of commercial CO_2 pipelines in the United States. *PHMSA* establishes pipeline safety regulations at the federal level. DOE does not have regulatory oversight of CO_2 pipeline safety.

Report on Future Market Growth of CCS Industry.

According to a recent study, the global CCS market is expected to reach $15.2 billion by 2029. The report, "*Carbon Capture and Storage Market Share, Size, Trends, Industry Analysis Report By Application; By Capture Type; By Region, Segments & Forecast, 2022 - 2029*," provides insight into the current market dynamics and offers an analysis of future market growth. (Purchase required.)

RGGI Reports Made Available.

Potomac Economics, the independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) CO_2 allowance market, released their annual report evaluating activity in the market for RGGI CO_2 allowances in 2021. The *Annual Report on the Market for RGGI CO_2 Allowances: 2021* focuses on allowance prices, trading and acquisition of allowances in the auctions and the secondary market, participation in the market by individual firms, and market monitoring. Potomac also released the *Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2022*, which addresses the period from January through March 2022.

Joint Venture Aims to Increase Carbon Storage Access.

Caracara Services and a subsidiary of Battalion Oil Corporation entered into a joint venture to develop and fund a gas treatment and carbon storage facility in the Delaware Basin of West Texas (USA). Caracara Services constructs, owns, and operates carbon capture, utilization, and storage (CCUS) infrastructure.

JULY 2022

Virtual Carbon Negative Shot Summit Hosted by DOE.

DOE hosted the virtual Carbon Negative Shot Summit on July 20, 2022. DOE launched the *Carbon Negative Shot*, the third target within the *Energy Earthshots Initiative*, to advance the development of the emerging CDR industry. More information about Carbon Negative Shot is available via *video* and *infographic*.

FECM Welcomes New Assistant Secretary.

DOE's FECM welcomed new Assistant Secretary Brad Crabtree, who has nearly three decades of experience in energy and climate policy. The Assistant Secretary will lead and direct FECM's research and development (R&D) programs that support the Biden Administration's goals of achieving net-zero GHG emissions by 2050.

DOE Funding to Develop Hydrogen Turbines and Production with CCS.

DOE announced funding for *six R&D projects* to develop technologies for more efficient hydrogen turbines and production with carbon capture and storage (CCS). DOE's National Energy Technology Laboratory (NETL), under the purview of FECM, will manage the projects.

U.S. Supreme Court Ruling on EPA Climate Standards.

The U.S. Supreme Court released a decision on the U.S. Environmental Protection Agency's (EPA) authority to set climate standards for power plants. The opinion of the court is *available online*.

Report Calls for Scottish CCS Cluster.

An energy transition report recommended the United Kingdom (UK) government move forward with the Scottish CCS cluster. *Energy Transition 35* was produced by the Aberdeen & Grampian Chamber of Commerce, alongside KPMG and ETZ.

Global Businesses Test Voluntary Carbon Market.

Global businesses were invited to test a *Provisional Claims Code of Practice* for corporate claims made regarding the voluntary use of carbon credits. The benchmarks within the Provisional Code, which were unveiled at an event co-hosted by the Voluntary Carbon Markets Integrity Initiative and the UK government, set claims in the context of progress made against the achievement of a company's long-term, net-zero commitment.

Canada Launches System to Support Domestic Carbon Offset Trading Market.

The Canadian government launched a credit system for GHG offsets as part of its overall plan to reduce carbon emissions. The GHG offset credit system is intended to support a domestic carbon offset trading market.

Partnership Aims to Spur CO_2 Storage Investment.

Singapore's Climate Impact X and Finland's Puro.earth announced a partnership aimed at increasing the availability of nature- and technology-based carbon-removal credits. Through the partnership, the companies intend to spur investment in CCS projects by providing a choice of offsets to reduce emissions.

CCUS-Focused Roundtable Held.

Experts and decision-makers convened in Doha, Qatar, to discuss the current and future role of CCUS. The "CEO Roundtable" was hosted by the Al-Attiyah Foundation—a non-profit global energy and sustainable development organization.

AUGUST 2022

DOE Announces NOIs, Launches Online Resources.

DOE issued Notices of Intent (NOIs) to fund two programs funded by the Bipartisan Infrastructure Law (BIL)—the *Carbon Capture Demonstration Projects Program* and the *Carbon Dioxide Transport/Front-End Engineering Design (FEED) Program*. Together, these programs help to advance the administration's goal of a net-zero greenhouse gas (GHG) emissions economy by 2050. In addition, DOE's Office of Fossil Energy and Carbon Management (FECM) launched two new interactive tools. The *Carbon Matchmaker Tool* is an online information resource designed to increase awareness of carbon management funding opportunities; support private sector development of carbon capture, storage, and transportation infrastructure and carbon dioxide removal (CDR) pathways; and facilitate regional business development opportunities and education. The *Carbon Management Interactive Diagram* is an online tool that highlights carbon management programs in the BIL and through other DOE funding opportunities, as well as educates users about resources that fall under each program.

White House Seeking Nominations for CCUS Task Forces.

The White House Council on Environmental Quality (CEQ) is seeking nominations for two task forces that will provide input to inform the responsible development of CCUS. The task forces will provide recommendations to the federal government on how to ensure that CCUS projects are permitted in an efficient manner, reflect the input and needs of a wide range of stakeholders, and deliver benefits rather than harms to local communities.

DOE Issues NOI for Carbon Storage FOA.

DOE issued an NOI for a Funding Opportunity Announcement (FOA) titled "*Regional Initiative to Accelerate Carbon Management Deployment: Technical Assistance for Large-Scale Storage Facilities and Regional Carbon Management Hubs*." The objective of the planned FOA is to establish a consistent, effective mechanism for providing technical assistance to develop multiple large-scale carbon storage facilities and regional carbon management hubs that could store hundreds of millions of tons of carbon dioxide (CO_2) and inject more than 5 million metric tons of CO_2 per year.

Consortium Wins FEED Contract for UK CCS Station.

A consortium of Aker Solutions, Siemens Energy, and Doosan Babcock was awarded a FEED contract for a proposed power station with CCS. The consortium will deliver the engineering design for SSE Thermal and Equinor's proposed Keadby 3 Carbon Capture Power Station in North Lincolnshire, United Kingdom (UK). The plant is expected to be capable of capturing up to 1.5 million metric tons of CO_2 a year.

Report Offers Insights on CCUS Global Market to 2027.

According to a new report, the global CCUS market is estimated to be $2.84 billion in 2022 and is projected to reach $9.43 billion by 2027 (growing at a compound annual growth rate of 27.14%). The "*Global Carbon Capture, Utilization, and Storage (CCUS) Market (2022-2027) by Service, Technology, End-Use Industry, Geography, Competitive Analysis, and the Impact of Covid-19 with Ansoff Analysis*" report includes qualitative analysis, verifiable data from authentic sources, and projections about market size. (Purchase may be required.)

SEPTEMBER 2022

DOE/NETL Hosts 2022 Carbon Management Project Review Meeting.

For the first time since 2019, DOE's National Energy Technology Laboratory (NETL) hosted their annual carbon management project review meeting as an in-person event. The 2022 Carbon Management Project Review Meeting was held in Pittsburgh, Pennsylvania (USA), August 15–19, 2022. The meeting included a mixture of plenary and parallel sessions and poster presentations providing updates on DOE/NETL-funded carbon capture, utilization, and storage (CCUS) research projects being conducted to advance carbon management technologies and ensure a sustainable clean energy future for the nation.

NETL, Partners Release Resource on Computational Tools to Complete CO_2 Storage Permit Applications.

NETL collaborated with the U.S. Environmental Protection Agency (EPA), other contributing national laboratories, and DOE's Regional Initiatives to Accelerate CCUS on a report that identifies computational tools useful for addressing aspects of the dedicated carbon storage (Class VI) well permit application under EPA's Underground Injection Control (UIC) Program. "*Rules and Tools Crosswalk: A Compendium of Computational Tools to Support Geologic Carbon Storage Environmentally Protective UIC Class VI Permitting*" is intended to serve as a resource for industry, regulatory, academic, and public stakeholders.

Carbon Negative Shot Summit Recap.

DOE's Carbon Negative Shot Summit was attended by more than 1,700 people from 39 countries. A *two-minute recap video* of key moments from the summit is available, as is the *full recording*.

Report on Transition to Low-Carbon Energy Sources.

Zenon Research *released a report* on transitioning to low-carbon energy sources. Although focused on mature technologies, such as solar and wind energy, the report also calls for investment in other transition areas, such as mobility, electrified heat, storage, and carbon capture and storage (CCS).

Public Consultation on Core Carbon Principles Completed.

The Integrity Council for the Voluntary Carbon Market held a 60-day public consultation on draft Core Carbon Principles (CCPs), which propose fundamental, interlinked criteria for carbon credits that create verifiable climate impact with social and environmental safeguards. The draft CCPs, and accompanying draft Assessment Framework, are designed to build an understanding of carbon-crediting programs and credit types and establish a pathway for improvement. The public consultation was overseen by the British Standards Institute.

UK CCS Supply Chain Report Released.

A *report* commissioned by the United Kingdom's (UK) Department for Business, Energy, and Industrial Strategy (BEIS) found that CCS in the UK could be worth ~$120 billion to local manufacturing employers. Produced by Offshore Energies UK through the North Sea Transition Deal, the report identified 13 actions for the UK government and industry to undertake to help meet net-zero goals and benefit UK jobs and economy.

New York DEC Announces Grants to Safeguard Carbon Storage.

The New York Department of Environmental Conservation (DEC) announced nearly $1 million in awards to establish community forests in western and central New York (USA). The inaugural round of the Community Forest Conservation Program grants is expected to help safeguard ecosystem benefits forests provide, including carbon storage.

Update on Japanese Government's Carbon Credit Report.

The Japanese Ministry of Economy, Trade, and Industry (METI) established the "Study Group on the Preparation of an Operational Environment to Ensure the Proper Use of Carbon Credits to Achieve Carbon Neutrality" in 2021. The study group provided an *update on their carbon credit report*.

About DOE'S CARBON TRANSPORT and STORAGE **PROGRAM**

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

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

Carbon Transport and Storage Program Resources

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more information related to the Carbon Transport and 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 TRANSPORT and STORAGE **NEWSLETTER**

Compiled by the National Energy Technology Laboratory, this newsletter is a monthly summary of public and private sector carbon transport and 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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There are several ways to join the conversation and connect with NETL's Carbon Transport and Storage Program:

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