U.S. DEPARTMENT OF ENERGY | OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT

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

CSN CARBON STORAGE NEWSLETTER

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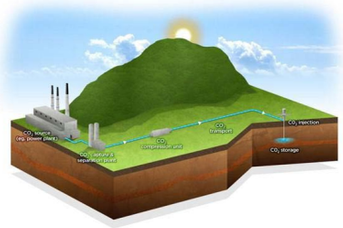
CARBON STORAGE PROGRAM DOCUMENTS and REFERENCE MATERIALS

- Carbon Storage Educational Resources
- Program Reports, Plans, and Roadmaps
- Conference Proceedings
- Carbon Storage Portfolio
- Systems Analysis
- Peer Review
- Best Practices Manuals
- Fossil Energy and Carbon Management Techlines

This newsletter is compiled by the National Energy Technology Laboratory to provide information on recent activities and publications related to carbon storage. It covers domestic, international, public sector, and private sector news in the following areas:

DOE/FECM/NETL HIGHLIGHTS

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.

CONTINUE

DOE/FECM/NETL HIGHLIGHTS *(cont.)*

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***," aims to increase the capability of algal systems to capture carbon dioxide (CO_2) and put it to productive use. Applications are due May 27, 2022.

From *energy.gov*. 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.

ANNOUNCEMENTS

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.

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.

ANNOUNCEMENTS *(cont.)*

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.

PROJECT AND BUSINESS DEVELOPMENTS

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.

PROJECT AND BUSINESS DEVELOPMENTS *(cont.)*

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.

LEGISLATION AND POLICY

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.

Changes Made to Forest Carbon Offset Bill.

The West Virginia House and Energy Manufacturing Committee (USA) made changes to a bill that would limit use restrictions in forest carbon offset agreements. While there is currently no time limit, ***House Bill 4483*** would set a maximum time length for such agreements, under which businesses invest in environmental projects to offset their CO_2 emissions. The committee revised the maximum number of years allowed under the bill for carbon offset agreements from 30 to 40 years.

From *Charleston Gazette-Mail*. February 2022.

EMISSIONS TRADING

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.

SCIENCE

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.

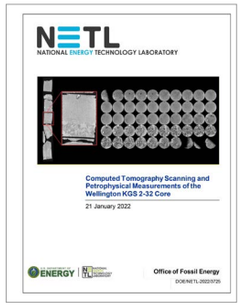
"Mechanical Trees" Could Help Store CO_2.

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.

PUBLICATIONS

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 $CaCl_2$, which react with CO_2 to produce the harmless solids $CaCO_3$ (limestone) and NaCl (salt) via intermediates such as $NaHCO_3$ and Na_2CO_3. 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 Cl_2 are produced simultaneously. Additionally, sea water contains both NaCl and $CaCl_2$ 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.)

PUBLICATIONS *(cont.)*

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 CH_4 and CO_2 adsorption characteristics were investigated. CH_4 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 CH_4 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 CH_4 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.)

PUBLICATIONS *(cont.)*

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 $CaCO_3$ 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 HCO_3^- and precipitation of $CaCO_3$ due to the Ca^{2+} 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.)

PUBLICATIONS *(cont.)*

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.)

ABOUT DOE'S CARBON STORAGE PROGRAM

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

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

Carbon Storage Program Resources

Newsletters, program fact sheets, best practices manuals, roadmaps, educational resources, presentations, and more information related to the Carbon Storage Program is available on ***DOE's Energy Data eXchange (EDX) website***.

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ABOUT NETL'S CARBON STORAGE NEWSLETTER

Compiled by the National Energy Technology Laboratory, this newsletter is a monthly summary of public and private sector carbon storage news from around the world. The article titles are links to the full text for those who would like to read more (note that all links were active at the time of publication).

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