

CSN

CARBON STORAGE
NEWSLETTER

NOVEMBER 2019

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:

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DOE/NETL HIGHLIGHTS

DOE Announces Funding to Collaborate Internationally and Accelerate CCUS.

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

*DOE Ranked Global Leader in CCS Research.*

DOE was described as a global leader in carbon capture and storage (CCS) research in a [report](#) issued by the peer-reviewed journal *Science of the Total Environment*. DOE ranked first in number of publications and "h-index," which measures the productivity and citation impact of a scientist. Notable advances include the development of the Regional Carbon Sequestration Partnerships (RCSPs), which has helped DOE characterize the carbon storage resource potential throughout the United States, verifying the major resources available to store carbon dioxide (CO₂). Through the work of the RCSPs, six large-scale projects have cumulatively injected more than 10 million tons of CO₂. In addition, DOE has prepared a series of carbon storage [Best Practice Manuals](#) that disseminate lessons learned from the projects to the public. [Click here for more information on DOE's carbon storage research.](#) From [energy.gov](#) on October 15, 2019.

ANNOUNCEMENTS

NETL Director Delivers Keynote Address.

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

*NETL-Developed Model Helps Evaluate CO₂ Storage Potential.*

FE/NETL developed the CO₂ Prophet Model, which is an oil reservoir simulator that calculates CO₂ retention and oil production for enhanced oil recovery (EOR) projects. The CO₂ Prophet Model is available online, along with supporting documentation, and provides key input to the FE/NETL Onshore CO₂-EOR Cost Model (currently in beta-testing). Integrated, these models enable rapid evaluation of the economics and CO₂ storage potential of multiple oil field and residual oil zone units.

DOE Announces Funding for CCUS Projects.

DOE's FE announced approximately \$110 million in federal funding for cost-shared R&D projects under three Funding Opportunity Announcements (FOAs). Approximately \$75 million is for awards selected under two FOAs announced in fiscal year 2019 (FY 2019), with \$35 million for a new FOA. The projects will build upon DOE's large-scale CCUS pilot and demonstration projects to test, mature, and prove CCUS technologies at commercial scale. Responses for the new FOA are due by January 15, 2020.

ANNOUNCEMENTS *(cont.)*

NETL-Developed Tool Used in Carbon Storage Study.

NETL's advanced carbon storage estimation tool, the CO₂ Storage prospective Resource Estimation Excel aNalysis (CO₂-SCREEN), was used to assess the feasibility of a commercial-scale CO₂ storage complex in the Northern Michigan Basin (USA). CO₂-SCREEN provides researchers and decision makers with a mechanism to calculate CO₂ storage resources to help assess a site. Use of the tool was documented in a *study* published in the *International Journal of Greenhouse Gas Control*.



Conference Proceedings Available for NETL's Project Review Meeting.

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



DOE Invests in Projects to Advance Coal Power Generation.

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

FY 2019 Carbon Storage Newsletter Annual Index Available.

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



Report Released on Investment of RGGI Proceeds.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released a report tracking the *investment of proceeds* in 2017 generated by their CO₂ allowance auctions. "*The Investment of RGGI Proceeds in 2017*" also provides state-specific success stories and program highlights. According to the report, \$315.6 million in RGGI proceeds were invested in energy programs in 2017.

PROJECT and BUSINESS DEVELOPMENTS

Qatar to Build CCS Plant.

Qatar officials announced the commissioning of a CCS facility to be located in Ras Laffan, Qatar, with a planned capacity of 2.1 million tons of CO₂ per year. According to officials, Qatar also plans to use CO₂ for EOR operations. From *Oil Price* on October 8, 2019.

Companies Sign MOU to Advance CCS.

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

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

Velocys, Inc., and Oxy Low Carbon Ventures, LLC (OLCV) signed an agreement to capture CO₂ from a planned biomass-to-fuels project in Natchez, Mississippi (USA) and store it underground. As part of the agreement, OLCV will transport and store the CO₂ captured from the planned Bayou Fuels facility (once it is completed), enabling the production of transportation fuels that have a net-negative carbon intensity. The Bayou Fuels project is expected to convert woody biomass into transportation fuels using Velocys' Fischer-Tropsch process. From *Velocys News* on October 10, 2019.

MITEL, Founding Members Renew Research Collaboration.

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



Aker Solutions Unveils Low-Carbon Strategy.

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

LEGISLATION and POLICY

Legislation to Invest in Carbon Capture, Storage Introduced.

Legislation to establish a program leading to the construction of transportation infrastructure for anthropogenic CO₂ was introduced in the U.S. House of Representatives. Under the "Investing in Energy Systems for the Transport of CO₂ (INVEST CO₂) Act," CO₂ captured at industrial sources would be transported via pipeline for storage or for beneficial use. From *Congresswoman Cheri Bustos Press Release* on October 29, 2019.

Amendment Allows for Transboundary CCS Projects.

Parties to the *London Protocol* agreed that transboundary export of CO₂ for the purpose of CCS could now be provisionally allowed under certain circumstances. The International Maritime Organization (IMO) resolution will allow for subsea CCS projects to be shared across national boundaries. Since

2006, the London Protocol has provided the basis in international environmental law for governments to allow CCS under the seabed. According to IMO officials, adoption of the resolution is expected to limit barriers for countries looking to pursue CCS under such scenarios. From *The Maritime Executive* on October 14, 2019.

Germany Approves Legislation to Reduce CO₂ Emissions.

The German cabinet approved legislation aimed at reducing CO₂ emissions by 55% in 2030. The legislation includes annual targets for CO₂ emissions specific for each sector. A monitoring commission will assess the annual targets every year, triggering additional measures if they are not met. From *S&P Global* on October 9, 2019.

EMISSIONS TRADING

Governor Signs Executive Order to Begin Process of Joining RGGI.

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



RGGI States Initiate Auction Process for Auction 46.

The states participating in RGGI released the *Auction Notice* and application materials for their 46th quarterly CO₂ allowance auction, to be held December 4, 2019. The Auction Notice provides potential participants with the information needed to submit a Qualification Application and indicate their intent to bid. Auction 46 will offer 13,116,444 CO₂ allowances for sale at a minimum reserve price of \$2.26. A 10 million CO₂ allowance cost containment reserve (CCR) will also be made available (the CCR will be accessed if the interim

clearing price exceeds the CCR trigger price of \$10.51). Auction 46 will be the last quarterly auction in which states will offer CO₂ allowances for purchase to meet CO₂ interim compliance obligations for the 2019 interim control period, which began on January 1, 2019. From *RGGI* on October 8, 2019.

Indonesia Starts Fund for Carbon Trading.

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

New Digital Exchange Allows Trading of Carbon Credits.

A global blockchain-based carbon exchange for the transportation industry was launched, providing a marketplace for stakeholders to trade carbon emissions. The AirCarbon Exchange will provide a supply of carbon credits, known as eligible emission units, for buyers to acquire CO₂ offsets. From *The Business Times* on October 30, 2019.

SCIENCE NEWS

Researchers Develop New CO₂ Capture, Conversion Material.

A team of researchers developed a material that can selectively capture CO₂ and convert it into useful organic materials. Researchers at Kyoto University, the University of Tokyo, and Jiangsu University in China collaborated on designing the material, which is a porous coordination polymer (PCP) that consists of zinc metal ions. Testing revealed that the material can selectively capture CO₂ molecules with 10 times more efficiency than other PCPs. After capturing the carbon, the converted material can be used to make polyurethane, a material with a wide variety of applications, including clothing, domestic appliances, and packaging. The research was published in the journal *Nature Communications*. From *Kyoto University Institute for Integrated Cell-Material Sciences* on October 11, 2019.

Report Shows Glacial Rivers Absorb CO₂ Faster than Rainforests.

University of British Columbia researchers found that the glaciers of Canada's high Arctic absorb CO₂ at a faster rate than the Amazon rainforest. The team of researchers collected meltwater samples on Ellesmere Island (Canada), where several glaciers flow into Lake Hazen; the team also gathered samples in the Rocky Mountains and Greenland. After analysis, the findings, *published in the Proceedings of the National Academy of Sciences*, showed that during high-melt periods, glacial river water absorbs 40 times as much CO₂ as the Amazon rainforest. From *The Guardian* on October 25, 2019.

Study Highlights CO₂ Storage Potential of Antarctic Krill.

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

JOURNAL ARTICLES

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

The following is the abstract of this article: "A coupled reservoir-well simulation scheme is established to analyze quantitatively multi-phase fluid flow and heat transport due to carbon dioxide (CO₂) injection in a reservoir rock-injection well system and to evaluate rigorously the CO₂ injection efficiency in terms of the CO₂ injection rate and injectivity. Two different cases of the CO₂ injection pressure and temperature at the well head are then simulated using the coupled reservoir-well simulation scheme within a multi-phase thermo-hydrological numerical model. The results of the numerical simulations show that the fluid pressure and temperature and the CO₂ injection rate and injectivity in the reservoir rock-injection well system can be quantitatively evaluated using the coupled reservoir-well simulation scheme. The fluid pressure and temperature in the injection well including the well head and bottom can also be simply predicted with assumptions of the hydrostatic fluid pressure transition and the adiabatic fluid temperature transition from the well head to the well bottom using the thermodynamic equation of state (EOS) data of CO₂. In addition, the CO₂ injection rate and injectivity have very close relationships with the fluid pressure and temperature at the well bottom, respectively, which determine the fluid pressure difference between the injection well bottom and the far-field reservoir rock and the kinematic viscosity of CO₂ at the well bottom. The CO₂ injection rate increases almost linearly with the fluid pressure difference, whereas the CO₂ injectivity varies unsystematically with it. Instead, the CO₂ injectivity has an excellent linear relationship with the reciprocal of the kinematic viscosity (i.e., kinematic fluidity) of CO₂. These results can be utilized as practical guidelines to determine optimal injection operation schemes for sustainable, safe, and efficient geologic storage of CO₂." **Jung-Hwi Kihm, Jai-Yong Park, Sungho Lee, Jun-Mo Kim, and Byoung-Woo Yum**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

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

The following is the abstract of this article: "Understanding the main mechanisms affecting long-term migration and redistribution of injected CO₂ in geological carbon storage is needed for developing predictive models to assess environmental risks and designing monitoring schemes. Preparation of a postinjection site care plan is required for CO₂ injection wells, including monitoring of pressure changes and injected CO₂ plume. Knowledge gaps exist regarding assessment of postinjection monitoring timeframes for the CO₂ plume because the processes driving long-term CO₂ plume migration and trapping are not fully understood. In the postinjection stage of geological carbon storage, redistribution of CO₂ occurs mainly due to buoyancy and capillary forces. This work presents experimental and modeling studies to investigate processes contributing to postinjection plume distribution and stabilization. [The authors] conducted a flow cell experiments (0.5 m × 0.05 m × 0.01 m) with two immiscible fluid phases in a glass bead porous medium to study postinjection plume behavior. [The authors] employed a hysteretic macroscopic two-phase flow model to interpret the experimental results and to understand main processes leading to plume stabilization. [The authors'] findings show that capillary pressure hysteresis explains the experimentally observed plume shape and redistribution at early postinjection stages; however, the long-term plume migration and eventual plume stabilization can only be represented when in addition microscale heterogeneity is accounted for. Results also show that plume stabilization can be extremely slow and that the migration of the plume front can occur through multiple intermittent bursts over long times. Further studies are needed to understand implications of the results for more realistic porous media and large-scale storage reservoirs." **Abdullah Cihan, Shibo Wang, Tetsu K. Tokunaga, and Jens T. Birkholzer**, *Water Resources Research*. (Subscription may be required.)

Reframing the Value Case for Carbon Capture and Storage.

The following is the abstract of this article: "In meeting long term climate ambitions at regional and national levels, there is a need to retain and

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

Targeted carbon tax reforms.

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

Prediction of the lifespan of cement at a specific depth based on the coupling of geomechanical and geochemical processes for CO₂ storage.

The following is the abstract of this article: "The injection of carbon dioxide (CO₂) captured from combustion-based processes into underground formations is one of a number of plausible methods to reduce its release into the atmosphere and consequential greenhouse gas warming. Once the gas has been captured efficiently and effectively, depleted oil and gas reservoirs are seen as high potential candidates for carbon storage projects. However, legacy issues associated with a high number of oil and gas wells abandoned during the last few decades put the carbon capture and storage projects (CCS) at risk. These include any defects within the cement surrounding the well casing or for capping an abandoned well that can become unwanted CO₂ leakage pathways. To predict the lifespan of these cements due to exposure to CO₂-bearing fluids at the conditions found underground, the geochemical processes need to be coupled with the geomechanical changes within the cement matrix. In a viable CCS project for sequestering CO₂, the cement matrix should be capable of withstanding acidic environments formed by dissolution of CO₂ in brine for more than ten thousand years. This work aims at providing a framework to predict the behaviour of cement due to CO₂ exposure under reservoir conditions. The results show that the chemical reactions and geomechanical changes within the cement matrix can result either in its radial cracking or radial compaction. Both of these behaviours are investigated as possible phenomena which may affect the CO₂ leakage, and therefore the viability of the site for long term carbon storage." **Mohammadreza Bagheri, Seyed M. Shariatipour, and Eshmaiel Ganjian**, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

JOURNAL ARTICLES *(cont.)*

SimCCS: An open-source tool for optimizing CO₂ capture, transport, and storage infrastructure.

The following is the abstract of this article: “Commercial-scale carbon capture and storage (CCS) technology will involve deploying infrastructure on a massive and costly scale. This effort will require careful and comprehensive planning to ensure that capture locations, storage sites, and the dedicated CO₂ distribution pipelines are selected in a robust and cost-effective manner. Introduced in 2009, *SimCCS* is an optimization model for integrated system design that enables researchers, stakeholders, and policy makers to design CCS infrastructure networks. *SimCCS*^{2.0} is a complete, ground-up redesign that is now a portable software package, useable and shareable by the CCS research, industrial, policy, and public communities. *SimCCS*^{2.0} integrates multiple new capabilities including a refined optimization model, novel candidate network generation techniques, and optional integration with high-performance computing platforms. Accessing user-provided CO₂ source, sink, and transportation data, *SimCCS*^{2.0} creates candidate transportation routes and formalizes an optimization problem that determines the most cost-effective CCS system design. This optimization problem is then solved either through a high-performance computing interface, or through third-party software on a local desktop computing platform. Finally, *SimCCS*^{2.0} employs an open-access geographic information system framework to enable analysis and visualization capabilities. *SimCCS*^{2.0} is written in Java and is publicly available via GitHub to encourage collaboration, modification, and community development.”
Richard S. Middleton, Sean P. Yaw, Brendan A. Hoover, and Kevin M. Ellett, *Environmental Modelling & Software*. (Subscription may be required.)

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

The following is the abstract of this article: “Carbon capture and storage (CCS) plays a vital role in achieving carbon dioxide (CO₂) emission reduction for the power sector. It is meaningful to explore how to promote widespread adoption of CCS technology by power plants more smoothly. Distinguished from previous literature, this paper firstly established a government-enterprise evolutionary game framework to study issues of CCS adoption at the micro level. By expounding the conflict of interests on CCS adoption between governments and coal-fired power plants in China, an evolutionary game model was built to analyze the evolutionary stability and discuss the systematic dynamic evolutionary processes. Based on the simulation method, the theoretical consequences were verified, and the effects of critical parameters on the evolution trajectories were analyzed. This study found that: (i) for impelling the system to tend towards the optimal evolutionary stable strategy (ESS), it was essential to strengthen governmental supervision and improve the enthusiasm of power plants to adopt CCS technology. (ii) the initial willingness of stakeholders would affect the evolutionary trajectories. (iii) it was significant to increase governments’ political achievements and reduce its supervisory cost, improve policy support for power enterprises deploying CCS and its low-carbon power generation revenue, and decrease their CCS adoption cost.”
Tian Zhao and Zhixin Liu, *Energy*. (Subscription may be required.)

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

The following is the abstract of this article: “A number of studies show that large-scale deployment of Carbon Capture and Storage (CCS) is necessary to limit the increase in global average temperature to less than 2°C by 2100. However, some experts and citizens worry about the integrity of carbon dioxide storage sites due to the possibility of future leakage. [The authors] introduce a two-period model where two emission mitigation technologies are available to society in the first period: CCS, with a risk of carbon dioxide leakage in the second period, and a riskless mitigation alternative, such as renewable energy. [The authors] first solve the model assuming that society does not know what the future rate of leakage will be. [The authors] then solve the model assuming that society will eventually learn the actual leakage rate. [The authors] find that, in a trading market in period one, reductions of CO₂ emissions through CCS should generate a less than proportional amount of CO₂ allowances. Estimates

from simulations, using a coarse range of parameters, indicate that the discount factor of CCS allowances lies in the range (0.72, 1). Site-specific data is required to determine site-specific risks of leakage and discount factors.”
Jorge H. García and Asbjørn Torvanger, *Energy Policy*. (Subscription may be required.)

The importance of lithofacies control on fluid migration in heterogeneous aeolian formations for geological CO₂ storage: Lessons from observational evidence and modelling of bleached palaeoreservoirs at Salt Wash Graben, Utah.

The following is the abstract of this article: “Exhumed bleached palaeoreservoirs provide a means of understanding fluid flow processes in geological media because the former movement of fluids is preserved as visible geochemical changes (grey bleaching of continental red-beds). The bleached palaeoreservoirs of the Jurassic Entrada Sandstone occur in a region (Utah) where there are high fluxes of naturally-occurring CO₂ and form outcrop analogues for processes related to geological storage of CO₂. In this paper a bleached palaeoreservoir now exposed at outcrop is used to test the importance of geological heterogeneity on fluid flow. The bleached palaeoreservoir is developed in ‘wet aeolian’ lithofacies composed of alternating layers of sandstone and cemented muddy sandstone that range across three or more orders of magnitude in permeability. Despite these permeability contrasts the bleaching shows a remarkably uniform distribution within the palaeoreservoir that crosses lithofacies boundaries. Evidence from bleaching therefore suggests that geological heterogeneity within the range 1–10³ millidarcies should not greatly impede the relatively uniform distribution of low-viscosity CO₂ charged fluids throughout a reservoir: a conclusion that has been substantiated here by flow modelling. Residence time is an important factor and where flows are transient the distribution of bleaching and modelling shows that flows are confined to high-permeability lithofacies.”
Andrew J. Newell, Azadeh Pourmalek, Andrew S. Butcher, and Seyed M. Shariatipour, *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Technologies and practice of CO₂ flooding and sequestration in China.

The following is the abstract of this article: “The latest advancement of CO₂ flooding and sequestration theory and technology in China is systematically described, and the future development direction is put forward. Based on the geological characteristics of continental reservoirs, five theories and key technologies have been developed: (1) Enriched the understandings about the mass transfer characteristics of components between CO₂ and crude oil in continental reservoirs, micro-flooding mechanism and sequestration mechanism of different geological bodies. (2) Established the design method of reservoir engineering parameters, injection-production control technology and development effect evaluation technology of CO₂ flooding, etc. (3) Developed a series of production engineering technologies such as separated layer CO₂ injection technology, high efficiency lifting technology, on-line wellbore corrosion monitoring and protection technology. (4) Innovated a series of surface engineering technology including CO₂ capture technology, pipeline CO₂ transportation, CO₂ surface injection, and production gas circulation injection, etc. (5) Formed a series of supporting technologies including monitoring, and safety and environmental protection evaluation of CO₂ flooding reservoir. On this basis, the technological development directions in the future have been put forward: (1) Breakthrough in low-cost CO₂ capture technology to provide cheap CO₂ gas source; (2) Improve the miscibility technology between CO₂ and crude oil to enhance oil displacement efficiency; (3) Improve CO₂ sweeping volume; (4) Develop more effective lifting tools and technologies; (5) Strengthen the research of basic theory and key technology of CO₂ storage monitoring. CO₂ flooding and sequestration in the Jilin Oilfield shows that this technology has broad application prospects in China.”
Yongle Hu, Mingqiang Hao, Guoli Chen, Ruiyan Sun, and Shi Li, *Petroleum Exploration and Development*. (Subscription may be required.)

REPORTS and OTHER PUBLICATIONS

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

The following is from the “Purpose of the Study” of this CMC Research Institutes and Canadian Business for Social Responsibility document: “Carbon Capture, Utilization and Storage (CCUS) technologies can play a significant role in meeting national and international greenhouse gas (GHG) emission reduction targets. With research, development and scale-up infrastructure in place, along with many decades of experience in developing full-scale CCUS facilities, Canada has an opportunity to become a global leader and exporter of CCUS knowledge and technology. This report seeks to provide an overview of the risks and opportunities for development, testing, implementation, and export of CCUS in Canada. By identifying barriers to national growth of CCUS, stakeholders can determine effective ways to build a national and international market for CCUS. This report is intended to serve as a primer, and will: [1] Provide an overview of the CCUS marketplace and recent CCUS technology developments (both in Canada and globally). [2] Identify who is developing innovative, commercially viable CCUS technology. [3] Highlight the challenges and opportunities to convert industrial CO₂ emissions into feedstock for value-added products.”

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

The following is from the Executive Summary of this document: “This study explores multiple ways to achieve net-zero emissions from EU steel, plastics, ammonia and cement production while keeping that production in the EU. It quantifies the potential impact of different solutions and finds that emissions from those industries can be reduced to net zero by 2050, confirming the findings of the pathways presented in the Commission’s *A Clean Planet for All*. Many new solutions are emerging, thanks to a more circular economy with greater materials efficiency and extensive recycling of plastics and steel, as well as innovative industrial processes and carbon capture and storage. Many different industrial strategies and pathways can be combined to achieve net-zero emissions. The analysis finds that the impact on end-user/consumer costs will be less than 1% regardless of the path pursued – but all pathways require new production processes that are considerably costlier to industry, as well as significant near-term capital investment equivalent to a 25–60% increase on today’s rates. Keeping EU companies competitive as they pursue deep cuts to emissions will thus require a new net-zero CO₂ industrial strategy and policy agenda. There is a need to accelerate innovation, enable early investment, support costlier low-CO₂ production, overcome barriers to circular economy solutions, and ensure that companies can access the large amounts of clean electricity and other new inputs and infrastructure they need. Time is short, with 2050 only one investment cycle away, and any further delays will hugely complicate the transition. As the EU ponders its industrial future, this transformation should be a clear priority.”



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 CO₂, 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 CO₂ emissions. The program also serves to increase the understanding of the effectiveness of advanced technologies in different geologic reservoirs appropriate for CO₂ 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 CO₂ behaves in the subsurface. These objectives are key to increasing confidence in safe, effective, and permanent geologic CO₂ storage.

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

Carbon Storage Program Resources

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



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

ABOUT NETL'S CARBON STORAGE NEWSLETTER

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

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