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

CSN CARBON STORAGE NEWSLETTER

APRIL 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:

CARBON STORAGE PROGRAM DOCUMENTS and REFERENCE MATERIALS

NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE/NETL HIGHLIGHTS

DOE Announces Funding to Accelerate CCUS.

The U.S. Department of Energy (DOE) announced federal funding for cooperative agreements that will help accelerate the deployment of carbon capture, utilization, and storage (CCUS). Through *this Funding Opportunity Announcement (FOA)*, DOE will look to award cooperative agreements to research and development (R&D) projects that will help identify and address regional storage and transport challenges currently facing the development of CCUS. Specifically, this FOA seeks to preserve, share, and advance existing R&D by addressing key technical challenges; facilitating data collection, sharing, and analysis; evaluating regional infrastructure; and promoting regional technology transfer. The selected projects will support the Office of Fossil Energy's (FE) *Carbon Storage Program*. From *energy.gov* on April 1, 2019.

DOE Selects Carbon Storage Project for Funding.

DOE selected a carbon capture project and a carbon storage project to receive federal funding. The associated geologic storage project was selected under the FOA "Developing Technologies for Advancement of Associated Geologic Storage for Basinal Geo-Laboratories." Supported by FE's Carbon Storage Program and managed by the National Energy Technology Laboratory (NETL), the University of Wyoming project plans to establish the technical and economic viability of associated carbon dioxide (CO_2) storage and oil recovery in the greenfield residual oil zones of the Powder River Basin of Wyoming and Montana (USA). It joins *two other associated geologic storage projects* announced to receive funding in August 2018. From *energy.gov* on March 29, 2019.

DOE Announces Funding for FEED Studies.

DOE announced federal funding for cost-shared R&D for front-end engineering design (FEED) studies for CO_2 capture. Supporting FEED studies for commercial CO_2 capture systems helps to understand the costs associated with CCUS. The projects will be funded by FE's Carbon Capture Program. From *energy.gov* on March 14, 2019.

ANNOUNCEMENTS

DOE/NETL Announces Funding Opportunity.

DOE/NETL announced a funding opportunity to develop and validate innovative transformational sensor systems. Research and Design will need to improve the ability to characterize and predict movement of fluids in the subsurface, and will include field-laboratory validation of the proposed component sensor system. Concept Papers for FOA 1998 are due on May 8, 2019, and full applications are due on June 21, 2019 (Concept Paper submission is required for applicants to be permitted to submit a full application).

DOE/NETL Studies Focus on Geologic Storage of CO_2.

DOE/NETL developed three studies that evaluated industrial analogs to CO_2 geologic storage. The three analogs studied (*underground natural gas storage*, *deep well waste disposal*, and *CO_2 enhanced oil recovery [EOR]*) were selected because of their commonalities with CO_2 geologic storage. The studies aim to draw insights and lessons learned from the history of other commercially prominent analogous industries and to help address technical and policy-related questions concerning captured CO_2 geologic storage moving forward.

ANNOUNCEMENTS *(cont.)*

DOE's Office of Science Graduate Student Research Program Accepting Applications.

DOE's Office of Science Graduate Student Research (SCGSR) Program is accepting applications through May 9, 2019, for the 2019 Solicitation. The SCGSR Program provides supplemental awards to U.S. graduate students to pursue part of their graduate thesis research at a DOE laboratory/facility. Priority Research Areas for 2019 Solicitation 1 include Biological and Environmental Research, which contains improving carbon storage capabilities. Applications are due May 9, 2019.

DOE Issues Request for Information.

DOE's FE and NETL *issued a Request for Information (RFI)* for strategies for improving or creating emission-reduction or utilization technologies for hazardous substances resulting from coal combustion. FE funds research, development, and demonstration (RD&D) projects to reduce the risk and cost of advanced carbon technologies and further the sustainable use of the nation's fossil resources.

USGS Conducts Review of Carbon Mineralization.

The U.S. Geological Survey (USGS) published a review of potential carbon storage in igneous and metamorphic rocks through carbon mineralization. The report, titled "*Carbon Dioxide Mineralization Feasibility in the United States*," explores the feasibility of CO_2 storage through carbon mineralization, which is the process by which CO_2 becomes a solid mineral.

Grants Awarded to Enhance Carbon Storage.

The California Department of Forestry and Fire Protection (USA) announced grants to 16 projects that promote healthy forests to help enhance carbon storage.

Workshop Explores Potential for Carbon Storage Economy.

Cornell University's Atkinson Center for a Sustainable Future (USA) hosted a workshop to outline a research agenda to support a carbon storage economy. The workshop, which drew participants from academia, non-governmental organizations, businesses, and government, emphasized the human and societal dimensions of CO_2 removal.

CCUS Investments Day.

The Oil and Gas Climate Initiative (OGCI) is holding a CCUS investment day in Chicago, Illinois (USA), in September 2019. OGCI member companies, selected financial firms, business partners, and policy makers will be in attendance to hear presentations seeking investment for commercial projects that result in the utilization or storage of CO_2, or technologies that can lower the cost of CO_2 capture or create products that utilize CO_2.

CCUS Advisory Group Launched.

A government- and industry-backed CCUS advisory group was launched in the United Kingdom (U.K.). In addition to providing advice on potential incentives and regulations for the CCUS market in Britain, the group will also advise on potential challenges of the technology and support the review of delivery and investment framework.

PROJECT and BUSINESS DEVELOPMENTS

Aker Solutions Selected for CCUS Work.

The Swedish fuel company Preem selected Aker Solutions to perform CCUS work at a Scandinavian oil refinery in Lysekil on the Swedish west coast. Aker Solutions will conduct a feasibility study of the technological and economic impact of implementing CO_2 capture at Preemraff Lysekil, Scandinavia's largest refinery. The scope of work also includes pilot testing of CO_2 capture from the oil refinery flue gas under industrial conditions. According to Aker Solutions officials, the refinery in Lysekil is a potential candidate for carbon capture and storage (CCS). From *Aker Solutions News* on February 27, 2019.

Oil and Gas Authority to Research Renewable Energy.

The U.K.'s Oil and Gas Authority (OGA) research into powering the North Sea oil and gas assets with renewable energy sources is assessing CCS technology. *According to an OGA press release*, OGA will publish a policy position as well as a strategy that will cover CO_2-EOR. From *Energy Voice* on March 21, 2019.

LEGISLATION and POLICY

CO_2 Storage Bill Passes House.

Indiana (USA) legislation that would create a pilot program to store CO_2 underground passed the House and is returning to the state Senate. The bill would create a pilot program that allows one company to store CO_2 underground by taking ownership of the land, if approved by the Indiana Department of Natural Resources. From *Indiana Public Media* on March 26, 2019.

Nevada Introduces Carbon-Free Bill.

Nevada (USA) legislators introduced a bill that would require 100 percent carbon-free emissions by 2050. In addition, SB 358 would double Nevada's renewable portfolio standard to 50 percent by 2030. From *Utility Dive* on March 20, 2019.

Flemish Government Approves CO_2 Package.

The executive branch of the Flemish Region of Belgium approved a plan to manage CO_2 emissions over the next 20 years and become carbon-neutral by 2050. As part of the plan, the Flemish government will focus on carbon capture and use projects. From *Brussels Times* on March 24, 2019.

South Africa Parliament to Consider Carbon Tax Legislation.

The National Council of Provinces of the Parliament of South Africa is considering carbon tax legislation. The Carbon Tax Bill would create a mechanism that puts a price on carbon emissions in South Africa. From *Eyewitness News* on March 25, 2019.

EMISSIONS TRADING

Dutch Government to Introduce CO_2 Tax.

The Dutch government intends to introduce a tax on CO_2 emissions for companies, according to the Prime Minister. The plan would be in addition to the European Union's (EU) current Emissions Trading System. From *Reuters* on March 13, 2019.

RGGI Announces Auction Results.

The states participating in the Regional Greenhouse Gas Initiative (RGGI) released the results of their 43rd auction of CO_2 allowances. The first auction of 2019 (Auction 43) saw 12,883,436 CO_2 allowances sold at a clearing price of $5.27, with bids ranging from $2.26 to $7.12 per allowance. The auction generated $67.9 million for reinvestment in strategic programs, including energy efficiency, renewable energy, direct bill assistance, and greenhouse gas abatement programs. More information is available in the *Market Monitor Report for Auction 43*. From *RGGI News Release* on March 15, 2019.

SCIENCE NEWS

Researchers Study Mineral Trapping for CO_2 Storage.

A computational study conducted by a Japanese-led group of international researchers showed the potential for "mineral trapping" to be used for CO_2 storage. Researchers from Kyushu University ran computer simulations of CO_2 reacting with rock surfaces to show how trapped CO_2 can be converted into minerals. The results of the simulations were *published in The Journal of Physical Chemistry C*. From *EurekAlert!* on March 8, 2019.

Bamboo May Have Carbon Storage Potential.

Farmers in the Philippines' province of Antique are being asked to plant more bamboo to mitigate potential CO_2 emissions. According to speakers at the "Change Adaptation and Mitigation Summit of the Provincial Disaster Risk and Reduction and Management Council," bamboo is a potential resource for carbon storage. From *Panay News* on March 24, 2019.

Scientists Turn CO_2 Into Solid Carbon for Storage.

Research conducted by RMIT University, Melbourne, Australia, has led to the development of a new CO_2 capture process that converts CO_2 gas into solid carbon, making it easier to store. Researchers used a liquid metal electrocatalyst to convert the CO_2 at room temperature; previously developed electrocatalysts were only able to convert CO_2 to solid carbon at temperatures above 600°C. Results of the study were *published in the journal Nature Communications*. From *The Chemical Engineer* on March 25, 2019.

Scientists Measure Ocean Sink for CO_2 Emissions.

An international team of scientists studied the amount of manmade CO_2 emissions stored in the ocean from 1994 to 2007. According to their research, *published in the journal Science*, the ocean stored as much as 34 gigatons of manmade atmospheric CO_2 during the 13-year span (31 percent of all anthropogenic CO_2 emitted during that time). From *chemeurope.com* on March 18, 2019.

Technique Could Lead to CO_2 Reductions.

A team of researchers from Washington State University is working to develop ways to capture, store, and use the CO_2 emitted during energy production. In their research, *published in the journal ACS Applied Materials and Interfaces*, the team developed a way to create hollow, nanorod-shaped porous materials to separate the CO_2 in a way that is applicable to real-life conditions. From *Washington State University News* on February 26, 2019.

JOURNAL ARTICLES

Effect of thermal stress on wellbore integrity during CO_2 injection.

The following is the Abstract of this article: "Wellbore integrity is a critical component of long-term carbon storage. Depleted reservoirs that are potential CO_2 storage sites, typically contain several wells. Due to years of operations and abandonment, these wells can have cracks in the cement, cement-casing interface, and/or cement-formation interface. During CO_2 injection, changes in temperature may result in stress variations that can further damage the well, threatening its integrity. The temperature difference between the cold injected CO_2 and warm reservoir, and different thermal properties for the wellbore casing, cement, and the lithology, will stress the near wellbore environment, potentially extending pre-existing defects creating leakage pathways from the storage reservoir to the overlying strata. [The authors] have conducted a systematic numerical study to explore the role of CO_2 injection temperature, downhole effective in-situ horizontal stress, and the thermo-mechanical properties by coupling a linear elastic stress model with heat conduction. [The authors] consider conditions in non-perforated casing above the injection zone where conductive heating is dominant. The injection temperatures considered covers current industrial practice as well as sub-zero temperatures. The latter represents direct injection following ship transport, without pre-heating.

In this study, [the authors] consider the connection between damage risk and the temperature difference between the injected CO_2 and the formation and downhole effective in-situ horizontal stress. The study found that the negative impacts of thermal stress in the wellbore environment are mitigated by the presence of effective in-situ horizontal stresses. Stresses normal to the well have the potential to reduce the tensile stress and stress intensity factor. In the absence of sufficient effective in-situ horizontal stress, thermal stress may cause the fracture to propagate due to high stress concentration near the fracture edges. In general, formations with large effective in-situ horizontal stress can prevent leakage paths from growing even when large temperature difference exists between the formation and the injected CO_2. [The authors'] simulations suggest that CO_2 can be injected at sub-zero temperatures, suitable for ship transport, when the downhole effective in-situ horizontal stress is greater than 10 or 12 MPa, depending on the location of the pre-existing cracks. For onshore transportation, injection of liquid CO_2 results in minimal damage, provided there is ample in-situ horizontal stress." **Pratanu Roy, Joseph P. Morris, Stuart D.C. Walsh, Jaisree Iyer, and Susan Carroll,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

JOURNAL ARTICLES *(cont.)*

Best practices and recent advances in CCS cost engineering and economic analysis.

The following is the Abstract of this article: "Cost engineering and economic analysis are key elements of the performance assessment of carbon capture and storage (CCS) technology. The CCS field has seen noticeable advances in the transparency and rigor of costing studies, but there is still significant room for improvement in three major areas: the more rigorous application of good cost engineering practices; the inclusion (and progression) of recent methodological advances; and adaptation to changing policy focus. Here, [the authors] discuss each of these three areas, bringing diverse information sources together into one paper, and [summarizing] important advances made in recent years, with the goal of strengthening CCS cost engineering and economic analysis in general. The first part of the paper discusses equipment design and sizing; cost indices and location factors; process and project contingency costs; CO_2 transport and storage costs; and uncertainty analysis and validation. The second part discusses new insights and advances in capture plant integration costs; the costs of steam supply; flexible dispatch of power plants with CCS; a hybrid method for the costing of advanced CCS technologies; qualitative uncertainty analysis methods; and calculation methods for CO_2 avoidance costs in non-power industries. The third part highlights several recent changes in the policy environments and how they affect the requirements of CCS costing studies. [The authors] close the paper by echoing earlier calls for the transparent reporting of assumptions and input variables underlying costing studies and by [prioritizing] three CCS costing issues for further methods and guideline development." **Mijndert van der Spek, Simon Roussanaly, and Edward S. Rubin,** *International Journal of Greenhouse Gas Control*. (Subscription may be required.)

Low carbon unit commitment (LCUC) with post carbon capture and storage (CCS) technology considering resource sensitivity.

The following is the Abstract of this article: "This paper proposes a new methodology for scheduling of thermal generation plants equipped with Amine based post combustion carbon capture technology. The methodology develops a generic and simplified model for operational planning of thermal generators through unit commitment. The performance indices developed in this paper can accommodate the resource sensitivity of the fuel used for combustion. The proposed performance indices are coupled to unit commitment procedure through intelligent scheduling methodology considering both economic and environmental concerns of the system. The proposed models can be readily integrated into the unit commitment algorithm using the test system data and fuel composition. The same provides a simple and near appropriate model to consider resource sensitivity as compared to detailed (or) dedicated modeling carried out in Aspen, APEA, promax etc. The impact of resource sensitivity and scheduling strategy has been illustrated using a 10 unit thermal generation test system with amine based post combustion carbon capture technology. The resource sensitivity of the model has been demonstrated using three different compositions of fuel/coal viz. sub-bituminous, bituminous and lignite coals. The simulation results of resource sensitivity at various capture efficiencies are presented and discussed in detail with respect to various performance indices developed. The models developed in this paper can be integrated to wide range of thermal generation plants with wide range of coal type (or) fuel compositions across the globe." **Srikanth ReddyK, Lokesh Panwar, B.K. Panigrahi, and Rajesh Kumar,** *Journal of Cleaner Production*. (Subscription may be required.)

Quantities versus prices for best social welfare in carbon reduction: A literature review.

The following is the Abstract of this article: "Weitzman's price-quantity analysis framework has been widely used, and in the field of climate economy it is applied to choose proper emissions reduction instruments for best welfare under uncertainty. This article summarizes the principle and method of selecting carbon emission reduction instruments by price versus quantities decision criterion. The probability of uncontrollable outcomes under uncertainty is reduced by comparing marginal abatement costs with marginal abatement benefits. On this basis, the following outreach research are summarized on some key issues such as dynamic analysis, assumptions improvements, elements expansion and hybrid policies. This topic drives a lot of research but no review has been conducted. [The authors] sum up the time-correlated cost and multi-period policy research to extend the static framework to dynamic analysis. There are also many studies that relax the strong assumptions of original framework including correlated uncertainty between cost and benefit, stock effect of carbon, nonlinear marginal cost and benefit, distributional inefficiency and extension of partial equilibrium. In addition, more elements around emissions control have been included and specified such as uncertainty, incomplete enforcement, technology innovation and multiple pollutants. [The authors] also summarize the researches of hybrid policy which combines quantity and price control to be a new regulation method and dual regulation which suggest applying both quantity and price control in different departments. It is found that early researches favor carbon tax while quantity regulation has gradually become popular. Finally, this article puts forward some research directions worth more exploring at both theory and application level." **Bao-Jun Tang, Xiang-Yu Wang, and Yi-Ming Wei,** *Applied 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 [CO_2] 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 [CO_2] leakage in the second period, and a riskless mitigation alternative, such as renewable energy. [The authors] first solve the model assuming that society does not know what the future rate of leakage will be. [The authors] then solve the model assuming that society will eventually learn the actual leakage rate. [The authors] find that, in a trading market in period one, reductions of CO_2 emissions through CCS should generate a less than proportional amount of CO_2 allowances. Estimates from simulations, using a coarse range of parameters, indicate that the discount factor of CCS allowances lies in the range (0.72, 1). Site-specific data is required to determine site-specific risks of leakage and discount factors." **Jorge H. García and Asbjørn Torvanger**, *Energy Policy*. (Subscription may be required.)

REPORTS and OTHER PUBLICATIONS

Dynamic reduced order modelling (ROM) of chemical and mechanical processes in CO_2-cement systems.

The following is from the Abstract of this National Risk Assessment Partnership (NRAP) Technical Report: "Damaged wells pose a significant risk of leakage of reservoir fluids stored in a geological CO_2 storage site. The leaking CO_2 can react with well cement and alter its chemical, mechanical, and hydraulic properties. Recently, [the authors] have developed an experimentally-calibrated model that couples two-phase flow, reactive transport of brine, cement geochemistry, and geomechanics to predict the leakage of reservoir fluids through a fractured pathway in a cemented well (Iyer, et al. 2018, Iyer, et al. 2017, Walsh, et al. 2013, Walsh, et al. 2014, Walsh, et al. 2014). [The authors] are developing a reduced order model (ROM) to rapidly assess the evolution of leakage flux from a well for a wide range of CO_2 storage sites scenarios, because the coupled numerical model is computationally very expensive. The coupled numerical model was used to run simulations needed to train the ROM by applying quasi-Monte Carlo sampling of seven inputs parameters, with some physical restrictions, to ensure efficient and additive sampling. The ROM uses the reservoir overpressure and saturation, the fracture aperture, length, and width, the normal stress acting on the fracture, and the reservoir depth as inputs. To ensure a sensitive response the input variables and the output leakage rate were post-processed using a logarithmic transformation followed by normalization. The coupled model solves several partial differential equations that describe the spatial and temporal evolution of pressure, velocity, concentrations, and extent of reaction. As a result, the solution at any time depends on the solution at previous times. To preserve this notion of memory the ROM was developed such that the leakage rate at any given time depends not only on the input parameters like pressure, saturation, etc., but also on the predicted leakage rate in the previous time steps. This process was found to perform significantly better than any approach that ignored this notion of memory…"

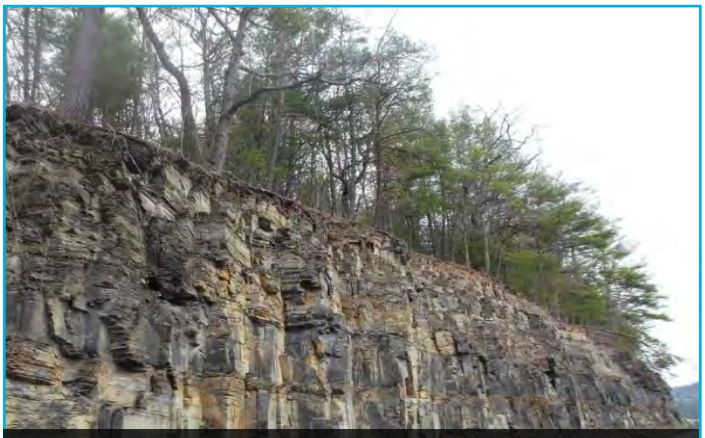
ABOUT DOE'S CARBON STORAGE PROGRAM

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*.



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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