

CSN

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CARBON STORAGE
NEWSLETTER

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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- ▷ PROJECT and BUSINESS DEVELOPMENTS
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CARBON STORAGE PROGRAM
DOCUMENTS and
REFERENCE MATERIALS

- ▷ Carbon Storage Educational Resources
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- ▷ Conference Proceedings
- ▷ Carbon Storage Portfolio
- ▷ Systems Analysis
- ▷ Peer Review
- ▷ Best Practices Manuals
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DOE/NETL HIGHLIGHTS

DOE Invests to Advance Associated Geologic Storage.

The U.S. Department of Energy's (DOE) *Office of Fossil Energy (FE)* selected two projects to receive Federal funding for cost-shared research and development (R&D). Selected under Funding Opportunity Announcement (FOA) DE-FOA-0001829, "*Developing Technologies for Advancement of Associated Geologic Storage in Basinal Geo-Laboratories,*" the projects will address technical research needs and key challenges in advancing associated geologic storage in support of DOE's *Carbon Storage Program*. In addition, the projects will support the development of best practices for commercial implementation of carbon storage technologies. From *energy.gov* on August 28, 2018.

NETL Explores Subsurface Data to Ensure Safe Carbon Storage.

Researchers at DOE's National Energy Technology Laboratory (NETL) are exploring rock pores to better understand the interaction between liquids and gas. The measurements collected are being used to expand scientific knowledge of the subsurface environment to ensure safe and effective carbon storage and enhanced resource recovery. NETL's Reservoir Engineering Team is using SyGlass – imaging technology that enables 3D visualization and analysis of volumetric data at the submillimeter scale – to investigate how carbon dioxide (CO₂) physically reacts with water within rock pores. From *DOE/NETL News Release* on August 15, 2018.



Two views of fractured Marcellus shale rock core colored to reflect mineral density.

DOE Invests in Technologies that Assess Subsurface Stress for Carbon Storage.

DOE's Office of Fossil Energy (FE) has selected five projects to receive Federal funding for cost-shared R&D through FE's *Carbon Storage Program*. The projects, supported through DE-FOA-0001826 "*Developing Technologies to Advance the Understanding of State of Stress and Geomechanical Impacts within the Subsurface,*" will provide tools for measuring, estimating, and understanding underground stress impacts that may occur in carbon storage activities. The NETL-managed projects were selected under two Areas of Interest (AOI): AOI 1 – Tools and Methods for Determining Maximum Principal Stress in the Deep Subsurface, and AOI 2 – Methods for Understanding Impact of Vertical Pressure Migration Due to Injection on State of Subsurface Stress. From *energy.gov* on July 25, 2018.

ANNOUNCEMENTS

NETL Develops Methods and Tools to Estimate Prospective CO₂ Storage in the Subsurface.

NETL has developed a tool to better predict CO₂ storage potential in geologic formations. The CO₂ Storage prospective Resource Estimation Excel aNalysis (CO₂-SCREEN) is an online tool that applies NETL's methods to calculate prospective CO₂ storage resources. CO₂-SCREEN is available on NETL's online collection of capabilities and resources known as the *Energy Data eXchange (EDX)*.

*RGGI Releases Secondary Market Report.*

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO₂ allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "Report on the Secondary Market for RGGI CO₂ Allowances: Second Quarter 2018" addresses the period from April through June 2018.

ANNOUNCEMENTS *(cont.)*

Record-High Supply, Demand on Voluntary Carbon Markets in 2017.

According to a report by Ecosystems Marketplace, the supply of carbon credits on voluntary markets worldwide reached 62.7 million metric tons of CO₂ equivalent (MtCO₂e) in 2017, while 42.8 MtCO₂e offsets were purchased and retired. Both totals are the most on record. The report, titled “*Voluntary Carbon Markets Insights: 2018 Outlook and First-Quarter Trends*,” also examines trends from the first quarter of 2018.

Indian State to Estimate Emissions Trends.

The Indian state of Sikkim will assess its carbon footprint and estimate a trend for emissions. The Sikkim Climate Inventory and Monitoring System studies all sectors in the Himalayan state (e.g., transport, tourism, industry, roads, agriculture) to estimate their carbon emissions. The total is then juxtaposed with the carbon storage by the state’s forests to find out its carbon footprint.

Cities Sign Net-Zero Carbon Declaration.

Nineteen global cities signed a “*Net-Zero Carbon Building Declaration*,” pledging to make “Net-Zero Carbon” buildings by 2030 and upgrade existing buildings to net-zero standards by 2050. The declaration, orchestrated by the *C40 Cities Climate Leadership Group*, builds on a *similar initiative* (in June 2018) from the World Green Building Council that called on businesses to commit to making all new building net zero by 2030.

Reports Assess Economic, Energy, Environmental Implications of Federal Carbon Taxes.

Columbia University’s Center of Global Energy Policy (New York, USA) released four reports that assess the economic, energy, and environmental implications of Federal carbon taxes. The independent, peer reviewed reports use state-of-the-art modeling tools to analyze the implications of an upstream carbon tax that starts at \$14, \$50, and \$73 a ton through a hypothetical first decade of policy implementation (2020s).

PROJECT and BUSINESS DEVELOPMENTS

DOE, India Partner on CCS.

DOE has partnered with an Indian firm to advance the adoption, use, and research of commercial-scale coal gasification and to develop carbon capture, utilization, and storage (CCUS) technologies in India. As part of the agreement, DOE’s National Carbon Capture Center (NCCC) will provide knowledge-sharing relevant to private and state enterprises in India. From *India Post* on September 1, 2018.



Agreement Reached on Alberta Carbon Trunk Line.

Enhance Energy and Wolf Carbon Solutions, Inc., announced a project development and coordination agreement related to the construction and operation of the Alberta Carbon Trunk Line (ACTL). The ACTL pipeline will collect CO₂ from industry and transport it to aging reservoirs throughout central and southern Alberta, Canada, for secure storage and enhanced oil recovery (EOR) projects. Under the agreement, Wolf Carbon Solutions will construct, own, and operate the CO₂ capture and pipeline transportation assets, while Enhance will be the owner and operator of the CO₂ utilization and storage portion of the ACTL project through its EOR operations. Initial CO₂ flow rates are expected to start at 800 metric tons per day in the fourth quarter of 2019 and increase to 4,400 metric tons of CO₂ per day by the end of 2019. From *Wolf Midstream News* on August 2, 2018.

DOE-Funded Project to Use Microbes to Convert CO₂ to Natural Gas.



A DOE-funded, power-to-gas project is using microbes to convert CO₂ directly into renewable natural gas. The research, which is being conducted by Lawrence Livermore National Laboratory (LLNL) in collaboration with Southern California Gas Co. and Stanford University, will leverage previous research conducted by Stanford’s Spormann Laboratory, as well as advances in 3D printer carbon aerogel electrode materials made by LLNL. From *Lawrence Livermore National Laboratory* on August 6, 2018.

China Establishes Large-Scale CCS Facility.

China’s carbon capture and storage (CCS) facility in Jilin has been established as the 18th large-scale CCS facility in the world, reaching a storage capacity of 0.6 million metric tons of CO₂ per year. Located in northeastern China, Jilin CCUS is capturing CO₂ from a natural gas processing plant at the Changling gas field and transporting it by pipeline to onshore injection sites. From *Gas World* on August 13, 2018.

LEGISLATION and POLICY

Bill Promotes CCUS Technology.

A bill that promotes biogas and CCUS technologies to increase biogas production has been introduced into Congress. The *Carbon Utilization Act of 2018* incentivizes the use of CCUS technologies for farmers, ranchers, biotech, and small businesses by broadening U.S. Department of Agriculture (USDA) loan guarantees, rural development loans, and research programs to include CCUS technologies. In addition, the bill promotes collaboration between government agencies and creates education programs that highlight carbon capture technology. From *Biomass Magazine* on August 6, 2018.

Scottish Government Sets 2050 Carbon Target.

The Scottish government unveiled a new proposal to reduce emissions by at least 90 percent by 2050. The Zero Greenhouse Gas Plan is a 10 percent increase over current legislation; while it matches the Government’s first interim target of a 56 percent reduction by 2020, the interim goal of 77 percent by 2030 differs from the government’s 66 percent reduction target. From *The Daily Record* on August 13, 2018.

EMISSIONS TRADING

Québec-California Carbon Market Joint Auction Held.

The California Air Resources Board (CARB) and Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change (MDDELCC) held a joint auction of greenhouse gas (GHG) allowances on August 14, 2018. The auction included a Current Auction of 2016 and 2018 vintage allowances and an Advanced Auction of 2021 vintage allowances. From *Québec's Ministry of Sustainable Development, Environment, and the Fight Against Climate Change* on August 14, 2018.

Singapore To Use Study on Carbon Pricing for Future Tax.

Singapore's National Climate Change Secretariat (NCCS) commissioned a study on carbon pricing in other countries that will be used to help shape any potential carbon taxes in Singapore. The study will quantify the effectiveness of various measures in reducing carbon emissions across different jurisdictions and will also look at direct costs from carbon taxes or emissions trading schemes and indirect costs from compliance. Beginning in 2019, Singapore will begin pricing carbon at \$5/metric ton of emissions through 2023, at which point the rate will be reviewed with the intention of raising it to \$10 to \$15/metric ton by 2030. From *The Straits Times* on August 13, 2018.

Countries Plan Carbon Trading.

Six countries are preparing the first carbon trades under the 2015 United Nations (UN) pact. According to the World Bank Group, the nations are assessing projects to reduce GHGs in exchange for emission credits that can be used to comply with set goals. From *Financial Post* on August 16, 2018.

CLIMATE and SCIENCE NEWS

Lab-Made Mineral Developed to Address CO₂ in the Atmosphere.

Scientists from Trent University in Ontario, Canada, have developed a way to create the mineral magnesite at room temperature, allowing for the possibility to expand the process to industrial scale. If implemented at scale, CO₂ could potentially be stored long-term in the mineral. According to the research, the new method moves the rate of magnesite formation from hundreds to thousands of years in nature to within 72 days in a lab. Based on previous studies, magnesite can remove approximately half its weight in CO₂ from the atmosphere. Thus, by speeding up the process of creating the mineral, magnesite could represent a legitimate resource for removing and storing atmospheric CO₂. From *Forbes* on August 15, 2018.

Underwater Canyon Storing CO₂.

A research expedition to an Irish underwater canyon has revealed a process that removes CO₂ from the atmosphere and stores it under the sea. Led by the University of College Cork (Ireland), the research team built a map of the boundaries and interior of the Porcupine Bank Canyon (where Ireland's continental shelf ends), discovering a process at the edge of the canyon that pulls CO₂ from the atmosphere and stores it under the sea. The rim of the canyon is populated with cold-water corals that thrive on dead plankton, which are built up from carbon extracted from atmospheric CO₂. As the coral consume the dead plankton, they assume the same carbon. Over time, as the coral die, they fall into canyon, essentially storing their CO₂ under the sea. From *Live Science* on August 10, 2018.

RGGI States Announce Results of 41st Auction.

RGGI Inc.



The RGGI-participating states released the results of their 41st auction of CO₂ allowances, in which 13,590,107 CO₂ allowances were sold at a clearing price of \$4.50. Bids ranged from \$2.20 to \$6.20 per allowance. None of the 10 million cost containment reserve (CCR) allowances were sold (CCR is a fixed additional supply of allowances only available for sale if CO₂ allowance prices exceed certain price levels [\$10.25 in 2018]). Auction 41 generated \$61.2 million for reinvestment in strategic programs, such as energy efficiency, renewable energy, and GHG abatement programs. To date, proceeds from all RGGI CO₂ allowance auctions have generated \$3 billion. From *RGGI News Release* on September 7, 2018.

CO₂ Levels May Lead to Nutritional Deficiencies.

Potentially rising levels of atmospheric CO₂ may deplete nutrients in crops, according to a new study. Researchers from Harvard's T.H. Chan School of Public Health studied the effects of CO₂ on crops such as rice and wheat, finding that elevated CO₂ levels could lead to zinc, protein, and iron deficiencies, putting people at risk for anemia and other illnesses. The study, titled "*Impact of anthropogenic CO₂ emissions on global human nutrition*," appeared in the journal *Nature Climate Change*. From *Fortune* on August 27, 2018.

Thawing Permafrost Could Release CO₂.

According to the National Geographic, a field experiment in northern Siberia has revealed that some layers of permafrost are no longer freezing, potentially releasing previously stored CO₂ into the atmosphere. Scientists drilled into the soil in Cherskiy (Russia), located 200 miles north of the Arctic Circle, and found "slushy mud" in areas that should have been frozen. Beneath the soil is the permafrost, which in this region has been frozen for hundreds to thousands of years, and stores billion of tons of CO₂. According to the study, the permafrost may continue to thaw at an accelerated rate without its protective layer of frozen ground. From *Earth.com* on August 23, 2018.

JOURNAL ARTICLES

Understanding key elements in establishing a social license for CCS: An empirical approach.

The following is the Abstract of this article: "This paper presents results of empirical research with the broad aim of exploring societal responses to CO₂ storage, framed around the concept of social license to operate (SLO). [The authors] describe a mixed method approach incorporating stakeholder interviews and focus groups deployed in two case study locations in the UK. The approach helps [the authors] to build up an understanding of the social context in which CCS will be introduced, in terms of the specific local conditions and with reference to the influence of local experiences of other technologies (such as hydraulic fracturing (fracking), for example). This understanding is then used to guide further empirical research, from which [the authors] assess the extent to which an SLO for CCS is emerging. Results show that perceptions of trust and confidence in key institutions to safely manage projects are highly dependent not just on the track record of the [organizations] but are strongly influenced by past experiences with different technologies. While the indications for achieving an SLO for CCS are currently positive, consolidating and maintaining that support depends on the evolving social, industrial and political landscape." **Clair Gough, Rebecca Cunningham, and Sarah Mander**, *International Journal of Greenhouse Gas Control*. (Subscription may be required).

A review of optimization and decision-making models for the planning of CO₂ capture, utilization and storage (CCUS) systems.

The following is the Abstract of this article: "CCUS is considered as one of the key strategies for mitigating climate change. This technology involves CO₂ capture from stationary sources, followed by distribution of CO₂ to different intermediate utilization and/or final storage options. [Carbon dioxide] capture and utilization (CCU) by itself offers resource conservation benefits by displacing the need for extracted CO₂ from natural sources. On the other hand, CCS provides CO₂ emissions reduction by sequestration of captured CO₂ for long-term storage. Combining CCS and CCU can potentially result in valuable symbiosis, but remains debatable due to gaps between the roles of these technologies in energy engineering. Such gaps have resulted in slower commercial deployment of CO₂ capture. Some important issues resulting from these technologies have been addressed in previous studies through process systems engineering (PSE) methodologies, which are able to provide rigorous decision support during CCUS planning. This review paper provides an in-depth discussion of the state-of-the-art of these tools, and also discusses recent developments on integrating CCUS components in large-scale planning. While recent literature in this area reveals the availability of tools for planning and policy-making, further research opportunities are identified through the bibliometric trends that show how CCUS research can develop further." **John Frederick D. Tapia, Jui-Yuan Lee, Raymond E.H. Ooi, Dominic C.Y. Foo, and Raymond R. Tan**, *Sustainable Production and Consumption*. (Subscription may be required)

Element mobilization and immobilization from carbonate rocks between CO₂ storage reservoirs and the overlying aquifers during a potential CO₂ leakage.

The following is the Abstract of this article: "Despite the numerous studies on changes within the reservoir following CO₂ injection and the effects of CO₂ release into overlying aquifers, little or no literature is available on the effect of CO₂ release on rock between the storage reservoirs and subsurface. This is important, because the interactions that occur in this zone between the CO₂ storage reservoir and the subsurface may have a significant impact on risk analysis for CO₂ storage projects. To address this knowledge gap, relevant rock materials, temperatures and pressures were used to study mineralogical and elemental changes in this intermediate zone. After rocks reacted with CO₂-acidified 0.01 M NaCl, liquid analysis showed an increase of major elements (e.g., Ca and Mg) and variable concentrations of potential contaminants (e.g., Sr and Ba); lower aqueous concentrations of these elements were observed in N₂ control experiments, likely due to differences in pH between the CO₂ and N₂ experiments. In experiments with As/Cd and/or organic spikes, representing potential contaminants in the CO₂ plume originating in the storage reservoir, most or all of these contaminants were removed from the aqueous phase. SEM and Mössbauer spectroscopy results showed the formation of new minerals and Fe oxides in some CO₂-reacted samples, indicating potential for contaminant removal through mineral incorporation or adsorption onto Fe oxides. These experiments show the interactions between the CO₂-laden plume and the rock between storage reservoirs and overlying aquifers have the potential to affect the level of risk to overlying groundwater, and should be considered during site selection and risk evaluation." **Amanda R. Lawter, Nikolla P. Qafoku, R. Matthew Asmussen, Ravi K. Kukkadapu, Odeta Qafoku, Diana H. Bacon, and Christopher F. Brown**, *Chemosphere*. (Subscription may be required).

Metamodeling-based approach for risk assessment and cost estimation: Application to geological carbon sequestration planning.

The following is the Abstract of this article: "CCS is being evaluated globally as a geoengineering measure for significantly reducing greenhouse emission. However, long-term liability associated with potential leakage from these geologic repositories is perceived as a main barrier of entry to site operators. Risk quantification and impact assessment help CCS operators to screen candidate sites for suitability of CO₂ storage. Leakage risks are highly site dependent, and a quantitative understanding and categorization of these risks can only be made possible through broad participation and deliberation of stakeholders, with the use of site-specific, process-based models as the decision basis. Online decision making, however, requires that scenarios be run in real time. In this work, a Python based, Leakage Assessment and Cost Estimation (PyLACE) web application was developed for quantifying financial risks associated with potential leakage from geologic carbon sequestration sites. PyLACE aims to assist a collaborative, analytic-deliberative decision making processes by automating metamodel creation, knowledge sharing, and online collaboration. In PyLACE, metamodeling, which is a process of developing faster-to-run surrogates of process-level models, is enabled using a special stochastic response surface method and the Gaussian process regression. Both methods allow consideration of model parameter uncertainties and the use of that information to generate confidence intervals on model outputs. Training of the metamodels is delegated to a high performance computing cluster and is orchestrated by a set of asynchronous job scheduling tools for job submission and result retrieval. As a case study, workflow and main features of PyLACE are demonstrated using a multilayer, carbon storage model." **Alexander Y. Sun, Hoonyoung Jeong, Ana González-Nicolás, and Thomas C. Templeton**, *Computers & Geosciences*. (Subscription may be required).

JOURNAL ARTICLES *(cont.)*

An optimization model for carbon capture & storage/utilization vs. carbon trading: A case study of fossil-fired power plants in Turkey.

The following is the Abstract of this article: “[The authors] consider fossil-fired power plants that operate in an environment where a cap and trade system is in operation. These plants need to choose between CCS, CCU, or carbon trading in order to obey emissions limits enforced by the government. [The authors] develop a mixed-integer programming model that decides on the capacities of carbon capture units, if it is optimal to install them, the transportation network that needs to be built for transporting the carbon captured, and the locations of storage sites, if they are decided to be built. Main restrictions on the system are the minimum and maximum capacities of the different parts of the pipeline network, the amount of carbon that can be sold to companies for utilization, and the capacities on the storage sites. Under these restrictions, the model aims to minimize the net present value of the sum of the costs associated with installation and operation of the carbon capture unit and the transportation of carbon, the storage cost in case of CCS, the cost (or revenue) that results from the emissions trading system, and finally the negative revenue of selling the carbon to other entities for utilization. [The authors] implement the model on General Algebraic Modeling System (GAMS) by using data associated with two coal-fired power plants located in different regions of Turkey. [The authors] choose EOR as the process in which carbon would be utilized. The results show that CCU is preferable to CCS as long as there is sufficient demand in the EOR market. The distance between the location of emission and location of utilization/storage, and the capacity limits on the pipes are an important factor in deciding between carbon capture and carbon trading. At carbon prices over \$15/ton, carbon capture becomes preferable to carbon trading. These results show that as far as Turkey is concerned, CCU should be prioritized as a means of reducing nation-wide carbon emissions in an environmentally and economically rewarding manner. The model developed in this study is generic, and it can be applied to any industry at any location, as long as the required inputs are available.” **Semra Ağralı, Fehmi Görkem Uçtuğ, and Burçin Atılgan Türkmen**, *Journal of Environmental Management*. (Subscription may be required.)

Diffusive leakage of brine from aquifers during CO₂ geological storage.

The following is the Abstract of this article: “The area of investigation in this study is designed around an improved understanding of fundamentals of the diffusive leakage of brine from a storage aquifer into overlying and underlying low permeability layers during geosequestration of CO₂ through development of a theoretical model. Here, [the authors] consider a two-dimensional domain in cylindrical coordinates, comprised of an aquifer and an overburden, where the interaction between the two media is handled by imposing the continuities of pressures and fluid fluxes at the aquifer-overburden interface. This coupled problem is solved by successive implementation of the Laplace and finite Hankel transforms. The developed solutions can be used to analyze diffusive leakage of brine from the aquifer into overburden and generate type curves for average pressures in the aquifer and overburden during injection and post injection periods. The results show that the leakage rate at early times is scaled with $t^{1/2}$ while it remains constant at late times. It is also shown that the average pressure in the aquifer is scaled with t for short and long times. Moreover, the average pressure in the overburden is scaled with t at late times while it is scaled with $t^{3/2}$ at early times. In addition, the results reveal that factors affecting diffusive leakage rate through intact overburden during CO₂ storage are, in decreasing order of significance, thickness of overburden, thickness of aquifer, aquifer to overburden permeability ratio, and aquifer to overburden porosity ratio. However, thickness of aquifer has minimal effect on diffusive leakage of brine within post injection period. To evaluate the theoretical model, case studies for two potential sites in United Kingdom, one in Lincolnshire and the other one in the Firth of Forth, are conducted. The field studies show

that the diffusive leakage from the aquifer into the overburden diminishes ~40 years after the injection has ceased for Lincolnshire while it stops after ~12 years for Firth of Forth. The average amount of the brine leaked from the aquifers per standard cubic meter (Sm³) of the injected CO₂ through diffusive leakage was found to be 6.28×10^{-4} m³ of brine (or 0.330 kg of brine/kg of CO₂) over ~70 years for Lincolnshire and 4.59×10^{-4} m³ of brine (or 0.242 kg of brine/kg of CO₂) over ~42 years for Firth of Forth.” **Morteza Dejam and Hassan Hassanzadeh**, *Advances in Water Resources*.

The contribution of China's bilateral trade to global carbon emissions in the context of globalization.

The following is the Abstract of this article: “Controlling and reducing carbon emissions for mitigation of climate change are a global common consensus. It is imperative for legitimately and effectively ascertaining responsibilities among countries to study CO₂ emissions embodied in the international trade. As the largest exporter and the second largest importer in the world, the large amount of CO₂ emissions embodied in China's bilateral trade have a significant impact on China's and global carbon emissions. Based on the single region input-output tables using the non-competitive imports assumption, this study estimated CO₂ emissions embodied in China's bilateral trade with 219 countries/regions over the period of 2000–2014, and analyzed the contribution of China's bilateral trade to global carbon emissions under the assumption of non-trade scenario. The results show that, CO₂ emissions embodied in China's exports and imports in 2014 were 2561.1 Mt and 1209.9 Mt respectively, and CO₂ emissions embodied in exports were higher than those in imports throughout the period. It is indicated that China had produced a large amount of CO₂ emissions for other countries through the international trade. And meanwhile, China avoided a large amount of CO₂ emissions with the rapid growth of imports. And furthermore, the net CO₂ emissions embodied in China's bilateral trade had been declining since 2011. At last, China's bilateral trade had extremely little impact on global carbon emissions. It is concluded that there is a possibility of reducing global carbon emissions based on the results of China's bilateral trade with countries along the routes of Silk Road Economic Belt and 21st-Century Maritime Silk Road.” **Tao Ding, Yadong Ning, and Yan Zhang**, *Structural Change and Economic Dynamics*. (Subscription may be required.)

Technology-adjusted national carbon accounting for a greener trade pattern.

The following is the Abstract of this article: “Crediting green trade patterns is essential for effective national carbon accounting. Neither production- nor consumption-based accounting satisfies this condition. Thus, Kander et al. proposed a technology-adjusted consumption-based carbon accounting method that focuses on interregional differences in sectoral carbon intensity. The intermediate input structure is also closely related to the production technology level. Therefore, this study recommends a new technology-adjusted consumption-based carbon accounting framework that distinguishes between direct and cumulative exports, forward and backward industrial linkages, and different trade patterns. Based on the consideration that production-based accounting will remain the core indicator for regional emissions in the near future, this study proposes a technology-adjusted production-based accounting framework. The empirical study is based on the World Input-Output Database, and the results indicate that technology-adjusted carbon accounting will redraw the global emissions map if the intermediate input linkage is considered. The technology-adjusted carbon accounting method satisfies the conditions of additivity, sensitivity, monotonicity, and scale invariance, through proper selection of the world average emissions multipliers.” **Zengkai Zhang**, *Energy Economics*. (Subscription may be required.)

REPORTS and OTHER PUBLICATIONS

History, Sampling, Porosity and Permeability Testing of Salem Limestone, Oriskany Sandstone and Marcellus Shale.

The following is the Abstract of this NETL document: "This report describes measurements of the fluid storage and transmission properties of Salem Limestone, Oriskany Sandstone, and Marcellus Shale. Test results are assessed in the context of confining stress applied to the sample and sample preparation procedures. For perspective, a general geologic description is provided for each rock type. The current regional stress state was also considered in terms of the test specimens' propensity for preferential fracturing. As part of the test program, two different methods for sample testing were used depending on rock type. Combined permeability and porosity tests were performed on small, cylindrical plug samples one inch (2.54 cm) in diameter by at least two inches (5 cm) in length. Helium gas was used in testing for both the Salem Limestone and Oriskany Sandstone, whereas nitrogen gas was used for Marcellus Shale. Porosity to gas and high-pressure, pulse-decay gas permeability were evaluated on all samples at four net confining pressure steps: 500 psi (3.4 MPa), 1,000 psi (6.9 MPa), 1,500 psi (10.3 MPa), and 2,000 psi (13.8 MPa). Test results for each rock type were generally uniform. Under conditions of increasing net confining pressure, the average matrix porosity of the Salem Limestone ranges from 7.62% to 7.83%, and matrix permeability ranges from 1.81 to 1.87 mD. The Oriskany Sandstone's average matrix porosity ranges from 6.05% to 6.43% and matrix permeability ranges from 4.8 to 9.1 mD. The Marcellus Shale plug samples were cut in two different directions; in one group the cylinder axis was cut perpendicular to the bedding plane and the other group was cut parallel to the bedding plane. Porosity measured in the group of perpendicular samples ranges from 4.34% to 7.72% and permeability ranges from null to 0.5 mD. Porosity of the parallel sample group ranges from 0.54% to 1.32% and permeability readings from 0.02 to 1.12 mD. Interpretation of the results concluded that porosity and permeability are relatively insensitive to the sample preparation methods used in this study, and the recorded values are reasonable when compared with published data or other representative samples."



Oriskany Sandstone outcrop in U.S. Silica quarry near Berkeley Springs, West Virginia. Photo Credit: Daniel Soeder.

Risk Reduction of CO₂ Storage with Stochastic Simulations.

The following is from the Executive Summary of this NETL Technical Report Series document: "The purpose of this project was to create an efficient and flexible tool based on principal component analysis (PCA) for a generation of differentiable realizations of porosity and permeability fields. Of particular interest were data which had significant connectivity between patches of the same rock type, which is called 'binary.' The efficiency requirement needed a so-called kernel PCA, and the binary images were found with the method called optimization based PCA (OPCA) for which interpretation is provided. The ability to honor given data at particular locations is also incorporated. The tool worked very well and efficiently for two dimensional (2-D) simulations. Furthermore, the tool was applied to a three-dimensional (3-D) dataset and determined that conditioning can be used to maintain the connectivity between vertical layers. Since kernel-based tools need snapshots, several tools that generate snapshots were also created. These tools are based on PCA or on novel filtering techniques. The next steps for this project include new techniques to combine PCA with upscaling, testing models with more data, expanding OPCA and filtering, and extending techniques to work more appropriately with non-Gaussian data."

An independent assessment of the UK's Clean Growth Strategy: From ambition to action.

The following is from the Executive Summary of this UK Committee on Climate Change document: "Under the Climate Change Act, the Government is required to publish a set of policies and proposals that will enable the legally-binding carbon budgets, on track to the 2050 target, to be met. The Clean Growth Strategy, published in October 2017, presents the Government's plans. In this report [the authors] set out [their] assessment of that Strategy. [The authors'] key conclusions are: [1] The Government has made a strong commitment to achieving the UK's climate targets. It has placed the low-carbon economy at the heart of the UK's industrial strategy, framing the Clean Growth Strategy as a positive contribution to the economy (rather than a burden to be [minimized]). It has committed to a position of international leadership. There is great interest internationally in the model provided by the UK Climate Change Act. This makes it all the more important to have plans in place to meet the targets through domestic actions – this is the basis on which the carbon budgets were set. [2] Policies and proposals need to be firmed up. The Strategy includes some new policies to reduce emissions. In other areas – covering the majority of the emissions reductions in the Strategy – it sets out some ambitious new proposals, but policy to deliver those aspirations has not yet been worked up. Development of policy in these areas (e.g. upgrading as many homes as possible to Energy Performance Certificate Band C by 2035, improved standards of new buildings, phasing out the sale of new conventional petrol and diesel cars and vans by 2040) will need to progress urgently. [3] Gaps to meeting the fourth and fifth carbon budgets remain. These must be closed. Whilst the Strategy sets out a '2032 Pathway' for sectoral emissions that would just meet the fifth carbon budget, there is no clear link to the policies, proposals and intentions that the Strategy presents. [The authors'] assessment of the policies and proposals set out in the Strategy indicates that, even if these deliver in full, there remain gaps of around 10-65 MtCO₂e to meeting both the fourth and fifth carbon budgets on the basis of central projections."

ABOUT DOE'S CARBON STORAGE PROGRAM

The **Carbon Storage Program** advances the development and validation of technologies that enable safe, cost-effective, permanent geologic storage of CO₂. The Carbon Storage Program also supports the development of best practices for CCS that will benefit projects implementing CCS at a commercial scale, such as those being performed under NETL's Clean Coal Power Initiative and Industrial Carbon Capture and Storage Programs. The technologies being developed and the small- and large-scale injection projects conducted through this program will be used to benefit the existing and future fleet of fossil fuel power-generating facilities by developing tools to increase our understanding of the behavior of CO₂ in the subsurface and identifying the geologic reservoirs appropriate for 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 are available via the [Carbon Storage Program Publications webpage](#).

Get answers to your carbon capture and storage questions at NETL's [Frequently Asked Questions webpage](#).

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.



National Energy Technology Laboratory

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