CSN CARBON STORAGE NEWSLETTER

JUNE 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:

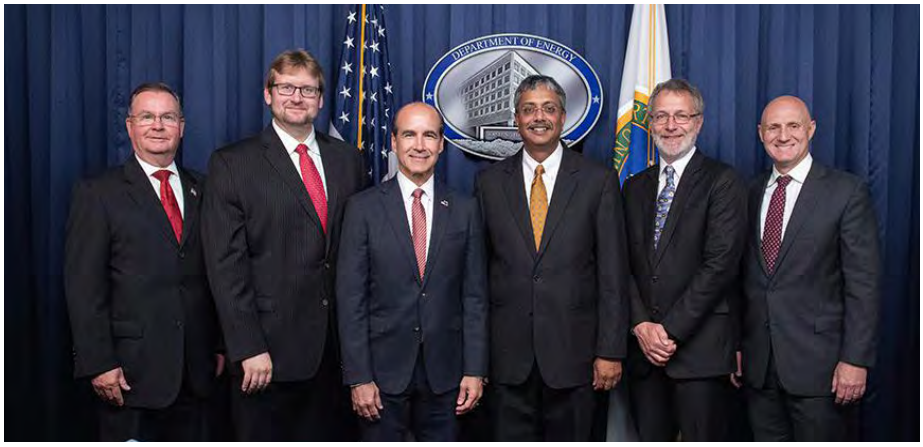
CARBON STORAGE PROGRAM DOCUMENTS and REFERENCE MATERIALS

NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE/NETL HIGHLIGHTS

NETL Signs Partnership with ExxonMobil and NREL.

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) signed a research and development (R&D) partnership with ExxonMobil and the *National Renewable Energy Laboratory (NREL)*. Per the *cooperative research and development agreement (CRADA)*, ExxonMobil is investing up to $100 million over 10 years for the R&D of advanced lower-emissions technologies. The agreement will support research and collaboration in bringing biofuels and carbon capture and storage (CCS) to commercial scale. In addition to developing technologies related to energy efficiency and greenhouse gas (GHG) mitigation, the joint research will also focus on reducing emissions from fuel and petrochemicals production; stimulate collaborative projects among ExxonMobil, NREL, and NETL; and facilitate work with other national laboratories, such as the Idaho National Laboratory. From *National Energy Technology Laboratory* on May 8, 2019.



ANNOUNCEMENTS

DOE/NETL's Carbon Capture, Utilization, Storage, and Oil and Natural Gas Programs Annual Meeting.

Registration is currently open for DOE/NETL's "Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting," to be held August 26–30, 2019, at the David L. Lawrence Convention Center in Pittsburgh, Pennsylvania, USA.

EU Plans Satellite Fleet to Monitor CO_2.

The European Space Agency announced plans to launch a fleet of satellites to create a global observation system capable of monitoring carbon dioxide (CO_2) emissions. The fleet is expected to launch in 2025, and the data will be used to inform the United Nation's *global stocktake* of GHGs three years later.

New International System for Classifying CO_2 Storage Resources.

The Society of Petroleum Engineers adopted and approved the *CO_2 Storage Resources Management System (SRMS)*, which uses common terminology, instinctive criteria, and clear definitions to classify storage resources. The full guidelines of the CO_2 SRMS are scheduled for publication later this year.

ANNOUNCEMENTS *(cont.)*

Energy Companies Sign MOU to Explore CCUS.

Drax Group, Equinor, and National Grid Ventures signed a Memorandum of Understanding (MOU) that includes collaboration on the potential construction of a large-scale carbon capture, utilization, and storage (CCUS) network in the United Kingdom (U.K.) Humber region in the mid-2020s. In addition, work under the MOU will explore the opportunity to scale-up the bioenergy CCS pilot project at the Drax Power Station.

CCS Facility Back Online After Scheduled Maintenance.

Unit 3 of the CCS facility at the Boundary Dam Power Station (located near Estevan, Saskatchewan, Canada) is back online after a scheduled two-month shutdown. In addition to calibration testing of the sensors, the boilers were inspected and work on auxiliary equipment was performed.

Report Studies Role of CCUS in California.

The Energy Futures Initiative published the findings of a study that assessed the impact of CCUS on California's (USA) economy. The study, titled "*Optionality, Flexibility, & Innovation: Pathways for Deep Decarbonization in California*," identified policies and technologies that currently contribute to the state's ability to meet its low-carbon energy goals.

PROJECT and BUSINESS DEVELOPMENTS

Quest CCS Facility Reaches Milestone.

Shell's Quest CCS facility in Alberta, Canada, has captured and stored 4 million metric tons of CO_2, according to officials. The designs, certain intellectual property, and data from Quest were made publicly available in order to benefit future CCS projects. The Quest CCS facility captures and stores approximately one-third of the CO_2 emissions from the Shell-operated Scotford Upgrader near Fort Saskatchewan, Alberta. The CO_2 is transported through a pipeline and stored underground. From *Shell News Release* on May 23, 2019.

CCS Project Gains Funding.

A CCS venture in Indiana (USA) secured funding to develop a CCS project capable of storing up to 1.75 million metric tons of CO_2. The Wabash Valley Resources (WVR) project is expected to capture nearly 100% of the plant's CO_2 and store it in the Mount Simon Sandstone approximately 7,000 feet underground. According to MVR officials, the company will utilize the investment from the Oil and Gas Climate Initiative to produce ammonia with a near-zero carbon footprint. From *Gasworld* on May 21, 2019.

Engineering Begins on DAC and Storage Plant.

An international oil and gas exploration and production company and a Canadian-based clean energy company will begin engineering and design of a direct-air capture (DAC) and storage facility. Oxy Low Ventures, LLC (OLCV) and Carbon Engineering Ltd. (CE) are evaluating a facility, to be located in the Permian Basin, that will be capable of capturing 500 metric kilotons of atmospheric CO_2 per year for use in enhanced oil recovery operations. Construction is expected to begin in 2021 pending initial approval by OLCV and CE, with the plant becoming operational within approximately two years. From *Occidental News Release* on May 21, 2019.

North Sea Gas Fields To Be Used for CO_2 Storage.

The Rotterdam, Antwerp, and Ghent ports in Europe will be used to capture and store approximately 10 million metric tons of CO_2 emissions under the North Sea. According to the Dutch government, the ports will be used in the transport of the CO_2 into a porous reservoir of sandstone approximately two miles below the seabed. Plans call to begin construction of the CO_2 network by 2026, with the project to be completed by 2030. A further expansion is expected after 2030. From *The Guardian* on May 9, 2019.

China Implements CCS Project.

China implemented a CCS demonstration project in saline aquifers in Ordos, North China's Inner Mongolia Autonomous Region. The demonstration project was launched in 2010 and had completed carbon capture, purification, pressurization, and drilling work by the end of that year. Carbon dioxide produced by coal liquefaction will be liquefied after it is captured and transported to the operation area by special tankers, where it will be injected into saline aquifers at depths ranging from approximately 4,900 to 8,200 feet underground for storage. From *Chinanews.com* on May 9, 2019.

Consortium Launches Industrial-Scale CCS Project.

A consortium of European stakeholders launched a project to demonstrate CO_2 capture from industrial activities as part of a study dedicated to the development of the future European Dunkirk North Sea CCS cluster. The project is part of Horizon 2020, the European Union's (EU) research and innovation project. The Dunkirk North Sea cluster, which is expected to be capable of capturing, packing, transporting, and storing 10 million metric tons of CO_2 per year, is expected to be operational by 2035. From *Oil & Gas Journal* on May 28, 2019.

Partnership to Demonstrate CCUS.

Inventys *announced a partnership* to develop and demonstrate a full-cycle solution to capture and reuse CO_2 from a cement plant. Project CO2MENT, being conducted in partnership with Lafarge Canada Inc., LafargeHolcim, and Total, will evaluate the potential for a new business model for supplying post-combustion CO_2 to the existing CO_2 market, as well as assessing the economic feasibility of newly developed CO_2 utilization technologies. From *Carbon Capture Journal* on May 29, 2019.

LEGISLATION and POLICY

Newly Introduced Legislation Promotes Carbon Storage.

Two U.S. Senators introduced legislation that promotes more carbon storage. In addition, *the bill* allows for the use of biomass from certain federal lands needing ecological restoration to develop renewable fuels to promote "healthier forests" and "cleaner transportation fuels." A one-pager of the bill is *available online*. From *U.S. Senator Ron Wyden Press Release* on May 22, 2019.

South Africa Carbon Tax Signed into Law.

The South African President signed a carbon tax into law, effectively adopting a carbon-pricing program for the country. The tax will be introduced in phases: Phase I will begin in December 2022, taxing carbon at an approximate rate of $8.35/per ton of CO_2 equivalent. The South African government will assess the impact of the tax and the nation's progress toward emissions goals before the second phase of the policy, which will start in 2023 and end in 2030. From *National Public Radio* on May 26, 2019.

EMISSIONS TRADING

Oregon Legislature Approves Cap-and-Trade Bill.

Oregon (USA) Legislature's Joint Carbon Reduction Committee approved a cap-and-trade bill that could put a progressively declining cap on GHGs across the state. Under the proposal (H.B. 2020), Oregon's largest emitters would be required to purchase carbon credits for each ton of emissions they release annually. Before becoming law, the bill goes to the Oregon Joint Ways and Means Committee before heading to the House floor for a vote. From *Statesman Journal* on May 17, 2019.

RGGI Secondary Market Report Made Available.

The independent market monitor for the Regional Greenhouse Gas Initiative (RGGI) released a report containing information on the secondary market for RGGI CO_2 allowances, including future prices, market activity, and allowance holdings. Potomac Economics' "*Report on the Secondary Market for RGGI CO_2 Allowances: First Quarter 2019*" addresses the period from January through March 2019. The report is part of Potomac's ongoing monitoring of the RGGI auctions and the secondary markets where CO_2 allowances are traded, and is based on data reported to the U.S. Commodity Futures Trading Commission and the Intercontinental Exchange, as well as other data. From *RGGI News Release* on May 9, 2019.

RGGI Inc.

SCIENCE NEWS

Scientists Study Seaweed's Ability to Store CO_2.

New research measured the importance of the coastal ocean as a potential global carbon sink and the relevance of macroalgae (seaweed) in storing CO_2. Led by scientists from the U.K.'s Plymouth Marine Laboratory, the study assessed how much of the organic macroalgal CO_2 was stored in the sediment. In addition, the study, which was part of the Natural Environmental Research Council and the U.K.'s Department for the Environment, Food, and Rural Affairs-funded Marine Ecosystems Research Programme, highlighted the importance of macroalgae in supporting seabed organisms through the winter months when other food resources were low, as well as how they contribute to carbon storage. From *Plymouth Marine Laboratory* on May 23, 2019.

New Process Converts CO_2 Into Useful Products.

Researchers from the University of Toronto (U of T) engineering department developed a new electrochemical path to convert CO_2 into valuable products. Currently, implementing DAC technology to convert CO_2 requires temperatures above 900°C; the U of T's alternative process applies an electrolyzer to drive chemical reactions, skipping the heating step. From *Carbon Capture Journal* on June 3, 2019.

Patent Awarded to Store CO_2 During Crop Harvesting.

A Newton, Kansas (USA) company received a patent from the U.S. Patent Office for a system that will enable farmers to permanently store CO_2 in the soil. The new TRIBINE Harvester system will be used during grain harvesting and, according to officials, has the potential to store up to 1.4 tons of CO_2 per acre in the soil when combined with other crop practices. From *High Plains Journal* on May 29, 2019.

JOURNAL ARTICLES

420,000 year assessment of fault leakage rates shows geological carbon storage is secure.

The following is from the abstract of this article: "… CCS can directly reduce industrial CO_2 emissions and is essential for the retention of CO_2 extracted from the atmosphere. To be effective… CO_2 must be securely retained for 10,000 years (10 ka) with a leakage rate of below 0.01% per year of the total amount of CO_2 injected. Migration of CO_2 back to the atmosphere via leakage through geological faults is a potential high impact risk to CO_2 storage integrity. Here, [the authors] calculate for the first time natural leakage rates from a 420 ka paleo-record of CO_2 leakage above a naturally occurring, faulted, CO_2 reservoir in Arizona, USA. Surface travertine ($CaCO_3$) deposits provide evidence of vertical CO_2 leakage linked to known faults. U-Th dating of travertine deposits shows leakage varies along a single fault and that individual seeps have lifespans of up to 200 ka. Whilst the total volumes of CO_2 required to form the travertine deposits are high, time-averaged leakage equates to a linear rate of less than 0.01%/yr. Hence, even this natural geological storage site, which would be deemed to be of too high risk to be selected for engineered geologic storage, is adequate to store CO_2 for climate mitigation purposes." **Johannes M. Miocic, Stuart M. V. Gilfillan, Norbert Frank, Andrea Schroeder-Ritzrau, Neil M. Burnside, and R. Stuart Haszeldine,** *Scientific Reports.* (Subscription may be required.)

Establishing rates of carbon sequestration in mangroves from an earthquake uplift event.

The following is the abstract of this article: "[The authors] assessed the carbon stocks (CS) in mangroves that developed after a magnitude 7.1 earthquake in Silonay, Oriental Mindoro, south Luzon, The Philippines in November 1994. The earthquake resulted in a 50 cm uplift of sediment that provided new habitat within the upper intertidal zone which mangroves colonized (from less than 2 ha pre-earthquake to the current 45 ha, 23 years post-earthquake). The site provided an opportunity for a novel assessment of the rate of carbon sequestration in recently established mangroves. The carbon stock was measured in above-ground, below-ground and sediment compartments over a seaward to landward transect. Results showed a mean carbon stock of 549 ± 30 Mg C ha^{-1} (of which 13% was from the above-ground biomass, 5% from the below-ground biomass and 82% from the sediments). There was high carbon sequestration at a 40 cm depth that can be inferred attributable to the developed mangroves. The calculated rate of C sequestration (over 23 years post-earthquake) was 10.2 ± 0.7 Mg C ha^{-1} yr^{-1} and is comparable to rates reported from mangroves recovering from forest clearing. The rates [the authors] present here from newly developed mangroves contributes to calibrating estimates of total CS from restored mangroves (of different developmental stages) and in mangroves that are affected by disturbances." **Severino G. Salmo, Vanessa Malapit, Maria Carmela A. Garcia, and Homer M. Pagkalinawan,** *Biology Letters.* (Subscription may be required.)

Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany.

The following is from the abstract of this article: "…This research takes a social science perspective and investigates the awareness, general perception and acceptance of CCS in comparison to [carbon capture and utilization (CCU)] by applying an online survey in Germany (2017, n = 509). In addition, the risk perception of single steps in the CCU/CCS process chains was explored (CCS: CO_2-capturing, CO_2-transport, CO_2-storage; CCU: CO_2-capturing, CO_2-transport, temporary CO_2-storage, production, product usage, product disposal). Significant differences were found for the perception and acceptance of CCS and CCU: while both technologies were generally accepted, CCU was perceived significantly more positively than CCS. CCS-acceptance was negatively influenced by storage and transport risks; for CCU, disposal and product risks decreased acceptance. [The authors'] results contribute to the development of communication concepts for a successful implementation of CO_2-based technologies by considering public concerns." **K. Arning, J. Offermann-van Heek, A. Linzenich, A. Kaetelhoen, A. Sternberg, A. Bardow, and M. Ziefle,** *Energy Policy.* (Subscription may be required.)

A Review on Public Understanding of Carbon Dioxide Capture and Storage (CCS) in South Korea.

The following is the abstract of this article: "Since the Paris Agreement, member countries have set national goals clearly stated in the 'Intended Nationally Determined Contributions' (INDC) to reduce the intended amount of carbon dioxide. In many other countries, the government has invested in national R&D to promote cleaner energy and Carbon Capture and Storage (CCS) projects that is considered as one of the most pragmatic means to achieve the set mitigation target in a national scale. In some country, the control and management of CO_2 has been implemented in new technical systems called CO_2 smart grids. However, along with continual CCS R&D, laws and regulatory interventions supporting its technical pillars should mutually encompass its development. Without public understanding, technological development cannot be fully implemented by the involved public and private entities permitting to attain the set mitigation targets. In previous research, only few studies on public understanding have linked its policies to the actual valid legislation. This article therefore aims to review the overall public understanding conditions on CCS in Korea and to systematically outline public understanding in actual Acts as well as in the Draft of Korean integrated CCS Act. Finally, this research tried to imply regulatory intervention guidelines on public understanding of CCS along with possible improvement for the next revision of the Korean CCS Act." **Moonhyun Koh, Bola Ju, and Woongchan Seo,** *Energy Procedia.* (Subscription may be required.)

The economics of CCS: Why have CCS technologies not had an international breakthrough?

The following is the abstract of this article: "Eleven years on since the United Nations' Intergovernmental Panel on Climate Change was awarded the Nobel Peace Prize in recognition of its efforts in combating climate change, fossil fuels remain the most dominant global energy source. As the total replacement of fossil fuel energy is not expected to take place immediately in the near future, the International Energy Agency has repeatedly declared carbon capture and sequestration (CCS) as a key technology for mitigating climate change. However, CCS lacks the scale required for substantial reduction in carbon dioxide emissions from fossil fuel power generation. Even though CCS is one of the key technologies for mitigating climate change, why has this technology not had an international breakthrough? To shed light on this question, this paper employs a simple model of energy generation, scrutinizes the economic drivers of CCS based on the analytical results, and discusses the possible obstacles that can prevent a widespread rollout of the technology. This is followed by a state-of-the-art in literature pertaining to the economics of CCS, and a discussion that points to a dichotomy between the economic theory and reality. The study concludes with some policy suggestions and directions for future research." **Tunç Durmaz,** *Renewable and Sustainable Energy Reviews.* (Subscription may be required.)

JOURNAL ARTICLES *(cont.)*

CO_2-enhanced oil recovery and CO_2 capture and storage: An environmental economic trade-off analysis.

The following is the abstract of this article: "CO_2 enhanced oil recovery can play a significant role in stimulating carbon capture and storage because of additional oil revenues generated. However, it also leads to additional greenhouse gas emissions. [The authors] estimate the global warming potential of different CO_2 capture scenarios with and without enhanced oil recovery. During a 10 year period in which oil and electricity are produced without CO_2 being captured, the global warming potential is 11 $MtCO_2$ equivalents. [The authors] show that if CO_2 is captured and used for 15 years of enhanced oil recovery, the global warming potential decreases to 3.4 $MtCO_2$ equivalents. This level is 100% higher compared to the scenario in which the captured CO_2 would be stored in an offshore aquifer instead. If the capture of CO_2 is stopped when the oil reservoir is depleted, the global warming potential resulting from 10 years electricity production is 6 $MtCO_2$ equivalents. However, if CO_2 is stored in the depleted reservoir, the global warming potential is six times lower during that period. Electricity production and oil refining are the main contributors to the global warming potential. The net present value analysis indicates that for CO_2 prices lower than or equal to 15 €/t and oil prices greater than or equal to 115 €/t, it is most profitable to capture CO_2 for enhanced oil recovery only. Because of the low CO_2 price considered, large incomes from oil production are required to stimulate CO_2 capture. The environmental economic trade-off analysis shows that if CO_2-enhanced oil recovery is followed by CO_2 capture and storage, costs increase, but the net present value remains positive and the global warming potential is reduced. Authorities could use these outcomes to support the development of economic mechanisms for shared investments in CO_2 capture installations and to mandate both oil producer and large CO_2 emitting firms to store CO_2 in depleted oil fields." **Pieter Roefs, Michele Moretti, Kris Welkenhuysen, Kris Piessens, and Tine Compernolle,** *Journal of Environmental Management*. (Subscription may be required.)

Anatomy of Emissions Trading Systems: What is the EU ETS?

The following is the abstract of this article: "An anatomy identifies four main components of actual or proposed Emissions Trading Systems (ETS): (1) Pursued policy goals with the ETS instrument; (2) Public authority allocations of permits to the regulated participants; (3) Carbon emissions price levels; and (4) Participants' abatement expenses dependent on the ready availability of affordable abatement techniques or of low-carbon innovation opportunities. These components cover a range of options. A different assemblage of options delivers different ETS exemplars. Two main exemplars are identified. The actual EU ETS is highly successful in meeting the goal of low financial burdens on EU industry, thereby precluding carbon leakage. The other exemplar opts for high carbon emissions prices in the EU to induce industrial innovations towards a low-carbon economy. Incumbent industrial interests oppose this exemplar. Contrary to current policy discourse and to wishful proposals, both ETS exemplars cannot co-exist. ETS anatomy offers insight and structure for thorough analysis and evaluation of existing ETS, resulting in context–specific and appropriate designs of the carbon trading systems." **Aviel Verbruggen, Erik Laes, and Edwin Woerdman,** *Environmental Science & Policy.* (Subscription may be required.)

Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures.

The following is the abstract of this article: "Considering the cap-and-trade regulation and manufacturer's two types of strategies: adopting green technology (GT) and purchasing carbon credits (PC), [the authors] develop game models to investigate the manufacturer's production and emission abatement decisions as well as the governmental emission cap regulation in a supply chain with three power structures (Manufacturer Stackelberg (MS), Retail Stackelberg (RS) and Vertical Nash (VN)), and analyze how a manufacturer's low carbon strategy changes with the various governmental cap under the three supply chain power structures. The main conclusions are as follows. If the manufacturer adopts green technology strategy, supply chain power structure will not affect social welfare. High consumer's low-carbon preference is more beneficial to the social welfare, the government should advocate the consumer's preference for low carbon product. If the manufacturer purchases carbon credits, the government under the power structure of VN will gain the most social welfare." **Suyong Zhang, Chuanxu Wang, Chao Yu, and Yangjun Ren,** *Computers & Industrial Engineering.* (Subscription may be required.)

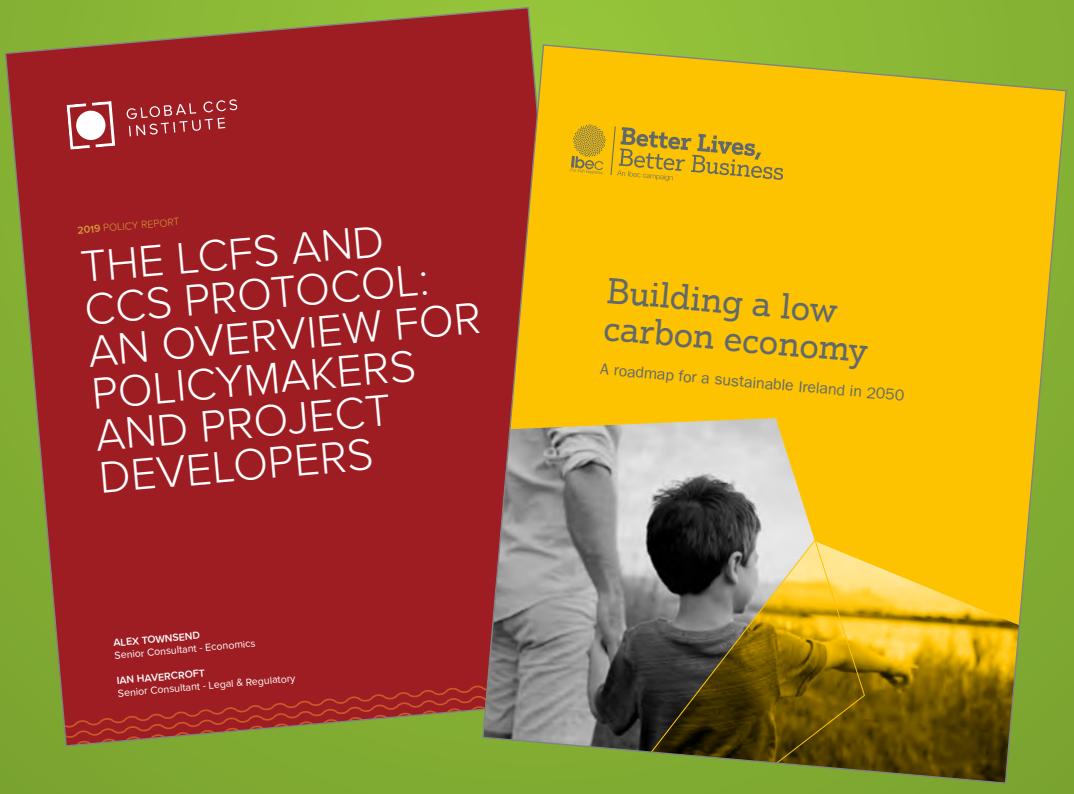
REPORTS and OTHER PUBLICATIONS

The LCFS and CCS Protocol: An Overview for Policymakers and Project Developers.

The following is from the Introduction of this Global CCS Institute document: "This report provides a summary of the CCS Protocol of the California Low Carbon Fuel Standard ('LCFS') and how it compares to other significant regulations and policies in the US associated with the injection and geologic sequestration of CO_2. The other regulations and policies covered include the Underground Injection Control ('UIC') Program, GHG Reporting Program and 45Q tax credits…The report was written to inform policymakers and CCS project developers interested in understanding the main elements of the regulations and the requirements a CCS project would need to fulfill to generate LCFS credits. The report necessarily simplifies the regulatory text and interested readers are encouraged to read the LCFS Regulation Order and CCS Protocol in full to get a better understanding of the detailed requirements of the regulations."

Building a low carbon economy: A roadmap for a sustainable Ireland in 2050.

The following is from the Executive Summary of this Irish Business and Employers Confederation (Ibec) document: "…This report sets out an Ibec vision for a competitive low carbon economy in the year 2050 and a roadmap for Ireland to achieve this ambition that safeguards [the country's] energy security and competitiveness. The report has been developed in consultation with Ibec member companies and with guidance from the SFI MaREI Centre's Energy Policy and Modelling team at UCC. Ibec has also considered the findings and recommendations of the 2019 International Energy Agency's (IEA) review of Irish energy policy and the Joint Oireachtas Committee on Climate Action's 2019 report 'Climate Change: A Cross-Party Consensus for Action.'"



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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NATIONAL ENERGY TECHNOLOGY LABORATORY

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1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Program staff are also located in
Houston, Texas and **Anchorage, Alaska**.

CUSTOMER SERVICE: 1-800-553-7681

www.netl.doe.gov

Contact

Traci Rodosta
304-285-1345
traci.rodosta@netl.doe.gov

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