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News and Highlights

Status of CCUS research and governance by worldwide geological surveys and organizations

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Over the past decade, energy-related carbon dioxide (CO_2) emissions have steadily increased worldwide, reaching 33.4 billion tons in 2019. Most climate scenarios suggest that carbon capture, utilization, and storage (CCUS) is critical for the reduction of direct CO_2 emissions from industrial processes and the use of fossil fuels in power generation, industrial activities, and fuel conversion. Consequently, CCUS has emerged as a significant strategic option for addressing climate change embraced by various governments. Several countries and regions, including the United States of America (U.S.), Canada, Australia, the United Kingdom (U.K.), and the European Union (EU), have established CCUS-related policies. These policies aim to provide financial support for large-scale projects, augment operational expenses, and facilitate the formation of CCUS industrial hubs, substantially driving the development of CCUS. The CCUS research and governance are primarily taken by worldwide Geological Surveys and other geological organizations

1. Policies

(i) The United States

In 1997, the U.S. began appropriating funds to its Department of Energy for the research, development, and demonstration (RD&D) of carbon capture and storage (CCS). During 2005–2007, CCS RD&D projects under the U.S. Department of Energy were authorized for the first time. During 2008–2009, efforts were first made in significant CCS market development and appropriation legislation. In 2018, section 45Q credit for CO_2 storage was reformed as part of the *Bipartisan Budget Act*, allowing carbon capture projects to receive \$35/ton of CO_2 (tCO_2). In 2020, the *Energy Act* tripled the funds appropriated for CCS RD&D projects.

On February 16, 2021, the *Accelerating Carbon Capture and Extending Secure Storage through 45Q* (*ACCESS 45Q*) *Act* was introduced, amending section 45Q. Specifically, this bill provides a direct pay elective for the full value of the credit and extends the date for projects eligible for the 45Q tax credit to begin construction by 10 years (by the end of 2035). Furthermore, this bill allows the 45Q credit to offset tax obligations arising from the Base Erosion and Anti-Abuse Tax (BEAT).

On March 10, 2021, the *Carbon Capture Modernization Act* was introduced. It amends the legal provisions passed in 2005 and 2008, allowing coal-fired power plants retrofitted with carbon capture technologies to qualify for a 30% investment tax credit (ITC) under the *United States Qualifying Advanced Coal Project Credit* legislation (48A).

On March 17, 2021, the *Storing CO_2 and Lowering Emissions* (SCALE) *Act* was proposed, mainly including (1) establishing a *CO_2 Infrastructure Finance and Innovation Act* program; (2) formulating a secure geologic storage infrastructure development program; (3) increasing funding for permitting Class VI wells at EPA (required for underground CO_2 storage in saline geological formations); (4) providing funds for states and municipalities to purchase low-carbon and zero-carbon products derived from CO_2 and oxocarbons.

On March 25, 2021, the *45Q Carbon Capture, Utilization, and Storage Tax Credit Amendments Act* was introduced, amending three clauses of the *Act* as follows: (1) extending the date by which 45Q-eligible projects have to commence construction by five years; (2) creating a direct payment option for 45Q and 48A tax credits; (3) allowing the 45Q credit to offset tax obligations arising from the BEAT. In addition, this act amended the 48A tax credit provisions, allowing coal-fired power plants with retrofitted carbon capture technologies to be eligible for a 30% ITC under 48A.

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It also increases the 45Q credit value for direct air capture projects from $50 to $120 per metric ton for CO_2 captured and safely stored in saline geologic formations and from $35 to $75 per ton for CO_2 stored in oil and gas fields.

On March 26, 2021, the *Financing Our Energy Future Act* was proposed. It ensures the availability of tax-advantaged master limited partnerships (MLPs) as a tool for financing CCS projects, thereby reducing the cost of equity and providing project developers with access to capital on more favorable terms.

In 2022, the *Inflation Reduction Act* was enacted, further reinforcing the already successful section 45Q. Furthermore, CCS legislation continues in the U.S.

(ii) Canada

In December 2020, the Canadian government introduced *A Healthy Environment and a Healthy Economy*. This plan proposes developing a comprehensive CCUS strategy for Canada and launching a net-zero challenge to large-scale industrial emitters, aiming to achieve net-zero emissions by 2050. Moreover, the Canadian government launched the *Strategic Innovation Fund (SIF) - Net-Zero Emissions Accelerator* initiative and invested $ 3 billion Canadian dollars over the coming five years to support various measures, including the decarbonization projects of large-scale industrial emitters. In December 2020, Natural Resources Canada issued the *Hydrogen Strategy for Canada*, which elaborates on Canada's experience in blue hydrogen production and continuous potential for CCS in the grand low-carbon hydrogen strategy.

On April 19, 2021, Canada released the Budget 2021: *A Recovery Plan for Jobs, Growth, and Resilience*, announcing significant measures to support CCUS. It proposes to provide $319 million over seven years, starting in 2021–2022, for Natural Resources Canada to support CCUS RD&D. The purpose is to enhance the commercial viability of CCUS technologies. This budget also proposes to introduce an investment tax credit for capital invested in CCUS projects (including DAC and hydrogen production) with the goal of reducing at least 15 megatons of CO_2 annually. This measure will come into effect in 2022. The Canadian government pledged prompt action with a 90-day consultation period with stakeholders on the design of the investment tax credit, after which it would announce more details—including the rate of the incentive.

(iii) Australia

In 2006, the Australian government enacted the specialized *Offshore Petroleum and Greenhouse Gas Storage Act 2006*. An effective regulatory framework for offshore CCS projects' environmental and safety supervision has been established through a series of amendments to this act.

In 2020, the Australian government issued the *Technology Investment Roadmap: the Australian Government's first Low Emissions Technology Statement*. This statement outlines the priority technologies with the potential for transformational economic and emissions outcomes, including CCS, clean hydrogen, energy storage, low-carbon materials, and soil carbon. Following this technology investment roadmap, the Australian government committed to investing AUD 263.7 million to support the development of CCS/CCUS projects and hubs and AUD 275.5 million for the development of four clean hydrogen hubs in regional Australia. In June 2021, Australia and Singapore announced a joint initiative for low-emission fuels and technologies, including clean hydrogen and clean ammonia.

A CCS plan draft issued by the Australian government included CCS under the government's Emissions Reduction Fund (ERF). This allows eligible CCS projects to generate Australian Carbon Credit Units (ACCUs), which can be sold to the Australian Government through a carbon abatement contract or to companies and other private buyers in the secondary market. As a financial incentive plan for CO_2 emission reduction through CCS, the plan holds great significance for the widespread deployment of CCS projects.

(iv) The United Kingdom

The *Climate Change Act 2008* of the U.K., as an amendment to the *Energy Act 2004*, sets the target for 2050, including carbon emission reduction and carbon budgets. This act facilitated the establishment of a Committee on Climate Change—an independent, statutory body. The purpose of this committee is to advise the U.K. and devolved governments on emissions targets. Furthermore, it reports to Parliament on progress made in reducing greenhouse gas emissions and preparing for and adapting to the impacts of climate change. The CCUS Advisory Group, under this committee, is in charge of reviewing the progress and priorities of CCUS.

The *Energy Act 2012*, issued by the U.K. government, creates a mechanism for the government to price low-carbon electricity and participate in the market *via* contracts for difference. Furthermore, this act proposes to build a capacity market to incentivize investment in electricity supply.

In July 2018, the Department for Business, Energy & Industrial Strategy (BEIS) initiated the *CCUS Innovation Programme* to provide grant findings for world-leading research and innovation projects that significantly reduce the cost of capturing and sequestering CO_2. Up to £24 million of grant funding was made available under this programme to support feasibility studies, industrial research, experimental development projects, and infrastructure projects. The selected projects include the negative CO_2 emissions from full scale bioenergy with carbon capture and storage (BECCS) utilizing non-amine CCS chemistry led by C-Capture and the HyNet Phase 1: Industrial CCS led by Progressive Energy.

In 2020, the U.K. government formulated a *Ten Point Plan for a Green Industrial Revolution*, followed by the release of a white paper. Based on this plan, the U.K. government determined the energy-related measures and set out a plan of net-zero emissions for the U.K.. This plan reiterates the projected role of CCUS in achieving the emission goal and underscores the increasing importance of hydrogen energy.

(v) The European Union

In 2008, the *Climate Action and Renewable Energy*

Package (*CARE Package*), also known as an extension of the EU's climate change policy, was issued. The bill involves (1) broadening the control range of greenhouse gases; (2) endorsing a burden-sharing agreement among member states; (3) developing a binding target of increasing the level of renewable energy; (4) setting new rules for CCS and environmental subsidies.

In 2009, the European Parliament and the Council introduced *Directive 2009/31/EC*, commonly referred to as the *EU CCS Directive*. This directive became the national legislation of all EU member states during 2010–2014.

The European Commission adopted the *Trans-European Networks for Energy* (TEN-E) *Regulation* to coordinate energy infrastructure across EU member states. In December 2020, it revised this regulation to ensure consistency in energy infrastructure policies among EU member states. In addition, the revised *TEN-E Regulation* proposes that future carbon transport will rely primarily on maritime transport.

In July 2021, the European Commission introduced a *Fit for 55* package, aiming to align the EU's climate, energy, land use, transportation, and taxation policies with the goal of cutting the EU's greenhouse gas emissions by 55% compared to 1990 by 2030. Among the 13 legislative proposals in the package 's first part, one pertaining to CCS is the EU Emissions Trading System (ETS) law. The revised ETS suggests integrating all carbon transport modes into the EU ETS. Corresponding monitoring and reporting regulations will be updated accordingly.

(vi) Spain

In 2010, *Directive 2009/31/CE* of the European Parliament and the Council was transformed into the legal framework of Spain, namely Law 40/2010 on geological CO_2 storage. The purpose of this law is to incorporate into the Spanish internal legal system the provisions contained in the aforementioned directive, adapting them to Spanish industrial, geological, and energy reality and establishing a legal basis for the geological CO_2 storage on the premise of environmental security, thus contributing to the fight against climate change.

This law solely regulates the activities of geological CO_2 storage, only involving the prediction related to CO_2 capture and transport. For carbon capture, relevant facilities must follow integrated pollution control regulations. Therefore, they should hold relevant integrated environmental authorizations and comply with relevant environmental impact assessment regulations. As for CO_2 transport, an environmental impact statement is required for a proposed pipeline transport network. In light of these, the above two types of regulations were revised according to the final provisions of the law.

Law 40/2010 comprises six chapters. Chapter I contains the general provisions of the geological carbon storage regime. Chapter II regulates research permits and storage authorizations. Obtaining a research permit will be mandatory for an exploration intended to determine the storage capacity or suitability of a specific storage site. Chapter III deals with the operation and closure of CO_2 storage sites, as well as the derived obligations. A series of information obligations and an inspection system are established to guarantee the safety of the sites. Chapter IV regulates third-party access to transport networks and storage sites. Access must be provided in a transparent and non-discriminatory manner, and basic criteria for access are offered. This chapter also contemplates the resolution of potential domestic and transnational conflicts. Chapter V details the regulations for the registration of storage licenses, as well as the registration of closed storage sites and surrounding storage complexes. It also stipulates public access to information related to geological CO_2 storage in accordance with relevant provisions. Chapter VI establishes the penalty regime. This chapter distinguishes between very serious, serious, and minor offenses. It identifies various typical behaviors related to non-compliance with obligations imposed by laws, as well as the corresponding sanctions, which can reach € 5 million.

(vii) Romania

Romania has established a regulatory framework for geological CO_2 storage. This framework is the implementation of Directive 2009/31/EC and has been transformed into Romanian legislation through Law 114/2013 (endorsing the Government Emergency Ordinance No. 64/2011). The competent supervisory and regulatory authority in geological CO_2 storage is the National Agency for Mineral Resources ("NAMR"), which also supervises the exploitation of hydrocarbons and all other natural resources. The geological CO_2 storage service under the NAMR has released specific procedures for granting exploration and CO_2 storage permits.

(viii) Japan

In June 2019, the Japanese government approved a long-term strategy under the *Paris Agreement*. This strategy comprises the CCS objective of introducing CCS into coal-fired power generation by 2030 for commercialization. Given the need for CO_2 storage, further research is required on suitable storage sites. The Japanese government seeks to achieve optimal CO_2 transport from capture to utilization/storage sites by introducing public-private cooperation partnerships. Moreover, the Japanese government seeks early adoption of CCS and carbon capture and utilization (CCU) in society. The Japanese government has begun regarding CO_2 as a resource and cooperating with industrial, academic, and governmental sectors of other countries to foster the required innovations for carbon recycling, namely CCS and CCU. Specifically, the Japanese government will expedite the efforts of a wide array of stakeholders, aiming to establish the first commercial-scale CCU technology by 2023 and achieve the widespread application of the technology in 2030 and beyond.

(ix) South Africa

CCS has been recognized as a mechanism to aid South Africa in achieving its CO_2 emission reduction goals and a national flagship priority program in the *National Climate Change Response White Paper*.

The CCS in South Africa initially focused on geological storage since the CCS technology would not serve as a viable option for CO_2 emission reduction without secure and permanent storage. Following the publishment of the *Atlas on Geological Storage of Carbon Dioxide in South Africa* in 2010, the South African government initiated the Pilot CO_2 Storage Project (PCSP) *via* the South African National Energy Development Institute (SANEDI).

With the advancement of the PCSP, other aspects of CCUS, such as carbon capture, carbon utilization, and mineral carbonation, have been integrated into the CCUS program.

The Minister of the Mineral Resources and Energy Ministry approved the transfer of the CCUS program from the SANEDI to the Council for Geoscience, with the program primarily changing the PCSP site into Mpumalanga, which is closer to the major source of CO_2 emissions.

(x) China

In 2013, the National Development and Reform Commission (NDRC) released a *Notice on Promoting the Experimental Demonstration of Carbon Capture, Utilization, and Storage*. This notice requires implementing CCS pilot projects and enhancing the support and guidance for CCUS experimental demonstration from six aspects. The purpose is to practically promote the healthy and orderly development of CCUS. The State Council issued the *National Medium*- and *Long-term Plan for Major Science and Technology Infrastructure Construction* (2012–2030) for exploring the construction of pre-research facilities for CCUS in order to provide technical support for tackling global climate change. In 2014, the NDRC issued the *National Climate Change Plan (2014–2020)*, proposing implementing an integrated demonstration project for CO_2 capture, oil displacement by CO_2, and CO_2 storage and listing CCUS as the priority low-carbon technology to be developed.

In 2019, China pledged to achieve carbon neutrality, and various ministries and commissions of this country aggressively reached a consensus on the role of CCS in decarbonization. China ’s 14th Five-Year Plan proposed establishing large-scale CCUS demonstration projects for the first time. In May 2021, the Ministry of Ecology and Environment, together with several ministries and commissions, voiced support for CCUS pilot and demonstration projects in free trade zones. The *China-U.S. Joint Statement Addressing the Climate Crisis*, issued in April 2021, also included CCUS. In June 2021, the NDRC issued a notice to request information on CCUS projects, aiming to support significant projects in the near future.

On July 16, 2021, China ’s Emissions Trading System (ETS) entered service. Despite the fact that the current applications are limited to only the power sector, the ETS will be expanded to other industries. A methodology must be developed to align CCUS with ETS requirements. CCUS standards are being formulated by the CCUS Standardization Working Group, established by the National Technical Committee 548 on Carbon Management of Standardization Administration of China (SAC/TC548), the National Technical Committee 20 on Energy Fundamentals and Management of Standardization Administration of China (SAC/TC 20), and the National Technical Committee 207 on Environmental Management of Standardization Administration of China (SAC/TC 207).

2. Current projects

(i) The United States

In 2019, the U.S. Geological Survey (USGS) released a comprehensive national geological carbon storage assessment report. This report reveals that the U.S. has the potential to store 300 billion tons of CO_2 in its nationwide geological basins. The Kansas Geological Survey has contributed to the Integrated Mid-Continent Stacked Carbon Storage Hub (IMSCS-HUB), which is in the stage of advanced development. Operations are expected to commence between 2025 and 2035, with an estimated CO_2 storage capacity of approximately 2 million tons per year.

(ii) Canada

Canada, at the forefront of CCS technology worldwide, is committed itself to exploring this technology. Between 2000 and 2012, Natural Resources Canada, along with the U.S. Department of Energy and the International Energy Agency Greenhouse Gas R&D Program (IEAGHG), conducted an international research project: the Weyburn-Midale CO_2 Monitoring and Storage Project, which focuses on CO_2 injection and geological storage in depleted oil fields.

(iii) Australia

The Geoscience Australian (GA) is currently collaborating with CO_2CRC to assess the feasibility of small-scale, shallow CO_2 fault injection experiments at the CO_2CRC Otway International Test Centre in Victoria. Through the project entitled Identifying Australia’s Hydrocarbon and CO_2 Storage Potential in Residual Oil Zones (ROZs), the GA aims to identify and assess ROZs in Australia’s oil-producing basins in order to determine their potential oil and CO_2 storage resources for Australia. This project is a part of the second phase of the *Exploring for the Future Program* (2020–2024) of Australia.

(iv) The United Kingdom

The British Geological Survey (BGS), in partnership with the Natural Environment Research Council (NERC), is developing plans for a new facility, the CO_2 Storage Research Facility (CSRF). The purpose of this facility is to investigate deep geological CO_2 storage and its role in achieving net-zero emissions in the U.K., as well as to accelerate our understanding of CO_2 storage. A carbon storage scoping study, commissioned by the BGS in October 2020 and funded by the U.K. Research and Innovation’s (UKRI) Infrastructure Fund and the NERC Capital programme, identified the strategic need for national research infrastructure in CO_2 storage for the first time. Additionally, the Net Zero Teesside Project, led by British Petroleum (BP), is expected to begin operations in 2026, with an estimated capacity to capture five million tons of CO_2 each year.

(v) Ireland

The Geological Survey of Ireland (GSI) is a participant in

the EU's Seventh Framework Programme (FP7), having co-authored a crucial report on CO2 storage site selection and taken part in several CO_2 storage projects. These projects include an assessment of the potential for geological storage of CO_2 in Ireland and the basin-by-basin analysis of co_2 storage potential of all-island Ireland. From 2012 to 2014, the GSI collaborated with the BGS on a joint project to reassess shared saline aquifer basins in the Irish Sea. In addition, the GSI reassessed existing seismic and well data on the Central Irish Sea Basin and the northeastern part of the North Celtic Sea Basin in order to determine whether faults could serve as large-scale reservoirs for CO_2 storage.

(vi) Norway

Equinor, Norway 's state-owned oil company, has led multiple CO_2 storage projects, including the H_2morrow project in North Rhine-Westphalia, Germany; the Magnum project in Eemshaven, Netherlands; the Sleipner CCS project in the North Sea, Norway; the Snøhvit CO_2 Storage project and the Longship CCS project (including the Northern Lights project) in the Barents Sea, Norway; and the Preem-CCS project and the Stockholm Exergi bio-CCS project in Sweden.

(vii) France

As a pivotal participant in research and innovation in CO_2 geological storage, the French Geological Survey has been undertaking extensive work in this field, including evaluating geological storage potential and characterizing related reservoirs, estimating three-dimensional dynamic features of CO_2 geological storage and accordingly analyzing CO_2 geological storage capacity (volumetric approach), establishing and optimizing CO_2 injection strategies and techniques, simulating water-fluid-rock interactions on an oil well or storage system scale, and tracking site conditions through appropriate monitoring.

(viii) China

As early as 2010, the China Geological Survey (CGS) organized and implemented the National CO_2 Geological Storage Potential Assessment and Demonstration Project, preliminarily assessing the potential of China's sea areas for CO_2 geological storage. In 2021–2022, under the unified deployment of the CGS, the Qingdao Institute of Marine Geology took the lead in the evaluation of the potential of China 's sea areas for geological CO_2 storage, with participation of the Guangzhou Marine Geological Survey and the Development and Research Center of CGS. In August 2021, the first offshore CO2 storage demonstration project implemented by the China National Offshore Oil Corporation (CNOOC) was launched.

(ix) Other countries

The INA MOL has launched the enhanced oil recovery with CO_2 (CO_2-EOR) project in Zagreb County, Croatia, the iCORD project in central Croatia, and the bio-refinery project in Sisak-Moslavina County, Croatia. The INEOS Oil & Gas Denmark led Project Greensand. The French Institute of Petroleum and New Energies (IFPNE) contributed to the DMX Demonstration project in Dunkirk of France.

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