CARBON SEQUESTRATION LEADERSHIP FORUM

TECHNICAL GROUP

Monitoring Progress of the Technology Roadmap (TRM) 2021

Update on progress of Recommended Priority Actions to meet the TRM targets.

Period May 2021 – September 2022

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Executive Summary

The Carbon Sequestration Leadership Forum Technical Group (CSLF TG) issued a Technical Roadmap (TRM) in April 2021. The TRM highlighted the challenging deployment pathway for CCUS in the coming decades, based on IEA Sustainable Development Scenario (SDS):

- By 2030: CO_2 capture and storage should increase by a factor of 10 – 15 from the 2020 level of 40 million tonnes (Mt) CO_2 per year.
- By 2050: CO_2 capture and storage should increase by a factor of 100 or more from the 2020 level.

To meet these challenges the TRM 2021 recommended that efforts were required in the following key areas:

- Technology development, innovation, and cost reduction.
- Strategic build-out of CCUS projects and hubs.
- Development of strategy, policy, legal and financial frameworks.

In this report, the CSLF Technical Group presents highlights regarding the progress in the key Recommendations on CCUS of the CSLF Technology Roadmap (TRM) 2021:

1. **Technology development, innovation, and cost reduction:**

- Several CSLF members have allocated significant funding to Research. Development and Demonstration (RD&D) for CCUS, including Australia, Canada, China, the European Union (EU), Japan, the Netherlands, Norway, the United Kingdom, and the United States of America. International partnerships like Accelerating CCS Technologies, ACT, the Clean Energy Transition Partnership (CETPartnership) and the Asia CCUS Network, are further examples of continued willingness to invest in RD&D for CCUS.
- Transferring knowledge is continuously taking place, amongst other in numerous workshops.
- There has been significant increase in activities and funding for Negative Emission Technologies (NETs), Carbon Dioxide Removal (CDR) and Greenhouse Gas Removal (GGR), as seen in several national and international initiatives. Mission Innovation (MI) has initiated a mission on Carbon Dioxide Removal (CDR) to accelerate uptake of, and other international CCUS organisations like CEM CCUS, GCCSI, IEA, IEAGHG and CSLF TG have organized webinars and workshops and issue reports on the topic.

The progress is rated as good and contributes to the meet the challenge of the CSLF TRM 2021. Green. 

2. **Infrastructure projects and hubs are moving forward:**

- One additional project has come into construction (Northern Lights in Norway) and three others have received significant private and public funding to proceed to Final Investment Decision (FID; East Coast Cluster and Hynet in the United Kingdom, and Porthos in the Netherlands).
- The number of infrastructure projects and hubs in planning has increased by a factor of two.
- New funds made available for infrastructure and hubs projects: US Bipartisan Infrastructure Bill for DAC and hydrogen hubs; European Commission Projects of

Common Interest (PCI) with four projects in addition to Northern Lights and Porthos; and Canada's Budget 2022 broadened the role of the Canada Infrastructure Bank (CIB) – an arm's length Crown corporation – to invest in private sector-led low carbon infrastructure projects (including CCUS).

- The Oil and Gas Climate Initiative (OGCI) has launched The CCUS Hub Platform, which is a website dedicated to CCUS hub.
- In Canada, the province of Alberta is leading a competitive process to allocate CO_2 pore space to hub operators – with 6 proposals selected in March 2022 to explore carbon storage hub development in the Alberta Industrial Heartland Region (Phase 1). Phase 2 will enable carbon storage hub development in the rest of Alberta.

Progress is encouraging as an extensive number of potential hubs and clusters have been identified, and several are in early planning. However, the progress is insufficient to meet the challenge of a 10-15-fold increase in captured and stored CO_2 by 2030. ***More projects need to enter the Front-End Engineering and Design (FEED) phase and make the final investment decision.*** Yellow.

3. Development of strategy, policy, legal, and financial frameworks

- 123 countries have submitted updated Nationally Determined Contributions to the UNFCCC but just 16 include CCS and three implicitly include CCS. COP26 adopted the Glasgow Climate Pact and important changes to Article 6 of the Paris Agreement.
- In addition to the UNFCCC agreements, several bilateral, multilateral, and global agreements have come into place
- National or regional CCUS strategies, incentive frameworks, business models, risk-sharing mechanisms, and legal, regulatory, and accounting frameworks are being implemented, or about to be implemented, in several countries, including Australia, Canada, China, Denmark, Finland, Germany, Indonesia, Japan, the Netherlands, Nigeria, Norway, Saudi Arabia, South Africa, United Arab Emirates, United Kingdom, and United States.

Progress is encouraging but insufficient to meet the challenge of a 10-15-fold increase in captured and stored CO_2 by 2030. **More countries need to put the necessary regulations and financial frameworks in place.** Yellow.

<u>Overall conclusion</u>

Despite the progress and the fact that several new CCUS projects have been announced since April 2021, **the deployment of CCUS lags behind what is needed to meet the challenge** to increase CCUS deployment by a factor of 10 -15 above 2020 level (40 Mt CO_2/year) by 2030, as well as what is required in the scenarios of IPCC and IEA. Yellow.

1. Introduction

The CSLF TG has an obligation to monitor progress on recommendations in the TRM. This note gives status as of August 2022 on monitoring recommendations in the CSLF Technology Roadmap (TRM) 2021.

The CSLF TRM 2021 does not give specific targets for deployment of Carbon Capture Utilization and Storage (CCUS). However, the document stresses the challenging deployment pathway for CCUS in the coming decades, based on the IEA Sustainable Development Scenario (SDS), which reaches net-zero emissions by 2070:

- By 2030: The isolation from the atmosphere by CO_2 capture and storage should have increased by a factor of 10–15 from the 2020 level of 40 million tonnes (Mt) CO_2 per year.
- By 2050: The isolation from the atmosphere by CO_2 capture and storage should have increased by a factor of 100 or more from the 2020 level of 40 Mt CO_2 per year.

To achieve net-zero CO_2-emissions by 2050, the above numbers will have to increase by around 40% (IEA 2021[1]; UNEP, 2021[2]; IPCC, 2021,2022[3]).

The CSLF TRM 2021 gives the following Key Recommendations for deploying CCUS in a pace that will contribute to reaching the above reductions:

<u>Technology development, innovation, and cost reduction</u>

- Investing heavily in Research, Development and Demonstration (RD&D) to:
  - Reduce capture costs by 25% from the 2020 level ($60/t CO_2 avoided, average of commercial technologies).
    - Bring enabling and emerging capture technologies to technology readiness level 7 or above.
    - Reduce storage monitoring and verification costs by 25% relative to 2020.
    - Mature sustainable NETs.
    - Continue the development and deployment of CO_2 utilisation technologies.
    - Develop novel, emerging, and enabling technologies along the whole CCUS chain.
- Transferring knowledge continuously from existing large-scale projects to new projects.
- Making investments in public–private partnerships or projects that continue to develop and mature promising utilisation technologies (technology push), including transparent methods for lifecycle analyses (LCAs) and technoeconomic analyses (TEAs), and establishing a goal that a certain percentage of all government-procured products meet a low-carbon or "green" standard.
- Taking several actions in the science and technology of Negative Emissions Technologies (NETs) and continuing to invest in transformational Research and Development (R&D) and advance the most promising technologies to pilot scale and demonstration testing.

<u>Strategic build-out of CCUS projects and hubs</u>

- Making all efforts to ensure that all future projects under development today, or an equivalent volume of carbon capture capacity, are brought to operation by 2030.

[1] https://www.iea.org/reports/net-zero-by-2050
[2] https://www.unep.org/resources/emissions-gap-report-2021
[3] https://www.ipcc.ch/assessment-report/ar6/

- Rapidly identifying, planning, and building out strategic power and industrial CO_2 capture clusters, with common CO_2 transportation and storage infrastructure (hubs), to ensure a 10-fold increase of industrial production facilities and power and heat plants, including waste-to-energy plants, with CCUS by 2030. This will be essential for cost-effective CCUS.
- Implementing CCUS at a substantial fraction of fossil fuel hydrogen production facilities (for example, a fraction of one-third will be required in 2030 in the IEA SDS).
- Ensuring that sufficient CO_2 storage sites be characterized and developed, and necessary permits obtained.

<u>Development of strategy, policy, legal, and financial frameworks</u>

- Implementing policies to mitigate the impacts of climate change, and ideally, defining the role that CCUS can hold in a portfolio of responses.
- Developing national or regional CCUS strategies and implementation plans.
- Developing incentive frameworks, business models, and risk-sharing mechanisms that will enable CCUS projects to be financeable, including placing a value on CO_2 emissions reductions and differentiating between business and financial risks.
- Implementing legal, regulatory, and accounting frameworks to ensure safety and environmental integrity of CO_2 capture, storage, utilisation, and transport operations while ensuring regulatory pathways to support the operational aspects of projects.
- Implementing frameworks to enable cross-border transport of CO2 for storage purposes.
- Communicating the importance of CCUS.
- Sharing best practices to foster cost reduction and to help countries and industries accelerate CCUS investment.

This report summarizes progress within these areas using traffic light ratings as follows:

Good, the progress contributes to reaching the target

Room for improvement, progress registered but insufficient to reach the target unless new actions are initiated

Poor progress, the target will not be reached. Strong actions required

2. Results

In general, there has been a growing interest for CCUS in non-members of CSLF. In Europe one notices activities that involve countries that have not been strongly engaged in CCUS. Two examples are given below under international partnerships.

2.1. Technology development, innovation, and cost reduction

There is significant and increasing RD&D activities around the globe. Progress in research is briefly illustrated below for CO_2 capture technologies, otherwise emphasis is on funding schemes. These usually include RD&D, private-public funding, transferring knowledge continuously from existing large-scale projects to new projects and negative emissions technologies (NETs).

2.1.1. Capture technology development, innovation, and cost reduction results

This section was prepared by Frank Morton, US National Carbon Capture Center, NCCC:

Generally, results have been good for capture technology development, innovation, and cost reductions for CCUS R&D up to TRL 7. Funding and policy support from government has been excellent and improving, and private support has been increasing due to governmental incentives and even niche commercial opportunities. Funding and policy support is beginning to be available for large scale demo and commercial deployment of CCUS technology. Even though deployment of climate scale CCUS technology is not rising to roadmap levels for achieve Net Negative Carbon Emission goals by 2050, optimism is rising that deployment can start soon making long-term goals realistic.

- Amine solvents – Development of this near-commercial technology continues to achieve R&D goals with cost reductions continuing due to both fundamental chemistry tweaks and process intensification. Additionally, reaching 95% CO_2 capture rates has proven to cost-effective and development continues toward 99% capture which could delay the need for large-scale implementation of Carbon Dioxide Removal (CDR). Scale-up to demo projects and commercial deployment are needed to complete the optimization of this technology and prove R&D results. Public and private funding is beginning to become available because of recent legislation.
- Membranes, Sorbents, Advanced Concepts, Process Intensification - Progress continues at low-TRL level with continued support from both public and private funding with significant international knowledge sharing. However, more information from scale-up R&D is needed to increase the rate of improvement of both performance and cost reduction. Recent increases in funding and the additional driver from private Net-Negative Carbon Emission goals should contribute the needed increases in technology performance.

Direct Air Capture (DAC)

- DAC is receiving unprecedented funding and policy support with resulting R&D and scale-up advancements. Continued funding and policy support is expected to continue, so this technology that is important to achieving final net-negative carbon emission goals can

be expected to continue showing improvements. Scale-up and commercialization at an appropriate rate is needed to confirm early achievements.

Utilization

- Utilization continues to be a necessary part of a net-negative future by contributing to funding early carbon capture adopters and making many processed more cost-effective. Scale-up and commercialization is needed to confirm early success.

2.1.2. Examples of significant RD&D funding

This monitoring note will give examples of general programmes and funding schemes in CSLF member as well as non-CSLF member countries, provided by CSLF members directly, through Clean Energy Ministerial CCUS Initiative (CEM CCUS) or through easily available public information.

2.1.2.1. CSLF member states

Australia

The Australian Carbon Capture Use and Storage Development Fund provides businesses with grants for pilot projects or pre-commercial projects located in Australia. The projects must aim to reduce emissions across energy generation, natural gas or hydrogen production and heavy industries; foster existing, pilot or pre-commercial CCUS facilities that could connect into a regional CCS hub in the future; aim to compress, transport and store carbon dioxide (CO_2) at less than $20 per tonne of CO_2; leverage expertise and viable geological storage resources for CCUS in Australia; and support new opportunities to use carbon dioxide in the development of CO_2-derived products and services. Projects must be completed by 30 June 2025. In June 2021 six projects were awarded grants for a total of AUD $ 50 million. (https://www.minister.industry.gov.au/ministers/taylor/media-releases/412-million-new-investment-carbon-capture-projects). The grant recipients are:

- Santos Limited to deploy the low-cost capture and storage of CO_2.
- Mineral Carbonation International towards the construction of a mobile demonstration plant that captures and uses CO_2 to produce manufacturing and construction materials.
- Energy Developments Pty Ltd towards the capture and use of CO_2 emitted from the production of biomethane at landfill sites.
- Carbon Transport and Storage Company to demonstrate the viability of carbon capture and storage from a coal-fired power station support the development of a geological storage site.
- Corporate Carbon Advisory Pty Ltd towards Australia's first demonstration of a direct-air-capture (DAC) and storage with geologically sequestering of CO_2.
- Boral Limited towards a pilot scale carbon capture and use project to improve the quality of recycled concrete, masonry, and steel slag aggregates.

A decision is yet to be made on the $250 million CCUS Hubs and Technology Program.

The Australian government releases offshore areas for CO_2 storage through an annual Greenhouse Gas Offshore Acreage Release. These provide a key mechanism to support investment in Australia's CCUS projects, while also supporting the reduction of emissions. Five permits were awarded from 2021 Release. The Area nominations for the 2022 Release

closed on 31 July 2022, with public consultation proposed in September 2022, and release scheduled for December 2022.

Canada.
Through Budget 2021, the federal government is investing $319M in research, development, and demonstrations to advance the commercial viability of CCUS technologies. These funds will support businesses, academia, non-profits, government, and public laboratories. Natural Resources Canada (NRCan) is delivering on this investment through funding calls and by supporting critical research at federal labs.

- The first CCUS call (up to $50M) will support Front-End Engineering and Design (FEED) studies for projects that have the potential for significant mitigation – with 11 applicants selected in July 2022 to advance to final due diligence and agreement negotiation. Selection does not guarantee funding.
- The second CCUS call (up to $81.5M), also announced in July 2022, will support earlier-stage RD&D activities across three different focus areas – capture, storage/sequestration, and utilization.
- In addition, federal laboratories are currently participating in a CCUS federal R&D program to help advance the commercialization of CCUS technologies.

Additionally, CCUS projects may also be supported by the $8B Strategic Innovation Fund - Net Zero Accelerator (NZA) initiative, which is a fund that will invest in large-scale decarbonization projects in key industrial sectors to ensure that Canada remains competitive in a net-zero economy.

At a provincial level, the Carbon Capture Kickstart funding opportunity led by Emissions Reductions Alberta (ERA) is committing $40M to fund 11 projects (pre-construction facility studies) worth $194M. If successful, these projects in diverse industrial sectors such as power generation, cement, fertilizer, forest products, and oil & gas could lead to over $20B in capital expenditures, create thousands of jobs, and reduce Alberta's annual industrial emissions by almost 10 per cent. All funded projects plan to be up and running by 2030. Further, ERA and NRCan – via NRCan's CCUS FEED call – are working to jointly leverage funds for five projects in Alberta.

China
CCUS has been included in China's carbon mitigation strategies since the 12th Five-Year Plan (2011–2015). An updated Roadmap for Development of CCUS Technology in China (May 2019, the Ministry of Science and Technology and the Administrative Centre for China's Agenda 2) set goals for reducing the cost and energy consumption of CO_2 capture by 10 percent to 15 percent in 2030 and by 40 percent to 50 percent by 2040. The later 14th Five-Year Plan, covering the years 2021-2025 and released in March 2021, highlighted the role of CCUS in low-carbon development and called for implementing near-zero-emissions CCUS demonstration projects. Several CCUS hub pilot projects are in the pipeline, see Figure 1 in Section 2.2. (https://www.energypolicy.columbia.edu/research/global-energy-dialogue/us-china-roundtable-carbon-capture-utilization-and-storage).

EU
Several funding mechanisms for R&D and demonstration projects have been created via the research framework programmes and other EU funding mechanisms. Current EU funding

schemes dedicated to supporting CCS and CCU are the following programmes: (https://ec.europa.eu/clima/eu-action/carbon-capture-use-and-storage_en#eu-funding-for-ccs-and-ccu):

- The Innovation Fund mobilises over EUR 25 billion, depending on the price of carbon, over ten years for breakthrough technologies in carbon capture, use and storage, as well as in renewable energy, energy-intensive industries, and energy storage. Specifically, in November 2021, four CCUS projects in Finland, Belgium, Sweden and France were selected for funding to support CCS projects in hydrogen, chemical, bioenergy and cement production, respectively. Norway's North Sea storage site may be a storage site for some of the projects (https://www.globalccsinstitute.com/news-media/latest-news/three-ccs-projects-to-be-funded-through-the-eu-innovation-fund/). In July 2022, the Innovation Fund granted support to additional 17 projects in Bulgaria, Finland, France, Germany, Iceland, the Netherlands, Norway, Poland and Sweden, with projects ranging from low-carbon cement production, carbon mineral storage site development and sustainable aviation fuel production. (https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4402).
- Connecting Europe Facility (CEF) supports cross-border CO_2 transport networks**,** which includes the Projects of Common Interest (PCI), described below in Section 2.2.
- The Recovery and Resilience Facility (RRF) aims to mitigate the economic and social impact of the coronavirus pandemic through investments in flagship areas such as clean technologies and renewables, e.g. CCS and CCU.
- The Just Transition Fund (JTF) provides support to territories facing serious socio-economic challenges arising from the transition towards climate neutrality, i.a. support for CCS and CCU technologies.
- Horizon Europe and Horizon 2020 supports research, pilots and small-scale demonstration projects related to carbon capture, utilisation, and storage.

Germany
Funding for CDR R&D (10 Research networks, 21 Million Euros)

Japan.
Based on Japan's Green Development Strategy, the Ministry of Economy, Trade and Industry (METI) launched the Green Innovation Fund Project (Fund), a JPY 2 trillion (around USD 16 billion) fund set up with the New Energy and Industrial Technology Development Organization (NEDO) to provide 10 years of continuous support to business-led decarbonization initiatives, ranging from R&D and demonstration to social implementation, with ambitious and specific goals shared between the public and private sectors. (https://www.bakermckenzie.com/en/insight/publications/2022/04/green-innovation-fund). The programme (https://www.nedo.go.jp/english/activities/activities_ZZJP_100141.html) include:

- Large-scale CO_2 capture and storage (CCS) demonstration testing at Tomakomai. This testing involves separating/capturing CO_2 (at a level of approximately 100,000 tons per year) from gas emitted by oil refineries and then storing the CO_2 underground at a depth of more than 1,000 meters. Specifically, testing is being carried out on the following: the operation of equipment that separates/captures CO_2 at a level of approximately 100,000 tons per year, the injection and storage of CO_2 at a level of approximately 100,000 tons per year, and the monitoring of stored CO_2.
- R&D of CO_2 storage technologies to safely carry out CCS operations. This activity aims to realize the commercialization of technologies necessary to safely store CO_2 on a large

scale. Specifically, NEDO is carrying out the following activities: the development of technology to manage the safety of large-scale CO_2 injection and storage operations, the development of technology to effectively inject CO_2 into large-scale reservoirs, the establishment of conditions for disseminating CCS technologies, and the establishment of CCS-related standards.
- R&D on CO_2 separation/capture technologies that aims to greatly reduce costs associated with CO_2 separation/capture by developing commercial technologies.

The Netherlands
- This subsidy is intended for companies and organisations (non-profit and otherwise) in sectors such as industry, mobility, electricity, agriculture and the built environment.
- The SDE++ provides a 15-year CfD-like subsidy support covering the 'uncommercial' cost of CCS operation, i.e. the cost above the EU ETS price. Free allowances under the ETS are retained and volumes of CO_2 from industrial applications that are captured and stored do not incur a charge under the new Dutch carbon tax system.
- a feed-in contractual subsidy mechanism under the SDE ++ scheme to reward the most cost-efficient CO_2 reductions in industry. This covers the uncommercial part of investing and operating CCS on industrial plants .
- CATO is the Dutch national R&D programme for CO_2 capture, transport, and storage in nearly 40 partners cooperate. Building on the success of CATO-1 and CATO-2 the Dutch programme on CO_2 Capture and storage's continues. Besides the contribution of our industrial partners, the third phase of CATO will be funded by different sources from the government. The CATO program office will coordinate all the programmes under the CATO umbrella to strengthen the CSS network and knowledge transfer.

Norway
- The Norwegian government has allocated NOK 19.4 billion for the Longship project, a full CCS chain, for investment and 10 years operation. The total budget is NOK 25.1 billion. (As of August 2022, 1 USD ~ 10 NOK). The Norwegian government intends to contribute to development of CCS technologies and will build on established measures and incentives. The aim is to take CCS technology out into the world, and a prerequisite for the project is international cooperation and follow-up. The government places major emphasis on Longship's being a cost- effective solution for carbon capture and storage and a technology that many can utilise.
- The CLIMIT programme provides financial support for development of carbon capture and storage (CCS) technology. The programme is aimed at companies, research institutes, universities, and colleges, often in collaboration with international companies and research institutions, which can help accelerate the commercialisation of CCS. The CLIMIT programme is a collaboration between Gassnova, a state enterprise, and the Research Council of Norway. The Research Council's projects are often referred to as CLIMIT R&D, while Gassnova's part is referred to as CLIMIT Demo. For the fiscal year 2022 the CLIMIT budget is NOK 154 million.
- ENOVA is a state enterprise with a mission to support development and implementation of new energi and climate mitigating technologies. By October 2022, ENOVA supports a full-scale CCS facility for waste incineration and expects more to come.
- Innovation Norway is an important instrument for innovation and development of Norwegian enterprises and industry. It is possible to get funding for CCUS-related projects.

Saudi Arabia

The CCUS Joint Research Center is conducting two projects that fully funded from the King Abdulaziz City for Science and Technology (KACST) “Saudi National Research Centers”. The two projects are:

- Geological Formations Assessment for CO_2 Storage, which will be Investing seismic data, well records, petrophysical information and geological information, and conducting the geophysical survey necessary to build an integrated geological model with a test of the critical conditions required for storing carbon dioxide in the appropriate geological layers in the Kingdom. The project serves several national initiatives such as "Green Saudi Arabia" and the initiative of His Highness the Crown Prince to establish a "regional carbon capture, use and storage complex".
- 2) Development of Prototype for CO_2 Capture System, which is a development of a device for capturing carbon dioxide that can simulate the capture process in the laboratory when carbon dioxide gas is passed, and it consists of an integrated electronic control system integrated into the system Manufacture and development of carbon dioxide capture materials such as zeolite, mineral oxide and natural recyclable materials from plant wastes.

Both projects grant a total of $8 million. These projects must be completed by end of December 2025.

South Africa

A pilot project is initiated, targeted finalisation in the 2023/24 financial year.

United Arab Emirates (UAE)

ADNOC Announces Comprehensive 2030 Sustainability Goals and CCUS expansion capacity of 500% in the next 10 years.

United Kingdom (UK)

In November 2020, the UK government published the Ten Point Plan for a Green Industrial Revolution. One of the ten points was CCUS and this resulted in several funding schemes for CCUS:

- CCUS cluster sequencing process (https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-2). The Ten Point Plan included a commitment to deploy CCUS in a minimum of two clusters by the mid-2020s, and four clusters by 2030 at the latest, with an ambition to capture 10MtCO_2/year by 2030. For status as of August 2022, see Section 2.2.2. , the status is:
- Up to £170m from the Industrial Decarbonisation Challenge Fund being delivered between 2021 - 2024 through the Industrial Decarbonisation Challenge. Up to £100m funding to research and develop Direct Air Capture technology and other Greenhouse Gas Removal technologies, with initial projects receiving funding. £140m to set up the Hydrogen Revenue Support Scheme.
- Carbon Capture, Usage and Storage (CCUS). Innovation 2.0 competition: call 2 (https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-innovation-20-competition-call-2). £20 million in grant funding will be available for projects developing novel CCUS technology and processes that reduce the cost of deployment. The programme will:

  - Bring down the cost of capturing and sequestering CO_2.
  - Help UK industry to understand the opportunity for developing.
  - Facilitate deploying next generation carbon capture technologies from 2025.
  - Support innovation in novel CCUS technology by increasing its technology and commercial readiness level (TRL & CRL).
  - Demonstrate and de-risk next generation CCUS technologies to allow it to deploy commercially from 2025.
- The Carbon Capture and Storage Infrastructure Fund (https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage). The fund was first announced in March 2020, and its allocation of £1bn was confirmed at the Spending Review in November 2020. The fund will support business models for Transport & Storage (T&S), power, industrial carbon capture (ICC), low carbon hydrogen and potentially bioenergy with carbon capture and storage (BECCS).

United States of America (USA)

Through the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law, USA will spend USD10+ billion in new carbon management funding over 5 years. (https://www.energy.gov/sites/default/files/2021-12/FECM%20Infrastructure%20Factsheet.pdf). The priority areas are:

- Carbon Dioxide Removal - Direct Air Capture.
  - $3.5 billion are allocated for fiscal years 2022-2026 to the development of four regional Direct Air Capture Hubs. Each hub will have the capacity to capture and store and/or utilize one million metric tons of CO_2 per year, will be networks of DAC projects, potential CO_2 off-takers, transportation infrastructure and storage infrastructure.
  - DAC Technology Prize Competition: In FY 2022, DOE is allocated $115 million funding fortwo prize competitions focused on DAC technologies: $100 million for commercial technologies and $15 million for pre-commercial technologies.
- Carbon Capture Demonstrations and Large Pilots: $3.5 billion is allocated through the newly established Office of Clean Energy Demonstrations, of which $2.5 billion is for demonstrations.
  - Each demonstration project shall be designed to further the development, deployment, and commercialization of technologies to capture and sequester carbon dioxide emissions from new and existing coal electric generation facilities, natural gas electric generation facilities, and industrial facilities.
  - The term “large-scale pilot project” means a pilot project that
    - Represents the scale of technology development beyond laboratory development and bench scale testing, but not yet advanced to the point of being tested under real operational conditions at commercial scale.
    - Represents the scale of technology necessary to gain the operational data needed to understand the technical and performance risks of the technology before the application of that technology at commercial scale or in commercial-scale demonstration.
    - Is large enough (i) to validate scaling factors; and (ii) to demonstrate the interaction between major components so that control philosophies for a new process can be developed and enable the technology to advance from

large-scale pilot project application to commercial-scale demonstration or application.

- Front-End Engineering Design Studies
  - Carbon Capture Technology Program: For FYs 2022-2026 $100 million is allocated for carbon capture technologies and a front-end engineering and design program for CO_2 transport infrastructure required to enable carbon capture, utilization and storage deployment.
- Carbon Dioxide Utilization and Storage
  - Carbon Storage Validation and Testing: $2.5 billion for fiscal years 2022-2026 to develop new or expanded large-scale commercial carbon sequestration projects and supporting transport infrastructure. These projects will prioritize commercial capacity development and the ability to support storage from multiple carbon capture facilities
  - Carbon Utilization Program: $310 million for FYs 2022-2026, is allocated for the Carbon Utilization Program, which will be granted to entities to procure and use commercial or industrial products that utilize CO_2 in a manner resulting in a product with significantly lower greenhouse gas emissions than alternatives.
- The CHIPS and Science Act is allocated $1 billion for carbon dioxide removal RD&D.

In addition, the newly established Office of Clean Energy Demonstrations is allocated $8 billion for at least four projects Hydrogen Hubs of which g at least one using fossil fuels with carbon management.

2.1.2.2. Non-CSLF member states

Denmark

- Combined funding for CC(U)S 37,2 bill. DKK (approx. 5 billion EUR; all in 2022-prices) with a total reduction estimate of 3,2 million tonnes CO_2 yearly from 2030
- Three companies pre-qualified for first tender round of CCUS funds for reduction of 0,4 million tonnes yearly from 2026, winner will be announced approx. primo 2023

Finland

- Finland currently hosts an active business cluster and investment portfolio of carbon capture and utilisation projects (e.g e-fuels production). Also, opportunities for long-term storage and permanent storage (CCS) are being studied by the companies.
- Investment pipeline is around 20 projects corresponding investments of approximately 1 billion euros. Many investments include hydrogen production.

Indonesia

A CCUS Project by BP Berau Ltd., Ubadari and Vorwata EGR Field development with onshore compression and CCUS, to increase production 0,5TSCF by 2045 and reduce CO_2 emission 33 MT by 2045 has been approved.

2.1.2.3. International partnerships.

The CO_2GeoNet update of CO_2 geological storage in 32 European countries from October 2021. The report addresses the following: national policies and climate-protection strategies; national legislation and regulations; national storage options, potential and capacity; large-

scale demonstration projects, pilot and test sites for CCS; research activities with respect to CO_2 storage; national actors driving CCS forward, public awareness and engagement. The overall conclusion is that the information compiled in the report reveals clear progress in Europe since 2012 in bringing CCS back onto national agendas to help to meet climate targets. This includes a move from research to implementation, developing CCS networks with hubs and clusters, the emergence of companies and sites offering a CO_2 transport and storage service" and PCI creating nuclei/stimuli to advance projects. More specifically, conclusions include are:

- In most Member States' National Energy and Climate Plans (NECP), CCS is mentioned as one of several options under consideration for decarbonizing industry and/or power generation or as a negative emission technology
- Planned activities in the individual Member States relating to CCS differ significantly, ranging from support for research activities, national capacity assessments and feasibility studies to an implementation of specific large-scale CCS projects.
- The EU Directive 2009/31/EC on the geological storage of CO_2 ("EU CCS Directive") has been transposed into national legislation in all EU Member States, Norway, and the UK
- As of June 2021, the geological storage of CO_2 is permitted in 19 of the 32 countries studied, though some countries exclude specific regions or impose limitations of the amount of CO_2 that could be injected annually. In the other 13 countries studied, CO_2 storage is *de facto* prohibited (9 countries) or neither allowed nor prohibited since it is not covered by specific laws (4 countries).
- Across Europe there is very limited experience with licencing procedures for CO_2 storage. Only Norway has practical experience with operational industrial-scale CO_2 storage sites (Sleipner, Snøhvit) that were regulated under the Norwegian Acts relevant for emissions from petroleum activities
- The level of knowledge, the quality of datasets and the format of presentation differ significantly from country to country. Detailed and comprehensive national storage atlases and databases are available in Norway, the UK, Spain, and the Nordic countries (Nordic CO_2 Storage Atlas), less detailed or partial assessments have been performed in many other countries, while in some countries, particularly in Eastern and South-Eastern Europe, only basic assessments have been carried out.
- In Europe, two large-scale CO_2 storage sites are currently in operation, namely Sleipner since 1996 and Snøhvit since 2008, both in the Norwegian Sector of the North Sea. On a pilot scale, the Icelandic Carbfix pilot project has developed CO_2 geological storage in basaltic rocks by rapid mineralisation
- In several European countries, test facilities are available for developing and optimising CO_2 capture technologies at different scales. Over the last few years, focus has shifted from capturing flue gases from fossil-fuelled power plants to pilots for capture on industrial facilities
- 1 out of 32 countries that responded to the questionnaire reported having at least one research institution carrying out CO_2 storage-related research; some countries reported more than fifteen institutions actively engaged. Fourteen of these countries reported hosting large-scale CCS research infrastructure, ranging from test sites to laboratory facilities.

The CCS4CEE project that brought together 11 countries in Central and Eastern Europe. The project addresses the "Climate Change Mitigation and Adaptation" programme area by

focusing on the challenge of achieving the deep reduction of GHG emissions across all sectors of the European economy by 2050 through deployment of carbon capture and storage (CCS) technologies. The project has held national seminars on CCS deployment in participating countries and have issued reports on issued reports on the assessment of current, past experiences and potential for CCS in the participating countries. Conclusions from the project are:

- CCS technologies are poised to help attain the EU's 2050 net-zero target, mainly by effecting emission reduction in energy-intensive industries and underpinning carbon removal solutions.
- There is a need for a carefully planned and well-coordinated scale-up of emerging CO_2 transport and storage networks, and for national governments to come forward with more ambitious support schemes for CCS projects.
- The understanding of CCS technologies in partner countries remains overwhelmingly limited.
- Attitudes towards climate change, a key narrative within which CCU and CCS are nested, are less urgent in partner countries than observed in western EU countries.
- Despite overall low public knowledge of CCS, opposing public attitudes have shown their potential to derail CCS projects. The most prominent example of public opposition is from Poland's attempt to establish the Bełchatów CCS demonstrator.
- In addition to low public knowledge, the positioning of institutions on CCU and CCS is, at best, vague.
- In some cases, the positions of national authorities are negative and conflicting: in Lithuania, the explicit position of the Parliament against CO_2 storage is at odds with the Ministry of Energy, which was exploring a CCS project at the time the ban on CO_2 storage was introduced.
- It is apparent that the need for addressing social acceptance of CCU and CCS in partner countries is threefold:
    - A robust position from leading and trustworthy institutions.
    - Concerted dialogue, and education of the public on climate change and CCU/CCS.
    - Relevant, factual media coverage.
- Given the socio-economic status of partner countries, the social acceptance aspects of CCU and CCS may in fact be one of the underestimated challenges of deploying these technologies.

Accelerating CCS Technologies, ACT. Funding agencies from 16 countries, regions, and provinces collaborating on transnational calls and knowledge sharing within CCUS. Consortium established in 2016 under Horizon2020. ACT has had three calls. The fourth call, in May 2022, had members from four countries (Germany, India, Norway and the United States) and the Canadian Province of Alberta.

The Clean Energy Transition Partnership (CETPartnership) is a multilateral and strategic partnership of national and regional research, development and innovation (RDI) programmes in European Member States (26 states) and Associated Countries (five+ one associated partner) aiming to boost and accelerate the energy transition and to support the implementation of the European Strategic Energy Technology Plan (SET Plan). The CETPartnership aims to empower the clean energy transition and contribute to the EU's goal of becoming the first climate-neutral continent by 2050, by pooling national and regional RDTI funding for a broad variety of technologies and system solutions required to make the

transition. There are seven Transition Research Initiatives (TRIs), of which TRI3 is Enabling Climate Neutrality with Storage Technologies, Renewable Fuels and CCU/CCS.

The Asia CCUS Network, an industry-academia-government platform aimed at promoting CCUS applications and boosting the business environment for CCUS development throughout Asia. More than 100 companies and organisations, together with Asia-Pacific governments, are co-operating in developing carbon capture, storage and utilisation (CCUS) projects as part of global efforts to achieve carbon neutrality by 2050. By June 2021 13 countries, comprising the 10 members of the Association of Southeast Asian Nations (Asean), Japan, the US and Australia, had expressed their intention to participate in the initiative, along with more than 100 international organisations, companies, financial and research institutes. At the launch of the network, Japan proposed $10bn in government funding for renewable and low-carbon projects in Asean nations under the Asia Energy Transition Initiative aiming to support development and demonstration of clean energy technology, including CCUS, towards decarbonisation. (Japan yesterday also proposed $10bn in government funding for renewable and low-carbon projects in Asean nations under the Asia Energy Transition Initiative aiming to support development and demonstration of clean energy technology, including CCUS, towards decarbonisation. (https://www.argusmedia.com/en/news/2227027-japan-drives-cooperation-on-carbon-capture; https://www.meti.go.jp/english/press/2021/0622_001.html)

2.1.2. Transferring knowledge

The CSLF Technical Group is active in leveraging knowledge and experience from large-scale projects. During the period June 2015 – November 2019, CSLF Technical Group meetings included nine workshops or special presentations to leverage knowledge and experience from large-scale projects. In 2022, the TG changed the meeting structure to include more knowledge sharing, as exemplified at the CSLF Technical Group meeting in Bergen, Norway, June 2022. At that meeting, panels discussed learnings from large-scale projects as well as laboratory and pilot-scale testing.

During the covid19 pandemic, organisations like CEM CCUS, IEAGHG, OGCI, CO2GeoNet, UKCCSA and GCCSI have held webinars where large-scale projects, operational, in construction or in advanced planning, have contributed knowledge and experience to large audiences. In particular, the CSLF TG organised a virtual workshop on industrial clusters and infrastructure hubs in cooperation with OGCI and IEAGHG.

DOE's Annual CCUS Meetings have included updates on large-scale CCUS projects:

- 2021 Carbon Management and Oil and Gas Research Project Review Meeting - Integrated CCUS Projects and FEED Studies
- 2020 Integrated Project Review Meeting - CCUS Integrated Projects

GHGT-15, in 2021, had a session on Demonstration Projects & Major National & International CCS Research Developments & Demonstration Programs

CO2 Data Share - The project CO_2 Storage Data Sharing Consortium – CO_2 Data Share – aims to establish a common platform for international sharing of reference data related to CO_2 storage. The concept is designed to promote research and development of new technology based on data and experience from demonstration.

Gassnova issued a report on lessons learned from the development of the Longship project, aimed at informing subsequent CCS projects, government actors and others who work to facilitate the use of CCS.

Further, the Quest and Alberta Carbon Trunk Line projects funded by the governments of Canada and Alberta are required to share technical information and lessons learned to help other future CCUS projects benefit from their lessons learned. Knowledge Sharing reports for these two CCUS projects are available on the Government of Alberta's website, while Alberta Innovates has enabled funding to support CCUS knowledge development and provided public access to its historical reports on its project library web page. Information on NRCan's investments in clean energy innovation and RD&D – including CCUS – is also available on NRCan's Current Investments page.

2.1.3. Developing and maturing Negative Emissions Technologies (NETs)

Support for Negative Emissions Technologies (NETs), Carbon Dioxide Removal (CDR) and Greenhouse Gas Removal (GGR) have seen significant progress the last few years:

- During COP-26 in November 2021, the US Secretary of Energy announced the US Carbon Negative Shot.
- CDR and DAC has become part of the US The Infrastructure Investment and Jobs Act (see 2.1.1).
- The US DOE has held meetings on CDR:
  - 2021 Direct Air Capture Kickoff Meeting .
  - 2021 Carbon Management and Oil and Gas Research Project Review Meeting - Carbon Dioxide Removal Research.
- Mission Innovation (MI) has initiated a mission on Carbon Dioxide Removal (CDR) to accelerate uptake of net negative emission technologies (NETs).
- CSLF organised workshop on CDR in June 2022.
- The conference GHGT-15 had a separate session on NETs.
- Major CCUS organisations like GCCSI, CEM CCUS and IEAGHG have invited to webinars on CDR or NETs.
- UK GGR Programme, The £8.6m research programme – co-supported by three Research Councils and the UK government – ran from 2017 to 2022. It sought to address the uncertainties relating to the cost effectiveness, scalability, and wider environmental and societal consequences of balancing the climate equation through 'negative emissions'.
  - The programme consisted of eleven component projects (4 consortia, 7 topic-specific projects) and involved over 20 universities and 30 research partners. Researchers from the programme have published nearly 300 research articles.
  - The next stage of research into GGR has now started with the launch of the GGR Demonstrators (GGR-D) Programme in 2022 which is co-ordinated by the Greenhouse Gas Removal hub (CO2RE).
- Several reports on CDR/NET from a variety of organisations, including IEAGHG, IEA, GCCSI, and the Energy Transition Commission (ETC).
- CDR technologies have a prominent appearance in the IPCC 6th Assessment Report (AR6).
- EU has started work on the necessary rules to monitor, report and verify the authenticity of these removals.

2.1.4. Summary and conclusion

Several countries have established programmes for CCUS with significant funding. Together, these programmes should have the potential to:

- Reduce capture and storage costs by 25% from the 2020 level.
- Bring enabling and emerging capture technologies to technology readiness level 7 or above, including NETs.
- Continue the development and deployment of CO_2 utilisation technologies.
- Develop novel, emerging, and enabling technologies along the whole CCUS chain.

The programmes involve public-private partnerships, although to varying degree. There is also a continuous transfer of knowledge and experience from large-scale projects to new projects.

Conclusion

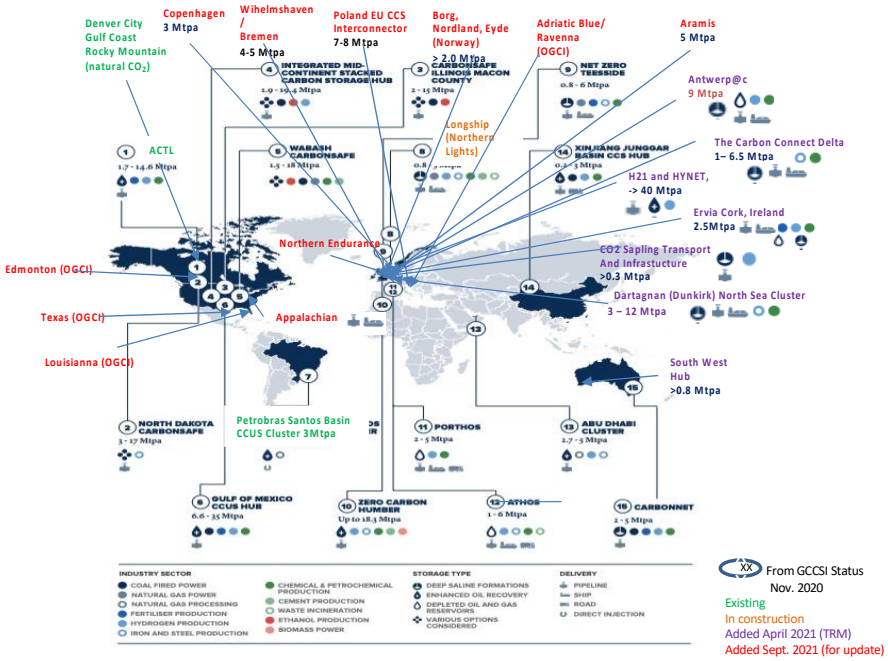
The progress within technology development, innovation and cost reductions is good.

2.2. Strategic build-out of CCUS projects and hubs

2.2.1. Identifying hubs and clusters

Figure 1 shows industrial hubs and clusters identified by literature search by the CSLF Technical Group up to and following the CSLF TRM 2021 until June 2022. It is likely that the maps do not include all proposed industrial hubs and clusters. Around 40 new projects were identified in the period April 2021 – Jun 2022, clearly showing that there is a rapid interest and willingness to identify and start planning of strategic power and industrial clusters with common transport and storage infrastructure.

By September 2021 (TRM 2021, GCCSI 2021 and literature search)



Additions September 2021- August 2022 (literature search)

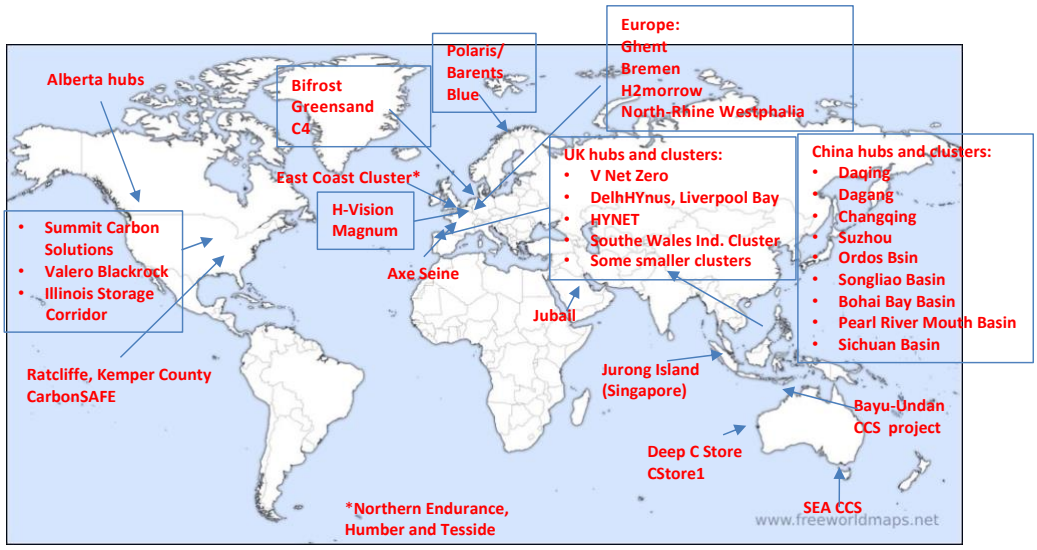


Figure 1. Identified infrastructure and industrial hubs by the CSLF Technical Group. Upper panel: Up to September 2021; Lower panel: September 2021 – June 2022. The sources are indicated above the maps. Some of the hubs in the lowert map may have been first announced a bit earlier but became more known after September 2021. The figure does not claim to be exhaustive.

Efforts to identify industrial CCUS hubs in the United States of America include:

- In February 2022 the Great Plains Institute issued an Atlas of Carbon and Hydrogen Hubs for United States Decarbonization.
- DOE organized a full day workshop on Models for Deployment of CCUS Hubs in September 2021.

In Canada, Phase 1 of Alberta's Carbon Sequestration Tenure competition resulted in 6 proposed hubs that will further evaluate if they can safely and permanently store CO_2 captured from Alberta's Industrial Heartland region. Phase 2 looks to develop carbon storage hubs in the rest of Alberta – with selections expected in 2022. Phase 1 hubs selected include:

- Meadowbrook Hub Project, Bison Low Carbon Ventures Inc. (north of Edmonton).
- The Open Access Wabamun Carbon Hub, Enbridge Inc. (west of Edmonton).
- The Origins Project, Enhance Energy Inc. (south of Edmonton).
- Alberta Carbon Grid™, Pembina Pipeline, TC Energy (north/northeast of Edmonton).
- Atlas Carbon Sequestration Hub (Atlas Hub), Shell Canada Limited, ATCO Energy Solutions Ltd., Suncor Energy Inc. (east of Edmonton).
- Wolf Midstream and partners (east of Edmonton).

Finally, a major project to identify industrial CO_2 clusters and transport and storage infrastructure is the Oil and Gas Climate Initiative (OGCI) CCUS KickStarter Initiative, launched in 2019 to help establish multiple low-carbon hubs. These CCUS hubs take carbon dioxide from several emitting sources, such as heavy industries and power, and then transport and store it using common infrastructure. OGCI companies are now developing over 20 CCUS hubs around the world.

The Kickstarter Initiative has later been expanded. In 2022, OGCI launched The CCUS Hub (https://ccushub.ogci.com/) to help regulators, industrial emitters and transport & storage operators to identify potential hubs and learn lessons on how best to set them up from the most advanced hubs. The platform has three parts:

1. The CCUS Hub Search (https://ccushub.ogci.com/ccus-hub-search/) is an interactive map tool, developed by BCG and OGCI. CO_2 sources from a range of emitting industries are matched with possible storage locations, thereby identifying 279 potential CCUS hubs in 56 countries. Based on this, possible and optimal hub areas are identified, based on estimates of cost per tonne. The whole chain, capture, transport and storage, is included. The tool is designed as a starting point for political decision-makers, industrial emitters and potential hub developers who want an overview of the potential viable CCUS hubs in their country, region or sector.
2. The Playbook, is based on in-depth interviews with hub developers, transport & storage operators, regulators and emitters in the more advanced hubs supported by OGCI as part of its KickStarter initiative. The Playbook can be downloaded from https://ccushub.ogci.com/about-us/.
3. Hubs in Action (https://ccushub.ogci.com/hubs-in-action/) overviews of six emerging CCUS hubs that were part of OGCI's initial KickStarter initiative. OGCI member companies are now actively involved in over 20 emerging hubs and there are at least 40 hubs globally in planning or in the works. New hub profiles will be added to this section over the coming months. The six emerging hubs/clusters are:

a. Net Zero Teesside, UK.
b. The Northern Lights/Longship, Norway.
c. Porthos, The Netherlands.
d. China Northwest, China.
e. Ravenna, Italy.
f. Louisiana, USA.

2.2.2. Projects that will be in operation before 2030

Most of the hubs in Figure 1 are in early stages of planning and are unlikely to be in operation by 2030. However, one will certainly be and other three are very likely to be in operation in time frame 2024 – 2027. These are:

- The Porthos project in the Netherlands is about to complete the FEED studies and is aiming for FID in the second half of 2022. The Dutch government has awarded €2.1 billion from the SDE++ funding scheme in subsidies to companies that will deliver CO_2 to the Porthos CO_2 transport and storage project. Three issues must be concluded before the FID can be taken in the second half of 2022:
  1. Technical development of the transport and storage infrastructure
  2. Environmental Impact Assessment and permits
  3. Agreements with companies to supply CO_2 and with the Dutch government to enable CCUS.

  Porthos is expected to come online by 2024/25.

- Longship, in Norway, a project in which 400 000 tonnes CO_2/year is captured from each of a cement plant and a waste-to-energy facility in south-east Norway and transported by ship to a terminal on the west coast and pipe to storage site in the North Sea, passed FID and is well into construction. The pipeline from the terminal to the Aurora storage site, operated by a joint venture called Northern Lights, has capacity to receive CO_2 from other sources as well, and memoranda of understanding (MoU) has been signed with several potential CO_2 sources in Europe. In late August 2022, the fertilizer producer Yara signed an agreement with Northern Lights to store additional 800 000 tonnes CO_2/year from their plant in Sluiskil, the Netherlands.

  Longship is expected to come online by 2024/25.

- The HyNet and the East Coast Cluster are carbon capture, utilisation, and storage projects in the United Kingdom are part of the CCUS cluster sequencing process is described in Section 2.1.2.1northern England that are the initial beneficiaries of a £1 billion ($1.38 billion) pot of state funding, with the Scottish Cluster as a backup option if talks with either of the preferred contenders fall through. In August 2022 the UK Government announced a short list of 20 power, industrial and hydrogen projects to be considered for financing under Phase 2 of its Carbon Capture, Usage and Storage (CCUS) Cluster Sequencing programme. The Phase 2 competition is targeted at CCUS projects wishing to connect to the CO_2 transport and storage infrastructure that will be developed for these clusters. Among the 20 shortlisted projects, 14 link to the East Coast cluster and 6 to the HyNet cluster Most shortlisted projects are industrial carbon capture (13), including

Waste-to-Energy, oil refinery, and the fertiliser industry. The remaining projects are hydrogen (4) and power plants coupled with CCS (3).

Projects of common interest (PCIs) are key cross border infrastructure projects that link the energy systems of EU countries. Projects on the list qualify for EU support. The fifth PCI list, adopted in November 2021, included the following projects in addition to Porthos and Northern Lights (the transport and storage part of Northern Lights) that have potential to become online by 2030:

Name	Description	Comments
CO2 Sapling Transport and Infrastructure Project	CO2 Sapling Project is the transportation infrastructure component of the Acorn full chain CCS project	Also on third PCI list of 2017
Aramis	Cross-border CO_2 transport and storage project (intake from emitters in the hinterland of Rotterdam harbour area and storage to location on the Dutch continental shelf)	New
Dartagnan	CO_2 export Multimodal HUB from Dunkirk and its hinterland (emitters from the industrial cluster in the area of Dunkirk, France with storage where available in the North Sea country territories)	New
EU CCS Interconnector	Poland – EU CCS Interconnector (emitters from the industrial cluster in the area around Gdansk, Poland with storage where available in the North Sea country territories)	New

In the United States, the Department of Energy (DOE) has allocated $2.5 billion for Fiscal Years 2022-2026 to develop new or expanded large-scale commercial carbon sequestration projects and supporting transport infrastructure. These projects will prioritize commercial capacity development and the ability to support storage from multiple carbon capture facilities.

In Canada, Pathway Alliance is conducting a FEED study to lead to the construction of a first-of-a-kind carbon capture and storage network which could gather captured CO_2 from approximately 20 oil sands facilities and transport it to a hub in Alberta for safe underground storage (https://www.eralberta.ca/projects/details/oil-sands-ccus-pathways-to-net-zero/).

2.2.3. Hydrogen production with CCU

Many of the hubs include hydrogen production from fossil fuel, particularly natural gas, with CCUS.

The US Bipartisan Infrastructure Bill includes $3.5 billion for the development of hydrogen hubs.

2.2.4. Summary and conclusions

Four of the hubs and clusters project under development by the publication of the CSLF TRM 2021 (April 2021) are very likely to be brought to operation by 2030. These projects have ensured storage site characterisation. It is uncertain how many other or projects under planning will come online by 2030.

Several potential strategic industrial CO_2 capture clusters with common CO_2 transportation and storage infrastructure (hubs) have identified and have become in planning since the CSLF TRM 2021 was published. However, it is uncertain if these will come online in sufficient number by 2030 to ensure a 10-fold increase of industrial production facilities, power and heat plans and waste-to-energy plants[4].

Several of the identified clusters include hydrogen production from fossil fuels with CCUS.

Conclusion
Progress is good in the way that an extensive number of potential hubs and clusters have been identified and several are in early planning**. However, more projects need to enter FEED and pass FID meet the challenge of a 10-15 fold increase in captured and stored CO_2 by 2030.**

2.3. Development of strategy, policy, legal, and financial frameworks

2.3.1. Agreements under the United Nations Framework Convention on Climate Change (UNFCCC) Umbrella.

An important milestone since April 2021 was the 26th Conference of the Parties (COP26) in Glasgow, Scotland, 31 October – 12 November 2021. From this meeting, one can note that

- 123 countries had submitted updated Nationally Determined Contributions to the UNFCCC but just 16 include CCS (Norway, UAE, Australia, Iceland, USA, Canada, Malawi, Qatar, Tunisia, Pakistan, Kuwait, Togo, Bahrain, Saudi Arabia, China, Mongolia) and 3 that implicitly include CCS (UK, EU, Indonesia).
- Further, of the 43 countries that had submitted Long-term GHG strategies (mid-century) as of 9th November 2021, 33 contain CCS as a mitigation activity.
- The parties decided to adopt:
  - Glasgow Climate Pact.
  - Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement.
  - Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement.
  - Work programme under the framework for non-market approaches referred to in Article 6, paragraph 8, of the Paris Agreement.

From the updated NDCs, one can note that the total global GHG emission level in 2030, taking into account the implementation of all the latest NDCs, is expected to be 15.9 per cent above the 2010 level. When these numbers are compared to the IPCC's estimate that limiting global average temperature increases to 1.5°C requires a reduction of CO_2 emissions of 45% from the 2010 level by 2030 or a 25% reduction by 2030 to limit warming to 2°C, the conclusion is that world is far from being on track to reach the goal of the Paris Agreement[5].

[4] From the left map in Figure 1, 5 hubs and clusters were operational in April 2021. A stricter definition will say only one.
[5] https://unfccc.int/documents/307628

In 2021 the global energy-related CO_2 emissions are estimated to have been 36.3 Gt in 2021[6], the highest ever. Global energy-related CO_2 emissions have steadily increased over the past ten years. This underscores the challenge.

2.3.2. International Agreements outside UNFCCC[7]

- Global Methane Pledge - 105 countries to reduce methane emissions by 30% by 2030
- Glasgow Financial Alliance for Net Zero (GFANZ) - 450 banks, asset managers and insurers, to deliver $130 trillion to transition global economies by 2050
- US-China Joint Glasgow Declaration – cooperation agreement including on CCUS and DAC, methane, China to phase down coal
- Global Coal to Clean Power Transition Statement - 46 countries, to rapidly scale up technologies and policies to achieve a transition away from unabated coal power generation.
- International Just Energy Transition Partnership - pledged $8.5 billion to end South Africa's reliance on coal, France, Germany, UK, the US and EU (although no mention of unabated coal at this stage)
- Beyond Oil and Gas Alliance (BOGA) - Costa Rica, Denmark, France, Greenland, Ireland, Quebec, Sweden and Wales (UK), commit to ending oil and gas exploration and production. Does not consider abated end-use of gas and oil.

2.3.3. National or regional CCUS strategies.

Strategies, incentive frameworks, business models, and risk-sharing mechanisms, legal, regulatory, and accounting frameworks have been implemented in several countries. Below follow some examples:

2.3.1.1. CSLF member states

Australia

The Climate Change Bill 2022 has emissions reductions targets of 43 per cent below 2005 levels by 2030, and net zero emissions by 2050. The Bill passed into Parliament and enshrined into law on 8 September 2022.

Canada

Through its 2030 Emission Reduction Plan, the government reaffirmed that a CCUS Strategy for Canada is in development, which is expected to be released in 2022. CCUS is critical to six key pathways in the Strategy: decarbonizing heavy industries, oil & gas, the power sector, enabling low-carbon hydrogen, negative emissions technologies/carbon dioxide removal, and CO_2-based industries. In Budget 2022, the Government of Canada announced design details of an investment tax credit (ITC) for CCUS projects that permanently store CO_2 in dedicated geological storage or in concrete, starting in 2022-23. Budgeted at CAD $2.6B/5 years, the ITC will apply to eligible expenses incurred before 2041, but rates will be reduced by 50% from 2031 (to incentivize projects this decade).

[6] https://iea.blob.core.windows.net/assets/c3086240-732b-4f6a-89d7-db01be018f5e/GlobalEnergyReviewCO2Emissionsin2021.pdf
[7] Adapted from ther IEAGHG

Canada's major oil sands producers announced in June 2022 the combination of three existing industry groups, all focused on responsible development, into a single organization called the Pathways Alliance with the goal to reduce annual oil sands emissions to net zero by 2050. The new organization incorporates the Oil Sands Pathways to Net Zero Alliance, launched in 2021, Canada's Oil Sands Innovation Alliance (COSIA), created in 2012, and the Oil Sands Community Alliance (OSCA), created in 2013 (https://pathwaysalliance.ca/key-oil-sands-groups-join-forces-under-pathways-alliance-banner/).

China

The Current Chinese government strategy for CCUS includes

- National 14th Five-year Plan
- Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy
- Action Plan on Peaking Carbon Dioxide Emission before 2030
- Scientific and Technological Deployment Strategy for Carbon Dioxide Peaking and Carbon Neutrality
- Implementation Plan of Synergetic Reduction of Pollution and Carbon Dioxide
- Implementation Plan for Carbon Peaking in Industrial Sector
- Deployment policies and programmes in place
    - CCUS research projects supported by the National Key R&D Programme
    - China Carbon Emission Trade Exchange (CCETE) officially launched
    - National Guidance of Promoting CCUS Demo projects

EU

The EU has also developed a Strategic Energy Plan (SET Plan), where CCUS is one of of ten priority actions (https://www.ccus-setplan.eu/news-events/news/; https://www.ccus-setplan.eu/about-set-plan/).

The Trans-European Networks for Energy (TEN-E) is a policy that is focused on linking the energy infrastructure of EU countries. As part of the policy, nine priority corridors and three priority thematic areas have been identified. The three priority thematic areas, which relate to the entire EU, include smart grids deployment, electricity highways, and a cross-border carbon dioxide network.

Germany:

- The Climate Law states 65 % reduction in emissions by 2030, Climate Neutrality by 2045, and negative emission from 2050
- The three party-coalition Coalition Agreement states *"We acknowledge the need also for technical negative emissions and will develop a long-term strategy for dealing with the approximately 5 percent of unavoidable residual emissions."*
- On State (Länder)-level: North Rhine-Westphalia released new Carbon Management Strategy in Oct. 2021.

Japan

Japan's industry ministry plans to create a legal framework for carbon capture and storage (CCS) to enable companies to start storing carbon dioxide underground or under the seabed by 2030 to help the nation achieve its 2050 carbon neutral goal[8].

[8] https://www.reuters.com/business/sustainable-business/japan-plans-set-legal-framework-carbon-storage-2022-04-21/

The Netherlands

The Dutch Climate Agreement is part of the Dutch climate policy. It is an agreement between many organizations and companies in the Netherlands to combat climate change. The agreement allows CCS in industry only (e.g. steel, refinery, hydrogen, fertilizer, waste incineration) but allows for subsidies, e.g through the SDE++ programme. The deployment of CCS is limited in 3 ways:

- There is a cap on the amount of subsidized CO_2 captured and stored.
- CCS only subsidized if no cost-effective alternatives.
- After 2035 no new subsidies granted to fossil CCS projects.

Negative emissions (DAC's + BECCS) are only foreseen after 2030.

In November 2021 the Netherlands and Norway signed a Memorandum of Understanding to promote bilateral cooperation in the field of carbon capture and storage (CCS), and exploring future areas of energy cooperation related to the North Sea

Norway

Norway introduced a CO2 tax in 1991 to contribute to cost efficient reductions of CO2 emissions. As a result of the tax, the gas field Sleipner started injection of CO2 removed from the produced natural gas in 1996. In more recent years, Norway has introduced regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transportation of CO_2 on the continental shelf. The first permit was issued to Northern Lights in 2019. In 2022 the Ministry of Petroleum and Energy has awarded two new exploration licenses for CO2 storage acreage, one in the North Sea and one in the Barents' Sea. Subject to acceptance of work commitments another license in the North Sea will be awarded in the fall of 2022.

The Law on Climate Targets (Climate Law) of 2017 (modified 2021) states that Norway shall reduce GHG emissions by 50-55% by 2030. By 2050, Norway shall be a low emissions society where GHG emissions are reduced to prevent harmful global warming as described by the Paris Agreement of December 12, 2015, Article 2 no. 1 Paragraph a, and based on the best available scientific knowledge, global and national circumstances. The law shall be compatible with Norway's NDCs and the relevant agreements with the EU on common implementation.

Other: An agreement with the Netherlands as described above. Norway has MoUs on CCS cooperation with the UK, The Netherlands and Belgium. Norway is open to enter into negotiations on bilateral agreements for import of CO_2 from other countries.

Saudi Arabia

- Current Management strategy for CCUS identified 20 initiatives across CCUS value Chain; this includes – 12 Technical Initiative, 4Regulation/Governance Initiatives; 2 R&D Initiatives, and 2 Enablers Initiatives.
- Ministry of Energy established Circular Carbon Economy National Program (CCE-NP) to supervising implementation across Hydrogen and Carbon management with a steering

Committee from government entities, research institutes and national champion to enable CCUS.

South Africa
CCUS identified as a key enabler of the Just Transition in SA as part of 2050 developmental goals.

UAE
- UAE has set target to become Net Zero by 2050 strategic initiative is working on the National Net Zero Strategy 2050.
- In its 2nd Nationally Determined Contribution (NDC) the UAE aims to reduce emissions by 23.5% by 2030, relative to the Business As Usual (BAU) scenario.
- UAE has delivered a Hydrogen Leadership roadmap (2021).
- A National Hydrogen Strategy which will include the CCUS/CCS hubs is anticipated to be published later 2022.
- Work on a Hydrogen Regulatory framework is ongoing.

UK
- The UK is committed to progressing CCUS as part of our 2050 Net Zero Strategy, utilising industrial "clusters" to capture and store 20-30 MtCO2 per year by 2030.
- Published the CCUS Investor Roadmap (Apr '22), summarising the government and industry's work on CCUS, outlining opportunities to drive investment for CCUS.
- Designed the CCUS (ICC, Power, Transport and Storage) and hydrogen business models to provide clear and long-term sight of revenue models, as well provide a stable investment environment for investment (updated in 2022).

USA
- New climate goals: 50% emissions reduction by 2030, 100% clean electricity by 2035, and net-zero carbon emissions by 2050.
- New goals on justice and equity and community engagement.
- Inflation Reduction Act: Reduce greenhouse gas emissions by about 1 gigaton in 2030, or a billion metric tons. Includes enhancements to 45Q tax credit (e.g., credit value increases, direct pay, extension of commence construction window, lower capture threshold)
- CHIPS and Science Act: $1 billion for carbon dioxide removal RD&D ($67 billion total for DOE).
- Bipartisan Infrastructure Law: $12 billion for carbon management approaches .
- Regional Initiative to Accelerate CCUS Deployment, Carbon Storage Assurance Facility Enterprise (CarbonSAFE), CCUS Demonstrations, and FEED Studies.

2.1.3.2. Non-CSLF member states

Denmark:
Key climate policy targets
- 70% reduction target by 2030 and climate neutrality by 2050
- CCS important technology to reduce emissions in otherwise hard to abate sectors e.g. cement, heavy industry, waste incineration
- Capture potential of large emitters in Denmark is estimated at 4,5-Mt pr. year in 2030, and geological storage capacity ui estimated to 400-700 Mt.

- Denmark aspires to become a Nordic Hub for CCS, storing not only from Denmark but also other countries

Current government strategy for CCUS

- Part 1: Storage (June 2021)
- Part 2: Capture and transportation (Dec. 2021)
- Part 3: Power to X strategy (March 2022)
- Part 4: State participation in CCS storage activities (June 2022)
  (Important related development: Carbon taxation reform in June 2022)

Finland

Key climate policy targets and CCUS-related deployment

- Climate neutrality by 2035
- The Sustainable Growth Programme for Finland allocated EUR 150 million to hydrogen and carbon capture and utilisation projects.
- E-fuels will be included in the transport fuel distribution obligation from the beginning of 2023.
- Government has initiated a strategic research project for carbon use and removals

Current Climate and Energy Strategy (2022) includes CCUS

- The development and use of carbon capture and utilization (CCS/CCU) technologies and solutions will be accelerated.
- E-fuels will amount to 3 per cent of all transport fuels by 2030.
- The legislative framework for CCS/CCU regulation at the EU level will be promoted.
- CCS/CCU techniques to reduce CO_2 emissions caused by waste incineration will be piloted.
- Legislative framework for carbon dioxide removal solutions, will be assessed.

Indonesia

Key climate policy targets

- Net Zero Emissions (NZE) 2060
  - Modelling roadmap NZE 2060, in balance of high ambition, science and the real economy
  - Inter-ministerial discussion on Long Term Strategy for Low Carbon and Climate Resilient for target carbon emission from energy sector.
  - Include CCS option in carbon emission strategy for steel and cement industry.
- NDC 2021 for carbon emission reduction by 2030
    - Alignment strategic plan 2030 into energy sector long term strategy NZE 2060
    - 2021-2022 prospect of CO_2 emissions reduction from upstream oil and gas by around 20 MTPA
    - 2030 net zero routine flaring policy for oil and gas activities
  - Current government strategy for CCS-CCUS
    - Involving research institutions as centre of Experts on CCS-CCUS
    - Strengthening cooperation to deploy CCS-CCUS project
  - Deployment policies and programmes in place
    - Carbon pricing system, cap and trade, cap and tax scheme in place, Issuance Act No. 7
    - Issuance Presidential Regulation Number 98 of 2021 regarding carbon pricing.

Nigeria

Key climate policy targets

- Revised NDC update: 20% unconditional and 47% conditional emissions reduction targets by 2030.
- Net Zero target (Energy Transition) by 2060.
- Long-Term Emissions Reduction Plan to achieve 50% by 2050 using a climate technology led approach.

Current government strategy for CCUS

- Identify near-term needs and opportunities for CCUS development and deployment that are consistent with Nigeria's net zero emission target by 2060.
- Creating an enabling environment through identifying storage resources; matching emission point sources and industrial clusters with CO_2 storage; developing legal and regulatory frameworks; performing techno-economic assessments; engaging with stakeholders; supporting capacity development; and ultimately piloting and demonstration of CCUS in industrial settings.

National CCUS Centre of Excellence Deployment policies and programmes in place

- Energy Transition Plan.
- Climate technology Need Assessment.
- Climate Change Bill.

Conclusion:

Progress is encouraging but insufficient to meet the challenge of a 10-15-fold increase in captured and stored CO_2 by 2030. ***More countries need to put the necessary regulations and financial frameworks in place.***

3. Overall evaluation of progress towards 2030

3.1. Progress towards meeting the challenges of the CSLF TRM 2021

The challenge outlined in the CSLF TRM 2021 is that the isolation from the atmosphere by CO_2 capture and storage should have increased by a factor of 10–15 from the 2020 level of 40 Mt CO_2 per year by 2030.

Several new CCUS projects have been announced since April 2021, many of them in connection with industrial hubs and infrastructure project (see. 2.2.3). However, most of them are at very early stages of planning and it is unlikely that the projects will be in operation by 2030. They may will most probably not add sufficiently to the 300 Mt CO_2/year increase in captured and stored CO_2 that the CSLF TRM 2021 indicated by 2030. Thus, regardless of progress in the announced plans, the deployment of CCUS lags behind what is needed to reach the recommended increase of CCUS deployment by a factor of 10 -15 above 2020 level (40 Mt CO_2/year) by 2030, as well as what is required in the scenarios of IPCC and IEA.

Overall Rating:

Progress is encouraging but insufficient to meet the challenge of a 10-15-fold increase in captured and stored CO_2 by 2030**.**

More countries need to put the necessary regulations and financial frameworks in place.

3.2. Concluding remarks

Deployment of CCUS at scale is not possible without supportive policy settings, long-term political commitment, public acceptance, and the appropriate financial support for early and long-term CCUS deployment.

The CSLF Technical Group invites all its members, Clean Energy Ministerial members, and all other relevant countries, as well as industry and the financial sector, to join forces to work together to achieve rapid and tangible progress on the above pathway.

The CSLF, together with other international CCUS Initiative, will continue to offer a platform for its member governments, industry, and the financial sector to come together to identify both immediate and longer-term investment opportunities and to accelerate CCUS deployment