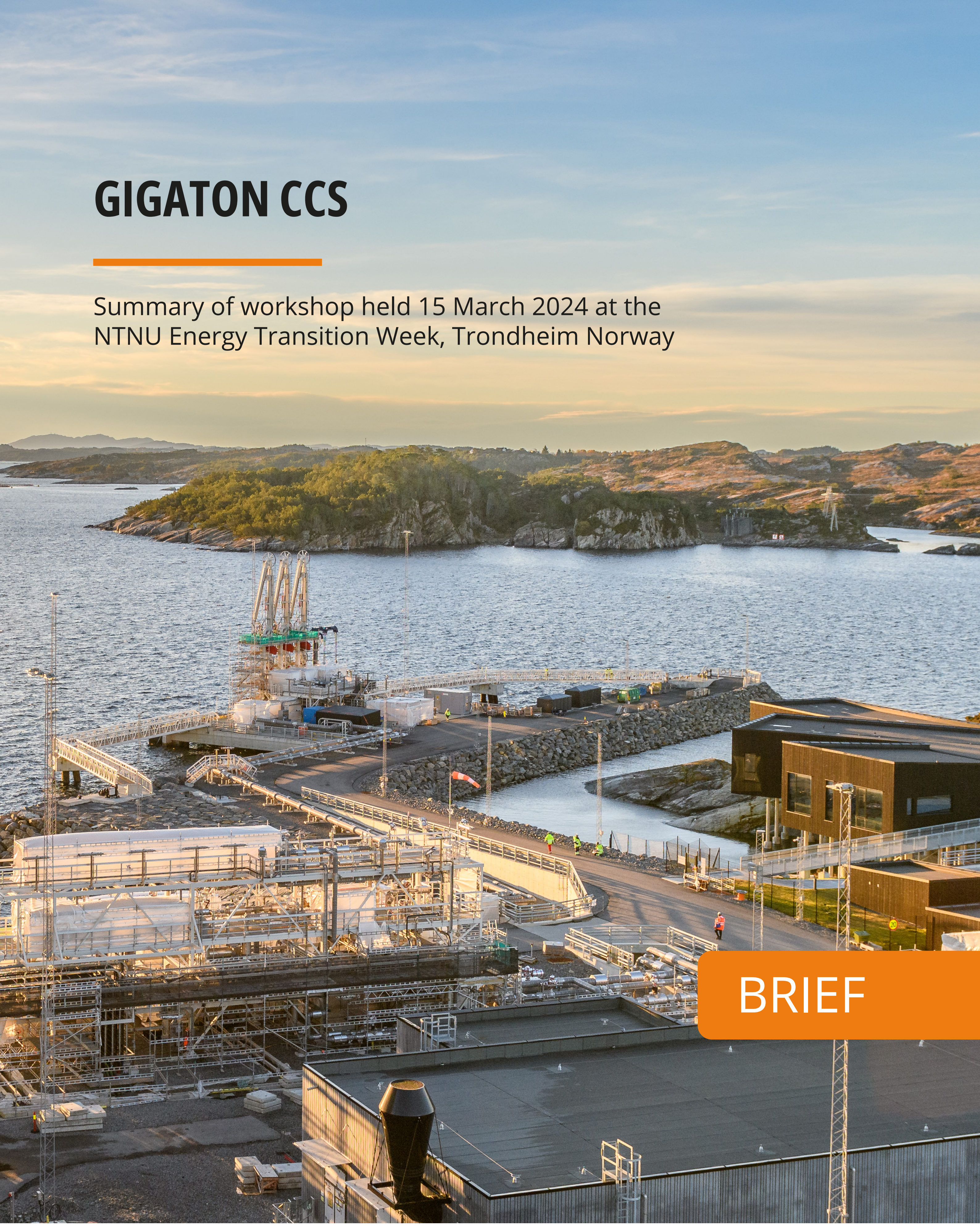
GIGATON CCS

Summary of workshop held 15 March 2024 at the NTNU Energy Transition Week, Trondheim Norway



BRIEF

NTNU ENERGY TRANSITION

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Brief 02/2024

Link to workshop programme

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Note:
This report should not be used as scientific facts and conclusion, but rather as a summary of important issues and aspects discussed at the workshop.

Cover page: Northern Lights storage tanks
Photo by Svein Ove Søreide

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IN BRIEF

It is widely recognized that carbon capture and storage (CCS) deployment at gigaton scale is vital for a just and sustainable transition to net-zero emissions. Proposed initially as a method of disposing CO_2 emissions that are difficult to eliminate, e.g. from steel and cement production and waste handling, CCS is now also being utilized to mitigate both past and future emissions from the atmosphere (carbon dioxide removal, CDR).

Interest in CCS as a climate mitigation tool is at an all-time-high. Where are we now? Are we getting closer to the tipping point leading us in the right direction with CCS implementation? What will it take to build the necessary momentum? And is the industry ready? Our recent workshop 'Gigaton CCS' served as a vibrant platform for exploring this. The rich discussions and highlights from leading experts in the domain are briefly encapsulated in this workshop summary document.

Launching large-scale CCS projects of significance is complex, costly, area- and energy-intensive and involve complex regional and local conditions that are best solved through collaboration, robust policies and incentive schemes and societal acceptance. Successful examples are vital to pave the way for future initiatives. As such, the Norwegian Longship and Northern Lights projects, if successful, will help reduce costs and build credibility for the technology.

The limited growth rate observed poses a significant challenge to meeting climate goals. Decision-makers must consider the potential impact of slow CCS growth and plan for contingencies if necessary.

CONTENT

TEASER: IS CCS REALLY THAT EXPENSIVE?

It is relevant to ask the question '**Is CCS really that expensive?**'. A recent study led by SINTEF Energy Research has analyzed the costs and benefits of implementing CCS into various industrial applications (including cement, iron and steel, oil and gas production, natural gas processing, refineries, ship propulsion, pulp and paper mill, urea production, waste-to-energy, and direct air capture) on the cost and environmental footprint of different end-products and end-services (bridges, wind turbines, container transport by ship, magazines, avocado, waste treatment, long distance air travel and beer).

The research shows that for many of the cases looked at, we can achieve at least 50% emission reduction at a maximum cost increase of 2% on the price that would be paid by end-users. Moreover, a recent survey reveals that 69% of the global population is willing to pay a portion (1%) of their income to reduce emissions significantly (Andre et al., 2024). This shift in mindset is crucial as increasing costs for consumers need to be acceptable, and this study indicates that that is feasible for most cases.

SETTING THE SCENE

Why the need for gigaton CCS

Oil and gas make up the majority of the current energy system (Figure 1) and will remain significant sources for many years to come. Figure 1 shows that as cheap fossil fuels became available, we vastly expanded our use of them. Our overall dependencies of fossil fuels uphold the CO_2 emissions despite of exponential growth in renewables.

The IPCC's latest assessment report shows that the global greenhouse gas emissions trajectory is higher than previously assumed and that net zero 2050 goals may not be sufficient to meet the ambitious climate targets of 1.5 – 2.0 deg C. Furthermore, projections for electricity demand have not accounted for increasing demand from e.g., data centers, which poses a challenge for decarbonization.

Where are we now with CCS and what projections do we see?

Decarbonization of the society will require CCS effort of 2-6 gigatons captured and stored CO_2 annually by 2050. However, despite the significant storage capacity anticipated available for CO_2 injection globally, CCS scale-up is currently in its early stages, with only a few hundred million tons of planned capacity, see Figure 2. To achieve the necessary 1 gigaton capacity by 2030, annual growth rates of 20-30% are required. The top five countries with projects in their pipelines are US, UK, Canada, China, and Norway, and the announced CO_2 capture project portfolio in 2030 is expected to be diverse, including capture on natural gas processing plants, H_2 / Ammonia plants, power and heat, cement plants, waste incineration and biofuels.

The limited growth rate observed for CCS thus far poses a significant challenge to meeting climate goals. Decision-makers must consider the potential impact of slow CCS growth and plan for contingencies if necessary. Meanwhile, planning for sluggish CCS scaling while redoubling efforts to rapidly scale the technology can help reduce risks of large and extended temperature overshoot. It is therefore essential to un-

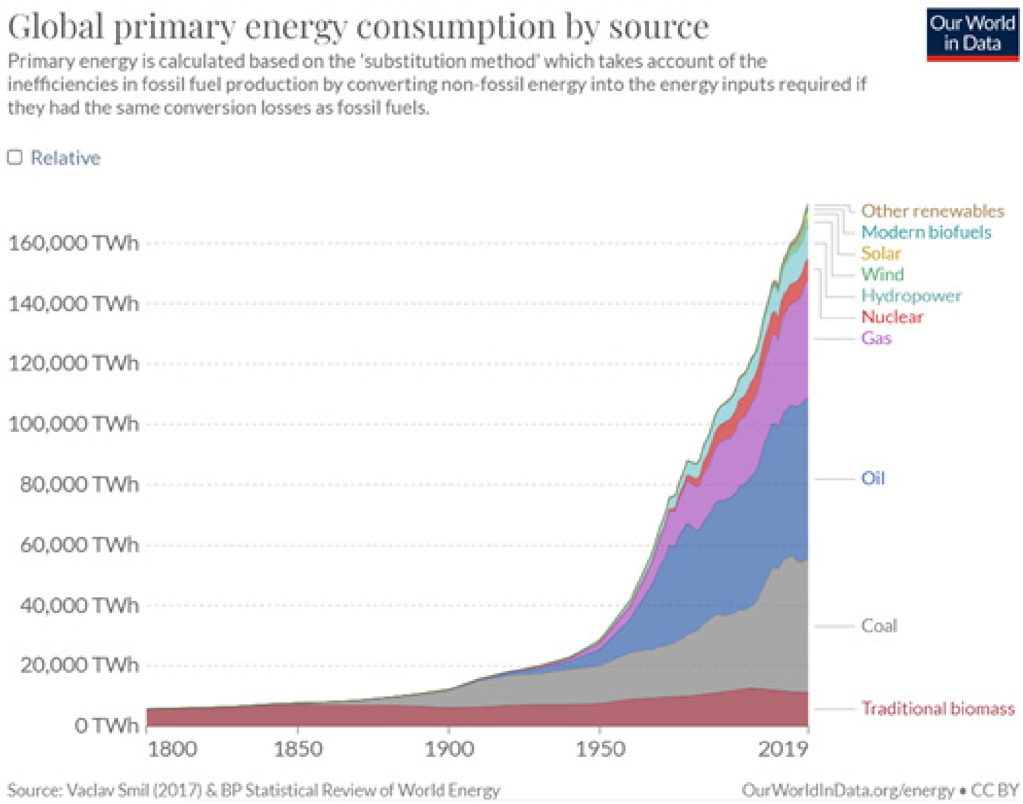

Figure 1: Global primary energy consumption by source (Source: Our World in Data; Vaclav Smil (2017) & BP Statistical Review of World Energy).

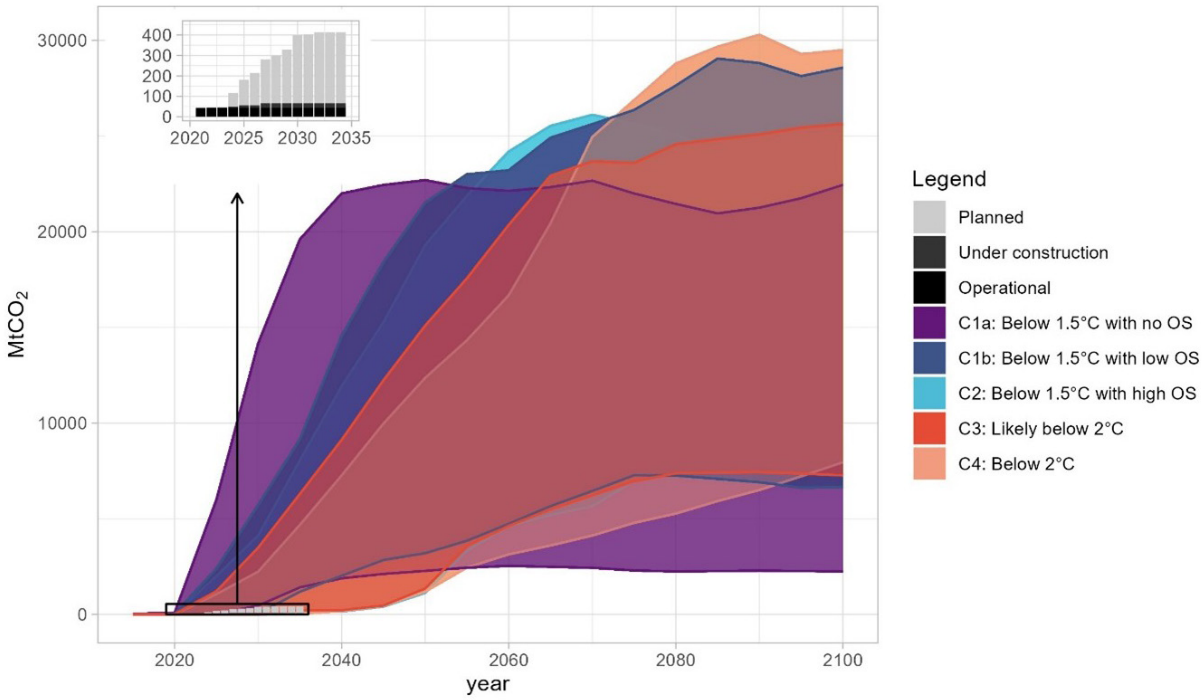

Figure 2: Projected CCS diverges from real-world planned capacity (Source: Jay Fuhrman, PNNL).

derstand the necessity for CCS in many parts of the economy while also being cautious about unrealistic projections and marketing tactics. CCS projects like Norway's Longship and Northern Lights, if successful, will help reduce costs and build credibility for the technology.

Where are we with Carbon Capture and Storage technologies?

Capture technologies: The announced CO_2 capture project portfolio in 2030 is expected to be diverse, including capture from natural gas processing plants, H_2 / Ammonia plants, power and heat, cement, waste incinerations and biofuels. However, there are challenges associated with scaling up CCS, such as the large energy requirements needed to run the capture process and downstream transport and intermediate storage capacity. Investment in energy reduction measures is necessary to reduce the overall cost of CO_2 capture. Large scale capture plants require also significant land area and substantial absorber towers, making integration into existing plant areas challenging.

Despite technical challenges, companies such as Aker Carbon Capture, believe they can scale up their carbon capture plants from today's smaller scale units to 2 million tons CO_2/year units. However, these large-scale deployments also depend on the energy system and the supply of energy.

Transport technologies: CO_2 is transported either by truck, ship, or in pipelines from the capture plant to permanent storage location. It is critical to dimension these transport systems in a way that cater for the complex nature of CO_2, both in terms of corrosion issues as well as the phase behavior of CO_2. Pure CO_2 has two phases – it acts like a liquid at high pressures and transitions into gas when the pressure is lowered. The phase behavior becomes more complex when other components are added. NTNU and SINTEF have been studying CO_2 mixtures for decades and have made significant progress in understanding depressurization mechanisms using equilibrium cells at high pressure and various temperatures and harsh environments. These studies have led to a better understanding of the trajectory of the CO_2 mixtures, which again will lead to safer and more effective transport of CO_2. However, more research is required to fully understand the flow behavior of CO_2 mixtures.

Storage technologies: Effective storage of large amounts of CO_2 over a long period at a reasonable cost and in an environmental-friendly manner is crucial in CCS. Depleted oil and gas reservoirs and saline aquifers are believed to be abundant storage sites globally, with some successful experiences such as Equinor's storage of CO_2 in the Sleipner area since 1996 and in the Snøhvit field since 2008.

However, four key storage tasks and problems need to be solved to reach cost efficient and environmental-friendly standards: i) building cost-efficient CO_2 facilities and wells, ii) ensuring CO_2 storage integrity and monitoring, iii) optimizing CO_2 storage maturation, and iv) developing CCS data and digital solutions. Currently, the cost of CO_2 systems is higher than that of oil and gas equivalents, and well integrity and well control remain issues. It is also crucial to understand and manage the environmental consequences, reliable CO_2 containment at scale and monitoring in accordance with authority requirements.

As part of scaling up, it is important to accelerate screening and maturation of storage sites and clusters, de-risk and optimize CO_2 injection concepts, and develop fit-for-purpose IT architecture and platforms to better steer injection optimization. By addressing these challenges, cost-efficient, environmentally friendly, and safe storage of large amounts of CO_2 can be achieved.

IS THE INDUSTRY READY?

Success of CCS on a large scale will require success stories to pave the way for further future developments. Therefore, if the Longship and Northern Lights projects in Norway are successful, they could provide essential input for cost reduction measures and the technology and policy development necessary for global upscaling of CCS.

The Longship CCS project is Europe's first complete value chain for capturing, transporting, and storing industrial CO_2 emissions. Its stakeholders include Heidelberg Materials, with a CO_2 capture plant at their cement factory in Brevik, and Hafslund Oslo Celsio, who are developing a CO_2 capture project on their waste-to-energy facility in Oslo. CO_2 will be transported by ship from the capture sites to the Northern Lights onshore facility in Øygarden before being piped into a subsea storage reservoir. Heidelberg Material and Hafslund Oslo Celsio are expected to deliver about 400,000 tons of CO_2 each annually to the Longship project, equivalent to 1.6% of Norway's total emissions. Heidelberg Materials plans to transport its first batch of CO_2 for storage at the Northern Lights storage site in 2025.

Northern Lights offers CO_2 transport and storage as a service to the market, and it has already entered into agreements with Yara in the Netherlands and Ørsted in Denmark, as well as Hafslund Oslo Celsio and Heidelberg Materials.

Longship's experiences in adapting to current legislation have been shared with stakeholders across Europe, and the EU and Norway are working to improve the framework for reducing industrial emissions and providing CO_2 storage. Northern Lights and the Longship project are critical to achieving climate goals, and Norway is at the forefront of developing a technology that can store significant amounts of CO_2 from multiple countries.

Northern Lights is a **joint venture (JV)** with Equinor, Shell and TotalEnergies as partners. Establishing a JV offers significant benefits, including the ability to create a slim and fit-for-purpose organization that can access expertise and competence from various disciplines across their respective parent organizations as needed.

Both the Longship and Northern Lights projects have received state and public funding.

Waste is a major contributor to climate emissions worldwide, and the **Hafslund Oslo Celsio's** incineration plant in Klemetsrud is one of Oslo's largest CO_2 emitters. Therefore, capturing and storing the plant's CO_2 is crucial for Oslo's climate goals as well. If successful, this concept can be replicated on 500 waste incineration plants across Europe. About half of the CO_2 captured from a waste plant is negative emissions. By targeting these sources, not only does it prevent CO_2 from reaching the atmosphere but is also captures biogenic CO_2 that was recently part of the atmosphere and captured by the biomass in the waste. CO_2 capture on Europe's 500 replicable waste incineration plants, could contribute to 35 million tons of carbon removals annually.

The cement industry accounts for around 7% of global emissions, and **Heidelberg Materials** is the largest cement producer in Europe and the second largest globally. They aim to reduce their CO_2 emissions by 47% by 2030 compared to 1990 and have 13-14 carbon capture projects in their pipeline globally, with Brevik as part of Longship being the first. Slite in Sweden will hopefully be next in line, where the cement plant will be fueled by biomass, hence generating negative emissions. The Slite plant will capture 1.8 million tons of CO_2 annually, equivalent to 4% of Sweden's annual emissions. To accelerate project realization, Heidelberg Materials requires energy and CO_2 infrastructure, upfront Energy ETS-payments, public procurement incentives for low-carbon materials, and BECCS (bio-energy with carbon capture and storage) recognition in the EU ETS.

Equinor recognizes that oil and gas will remain part of the current energy mix for some decades and hence needs to decarbonize existing fossil energy sources through CCS and Blue Hydrogen to achieve its net-zero

CO_2 emission target by 2050. Therefore, the transport and storage of CO_2 form one of its strategic business goals, with the Northern Lights and Smeaheia projects as examples where third parties can store CO_2.

Based on solid progress, Equinor recently raised its ambition to 30-50 million tons per annum by 2035 (Equinor share) for transport and storage capacity, up from 15-30 million tons per annum CO_2. The North Sea has a special focus. The company is also expanding its portfolio in the US, with the Bayou Bend CCS hub project that can store up to 1 billion tons of CO_2. Equinor is also involved in a project investigating to build a dedicated CO_2 pipeline (the "CO_2 highway") from Northwestern Europe to storage locations in the North Sea. This pipeline could alone transport 30 million tons of CO_2 annually.

Ultimately, all pathways towards climate neutrality require carbon management solutions, and CCS will complement renewables and energy efficiency. Nevertheless, implementing large-scale CCS projects will require clever policies and incentives. Policies and incentives to support the growth of CCS continue to be developed, as seen in the highlights from the EU below.

THE EU INDUSTRIAL CARBON MANAGEMENT (ICM) STRATEGY

Despite EU's existing suite of policies supporting industrial carbon management and the projects currently under planning and development, operational large-scale CCS projects are currently limited in Europe.

Urgent action is needed to achieve our climate goals, and the EU's Industrial Carbon Management (ICM) strategy was adopted on 6 February 2024, in connection with the 2040 climate targets.

Starting with the binding requirement to capture 50 million tons of CO_2 by 2030 as part of the proposed Net Zero Industry Act (NZIA), the ICM aims to scale up to capturing 280 million tons in 2040, increasing to 450 million tons in 2050, with 250 million tons of corresponding storage capacity, Figure 3.

The policy framework is based on three pathways: i) fossil CCS from industrial sources, ii) BECCS and direct CO_2 capture from the atmosphere (DAC) and iii) utilizing CO_2 as a valuable resource (CCU). The strategy identifies a set of actions and a comprehensive policy framework to be taken both on the EU level, as well as on member state level to scale up these technologies and the necessary infrastructure.

The EU foresee **CO_2 networks** developing in hubs. Bundling emissions in clusters will help reducing costs.

The strategy aims to create a **single market for CO_2** so that it can flow freely across borders and the different carbon management pathways. EU has started to prepare a regulatory package for both transport and storage of CO_2 and initiated work on network planning and integration. A key priority for 2024 is to develop a set of standards for CO_2 streams. The different EU countries have different starting points, so a flexible approach is required to avoid the risk of over-regulating a developing market.

Carbon capture will require significant additional energy to power this energy-intensive process, and, in the case of biogenic carbon, sustainable sourcing of biomass. Supporting measures to coordinate within and between the pathways of carbon management is needed to establish a sound business case and give more certainty for investors.

CO_2 transport infrastructure is key, and the transport network could reach a length of 7,000 kilometers in 2030 and up to 19,000 kilometers in 2050, costing €6-20 billion by 2030 and €9-23 billion by 2050. For comparison, the entire Gassled gas pipeline network in the North Sea is 8,600 kilometers.

The EU sees the North Sea basin as the key area for **CO_2 storage**, however storage sites in the southern and eastern Europe should also be developed to reduce investment costs. The geological knowledge of CO_2 storage capabilities in Europe is scarce, so the strategy proposes to create a **storage atlas for Europe**.

While CCS industrial projects should develop and operate on commercial basis, some financing support will be needed to create the European market and infrastructure.

The EU already has several policies in place supporting carbon capture and storage, including the CCS Directive, the EU Emission Trading System (ETS), the Revised TEN-E Regulation, Project of Common Interest (PCIs), Project of mutual Interest (PMIs), the EU Innovation Fund, and the stakeholder dialogue arena CCUS Forum. An EU certification framework for carbon removals is soon to be adopted, and 20 member states have already included industrial carbon management solutions in their draft national energy and climate plans (NECPs). A revitalization of the CCUS Forum is planned. The proposed Net Zero Industry Act (NZIA) recognizes carbon capture and storage as strategic net-zero technologies and supports project deployment with regulatory measures, including accelerated permitting procedures.

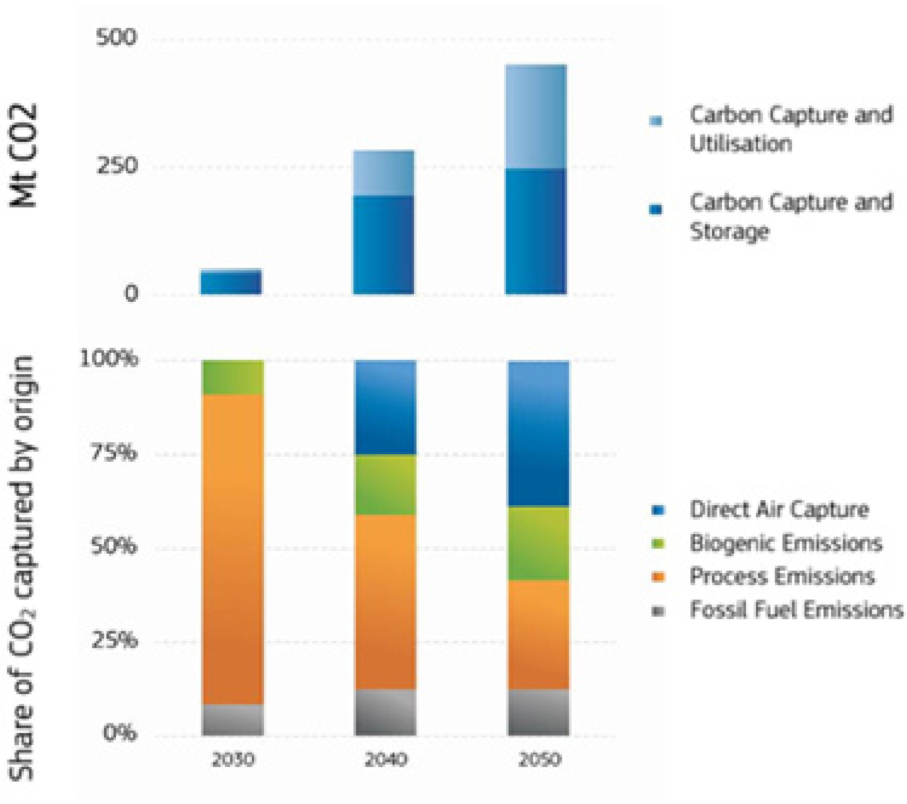

Figure 3: Volume of CO_2 captured for storage and utilization in the EU (above chart) and share of the CO_2 captured by origin (below chart) (Source: Communication from the EU Commission, February 2024)

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