4th Report of the Thematic Working Group on: Policy, regulation and public perception

The role of Carbon Dioxide Removals for Net Zero

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Executive summary

This report aims to provide a short overview of carbon dioxide removals (CDRs), their role in climate mitigation, current options based on nature-based solutions and negative emissions technologies (NETs), key policies across Europe as well as examples from projects on the ground.

The consensus based on credible models by the IPCC and European Commission agree that CDRs will have a role to play to support the achievement of net-zero by 2050 by addressing residual emissions from hard-to-abate sectors. However, it is important to stress the distinct function of CDRs as compared with emission reduction efforts. CDRs deployment must not be used as an excuse to delay current, urgent emissions reduction actions. CDRs should be used only to balance the residual emissions from sectors that are unlikely to achieve full decarbonisation by 2050.

Even with the increased attention on CDRs which has been seen in recent years and months, the concept is relatively new and often misinterpreted or misunderstood. To ensure that the deployment of CDRs results in positive climate outcomes a clear accounting, monitoring, reporting and verification framework is a pre-requirement. The recent European Commission Communication on Sustainable Carbon Cycles promises to propose a robust regulatory framework for accounting and certification of carbon removals. The Communication provides a strong backing for CDRs and acknowledges the importance of both nature-based solutions and technology options. Several other EU policies are also relevant for carbon dioxide removals, and these are briefly described in the report. In addition, current UK policy underpinning the deployment of carbon removal options is provided.

Finally, the report contains information from innovative European projects, and members of the CCUS Projects Network, working on the ground to realise carbon dioxide removals - KVA Linth (waste-to-energy project, Switzerland), Drax (BECCS project, UK) and Fortum Oslo Varme (waste-to-energy project, Norway).

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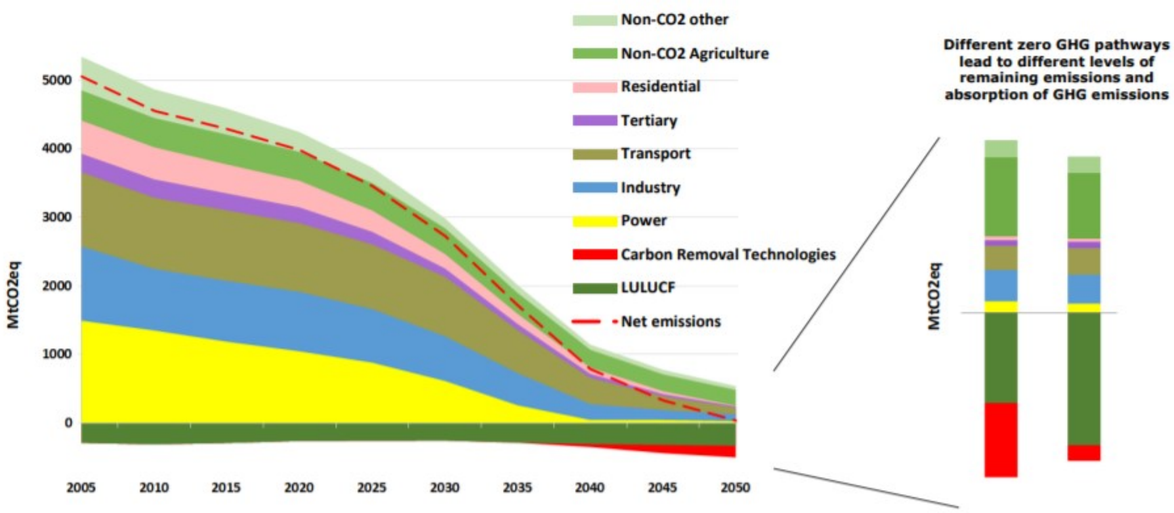
The role of Carbon Dioxide Removals for Net Zero

1 Introduction

Europe is undergoing transformative change in its quest to become the first carbon-neutral continent by 2050. The European Green Deal, presented in December 2019, aims at transforming the European Union (EU) into a modern, resource-efficient, and competitive economy. It aims at achieving a climate-neutral and prosperous continent by 2050. The European Climate Law, adopted in July 2021, writes into law the targets set out in the European Green Deal. It also sets a transitional target of reducing Greenhouse Gas (GHG) emissions by 55% in 2030 (compared to 1990 levels).

To achieve climate-neutrality by 2050, the models presented in the Intergovernmental Panel on Climate Change (IPCC) special report on Global Warming of 1.5°C[1] acknowledge that carbon dioxide removals (CDRs) will be needed to address residual emissions from hard-to-abate sectors. The EU's Long-Term Strategy also foresees a trajectory towards limiting the temperature increase to 1.5°C by 2050 where there is a need for negative emissions as shown in Figure 1-1. CDRs have a prominent role especially in two of the EU's Long-Term Strategy scenarios. The 1.5C TECH scenario focuses more on technological solutions and predicts a need for a negative emissions volume of 600 million tonnes per year (Mt/y). Under the 1.5C LIFE scenario CDRs are mostly achieved by nature-based solutions with a volume of 500 Mt/y of GHG emissions being removed.[2]

Figure 1-1 GHG emissions trajectory in a 1.5 ◦C scenario



Source: European Commission (2018) A Clean Planet for All

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[1] IPCC Special Report Global Warming of 1.5ºC, Intergovernmental Panel on Climate Change, 2018. Available at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

[2] EC (2018) In-Depth Analysis in Support of The Commission Communication COM(2018) 773. Available at: https://ec.europa.eu/clima/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf

Textbox 1-1 Clarification on terminology

There are various terms used to denote the negative emissions that will be needed to offset very hard-to-abate GHG emissions. These include **carbon dioxide removal** (CDR), **negative emissions** and **greenhouse gas removals** (GGR). In this report we are focusing on carbon dioxide removals only, as the terms GGR and negative emissions could apply to GHGs other than carbon dioxide in this report we will use the term carbon dioxide removals, CDR. **Negative emission technologies** (NETs) include CCS applied to technologies such as power generation from biomass combustion or direct air capture. This term will be used to distinguish the technology-based CDR options from nature-based ones.

Given that the term might be counterintuitive it is pertinent to stress that throughout the report 'positive emissions' are those released into the atmosphere and thus undesirable. As such, negative is good and positive is bad.

1.1 Carbon Dioxide Removals

On the most basic, conceptual, level CDR refers to removing carbon dioxide (CO_2) from the atmosphere and permanently storing it. The IPCC defines CDRs as 'anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial or ocean reservoirs, or in products'.[3] This can be accomplished by nature-based solutions such as forestation, soil management and wetland restoration or though negative emissions technologies (NETs) like bioenergy with carbon capture and storage (BECCS) or direct air capture with CCS (DACCS). These options are explained and discussed further below.

When it comes to evaluating which concrete options/projects do constitute CDRs, the below criteria have been proposed by the Zero Emissions Platform[4]:

1. Carbon dioxide is physically removed from the atmosphere.
2. The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent.
3. Upstream and downstream greenhouse gas emissions, associated with the removal and storage process, are comprehensively estimated and included in the emission balance.
4. The total quantity of atmospheric carbon dioxide removed and permanently stored is greater than the total quantity of carbon dioxide equivalent emitted to the atmosphere.

Whereas principles one and two above can serve as quick screening criteria, principles three and four should be carefully considered only when the first two principle are met. The practical application of

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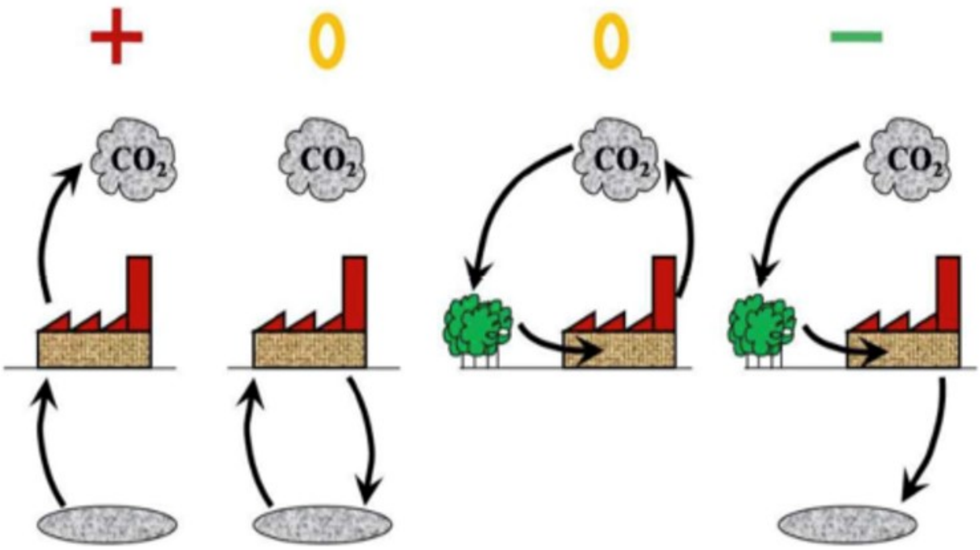
[3] Ibid. 2

[4] Zero Emissions Platform (2020) Europe needs a definition of Carbon Dioxide Removal. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/Europe-needs-a-definition-of-Carbon-Dioxide-Removal-July-2020-3.pdf

the above rules to evaluate whether a given process/projects can be called a CDR is demonstrated elsewhere[5]. It is important to stress the importance of a robust accounting framework based on life-cycle assessments (LCAs) to ensure that the options proposed do not emit more carbon than they remove[6].

Figure 1-2 illustrates different scenarios of CO_2 trajectories. In the first case (far left) fossil fuels are extracted from the ground, used for energy or in the petrochemical industry and the resulting CO_2 by-product is emitted into the atmosphere. The result is a net positive increase of CO_2 in the atmosphere. In the second and third cases no net CO_2 is emitted into the atmosphere given that the extracted CO_2 (in the form of fossil fuels) is captured and stored permanently underground or the CO_2 captured by plants and trees is re-emitted into the atmosphere when combusted. Finally, in the case illustrated on the far right, CO_2 from the atmosphere is taken up by plants for photosynthesis, these plants are used for bioenergy and the CO_2 generated is captured and stored undergrounds resulting in a net removal of CO_2 from the atmosphere.

Figure 1-2 Illustration of principles required to account for Carbon Dioxide Removals



Source: GCEP (2012) Assessment report from GCEP Workshop on Energy Supply with Negative Carbon Emissions

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[5] Ibid. 4

[6] For further information on this please see: Preston Aragones for the CCUS Projects Network (2021). Carbon removal: a crucial yet confusing element of climate mitigation. Available at: https://www.ccusnetwork.eu/news/carbon-removal-crucial-yet-confusing-element-climate-mitigation
Zero Emissions Platform (2020) Europe needs a definition of Carbon Dioxide Removal. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/Europe-needs-a-definition-of-Carbon-Dioxide-Removal-July-2020-3.pdf
Zero Emissions Platform (2021) Europe needs robust accounting for Carbon Dioxide Removal. Available at: https://drive.google.com/drive/folders/1v_JzWthEGBCAe08ghlaOU-Qir0_LmodH

1.2 Nature-based solutions

Nature-based solutions (NBS) for carbon dioxide removal rely on the sequestration of CO_2 by plants and/or other organic matter leading to a net removal of CO_2 from the atmosphere. On the other hand, enhanced natural processes are based on the intensification or acceleration of natural processes that trap CO_2. This can include addition of biochar to soils or enhanced weathering. Table 1-1 lists the main NBS solutions to CDR available, their potential for removing carbon dioxide from the atmosphere, estimated costs, benefits and drawbacks.

Table 1-1 List of the main nature-based solutions for CDR[7]

NBS	CDR potential	Costs	Benefits	Drawback
Forestation	0.5 – 3.6 $GtCO_2$/y	5-50 $/t$CO_2$	• Readily available for large-scale deployment	• Could result in albedo offsetting the positive CDR impact • Saturation of forest sinks • Vulnerability to disturbance (fires)
Soil carbon sequestration	2 – 5 $GtCO_2$/y	0-100 $ /tCO_2	• Readily available for large-scale deployment	• Risk of saturation and reversibility
Wetland restoration	Costal wetland restoration: 0.2 - 0.84 Gt CO_2e/y Peatland restoration 0.15 - 0.81 Gt CO_2e/y	Mangrove restoration: 510 $ /tCO_2	• Co-benefits: flood protection and mitigation, habitat creation, improved water quality	• Wetlands are a source of methane – a GHG • Uncertainty regarding net effects of wetlands on climate and metrics to use
Enhanced natural processes				
Enhanced weathering	2-4 Gt CO_2/y	50-200 $/t$CO_2$	• Climate change mitigation	• Concerns regarding potential increase in water pH, release of heavy metals, impacts on health due to particles of respirable size • Large demand for energy and infrastructure
Ocean fertilisation	N/A	N/A	• Potential for climate change mitigation	• Biological and chemical responses to fertilization are variable and difficult to predict. • Could results in harmful algal blooms. • Could result in production of harmful gases in the surface ocean offsetting the climate benefits • Potential harmful effects on seafloor ecosystems[8]
Biochar	0.3 – 2 Gt CO2/y	90-120 $/t$CO_2$	• Positives effects on soil quality, nutrients and water cycles	• Potential adverse effects on plant defences and albedo changes

[7] Information based on: EPRS (2021) Carbon dioxide removal: Nature-based and technological solutions
[8] Wallace, D.W.R. et al. (2010) Ocean Fertilization. A Scientific Summary for Policy Makers. Available at: http://www.igbp.net/download/18.1b8ae20512db692f2a680004381/1376383081959/oceanfertilization.pdf

1.3 Negative Emissions Technologies

1.3.1 Bioenergy with CCS (BECCS)

The term BECCS is generally applied to the combustion of biomass to generate power (heat and / or electricity). The CO_2 emitted during the process that converts biomass into energy is captured and stored in geological sinks via carbon capture and storage (CCS). Given that the biomass has previously captured CO_2 from the atmosphere via photosynthesis the overall result is that CO_2 is removed from the atmosphere.

There are several different bioenergy conversion processes. These include biogases as well as solid biomass combustion from processes such as anaerobic digestion (AD), which includes landfill and sewage treatment, wet-waste and crop residue feedstocks.

An important characteristic of BECCS is that it can be implemented in a broad range of sectors. Fuel-switching or co-firing of biomass, including waste biomass, enable decarbonisation of a number of industries including the pulp and paper industry which has long utilised waste biomass for heat and power production. Biogas can be used for electricity generation or in a combined heat and power (CHP) system to provide both electricity and heat. Combustion of solid biomass is the most common form of bioenergy in the world, most of it is used for generating fire for heating and cooking, mostly in developing countries. In addition, biomass can be fermented to produce alcohols such as bio-ethanol, which is used as a fuel.

A crucial consideration associated with BECCS is the sustainability of biomass given that the deployment of BECCS is ultimately reliant on the availability of sufficient, sustainably sourced, biomass. Important considerations with the use of bioenergy are the GHG emissions associated with land-use changes, potential adverse effects on biodiversity, the water footprint, and the adverse effects of fertiliser application such as poor water quality and non-CO_2 GHG emissions.[9]

Waste-to-energy

Waste-to-energy (WtE) can be considered a special case of BECCS (also referred to as energy-from-waste (EfW)). Generally, 40-60% of municipal solid waste used as input in WtE facilities is of biogenic origin[10]. Thus, by coupling the WtE process to CCS, WtE could be partially classified as BECCS and lead to negative CO_2 emissions.

A special report on WtE with CCS by the International Energy Agency's GHG Technical Group (IEAGHG) identified the EU Emissions Trading System (ETS) as a significant CO_2 reduction scheme in Europe, which however does not include waste incineration plants processing municipal solid waste. Specific incentives in Germany, The Netherlands, and Norway support the implementation of CCS in WtE incinerators. The UK is carrying out different green funding through schemes such as the 2017 Clean Growth Strategy.[11] The study also finds that the key elements to consider when evaluating the

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[9] EPRS (2021) Carbon dioxide removal: Nature-based and technological solutions. Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689336/EPRS_BRI(2021)689336_EN.pdf

[10] IEA Bioenergy (2021) Deployment of bio-CCS: case study on Waste-to-Energy. Available at: https://www.ieabioenergy.com/wp-content/uploads/2021/05/Becidan-2021-FINAL-IEA-Bio-BECCS-FOV-Case-study.pdf

[11] IEAGHG Technical Report 2020-06 – CCS on Waste to Energy. Available at: https://www.club-co2.fr/files/2021/01/2020-06-CCS-on-Waste-to-Energy.pdf

profitability of retrofitting CCS to WtE plants include location, type of CO_2 capture system, feedstock, incineration technology and the installation scenario (i.e. greenfield or retrofit).[12]

Other biogenic emissions

The alcoholic beverage industry also produces CO_2 through the fermentation process - whisky, gin, wine, and beer production - as a by-product of the process. Although the quantity of emissions is not as large as other point sources such as WtE, as we progress along the pathway to net zero the potential for negative emissions will become more economically viable, and in addition those emissions that we do not capture must be counted. For example, in Scotland an estimate of the potential for negative emissions from the production of grain whisky across seven sites in 2018 was of the order of 250 $ktCO_2$/yr.[13] However, there are advantages in cost over other sources of emissions, in that the CO_2 from these fermentation processes is almost pure, and therefore less energy is required for its collection.

As innovation develops and the move away from fossil fuel use builds, other sources of biogenic emissions may appear, such as pharmaceutical manufacture using biotechnology processes.

Thus, there are many sectors where CCS can be applied and enable negative emissions. Capture equipment is available to separate as little as 3.5 tCO_2/day or 1.300 tCO_2/yr[14], for the cases where the biogenic emissions of CO_2 are available in quantities such that capture is economically viable or desirable in terms of climate mitigation.

1.3.2 Direct Air Capture with CCS (DACCS)

Direct Air Capture with CCS is based on capturing CO_2 from the air and it encompasses several different technologies. The two main technology approaches are based on liquid and solid DACCS. Liquid DACCS passes air through chemical solutions that bind the CO_2 and remove it. Using high-temperature heat, the technology separates the solution and returns the rest of the air to the environment. Solid DACCS is based on a similar concept but the absorbent which captures the CO_2 is solid. The solid filters are heated and placed under a vacuum to release the concentrated CO_2, which is then captured and stored.[15]

Benefits of DACCS include its limited land and water footprint. The technology is also well suited for constructing plants on non-arable land close to suitable storage, thus bypassing the need for long-distance CO_2 transport.

On the other hand, the fact that CO_2 in the atmosphere is dilute means that the energy needed to capture the molecule from air is much higher than in the case of more concentrated streams such as, for example, flue gases from power stations and cement plants. Thus, the source of energy (e.g. fossil fuels vs. renewables) used to capture the CO_2 will determine how net-negative the system is (see section 2.1 on accounting principles). The energy requirements also impact the overall costs of the technology, especially as regards the operational costs (OPEX).

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[12] Ibid. 11

[13] Brownsort, P. (2018) Negative emission technology in Scotland: carbon capture and storage for biogenic CO2 emissions. Available at https://www.sccs.org.uk/images/expertise/reports/working-papers/WP_SCCS_2018_08_Negative_Emission_Technology_in_Scotland.pdf

[14] Ibid.

[15] IEA (2021) Direct Air Capture. Available at: https://www.iea.org/reports/direct-air-capture

At present, there are 19 DACCS plants operating worldwide, capturing a little over 0.01 Mt CO_2/yr.[16] In September 2021, a new DACCS plants came into operation in Iceland. The plant is capturing 4 kt CO_2/yr for storage in basalt formations.[17] In the sections below we provide a detailed description of key European NETs projects undertaken by members of the CCUS Projects Network.

Table 1-2 List of the main negative emissions technologies[18]

NET	CDR potential	Costs	Benefits	Drawback
BECCS (including biomass combustion for CHP, WtE/EfW, AD, waste processing, biomethane upgrading)	0.5 – 5 Gt CO_2/y 200 Mt CO2/y in Europe[19]	NA 15-400 $/t$CO_2$ avoided[20] Costs vary widely, depend on sector	• CCS has large capacity and low vulnerability, no issues associated with saturation or permanence. • Renewable, low-carbon electricity is generated in the process	• Potential for competition for land • Concerns related to bioenergy production: GHG emissions due to land-use change, adverse impact on biodiversity, changes in albedo, the waterfootprint
DACCS	0.5 – 5 Gt CO_2/y by 2050	100-300 $/t$CO_2$ (assuming economies of scale)	• CCS has large capacity and low vulnerability, no issues associated with saturation or permanence. • Limited land and water footprint	• High costs • Large energy requirements
Fermentation (distilling, beer and wine production, biotechnology processes for pharmaceuticals)	Unknown	Unknown	• High concentration sources of CO_2	• Distributed, low quantity sources

2 Potential of different CDR solutions

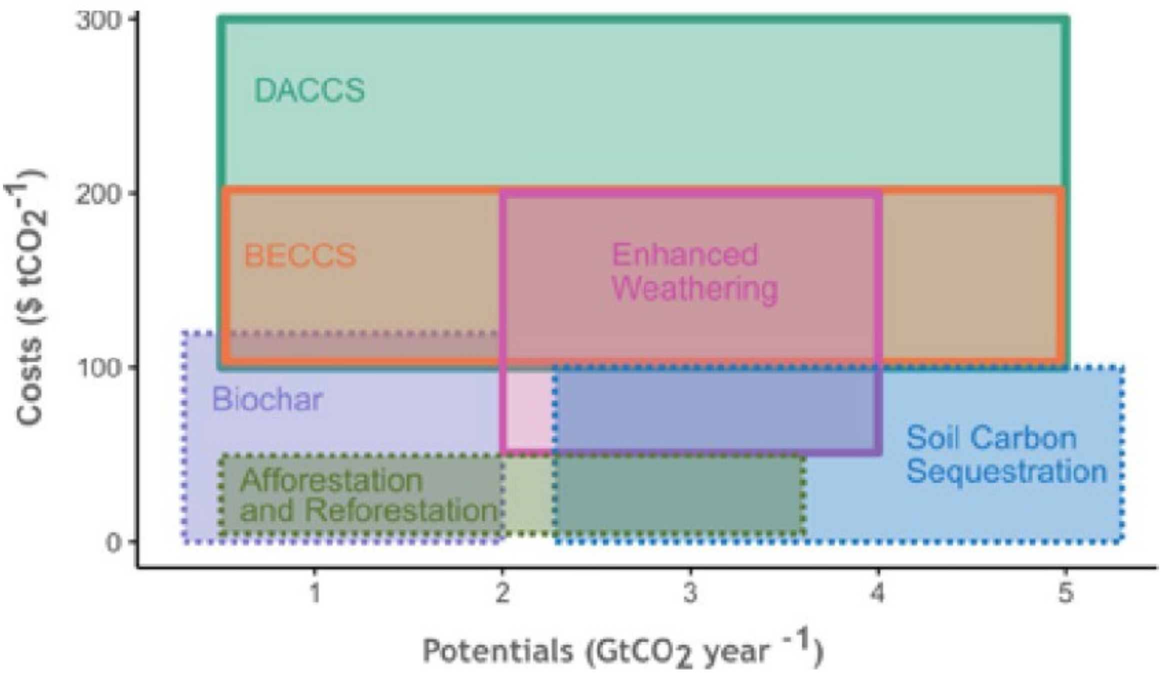
There are still many uncertainties regarding the deployment, timing, and extent to which different CDRs will be needed in the future. The timing of the deployment of CDRs will differ from emission reduction options. CDR options will depend on the concentration of CO_2 in the atmosphere and may need to continue to be deployed beyond 2050 to compensate for residual emissions. Technology readiness of certain options is another important factor as some of the CDRs described are at low technology readiness levels (TRLs). Furthermore, whereas in the case of emissions reduction one tonne of CO_2 reduced has the same benefit in the short, medium and long-term, this is not the case

[16] Ibid.
[17] Ibid.
[18] Information based on: EPRS (2021) Carbon dioxide removal: Nature-based and technological solutions
[19] Rosa, L. et al. (2021) Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe. Available at: https://pubs.rsc.org/en/content/articlelanding/2021/ee/d1ee00642h
[20] GCCSI (2019) Bioenergy and Carbon Capture and Storage. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2019/03/BECCS-Perspective_FINAL_18-March.pdf

with certain negative emissions technologies. Certain CDR options can have positive impacts on the atmospheric concentration of CO_2 in the short-term but not in the long-term and vice-versa.[21]

Figure 2-1 provides an illustration of the carbon dioxide removal potentials of different solutions versus the costs associated with them. Information on emissions removal potentials and costs can also be found in Table 1-1 for nature-based solutions and Table 1-2 for negative emissions technologies. Based on the figure below, technology-based options have the largest potential for removing emissions, yet they are also the most expensive. Nonetheless, it is expected that the costs for BECCS and DACCS should fall substantially with learning and deployment and once the technologies are scaled-up.

Figure 2-1 Estimated costs and 2050 potentials of CDR alternatives



Source: IPCC (2018) Chapter 4 of Special Report Global Warming of 1.5 ◦C

3 Policy development, incentives and markets

3.1.1 EU Policy

In the European Union, the **European Green Deal**, presented in December 2019, sets out the new growth and decarbonisation vision for the EU. The **European Climate Law**, adopted in July 2021, writes into law the targets set out in the European Green Deal for Europe's economy to become a climate neutral continent by 2050. The European Climate Law requires that any carbon emissions remaining in Europe by 2050 are balanced by carbon removals, "with the aim to achieve negative emissions

[21] CEPS (2021) Setting the Context for an EU Policy Framework for Negative Emissions. Available at: https://www.ceps.eu/wp-content/uploads/2021/09/PI2021-12_EU-policy-framework-for-negative-emissions.pdf

thereafter".[22] Net removals are expected to contribute a little less than 225 Mt of CO_2-equivalents (CO_2e) towards the 2030 target while to achieve the 2050 targets the focus will be on enhancing carbon sinks to reach net-zero.[23]

As part of the European Green Deal, the **Circular Economy Action Plan** mentions that the European Commission "will explore the development of a regulatory framework for certification of carbon removals".[24] Creating a carbon market and certification rules for carbon removals are also mentioned in the **Farm-to-Fork Strategy**.[25] The Commission is driven by the need to incentivise sustainable carbon removals in view of its climate targets by supporting the creation of new business models to reward actions aims at carbon removals.

The **Fit-for-55** packaged released in July 2021 and focused on updating several pieces of legislation in line with the updated 2030 target of 55% GHG emissions reduction (compared to 1990). Especially relevant for CDRs will be the revisions to the **EU Emissions Trading System** (ETS). The proposal from the European Commission contains a suggestion to remove the obligation to surrender allowances for carbon stored in long-lived products. This would incentivise carbon capture and utilisation (CCU) and could indirectly benefit CCS-based negative emissions technologies given that infrastructure can be shared between CCUS technologies that reduce emissions and those that deliver net negative emissions (BECCS, DACCS).[26]

The update to the **Land-Use Change and Forestry (LULUCF) Regulation** will have an impact on the incentives to maintain and/or expand the nature-based carbon sinks in the EU. The **Effort-Sharing Regulation (ESR)** which encompasses the agriculture sector affects the emissions produced by this sector and therefore will influence the remaining negative emissions goals.[27]

The work programme of the European Commission for 2022, published on 19 October 2021, foresees the presentation of the **legislative proposal for carbon removal certification** for the final quarter (Q4) of 2022. An impact assessment will accompany the proposal.

The EU Communication on **Sustainable Carbon Cycles**[28] published on 15 December 2021, provides additional impetus to the deployment of CCUS and support to CDRs both nature-based and technology-focused. The Communication reiterates support for CCUS to mitigate GHG emissions. It puts forward commitments to assess the developments of CO_2 transport networks in Europe and to update guidance documents under the **CCS Directive**. In addition, the Communication mentions the possibility of including carbon contracts for difference (CCD) under the revised EU ETS. With regards to CDRs, the Communications stresses the need for a robust regulatory framework for accounting and

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[22] EU (2021) "European Climate Law". Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN
[23] https://data.consilium.europa.eu/doc/document/PE-27-2021-INIT/en/pdf
[24] EC (2020) Circular Economy Action Plan. Available at: https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf
[25] EC (2020) COM (2020) 381 final. Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF
[26] CEPS (2021) Setting the Context for an EU Policy Framework for Negative Emissions. Available at: https://www.ceps.eu/wp-content/uploads/2021/09/PI2021-12_EU-policy-framework-for-negative-emissions.pdf
[27] Ibid.
[28] EC (2021) COM (2021) 800 final. Sustainable Carbon Cycles. Available at: https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

certification of carbon removals which will be presented by the end of 2022. As part of the Industrial Sustainable Carbon challenge the Commission aspires to remove 5 Mt of CO_2 annually from the atmosphere through frontrunner projects by 2030.

3.1.2 UK Policy

The UK government has embedded the requirement for CDR (and other GHG removals) in its policy, recognising that they will "play a critical role in balancing residual emissions from the hardest to decarbonise sectors such as aviation, agriculture, and heavy industry". [29]

Net Zero Strategy: Build Back Greener[29]

The UK Net Zero Strategy, published in October 2021 has six key commitments in relation to engineered greenhouse gas removals (GGRs), which include:

- an ambition **to deploy at least 5 $MtCO_2$/yr of NETs by 2030**[30];
- £100M of innovation funding for DACCS and other GGRs;
- developing incentives and business models in 2022;
- exploring the role of the UK ETS as a market for GGRs, exploring regulatory oversight of robust monitoring, reporting and verification (MRV), in line with the MRV Group recommendations[31]; and
- seeking an amendment of the Climate Change Act to enable engineered removals to contribute to UK carbon budgets.

UK government has also signalled its intention to address the lack of an established market, or customer demand, for GGRs by consulting on business models for engineered greenhouse gas removals in 2022.

In November 2021, the government published its **Biomass Policy Statement**.[32] This has a very strong focus on BECCS and discusses the potential for greenhouse gas removals from biogenic sources beyond just biomass power. More detail will be included in the strategy, but the policy statement sets out the government's priorities and key principles for biomass use, one of which is that biomass is to be used with CCUS where feasible, and otherwise only in hard-to-decarbonise sectors. The report states that as the technology develops, the government will expect biomass use to be focused where it can deliver negative emissions. The government says it will develop strict biomass sustainability criteria for BECCS, building on existing biomass sustainability criteria, which are currently being reviewed. "Any BECCS deployment must be genuinely and credibly 'net- negative', meaning it must

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[29] HM Government, UK, *Net Zero Strategy: Build Back Greener* Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[30] As advised by the Climate Change Committee and National Infrastructure Commission

[31] Monitoring, reporting, and verification of GGRs: task and finish group report. Available at: https://www.gov.uk/government/publications/monitoring-reporting-and-verification-of-ggrs-task-and-finish-group-report

[32] Dept. for Business, Energy & Industrial Strategy, HM Government, UK, *Biomass Policy Statement*, last access 10/12/2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031057/biomass-policy-statement.pdf

remove more GHG emissions from the atmosphere than it creates, and store them in long-term geological storage. This assessment would include all GHGs (including methane and nitrous oxide) from the whole BECCS supply chain, including carbon capture at the capture plant and eventual store." The government's ambitions for BECCS cover biomass used in industry as well as in power generation.

The government recognises the potential for CDR from municipal solid waste (MSW), this appears to include both separately collected food waste (presumably for use in anaerobic digestion with CCS) and the biogenic component of residual waste that is incinerated in WtE operations. In the future, WtE plants are expected to be covered by new carbon capture-readiness requirements, which currently only apply to power stations over 300 MW. Residual waste in the UK is estimated to comprise approximately a 50:50 ration of fossil and biogenic material. The Government is exploring the inclusion of GGRs in the UK ETS, or a separate but linked market, in the future.

Funding to support the development of CDR in the UK

Net Zero Innovation Portfolio (NZIP)

The NZIP is a £1billion fund, providing funding for low-carbon technologies and systems. These include:

- **CCUS Innovation 2.0 competition**[33] - To bring down the cost of capturing and sequestering CO_2 and helping UK industry to understand the opportunity for developing and deploying next generation carbon capture technologies from 2025.
- **Biomass Feedstocks Innovation Programme**[34] - To bring down costs and reduce barriers within the full biomass to energy value chain. This includes improving the productivity of the UK's biomass supply, the availability of conversion technologies, and the generation processes for energy vectors such as biomethane, green hydrogen, biofuels and electricity.
- **Direct Air Capture and Greenhouse Gas Removal Technologies competition**[35] - To support the research and development of direct air capture technologies in the UK.

A NZIP Innovation Programme by the Department of Business, Energy & Industrial strategy (BEIS) currently in development[36]. It will provide funding to innovate and improve capital expenditure (CAPEX), operational expenditure (OPEX) and overall performance in feedstock pre-processing for biomass gasification, syngas upgrading and treatment for the generation of biohydrogen with co-deployment of CCS, including considering the development of biohydrogen from other sources such as anaerobic digestion.

Indirect funding includes the £171M Industrial Decarbonisation Challenge funding for CCUS deployment projects and the £1Bn CCS Infrastructure Fund (CIF) to enable investment in the Cluster

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33 Government of UK (2021) CCUS Innovation 2.0 competition: guidance and how to apply. Available at: https://www.gov.uk/government/publications/ccus-innovation-20-competition

34 Government of UK (2021) Biomass Feedstocks Innovation Programme. Available at:https://www.gov.uk/government/publications/apply-for-the-biomass-feedstocks-innovation-programme

35 Government of UK (2020) Direct Air Capture and other Greenhouse Gas Removal technologies competition. Available at: https://www.gov.uk/government/publications/direct-air-capture-and-other-greenhouse-gas-removal-technologies-competition

36 BEIS (2021) Biomass Policy Statement. Available at: https://www.theccc.org.uk/publication/sixth-carbon-budget/

Sequencing for CCUS Deployment and business models – all of which will drive the development of the necessary transport and storage infrastructure.

3.1.3 CDR markets

Many countries and regions agree that CDRs are needed to offset hard-to-abate sectors like aviation and agriculture. CDR markets, based on the purchasing of carbon credits certifying that a given quantity of GHGs has been kept out of the air or removed from it would provide a way for companies to address emissions that they are not able to eliminate.[37] But the question is how will this work in the context of regional and national boundaries, national reporting, and situations where an international company may be offsetting emissions in one region against emissions in another? It will be a complex situation, and the monitoring, reporting and verification (MVR) of CDR will need to be set in a tight framework of international standardisation of full life-cycle accounting.

One of the barriers to the development of CDR currently is the lack of a robust market – further barriers include the lack of a requirement to report biogenic emissions, the need for a standard accounting process to evidence CDR, and the current high capital and operational costs.

Most governments, and the United Nations (UN) as evidenced by the recent Article 6 agreement at Conference of the Parties (COP)26, believe that CDR markets will drive the development of CDR by providing a revenue stream and making such projects attractive to private investment.

Both the EU and the UK are exploring the role of CDR in ETS markets, with a view that this will ultimately give polluters a strong financial incentive to invest in CDR to offset for their hard-to-abate emissions. Given that the EU ETS is one of the most important emissions trading systems in the world, any regulatory adjustments to include CDRs would have a significant impact on global emissions trading and policies aimed at a net-zero emissions future.

There is a growing interest in Voluntary Carbon Markets[38] which some financial institutions view as a route to effectively 'crowd-funding' the development of engineered CDR projects.

The focus in Article 6 and government policies is to avoid double counting, and ensure verifiable, real emission reductions. It remains the case that it is not clear how these markets will ensure that all emission reduction options are executed across industry and business sectors, prior to resorting to purchasing CDR – that is a CDR market cannot enable offsetting emissions resulting from a lack of action on emissions reduction.

4 Views from CCUS Projects Network members on CDRs and the role of their projects

Member projects of the CCUS Projects Network were invited to answer a series of questions and submit their views on the role of CDRs. The projects all agree that CDRs will have an important role in reaching net zero but also recognise that currently there are barriers to delivery due to the lack of

[37] McKinsey&Co. (2021). A blueprint for scaling voluntary carbon markets to meet the climate challenge.
[38] As opposed to compliance markets such as e.g. the EU ETS

incentives and a market. They are hopeful that these are under development around the world and will enable their projects to contribute to net zero targets in the near future.

4.1.1 Drax, UK – BECCS

Do you believe that Carbon Dioxide Removals (CDR) will be needed to meet Net Zero targets? How will your project contribute?

GGR's are vital to achieve net zero in the UK with the Climate Change Committee estimating at least 58MtCO_2 of negative emissions from 'engineered' GGRs such as BECCS will be needed to offset residual positive emissions from sectors such as aviation and agriculture[39]. In 2021 the UK government's Net Zero Strategy[40] announced an ambition to deploy at least 5 MtCO_2/year of engineered removals by 2030, building rapidly to 23 MtCO_2/year by 2035, and committed to amending the Climate Change Act so that engineered removals could contribute to UK carbon budgets. In the EU the Commission adopted the Communication on Sustainable Carbon Cycles[41] in Dec 2021 which also outlines a 5 MtCO_2/yr target for engineered removals by 2030. However, studies have shown that the EU could need as much as 250 MtCO_2/yr of carbon removal via BECCS and DACS by 2050[42]. Recognising the need to scale up carbon removals, the EU plan to develop a Carbon Removal Certification Scheme by the end of 2022. The progress being made in the UK and EU towards defining CDR targets and standards clearly demonstrates recognition at a national level that negative emissions are essential for meeting Net Zero targets.

Drax plans to deploy BECCS at two biomass generation units at our power station in the UK, which would deliver 8 MtCO_2/year of negative emissions by 2030, meeting all of the UK's near-term target for GGRs.

Do you record your negative emissions? Are they measured or calculated? What do you expect your average annual negative emissions to be in tCO2/yr?

Drax plans to deploy BECCS at two biomass generation units, each with the potential to deliver 4 MtCO_2 of negative emissions per BECCS unit. Drax currently publishes information on the Scope 1, 2 and 3 emissions associated with Drax's operations (including our existing biomass generation units) on our website, which are calculated following IPCC and GHG Protocol methodologies. Average biomass supply chain GHG emissions are independently assured.

Drax has appointed Worley to carry out the FEED study for the BECCS project, which will include metering in the engineering design for the conversion of two biomass generation units to BECCS. In total, the project could deliver 8 MtCO_2/year of negative emissions. Specific requirements for

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[39] Climate Change Committee (2020) Sixth Carbon Budget. Available at: https://www.theccc.org.uk/publication/sixth-carbon-budget/

[40] Government of UK (2021) Net Zero Strategy: Build Back Greener. Available at: https://www.gov.uk/government/publications/net-zero-strategy

[41] https://ec.europa.eu/clima/eu-action/forests-and-agriculture/sustainable-carbon-cycles_en

[42] https://www.frontiersin.org/articles/10.3389/fclim.2021.682882/full#B8

monitoring and metering of CO_2 in CCS and engineered GGR projects are being developed through the UK's CCUS Cluster Sequencing Process.[43]

What are the current barriers to your project delivering CDR? What incentives would encourage the delivery of CDR?

There are three essential components to deliver a GGR project: 1) the demonstration and development of suitable capture technology; 2) access to CO2 transport and storage infrastructure; 3) an investable commercial proposition for the project. Significant progress has been made on all these fronts which enable Drax to continue investing in the BECCS project:

- Drax has proven the technical capabilities of BECCS through the operation of pilot capture facilities at the Drax power station and our transport and storage partners, the Northern Endurance Partnership, have experience in delivering CCS projects in the North Sea. Drax has signed a long-term agreement for use of MHI's carbon capture technology and appointed Worley to lead the FEED study for the BECCS project, demonstrating our confidence in the technical delivery of the project.
- Drax's BECCS project is an anchor project in the East Coast Cluster (ECC), a negative emissions and CCUS hub in the Humber and Teesside region of the UK. The ECC has been named a priority 'Track 1' cluster in the UK's CCUS Cluster Sequencing Process, which means government will prioritise the development of CO2 transport and storage in the Humber-Teesside region and projects associated with the ECC will have first opportunity to apply for government-backed contracts, enabling deployment in the mid-2020s.
- The UK government intend to hold a consultation on business models for GGRs in early 2022, building on published options for business models to support BECCS power projects. The government will also open a call for evidence on the inclusion of GGRs in the UK ETS and continue to develop MRV protocols for GGRs.

For GGR projects to be operational by 2030, developers will need sufficient clarity around GGR business models to enable projects to take FID in 2023-2024. Therefore, it is essential that government continues to develop business models for GGRs throughout 2022.

While FOAK projects will require government support, it is essential that government develop a long term strategy to support GGRs, which could include allowing negative emissions projects to participate in the ETS and/or enabling GGR projects to participate in the voluntary carbon market, both of which would allow government subsidies to decrease over time.

Other support from the government could include:

[43] Government of UK (2021) Cluster sequencing for carbon capture, usage and storage (CCUS) deployment: Phase-2. Available at: https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-2

- The development of a Greenhouse Gas Removals Strategy, which outlines government objectives for GGR deployment and robust principles to ensure sustainability and compatibility with net zero.
- A commitment to a minimum level of CCUS enabled GGR deployment which is in line with other CCUS targets set by the government.
- Ensure that GGR targets are consistent with a clear 2050 net zero pathway and compatible with interim carbon budgets.
- Build public support for GGRs and ensure that the value that a diverse portfolio of GGR technologies will bring, is recognised by the public.

Do you expect a CDR market to develop? - Internationally? As part of the ETS? Do you see a role for Voluntary Carbon Markets?

In the long-term carbon markets such as the UK-ETS and voluntary markets could be used to support GGR deployment however they are not suited to initial deployment due to their immaturity and, in the case of the UK-ETS, currently they lack remuneration for negative emissions. In the medium- term, they could be used to supplement the income received through government support mechanisms. The UK government is actively considering if and how GGRs could be included in the UK ETS.

Interest in the voluntary carbon market is likely to grow rapidly, particularly following the agreement of Article 6 at COP26, paving the way for corresponding adjustments in national inventories to be made if negative emissions are traded internationally. Organisations such as the Task Force for Scaling Voluntary Carbon Markets, Voluntary Carbon Market Initiative and CCS+ Initiative are already developing rules and methodologies to enable negative emissions credits to be bought and sold by corporates. The voluntary carbon market has the potential to reduce direct support required by government, so it is essential that policy mechanisms are designed to support the participation of GGR projects in the voluntary carbon market.

What are your views on the ability to verify removals and the regulation required, taking into account considerations of permanence of removal?

Across GGR technologies, lifecycle and supply chain emissions are accounted for differently. For example, BECCS is heavily scrutinised across the lifecycle emissions of biomass and across supply chain emissions. This scrutiny often does not extend to other GGR technologies, or even other decarbonisation technologies. There should be consistency in the way in which all technologies are assessed on lifecycle and supply chain emissions to enable a meaningful comparison. In absence of this like-for-like assessment certain GGR technologies may be unfairly penalised in their deployment, leading to a suboptimal solution for GGR deployment.

The ability to verify removals and the permanence of these removals will be highly important to ensure integrity of a UK GGR strategy and to ensure confidence in CO_2 sequestration of various projects that will deploy.

Key to this is establishing what timeframe will be used to verify removals. Some removals such as BECCS can be accurately measured on a constant basis by measuring the rate of captured and storage of CO2 from a project. This metered measurement from capture facilities is accurate and easy to verify. For other removals, such as afforestation, sequestration will likely be estimated over a much longer timeframe and it may be more difficult to verify carbon removal.

Given these key differences it may be useful for governments to consider rewarding GGR types differently depending on ability to measure and permanently store CO_2. Engineered removals such as BECCS and DACCS are easy to measure on a highly accurate basis given CO_2 sequestration through a T&S network requires accurate measurement. This ability to accurately measure is not characteristic of all GGR technologies and it may be beneficial to account for this within a policy framework given the ability to accurate measure emissions and removals is a prerequisite of net zero.

Each GGR technology will have differing characteristics when it comes to permanence, for example BECCS and DACCS are able to provide a high level of confidence in the volume of atmospheric CO_2 removed by storing the CO_2 permanently in underground stores. In contrast, some 'nature-based' solutions such as afforestation will require continued maintenance of the forest or cycles of harvest and regrowth to continue to sequester emissions and minimise the risk of release from an unforeseen incident.

How do you see your plant developing in the future? Do you see your model being replicated across Europe?

Drax's current plans are to develop BECCS at two of four existing biomass generation units at our site in the UK. There is significant potential for additional BECCS deployment in the UK both at the Drax Power Station and in CCUS clusters around the UK. BECCS power delivers firm, baseload low carbon power and negative emissions, supporting the decarbonisation of power and hard to decarbonise sectors. As T&S infrastructure develops in the EU there is significant potential for deployment in regions with supportive power prices, policy mechanisms that remunerate negative emissions, access to CO2 storage, and available biomass feedstock from active forestry and agriculture sectors.

What key learning or advice would you share with other companies looking at negative emissions?

Aim high! Drax was the first energy company in the world to announce an ambition to be carbon negative by 2030. We are confident we can achieve it and aim to be a global leader in negative emissions. Achieving this carbon negative ambition is critical to beating the climate crisis. It will also enable a just transition, protecting jobs and creating new opportunities for clean growth – delivering for the economy as well as the environment.

4.1.2 KVA Linth , Switzerland – WtE plant

Do you believe that Carbon Dioxide Removals (CDR) will be needed to meet Net Zero targets? How will your project contribute?

We are convinced that CDR can contribute significantly to reach Net Zero in Switzerland. The Swiss government also shares this view. Our project alone can only play a negligible role in relation to total CO_2 emissions of Switzerland or Europe. In the cantonal climate strategy, however, it leads to a significant reduction in CO_2 emissions.

We also strive to ensure that our flagship project can be easily replicated within the Swiss WtE-industry with the support of VBSA association. The experience gained at our location can then be transferred to other waste incineration plants with little effort. In this respect, we see analogies to the Norwegian Longship Project in the overall objectives, albeit on a smaller scale.

Do you record your negative emissions? Are they measured or calculated? What do you expect your average annual negative emissions to be in tCO_2/yr?

So far, negative emissions have been calculated on the basis of the current, typical waste composition (approx. 50% from biogenic and 50% from fossil sources). In the medium term, the exact proportion of CO_2 from biogenic sources can also be determined via the carbon isotope ratios in the exhaust gas compared with the ambient air (EMPA-method).

On the basis of today's figures and plant design, we expect negative emissions in the order of 55,000 – 60'000 t/a in 2030.

What are the current barriers to your project delivering CDR?
There are currently many open questions on various topics that prevent the rapid implementation of CDR in power plant operation. A selection (without claiming to be exhaustive):

- Selection of most reliable process suitable for WtE systems (find "proven" process technology for WtE, as most of the practical experience exists in the field of petroleum/gas industry)
- Approval process (environmental impact study, HAZOP, etc.)
- Political process / acceptance by the local population
- Lack of infrastructure for the transport of the captured and liquefied CO_2 to the storage facilities or potential users (by pipeline, rail tank wagons, etc.)
- Logistical hurdles (e.g. intermediate storage between rail/pipeline and ship, etc.)
- Financing of the project
- Market for trading in CO_2 certificates
- Legal framework for the export of CO_2 to foreign storage facilities

What incentives would encourage the delivery of CDR?

- The prospect of selling CO_2 certificates to industrial sectors that are difficult to decarbonise.
- State funding for WtE-specific research with the aim of piloting and optimizing the existing process technology.
- Government support in setting up the necessary infrastructure.
- Elimination of grid fees when purchasing electrical energy for energy-consuming production steps such as compression/liquefaction of CO_2 or electrolysis for H_2-production (for e.g. Power-to-X technologies).

Do you expect a CDR market to develop? - Internationally? As part of the ETS? Do you see a role for Voluntary Carbon Markets?

We see great opportunities that an international CDR market will develop, especially as part of the CTS. However, for our plant, we also see opportunities in a VCM in association with local emitters (e.g. cement industry or quicklime production).

What are your views on the ability to verify removals and the regulation required, taking into account considerations of permanence of removal?

We currently lack practical experience to reliably answer this question. The dialogue with operators of a possible storage site (Northern Lights) indicates, however, that only the effectively injected amount of CO2 can be used to verify the captured amount of CO_2. Transport losses are thus also taken into account.

Regarding the permanence of storage, we don't have the expertise to make any statements about possible losses from the storage site or the need long-term "correction factors" of the injected amount of CO_2.

How do you see your plant developing in the future? Do you see your model being replicated across Europe?

We assume that carbon capture in the KVA Linth (or another Swiss WtE-plant) will be in operation on an industrial scale by 2030 at the latest. In addition to the capture of CO_2, we also strive for the optimized use of waste heat and its integration into district heating networks.

Prior to the large-scale industrial process, pilot tests are to be carried out, which enable the selection of the most suitable process mode for WtE-plants.

The long-term goal of our project is the application of Carbon Capture in as many other Swiss waste incineration plants as possible.

What key learning or advice would you share with other companies looking at negative emissions?

In our opinion, it is too early to make a statement. However, we are convinced that efforts should be bundled among stakeholders within the relevant industries so that research results can be shared, and accelerate the development. It makes no sense that every interested company has to "reinvent the wheel".

4.1.3 Fortum Oslo Varme, Norway – WtE plant

Do you believe that Carbon Dioxide Removals (CDR) will be needed to meet Net Zero targets? How will your project contribute?

Fortum Oslo Varem see CDR as key on the pathway to Net Zero in Europe and we aim to remove 200 000 t/y by capturing biological CO_2 from waste incineration of residual waste in this project.

Do you record your negative emissions? Are they measured or calculated? What do you expect your average annual negative emissions to be in tCO2/yr?

The capture plant has not yet been built but hope to have it in operation by 2026. Part of this process will be how we address emission measurement and analysis.

What are the current barriers to your project delivering CDR?

The main issue for delivering CDR projects is the financing, there are currently no incentives to drive investment.

What incentives would encourage the delivery of CDR?

Fortum would like to see a market for CDR develop with certification of the emission offset.

Do you expect a CDR market to develop? - Internationally? As part of the ETS? Do you see a role for Voluntary Carbon Markets?

Fortum expect to see the development of an international CDR market, especially in view of Article 6, and do not envisage this being part of the ETS. We also see a strong role for Volunatry Carbon Markets in funding these proejcts.

What are your views on the ability to verify removals and the regulation required, taking into account considerations of permanence of removal?

It is very mportant to have a common framework and legislation to ensure permanent removal and avoid double-counting, as well as ensuring the use of sustainable biomaterials.

How do you see your plant developing in the future? Do you see your model being replicated across Europe?

Yes, absolutely – this is an important demonstration project for the WtE sector in Europe, and combined with CDR this will help the financing of future projects.

5 Conclusions

This report aimed to prove a short overview on the topic of carbon dioxide removals, why are there needed and what are the key nature-based and technology options, European policy developments and projects. Based on the analysis, it is possible to conclude the following:

- Most credible, science-based models and scenarios conclude that CDRs will be needed to address residual emissions in hard to abate sectors if the goal of climate-neutrality is to be achieved by 2050.
- It should be stressed that, CDRs deployment must not be used as an excuse to delay current, urgent emissions reduction actions. CDR options are not substitutes for the required, ambitious emission reduction efforts needed to attain net-zero. Their purpose is different from that of emission reduction options, and they should be used only to balance the residual emissions from sectors that are unlikely to achieve full decarbonisation by 2050.
- There is still much misunderstanding around terminology and what does or does not constitute a CDR. Clear definition, and a robust and transparent accounting framework that includes life-cycle analysis of the full-value chain are preconditions to ensure CDRs can support positive climate outcomes.
- Whereas nature-based solutions, especially, afforestation and reforestation, can be seen as low-cost, non-regret solutions with multiple co-benefits (biodiversity, clean air, water quality etc.) their removal potential is lower compared to negative emissions technologies such as BECCS and DACCS and the permanent storage of the removed emissions is not guaranteed (e.g. fires).
- Negative Emissions Technologies have a high emissions reduction potential and are based on CCS, which is a tested and proven technology. To guarantee their climate-positive impact of these technologies it is essential that the biomass used for BECCS comes from sustainable sources and that the energy requirements for BECCS and DACS are met by renewable or low-carbon energy sources.
- CDR projects are becoming a reality in Europe already today. Members of the CCUS Projects Network are leading the way by implementing innovative projects to remove CO_2 from the atmosphere.

Glossary of Terms

Abbreviation	Full name
AD	Anaerobic Digestion
BECCS	Bioenergy and Carbon Capture and Storage
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture Utilisation and/or Storage
CDR	Carbon Dioxide Removals
CfD	Contracts for Difference
CHP	Combined Heat and Power
CIF	CCS Infrastructure Fund
COP	Conference of the Parties
DACCS	Diract Air Capture and Storage
EC	European Commission
EfW	Energy-from-Waste
ETS	Emissions Trading System
EU	European Union
GHG	Greenhouse Gas
IEA	International Energy Agency
IPCC	International Panel on Climate Change
LCA	Life Cycle Assessment
MVR	Monitoring, Reporting and Verification
NBS	Nature Based Solutions
NET	Negative Emissions Technologies
NZIP	Net Zero Innovation Portfolio
OPEX	Operational Expenditure
TRL	Technology Readiness Levels
UN	United Nations
WtE	Waste-to-Energy

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