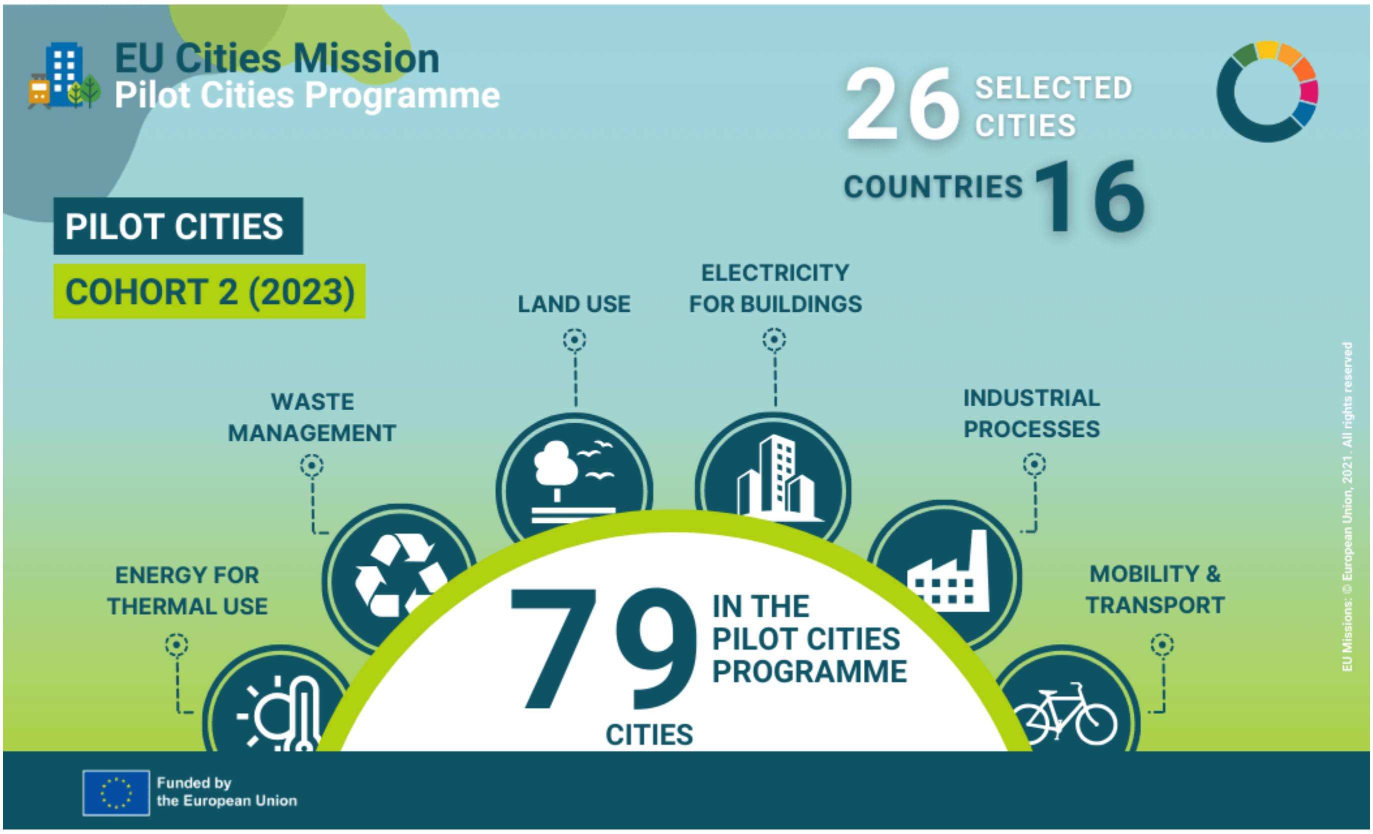

WtE CCS - Barriers and enablers

WP2 CCWaste4NetZero

CCWaste4NetZero

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SUMMARY
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This report summarises the activities ACT 06, 07, 08, 09, 10 and 11 in WP2 of the CCWaste4NetZero project.

Based on the insights contained in this report, concrete recommendations articulated along 14 axes are proposed as key ingredients in a WtE CCS cookbook. The axes were carefully selected to encompass all main dimensions of a WtE CCS project.
Different recommendations are aimed at different actors (municipalities, WtE operators, authorities, technology, R&D) and cover all stakeholders interested in developing a CCS WtE project in Europe.

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Excerpt from Rakkestad CCU permit.

Summary

The CCWaSte4NetZero-project is a pioneering initiative aimed at implementing Carbon Capture and Storage (CCS) in a waste-to-energy (WtE) facility as part of Trondheim's strategy to achieve climate neutrality by 2030. Recognizing that WtE incineration is one of the city's largest single sources of emissions, the project establishes a common starting point by engaging key stakeholders, including municipal authorities, industrial actors, research institutions, and the public, to align on the importance of WtE-CCS. A central focus of the projects' Work Package 2 (WP2) is to develop a shared understanding of systemic challenges and opportunities, ensuring that WtE-CCS is integrated into the city's broader climate action and circular economy strategies. By learning from best practices in Zurich, Oslo, and other European cities, Trondheim aims to position itself as a leading example in urban CCS deployment.

A critical component of WP2 is to identify barriers and drivers of CCS. WP2 also builds on research insights from ACCSESS (EU Horizon 2020), CaptureX, IEA Bioenergy project on BECCUS, CCS Mid-Norway and KSP CircWtE, which provide valuable knowledge on business models, regulatory frameworks, and technical integration. Policy alignment at the EU, national, and municipal levels is essential for the project's realization, as it ensures that CCS incentives, financial mechanisms, and carbon taxation policies support its implementation. Additionally, Trondheim's WtE operator is active in the KAN-network, a group of eight Norwegian WtE plants exploring CCS, enhances shared learning and infrastructure development for CO_2 transport and storage.

The project's key objective is to develop a viable business model that makes CCS financially sustainable and scalable while securing public trust and policy/regulatory support. By integrating technological advancements with governance, finance, and public participation, The CCWaSte4NetZero partnership may become a replicable model for other European cities seeking to implement CCS in urban waste management. The initiative demonstrates that cities can take a leading role in driving CCS adoption, ensuring that waste incineration remains a sustainable solution within the broader transition to a climate-neutral, circular economy.

Based on the insights contained in this report, concrete recommendations articulated along 14 axes are proposed as key ingredients in a WtE CCS cookbook. The axes were carefully selected to encompass all main dimensions of a WtE CCS project. Different recommendations are aimed at different actors (municipalities, WtE operators, authorities, technology, R&D) and cover all stakeholders interested in developing a CCS WtE project in Europe.

1 Part 1: General – Barriers and Drivers

1.1 ACT 06: Establish a common starting point regarding the importance of CCS from WtE in a climate city context, including the roles of different stakeholders

CCWaSte4NetZero project and report's aim

In the end of 2023, the project "Cities as a Test Bed for Climate Neutrality: Implementing Carbon Capture and Storage (CCS) in Waste-to-Energy for a Net-Zero City (CCWaSte4NetZero)" was granted by NetZeroCities (NZC under the European Union's 'Horizon Europe' research and innovation programme) as part of the Pilot Cities Programme, cohort 2. The project consists of a triple-helix partnership between local authority, business and research institution: Trondheim Municipality, Statkraft Varme and later Lunera Energi, SINTEF Energy Research and SINTEF Digital. The project lasted for two years from May 2024. The goal of this pilot project is to solve key barriers to implement CCS from WtE plants, among others by increasing the political and social acceptance. The project has the following six work packages (WP):
WP1: management
WP2: identify barriers and drivers
WP3: citizens engagement and stakeholder involvement
WP4: the climate plan and Climate City Contract
WP5: enabling sustainable business model
WP6: strategies to overcome key barriers to climate transition in transport and zero-emission construction sites
This report aims to summarise project activities and findings from WP2.

Introduction

The importance of Carbon Capture and Storage (CCS) in waste-to-energy (WtE) facilities is crucial for achieving climate neutrality in urban environments. CCS technology enables cities to significantly reduce greenhouse gas (GHG) emissions from waste incineration, which is a hard-to-abate emissions sector.
The City of Trondheim has been active in climate management for over two decades. The first municipal climate action plan was adopted by the City Council in 2001. The fourth and latest version, *Klimaløftene*[1] (The Climate Pledges), was adopted in April 2024, laying the foundation for the city's ambitions and efforts towards climate neutrality. The goal is to reduce the direct greenhouse gas (GHG) emissions by 80 percent (compared to 2009 level) and become climate-neutral by 2030. The waste-to-energy facility at Tiller itself accounts for approx. 25 percent of emissions.
The WtE-facility at Tiller was owned by Statkraft Varme AS. In December 2025, the WtE plant and district heating in Trondheim and Stjørdal was acquired by PATRIZIA SE and renamed to Lunera Energi AS. This facility, unlike many others in Norway, is fully privately-owned. To make joint efforts for the realisation of CCS, Trondheim Municipality and Statkraft Varme signed a cooperation agreement in 2022. This agreement has been extended and is still valid to-date.
<u>Roles of Key Stakeholders in a CCS implementation project</u>
A collaborative approach is necessary to implement CCS successfully. Key stakeholders include:

- Municipal Authorities: Responsible for climate strategy, emissions reduction plans, permits and regulations, and local policy development in general. Contributing to viable framework and commercial condition for CCS. They set the waste collection charges/fees ("renovasjonsgebyret" in Norwegian) that cover municipal waste removal (i.e. not all waste types), covering sorting, transportation, and treatment services. These fees must not exceed the actual costs of producing that

[1] https://www.trondheim.kommune.no/tema/klima-miljo-og-naring/miljo/klimaplan-klimaloftene/

service, a fundamental financial principle used by municipalities in Norway ("selvkostprinsippet" in Norwegian - The Cost Recovery Principle or Self-Cost Principle). In this context, Lunera Energi, a private actor, was awarded the handling of residual waste after they won a public tender/bid (*anbud*) proposed by Trondheim Municipality. In many Norwegian municipalities, the WtE facility itself is (inter)municipally owned and operated, also with the self-cost principle in force for the waste fractions under municipal responsibility.

- Waste Management Companies: Important for sharing knowledge about technical solutions throughout the entire value chain. Commercial positions and advocacy work.
- Industry and Business Sector: Important for influencing the authorities in the work to establish viable framework conditions for CCS, as well as for transport and storage infrastructure.
- Citizens and NGOs: Public perception and acceptance play a major role in the feasibility of CCS projects. NGOs important to both support CCS, generally and for WtE, and contribute to necessary regulatory and commercial framework for CCS.
- Research Institutions: Provide scientific support, technical insights, and policy recommendations.
- National and EU Authorities: Establishing regulatory frameworks and financial incentives for CCS deployment.
- Customers of CRCs (Carbon Removal Credits): verifying that it is possible to sell CRCs from WtE plant to an acceptable price.

By engaging these stakeholders, the project (i) creates a shared understanding of CCS as a viable climate mitigation measure and part of a systemic transition toward carbon neutrality and circularity, and (ii) strengthens the possibility for necessary regulatory and commercial changes.
In collaboration with "WP5 enabling sustainable business model" several meetings were held between the partners, followed by discussions, to make sure we established a common starting point. The topics covered were:

- CCS in a global, European and Norwegian perspective
- Status WtE-CCS in Trondheim, including financial model
- WtE-CCS value chain:
  - Waste incineration/treatment and circular economy
  - Energy supply and district heating
  - District heating role as part of the total energy system
  - Carbon capture
  - Carbon transport
  - Carbon permanent storage
- Case studies:
  - Norway: Oslo and Rakkestad (CCU, added at a later stage)
  - Scandinavia: Helsingborg
  - Europe: Zurich
- Trends in circular economy, urban energy systems, technology and CCS framework
- Market assessment for carbon removals
- Status and development for regulatory framework
- Revenue and financial support models/structures from other countries, and evaluate financial opportunities/support schemes

1.2 ACT 08: Overview of policy and framework conditions for CCS in waste incineration plants on EU, national and local levels

CCUS is a cornerstone of the EU's climate neutrality strategy under the European Green Deal and Climate Law, particularly for hard-to-abate sectors such as Waste-to-Energy (WtE). Recent initiatives like the Net-Zero Industry Act (NZIA) and Clean Industrial Deal (CID) aim to accelerate CCUS deployment and infrastructure development across Europe. The policy and regulatory frameworks for waste, CCUS and waste-CCUS are complex, intertwined and constantly evolving. This section list important elements (not ranked) at the EU, national and local levels. These elements are discussed all along the report.

1.2.1 Central European policies and regulations relevant for CCUS (not WtE specific) – also now named Industrial Carbon Management (ICM) per March 2026:

The European Green Deal (2019) mandates significant emissions reductions and identifies CCUS as a key technology for industrial decarbonization, with the aim to cut emissions by at least 50% by 2030, rising towards 55%, while legally binding the 2050 neutrality goal through the European Climate Law.
The Carbon Border Adjustment Mechanism, CBAM (2023) is EU's tool for pricing the carbon embedded in imported carbon-intensive goods and encouraging cleaner production outside the EU. It enters its full regime in 2026, following a 2023–2025 transitional phase aligned with the gradual phase-out of free ETS allowances to support industrial decarbonisation. Norway has formally decided to join the EU's CBAM to prevent carbon leakage and ensure a level playing field for Norwegian industry. As of March 2026, the process is in an active implementation phase in Norway.
The *Industrial Carbon Management (ICM) Communication/Strategy (2024)* sets out a strategy to integrate capture, transport, storage and use of CO_2 as part of achieving climate neutrality and at least 55% GHG reduction by 2030, and 90% by 2040. It foresees scaling CO_2 storage capacity, integrating hard-to-abate industrial sectors, and developing cross-border CO_2 infrastructure and markets.
The *Net Zero Industry Act (NZIA, 2024)* comes out of the so-called 'Green Deal Industrial Plan' aiming at increasing the competitiveness of green European industries, focusing on simplified regulations, faster access to funding, skills and open trade. Most relevant for CCUS in the NZIA is the target of 50 Mt CO_2 storage capacity by 2030 requiring European oil and gas producers to help achieve the EU 2030 CO_2 injection capacity target. NZIA is considered EEA-relevant and is in the process of being incorporated into the EEA Agreement, while the EFTA Court confirmed in Feb. 2026 that the EEA Agreement also covers the Norwegian Continental Shelf, opening for inclusion of Norway's CCS projects under NZIA storage targets.
The *Clean Industrial Deal (CID, 2025)* mobilises €100B for clean tech and positions decarbonisation as a growth driver. It contains measures to make decarbonisation a driver of industrial growth, aiming at lowering energy costs and creating jobs. The CID targets the full industrial value chain, with specific support for energy-intensive sectors such as steel, metals and chemicals. Circularity is another core pillar, promoting recycling, reuse and sustainable production. Also, the clean tech sector is important in the CID, being important to the European industrial transformation.
The *Carbon Removals and Carbon Farming (CRCF) Regulation (EU/2024/3012),* established the EU's first voluntary certification framework for carbon removals, carbon farming, and carbon storage in products. By defining EU-wide quality criteria and setting out monitoring and reporting requirements, the CRCF aims to boost investment in innovative removal technologies and sustainable carbon farming practices, while reducing the risk of greenwashing. Norway has been an active proponent in the development of the CRCF. Since the regulation was adopted in the EU (Dec. 2024) and the first methodologies became available in Feb. 2026, Norway is in a phase of national adaptation. Furthermore, DG CLIMA is exploring the design of an EU purchasing programme ("Buyers' Club", launch scheduled in May 2026 at the EU CRCF Days) for permanent CDR to encourage investment, boost technological progress and help meet EU climate targets[2].
The *EU Emissions Trading System (ETS)* is being revised under the "Fit for 55" package, strengthening its impact on CCUS by expanding carbon pricing, improving incentives, and introducing rules for

[2] https://climate.ec.europa.eu/news-other-reads/news/new-eu-studies-explore-purchasing-programme-boost-permanent-carbon-removals-europe-2025-08-27_en

non-permanent CCU to prevent double counting. Ongoing assessments focus on better supporting CCS/CCU deployment and ensuring that ETS revenues contribute fairly to industrial decarbonisation. Key issues under review include how CCU products are accounted for, how CCS investments are funded, and how the ETS can align with 2050 climate goals, particularly in relation to cross-border CO_2 infrastructure. See next section (1.2.2) regarding WtE and EU ETS.

The *Industrial Accelerator Act (IAA)* previously referred to as the *Industrial Decarbonisation Accelerator Act*, is a legislative proposal from the European Commission expected to be adopted in spring 2026. Its purpose is to strengthen the competitiveness of European industry, accelerate decarbonisation, and ensure "Made in Europe" criteria in strategic sectors. Norway is, in principle, positive towards the IAA.

Financing and risk mitigation: Tools include Carbon Contracts for Difference (CCfDs)[3], state guarantees, and credit insurance etc. EU Innovation Fund and Modernization Fund remain key sources.

Designing Europe's CO_2 market and infrastructure (ZEP, Sept 2025) EU is developing policies to enable well designed CO_2 market and CO_2 transport network (pipelines, ships, trains) with cross-border coordination under NZIA and ICM Strategy. This includes aspects such as: How to ensure fair access and pricing while avoiding monopolistic behaviour?

The *European Climate Law* adopted in June 2021 and in force since July 2021, this law legally binds the EU to reach climate neutrality by 2050. It mandates a, intermediate net greenhouse gas emission reduction of at least 55% by 2030 compared to 1990 levels. Norway supports the EU's ambitions and has chosen to closely align itself with the EU's climate regulations through its own climate agreement with the EU.

The *European Innovation Act (IEA)* is a forthcoming EC initiative designed to boost EU competitiveness by bridging the gap between research and market commercialization. As of March 2026, Norway has a positive attitude towards the main objectives of the European Innovation Act, but the act has not yet been formally adopted in the EU or ratified in Norway. Since the proposal is expected to be presented by the EC during spring 2026, the process is still at an early stage.

The *Industrial Decarbonisation Bank (IDB)* is a new flagship initiative under the EU's CID (see above), aiming to mobilise over €100 billion for the decarbonisation of European industry, i.e. support the rollout of mature technologies to reduce emissions in energy-intensive industries. It is mainly funded by the EU Innovation Fund (revenues from ETS) supplemented by national funds. The IDB (and the Innovation Fund) finance the capture, transport, and storage of CO_2 to achieve the target of 50 million tonnes annual injection capacity by 2030, as set out in the NZIA. Also, through instruments such as CCfD, the bank helps create a commercial market for carbon management. Also:

- ICM (see above) is one of the pillars of the IDB's strategy for addressing hard-to-abate emissions
- NZIA (see above) is a key legal act for the IDB

Development of the CO_2 transportation infrastructure and markets is legislative proposal to be presented Q3 2026.

Taxonomy & WtE is presented in the next section (1.2.2).

Considered but not included: *Public Procurement Directive*; The *European Research Area Act (ERA Act)*; and EU's *Multiannual Financial Framework* (MFF 2028–2034).

[3] A government agreement that guarantees a fixed price for carbon emissions avoided, bridging the gap between CCS operational costs and uncertain carbon market prices. If carbon prices are lower than the agreed "strike price," the government pays the difference to the operator, providing financial certainty, reducing investment risk, and accelerating deployment

1.2.2 Waste treatment and WtE Sector Specific regulations (not only directly related to CCS)
Waste Framework Directive & *the BREF BAT WI* that is legally binding. It covers all WtE-relevant Best Available Technologies (BAT) to follow EU emissions limits (BAT-AEL Associated Emission Levels) transposed in Norwegian regulation in Avfallsforskriften kap. 10
District heating framework and regulations in Norway (price regulation, mandatory connection and more) and energy efficiency (Norwegian formula and *EU R1 formula*, a performance indicator for the level of recovery of energy from waste in a plant dedicated to the incineration of MSW)
The Norwegian *Waste Incineration Tax* (*avgift på avfallsforbrenning*) on fossil CO_2 emissions
EU waste recovery targets (translated as waste sorting (for recovery) targets in Norway's Avfallsforskriften kapittel 10a) promoting waste (MSW, different fractions) recycling (material recovery) together with mandatory segregation (separate collection) of certain MSW fractions, e.g. food waste, plastic packaging waste, metal and glass (packaging) waste, textile waste.
EU Landfill Directive limiting the proportion of waste (MSW) that can be landfilled. A significant number of EU countries are behind in meeting the requirements of the Landfill Directive. While the EU as a whole has reduced landfilling, numerous member states face a high risk of missing the target of reducing the landfilling of municipal waste to 10% or less by 2035.
Norwegian landfill ban for biodegradable waste (enforced since July 2009) led to a significant increase in Norwegian WtE capacity in 2009-2012.
EU ETS does not currently include WtE. A European Commission report due in July 2026 will assess the feasibility and potential scope of WtE incorporation (as well as the possible inclusion of other waste management processes, in particular landfills) in the EU ETS, following which final decisions will be taken. The latest developments were discussed at an ESWET-CEWEP event, "Waste & Emissions Trading: A Climate Policy Aligned with Circularity?". DG CLIMA (Directorate-General for Climate Action of the European Commission) presented the 3 main policy options (PO1: No inclusion of additional waste management processes in the EU ETS; PO2: Inclusion of municipal waste incineration installations in the EU ETS and PO3: Inclusion of all waste incineration installations and landfills of non-hazardous waste in the EU ETS) and added that if inclusion is proposed, it would be in 2030 at the earliest. ESWET and CEWEP recently presented their standpoint regarding waste & EU ETS, including carbon pricing, financial responsibility and the need for a tailored framework. The stated intention for inclusion is that this additional cost of WtE can stimulate waste prevention and recycling. Furthermore, under the scheme, municipal waste incineration plants with a thermal input exceeding 20 MW must report their CO_2 emissions starting from January 1, 2024. These plants must submit a monitoring plan and have their annual emission reports verified and submitted by their national authorities.
EU Taxonomy is a classification system establishing a unified framework that defines which economic activities can be considered environmentally sustainable to guide investment and prevent greenwashing. WtE is currently excluded, and it is little probable that it will be included. This can seriously affect its access to funding. What about the inclusion of WtE-CCS? A careful look at the situation is that, as of March 2026, WtE — with or without CCS — is not included, and no technical screening criteria exist for inclusion. The current Taxonomy framework is viewed by many WtE actors as a barrier to CCUS investment. However, no official source states that future inclusion is impossible, only that none is currently in development. Activities directly related to CCS are considered green provided they meet specific technical criteria.
EU Circular Economy Act (CEA) is expected in Q3 2026, it is a key legislative initiative under the CID (2024-2029, see 1.2.1) designed to transition Europe from a linear to a circular economy. It aims to reduce waste, foster high-quality recycling, and create a market for secondary raw materials.
The Waste market is international. Transboundary transport of waste is strictly regulated but allowed for most waste fractions. Norway exported more than 800000 tons combustible waste to Sweden WtE in 2024. For comparison, about 1700000 tons MSW were energy recovered in Norway in 2024.
Extended Producer responsibility (EPR) is an obligation that makes producers responsible for the life cycle of their products, including waste management. This means that producers are responsible for the collection and treatment of certain products (e.g. packaging, textiles, etc.) after they have been used. The aim is to reduce waste and achieve environmental goals such as recycling targets. CEWEP and ESWET advocate for

the further development of EPR schemes to cover the treatment of unrecyclable residual waste containing fossil carbon.

1.2.3 National CCS-related Policies (Norway)

Longship CCS Project: Norway's national framework supports CCS development, including Northern Lights, the world's first cross-border CO_2 transport and storage facility (in August 2025, the first CO_2 volumes were injected and successfully stored in the reservoir).
Carbon Taxation: Generally, the stated intention with a fossil CO_2 tax is to help realise CCS from WtE and increase material recycling. Norwegian authorities plan for an increase in fossil CO_2 taxes towards 2035, but this may be replaced by EU ETS. See 1.2.1 and 1.2.2 for more details.
Regarding EU policies and Norwegian relevance, see section 1.2.1.

1.2.4 Local CCS-related Policies (Trondheim)

The project has sought to engage with policymakers to ensure that Trondheim's CCS initiative aligns with broader regulatory frameworks while advocating for necessary policy adjustments to facilitate implementation. Below is an overview of the local policy context. It is important to integrate WtE-CCS with waste reduction and recycling policies (Circular economy, WtE and CCS as a climate mitigation measure):
The Trondheim Promise (Trondheimsløftet): Municipal Master Plan's Societal Part (2020–2032): Trondheim Municipality has significantly stepped up its efforts regarding the circular economy in recent years. One of the three main goals is that "Trondheim takes responsibility for a greener and more circular society".
Municipal Plan for Waste Management (2018–2030): This is the foundational document for the city's waste management. It dictates that waste systems should be planned as an integrated part of urban development. A key goal is to adapt to EU requirements of at least 65% material recovery of municipal waste (a target that will gradually tighten towards 2035).
The Climate Promises (Klimaløftene): Municipal Plan for Energy and Climate (2024–2030): This plan states that direct GHG emissions in the city must be cut by at least 80% by 2030 (2009 level). It sets clear requirements that waste must be handled without emissions, and that resources must be kept in circulation. CCS is identified as a key measure to meet the city's 2030 neutrality target.

1.2.5 Possible national (Norwegian) policy and financing instruments for CCS

Many elements of the regulatory and funding tools for CCS are still under development, shifting and unstable (both at the EU and) at the national level. These uncertainties are a major hinder to the deployment of CCS. Analyses and assessments of said tools have therefore a limited shelf-life. Recent efforts include:

- Clean Air Force Task's work on Carbon Contracts for difference (CCfD) design[4]
- Baringa's 2026 report identifying investment barriers – commercial, regulatory, financial and educational – with three recommendations - 1: Unlock stalled projects by establishing a pre-FID development capital fund; 2: Create bankable revenue streams by aggregating demand and structuring offtake solutions; 3: Accelerate learning cycles and investor confidence via a global CCS financing lessons forum[5]
- Prosess21 2026 report with recommendations on how to scale-up CCS in Norway[6]
- Key actors (e.g. Bellona, SINTEF) participated to a CCS roundtable in early 2026 and will send recommendations to the government to enable the large-scale deployment of CCS in Norway.

[4] CATF, Designing Carbon Contracts for Difference,2024, https://www.catf.us/resource/designing-carbon-contracts-for-difference/.
[5] Baringa, Unlocking Private Capital - Scaling Investment in the CCS Sector, 2026, https://www.baringa.com/globalassets/insights/low-carbon-capital/unlocking-private-capital-in-carbon-capture-and-storage-2026.pdf, Presented at Gassnova's Knowledge Sharing 2026 - CCS & CDR Summit, 14-17 April, Sandefjord.
[6] PROSESS21, Fjerne utslipp, bevare industri, 2026, https://www.prosess21.no/siteassets/260209-prosess21-fjerne-utslipp_bevare-industri.pdf.

- Norwegian Environment Agency 2026 report on climate[7] indicates that CCS WtE is a key measure for Norway to reach its climate goals and proposes elements for a national support program

KAN, THEMA Consulting and Carbon Limits assessed in a 2024 joint report which policy instruments would be most effective, while also ensuring that socio-economic principles are maintained. CCS measures account for about one third of Norway's emission reduction potential by 2035. According to the Norwegian Environment Agency, carbon capture and permanent storage of emissions from waste incineration plants are essential for reducing fossil emissions and removing biogenic emissions from the facilities and are necessary to meet Norwegian climate objectives.
Policy instruments should target barriers that prevent the realisation of socio-economically profitable CCS projects at WtE plants. The main barriers to realising CCS for waste incineration are:

- Incomplete CO_2 pricing. Carbon removal is not valued on a par with the capture of fossil emissions, despite being equally beneficial. In addition, various fossil emissions are priced and taxed differently depending on whether they are included in the quota market or not, and there is considerable uncertainty regarding future CO_2 pricing.
- Additional costs related to scaling up and commercialisation. The capture technology itself is mature but has not been widely implemented yet. Furthermore, the regulatory framework is not sufficiently developed. This means additional costs associated with scaling up, developing commercial solutions, including business models and financing. The first projects to be realised will therefore provide learning effects and cost reductions, also for the authorities.
- Coordination challenges and lack of a regulatory framework for transport and interim storage. By establishing and using shared infrastructure for the transport and storage of CO_2, also from sources other than waste incineration, the volume increases and unit costs can be significantly reduced.

Several economic policy instruments are relevant to strengthen incentives for CCUS at WtE plants:

- CO_2 pricing: taxes/negative taxes, quotas/certificates, subsidies and *CCfD.*
- Support for commercial maturity: support for pilots, support for feasibility studies and investment aid, as well as subsidies and contracts for difference.
- Government coordination of infrastructure for transport and interim storage: certification of transport providers, tendering of transport routes, establishment of a system operator, and mechanisms for financing during a start-up phase.

The resulting recommendation is the implementation of Carbon Contracts for Difference (CCfD) in combination with feasibility support and state responsibility for coordinating infrastructure. CCfD can be designed to account for different CO_2 emission pricing and the lack of pricing for removal, mitigate risks related to future CO_2 prices, and cover additional costs associated with commercial maturity.
Contracts for difference can be awarded through competition (auction) or individually through negotiations.

As per March 2026, the Norwegian CCS regulatory environment is primarily centred on the Longship project, but several ongoing initiatives and regulatory discussions affect the sector. The proposed National budget for 2027 may introduce a reversed tax for carbon removals, while Enova is working on a possible investment programs and support scheme for transport and permanent storage. KAN's updated position[8] on the matter of national policy and financing instruments for CCS has three main points:

- A reverse CO_2 tax must reflect the escalation of the Norwegian fossil CO_2 tax
- The need for investment support for both capture projects and CO_2 terminals
- It must be possible to combine different support schemes and the sale of carbon removal certificates

[7] Miljødirektoratet (Norwegian Environment Agency), Klimatiltak i Norge 2026: Veivalg og utslippsbaner mot 2050, https://www.miljodirektoratet.no/publikasjoner/2026/februar-2026/klimatiltak-i-norge-2026/.
[8] KAN-posisjon for å bruke de 700 millionene i punktutslippsprogrammet i 2026 og det kommende støtteprogrammet for negative utslipp.

2 Part 2: Learning from other cities

2.1 ACT 10: Learning from Hafslund Celsio WtE CCS project in Oslo. Dialogue with the KAN-project that embraces 8 Norwegian WtE-plants that collaborate on CCS

Oslo's experience with CCS WtE (see also section 4.1) serves as a benchmark for Trondheim's efforts. Key aspects of learning include:

- Regulatory takes time and effort; important to have early focus on e.g.: zoning plan and EIA (Environmental Impact Assessments), dispersion analyses, emission permits (see Appendix).
- Transport & storage; evaluate and decide concept for transport to intermediate storage; Truck or pipeline.
- Port terminal & permanent storage; access to and constructability for intermediate storage and early discussion with provider of permanent storage.
- Layout & constructability CC plant: secure area, optimize layout, secure rig and construction site.
- Project organisation & execution model; establish a robust organisation e.g. secure necessary internal competence and capacity.
- Business plan & cost estimates; optimization of business case, financing support, CDR and potential revenue stream.
- Stakeholders; early communication with and involvement of the municipality and nearby 3rd parties.

The KAN-network, a collaboration among eight Norwegian WtE plants working on CCS, offers additional knowledge-sharing opportunities. The WtE plant in Trondheim's participation in this network have ensured alignment with national CCS developments and provide access to shared infrastructure solutions.
As the Oslo CCS project is furthest along in its realisation, it has been especially important learning from its experience. This mainly connected to project management of this kind of complex projects, cooperation with national authorities, and technical solutions and challenges. In addition, the Oslo CCS project has been a forerunner when it comes to establish agreements for biogenic credits from carbon capture and has verified that it is possible to sell credits from WtE plants. This has made it easier for all partners both to understand what is required to sell and follow up biogenic credits, as well as verification of the price level.

2.2 ACT 11: Learning from Zurich and other relevant European cities with similar projects

The project seeks to leverage knowledge and best practices from cities that have implemented or are exploring CCS in waste incineration. Zurich, Oslo, and other European cities provide valuable case studies.

2.2.1 Key Learnings from Zurich (WtE is managed by a municipal company, ERZ)

- Policy Integration: Zurich has successfully embedded CCS into its long-term climate and energy policies. In 2022, people of Zurich defined with clear majority of 74.89% in a public vote an ambitious pathway to reach net zero by 2040, which is now fixed in the city constitution.
- Public Engagement: The city has developed effective public communication and engagement strategies to increase acceptance[9,10]. Swiss researchers write "In a nutshell, ongoing stakeholder engagement and tailored public communication are crucial to address evolving information needs. We recommend providing clear examples, involve relevant stakeholders early, and adapt strategies dynamically to build capacities for evidence-based decisions regarding CCTS/CCUS pathways. For

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[9] S. Eberenz et al., Nine recommendations for engaging with the public and stakeholders for Carbon Capture, Transportation, Utilization, and Storage, Energy Research & Social Science, 2024, 103804, https://doi.org/10.1016/j.erss.2024.103804.
[10] I. Dallo et al., Social perspectives of carbon capture, transportation, utilization, and storage in Switzerland, Energy Research & Social Science, 2024, 103588, https://doi.org/10.1016/j.erss.2024.103588.

a differentiated public debate, presenting CCTS/CCUS pathways as complementary to broader climate strategies and renewable energy adoption is key." Furthermore, in another article on social perception and communication Swiss research concludes that "it is vital to foster a dialogue with the public from the beginning of a project and to iteratively assess their information needs and open questions and, consequently, to design people-centred information material. Thereby, testing and evaluating this material is pivotal: only through co-design a bridge between the scientific communities and society can be built."
- Technological innovations: lessons on optimizing CCS technology for energy- and cost-efficiency.
- Unlike cities outside Switzerland, Zurich has held referendums about their climate plans and about implementing CCS and therefore can manifest a clear support for CCS.

2.2.2 Key learnings from Helsingborg

- Helsingborg in Sweden is a mission city like Trondheim. The goal is to become climate neutral by 2030. CCS is crucial to reach the climate goals.
- The energy company Öresundskraft, 100% municipality-owned, is planning to install CCS at the waste incineration facility Filbornaverket. With CCS, 200 000 tons of CO_2 can be removed.
- The project Innozhero received 54 M€ from the EU Innovation Fund in Oct. 2024 as well as 228 MSEK from the Swedish Energy Agency through Industriklivet (Industry Leap) in Jun. 2025.
- Part of the business plan is to sell negative emissions, and climate neutral district heating. Furthermore, WtE has been opted in under ETS by Sweden. ETS contributes to the financing of CCS via the EU Innovation Fund and Industriklivet (which is part of EU RRF - Recovery and Resilience Facility)[11]. It should be noted that each Swedish WtE plant is given free emissions allowances (that are to be gradually phased out in the coming years).
- Helsingborg are investigating selling a "premium service" to emission-free construction sites[12].
- Helsingborg will apply in the second round of reverse auctions for capturing biogenic CO_2 emissions and could also apply for other national funding related to decarbonisation.
- Representatives from Trondheim and Stavanger visited Öresundskraft in November 2025. The delegation got a thorough presentation about their CCS project followed by a site visit at Filbornaverket. The financing model includes three key elements: EU and national grants, sales of credits and avoided cost for EU ETS. Increase of waste management fee is not taken into consideration. IIn early 2026, the City Council is expected to make the final decision to commence construction and move the project into full implementation[13].

2.2.3 Key learnings from Stockholm

Below is a synthesis of lessons learned from the Stockholm Exergi project (the largest BECCS that aims to capture 800 000 tons of biogenic CO_2) covering technical, commercial, regulatory, and societal aspects:

- Business case drives the project: Stable, long-term CDR revenue is essential for investment.
- Policy alignment is critical: National and EU rules must consistently recognize negative emissions.
- Early stakeholder engagement pays off: Continuous dialogue improves social acceptance and reduces permitting risks.
- Integration with existing assets lowers risk: WtE and bio-CHP integration is a major enabler.

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[11] Regeringens skrivelse 2024/25:84, Riksrevisionens rapport om Industriklivet, 2024, https://www.regeringen.se/contentassets/eb7183bcf3934ca0960ad27e30b88c12/riksrevisionens-rapport-om-industriklivet-skr.-20242584.pdf

[12] Wihlborgs press release, Wihlborgs signs carbon reduction certificate agreement with Öresundskraft, 4 March 2025, https://www.wihlborgs.se/en/investor-relations/press-releases/2025/wihlborgs-signs-carbon-reduction-certificate-agreement-with-oresundskraft/

[13] Bioenergy International, City Council approves Öresundskraft's CCS project, 30 April 2025, https://bioenergyinternational.com/city-council-approves-oresundskrafts-ccs-project/

- Permitting is a critical item: Environmental approval timelines can dominate schedule.
- Transport and storage can be bottlenecks: Cross-border coordination is not trivial.
- Capture technology is not the main uncertainty: Business, regulatory, & contract issues dominate.
- Phased development is critical: Pilots and FEED studies are crucial before final investment.
- Public funding must be simple: Complex support schemes weaken investor confidence.
- BECCS requires system thinking: Success depends on aligning utilities, storage operators, regulators, and buyers.

2.2.4 Key learnings from Rakkestad

Rakkestad is not a CCS, but a CCU project at the relatively small scale of 10000 tons CO_2/y (and without energy integration), but it can still bring valuable lessons on the development of a CC project with WtE. It is in operation, capturing CO_2 from an Østfold Energi WtE plant (10000 tons MSW/y). Here are information and lessons learned collected during a site visit in March 2026:

- The communication with the Norwegian Environment Agency was good. It took about 9 months to get the CCU permit, separate from the WtE permit, see excerpt in Appendix
- No big problem, many small and medium ones
- WtE and CCU are treated and operated as two separate processes. WtE does not have to "care" about the CCU plant (also WtE must pay the Norwegian combustion fee on fossil CO_2)
- Construction was fast, only a few months, using among other things modules; however, the transport of some modules can be challenging, and some construction must be done locally
- Carbon Centric owns and operates the CCU unit. Economic data is sensitive, but the 17.2 mill. NOK support by Enova[14] was mentioned as a welcomed, albeit minor contribution
- Extra flue gas cleaning is carried out after the WtE plant
- The captured CO_2 is certified as food grade and collected by Linde, about one truck per day
- The energy penalty is not negligible

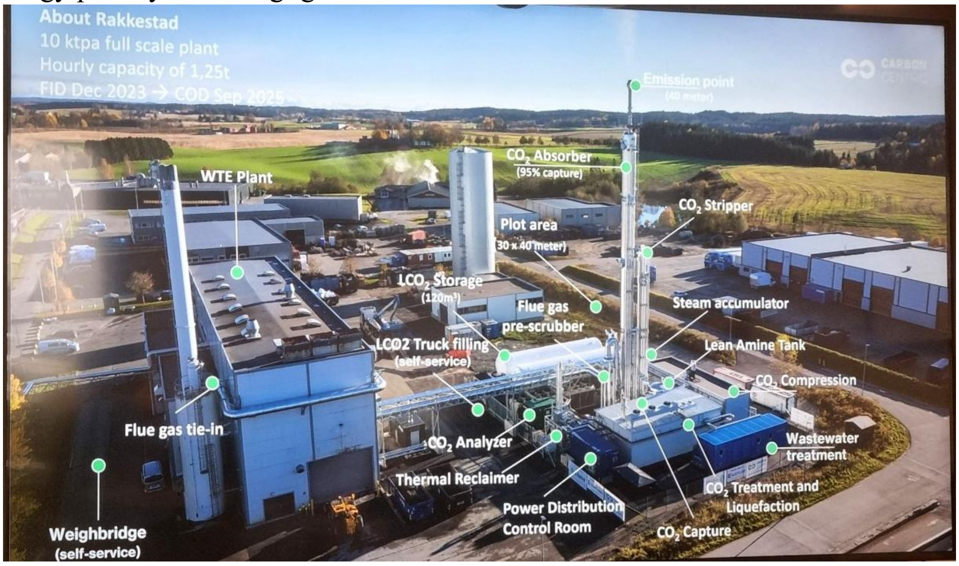


Figure 2.1 Rakkestad WtE & CCU unit. (Picture by Fabio Poretti, CEWEP).

Cities have their own local conditions (infrastructure, public perception, framework, regulations, funding) to consider but also many common challenges. By incorporating these learnings, the CCWaSte4NetZero project aims to refine its roadmap for CCS implementation in Trondheim and beyond. See Appendix for a selected list of CCUS projects across Europe.

[14] Norwegian government-owned enterprise. Provides financial support to businesses and households for projects on renewable energy, energy efficiency, and innovative climate-friendly technology.

3 Part 3: Prospects - Trondheim

3.1 ACT 07: Survey, interviews and dialogue with targeted public and private stakeholders and the public to develop a knowledge basis on barriers and drivers

This chapter presents the findings of the 2024 and 2025 Trondheim Climate Surveys, conducted to assess public attitudes and behaviours toward climate action, sustainability, and WtE/CCS. By combining survey data from a representative sample of Trondheim's population with stakeholder interviews and public dialogues, this deliverable identifies key systemic barriers and drivers influencing climate policies and initiatives. The insights gathered provide a foundation for understanding public perception, regulatory challenges, financial feasibility, and societal considerations related to WtE/CCS, offering valuable input for shaping communication strategies, policy recommendations, and stakeholder engagement efforts.

To develop a sound knowledge base, the deliverable includes:

- Surveys: A representative sample of Trondheim's citizens to gauge awareness and attitudes toward CCS.
- Stakeholder Interviews: Discussions with citizens, municipal authorities, and policymakers (linked with WP3 deliverables).
- Public Dialogue: Citizen assemblies and participatory events to facilitate knowledge exchange. (linked with WP3 deliverables).

3.2 Summary of the 2024 & 2025 Climate Surveys in Trondheim

3.2.1 About the Surveys

The 2024 and 2025 climate surveys in Trondheim, developed by Trondheim municipality and SINTEF, was conducted by Sentio, and examines residents' attitudes and behaviours related to climate and sustainability. The survey includes themes such as municipal climate efforts, land use, energy, mobility, consumption, WtE/CCS, and climate adaptation. The study drew on responses from residents aged 18 and over, with samples of 1,002 in 2024 and 1,005 in 2025.

3.2.2 Key Findings

Table 3.1 Summary - Trondheim Climate Surveys (2024 & 2025).

Category	2024 Survey (Key Findings)	2025 Survey (Key Findings)
Municipal climate efforts	- 75% say reaching the 2030 climate goal is important. - 61% say strong action across multiple areas is needed to meet these goals.	- 70% say reaching the climate target is important (declined from 2024) - 63% say strong measures are needed across areas to reach the goals.
Nature & land use	- Over 80% oppose developing outdoor/nature areas; 75% oppose building on cultivated farmland - 70% agree nature has been overdeveloped and want to prevent further encroachment.	- 86% oppose developing outdoor nature areas; 78% oppose using farmland for development (both higher than 2024). - 75% say development of natural areas has gone too far.

Category	2024 Survey (Key Findings)	2025 Survey (Key Findings)
Energy & electricity use	- 75% say shifting from fossil to renewable energy is necessary to reduce emissions. - 70% say policymakers should prioritize electricity use; most residents plan energy-saving measures (e.g. turning off unused devices).	- 73% say shifting from fossil to renewable energy is necessary to reduce emissions. - 70% say politicians must prioritize electricity use; most plan measures to save energy (e.g. switching off idle appliances).
Mobility & transportation	- 52% say overall traffic levels are too high. - 47% plan to cycle or walk more over the next 12 months.	- 53% say traffic levels are too high (similar to 2024). - 50% plan to cycle or walk more over the next year (up slightly).
Consumption & waste	- Vast majority agree consumption must be reduced; only 13% find repairs easy or cheap. - 70% would repair items if it saved money and would reuse/donate clothes; 60% sort their waste.	- 12% find repairs easy or cheap; 81% willing to repair items if it saves money (up from 75% in 2024). - Over 90% plan actions to reduce waste, commonly by sorting trash and donating clothes.
CO_2 capture & storage (CCS)	- 45% say waste incinerator emissions should be reduced (most respondents support this) - Majority view a CO_2 capture plant as a positive climate project; opinions split on making Trondheim a CCS "showcase" or raising fees to fund it.	- 46% say waste incinerator emissions should be reduced (majority of those with an opinion support this). - 54% say carbon capture at the incinerator would be a good climate project; views remain mixed on a CCS showcase or higher fees to build it.
Adaptation & preparedness	- 50% are concerned that Trondheim is not well prepared for climate change (growing concern). - 80% say local food is important for climate resilience; 33% are willing to grow food themselves.	- Over 50% worry the city is not prepared for climate change (rising trend); 31% experienced extreme weather problems last year. - 83% say local food is important for preparedness; 63% will buy local produce and 37% are willing to grow food (vs 33% in 2024).

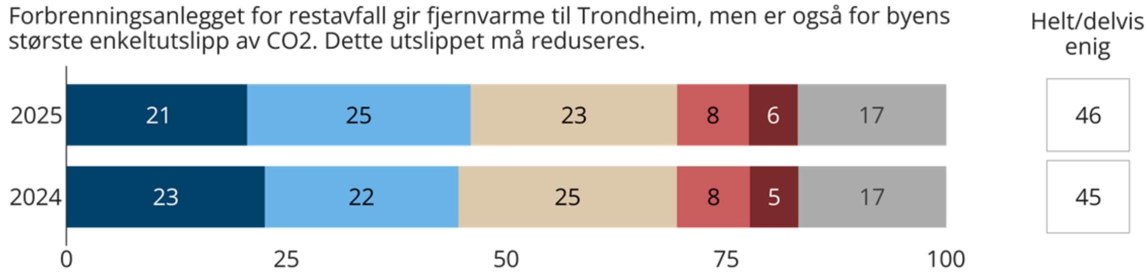
Source: Trondheim municipality/SINTEF/Sentio (2024/2025).

3.2.3 Survey Results - WtE/CCS

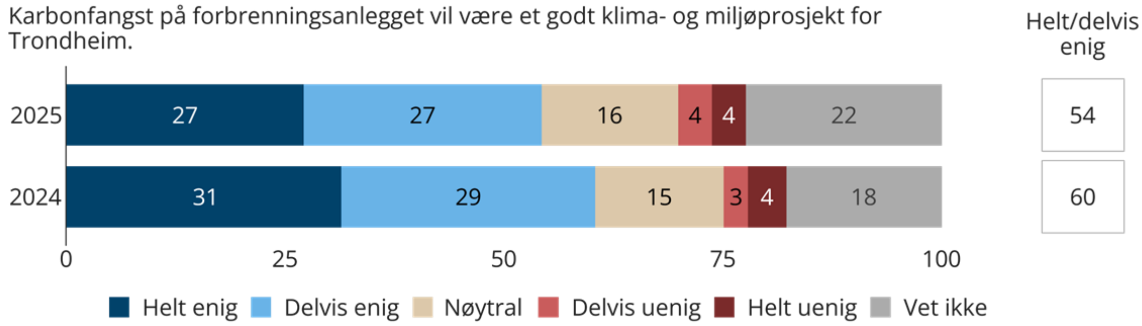
The 2024 and 2025 survey findings on CCS both reveal mixed attitudes among Trondheim residents regarding emissions reduction and carbon capture projects. 45% (2024) and 46% (2025) of respondents believe that emissions from waste incineration plants must be reduced, while many remain neutral or uncertain. Among those who have an opinion, a clear majority supports cutting emissions. Similarly, most respondents view CO_2 capture as a beneficial climate and environmental initiative.

However, opinions are divided when it comes to the costs associated with implementing CO_2 capture facilities. As shown in Figure 3.1, 36% (2024) compared to 40% (2025) agree that residents should accept higher waste management fees to fund such a project, while 39% (2024) and 35% (2025) disagree. Notably, wealthier respondents are more willing to pay additional fees compared to those facing financial difficulties. Despite general support for emissions reduction, there is limited enthusiasm (only about a third of the respondents) for Trondheim becoming a showcase city for CO_2 capture technology.

The waste incineration plant provides district heating to Trondheim, but it is also the city's largest single source of CO_2 emissions. These emissions must be reduced.

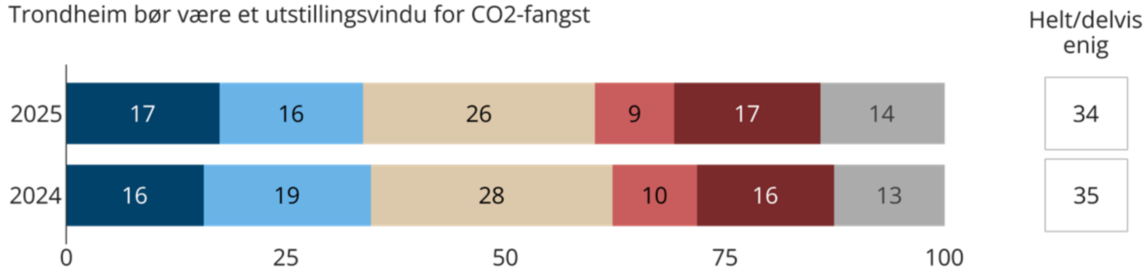


Carbon capture at the waste incineration plant would be a good climate and environment project for Trondheim.



Fully agree / Partially agree / Neutral /Partially disagree / Fully disagree / Do not know.

Trondheim should be a showcase for CO_2 capture.



Trondheim's inhabitants must accept higher waste fees so that we can build a CO_2 capture unit at the waste incineration plant.

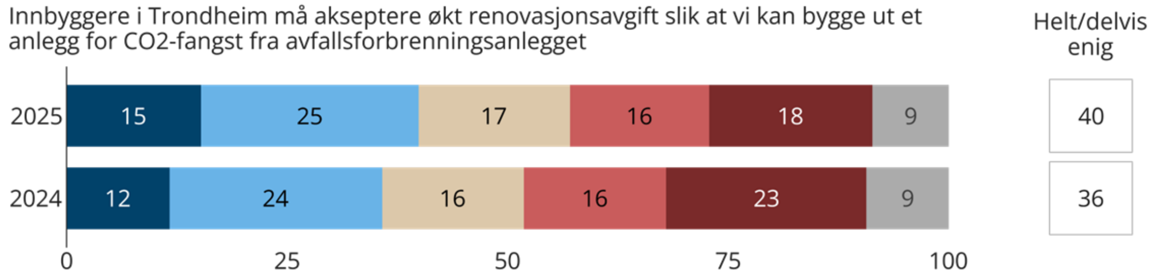
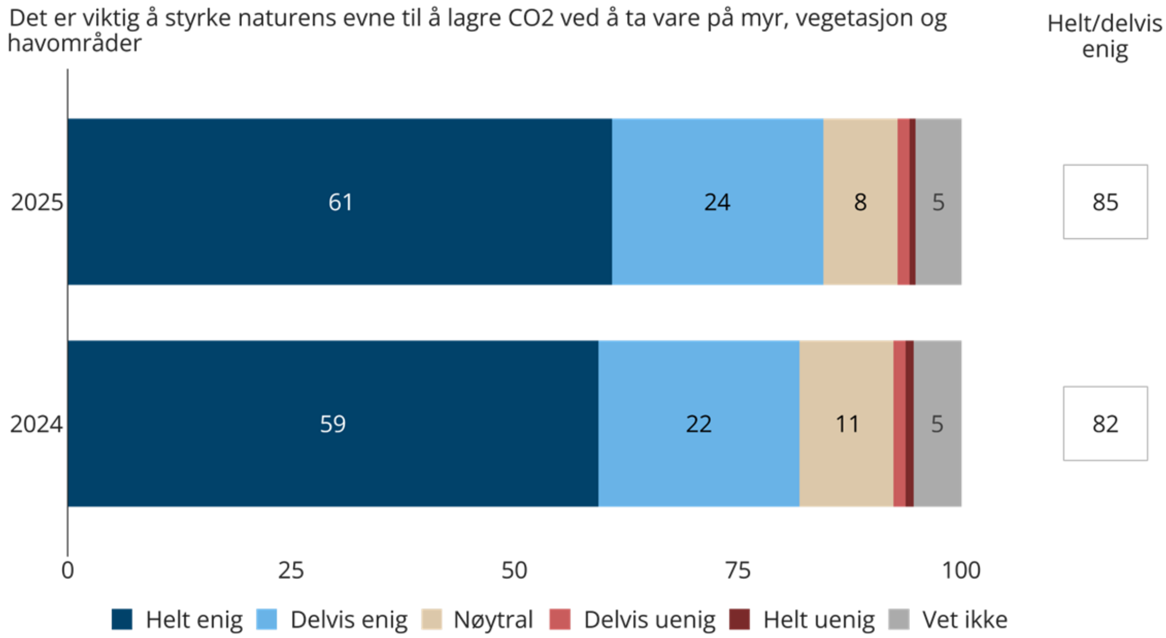


Figure 3.1. Attitudes towards WtE/CCS. *Helt/delvis enig = Fully/partially agree.*

Further, Figure 3.2 shows that a strong majority (over 80% in both 2024 and 2025) agrees that strengthening nature's ability to store CO_2 is essential. This includes preserving ecosystems such as peatlands, vegetation, and marine environments that naturally sequester carbon. Unlike the more controversial stance on industrial CO_2 capture, this form of climate mitigation enjoys broad and consistent support across different demographic groups.

It is important to strengthen Nature's CO_2 storage capabilities by preserving wetlands, vegetation, and marine areas.



Fully agree / Partially agree / Neutral /Partially disagree / Fully disagree / Do not know.

Figure 3.2. Importance of nature's ability to CO_2. Helt/delvis enig = Fully/partially agree.

The CCS findings remained broadly consistent between 2024 and 2025. The slight rise from 45% to 46% backing emission cuts and the 54% endorsement of CO_2 capture in 2025 suggest steady, albeit slightly declining, support for the technology. Importantly, both years show that while a majority view carbon capture initiatives favourably, substantial shares remain neutral or opposed to significant new measures (like becoming a regional CCS leader or paying higher fees). This indicates that public support for CO_2 capture in Trondheim is generally strong but cautious, with minimal change from 2024 to 2025.

3.2.4 Survey Findings Conclusion

The 2024 and 2025 surveys indicate growing concern about climate change, but declining consensus on how important it is to reach Trondheim's climate goals. While many residents support environmental measures, willingness to adopt individual actions varies, particularly regarding sustainable consumption and transportation. Moreover, there is broad agreement on preserving natural spaces, transitioning to renewable energy, and improving preparedness for climate impacts. However, engagement with the municipalities' climate efforts appears to be weakening, highlighting a need for better communication and public involvement.

Overall, the survey suggests that while many Trondheim residents recognize the importance of reducing CO_2 emissions, opinions on technical and financial solutions vary. As noted, inhabitants strongly support climate strategies based on nature preservation, but uncertainty remains regarding large-scale carbon capture projects, particularly in terms of funding and implementation.

3.3 Summary of Barriers and Drivers – ACT07

Barriers Identified

- Public support for CCS weakens significantly when higher waste management fees are involved, with lower-income households particularly reluctant to bear additional costs.
- While CCS is generally viewed positively, there is limited enthusiasm for Trondheim becoming a CCS "showcase" city, reflecting scepticism toward ambitious or highly visible industrial climate projects.
- A substantial share of respondents remains undecided or neutral on CCS and WtE emission reductions, indicating limited knowledge, unclear benefits, or insufficient communication about the technology.
- Reduced belief in achieving the 2030 climate goals and weakening engagement with municipal climate efforts may undermine trust and willingness to support complex initiatives like CCS.

Drivers for CCS Adoption

- A clear majority of respondents with an opinion agree that CO_2 emissions from waste incineration should be reduced, providing a strong normative basis for CCS implementation.
- More than half of respondents in 2025 view carbon capture at the waste incinerator as a good climate project, suggesting stable baseline acceptance.
- High and growing concern about climate change impacts and preparedness increases openness to mitigation measures, including CCS, when framed as part of a broader climate strategy.
- Strong public support for CO_2 sequestration—especially through natural systems—creates opportunities to position CCS as a complementary measure alongside ecosystem protection rather than as a competing solution.

3.4 Conclusions – ACT07

The insights from these surveys shape communication strategies and policy recommendations to improve public support and stakeholder commitment. The findings from ACT 07 demonstrate that while Trondheim's citizens express concern about climate change and broad support for nature-based climate solutions, there remains ambivalence toward technical and financial aspects of CCS.

Public understanding of WtE/CCS technologies is limited, and acceptance is influenced by perceptions of cost, safety, and tangible local benefits. Systemic barriers such as financial uncertainty, regulatory misalignment, and public scepticism are key issues that need continuous attention for large-scale CCS adoption. However, Trondheim's climate neutrality ambition, supportive EU and national frameworks, and opportunities for innovation and green job creation are drivers for progress.

Overall, strengthening communication, transparency, and participatory engagement will be essential to build trust and align societal, political, and economic interests. These insights form a valuable foundation for developing effective policy recommendations, stakeholder strategies, and public outreach to advance Trondheim's transition toward a sustainable, climate-neutral future.

4 Part 4: Learning from ongoing research projects

4.1 ACT 09: Learning from ongoing research projects

The CCWaSte4NetZero project builds upon previous and ongoing CCS research projects, including:

1. ACCSESS (EU Horizon 2020 Grant 101022487 led by SINTEF Energy Research): Aims at providing access to cost-efficient, replicable, safe and flexible CCUS, including as an enabler for sustainable urban development. Seven deliverables are summarised here, including a handbook with the aim to support informed adoption of CCS in urban areas. Personnel from Trondheim municipality have contributed with input to this handbook[15].
2. CaptureX (Norwegian Research Council (RCN) & CLIMIT): Investigates socio-technical challenges in CCS adoption, including public perception and policy barriers.
3. CCS Mid-Norway Project (Gassnova & CLIMIT): Focuses on regional CCS implementation, emphasizing the benefits of locally coordinated logistics and cost-sharing.
4. Deployment of BECCUS Value Chains (IEA Bioenergy inter-task project) and especially WP2 – Full-scale Waste-to-Energy CCS (Hafslund Celsio Klemetsrud plant in Oslo) in Norway: presenting the key technical, logistical as well as economical aspects of the project including a timeline
5. CircWtE (RCN KSP project) focuses on the future of waste management in a circular economy, including WtE, as well as future trends regarding MSW streams amounts and compositions including biogenic/fossil C

The integration of these research findings will enhance the feasibility and effectiveness of Trondheim's CCS initiative.

4.1.1 ACCSESS (Providing access to cost-efficient, replicable, safe and flexible CCUS)
ACCSESS is an Innovation Action developed with a vision to develop replicable CCUS pathways towards a climate neutral Europe in 2050[16]. Project duration is 2021-2026, with a total budget of 19 MEUR, of which 15 MEUR is EU H2020 funding. The project essentially consists of three main parts[17]:

1. CO_2 capture and utilisation (65% of total budget), including desktop studies of CO_2 capture integration in pulp and paper, cement, waste to energy and biorefineries, as well as pilot testing in industrial sites of two technologies, both CO_2 capture and CO_2 utilisation, the latter in terms of mineralisation with CO_2 of industrial alkaline wastes.
2. Development and analysis of CO_2 chains from continental Europe and the Baltics to the Norwegian Continental shelf.
3. Societal aspects of CCUS, working on (among other things) CCUS products value chain analysis, citizen engagement and acceptance and development of a handbook on CCUS for cities.

The most relevant open reports from ACCSESS are briefly summarised below. Once approved, all public reports and scientific publications are uploaded to the EU repository Zenodo in a dedicated ACCSESS community[18]. Not all reports have been approved by the funding agency CINEA at the time of writing this report, since the project has not yet concluded.

[15] I. Zhuravlova et al., Handbook on unleashing the CCUS potential for sustainable urban development (D12.11), https://doi.org/10.5281/zenodo.19370888, 2025.
[16] ACCSESS website: https://www.projectaccsess.eu/.
[17] R.M. Montañés et al., The ACCSESS project – developing replicable CCUS pathways for climate neutrality, Proceedings of the 17th International Conference on Greenhouse Gas Control Technologies (GHGT-17) 20-24 October 2024, Calgary, Canada, http://dx.doi.org/10.2139/ssrn.5025957.
[18] ACCSESS community in Zenodo.org: https://zenodo.org/communities/accsess.

Capture Ready Waste to Energy plants (D7.2)[19]. This deliverable provides an overview of the challenges of integrating solvent-based CO_2 capture in a WtE plant, focusing on the interface between the air pollution control/flue gas treatment (APC/FGT) section and the CO_2 capture unit. In an IEAGHG technical report on CCS from WtE, concentration limits were recommended to keep the solvent degradation at acceptable levels. The current BAT-AELs (BAT-associated emissions limits found in the BREF BAT WI document) on waste incineration, as well as real-life operational data from WtE plants, show that continuously keeping the concentration of SO_2, NOx and dust below the levels recommended by IEAGHG is unlikely. However, pilot campaign experience shows that solvent-based CO_2 capture plants can successfully operate on a range of flue gas contaminant concentrations. The impact on CO_2 capture plant efficiency and solvent degradation (and thus operating costs) needs to be clarified in such situations. Therefore, for flue gas contaminant concentrations in the range of the BAT-AELs for WtE plants, there are no clear, general indications that successful operation of a CO_2 capture plant would not be possible, albeit with challenges and limitations (e.g. risk of corrosion, increased OPEX).
Additional acid gas removal steps have been implemented in a few demonstration plants upstream CO_2 capture pilot plants, going beyond the BAT-AELs. In this work, we quantified the trade-off between the cost of solvent replacement due to degradation and additional cleaning of the flue gas using NaOH-dosing in the direct contact cooler (DCC). The cost of utilising the DCC of the carbon capture unit for additional acid gas removal is significantly lower than the cost associated with solvent replacement due to degradation.
The relationship between oxygen concentration and solvent degradation provides an additional motivation for implementing solutions that can help keep flue gas O_2 concentration as low as possible at WtE plants. However, this could be challenging to achieve in practice in WtE plants and might require optimised combustion control systems with increased monitoring.
It is essential to remember that there is no one-size-fits-all solution; each WtE flue gas line is unique and requires a case-to-case study, mainly due to heterogeneous and varying MSW composition and a tailored APC/FGT. Additionally, improvement of combustion control system incl. additional and/or new sensors and measuring devices for optimal "dual/integrated" operation of WtE and CCS (that should not be seen as separate islands) will probably be an essential measure to ensure smooth implementation.

Retrofitting amine CO_2 capture to a WtE plant (D12.6)[20]. This document is one of five “Neutral solution packages” (NSP) developed by Fraunhofer with support from other ACCSESS researchers. The ‘Neutral’ in NSP reflects its design for broad applicability across diverse urban contexts, without being tied to a specific site. ‘Solution’ indicates a strategic response that effectively tackles the challenges in the given context, while ‘Package’ conveys the comprehensive and all-inclusive nature of the guidelines. It is not stated explicitly in the document, as it is supposed to be neutral, but this document contains a summary of experiences from Hafslund Celsio and the development of their CO_2 capture project.

Transforming Municipalities – the Handbook for Urban CCUS strategies (D12.11)[15]. This report takes the approach that municipalities can play an important role in decarbonisation. More knowledge about the role CCS/CCU could play a role is needed, and an overview of relevant topics is provided in the handbook. The handbook was developed based on, among other things, interviews with representatives of frontrunner cities, including Tove-Lill Karlsen from Trondheim. The handbook states that “As key agents of change, municipalities are invited to take the lead in planning and executing CC(U)S projects by initiating stakeholder cooperation and engagement, aligning regulatory frameworks, and fostering public trust. Public outreach efforts, including awareness campaigns and transparent communication, are essential to gaining community support and addressing concerns. Additionally, municipalities can provide financial incentives and support obtaining national and international funding, such as green bonds or grants, attracting investment and offsetting initial costs. Beyond local efforts, through active leadership, municipalities should

[19] V. Skjervold, Capture ready Waste-to-Energy plants (D7.2), https://doi.org/10.5281/zenodo.17566859, 2024.
[20] I. Zhuravlova et al., Retrofitting amine CO_2 capture to a WtE plant (D12.6), https://doi.org/10.5281/zenodo.14288909, 2024.

actively create and join collaboration networks with other municipalities, research institutions, and private sector partners to share best practices, access technical expertise, and leverage funding opportunities. By fostering these partnerships, cities can accelerate innovation, scale up CC(U)S initiatives, and enhance their collective impact on global climate action. Through strategic leadership and collaboration, municipalities can champion sustainable development and pave the way for a more resilient urban future."
A webinar by ACCSESS partner Fraunhofer on the theme of integrating CCS urban climate neutrality strategies can be found on the internet[21].
Citizens' concerns and recommendations in relation to CCUS (D12.17)[22]. This report presents results from (a) a multilingual survey about CCUS, (b) a sentiment analysis of CCUS based on posts on X (formerly Twitter) and (c) a review and analysis of newspaper coverage of CCUS.

a) In the survey, many respondents identified CCUS as a valuable technology for climate mitigation. However, significant concerns emerged around issues such as greenwashing, environmental risks, investment costs, and transparency.
b) The discourse on X revealed polarized sentiments, with slightly more negative than positive opinions.
c) The newspaper analysis was conducted using Python and web scraping tools. The primary source of news articles was Google News, which provides aggregated content from a wide range of global media sources. A total of more than 31 000 articles were analysed from 3 October 2012 to 13 September 2024 in multiple languages, including English, French, Italian, Norwegian, Spanish, and German. 1199 with 1242 mentions of Carbon capture articles in 45 newspapers were identified as relevant for further analysis. Thereafter sentiment and content were categorized per newspaper source. In sum, newspapers were found to report more negatively than positively about carbon capture. Out of the 1242 analysed mentions of CCUS/Carbon capture 53% were negative, 10% were positive and the rest neutral. The five newspapers with the most mentions of CCS were The New York Times, CleanTechnica, The Register, Euronews and China Daily. Of these, China Daily was found to be the only newspaper with more positive than negative sentiments of CCUS/Carbon Capture. Further analysis of the contents reported by the newspapers can be found in the report.

How to implement CO_2 capture in Waste to Energy (D12.14[23], note: this deliverable is under approval process by CINEA per 14.04.2026). This summary report presents key insights from ACCSESS on the implementation of CCS in the Waste to Energy sector. The main technological challenges with implementing CO_2 capture in WtE are summarised: (a) WtE flue gas fluctuations; (b) Line-specific considerations; (c) Emissions from the CO_2 capture process; (d) Regulatory alignment and permitting challenges; (e) Flue gas cleaning; (f) Energy integration; (g) space.
Implementation was further discussed in a conference article[24] concluding that there is no one-size-fits-all solution; each line is unique and requires a case-to-case study, mainly due to heterogeneous and varying MSW composition and a tailored FGT. Additionally, improvement of combustion control system incl. additional and/or new sensors and measuring devices for optimal "dual/integrated" operation of WtE and CCS (that should not be seen as separate islands) will probably be an essential measure to ensure smooth implementation of capture-ready WtE plants. Key lessons for accessing transport and storage infrastructure:

- Early dialogue with transport and storage providers is critical.
- Clustering several emitters into regional hubs can reduce infrastructure cost.
- Agreement on CO_2 quality specifications.
- For WtE, urban siting and biogenic CO_2 fractions could create both logistical constraints and opportunities for CDR revenue streams.

[21] https://www.youtube.com/watch?v=yjOqxOhkR_M
[22] S. Kaltenegger et al., Citizen concerns and recommendations in relation to CCUS (D12.17), 2025.
[23] A. Brunsvold-Hellemans et al., How to implement CO_2 capture in Waste to Energy (D12.14), 2025.
[24] A. Brunsvold et al., Capture-ready Waste-to-Energy (WtE) plants, Proceedings of the 17th International Conference on Greenhouse Gas Control Technologies (GHGT-17) 20-24 October 2024 Calgary, Canada, https://doi.org/10.2139/ssrn.5064323.

A generic view on how to build CO_2 capture business models is provided, which is common for the entire ACCSESS project, after which perspectives specific to Waste to Energy industry are provided, where the main factors are: biogenic share of CO_2/opportunity for carbon removal credits; urban integration, public perceptions, EU ETS situation, BREF BAT WI alignment and WtE & EU taxonomy alignment.

WtE product value chains (D12.9[25], note: this deliverable is under approval process by CINEA per 14.04.2026). A scientific article[26] shows that when the cost for CCS implementation (value chains considered: cement, pulp, WtE, and refinery industries) is distributed along the product value chain, assuming full cost pass-through, it potentially imposes a small cost increase on end-consumers, assuming that the end-product producer can maintain a sufficiently large profit margin. While the cost increases only marginally for the end-user (0.3–3.3%), the related emissions are reduced by up to 36%.

Guidelines for regulating post-combustion capture facilities at national and regional levels (D12.7[27]). The report provides a comprehensive overview of European and Norwegian regulatory frameworks for CO_2 capture, with significant relevance for WtE-CCS, particularly Hafslund Celsio (Oslo), which is one of Norway's flagship full-scale CCS projects.

1. Regulatory Context Affecting Waste Incineration and CCS

European Framework:

- The EU Clean Air Policy (Directive (EU) 2024/2881) sets stricter limits for air pollutants, requiring improved monitoring, early action, and transparency. This raises the bar for WtE plants with CCS regarding amine slip, nitrosamine/nitramine, and other atmospheric emissions.
- The CCS Directive (2009/31/EC) governs safe CO_2 storage, and Norway applies it via the Storage Regulation and amendments to the Pollution Regulation.

Norwegian Framework:

- The Pollution Control Act requires permits for activities that may pollute; CCS plants fall under this act.
- Emission permits must include:
    - detailed assessment of air and water emissions,
    - baseline studies (air, water, soil),
    - chemical and waste management plans,
    - environmental risk and emergency preparedness assessments.

These frameworks ensure that WtE CCS projects integrate BAT for capture and amine management. (Editor's note (not in deliverable): there is currently no "BREF CCS" document).

2. Full-Scale CCS at Waste-to-Energy: Hafslund Celsio (Oslo)

Role in Longship Project:

- Celsio is one of two CO_2 sources in the Longship CCS project, along with Heidelberg Materials.
- The plant aims to capture >90% of CO_2 emissions. About half of its CO_2 comes from fossil sources (plastics) and half from biogenic waste.

Emission Characteristics and Permitting Requirements:

Celsio's CCS implementation results in new emissions to air and water, triggering a revised permit[28]. (Editor's note (not in deliverable): the emissions to air table from the 01.08.2024 revised permit that encompasses both WtE and CCS is provided in Appendix).

[25] A. Hörbe Emanuelsson et al., Quantifying the value chain for climate neutral and climate positive housing, in terms of cost for CCUS with CDR along the value chain energy carriers (D12.9), 2025.
[26] A. Hörbe Emanuelsson et al., The Cost to consumers of Carbon Capture and Storage—A product value chain analysis. Energies 16, 7113, 2023, https://doi.org/10.3390/en16207113.
[27] M. Zeeshan, Guidelines for regulating post-combustion capture facilities at national and regional levels (D12.7), 2025.
[28] Miljødirektoratet, Vedtak om endret tillatelse etter forurensningsloven til Hafslund Celsio AS avd Klemetsrudveien, 01.08.2024.

Environmental & Health Assessment:
- Atmospheric dispersion models show amine-derived deposits (nitrosamines/nitramines) below drinking water and health thresholds recommended by the Norwegian Institute of Public Health (FHI).
- Water effluents contain dust, NO_x, SO_2, trace pollutants, requiring purification before discharge.

Permit Status:
- As of March 2023 (Editor's note: latest updated permit is dated 01.08.2024, see Appendix for excerpt), Celsio has an approved permit for carbon capture and intermediate CO_2 storage.
- Emission limits define allowed levels for amines, heavy metals, particulate matter, and other pollutants.

3. Main Implications for Waste Incineration with CCS
- Amine management and atmospheric chemistry remain the primary environmental concerns.
- Stricter EU air-quality rules will push WtE plants toward advanced emission controls.
- Permits require comprehensive modelling of amine slip, degradation products, and deposition onto drinking water sources.
- Wastewater from CCS units is a major consideration, especially given contaminants in DCC effluents.
- Baseline studies, continuous monitoring, and BAT-compliant mitigation systems are mandatory for obtaining and maintaining operating permits.

4.1.2 CaptureX (Socio-technical drivers, opportunities and challenges for large-scale CCUS)
CaptureX is a research project funded by the Research Council of Norway (CLIMIT programme, 2021-2025). Departing from the multidisciplinary sustainability transitions research field, CaptureX builds on a socio-technical perspective to analyse CCUS innovation dynamics in Norway and other Northern European countries. Beyond Norway, case studies have been conducted in the UK and Netherlands, whereas policy analysis has compared Norway with Sweden[29] and other proximate countries.[30] Innovation is here understood broadly, including not only early phases of technology development, but also diffusion and application in various industries.
CaptureX investigated innovation processes across CCUS value chains, on specific types or categories of CCS technology, and also assessed system strengths and weaknesses in the Norwegian CCS innovation system.[31] Another important topic addressed has been technology strategies and business models of key industrial actors, and how those are often conditioned by broader regional industrial transformation processes, notably concerning the establishment of necessary CO_2 infrastructure. CaptureX has also investigated the role of legitimation processes and policies in supporting (or hampering) the development and diffusion of CCUS. A comparative analysis of the CCS strategies for the waste incinerators in Trondheim, Oslo, Bergen and Fredrikstad (all in Norway) was also conducted.

Key CaptureX takeaways for CCWaSte4NetZero - generic
- Since the Paris Agreement in 2015, CCS has gained momentum as a key technology for climate emission mitigation, notably in the hard-to-abate energy-intensive process industries
- While Norway is a frontrunner in CCS, notably with the Longship full-scale demonstration project, current policy instruments and framework conditions are generally insufficient to support investment decisions on CCS. Apart from the two CO_2 capture projects that are part of Longship, only small CCS projects and pilots have materialised. Beyond Longship, there is no policy support tool in place in Norway to support large-scale CCS investment decisions. See section 1.2 for more information about current regulation and incentives.

[29] M. Steen et al., Perceptions of decarbonisation challenges for the process industry in Sweden and Norway, Energy and Climate Change 5, 100167, 2024, https://doi.org/10.1016/j.egycc.2024.100167.
[30] T Hansen et al., How aligned are industry strategy and government policy for the decarbonisation of energy-intensive process industries? Climate Policy 24, 1149-1162, 2024, https://doi.org/10.1080/14693062.2024.2363490.
[31] M. Steen et al., CCS technological innovation system dynamics in Norway, International Journal of Greenhouse Gas Control 136, 104171, 2024, https://doi.org/10.1016/j.ijggc.2024.104171.

- A general challenge for CCS in Norway (beyond the oil & gas sector), is that emission points are generally small and geographically dispersed. This creates challenges for developing the necessary CO_2 transport and storage infrastructure. There have however been many regional initiatives and studies to find feasible alternatives for co-development of CO_2 infrastructure, including in Mid-Norway. Co-development of infrastructure for different emitters will likely be important for increasing feasibility but comes with significant coordination challenges. In the absence of prospects for CO_2 transport and storage, actors explore opportunities for CCU (Note: see 2.2.3 about the CCU unit in Rakkestad).
- For many emitters, CCS is one of several options (e.g. electrification, hydrogen, biofuels) for emission reductions. Different options may have synergies (e.g. biofuels + CCS) but also compete or form part of a sequential process of emission reductions (e.g. first implement biofuels and electrification, thereafter CCS).
- Legitimacy for CCS in Norway is generally high, but previous research on other technologies (e.g. onshore wind power) suggests that (local) social acceptability can quickly change as projects mature and start materializing. Transparency and outreach activities towards societal stakeholders is therefore important.

Key CaptureX takeaways for CCWaSte4NetZero – CCS in waste-to-energy[32]

- The bulk of large waste incinerator operators in Norway see CCS as an important technological solution for mitigating greenhouse gas emissions
- Municipal climate targets, especially in the major cities, are an important driver for CCS in WtE
- The overall economic framework conditions for WtE operators have been challenging in recent years, constraining financial capacities to develop and invest in CCS.
- CCS-enabling business models involve revenue streams on the capture and storage of biogenic CO_2 (i.e. BECCS – CDR), as Hafslund Celsio has managed to do in Oslo.
- There are no one-size fits all 'plug and play' solutions for installing CCS on WtE plants. CC units need some degree of tailoring to specific incinerators (e.g. gas cleaning). Space is often a constraint.
- CCS influences how waste incinerators are integrated with other infrastructures, notably district heating and electricity. Due to the energy needs of CC, reductions in energy output are expected.
- A general challenge for WtE operators (apart from Hafslund Celsio which is part of the Longship project) is access to infrastructure for CO_2 transport and storage.
- Public acceptance of CCS is not considered a major issue per se, but there have been local concerns around issues such as area use, increased traffic, emissions from capture units.
- Public acceptance issues are likely to become more apparent as CCS projects mature.

4.1.3 CCS Mid-Norway Project (2021-2023)[33]

A cluster cooperation between five large CO_2 emitters in mid-Norway (Elkem Thamshavn (phase 1), Hydro Sunndalsøra (phase 2), Equinor Tjeldbergodden, Franzefoss Minerals (NorFraKalk & Verdalskalk), Statkraft Varme (now Lunera Energi) & Wacker Chemicals Norway (Holla)) have assessed common solutions for ship transport and permanent storage. Key takeaways:

- Possible synergies with shared solutions with approx. 20% cost reduction
- Due to differences in timelines between industrial players in Mid-Norway, it is not possible to realize this potential before after 2035 at the earliest

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[32] Feasibility assessment of CCS for the waste incineration plants in Trondheim, Oslo, Bergen and Fredrikstad published in Hansen et al., Capturing context: A sociotechnical feasibility assessment of carbon capture and storage in Norwegian waste incineration. Energy Research & Social Science 125, 104118, 2025, https://doi.org/10.1016/j.erss.2025.104118.

[33] Final report available at https://www.sintef.no/en/projects/2021/ccs-midt-norge-an-industry-cluster-for-co2-capture-and-storage-in-central-norway/.

- Possible to reach a stronger influence through a unified position and approach towards Norwegian national authorities regarding support for transport and storage

The project led to increased competence across all companies, achieved both through internal knowledge sharing and collaboration with other clusters.

4.1.4 IEA Bioenergy project on BECCUS (Phase 2, 2023-2025)[34]

Work Package 2 of this project focused on Hafslund Oslo Celsio Klemetsrud WtE plant[35] with a challenging journey (so far), even though it should not be surprising for such an ambitious, first-of-its-kind project, and with the dedication and enthusiasm of many, the project is becoming a reality. Here are lessons learnt:

- Things often take much more time than expected
- Do not underestimate infrastructure needs - electricity, transport, the significant need for space (especially challenging in urban settings), harbour (temporary storage)
- Do not underestimate the need for adequate project organization/management
- Such initiatives may be subject to political and societal (public perception) challenges
- Pitfalls are many for a first-of-its-kind project with many processes of varying maturity
- Integration within an existing operational plant is complex. Addressing interface challenges (e.g. additional flue gas cleaning) is key
- A cost-reducing phase (including changing suppliers) was a bold move and seemed risky, but it appears to have been the right decision to reinvigorate the project
- Most challenges encountered (so far) were not directly related to CCS technology per se

An additional important aspect is the possible revenue streams related to CCS and WtE. Approximately 50% of the CO_2 emitted from WtE plants is biogenic. Storing permanently WtE CO_2 may lead to the net removal of CO_2 from the atmosphere. This enables WtE plants to sell carbon removal certificates (CDR) on the promising voluntary carbon removal market (VCM). Hafslund Celsio signed agreements in 2025 with Frontier and Microsoft for the offtake of several hundred thousand tons of CO_2.

4.1.5 RCN KSP CircWtE (WtE and MSW management systems in Circular Economy, 2021-2025)

CircWtE main objective was to determine how future municipal solid waste (MSW) management systems will look in a circular economy, and what role they will have in the energy system. CircWtE did not work directly on CCS but several takeaways are still relevant for CCWaSte4NetZero:

- The total amount of waste going to WtE might decrease in the coming decade, but the extent of this decrease is difficult to evaluate, it could very well be very limited due to increased population and wealth. Local variations will occur (including regions with increasing amounts of waste to WtE)
- The combustion-relevant properties of the waste going to WtE in the future (LHV, moisture, etc.) will evolve in the future and may impact WtE plant operation. This includes the biogenic/fossil ratio, but probably to a limited extent, with the biogenic CO_2 proportion remaining around 50%[36]
- Significant amounts of combustible Norwegian waste (mainly residual waste and wood waste) are exported and incinerated in Sweden to produce district heat[37]. The number was above 800 000 tons in 2024. Any changes in this trade may impact CCS in Norway, while CCS implementation may in turn impact waste transport across the border.

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[34] IEA Bioenergy Inter-task project BECCUS phase 2 publications at https://task40.ieabioenergy.com/inter-task-beccus-2-0/.
[35] M. Becidan, Full-scale Waste-to-Energy CCS in Norway, Published by IEA Bioenergy, 2025, https://www.ieabioenergy.com/wp-content/uploads/2025/10/IEA-Bioenergy_Intertask_BECCUS_Phase2_Oslo_WtE_final-report.pdf.
[36] E Magnanelli et al., Circular economy and Waste-to-Energy: A case study on status and perspectives on CO_2 emissions and key incineration properties towards 2035 in the city of Oslo, Waste Management Bulletin 4, 100301, 2026, https://doi.org/10.1016/j.wmb.2026.100301.
[37] M. Becidan, Er det greit å eksportere norsk avfall?, 2025, https://blogg.sintef.no/energi/er-det-greit-a-eksportere-norsk-avfall/.

1 Conclusions

The CCWaSte4NetZero project represents a crucial step in Trondheim's journey toward climate neutrality. By addressing technical, financial, and social challenges associated with CCS for WtE, the project:

- Strengthens policy frameworks at municipal, national, and EU levels.
- Develops a viable business model that balances costs, incentives, and regulatory support.
- Enhances public and stakeholder engagement.
- Leverages international best practices from Zurich, Oslo, and European CCS initiatives.
- Includes research insights from ACCSESS, CaptureX, and other CCS and/or waste projects.

By combining technology, governance, finance, and public participation, this project sets the foundation for a replicable CCS model that other European cities can adopt. Based on the insights found in this report, concrete recommendations articulated along 14 axes are proposed as ingredients in a WtE CCS cookbook. The axes were selected to encompass all dimensions of a WtE CCS project. Different recommendations are aimed at different actors (municipalities, WtE operators, authorities, technology, R&D) and cover all stakeholders interested in developing a CCS WtE project in Europe.

1. Societal aspects

1. Communicate **CCS through co-benefits, such as** cleaner air and climate neutrality.
2. Use **targeted/tailored public engagement** on a regular basis.
3. Develop and use **transparent communication tools** (incl. infographic) for emissions, costs, benefits & risks to build and foster trust.

2. Regional and national coordination

1. Align municipal climate, waste & energy plans.
2. Implement **a regional waste strategy** for predictable CO_2 capture operation.
3. Explore **coordination possibilities with other regional CO_2 emitters**, to leverage funding/innovation/impact opportunities.
4. **Push for national authorities to deliver** a stable framework for incentive instruments (such as CCfD, reversed auctions) and regulations, as well as strategic coordination for infrastructure.

3. Infrastructure

1. Reserve **space** for equipment, i.e. absorber/stripper, DCC & buffer tanks.
2. Secure **transport and storage MoUs** early.
3. Evaluate infrastructure **synergies with regional CCS clusters** to reduce costs.

4. Business models

1. Explore how to **stack revenues** such as Innovation Fund, national funding opportunities, ETS avoidance + CDR/removals + waste fees + energy sales.
2. Explore opportunities for **private capital** investments

5. EU ETS (Emissions Trading System)

1. Prepare **ETS-ready MRV systems** using the mandatory EU monitoring plans required from 2024.
2. Run **ETS-scenario modelling** to replace the Norwegian combustion tax with future ETS cost curves.
3. Push nationally for **predictable CO_2-pricing** across waste fractions to reduce uncertainty.

6. EPR (Extended Producer Responsibility)

1. Support **modulated EPR fees** for hard-to-recycle plastics (and textiles) to finance CCS on fossil CO_2.
2. Document the **avoidance value** of CO_2 emissions from fossil plastics and textiles combustion.
3. Collaborate with national authorities for **EPR revenue to co-fund CCS OPEX** at WtE plants.

7. CDR (Carbon Dioxide Removal)

1. Implement **high-quality biogenic MRV**, aligned with CRCF/VCM rules.
2. Pilot **third-party verification** early, aligned with CRCF/VCM rules.
3. Explore **long-term offtake agreements** for stable CDR revenues.

8. EU Taxonomy

1. Attempt to obtain **green loan for CCS** even if WtE remains excluded.
2. Collaborate on approaches to validate that only **non-recyclable** (and difficult to recycle) **residual waste** is treated by WtE - critical for possible inclusion.

9. Permitting

1. Explore **permitting pathways** with authorities (integrated vs separated).
2. Conduct **baseline environmental surveys** early (air, soil, water).
3. CO_2 capture with amines – agree on **amine/nitrosamine (degradation products) modelling approach** (formation, dispersion and destruction processes) with the authorities.

10. Plant operation - WtE & CO_2 capture

1. WtE - Consider upgrading, if necessary, **flue gas treatment to meet capture-quality requirements**.
2. CO_2 capture with amines – monitor **solvent degradation** to evaluate need to improve plant operation.
3. CO_2 capture – **Tailor DCC operation** to incoming gas and capture technology.

11. Waste

1. Implement continuous **waste composition monitoring** to reduce CO_2 capture process fluctuations.
2. Strengthen quality control on **waste sorting** to stabilise WtE feedstock.

12. Energy

1. Quantify **energy demand impacts** and integrate CCS into energy planning to maintain energy security.
2. Investigate **energy integration solutions** to reduce the CO_2 capture energy penalty.
3. Use CCS to communicate about **climate-positive district heating** from waste (biogenic fraction).

13. Circular Economy

1. Consider implementing **advanced mixed waste sorting** alongside CCS.
2. Evaluate **CRM recovery from WtE bottom & fly ash** as potential additional revenue stream.
3. Communicate **WtE CCS** as a **complement to recycling**—not a competitor.

14. Innovation/R&D

1. Develop **alternatives to amine-based capture technologies**.
2. Assess **WtE sector-specific flue gas characteristics** to understand resulting CO_2 capture requirements.
3. Join **modelling** R&D - energy integration, techno-economic analysis, national/European infrastructure.

2 Appendices

Overview of major planned first-of-its-kind BECCUS projects in Europe (per 10.2024)
IEA Bioenergy, https://task40.ieabioenergy.com/inter-task-beccus-2-0/.

Project/company	Location	Type of primary energy facility	Facility capacity	Feedstock	Capture rate biogenic CO_2 Mt/a	Project phase
Asnæs 6 CHP Station /Ørsted	Denmark	Biomass combustion	25 MWel, 129 MWth	Wood chips	0.28	implementation
Avedøre Power Station /Ørsted	Denmark	Biomass combustion	100 MWel	Straw	0.15	implementation
Amagerværket4/ Hofor	Denmark	Biomass combustion	150 MWel, 415 MWth	Wood chips	1.1	planning
BECCS Stockholm/ Stockholm Exergi	Sweden	Biomass combustion	130 MWel, 280 MWth	Wood chips	0.8	planning
Jordbro/ Vattenfall	Sweden	Biomass combustion	279 MWth, 20 MWel	Wood chips, waste wood	0.15	planning
Hafslund Celsio/ Hafslund	Norway	Waste-to-energy (50% biogenic share)	55.4 MWth, 10.5 MWel	Municipal waste, waste from industry	up to 0.2*	planning
Emshaven/RWE	The Netherlands	currently: co-firing (15%); in 2030: 100% biomass	2 x 785 MWel	Hard coal (currently), wood pellets, agro pellets	8-10	planning
Amer/RWE	The Netherlands	currently: co-firing (80%); in 2025: 100% biomass	645 MWel, 350 MWth	Hard coal (currently), wood pellets, agro pellets	3-4	planning

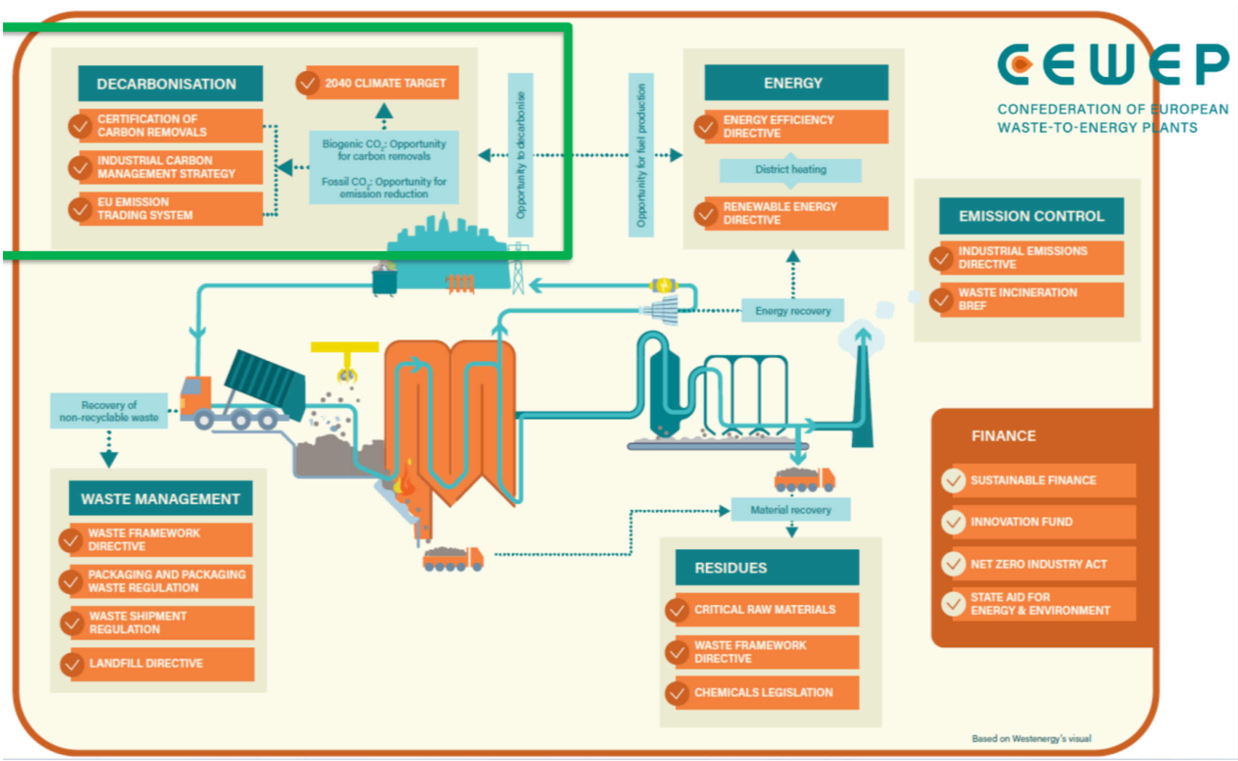
Notes: * Hafslund Celsio: Capacity of the capture unit is 400 kt/year. Assuming 50% biogenic fraction. **Disclaimer:** No guarantee for completeness.

Overview of some CCUS projects & initiatives in the European WtE sector (2022).
The Climate Roadmap of the European Waste-to-Energy Sector The path to Carbon Negative. Fabio Poretti, Ella Stengler (CEWEP). 16th International Conference on Greenhouse Gas Control Technologies, GHGT-16, 23rd-27th October 2022, Lyon, France.

Table 1: Overview of some Carbon Capture Use and/or Storage (CCUS) projects & initiatives in the European WtE sector

Country	*Type of CCS or CCU project (WtE Company Name, Location)*
Belgium	Antwerp@c Power-to-Methanol CCU project (Indaver, Doel-Port of Antwerp)
Denmark	CCS projects as part of the C4 – Carbon Capture Cluster Copenhagen (Amager Resource Center - ARC, Copenhagen), (Vestforbrænding, Glostrup-Copenhagen), (ARGO, Roskilde - west of Copenhagen); Various CCUS projects and investigations (Fortum, Nyborg), (Nordværk – ex RenoNord, Aalborg), (Kredsløb, Aarhus), (Energnist, Esbjerg), (Norfors, Hørsholm), (AffaldPlus, Næstved) [26]
Finland	All WtE plants in Finland have a CCU project planned or they have announced that are looking into Power-to-Gas projects: CCU Waste-to-Material Carbon2x pilot (Fortum, Riihimäki); CCU EnergySampo project for the production of synthetic methane (Westenergy, Mustasaari); CCU Nordic Ren-Gas projects for the production of synthetic methane or other products (Kotkan Energia, Korkeakoski- Kotka), (Tammervoim, Tampere), (Lahti Energia, Lahti); Other Power-to-Gas CCU projects (Vantaan Energia, Vantaa), (Riikinvoima, Leppävirta), (Oulun Energia, Oulu), (Lounavoima, Salo)
France	CCU pilot project for CO_2 use in algae production (SUEZ, Créteil - Paris), (Syctom, Saint-Ouen - Paris)
Germany	CCU project in preparation phase for methanol synthesis (EEW, Stavenhagen); CCU project for the production of synthetic methanol (ZASt, Zella-Mehlis)
Italy	CCS Ravenna Hub project (Herambiente, Ravenna); Hot Potassium Carbonate Test Installation (A2A, Corteolona)
Netherlands	CCU first large-scale facility with CO_2 delivery to the greenhouse horticulture sector via Air Liquide (AVR, Duiven); CCU pilot plant for CO_2 transformation into $NaHCO_3$ and further captured CO_2 applications (Twence, Hengelo); CCU pilot plant for CO_2 liquefaction and delivery to the greenhouse horticulture sector via OCAP (HVC, Alkmaar); CCUS planned projects and investigations at different stages (AVR, Rozenburg), (AEB, Amsterdam), (Attero, Moerdijk), (REC, Harlingen), (ARN BV, Weurt); OSIRIS CCU project for CO_2 capture and supply to two greenhouse clusters (PreZero, Roosendaal); HyNetherlands CCU project for methanol production (EEW, Delfzijl)
Norway	CCS first large-scale project as part of the wider Longship project (Hafslund Oslo Celsio, Klemetsrud); CCS Borg CO_2 cluster (Frevar, Fredrikstad), (Kvitebjørn Bio-El, Fredrikstad), (Sarpsborg Avfallsenergi, Sarpsborg); Other CCUS projects (Statkraft Varme, Trondheim), (Returkraft, Kristiansand), (BIR Ressurs, Bergen), (Forus Energi, Stavanger), (Østfold Energi, Rakkestad), (Kvitebjørn Varme, Tromsø), (Eidsiva Bioenergi, Trehøringen Energy Center in Hamar)
Portugal	CCU Power-to-Liquid project for the production of synthetic aviation fuels (LIPOR, Maia/Porto)
Sweden	HySkies CCU project for the production of synthetic aviation fuels (Vattenfall, Uppsala); CCS studies (Renova, Gothenburg), (SYSAV; Malmö); Hot Potassium Carbonate pilot unit (Öresundskraft, Filbornaverket- Helsingborg)
Switzerland	CCS investigation study (KVA Linth, Niederurnen); All 29 Swiss WtE plants committed to CCS on the long-term (see press release www.vbsa.ch) [27]
UK	CCS East Coast Cluster (SUEZ, Haverton Hill/Teesside); CCS Hynet North West project (Viridor, Runcorn), (Protos - Covanta, Ellesmere Port); CCS project (Cory, Belvedere - southeast London); Carbon Capture tests (Veolia, Sheffield); see more comprehensively the report on the CCUS Development Pathway for the UK WtE sector [28]

Key regulations in the WtE sector - a graphic illustration (CEWEP).
Presented by Fabio Poretti (CEWEP) at Sirk Norge avfallsforbrenningsseminaret, 18-19 March 2026, Fredrikstad, Norway.



Excerpt from Klemetsrud WtE & CCS permit

Decision on amended permit under the Pollution Control Act for Hafslund Celsio AS, Klemetsrudveien division (Vedtak om endret tillatelse etter forurensningsloven til Hafslund Celsio AS avd Klemetsrudveien), 01.08.2024, 22 pages total.

Emissions to air

Utslippsgrense: emission limit. Enhet: unit. Midlingstid: averaging period. Målefrekvens: measurement frequency.

Maksimal avgasstrøm på ovnslinje 1, 2 og 3 er på 74 000 Nm^3/time, 74 000 Nm^3/time, og 195 000 Nm^3/time respektivt.

Når karbonfangstanlegget er i drift, skal utslippsgrenser og målekrav i tabell 4 gjelde.

Tabell 4 Utslippsgrenser for kanaliserte utslipp med krav om målinger jf. punkt 11.

Utslippsparameter	Utslippsgrense	Enhet	Midlingstid	Målefrekvens
Totalt støv	6	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Cd+Tl	0,024	mg/Nm^3	gjennomsnitt i prøvetakingsperioden	minst én måling hver sjette måned
Sb+As+Pb+Cr+Co+Cu+Mn+Ni +V	0,36	mg/Nm^3	gjennomsnitt i prøvetakingsperioden	minst én måling hver sjette måned
Hydrogenklorid (HCl)	9,6	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Hydrogenfluorid (HF)	1,2	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Svoveldioksid (SO_2)	48	mg/Nm^3	døgnmiddelverdi	kontinuerlig
	200	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Summen av nitrogenmonoksid og nitrogendioksid, uttrykt som NO_2	80	mg/Nm3	årsmiddelverdi	kontinuerlig
Karbonmonoksid (CO)	60	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Ammoniakk (NH_3)	18	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Totale flyktige organisk karbon (TOC)	12	mg/Nm^3	døgnmiddelverdi	kontinuerlig
Polyklorerte dibenzo-p-dioksiner og -furaner (PCDD/F)[1)]	0,072	ng I-TEQ/Nm^3	gjennomsnitt i prøvetakingsperioden	minst én korttidsprøvetaking hver sjette måned
	0,096		Langtidsprøvetaking[2)]	
PCDD/F + dioksinlignende polyklorerte bifenyler (dioksinlignende PCB)[1)]	0,096	ng WHO-TEQ/Nm^3	gjennomsnitt i prøvetakingsperioden	minst én korttidsprøvetaking hver sjette måned
	0,12		Langtidsprøvetaking[2)]	
Summen av kvikksølv og kvikksølvforbindelser, uttrykt som Hg	24	$\mu g/Nm^3$	gjennomsnitt i prøvetakingsperioden	
	12	$\mu g/Nm^3$		
Aminer totalt	1	mg/Nm^3	ukemiddelverdi	kontinuerlig
Ketoner /aceton				kontinuerlig
Aldehyder				kontinuerlig

1) Hvis utslippet av dioksinlignende PCB er påvist til under 0.01 ng WHO-TEQ/Nm^3 skal utslippsgrenseverdiene for PCDD/F brukes. Dersom utslippet av dioksinlignende PCB ikke er påvist å være under 0.01 ng WHO-TEQ/Nm^3 skal utslippsgrenseverdiene for PCDD/F + dioksinlignende PCB brukes.

2) Utslippsgrenseverdien gjelder ikke hvis det er påvist at utslippsnivåene er stabile.

Excerpt from Rakkestad CCU permit

Permit for activities under the Pollution Control Act for Carbon Centric AS (Tillatelse til virksomhet etter forurensningsloven for Carbon Centric AS), 2023, 16 pages total.

Emissions to air

Utslippsgrenser døgnmiddelverdi: emission limit 24-hour average value. Utslippsgrenser langtidsgrense (g/år): emission long-term limit (gram/year).

Maksimal avgasstrøm er på 10 000 Nm^3/time.

Tabell 2. Grenseverdier for utslipp av komponenter med krav om målinger jf pkt. 11.2

Utslippsparameter	**Utslippsgrense døgnmiddelverdi (mg/Nm^3)**	**Utslippsgrenser langtidsgrense g/år**
Svoveldioksid (SO_2)	6	
Summen av nitrogenmonoksid og nitrogendioksid, uttrykt som NO_2	175	
Karbonmonoksid (CO)	15	
Aminer totalt	5,35	
Ammoniakk (NH_3)	3,5	
støv		
TOC		
HCl		
HF		
dioksiner		
Tungmetaller		

Emissions to water network

Utslippsgrenser døgnmiddelverdi: emission limit 24-hour average value. Mengde (år): yearly amount.

Avløpsvann skal ikke ha temperatur over 45 °C, pH skal være mellom 6 og 9,5. Maksimum avløpsmengde til kommunalt nett er 1 m^3/time.

Tabell 1. Grenseverdier for utslipp til kommunalt nett

Utslippsparameter	**Utslippsgrenser døgnmiddelverdi (mg/l)**	**Mengde (år)**
Tungmetaller		
TOC		
TSS		

Det skal utføres følgende målinger av utslipp til vann:

- kontinuerlige målinger av pH, temperatur og vannmengde i avløpsvann

Acronyms

ACT - Accelerating CCS Technologies. International initiative to establish CCUS to combat global warming.
APC – Air Pollution Control
BAT-AEL – Best Available Techniques-Associated Emissions Levels
BECCUS - Bioenergy CCS
BREF WI - BAT Reference Document for Waste Incineration, BAT – Best Available Techniques
CAPEX – Capital Expenditures
CBAM - Carbon Border Adjustment Mechanism
CCfD - Carbon Contracts for Difference
CC, CCS, CCTS, CCU, CCUS – Carbon Capture, CC & Storage, CC & Transport & Storage, CC & Use or Storage
CDR – Carbon Dioxide Removal
CEA – Circular Economy Act
CEWEP – Confederation of European Waste-to-Energy Plants
CHP – Combined Heat and Power
CID – Clean Industrial Deal
CLIMIT - Norway's national programme for research, development and demonstration of CO_2 capture and storage
CRC – Carbon Removal certification
CRCF – Carbon Removals and carbon farming
CRI - Competitive Readiness Index
CRM – Critical Raw Materials
DCC – Direct Contact Cooler
DG CLIMA - Directorate-General for Climate Action of the European Commission
EC – European Commission
EEA - European Economic Area
EFTA - European Free Trade Association
EIA – Environmental Impact Assessment
EPR - Extended Producer Responsibility
ERA – European Research Area
ESWET - European Suppliers of Waste-to-Energy Technology
ETS – Emissions Trading Scheme
EU – European Union
FEED - Front-End Engineering Design
FGT – Flue Gas Treatment
FHI – Folkehelseinstituttet (Norwegian Institute of Public Health)
FID – Final Investment Decision
Gassnova - the Norwegian state enterprise for carbon capture and storage
GHG - Greenhouse Gases
H2020- Horizon 2020 (EU's research and innovation funding programme 2014-2020)
IAA – Industrial Accelerator Act
ICM – Industrial carbon Management
IEA, IEAGHG - International Energy Agency, IEA Greenhouse Gases
ITP – Intertask Project (at IEA Bioenergy)
KAN - Klimakur for Avfallsforbrenning Nettverk
KSP - Collaborative and Knowledge-building Project (at RCN)
LHV – Lower Heating Value
MFF - Multiannual Financial Framework
MoU – Memorandum of Understanding
MRV - Monitoring, Reporting, and Verification
MSW – Municipal Solid Waste
NGO - Non-Governemental Organisation
NSP – Neutral Solution Packages
NZC – Net Zero Cities

NZIA – The Net-Zero Industry Act
OPEX – Operational Expenditures
PO - Policy Option
RCN – Research Council of Norway
TCM – Technology Centre Mongstad
VCM – Voluntary Carbon Market
WP – Work Package
WtE – Waste-to-Energy
ZEP – Zero Emissions Platform