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Energy-from-Waste as a carbon dioxide removal pathway in the United Kingdom

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Executive Summary

This report evaluates the potential of Energy-from-Waste (EfW) combined with Carbon Capture and Storage (CCS) to generate high quality, highly durable carbon dioxide removal (CDR) Credits. With over fifty operational EfW plants, generating CDR credits for EfW with CCS presents a significant opportunity for the UK.

CDR credits have largely been traded in unregulated voluntary markets, where registries set the rules for Monitoring, Reporting and Verification (MRV), however governments are increasingly developing regulations that formalize MRV requirements. This report sets out the crediting process, the requirements of a robust MRV framework and considerations for durable storage of captured carbon dioxide (CO_2).

Quantifying robust CDR Credits from EfW facilities with CCS requires applying a scientifically robust methodology considering the CO_2 removed and stored, counterfactual CO_2 storage and GHG emissions associated with the process, as well as thorough evidencing of measures such as financial additionality. Considerations and challenges for generating high quality CDR credits for EfW with CCS are explored in this report, with a focus on the following key aspects:

- **Quantification of CO_2 storage** where shared transport and storage infrastructure make conventional quantification at point of injection challenging.
- **Determination of counterfactual CO_2 storage** for biogenic feedstocks where waste management in the baseline scenario is part of a highly regulated waste management system.
- **Conservative estimation and allocation of emissions** for mixed biogenic and fossil CO_2 streams, in alignment with compliance accounting, whilst not disproportionately hindering operability.
- **Minimising and appropriately accounting for potential leakage** associated with activity-shifting and market impacts, taking account of the wider regulatory context.
- **Applying sustainable feedstock sourcing principles** to the waste management context with consideration of payment structures and waste types.
- **Satisfying financial additionality requirements** with consideration of market mechanisms, such as gate fees and participation in government business models.

This report proposes options and next steps for each aspect of high quality MRV needed to establish EfW with CCS as a CDR pathway.

EfW coupled to carbon capture and geological carbon storage technologies has the potential to generate highly durable high quality CDR credits, which carry a high value in the Voluntary Carbon Market. The waste regulatory context in the UK and the DESNZ business model contribute to supporting regulatory and financial additionality for projects. This report concludes that there is a clear pathway towards applying MRV for EfW facilities with CCS to generate high quality and high durability CDR credits from their operations.

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1 Introduction

Energy-from-Waste (EfW) is a waste management approach that combines a societal hygiene service with energy and heat recovery. EfW processes combust residual waste safely and generate electricity and heat. EfW facilities can incorporate point-source carbon capture technology to remove carbon dioxide (CO_2) from the flue gas resulting from waste combustion, which allows the CO_2 to be concentrated and sent downstream for long-term storage, for example by sequestration in geological formations. Waste used as an input to EfW processes currently contains a mixture of approximately a 50/50 split of fossil and biogenic carbon. Biogenic carbon is a result of biomass in the waste stream that is part of the natural carbon cycle in the biosphere. Without the EfW process, this biomass would biodegrade returning the biogenic carbon to the atmosphere. The use of carbon capture and storage (CCS) at an EfW facility results in negative emissions from the atmosphere as a result of permanently removing the biogenic carbon from the biosphere carbon cycle, for which carbon dioxide removal (CDR) Credits can be generated.

As well as functioning as a CDR pathway, EfW has a number of co-benefits, including:

- Diverting waste away from landfills, leading to wider environmental benefits including reducing methane emissions, conserving land and natural habitats, and preventing soil and water contamination.
- Reducing reliance on fossil fuels for combustion-based energy and heat generation, reducing the dependence on finite fossil resources in the energy system.
- Baseload energy generation. Combustion-based energy generation is highly dispatchable and is an important stabilizing factor to reduce grid volatility.
- Production of heat which is not required by the EfW facility and can be dispatched to industrial neighbours and homes nearby, enabling decarbonisation.
- Carbon negative energy and heat generation when combined with CCS.

EfW as a CDR pathway is a substantial opportunity in the UK, with more than fifty EfW plants currently operational. EfW is a leading industry bringing forward commercial scale CCS from 2028, in partnership with the Department for Energy, Security and Net Zero (DESNZ) in their Cluster Sequencing Competition. The application of CCS technology at EfW sites is not standard practice yet, with the first UK pilot of CCS technology at an EfW facility launched by enfinium in late 2024[1]. Under a suitably robust framework EfW processes with CCS may generate significant volumes of high quality CDR, allowing for financial viability of the CCS activities by the sale of CDR Credits.

This report will analyse the viability of generating high quality, highly durable CDR Credits as an output from the operations of EfW processes coupled with CCS. This includes the establishment of an MRV

[1] Enfinium (2024) UK-first carbon capture pilot on energy from waste facility goes live (available online accessed: 21/01/25)

framework for EfW with CCS, an analysis of implications of the UK regulatory environment in relation to additionality and outlining a pathway for durable carbon storage.

This report has been prepared by Isometric in partnership with the Coalition for Negative Emissions and an expert group with representatives from Cory Group, Encyclis, Enfinium, Veolia and Viridor (with DESNZ as Observers during the process).

2 Pathways for monitoring, reporting and verification

2.1 The importance of monitoring, reporting and verification

MRV is the procedure by which processes generating negative emissions are assessed and their overall carbon impact verified and monitored. When a net tonne of CO_2 equivalent (CO_2e) has been verifiably removed from the atmosphere, this activity is associated with the generation of a CDR Credit, issued by a registry. To date, CDR Credits have largely been traded in voluntary markets, with the market essentially unregulated and registries (e.g. Isometric) setting rules for MRV. However, governments are increasingly developing regulations which establish MRV requirements, such as the EU Carbon Removal and Carbon Farming (CRCF) regulations. Ensuring that processes follow robust MRV requirements in the current early-stage market and can then later comply with rules established under these emerging regulations is critical to ensuring ongoing operations from early projects and future buyer demand. Robust MRV requirements will both form the basis for compliance market integration of CDR, as well as setting a quality standard that voluntary Credits may be measured against in future.

In some geographies, including the UK, Emissions Trading Schemes (ETS) are being expanded to include EfW facilities. The UK has announced that CDR will be included as an option for meeting ETS obligations in the future, so EfW companies will be able to benefit from CCS activities through both reducing their own liabilities under the ETS and potentially selling surplus allowances in the form of CDR Credits to other ETS participants. This is subject to the contract conditions of the Cluster Sequencing process[2] where projects take a subsidy contract from the UK Government, noting that projects may be able to proceed without UK Government contracts if carbon prices are high enough and CDR offtakes can underpin investment decisions. The application of a robust MRV framework will almost certainly form a prerequisite for ETS integration. Beyond participation in emerging carbon markets and compliance systems, some governments are directly financing CDR with an aim towards reducing national carbon emissions - which is emerging as a further opportunity for developing projects with overall negative emissions. Some government schemes involve the direct procurement of CDR in the form of CDR Credits, while others provide financial support in the form of Contracts for Difference, subsidies, and other instruments. In this context, robust MRV is usually an essential criteria when seeking government support through these mechanisms.

[2] Department for Business, Energy and Industrial Strategy (2021) Cluster Sequencing for Carbon Capture Usage and Storage Deployment: Phase-1 (available online).

2.2 The crediting process

The process of generating CDR Credits corresponding to a project's activities is a multi-stage process which involves participation of key stakeholders, including the operator of the CDR project (the "Project Proponent"), a registry, and an accredited third party auditor (the "Validation and Verification Body" (VVB)). The crediting process typically proceeds with the following steps:

1. **Development of a Project Design Document (PDD).** The PDD provides high-level information about a project, which is initially checked by the registry against the requirements of an applicable protocol (or "methodology") to ensure that the project configuration is theoretically eligible for crediting.

2. **Development of a GHG statement.** When projects submit claimed removals to a registry, the project's removals, counterfactual and emissions must be presented together in net metric tonnes of CO_2e as part of a GHG statement. This is developed in accordance with the requirements of an applicable Protocol. The project should develop internal analysis and data management systems to permit execution of a GHG Statement on their operations at a regular cadence for eventual verifications.

3. **Allocation of a VVB.** An accredited third party auditor (VVB) is allocated to the project. The VVB will later conduct the initial project validation (see step 4) and regular project verifications (see step 5).

4. **Initial project validation.** Physical site visits are conducted by the VVB to ensure that the real-world project operations are accurately represented in the PDD. This process aims to establish that (i) the PDD is complete with respect to the actual project activities, and (ii) the project has all necessary systems and processes in place to ultimately comply with the monitoring requirements of the applicable Protocol.

5. **Regular project verifications.** GHG Statements are prepared at regular intervals corresponding to periods of project operations. Each verification is supported by the submission of evidence by the project proponent to the VVB, which is then assessed for legitimacy and compliance with the applicable protocol. The outcome of this process is the issuance of CDR Credits onto a registry for each period of operations, corresponding to the amount of net CO_2e removal claimed in the relevant GHG Statement(s). These CDR Credits can be transferred to customers who then retire the Credits against their own emissions for the purpose of emissions reporting or compliance market participation.

3 Generating high quality CDR Credits from EfW with CCS

3.1 GHG statement

3.1.1 General

As set out in Section 2.2, projects must generate a GHG Statement at regular intervals corresponding to each period of claimed removals, known as a Reporting Period. This quantifies the project's removals, counterfactual and emissions in net metric tonnes of CO_2e, as described by the following equation:

$$CO_2e_{Removal} = CO_2e_{Stored} - CO_2e_{Counterfactual} - CO_2e_{Emissions}$$

Where:

- $CO_2e_{Removal}$ is the total net CO_2e removal for a Reporting Period, in tonnes of CO_2e[3].
- CO_2e_{Stored} is the total gross CO_2 removed from the atmosphere and permanently stored, for the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{Counterfactual}$ is the total counterfactual CO_2 removed from the atmosphere and stored as biogenic carbon in the absence of the project, for the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{Emissions}$ is the total GHG emissions, for the Reporting Period, in tonnes of CO_2e.

The Reporting Period represents an interval of time over which removals are calculated and reported for verification. Projects listed on the Isometric registry may define their own Reporting Period, with a minimum length of one month.

3.1.2 CO_2e Stored

For projects storing CO_2 by geological sequestration, CO_2e_{Stored} represents the mass of CO_2 present in the injectant that is stored in the geological or engineered storage formation. This is calculated by using the total mass injected and the average concentration of CO_2 in the injectant over the reporting period. In general, measurements to determine CO_2e_{Stored} should be made directly upstream of the point of injection into the subsurface. This approach ensures that Credits are based on the actual CO_2 stored, inherently accounting for any CO_2 losses from the system during transportation and storage activities.

[3] Only CO_2 is included for the quantification of CO_2e $_{Stored}$ and CO_2e $_{Counterfactual}$, while all GHG emissions are included when calculating CO_2e $_{Emissions}$. All terms are reported in CO_2e in equations for consistency.

Considerations for EfW

Biogenic fraction

As established in Section 1, only the biogenic fraction of captured carbon is eligible for the generation of CDR Credits. Therefore, the calculation of CO_2e_{Stored} must take into account the fractions of biogenic and fossil carbon in the captured stream. This is discussed in more detail in Section 3.4.2.1.

Shared transport and storage infrastructure

EfW facilities in the UK will predominantly rely on shared infrastructure for transport and storage of CO_2 as part of industrial clusters, storage clusters, or large ports. This poses challenges to adopting conventional requirements of quantifying CO_2e_{Stored} at the point of injection, because CO_2 streams from multiple projects may be mixed in the same pipeline or container(s) at different points.

One option to address this challenge is to take an assumptions-based approach to CO_2 losses from transport and storage infrastructure. This would require using conservative estimates of potential CO_2 leaks. This may also require using emissions accounting estimates, such as for transport and storage operations, from the point at which a project can no longer measure activities. If crediting takes place at the point of CO_2 capture, then all emissions must be estimated as the transport and storage activities would not yet have taken place. Credits linked to capture rather than storage could be deemed to be ex-ante, given that the removal may not have been completed (CO_2 may have not been stored) at the time of credit issuance. This is typically not acceptable under conventional carbon market practices, with most buyer demand existing only for Credits that are issued ex-post. However, it may be possible to credit at the point of storage under a chain-of-custody model with appropriate data sharing across entities if the chain-of-custody model enables appropriate storage activity data to be shared.

When using shared infrastructure, a thorough chain-of-custody model will be required to tie any future observed reversal events proportionally back to the entities that contracted the storage operator. Furthermore, robust safeguards should be in place to ensure that any observed leaks fall beneath the assumed value for leaks in the GHG Statement and that adjustment measures, or registry reversal processes are triggered in instances where observed leaks exceed ex-ante assumptions. Data sharing and transparency across each part of the transport and storage chain may be challenging for the EfW operator to secure and a coordinated approach across multiple entities will likely be required. It is unclear at this stage how this will work in practice.

An assumptions-based approach would be a divergence from standard practice and will require further research into the specific contexts under consideration prior to implementation in an MRV methodology. The outcome of an assumptions-based approach must be applicable across CDR pathways, given that shared infrastructure is used in numerous contexts.

3.1.3 CO_2e Counterfactual

$CO_2e_{Counterfactual}$ is the total counterfactual CO_2 removed from the atmosphere and stored as biogenic carbon in the baseline scenario. To ensure that the inclusion of biomass is conservative, a time-based threshold, such as 15 years as outlined in the Isometric Biomass Feedstock Accounting Module, can be applied. A time-based threshold is not adopted in all methodologies, but is widely considered to be an appropriately conservative approach and serves to safeguard against generating Credits using biomass that would have naturally remained durably stored for a significant period of time in the absence of the project. In instances where the biomass was anticipated to have decomposed under anaerobic conditions, the potential for methane emissions may be used to adjust the total counterfactual CO_2 stored, for example by following the methodology established in the Isometric Biomass Feedstock Accounting Module[4].

Two different baseline scenarios are possible for EfW projects, which can be used as the basis for determining $CO_2e_{Counterfactual}$:

- New-build: The baseline scenario assumes that all activities associated with the project and the wider facility do not take place and no associated infrastructure is built.
- Retrofit: The baseline scenario assumes that the activities associated with the CCS component of the wider facility do not take place and no additional infrastructure associated with CCS is built.

At present, at least one of the following is generally required to evidence the counterfactual fate of the waste biomass feedstock used for project operations:

- Confirmation of the counterfactual fate of the biomass, such as an affidavit or contractual clause in purchase records.
- Historical evidence of the counterfactual fate of the biomass.
- A qualitative assessment that the most economically viable option would have a durability that is lower than the time-based threshold.

Considerations for EfW

Determining the baseline scenario

For a Retrofit EfW facility $CO_2e_{Counterfactual}$ would be zero, because in the baseline scenario the biogenic feedstock was combusted with no CCS and all biogenic CO_2 is released to the atmosphere.

For a New Build EfW facility, it is less straightforward as the facility did not exist in the baseline scenario and therefore the waste would have been handled elsewhere. The counterfactual waste management

[4] Any adjustment to the total counterfactual CO_2 stored to account for the avoidance of other potent GHGs would fall under the time-based threshold, which in itself represents a high degree of conservatism. Further information can be found in the Isometric Biomass Feedstock Accounting Module.

process may be landfill, anaerobic digestion, or a different EfW facility. If evidence can be provided to show that the biogenic waste would have decomposed entirely within the defined time-based threshold, then $CO_2e_{Counterfactual}$ will be zero. However, this will not always be the case, especially for counterfactual waste handling under anoxic conditions.

Determining the counterfactual waste management process for New Build facilities

The waste feedstock used by EfW projects is part of an integrated and regulated waste management system, where there is an inability to track individual feedstocks to feedstock suppliers. Furthermore, biogenic waste composition may constitute various components such as food waste, wood waste and textiles, each with different decomposition rates. Options for determining the counterfactual waste management process are set out below.

Consideration 1

Standardised assumptions may be used to inform counterfactual waste management scenarios. For example, assumptions may be based on published datasets like local authority waste management data and average data on landfill conditions and monitoring for various landfill types. This would require a detailed breakdown of waste composition, as well as research into appropriate decomposition rates under various counterfactual waste management scenarios and for various types of waste.

Consideration 2

Market mechanisms and policy underpinning counterfactual waste management may be considered. The waste management sector in the UK and the development of new EfW facilities are subject to rigorous regulation and policy oversight. The Government recently announced a set of restrictions including a requirement for New Build plants to help to lower the volume of unrecyclable waste being sent to landfill[5]. However, the market is nearing saturation, with landfills and waste exports expected to phase out in the coming years. Forthcoming policies are also likely to restrict the disposal of biogenic waste in landfills. Given these dynamics, a counterfactual scenario that excludes waste combustion may not be appropriate and it may be more suitable to align the baseline scenario with the Retrofit definition for New Build projects, reflecting the ongoing evolution of waste management practices.

Consideration 3

Project-specific information may be available to determine counterfactual waste management, for example as documented in planning, strategy and modelling associated with planning and justification of the facility.

[5] Department for Environment, Food & Rural Affairs (2024) Government to crack down on waste incinerators with stricter standards for new builds (available online)

The above considerations relating to the determination of the counterfactual waste management process for New Build EfW with CCS sites should be considered in the development of registry methodologies.

3.1.4 CO_2e Emissions

Greenhouse gas (GHG) emissions related to a CDR project may be direct emissions, for example flue gas emissions, or indirect emissions, for example as a result of construction or use of consumables. As part of a conservative accounting scheme for CDR Credits, all GHG emissions related to the CDR project should be considered in the GHG Statement.

Project emissions must be quantified as part of the GHG Statement, as described by the following equation:

$$CO_2e_{Emissions} = CO_2e_{Establishment} + CO_2e_{Operations} + CO_2e_{End-of-life} + CO_2e_{Leakage}$$

Where:

- $CO_2e_{Emissions}$ is the total GHG emissions for the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{Establishment}$ is the total GHG emissions associated with project establishment for the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{Operations}$ is the total GHG emissions associated with operational processes for the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{End-of-life}$ is the total GHG emissions that occur after the Reporting Period, in tonnes of CO_2e.
- $CO_2e_{Leakage}$ is the total GHG emissions associated with the project's impact on activities that fall outside of the system boundary of a project, over the Reporting Period, in tonnes of CO_2e.

Existing industry methodologies, for example the Isometric Biogenic Carbon Capture and Storage Protocol, establish in detail the system boundary requirements and emissions sources and sinks that must be considered as part of $CO_2e_{Emissions}$ when preparing each GHG Statement. Particularly, it may be appropriate for EfW projects to adopt a narrow system boundary where only components of the system related to CCS are considered, for example if:

- The project is a retrofit to an existing facility.
- The project can establish that the energy co-product alone was financially viable without the sale of CDR Credits. This would indicate that the facility was not built for the purposes of CCS.
- The project produces energy that is sold into a grid that is regulated under a cap-and-trade programme at the point of crediting.

Based on the above, it is likely that EfW projects in the UK should be able to demonstrate the applicability of a narrow system boundary.

Considerations for EfW

Emissions allocation for biogenic vs fossil CO_2 streams

The flue gas from EfW facilities contains both fossil and biogenic CO_2, typically in roughly equal quantities. EfW projects may therefore wish to carry out emission allocation of project emissions between the fossil and biogenic components, as project activities are associated with avoiding direct fossil emissions as well as contributing to achieving biogenic removals. In practice, undertaking emissions allocation will require that any emissions allocated to the fossil component of the captured CO_2 stream are suitably handled under parallel voluntary or regulated emissions accounting schemes to ensure that all project emissions are robustly accounted for within the overall system.

The UK ETS is due to be expanded to include waste incineration and EfW from 2028, as well as the integration of Greenhouse Gas Removals (GGRs) from 2028 at the earliest. Public consultation comments are currently being reviewed for both proposals. Although the details are not yet clear, integrating EfW into the UK ETS would likely require EfW facilities to report direct emissions associated with combustion from stationary sources at installations. These emissions would be regulated under the UK ETS. The use of CCS would lead to a reduction of direct fossil CO_2 emissions under the inclusion of EfW into the UK ETS. It is unclear how the integration of GGRs will be regulated and what MRV requirements would be in place in terms of emissions accounting.

The scope of emissions accounting for the UK ETS is much narrower than what would be required for a robust CDR certification scheme. This is because the UK ETS only regulates point-source emissions directly under the control of operators. Wider supply chain emissions are addressed at the policy level through broader decarbonisation mechanisms.

There are several options for emissions allocation based on the biogenic and fossil CO_2 fraction in the captured stream, which are set out in the list and Figure 1 below.

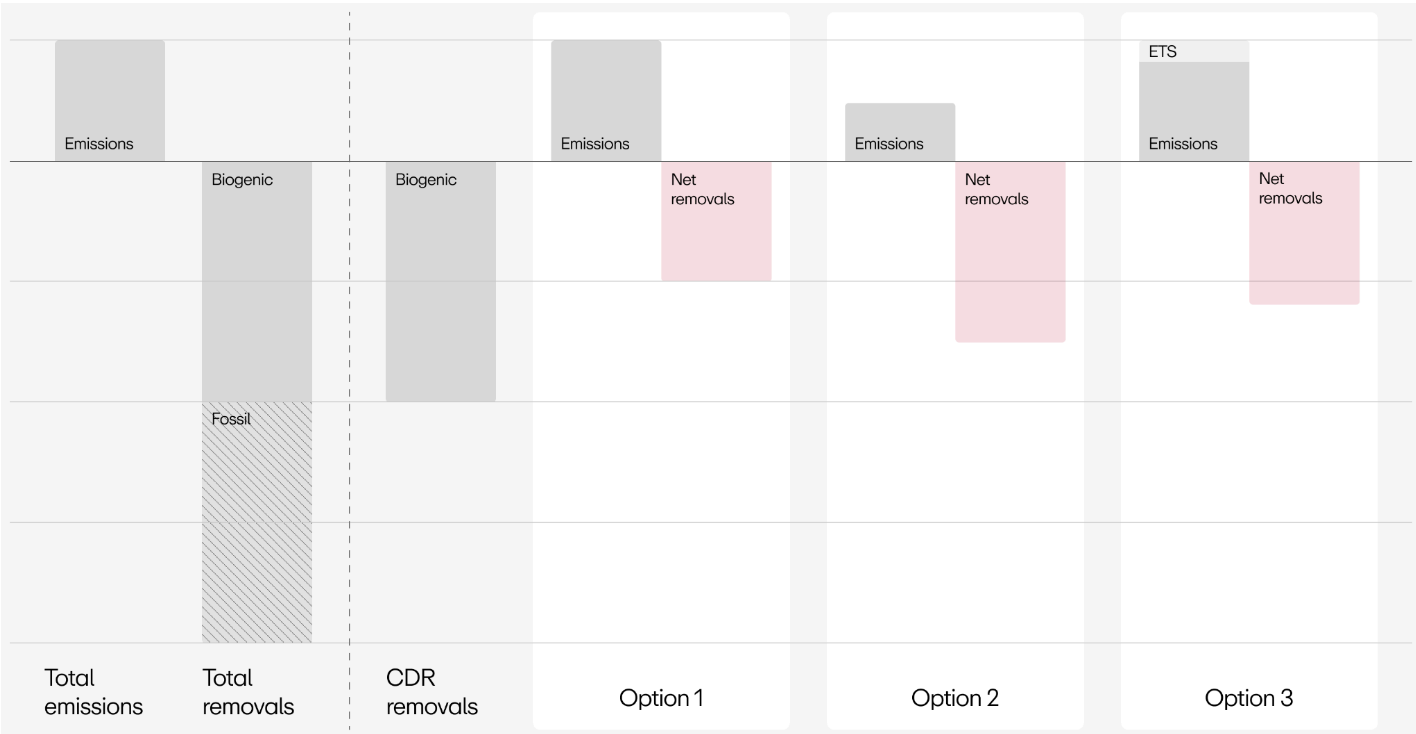

Figure 1: Illustrative diagram of the impact of different options for emission allocation between biogenic and fossil CO_2 streams on project GHG accounting.

Option 1

Allocate all direct and indirect GHG emissions to CDR.

The fossil CO_2 stream must still comply with all relevant emission accounting regulations and requirements, which may mean direct emissions are double counted. Removals must not be double counted. Total project emissions are presented in the GHG Statement with no allocation procedure in place.

This is the most conservative approach to take, but will likely lead to emissions being double counted and potential financial infeasibility of the CCS project. This approach may lead to a misinterpretation of Credit quality when comparing EfW + CCS Credits with other CDR pathways such as Bio-energy with CCS and the potential for unintended consequences which need to be considered at a system level.

Option 2

Allow allocation based on the CO_2 stream biogenic and fossil fractions

Quantify all emissions associated with the project (direct and indirect) and then allocate emissions to removals proportionally in line with the biogenic fraction in the captured stream.

Total project emissions, as well as emissions following allocation, would be presented in the GHG Statement for removals crediting.

This approach would enable proportional allocation based on physical properties and best reflects the reality of what is happening at the facility, with both biogenic removals and avoided CO_2 emissions being captured and stored. However, it is likely that the emissions accounting systems in place will not align, given that the current UK ETS only requires reporting of direct emissions from combustion at stationary sources at installations. Therefore this will lead to a substantial risk of over-crediting claimed removals because a significant proportion of project emissions are not accounted for.

Option 3

Allow the subtraction of regulated emissions from total reported emissions.

All emissions that are otherwise reported as part of compliance with a regulatory scheme, for example the ETS, can be subtracted from project emissions for the purpose of issuing CDR Credits. Total project emissions and emissions following allocation would be presented in the GHG Statement for removals crediting.

This would ensure that all emissions associated with the facility and project operations are accounted for and would avoid double counting of emissions. However, it is likely that the majority of emissions will be allocated to CDR under this approach, given that the current UK ETS is limited to direct emissions from combustion.

The options proposed above should be considered as part of any future methodology development. It is unclear how the UK Government will consider upstream and downstream emissions associated with project activities as part of the integration of GGRs into the UK ETS. It is likely that an interim proposal is established by a registry methodology which may need to be revised in line with UK ETS developments.

CO_2e Leakage

Leakage is defined as emissions associated with a project's impact on activities that fall outside of the system boundary of a project. Leakage may be direct, for example activity-shifting or replacement of services or products, or it may be indirect, for example leading to a change in market dynamics which incentivises changes in behaviour. For quantification of $CO_2e_{Leakage}$, projects must demonstrate that leakage emissions have been minimised or appropriately accounted for in emissions accounting.

For EfW facilities it is important to ensure that the sale of Credits does not lead to adverse indirect impacts causing an increase in emissions elsewhere, for example influencing consumer behaviour so that more waste is produced, or influencing market impacts so that less waste is recycled or more waste is incinerated. Regulatory measures already exist to prevent such adverse impacts at a system level through the Resources and Waste Strategy (and specifically through Extended Producer Responsibility) in the UK, such as the waste hierarchy as stipulated in Article 4 of the revised EU Waste Framework Directive (Directive 2008/98/EC). Furthermore, EfW facilities have contracted waste limits and are limited to maximum tonnages as per their permit.

The potential leakage emissions and existing mechanisms in place to mitigate leakage should be considered in any future MRV development. Considerations for feedstock eligibility in relation to leakage are expanded on in Section 3.2.

3.2 Feedstock sourcing

The sustainability of biogenic feedstocks is generally determined by the potential market leakage impact, the counterfactual CO_2 storage scenario, and whether the feedstock is purpose-grown. Under existing industry methodologies, such as the Isometric Biomass Feedstock Accounting Module, determining feedstock eligibility requires the following considerations:

1. **Potential market leakage:** creating a market for biomass feedstocks may generate new revenue that alters producer behaviour in ways that increase GHG emissions, for example deforestation. This may be direct where feedstock procurement affects the market price, or indirect where payments affect the supplier's behaviour. This is generally managed in methodologies by evidencing that no payment, or minimal payment, was made for the feedstock. Alternatively, if a feedstock is a residue from another process, and the process is managed under responsible sourcing regimes, this may be sufficient to demonstrate that market leakage risk is minimized.
2. **Counterfactual storage eligibility:** it is assumed that the feedstock would otherwise decay rapidly to release CO_2 into the atmosphere in the counterfactual scenario where there is no intervention from the project. This is discussed in more detail in Section 3.1.3.
3. **Dedicated energy feedstock:** use of the biomass feedstock must not lead to secondary impacts associated with energy production, such as land use change. This is generally managed by ensuring the biomass feedstock was not grown for the purposes of energy production and does not have a likely counterfactual energy production use.

Additional sourcing principles are included in some methodologies, such as consideration of historical land use where biomass is grown, tillage practices, and sustainable feedstock harvesting.

The principles outlined in this section would need to be updated for applicability to EfW facilities and the inclusion of biogenic wastes in the definition of biomass feedstocks, as described in the following section.

Considerations for EfW

Typically, biomass feedstock sourcing principles in crediting methodologies focus on biomass feedstocks that are agricultural residue, forestry thinnings or byproducts of forestry, and industrial biomass residues. In order to accommodate EfW projects, biomass feedstock applicability in existing methodologies must be expanded to consider the biogenic portion of wastes managed under waste management and permitting regimes.

EfW projects in the UK are compensated through gate fees as payment for accepting and processing residual solid waste. Eligibility requirements related to market leakage must reflect the relevant payment and processing mechanism in place, as well as the specific waste types accepted by EfW facilities. In order for biomass feedstocks at EfW projects to be deemed sustainable, it is likely that forthcoming methodologies will require evidence of waste classification and permitting, as well as confirmation that the waste handled is restricted to residual waste only.

3.3 Additionality

It is essential that CDR claims are considered to be additional, meaning that the claims must represent removals which would not have occurred in the absence of the intervention by the project. All CDR Credits must satisfy three key criteria to be considered credibly additional:

1. **Environmental additionality:** the project activities need to result in net-negative emissions from the atmosphere, as baselined against the counterfactual scenario where the project activities do not occur.

2. **Financial additionality:** carbon finance resulting from the sale of carbon Credits is essential for the project to be financially viable.

3. **Regulatory additionality:** the project activities should not be mandatory under any relevant regulations in the region of project operations.

3.3.1 Environmental additionality

Environmental additionality is self-evident from the preparation of a suitably robust GHG Statement, as set out in Section 3.1, which demonstrates that the project activities are net-negative in terms of CO_2e emissions.

3.3.2 Financial additionality

Financial additionality is evidenced by the preparation of a financial analysis of the project, showing that the revenue from the sale of CDR Credits is essential to yield an Internal Rate of Return (IRR) either greater than zero, or greater than the required rate of return in cases where there is external capital investment. In the UK context, financial additionality of EfW projects may be influenced by both the provision of gate fees and by possible participation in government business models.

3.3.2.1 Revenue streams

EfW projects are compensated through gate fees as payment for accepting and processing solid waste. Gate fees can range from £110-151[6] per tonne of waste, with a median value of £116[7] per tonne and reported gate fees have been increasing in recent years[8]. In addition to revenue generated from gate fees, the sale of electricity and heat generates additional revenue in the range of £35 - £65 /MWh[8].

The additional revenue resulting from the sale of CDR Credits (with estimated prices at £160[9] - £200/tonne CO_2e[10]) is expected to compensate for the costs of the selected carbon capture technology, transport and storage[11]. The costs of carbon capture technology can vary depending on the selected capture technology, but are typically around £150/tonne CO_2 with additional costs for transport and storage that vary between £5 - £150/tonne CO_2[12,13,14]. Revenue from CDR Credits is essential for the economic viability of a project to demonstrate financial additionality. However, EfW projects should take into account all revenue streams for the purpose of satisfying financial additionality on a project-specific basis as fluctuations in any component may ultimately lead to an invalidation of additionality. The financial additionality assessment should include careful consideration of changes in waste handling practices, leading to any increase in gate fees that could shift the IRR of the project and impact financial additionality.

Financial additionality must be reviewed at a regular cadence (for example every five years, as per the Isometric Biogenic Carbon Capture and Storage Protocol), or whenever project operating conditions change significantly.

3.3.2.2 Industrial Carbon Capture Business Models

The UK government is planning to provide financial support to projects capturing carbon at EfW sites through the Waste Industrial Carbon Capture (ICC) business model. Projects opting to operate under this business model will receive significant financial support, aiming to compensate the project in full for capital and operating costs associated with carbon capture activities, as well as compensation to cover costs to the project associated with transport and storage of captured CO_2. The present draft of the

[6] WRAP (2024): "Comparing the costs of alternative recycling and waste treatment options". (available online).
[7] Reference value for residual waste mixed with bulky waste (available online).
[8] Reported prices are increased from 2022 onwards as a result of the energy crisis (available online).
[9] Babin et al. (2021): "Potential and challenges of bioenergy with carbon capture and storage as a carbon - negative energy source: A review". (available online).
[10] Rousannaly et al. (2024): "Putting the costs and benefits of carbon capture and storage into perspective: as multi-sector to multi-product analysis". (available online)
[11] Estimated CDR credit prices are subject to price fluctuations which are difficult to determine as they are subject to market variability and willingness to pay.
[12] Oxford Institute for Energy Studies (2024): " Carbon capture from energy-from-waste (EfW): A low hanging fruit for CCS deployment in the UK?". (available online)
[13] Jamasb and Nepal (2010): "Issues and options in waste management: A social cost-benefit analysis of waste-to-energy in the UK". (available online).
[14] Budinis et al. (2018): "An assessment of CCS costs, barriers and potental". (available online).

Waste ICC business model incorporates a mechanism of symmetrical payments whereby the Applicable Carbon Reference Price[15] is used to ensure that the payment mechanism in place does not exceed the financial support provided by the government. If the project generates revenue through the sale of CDR Credits resulting from the project activities, 90% of the generated revenue must be paid back to the government while the remaining 10% allows the Projects to cover any administrative and operational expenses. A cap is applied to symmetrical payments such that the repayments to the government will not exceed the payments which would be made to the project to cover capital and operating costs.

The provision of funds to EfW projects via the Waste ICC business model covering the totality of project capital and operating costs would preclude the project from satisfying the definition of financial additionality established above. However, due to the symmetrical payments mechanism whereby 90% of the generated revenue must be paid back to the government, and given that highly durable CDR Credits have a high value in the Voluntary Carbon Market (VCM), the financial support provided to EfW projects via the business model would likely be either substantially reduced or eliminated in instances where there is sufficient buyer demand for the CDR Credits generated by the project[16]. Therefore, the Waste ICC business model acts as a mechanism of financial risk mitigation for EfW projects, ensuring that costs are recuperated in circumstances where there is not sufficient demand in the VCM but providing a level of support which does not impact on financial additionality in the case where CDR Credits are generated and sold. Therefore, EfW projects can be considered as having a lower risk for financial additionality when operating under the Waste ICC business model.

It is also important to note that the government scheme providing the financial support represented by the Waste ICC business model itself operates with limited resources. The government aims to support project development while the remaining parts of the supply chain, such as infrastructure, are still under development, and recuperate costs of the scheme via the symmetrical payments mechanism. Directly using these resources to widen the availability of the business model to a larger number of projects by removing part of the capex and opex development risks, will allow projects to receive finance as the market matures and grows. While challenging to quantify, the impact of the sale of CDR Credits while operating under the business model will certainly be positive at the system level.

3.3.3 Regulatory additionality

There are currently no planned or operational regulatory frameworks in the UK which mandate the application of CCS at EfW sites. However, new build plants must show Decarbonisation Readiness and have evidential consideration of carbon capture plants for each facility, including land allocation. Given that the project activities which lead to the generation of CDR Credits are not mandatory in the

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[15] The Applicable Carbon Reference Price is market based using as reference the ETS market price (available online).

[16] An additional clause related to the GGR fallback price payments minimizes the risk of the project's financial additionality when operating under the ICC Business Model.

applicable regulatory environment, EfW projects equipped with CCS will be considered to be additional from a regulatory perspective.

The UK government plans to incorporate EfW projects under the UK Emissions Trading Scheme (ETS) in 2028. Under the ETS, EfW projects will be required to purchase emissions allowances corresponding to their direct emissions of CO_2. While this mechanism will act to incentivise CCS activities at EfW sites, as the cost of emitting may become larger than the unit cost of deploying CCS, activities related to the generation of CDR Credits will remain voluntary. However, it should be noted that without CCS the EfW industry will not decarbonise sufficiently to reach mandated net zero targets except through purchasing CDR Credits from other projects.

3.4 Storage and monitoring

3.4.1 Storage

Capture of CO_2 from flue gases at EfW plants results in a high-purity CO_2 output stream. This can be transported and durably stored via a variety of pathways, including:

1. Injection into subsurface saline aquifers or depleted oil and gas reservoirs.
2. Injection into subsurface mafic/ultra-mafic formations for in-situ mineralization.
3. Conversion into carbonate minerals in closed engineered systems (ex-situ mineralization) and subsequent storage in either closed or open environments.
4. Incorporation into building materials by carbonation.

All of the storage approaches outlined above have workable pathways towards high durability and robust monitoring practices. However, the UK policy landscape is signalling a strong preference towards geological storage of captured CO_2 in saline aquifers and depleted oil and gas reservoirs. Geological carbon storage is technologically mature, with a substantial basis of research and industry data demonstrating it to be robust and highly durable under adequate monitoring and risk management practices. Therefore, EfW coupled to carbon capture and geological carbon storage technologies has the potential to generate high quality CDR Credits which are likely to carry a high value in the VCM.

3.4.2 Monitoring

3.4.2.1 Monitoring of project activities

Ongoing monitoring of project activities is necessary to collect the required data for generating a GHG Statement at each project verification event. For geological storage, online sensors positioned immediately upstream of the point of injection into the subsurface are required to monitor the mass of CO_2 injected, including sensors to monitor the mass flow rate, and CO_2 composition of the injected stream. Additionally, suitable measurements must be made on a continuous or regular basis to quantify emissions impacts associated with all project utilities and consumables, including electricity usage, fuel consumption, transportation, and the use of process feedstocks (e.g. sorbents, water, etc.).

As outlined in Section 3.1, continuous monitoring of the fossil and biogenic fractions of carbon in the captured CO_2 stream is required to (i) enable quantification of CO_2e_{stored} in terms of the biogenic fraction only, and (ii) enable operationalisation of emissions allocation procedures of project emissions between the fossil and biogenic components of the captured stream. As established in the Waste ICC business model, the requirements of which are likely to be adopted as part of any future ETS integration, monitoring of the fossil and biogenic fractions of the captured CO_2 stream can be achieved by carbon-14 radio-carbon dating. Alternative approaches could be considered as part of a future CDR methodology, provided that such approaches are shown to be scientifically robust and to be in compliance with any applicable regulations in the region of project operations.

3.4.2.2 Long-term monitoring

Long-term monitoring of CO_2 stored by injection into geological formations is required to ensure the integrity of CDR Credits issued for EfW operations. In the UK, geological carbon storage activities are regulated under the Energy Act 2008, with the North Sea Transition Authority (NSTA) issuing carbon storage licences to projects. As part of the licensing process, projects are required to outline a storage monitoring plan in compliance with regulations. As a component of MRV activities for issuing CDR Credits, projects are required to comply with local permitting regulations (i.e. those of the NSTA). Broadly, monitoring requirements consist of (i) physical measurements at the injection site (e.g. temperature and pressure), (ii) mathematical reservoir modelling to predict migration of injected CO_2, and (iii) monitoring the mechanical integrity of the reservoir caprock.

When issuing CDR Credits, projects should reserve a proportion of the generated Credits within a "buffer pool". Credits in the buffer pool are held by the issuing registry, and are used as a risk management tool. If ongoing long-term monitoring of CO_2 storage observes a reversal from the storage reservoir, Credits held within the buffer pool are retired in a magnitude corresponding to that of the observed reversal to neutralise the impact and maintain the validity of the issued Credits. Appropriate buffer pool sizes vary between different CDR pathways, however it is recommended that a buffer pool of 2% of all generated Credits provides adequate risk management for projects storing captured CO_2 by injection into geological formations. This buffer pool size reflects the very low reversal risk of this established CO_2 storage technology. Projects can anticipate that this buffer pool size will gradually reduce over time as more significant amounts of real-world data are collected from live projects.

4 Summary and next steps

This report establishes a framework to generate CDR Credits as an output from the operations of EfW facilities equipped with CCS in the UK, including considerations for quantification of net removals, feedstock sourcing, additionality, and monitoring requirements. This report establishes that there is a clear pathway for EfW with CCS to generate high quality and high durability CDR Credits. Each of the considerations for high quality CDR should be addressed robustly in the MRV programme adopted, with clear requirements outlined for eligibility and evidence requirements.