MRV options for inclusion of Energy from Waste plants and Waste Incinerators within the UK ETS

Project report and findings

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Sign off

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About CS NOW

Commissioned by the UK Department for Energy Security & Net Zero [formerly the Department of Business, Energy and Industrial Strategy (BEIS)], Climate Services for a Net Zero Resilient World (CS-N0W) is a 4-year, £5 million research programme, that will use the latest scientific knowledge to inform UK climate policy and help us meet our global decarbonisation ambitions.

CS-N0W aims to enhance the scientific understanding of climate impacts, decarbonisation and climate action, and improve accessibility to the UK's climate data. It will contribute to evidence-based climate policy in the UK and internationally, and strengthen the climate resilience of UK infrastructure, housing and communities.

The programme is delivered by a consortium of world leading research institutions from across the UK, on behalf of the Department for Energy Security & Net Zero. The CS-N0W consortium is led by Ricardo and includes research **partners Tyndall Centre for Climate Change Research**, including the Universities of East Anglia (UEA), Manchester (UoM) and Newcastle (NU); institutes supported by the **Natural Environment Research Council (NERC)**, including the British Antarctic Survey (BAS), British Geological Survey (BGS), National Centre for Atmospheric Science (NCAS), National Centre for Earth Observation (NCEO), National Oceanography Centre (NOC), Plymouth Marine Laboratory (PML) and UK Centre for Ecology & Hydrology (UKCEH); and **University College London (UCL)**.

Contents

Abbreviations

ACT – Advanced conversion technology

ATT – Advanced Thermal Treatment

AMS – Accelerator Mass Spectrometry

BI - Beta-Ionization

C14 – Carbon-14

CO_2 – Carbon Dioxide

CCS – Carbon Capture and Storage

CCUS - Carbon Capture, Usage And Storage

CEMS – Continuous Emission Monitoring System

CEWEP - Confederation of European Waste-to-Energy Plants

CI – Confidence Interval

CO – Carbon Monoxide

DESNZ - Department of Energy Security and Net Zero

EfW - Energy from Waste

EU ETS – European Union Emissions Trading System

FTIR - Fourier transform infrared

GHG – Greenhouse Gas

ICC BM – Industrial Carbon Capture Business Model

IED - Industrial Emissions Directive

IPCC – Intergovernmental Panel on Climate Change

HSE – Hospital and Small Emitter

LTSS – Long-Term Sampling System

LTS – Long-Term Sampling

LSC – Liquid Scintillation Counting

M_{ort} – Manual Sorting Method

MCERTS - Monitoring Certification Scheme

MRR – Monitoring and Reporting Regulations

MRV – Monitoring, Reporting & Verification

MSW – Municipal Solid Waste

PI – Pollution Inventory

PEMS - Predictive Emissions Monitoring System

PRTR - Pollutant Release and Transfer Register

PSM - Proportional Scintillation Method

QAL – Quality Assurance Level

REGO – Renewable Energy Guarantee of Origin

RDF – Refuse Derived Fuel

RHI – Renewable Heat Incentive

RO – Renewables Obligation

ROC – Renewable Obligation Certificate

SDM - Selective Dissolution

SRF – Solid Recovered Fuel

TLS – Tuneable Laser Spectroscopy

UK ETS – United Kingdom Emissions Trading Scheme

USE – Ultra Small Emitter

Executive summary

The Department for Energy Security & Net Zero is seeking to improve the evidence base to inform the options for establishing a suitably accurate, rigorous, and proportionate Monitoring, Reporting and Verification (MRV) system for the inclusion of Energy from Waste (EfW) and other waste incineration into the UK Emissions Trading Scheme (UK ETS). It will be important for operators across different sizes and types of plant to be able to implement a method that is sufficiently accurate and verifiable to enable calculation of the fossil carbon dioxide (CO_2) emissions to atmosphere from the installation, separate from the biogenic CO_2 emissions.

Ricardo engaged with key stakeholders including operators, trade associations, policymakers, regulators, technology suppliers & laboratories, and European stakeholders. This engagement took the form of questionnaires and interviews and has informed the project team's understanding of the key challenges regarding MRV and the inclusion of the EfW and waste incineration sector in the UK ETS. A summary of key recommendations to the Department for Energy Security and Net Zero are presented below.

Recommendations to the Department for Energy Security & Net Zero
• A limited number of responses were received from hazardous waste incinerator operators and zero responses from clinical waste incinerator operators. This is concerning because it is likely that the MRV methods described throughout this report will not be appropriate for all hazardous and clinical sites. The Department for Energy Security & Net Zero should therefore seek to engage with these sectors further to understand where measurement-based reporting is appropriate, and what steps need to be taken to facilitate calculation-based reporting. The latter will likely include the development of a robust and comprehensive set of emission factors (EFs) for hazardous and clinical waste streams. Data from the Department for Energy Security & Net Zero, which employs an estimated biogenic fraction of clinical and hazardous

waste, indicates that all clinical facilities and a number of the hazardous facilities fall below the proposed UK ETS inclusion threshold of 25,000 fossil tonnes CO_2 (tCO_2) for Hospital and Small Emitters (HSE), whilst several clinical sites will also fall below the 2,500 fossil tCO_2 threshold for Ultra Small Emitters (USE). Therefore, some of the technologies mentioned in this report would not be applicable to those sites.

- This study has revealed that there is limited information regarding the uncertainty of these MRV methods available in literature or from industry. Information from literature reviews and feedback from stakeholder engagement suggests that it may prove challenging for operators to meet the current UK ETS uncertainty requirements (or potentially impossible for the higher tiers). The Department for Energy Security & Net Zero should work with industry over the coming years to gather data regarding the uncertainty of the MRV methods described. This should then feed into a review of the uncertainties required under the UK ETS for EfW and waste incineration. It is also recommended that options other than uncertainty ranges are explored, such as tiers for determination of biomass fractions. The Department for Energy Security & Net Zero should seek to obtain the data that Ofgem were unable to provide Ricardo regarding EfW under the Renewables Obligation (RO), as this may provide a useful starting point.

- The biggest concern regarding integration of EfW and waste incineration into UK ETS expressed by the operators is the disaggregation of ETS cost between customers. The Department for Energy Security & Net Zero should work with key stakeholders, ahead of the 2026 starting point, to develop practical and safe methodologies that will allow operators to fairly allocate UK ETS costs to waste producers.

- The Department for Energy Security & Net Zero should work with stakeholders to develop a robust and comprehensive set of emission factors for waste streams into waste incineration and EfW sites. This will aid the accurate adoption of calculation-based approaches, which will likely be important for HSE and USE (from whom Ricardo received fewer responses).

- The Department for Energy Security & Net Zero should review the frequency of potential waste sampling required under the UK ETS to ensure that it is not impracticable or financially unviable.
- The Department for Energy Security & Net Zero may wish to review, and where appropriate, align biogenic-fossil CO_2 reporting under the UK ETS and the Waste industrial carbon capture business model. This could help to streamline and simplify reporting for EfW operators.

Report Structure

Section 1 – Introduction

Introduces the aims of the study and the EfW / waste incineration sector in the UK.

Section 2 – UK ETS and Other Monitoring Requirements

Presents a background on the current emission reporting guidelines and requirements under the UK ETS, focusing on what levels of uncertainties are required.

Section 3 – Waste Incineration and the UK ETS

Describes the EfW / waste incineration sector in the UK, and how these sites might be integrated into the existing UK ETS structure.

Section 4 – MRV Methods the Waste Sector Could Adopt

Details the measurement-based MRV methods under review, including advantages, limitations, cost, burden, requirements, suitability, and uncertainty.

Section 5 – Stakeholder Responses

Presents a summary of the findings from engagement with key stakeholders.

Section 6 – Conclusions and Recommendations

Key findings for the Department for Energy Security and Net Zero.

1. Introduction

1.1. Study Aims

The Department for Energy Security and Net Zero is seeking to improve the evidence base to inform the options for establishing a suitably accurate, rigorous and proportionate[1] Monitoring, Reporting and Verification (MRV) system for the inclusion of Energy from Waste (EfW), waste incineration with no energy recovery facilities, and waste-to-fuel facilities that process part-fossil, part-biogenic materials, into the UK Emissions Trading Scheme (UK ETS) from 2026 onwards, with an MRV only period running for 2 years ahead of full inclusion from 2028. It will be important for operators across different sizes and types of plant to be able to implement a method that is sufficiently accurate and verifiable to enable calculation of the fossil carbon dioxide (CO_2) emissions to atmosphere from the installation, separate from the biogenic CO_2 emissions, as it is the fossil carbon component that will need to be determined such that ETS credits from these installations are fungible within the wider ETS trading.

Consistent with international guidance and reporting protocols, biogenic emissions of CO_2 arising from the combustion of biomass, biofuels or bio-gases are not reported within the UK Greenhouse Gas (GHG) inventory totals submitted to the United Nations Framework Convention on Climate Change (UNFCCC), nor within the scope of UK Carbon Budgets, nor within organisational-level "Scope 1" emission reporting (e.g. under the GHG Protocol[2]).

Within the UK ETS, operators of installations that burn either biogenic or mixed fossil-biogenic fuels (e.g. scrap tyres in cement kilns, part-fossil fuels in power stations) already implement methods to estimate and report the fossil and biogenic CO_2 emissions separately, with the fossil CO_2 then considered in ETS. This study aims to research MRV options that are available to UK operators of EfW and waste incineration plants to generate separate calculations or estimates of the fossil and biogenic CO_2 emissions to atmosphere.

[1] With respect to emitter size

[2] GHG Protocol, 2019. *Scope 1 & 2 GHG Inventory Guidance.*

1.2. Methodology

Ricardo has undertaken extensive desk-based research and stakeholder engagement to compare and evaluate MRV options. The project was delivered through five tasks, some of which were delivered simultaneously, as illustrated in Figure 1.

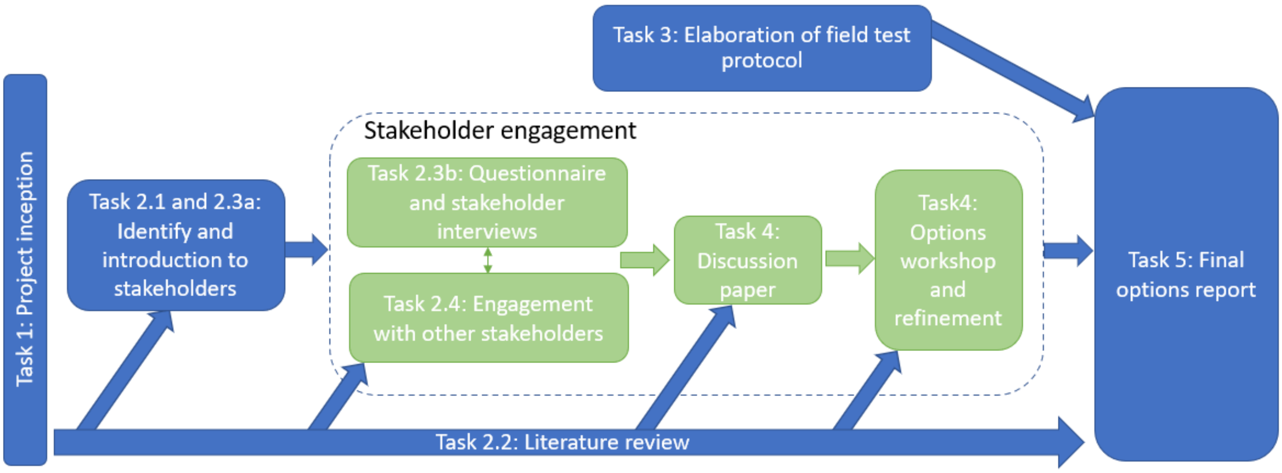

Figure 1: Overview of project tasks

Task 1: Project inception – The inception phase identified an initial list of stakeholders and identified the types of waste incineration to be considered in the study.

Task 2: Information gathering:

Task 2.1: Identify key stakeholders – Operators (EfW, hazardous, clinical), trade associations, policymakers, regulators, technology suppliers & laboratories, and European stakeholders.

Task 2.2: Literature review – Ricardo undertook a literature review of published guidance, academic papers, and measurement standards.

Task 2.3a: Identify plant and emission data – Relevant plants in the UK were identified by contact with the Department for Energy Security & Net Zero, Defra and Ofgem.

Task 2.3b: Operator consultation – Operators were contacted with a questionnaire, some of which were followed up with an interview.

Task 2.4: Engagement with other stakeholders – Specialised questionnaires and interviews were devised for trade associations, policymakers, regulators, technology suppliers & laboratories, and European stakeholders.

Task 2.5: Summarising findings – An interim document was prepared to summarise findings around the desired output themes: costs, uncertainty, variability of results, monitoring burden, method requirements.

Task 3: Elaboration of Field Test Protocol to Assess Candidate Methodologies – This is a standalone task informed by the literature review and stakeholder responses (presented in Appendix A).

Task 4: Stakeholder workshop – A discussion paper was shared with the group of stakeholders and comments invited with a focus on the knowledge gaps and uncertainties.

Task 5: Project report – The findings of the project, including the workshop and field test protocol, have been synthesised into a comprehensive project report.

1.3. Waste Incineration

There are several types of waste, though not all of these are appropriate for incineration.

Table 1: List of waste types

Waste Type	Description
Municipal Solid Waste (MSW)	Generated from households, offices, hotels, shops, schools and other institutions. The major components are food waste, paper, plastic, textiles metal and glass.
Clinical Waste	Waste produced by healthcare facilities, such as hospitals, clinics, and veterinary practices. It includes materials like used needles, pharmaceutical waste, contaminated dressings, and medical equipment.
Construction & Demolition Waste	This waste includes materials like concrete, bricks, wood, metals, plastics, and insulation.
Hazardous Waste	This type of waste contains substances that pose a risk to human health or the environment. Examples include chemicals, solvents, batteries, fluorescent tubes, and certain types of medical waste.
Industrial Waste	This waste can encompass a wide range of materials, such as manufacturing by-products, chemical waste, and residues from industrial operations.
Refuse derived fuel (RDF)	This is produced from domestic and business waste, which includes biodegradable material, as well as plastics. Non-combustible materials such as glass and metals are removed, and the residual material is then shredded. RDF is used to generate energy at

Waste Type	Description
	recovery facilities and can be used in cement kilns (depending on the facility's specification).
Solid recovered fuel (SRF)	This is produced from mainly commercial waste including paper, card, wood, textiles, and plastic. SRF goes through additional processing, often to a defined fuel specification. It tends to have a higher calorific value than RDF and is used to generate energy at recovery facilities; it can be used in cement kilns depending on the facility's specification.

1.4. Energy From Waste

Conventional EfW

Combustion with energy recovery is currently the most common way of extracting energy from waste that cannot be, or is not currently, reused or recycled. Heat generated from the combustion process is used to raise steam, which is subsequently passed through a turbine to generate power. Much of this power is exported to the national electricity grid. Heat can also be exported directly from the plant into a district heating network or to an industrial heat user. EfW plants tend to process MSW.

Advanced EfW

Less widely deployed processes include advanced thermal treatment (ATT) and advanced conversion technology (ACT), which utilise pyrolysis and/or gasification to extract energy from the waste. Pyrolysis involves the thermal degradation of a substance in the absence of oxygen[3]. Gasification is a partial oxidation process. ATT/ACT processes typically produce a synthesis gas ('syngas') which can then be combusted to generate heat and electricity or can be further refined into an oil, which can also be burnt as a fuel to generate heat and

[3] DEFRA, 2013. *Advanced Thermal Treatment of Municipal Solid Waste.*

electricity or may be processed for use as a transport fuel. ATT/ACT processes usually require more homogenous feedstocks such as waste tyres.

1.5. Waste Incineration without Energy Recovery

Some non-MSW, such as clinical wastes and hazardous waste, are incinerated at installations that do not recover energy. Energy recovery is generally not performed for the following reasons:

- **Priority:** The primary aim is waste treatment.
- **Reliability:** These plants have greater downtime than conventional incineration facilities.
- **Scale:** Typically very small plants and hence the absolute quantity of heat and power that could be generated is notably smaller than conventional incinerators.
- **Cost:** Because the installations tend to be small capacity, energy recovery is often not as financially viable.

However, it should be noted that these are only general trends; some sites that incinerate healthcare and hazardous waste do recover energy.

2. UK ETS and Other Monitoring Requirements

2.1. Overview of UK ETS monitoring approaches

In the context of the UK ETS, the CO_2 generated from the combustion of biomass, biofuels, biogases or the bio-component of mixed fossil- and biomaterials is considered biogenic. Currently, operators using solid or gaseous biomass, or bioliquids for non-energy purposes, can apply an emission factor of zero for the fraction of the fuel or material that is biomass. Bioliquids used to generate energy can only apply an emission factor of zero if they meet certain sustainability criteria set out in Article 17(2) to (5) of the Renewable Energy Directive 2009/28/EC (Article 38(2) of the Monitoring and Reporting Regulations (MRR) as applied to the UK ETS with the modifications set out in Schedule 4 to the GHG ETS Order 2020)[4]. The Department for Energy Security & Net Zero is currently considering applying this approach to all biomass materials (and therefore all biogenic emissions). If those criteria cannot be met, the emissions associated with the use of the biomass material must be reported as fossil emissions.

There are broadly two monitoring approaches:[5]

- **Calculation**: Typically involves compositional analysis and/or the application of assumptions to derive an estimated calorific value and/or composition (i.e. biogenic and/or fossil carbon content) of the fuel/feedstock to formulate an appropriate emission factor (EF) that is representative of the fuel/feedstock. EFs are then multiplied by the mass flowrates of fuel/feedstock entering the process to derive an emission estimate for fossil CO_2 and biogenic CO_2.

- **Measurement**: Each operator is given the responsibility of determining the fossil and biogenic CO_2 emitted from the site via direct measurement.

The UK ETS has a well-established tiered system of MRV methods that enables regulators and operators to establish a proportionate approach that reflects the level of fossil

[4] BEIS, 2021. *UK Emissions Trading Scheme (UK ETS): monitoring and reporting biomass in installations.*
[5] Please see Appendix B for information regarding the fall-back method.

emissions, per installation and per source stream, within a given installation. For high-emitting fossil carbon source streams, a higher-tier monitoring method will be specified within the installation Emission Monitoring Plan that can achieve a specified low level of uncertainty in the annual fossil carbon emission estimate. Conversely, for small-emitters a simpler and cheaper monitoring approach which generates emission estimates associated with higher uncertainty may be specified by the regulator, to ensure that the UK ETS does not confer a disproportionate cost to operators of smaller, lower-emitting sites.

It is understood through engagement with regulators that, if the required tier cannot be achieved due to challenges in determining uncertainty ranges, regulators will accept other monitoring methods, provided that the operator can prove that the method used is the most accurate method available to them.

2.2. UK ETS Categories and Tiers

Under the ETS, installations are categorised in Article 19 of the MRR as follows:[6]

Category A installation: annual emissions ≤ 50,000 tonnes of CO_2e

Category B installation: 50,000 < annual emissions ≤ 500,000 tonnes of CO_2e

Category C installation: annual emissions > 500,000 tonnes of CO_2e

These categories are of importance because they define which 'tier' a site falls within. Annex II and VIII of the MRR (2018/2066) set out the tier definitions for calculation-based and measurement-based methodologies related to installations. A 'tier' is defined in the Regulations as *'a set requirement used for determining activity data, calculation factors, annual emission and annual average hourly emission, and payload'*.

[6] Excluding biogenic CO_2.

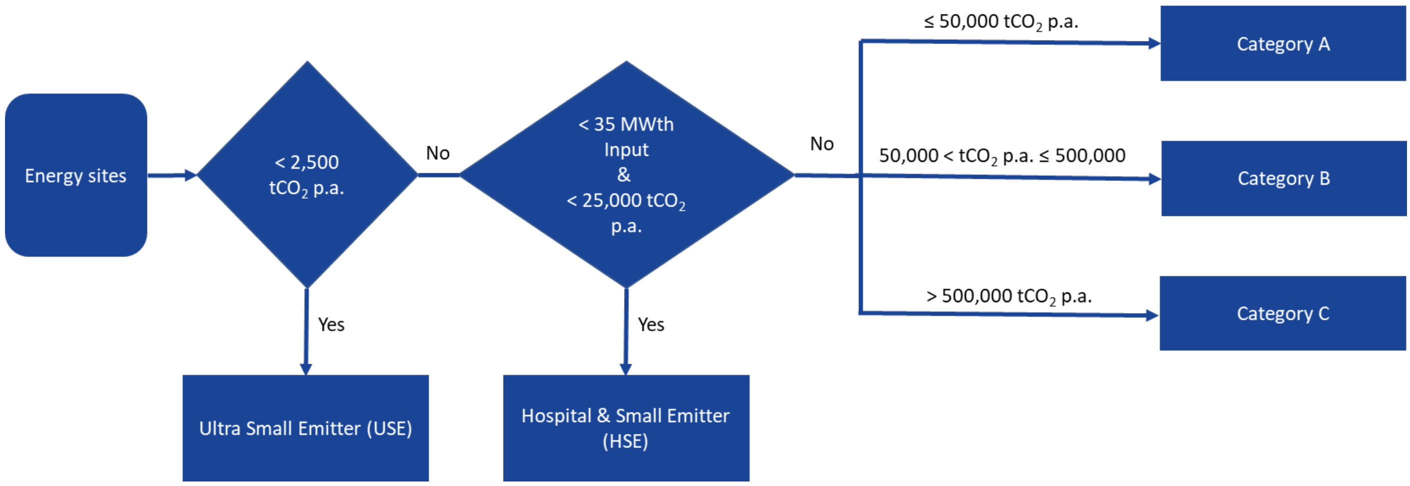

Figure 2: Flow diagram for site classification based on existing UK ETS regulations

2.3. UK ETS Measurement-based Methodology and Tiers

The purpose of this report is to understand and assess the methods that EfW and waste incineration sites could adopt under the UK ETS. Article 41 of the MRR sets out the tier requirements for measurement-based methodologies:

Table 2: Tiers for CEMS (maximum permissible uncertainty for each tier). Source: MRR Annex VIII Section 1

	Tier 1	Tier 2	Tier 3	Tier 4
CO_2 emission sources	±10%	±7.5%	±5%	±2.5%

For each major emission source, a category A installation must aim to meet tier 2, whilst categories B and C must aim for tier 4. *'However, the operator may apply a tier one level lower than required in accordance with the first subparagraph for category C installations and up to two levels lower for category A and B installations, with a minimum of tier 1, where it shows to the satisfaction of the competent authority that the tier required in accordance with the first subparagraph is technically not feasible or incurs unreasonable costs.'* This is illustrated in Table 3.

Table 3: Summary of the Tier Requirements by Category (for the measurement-based methodology)

CO_2 emission uncertainty	Tier 1 ±10%	Tier 2 ±7.5%	Tier 3 ±5%	Tier 4 ±2.5%
Category A				
Category B				
Category C				

2.4. UK ETS Calculation-based Methodology

Whilst the focus of this report is measurement-based methodologies, under the UK ETS sites can opt for a calculation-based approach. A calculation-based methodology relies on the use of activity data obtained by measurement together with additional emission factors from laboratory analyses or default values to give a greenhouse gas emission value.

Calculation-based methods have not been explored in detail in this report. However, it is acknowledged that this approach may be more suitable for use by some (e.g. small) emitters, due to the financial or operational constraints of direct-measurement approaches.

Information provided by the Confederation of European Waste-to-Energy Plants (CEWEP) states that the EU's proposed amended text of the MRR would *'maintain full flexibility to EfW operators to either apply a calculation-based or a measurement-based methodology, pursuant to Article 21'*[7]. Similarly, conversations with stakeholders identified that some national ETS systems which already include waste incineration allow the use of emission factors, if only as an interim approach. For example, the calculation approach is allowed in Norway and the Netherlands[8,9]. However, at present, there is limited availability of robust and collated fossil CO_2 emission factor data that could be used for a calculation-based reporting approach for MSW, hazardous and clinical waste streams. The UK ETS provides (total) CO_2 emission factors for MSW for certain industry sectors but there are no emission factors for hazardous or clinical waste[10].

2.5. Tiers for Small and Ultra Small Emitters in UK ETS

The UK ETS guidance states that small emitters (those emitting less than 25,000 tCO_2e per annum and with a thermal capacity of less than $35MW_{th}$, i.e. HSE installations) are exempt from *"demonstrating that it would lead to unreasonable costs or it is not technically feasible to apply a higher tier than tier 1"* and that they may *"apply tier 1 as a minimum to determine activity data and calculation factors for all source streams, and to determine emissions by measurement-based methodologies (unless you can be more accurate without additional effort)"*[11]. For example, a small emitter using a solid fuel and a measurement-based methodology will need to meet a maximum uncertainty of ±10%.

[7] CEWEP, 2023. *CEWEP feedback to Amendment of EU ETS Monitoring and Reporting Regulation (MRR) with focus on the provisions for Waste-to-Energy (WtE).*

[8] The Norwegian Tax Administration, 2023. Available at: *Waste incineration tax*. Accessed: 09.10.2023.

[9] Dutch Emissions Authority (NEA), 2021. *Information document waste incineration plants: Industrial monitoring plan for the CO2 levy. 10 September 2021.*

[10] UK GOV, 2023 *Using UK greenhouse gas inventory data in UK ETS monitoring and reporting: the country-specific factor list - GOV.UK (www.gov.uk)* . *Accessed 05.10.23.*

[11] UK GOV, 2023. *UK Emissions Trading Scheme for installations: how to apply* Accessed: 29.09.2023.

If an installation emits less than 2,500 tCO_2e in the relevant period, the installation can opt out of the UK ETS for this installation. The installation will need to be registered as an 'ultra-small emitter' (USE) and emissions must still be monitored and the regulator notified if emissions exceed the agreed threshold, at which point the installation must apply for a UK ETS permit as either a HSE or a regular installation and meet the relevant tiers. As a USE is excluded from the UK ETS, there are no tier requirements for the monitoring. However, a monitoring plan does need to be submitted and approved by the regulator to ensure that an appropriate method of monitoring their emissions is being used. The monitoring plan will be approved in relation to the installation under Articles 11 to 13 of the MRR.

2.6. Frequency of Analyses for UK ETS

Several of the MRV methods discussed within this report require waste sampling. Article 35 of the MRR sets out the requirements for frequency of analyses: *The operator shall apply the minimum frequencies for analyses for relevant fuels and materials listed in Annex VII.*

'The competent authority may allow the operator to use a frequency that differs from those referred to in paragraph 1, where minimum frequencies are not available' or where the operator can demonstrate that historical data shows a very low variation in uncertainty or that using the required frequency would incur unreasonable costs.

Table 4: (excerpt) Minimum frequency of analyses (Article 35). Source: Annex VII of the MRR.

Fuel/material	Minimum frequency of analyses
Other fuels	Every 10,000 tonnes of fuel and at least four times a year
Untreated solid waste (pure fossil or mixed biomass/fossil)	Every 5,000 tonnes of waste and at least four times a year
Liquid waste, pre-treated solid waste	Every 10,000 tonnes of waste and at least four times a year

Implications of ETS Sampling Frequency

At this stage, it is worth highlighting that a sampling frequency of every five kilo-tonnes of waste would be a challenge for most EfW sites, which are typically designed to process more than 100 kilo-tonnes of waste per annum. During stakeholder engagement, it was suggested that this frequency of sampling would likely be practicably unfeasible and expensive for most EfW sites. The current sampling frequency for solid waste under the ETS may therefore need to be modified to account for the practical issues in sampling, storing, and sorting or preparing solid waste samples on an EfW installation.

Whilst hazardous and clinical waste incineration sites are typically designed for a lower waste throughput, sampling of the waste is typically limited or completely avoided for health and safety reasons.

2.7. Treatment of Data Gaps in UK ETS

Article 23 of the MRR sets out the approach to take when there is a temporary change to the monitoring methodology used. In such an event, the operator is required to notify the competent authority of the change and to apply the highest achievable tier *'until the conditions for application of the tier approved in the monitoring plan have been restored'*. Article 66 of the MRR outlines the approach to treating data gaps - *'Where data relevant for the determination of the emissions of an installation are missing, the operator shall use an appropriate estimation method to determine conservative surrogate data for the respective time period and missing parameter.'*

In most cases, as part of the ETS permit application, the operator will submit a written procedure setting out which approach to calculating/measuring emissions they will use in the event of a loss of data that prevents the use of their usual approved approach. Therefore, the operator would simply follow that procedure in this circumstance.

Relevance to Continuous Flue Gas Sampling

This is important because several EfW operators who are intending to install continuous flue gas samplers for C14 analysis (which is described in section 4.4) have expressed concern regarding the loss of samples and that they therefore intend to install two samplers per line. Based on the regulations laid out above however, this may not be necessary if the operator can adopt an '*appropriate estimation method'.*

However, operators in the UK ETS are encouraged to monitor their emissions as accurately as possible. A data gap methodology is only there to fall back on during times of unforeseen issues. If the operator suspects there will be regular loss of samples, the expectation is that they would counter this by installing more accurate technology e.g. two lines of sampling. This is also more beneficial to the operator as data gap methodologies are designed to ensure that the fossil CO_2 emission estimate is conservative, i.e. they will estimate emissions to be greater than if they had been accurately sampled, increasing operator trading costs.

2.8. Current UK ETS Biomass Guidance

Current UK ETS guidance for monitoring and reporting biomass in installations[4] sets out methodologies applicable to tier 2 and tier 3. For the estimation method (tier 2), the guidance states "*Estimation methods must be based on scientifically proven methods. Preference should be given to methods at least partly referring to EN, ISO or national standards as well as to peer-reviewed publications*."

For analytical methods (tier 3), and EN ISO 21644 (for SRF) the UK ETS biomass monitoring guidance states that "*operators must use the carbon-14 method unless they can demonstrate to the satisfaction of their regulator that this method leads to unreasonable costs or is technically not feasible*".

It is understood from dialogue with stakeholders that some believe that this comment may be applicable to analytical approaches for all waste (not just SRF). This has led to some uncertainty amongst operators regarding whether this method will be mandated for EfW and waste incineration installations as well.

However, the Guidance also states that *'standards must be appropriate for their use'* and a standard designed for use with SRF is unlikely to be applicable to MSW due to the more variable (heterogeneous) material and size composition of MSW compared to the more homogenous nature of SRF. Not all MRV methods are suitable for all sites and waste types, and therefore a non-prescriptive approach is likely to be a more effective way of managing EfW and waste incineration in the ETS.

Annex II Section 2.4 of the MRR sets out the current tier requirements for installations reporting biomass fraction, per the table below.

Table 5. Tiers applicable to biomass fraction for calculation-based approach, per Annex II Section 2.4 of the MRR

	Tier 1	Tier 2	Tier 3
Biomass fraction	Value published by the competent authority or European Commission, or values in accordance with the requirements in Article 31(1).	An approved estimation method in accordance with Article 39(2). For some fuels, the estimation can be based on mass-balance.	Analyses in accordance with Articles 32 – 35 and Article 39(2).

Category A facilities and HSE are required to meet at least Tier 1 while Category B and C facilities are required to meet the highest available tier (tier 3), with the option to drop down one or two tiers (dependent on category) if technically or financially unfeasible.

2.9. Other MRV Systems Pertinent to Energy from Waste Plants

Renewables Obligation

The Renewables Obligation (RO) scheme places an annual obligation on electricity suppliers to present to Ofgem a specified number of Renewables Obligation Certificates (ROCs) per megawatt hour (MWh) of electricity supplied to their customers during each year[12]. ROCs are issued to operators of accredited renewable generating stations for the eligible renewable electricity they generate. Only the renewable fraction of waste is rewarded with ROCs and this proportion can either be measured, or for municipal waste, can be 'deemed' at 50% if agreed with Ofgem [13].

When the RO began, it was decided that there would be no requirement placed on EfW operators as to exactly which MRV methods they must use. The RO opened in 2002, closed to new entrants in 2017, and offers ROCs to sites for 20 years. The RO would therefore be in operation for 35 years. Given this long time span, Ofgem wanted to ensure that operators were able to use novel MRV methods as and when they became available, rather than restricting use to the methods in widespread use at the start of the scheme.

[12] Ofgem, 2023. Renewables Obligation (RO). *Accessed: 09.10.2023.*

[13] DEFRA, 2014. *Energy from waste: A guide to the debate*. February 2014 (revised edition).

EfW operators have been able to propose and adopt site-specific MRV methods which meet Ofgem's requirements for the RO.

Pollution Inventory Reporting

Many combustion and industrial process installations across the UK that are regulated under the Industrial Emissions Directive (IED) are required to report their annual CO_2 emissions in accordance with the requirements of their environmental permit. Emission data are reported to the regulator's Pollution Inventory [14] (PI) and included in the UK Pollutant Release and Transfer Register (PRTR). The threshold for PRTR reporting for CO_2 is 100,000 tonnes per year (although operators can report lower emissions at their discretion).

Guidance states that *'although incinerators are not subject to the EU ETS requirements the EU ETS methodology is considered best practice'* [15] although the use of emission factors from the H2 Energy Efficiency guidance [16] (*subsequently withdrawn in 2016*) was also allowed. The general guidance note states that *'the mass of CO_2 emitted from its combustion or use is a PI reporting requirement. Emissions of CO_2 attributable to biomass should be reported in the qualification box of the PI reporting form'* [17]*.* Either a calculation-based or measurement-based approach is allowed for this reporting. Rather than specifically targeting the reduction of particular pollutants like the UK ETS or the RO scheme, the aim of PI reporting is to provide public access to environmental data and to provide the UK regulatory agencies with data to assist the development of regulations, as well as to help the government meet national and international environmental reporting commitments, such as the PRTR [18].

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[14] The pollution emission registers managed by regulators across the UK are: the Environment Agency Pollution Inventory [link]; Natural Resources Wales Emissions Inventory [link]; The Scottish Pollutant Release Inventory [link]; the Northern Ireland Environment Agency Pollution Inventory [link].

[15] EA, 2020. *Pollution inventory reporting – incineration activities guidance note*.

[16] EA, 2002. *Environmental permitting: H2 Energy Efficiency - IPPC Accessed: 09.10.2023* UK.

[17] EA, 2012. *Pollution inventory reporting – general guidance notes. Version 5, December 2012.*

[18] DEFRA, 2012. UK Pollutant Release and Transfer Register (PRTR) data sets. Accessed: 09.10.2023.

For CO_2 reporting to the Pollution Inventory, operators are not typically required to make any distinction between emissions of CO_2 from fossil or biogenic sources; one annual total (i.e. fossil + biogenic) CO_2 emission per installation is typically reported.

The Waste Industrial Carbon Capture Business Model

The Waste Industrial Carbon Capture business model (ICC BM) aims to provide capital and operating support to industrial sites within the industrial clusters, including waste incineration. Though still in development, it will include a contract for up to 15 years that provides the emitter with a payment per tonne of captured and stored CO_2 to cover operational, travel and storage costs. Capital expenditure costs will also be covered in the initial 10 years of the contract but will not be in the possible 5-year extension periods[19]. For projects that have applied through the Phase 2 Cluster Sequencing Process for carbon capture, usage and storage (CCUS) deployment, government capex co-funding via the CCS Infrastructure fund will also be provided where relevant. Under the Waste ICC BM contract, the only permitted method for assessing the biogenic-fossil split of CO_2 emissions will be C14 analysis. This must take the form of a monthly composite sample, collected using continuous sampling via a long-term sampling system (LTSS). The sample must be analysed at an accredited laboratory. No other methodologies will be permitted under the Waste ICC Contract[20].

Under the Waste ICC BM, the payment equations include the applicable emissions percentage, which are the emissions subject to ETS, i.e. the fossil portion. While projects would report the biogenic fraction from the lab report, this would be used to give the fossil fraction, which is the value applied in the payment formula on the applicable emissions.

Implications for the UK ETS

The monitoring requirements for the Waste ICC BM and the extension of the UK ETS to waste incineration are being developed in parallel by the Department for Energy Security and Net Zero and any opportunities for consistency in approach could reduce operator

[19] BEIS, 2022. Carbon Capture, Usage and Storage. Government response to consultation on the Industrial Carbon Capture business model *Accessed: 09.10.2023.*

[20] BEIS, 2022. Carbon Capture, Usage and Storage. Industrial Carbon Capture Business Models Summary. *Accessed: 03.10.2023.*

burden. Conversely, the RO is managed by Ofgem and is now closed to new applicants. Modification of the reporting mechanisms under the RO are not proposed, but requirements for the Waste ICC BM and the UK ETS should be aligned as much as possible.

3. Waste Incineration and the UK ETS

3.1. Energy from Waste

As of 2022, there are 57 fully functional EfW sites in the UK, most of which are in England. The permitted capacities of these sites range from 26 kt pa to 1,100 kt pa. The total nationwide permitted capacity of the EfW sector has been steadily increasing over the past decade, now at a total of 17.5 Mt pa. Approximately 15.3 Mt of waste were combusted at these 57 EfW sites in 2022, generating a total of 9,428 GWh_e which is exported to the electricity grid, representing ~3% of total UK power generation[21].

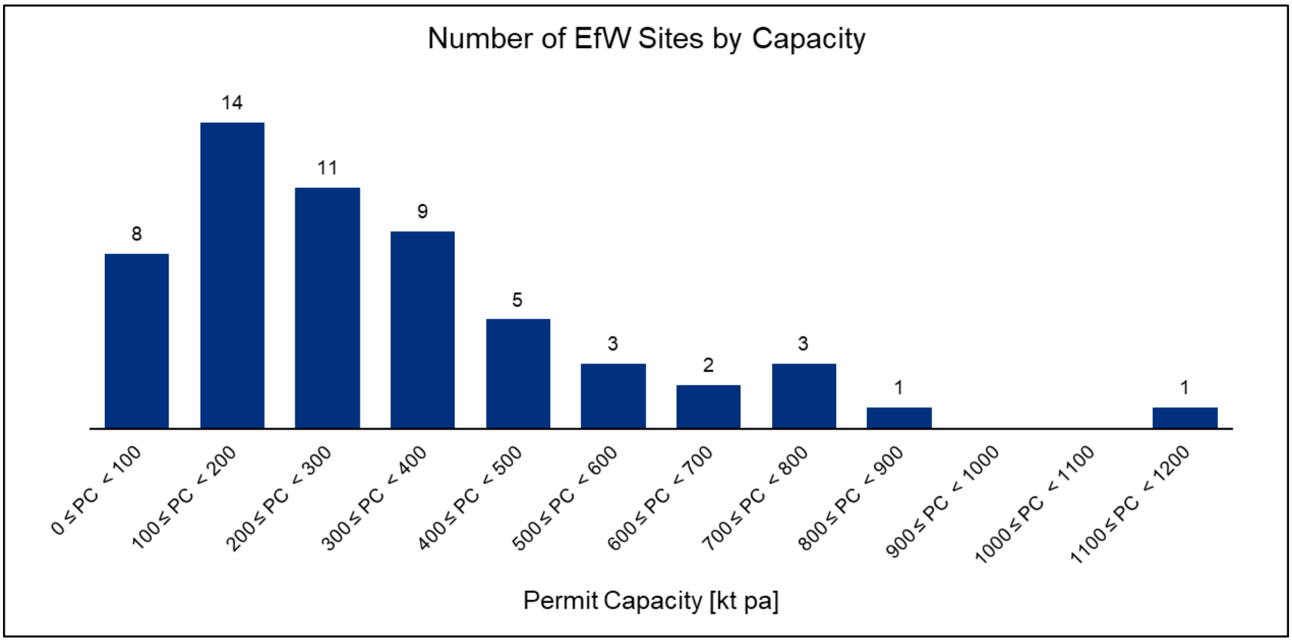

Figure 3: Permitted capacities of the EfW sites in the UK (in operation)

3.2. Hazardous and Clinical Waste Incineration

There are 19 clinical waste incineration sites and 8 hazardous waste incineration sites in the UK. Permitted capacities range from 4 kt pa to 100 kt pa, with a total nationwide permitted capacity of 653 kt pa (notably less than the total permitted capacity of EfW at 17.5 Mt pa). There are 18 operators of clinical and hazardous waste incineration sites.

[21] Tolvik Consulting, 2023. *UK Energy from Waste Statistics – 2022.*

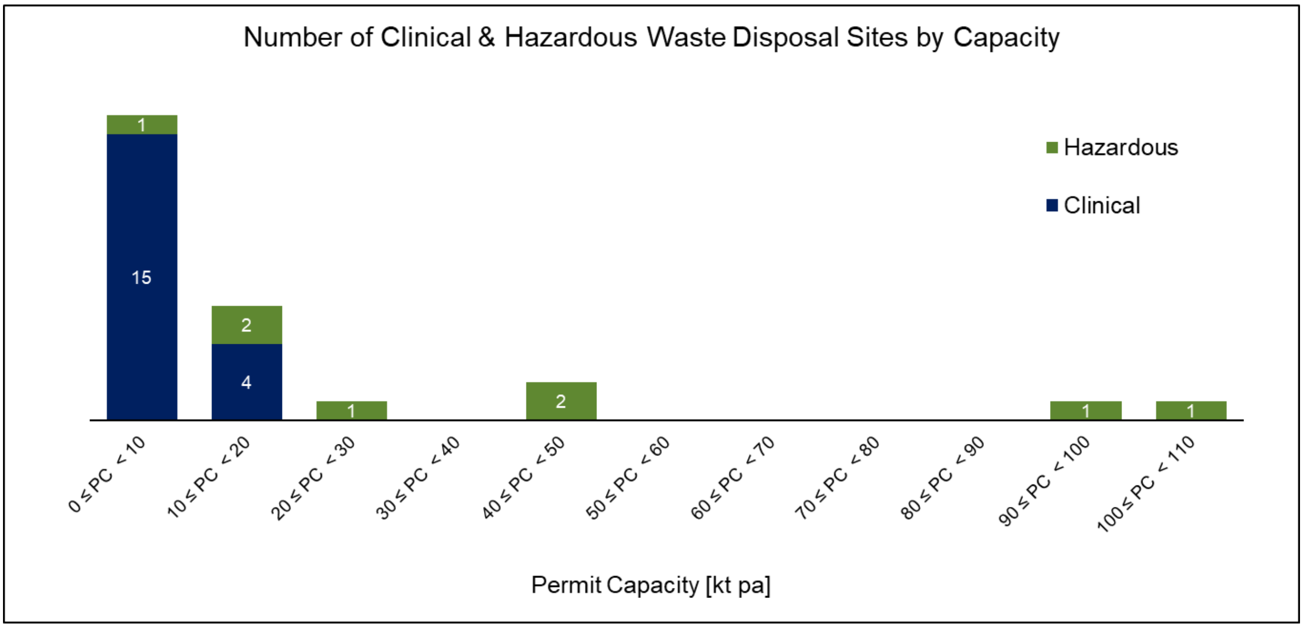

Figure 4: Permitted capacity of clinical & hazardous waste incineration sites in the UK (in operation)

3.3. The Inclusion of EfW and Waste Incineration in the ETS

The inclusion of EfW and waste incineration in the UK ETS is a significant policy development for the waste sector because the carbon cost that will be placed on these sites is substantial. Based on the existing ETS regulations, the data available regarding the operation, capacity and design of waste incineration sites across the UK and applying assumptions regarding the fossil carbon content of hazardous and clinical waste based on IPCC guidance [22], Ricardo has estimated the number of sites that will fall under each category of the ETS, as shown in Figure 5.

Ricardo predicts that the majority of EfW sites would sit within UK ETS Category A and B, with a small number of sites assigned as HSE or USE. The hazardous waste incineration sites are expected to sit across HSE, Category A and Category B. All clinical waste incineration sites are expected to be assigned as either HSE or USE. Data from DESNZ, which employs an estimated biogenic fraction of clinical and hazardous waste, indicates that all clinical facilities and a number of the hazardous facilities are expected to fall below the proposed inclusion threshold of 25,000 fossil tCO_2 for HSE, whilst several clinical sites will

[22] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_5_Ch05_IOB.pdf Table 5.2 presents IPCC defaults for carbon content and fossil share of carbon, per waste type.

also fall below the 2,500 fossil tCO_2 inclusion threshold for USE. As noted in Section 2, the measurement-based reporting requirements for ETS are as follows:

- Category A will have to meet an uncertainty of ±7.5–10%, depending on if they are assigned to Tier 1 or 2.
- Category B will have to meet an uncertainty of ±2.5–7.5%, depending on if they are assigned to Tier 2, 3 or 4.
- Category C will have to meet an uncertainty of ±2.5–5%, depending on if they are assigned to Tier 3 or 4.
- HSE will have to meet an uncertainty of 10% when assigned to Tier 1.

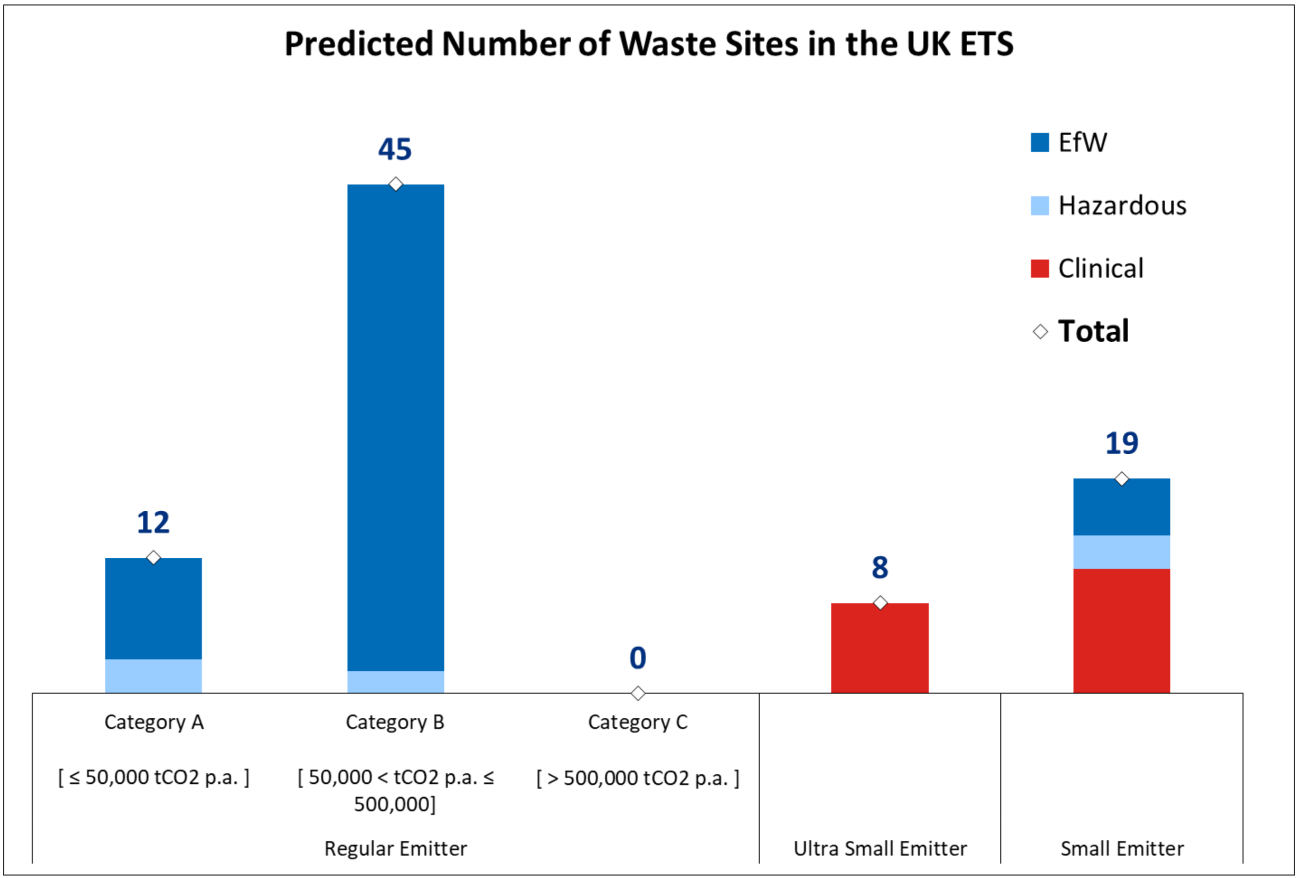

Figure 5: Predicted number of waste sites in the UK ETS (Including fossil CO_2 from waste and support fuels, excluding biogenic CO_2)

There are no tier requirements for USE as these installations are able to opt out of the UK ETS, although they must submit a monitoring plan for approval by the regulator.

Whilst there is currently insufficient data regarding the uncertainty of MRV methods in literature or industry (as discussed in Section 4.7), there is widespread concern within the sector that the existing uncertainties under the UK ETS may be challenging or impossible to achieve for the waste sector.

It is understood that the European Commission is currently reviewing the MRR with this in mind and therefore the tier requirements for waste incineration installations may differ from those currently included in the MRR.

4. MRV Methods the Waste Sector Could Adopt

The following section describes the MRV methods that waste incineration sites could adopt to ascertain the biogenic-fossil split of CO_2 emissions.

When selecting an appropriate MRV method, several factors need to be considered, including:

- **Cost**: Each of the methods presented will have different capital and operating costs. It is important that the magnitude and nature of these costs is understood. It is thought that larger waste incineration sites will be better equipped to handle cost increases than smaller sites.

- **Monitoring burden and requirements:** Burden describes the additional work that operators must undertake to perform these MRV methods. The monitoring requirement considers the actual physicality of each method, such as the space requirements on site and the new equipment requirements to fulfil the method.

- **Uncertainty:** When measuring and reporting fossil CO_2 emissions under the ETS, a specific degree of uncertainty must be met. It is therefore important that the MRV method implemented has a comprehensive and clear uncertainty measurement. By nature, waste is a heterogenous feedstock which often varies seasonally. The MRV method selected should be able to account for this variability and therefore have an acceptable yearly reported uncertainty.

4.1. MRV Methods

Several techniques exist for analysing the biogenic and fossil content of waste or products of combustion. The most widely used methods are as follows:

I. **The manual sorting method**
II. **The selective dissolution method**
III. **The radiocarbon method (C14 method)**
IV. **The balance method**

Each method is underpinned by international standards, which provide guidance to industry on how to measure biogenic and fossil derived carbon emissions. These standards are outlined in Table 6. Additionally, there are several supporting standards which can be used across various methods. These include, but are not limited to, standards which are applicable to some or all methods. For example, for post combustion methods, BS EN 14181 quality assurance of continuous emissions measuring systems and, BS EN 15259 for choice and validation of sampling position.

Table 6: Methods described in the standards reviewed

Standard	Manual sorting method	Selective dissolution method	Radiocarbon method	Balance method
ISO 21644 Solid recovered fuels – Methods for the determination of biomass content [23]	✓	✓	✓	
ISO 13833 Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-fuel derived carbon dioxide – Radiocarbon sampling and determination[24]			✓	
ASTM B6866:22 Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon analysis			✓	
ISO 18466 Stationary source emissions – Determination of the biogenic fraction in CO_2 in stack gas using the balance method				✓

[23] It is worth nothing that this standard addresses SRF as a feedstock not MSW. Throughout this work, Ricardo was unable to find a standard which covered manual sorting for MSW specifically.
[24] For determination of the ratio of biogenic and fossil CO_2 in in exhaust gases.

4.2. The Manual Sorting Method

In the manual sorting method, a sampling strategy is developed to either sample incoming waste deliveries or to sample from the waste bunker at regular intervals. Obtaining a representative sample is difficult because of the large range of material size and reduction to a manageable representative quantity to allow hand sorting is a challenge for MSW but is usually more manageable for processed wastes (SRF). The samples are sorted into fractions, e.g., paper/card, wood, glass, plastics, etc. The samples are sieved to remove all particles smaller than 10 mm, which are classified as fines. The fractions are then heated to 105°C until a constant mass is obtained. The dried fractions are aggregated into the following three categories: biomass, non-biomass and inert. Each category is weighed to understand the make-up of the waste.

Costs

Stakeholder responses indicate each sample requires one weeks' worth of work to physically sort the waste, which costs approximately £600 to £1,200 each time.

Monitoring Burden and Requirement

The time burden of performing manual sorting depends on the frequency of sampling. The process of manually sorting the waste is often sub-contracted out and can take approximately one-week of physical work per sample. The site performing manual sorting is required to have a suitability large space onsite where the manual sorting process can be safely performed. Note that management of the waste sorting area to avoid odour and other issues is important. Ventilation of the area may also be required to improve the safety of the working environment.

4.3. The Selective Dissolution Method

The selective dissolution method relies on the principle that when placed in a concentrated solution of sulphuric acid and hydrogen peroxide, biomass materials will dissolve, whilst fossil derived materials will not. By comparing the quantity of carbon in the initial sample and post dissolution, the quantity of biomass and fossil material can be derived.

An important limitation of the selective dissolution method comes from the fact that some fossil fuel-based materials will dissolve in the sulphuric acid hydrogen peroxide mixture, e.g., coal or polyurethane plastics. Whilst some biomass materials will not dissolve, e.g., charcoal, which is described in greater detail in Section 4.6.

Costs

No cost data for selective dissolution was found in literature nor provided by stakeholders during the interviews.

Monitoring Burden and Requirement

The dissolution process is performed offsite at a laboratory, but a representative sample must first be gathered onsite. A suitability large space onsite where sample can be safely collected is therefore required. Ventilation of the area may also be required to improve the safety of the working environment.

4.4. The Radiocarbon Method (C14 method)

The radiocarbon method utilises the half-life of ^{14}C to ascertain the biogenic-fossil fuel makeup of the waste. The majority of carbon in the environment is ^{12}C (~99%) and ^{13}C (~1%), but there are also trace amounts of ^{14}C. ^{14}C has a half-life of 5,780 years, therefore a fossil fuel material will contain close to zero ^{14}C, whilst biomass materials will contain trace levels of ^{14}C. Throughout the rest of the report the radiocarbon method will continue to be abbreviated to 'C14'.

There are three distinct ways in which a sample of carbon can be obtained for C14 analysis:

I. **Feedstock sampling and analysis:** A representative waste sample is collected onsite and sent to a laboratory for C14 testing. At the lab, the waste sample is combusted, and a portion of the combustion gas is collected. C14 analysis is then performed on this sample of flue gas. This type of C14 analysis is not widely performed in industry.

II. **Flue gas grab sampling:** A spot sample of flue gas is collected at the stack. This sample is then sent to a lab where the C14 analysis is performed. This method has been used by several EfW sites during their initial trial of C14, however it is not expected to be widely deployed on a permanent basis for the larger sites.

III. **Continuous flue gas sampling:** The CO_2 present in the stack gas sample is continuously absorbed in an alkaline medium or transferred to a gas bag or lecture bottle over an extended period of operation (typically one month). This sample is then sent to a lab where the C14 analysis is performed. EfW operators have expressed a preference for adopting this method for reporting under the ETS.

Regardless of how the sample flue gas is collected, there are three main methods for analysing the ^{14}C content in the CO_2: Accelerator Mass Spectrometry (AMS), Liquid Scintillation Counting (LSC) and beta-ionisation, as described below (and in BS EN ISO 13833:2013).

Accelerator Mass Spectrometry

AMS is an advanced form of mass spectrometry that combines traditional mass spectrometry with particle accelerators to achieve high precision and sensitivity. The basic principle behind accelerator mass spectrometry involves three main steps:

I. **Sample Preparation:** The sample is prepared by chemically extracting or purifying the isotopes of interest.

II. **Ionisation and Acceleration:** The extracted sample is ionised and then accelerated to high velocities using a particle accelerator.

III. **Mass Analysis and Detection:** The accelerated ions pass through a series of magnetic and electrostatic fields, which separate them based on their mass-to-charge ratio. The detector measures the number of isotopic atoms reaching it and generates a signal that is proportional to the concentration.

14Chrono, a radiocarbon dating and isotope analysis laboratory, states that some of the advantages of the AMS method over the LSC method are smaller sample size needed and easier to obtain enough sample material, and shorter measurement times (e.g. "10-15 minutes for AMS versus days to months for LSC") [25].

[25] 14CHRONO, 2023. About AMS Accessed: 29.09.2023

Liquid Scintillation Counting

LSC involves mixing a liquid scintillator, which is a substance that emits light when it interacts with ionising radiation, with the sample to be measured. The steps in liquid scintillation counting are as follows:

I. **Sample Preparation:** The sample is dissolved or suspended in a liquid medium and combined with the liquid scintillator.

II. **Light Emission:** When a radioactive particle interacts with the liquid scintillator, it transfers some of its energy to the scintillator molecules. This energy excites the scintillator molecules, causing them to emit light photons.

III. **Light Detection and Analysis:** The emitted photons are detected by a sensitive photomultiplier tube (PMT) or a similar device. The PMT converts the photons into electrical signals that can be amplified and counted.

Beta-ionisation

The beta-ionisation method determines the isotopic abundance of ^{14}C indirectly. ^{14}C emits beta-particles when it decays, these particles are detected and measured. This measured activity of the sample is calculated relative to the measured activity of a reference material with standardised ^{14}C amount. It is worth noting that Beta-ionisation is not a widely deployed method.

Costs

Stakeholder responses indicate the installation of a continuous flue gas sampler at the stack typically costs £30,000 to £80,000 per line. Several operators have expressed concern regarding the risk of loss of flue gas samples and therefore intend to install two samplers per line. The total operating cost associated with continuous flue gas sampling is expected to be approximately £10,000 to £20,000 per year, with the analysis of each sample approximately costing between £400 and £650.

Monitoring Burden and Requirement

The burden and requirements of C14 depends on the sampling approach taken. If feedstock sampling and analysis is adopted, a suitability large space onsite is required where a representative sample can be safely collected. There are significant challenges in collecting and managing a representative sample of physically heterogenous material such as MSW. If stack sampling is selected, then a suitable access fitment at the stack is needed to extract the sample. If there is not a readily available access fitment, it will need to be installed during planned shutdown.

There are currently a limited number of laboratories capable of performing C14 analysis. However, it was suggested in stakeholder interviews that an increase in demand for C14 analysis will drive the market to increase the number of laboratories providing this analysis. It is important to note that the lead-times and investment costs for development of new laboratory capability require market certainty and there would likely be some lag in this market change.

Waste incineration sites typically combust conventional fossil fuels during start up (natural gas, gas oil, light fuel oil), the CO_2 from which would need to be reported under the ETS. These emissions would likely be reported using a calculation-based method. Most EfW operators identified with the expectation that continuous C14 samplers would start/stop sampling in line with the CEMS (avoiding startup/shut down). Operators commented that this may help to avoid double counting of emissions from auxiliary fuel, i.e. by counting the emissions contributing to the C14 analysis as well as counting those from consumption of the fossil-based support fuel.

4.5. The Balance Method

The balance method uses a mathematical model derived from first principles which establishes a set of mass and energy balances describing the waste incineration system. Input to the model consists of real-time operational data, as well as values from literature. The most widely deployed commercial example of this method is BIOMA. A full list of model inputs and measurement methods is shown in Table 7 and Table 8. This method typically involves the use of a software package that is fed live data regarding plant operation and for emissions data is effectively a Predictive Emission Monitoring System (PEMS).

Table 7: BIOMA Variable Inputs (Source: Ramboll)

Variables	Unit	Period	Typical Method of Measurement
Waste Processed	tonnes	Annual	Plant weighing procedures
Bottom Ash Produced	tonnes		
Fly Ash Produced	tonnes		
Flue gas flow	m^3/h	Hourly	Continuous meter
CO_2 flow	m^3/h		
O_2 flow	m^3/h		
Steam production	tonnes/hr		
Steam pressure	bara		
Steam temperature	°C		
Feed water temperature	°C		
Auxiliary Energy	kWh		
Waste Processed	tonnes		
Auxiliary Fossil Fuel Use	litres/tonnes/m^3	Annual	Metering

Table 8: BIOMA Constant Parameters (Source: Ramboll)

Ref	Constants	Units	Period	Basis
A1	Boiler Efficiency	%	Once	Measuring Method
A2	Bottom ash water	%	Annual	Chemical Analysis
A3	Bottom ash metal	%	Annual	Sorting Data
	Chemical composition of biogenic and fossil matter	various	Not known	Lit review and research by software developer

Costs

Stakeholder responses indicate that the installation of the BIOMA system costs approximately £50,000 per line, with operating costs of ~£15,000 per year.

Monitoring Burden and Requirement

The adoption of the balance method requires the installation of suitable IT kit to run the BIOMA software and integration with process operational data. The results from BIOMA are dependent on the operational data, and therefore frequent calibration of meters is required. For sites already operating BIOMA under the RO, Ofgem require an audit of the system be performed annually (by Ramboll).

4.6. Suitability of Methods based on Waste Type

Not all of the MRV methods described in this section are appropriate for all waste types, a summary of the suitability of these methods is described below.

Table 9: Summary of MRV suitability

Method	Application	Waste Feedstock suitability
Manual sorting method	Pre-combustion	Not suitable for: • Biomass concentrations <5% and >95% [26]. • Recovered fuels with particle size <10mm and SRF that is pelletised [26]. • May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.
Selective dissolution method		Not suitable for: • Waste containing >10% natural and/or synthetic rubber [26]. • Sum of content of hard coal, coke, brown coal, Lignite, degradable fossil plastics, non-degradable biogenic plastic, oil/fat, wool, viscose, nylon, polyurethane, or molecular amino groups & silicon rubber >5% [26]. • Waste containing inorganic carbonates (additional precautions required) [26].

[26] ISO 21644:2021(E) – Solid recovered fuel – Methods for the determination of biomass fuel.

Method	Application	Waste Feedstock suitability
		• May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.
Radiocarbon method (pre-combustion waste sampling)		Not suitable for: • May not be suitable for hazardous waste and clinical waste, due to potential artificial ^{14}C isotopes or other radioactive material in the waste. Laboratories may not accept samples. • May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.
Radiocarbon method (Flue gas spot/continuous sampling)	Post-combustion	Not suitable for: • Wastes containing <2% biogenic CO_2 [26]. • Waste containing inorganic carbonates (additional precautions required) [27]. • Some concern was identified by stakeholders that the method may not be suitable for hazardous waste and clinical waste, due to potential artificial ^{14}C isotopes or other radioactive material in the waste and laboratories may not accept samples. This is not yet evidenced. • Processes that consume contaminated waste wood as only fuel.
Balance method	Uses pre- and post-combustion operational data	Not suitable for: • Hazardous or clinical waste (as the BIOMA system is designed for EfW that process MSW).

[27] ISO 13833:2013(E) – Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide – Radiocarbon sampling and determination.

4.7. Uncertainty

4.7.1. Overview

Quantifying uncertainty budgets presents a challenge in emissions quantification within the waste sector under the UK ETS framework. The calculation of uncertainty budgets necessitates the systematic identification, quantification, and aggregation of individual uncertainties associated with each step of the estimation process. As indicated in Section 2, the UK ETS currently requires that the annual uncertainty of the fossil carbon emissions needs to be within specified limits (in general higher emissions require lower uncertainties). It is expected that integrating energy from waste sites into the UK ETS will require a nuanced approach when assessing the uncertainty budgets of each methodology.

There is currently limited data regarding the uncertainty of these MRV methods in literature or industry. However, early indication from literature reviews and stakeholder engagement suggests that it may prove challenging for operators to meet the current UK ETS uncertainty requirements (or potentially impossible for the higher tiers). Uncertainty requirements for waste incineration may therefore need to be reviewed ahead of inclusion of the sector in the UK ETS, or an alternative approach to requirements should be explored that does not necessitate uncertainty ranges to be established.

4.7.2. Calculating Uncertainty Budgets

Uncertainty budgets are calculated by systematically identifying, quantifying, and then aggregating the individual uncertainties associated with each process step. The component uncertainties are combined using established statistical methods resulting in a comprehensive uncertainty budget for each MRV method. Generally, the following steps should be followed to accurately determine an uncertainty budget:

I. Specify what is being measured and the parameters on which it depends.

II. Identify possible sources of uncertainty for each parameter.

III. Quantify the component standard uncertainties.

IV. Determine the per-sample uncertainty of the measured value at a confidence level of 95%.

V. Determine the annual reported uncertainty of the measured value at a confidence level of 95%.

Statistically combining uncertainties involves using mathematical tools to blend the various sources of uncertainty identified within an assessment. Typically, a combined uncertainty is calculated that accounts for the relationships and dependencies between individual sources of uncertainty. The result is an uncertainty budget that encapsulates the overall uncertainty of the emissions estimation, providing decision-makers with an understanding of the reliability and precision of the data.

However, at the time of delivering this project, there are elements for each methodology where there is limited information on uncertainties, making it difficult to compare uncertainty with UK ETS Tier requirements and between estimation approaches. Some component uncertainties which are difficult to quantify are present across all methodologies (e.g. sampling), or unique to each method (e.g. subjective categorisation which is present only in the manual sorting method).

4.7.3. Cross-Method Sources of Uncertainty

Among the various methods employed for emissions quantification, certain component uncertainties are shared. Notably, sampling uncertainties, which relate to the collection of representative waste samples, encompassing factors such as seasonal variability. Effectively managing and quantifying these shared uncertainties will help to ensure robust emissions calculations.

Sampling Uncertainty

Both pre-combustion and post-combustion sampling methods have their own unique sources of uncertainty and should be undertaken using recognised sampling methods using the hierarchy of EN, ISO and national standards, as outlined in Appendix A5 Protocol for Comparing Methodologies.

Pre-combustion sampling typically encounters uncertainties due to the heterogeneous nature of waste. This type of sampling generally provides periodic samples and these need to be collected to provide coverage of the annual throughput. Periodic sampling of waste relies on relatively small samples when compared to the total waste feedstock, with a risk of underrepresenting waste diversity and not providing a complete understanding of the fossil CO_2 liability. For example, the selective dissolution method mills the waste feedstock prior to sampling and can require only a few grams[28,29] of ground waste from a waste bunker which can approach 100 tonnes. More heterogeneous waste (i.e. MSW) may require a larger sample with more extensive milling and other sample preparation to obtain an adequately representative analytical sample. Feedstock sampling can introduce selective sorting errors, impacting accuracy by favouring or excluding specific waste components. Similarly, waste can comprise a wide range of material with very diverse sizes which requires care to ensure sufficient total sample size and appropriate reduction to representative samples. Currently, there is no international standard which outlines sampling techniques for heterogeneous waste feedstocks such as MSW. This is an issue for sites where waste is diverse in nature and size, as they will need to follow a sampling methodology which ensures samples are adequately representative. These sampling uncertainties are critical considerations in the overall emissions uncertainty budget and are not yet quantified.

Post-combustion sampling methods offer an opportunity for capturing the heterogeneous nature of waste more comprehensively. A key benefit of emission sampling is that it is post combustion and the exhaust is gaseous with a relatively homogeneous composition (mainly CO_2, O_2, N_2 and moisture with relatively minor concentrations of other materials). A robust sampling plan is needed to achieve representative samples for analysis but, there are existing sampling and analysis standards, some of which have been applied at EfW plants for many years, and these can help to manage sampling and analysis uncertainties. Among these methods, two notable approaches are periodic 'grab' sampling and continuous

[28]M. Séverin, C. Velis, P. Longhurst, S. Pollard, 2010, *The biogenic content of process streams from mechanical-biological treatment plants producing solid recovered fuel,* Waste Management 30(7), 12.

[29] J. Mohn, S. et al., 2008. *Determination of biogenic and fossil CO2 emitted by waste incineration based on 14CO2 and mass balances.*

sampling. As ’grab’ sampling is a periodic measurement, it carries the risk of not fully capturing variations in waste composition over prolonged periods. In contrast, continuous sampling can store between 1 day to 1 month of flue gas and is often designed to be flow proportional, offering a more robust means of sampling emissions over time and providing a more accurate representation of the waste stream's heterogeneity. A flow proportional continuous sampling system supplier quoted uncertainty of between ±1-2% based on experience of 2 plants, however no confidence interval (CI) has been specified.

Attention to sampling protocols, particularly pre-combustion sampling, is required to ascertain and compare the overall uncertainty budgets of the MRV methods. At this stage, there is limited data on uncertainty for different sampling methods, which creates difficulties when comparing the overall uncertainty budgets of the MRV methods.

Annual Reported Uncertainty

Calculating the annual uncertainty of reported fossil carbon emissions involves accounting for both the per-sample uncertainty and annual uncertainty (sampling period & frequency, and waste seasonality). To accurately reflect the latter, multiple samples throughout the year are required as a single sample cannot reliably reflect CO_2 emissions over an entire year.
Periodic sampling such as pre-combustion feedstock sampling and post-combustion grab sampling from the flue stack provide valuable insights, but only capture snapshots of CO_2 emissions across the year. Also, the composition of waste feedstock may have irregular fluctuations due to an event affecting the producers of waste. If a sample is taken during this time, the calculated fossil carbon content will be irregular. To partially mitigate these risks, a more accurate method involves utilising continuous sampling procedures. This provides a more dynamic understanding of fossil carbon emissions throughout the year.

The necessary sampling period & frequency will vary based on the size of the emitter. Annual reported uncertainty calculations will be influenced by waste feedstock statistics (representing the heterogeneity of the waste and seasonal variability) and the uncertainty per sample.

4.7.4. Manual Sorting Method Uncertainty

The manual sorting method introduces several sources of error and uncertainty, making it challenging to quantify and aggregate into a net uncertainty value. These uncertainties arise from various factors inherent to the method in addition to sampling uncertainties, which include:

- *Human Error*: The manual nature of the process introduces the potential for human error in both sample collection and waste categorisation. Training and operator subjectivity can significantly impact the accuracy of the results.
- *Mixed Materials*: Mixed materials such as those containing both biomass and non-biomass components pose a challenge for manual separation. These particles cannot always be effectively distinguished during the sorting process.
- *Particle Size Limitations*: Manual separation becomes impractical for particles below a certain size, typically less than 10mm, which are classified as fines and removed from the analysis. This can lead to discrepancies in waste categorisation.
- *Mimicking Materials*: Certain materials may mimic the physical appearance or properties of other categories, leading to misclassification. For example, biodegradable plastics can be mistaken for conventional plastics.
- *Composite Materials*: As waste is separated into several fractions (wood, glass, plastics), handling of composite materials often found in mixed waste streams like MSW or SRF may yield uncertain values. Due to this systematic limitation, composite components may be disregarded [30].

[30] J. Mohn, S. Szidat, J. Fellner, H. Rechberger, R. Quartier, B. Buchmann, L Emmenegger, 2008. *Determination of biogenic and fossil CO2 emitted by waste incineration based on 14CO2 and mass balances.*

4.7.5. Selective Dissolution Method Uncertainty

The liquid dissolution method involves immersing a representative waste feedstock sample in an acidic solution to selectively dissolve biogenic material, leaving fossil derived carbon for analysis. There are several factors impacting the uncertainty of results:

- *Dissolving Fossil Derived Material*: Materials such as coal or polyurethane plastics may dissolve, overstating the quantity of biogenic material and understating the quantity of fossil material present.
- *Biogenic Derived Material Not Dissolving*: Materials such as charcoal may not dissolve.
- *Biodegradable Components*: Some waste feedstocks (i.e. SRFs) have biodegradable components that are not biomass, e.g. nylon, or when biomass materials are present that are not fully biodegradable [31].
- *Chemical Analysis, Measurement Equipment and Calibration*: Errors can arise during the chemical analysis of the dissolved carbon, affecting the accuracy of the results. Analytical techniques may have their own associated uncertainties. The precision and accuracy of measurement equipment used during the process can introduce uncertainty.
- *Data Handling and Recording*: Errors in recording and handling data, as well as potential data transcription errors, can affect the reliability of results.

Testing houses will be required to provide an aggregated uncertainty of all testing and analysis. A testing house has provided an uncertainty of ±7% for this method, however the component uncertainties included in this overall figure are not clear. They also note that this is calculated from a relatively homogenous waste feedstock and therefore may not be representative of MSW or other more heterogeneous feedstocks.

[31] Beta Analytic, 2023. *Carbon-14 Analysis vs. Selective Dissolution Method,* Accessed: 20.09.2023.

4.7.6. Radiocarbon Method Uncertainty

The AMS, LSC and Beta-ionisation methods can all be simplified into three separate process steps with their own unique aggregate uncertainties, as outlined below.

1. *Representative Sampling:* Either pre-combustion waste feedstock or post combustion grab or continuous flue stack sampling.

2. *C14 Analysis:* Utilising AMS, LSC or Beta-ionisation methods to derive biogenic to fossil carbon emissions within the sample.

3. *Calculation:* Calculation of total fossil derived carbon emissions over the reporting period.

The determination of fossil carbon within a sample is often performed by technical service providers who are able to quote the given uncertainty for analysis. Testing houses perform C14 analysis by (I) completing chemical analysis to determine the presence of the isotope ^{14}C, (II) use a radiocarbon factor to calculate the biogenic content in the sample and (III) calculate the biogenic to fossil derived carbon emissions in the sample. All living biological material has a constant amount of radiocarbon per unit weight of total carbon, formed by cosmic radiation bombarding nitrogen molecules. Therefore, uncertainty values relating to C14 analysis will encompass the chemical analysis, ^{14}C carbon factors and uncertainty correlating to the biogenic-fossil carbon calculation.

In assessing uncertainties for C14 analysis methods, testing houses and literature report varying levels of uncertainty. AMS analysis has been quoted as ±3% by a test house with no CI specified, while literature sources suggest uncertainties can range from ±1-7%[32] (for solid refuse-derived fuels). For LSC, a test house has specified an uncertainty of ±2.8%,

[32] T. Schwarzböck, P. Aschenbrenner, S. Spacek, S. Szidat, H. Rechberger, J. Fellner, 2008. *An alternative method to determine the share of fossil carbon in solid refuse-derived fuels – Validation and comparison with three standardized methods*, Fuel, 220, 916-930.

with literature reporting ranges from ±7-10%[33] and 12.1%[34] at 95% CI for MSW and SRF fuels respectively. Notably, test houses may omit certain uncertainties which they consider out of their scope, underscoring the importance of identifying and accounting for these components in overall uncertainty calculations. For example, the LSC test house uncertainty of ±2.8% does not include uncertainties correlating to total CO_2 concentration or exhaust gas flow (derived from continuous monitoring systems on the plant). Furthermore, literature-based assessments may have less representative uncertainties relating to CEMS data and sampling procedures as they are site specific. In general, the methods covered in ISO 13833 Annex D have an average uncertainty of 5% for waste samples with 10-100% biogenic content.

The total hourly fossil CO_2 emissions is calculated from the biogenic fraction and use of CEMS for flue gas CO_2 concentration and flow rate.

The Environment Agency specifies the maximum allowable uncertainty of CEMS of flue gas flow rate and total CO_2 concentration as ±10%[35]. The uncertainties of each for this calculation can be combined using the usual Root Sum of Squares approach (RSS). For example, combining the flow CEMS and total CO_2 concentration CEMS maximum uncertainties of ±10% and the average uncertainty of ±5% for radiocarbon methods from ISO 13833, using the RSS approach would calculate an uncertainty of $Ua = \sqrt{10^2 + 10^2 + 5^2} = \pm 15\%$. This example does not consider all of the uncertainties associated with sampling or include 'real world' uncertainty measurements for flow, total CO_2 concentration or biogenic (fossil) fraction, however it is helpful in showing that while the radiocarbon method is widely accepted as one of the more accurate measurement methodologies, it will be a challenge for sites to meet the existing ETS uncertainty tiers for

[33] A. Larsen, K. Fuglsang, N. Pedersen, J. Fellner, H. Rechberger, T. Astrup, 2013, *Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty*, Waste Management & Research, 31(10), 56–66.

[34] G. Muir, S. Hayward, B. Tripney, G. Cook, P. Naysmith, B. Herbert, M. Garnett, M. Wilkinson, 2014. *Determining the biomass fraction of mixed waste fuels: A comparison of existing industry and ^{14}C-based methodologies*, Waste Management, 35, 293-300.

[35] Environment Agency, 2021. *Technical Guidance Note M20 (Monitoring). Quality assurance of continuous emissions monitoring systems – application of EN 14181.*

measurement-based methodologies outlined in section 2.3. Lower uncertainty values can be achieved with ideal equipment and analysis (for example optimising sampling location and measurement equipment for total CO_2 and flow measurements), however according to stakeholder feedback, the uncertainty of flow measurement is likely to be a key constraint in achieving lower overall uncertainty ranges. This can be accounted for by taking a nuanced uncertainty tier approach when including EfW sites in the UK ETS.

The presence of ^{14}C in the atmosphere may have some impact on C14 analysis in the future. A paper published in Proceedings of the National Academy of Sciences (PNAS) in 2015 stated that burning fossil fuels is potentially diluting levels of ^{14}C in the atmosphere and may make it impossible to carry out radiocarbon dating in future[36]. This has been described as the 'Suess' effect[37] [38]. A similar effect has also been described as a result of nuclear testing following World War II, which "caused the ^{14}C concentration in the atmosphere to almost double"[37] [38]. This effect is called the 'bomb peak'. The radiocarbon method addresses current atmospheric ^{14}C levels by utilising a reference ^{14}C value within the methodology. Nevertheless, fluctuations in atmospheric levels may necessitate yearly adjustments to the reference carbon values to ensure accurate ^{14}C normalisation. While this factor may need to be adjusted over time, this is not considered a significant issue when assessing the suitability of C14 analysis methodologies.

[36] Graven, 2015. *Impact of fossil fuel emissions on atmospheric radiocarbon and various applications of radiocarbon over this century*, PNAS, 112 (31) 9542-9545.

[37] Reinhardt, T., Richers, U., & Suchomel, H, 2008. *Hazardous waste incineration in context with carbon dioxide. Waste management & research*, 26(1), 88-95.

[38] Stuiver, M. & Quay, P. D, 1981. *Atmospheric 14C changes resulting from fossil fuel CO2 release and cosmic ray flux variability*. Earth and Planetary Science Letters, 53, 349–362.

In addition to the uncertainty sources described, there are additional areas with potential for bias:

- *Sample losses:* during sampling (system leakage and non-recovered sample from test equipment), transit (sample degradation) and extraction of ^{14}C from sample pre-analysis.

- *Saturation of absorption media:* during prolonged sampling periods (which leads to the under reporting of ^{14}C).

- *Absorption of ambient* CO_2*:* Absorption into samples if incorrectly handled in laboratory (over reporting of ^{14}C).

4.7.7. Balance Method Uncertainty

The uncertainty of the balance method is a combination of systematic and random errors which affect model inputs. While random errors cause one measurement to differ from the next and will be more prevalent in steps such as plant weighing procedures, systematic errors will affect continuous measurements due to the incorrect installation, commissioning, or maintenance of instrumentation.

Systematic uncertainty of emission data used by the model can be reduced by following quality assurance measures as outlined in BS EN 14181 – Quality Assurance of Automated Testing Systems measuring emissions to air. This standard is referenced within the balance method's overarching standard, ISO 18466, and is a European standard that covers approval, calibration, testing and performance of continuous emission monitoring systems (CEMS).

Three different quality assurance levels (QAL1, QAL2, and QAL3) are defined:

- **QAL 1** – Suitability of a CEMs for measuring task (before or during the purchase period of the CEMs).
- **QAL 2** - Validation of the CEMs following its installation.
- **QAL 3** – Control of the CEMs during its ongoing operation on an industrial plant.
- An annual surveillance test (AST) is also defined.

Sensitivity analysis' show that the most sensitive parameters in the balance method are the flue gas CO_2 and O_2 concentrations and assumptions for the chemical composition of biogenic and fossil matter[39]. Therefore, efforts to minimize uncertainties in the balance method should prioritize obtaining precise data for O_2 and CO_2 levels in dry flue gas and regular monitoring of biogenic and fossil matter composition. This is supported in ISO 18466 (determination of the biogenic fraction using balance method), which outlines that systematic uncertainty may be neglected if QAL2 calibrations are performed for (as a minimum) O_2 and CO_2. Literature sources define the uncertainty band of the balance method as ±6-10% with a 95% CI [40], however the technical supplier has noted that the calculated uncertainty will fluctuate depending on operator inputs of various factors, measurements and verification stages.

There are several other overarching factors which impact the uncertainty of the balance method:

- Potential for procedural bias; some measurements will be based on industry best practice or site-specific procedures (for example bottom ash or fly ash annual tonnage).

- Any fluctuation or inaccuracy with the indicator data impacting calculated results may be difficult to identify. This risk is reduced by third-party validation, system flags if

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[39] A. Larsen, K. Fuglsang, N. Pedersen, J. Fellner, H. Rechberger, T. Astrup, 2013, *Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty*, Waste Management & Research, 31(10), 56–66.

[40] A. Larsen, K. Fuglsang, N. Pedersen, J. Fellner, H. Rechberger, T. Astrup, 2013, *Biogenic carbon in combustible waste: Waste composition, variability and measurement uncertainty*, Waste Management & Research, 31(10), 56–66

there is high variability of results year on year and following QAL2 and QAL3 procedures.

- The proprietary nature of balance method software means that the calculations are not transparent and therefore tracing the calculations to relevant standards could be difficult.
- In any model-based approach, there is the potential for data manipulation. There is potential for bias when inputting reference data, constants, or facility specific inputs. For example, operators will input boiler efficiency value which is often based on plant commissioning data. The software can include checks to determine if a value inputted by an operator is outside the expected range, but third-party validation can also be effective in reducing this risk.

5. Stakeholder Responses

The incorporation of EfW and waste incineration into the UK ETS imposes a significant carbon cost on these facilities, marking a significant policy development in the waste sector. Questionnaires were sent to stakeholders, both inside and outside of the UK, with follow-up interviews organised to discuss some responses in greater detail.

Table 10 presents the key findings from the engagement with stakeholders.

Table 10: Key stakeholder responses according to sub-topics[41]

MRV method(s)	**Operators:** Operator responses show a clear preference for C14. Manual sorting and selective dissolution are less favoured as they tend to be labour intensive and are perceived as being less accurate. Several sites are using BIOMA and state that the calibration requirements needed to operate the system accurately are a burden. None of the operators spoken to intend to use BIOMA for the UK ETS. Some operators expressed a preference for continuing with some form of feedstock sorting method to assess waste from customers. **Trade Associations:** Several operators have abandoned BIOMA. BIOMA is very sensitive to the inputs and this could lead to imprecise measurements when compared to the C14. **European counterparts:** Only the balance (BIOMA) and radiocarbon methods are permitted by the Danish Energy regulator. Frequency of sampling required is every 2 weeks for large plants, monthly for smaller plants. Operators must derive monthly averages and then aggregate to annual data. Radiocarbon is preferred over BIOMA by the Danish Regulator.
MRV costs	**Operators:** The cost of C14 installation and operation is seen as minor compared to UK ETS cost burden. All EfW operators who are able to pass the UK ETS cost onto their customers through Qualifying Change in Law provisions in contracts, intend to do so. There is concern within the sector regarding how the ETS cost will be split between customers.

[41] The information outlined in this table was provided to Ricardo by stakeholders.

	Trade Associations: Spot sampling at a high frequency can become expensive. **Policy Makers**: Concern that in the absence of a way to apportion costs there could be impacts on recycling. May be higher impacts for rural/remote regions with less choice in waste recovery. Some concerns about carbon leakage. **Regulators**: If operators need to apply for a permit, the admin cost to the regulator will be passed onto the site. Funding may be required to complete data collection tasks including drafting guidance and developing standards.
MRV uncertainty	**Operators:** Widespread concern within the sector that the existing uncertainty tiers under the UK ETS may be challenging or impossible to achieve for the waste sector. Operators are keen to install the most accurate method possible given large financial burden of the ETS. Concerns that sampling equipment (CEMS) may need upgrading to meet any uncertainty requirements. **Trade Associations**: The uncertainty associated with feedstock waste sampling is significant and therefore memberships do not support its use for determining total at the stack CO_2 emissions or emissions split. The UK ETS has very stringent uncertainty levels for currently covered sectors, which trade associations believe would be impossible for the EfW sector to meet. More flexibility should be given for different sized plants and more uncertainty levels should be defined.
Monitoring burden	**Trade Associations:** Some Trade Associations are working towards developing an evidence base to generate emissions factors / waste type characterisations of waste that is reflective of the sector. Industry guidance is required on how a sampling regime should be conducted to ensure alignment across the sector. There is a small number of

	suppliers which limits the ease of accessing the technology at pace for all EfW facilities. It is still unclear what the minimum level/frequency of measuring should be, it is dependent on plant size/type and waste composition. **Policy Makers:** Some concern with number of available laboratories.
Method Requirements	**Trade Associations:** To reduce complexity in compliance, any new UK ETS regulations should look to align with existing standards / requirements on EfW and waste incineration facilities as far as possible. **Policy Makers:** Importance of standardised guidance was stressed.
Other Concerns	**Operators:** Several sites expressed concern over the possibility and consequences of losing flue gas samples (for C14 analysis) and limited space at the stack to install further sampling devices. Interest in continuous samplers which would start/stop sampling in line with the CEMS (avoiding startup/shut down). Some operators fear long wait times for results due to limited C14 lab availability. **Policy Makers:** Important to ensure that ETS and CCS incentive requirements are aligned. **Trade Associations**: Determining a methodology for understanding the carbon liability for individual waste producers. In the early implementation stages, a more straightforward waste categorisation approach should be applied to the sector.

6. Conclusions and Recommendations

This section presents the study conclusions, highlighting where data is missing or limited, with recommendations of future work for the Department for Energy Security & Net Zero.

6.1. Conclusions

MRV Methods for EfW

- EfW operators are already using a range of MRV methods (manual sorting, selective dissolution, BIOMA, C14), and there are 8 EfW sites under the RO reporting the biogenic-fossil split of their waste.

- EfW operators find feedstock sampling & analysis to be labour intensive and more uncertain than C14 and BIOMA.

- Several sites are using BIOMA. There is however a perception that this method is a "black box", with a lack of understanding of how the outputs are calculated. Operators indicated that they would prefer something more clearly empirical and defendable. None of the operators spoken to intend to use BIOMA for the UK ETS.

- From the engagement with EfW operators and trade associations, it is apparent that continuous flue gas sampling C14 analysis is the preferred MRV method for EfW sites. Operators believe this offers them the most defendable and least uncertain measurement of biogenic-fossil split.

- Under the Waste ICC BM, the only permitted method for assessing the biogenic-fossil split of CO_2 emissions will be C14 analysis. This must take the form of a monthly composite sample, collected using a long-term sampling system (LTSS).

MRV Methods for Hazardous and Clinical

- With regard to hazardous and clinical waste incineration sites, manual sorting methods are unlikely to be appropriate due to the safety concerns of waste handling. BIOMA is not appropriate for these sites because it was designed for EfW systems. Finally, C14 is unlikely to be appropriate for all sites due to the radioactive material present in the waste. A calculation-based method for reporting is therefore likely to be the most appropriate method for hazardous and clinical waste incineration sites.

- Data from the Department for Energy Security & Net Zero indicates that all clinical facilities and a number of the hazardous facilities fall below the proposed UK ETS inclusion threshold of 25,000 fossil tCO_2 for HSE, whilst several clinical sites will also fall below the 2,500 fossil tCO_2 inclusion threshold for USE. Therefore, some of the technologies mentioned in this report would not be applicable to those sites; it is recommended that simplified monitoring methods be permitted for HSE and USE.

Uncertainty

- The need to quantify uncertainty budgets presents a major challenge for the waste sector. This task is essential for accurate emissions reporting, yet no single method currently offers a comprehensive aggregate uncertainty value (in literature or industry). Due to the significant challenges in determining the uncertainty budgets of the available MRV approaches, it is recommended that other options to uncertainty ranges should be considered e.g. requirements for the determination of biomass fraction.

- The current UK ETS MRR guidelines defines the level of uncertainty a site must be able to demonstrate. Whilst there is currently insufficient data regarding the uncertainty of these MRV methods, there is widespread concern within the waste sector that the uncertainties of exhaust flow measurement, total CO_2 concentration and fossil fraction are likely to be higher than permitted under current UK ETS tiers.

- The uncertainties or permitted tiers under the UK ETS may require moderation for waste incineration, or an alternative approach to tiers requiring for uncertainty budgets to be evidenced should be considered.

Cost

- EfW operators typically intend to pass the carbon cost from the ETS onto customers. However, there is great uncertainty regarding how the ETS cost can be accurately disaggregated between customers in a safe and practical manner (because this would require understanding of waste composition).

- Whilst the cost data captured regarding MRV installation and operation was patchy, EfW operators are typically not concerned about the costs associated with the installation and operation of MRV. They view this as a minor cost when compared to the magnitude of the ETS cost. Some operators also expressed an interest in passing installation and maintenance costs onto customers too. It is worthing noting that the larger operators seem to be more proactive in installing and trialling MRV methods.

Burden and Requirements

- From the engagement with EfW operators and trade associations, it is understood that the adoption of a MRV method by 2026 is not a concern to operators. In fact, many of the larger operators are already trialling C14 with intent to roll out.

- Several EfW sites expressed an interest in continuous C14 samplers which would start/stop sampling in line with the CEMS (avoiding startup/shut down). This may prevent double counting of emissions from auxiliary fuel.

- Several EfW operators noted that they were considering installing two continuous flue gas samplers per line as back-up in case one sample is lost.

- Several operators raised concern regarding the limited space at the stack to install further sampling devices. Furthermore, some operators expect that their flue gas sampling equipment (CEMS) would need upgrading to meet overall uncertainty requirements.

- The monitoring requirements for the Waste ICC BM and the extension of ETS to waste incineration are being developed in parallel by the UK ETS Authority and the Department of Energy Security & Net Zero and any opportunities for consistency in approach could reduce operator burden. Conversely, the RO is managed by Ofgem and is now closed to new applicants, we therefore recommend that the reporting mechanisms under the RO are not modified.

- The current MRR guidelines dictate the frequency of sampling that must be performed for waste streams under the UK ETS. Should a site opt for a periodic sampling method (manual sorting/selective dissolution), the current required sampling frequency is likely too high for EfW sites on the grounds it will be practically unfeasible and expensive. Furthermore, sampling of the hazardous and clinical waste is typically limited or completely avoided for health and safety reasons. The sampling frequency under the ETS may therefore need modifying to account for the magnitude and nature of waste throughput.

Other

- Whilst the purpose of this report was to assess the measurement-based MRV methods available to waste incineration sites, it has highlighted the limited availability of fossil CO_2 emission factor data that could be used for a calculation-based reporting approach (work would be needed to develop UK-specific emission factors).

- One concern that was raised in several interviews with operators and other stakeholders is that - at least in the short-term - the limited laboratory capacity available in the UK and EU to perform C14 analysis of stack samples is likely a limiting factor in the ability of the sector to rapidly adopt C14 analysis. Current expertise and capacity appears to be limited to a handful of laboratories, e.g. the only accredited labs are located in the USA and Denmark.

6.2. Recommendations

Recommendations for the Department for Energy Security & Net Zero

- A limited number of responses were received from hazardous sites and zero from clinical. This is concerning because it is likely that the MRV methods described throughout this report won't be appropriate for all hazardous and clinical sites. The Department for Energy Security & Net Zero should therefore seek to engage with these sectors further to understand where measurement-based reporting is appropriate, and what steps need to be taken to facilitate calculation-based reporting. The latter will likely include the development of a robust and comprehensive set of emission factors for hazardous and clinical waste streams. Data from the Department for Energy Security & Net Zero, which employs an estimated biogenic fraction of clinical and hazardous waste, indicates that all clinical facilities and a number of the hazardous facilities fall below the proposed UK ETS inclusion thresholds of 25,000 fossil tCO_2 for Hospital and Small Emitters (HSE) whilst several clinical sites will also fall below the 2,500 fossil tCO_2 threshold for Ultra Small Emitters (USE). Therefore, some of the technologies mentioned in this report would not be applicable to those sites.

- This study has revealed that there is limited information regarding the uncertainty of these MRV methods available in literature or industry. However, early indication from literature reviews and stakeholder engagement suggests that it may prove challenging for operators to meet the current UK ETS uncertainty requirements (or potentially impossible for the higher tiers). Lower uncertainty values may be achieved with ideal equipment and analysis (for example optimising sampling location and measurement equipment for total CO_2 and flow measurements), however the uncertainty of flow measurement is likely to be a key constraint in achieving lower overall uncertainty ranges. The Department for Energy Security & Net Zero should work with industry over the coming years to gather data regarding the uncertainty of the MRV methods described. This should then feed into a review of the uncertainties required under the UK ETS for waste incineration. It is also recommended that options other than uncertainty ranges are explored, such as tiers for determination of biomass fractions. The Department for Energy Security & Net Zero should seek to obtain the data that Ofgem were unable to provide Ricardo regarding EfW under the RO as this may provide a useful starting point.

- The biggest concern regarding integration of waste incineration into ETS expressed by the operators is the disaggregation of ETS cost between customers. The Department for Energy Security & Net Zero should work with key stakeholders ahead of the 2026 starting point to develop practical and safe methodologies that will allow sites to allocate fairly ETS costs to waste producers.

- The Department for Energy Security & Net Zero should work with stakeholders to develop a robust and comprehensive set of emission factors for waste streams into waste incineration and EfW sites. This will aid the accurate adoption of calculation-based approaches, which will likely be important for small emitters (from whom Ricardo received fewer responses).
- The Department for Energy Security & Net Zero should review the frequency of waste sampling required under the UK ETS to ensure that it is not impracticable or financially unviable.
- The Department for Energy Security & Net Zero may wish to review, and where appropriate, align biogenic-fossil CO_2 reporting under the UK ETS and the Waste ICC BM. This could help to streamline and simplify reporting for EfW sites under this business model.
- The Waste ICC BM and the extension of the UK ETS to waste incineration are being developed in parallel by The Department for Energy Security & Net Zero and any opportunities for consistency in approach could reduce operator burden.

APPENDICES

Appendix A – Elaboration of Field Test Protocol

Appendix B – Further Information regarding the UK ETS

Appendix A – Elaboration of Field Test Protocol

A1. Introduction

The Department for Energy Security and Net Zero (DESNZ) is seeking to improve the evidence base to help inform options for establishing a suitably accurate, rigorous and proportionate to emitter size Monitoring, Reporting and Verification (MRV) system for the potential inclusion of Energy from Waste (EfW), waste incineration with no energy recovery facilities, and waste-to-fuel facilities that process part-fossil, part-biogenic materials, into the UK Emissions Trading Scheme (UK ETS) from 2026 onwards, with an MRV only period running for 2 years ahead of full inclusion from 2028. As part of this work a need for a test protocol to compare MRV methodologies was identified.

There are several challenges around comparing methodologies to provide an annual biogenic or fossil carbon dioxide emission. Variations between methodologies in reported biogenic or fossil CO_2 emissions can arise from a variety of sources.

Variation in source waste over time:

- Process variability
- Sampling uncertainty
- Analytical uncertainty
- Model uncertainty
- Total carbon measurement/methodology

Some variations may be common to all methodologies and some to selected methodologies and subject to other contributing factors.

Consequently, it is likely that one approach may not fit all applications and some consideration to the selection of an approach will be required. To prove and assess methods an extensive test programme against the range of possible waste composition, types of technology and range of operation and emission composition on an EfW plant would be needed. A test protocol could then be developed to compare each methodology on a common basis (emission of fossil carbon per tonne of waste input or other metric). Typically, the outputs from each methodology would be assessed over the same period and would be compared through repeat tests and statistical functions used to assess variation of individual methods and between methods.

A more practical focus for a short-term evaluation of methodologies would be on a single EfW facility where one methodology is already in use and where alternative methods could be put into operation enabling a direct comparison over a longer period.

Hazardous and clinical waste sites are not considered, as further evidence is needed to establish what methods would be applicable for these facilities.

This section describes the necessary considerations for a test protocol to assess methodologies for determining biogenic CO_2 emissions (and hence fossil CO_2 emissions) from an energy from waste (EFW) source. These include fundamental criteria that are described in:

- Emissions measurement standards such as measurement location, selection of equipment, selection of appropriate methods, quality assurance and quality control and determining measurement uncertainty, and
- Fuel/waste analysis methods

A2. Summary of Approaches to Assess Biogenic and Non-biogenic CO_2 Emissions

A2.1. Measurement Approaches

As mentioned in the main report there are generally two approaches:

- Individual plant monitoring – where each operator is given the responsibility of determining the fossil and biogenic CO_2 emitted by the site.
- Emissions factor approach – which requires making assumptions regarding the composition of the waste to formulate an appropriate emission factor.

The emissions factor approach is a simpler method for calculating the emissions from the incineration of fossil material and still ensures that there would be a price on the associated carbon costs of those emissions. However, as the waste processed by incinerators and EfW plants is highly heterogeneous, the composition varies significantly within the plant and between plants across the UK. Whilst regional or national emission factors can be developed, they cannot fully account for the heterogeneity of waste being incinerated by different plants, but may be an appropriate approach for plants with lower emissions.

Individual plant monitoring is therefore a more accurate approach. Several MRV techniques exist for analysing the onsite composition of waste. The most widely used methods are as follows:

- The manual sorting method
- The selective dissolution method
- The ^{14}C method
- The balance method

All these methods (including application of national or regional emission factors) typically require combination with flue gas total CO_2 concentration and flue gas flowrate to determine annual fossil/biogenic CO_2 emission.

The international standards providing guidance to industry for measurement of biogenic and fossil derived carbon emissions are outlined in Section A3.2.

The detailed information which describes the MRV methods, and the factors which need to be considered when selecting an appropriate MRV method are included in the main report. Key features of the methods are given in the following Table A1.

Table A1: Summary of MRV Methods

Method	Application		Frequency	Waste Feedstock Availability
Manual sorting method *(pre-combustion)*	Sorting of samples collected from incoming waste deliveries or the waste bunker		Periodic	Not suitable for: • Biomass concentrations <5% and >95%[42]. • Recovered fuels with particle size <10mm and SRF that is pelletised[42]. • May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.
Selective dissolution method *(pre-combustion)*	Comparing the quantity of carbon in the initial sample gathered onsite and post dissolution		Periodic	Not suitable for: • Waste containing >10% natural and/or synthetic rubber[42]. • Sum of content of hard coal, coke, brown coal, Lignite, degradable fossil plastics, non-degradable biogenic plastic, oil/fat, wool, viscose, nylon, polyurethane, or molecular amino groups & silicon rubber >5%[42]. • Waste containing inorganic carbonates (additional precautions required)[42]. • May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.
^{14}C method	**Feedstock sampling and analysis** *(pre-combustion)*	Collection of a representative waste sample onsite and performing ^{14}C analysis	Periodic	Not suitable for: • May not be suitable for hazardous waste and clinical waste, due to potential ^{14}C or other radioactive material in the waste. Laboratories may not accept samples. • May not be suitable for hazardous and clinical waste where physical sampling of the waste is limited or completely avoided for health and safety reasons.

[42] ISO 21644:2021(E) – Solid recovered fuel – Methods for the determination of biomass fuel

Method	Application		Frequency	Waste Feedstock Availability
	Flue gas grab sampling *(post-combustion)*	Collection of flue-gas sample from the stack and performing ^{14}C analysis	Periodic	Not suitable for: • Wastes containing <2% biogenic CO_2[42]. • Waste containing inorganic carbonates (additional precautions required) [43] • A small number of stakeholders indicated concern that ^{14}C methods may not be suitable for hazardous waste and clinical waste, due to potential ^{14}C or other radioactive material in the waste. At least one radiocarbon laboratory indicated that they do not accept samples from clinical and hazardous waste sources. • Processes that incinerate contaminated waste wood.
	Continuous flue gas sampling (using continuous sampler). Analysis of integrated (long-term) sample. *(post-combustion)*	Collection of the CO_2 present in the stack gas via absorption in alkaline media or integrated gas sample over an extended period of operation (typically one month) and performing ^{14}C analysis	Continuous	
Balance method *(Uses pre- and post-combustion operational data)*	Running the BIOMA software using a mathematical model based on a set of mass and energy balances and integration with process operational data		Continuous	Not suitable for: • Hazardous or clinical waste (as the BIOMA system is designed for EfW facilities that process municipal solid waste (MSW)). Note that, at the time of writing, BIOMA is the only commercially available balance method. Potentially the balance method could be applied to other types of process and feedstock with appropriate process data.

[43] ISO 13833:2013(E) – Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide – Radiocarbon sampling and determination.

A3. Assessment Protocol Considerations

The methods used will have an associated uncertainty and must meet the requirements for MRV. However, there are several factors that impact/influence the application of any method. The nature of the EfW process means that there is significant variability in the processed waste, combustion control and subsequent emissions.

The aim of the protocol is to:

- Assess the suitability of a methodology for MRV for ETS
- Enable consistent comparison of methodologies

However, the methodologies can include significant differences (for example pre-combustion and post-combustion analysis, and significant differences in sampling strategy – periodic or continuous integrated sampling). The aim is to produce principles that can be applied to a comparison protocol of any pair of methodologies but with consideration of, for example, differing analytes and sampling duration.

A3.1. ETS Requirements

The UK Emissions Trading Scheme (ETS) is established through The Greenhouse Gas Emissions Trading Scheme Order 2020, which provides continuity of emissions trading for UK businesses.

In the context of the UK ETS, the CO_2 generated from the combustion of biomass, biofuels, biogases or the bio-component of mixed fossil-biomaterials is considered biogenic. Generally, these biogenic CO_2 emissions are excluded from the ETS accounting mechanisms (bioliquids are only excluded if they meet sustainability criteria and DESNZ are considering requiring sustainability criteria for all biomass), whereas CO_2 emissions from fossil materials are included within the ETS accounting mechanisms.

The UK ETS has established a tiered system of MRV methods that enables regulators and operators to set a proportionate approach which reflects the level of fossil emissions, per installation and per source stream within a given installation, to ensure that the UK ETS does not confer a disproportionate cost to operators of smaller, lower-emitting sites.

The categorization of the installations under the ETS is given in the Monitoring and Reporting Regulations (MRR) and these categories define which uncertainty 'tier[44]' a site needs to achieve:

- Category A installation: annual emissions ≤ 50,000 tonnes of CO_2e
- Category B installation: 50,000 < annual emissions ≤ 500,000 tonnes of CO_2e
- Category C installation: annual emissions > 500,000 tonnes of CO_2e

[44] Tier: A set requirement used for determining activity data, calculation factors, annual emission and annual average hourly emission, and payload

MRR set out the tier definitions for calculation-based and measurement-based methodologies related to installations:

a) Calculation-based Methodology: This typically is based on the use of activity data obtained by measurement together with emission factors from laboratory analyses or default values to give a greenhouse gas emission value. However, limited robust and collated fossil CO_2 emission factor data is currently available, for calculation-based reporting for MSW, hazardous and clinical waste streams. The UK ETS provides (total) CO_2 emission factors for MSW for certain industry sectors but there are no emission factors for hazardous or clinical waste [45].

b) Measurement-based Methodology: Each operator is given the responsibility on the determination of the fossil and biogenic CO_2 emitted by the site via direct measurement. For each major emission source, a category A installation must aim to meet tier 2, whilst categories B and C must aim for tier 4 although lower Tiers can be used if operators can justify that a higher tier approach is not technically feasible or improvement would lead to unreasonably high costs. The summary of the tier requirements for measurement-based methodology is shown in Table A2.

Table A2: Summary of the Tier Requirements by Category (for the measurement-based methodology)

CO_2 emission uncertainty	Tier 1 ±10%	Tier 2 ±7.5%	Tier 3 ±5%	Tier 4 ±2.5%
Category A				
Category B				
Category C				

In the UK ETS guidance, it is stated that small emitters (those emitting less than 25,000 tCO_2e per annum and with a thermal capacity of less than $35MW_{th}$) will have to meet a maximum uncertainty of ±10% when assigned to Tier 1.

The current sampling frequency for solid wastes under the ETS is given in MRR, which is defined as "every 5,000 tonnes of waste and at least four times a year". As most EfW sites are typically designed to process more than 100 kilo-tonnes of waste per annum, this frequency of sampling would likely be challenging. During stakeholder engagement, it was suggested that this frequency of sampling would likely be practicably unfeasible and expensive for most EfW sites. The current sampling frequency for solid waste under the ETS may therefore need to be modified to account for the practical issues in sampling, storing, and sorting or preparing solid waste samples on an EfW installation.

[45] UK GOV, 2023 *Using UK greenhouse gas inventory data in UK ETS monitoring and reporting: the country-specific factor list - GOV.UK (www.gov.uk)* . *Accessed 05.10.23.*

A3.2. EN/ISO Standards for Biogenic Carbon

The MRV methods are described in this section, which could be adopted by waste incinerating sites to determine the biogenic-fossil split of CO_2 emissions.

The most widely used methods to analyse the biogenic and fossil content of waste or products of combustion are given below.

- The manual sorting method (waste analysis)
- The selective dissolution method (waste analysis)
- The ^{14}C method (waste or exhaust gas analysis)
- The balance method (waste and exhaust gas analysis)

Each method provides guidance for measurement of biogenic and fossil derived carbon emissions, which is underpinned by international standards. These standards are outlined in Table A3 and summarized in following sections.

Table A3: The MRV Methods described in the International Standards

Standard	Manual sorting method	Selective dissolution method	^{14}C Method	Balance method
ISO 21644 Solid recovered fuels – Methods for the determination of biomass content [46]	✓	✓	✓	
ISO 13833 Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-fuel derived carbon dioxide – Radiocarbon sampling and determination[47]			✓	
ASTM B6866:22 Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon analysis			✓	
ISO 18466 Stationary source emissions – Determination of the biogenic fraction in CO_2 in stack gas using the balance method				✓

[46] It is worth nothing that this standard addresses SRF as a feedstock not MSW. Throughout this work, Ricardo was unable to find an international standard which covered sampling and analysis for MSW specifically.

[47] For determination of the ratio of biogenic and fossil CO_2 in in exhaust gases.

A3.2.1. ISO 13833:2013 Stationary Source Emissions — Determination of the Ratio of Biomass (Biogenic) and Fossil-derived Carbon Dioxide — Radiocarbon Sampling and Determination

This international document specifies sampling and analysis methods used for the determination of the ratio of biomass and fossil-derived carbon dioxide (CO_2) in the total CO_2 from flue gases of stationary sources, based on the ^{14}C method.

To specify the biogenic CO_2 fraction in the exhaust gas, below mentioned activities are performed.

- Representative sampling of CO_2.
- Measurement of the sampled ^{14}C.
- Calculation of the biogenic CO_2 fraction in the stack gas emitted during the sampling period.

In this standard, the procedures to collect the gas samples and for absorption of CO_2 in liquid alkaline media and solid absorber are defined in detail. The principle of sampling of CO_2 in stack gas is similar to the sampling of other acid gaseous substances like SO_2, and standard equipment as used for other gaseous component can be used for sampling.

After sampling, the ^{14}C content of the collected samples can be determined using following methods.

- Accelerator Mass Spectrometry (AMS)
- Beta-Ionization (BI) Measurement (Gas Proportional Counter)
- The Liquid Scintillation Counting Technique (LSC)

The detailed calculations for determination of the ratio of biogenic CO_2 in the total CO_2 of a sample from the measured ^{14}C content are included in this international standard.

A3.2.2. ISO 21644 Solid Recovered Fuels – Methods for the Determination of Biomass Content

This document includes three methods used for determination of the biomass content in solid recovered fuels (SRF), namely the ^{14}C content method, the selective dissolution (SDM), and the manual sorting method (M_{sort}). The biomass content in the fuel provides an estimation regarding the biogenic fraction content.

In this standard, the two methods are proposed for ^{14}C measurement, Proportional Scintillation Method (PSM) or Accelerated Mass Spectrometry (AMS), which requires specialized instruments and personnel. The principle of this method is based on the determination of the ratio of ^{14}C to the total carbon content, i.e., the biomass content of the SRF. The amount of biomass carbon in solid recovered fuel is proportional to this ^{14}C content.

The principle of the SDM method is based on the determination of biomass by the treatment with a sulphuric acid / hydrogen peroxide mixture since the biomass in the SRF can be dissolved. The limitation of this method is that not all the biomass materials have a 100% degradability and some non-biomass materials can dissolve during selective dissolution.

The M_{sort} method for the determination of the biomass content is based on the visual assessment of fractions and their separation because of their nature, which are either (mostly) biomass or (mostly) non-biomass. Since this method is based on manual sorting, it is not applicable with a particle size smaller than 10 mm. Also, the presence of other materials such as degradable plastics or mixed materials which are made of both biomass and non-biomass indistinguishably connected can affect the results.

A3.2.3. ISO 18466 Stationary Source Emissions – Determination of the Biogenic Fraction in CO_2 in Stack Gas Using the Balance Method

In this standard, the balance method is described for the determination of the biogenic fraction in CO_2 in stack gas, a mathematical model is applied which is based on operating data of the plant (including stack gas composition) and information about the elementary composition of biogenic and fossil matter present in the fuel used. The model can output fossil/biogenic carbon emissions and is a type of Predictive Emissions Monitoring System (PEMS). Results obtained using this model can be complementary to the results obtained with ISO 13833 which determines the biogenic fraction in stack gas from plants with unknown fuel composition by using the ^{14}C method.

This standard explains the input and output parameters required to apply the balance method. The main waste input parameters are mass of waste feed and other additional fuels and their elementary compositions, composition of moisture and ash free biogenic and fossil organic matter in the waste feed, the ratio of different waste types in the waste feed and average temperature of feed water for the boiler. The required output parameters are CO_2 and O_2 concentration in dry flue gas, flue gas flow volume and moisture content, steam produced, temperature and pressure of steam and total dry mass of solid residues.

The balance method combines the standard data of the chemical composition of biogenic and fossil organic matter with routinely measured operating data of the plant. The following requirements are described in this international standard regarding operation of the model.

- After installation of the model, validation is required to provide certainty that the measurements used do not contain systematic errors.
- The calculations and input data quality shall be monitored continuously throughout the year (minimum monthly evaluations).
- The user shall be able to see the warnings and error messages, both results and inputs and extract the results to a database program.

A3.3. Measurement of Total Carbon Dioxide

A3.3.1. Measurement Standards

The measurement methods for carbon dioxide are described in Table A4. The CEN technical specifications (CEN TS) are not standards but are listed in the Environment Agency's Guidance on stack emissions - techniques and standards for periodic monitoring (updated 17 November 2022)[48]

Table A4: Total carbon dioxide emission measurement methods

Standard	Description
CEN TS 17405 (NDIR analyser) - Stationary source emissions - Determination of the volume concentration of carbon dioxide - Reference method: infrared spectrometry	This document specifies the reference method for the measurement of carbon dioxide (CO_2) based on the infrared absorption principle. The sampling and the gas conditioning systems, characteristics and performance criteria required to ensure representative sampling are included, to enable the measurement in flue gases emitted to the atmosphere from ducts and stacks. However, this does not differentiate between biogenic and fossil derived CO_2. This applies primarily to portable automated measuring systems used for periodic measurement and the calibration and verification of installed systems, for regulatory or other purposes.
CEN TS 17337 (FTIR)	This document describes a method for sampling and determining the concentration of gaseous emissions to atmosphere of multiple species from ducts and stacks by extractive Fourier transform infrared (FTIR) spectroscopy. FTIR is capable of measuring concentrations of CO_2 as the method involves the interpretation of a generated spectra and the subsequent analysis against a fingerprint spectra. This method is applicable to periodic monitoring and to the calibration or control of automated measuring

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Standard	Description
	systems permanently installed on a stack, for regulatory or other purposes.
ISO 12039:2019 Stationary source emissions Determination of the mass concentration of carbon monoxide, carbon dioxide and oxygen in flue gas Performance characteristics of automated measuring systems	This document specifies the components required (extractive and in-situ) and the most important performance characteristics of automated measuring systems for carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) to be used on stationary source emissions. Describes methods and equipment for the measurement of concentrations of these gases using installed measuring systems. The method allows continuous monitoring with permanently installed measuring systems of CO, CO_2 and O_2 emissions. This international standard describes extractive systems and in situ (non-extractive) systems in connection with analysers that operate using, for example, the following principles: — infrared absorption (CO and CO_2); — tuneable laser spectroscopy (TLS) (CO, CO_2 and O_2). Other instrumental methods can be used provided they meet the minimum requirements proposed in this document.

A3.4. Measurement of CO

CO is a product of incomplete combustion of carbon and can be generated in EfW caused by upset conditions. Such conditions are usually short-term but can cause quite high concentrations. However, emission limit values apply for CO and emissions are likely to be insignificant when compared to annual quantities of CO_2 generated.

A3.5. Measurement of Exhaust Gas Flow

There are two standards that relate to flow measurement from stationary sources which are implemented to measure flows both periodically and continuously from EfW.

- EN ISO 16911-1:2013 Stationary source emissions Manual and automatic determination of velocity and volume flow rate in ducts Part 1: Manual reference method.
- BS EN ISO 16911-2:2013 Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts Part 2: Automated measuring systems.

EN ISO 16911-1 describes a methodology for the periodic determination of the axial velocity and volume flow rate of gas within emissions ducts and stacks. The standard outlines an approach to calculate the:

- Volume flow from the average velocity.
  - If differential pressure is used the gas composition must be measured to enable the density (molar mass) to be determined as this impacts the pressure measurement. Differential pressure devices such as pitot probes are calibrated air which has a different composition (and hence density (molar mass)) to stack gas.
  - Molar mass is determined by measuring CO_2, O_2 and moisture. This is measured as part of initial assessment on site and is only measured once.
- Associated uncertainty budget.
- Conversion to standard conditions i.e. Dry, 101.325 Kilopascal (kPa) and 273.15 Kelvin (K). (NB moisture measurement is involved).

When used as standard reference method, the performance characteristics must be shown to be equal to or better than the performance criteria defined in ISO 16911-1:2013, with an overall uncertainty expressed at a level of confidence of 95%. The standard describes approaches/methods that have a range of uncertainties ranging from 1% to 10% at flow velocities of 20 m/s.

EN ISO 16911-2 was primarily devised for continuous measurement of the flowrates from Incineration and large combustion plants following the approach outlined in EN 14181 with the objective of reducing the systematic error associated with flow measurement which impacts on the achievable uncertainty.

This approach includes:

- Quality Assurance Level 1 (QAL1) type approval against defined criteria (all parts of EN15267).
- Selection of location for automated measuring system.
  - With/without pre investigation determines whether there is significant change in the profile under changes of process conditions. Change in profile has the greatest impact on the systematic and hence on the uncertainty of measurement.
  - Predictable flow profile.
  - Qualifying utilising quality assurance level 2 i.e. producing a calibration function relating response to measurements made using:
    - A reference method as described in EN16911-1.
    - Fuel-based calculations (not applicable for waste fuels used in EfW).

- Surrogate based on parameters such as fan characteristics and pressure drop across components.

The standards calibrate the flow of automated measuring systems in $m^3 s^{-1}$ at actual operating conditions. However, concentrations using CEMS are measured at reference conditions of 273K, dry and 101.325 kPa. Consequently, temperature pressure and moisture measurements must be made to convert the measure volumetric flow rate to the same conditions to enable the determination of mass emission rate. These add additional uncertainty to the overall calculation of mass flow.

Methods further to these can be used provided that the user can demonstrate equivalence, based on the principles of CEN/TS 14793[49].

An important aspect of these standards is that they are used in conjunction with EN15259 which is covered under the Section A3.6.3 of this report, and the prescribed requirements relating to the measurement locations in rectangular and circular ducts.

A3.6. Other Relevant Standards

There are measurement standards that provide a recognised/accepted method with a known methodology for determining uncertainty. These standards are described in the following sections.

A3.6.1. BS EN 14181:2014 Stationary Source Emissions. Quality Assurance of Automated Measuring System

This standard defines the quality assurance and quality control procedure that should be implemented when using CEMS. This involves a series of quality assurance levels including certification of equipment, correct installation, generation of calibration function against reference methods and on-going control.

The approach outlined to generate a calibration function using reference methods provides a methodology that could be utilised to generate a calibration function for long-term methods such as continuous measurement of biogenic CO_2. This proposed approach would need further investigation and verification to assess the applicability.

A3.6.2. ISO 11771:2010 Determination of Time Averaged Mass Emissions and Emission Factors – General Approach

This standard provides a general approach to the determination of a time averaged mass emissions and emission factors.

[49] CEN/TS 14793:2005: Stationary source emission - Intralaboratory validation procedure for an alternative method compared to a reference method.

The standard defines a generic method to determine time averaged mass emissions from a process by establishing:

- Mass emission rates by using time series measurement of concentration and gas flow. This can be done either by manual reference methods or automatic methods such as Continuous Emission Monitoring Systems (CEMS). An estimation of the uncertainty of the average is required, which is also a requirement for EU ETS and MRV reporting.
- Time average mass emission rates using time series of emission rate values.
- The uncertainty characteristics and the expanded uncertainty of the average.
- Time average emission factors for a specific installation or a group of similar processes. The respective uncertainties are also required. Specific installation emission factors are likely to give a more accurate determination of the mass emissions as these would account for variations in the fuel, process, and operational practices.
- A quality management system that supports the inventory determinations.

It is applicable to the determination of emission factors including emissions from industrial processes where calculation from fuel and raw material is not practical. These include greenhouse gases, and other air pollutants including fine particulate material.

Measurement-based methods and calculation-based methods that use measurement data are described including:

- Planning and execution of the measurement programme to collect data.
- Selection of sampling methods.
- Calculation of results.
- Estimation of uncertainty.
- Determination of emission factors, and the reporting of information in a form that enables users to apply them.

In addition, the following are also considered in the standard:

- Generation of a time-averaged mass emission rate data of a known quality, for a defined period of time, and a documented set of operational conditions.
- Generation of complete datasets representative of a known time period (i.e. a calendar year) by filling gaps in mass emission rate data series and combining data sets numerically.

The standard provides an approach to determine the time averaged emission rates that can be used for EU ETS and MRV reporting.

A method for the quantification of the uncertainty of a time average of a set of air quality data obtained at a specified location over a defined averaging time is also defined in ISO 11222:2002[50].

A3.6.3. EN 15259: Stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report.

This provides criteria for assessing a sampling plane to ensure that representative samples are taken from the process. This determines if single point sampling is acceptable for gaseous measurement or if multi-point sampling is required**. This should be included as part of the protocol to ensure that the gaseous samples are representative.**

It is important that the EN15259 is followed during the measurement to confirm that the:

- position is representative.
- sampling approach will provide representative data i.e. single or multipoint sampling required.

All EfW would have had a EN 15259 homogeneity test undertaken confirming that the sampling position meets requirements. If there have been changes applied to the duct since this test has been performed, another homogeneity test should have been undertaken.

A3.7. MCERTS

A3.7.1. Performance Standards for Long-term Biogenic Samplers (Draft Document)

The Monitoring Certification Scheme (MCERTS) was established by the Environment Agency for providing guidelines on the standards required to be followed when monitoring emissions.

There is currently an MCERTS performance standard for long-term continuous isokinetic samplers[51]. Although isokinetic sampling (where the velocity at the inlet of the sampling system matches the velocity of the flue gas at the point of measurement and a key requirement when sampling particulate matter) is not required for gaseous sampling, this capability means that such systems can collect a flow-proportional sample which can reduce uncertainty compared to fixed sampling rate systems.

A draft MCERTS performance standard is being prepared by the Environment Agency, which is for **long-term samplers for the determination of biogenic carbon dioxide (CO_2-LTS)**. This draft standard sets out the necessary standards to be met and includes tests to demonstrate if it meets the required standard.

The draft certification requirements are included in following standards:

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[50] ISO 11222:2002: Air quality - Determination of the uncertainty of the time average of air quality measurements

[51] Performance Standards and Test Procedures for Automatic Isokinetic Samplers Environment Agency Version 3 September 2016

- EN 15267-1 Air quality – Certification of automated measuring systems – Part 1: General aspects
- EN 15267-2 Air quality – Certification of automated measuring systems – Part 2: Minimum requirements for product quality assurance, initial assessment, and on-going surveillance

The general criteria specific to all automated measuring systems and performance criteria and test procedures for laboratory testing and field testing for CO_2-LTS are included in this standard.

The following standards are required for the testing of CO_2-LTS under draft MCERTS:

- EN ISO 13833 – Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide – Radiocarbon sampling and determination
- EN 15267-3 Air quality – Certification of automated measuring systems – Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources
- EN ISO 16911-2 Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts Part 2: Automated measuring systems
- EN 15259: Air Quality – Measurement of stationary source emissions – Requirements for measurement sections and sites and for the measurement objective, plan, and report.

A3.7.1.1 Performance Criteria and Test Procedures for Laboratory Testing

The performance criteria are applied to CO_2-LTS with all the components, not to the individual parts. The test report is prepared accordingly.

The evidence of compliance with the requirements of the related product, including the requirements on electromagnetic compatibility and voltage limits, are required to be supplied by manufacturers. The CO_2-LTS is also needed to have a protection against unauthorised access.

The CO_2-LTS is required to show their operational status and process status information of the plant which includes the signals covering normal operation, stand by, maintenance mode and malfunction error signals. A communication of the operational status from CO_2-LTS to the plant control system shall be provided.

The equipment to be used shall be placed considering weather conditions and providing necessary weather protections.

The CO_2-LTS shall be capable of being operated at a supply voltage of +15% and -10%. Also, the ambient temperature is required to meet following conditions:

- -20°C to +50°C for assemblies installed outdoors
- +5°C to +40°C for assemblies installed indoors, where the temperatures do not fall below +5°C or rise above +40°C

Testing with sampling line in different lengths is required to be conducted and a suitable sampling line shall be agreed. The type of sampling system including the length of the sample line shall be described in the test report by testing laboratory.

The performance criteria of CO_2-LTS to be tested in a laboratory are given in Table A5.

Table A5: CO_2-LTS Performance Criteria for the Laboratory Test

Performance characteristic	Performance criteria
Minimum operational velocity range for proportional sampling	5 – 30 m s^{-1}
Accuracy of proportional sampling rate/day	+5%
Lack of fit of proportional sampling rate/day	+5%
Accuracy of volume measurement ml/day	+5%
Blank value of CO_2 absorber	< 0.5% of max sorption
Storage capability of sample media, such as cartridge or sorption tube	125%
Losses of measured CO_2 in the sample gas line	< 5%

The CO_2-LTS is required to have the capability to adjust the sample volume since the sample portion is dependent on the measured stack gas velocity to meet the performance criteria for the performance test according to EN 15267-3 and EN16911-2.

The proper labelling for the measuring filters, cartridges or absorption tubes shall be provided including site identification, date and sample times, sampling duration and extracted gas volume.

It is important that the start time, sampling duration and pause intervals are required to be adjusted and adapted based on the operational conditions of the plant.

A3.7.1.2. Performance Criteria and Test Procedures for Field Testing

The performance criteria and test procedures in EN 15267-3 are required to be followed where applicable. The main requirements for the field test are given as follows:

- The requirements included in EN 15259 are required to be followed for the sample location.
- The sampling system shall be established properly in accordance with the manufacturer's installation procedures.
- Sampling needs to be performed at a representative position in the stack during normal plant operating conditions. Preliminary comparison measurements against the reference method are also required to verify the selected sampling point and the proper configuration of the CO_2-LTS.

- Field tests are required to be implemented at a suitable industrial process, preferably a municipal waste incinerator with PmC levels between 50 and 70 PmC.
- A leak test is needed to be completed on the mainstream parts, by using an O2 meter on the outlet or by applying a vacuum.
- The flow of the sampling is required to be checked periodically during sampling period.
- An adequate sample mass, which corresponds to 2g for analysis with accelerator mass spectrometry and 7 – 8g for analysis with liquid scintillation, shall be collected.
- The remaining capacity of a CO_2 absorber is required to be more than 25 % of the total capacity of the absorber.

The performance criteria of CO_2-LTS to be field tested are given in Table A6.

Table A6: CO_2-LTS Performance Criteria for the Field Test

Performance characteristic	Performance criteria
Maintenance interval	**>1 month**
Availability during field test	>80% or 95% to be decided
Reproducibility	<3% biogenic
Lack of fit	<3% biogenic
Repeatability standard deviation at upper reference point	<10% (to be decided if needed)
Verification with reference method	±3 PmC

Field tests are required to be performed to demonstrate the verification of the CO_2-LTS against the reference method EN ISO 13883. Parallel measurements for a specified time shall be conducted for this verification by a test laboratory accredited to EN ISO/IEC 17025.

In addition, at the beginning and end of the field test, a lack of fit test shall be performed with gas mixing system which is complied with national standards and the ability to provide gas concentrations with a maximum expanded uncertainty of 33% of the lack of fit criterion.

Considering the outage times such as malfunctions, leak checks etc., the availability of the sampling system is required to be at least 95% during the field test.

The response of CO_2-LTS shall be checked visually in the field test and the contamination shall be evaluated at the end of the test. Also, the reproducibility is required to be calculated based on all paired measurement values, in compliance with EN 15267-3.

A3.7.2. MCERTS CEMS – Continuous Emissions Monitoring

A3.7.2.1. Carbon Dioxide

There are eighteen CEMS currently certified under the MCERTS scheme to measure (total) carbon dioxide. These include a variety of detection principles i.e., Non-destructive Infra-red, Gas filter correlation and Fourier infrared transform (FTIR).

The certified ranges listed are 0-15, 0-20, 0-22.5, 0-30, 0-75 (%) with the quoted measurement uncertainty ranging from 2.1 to 10.3%.

However, not all CEMS currently fitted to measure the emissions from EfW have the capability to measure CO_2. For some systems, such as FTIR based systems, it can be relatively simple to add the capability to measure CO_2. This is achieved by adding spectra to the application used in the unit. Additional work will be needed to set-up the analyser.

Other systems currently in place on EfW plants comprise of individual analysers measuring individual components (or a limited number of components) and may need the addition of new analyser units and changes to sampling and gas conditioning systems to accommodate measurement of CO_2.

It may not be possible to reconfigure some systems, and these will need to be replaced to enable the continuous measurement of CO_2. Future planning could include the recommendation that all replacement CEMS should include CO_2.

The future application of carbon capture systems (CCS) mean that typical CO_2 emissions may be typically <1%, which is below 10% of the certified measurement range where the uncertainty of measurement will increase. If the measurement of CO_2 is required after CCS, then the certification ranges should be lowered to appropriate levels. The assessment of measurement uncertainty is part of the certification, so is useful in constructing the uncertainty budget for ETS. However, operation of CCS could also reduce ETS requirements for reporting.

A3.7.2.2. Flow Measurement

There are MCERTS-certified automated measuring systems that measure flow, these utilise:

- Averaging pitots
- Acoustic time of flight

These also have quoted measurement uncertainties of 1.6 to 5%.

However, some systems are cross duct/stack and others measure only a small area of the duct. Consequently, calibration against the whole area and positioning of point of measurement is critical in obtaining representative data. The application of EN15259 and EN16911 parts 1 and 2 to locate the systems and evaluate the profile.

A3.7.3. MCERTS Companies and Personnel

The MCERTS scheme also covers emission monitoring companies and personnel undertaking emissions monitoring, setting requirements for standards and competency. There is a requirement for operators of EfW to use certified companies and personnel to measure their emissions. Current accreditations include gaseous emissions measurements, flow measurements and EN14181 QA/ QC of CEMS.

However, current requirements relate to demonstration of compliance with emission limit values and do not include requirements for the measurement of ETS. A specific scope can be added to include ETS requirements.

Use of MCERTs/UKAS accredited organisations provides a level of confidence that the measurements will be undertaken in accordance with recognized sampling methods/standards. However, the measurement of biogenic carbon is not currently included in the MCERTS/UKAS accreditation scheme. The MCERTS scheme includes the laboratories that undertake the analysis of the samples. Currently there are no laboratories in UK which are accredited to undertake the analysis for biogenic carbon (^{14}C) in emission samples, but more laboratories may be available in the future based on the expansion to waste proposals of the UK and EU.

A3.7.4. MCERTS Equipment

The use of certified equipment for measurements provides confidence in the performance of the analysers used. The EA monitoring certification scheme certifies following equipment:

- CEMS. Some of which are certified to measure concentration of CO_2. However, these systems do not differentiate between biogenic and non-biogenic carbon dioxide.
- Continuous Samplers. These devices sample isokinetically, normally at a single or two sampling position in a sampling plane. Consequently, these would not follow the principles of multi- point sampling if required. This the same as a CEMS. These devices produce an average over the period of sampling. There are commercially available systems that have been used to measure biogenic carbon emissions from EFW.

A3.8. The Monitoring and Reporting Regulation – Continuous Emissions Monitoring Systems (CEMS)

MRR Guidance document No.7 outlines requirements for the use of CEMS to support the requirements of EU ETS.

The application of CEMS always requires two elements:

- Measurement of the GHG concentration; and
- Volumetric flow of the gas stream where the measurement takes place.

Emissions are determined for each hour of measurement from the hourly average concentration and the hourly average flow rate. Thereafter all hourly values of the reporting year are summed up for the total emissions of that emission point. Where several emission points are monitored (e.g., two separate stacks of a power plant), this data aggregation is carried out first for each source separately, before adding the mass emissions of all sources to provide a total emission.

In addition to the requirements outlined in section A2 about measurement-based methodologies, the following general requirements are to be considered:

- CEMS are put on equal basis as calculation-based approaches. However, minimum tier requirements have been defined implying uncertainty levels comparable to those of calculation approaches are applicable. Consequently, operators need to demonstrate that uncertainty requirements can be met with the proposed approach.
- CO emitted to the atmosphere shall be treated as the molar equivalent amount of CO_2 and as such need to be considered.
- Flue gas flow may be determined either by direct measurement, or by a mass balance using only parameters which are easier to measure, namely input material flows, input airflow and concentration of O_2 and other gases which need to be measured for other purposes. However, the use of input flows for EfW is not as accurate as for example a gas turbine due to the heterogenous nature of the fuel.
- All measurement equipment must be suitable and regularly maintained and calibrated. Under the MCERTS scheme CEMS are evaluated on an EfW or large combustion plant so provide guidance on the acceptability of the systems in the EfW environment.
- Under the MRR requirements, missing data due to equipment failures can be conservatively replaced. Any approach adopted should be outlined in a monitoring plan. Some EFW plants have built redundancy into their CEMS i.e. there are back-up systems in place so that there is no loss of data if there is equipment failure. This is a consequence of the requirements for incineration in IED i.e. waste cannot be fed without an operating CEMS.

EN 14181 (Stationary source emissions – Quality assurance of automated measuring systems) for quality assurance is required under MRR, but EfW operators already implement for all of the components required for other aspects of regulatory compliance. The addition of CO_2 would not be challenging. In fact, some operators already utilise EN14181 for flow and CO_2 measurements.

EN 14181 does not cover quality assurance of any data collection or processing systems (i.e. IT systems), However, there are now CEN standards that provide a quality assurance and quality control (QA/QC) system for software and hardware. These standards are implemented as part of EfW permit requirements and support the need for an appropriate quality assurance as required by MRR. In addition, the following standards are required.

- EN 15259 (Measurement of stationary source emissions – Requirements for measurement sections and sites and for the measurement objective, plan and report), and

- EN ISO 16911-2 (Stationary source emissions - Manual and automatic determination of velocity and volume flow rate in ducts - Part 2: Automated measuring systems)

All methods applied should be based on EN standards. Where such standards are not available, the methods shall be based on suitable ISO standards, standards published by the Commission or national standards. Where no applicable published standards exist, suitable draft standards, industry best practice guidelines or other scientifically proven methodologies shall be used, limiting sampling and measurement bias.

All laboratories carrying out measurements, calibrations and relevant equipment assessments for CEMS shall be accredited in accordance with EN ISO/IEC 17025 for the relevant analytical methods or calibration activities. The 2018 revision of the MRR allows both calculation and measurement approaches including:

- Methods that use radiocarbon analyses of samples taken from the flue gas by continuous long-term sampling and not continuous measurement i.e. calculation method. For this purpose, EN ISO 13833 "Stationary source emissions – Determination of the ratio of biomass (biogenic) and fossil-derived carbon dioxide – Radiocarbon sampling and determination" is to be applied.
- The "balance method", which is an estimation method in MRR terminology (based on ISO 18466 Stationary source emissions – Determination of the biogenic fraction in CO_2 in stack gas using the balance method).

A4. Assessment of Methodologies – Issues and Considerations

A4.1. Summary of Method Constraints

Determination of fossil carbon emission for ETS requires a range of data based on the approach adopted:

- Pre-combustion approach (waste analysis) – determination of total carbon and biogenic carbon fraction in waste coupled with a combustion efficiency.
- Pre- and post-combustion approach (waste analysis and exhaust gas analysis) - determination of biogenic carbon fraction in waste coupled with total CO_2 release.
- Post-combustion approach (exhaust gas analysis) - determination of biogenic carbon fraction in exhaust gas waste coupled with total CO_2 release.

Table A7 summarises the main methodology constraints for the different approaches to determining biogenic/fossil carbon content and indicates that application of a wholly pre-combustion approach for MSW is unlikely (although for Refuse Derived Fuel/Solid Recovered Fuel (RDF/SRF), a pre-combustion approach should be achievable). **As the other approaches for MSW would involve use of exhaust gas total CO_2 and flowrate data then a comparison of methodologies for MSW can be simplified to compare the biogenic/fossil CO_2 fraction methods.**

Table A7: Limitations of biogenic carbon determination for EfW

Method	Application	Method features and constraints
Manual sorting method	Pre-combustion	• MSW – there is no international standard for sampling, manual sorting, selective dissolution or ^{14}C method (ASTM could be applied) for MSW. Limited number of samples likely in a year due to complexity of sampling, sorting and reducing samples to representative samples for analysis. • RDF/SRF – international standards in place so should be possible to develop systems. • Manual sorting and selective dissolution are indirect approaches for biogenic content.
Selective dissolution method		
^{14}C method (pre-combustion waste sampling)		
^{14}C method (Flue gas spot/continuous sampling)	Post-combustion	• MSW and RDF/SRF - biogenic carbon emissions can be calculated by a range of approaches ranging with long-term integrated samples or short-term periodic samples.

Method	Application	Method features and constraints
Balance method	Uses pre- and post-combustion operational data	• MSW - predictive emission monitoring system for MSW using process parameters and default assumptions or plant-specific data to develop emission estimates. • RDF/SRF – models may exist (Bioma is designed for MSW).

A benefit of a wholly post-combustion approach is the potential for use of continuous data (for flow and total CO_2 concentration) with long-term integrated, flow proportional samples for biogenic/fossil carbon analysis – this combination offers the most representative annual determination of fossil CO_2 and the potential for the lowest uncertainty.

A4.2. Areas Without International Standards

A4.2.1. Annual Emissions Measurement

There are some gaps within emission monitoring standards when considering ETS. For ETS, the main focus is an annual emission determination but, the main objective of emission monitoring standards is to assess or demonstrate compliance with emission limit values which are generally defined in terms of short-term (for example hourly or daily) emission concentration limits within defined measurement uncertainties. Emission concentrations are typically normalised to a standard reference condition which introduces additional calculations and measurements and generally increases uncertainty.

A4.2.2. Waste Sampling

There are no international standard methods for the sampling and determination of biogenic carbon from MSW. MSW pre-combustion sampling is generally undertaken in accordance with industry protocols. The characteristics of MSW (chemically and dimensionally heterogeneous material) means obtaining a representative analytical sample for radiocarbon or other analysis is a challenge (samples for chemical analysis are typically milled and ground to a very small quantity - only a few grammes are needed for analysis). For manual sorting, a larger sample is possible, but characterisation is subjective as it relies on visual assessment of the waste materials in the sample.

A4.3. Other Considerations

The absence of national emission factors for biogenic/fossil CO_2 emissions from EfW. At present, there is limited availability of robust and collated fossil CO_2 emission factor data that could be used for a calculation-based reporting approach or to verify a measurement-based approach for MSW, hazardous and clinical waste streams. As noted in the main report (Section 2.4), the UK ETS provides total CO_2 emission factors for MSW for certain industry sectors but there are no biogenic/fossil emission factors (and no emission factors for hazardous or clinical waste).

Emission monitoring is undertaken using certified and accredited systems. However, currently there is not a certification system for measurement systems, personnel, monitoring companies and sample analysis for monitoring biogenic carbon.

A5. Protocol for Comparing Methodologies

All sampling should be undertaken using recognised sampling methods using the hierarchy of EN, ISO and, national standards for example, British Standards (BSI), German Standards (DIN) and other documented standards/methods for example US Environmental Protection Agency (US EPA) or industry standards.

There are several approaches available that could provide biogenic data either individually or in combination. This enables different approaches to be adopted for different applications. However, there are factors that impact on the data produced. The following sections outline some of the impacts and implications of how monitoring methods are applied.

It has been assumed that all requirements, procedures, and standards that are utilised in compliance emission monitoring are also used in association with the measurement of biogenic carbon, for example:

- EN 15259 – monitoring plan, verification of sampling plane.
- EN 14181- calibration QA/QC procedures.
- CEN TS 17405/CEN TS 17337 measurement of total CO_2.
- EN 16911 part 1 or 2 – flow measurement.

Comparison of methodologies must consider the number of comparison data points needed. There should be a minimum number of data points that enable a statistical assessment. Standards such as EN14181 where data sets are compared require a minimum of 15 data pairs.

A5.1. Waste Sampling and Emission Sampling Comparisons

A5.1.1. Waste

Typically waste analysis can only review a small quantity of material relative to the total amount of MSW going into a EFW unit. This and the heterogenous nature of MSW (both in terms of composition and size range) requires care in the sampling and in processes for sample reduction to obtain representative samples for analysis and, increases uncertainty in the analysis compared to commercial fuels. Collection of increments over an extended period can allow a more representative sample over the assessment period, but this is difficult for MSW as material is not inert and organic material decays.

A5.1.2. Emissions

A key benefit of emission sampling is that it is post combustion and the exhaust is gaseous with a relatively homogeneous composition (mainly CO_2, O_2, N_2 and moisture with relatively minor concentrations of other materials). A robust sampling plan is needed to achieve representative samples for analysis but, there are existing sampling and analysis standards, some of which have been applied at EfW plant for many years, and these can help to manage sampling and analysis uncertainties. Monitoring emissions for biogenic/fossil carbon involves:

- Continuous measurement using total CO_2 CEMS and continuous flow measurement.
  - Both of which are supported by technologies and standard methods of determined performance/uncertainty.
  - However, current MCERTS CO_2 CEMS certification ranges may not be appropriate for future measurement of low concentrations of CO_2 found after CCS. These systems measure total CO_2.
- Use of continuous samplers for determining biogenic or fossil fraction which provide an average over the chosen sampling period – typically a monthly sampling period. This data is not provided in real time but provides a biogenic (fossil) carbon factor that can be applied to continuous measurement of total CO_2.

A5.1.3. Potential Issues in Comparing Waste and Emission Sampling Procedures

When comparing methodologies for determining biogenic carbon in the waste going to the process and the biogenic carbon emitted the following need to be considered:

- Material going into the unit - material going into the bunker is not necessarily the material that is going into the incinerator unit. Material can be in the bunker for some time, and it is best practice to mix the waste in the bunker so that the waste is as homogenous as possible prior to incineration. Consequently, the 'ideal' point where waste is sampled should be just prior to feeding into the unit. If waste sampling is prior to the bunker, then additional time for material to transit the bunker needs to be considered – particularly if undertaking short emission sampling periods.
- Travel time in incineration system – this is the duration between entry of waste into the furnace, the combustion process and the products of combustion appearing at the measurement point. This will be different for different processes i.e., moving grate and fluidised bed units. The travel time will be important for short emission sample collection periods.
- Response time of the analyser systems - some sampling systems involve long lengths of heated lines which influence the response time of the system. Although this may be relatively small it will be important for short emission sample collection periods.
- Sampling periods – the measurement period is dictated by the methodology being used.

A5.1.4. Potential Issues in Comparing Emission Sampling Procedures

Measurement methods that enable the determination of biogenic carbon in the emission by analysing collected samples have varying sampling periods 'snap shots' for the sampling periods.

- Bag samples – 30mins
- Sampling into reagents that absorb CO_2 - periods range up to a week.
- Long-term sampling up to 1 month per sample
  - Liquid sampling (absorption into alkaline media)

- Solid sampling (absorption into solid alkaline scrubber)
- Gas sampling if standard gas analysis probes and pre-sample systems are present (physically collection of gas samples into gas bottles)

In practise, the sampling period is determined by the capacity of the vessel used or the absorption capacity of the reagent. The assessment of any method must include review of the sample period and its impact on the uncertainty relative to the annual value required.

The period for sampling can be aligned with corresponding CEMS total CO_2 data. As the CEMS total CO_2 data are based on one-minute averages, continuous measurement provides large amounts of data which can be used to correlate data over different sampling periods. The bag and continuous samplers provide a determination of the biogenic carbon of the period that can be used to provide and factor or calibration function to calibrate the CEMS total CO_2 to biogenic and/or fossil CO_2.

When comparing methodologies for determining biogenic carbon in the emissions, the following need to be considered:

- Response time of the sampling systems - some sampling systems involve long lengths of heated lines which influence the response time of the system. Although this may be relatively small it will be important for short emission sample collection periods.
- Sampling periods – the measurement period is dictated by the methodology being used.

A5.2. Long-term and Short-term Method Comparisons

Collecting samples for short periods relative to the required annual period introduces significant uncertainty. The shortness of the sampling period can be offset by increasing the number of samples throughout the period.

The following approaches are examples of measurement methodologies and associated periods:

- Biogenic CO_2 in emission samples from use of samplers providing short or longer (monthly) term sample collection.
- Total CO_2 using CEMS combined with an emission factor applied to generate biogenic carbon emissions.
- Waste analysis – typically short-term although some samples may be collected incrementally and integrated over an extended period.

As described in Section A5.1, typically waste analysis can only review a small quantity of material relative to the total amount of MSW going into a EfW unit. This and the heterogenous nature of MSW (both in terms of composition and size range) requires care in the processes for sample collection and sample reduction to obtain representative samples for analysis and increases uncertainty in the data. Collection of increments over an extended period can allow a more representative sample over the sampling period but sample storage is difficult for MSW as material is not inert – organic material decays.

Assessing the material that goes into an EfW unit is challenging due to the operational practices implemented by operators to produce a more homogenous feed. Note that a sampling plan has to consider how waste is processed by a facility – it can take several hours for material to transit from delivery to incineration and, sampling waste can often require modification to normal operation. The period for which material is in the bunker can result in organic material breaking down changing the composition of the material.

Periodic emission sampling can use sampling periods ranging from 30 minutes to weeks depending on the sampling methodology applied. Consequently, to achieve long-term annual values, short-term periods need to be combined. This can be achieved utilising the approaches outlined in ISO 11771:2010 and ISO 11222:2002. However, for short duration periodic samples there will be significant periods where there is no data present and hence the uncertainty of the determined long-term data could be significant. This lack of coverage is an important implication of short-term measurements when compared with long-term measurements.

Longer term measurement data, such as those generated by long-term samplers operating on a month sampling cycle, results in 12 samples per year. There are only limited gaps in coverage, representing the very short period when the sample media is changed (typically an absorbant cartridge or a flue gas sample container) . This data effectively produces an integrated average measurement for the sampling period. However, to achieve an annual biogenic (and fossil) carbon measurement an average of an average would be generated. For short-term samples, such as 30 minute bag samples, even with large numbers of samples, the gaps in coverage can be large.

The fundamental difference between long-term continuous measurement and short-term measurements is the quantity of data and hence the quality and confidence that can be associated with data.

A5.3. Measurement of Carbon Dioxide Emissions and the Determination of Mass Emission from the Stack

The objective of any measurement of emissions is to provide data that is representative of the process being sampled. The objective of this report is the measurement of biogenic and fossil carbon to assess the various options approaches, time periods, analysis, calculations, and associated uncertainties. However, the data needed for reporting is an annual value and consequently the methodology applied to calculate an annual value impacts the value and the associated uncertainty.

The measurement of total CO_2 is documented and supported by standards involving all stages of measurement to ensure that measurement is representative of the emissions of the process. The standards describe all the aspects of the measurement.

Operators of EfW are using CEMS and associated data acquisition and handling systems for gaseous pollutant (and particulate matter) concentration measurement and, flow measurement. All of which conform to recognised standards, which demonstrate the ability of the systems to demonstrate compliance against regulatory requirements. This, in theory, also enables uncertainty budgets to be developed for the measurements; however, as discussed in the main body of this report, at the time of the study the uncertainty values for biogenic or fossil CO_2 are not available. Some CEMS are measuring CO_2 and there are MCERTS-certified CO_2 CEMS, but this is a measurement of total CO_2 and not biogenic carbon.

Note that measurement of CO_2 does not include any carbon that forms CO during periods of poor combustion. However, amounts of CO are likely to be minor in comparison with CO_2 (operators have to control CO to demonstrate good combustion control systems are in place).

Continuous emissions measurement of CO_2 using CEMS provides large quantities of data based on one minute data points, these can be averaged over the period of a year resulting in an annual average with an uncertainty budget that can be determined using CEMS assessment approaches[52].

To provide a mass emission rate, the measured CO_2 concentration needs to be combined with the volumetric flow rates. This can be on the same basis as concentration measurement i.e. one-minute averages. Consequently, again providing a large amount of basic data for mass emissions with an associated uncertainty.

Positioning of measurement instrumentation at a representative point at a sampling plane with a homogeneous profile will improve the uncertainty of the measurements.

A5.4. Measurement of Biogenic Carbon Dioxide Fraction

Periodic sampling provides short-term samples typically over a period of 30 minutes to several hours. Continuous samplers are available that can be configured to collect a sample over a period ranging from hours to a month. The continuous samplers can sample isokinetically i.e., the sample is proportional to the flow at the point of measurement.

The sampled gas is collected or passed through a solid or liquid absorbent that absorbs carbon dioxide which can then be analysed for ^{14}C as described in EN ISO 138833. This provides an average measurement of the fraction of biogenic carbon for the period of measurement. When combined with measurement of total CO_2 emission rate (exhaust gas flow and total CO_2 concentration) the biogenic (and fossil) mass emission can be determined.

Continuous sampling systems only sample at a single or two points within the sampling plane, consequently the position of the sampler is critical to ensure that the measurement is representative of the total emission from the process.

The characteristics of the sampling plane are critical in the measurement. A homogeneous profile is important and, if the profile changes with different operating conditions, then the measurement may no longer be

[52] Including EN 14181: 2014 – Stationary Source emissions. Quality assurance of continuous emissions monitoring systems

representative. Therefore assessment/characterisation of the sampling plane under the range of operating ranges is recommended.

There is an MCERTS certification scheme/performance standard and test procedure for automatic isokinetic samplers[51]. These samplers are capable of being configured for the measurement of a range of pollutants and can be adapted for collection of samples for determination of biogenic CO_2. An MCERTS performance standard is in preparation for long-term samplers for biogenic CO_2 determination (see Section A3.7.1).

A5.5. Balance Method Comparisons

The balance method uses operational data collected from sensors monitoring various parameters relating to the process. Balance methods involve balancing masses/energy across the EfW waste process i.e. producing a model of the process. Balancing these equations/parameters in the model can be used to determined parameters within the model. BIOMA is an example of a balance method. The inputs used by the Bioma commercial software are detailed in Tables 6 and 7 in the main report. Examples of the key inputs for energy from waste processes include.

- Waste feed rates – typically EfW plant generate feed rates on an hourly basis.
- Bottom ash produced – measured annually.
- Fly ash produced – measured annually.
- Flue gas flow – measured hourly.
- CO_2 flow – measured hourly.
- Waste composition – operator or default data to provide biogenic content.

The quality of the process data collected for use in balance methods is dependent on the quality and suitability of sensors used and their maintenance and calibration. Sensors utilised for process control will be of high quality and well maintained as these collect data critical to the operation of the process. However, some are not necessarily of high quality providing indicative data rather than quantitative data. Combining measurement uncertainties of all process sensors provides a mechanism for devising an uncertainty for the method or uncertainty for part of the method.

The measurement of the emissions for balance methods e.g., total carbon dioxide (CO_2) and flow etc on EfW are undertaken using equipment capable of providing data that meets regulator's requirements with defined uncertainties. Although the total CO_2 concentrations have no emission limit value, installed CEMS are calibrated using EN14181 and standard reference methods. These measurements consequently have defined measurement uncertainties. The balance method incorporates data ranging in quality, uncertainty resolution and magnitudes. Period as an example ranges from hourly to annually. Examples showing the differences.

- Quantity of waste processed - an annual measurement
- Feed rates - tonnes per hour

- Emission concentrations - %, g m^{-3}
- Flow rates - m^3 hr^{-1} or m^3 s^{-1}

Although, an EfW is operated continuously, variation in waste and in plant operations (for example maintenance and breakdown events) can result in significant variation in hourly data.

The following considerations should be made when using or comparing balance methods or combined fuel analysis and emissions determinations.

- Waste feed rate measurement – consider the quality of the measurement both calibration and, resolution of data. The rate varies throughout EFW operation because of several factors including, for example, homogeneity of processed waste. Consequently, the choice of appropriate sampling periods and number of samples throughout the period of operation should be considered to ensure collected data is representative for the unit.
- Periodicity of waste analysis – waste composition varies throughout the operating period and the period of undertaking sampling and analysis should be considered when assessing inputs to balance method to ensure that the determination of the composition of biogenic carbon is representative of input and hence the output of the unit.
- Waste analysis methodology – consider the uncertainty of the methods used and the units provided.
- Assumptions in place in the balance method – for example is the waste composition a default value, how frequently is it updated.
- Consider the delay time between waste input and the generation of the emissions to align operations data and emissions. The time it takes for waste to travel through the system should be considered. The time through the unit will depend on the type of technology used, temperature, feed rates, grate speeds, combustion air rates, internal volumes and lengths of ductwork.
- Emissions and flow measurements – available facilities, appropriate equipment, location, correct installation, verification calibration, on-going control, and maintenance.
    - CEMS measurements calibrated relative to the cross section of the sample plane.
    - Continuous samplers – is the sampling location in a plane representative of the total emission.
- Quality of data is dependent on the procedures utilised, personnel undertaking measurements, quality/suitability of the equipment used (for example CEMS and process monitoring sensors).
- Resolution of sensors – there may be orders of magnitude differences in the measurements made by different sensors, for example feed rate measured in tonnes per hour – emissions measured in kg hr^{-1}.
- Periodicity of updating parameters - when comparing outputs are the parameters updated at comparable rates and providing data in a similar time scales. Typical time scales annual, monthly, hourly or minute data.
    - CEMS data is usually made up from one minute averages to produce other averages.
    - Continuous samplers monthly/two months

    - Feed rates hourly from the inlet hoppers. However, some units will measure feed rates using calibrated load cells attached to cranes i.e., from the weight of each load placed into the feed hopper.
- Modifications of approach/methodology for site-specific requirements - there will be differences between EfW sites and possibly between individual units on the same site. These differences mean that any general model will need to be effectively tuned to a specific site or unit.
- The balance/model is like a predictive emission monitoring system (PEMS) consideration should be given to utilising standards/guidance for the use of PEMS.
    - PD CEN/TS 17198:2018 Stationary source emissions. Predictive Emission Monitoring Systems (PEMS). Applicability, execution, and quality assurance

A6. Other Assessments of Methodologies

The quality of a measurement result strongly depends on the performance of the measuring method used. Field evaluation of the methodologies provides a mechanism for evaluating the methods as they are applied to the measurement on an EfW, typically this is achieved by comparison between methods and against a reference method. There is an ISO standard that can be used to assess the performance of sampling methods with reference to uncertainty:

- ISO 14956:2002 Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty

The use of this standard is required by regulatory authorities when methods other than the prescribed methods are proposed to monitor air quality pollutant emissions from a source regulated under EU regulation.

The standard outlines a process for assessing a measurement against a target or reference uncertainty using relevant performance characteristics of the measuring method. The MRV and ETS set uncertainty requirements related to the tiers of reporting. This provides a measure against which a method's uncertainty can be assessed to determine if it can meet the reporting uncertainty requirements.

A7. Summary

There are several approaches that can be adopted to provide biogenic and fossil CO_2 data either individually or in combination. It is important that all sampling should be undertaken based on recognised sampling methods. There are a range of factors that can affect the produced data which should be taken into consideration when developing a protocol to compare methods. These factors include the number of data points needed. There should be a minimum number of data points that enable a statistical assessment. Standards such as EN14181 where data sets are compared require a minimum of 15 data pairs.

In developing a comparison protocol, the process variation needs to be considered which can be reviewed utilising the units CEMS. These provide a visualisation of the variation in the CO_2 (alternatively if CO_2 is not present O_2 can be used). An assessment CEMS data could provide an indication for the appropriate/representative period of testing. The process monitoring/control systems is also a useful source of information useful in developing a comparisons protocol. The key considerations on sampling and analysis methods are described below:

Methods/Approaches

There are different approaches and methods that can be implemented to determine biogenic or fossil CO_2 emissions.

- Approaches which require waste sampling and analysis
- Approaches which require only emission sampling and analysis.
- The balance method is based on operational data of the EfW (site specific) and historic waste composition and applies algorithms to develop emission estimates based on energy and mass balance calculations.

In addition, an emission factor approach may be appropriate in some circumstances.

When developing a protocol to compare methodologies, it is important to define the type of methods to be compared as the different characteristics of the waste sampling, emission sampling and balance method need to be understood. For example, waste sampling and characterisation is complex for MSW with samples typically collected periodically whereas for emission sampling, recognised standard methods can be adopted, considering the requirements of existing sampling and analysis:

- Continuous measurement using total CO_2 CEMS and continuous flow measurement.
- Use of continuous samplers for the biogenic/fossil CO_2 fraction – typically adopting a monthly sampling period other periods can be selected. These are proportional flow measurement devices.

Clear definition of the approaches to be compared and the data that will be obtained allows preparation of a clear list of measurements and identification of potential issues including, for example, misalignment of sampling duration or analysis frequency (e.g. continuous and periodic emission sampling). Identification of such issues allows development of an appropriate test protocol which will include consideration of solutions which may need to be site-specific and/or deviate from reference methodologies (for example to align sample collection durations for waste and periodic and continuous sampling).

Selection of Sub-Method

Some of the Standards for determination of biogenic carbon allow application of different techniques and hence it necessary to set out which approach will be applied as these can define sampling periods and other requirements which will need to be considered in the sampling protocol:

- Manual waste sorting method includes sorting of samples collected from incoming waste deliveries to the site. This is not necessarily the waste that enters the unit as there maybe process such as material recovery and shredding that take place prior to combustion.
- Selective dissolution method applies to RDF/SRF-type materials.
- The ^{14}C method includes two different approaches for sampling that can be applied either pre-combustion (waste analysis) or post-combustion (exhaust gas analysis).
    - Feedstock sampling and analysis (pre-combustion analysis) includes collection of a representative (this needs to be considered across annual operations due to variability of wastes) waste sample onsite and performing ^{14}C analysis.
    - Flue gas grab or continuous sampling (post-combustion analysis) includes collection of flue-gas sample from the stack for a specified period and performing ^{14}C analysis.
        - Flue gas sampling requires measurement of total CO_2 based on the reference standards/technical specifications to ensure that the gaseous samples are representative.
        - Measurement of exhaust gas flow is required to be performed based on standard reference methods.
- After sampling, the ^{14}C content of the collected samples can be determined using different methods, namely AMS, BI Measurement and LSC which can be selected based on the specialised instrument and personnel availability (currently a limited number of laboratories capable of performing ^{14}C analysis).
- The balance method both uses pre- and post-combustion process operational data and includes running the BIOMA software which is a commercially available balance method. Bioma software outputs data as hourly averages which can both be compared with data generated by CEMS/continuous samplers and other forms of measurement.
- Application of a wholly pre-combustion approach for MSW is unlikely although a pre-combustion approach should be achievable for RDF/SRF.

Sampling Facilities

- If manual sorting, the dissolution process, or feedstock sampling before ^{14}C analysis is adopted, a representative sample is gathered and stored onsite. Manual sorting requires a large space onsite where samples can be collected and sorted.
  - Management of the waste sorting area to avoid odour and other issues are important. Ventilation of the area may also be required to improve the safety of the working environment.
  - Since waste samples are required to be collected and sorted manually, this requires physical work of plant operators or subcontractor for a defined sampling period per sample.
- For stack sampling, suitable access fitment (sampling ports and plane etc.) in a suitable location at the stack is needed to extract the sample. If there is not a readily available access fitment, it will need to be installed during planned shutdown.

Sampling Periods

- Waste sampling is performed typically short-term although some samples may be collected incrementally and integrated over an extended period.
  - Short-term sampling of waste needs to consider the operation as it can take several hours for material to transit from delivery to incineration. If waste sampling is prior to the bunker, then additional time for material to transit the bunker needs to be considered. This needs to be aligned if emissions and waste sampling are being compared.
  - The travel time of waste, that is between entry of waste into the furnace, the combustion process and combustion products at the measurement point, is needed to be aligned if emissions and waste sampling are being compared.
- Biogenic CO_2 in emission samples from use of samplers providing short or longer (monthly) term sample collection.
  - Periodic emission sampling use periods ranging from 30 minutes to weeks depending on the applied methodology. For short-term samples, there may be no data present in some periods and this lack can affect the compilation of short-term measurements to compare with longer term averages.
  - Longer term measurement data, such as those generated by long-term samplers operating on a month sampling cycle results in 12 samples to derive an annual average of total per year. Comparison with shorter-term sampling may require modification of sampling periods in order to provide more comparison data.
- The fundamental difference between long-term continuous measurement and short-term measurements is the quantity of data and hence the resolution and confidence that can be associated with data comparisons.

Existing Monitoring Availability and Quality

- The availability of CEMS for continuous emissions measurement of CO_2 and flow measurement provides large quantities of data based on one minute data points.
  - All measurement equipment must be suitable under the MCERTS scheme, and regularly maintained and calibrated to demonstrate the ability of the systems for compliance against regulatory requirements. Calibration of CEMS and flow is undertaken using the processes based on EN14181.
  - To provide a mass emission rate, the measured CO_2 concentration needs to be combined with the volumetric flow rates. This can be on the same basis as concentration measurement i.e. one-minute averages.
- The position of the sampler and the characteristics of the sampling plane is critical to ensure representative sample is taken. If the profile is found to be homogeneous a single point of measurement can be used and is defined as representative of the total emission from the process. However, even in a homogenous profile there is likely to be variations consequently it is recommended to sample at a point that is the most representative.
- EN 14181 for quality assurance is required under MRR, but EfW operators already implement for all of the components required for other aspects of regulatory compliance. The addition of CO_2 would not be challenging.
- For balance method comparisons, the data quality is dependent on the quality and suitability of process sensors used and their maintenance and calibration.

Contractors/Analysis

- There are eighteen CEMS currently certified under the MCERTS scheme to measure (total) carbon dioxide, and a range of MCERTS-certified automated measuring systems that measure flow.
- Where total CO_2 and exhaust gas flow are needed to compare methodologies, the test protocol needs to consider the quality of such measurements. Not all CEMS currently fitted to measure the emissions from EfW have the capability to measure CO_2.
  - For some systems, it can be relatively simple to add the capability to measure CO_2, e.g. adding CO_2 IR spectra to the application used in a FTIR unit.
  - Other systems currently in place on EfW plants comprise of individual analysers measuring individual components, which may need the addition of new analyser units and changes to sampling and gas conditioning systems to accommodate measurement of CO_2.
  - It may not be possible to reconfigure some systems, and these will need to be replaced to enable the continuous measurement of CO_2.
- Note that the measurement of biogenic carbon is not currently included in the MCERTS/UKAS accreditation scheme and currently there are no accredited laboratories in UK to undertake the

analysis for biogenic carbon (^{14}C analysis) in emission samples. MCERTS-certified contractors offer a variety of emission sampling which should be applicable to some sampling and measurement work. The test protocol needs to consider accreditation and certification required.

Other External Measurements/Sampling Needed

- The use of CEMS for measurement of total CO_2 in a test protocol should be subjected to the requirements of BS EN 14181. This requires frequent calibration (QAL2) of CEMS and concentration using EN methods, by accredited external experts.
- For the positioning of the new emission measurement systems or in case of changes applied to the duct, a EN 15259 homogeneity test is required to be performed by external laboratory.
- Since the results from BIOMA are dependent on the operational data, and therefore frequent calibration of process meters/sensors is required.
- For waste sampling, one of the most important factors affecting data is results of weighbridge, and an operating weighbridge shall be calibrated once a year. Also, the process machines such as cranes, should be calibrated/controlled on a periodic basis by external experts.

Appendix B – Further Information Regarding the UK ETS

Fall-back Methodology

Article 22 of the MRR sets out the requirements for non-tier monitoring methodologies (i.e. fall-back methodologies). An operator may use a monitoring methodology that is not based on tiers (‘the fall-back methodology’) for selected source streams or emission sources, provided they meet certain criteria set out in that article.

Article 22 states that: *By way of derogation from Article 21(1), the operator may use a monitoring methodology that is not based on tiers (hereinafter ‘the fall-back methodology’) for selected source streams or emission sources, provided that all of the following conditions are met:*

a) *‘Applying at least tier 1 under the calculation-based methodology for one or more major source streams or minor source streams and a measurement-based methodology for at least one emission source related to the same source streams is technically not feasible or would incur unreasonable costs.’*

b) *‘The operator assesses and quantifies each year the uncertainties of all parameters used for the determination of the annual emissions in accordance with the ISO guide to the expression of uncertainty in measurement (JCGM 100:2008) or another equivalent internationally accepted standard, and includes the results in the annual emissions report.’*

c) *‘The operator demonstrates to the satisfaction of the competent authority that by applying such a fall-back monitoring methodology, the overall uncertainty thresholds for the annual level of greenhouse gas emissions for the whole installation do not exceed 7,5 % for category A installations, 5,0 % for category B installations and 2,5 % for category C installations.’*

As they are not based on prescribed tier requirements, fall-back methodologies can also encompass a large range of different monitoring approaches. It is considered unlikely, even impossible in some cases, that a waste operator would be able to meet all of the currently required criteria for the fall-back methodology with the monitoring methods currently established (such as uncertainties, as is explored further in Section 4). The fall-back methodology has therefore not been explored further in this report.

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