Good Practice Guidance for Assessing the GHG Impacts of Waste Incineration

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United Kingdom Without Incineration Network

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About UKWIN

The United Kingdom Without Incineration Network (UKWIN) was founded in March 2007 to promote sustainable waste management. UKWIN works at a national level to make expertise available to those wishing to participate in environmental decisions relating to waste management, including providing support with accessing environmental information and pursuing justice in environmental matters.

UKWIN advocates for economic, policy and legislative drivers to support sustainability in general, and more specifically to support the move away from incineration and towards a sustainable low-carbon circular economy. UKWIN also highlights social, environmental and economic issues associated with incineration, including through social media and our website, and by contributing to relevant public consultations, as well as through ongoing work with academics and journalists.

For more about UKWIN see our website at: [redacted]

Acknowledgements

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The cover photograph shows the Edmonton incinerator in November 2010.

INTRODUCTION

UKWIN offers this guidance to improve the way greenhouse gas (GHG) impacts of waste incineration are evaluated. Good policy decisions require a methodology that takes account of factors such as expected changes to waste composition, the carbon sink effect of landfilling waste, typical incinerator underperformance, and the rapid decarbonisation of grid electricity. Crucially, most waste being incinerated could have been recycled or composted to provide substantial GHG savings and other benefits.

This good practice guide provides recommendations for assessing GHG impacts of waste incineration. It is intended to be used by those carrying out such assessment as well as those reviewing or determining how much weight to give to such assessments. The guide was created due to the inconsistent quality of such assessments (including those used to inform planning, permitting and policy decisions), and highlights areas where there is a genuine risk that adverse impacts of waste incineration could be significantly understated or misrepresented.

The recommendations are based on an extensive review of approaches being taken or recommended by climate change professionals to assess the direct or relative GHG impacts of waste incineration and other waste management options. Consideration is also given to analysis carried out for this guide which indicates that real world performance reported at UK incinerators can be significantly worse than the climate change performance claimed within planning or permitting applications.

Incineration is often marketed as an environmentally-friendly alternative to landfill, but many environmentalists and experts place incineration alongside landfill as something from which we need to move away due to its adverse climate impacts, especially if we are to move towards a Net Zero circular economy.

As explained in the guide, the level of the emissions from incineration and landfill are dependent on a number of variable factors including the composition of the waste and the carbon intensity of the energy which would be displaced by any energy generated from the combustion of waste or of landfill gas. These factors are expected to change over time, and these changes could be seen as undermining (or further undermining) the case that incineration is better than landfill in GHG terms.

This guide expects readers to have a general understanding of how the GHG impacts of incineration are usually assessed and the terminology and concepts normally employed. A good starting point for those wanting to learn these basics is UKWIN's evaluation of the climate change impacts of waste incineration in the UK, available from [redacted]. That report explains how new incinerators can have worse GHG impacts than landfill even when methane is taken into account.

KEY RECOMMENDATIONS

TRANSPARENCY AND OPENNESS TO SCRUTINY

1. Methodology and modelling assumptions, including underlying data and how it was derived, should be transparent and verifiable. Scrutiny of environmental claims made to support waste incineration should be facilitated rather than frustrated.

IMPACT OF WASTE COMPOSITION AND TECHNOLOGY ON ENERGY AND GHG OUTPUTS

2. Key outputs such as power export and greenhouse gas (GHG) emissions are dependent on waste composition and the processes used. When modelling future emissions it is necessary to ensure that outputs are internally consistent with inputs.

3. GHG impacts can be highly sensitive to waste composition. Waste composition assumptions should be justified and sensitivity analysis should be used to show the impacts of future changes such as increased food and biowaste collection.

4. While heat export, carbon capture, and pre-treatment to remove plastics can potentially reduce overall GHG impacts of incineration, there are also uncertainties regarding deliverability and/or overall impacts. Sensitivity and lifecycle analysis can be used to explore a range of possibilities and to reflect relevant uncertainties.

THE ROLE OF LANDFILL AS A BIOGENIC CARBON SINK

5. To produce a valid comparison when comparing waste treatment options such as landfill and incineration that release different quantities of biogenic CO_2 it is necessary to account for these differences, especially the impact of the biogenic carbon sink in landfill.

DISCREPANCIES BETWEEN THEORETICAL AND REAL WORLD PERFORMANCE

6. The carbon performance of modern waste incinerators is often significantly worse than was predicted through modelling at the planning and permitting stages. This discrepancy between predicted and actual carbon performance needs to be taken into account when modelling, and robust sensitivity analysis is needed to ensure that CO_2e emissions from incineration are not significantly underestimated.

7. Power export underperformance, e.g. due to turbine or generator failure or during commissioning, is a realistic prospect for modern waste incinerators that needs to be taken into account when modelling anticipated power output and associated climate impacts.

DISPLACEMENT OF OTHER SOURCES OF ELECTRICITY AND/OR HEAT

8. When considering the carbon intensity of displaced energy it is necessary to take account of the progressive decarbonisation of the energy supply rather than simply assuming that a new energy source would displace fossil fuels. The carbon intensity of electricity displaced by a new incinerator can be estimated using the average BEIS Long-Run Marginal Emissions Factor (MEF) over the lifetime of the plant.

WASTE TREATMENT COMPARATORS/COUNTERFACTUALS

9. When considering how waste would be treated if it were not sent to an incinerator, account should be taken of the prospect that it might otherwise have been reduced, reused, recycled or composted. Account should also be made of how landfilled waste could be bio-stabilised to reduce methane emissions.

LOW CARBON CLAIMS

10. Energy from mixed waste incineration should not be described as 'low carbon'. Incineration involves the direct release of significant quantities of CO_2.

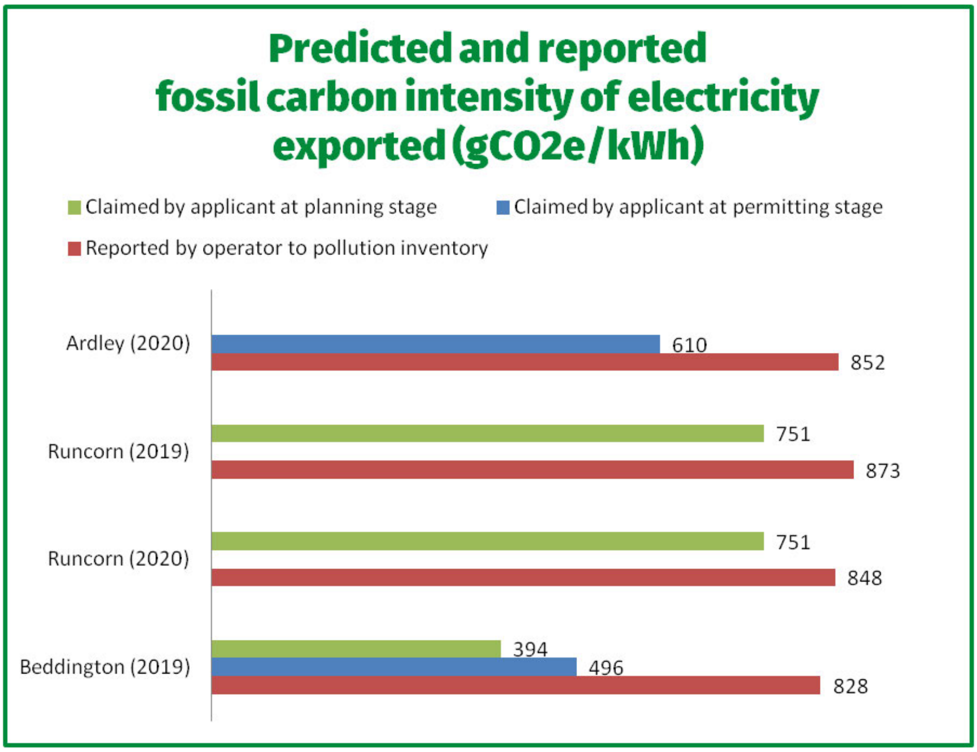
KEY FINDINGS

As set out in the section entitled 'Discrepancies between theoretical and real world performance', original analysis was conducted for this guidance to investigate current real world performance of the UK's Municipal Waste Incinerators (MWIs) based on information reported by operators and how this performance compares to historic GHG modelling carried out by the applicant for these facilities.

This research found that incinerators often perform significantly worse than modelled for planning applications and environmental permits. Incinerators often deliver lower levels of electricity generation and higher levels of fossil CO_2 emissions, resulting in a higher carbon intensity than claimed by those promoting such schemes.

The analysis found that for the incinerators studied, on average:

- The proportion of CO_2 that was fossil CO_2 was 13 percentage points higher than predicted at the planning or permitting stage.
- The fossil carbon intensity of electricity exported to the grid was around 49% higher than predicted by the applicant at the planning or permitting stage.
- Reported fossil CO_2 released per tonne of waste feedstock incinerated was around 20% higher than that predicted at the planning or permitting stage.
- Electricity generated by incinerators was 15% lower than implied by the claimed headline megawatt (MW) generation figure, i.e. an incinerator advertised as being capable of generating 10MW of electricity typically only generated 8.5MW.
- Electricity exported was around 28% lower headline MW generation figures.



GLOSSARY OF TERMS USED

Term	Meaning
BEIS	Department for Business, Energy & Industrial Strategy, a part of the UK Government.
Biogenic carbon	Carbon from biogenic sources such as paper, card and food waste. When combusted, one tone of biogenic carbon results in the release of 3.667 tonnes of biogenic CO_2.
Biogenic CO_2	Carbon dioxide from biogenic sources such as paper, card and food waste. This is sometimes said to be part of a 'short cycle' of carbon emission and re-absorption through new growth.
CCGT	Combined Cycle Gas Turbine.
CH_4	Methane, a greenhouse gas.
CHP	Combined Heat and Power. Refers to incinerators exporting both heat and electricity.
CO_2	Carbon dioxide, a greenhouse gas.
CO_2e	Carbon dioxide equivalent. This includes CO_2 as well as other greenhouse gasses expressed in relation to their equivalent level of GHG impact within a given timeframe.
Defra	The Department for Environment, Food & Rural Affairs, a part of the UK Government.
EfW Guide	This is a reference to 'Energy from waste: A guide to the debate' which was produced by the UK Government. The most recent version was released in February 2014.
Energy from Waste (EfW)	This can mean thermal treatment (incineration, gasification, pyrolysis) or a wider class of technologies which could also include anaerobic digestion, energy generated from landfill gas capture, and/or the conversion of waste into fuels such as transport fuels.
EA	The Environment Agency, a UK Government agency.
ERF	Energy Recovery Facility, e.g. a waste incinerator that generates energy.
Fossil carbon	Carbon from fossil fuel sources (e.g. conventional plastics). When combusted, one tone of fossil carbon results in the release of 3.667 tonnes of fossil CO_2.
Fossil carbon percentage	Depending on the context, this can either be the percentage of material which is fossil carbon or the proportion of the carbon which is fossil rather than biogenic carbon.
Fossil CO_2	This primarily refers to carbon dioxide from fossil fuel sources (e.g. conventional plastics). However, it is also used to refer to other greenhouse gases, such as methane, which are not considered to form part of the 'short cycle' of biogenic CO_2.
GHG	Greenhouse gas(es). A gas such as carbon dioxide (CO_2), methane (CH_4) or nitrous oxide (N_2O) that contributes to global warming.
GWP	Global Warming Potential. This is a multiplier used to convert non-CO_2 emissions into CO_2 equivalents to take account of their different assumed level of global warming impact within a given timeframe.
ktpa	Kilotonnes per annum (1,000 tonnes per year).
LCA	Life Cycle Analysis.
MELMod	Methane emissions from landfill model (used by the UK Government).
MBT	Mechanical and Biological Treatment. Involves recycling and/or composting with residues going to incineration or landfill. Can be focussed more on RDF production than on maximising recycling.
MRBT	Material Recovery and Biological Treatment. A form of MBT focussed on maximising recyclate recovery, generally involving bio-stabilised residues going to a controlled landfill rather than to incineration.
MW	Megawatt.
N_2O	Nitrous oxide, a greenhouse gas.
RDF	Refuse derived fuels. A form of processed waste feedstock.
SRF	Solid recovered fuels. Refuse derived fuel produced to a detailed specification, e.g. to be burned at cement kilns.
tpa	Tonnes per annum (year).
tCO_2e	Tonnes of CO_2e (often expressed per annum / year).
UK	The United Kingdom of Great Britain and Northern Ireland.
UKWIN	The United Kingdom Without Incineration Network, founded in March 2007 to promote sustainable waste management. See: [redacted]

TRANSPARENCY AND OPENNESS TO SCRUTINY

> **RECOMMENDATION #1: Methodology and modelling assumptions, including underlying data and how it was derived, should be transparent and verifiable. Scrutiny of environmental claims made to support waste incineration should be facilitated rather than frustrated.**

Decisions relating to waste management and energy generation can have significant and long-lasting impacts on greenhouse gas (GHG) emissions and therefore on climate change. In some cases there is a legal requirement for these environmental impacts to be assessed and/or taken into account in decision-making (e.g. regarding a planning application) or strategic planning, and in other cases it is simply good practice to do so.

It is crucial that assumptions, assessments and analyses that underpin environmental decisions accurately take account of the likely impacts of the specific proposal being considered and available alternatives. Poor quality decisions can cause environmental, economic and social harm, give rise to unanticipated opportunity costs, and undermine public trust. This is especially important for incinerator decisions in light of the Committee on Climate Change's June 2021 warning that:[1]

> *"Decisions on...planning and expansion of waste incineration are not only potentially incompatible with the overall need to reduce emissions but also send mixed messages and could undermine public buy-in to the Net Zero transition."*

Transparency regarding methodologies and modelling assumptions is important, especially when the party who holds key information about a project or proposal has a financial interest in the conclusions reached by any impact assessment. Even where those undertaking the analysis are acting independently, they might still be relying on key assumptions or paradigms provided by a client who has a conflict of interest. As such, it is also important to be clear about the origin and basis of key modelling assumptions and choices regarding modelling methodology.

Genuine scrutiny by interested parties should be facilitated through the provision of explanations and clarifications, rather than frustrated through obfuscation and the use of opaque and inscrutable methodologies. Similarly, if incinerator operators want to claim a genuine interest in addressing climate change then they should be expected to accurately monitor and publish the information they hold regarding the actual performance of their own incinerators, the key inputs to their facilities (such as feedstock composition), as well as key outputs such as greenhouse gas emissions.

1 [redacted]

IMPACT OF WASTE COMPOSITION AND TECHNOLOGY ON ENERGY AND GHG OUTPUTS

> **RECOMMENDATION #2:** Key outputs such as power export and greenhouse gas (GHG) emissions are dependent on waste composition and the processes used. When modelling future emissions it is necessary to ensure that outputs are internally consistent with inputs.

> **RECOMMENDATION #3:** GHG impacts can be highly sensitive to waste composition. Waste composition assumptions should be justified and sensitivity analysis should be used to show the impacts of future changes such as increased food and biowaste collection.

> **RECOMMENDATION #4:** While heat export, carbon capture, and pre-treatment to remove plastics can potentially reduce overall GHG impacts of incineration, there are also uncertainties regarding deliverability and/or overall impacts. Sensitivity and lifecycle analysis can be used to explore a range of possibilities and to reflect relevant uncertainties.

The UK Government's Energy from Waste (EfW) Guide notes that: *"To understand fully the relative benefits of energy from waste against other solutions a full life cycle assessment for the specific circumstances will be required".*[2]

One of the key parameters for the impacts of a waste incinerator is the composition of the feedstock. The specific type of waste (paper, plastic, food, etc.) impacts on how much energy is generated, how much fossil and biogenic CO_2 is released, and how much waste can be processed. As a Defra report put it:

> *"One tonne of waste does not have a constant carbon content as it varies depending upon the waste components. The relative proportions of biogenic and fossil carbon also depend upon the waste components, as do other important factors such as the calorific value... The calorific value of the waste is how much (chemical) energy is stored in the waste per tonne that could potentially be converted into useful electrical or heat energy when burned. Waste such as plastic has a high calorific value whereas other wastes such as kitchen waste that is very wet have much lower values. This is due to the water adding significantly to the weight while adding nothing in energy terms. Energy is used to convert all the water to steam during combustion".*[3]

[2] https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate

[3] http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

It is therefore necessary for there to be consistency when modelling the anticipated performance of proposed incineration capacity, with a direct link made between the energy and carbon content of a defined feedstock and the intended energy generation capacity of the proposed plant.

For mixed waste the precise feedstock composition might not be known and it can be expected to change over time. This means that for an accurate assessment it is usually necessary for a range of feedstock compositions with different properties to be modelled. When mixed waste is processed to produce Reduce Derived Fuels (RDF) or Solid Recovered Fuels (SRF) this changes the composition by removing materials and by removing the water content, and for incineration plants that rely on these processed feedstocks account need to be taken of the impact that these processes can have on the properties of their anticipated feedstock.

Zero Waste Scotland noted in July 2021 how:

> *"The emissions of residual municipal waste sent to both EfW and landfill is highly dependent on the composition of that waste. Waste composition is varied and changes over time".*[4]

The UK Government acknowledged back in 2011 that:

> *"Waste infrastructure has a long lifetime and therefore changes in the composition and potential volumes of waste in the future cannot be ignored in the development and selection of technologies now".*[5]

This is similar to what has been noted by the UK Government in the EfW Guide:

> *"Changes in composition due to enhanced recycling will alter the properties of the residual stream in ways such as calorific value and biogenic content".*

It may be necessary to consider the consistency between assumptions regarding anticipated feedstock availability and anticipated feedstock composition. For example, if it is assumed that there will be less food and plastic in the residual waste in the future then this could be expected to reduce the overall amount of waste available for incineration. The role of composition with respect to the potential for a given material to be minimised, recycled or prevented is covered in more detail below (in the section entitled 'Waste treatment comparators/counterfactuals').

4 [redacted]
5
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69401/pb13540-waste-policy-review110614.pdf

EXAMPLES OF NATIONAL WASTE TREATMENT OPTION ANALYSIS THAT TAKE ACCOUNT OF CHANGES IN WASTE COMPOSITION

Report, Client, Date	Future compositions modelled	Relevant findings
The climate change impacts of burning municipal waste in Scotland - Technical Report (Zero Waste Scotland, July 2021)[6]	*"The study also included a sensitivity analysis, to assess the likely effects of future changes in key variables, such as changes to the composition of municipal waste…* *Plastic content of waste was varied to show the effects of changing fossil carbon content of waste. In the main model, plastic waste is assumed to make up 15% of the weight of residual municipal waste and 69% of its fossil carbon content. This composition is varied by +/- 10% in the sensitivity analysis. The composition of other materials were adjusted proportionately.* *Food and paper content was varied to show the effect of changing biogenic carbon content of waste. In the main model, these two waste categories make up 43% of the weight of residual municipal waste and 59% of its biogenic carbon content. This composition is varied by +/- 10%. The composition of other materials were adjusted proportionately. "*	*"The results show that changes in waste composition and technology can considerably alter the climate change impacts of management of residual municipal waste…* *The fossil content of waste is the most significant factor affecting [fossil] greenhouse gas emissions per tonne of waste burnt in EfW plants. For landfill, the most significant factor is the biogenic content of waste entering landfill.* *When fossil carbon increases (e.g. if the proportion of plastic waste in municipal residual waste rises), EfW [fossil] greenhouse gas emissions rise as more fossil carbon is released into the atmosphere. The net calorific value of waste also rises – burning more carbon releases more energy. EfW and landfill impacts are equal when the proportion of plastic in residual municipal waste is increased from the main model assumptions by 4.6% from 15.0% to 19.6%.* *When biogenic carbon decreases (e.g. if the proportion of food and paper waste in municipal residual waste falls), landfill greenhouse gas emissions fall. Assuming that all fossil carbon is sequestered, the removal of biogenic carbon reduces the amount of methane which eventually escapes from landfill as a greenhouse gas. Landfill and EfW impacts are equal when the proportion of food and paper waste in residual municipal waste falls from the main model assumptions by 10.4% from 43.1% to 32.7%."*

6 [redacted]

Report, Client, Date	Future compositions modelled	Relevant findings
Greenhouse Gas and Air Quality Impacts of Incineration and Landfill (ClientEarth, March 2021)[7]	Expected-2035 scenario: *"models the changes in residual waste composition that would be observed if the UK implemented the policies put forward in the EU's Circular Economy Package – specifically the aim of reaching a municipal recycling rate of 65% by 2035."*	*"In the Expected-2035 scenario, which represents the expected residual waste composition and energy context in 2035, electricity-only incineration performs worse than landfill, while incineration operating in CHP mode and landfill are essentially equivalent in climate terms."* **(More about Eunomia's assumptions regarding changes in UK residual municipal waste composition are explored in a sub-section below)**
Evaluation of the climate change impacts of waste incineration in the UK (UKWIN, October 2018)[8]	In addition to the base case waste composition, the impacts of adopting a 'reduced plastic case' and 'reduced compostable case' to take account of current and future changes were modelled.	Reducing the proportion of plastics in the modelled feedstock lowered the relative net GHG impacts from incineration compared to landfill, but the overall impact of incineration remained adverse. Reducing the proportion of compostable waste in the modelled feedstock improved landfill performance compared to waste incineration.

7 [redacted]

8 [redacted]

Report, Client, Date	Future compositions modelled	Relevant findings
Energy Recovery for Residual Waste – A carbon-based modelling approach (Defra, 2014)[9]	*"The model was used to identify the 'balance' or point between energy from waste and landfill for a given composition of waste - the overall net efficiency of EfW plant required for a tonne of waste going to EfW to have the same carbon impact as that same tonne of waste going to landfill. This balance point was examined for a range of theoretical waste compositions."* **Compositions modelled:** • Baseline • 80% / 60% / 40% / 20% of baseline biogenic waste • No biogenic waste • No fossil waste • No food • No food, no garden waste • No garden, 20% food, 20% wood • No textiles • No inert non combustible material (glass, metal etc • No plastics • 20% paper/card, 50% plastics, 30% food, 10% garden, textiles, glass and metal (good recycling area) • Plastic and paper with contaminants of food at 10% (RDF from an MBT process) • No wood • Double wood (e.g. if landfill restriction) • Reducing each component by a randomly generated percentage	*"The different compositions resulted in a wide range of biogenic content, CV and efficiencies required for EfW to be better than landfill…* *The biogenic composition has been plotted against the minimum net efficiency required for EfW to be better than landfill. Across the range of compositions it is clear that [when the impact of sequestered biogenic carbon is ignored] the model produces a highly correlated relationship, albeit slightly non-linear...* *Taking into account sequestered biogenic carbon in landfill will require greater EfW efficiency and/or biogenic content…* *By taking this approach materials which already have a high proportion of decomposable carbon are most greatly affected, i.e. Food, Paper and garden waste."* **(The importance of taking account of sequestered biogenic carbon in landfill is included in the section below entitled 'The role of landfill as a biogenic carbon sink')**

9 http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

EXAMPLES OF CARBON ASSESSMENTS FOR PROPOSED INCINERATORS THAT TAKE ACCOUNT OF DIFFERENT FEEDSTOCK COMPOSITIONS

Facility, Client, and Document Date	Feedstock cases considered
North Lincolnshire Green Energy Park (Solar 21, June 2021)[10]	• *"A single RDF composition has been selected for the assessment. To assess the potential variability in the results due to differences in the RDF composition, sensitivity analysis has been undertaken."* • *"Table 13 below shows the estimated net benefit in GHG emissions of the Project compared to the baseline landfill scenario for different combinations of biogenic content (as % of total C in RDF) and biodegradability (as DDOC), when varied by +/-10% from the values used in the main assessment."* • *"The analysis shows that a 10% reduction in either the biogenic carbon content or DDOC results in a net increase in GHG emissions from the Project compared to the Baseline landfill scenario. However, if the DDOC is increased by 10%, this almost entirely negates a 10% decrease in the biogenic carbon content."*
Riverside Resource Recovery Facility (Cory Riverside Energy, February 2021)[11]	• *"Waste composition will vary over time in line with government strategy, which aims to reduce the amount of both plastics and food waste in residual waste. Within the scenario below, a removal rate of approximately 2% per year for plastics (up to a maximum of 30%) and 3% per year for food waste (up to a maximum of 50%) is assumed."*
Alton Advanced Energy Recovery Facility (Veolia, December 2020)[12]	• *"The design case (case 1) for the Facility is a throughput of 330,000 tonnes per year of waste with a net calorific value (NCV) of 9.5 MJ/kg, assuming that the plant operates for 8,250 hours a year. This defines the thermal capacity of the Facility."* • *"A second case (case 2) has been assessed using a different waste composition, to consider the sensitivity of the assessment to waste composition. Case 2 assumes a waste with an NCV of approximately 10 MJ/kg. The thermal input into the Facility has been kept constant (as well as the operating hours which have been set at 8,250 hours per year), but waste throughput is reduced to approximately 312,562 tonnes, as the NCV of the waste is higher."* • Sensitivity analysis considered impacts of: 25% less plastic; 25% less food; 25% less plastic and food

[10] https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/north-lincolnshire-green-energy-park/
[11] 'Riverside Optimisation Project'. Application to vary consent GDBC/003/00001C-06
[redacted]
[12] Hampshire County Council planning application no. 33619/007

Facility, Client, and Document Date	Feedstock cases considered
Portland Energy Recovery Facility (Powerfuel Portland Ltd, September 2020)[13]	• Nominal capacity (182,640 tpa, NCV of 11 MJ/kg) • Maximum capacity (201,912 tpa, NCV of 9.95 MJ/kg)
Darwen Energy Recovery Centre (Suez, April 2019)[14]	• 500 ktpa throughput and 50:50 biogenic:fossil carbon ratio • 500 ktpa throughput and 45:55 biogenic:fossil carbon ratio • 440 ktpa throughput and 50:50 biogenic:fossil carbon ratio • 440 ktpa throughput and 45:55 biogenic:fossil carbon ratio • 440 ktpa throughput and 55:45 biogenic:fossil carbon ratio

MODELLING OF ANTICIPATED RESIDUAL WASTE COMPOSITION CHANGES

The aforementioned Eunomia report for ClientEarth entitled 'Gas and Air Quality Impacts of Incineration and Landfill' models potential changes in waste composition.

The scenario modelled for ClientEarth represents a situation where significant amounts of food waste is collected for composting in order to achieve the 65% target, with lower relative plastic waste collected (since there is much more food waste than plastic). Significant increases in plastic film collection were considered less likely as the UK currently collects little of this material separately. Other possible means of reaching or exceeding the 65% target are possible, and so sensitivity testing is important.

In Eunomia's modelling each of the material streams is associated with different material properties such as moisture, carbon percentage, biogenic carbon percentage and embodied energy content (see table below). The report identified that it was not safe to assume that reductions in the quantity of plastic waste and kitchen waste would balance out, not least due to the difficulty in recycling plastic film.

Eunomia's modelling assumes that: *"The capture rates of waste containing high amounts of biogenic carbon, like garden and food wastes, are much higher in the future Expected-2035 scenario than today".* As can be seen from the tables below, removing garden and food waste would reduce the biogenic fossil carbon percentage (and therefore increase the proportion of fossil carbon).

Eunomia also assumes that *"a significant amount of plastic will remain in the waste stream even if high recycling rates are achieved, because plastic film is typically not easily recycled"*.

[13] Dorset Council planning application no. WP/20/00692/DCC
[14] Blackburn with Darwen Council planning application no. 10/19/0495

As can be seen from the tables below, increasing the proportion of waste which is plastic film increases the proportion of carbon which is fossil carbon (and reduces the biogenic fossil carbon percentage).

Different material streams also behave differently in landfill. As noted in the UK Government's Energy from Waste (EfW) Guide:

> *"…considering the landfill route, all the fossil carbon stays in the ground and doesn't break down. The fossil carbon is sequestered, as is potentially up to half of the biogenic carbon depending on the exact conditions in the landfill. However, some of the biogenic material does break down with the carbon converted to a mixture of carbon dioxide and methane, known as landfill gas. A large proportion of this landfill gas would be captured and burnt, generating energy and offsetting power station emissions. Burning landfill gas produces biogenic carbon dioxide which, as for energy from waste, is considered short cycle. Crucially however, some of the methane would escape into the atmosphere".*

The amount of biogenic material which is converted into greenhouse gasses depends on the specific material stream and on any processing prior to landfill. As shown in a table below, for waste sent untreated to landfill the quantity of biogenic carbon which is assumed to biodegrade (i.e. dissimilable degradable organic carbon, known as DDOC) is estimated within the UK Government's MELMod model.

Moves across the UK to increase the separate collection of food and garden waste can be expected to significantly reduce the proportion of untreated mixed waste that would biodegrade in landfill. Separate food and garden waste collection would also reduce the proportion of biogenic carbon in the feedstock, potentially more so than efforts to remove plastics would reduce fossil carbon content.

Eunomia's report for ClientEarth considers the impact of aerobic biological stabilisation prior to landfill. Accurately estimating the characteristics of biogenic waste is less important when comparing incineration and landfill when account is taken of options to stabilise biowaste prior to landfill because this significantly increases the proportion of biogenic carbon that is sequestered in landfill.

POTENTIAL CHANGE IN UK MUNICIPAL RESIDUAL WASTE COMPOSITION BETWEEN 2020 AND 2035 (BASED ON 65% OVERALL MUNICIPAL RECYCLING RATE)

	Material stream	2020	2035	Change (percentage points)
Decrease	Kitchen waste	26.4%	15.1%	-11.3%
	Paper	14.7%	11.7%	-3.0%
	Card	6.3%	4.9%	-1.4%
	Aluminium	1.2%	0.7%	-0.5%
	Dense Plastic	7.9%	7.7%	-0.2%
Stable	Fines	2.3%	2.3%	0.0%
Increase	Textiles	5.3%	8.4%	3.1%
	Other misc. combustible	5.3%	8.4%	3.1%
	Nappies & sanitary	4.0%	6.5%	2.5%
	Other misc. non-combustible	3.8%	5.4%	1.6%
	Ferrous	2.4%	3.7%	1.3%
	Wood	2.3%	3.5%	1.2%
	Other putrescibles	2.5%	3.7%	1.2%
	Plastic Film	8.3%	9.4%	1.1%
	Glass	2.8%	3.3%	0.5%
	Garden waste	2.7%	3.1%	0.4%
	Potentially hazardous	0.5%	0.8%	0.3%
	WEEE	1.1%	1.3%	0.2%

Adapted from Table 2-2 of 'Greenhouse Gas and Air Quality Impacts of Incineration and Landfill' (Eunomia report for ClientEarth, March 2021)

ASSUMED PROPERTIES OF UNPROCESSED RESIDUAL WASTE MATERIAL STREAMS

	Material stream	Change (% points)	Moisture	Carbon	Proportion of C is biogenic	Embodied energy (MJ/tonne)
Decrease	Kitchen waste	-11.3%	70%	13%	100%	4.500
	Paper	-3.0%	15%	32%	100%	11.050
	Card	-1.4%	20%	31%	100%	12.800
	Aluminium	-0.5%	6%	0%	0%	0.000
	Dense Plastic	-0.2%	5%	66%	0%	31.907
Stable	Fines	0.0%	70%	14%	100%	4.200
Increase	Textiles	3.1%	20%	30%	50%	12.800
	Other misc. combustible	3.1%	20%	17%	50%	14.400
	Nappies & sanitary	2.5%	65%	7%	50%	6.300
	Other misc. non-combustible	1.6%	12%	0%	0%	2.526
	Ferrous	1.3%	5%	0%	0%	0.000
	Wood	1.2%	17%	32%	100%	14.940
	Other putrescibles	1.2%	70%	0%	100%	4.500
	Plastic Film	1.1%	15%	67%	0%	38.793
	Glass	0.5%	5%	0%	0%	1.406
	Garden waste	0.4%	55%	18%	100%	7.650
	Potentially hazardous	0.3%	5%	0%	0%	0.000
	WEEE	0.2%	5%	0%	0%	0.000

ASSUMED DECOMPOSABILITY OF BIOGENIC MATERIAL STREAMS WHEN SENT UNTREATED TO LANDFILL

Material stream	Biogenic carbon content	Degradability of biogenic carbon (DDOC percentage)
Food	32.0%	67.5%
Garden	44.0%	51.3%
Mixed Paper and Card	14.0%	49.4%
Miscellaneous combustibles	17.0%	44.5%
Textiles (and footwear)	19.0%	33.4%
Sanitary / disposable nappies	20.0%	28.7%
Wood	15.0%	28.5%
Soil and other organic waste	7.0%	3.6%
Miscellaneous non-combustibles	3.5%	0.0%
Glass	0.3%	0.0%
Plastics	0%	
Metals, White Goods and Other Non-biodegradable products	0%	
Non-organic fines	0%	

DDOC content based on MELMod Calculations using the AR5 (2014) data set (provided by BEIS)

Considering the impacts and deliverability of heat export, carbon capture and pre-treatment

A number of measures may offer the potential to reduce the GHG impacts of incineration including heat utilisation, pre-treatment, and carbon capture and storage/utilisation. Care needs to be taken when the theoretical promise of such technologies are assessed, especially in circumstances where there are no firm plans for them to be delivered. Sensitivity and lifecycle analysis can be used to help explore uncertainties regarding the deliverability and overall impacts of these measures.

HEAT EXPORT

In many cases assumptions regarding the benefits of CHP schemes rely on large heat demands, but it can be difficult to deliver to such a large district heating network in practice, especially in England where there is not the same level of year-round demand for heat as there is in some European countries.

Barriers to realising CHP potential include the expense (and the viability of the business case), the availability and willingness of suitable heat users, and logistical challenges in laying the necessary pipework (especially when retrofitting).

Poor customer experience at existing CHP scheme[15] could make it more difficult to recruit customers and partners to new schemes, while increased regulation to address such issues could add to financial costs and uncertainty.

CARBON CAPTURE

Claims are often made about the potential for carbon capture and storage to be added to existing or proposed incinerator plants in the future to reduce emissions. Issues relevant to such considerations include technological uncertainties, environmental impacts associated with the chemicals and processes used, locational barriers (such as lack of access to suitable places to store the captured CO_2), power requirements, and the expense of such schemes[16].

In relation to carbon capture and utilisation, care needs to be taken in considering the level of demand for CO_2 and the full lifecycle impacts of the CO_2 once it has been utilised.

15 [redacted]

16 [redacted]

MECHANICAL PRE-TREATMENT

As noted in Eunomia's report for ClientEarth entitled 'Gas and Air Quality Impacts of Incineration and Landfill', advanced mechanical pre-treatment could be used to target the removal of plastics, including dense plastics and plastic film, which could: *"reduce fossil carbon content of the residual stream and increase the material going to recycling, improving the overall 'climate performance' of the system".*

Whether this would occur in practice could depend on policy, regulatory and fiscal drivers. Furthermore, the impact of recyclate removal depends on what is then done with the removed material, which in Eunomia's modelling is assumed to be recycled.

Something that Eunomia's modelling takes into account is the additional energy expenditure associated with such pre-treatment processes.

As explained in the UK Government's Energy from Waste (EfW) Guide:

> *"Pre-treatment facilities require energy. When comparing possible energy from waste routes it is important to consider the impact of any pre-treatment required on the overall energy balance. Life cycle analysis can be used to determine if the energy used in separation can be offset by the carbon savings from the additional recyclable material collected."*

This is summarised in the EfW Guide into the following principle:

> *"Pre-treatment requires energy which needs to be considered as part of the overall environmental assessment of the solution."*

The EfW Guide also warns that:

> *"In considering waste composition the environmental requirements should be given as much weight as the technical plant requirements. Having a higher calorie fuel may make sense from an energy production viewpoint but if it is due to a higher plastic content creating fossil emissions it may be environmentally detrimental. This consideration needs to extend beyond the plant to the pre-processing and collection regimes that ultimately dictate waste composition and quality. "*

THE ROLE OF LANDFILL AS A BIOGENIC CARBON SINK

> **RECOMMENDATION #5 To produce a valid comparison when comparing waste treatment options such as landfill and incineration that release different quantities of biogenic CO_2 it is necessary to account for these differences, especially the impact of the biogenic carbon sink in landfill.**

General principle

The carbon content of wood, paper, card, kitchen and garden waste is known as 'biogenic carbon', whereas the carbon content of conventional plastics (which are derived from oil and other fossil fuels) is known as 'fossil carbon'. The CO_2 derived from these sources are known as 'biogenic CO_2' and 'fossil CO_2' respectively. However, the methane derived from biogenic carbon in landfill is often treated as if it were fossil CO_2e due to its higher assumed level of global warming potential (GWP).

Both biogenic CO_2 and fossil CO_2 have the same GHG properties and the same impact on climate change. The reason biogenic carbon is sometimes considered to be 'carbon neutral' relates to assumptions regarding the role of the originating material as part of a 'short cycle' of carbon being released and re-absorbed (as opposed to the 'long cycle' associated with fossil fuels). It does not follow that treating biogenic CO_2 as 'carbon neutral' justifies ignoring biogenic CO_2 where the biogenic carbon (and therefore the biogenic CO_2) would instead be removed from this short cycle, e.g. by being stored in landfill, as removing/storing the material would be 'carbon negative'.

In relation to waste sent to landfill, the UK Government's EfW Guide explains:[17]

> *"Both landfill and combustion of untreated mixed waste will result in the release of carbon into the atmosphere but for the same bag of waste they do so in different ways, in different amounts, with different potential impacts... considering the landfill route, all the fossil carbon stays in the ground and doesn't break down. The fossil carbon is sequestered, as is potentially up to half of the biogenic carbon depending on the exact conditions in the landfill. However, some of the biogenic material does break down with the carbon converted to a mixture of carbon dioxide and methane, known as landfill gas. A large proportion of this landfill gas would be captured and burnt, generating energy...Burning landfill gas produces biogenic carbon dioxide which, as for energy from waste, is considered short cycle. Crucially however, some of the methane would escape into the atmosphere".*

[17] https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate

This means that when comparing landfill with incineration it is important to consider both the adverse impacts of the gasses that are released and the climate benefits of the fossil and biogenic carbon that *"stays in the ground".*

When waste is burned at an incinerator practically all of the carbon is converted into carbon dioxide (CO_2) and immediately released into the atmosphere. In contrast, when waste is landfilled a large proportion of the carbon is 'sequestered', i.e. permanently or semi-permanently stored in the ground. This storage of carbon is known as a 'carbon sink'.

If two waste treatment options release different quantities of CO_2e then it is necessary to take this difference into account when comparing these processes, and this principle extends to biogenic CO_2. This is relevant both to comparing different landfill processes with one another (e.g. comparing sending waste directly to landfill with bio-stabilising that waste prior to landfill) and to comparing landfill options with alternatives to landfill (such as incineration).

When comparing incineration with landfill, assuming that the release of biogenic CO_2 from an incinerator is 'carbon neutral' does not justify ignoring the biogenic carbon sequestered in landfill. Instead, it follows that avoiding the release of biogenic CO_2 would be a 'carbon benefit' (net negative CO_2 emission) of landfill that must be taken into account. The incineration of one tonne of carbon releases 3.667 tonnes of CO_2, meaning that every tonne of biogenic carbon in the landfill sink avoids the release of 3.667 tonnes of CO_2 when compared to incineration.

Around 27% of the content of mixed residual waste is carbon.[18] It is commonly assumed that when mixed waste is sent directly to landfill without pre-treatment around half of the biogenic carbon is permanently sequestered. This would mean that for each tonne of waste sent directly to landfill, around half a tonne of biogenic CO_2 is effectively sequestered ($0.27 \times 0.5 \times 3.667 = 0.50$).

As explained in the previous section, changes in waste composition (e.g. arising from increased separate collection of food waste) could be expected to reduce the amount of biogenic carbon in the waste stream as well as increase the proportion of biogenic carbon which is sequestered (because food waste is relatively more likely to decompose in landfill when compared with other biogenic material such as paper, card, and wood).

18 [redacted]

Where there are uncertainties regarding the climate impacts of waste in landfill this could justify the use of sensitivity analysis to show the impacts of using a range of modelling assumptions. It is not valid to use modelling uncertainties (e.g. in relation to the rates of landfill gas capture) to rationalise ignoring the way that landfill acts as a carbon sink. The impact of modelling uncertainties may be far less than the impact of failing to account for biogenic carbon sequestration, and it is possible that the central assumption about which there is uncertainty might prove to be correct and/or overly pessimistic about the fate of the material in landfill.

Two methods to account for the biogenic carbon sink

Defra's 2014 report 'Energy recovery for residual waste – A carbon based modelling approach'[19] sets out two ways to account for the way that landfill acts as a partial carbon sink for the biogenic carbon:

- **Method 1 - Account for fossil CO_2 and sequestered biogenic carbon** - *"Estimate the amount of biogenic carbon sequestered and include the CO_2 produced from the same amount of carbon in the EfW side of the model (or subtract it from the landfill side)"*
- **Method 2 - Account for all carbon -** *"Include all carbon emissions, both biogenic and fossil on both sides of the model"*

A difference between the two methods is that Method 2 also takes into account the way that when carbon is released as methane from landfill this avoids the release of that carbon as biogenic CO_2, resulting in slightly lower estimates of relative greenhouse gas emissions from landfill than Method 1.

The Defra report notes that "*both approaches would address the issue of sequestered biogenic carbon".* While there is the potential for debate about the conceptual differences between the two approaches, both methods generally produce almost identical results when comparing incineration and landfill and so would only change the conclusions of an assessment if the difference between the two processes was minor.

19 http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

GHG impacts of biogenic carbon sink on incineration of different materials

The current model used to predict methane emissions from landfill for the UK Government's GHG Inventory reporting and for company reporting is known as MELMod. The MELMod AR5 dataset used by the Greenhouse Gas Inventory Team at BEIS includes figures for different waste streams (e.g. paper and card, plastics, etc.).

This MELMod dataset includes figures for the *'proportion [of] biogenic carbon sequestered in landfill'* within the 'material properties' section of the model. It also includes figures for the *'mass of fossil and potentially landfill sequesterable CO_2 emissions'* within the incineration ('EfW') section of the model. The mass of landfill sequesterable biogenic CO_2 emissions used in the MELMod dataset is calculated in line with the Method 1 approach outlined above, meaning that it uses the assumed level of sequestered biogenic carbon multiplied by 44/12 to account for how combusting one tonne of carbon results in the release of 3.667 tonnes of CO_2.

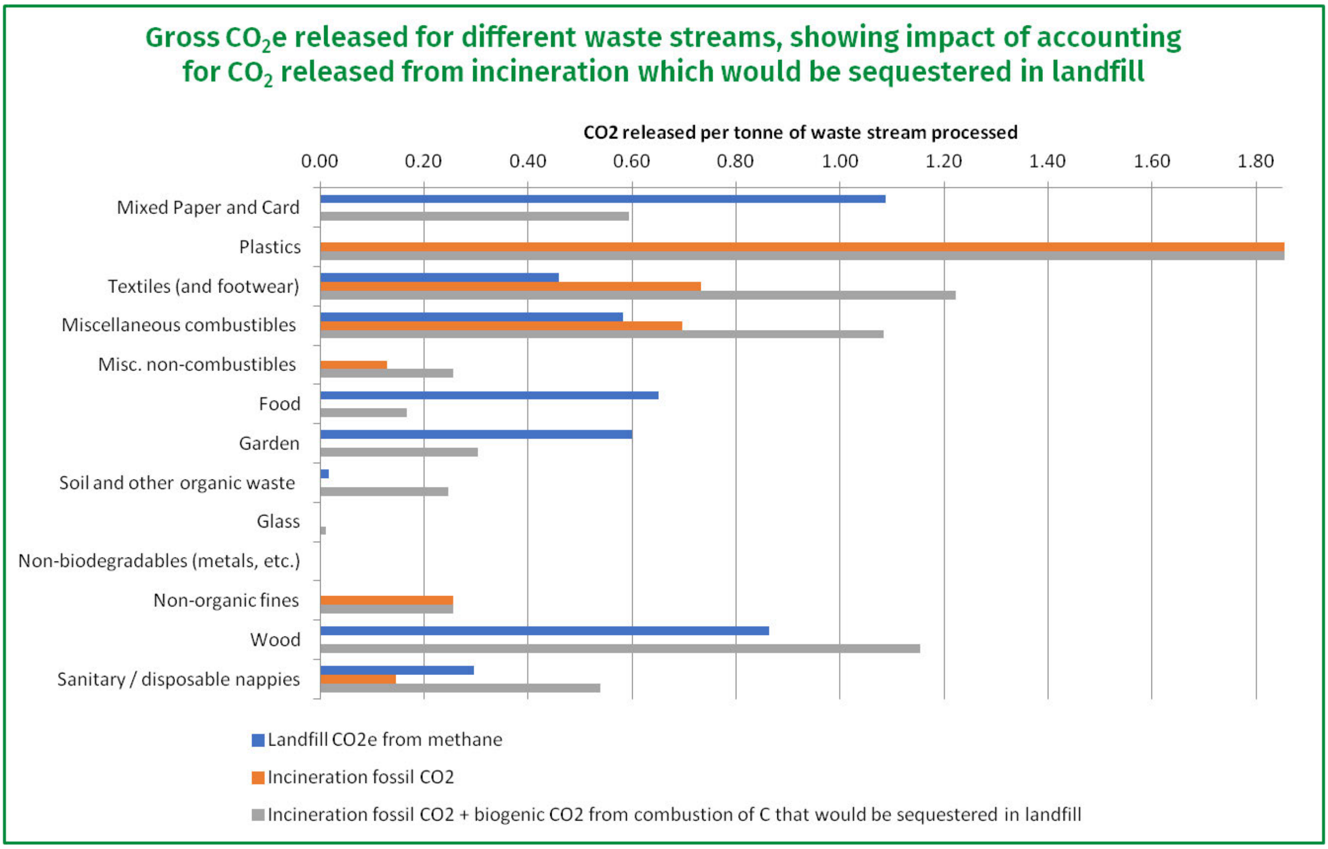
We have used this MELMod dataset to produce two charts (below) to illustrate the impact of accounting for the biogenic CO_2 released from incineration which would otherwise be sequestered in landfill. The first chart shows direct emissions while the second chart is emissions net of savings from displaced CCGT electricity generation.

This modelling indicates that taking account of biogenic carbon sequestration can have a significant impact on material streams such as food, garden waste, paper and card, textiles and wood. The incineration of plastic always results in a significant adverse impact compared to landfill. The modelling results also highlight how much of the claimed emissions savings from the incineration of various material streams is dependent on displacing a fossil fuel electricity supply, as discussed in more detail elsewhere in these guidelines. Assumptions regarding the carbon intensity of displaced electricity impacts on the relative net emissions between incineration and landfill because incineration generally results in more energy generation than landfill.

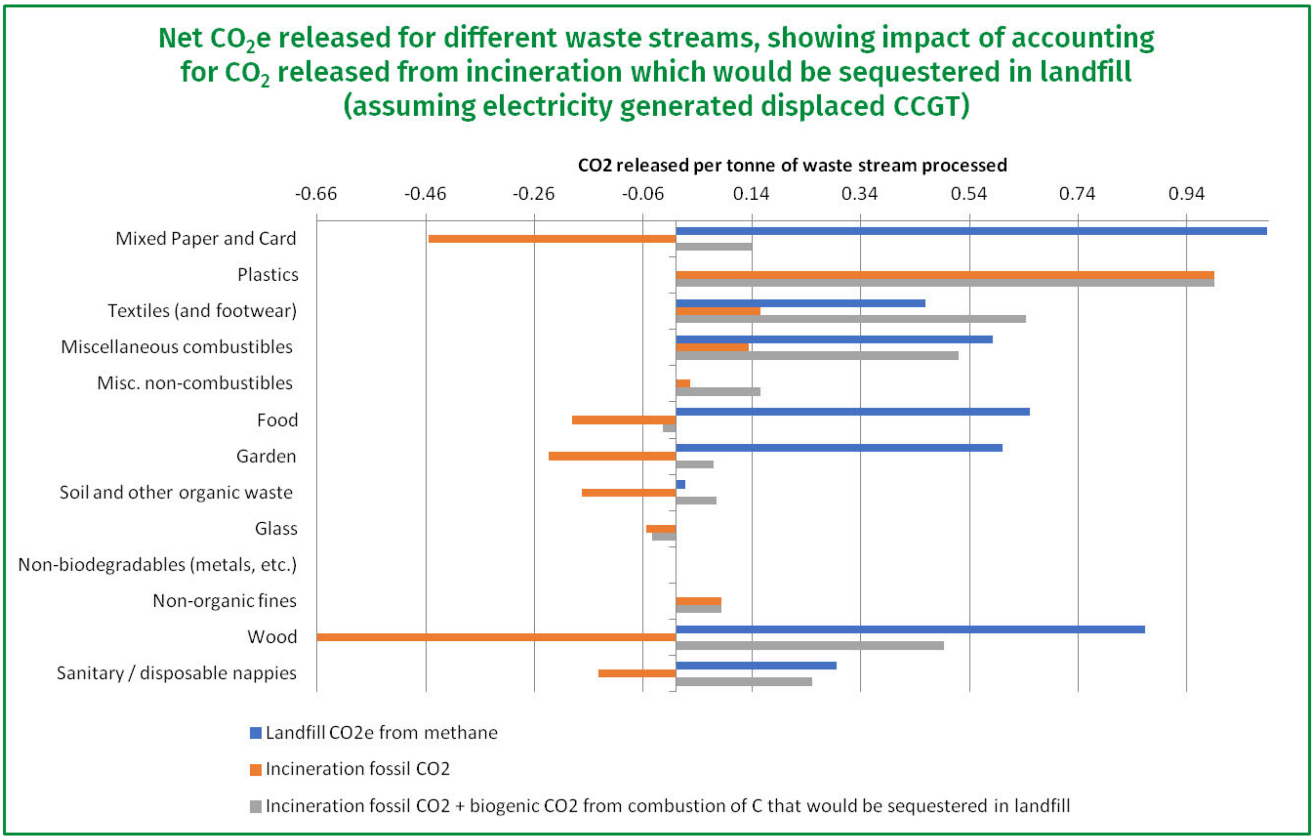
The modelling therefore illustrates how failing to account for the impacts of biogenic carbon sequestration in landfill and/or the decarbonisation of the electricity supply could result in the relative emissions from incineration being significantly understated and the relative emissions from landfill being significantly overstated.

The MELMod dataset used for the charts overleaf only includes the impact of sending waste directly to landfill or to incineration based on default assumptions regarding the impacts of these processes. This means that the modelling used for the charts does not, for example, take account of the impact of bio-stabilising waste prior to landfill in reducing the amount of methane released and increasing the proportion of biogenic carbon which would be sequestered. The impact of these and other considerations are explored in more detail elsewhere within this guidance.

ESTIMATES OF GROSS AND NET IMPACTS OF BIOGENIC CARBON SEQUESTRATION



Based on MELMod Calculations using the AR5 (2014) data set (provided by BEIS)



Based on MELMod Calculations using the AR5 (2014) data set (provided by BEIS)

The approach developed by the Technical University of Denmark

One of the more widely cited works in the academic literature justifying account being taken of biogenic carbon sequestration is the 2009 paper entitled 'C balance, Carbon Dioxide Emissions and Global Warming Potentials in LCA-modelling of Waste Management Systems'. The paper was written by Thomas H Christensen, Emmanuel Gentil, Alessio Boldrin, Anna W Larsen, Bo P Weidema, and Michael Hauschild from the Department of Environmental Engineering at the Technical University of Denmark and published in the journal of Waste Management & Research.

The approach is explained and applied by Turner et al. (2015)[20] as follows:

> *"Based on a simple carbon mass balance model, Christensen et al. (2009) asserts that where the IPCC GWP characterisation factors are used, which count biogenic carbon emissions to air (as CO_2) as neutral, biogenic carbon sequestered in landfill should be ascribed a GWP of −1."*

Arriving at the Global Warming Potential (GWP) figure of -1 requires the carbon to be converted into CO_2, and so the -1 figure is sometimes expressed as -44/12 or -3.67 for clarity. For example: J. Møller, A. Boldrin, and T.H. Christensen[21] state:

> *"Regarding GWP of biogenic and fossil CO2 we adopt the convention that GWP of CO_2, biogenic is 0, GWP of stored biogenic carbon is -44/12 and GWP of CO_2, fossil is 1 (Christensen et al., 2009). "*

The Environmental Assessment of Solid Waste Systems and Technologies (EASEWASTE) Model developed by the Technical University takes account of biogenic carbon sequestration in line with this approach. As explained by Christensen, et al.[22]:

> *"In landfills and where organic compost is used on land, not all of the biogenic carbon is quickly degraded and released. Since a time horizon must be specified for LCA modelling of landfills and use of compost on land any biogenic carbon not degraded within the set time horizon must be counted as sequestered carbon and hence considered to constitute a saving in global warming potential… EASEWASTE can handle time horizons of any length, and it is therefore able to distinguish between emissions of fossil and biogenic CO_2 and to count savings in global warming by sequestered biogenic carbon".*

[20] David A. Turner, Ian D. Williams, Simon Kemp, Greenhouse gas emission factors for recycling of source-segregated waste materials, Resources, Conservation and Recycling, Volume 105, Part A, 2015, Pages 186-197.

[21] Møller, J., Boldrin, A., & Christensen, T. H. (2009). Anaerobic digestion and digestate use: accounting of greenhouse gases and global warming contribution. Waste Management and Research, 27(8), 813-824.

[22] Christensen, Thomas & Bhander, Gurbakhash & Lindvall, Hanna & Larsen, Anna & Fruergaard, Thilde & Damgaard, Anders & Manfredi, Simone & Boldrin, Alessio & Riber, Christian & Hauschild, Michael. (2007). Experience with the use of LCA-modelling (EASEWASTE) in waste management. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA. 25. 257-62.

Approach of the Reference Model on Waste

One of the most high-profile considerations of the issue within a European context is the work carried out by Eunomia and the Copenhagen Resource Institute (CRI) in 2014 in a report for Directorate-General for Environment at the European Commission entitled 'Development of a Modelling Tool on Waste Generation and Management - Appendix 6: Environmental Modelling' which was used in the Impact Assessment of the European Circular Economy package.

The report's use of a credit to take account of avoided biogenic CO_2 emissions was accepted in a technical peer review by BIO Intelligence Service.[23]

According to the report, the approach taken was as follows:

> *"When accounting for the performance of biogenic materials in waste management systems, the default scenario is taken to be the situation where* <u>*all*</u> *of the biogenic carbon contained within the waste material is emitted as biogenic CO2 during the treatment process, i.e., assuming, amongst other things, that no sequestration of biogenic carbon takes place. These biogenic CO2 emissions would be excluded from the analysis under the life cycle approach, as this is considered to be emission relating to carbon recently incorporated into the biogenic materials from the atmosphere during plant growth. Under the life cycle accounting approach, our methodology therefore applies a credit where there is any deviation from this default scenario, as follows:*
>
> *1. Where landfill is concerned, a proportion of the biogenic carbon is actually emitted as methane rather than biogenic CO_2, and these emissions are accounted for in the analysis using the life cycle accounting approach. The carbon emitted as methane could not also be emitted as biogenic CO_2. As such, a credit is applied to account for this change to the default scenario outlined above.*
>
> *2. Depending upon the time horizon being considered, and depending upon the materials, some of the biogenic carbon may not have been emitted at the end of the time period considered. The time period used in the analysis becomes a determinant of how much CO_2 is deemed to be temporarily stored as a result of the management process being considered. Our method therefore applies a second credit to the landfill emissions related to the biogenic CO_2 which would have been emitted if the carbon had completely degraded in the time period…*

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23 [redacted]

The difference in the profile of emissions between these two types of facilities suggests that there is a need to consider the temporary storage of biogenic carbon in landfill within this study. As such, the application of the temporary storage credit as outlined above is in line with the recommendations outlined in Section 7 of the ILCD [International Reference Life Cycle Data System] handbook".

Other examples of accounting for the biogenic carbon sink

EXAMPLES OF GHG ASSESSMENTS AND METHODOLOGIES THAT TAKE ACCOUNT OF THE BIOGENIC CARBON SINK IN LANDFILL

Report & Client	Relevant Assessment Purpose	Approach
North Lincolnshire Green Energy Park - Climate & GHG Assessment (Solar 21, June 2021)[24]	Determining the project's climate impact by *"quantifying the emissions of GHGs and comparing this to the baseline"* with a focus on *"the impacts associated with the operation of the ERF"*	Method 1. *"Included in scope… Long term storage of biogenic carbon in landfill"*.
Greenhouse Gas and Air Quality Impacts of Incineration and Landfill (ClientEarth, March 2021)[25]	To examine the greenhouse gas impacts of alternative approaches to the treatment of residual waste, including comparing landfill; landfill with pre-treatment and bio-stabilisation; incineration; and incineration with pre-treatment that removes plastics.	Method 1. *"…a carbon credit is applied for the biogenic carbon which is stored in a landfill".*
WARM, the EPA's Waste Reduction Model (United States Environmental Protection Agency, November 2020)[26]	*"…to help solid waste planners and organizations track and voluntarily report greenhouse gas (GHG) emissions reductions, energy savings, and economic impacts from several different waste management practices. WARM calculates and totals these impacts from baseline and alternative waste management practices—source reduction, recycling, anaerobic digestion, combustion, composting and landfilling".*	Method 1. *"The storage of carbon in landfills is one of the greenhouse gas (GHG) emission offsets and sinks modeled by EPA's Waste Reduction Model (WARM)".* **More details below in section 'Landfill Carbon Storage in US EPA's Waste Reduction Model'.**

[24] https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/north-lincolnshire-green-energy-park/

[25] [redacted]

[26] [redacted] and [redacted]

Report & Client	Relevant Assessment Purpose	Approach
East Midlands Energy Re-Generation (EMERGE) Centre **Environmental Statement Appendix 8-4: Carbon Assessment and Sustainability** (Uniper, June 2020)[27]	*"…to determine the relative carbon impact of processing the waste in the EMERGE Centre (the Proposed Development) relative to the alternative option of disposing of waste in a landfill".*	Method 1. Sensitivity analysis includes *"Assigning a carbon sequestration benefit to the proportion of biogenic carbon in landfill".* **More details below in section 'Example of Method 1 being used by Uniper for an incinerator proposal'.**
EPS Ready Reckoner Guidance (Greater London Authority, May 2019)[28]	To model London boroughs' greenhouse gas performance against the emissions performance standard (EPS) of the waste chapter of the Mayor's London Environment Strategy.	Method 1. The carbon accounting methodology used within the model *"includes a sequestration credit to account for the un-emitted biogenic carbon in landfill that would otherwise be emitted as biogenic CO2".*
Evaluation of the climate change impacts of waste incineration in the United Kingdom (UKWIN, October 2018)[29]	*"This report evaluates the climate change impacts of waste incineration and is intended to inform policy makers, decision-takers, and the public".*	Method 1. *"… for the purpose of UKWIN's comparative analysis of incineration and landfill, all biogenic carbon which is assumed to be 'sequestered' (permanently stored) in landfill is attributed a 'carbon credit' to recognise the environmental benefit of removing carbon from the cycle. This is represented in the calculations as a negative value emission".*
Proof of Evidence on Energy, Renewable Energy, Combined Heat and Power and Effects on Climate Change for planning inquiry ref 3195373 (Veolia Environmental Services, May 2018)	*"…to estimate the carbon footprint of the ERF [incinerator proposed by Veolia for Hoddesdon] in operation, and the greenhouse gas benefits that it will secure in electricity-only and in CHP modes compared with the status quo".*	Method 1. Sequestered carbon subtracted as CO_2e in the landfill half of the model. **More details below in section 'Example of Method 1 being used by ERM for an incinerator proposal'.**

[27] Nottinghamshire County Council planning ref ES/4154. Volume 3, Appendix 8-4 (Carbon Assessment and Sustainability)
[28] https://www.london.gov.uk/sites/default/files/eps_ready_reckoner_guidance_finalv2_0.pd
[29] [redacted]

Report & Client	Relevant Assessment Purpose	Approach
The Potential Contribution of Waste Management to a Low Carbon Economy (Zero Waste Europe, October 2015)[30]	To determine *"Indicative Climate Change Impacts of Key Waste Management Activities", i.e. "the impacts of prevention and other ways of managing materials in respect of emissions of greenhouse gases".*	Method 2. Results are shown both including and excluding all CO_2 from biogenic sources.
Energy recovery for residual waste: A carbon based modelling approach (Defra, February 2014)[31]	*"This analysis set out to identify the critical factors that affect the environmental case for energy from waste (EfW) in comparison to landfill from a carbon perspective and the sensitivity of that case to those factors. In particular the aim was to examine the influences that the biogenic carbon content of the waste and the thermal efficiency of the EfW process have on the relative benefits of EfW and landfill".*	Methods 1 and 2. The impacts of using both methods are shown as sensitivity analysis in Chart 15. **More details above in section 'Two methods of calculation that accounts for the biogenic carbon sink'**
Assessment of the options to improve the management of biowaste in the European Union (European Union, November 2009)[32]	*"…to look into ways of improving bio-waste management in the EU, and to provide an appropriate assessment of policy options, including the environmental, economic and social impacts, as well as prospective risks / opportunities... the project is expected to contribute to the Commission's assessment of the bio-waste management options".*	Method 2. *"Impacts are shown both inclusive and exclusive of the biogenic CO2 emissions…"*
IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change, 2006)[33]	Producing National Greenhouse Gas Inventories.	Allows for counting of carbon stock change from harvested wood products in landfill and *"all important sources and sinks of all greenhouse gases".* **More details in 'IPCC and US treatment of landfill carbon sinks in GHG inventories'**

30 [redacted]

31 http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

32 [redacted]

33 [redacted]

Applying Method 1 to existing incinerator GHG assessments

Where the greenhouse gas (GHG) assessment fails to account for the impacts of biogenic carbon sequestration on relative biogenic CO_2 emissions it is sometimes possible for this to be corrected, even by third parties, based on the information provided within an existing climate change impact assessment report.

The basic formula is as follows:

Sequestered (avoided) biogenic CO_2 = sequestered biogenic carbon x 44/12

In essence, this is determining how much CO_2 one could expect to have been released were the waste to be incinerated. One converts carbon (C) to carbon dioxide (CO_2) by multiplying it by 44/12 which is sometimes shortened to 3.667, and so can also be expressed as:

Sequestered (avoided) biogenic CO_2 = sequestered biogenic carbon x 3.667

Where the quantity of biogenic carbon is not stated, it can sometimes be derived using known information and assumptions regarding the feedstock and how that material would behave in landfill:

a) If the quantity of biogenic carbon is stated and the amount of DDOC (dissimilable degradable organic carbon) is stated, then the carbon sequestered is the biogenic carbon which is not DDOC carbon:

   Sequestered biogenic carbon = biogenic carbon − DDOC carbon

b) If the amount of biogenic carbon and the degree of biogenic carbon sequestration are stated, then you can use the formula:

   Sequestered biogenic carbon = biogenic carbon x percentage sequestered

c) One can calculate the value from the basic assumptions about the waste, for example:

   Sequestered biogenic carbon = tonnes of waste x total carbon percentage of the waste x biogenic carbon percentage x biogenic carbon sequestration percentage

See the worked example overleaf, produced by UKWIN for the Ford incinerator proposal[34]. This demonstrates a process for calculating the impact of biogenic carbon sequestration in circumstances where not all of the information has been supplied (in this case compensating for the absence of a specified figure for sequestered biogenic carbon where the assumed level of Total DDOC carbon in landfill has been provided).

[34] West Sussex County Council Planning Reference WSCC/011/21 see: [redacted]

RELATIVE NET GHG IMPACT OF SEQUESTERING BIOGENIC CARBON IN LANDFILL

	Source	Figures
(a) Biogenic Carbon	ES Technical Annex D1 Table 1	39,918 tonnes p.a.
(b) Total DDOC Content (*"biogenic carbon not sequestered - degradable"*)	[a] x 50% as per applicant's central DDOC assumption	19,959 tonnes p.a.
(c) Sequestered biogenic carbon	[a] – [b] = [c]	19,959 tonnes p.a.
(d) avoided biogenic CO_2 due to biogenic carbon sequestration in landfill compared to emissions from Ford ERF	**[c] x 44/12**	**73,183 tonnes p.a.**

As such, based on the figures provided by the Ford ERF applicant, if the impact of biogenic carbon sequestration were taken into account then, based on the applicant's modelling parameters, there would be a reduction in the benefits ascribed to the proposed incinerator of 73,183 tonnes of CO_2 per year.

This difference in the rate of biogenic CO_2 release is not included in the figures provided by the Ford incinerator applicant, but it is possible to show the impact of taking biogenic carbon sequestration into account. This can be achieved by subtracting 73,183 from the figures provided by the applicant in their sensitivity analysis summary table of their Technical Annex D1 Carbon Assessment.

The Tables below show that if the applicant's central claim of a benefit of 48,102 tonnes of CO_2 per annum is reduced by 73,183 to take account of biogenic carbon sequestration in landfill then this results in the proposed Ford incineration facility being calculated to have a net disbenefit of 25,081 tonnes of CO_2 per annum.

As can be seen from the Table below, this disbenefit figure of 25,081 tonnes of CO_2 per annum is even higher if one assumes a lower grid displacement factor and/or a higher landfill gas capture rate.

When the grid displacement factor of 350g CO_2 per kWh is applied, as per the applicant's 2020 planning application, then even assuming a landfill capture rate of only 60% the result shows that the proposed incinerator would have an adverse impact relative to sending the same waste directly to landfill once biogenic carbon sequestration is taken into account.

The Ford case highlights the importance of actually calculating the impact of the landfill carbon sink rather than ignoring the impact that it can have on the conclusions of the assessment.

APPLICANT'S CLAIMED 'NET BENEFIT' FIGURES
AT 60-75% LANDFILL GAS CAPTURE RATE
WHICH DID NOT TAKE ACCOUNT OF THE LANDFILL CARBON SINK

Grid Displacement Factor (gCO_2 per kWh)	Landfill Gas Capture Rate 75%	68% (Applicant Central)	60%
	Tonnes CO_2/year of net benefit		
371	29,915	48,102	76,887
350	18,910	44,003	72,680
320	13,187	38,147	66,671
280	5,558	30,338	58,659

SUMMARY OF ADJUSTING THE APPLICANT'S 'NET BENEFIT' FIGURES
AT 60-75% LANDFILL GAS CAPTURE RATE
TO TAKE ACCOUNT OF THE LANDFILL CARBON SINK

Grid Displacement Factor (gCO_2 per kWh)	Landfill Gas Capture Rate 75%	68% (Applicant Central)	60%
	Tonnes CO_2/year of net benefit		
371	-43,268	-25,081	3,704
350	-54,273	-29,180	-503
320	-59,996	-35,036	-6,512
280	-67,625	-42,845	-14,524

Examples of Method 1 being used by ERM for incinerator proposals

Biogenic carbon sequestration was taken into account at a planning inquiry as part of the consideration of the impacts of Veolia's proposed 350,000 tpa incinerator at Hoddesdon, Hertfordshire. Taking the biogenic carbon sink into account reduced the assumed net emissions from landfill from 98,304 tCO_2e (tonnes of CO_2 equivalent) per year to 23,520 tCO_2e in the central modelling scenario, i.e. a reduction of 76%.

Veolia's expert witness accounted for fossil and sequestered carbon for the central analysis in his May 2018 Proof of Evidence on Climate Change when comparing the proposed Hoddesdon incineration facility with sending waste directly to landfill for the stated purpose of determining the *"overall carbon footprint of the facility".*[35]

Veolia's expert witness from the environmental consultancy known as ERM, split the assumed feedstock into 39 categories, and calculated each waste sub-fraction separately. The assessment had a different assumed level of dissimilable degradable organic carbon (DDOC content) for each sub-fraction which was used to determine how much CO_2 would be avoided due to the landfill biogenic carbon sink. This avoided CO_2 was subtracted from the landfill half of the model. If the avoided biogenic CO_2 was instead factored in by including it as CO_2 on the incineration half of the model then this would have increased the direct combustion emissions from 106,443 tCO_2e to 181,227 tCO_2e, i.e. an increase of around 70%.

Another example from ERM comes from the Preliminary Environmental Information Report (PEIR) submitted by Solar 21 relating to their Nationally Significant Infrastructure Project (NSIP) application for the proposed 760ktpa North Lincolnshire Green Energy Park.[36]

According to the June 2021 Climate & Green House Gases report for the scheme the estimated annual net GHG emissions for sending the feedstock to landfill was reduced from 364,108 tpa to 113,385 due to the assumed carbon savings arising from the biogenic carbon stored in landfill, i.e. a reduction of around 69%.

ERM's Climate report included sensitivity analysis for the impact of different levels of biogenic carbon and DDOC. According to the ERM report:

> *"The analysis shows that a 10% reduction in either the biogenic carbon content or DDOC results in a net increase in GHG emissions from the Project compared to the Baseline landfill scenario. However, if the DDOC is increased by 10%, this almost entirely negates a 10% decrease in the biogenic carbon content".*

[35] VES/SA/1 for PINS Ref APP/M1900/V/18/3195373

[36] https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/north-lincolnshire-green-energy-park/

Example of Method 1 being used by Uniper for an incinerator proposal

Uniper considered the impact of the biogenic carbon sink in landfill for their EMERGE incinerator proposal. The applicant found that taking account of the carbon sink reduced the assumed level of CO_2e landfill emissions from 182,291 tCO2e to 46,495 tCO_2e, i.e. a reduction of 74%. The consideration was contained within the sensitivity analysis of the applicant's June 2020 Carbon Assessment[37]. The document notes that:

> *"Under landfill conditions a proportion of the biogenic carbon will not decompose and therefore this carbon would not be released to the atmosphere as would be the case if the waste is combusted in the Proposed Development. Whilst CO_2 associated with biogenic emissions is considered carbon neutral, if this fraction is permanently sequestered in landfill, it could reasonably be considered to constitute a net carbon benefit".*

The analysis based on their central assumptions for biogenic carbon sequestration (DDOC content) and waste composition found that taking the impacts of biogenic carbon sequestration into account would result in their proposed incinerator having a net disbenefit of 27,718 tonnes of CO_2e per annum compared to sending the same waste directly to landfill.

The analysis calculated that, based on their central assumptions, if the proposed feedstock were landfilled then this would avoid the release of 135,797 tonnes of biogenic CO_2 which would otherwise have been released were the same waste to have been incinerated. Uniper used this finding to reduce their assumed level of landfill emissions from 182,291 tCO2e to 46,495 tCO_2e,

Uniper then compared the revised figure of 46,495 tCO_2e emissions from landfill with their central estimate that their proposed incinerator would release 76,212 tonnes of fossil CO_2e. Because 76,212 tCO_2e from incineration is 29,718 tCO_2e per annum worse than the 46,495 tCO_2e tonnes from landfill, this meant that their sensitivity analysis concluded that taking into account biogenic carbon sequestration would result in the proposed incinerator being 46,495 tCO_2e worse than sending the same waste to landfill based on their central modelling parameters. As the applicant put it, their analysis:

> *"…shows the effect on the assessment of considering sequestration…It can be seen that including sequestration…would suggest a disbenefit from the Proposed [Incineration] Development relative to landfill of around 30 kt…of carbon dioxide equivalent emissions per year".*

[37] Nottinghamshire County Council planning ref ES/4154. Volume 3, Appendix 8-4 (Carbon Assessment and Sustainability). Table 18: Sensitivity to assumptions regarding sequestration and DDOC.

Examples of statements supportive of taking the biogenic CO_2 or the landfill carbon sink into account for comparative analysis or other purposes

Statements explaining the decision to take the landfill carbon sink or all biogenic CO_2 into account are set out below, alongside statements promoting such practice as justifiable, desirable, best practice, and/or necessary to produce a valid assessment.

- **'Greenhouse Gas and Air Quality Impacts of Incineration and Landfill'** produced by Eunomia for ClientEarth (March 2021)[38] states that: "*…application of the above approach [of ignoring biogenic CO_2 releases] is problematic when accounting for landfill impacts, as a significant proportion of the biogenic carbon is not released as biogenic CO_2 (or as methane) but instead remains sequestered in the landfill; in this way, landfills act as an imperfect 'carbon capture and storage' facility. In contrast, all of the biogenic CO_2 emissions are released from incineration at the point of combustion. As such, the two systems are not being compared on a like-for-like basis where this approach is applied to considering emissions from residual waste treatment systems. Therefore, this omission of short cycle biogenic carbon emissions is acceptable as long as a carbon credit is applied for the biogenic carbon which is stored in a landfill. If no adjustment is made, the exclusion of the biogenic CO_2 emissions will overestimate landfill impacts relative to other forms of treatment in which all the biogenic carbon is released as CO_2 into the atmosphere.*"
- **'Carbon Assessment Review: Alton Advanced Energy Recovery Facility'** produced by Air Quality Consults for No Wey Incinerator (August 2020)[39] noted: "*The [applicant's] assessment has also scoped out the potential benefit from sequestering biogenic carbon that is likely to be associated with waste treatment by landfill. Independent research by Defra indicates that this "benefit" is not insignificant and would warrant further consideration*" and recommended that: "*Landfill CO_2e assessment to consider impact of sequestering biogenic carbon.*"

  'Alton AAERF Atkins Review Report' produced by Atkins for Hampshire County Council (October 2020)[40] agreed with Air Quality Consultants' recommendation, observing that following the recommendation: "*…would provide a more complete picture of the baseline scenario against which the development is being compared. Currently, this element is missing, which potentially misrepresents the impact of landfill as being higher than would be the case were this mechanism addressed.*"
- **'EPS Ready Reckoner Guidance'** produced by Eunomia for The Greater London Authority (May 2019)[41] stated: "*…if no adjustment is made, the exclusion of the biogenic CO_2 emissions will overestimate landfill impacts relative to other forms of treatment where all of the biogenic carbon is released as CO_2 into the atmosphere.*

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38 [redacted]
39 Hampshire County Council planning application no. 33619/007
40 Hampshire County Council planning application no. 33619/007
41 https://www.london.gov.uk/sites/default/files/eps_ready_reckoner_guidance_finalv2_0.pdf

As such, our landfill model includes a sequestration credit to account for the un-emitted biogenic carbon in landfill that would otherwise be emitted as biogenic CO_2, in line with the approach set out by Gentil et al (2009)."

- **'The Potential Contribution of Waste Management to a Low Carbon Economy'** produced by Eunomia for Zero Waste Europe (October 2015)[42] recommends that: *"All lifecycle studies engaged in comparative assessments of waste treatments should incorporate CO_2 emissions from non-fossil sources in their comparative assessment."*
- **'Energy recovery for residual waste: A carbon based modelling approach'** (Defra, February 2014)[43] stated: *"Landfill…acts as a partial carbon sink for the biogenic carbon. This is a potential additional benefit for landfill over energy from waste."*
- **'Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment'** by Levasseur et al. (July 2012)[44] stated: *"...not considering biogenic CO_2 can lead to biased conclusions. If a fraction of the biogenic carbon is assumed to be sequestered permanently, as was the case for the carbon sequestered…then the amount of biogenic carbon entering the product system is not equal to the amount leaving the system, which means that biogenic CO_2 emissions cannot be considered neutral."*
- **'Annex F: Environmental assumptions of assessment of the options to improve the management of bio-waste in the European Union'** produced by Eunomia and ARCADIS for the European Union (February 2010)[45] states that: *"Whatever the merits or otherwise of not reporting biogenic CO_2 for the purpose of national inventories, in comparative assessments between processes, it cannot be valid to ignore biogenic CO_2 if the different processes deal with biogenic CO_2 in different ways. Given that different processes often deal with non-fossil CO_2 in different ways, and that the atmosphere does not distinguish between molecules of greenhouse gas depending on their origin, the omission of non-fossil CO_2 from analyses appears dubious."*
- ***'Landfill Carbon Storage in EPA's Waste Reduction Model'*** by the United States Environmental Protection Agency (US EPA, October 2010) stated: *"The inclusion of landfill carbon storage factors allows WARM to more accurately model the carbon flows and emissions that occur for landfilled materials from a life-cycle perspective… By including landfill carbon storage, WARM provides a more complete accounting of the GHG emissions associated with different waste management options from a life-cycle perspective"*. (For more details see the below section on 'Landfill Carbon Storage in US EPA's Waste Reduction Model').

42 [redacted]

43 http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

44 'Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment' by Levasseur, Annie & Lesage, Pascal & Margni, Manuele & Samson, Réjean (2012).

45 [redacted]

- **'Life Cycle Assessments of Energy from Solid Waste'** by Finnveden et al. (August 2000)[46] states: *"The practise to disregard biotic CO_2-emissions can lead to erroneous results"*, and provides an example of how if one compares incineration with the landfill without taking account of the difference in the release of biogenic CO_2 then: *"This difference is however not noted [when one ignores biogenic CO_2], since the CO_2-emissions are disregarded and this is in principle a mistake"*.
- **'How to Account for CO2 Emissions from Biomass in an LCA'** by Rabl, et al. (2007) stated: *"...the CO_2 emitted during incineration has to be counted fully".*[47]
- **'Revised IPCC Guidelines for National Greenhouse Gas Inventories: Workbook'** (1996) states in its introduction that: *"Ultimately, each country should report all important sources and sinks of all greenhouse gases".*[48]

  (For more detail see the below section on 'IPCC and US treatment of landfill carbon sinks in GHG inventories')

IPCC and US treatment of landfill carbon sinks in GHG inventories

It is sometimes claimed that one has to ignore the impact of the landfill carbon sink because of the assumption that accounting for biogenic CO_2 would go against guidance from the Intergovernmental Panel on Climate Change (IPCC) regarding GHG inventory reporting. This does not stand up to scrutiny for several reasons.

Firstly, the IPCC provides guidance on GHG inventory reporting and not on conducting comparative assessments of different waste treatment options, and so the logic from one does not necessarily apply to the other. In most cases the primary purpose of carrying out a comparison between different waste treatment options is to understand their likely climate change impacts rather than their impact on what would be reported in a GHG inventory.

Secondly, the IPCC not only requires that biogenic CO_2 emissions from incineration are reported (as an information item) but it allows for the impacts of the landfill carbon sink to be accounted for within GHG inventories. This is the approach which has long been taken in the United States of America.

[46] Finnveden, J. Johansson, P. Lind and A. Moberg (2000) Life Cycle Assessments of Energy from Solid Waste, FMS: Stockholm. Available from:
[redacted]
[47] Rabl A (2007) How to Account for CO2 Emissions from Biomass in an LCA, International Journal of Life Cycle Assessment, 12, pp281.
[48] Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Workbook (Volume 2).
[redacted]l and [redacted]

According to Chapter 3 of Volume 5 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories:

> "*Some carbon will be stored over long time periods in SWDS [solid waste disposal sites, i.e. landfill]. Wood and paper decay very slowly and accumulate in the SWDS (long-term storage)*…
>
> *The long-term stored carbon in SWDS is reported as an information item in the Waste sector. The reported value for waste derived from harvested wood products (paper and cardboard, wood and garden and park waste) is equal to the variable 1B, CHWP SWDS DC, i.e., the carbon stock change of HWP [Harvested Wood Products] from domestic consumption disposed into SWDS of the reporting country used in Chapter 12, Harvested Wood Products, of the AFOLU Volume*".[49]

The US goes further on the basis that landfill is a significant carbon sink. As noted in the IPCC Guidelines for National Greenhouse Gas Inventories Workbook[50]:

> *"Ultimately, each country should report all important sources and sinks of all greenhouse gases"*.

From this perspective, it may be a matter of time before all countries take account of landfill carbon sinks within their own GHG inventories. In light of this prospect it would be prudent to take account of biogenic carbon sequestration in landfill (the landfill carbon sink) for all projects that may have climate impacts well into the future, e.g. when considering the relative climate impacts of an incinerator proposed today that would be expected to be operational in 30 or 40 years time.

A report from 2021 entitled 'Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019'[51] explains the approach that the US takes to accounting for biogenic carbon in accordance with IPCC guidelines.

Chapter 7 on Waste[52] states:

> *"Net carbon dioxide flux from carbon stock changes in landfills are estimated and reported under the Land Use, Land-Use Change, and Forestry (LULUCF) sector (see Chapter 6 of this Inventory)…"*

49 [redacted]

50 Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Workbook (Volume 2). [redacted]

51 https://[redacted]

52 [redacted]

Chapter 6 of the Inventory further explains:

> "*In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are put in landfills. Carbon (C) contained in landfilled yard trimmings and food scraps can be stored for very long periods.*
>
> *Carbon storage estimates within the Inventory are associated with particular land uses. For example, harvested wood products are reported under Forest Land Remaining Forest Land because these wood products originated from the forest ecosystem. Similarly, C stock changes in yard trimmings and food scraps are reported under Settlements Remaining Settlements because the bulk of the C, which comes from yard trimmings, originates from settlement areas. While the majority of food scraps originate from cropland and grassland, in this Inventory they are reported with the yard trimmings in the Settlements Remaining Settlements section…*"

This approach was explained in more details in an extant document published by the United States Environmental Production Agency (EPA) in 2010[53] which states that:

> *"Carbon storage represents a significant part of the overall landfill carbon balance for some materials. EPA estimated that the stock of carbon in U.S. landfills was about 9.5 million metric tons of carbon dioxide equivalent (MTCO2E) in 2008, which is equivalent to offsetting about 7.5 percent of landfill methane emissions. EPA follows the approach outlined by the Intergovernmental Panel on Climate Change (IPCC) international guidelines on GHG inventories, which accounts for the landfill carbon storage of harvested wood products. In addition, the U.S. Inventory of U.S. Greenhouse Gas Emissions and Sinks includes carbon storage for yard trimmings and food scraps in accordance with the IPCC recommendation that countries account for all significant emission sources and sinks."*

Landfill Carbon Storage in US EPA's Waste Reduction Model

The US Environmental Protection Agency's (EPA's) Waste Reduction Model (WARM) model credits landfill for its role as a carbon sink, and this is in line with Method 1(b) outlined above because the sequestered carbon credit is applied to the landfill element of the model.

53 [redacted]

According to the US EPA, the WARM model was created:

> "…*to help solid waste planners and organizations track and voluntarily report greenhouse gas (GHG) emissions reductions, energy savings, and economic impacts from several different waste management practices. WARM calculates and totals these impacts from baseline and alternative waste management practices—source reduction, recycling, anaerobic digestion, combustion, composting and landfilling.*"

The model is now in version 15, last updated November 2020.[54] To help explain the model, the EPA produced *'Landfill Carbon Storage in EPA's Waste Reduction Model'*[55]. According to this document:

> *"The storage of carbon in landfills is one of the greenhouse gas (GHG) emission offsets and sinks modeled by EPA's Waste Reduction Model (WARM). WARM allows users to estimate the life-cycle GHG emission benefits associated with waste management practices (recycling, source reduction, landfilling, incineration with energy recovery and composting…Accounting for landfill carbon storage in WARM along with landfill methane emissions provides a more comprehensive estimate of the GHG implications associated with landfilling materials."*

Providing a rationale for accounting for the impact of landfill carbon, the EPA notes:

> *"The inclusion of landfill carbon storage factors allows WARM to more accurately model the carbon flows and emissions that occur for landfilled materials from a life-cycle perspective."*

Under the WARM model treatment options for materials at the top tiers of the waste hierarchy (prevention through net source reduction, composting, and anaerobic digestion) generally perform significantly better than options at the bottom tiers of the waste hierarchy (landfill and combustion/incineration). As with other models, the incineration of plastics is shown to have a worse greenhouse gas impact than landfill even when energy generation is taken into account because incinerating plastics releases fossil CO_2 while no greenhouse gasses are released when plastic is landfilled. However, there are notably a number of instances where taking into account the impact of the biogenic carbon sink results in incineration being found to perform worse than landfill in terms of net greenhouse gas impacts.

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54 [redacted]

55 [redacted]

WARM MODEL APPROACH TO CARBON STORAGE FROM LANDFILLED PAPER

The EPA November 2020 documentation on using WARM model version 15 with Containers, Packaging, and Non-Durable Good Materials states:

> *"From a waste management perspective, landfilling some materials—including newspaper and phone books—results in net storage (i.e., carbon storage exceeds CH4 plus transportation energy emissions) at all landfills, regardless of whether gas recovery is present. At the other extreme, office paper and textbooks result in net emissions regardless of landfill gas collection and recovery practices."*[56]

The EPA's November 2020 document also shows the following table, which is based on US waste management practices:

Exhibit 3-27: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation	Net Landfill Carbon Storage	GHG Emissions from Transport-ation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Corrugated Containers	2.36	1.14	0.75	(0.72)	0.02	1.66	0.47	0.06
Magazines/ Third-Class Mail	1.08	0.46	0.36	(0.85)	0.02	0.25	(0.39)	(0.49)
Newspaper	0.94	0.43	0.28	(1.19)	0.02	(0.23)	(0.74)	(0.90)
Office Paper	3.50	1.61	1.05	(0.12)	0.02	3.40	1.54	0.95
Phone Books	0.94	0.43	0.28	(1.19)	0.02	(0.23)	(0.74)	(0.90)
Textbooks	3.50	1.61	1.05	(0.12)	0.02	3.40	1.54	0.95
Mixed Paper (general)	2.14	1.00	0.67	(0.72)	0.02	1.44	0.32	(0.04)
Mixed Paper (primarily residential)	2.07	0.97	0.65	(0.76)	0.02	1.33	0.25	(0.09)
Mixed Paper (primarily from offices)	2.03	0.91	0.64	(0.64)	0.02	1.42	0.31	0.00

Note: Negative values denote GHG emission reductions or carbon storage.

The EPA document explains how *"WARM calculates landfill carbon storage from paper products based on laboratory test data on the ratio of carbon storage per short ton of paper landfilled"* and provides an exhibit showing the calculations used:

Exhibit 3-28: Calculation of the Carbon Storage Factor for Landfilled Paper Products

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (g C/Dry g)	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of Carbon Storage to Wet Weight (g C/Wet g) (d = b × c)	(e) Amount of Carbon Stored ($MTCO_2E$ per Wet Ton)
Corrugated Containers	0.26	83%	0.22	0.72
Magazines/Third-Class Mail	0.28	92%	0.25	0.85
Newspaper	0.41	87%	0.36	1.19
Office Paper	0.04	91%	0.04	0.12
Phonebooks[b]	0.41	87%	0.36	1.19
Textbooks[c]	0.04	91%	0.04	0.12

[a] Based on estimates in Barlaz (1998), Wang et al. (2013), Wang et al. (2011), and Levis et al. (2013).
[b] Newspaper used as a proxy.
[c] Office Paper used as a proxy.

56 [redacted]

According to the EPA's WARM model documentation:

> *"A portion of the carbon contained in food waste does not decompose after disposal and remains stored in the landfill. Because this carbon storage would not normally occur under natural conditions (virtually all of the carbon in the organic material would be released as CO2, completing the photosynthesis/respiration cycle), this is counted as an anthropogenic carbon sink…"*[57]

The approach is summarised by the EPA in the following exhibits:

Exhibit 1-48: Calculation of the Carbon Storage Factor for Landfilled Food Waste

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (grams of Carbon Stored/dry gram of Material)[a]	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of Carbon Storage to Wet Weight (grams of Carbon/wet gram of Material) (d = b × c)	(e) Amount of Carbon Stored ($MTCO_2E$ per Wet Short Ton)
Food Waste	0.10	0.27	0.03	0.09

[a] Based on estimates developed by James W. Levis, Morton Barlaz, Joseph F. DeCarolis, and S. Ranji Ranjithan at North Carolina State University; see Levis et al. (2013).

Exhibit 1-49: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electric Generation	Net Landfill Carbon Storage	GHG Emissions From Transportation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Food Waste	1.62	0.63	0.52	(0.09)	0.02	1.39	0.54	0.42

Note: Negative values denote GHG emission reductions or carbon storage.

57 [redacted]

WARM MODEL APPROACH TO CARBON STORAGE FROM LANDFILLED GARDEN WASTE

According to the EPA's WARM model documentation:

> *"Because yard trimmings are not completely decomposed by anaerobic bacteria, some of the carbon in them remains stored in the landfill. This stored carbon constitutes a sink (i.e., negative emissions) in the net emission factor calculation."*

The approach is summarised by the EPA in the following exhibits:

Exhibit 2-10: Calculation of the Carbon Storage Factor for Landfilled Yard Trimmings

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (grams of Carbon Stored/dry gram of Material)[a]	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of Carbon Storage to Wet Weight (grams of Carbon/wet gram of Material) (d = b × c)	(e) Amount of Carbon Stored ($MTCO_2E$ per Wet Short Ton)
Yard Trimmings				0.54
Grass	0.24	0.18	0.04	0.14
Leaves	0.39	0.62	0.24	0.79
Branches	0.38	0.84	0.32	1.06

Note: Yard trimmings are calculated as a weighted average of grass, leaves and branches, currently based on an estimate in the *Facts and Figures* report for 2007 (EPA, 2008, p. 58). This information is not updated annually by EPA.

[a] Based on estimates developed by James W. Levis, Morton Barlaz, Joseph F. DeCarolis, and S. Ranji Ranjithan at North Carolina State University; see Levis et al. (2013).

Exhibit 2-11: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electric Generation	Net Landfill Carbon Storage	GHG Emissions From Transportation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Yard Trimmings	0.73	0.35	0.29	(0.54)	0.02	0.21	(0.18)	(0.24)
Grass	0.51	0.25	0.23	(0.14)	0.02	0.39	0.11	0.09
Leaves	0.59	0.26	0.22	(0.79)	0.02	(0.18)	(0.52)	(0.56)
Branches	1.30	0.65	0.44	(1.06)	0.02	0.26	(0.38)	(0.61)

Note: Negative values denote GHG emission reductions or carbon storage.

DISCREPANCIES BETWEEN THEORETICAL AND REAL WORLD PERFORMANCE

> **RECOMMENDATION #6: The carbon performance of modern waste incinerators is often significantly worse than was predicted through modelling at the planning and permitting stages. This discrepancy between predicted and actual carbon performance needs to be taken into account when modelling, and robust sensitivity analysis is needed to ensure that CO_2e emissions from incineration are not significantly underestimated.**

> **RECOMMENDATION #7: Power export underperformance, e.g. due to turbine or generator failure or during commissioning, is a realistic prospect for modern waste incinerators that needs to be taken into account when modelling anticipated power output and associated climate impacts.**

As set out in more detail below, original analysis was conducted for this guidance to investigate current real world performance of the UK's Municipal Waste Incinerators (MWIs) based on information reported by operators and how this performance compares to historic GHG modelling carried out by the applicant for these facilities.

This research found that incinerators often perform significantly worse than modelled for planning applications and environmental permits. Incinerators often deliver lower levels of electricity generation and higher levels of fossil CO_2 emissions, resulting in a higher carbon intensity than claimed by those promoting such schemes.

The analysis found that for the incinerators studied, on average:

- The proportion of CO_2 that was fossil CO_2 was 13 percentage points higher than predicted at the planning or permitting stage.
- The fossil carbon intensity of electricity exported to the grid was around 49% higher than predicted by the applicant at the planning or permitting stage.
- Reported fossil CO_2 released per tonne of waste feedstock incinerated was around 20% higher than that predicted at the planning or permitting stage.
- Electricity generated by incinerators was 15% lower than implied by the claimed headline megawatt (MW) generation figure, i.e. an incinerator advertised as being capable of generating 10MW of electricity typically only generated 8.5MW.
- Electricity exported was around 28% lower headline MW generation figures.

Underperformance at a number of individual facilities was significantly worse than the average. These findings are relevant to considerations of which central assumptions to adopt and they highlight the need for robust sensitivity analysis that takes into account how incineration has a history of carbon performance being significantly worse than predicted at the planning and permitting stages.

GHG performance of Viridor incinerators based on reported emissions

Annual GHG performance can be calculated based on information provided to the Environment Agency (EA) by incinerator operators within their Pollution Inventory returns and their Annual Performance Reports. Through these documents incinerator operators report CO_2 and N_2O emissions, imported and exported electricity, and the number of tonnes processed during the year covered by the report.

Unlike some operators, Viridor reports their CO_2 emissions as being based on actual measurements, and this makes Viridor's returns especially helpful in understanding the real world carbon performance of incinerators. The facilities considered below are all modern Municipal Waste Incinerators (WMIs), having first treated waste between 2015 and 2018.

See technical appendix below for more notes and commentary on the reported emissions.

REPORTED EMISSIONS FOR 2019 AND 2020

Incineration Plant	Carbon percentage in feedstock	CO_2e per tonne processed (tonnes)	Biogenic Fraction	Fossil CO_2e per tonne processed (tonnes)	Power Exported per tonne processed (kWh)	Fossil carbon intensity of energy exported (gCO2/kWh)
Ardley (2019)	26%	1.005	49%	0.537	58	9311
Ardley (2020)	26%	1.013	55%	0.479	563	852
Runcorn (2019)	28%	1.033	48%	0.537	615	873
Runcorn (2020)	27%	0.992	53%	0.464	547	848
Beddington (2019)	26%	0.973	51%	0.497	600	828
Peterborough (2019)	26%	0.970	60%	0.388	658	590
Peterborough (2020)	26%	0.937	60%	0.375	655	573

Note: The analysis assumes that the N_2O reported as 'Below Reporting Threshold' was zero. The value for Peterborough is based on a biogenic fraction claimed by the operator which they could not explain. Figures for CO_2e per tonne and fossil carbon intensity omit emissions associated with construction and demolition, importing and discharging water, and transport. Confirmed 2020 figures for Beddington were not available at the time of publication.

Comparing predicted and reported GHG performance at Viridor incinerators

Predicted emissions can be compared against real world emissions based on performance data reported by the operator to the Environment Agency.

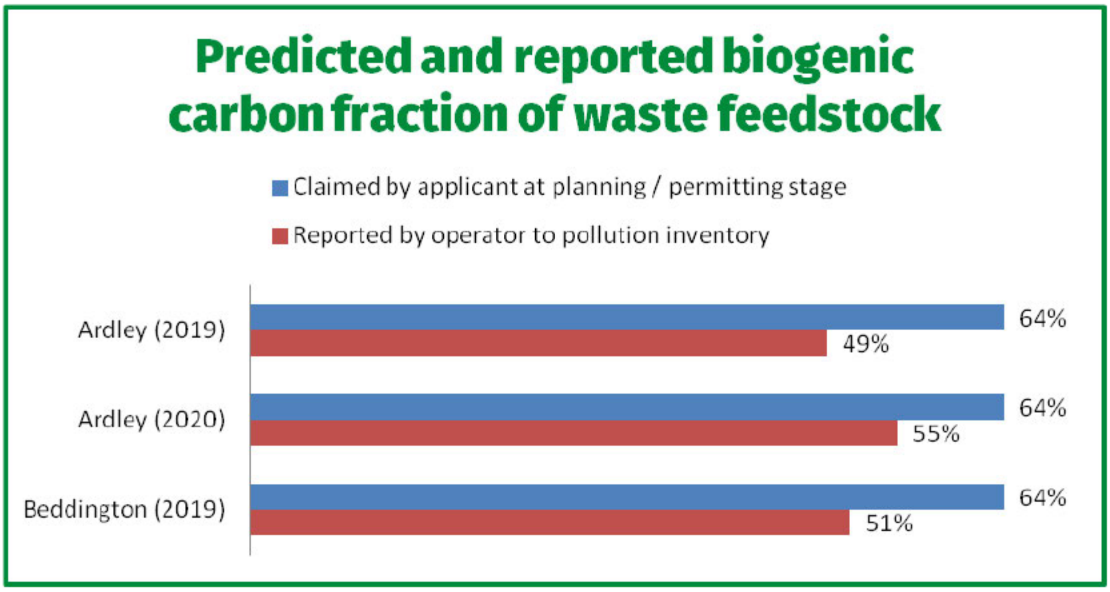
See technical appendix below for more notes and commentary on these comparisons.

BIOGENIC CARBON FRACTION

The predicted 64% biogenic carbon fraction which formed the basis of the modelling of GHG emissions used to secure environmental permits for Viridor's Ardley and Beddington incinerators appear to have been proven to have been overly optimistic.

From the data supplied by the operator we now know that the biogenic fraction was between 49% and 55% for the two facilities. This means that on average the real world performance was 13 percentage points worse than was predicted at the planning or permitting stage.

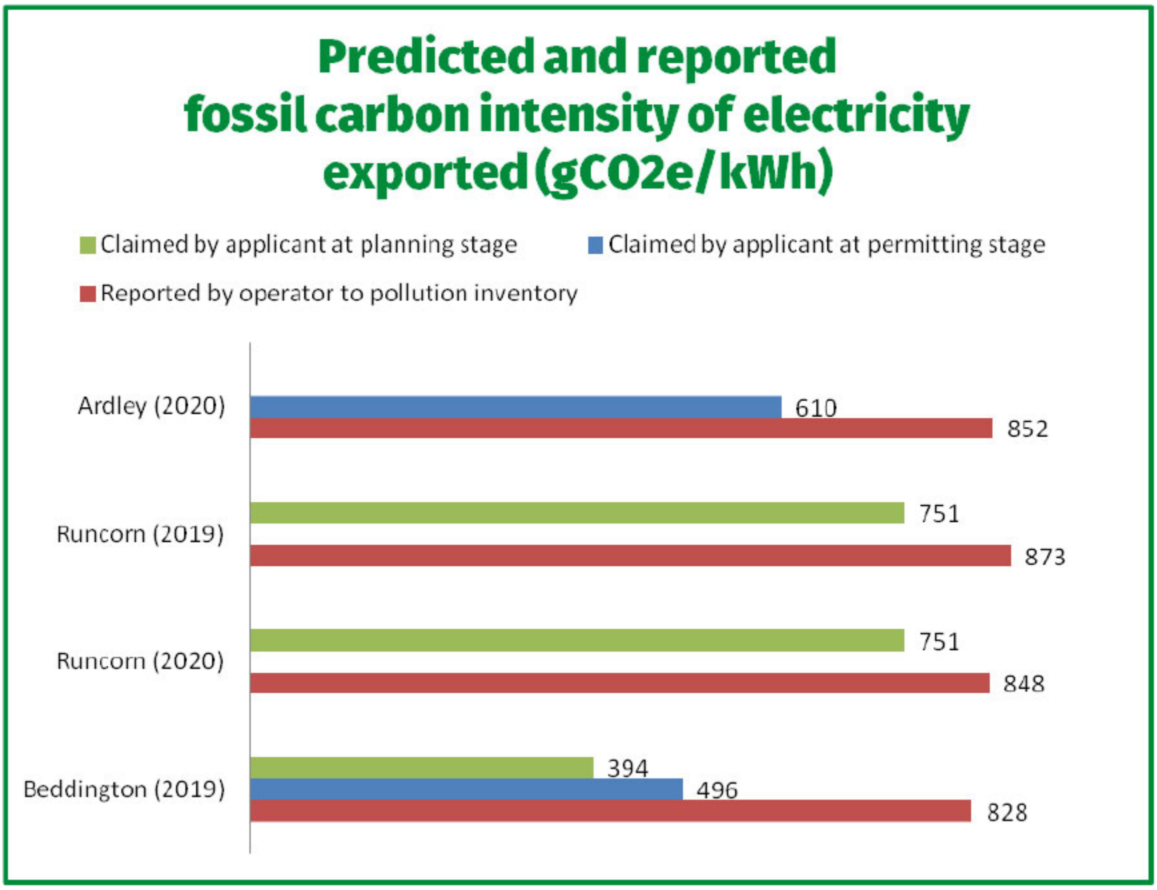
A 13 percentage point lower biogenic fraction means that a significantly lower proportion of the energy generated is considered 'renewable' and a significantly higher proportion of the energy is considered 'fossil derived'.



COMPARISON BETWEEN PREDICTED AND REPORTED BIOGENIC CARBON FRACTION

Incineration Plant and year of reporting	Biogenic carbon percentage of feedstock: Claimed by applicant at planning or permitting stage	Reported by operator to pollution inventory	Percentage points difference between predicted and reported emissions
Ardley (2019)	64%	49%	-15%
Ardley (2020)	64%	55%	-9%
Beddington (2019)	64%	51%	-13%
		Average	**-13%**

FOSSIL CARBON INTENSITY

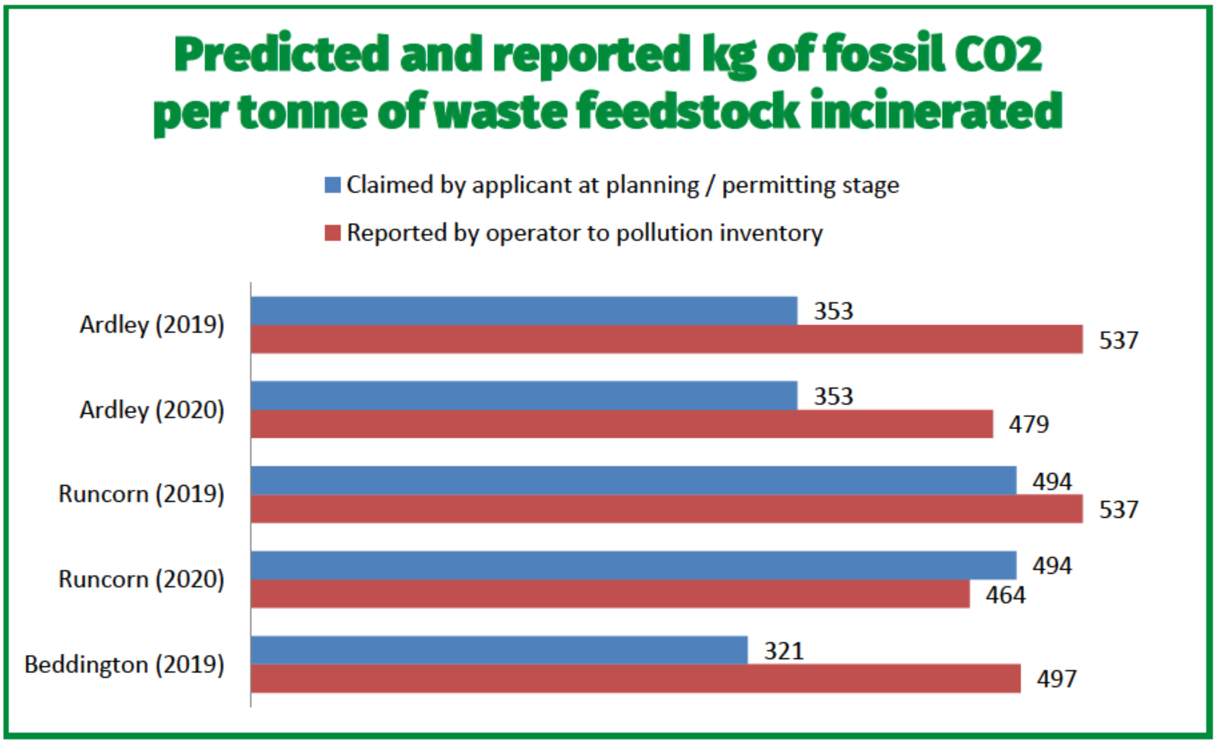


COMPARISON BETWEEN PREDICTED AND REPORTED FOSSIL CARBON INTENSITY

	Fossil carbon intensity (gCO2/kWh)				
Incineration Plant and year of reporting	**Claimed by applicant at planning stage**	**Claimed by applicant at permitting stage**	**Reported by operator to pollution inventory**	**Percentage higher reported emissions are than predicted at permitting stage**	**Percentage higher reported emissions are than predicted at planning stage**
Ardley (2020)	610		852	40%	
Runcorn (2019)		751	873		16%
Runcorn (2020)		751	848		13%
Beddington (2019)	496	394	828	67%	110%
			Average	**53%**	**46%**
			Combined Average		**49%**

FOSSIL CO_2E PER TONNE OF WASTE PROCESSED

Runcorn released less fossil CO_2 in 2020, but less energy was produced, presumably due to less RDF in the feedstock than predicted.



COMPARISON BETWEEN PREDICTED AND REPORTED TONNES OF FOSSIL CO2 RELEASED PER TONNE OF WASTE PROCESSED

	Kilograms of fossil CO_2e released per tonne processed			
Incineration Plant and year of reporting	Claimed by applicant at planning / permitting stage	Reported by operator to pollution inventory	Kilograms reported emissions are higher than predicted	Percentage reported emissions are higher than predicted
Ardley (2019)	353	537	185	34%
Ardley (2020)	353	479	127	26%
Runcorn (2019)	494	537	44	8%
Runcorn (2020)	494	464	-30	-6%
Beddington (2019)	321	497	176	35%
Average	**403**	**503**	**100**	**20%**

MW GENERATED AND EXPORTED

It is important to take account of how real world levels of electricity generated and the net amount of electricity exported to the grid can be significantly lower than the headline ('plated') figure for electricity generation. The difference between the electricity generated and the electricity exported is the electricity needed to power the facility.

The headline capacity of an incinerator is usually stated within its Annual Performance Report, but in some cases we have had to rely on other public material published by the operator.

The discrepancy between the headline and real world figures have been calculated to inform this guidance using the 2020 Annual Performance Reports provided by operators, which include the headline figure, the number of hours of operation, and the electricity actually generated, imported or used to power the plant.

The real world MW capacity figures are calculated by dividing the gross or net electricity generated or exported by the average hours of operation across all incinerator lines. Because the purpose of this comparison is to show the impact of the facility in adding to electricity generation, the imported electricity is subtracted from the net amount of electricity exported.

COMPARISON BETWEEN HEADLINE GENERATION CAPACITY AND ACTUAL MEGAWATTS (MW) OF ENERGY GENERATED AND EXPORTED FOR ELECTRICITY-ONLY INCINERATORS IN ENGLAND IN 2020

Incineration Plant (Operator)	Gross headline MW	Gross MW generated in 2020	Net MW exported in 2020	Percentage gross generated higher than headline	Percentage net exported higher than gross headline
Milton Keynes (Amey)	7	5.4	4.0	-23%	-43%
Exeter (Cyclerval)	4	3.8	3.0	-6%	-25%
Hartlebury (EnviRecover)	22	20.1	18	-9%	-20%
Lincolnshire (FCC)	13.1	13.1	11.6	0%	-12%
Greatmoor (FCC)	32	27.5	24.7	-14%	-23%
Allington (FCC)	43	35.2	26.1	-18%	-39%
Lakeside (Grundon & Viridor)	37	37.1	33.3	0%	-10%
Stoke (MES)	14	6.8	5	-52%	-66%
Dudley (MES)	7	5.8	5	-18%	-32%
Ferrybridge Multifuel 1 (enfinium)	80	54.3	48	-32%	-41%
Ferrybridge Multifuel 2 (enfinium)	80	72.9	66	-9%	-18%
Suffolk EfW (Suez)	25.25	24.2	21.3	-4%	-16%
Haverton Hill (Suez)	55	53.7	46.6	-2%	-15%
Cornwall (Suez)	24	20.1	17.7	-16%	-26%
Severnside (Suez)	40	39.5	36	-1%	-10%
Kirklees (Suez)	10	2.1	1	-79%	-94%
Wilton 11 (Suez)	49	27.4	22	-44%	-55%
Javelin Park (Urbaser)	17.4	17.8	15.5	+2%	-12%
Integra South East, Portsmouth (Veolia)	14	12.2	10.2	-13%	-27%
Newhaven (Veolia)	19	18.5	16.1	-2%	-15%
Integra North, Chineham (Veolia)	9	7.4	6.4	-17%	-28%
Integra South West, Marchwood (Veolia)	17	12.6	10.9	-26%	-36%
Battlefield, Shropshire (Veolia)	8	7.6	7	-5%	-11%
Staffordshire (Veolia)	29	26.8	24	-7%	-17%
Tyseley (Veolia)	27	25.9	22	-4%	-17%
Leeds (Veolia)	15	13.3	11	-11%	-24%
Runcorn (Viridor)	86	76.2	66	-11%	-23%
Avonmouth (Viridor)	37.2	39.9	33	+7%	-12%
Peterborough (Viridor)	9	7.5	6	-17%	-34%
Average				-15%	-28%

Evidence of power export unreliability in modern waste incinerators

As set out in the Table below, Tolvik has reported problems with turbine and generator availability within their recent annual EfW statistics reports.

TOLVIK OBSERVATIONS ON TURBINE AND GENERATOR NON-AVAILABILITY

Year being observed	Observation by Tolvik
2018	*"Poor turbine reliability - The stand out operational issue for 2018 was that total power export was unchanged on 2017 despite increased inputs. This was due to at least 6 EfWs experiencing significant turbine difficulties during the year. The key question is whether this poor reliability was a 'blip' or part of a longer term trend."*[58]
2019	*"Power export reliability - For the second successive year total power export from UK EfWs, when measured in terms of kWh generated per tonne of waste processed, fell as the result of major turbine/generator failures."*[59]
2020	*"There was a significant increase in the number of facilities reporting average Turbine Operations availability in excess of 95% during 2020 – up from seven in 2019 to 14. However six EfWs reported a figure below 75% including Bolton and Kirklees…, two ACTs…plus Hanford and Ferrybridge FM1"*[60]

EXAMPLES OF THE IMPACT OF POWER EXPORT UNRELIABILITY AT UK INCINERATORS BASED ON DATA PROVIDED IN ANNUAL PERFORMANCE REPORTS

Facility and Year	Power Import (MWh)	Power Export (MWh)	Net Power Exported (MWh)	Net Power Exported (KWh/t)	Hours of waste comb-ustion	Hours of turbine operation	Turbine availability during combustion (percentage of hours of waste combustion)
Ardley (2019)	22,248	16,142	-6,106	-22	7,857	624	8%
Bolton (2020)	7,830	0	-7,830	-148	5,252	0	0%
Kirklees (2020)	8,700	13,416	4,716	38	7,583	1,567	21%
FM1 (2020)	12,619	408,497	395,878	660	8,325	6,113	73%
Stoke (2020)	6,423	43,649	37,226	197	7,788	4,610	59%

Note: The turbine availability figure underestimates the amount of time the plant is operational without a turbine for multi-line plants. This is because the hours of combustion is based on an average of all incinerator lines rather than the number of hours where any combustion activity is taking place (as this figure is generally not specified within Annual Performance Reports).

58 [redacted]

59 [redacted]

60 [redacted]

DETAILS OF PLANTS USED AS EXAMPLES OF UNRELIABLE POWER EXPORT

Facility	Operator	Permit numbers	Permitted capacity
Ardley, Oxfordshire	Viridor	FP3134GU	326,300 tpa
Bolton, Greater Manchester	SUEZ	RP3036QU	120,000 tpa
Kirklees, West Yorkshire	SUEZ	BJ6178IX	135,000 tpa
Ferrybridge Multifuel 1 (FM1), West Yorkshire	SSE and Wheelabrator	SP3239FU	725,000 tpa
Stoke-on-Trent	MES Environmental (CNIM Group)	QP3234SX	210,000 tpa

EXPLANATIONS GIVEN FOR POWER EXPORT UNRELIABILITY

Facility (Year)	Explanation of unreliability in Annual Performance Report
Ardley (2019)	*"On 27 January 2019, a generator stator earth occurred at Ardley, resulting in the loss of generation capability. The generator was removed from Ardley on the 8th March 2019 for repairs within the UK. On 18th October 2019 the generator was removed from the UK to the Original Equipment Manufacturer in Austria to complete the repairs. The generator returned to Ardley on 23 January 2020 and began export 6 February 2020."*
Bolton (2020)	*"...since September 2017 when a major fire destroyed the turbine and associated equipment, the steam provided by the boiler is bypassed to a water cooled condenser where it is condensed back into water and fed back to the boiler. As such, the site has not generated any electricity throughout 2019."*
Kirklees (2020)	*"498 hours of unplanned downtime. Main Issues were: 2 X boiler tube leaks. Bottom ash extractor failure. Turbine remedial works…"*
FM1 (2020)	*"Annual boiler outages boilers 1 & 2 included refractory replacement, grate element inspection and replacement as necessary and pass 2/3 middle and bottom header replacements. Turbine initial outage inspection found axial clearances out of tolerance and subsequent inspections revealed significant damage to the shaft glands. The rotor and inner casings required removal to workshops in the UK and Germany respectively for machining."*
Stoke (2020)	*"During the outage, it was identified that the turbine required essential maintenance and repairs. This resulted in the turbine being removed from the site and sent to a specialist company to complete the works. For this reason, the plant did not generate as much electricity during 2020 when compared to previous years."*

ESTIMATE OF UK TURBINE AVAILABILITY IN 2019

Waste Combustion Hours (Simple Average from Tolvik EfW Statistics Report)	Turbine Operation Hours (Simple Average from Tolvik EfW Statistics Report)	Turbine availability during combustion (Turbine hrs ÷ Waste Combustion hrs)
89.5%	81.9%	**91.5%**

Implications of turbine non-availability

Incinerators require energy to run the plant, and this is commonly known as the incinerator's 'parasitic load'. When an incinerator is generating electricity this electricity is used to power the parasitic load, meaning that the amount of electricity exported by an incinerator is less than the amount of electricity generated.

When an incinerator is operating without its turbine(s) it is not only failing to export electricity but that incinerator also needs to import electricity to power the facility. This means that for periods of turbine non-availability an incineration plant has a negative electricity balance (i.e. it imports more electricity than it exports). Thus, turbine non-availability can have a significant adverse impact on the carbon performance of the facility. In 2019 the average parasitic load for incinerators across the UK was 13.7% excluding imported power and 16.2% including power import.[61]

Given the realistic prospect of turbine non-availability during the lifetime of an incinerator (including but not limited to the commissioning phase) and its significant impact on carbon performance, realistic modelling requires the impact of turbine non-availability to be taken into account.

61 [redacted]

DISPLACING OTHER SOURCES OF ELECTRICITY AND/OR HEAT

> **RECOMMENDATION #8: When considering the carbon intensity of displaced energy it is necessary to take account of the progressive decarbonisation of the energy supply rather than simply assuming that a new energy source would displace fossil fuels. The carbon intensity of electricity displaced by a new incinerator can be estimated using the average BEIS Long-Run Marginal Emissions Factor (MEF) over the lifetime of the plant.**

When assessing the relative impact of incineration compared to other waste treatment options it is usual for account to be taken of the fact that when incinerators (or indeed landfills with gas capture) generate energy this energy is displacing other forms of energy generation and that this displacement can have a carbon impact.

It has historically been assumed that the energy generated from incineration would displace energy generated from fossil sources such as combined cycle gas turbines (CCGT). However, as countries are decarbonising their electricity supplies it becomes increasingly likely that incineration would displace low carbon energy sources such as solar and wind power.

CCGT has a carbon intensity of around 340 gCO_2e/kWh[62], the BEIS Long-Run Marginal is 258 gCO2e/kWh for 2021 (falling to 25 gCO_2e/kWh by 2050), and the UK Gird Average is 105 gCO_2e/kWh in 2021 (and is also assumed by BEIS to fall to 25 gCO_2e/kWh by 2050). Nuclear has been estimated by the IPCC to have median lifecycle emissions of around 11 gCO_2e/kWh when infrastructure and supply chain emissions are taken into account. [63]

This means that the difference in choice for displaced emissions (and whether to use a fixed or falling value for sources that will change) can have a significant impact on the assessments of the impacts of waste incineration.

This section therefore investigates support for using the BEIS Long-Run Marginal Emissions Factors (MEFs), the UK grid average, and nuclear power as comparators against which to assess the impact of displaced electricity generation. This section also sets out some of the critiques that have been made regarding continuing to use CCGT as the comparator despite grid decarbonisation.

62 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794738/background-documentation-guidance-on-valuation-of-energy-use-and-greenhouse-gas-emissions.pdf

63 [redacted]

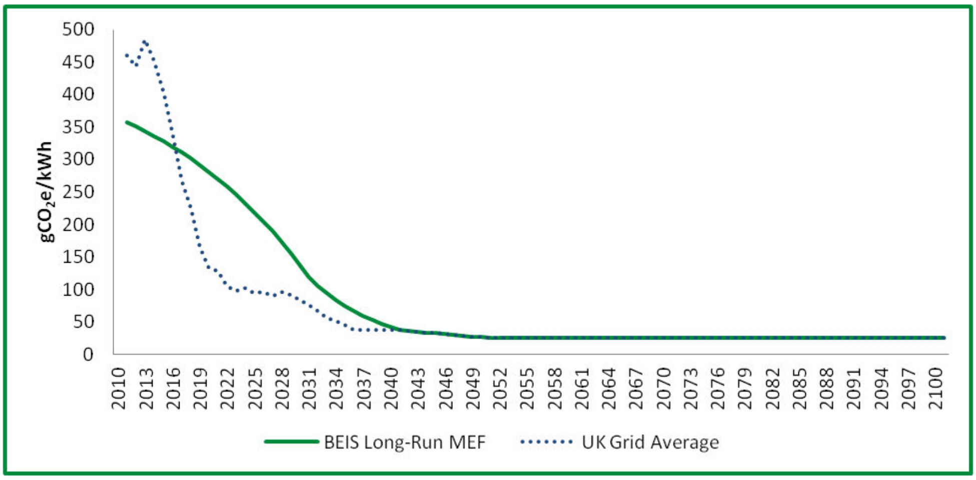
BEIS GUIDANCE ON ELECTRICITY EMISSIONS

The UK Department for Business, Energy & Industrial Strategy (BEIS) has produced relevant guidance on how to take account of the decarbonisation of the energy supply. The BEIS guidance document 'Valuation of energy use and greenhouse gas emissions for appraisal' notes:[64]

> *"For estimating changes in emissions from changes in grid electricity use, analysts should use the (long run) marginal grid electricity emissions factors in data table 1… There are complex mechanisms that determine the effects of sustained but marginal changes to the grid electricity supply (from either* ***displacement with other generation*** *or a demand reduction). A small reduction in grid electricity consumption will be met through a reduction in supply from a small subset of plant, rather than through an equal drop across all generation plant… Modelling undertaken by BEIS has estimated these longer-term dynamics, and they are reflected in the marginal emissions factors." (****emphasis added****)*

The 'data table 1' referred to by BEIS[65] provides 'Electricity emissions factors to 2100, kgCO2e/kWh'. The most recent version of the relevant data table is from March 2019, and so predates some of the Government's most recent commitments to decarbonisation, net zero and increases in the use of wind turbines. However, it still shows that there can be expected to be significant decarbonisation of the energy supply within the timeframe of both when new incinerators would be built and during their 25+ years of operation.

GRAPH BASED ON BEIS DATA TABLE 1: 'ELECTRICITY EMISSIONS FACTORS TO 2100' FIGURES FOR GENERATION-BASED ELECTRICITY GENERATION



[64] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794737/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal-2018.pdf

[65] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/793632/data-tables-1-19.xlsx

EXTRACT FROM BEIS DATA TABLE 1: 'ELECTRICITY EMISSIONS FACTORS TO 2100'

Year (Column B)	Generation-based Long-run Marginal Emissions Factor (Column F)	Generation-based Grid average (Column J)
2010	357 gCO_2e/kWh	460 gCO_2e/kWh
2011	350 gCO_2e/kWh	443 gCO_2e/kWh
2012	343 gCO_2e/kWh	485 gCO_2e/kWh
2013	336 gCO_2e/kWh	452 gCO_2e/kWh
2014	328 gCO_2e/kWh	402 gCO_2e/kWh
2015	320 gCO_2e/kWh	337 gCO_2e/kWh
2016	311 gCO_2e/kWh	266 gCO_2e/kWh
2017	301 gCO_2e/kWh	226 gCO_2e/kWh
2018	291 gCO_2e/kWh	165 gCO_2e/kWh
2019	281 gCO_2e/kWh	133 gCO_2e/kWh
2020	270 gCO_2e/kWh	128 gCO_2e/kWh
2021	258 gCO_2e/kWh	105 gCO_2e/kWh
2022	246 gCO_2e/kWh	98 gCO_2e/kWh
2023	233 gCO_2e/kWh	102 gCO_2e/kWh
2024	219 gCO_2e/kWh	95 gCO_2e/kWh
2025	205 gCO_2e/kWh	96 gCO_2e/kWh
2026	189 gCO_2e/kWh	90 gCO_2e/kWh
2027	173 gCO_2e/kWh	96 gCO_2e/kWh
2028	156 gCO_2e/kWh	91 gCO_2e/kWh
2029	138 gCO_2e/kWh	84 gCO_2e/kWh
2030	118 gCO_2e/kWh	76 gCO_2e/kWh
2031	105 gCO_2e/kWh	67 gCO_2e/kWh
2032	94 gCO_2e/kWh	56 gCO_2e/kWh
2033	84 gCO_2e/kWh	52 gCO_2e/kWh
2034	75 gCO_2e/kWh	45 gCO_2e/kWh
2035	66 gCO_2e/kWh	37 gCO_2e/kWh
2036	59 gCO_2e/kWh	37 gCO_2e/kWh
2040	37 gCO_2e/kWh	37 gCO_2e/kWh
2045	31 gCO_2e/kWh	31 gCO_2e/kWh
2050-2100	25 gCO_2e/kWh	25 gCO_2e/kWh

IMPACTS OF APPLYING THE BEIS LONG-RUN MEF OR UK GRID AVERAGE

One approach that has been advocated as best practice is to assume that the electricity generated by an incinerator in the UK would displace the BEIS Long-Run Marginal Emissions Factor (MEF) for the relevant year of operation. As set out below, this approach has been used in a number of incinerator planning applications to provide indicative analysis of the climate change impact of the proposal. It has also been used for broader analysis of the impacts of waste composition and grid decarbonisation on a variety waste treatment options including incineration.

One rationale for using the BEIS Long-Run MEF is that as an incinerator is a minor source of baseline electricity it would be displacing the short-run marginal source of electricity, and that the BEIS Long-Run MEF is the best proxy for this short-run marginal. For estimating future impacts this would in effect mean using the average of the BEIS Long-Run MEF figure over the operational lifetime of the project.

For example, an incinerator starting operations in 2021 and expected to operate for 30 years would displace the relevant BEIS Long-Run MEF for each of those 30 years, starting at 258 gCO_2e/kWh in 2021 and falling to 25 gCO_2e/kWh by 2050. This means that on average the MEF for displaced energy would be 89 gCO_2e/kWh.

For comparison, applying the same approach using the UK Grid Average would result in an average offset of 53 gCO_2e/kWh to reflect the anticipated fall of grid intensity from 105 gCO_2e/kWh in 2021 to 26 gCO_2e/kWh by 2050. As such, using the Long-Run MEF rather than the UK Grid Average could be considered a 'conservative' approach.

In some cases only the MEF for the year of commencement is used and it is assumed that the grid offset intensity will remain at this level. For example, if the 2021 MEF were used as the counterfactual then it would be assumed that the incinerator would displace energy with a carbon intensity of 258 gCO_2e/kWh for all 30 years of operation.

Using the BEIS Long-Run MEF based on the year when a new incinerator begins operations is still an improvement over assuming that only CCGT would be displaced but the approach significantly increases the risk that the benefit of electricity export from incineration would be overestimated. As can clearly be seen in the graph above, the current Grid Average (105 gCO_2e/kWh) is well below the current MEF (258 gCO_2e/kWh), and both figures fall each year until the 2040s (by which time the MEF is assumed to match the UK Grid Average).

Within the context of the anticipated long-term decarbonisation of the UK Grid, adopting CCGT as the counterfactual for new incinerators should be considered unacceptable because this is likely to significantly overstate the carbon intensity of the energy that would be displaced by new waste incineration capacity.

DEFRA GUIDANCE ON THE USE OF LONG RUN MARGINAL EMISSIONS FACTORS

For simplicity's sake, the initial version of the UK Government's Energy from Waste (EfW) Guide mentioned CCGT rather than the long-run marginal emissions factor (MEF) as the counterfactual for displaced electricity. In 2012, at the time the EfW Guide was being written, CCGT was associated with a carbon intensity of around 356 gCO2e/kWh and the relevant MEF was around 343 gCO2e/kWh.[66] Unfortunately, this simplification was then misinterpreted by some to mean CCGT would always be the appropriate comparator (energy generation counterfactual) to use for new incineration projects, even when the grid was significantly decarbonised.

In response to a query about the potential for this oversimplification to cause confusion, Defra stated in November 2013 that the only reason their EfW Guide referred to CCGT rather than the MEF was because:

> *"The detailed marginal energy mix is quite a complex concept to explain and was beyond the scope of the document. The current level of long run marginal mix [in 2013] is essentially equivalent to CCGT, as this dominates the current [2013] calculation".*

In their November 2013 letter Defra went on to explain that:

> *"For specific calculations the DECC guidance is correct, long run marginal emissions factors should be used".*[67]

The point was subsequently further clarified in the 2014 revision to the EfW Guide, which states at Footnote 29 to Paragraph 41 that:

> *"…When conducting more detailed assessments the energy offset should be calculated in line with DECC [now BEIS] guidance using the appropriate marginal energy factor https://www.gov.uk/government/publications/valuation-of-energy-use-andgreenhouse-gas-emissions-for-appraisal".*[68]

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[66] http://webarchive.nationalarchives.gov.uk/20121217150421/http://www.decc.gov.uk/assets/decc/statistics/analysis_group/81-iag-toolkit-tables-1-29.xls

[67] Page 7 of the Rebuttal Proof of Evidence by Alan Watson for the Javelin Park (Gloucestershire) incinerator inquiry (PINS Reference: APP/T1600/A/13/2200210), available from:
[redacted]

[68] Energy from waste: A guide to the debate February 2014 (revised edition), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf

Given the significant decarbonisation of the grid that has occurred since the Government's EfW Guide was revised, it should be considered that the reference to CCGT is now out-of-date, and that modelling should instead be based on the relevant BEIS long run marginal emissions factors (MEFs) in line with the footnote to the EfW Guide.

The use of the MEF, instead of CCGT, as the correct energy generation counterfactual is confirmed by Paragraph 68 of Defra's 'Carbon based modelling approach', which states that:

> *"It is assumed that the source of energy being replaced would have been generated using a plant with the carbon intensity (emissions factor) of the marginal energy mix in line with HMT Green Book guidance on appraisal and evaluation…"*.

The footnotes to Paragraph 68 of Defra's 'Carbon based modelling approach' make it clear that whilst CCGT was considered an appropriate counterfactual for use in 2013 it does not remain appropriate for future years because of the progress being made to decarbonise the UK's electricity supply. The report explicitly confirmed that *"use of the [BEIS] marginal factor is the correct approach for detailed analysis".*

EUNOMIA'S USE OF LONG RUN MARGINAL EMISSIONS FACTORS

In their 'Greenhouse Gas and Air Quality Impacts of Incineration and Landfill' report (ClientEarth, March 2021) Eunomia explained their use of the Long Run Marginal Emissions Factor for modelling the impacts of waste incineration, stating that:

> *"The sources of electricity generation which supply the grid are chosen, largely through the wholesale electricity markets, to meet a given level of demand. The cheapest source of generation is selected, then the next cheapest etc., until selected generation equals demand. The short-run marginal source of electricity is the source of electricity that would be brought online to meet a small increase in demand.*
>
> *The short-run marginal source of electricity is often assumed to be CCGT plant fuelled by natural gas. However, it is extremely likely that the contribution of gas generation will fall over the next decade; BEIS data indicates that the contribution of CCGT to total electricity demand will halve by 2035 from current day levels. As this occurs, other sources of generation will fill the gap, including (mostly) renewables, imported electricity and power storage. The carbon intensity of these sources is lower than that of gas…*

Individual incineration facilities are relatively small generators of electricity (in comparison to conventional power stations), and as such, the addition of one new facility would not be expected to result in a structural change to the electricity system. This suggests that the short-run marginal is a more appropriate factor to use. However, there is no data anticipating how the short-run marginal will be affected by the changes in decarbonisation set out above. As such, the long-run marginal figures provide a useful indicator of the trajectory of grid decarbonisation that is expected to occur over the coming decades.

The long-run marginal electricity emissions intensity as forecast by BEIS for the years 2020 and 2035 was used: 0.270 kgCO2e/kWh and 0.066 kgCO2e/kWh respectively. This approach is analogous to that taken in Defra's 2014 report comparing landfill to incineration."

EXAMPLES OF GRID DISPLACEMENT FACTORS WITH A CARBON INTENSITY LOWER THAN CCGT BEING CONSIDERED IN UK INCINERATOR PLANNING APPLICATIONS

Many recent planning applications have considered grid decarbonisation and/or the long-run marginal emissions factor, at least with respect to sensitivity analysis.

RECENT UK INCINERATOR PLANNING APPLICATIONS CONSIDERING LONG-RUN EMISSIONS FACTORS AND GRID DECARBONISATION

Facility, Client, and Document Date	Lower-carbon electricity emissions factors considered
North Lincolnshire Green Energy Park (Solar 21, June 2021)[69]	• 0.26 tCO_2e/MWh and 0.056 tCO_2e/MWh • *"Table 12 shows that when the electricity generation displacement factor is reduced by 30%, to 0.26 t CO2e / MWh, there is no longer a net carbon benefit for the Project."*
Riverside Resource Recovery Facility (Cory Riverside Energy, February 2021)[70]	• 0.258 tCO_2e/MWh (2021 long-run generation-based marginal) • 0.205 tCO_2e/MWh (2025 long-run generation-based marginal) • *"The government's policy is to decarbonise grid electricity. The government has recently set a target to bring all greenhouse gas emissions to net zero by 2050. This means that the benefit of displacing electricity will reduce… for illustrative purposes we have used the long run marginal generation-based emission factors [on a per-year basis]. These are only relevant if the Facility were to displace other renewable sources of electricity, and are considerably more conservative, starting at 0.258 kg CO2e/kWh in 2021 and dropping to 0.03734 kg CO2e/kWh by 2040."*

[69] https://infrastructure.planninginspectorate.gov.uk/projects/yorkshire-and-the-humber/north-lincolnshire-green-energy-park/

[70] 'Riverside Optimisation Project'. Application to vary consent GDBC/003/00001C-06.

[redacted]

Facility, Client, and Document Date	Lower-carbon electricity emissions factors considered
Alton Advanced Energy Recovery Facility (Veolia, December 2020)[71]	• *"…we have considered the lifetime benefits of the Facility on an illustrative basis. We have varied a number of assumptions over time, described as follows: The government's policy is to decarbonise grid electricity…starting at 0.233 kg CO2e/kWh in 2023 and dropping to 0.0276 kg CO2e/kWh by 2047"* [i.e. a per-year approach using the long run marginal emissions factor was adopted in the consideration of the cumulative benefit of the Facility over 25 years of operation]
Portland Energy Recovery Facility (Powerfuel Portland Ltd, September 2020)[72]	• 0.30 tCO_2e/MWh • 0.23 tCO_2e/MWh • *"The benefit of ERF over its lifetime will vary depending on how the national electricity grid decarbonises".* • *"for illustrative purposes we have used the long run marginal generation-based emission factor taken from the 'Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal', published by BEIS. This is considerably more conservative, starting at 0.2191 kg CO2e/kWh in 2024 and dropping to 0.00276 kg CO2e/kWh by 2048"* [i.e. a per-year approach using the long run marginal emissions factor was adopted in the consideration of the cumulative benefit of the Facility over 25 years of operation]
Northacre Renewable Energy Centre (Northacre Renewable Energy Ltd, July 2020)[73]	• 0.32 tCO2e/MWh • 0.28 tCO2e/MWh
Ford Circular Technology Park (Viridor and Grundon, June 2020)[74]	• 0.32 tCO2e/MWh • 0.28 tCO2e/MWh
Alton Advanced Energy Recovery Facility (Veolia, April 2020)[75]	• 0.27 tCO2e/MWh (2020 long-run generation-based marginal) • 0.23 tCO2e/MWh (2023 long-run generation-based marginal)
Former Wealden Brickworks, Horsham (Britaniacrest Recycling Limited , August 2019 Proof of Evidence)[76]	• 0.2556 kgCO2e/kWh from Greenhouse Gas Reporting – Conversion Factors 2019

[71] Hampshire County Council planning application no. 33619/007
[72]Dorset Council planning application no. WP/20/00692/DCC
[73] Wiltshire Council planning application no. 20/06775/WCM
[74] West Sussex County Council planning application no. WSCC/036/20
[75] Hampshire County Council planning application no. 33619/007
[76] Appeal reference APP/P3800/W/18/3218965. West Sussex County Council planning ref WSCC/062/16/NH

Facility, Client, and Document Date	Lower-carbon electricity emissions factors considered
Darwen Energy Recovery Centre (Suez, April 2019)[77]	Primary analysis used the 2017 BEIS long-run marginals on a per-year basis, e.g.: • 0.233 tCO2e/MWh for 2023 • 0.118 tCO2e/MWh for 2030 • 0.049 tCO2e/MWh for 2040 • 0.032 tCO2e/MWh for 2047 • *"The marginal source displaced may in practice vary from moment to moment depending on the operation of the capacity market, i.e. led by commercial considerations and National Grid's needs at any given time. For the purpose of this assessment, longer-term trends (annual averages) have been used as it is not possible to predict shorter-term variations with confidence… National Grid…publishes 'Future Energy Scenario' projections (National Grid, 2018) of grid-average carbon intensity under several possible evolutions of the UK energy market, which have been reviewed. The BEIS projection sits broadly in the middle of the National Grid range so has been considered representative."*
Waterbeach Energy From Waste Facility (AmeyCespa, July 2018)[78]	• 0.32 tCO2e/MWh • 0.28 tCO2e/MWh

UNIVERSITY OF EXETER'S CRITIQUE OF USING CCGT AS THE COUNTERFACTUAL

As noted in a letter dated 19th October 2020 from the Head of the Centre for Energy and the Environment at the University of Exeter:[79]

> *"Wiltshire Council has asked the Centre for Energy and the Environment to conduct a brief review of the carbon assessment for the proposed Northacre energy from waste (EfW) facility at Westbury in Wiltshire."*

In their October 2020 peer review, the Centre at the University of Exeter stated:

> *"DEFRA's 2014 energy from waste guide is used [by the applicant] as evidence to support the justification of gas combined cycle (CCGT) power stations being an emissions comparator. The guide predates the extensive changes that have taken place in the UK electricity system in the latter half of the decade including changes to the generation mix which have seen the UK published grid emission factor for company reporting declined from 0.494 kg CO2e/kWh in 2014 to 0.233kg CO2e/kWh in 2020, a 53% reduction…*

[77] Blackburn with Darwen Council planning application no. 10/19/0495
[78] Cambridgeshire County Council planning application no. S/3372/17/CW
[79] Wiltshire Council planning application no. 20/06775/WCM

The electricity offset emissions factor used [by the applicant] is incorrect. Adopting Government emission factors increases lifetime total facility emission by 249%."

Commenting on the applicant's response on their peer review, the University provided a further response dated 15th December 2020 which stated:

"The amount of CO_2 offset through the production of electricity is an important part of calculating net emissions from EfW plants. The Response to my review continues to insist that the high carbon factor for electricity generated from combined cycle gas turbines (CCGT) should be applied to electricity from the Northacre facility over the life of the plant. This is based on the false premise that CCGTs are a 'comparative technology'.

CCGTs are flexible generators which can respond to peaks in demand and short term market price signals; electricity production can be ramped up and down in minutes to make way for low carbon alternatives such as offshore wind as it becomes available to the grid. In contrast the Assessment states that the Northacre plant is designed to run at capacity for 7,884 hours per year, or 90% of the time. This operating characteristic makes the plant more appropriate for meeting baseload demand, much of which is currently met by nuclear power stations which have very low emissions factors. The 'comparative technology' argument should therefore lead to adopting emissions factors for nuclear power stations rather that CCGT…

The UK grid is decarbonising at an unprecedented rate and, with the scale of renewable energy development already committed, will continue to do so. As far back as 2017 the Greater London Authority recognised the role for the BEIS carbon factors for marginal electricity generation used in my review for setting waste performance standards for EfW. In the Energy White Paper ['Powering our Net Zero Future', HM Government, November 2020] the Government states its aim is to have 'an overwhelmingly decarbonised power system in the 2030s'. By adopting a high grid emission factor and extrapolating to a time when the electricity grid will be approaching zero carbon, the [Northacre applicant's] Assessment un-reasonably distorts the carbon benefits of electricity production from EfW."

ARK ENVIRONMENTAL'S ARGUMENT THAT NUCLEAR IS MORE REALISTIC COUNTERFACTUAL THAN CCGT

Ark Environmental were appointed by the No Wey Incinerator group to undertake a review of the Environmental Permit variation application for Veolia's Alton incinerator proposal.[80]

In their June 2021 representation, Ark Environmental argue that incineration is more likely to displace nuclear than to displace CCGT:

> *"As explored above, EFW plants typically have 80+% load factors, and the applicant's own assumptions are that the plant will generate 100% of the design capacity for 100% of operational hours. By comparing this with National Grid data for average annual load factors (ALFs) for different types of generation capacity, below, this suggests that EFW plants are able to run at, on average, higher load factors than any other type of generation, even nuclear. CCGT in comparison runs at only 51% load factor."*
>
> *"EFW CO_2 intensity should therefore be compared with the grid generation technology it is closest to, in this case nuclear, rather than CCGT. Nuclear generation has, nominally, zero carbon output. EFW does not."*
>
> *"Looking at individual plants rather than the whole market also shows that EFW is not comparable with CCGT, as it is providing a higher load factor than any other type of generation other than nuclear."*
>
> *"The high load factors of EFW plants can be explained because they can generate electricity cheaper than any other electricity source. This is because EFW unlike any other electricity source gets paid for their fuel (through gate fees, approximately 75% of an EFW plant's revenue according to Credit Suisse), so, electricity generation is simply a nice addition to their core income stream."*
>
> *"BEIS data shows that absent changes in government policy (for example imposition of a carbon tax on incineration, or forced installation of CCUS) EFW will continue to have the lowest electricity generation costs of any type of generation into the 2030s."*
>
> *"EFW plants can therefore underbid all other generation types until the mid-2030s at the earliest, and still make money selling electricity. It therefore seems unlikely that the applicant's statement that CCGT is an appropriate comparator is reasonable today, let alone in the future."*

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[80] EPR/VP3290ER/V004

"If the applicant would like to be compared to CCGT, they should reduce the forecast load factors for electricity generation to those comparable to CCGT"

"In summary, EFW plants are bidding against the whole electricity balancing market (and normally winning, hence the high load factors for EFW plants) and therefore the marginal grid displacement factor would seem to be a more appropriate measure of carbon intensity than that claimed by the applicant in their application."

AIR QUALITY CONSULTANTS LTD RECOMMENDS CONSIDERATION OF LONG RUN MARGINAL ON A 'YEAR YEAR' BASIS TO DETERMINE CUMULATIVE IMPACTS

The Carbon Assessment Review of the Alton Advanced Energy Recovery Facility produced by Air Quality Consultants Ltd in August 2020 included the following recommendations for carrying out an assessment of Veolia's planning application for an incinerator in Alton:[81]

- *"Calculate CO_2e emissions using government published long run marginal generation grid factors for 2023 and each year to 2048 (end of life)."*
- *"Calculate the cumulative emissions over the lifetime of the facility."*

ATKINS RECOMMENDS CONSIDERATION OF LONG TERM GRID DECARBONISATION

The Review Report produced by Atkins for Hampshire County Council (October 2020) with respect to Veolia's proposed Alton Advanced Energy Recovery Facility refers to the Institute of Environmental Management and Assessment (IEMA), stating:

"IEMA's best practice EIA [Environmental Impact Assessment] guidance…notes that the future baseline should be set to include anticipated future changes, for example 'UK grid decarbonisation projection scenarios or the adoption of renewables'…

For the electricity generation aspect of the development, a range of grid displacement factors are included in a sensitivity test, comparing a CCGT comparator with a long run marginal factor for 2023 (the year of completion). As the development will be operational through to the 2050s, it would have been appropriate to consider likely grid decarbonisation scenarios across that timeframe and consider the impact of the project in the context of these".

[81] Hampshire County Council planning application no. 33619/007

WASTE TREATMENT COMPARATOR/COUNTERFACTUAL

> **RECOMMENDATION #9: When considering how waste would be treated if it were not sent to an incinerator, account should be taken of the prospect that it might otherwise have been reduced, reused, recycled or composted. Account should also be made of how landfilled waste could be bio-stabilised to reduce methane emissions.**

One method used to assess the impacts of waste incineration is to consider it against alternative waste management options. In some cases, this assessment is premised on assessing a number of reasonable options and in other cases an incinerator is only assessed against a baseline option which is stated to represent what would otherwise occur (or be most likely to occur) were incineration not to be used.

According to the IEMA's 2017 Environmental Impact Assessment Guide to Assessing Greenhouse Gas Emissions and Evaluating their Significance[82] the first steps for a GHG emissions practitioner to consider when applying the IEMA's approach to identifying opportunities is 'do not build', which is to:

> *"evaluate the basic need for the project and explore alternative approaches to achieve the desired outcome/s"*.

Given the drive to support the top tiers of the waste hierarchy (reduction, preparation for re-use and recycling) and to minimise the adverse climate change impacts of waste management, it is not appropriate to simply assume that waste that is incinerated would otherwise be sent untreated to landfill.

As such, consideration should be given to the potential impacts of options to:

- **Avoid residual waste from arising in the first place** - including better source segregation of key waste streams and increased education to ensure that people put the right things in the right bins;
- **Minimise the impact of residual waste management** - including using MBT/MRBT to extract recyclates and using bio-stabilisation to minimise methane and biogenic CO_2 emissions from landfill.

This section explores a number of statements, arguments and data sources that consider the potential for, and impacts of, alternatives to sending incinerator feedstock untreated to landfills, and challenges the concept of a binary choice between using incineration and sending waste untreated to landfill.

82 [redacted]

EXAMPLES OF THE VIEW BEING EXPRESSED THAT INCINERATOR FEEDSTOCK WOULD NOT NECESSARILY OTHERWISE BE SENT UNTREATED TO LANDFILL

Source	Comment
Zero Waste Scotland 'The climate change impact of burning municipal waste in Scotland' (report webpage) (July 2021)[83]	*"Question: Is the focus on EfW misplaced?* *Answer: Residual waste treatment, whether landfill, or incineration, is the last port of call for waste. Our position is that we can make a lot more from the materials we have before EfW or landfill becomes the choice of disposal. If we are going to address the climate crisis, we must reuse products far more than we do just now. All our efforts need to go into keeping materials in use and in the system for as long as possible. Incineration and landfill are reserved for residual waste once all other, less environmentally damaging options, such as prevention, reuse and recycling, have been exhausted. The development of waste management technologies must consider the national climate change strategy to ensure Scotland is not locked into management routes which are higher carbon than necessary."*
The Climate Change Committee (CCC) 'Progress in reducing emissions: 2021 Report to Parliament' (24th June 2021)[84]	*"If EfW usage is left to grow unchecked, EfW emissions will quickly exceed those of the CCC pathway while undermining recycling and re-use efforts"* *"Energy from Waste (EfW) emissions, which have been rising rapidly, need to be constrained at approximately today's levels through increased waste prevention, re-use and recycling, and policy to enable EfW plants to be fitted with CCS from the late 2020s."*
Professor Sir Ian Boyd, 2012-2019 Chief Scientific Adviser, Department for Environment, Food and Rural Affairs Channel 4 Dispatches: 'Dirty Truth About Your Rubbish' (8th March 2021)[85]	*"There are a lot of people who are highly incentivised to incinerate waste. Because of the investments we make in waste power plants, we end up a lot of the time creating a market for waste, and therefore trying to generate more waste in order to generate the inputs for the power plants that we've made such large investments in. My feeling is that we've got to use the capacity we have rather than create more capacity, because if you create more capacity you create more demand for materials, and that is simply cranking up the amount of material that comes into the system, and the very last thing we should be doing is, when we throw it away, is putting it in an incinerator."*

83 [redacted]
84 [redacted]
85 [redacted]

Source	Comment
Welsh Government 'Beyond Recycling: A Strategy to make the circular economy in Wales a reality' (2nd March 2021)[86]	*"We have also seen innovation around Wales in tackling hard to recycle products including mattresses and nappies. But we know half of the household residual waste remaining in our black bags can still be recycled, with half of this being food waste. Three quarters of our residual commercial and industrial waste is also easily recyclable material. We therefore need to capture this material and stop sending recyclable waste to landfill or energy from waste plants and recycle it instead."*
Secretary of State for Business, Environment & Industrial Strategy (BEIS) Application for Wheelabrator Kemsley North Waste-to-Energy Facility Order (19th February 2021)[87]	*"As far as the possibility of waste being diverted from landfill to fuel the two projects is concerned, the Examining Authority considers that the projects would divert a significant proportion of waste from recycling rather than landfill...The Secretary of State sees no reason to take a different view to the Examining Authority in this matter."*
Zero Waste Scotland 'Dirty white elephants: Incinerators were supposed to solve the UK's waste crisis. Are they making it worse?' (4th February 2021)[88]	*"Using landfill for comparison is misleading because it falsely suggests dumping waste is the only alternative to burning it, according to Michael Lenaghan, a scientist at Zero Waste Scotland, a government-funded non-profit organisation* *'Landfill is not the only alternative to waste-to-energy,' he says. 'There is potential for lower carbon options for treating residual waste, but we would always stress that increased recycling, reuse and waste prevention are much better'."*
Durham County Council Low Carbon Economy Team Internal consultation Response for the proposed Hownsgill Industrial Park incinerator planning application (5th January 2021)[89]	*"In the context of a Council that has declared a climate emergency and the subsequent agreed CO_2 reduction targets for County Durham, no evidence has been submitted by the applicant that confirms any CO_2 reduction. Indeed the building of the facility and subsequent operation, could lock in further increases in CO_2, if feedstock fails to be sourced from material that would otherwise be destined for landfill."*

86 [redacted]

87 https://infrastructure.planninginspectorate.gov.uk/projects/south-east/wheelabrator-kemsley-generating-station-k3-and-wheelabrator-kemsley-north-wkn-waste-to-energy-facility/

88 [redacted]

89 Durham County Council planning application no. DM/20/03267/WAS

Source	Comment
Green Alliance 'Getting the building blocks right: Infrastructure priorities for a green recovery' (November 2020)[90]	*"Policy should…seek to dramatically reduce residual waste and support better product design, reuse, remanufacturing and high value recycling. Yet, over investment in EfW infrastructure risks locking the country into producing enough material to feed it, as has already happened in Scandinavian countries."*
Committee on Climate Change 'Policies for the Sixth Carbon Budget and Net Zero' (9th December 2020)[91]	*"Banning biodegradable waste from landfill from 2025 is a priority, and should be achieved via prevention, reuse and recycling, not via more energy-from-waste."* *"An expansion in Scottish EfW capacity occurred ahead of their original 2021 biodegradable municipal waste ban date, and a repeat of this should be avoided (across the UK), due to the risk of locking-in increased EfW fossil emissions."*
Friends of the Earth 'All you need to know about waste and recycling' (Current website)[92]	*"Friends of the Earth opposes incineration because it: … Destroys valuable materials that could be recycled into new products. Recycling avoids having to make products from virgin materials…"*
Centre for Energy and the Environment at the University of Exeter (for Wiltshire Council) 'A brief review of the carbon assessment for the proposed Northacre energy from waste facility' (19th October 2020)[93]	*"In general the Northacre Assessment [for the Northacre EfW facility] is outdated. More specifically: The assessment is based on landfill being the alternative to energy from waste when the August 2020 Waste Management Plan for England states that 'Disposal – in landfill for example – is regarded as the worst option'. 'Landfill should be the last resort' and 'its use should be minimised as much as possible' with its ongoing role being 'for inert waste that cannot be prevented, recovered or recycled'. The Assessment assumes that composition of waste to landfill is the same as that treated by EfW when the Committee on Climate Change (CCC) is recommending that no biodegradable material is landfilled after 2025, a policy development that will significantly alter landfill gas production.* *On this basis straightforward landfill is not an alternative for the residual waste which is proposed to be treated at Northacre and comparisons which claim negative carbon intensity on this basis are misplaced…"*

90 [redacted]
91 [redacted]
92 [redacted]
93 Wiltshire Council planning application no. 20/06775/WCM

Source	Comment
Greenpeace 'A Green Recovery: How We Get There' (June 2020)[94]	*"End approvals for new incineration (also called energy-from-waste) facilities and prevent the replacement or upgrade of old plants that are near retirement, in order to support an overall reduction"*
Libby Peake of Green Alliance 'Waste incineration levels double over five years' (17th September 2019)[95]	*"Years of neglecting the top options - recycling, reuse and, most importantly, reduction - are starting to take their toll. Most waste isn't an inevitability, but a failure of our current linear economy. Focusing exclusively on diverting material from landfill (in most instances into incineration) represents only a marginal improvement and risks detracting attention from the larger structural changes that will be required to make the economy more sustainable."*
London Assembly Environment Committee 'Waste: Energy from Waste' (February 2018)[96]	*"Investing in more EfW can negatively affect long term recycling rates. This investment needs to be paid for by an assured income stream, usually through contracts with local authorities to pay the EfW operator to take waste. Contracts are often lengthy – the majority are over 20 years. The terms of contracts, such as minimum annual payments, or a low fee per tonne of waste, can undermine the financial viability for the local authority of reducing waste, or sending it to other destinations such as recycling."*

Avoiding residual waste in the first place

At the top tiers of the Waste Management Hierarchy there are approaches which are consistent with the concepts of Zero Waste and the Circular Economy. Most of what is currently considered 'residual waste' could alternatively be reduced, reused, recycled, or composted rather than landfilled or incinerated. Many materials which are currently hard to recycle can be redesigned or 'designed out' altogether.

Avoiding residual waste results in significantly lower levels of GHG emissions than incineration, especially waste minimisation efforts (including re-use and repair).

RESIDUAL MUNICIPAL WASTE IN ENGLAND

Around 27.8 million tonnes of municipal residual waste was collected in England in 2016[97], with just over half of this coming from households[98] and just under half from businesses.

94 [redacted]

95 [redacted]

96 https://www.london.gov.uk/sites/default/files/waste-energy_from_waste_feb15.pdf

The UK Government expects their current policy measures, including their goal for England to achieve a 65% recycling rate for municipal waste, to reduce residual waste to around 20 million tonnes by 2035[99], a reduction of nearly 8 million tonnes when compared with 2016.

One reason for the anticipated reduction is that much of this 'residual waste' is actually recyclable or compostable, and therefore the Government claimed in January 2020 that: [100]

> *"…the measures in the resources and waste strategy and the Environment Bill will enable a paradigm shift, in relation to reducing, reusing and recycling our waste, that should limit the amount that ever has to go to incineration and landfill".*

Defra's August 2020 'Resources and Waste Strategy Monitoring and Evaluation Report' found that only 8% of England's residual waste from household sources was "*Difficult to Recycle or Substitute*", concluding that the majority of the residual waste was readily recyclable.[101]

According to Defra's Report:

> *"The large amount of avoidable residual waste and avoidable residual plastic waste generated by household sources each year suggests there remains substantial opportunity for increased recycling…*
>
> *The message from this assessment is that a substantial quantity of material appears to be going into the residual waste stream, where it could have at least been recycled or dealt with higher up the waste hierarchy."*
>
> *"Of total residual waste from household sources in England in 2017, an estimated 53% could be categorised as readily recyclable, 27% as potentially recyclable, 12% as potentially substitutable and 8% as difficult to either recycle or substitute."*

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97 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765915/rws-evidence-annex.pdf

98 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664594/LACW_mgt_annual_Stats_Notice_Dec_2017.pdf

99 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765915/rws-evidence-annex.pdf

100 [redacted]

101 https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england-monitoring-and-evaluation

"Of approximately 13.1 million tonnes of residual waste generated by household sources in England in 2017, around 7 million tonnes could be categorised as readily recyclable, 3.5 million tonnes as potentially recyclable, 1.6 million tonnes as potentially substitutable, and 1.0 million tonnes as difficult to recycle or substitute."

CHARTS FROM DEFRA'S 2020 RESOURCES AND WASTE STRATEGY MONITORING REPORT SHOWING HOW MUCH RESIDUAL WASTE IS CONSIDERED AVOIDABLE

Chart 13. Avoidable residual waste from household sources, England, 2017, proportion of total residual waste, by category (WP2a)

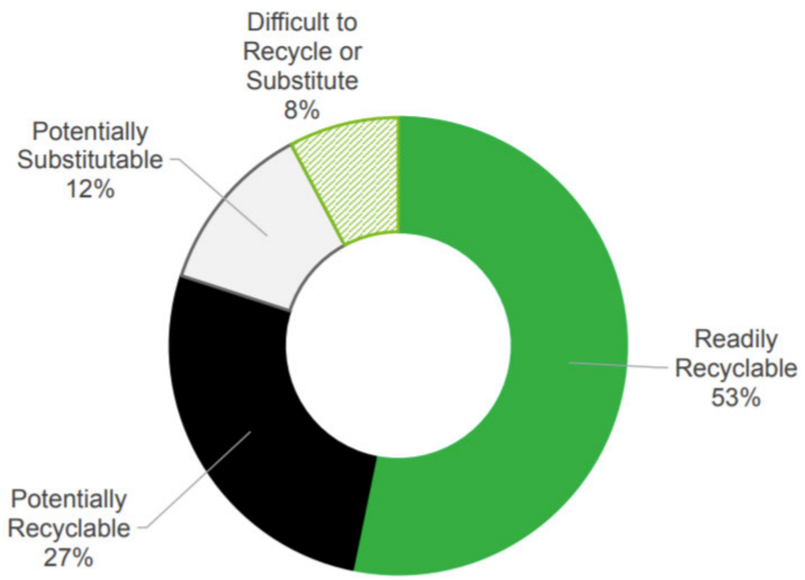
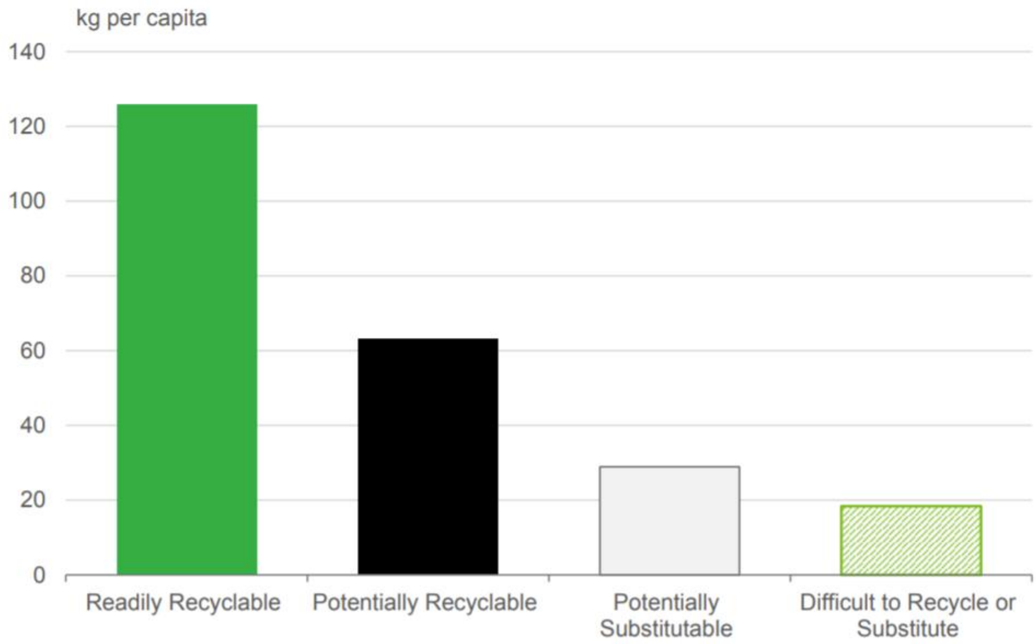


Chart 15. Avoidable residual waste from household sources, England, 2017, kg per Capita (WP2c)



COMMERCIAL & INDUSTRIAL WASTE IN WALES

A WRAP Cymru study entitled 'Composition analysis of Commercial and Industrial waste in Wales' was published in January 2020.[102]

According to WRAP Cymru:

> *"This study was conducted to provide Welsh Government and WRAP Cymru up-to-date data on the composition of mixed residual commercial and industrial (C&I) waste in Wales. The main objective was to estimate the proportion of the residual waste produced in Wales which could be avoided through recycling or composting."*

The study found that:

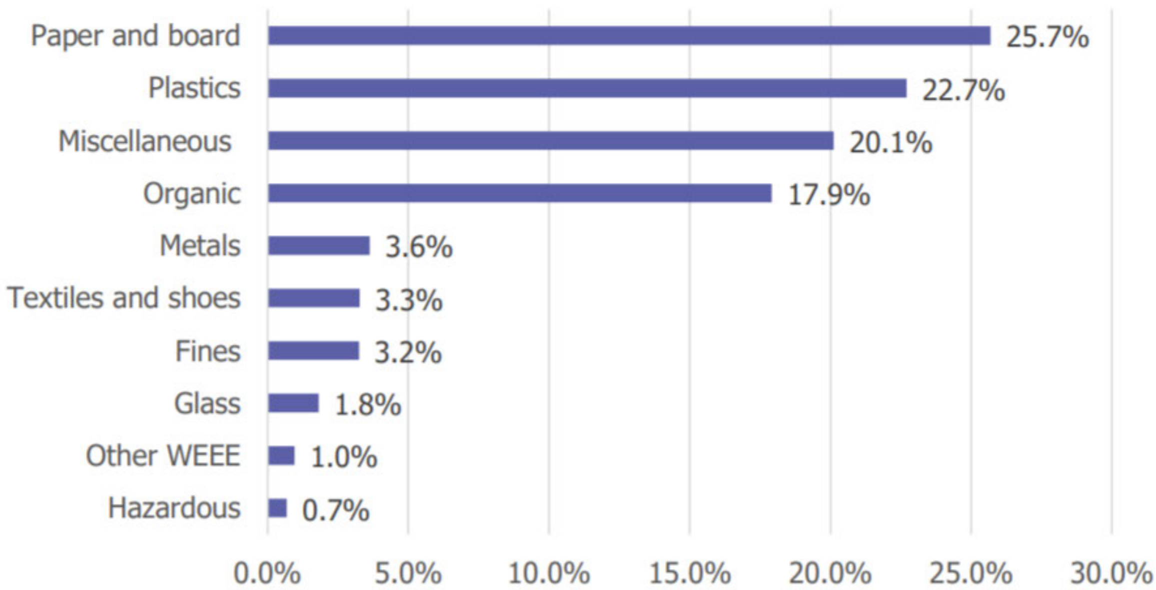
> *"The majority of the waste analysed (74.5%...) could have potentially been recycled."*

EXTRACTS FROM WRAP CYMRU WELSH COMMERCIAL & INDUSTRIAL WASTE STUDY

Table 3: Recyclability and biodegradability of commercial and industrial residual waste (EWC 19.12.12 & 20.02.01) in Wales

		Average	STDEV.S	C.I. 95%
Commercial	Recyclability	74.0%	13.8%	3.4%
	Biodegradability	60.5%	10.7%	2.6%
Industrial	Recyclability	80.5%	10.9%	8.7%
	Biodegradability	48.7%	11.0%	8.8%

Figure 1: Overall composition of C&I waste in Wales (main category level). N=108



102 [redacted]

REPORTS FROM THE COMMITTEE ON CLIMATE CHANGE (CCC)

The CCC has set out how to meet Net Zero GHG by 2050 and that to do so the UK will need to pursue significant reduction in waste arisings, improvements in recycling, and a move away from both incineration and landfill. This implies that the CCC believes a significant proportion of residual waste is avoidable and that avoiding it is necessary for the sake of the climate.

The CCC stated in their June 2020 Progress Report to Parliament that:

> *"Achieving significant emission reductions in the waste sector requires a step-change towards a circular economy, moving away from landfill and incineration (and the associated methane and fossil CO_2 emissions), and towards a reduction in waste arisings and collection of separated valuable resources for re-use and recycling. This applies at local, regional and national levels".*[103]

That same report stated that that one of the medium-term milestones to be on track to Net Zero by 2050 is that by around the 2030s: *"Local authority plans [will be] implemented to go beyond 70% recycling rate".* High recycling ambitions are also advocated in the CCC's December 2020 Sixth Carbon Budget Report[104] and these recommendations are repeated in their 2021 progress report to Parliament.[105]

POLICY RECOMMENDATIONS FOR HIGHER RATES RECYCLING AMBITIONS SET OUT IN THE CCC'S SIXTH CARBON BUDGET REPORT (DECEMBER 2020)

Area	Policy Recommendation
United Kingdom	*"Recycling rates (recycling, anaerobic digestion (AD) and composting) need to rise to 70% across UK by 2030 (and by 2025 in Scotland and Wales)."*
England	*"England should target 68% recycling by 2030 – household, commercial and industrial shares of this are achievable."* *"The non-household municipal waste sector has significant potential for improvement. RWS/CEP targets in England require 74% non-household municipal recycling by 2035 (up from 30-40% today)… Achieving 74%, or close to this level, by 2030 could be feasible with more support for smaller businesses during the mid/late-2020s, instead of during the 2030s."*
Wales and Scotland	*"Wales and Scotland should ensure compliance with their 2025 targets, and set new 2030 targets. Both countries should set out proposed recycling rate targets for 2030 that go beyond 70%."*
Northern Ireland	*"Northern Ireland should target 70% recycling across all wastes by 2030. Evidence from WRAP shows 'it is possible to achieve and surpass a municipal recycling rate of 65% in Northern Ireland well before the target date of 2035', with non-household municipal sectors potentially achieving over 80%."*

103 [redacted]
104 [redacted]
105 [redacted]

Minimising the impact of residual waste management

As noted above, one of the main sources of greenhouse gas emissions from landfilled material is methane, and the amount of methane released depends on the specific material streams being landfilled and on any pre-treatment prior to landfill.

BIOSTABILISATION PRIOR TO LANDFILL

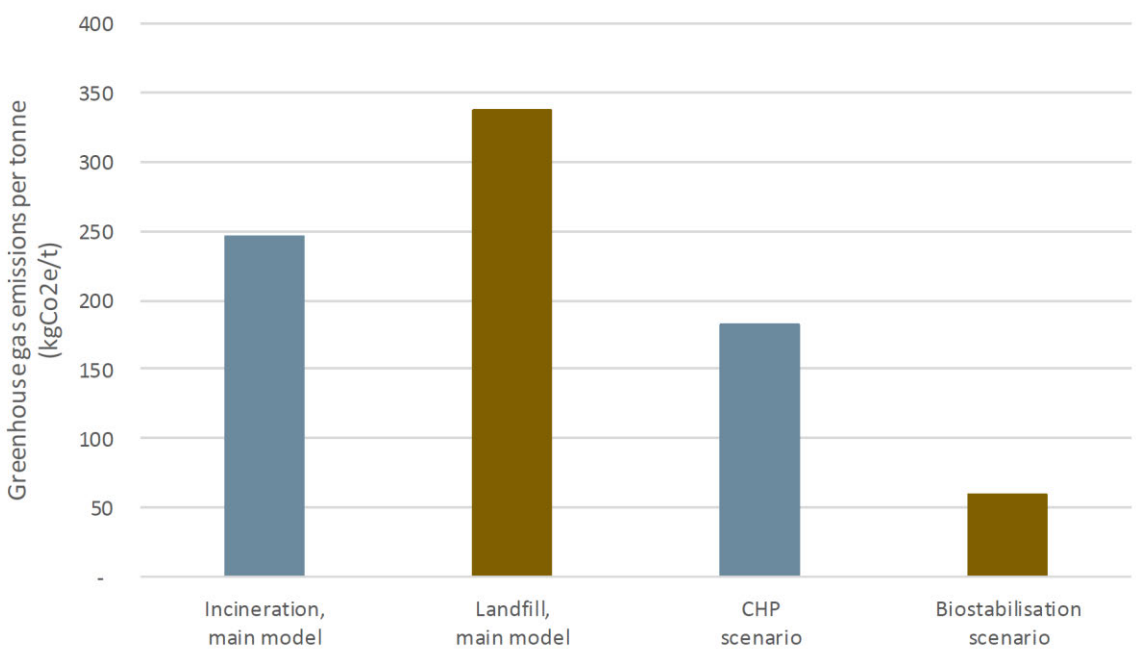
While removing food waste from the waste stream will reduce the proportion of biowaste that would degrade if sent directly to landfill, there is still a need to consider how these emissions could be minimised if biowaste is sent to landfill (e.g. as part of a 'transitional' strategy to treat residual waste as recycling rates improve while avoiding the 'lock-in' of waste incineration).

Even if there are potential challenges associated with the immediate use of bio-stabilisation, the potential savings from such approaches are very relevant when considering lower-cost medium-term residual waste treatment options that could allow for further increases in recycling and composting. This is especially relevant when considering whether or not to allow more waste incineration capacity which could lock in the use of that capacity for decades to come as the expense of the top tiers of the Waste Hierarchy.

The potential emissions savings from bio-stabilisation prior to landfill was considered in the July 2021 report from Zero Waste Scotland. The technical report summarises its findings in the following figure:

EXTRACT FROM ZERO WASTE SCOTLAND'S JULY 2021 TECHNICAL REPORT

Figure 16. Converting to CHP or biostabilisation technologies lowers the GHG emissions of waste management facilities



The supporting text below the figure explains:

> *"Figure 16 also shows a comparison to the potential savings from reducing biodegradable material to landfill. This could be achieved using biostabilisation. If levels of biogenic carbon can be reduced from 15% to 5% of residual municipal waste, landfill impacts would fall from 337 kgCO2e/t to 59 kgCO2e/t."*

Providing more detail, the report also notes:

> *"The estimated greenhouse gas emissions from biostabilisation in this study are in line with estimates from such plants operating in Europe. The biostabilisation scenario in this study is illustrative only and further, more detailed research is required to understand the environmental impacts of this scenario in a Scottish context more fully."*

> *"Biostabilisation as described in this report[3], refers to a specific type of technology where waste is pre-treated before landfill to reduces its biodegradable content, in accordance with the respiratory test criteria described in the section 4.2.b.i of the Waste (Scotland) Regulations 2012. Biostabilisation is a proven technology with plants operating across Europe, although there are no such plants in Scotland or the rest of the UK."*

Footnote 3 states:

> *"For example, J. de Araújo Morais et al. (2008) Mass balance to assess the efficiency of a mechanical–biological treatment, Waste Management, Volume 28, Issue 10 found that biochemical methane potential of residual municipal waste was reduced by over 80% after treatment."*

According to the conclusions of the report:

> *"The large potential savings from biostabilisation indicate this option warrants further consideration."*

It is explained within the 'frequently asked questions' section of the report's webpage that:

> *"…for residual waste which cannot be recycled, Biostabilisation technologies could offer a low carbon solution to landfill…"*

MBT OR MRBT SYSTEMS TO EXTRACT RECYCLATES AND BIO-STABILISE WASTE

'Mechanical and Biological Treatment' (MBT) and 'Material Recovery and Biological Treatment' (MRBT) processes can extract recyclates for recycling and then bio-stabilise any residues prior to landfill.

Assessments have found that MBT/MRBT approaches can result in significantly lower CO_2e emissions than sending the same waste to incineration, especially when the benefits of the biogenic carbon sink in landfill and the impact of the decarbonisation of the electricity supply are taken into account (see examples below).

MBT/MRBT systems are much cheaper to establish than incineration. This means that MBT/MRBT systems provide greater flexibility than incinerators, as they are more able to accommodate future improvements in waste prevention and recycling.

This means MBT/MRBT avoids the environmentally harmful impacts of feedstock 'lock-in' associated with residual waste treatment facilities such as incinerators[106] which cost hundreds of millions of pounds to build.[107]

Defra noted the potential benefits of MBT-landfill back in 2011, stating: [108]

> *"MBT (mechanical biological treatment)-landfill provides the best emissions performance in terms of the treatment/disposal of residual waste. It essentially involves landfilling somewhat stabilised wastes with some material recovery. The magnitude of the environmental impact depends on the extent to which the waste is stabilised."*

This issue was considered further by Eunomia and the Copenhagen Resource Institute (CRI) in 2014 in a report for Directorate-General for Environment at the European Commission entitled 'Development of a Modelling Tool on Waste Generation and Management - Appendix 6: Environmental Modelling' which was used in the Impact Assessment of the European Circular Economy package.[109]

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106 [redacted]

107 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221036/pb13889-incineration-municipal-waste.pdf

108 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69500/pb13548-economic-principles-wr110613.pdf

109 [redacted]

According to the European Waste Model document:

> *"The central aim of aerobic stabilisation processes is to produce an output which has a reduced biodegradability, thereby decreasing the environmental impacts associated with landfilling this material, although in some Member States such as France the stabilised output is applied to land. The pre-treatment process also typically removes metals and plastics for recycling"*

> *"Eunomia on behalf of WRAP, which was based upon a raft of published research. The body of research included work by Baky and Eriksson, Sonneson, and Komilis and Ham, all of whom investigated the link between the biochemical composition of the waste and the release of CO_2 within composting processes. This research, together with data sourced from technology suppliers, was used to model the degradation of carbon fractions within our model and the subsequent release of biogenic CO_2 from the process."*

Zero Waste Europe published a briefing note in January 2021 which includes information about the recyclate recovery performance of existing MRBT plants. The report explores MRBT's potential use as part of a 'bridge strategy' for managing residual waste within the context of the transition to a more circular economy.[110]

The report found that MRBT was the lowest-carbon option considered, with lower emissions even than incineration with plastics removed (referred to as 'MWS plus incineration' with MWS meaning 'municipal waste sorting').

According to the Zero Waste Europe report:

> *"...a MRBT system that combines biological treatment and sorting equipment allows us to 'stabilise' the organics that are included in residual waste, so as to minimise their impact once buried in a landfill, while also helping to recover materials such as metals, plastics, paper that are still included in residual waste after separate collection...with ongoing decarbonisation of energy, and factoring the GHG savings from aerobic degradation, prior to landfilling, of biodegradable materials included in waste, MRBT becomes the most climate-friendly option, both whether biogenic CO_2 is considered or not."*

> *"...replacing the RDF-production units in MBT plants with equipment to sort residual waste and recover the materials which are worth recovering...[This] could help ensure the:*

110 [redacted].

1. Reduction of the negative impacts at landfills, due to the biological treatment of the dirty organics;

2. Sufficient diversion of materials from landfills, due to process losses from biological stabilisation and the recovery of some of the other materials;

3. Flexibility of the operational lay-out, given that the sorting systems may similarly be used with materials from kerbside programmes for further separation of different metals, different polymers and different paper grades after separate collection, to help enhance the effectiveness of collection and subsequent recycling systems.

The combination of these operational goals can be described as…MRBT. This is key as it distinguishes [MRBT] from old-fashioned MBT to emphasise the intended goal of merging…recovery of some waste materials and biological stabilisation of fermentable materials before landfilling."

EXTRACT FROM JANUARY 2021 ZERO WASTE EUROPE REPORT

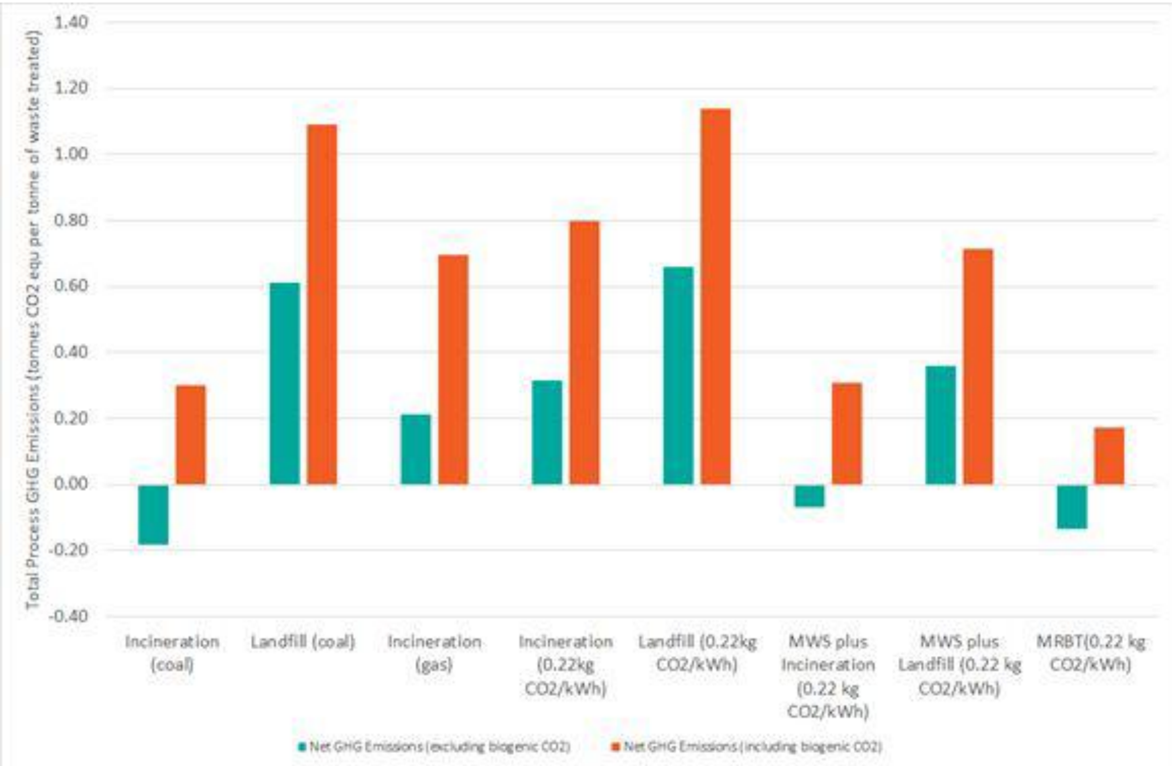


Figure 12: GHG emissions from treating 1 tonne of residual waste through different treatments assuming different carbon intensities of energy being avoided (0,22kg CO2/kWh) (MWS = mixed waste sorting).

More recently, the potential for increased aerobic biological stabilisation prior to landfill as part of a system that includes increased sorting prior to landfill was explored in the ClientEarth report 'Greenhouse Gas and Air Quality Impacts of Incineration and Landfill'.[111]

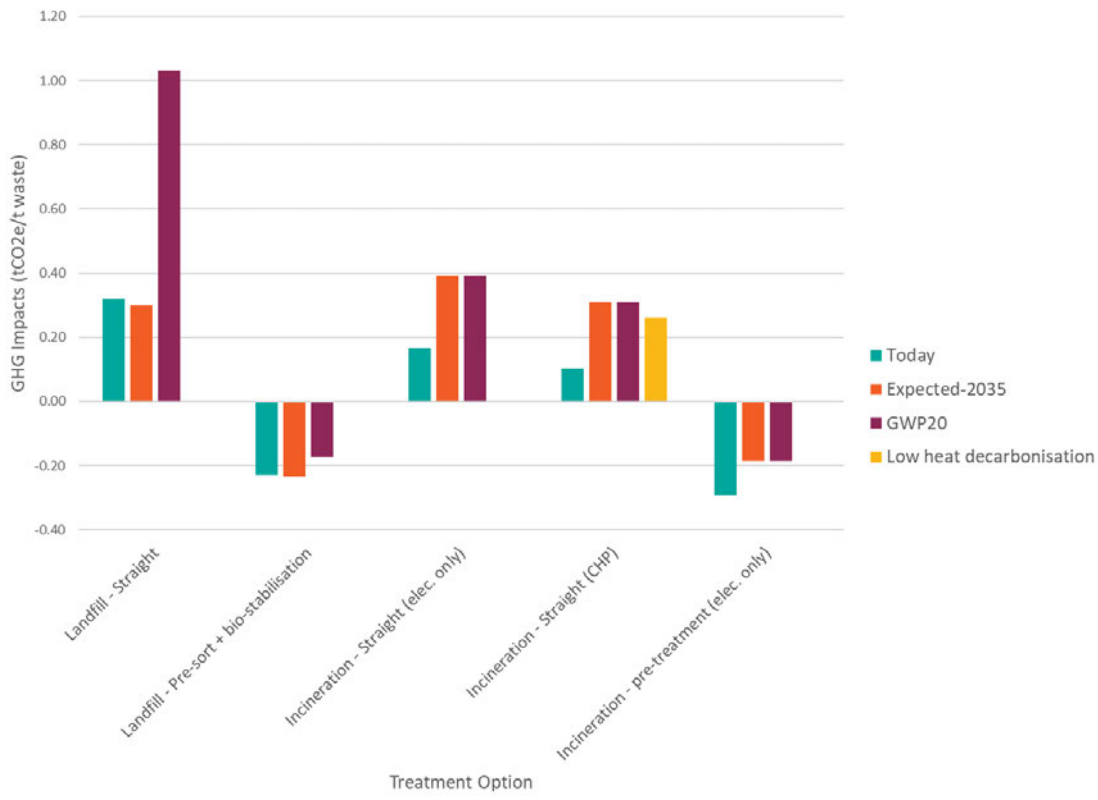
According to the ClientEarth report:

> *"The bio-stabilisation process allows the aerobic degradation of organic material in the residual stream to take place under controlled conditions, releasing biogenic carbon dioxide. This reduces the biogenic carbon content of the stream sent to landfill, thereby reducing methane emissions from the waste once in landfill."*

The report found that landfill with pre-sorting and bio-stabilisation was roughly on par with incineration with plastics removed and recycled (what it calls 'incineration - pre-treatment') but significantly better than incineration of a mixed waste feedstock that includes plastic (what it calls 'incineration straight') even with combined heat and power (CHP).

EXTRACT FROM DECEMBER 2020 CLIENTEARTH REPORT

Figure 2-1 The GHG impacts of the treatment options under each scenario



111 [redacted]

> **RECOMMENDATION #10: Energy from mixed waste incineration should not be described as 'low carbon'. Incineration involves the direct release of significant quantities of CO_2.**

It is misleading to refer to the energy from waste incinerators as 'low carbon'. The incineration of a tonne of waste typically results in the direct release of around 1 tonne of CO_2. Around half of the CO_2 in mixed waste is 'fossil CO_2', and this proportion can be significantly higher when food waste is separately collected[112].

As set out in the table below, the CCC noted that *"In a Net Zero world EfW facilities are likely to be significantly higher carbon than other forms of energy production"* and the CCC categorises unabated waste incineration as a 'high-carbon' activity.

In May 2021 the UK Government stated:[113]

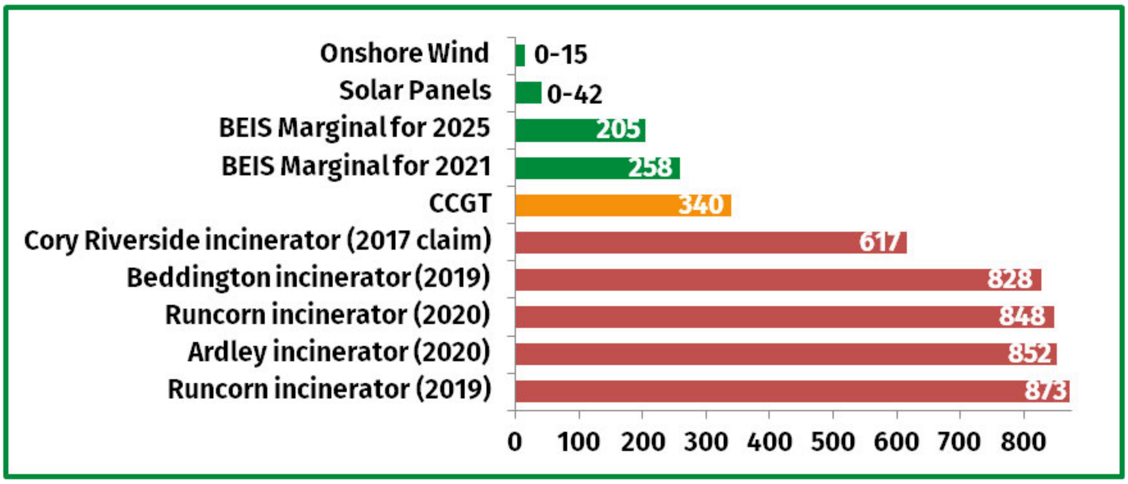
> *"Incineration of fossil derived waste is a contributor to greenhouse gas emissions. Total greenhouse gas emissions from waste incineration accounted for around 1.4% (6.47 million tonnes of carbon dioxide equivalent) of the UK's [non-biogenic] greenhouse gas emissions in 2019. Of this, about 6.19 million tonnes of [fossil] carbon dioxide equivalent was emitted from Energy from Waste plants. It is clear that we will need to reduce that impact. That is why the Government continues to take action, including through our Environment Bill measures, to reduce, re-use and recycle more of our waste and to move to a circular economy."*

Focussing on the fossil CO_2e released per net unit of energy exported to the grid, the annual reported real world carbon intensity of the incinerators set out above typically ranged from around 828 to 873 grams of fossil CO_2e per kWh exported. This is significantly higher than the carbon intensity of Combined Cycle Gas Turbines (CCGT) and the BEIS estimates for long-run and grid average fossil carbon intensity. The total CO_2 emissions released by these incineration plants is roughly double the fossil CO_2 figure because of the release of biogenic CO_2.

Even if one assumes the carbon intensity for incinerators is the same as that claimed by Cory Energy for their Riverside incinerator of 617 gCO_2/kWh[114], modern waste incinerators still have a significantly higher carbon intensity than the conventional use of fossil fuels (and far higher emissions than technologies like solar and wind).

112 [redacted]
113 [redacted]
114 [redacted]

COMPARISON OF FOSSIL CARBON INTENSITY OF ENERGY EXPORTED TO THE GRID FROM DIFFERENT ELECTRICITY GENERATION METHODS (GCO_2E /KWH)



SUMMARY OF THE FOSSIL CARBON INTENSITY OF INCINERATION COMPARED TO ALTERNATIVE ENERGY GENERATION METHODS

Type	Fossil carbon intensity (gCO_2e/kWh)	Source	Comparison to conventional use of fossil fuels
Onshore Wind	0-15	IPCC[115] (upper end of range includes construction CO_2e)	Lower carbon
Solar Panels	0-42		
BEIS Grid Averages (2019, 2021, 2025)	133, 105, 96	BEIS[116] (see above)	
BEIS Long-run Marginals (2019, 2021, 2025)	281, 258, 205		
CCGT (Central Grid Displacement Factor)	340	BEIS[117]	Same
Cory Riverside incinerator	617	Derived from Cory Riverside Energy claims[118] (see above)	Higher carbon
Runcorn, Ardley and Beddington incinerators	828-873	Derived from operator returns to the Environment Agency Pollution Inventory based on measurements (see above)	

115 [redacted]

116 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/793632/data-tables-1-19.xlsx

117 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794738/background-documentation-guidance-on-valuation-of-energy-use-and-greenhouse-gas-emissions.pdf

118 [redacted]

EXAMPLES OF ENERGY GENERATED FROM INCINERATION BEING REGARDED AS 'HIGH CARBON' OR AS NOT 'LOW CARBON'

Source	Relevant Findings / Statements
The climate change impacts of burning municipal waste in Scotland - Technical Report (Zero Waste Scotland, July 2021)[119]	*"The carbon intensity of EfW plants operating in Scotland in 2018 was higher than alternative energy sources. Electricity-only plants emitted nearly twice as many greenhouse gas emissions for each unit of power generated compared to the average of energy technologies supplying the marginal electricity grid in the UK in 2018. Converting these plants to combined heat and power systems would reduce their carbon intensity but not to the level of the UK grid. As a result, EfW can no longer be considered a source of low carbon energy within a UK and Scottish context."*
Greenhouse Gas and Air Quality Impacts of Incineration and Landfill (ClientEarth, March 2021)[120]	*"Incineration cannot be considered a 'green' or low carbon source of electricity, as the emissions per kWh of energy produced are higher than CCGT, renewables, and the aggregated marginal source of electricity in the UK. The carbon intensity deficit of residual waste incinerators will increase as the UK grid decarbonises. The use of incineration is therefore also incompatible with the achievement of local net zero climate change targets in respect of emissions from energy generation, unless coupled with carbon capture and storage. This technology is not yet commercially viable and its use will considerably increase the cost of waste treatment."* *"These results confirm that incineration is not a low carbon form of electricity production in either electricity-only or CHP mode. Incineration plants produce electricity that is more carbon intensive than CCGT, renewables and, most importantly, the marginal source of electricity in both scenarios. It should be noted that results here have been produced assuming the incinerator is relatively efficient in terms of energy generation: the performance of many older electricity-only plant will be considerably worse than that seen here, whilst actual CHP performance is also typically poorer in the UK than that considered in this analysis."*
'Dirty white elephants: Incinerators were supposed to solve the UK's waste crisis. Are they making it worse?' (4th February 2021)[121]	*"'It's misleading' to call the electricity low-carbon, says Ann Ballinger of Eunomia, a sustainability consultancy whose clients include the government. 'You are still burning a lot of plastic to get your energy in an incinerator, so that is pretty similar to burning oil.'…*

119 [redacted]
120 [redacted]
121 [redacted]

Source	Relevant Findings / Statements
	'Energy-from-waste is not low-carbon,' says Piers Forster, an atmospheric physicist at University of Leeds who sits on the UK Committee on Climate Change. 'In recent years the amount of biogenic waste sent to landfill has declined and many landfill sites are introducing methane capture, so claims of low-carbon energy are looking less and less supportable.' *The method incinerator operators use to count their own emissions is 'wrong', says Pedro Faria at CDP, a consultancy that helps many of the world's largest companies assess their climate impact: 'From the point of view of the Greenhouse Gas Protocol, the mix of avoided emissions with actual emissions is not allowed. You cannot mix those two things, they are two different ways of looking at reality.'* *Using landfill for comparison is misleading because it falsely suggests dumping waste is the only alternative to burning it, according to Michael Lenaghan, a scientist at Zero Waste Scotland, a government-funded non-profit organisation.* *'Landfill is not the only alternative to waste-to-energy,' he says. 'There is potential for lower carbon options for treating residual waste, but we would always stress that increased recycling, reuse and waste prevention are much better.'"*
Policies for the Sixth Carbon Budget and Net Zero (Committee on Climate Change, 9th December 2020)[122]	*"The dynamics of each sector, and the principle of minimising early scrappage, point to common timings on the phase-out of high-carbon assets on the path to Net Zero, regardless of what low-carbon solution replaces them (Table 1.2): …Emissions from the UK's growing fleet of energy-from-waste plants will need to be captured in order for energy-from-waste to be sufficiently low-carbon by 2050. Waste should be minimised, and any new plants should be built with CCS or CCS ready."* Table 1.2, which is entitled 'Phase-out dates of high-carbon activities under the Balanced Pathway', lists *"Energy-from-waste plants (unabated)"* as one of the 'high-carbon activities' to be phased out on the path to Net Zero.
Local Authorities and the Sixth Carbon Budget (Committee on Climate Change, 9th December 2020)[123]	*"Local authorities should carefully consider the fossil emissions from EfW plant†. In a Net Zero world EfW facilities are likely to be significantly higher carbon than other forms of energy production. Many facilities will need to reduce their emissions to continue to operate. Local councils will need to consider how current and new EfW plants will fit carbon capture and storage (CCS) equipment in the future, plus the impact of waste reductions and improved recycling (which will remove high calorific value materials from the feedstock)."*

122 [redacted]

123 [redacted]

Source	Relevant Findings / Statements
	†Footnote: *"Heat produced by unabated EfW plants (i.e. without CCS) is not particularly low-carbon – burning Municipal Solid Waste releases ~335gCO2/kWh of input (of which ~163gCO2/kWh is fossil CO2), compared to burning natural gas at ~184gCO2/kWh of input (all fossil CO2), so EfW can be worse in terms of fossil emissions once lower EfW generation efficiencies are accounted for compared to a gas boiler (although there are also upstream gas emissions as well). This will already be the case for EfW electricity generation compared to gas-fired generation. Source: CCC analysis*
Open letter on transitioning to a circular economy without more waste incineration (XR Zero Waste, November 2020)[124]	*"Dr Anne Velenturf from the Resource Recovery from Waste programme said 'Building EfW plants now, when we need to decarbonise, is inconsistent with the Paris Agreement and the UK's legally binding net-zero commitments. Extracting resources and manufacturing products costs a lot of energy and we should not let such invested energy go to waste in incineration plants. Ministers must consider whether planned construction of incinerators is compliant with climate obligations, otherwise the government effectively inhibits the decarbonisation of the UK economy.'"*
The impact of Waste-to-Energy incineration on climate (Zero Waste Europe, September 2019)[125]	*"Waste-to-energy incineration is sometimes promoted as a low-carbon source of energy, justifying increasing quantities of waste for use in electricity generation. The evidence, however, suggests that the carbon intensity of energy produced through incineration is around 2 times greater than the carbon intensity of the current EU average electricity grid intensity and has significantly more adverse climate impacts than conventional electricity generation from fossil fuels such as gas. Moreover, a number of reports indicate that much of what is currently used as incinerator feedstock could instead be recycled or composted, resulting in carbon savings and other environmental benefits. What's clear is that waste incineration is therefore not a low-carbon source of energy, in fact, strategies promoting waste to energy could seriously undermine the EU's efforts to reach net zero climate change emissions by 2050."*

124 [redacted]r
125 [redacted]

Source	Relevant Findings / Statements
Policy Brief: Why solid waste incineration is not the answer to your city's waste problem (C40 Cities Climate Leadership Group, July 2019)[126]	*"Solid waste incineration is often presented as a 'quick-fix' solution to reduce rapidly growing waste volumes while producing energy, especially for cities in the Global South. However, incineration is among the worst approaches cities can take to achieve both waste reduction and energy goals. It is expensive, inefficient, and creates environmental risks. It locks cities into high-carbon pathways by requiring them to continue producing lots of waste to feed the incinerator, undermining efforts to reduce waste generation or increase recycling rates."*
Fixing Fashion: Clothing Consumption and Sustainability - Fashion: It Shouldn't cost the Earth (Environmental Audit Committee, 19th February 2019)[127]	*"While incineration of unsold stock 'recovers' some energy from the products, it multiplies the climate impact of the product by generating further emissions… Climate changing emissions will have been generated when the products were created and more CO_2 will be produced when they are burnt. The waste hierarchy suggests that reuse and recycling comes first. This should be a priority means of dealing with unsold stock. Incineration should only be used as a last resort where there is a health and safety case for destroying the stock. The Government should ban incinerating or landfilling unsold stock that can be reused or recycled."*
Evaluation of the climate change impacts of waste incineration in the UK (UKWIN, October 2018)[128]	*"The 'carbon intensity' of energy produced through waste incineration is more than 23 times greater than that for low carbon sources such as wind and solar; as such, incineration is clearly not a low carbon technology."*
The Circular Economy - a Powerful Force for Climate Mitigation (Material Economics, June 2018)[129]	*"...plastic contains substantial embedded carbon in the material itself, which is released as CO_2 when plastics are incinerated...a continuation of the current shift towards burning plastics would result in substantial additional emissions in 2050...Clearly, the incineration of fossil-based plastics cannot continue in a low-carbon economy"*

126 [redacted]

127 [redacted]

128 [redacted]

129 [redacted]

TECHNICAL APPENDIX - DETAILS OF PREDICTED AND REAL WORLD PERFORMANCE OF WASTE INCINERATION PLANTS

GHG performance of Viridor incinerators based on reported emissions

VIRIDOR INCINERATION PLANTS

Plant	Permit number(s)	Permitted capacity	Year plant started treating waste
Ardley, Oxfordshire	FP3134GU, P3005LJ	326,300 tpa	2016
Runcorn, Cheshire	RP3638CG, XP3005LB	1,100,000 tpa	2015
Beddington, South London	TP3836CT, GP3305LN	347,422 tpa	2018
Peterborough, Cambridgeshire	NP3638ZS	85,000 tpa	2016

Peterborough was excluded from some calculations because it was based on a biogenic fraction claimed by the operator which they could not explain to the Environment Agency when queried.

Ardley's reported emissions for 2019 were excluded from some calculations because the performance was so poor that it would skew the calculations.

While values for reported emissions in the guide assume N_2O reported by the operator as 'Below Reporting Threshold' is zero, this appendix shows the impact of assuming this N_2O is either zero or at the reporting threshold.

Fossil carbon intensity is the fossil CO_2 element directly emitted emissions combined with the N_2O (where reported) and the CO_2 associated with imported electricity (based on the BEIS grid average for the year for reported emissions).

In some cases values are excluded because no figure is known to have been claimed at the planning / permitting stage.

Further notes:

- According to Viridor in a clarification made to the EA obtained under the Environmental Information Regulations (EIR): *"The reason for Peterborough's biogenic fraction being different to the other sites is not known"*.
- The figure for the biogenic fraction for Peterborough is exactly 60% in both 2019 and 2020, and so we assume it is a fixed specified figure rather than based on actual compositional analysis. A range of 50-60% biogenic content was specified by Atkins in a Phase 1 Energy Study produced for Peterborough City Council back in 2012, and this may be the origin of the 60% assumption. Uncertainty regarding the biogenic fraction results in uncertainty regarding the fossil CO_2e per tonne processed and fossil carbon intensity of energy exported.
- CO_2 and N_2O figures are based on monitoring of stack emissions.

- The reporting threshold for N_2O is 10 tonnes of N_2O. This 10 tonne figure is used in the sensitivity analysis in instances where N_2O is registered as being below the associated reporting threshold, on the basis that the actual figure might have been only just below the reporting threshold.
- Carbon Percentage is based on direct CO_2 emissions divided by tonnes processed.
- CO_2e per tonne is Direct CO_2 + Direct N_2O expressed as CO_2e (x298) + Imported electricity expressed as CO_2e (based on BEIS grid average industrial energy mix for the year) divided by tonnes processed.
- Information on Beddington in 2019 also takes account of information provided by Viridor to the South London Waste Partnership.
- Data obtained from the EA is made available under an Open Government License. For details of this license see http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/
- Information on the biogenic fraction is, in some or all cases, based on the proportion of the calorific value (CV) which is derived from biogenic material rather than based on the proportion of the carbon of the input material which is biogenic. According to Viridor's clarification to the EA: *"It is not known whether there is any material difference between a by weight and a by CV approach"*.
- The high fossil carbon intensity from Ardley in 2019 is primarily due to the turbine being offline, reducing electricity export and increasing electricity import.
- The Beddington incinerator was in commissioning during 2019, which could explain why it had lower levels of power export than in 2020.
- The 2019 Annual Performance Report for Ardley states: "On 27 January 2019, a generator stator earth occurred at Ardley, resulting in the loss of generation capability. The generator was removed from Ardley on the 8th March 2019 for repairs within the UK… The generator returned to Ardley on 23 January 2020 and began export 6 February 2020".
- According to Viridor's clarification to the EA: *"the biogenic fraction is determined by the use of the Bioma proprietary software at Runcorn".*

Comparison of reported real world emissions with those predicted at planning and permitting stages

ARDLEY

COMPARISON BETWEEN GHG PERFORMANCE PREDICTED FOR ARDLEY INCINERATOR AND REPORTED EMISSIONS

Incineration Plant	Carbon Percentage in feedstock	CO_2e per tonne processed (tonnes)	Biogenic Fraction	Fossil CO_2e per tonne processed (tonnes)	Power Exported per tonne processed (kWh)	Fossil carbon intensity of energy exported (gCO2/kWh)
Permit app (2009)	25%	0.935	64%	0.353	578	610
Reported (2019)	26%	1.005	49%	0.537	58	9,311
Reported (2020)	26%	1.013	55%	0.479	563	852

Ardley notes:

- The high fossil carbon intensity from Ardley in 2019 is primarily due to the turbine being offline, reducing electricity export and increasing electricity import.
- The 2019 Annual Report for Ardley states: *"On 27 January 2019, a generator stator earth occurred at Ardley, resulting in the loss of generation capability. The generator was removed from Ardley on the 8th March 2019 for repairs within the UK… The generator returned to Ardley on 23 January 2020 and began export 6 February 2020"*.

RUNCORN

COMPARISON BETWEEN GHG PERFORMANCE PREDICTED FOR RUNCORN INCINERATOR AND REPORTED EMISSIONS

Incineration Plant	Carbon Percentage in feedstock	CO_2e per tonne processed (tonnes)	Biogenic Fraction	Fossil CO_2e per tonne processed (tonnes)	Power Exported per tonne processed (kWh)	Fossil carbon intensity of energy exported (gCO2/kWh)
Planning app (2012)				0.494	658	751
Reported (2019)	28%	1.033	48%	0.537	615	873
Reported (2020)	27%	0.992	53%	†0.464 ‡0.467	547	†848 ‡854

† Assumes N_2O reported as 'Below Reporting Threshold' was zero.

‡ Assumes N_2O reported as 'Below Reporting Threshold' was at the reporting threshold.

Runcorn notes:

- The planning application is the Section 73 planning application (13/00011/S7). Claims were repeated in 3 the INEOS Climate Change Proof of Evidence (Dr Anthony Yates).
- Planning application figures are based on burning Refuse Derived Fuel (RDF). However, the facility subsequently moved to burning a mix of RDF and unprocessed municipal solid waste (MSW).

BEDDINGTON

COMPARISON BETWEEN GHG PERFORMANCE PREDICTED FOR BEDDINGTON INCINERATOR AND REPORTED EMISSIONS

Incineration Plant	Carbon Percentage in feedstock	CO_2e per tonne processed (tonnes)	Biogenic Fraction	Fossil CO_2e per tonne processed (tonnes)	Power Exported per tonne processed (kWh)	Fossil carbon intensity of energy exported (gCO2/kWh)
Planning app (2012)						394
Permit app (2012)	23%	0.858	64%	0.321	647	496
Reported (2019)	26%	0.973	51%	0.497	600	828

Beddington notes:

- The Committee Report for the 2012 planning application (Sutton Council ref D2012/66220/FUL) states: "The Mayor of London has set a Carbon Intensity Floor (CIF) in the municipal waste strategy for London, to ensure that facilities for energy generation using residual waste should have a carbon intensity less than, or equal to, the source of energy generation it displaces (typically a combined cycle gas turbine plant). The applicant has submitted evidence to show that, when operating with CHP, the ERF will meet the required CIF level."[130]
- A claimed carbon intensity of 393.7 is stated in Table 7.8 of the Needs Assessment of the planning application (Sutton Council ref D2012/66220/FUL). A sensitivity is provided for operating at higher throughput but with lower calorific value of 382g CO2e per kWh.
- Page 7 of the Needs Assessment states: "The CIF [Carbon Intensity Floor] does apply to individual energy from waste plant and is set at 400 gCCO2eq/kWh, approximately the carbon intensity of CCGT electricity generation. The South London ERF will more than meet this requirement. The applicant has agreed to an additional planning condition to monitor performance of the ERF against the CIF once heat is being delivered. This will help to demonstrate progress towards meeting carbon reduction targets".
- The claims for meeting the CIF are based on heat export, but the facility operated in electricity-only mode in 2019 (when the plant was in commissioning) and again in 2020.

[130] https://moderngov.sutton.gov.uk/documents/s27234/Beddington

PETERBOROUGH

COMPARISON BETWEEN GHG PERFORMANCE PREDICTED FOR THE PETERBOROUGH INCINERATOR AND REPORTED EMISSIONS

Incineration Plant	Carbon Percentage in feedstock	CO_2e per tonne processed (tonnes)	Biogenic Fraction	Fossil CO_2e per tonne processed (tonnes)	Power Exported per tonne processed (kWh)	Fossil carbon intensity of energy exported (gCO2/kWh)
Permit (2013)	24%	0.891	64%	0.328	659	498
Reported (2019)	26%	†0.970 ‡1.006	*60%	*†0.388 ‡0.425	658	*†590 *‡646
Reported (2020)	26%	†0.937 ‡0.974	*60%	*†0.375 *‡0.413	655	*†573 *‡630

† Assumes N_2O reported as 'Below Reporting Threshold' was zero.

‡ Assumes N_2O reported as 'Below Reporting Threshold' was at the reporting threshold.

* Value based on a biogenic fraction claimed by the operator which they could not explain.

Peterborough notes:

- No biogenic fraction is stated in the January 2009 planning application, but a figure of 68% is cited from the Draft UK Renewable Energy Strategy in favour of the application.
- The 60% biogenic fraction is believed to be an assumed value rather than one based on the 2019 or 2020 figure (as noted above), and this means the figures for fossil CO2 and fossil carbon intensity could be based on an incorrect fossil fraction. As such, total carbon percentage and CO2 per tonne are a more reliable point of comparison than fossil carbon intensity.