UNITED KINGDOM WITHOUT INCINERATION NETWORK

Evaluation of the climate change impacts of waste incineration in the United Kingdom

October 2018 ***(Rev 1.01: April 2019)***

KEY FINDINGS

Based on the data and methods set out in the report, the study found that:

- Waste incinerators currently release an average of around 1 tonne of CO_2 for every tonne of waste incinerated.
- The release of CO_2 from incinerators makes climate change worse and comes with a cost to society that is not paid by those incinerating waste.
- In 2017 the UK's 42 incinerators released a combined total of nearly 11 million tonnes of CO_2, around 5 million tonnes of which were from fossil sources such as plastic.
- The 5 million tonnes of fossil CO_2 released by UK incinerators in 2017 resulted in an unpaid cost to society of around £325 million.
- Over the next 30 years the total cost to society of fossil CO_2 released by UK's current incinerators would equate to more than £25 billion pounds of harm arising from the release of around 205 million tonnes of fossil CO_2.
- Electricity generated by waste incineration has significantly higher adverse climate change impacts than electricity generated through the conventional use of fossil fuels such as gas.
- 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.
- When waste is landfilled a large proportion of the carbon is stored underground, whereas when waste is burned at an incinerator the carbon is converted into CO_2 and immediately released into the atmosphere.
- Over its lifetime, a typical waste incinerator built in 2020 would release the equivalent of around 1.6 million tonnes of CO_2 more than sending the same waste to landfill. Even when electricity generation is taken into account, each tonne of plastic burned at that incinerator would result in the release of around 1.43 tonnes of fossil CO_2. Due to the progressive decarbonisation of the electricity supply, incinerators built after 2020 would have a relatively greater adverse climate change impact.
- Composition analysis indicates that much of what is currently used as incinerator feedstock could be recycled or composted, and this would result in carbon savings and other environmental benefits. Thus, incinerating waste comes with a significant 'opportunity cost'.

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Acknowledgements

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Report webpage: http://ukwin.org.uk/climate

THE IMPORTANCE OF GREENHOUSE GAS EMISSIONS AND CLIMATE CHANGE

The UK Government explains the issue as follows:

Rising levels of carbon dioxide and other greenhouse gases, such as methane, in the atmosphere create a 'greenhouse effect', trapping the Sun's energy and causing the Earth, and in particular the oceans, to warm. Heating of the oceans accounts for over nine-tenths of the trapped energy. Scientists have known about this greenhouse effect since the 19th Century.

The higher the amounts of greenhouse gases in the atmosphere, the warmer the Earth becomes. Recent climate change is happening largely as a result of this warming, with smaller contributions from natural influences like variations in the Sun's output. Carbon dioxide levels have increased by about 45% since before the industrial revolution. Other greenhouse gases have increased by similarly large amounts. All the evidence shows that this increase in greenhouse gases is almost entirely due to human activity. The increase is mainly caused by: burning of fossil fuels for energy; agriculture and deforestation; and the manufacture of cement, chemicals and metals.[1]

In October 2018 the Intergovernmental Panel on Climate Change (IPCC) stated:

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate...Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C.[2]

According to the World Wildlife Fund (WWF):

Global warming is likely to be the greatest cause of species extinctions this century. The Intergovernmental Panel on Climate Change says a 1.5°C average rise may put 20-30% of species at risk of extinction. If the planet warms by more than 3°C, most ecosystems will struggle.

Many of the world's threatened species live in areas that will be severely affected by climate change. And climate change is happening too quickly for many species to adapt.[3]

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[1] Climate change explained (BEIS, July 2018), available from: https://www.gov.uk/guidance/climate-change-explained

[2] Intergovernmental Panel on Climate Change (IPCC) SR15 Headline Statements, available from: http://report.ipcc.ch/sr15/pdf/sr15_headline_statements.pdf

[3] Climate change and wildlife, available from: https://www.wwf.org.uk/effectsofclimatechange

INTRODUCTION

This report evaluates the climate change impacts of waste incineration[4] and is intended to inform policy makers, decision-takers, and the public. The need for this study arises in response to the increasing quantities and proportions of UK waste that are incinerated and the necessity to consider the outcomes arising from this increasing level of incineration alongside the various conflicting claims that are made about the climate change impacts of waste incineration.

There are those in the waste industry who are marketing incineration as a solution to climate change even though evidence suggests that incineration is, in fact, part of the climate problem. This study sets out the available data in an accessible way to help decision makers and the public to make evidence-based choices that are better for our environment.

Plastics make up a significant proportion of the material burned by waste incinerators in the UK. Because conventional plastic is derived from petroleum it is a fossil fuel which is recognised as a source of harmful climate change emissions. For conventional power stations that burn fossil fuels such as coal and gas the issue of greenhouse gases released as a by-product of generating energy is addressed through the 'Emissions Trading Scheme' (ETS). However, municipal solid waste incinerators are not part of the ETS and are not subject to any other similar scheme to progressively reduce carbon emissions or to 'price in' the carbon cost of burning fossil fuel.

This means that, for decades, waste incinerators have been releasing harmful greenhouse gas emissions without compensating society for the associated harm that this has caused. The Department for Environment, Food & Rural Affairs (Defra) noted in 2011 that incinerators were "*creating GHG [greenhouse gas] emissions without paying the relevant price*".[5] An estimate of the unpaid carbon cost of waste incineration is set out below.

Because incinerating plastics is an inefficient way to generate electricity, incinerators release more greenhouse gases to produce the energy than would be emitted to generate the same quantity of energy through the conventional use of fossil fuels such as combined-cycle gas turbine (CCGT).

[4] In accordance with the Industrial Emissions Directive, a 'waste incineration plant' covers a range of technologies including conventional incineration, as well as gasification and pyrolysis. Some describe gasification and pyrolysis technologies by other names, including 'Advanced Thermal Treatment' or 'Advanced Conversion Technologies'. Incineration is sometimes referred to as 'Energy from Waste', however anaerobic digestion and landfill gas capture also generate energy from waste.

[5] The Economics of Waste and Waste Policy (June 2011), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69500/pb13548-economic-principles-wr110613.pdf

CO_2 RELEASED BY WASTE INCINERATION

Background

Government guidance explains that: *"CO_2 emissions may be a significant adverse impact of biomass/waste combustion [incineration] plant".*[6] According to Environment Agency (EA) guidance: *"Between 0.7 and 1.7 tonnes of CO_2 is generated per tonne of MSW [Municipal Solid Waste] combusted".*[7] This implies that a typical incinerator burning 265,000 tonnes of waste a year would be responsible for releasing somewhere between 185,500 tonnes and 450,500 tonnes of CO_2 each year of operation. Over the course of 30 years of operation this would amount to the release of between around 5.6 million and 13.5 million tonnes of CO_2.

HOW CARBON IN WASTE IS CONVERTED INTO CO_2 IN THE ATMOSPHERE

Burning one tonne of carbon produces 3.667 tonnes of CO_2. This is because when waste is incinerated the carbon (C) in the waste combines with the oxygen (O) in the air to make carbon dioxide (CO_2). The CO_2 created by the combustion process is then released into the atmosphere, exacerbating climate change.

The quantity of CO_2 released by incineration depends on the amount of carbon that is burned, also known as the feedstock's carbon content (i.e. the 'total carbon percentage' of the feedstock). The atomic weight of carbon is 12 and the atomic weight of oxygen is 16. As CO_2 is made up of one carbon atom bonded to two atoms of oxygen, CO_2 has an atomic weight of 44 (as 12 + (16×2) = 12 + 32 = 44). From this we know that the weight of CO_2 is 3.667 times the weight of the carbon used to create it (44 ÷ 12 = 3.667). As such, the amount of CO_2 that is released from incineration can be calculated based on the carbon content of the feedstock by multiplying the quantity of carbon by 44 and then dividing the result by 12 (or by multiplying the amount of carbon by 3.667).

For example, plastic typically consists of 52% carbon by weight[8] and therefore burning one tonne of plastic results in burning 0.52 tonnes of carbon. This 0.52 tonnes of carbon combines with the oxygen in the air resulting in the release of more than 1.9 tonnes of CO_2 into the atmosphere (0.52 tonnes of plastic × 3.667 = 1.907 tonnes of CO_2).

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6 National Policy Statement for Renewable Energy Infrastructure (EN-3), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/37048/1940-nps-renewable-energy-en3.pdf

7 Pollution inventory reporting – incineration activities guidance note, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296988/LIT_7757_9e97eb.pdf

8 Energy recovery for residual waste – A carbon based modelling approach, available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

CO_2 released by UK incinerators in 2017

In 2017 approximately 10.89 million tonnes of waste was incinerated.[9] Based on the range provided by the EA in their guidance[10], this equates to between 7.6 million and 18.5 million tonnes of CO_2 released by UK incinerators in 2017.

Based on a review of available waste composition data, as set out in Annex A (Table 6: Tonnes of CO2 per tonne based on published UK sources), it appears that **around 27.42% of the material used as incinerator feedstock in 2017 was carbon**, **suggesting that in 2017 the UK's 42 incinerators released a combined total of nearly 11 million tonnes of CO_2** (10.89 million tonnes of waste incinerated × 0.2742 × 3.667 = 10.95 million tonnes of CO_2 released).

This 11 million tonne CO_2 figure relates only to direct emission of CO_2 from incinerators and does not take account of either indirect emission (e.g. emissions arising from the transport of feedstock to the incinerator) or of other greenhouse gases (GHGs) emitted by incinerators (e.g. methane and nitrous oxide).

Furthermore, in addition to the 12 million tonnes of incineration capacity that was operational in 2017[11] there was 3.635 million tonnes of incineration capacity under construction in the UK in 2017.[12] The more waste that is burned, the more CO_2 that is released into the atmosphere by incineration. The release of CO_2 from waste incinerators makes climate change worse and comes with a cost to society.

The carbon price of waste incineration

For decades incinerators have been releasing harmful climate change emissions without compensating for the associated harm that this caused. As previously mentioned, Defra noted in 2011 that incinerators were "*creating GHG [greenhouse gas] emissions without paying the relevant price*".[13]

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[9] UK Energy from Waste Statistics – 2017, available from: http://www.tolvik.com/wp-content/uploads/Tolvik-UK-EfW-Statistics-2017.pdf

[10] Pollution inventory reporting – incineration activities guidance note, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296988/LIT_7757_9e97eb.pdf

[11] According to Tolvik, the headline incineration capacity for 2017 was 12.263 million tonnes. This is higher than the input tonnage of 10.89 million tonnes due to factors such as maintenance downtime and because two of the incinerators only came into operation part of the way into the year.

[12] UK Energy from Waste Statistics – 2017, available from: http://www.tolvik.com/wp-content/uploads/Tolvik-UK-EfW-Statistics-2017.pdf

[13] The Economics of Waste and Waste Policy (June 2011), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69500/pb13548-economic-principles-wr110613.pdf

Because operators do not pay for the cost to society of the fossil CO_2 released by incineration this cost is described as an 'environmental externality', i.e. a burden to society where the cost is not reflected in the price paid by those incinerating the waste. Costs to society associated with incinerator climate change emissions can be calculated.

This section of the report is focused on estimating the 'carbon price' of the direct release of CO_2 that derives from the incineration of fossil-based feedstock such as plastic.

The carbon associated with wood, paper, card, kitchen and garden waste can be classified as 'biogenic carbon', whereas carbon derived from oil (including plastics), natural gas and coal is known as 'fossil carbon'.

This report's financial calculations focus on fossil carbon, but that does not mean that the immediate release of CO_2 derived from biogenic sources through incineration is not accompanied by a cost to society.

The financial calculations in this report also exclude the cost to society of other incinerator emissions such as those released from burning petroleum-based start-up fuels, and those emitted by vehicles transporting material to and from the site.

The level of fossil CO_2 released by an incinerator depends on what is being burned.

As set out in Table 6 of this report (see Annex A), figures from the waste industry indicate that some proposed waste incinerators are expected to release more than 0.5 tonnes of fossil CO_2 per tonne of waste burned. This report uses a lower figure than 0.5 tonnes of fossil CO_2 per tonne of waste burned.

As set out in Annexes A and B, it can reasonably be assumed that **incinerators in the UK currently release an average of around 0.458 tonnes of fossil CO_2 per tonne of waste incinerated**.

If the assumed average figure of 0.458 tonnes of fossil CO_2 per tonne is multiplied by the 10.89 million tonnes of waste understood to have been incinerated in 2017 this gives a figure of **around 5 million tonnes of fossil CO_2 released in 2017 by UK incinerators** (0.458 × 10.883 = 4.984 million tonnes).

This report uses Government guidance[14] to arrive at a financial figure that reflects the harm caused by the release of fossil CO_2 into the atmosphere. Specifically, this report uses the relevant Department for Business, Energy and Industrial Strategy (BEIS) carbon price figures[15] which were produced *"to be used in policy appraisal and evaluation"* and which *"relate to the cost of mitigating emissions"* (i.e. the cost of reducing emissions to allow the UK's legally-binding climate change targets to be met).[16] The increased difficulty of CO_2 abatement as the grid decarbonises is reflected in future carbon prices.

Unlike power stations, waste incinerators are not part of the Emissions Trading Scheme, and therefore the relevant BEIS carbon prices to use are those for non-traded carbon. For 2017, BEIS's central non-traded carbon price is £65.11 per tonne. This means that **if UK incinerators released around 5 million tonnes of fossil CO_2 in 2017 then this would be associated with an unpaid cost to society of around £325 million** (10,883,000 × 0.458 = 4,984,414 and 4,984,414 × £65.11 = £324,535,196).

Table 1: Cost to society of fossil CO_2 released from UK incinerators in 2017

Tonnes of waste incinerated	Fossil CO2 per tonne	Tonnes of fossil CO2	Non-traded carbon price	Cost to society of fossil CO2 from incineration
10,883,000	0.458	4,984,414	£65.11	**£324,535,196**

BEIS's central non-traded carbon price rises year on year through to 2075. Assuming that the UK incinerates around 14.4 million tonnes[17] of waste each year for the 30 years from 2019 to 2049, using BEIS's central non-traded carbon prices and the assumed 0.458 tonnes of fossil CO_2 released per tonne burned, the total cost to society of just the fossil CO_2 released by UK incinerators would equate to **more than £25 billion pounds of harm arising from the release of around 205 million tonnes of fossil CO_2.**

The calculations used to arrive at these figures are provided as Table 8 in Annex A.

[14] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, available from: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[15] Table 3: Carbon prices and sensitivities 2010-2100 for appraisal, 2017 £/tCO2e from Data tables 1 to 19: supporting the toolkit and the guidance, available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/696677/Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2017__180403_.xlsx

[16] See: https://www.gov.uk/government/collections/carbon-valuation--2

[17] NOTE: According to Tolvik's UK Energy from Waste Statistics – 2017, input tonnage was 90.8% of the headline capacity in 2017. The 14,435,384 tonne figure is based on 90.8% of the 2017 headline incineration capacity figure of 12.263 million tonnes plus 90.8% of the 3.635 headline capacity figure for the incinerators that were under construction in 2017 (12,263,000 + 3,635,000 = 15,898,000 and 15,898,000 × .908 = 14,435,384).

CARBON INTENSITY OF ELECTRICITY GENERATED

Background

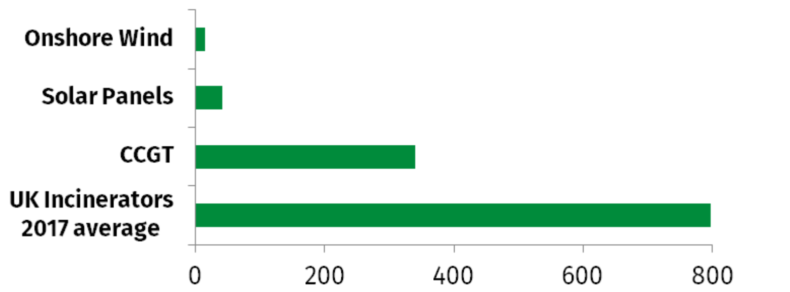
One approach to comparing the environmental impacts of different forms of energy generation is by comparing the 'emissions intensity' of the energy that is generated. In relation to greenhouse gas emissions this could mean, for example, examining how much fossil CO_2 is released per unit of electricity exported to the grid, i.e. the 'fossil carbon intensity' of the electricity.

England's National Planning Policy Framework (NPPF) states that: *"Low carbon technologies are those that can help reduce emissions (compared to conventional use of fossil fuels)"*.[18]

Comparing how much fossil CO_2 is released per unit of electricity exported to the grid for energy generated by burning waste in an incinerator, relative to the quantity of fossil CO_2 released per unit of electricity exported to the grid through the conventional use of fossil fuels, provides a means of assessing whether or not the energy generated through incineration meets the NPPF definition of a 'low carbon technology'.

One can also examine how energy generated through incineration compares with technologies such as wind and solar, as well as with evaluating incineration in relation to a 'marginal energy mix' (which can be expressed as a 'marginal energy factor' or 'MEF') that reflects the carbon intensity of the mix of energy sources that would be displaced by a new waste incinerator.

Figure 1: Fossil carbon intensity of electricity (gCO_2/kWh)



A watt (W) is a unit of power and a kilowatt (kW) is 1,000 watts. Ten 100-watt light bulbs operating for one hour would consume one kilowatt hour (kWh) of electricity (10 bulbs × 100W × 1 hour = 1,000 watt hours or 1 kilowatt hour). The quantity of fossil CO_2 released per unit of electricity exported to the grid can be expressed as grams (g) of CO_2 per kilowatt hour (kWh), i.e. gCO_2/kWh.

[18] Pages 70 and 71 of the July 2018 version of the National Planning Policy Framework, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/740441/National_Planning_Policy_Framework_web_accessible_version.pdf

In addition to CO_2, other greenhouse gases (GHGs) such as methane and nitrous oxide also have adverse climate impacts, with varying degrees of global warming potential. To provide a common unit of measurement for comparing the impacts of different GHGs these are converted into the number of tonnes of CO_2 required to have an equivalent climate change impact over a given time period. 'CO_2e' can be used to denote GHG emissions expressed as CO_2 equivalent. Due to inconsistencies across source data, UKWIN uses CO_2 and CO_2e interchangeably in this report in circumstances where it is not anticipated to have a significant impact on the calculations.

Fossil carbon intensity of the electricity grid

BEIS estimates that, for 2017, the UK's generation-based grid average from all sources (including CCGT, solar, wind, etc.) was 213gCO_2e/kWh.[19] This means that, on average, the equivalent of 213 grams of CO_2 was released for every kilowatt hour of electricity generated.

213gCO_2e/kWh represents a significant reduction from the estimate for 2010 of 459gCO_2e/kWh. This reduction is the result of efforts to 'decarbonise' the electricity supply, including the move away from coal and the move towards low carbon technologies such as wind and solar.

Carbon intensity from non-incineration sources

Conventional use of fossil fuels

In relation to the conventional use of fossil fuel, BEIS states that a typical combined-cycle gas turbine (CCGT) power plant produces electricity with a carbon intensity of around **340gCO_2e/kWh** (before transmission losses).[20]

Wind, solar and geothermal

An Intergovernmental Panel on Climate Change (IPCC) report from 2014 does not attribute any direct fossil or biogenic emissions to the operation of low carbon renewable sources such as wind, solar and geothermal.[21]

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[19] Table 1: Electricity emissions factors to 2100, kgCO2e/kWh, available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/696677/Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2017__180403_.xlsx

[20] Page 5 of Valuation of Energy Use and Greenhouse Gas Emissions – Background documentation (January 2018), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671204/Background_documentation_for_guidance_on_valuation_of_energy_use_and_greenhouse_gas_emissions_2016.pdf

[21] Technical Annex III of Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPPC), available from: https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_annex-iii.pdf

As such, based on the methodology used to assess the fossil carbon intensity from incinerators, the direct emissions arising from energy generated by low carbon sources such as wind and solar could be said to be **0gCO_2e/kWh**.

It should be noted that this report excludes both infrastructure (e.g. construction) and supply chain emissions in the figures for emissions released by waste incinerators. However, in order to provide context regarding the relative carbon intensity of electricity generated by waste incinerators compared to other forms of energy generation it is helpful to understand the full life-cycle analysis (LCA) impact of these non-incineration sources which consist of the 'Infrastructure & supply chain emissions'.

IPCC's Climate Change 2014: Synthesis Report provides the following estimated GHG emissions associated with the infrastructure and supply chain of low carbon technologies, based on life-cycle analysis:

Table 2: Emissions from low carbon sources, based on life-cycle analysis (LCA)

Technology	Infrastructure & supply chain emissions
Onshore Wind	**15** gCO_2e/kWh
Offshore Wind	**17** gCO_2e/kWh
Solar PV (rooftop)	**42** gCO_2e/kWh
Geothermal	**45** gCO_2e/kWh
Average of the above	***29.75*** *gCO_2e/kWh*

As can be seen from the figures for wind, solar and geothermal in Table 2 above, these low carbon sources of energy support the decarbonisation of the energy supply and emit significantly less carbon than the conventional use of fossil fuels, even when account is made of associated infrastructure and supply chain emissions.

Fossil carbon intensity of incineration

In 2006, a report produced for Friends of the Earth by environmental consultancy Eunomia estimated that future electricity-only incinerators would have a total carbon intensity of 1,405gCO_2e/kWh. Eunomia estimated a **fossil carbon intensity of 580gCO_2e/kWh** which implies a biogenic carbon intensity of 825gCO_2e/kWh.

The Eunomia report noted that: *"…typical UK incinerators, generating only electricity, are unlikely to be emitting a lower quantity of greenhouse gases, expressed in CO_2 equivalents, per kWh electricity generated than the average gas-fired power station in the UK"*.[22]

In 2011 the Minister of State for Climate Change stated that, based on the data available at that time, direct fossil CO_2 emissions from electricity generated through waste incineration were estimated to have been **540gCO_2e/kWh** in 2008.[23]

As set out in Annex B, estimates for fossil carbon intensity (i.e. the fossil CO_2 released per kWh of energy) from the incineration of waste are summarised in the following table:

Table 3: Fossil carbon intensity of energy from UK incinerators based on direct emissions

Description	Fossil Carbon Intensity
Minister of State (2011), UK incinerators 2008	**540** gCO_2/kWh
Eunomia (2006), electricity-only UK incinerators	**580** gCO_2/kWh
Cory (2018), Riverside incinerator in 2015	**617** gCO_2/kWh
Average carbon intensity of electricity generated by UK incinerators in 2017	**797** gCO_2/kWh
Inquiry evidence (2015), Bilsthorpe Energy Centre	**937** gCO_2/kWh
Average of the above	**694.2** gCO_2/kWh

Based on Tables 2 and 3 above, the mean average fossil carbon intensity of the incineration sources is more than 23 times the mean average of the low carbon sources (694.2 ÷ 29.75 = 23.33) even though the low carbon sources include infrastructure and supply chain emissions whereas the incineration figures are limited only to direct emissions.

[22] A Changing Climate for Energy from Waste?, available from: https://friendsoftheearth.uk/sites/default/files/downloads/changing_climate.pdf
[23] Written Answers to Questions – Monday 17 January 2011, available from: https://publications.parliament.uk/pa/cm201011/cmhansrd/cm110117/text/110117w0001.htm#1101173000926

Conclusions on fossil carbon intensity

As can be seen from the evidence summarised in Table 3 above, electricity generated by waste incineration has a significantly higher fossil carbon intensity (of between 540gCO_2/kWh and 937gCO_2/kWh) than electricity generated through the conventional use of fossil fuels (e.g. CCGT's fossil carbon intensity of around 340gCO_2/kWh). Thus, **incineration is clearly not a 'low carbon' technology** when considered in light of the NPPF definition.

This conclusion is unsurprising when one considers that waste incinerators rely on burning plastic (a fossil fuel made from petroleum) and that waste incinerators generate electricity inefficiently. The greater the proportion of the incinerator feedstock which is plastics, the greater the proportion of the energy content of the waste that is derived from fossil fuels. As can be seen from Table 10, even for a 'top of the range' electricity-only incinerator the net impact of burning 0.1348 tonnes of plastic results in a net fossil CO_2 release of 0.1929 tonnes of CO_2. This means that **even when electricity generation is taken into account, burning 1 tonne of plastic results in the release of around 1.43 tonnes of fossil CO_2** (0.1929 ÷ 0.1348 = 1.43).

According to Cory's Riverside carbon report, 16% of their incinerator's feed-stock in 2016 was made up of plastic and this provided 36% of the feedstock's calorific value (energy content).[24] These figures exclude the plastic content of the textiles that were incinerated. Cory's report claims half of the carbon and energy content of textiles incinerated at Riverside was biogenic, implying half the textiles were comprised of plastic from synthetic fibres. If one includes plastics from textiles based on these assumptions then 18% of the feedstock was plastic and this proportion of the feedstock's energy content provided more than 38.5% of the energy generated by the Riverside incinerator in 2016.

Given the quantity of fossil fuels being incinerated, the question of how much energy can be extracted in exchange for those fossil CO_2 emissions becomes relevant, and the relative inefficiency of electricity-only incinerators compared to other forms of power generation becomes significant.

In relation to the relative inefficiency of incineration compared to CCGT, footnote 80 of the Government's Energy from Waste Guide notes that: *"Typical conversion efficiency of waste fuel into usable electricity is 25% compared to >70% for natural gas to electricity in CCGT"*.[25]

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[24] Page 16 of Cory Riverside Energy: A Carbon Case, available from: https://www.coryenergy.com/wp-content/uploads/2018/01/Cory-Carbon-Report-v1.1.pdf

[25] Energy from waste: A guide to the debate February 2014 (revised edition), available from: https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate

Commenting on this issue, Keith Freegard (Axion Polymers Director and Vice-chair of the British Plastics Federation Recycling Group) explained that: *"Even the most modern burner designs are relatively inefficient at energy recovery, generating lower amounts of electrical power per tonne of fuel burned when compared to high efficiency, combined cycle gas turbine systems (CCGT). Both power generating units are ultimately doing the same task: converting carbon-rich fuels into electricity...while sending atmospheric-polluting carbon emissions up the exhaust stack as a major environmental cost associated with the beneficial electrical power supplied into the local grid".*[26]

In addition to performing poorly compared to CCGT, incineration performs very poorly compared to low carbon energy sources. As set out in Tables 2 and 3 above, **even when non-direct emissions are included for low carbon sources while being excluded for incineration, 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.**

A July 2018 report from ClientEarth noted that: "*even when energy is recovered in the [incineration] process, the net effect of incineration of plastic waste is to contribute to [i.e. exacerbate] climate change".*[27]

In June 2018, Material Economics published a report entitled 'The Circular Economy - a Powerful Force for Climate Mitigation'. The project, which was supported by the Ellen MacArthur Foundation, investigated the reductions in GHG emissions that could be achieved through a more circular economy on the pathway 2050.

According to the study: *"The largest net growth in emissions in our baseline scenario occurs in plastics. This is only partly because consumption increases, but more because plastics 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".*[28]

[26] Is 'storing' waste plastics better than burning? (2016), available from: http://www.recyclingwasteworld.co.uk/opinion/is-storing-waste-plastics-better-than-burning/149088/

[27] Risk unwrapped: plastic pollution as a material business risk, available from: https://www.documents.clientearth.org/wp-content/uploads/library/2018-07-24-risk-unwrapped-plastic-pollution-as-a-material-business-risk-ce-en.pdf

[28] The Circular Economy - a Powerful Force for Climate Mitigation, available from: http://materialeconomics.com/publications/publication/the-circular-economy-a-powerful-force-for-climate-mitigation

COMPARING INCINERATION WITH LANDFILL

The climate change impacts of waste incineration can also be compared with those associated with sending the same waste, untreated, directly to landfill.

The Government's 2011 Waste Review acknowledged that: *"...while energy from waste has the potential to deliver carbon and other environmental benefits over sending waste to landfill, energy recovery also produces some greenhouse gas emissions. It is important to consider the relative net carbon impact of these processes, and this will depend on the composition of feedstocks and technologies used"*.[29]

In August 2015 Planning Inspector Mel Middleton turned down a proposal for a 150,000 tonnes per annum (tpa) incinerator proposed for the Former Ravenhead Glass Warehouse at Lock Street, St. Helens, Merseyside. One of the reasons given by the Inspector for refusing planning permission was the poor *"carbon credentials"* of the incinerator, noting that: *"...generating electrical energy from waste can contribute to carbon emissions to a greater extent than depositing the same material as landfill. It is therefore not a simple exercise to demonstrate that an EfW [Energy from Waste plant, i.e. incinerator] will have a positive effect on overall carbon emissions..."*.[30]

In January 2018 Resource Minister Dr Thérèse Coffey, responding on behalf of Defra to a Parliamentary Question, made clear that: *"A comparison of the CO_2 impact of waste going to energy from waste and landfill is included in the analysis of the 2014 report 'Energy recovery for residual waste: A carbon based [modelling] approach'. No formal analysis has been undertaken since this report was published"*.[31]

UKWIN's climate change report applies Defra's carbon based modelling approach to a range of prospective feedstock composition profiles for both landfilling 265,000 tonnes of waste and for burning that same tonnage in a hypothetical incinerator built in 2020. This analysis takes account of direct emissions, emissions displaced through electricity generation, and biogenic carbon 'sequestered' in landfill (i.e. stored underground rather than immediately released as CO_2 into the atmosphere as would be the case with incineration). The results are set out in Figure 2 and Table 5, below.

[29] Paragraph 209 of the Government review of waste policy in England (2011), available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69401/pb13540-waste-policy-review110614.pdf

[30] Appeal decision Ref: 2224529, available from: https://acp.planninginspectorate.gov.uk/ViewCase.aspx?Caseid=2224529&CoID=0

[31] Waste Disposal: Written question – 124194, available from: https://www.parliament.uk/business/publications/written-questions-answers-statements/written-question/Commons/2018-01-22/124194/

The following are the three feedstock composition profiles that are used to evaluate the relative net carbon impacts of incineration compared with landfill using Defra's Carbon based modelling approach:

- The **Defra Base Case** uses the default values from Tables 5 and 8 of Defra's carbon based modelling report;
- The **Reduced Plastic Case** is the same as the Base Case, but halves the quantity of plastics (and proportionally increases other materials); and
- The **Reduced Compostable Case** is the same as the Base Case, but halves the quantity of food, garden and soil waste (and proportionally increases other material).

Table 4: Feedstock composition profiles

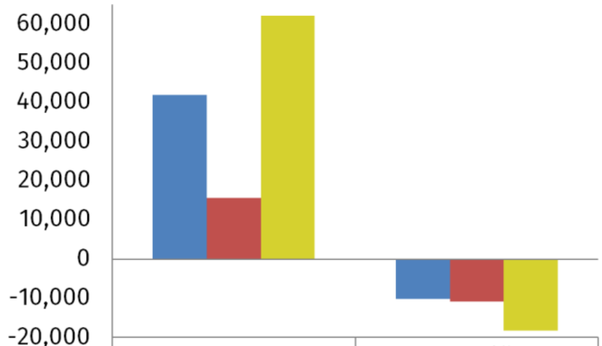
	Defra Base Case	Reduced Plastic	Reduced Compostables
Mixed Paper and Card	15.14%	16.32%	19.64%
Plastics	13.48%	6.74%	17.50%
Textiles (and footwear)	3.95%	4.26%	5.13%
Miscellaneous combustibles	5.90%	6.36%	7.66%
Miscellaneous non-combustibles	8.99%	9.69%	11.67%
Food	31.12%	33.55%	15.56%
Garden	3.11%	3.35%	1.55%
Soil and other organic waste	3.11%	3.35%	1.55%
Glass	5.37%	5.79%	6.97%
Metals, Other Non-biodegradable	2.25%	2.43%	2.93%
Non-organic fines	0.57%	0.61%	0.74%
Wood	3.11%	3.35%	4.03%
Sanitary / disposable nappies	3.90%	4.20%	5.07%

Technical Annex C provides details in relation to the:

- use of Defra's carbon based modelling approach (including the various formulas and calculations used and their results);
- choice of incinerator efficiency (25% overall GCV efficiency, equivalent to 30% overall NCV efficiency - an 'optimistic' assumption based on a figure cited in Defra's carbon based modelling approach as reflecting a hypothetical *"high-performing electricity-only plant"*);
- choice of marginal emissions factor (2020 BEIS MEF of 0.270, based on Government guidance on evaluating displaced power generation);
- approach to accounting for biogenic carbon sequestration (subtracting biogenic carbon sequestered from the landfill side of the equation, i.e. following method 1(b) as set out in Paragraph 174 of Defra's carbon based modelling approach document); and
- choice of waste throughput (265,000 tonnes per annum).

The results of the comparison are summarised as follows:

Figure 2: Tonnes of CO_2e released by incineration and landfill of 265,000 tonnes of waste



	Incineration	Landfill
Base Case	41,817	-10,123
Reduced Plastic	15,529	-10,918
Reduced Compostables	62,196	-18,259

Table 5: Relative net GHG impacts from a typical incinerator compared to landfill

	Defra Base Case	Reduced Plastic	Reduced Compostables
Direct emissions	25,864 tCO_2e	-11,475 tCO_2e	56,816 tCO_2e
Electricity offset	-46,879 tCO_2e	-40,704 tCO_2e	-54,140 tCO_2e
Biogenic carbon sequestration	72,955 tCO_2e	78,626 tCO_2e	77,778 tCO_2e
Total per year	**51,940 tCO_2e**	**26,447 tCO_2e**	**80,454 tCO_2e**
Total over 30 years	**1,558,200 tCO_2e**	**793,410 tCO_2e**	**2,413,620 tCO_2e**

Based on this analysis, even when account is taken of the release of methane from landfill (converted into CO_2e), a typical 265,000 tpa incinerator built in 2020 would emit between 26,447 and 80,454 tonnes of CO_2e per year more than sending the same waste directly to landfill, meaning that **with respect to climate change emissions for 30 years of operation the incinerator would be between 793,410 tCO_2e and 2,413,620 tCO_2e worse than landfill**. Due to the progressive decarbonisation of the electricity supply, incinerators built after 2020 would have a relatively greater adverse GHG impact.

These results are consistent with work carried out previously. In December 2017 UKWIN examined the climate change impact of the Cory incinerator in order to inform the London Assembly's investigation into Energy from Waste in London. This evidence used Cory's 'Carbon Case' report as a starting point, in which Cory used a slightly different methodology to that set out in Defra's Carbon based modelling approach.

UKWIN's 2017 report[32] set out two areas where applying a more refined methodology than the methodology adopted by Cory would: (a) allow the modelling to account for the difference in the quantity of biogenic CO_2 released through incineration relative to landfill; and (b) use the appropriate BEIS marginal emissions factor (MEF) to calculate the level of CO_2 displaced through energy generation.

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

Except for the fact that some of its feedstock is transported by barges, Cory's Riverside Resource Recovery Facility can be considered a typical modern large-scale electricity-only incinerator. As set out in UKWIN's 2017 report, when one applies the methodological improvements, Cory's own data shows that GHG emissions from the Riverside incinerator are significantly higher (between 6.7m and 10.5m tonnes higher over 30 years) than emissions from sending the same waste directly to landfill. This supports the general conclusion reached above through use of Defra's carbon based modelling approach as a basis for comparing incineration and landfill.

Whilst this analysis focuses on electricity-only incinerators, incineration facilities can operate in 'combined heat and power' (CHP) mode, and indeed a small number of UK incinerators do export some heat within a few kilometres e.g. for district heating of housing, industrial parks, and/or large premises. CHP means that some electrical output will be sacrificed to provide heat output, and so the impact of CHP on climate change emissions can be slightly worse or slightly better than electricity-only incineration, depending in part on how much of the exported heat is meaningfully used. Locating a sufficiently large heat requirement and overcoming logistical issues in relation to delivering to those heat users is difficult, and very few of the UK's incinerators currently operate in CHP mode.

It is noted that in some cases, operating a CHP scheme can increase 'lock-in' to, and reliance on, an incinerator which has adverse climate change impacts. Whilst CHP might in some cases make a facility marginally less harmful in GHG terms than if it were operated in electricity-only mode, it does not alter the conclusions that waste incineration is accompanied by adverse climate change impacts.

[32] UKWIN's December 2017 critique of 'Cory Riverside Energy: A Carbon Case', available from: http://ukwin.org.uk/files/pdf/UKWIN_December_2017_Cory_Riverside_Carbon_Critiques.pdf

RECYCLABILITY OF INCINERATOR FEEDSTOCK

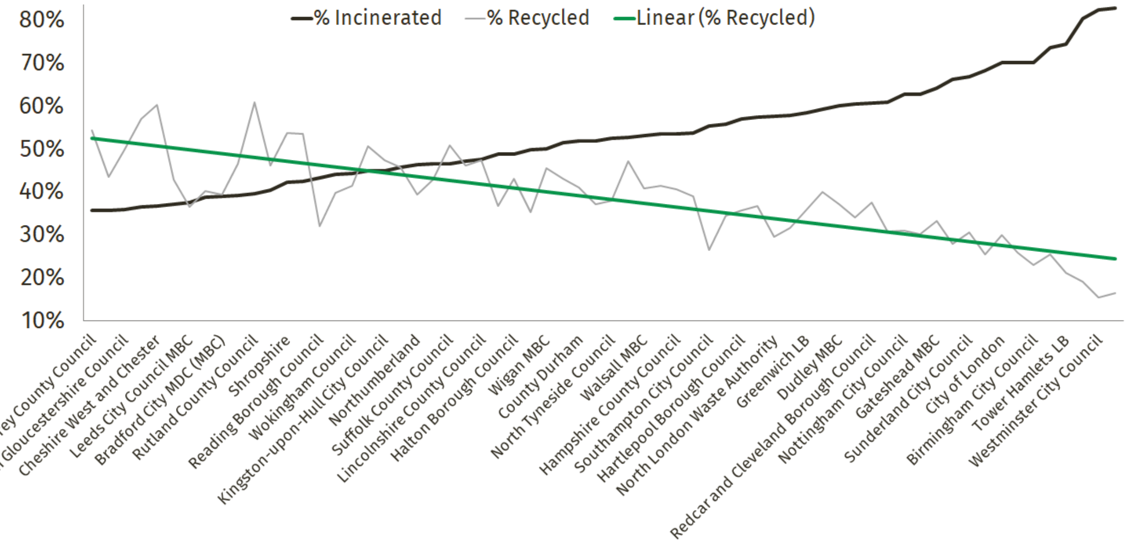
A number of surveys carried out around 2014/15 in different areas of England found that the kerbside recyclability of municipal waste put in residual waste bins, based on the kerbside recycling services available at the relevant local authorities, ranged from 52% to 57.9%, and one study[33] found that when recycling services available at Council bring sites are included an additional 10.1% can be added to this figure. Thus, **composition analysis indicates that a clear majority of 'residual waste' is readily recyclable**.

It is simply not the case that there is a binary choice between sending material for incineration or sending that same material untreated directly to landfill, for example:

- Unavoidable food waste can be redistributed, and where that is not possible it can be composted or sent for anaerobic digestion;
- Products can be reused or repaired;
- Dry recyclable material such as glass, plastics, paper, card and textiles can be recycled;
- Paper and card not suitable for recycling can be composted; and
- Residual biodegradable waste can be 'bio-stabilised' prior to landfill to reduce methane emissions.

Analysis of waste statistics shows that councils with above-average rates of incineration tend to have lower rates of recycling.[34]

Figure 3: Municipal waste treatment rates for councils with above-average incineration (2015/2016)



[33] Waste composition – kerbside, available from: http://edocs.southglos.gov.uk/wastestrategyevidence/pages/waste-composition-kerbside/

[34] UKWIN Bin the Burners Briefing about how incineration harms recycling, available from: http://ukwin.org.uk/btb/BtB_Incineration_Harms_Recycling.pdf

Figure 3 (above) displays the incineration and recycling rates of English Councils that had above-average rates of incineration in 2015/16 based on Defra statistics. The Councils are sorted by ascending rate of incineration, and the trend line highlights how those authorities with higher rates of incineration also tended to have lower rates of recycling. The graph in Figure 3 is an update of earlier UKWIN analysis which was based on 2012/13 waste data and which the House of Commons Environment, Food and Rural Affairs Committee (EFRACOM) described as "*showing an apparent correlation between high rates of incineration and low rates of recycling*".[35]

The observation that much of what is described as 'residual waste' is not genuinely residual, and that much of the feedstock used by incinerators could and should have been recycled or composted, is not new.

For example, Resource Futures Non-executive Chair Phillip Ward noted in September 2012 that: *"...black bag waste is not a single material. Resource Futures are the holders of comprehensive information about its composition and their study – published by Defra – shows that it is largely made up of regular recyclable materials..."*.[36]

More recently, Professor Ian Boyd, Chief Scientific Adviser at DEFRA, noted in January 2018 that: *"If there is one way of quickly extinguishing the value in a material, it is to stick it in an incinerator and burn it. It may give you energy out at the end of the day, but some of those materials, even if they are plastics, with a little ingenuity, can be given more positive value. One thing that worries me is that we are taking these materials, we are putting them in incinerators, we are losing them forever and we are creating carbon dioxide out of them, which is not a great thing...I think that incineration is not a good direction to go in"*.[37]

As part of their July 2018 National Infrastructure Assessment the National Infrastructure Commission noted that: *"Reducing the waste sent to energy from waste plants (incinerators) by recycling more plastic and converting more food waste into biogas can also help reduce overall emissions...The successful delivery of a low cost, low carbon energy and waste system requires...encouraging more recycling, and less waste incineration"*.[38]

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[35] Paragraph 77 of Waste management in England, Fourth Report of Session 2014–15, available from: https://publications.parliament.uk/pa/cm201415/cmselect/cmenvfru/241/241.pdf
[36] Reshuffling the waste hierarchy, available from: http://www.isonomia.co.uk/?p=1209
[37] Oral Evidence: The Work of Defra's Chief Scientific Adviser, HC 775, available from: http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environment-food-and-rural-affairs-committee/work-of-the-chief-scientific-adviser-defra/oral/78127.pdf
[38] National Infrastructure Assessment, available from: https://www.nic.org.uk/publications/national-infrastructure-assessment-2018/

Efforts to 'design out' waste and to promote the circular economy can be expected to significantly reduce the quantity of 'residual waste' that is available for treatment. Much of what is currently used for incinerator feedstock could be recycled or composted, which would result in carbon savings and other environmental benefits. Reduction and reuse could be expected to deliver even greater carbon and environmental benefits.

Quantifying the full 'opportunity cost' of incinerating recyclable materials falls outside the scope of this report, but it is worth noting that a significant proportion of what is currently in the 'residual waste' stream is already recyclable based on current council recycling services.

Summary of results from compositional analysis studies

South Gloucestershire Council commissioned analysis into their residual waste, which found: *"A total of 52 percent of the contents of the average black bin could have been recycled in 2014-15 through the existing kerbside recycling service...A further 10.1 percent could have been recycled through the Sort It recycling centres...In 2014-15 the council spent over £3m disposing of this recyclable material in the residual waste stream. The majority of this was processed into material used for energy production"*.[39]

According to Section 4.3 of the **Hertfordshire** Waste Composition Analysis published in May 2015: *"The overall recyclability of the residual waste relates to all the items present [in the kerbside residual waste stream] that could have been accepted into the kerbside recycling schemes currently operating in each of the Hertfordshire authorities that were sampled...Across Hertfordshire it is expected that 51.2% of all residual waste being disposed of is recyclable at the kerbside"*.[40]

A similar study in **Barnet Borough Council**, based on surveys carried out in November 2014 and April 2015, found that the overall recyclability of the household residual stream (i.e. all the items present that could have been accepted into the kerbside recycling containers that are available) ranged from 54.9% to 56.8%.[41]

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[39] Waste composition – kerbside, available from: http://edocs.southglos.gov.uk/wastestrategyevidence/pages/waste-composition-kerbside/

[40] Hertfordshire Kerbside Waste Composition Analysis (March - May 2015) Final Report, available from: http://bailey.persona-pi.com/Public-Inquiries/Rattys%20Lane%20-%20Hoddesdon/C%20-%20During%20PI%20dox/doc-54.pdf

[41] Kerbside Waste and Recycling Composition Analysis, Barnet Borough Council (November 2014 - April 2015), available from: https://files.datapress.com/barnet/dataset/waste-composition-analysis---houses/2015-10-12T14:06:11/BARNET%20WASTE%20ANALYSIS%202014_2015%20houses%202%20season%20final%20report%209%20July%202015.pdf

Similarly, according to surveys in **Warwickshire**: *"A waste composition analysis carried out in Feb/March 2014 showed that overall 57.9% of collected residual waste could have been recycled at the kerbside"*.[42]

In terms of Commercial and Industrial (C&I) waste, the **North West of England C&I Waste Survey** carried out for the Environment Agency in 2009 found that: *"...the recorded data suggests that up to 97.5% of the C&I waste landfilled in the [North West] region could be recycled if the correct facilities and services were available"*.[43]

In **Wales**, WRAP published a report in 2016 entitled 'National municipal waste compositional analysis in Wales'. The report details the work conducted by Resource Futures, where *"compositional analysis was carried out in all 22 local authorities and took place over two seasons – summer and winter in 2015"*.

According to the WRAP report: "*In the kerbside collected residual waste stream, 48.9% of the material was widely recyclable and 59.4% was biodegradable...Each of the residual waste streams included a proportion of widely recyclable material (recyclable paper and card, cartons, plastic bottles, glass bottles and jars, cans, tins, aerosols, aluminium foil, textiles and batteries) ranging from 39% in the HWRC stream to 63.3% within the commercial residual waste stream*".[44]

The key findings of UKWIN's Climate Change Report are set out on Page 1

[42] Warwickshire Waste Partnership 17 September 2014 Wheeled Bin Review, available from: https://democratic.warwickshire.gov.uk/Cmis5/Document.ashx?czJKcaeAi5tUFL1DTL2UE4zNRBcoShgo=4q0E1ezo4bT3scKUwLoCx%2Bm4qhGP20mLkwvRjMEie6G7cgZnjOwmqg%3D%3D&rUzwRPf%2BZ3zd4E7Ikn8Lyw%3D%3D=pwRE6AGJFLDNlh225F5QMaQWCtPHwdhUfCZ%2FLUQzgA2uL5jNRG4jdQ%3D%3D&mCTIbCubSFfXsDGW9IXnlg%3D%3D=hFflUdN3100%3D&kCx1AnS9%2FpWZQ40DXFvdEw%3D%3D=hFflUdN3100%3D&uJovDxwdjMPoYv%2BAJvYtyA%3D%3D=ctNJFf55vVA%3D&FgPlIEJYlotS%2BYGoBi5olA%3D%3D=NHdURQburHA%3D&d9Qjj0ag1Pd993jsyOJqFvmyB7X0CSQK=ctNJFf55vVA%3D&WGewmoAfeNR9xqBux0r1Q8Za60lavYmz=ctNJFf55vVA%3D&WGewmoAfeNQ16B2MHuCpMRKZMwaG1PaO=ctNJFf55vVA%3D

[43] North West of England Commercial and Industrial Waste Survey 2009 (for The Environment Agency, March 2010), available from: http://webarchive.nationalarchives.gov.uk/20140329075720/http://cdn.environment-agency.gov.uk/genw0410bsjm-e-e.pdf

[44] National municipal waste compositional analysis in Wales, available from: http://www.wrapcymru.org.uk/sites/files/wrap/Wales%20Municipal%20Waste%20Composition%202015-16%20FINAL.pdf

Technical Annexes

ANNEX A: CO_2 PER TONNE INCINERATED

Estimates for UK waste

Figures used for the UK's GHG Inventory Reporting

In response to a Parliamentary Question the Minister of State for Energy and Clean Growth stated in February 2018 that, for climate change reporting, the Government uses a figure of 0.3508 tonnes of CO_2 equivalent emitted for each tonne of municipal waste combusted in the UK's incinerators. This includes 0.3378 tonnes of CO_2 emitted by the incineration of waste that derives from fossil sources, e.g. plastics, with the remaining fraction derived from other GHG emissions (i.e. methane and nitrous oxide).[45]

According to the Minister's response, the source of these figures is the 2017 Energy Background Data spreadsheet, available from the National Atmospheric Emissions Inventory (NAEI) website.[46] This spreadsheet indicates, as part of the CEF worksheet (which sets out the Carbon emission factors (CEFs) used in the UK's GHG inventory), that the carbon figures for Municipal Solid Waste (MSW) - which include industrial/commercial combustion - derive from the Resource Futures report, published in 2012, entitled: 'Biodegradability of municipal solid waste'.[47]

The basis for the Government's figures therefore appears to be composition analysis of waste sent to landfill in 2010 and 2011 rather than compositional analysis of what is currently used as incinerator feedstock.

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[45] See: https://www.parliament.uk/business/publications/written-questions-answers-statements/written-question/Commons/2018-02-01/126078/

[46] NAEI Energy Background Data spreadsheet, available from: http://uk-air.defra.gov.uk/reports/cat07/1705121416_Energy_background_data_uk_2017_Final.xlsx from http://naei.beis.gov.uk/reports/reports?report_id=929

[47] Biodegradability of municipal solid waste (WR1003), available from: http://randd.defra.gov.uk/Document.aspx?Document=12266_WR1003BiodegradabilityofMSWReportfinal.pdf

Figures used by Defra for comparing incineration with landfill

A Defra report published in February 2014 entitled 'Energy recovery for residual waste – A carbon based modelling approach' was commissioned to assess the impact of changing feedstock and other factors on the relative emissions of incineration compared to landfill.[48]

The carbon intensity of the default waste composition assumption used for the Defra report can be determined using the total fossil and biogenic CO_2 figures in Table 5 of that report. It is stated that 0.34 tonnes of fossil CO_2 is released per tonne of waste, so 0.34 ÷ 3.667 = 0.0927 tonnes of fossil carbon per tonne of waste (i.e. a fossil carbon percentage of 9.27%).[49]

It is also stated that 0.52 tonnes of biogenic CO_2 is released, and 0.52 ÷ 3.667 = 0.1418 tonnes (i.e. 14.18%) of biogenic carbon per tonne of waste. Combined, this means a total of 0.2345 tonnes of C is in each tonne of waste (0.34 + 0.52 = 0.86, and 0.86 ÷ 3.667 = 0.2345), i.e. a total carbon percentage of 23.45%.

Defra's carbon based modelling approach report includes sensitivity analysis of other waste compositions, e.g. to investigate the impact of increased separate collection of food waste, however the default waste composition is what is used in Table 5 of the Defra report.

In December 2014 Isonomia published an article by Mike Brown (Managing Director of consultancy Eunomia) entitled 'Is waste a source of renewable energy?'.[50] In his attempt to improve upon the data contained within Table 5 of Defra's carbon based modelling approach Brown used Defra composition analysis published in June 2011 to estimate the composition of waste that might go to incineration.[51]

This resulted in a carbon content of 26.86%, of which 15.27% was fossil carbon and 11.59% was biogenic carbon. This equates to the release of 0.985 tonnes of CO_2 per tonne of waste incinerated, comprising 0.560 tonnes of fossil CO_2 and 0.425 tonnes of biogenic CO_2.[52]

[48] Energy recovery for residual waste – A carbon based modelling approach (WR1910), available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019
[49] Due to numerical rounding, this figure is slightly different from the carbon intensity implied by Defra's composition figures for each waste type. These variations do not impact upon the analysis.
[50] Is waste a source of renewable energy?, available from: http://www.isonomia.co.uk/?p=3501
[51] Detailed compositional assessment for municipal residual waste and recycling streams in England (WR1002), available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17303
[52] Composition Table 2: Results Using Resource Futures' 2011 Kerbside Collected Residual Waste Composition, available from: http://www.isonomia.co.uk/wp-content/uploads/2014/12/EfW-Composition-Tables.pdf

Waste industry estimates for specific incinerators

Analysis of actual incinerator feedstock

Incinerator operators do not tend to publish detailed information about the composition of the waste that they incinerate, but in March 2017 Cory published a carbon assessment based on analysis of a sample of the feedstock used by their Riverside incinerator in London.[53]

According to the operator's publication: *"In 2015, chemical analysis revealed 27% of the waste entering Riverside EfW contains carbon (C) by weight. This result is higher than the 23% used in the Defra carbon modelling study, but within the typical range of municipal solid waste in the UK (20-30%). Results highlight: 54.10% of the waste is biogenic in origin; 45.90% of waste is of fossil fuel origin"*.

Based on Cory's statements that 45.9% of the carbon is fossil based (page 16 of the report) and that 0.454 tonnes of fossil CO_2 is released per tonne of waste burned (page 17 of the report) it is possible to calculate the total carbon percentage as being more precisely 26.98% (which is rounded to 27% on page 16 of the report). As such, Cory's report indicates that around 1 tonne of carbon dioxide is emitted for each tonne of waste burned (1 tonne of feedstock × 0.2698 × 44 ÷ 12 = 0.989 tonnes of CO_2).

Cory calculated that 0.454 tonnes of fossil CO_2 is released per tonne of waste burned at the Riverside incinerator, which implies that 0.535 tonnes of biogenic CO_2 is also released per tonne of waste incinerated.

It is noteworthy that analysis commissioned by an incinerator operator, based on actual waste composition of a real-world incinerator, indicates that the carbon content of the feedstock is considerably higher than assumed by Defra in their modelling and reporting.

Anticipated feedstock composition from incinerator proposals

In addition to the feedstock composition analysis carried out for the operational incinerator described above, anticipated feedstock profiles for proposed incinerators also indicate that it would be reasonable to assume a higher carbon content (and indeed a higher fossil carbon content) than the default values assumed by Defra in their carbon based modelling report.

[53] Cory Riverside Energy: A Carbon Case, available from: https://www.coryenergy.com/wp-content/uploads/2018/01/Cory-Carbon-Report-v1.1.pdf

As part of the 2015 planning inquiry for the Bilsthorpe Energy Centre (Nottinghamshire), the applicant's climate change witness estimated that the feedstock for the proposed Bilsthorpe gasification plant would have a fossil carbon content of 34.10%. This comprised 14.93% fossil carbon content and 19.17% biogenic carbon content, which equates to the release of 1.25 tonnes of CO_2 per tonne of waste burned, of which 0.547 tonnes was assumed to be fossil CO_2 and 0.703 tonnes was assumed to be biogenic CO_2.[54]

Interestingly, the Bilsthorpe proposal intended to use plasma arc gasification which involved adding coke and limestone as part of the process. According to the applicant's climate change witness, for each tonne of waste fed into the gasifier the facility was expected to use 0.546 tonnes of coke (50,241 tonnes of coke ÷ 91,957 tonnes of feedstock). This coke was stated to result in an additional 0.138 tonnes of fossil CO_2 being emitted per tonne of waste fed into the gasifier (12,679.33 tonnes of coke CO_2 ÷ 91,957 tonnes of feedstock).

The evidence provided by the applicant's climate change witness also included information about the greenhouse gas (GHG) emissions associated with the introduction of limestone as part of the proposed gasification process. For each tonne of waste fed into the gasifier the facility was expected to use 0.083 tonnes of limestone (7,600 tonnes of limestone ÷ 91,957 of feedstock). This limestone was stated to result in an additional 0.036 tonnes of fossil CO_2 being emitted per tonne of waste fed into the gasifier (3,342 tonnes of limestone CO_2 ÷ 91,957 tonnes of feedstock).

As coke and limestone are not part of the waste feedstock they are not included in this analysis, but the prospect of introducing quantities of coke and limestone as part of gasification processes highlights the importance of considering the climate impact of start-up and support fuels as well as reagent additives when evaluating the total climate impacts of incineration in general, and for gasification and pyrolysis proposals in particular.

A proposal for a conventional incinerator in Waterbeach (Cambridgeshire) estimated that the feedstock would have a carbon content of 25.59%.[55] The applicant stated that 58.65% of this carbon was expected to be biogenic, which implies that 15% of the total waste to be used as feedstock would be biogenic carbon and 10.59% of the total waste to be used as feedstock would be fossil carbon. This translates to 0.938 tonnes of CO_2 per tonne of waste incinerated, of which 0.388 would be fossil CO_2 and 0.550 biogenic CO_2.

[54] APP/SMO/6B – Carbon Calculations, available from: http://www.nottinghamshire.gov.uk/media/109964/app-smo-6b.pdf

[55] Waterbeach Energy from Waste Facility – Carbon Assessment (July 2018), available from: http://planning.cambridgeshire.gov.uk/swift/apas/run/wphappcriteria.display (Planning ref 'S/3372/17/CW', document ref 'SUBDOC3_2018_08_01_Updated_Carbon_Assessment.pdf ')

Calculating CO_2 emissions per tonne of waste based on published UK sources

The following table sets out the CO_2 data derived from the sources outlined above and uses this to estimate the average CO_2 in the feedstock:

Table 6: Tonnes of CO_2 per tonne based on published UK sources

Source	Description	Total C %	Total CO_2 per tonne	Fossil Carbon %	Fossil CO_2 Per tonne	Biogenic Carbon %	Biogenic CO_2 per tonne
Defra Carbon based modelling approach (February 2014)	Table 5. Data set and calculations for the energy recovery half of the model	23.45%	0.860	9.27%	0.340	14.18%	0.520
'Is waste a source of renewable energy?', Mike Brown (December 2014)	Based on Resource Futures' 2011 Kerbside Collected Residual Waste Composition	26.86%	0.985	15.00%	0.560	12.00%	0.425
Cory Riverside Energy: A Carbon Case (January 2018, V1.1)	Riverside incinerator - 2015 feedstock composition analysis	26.98%	0.989	12.384%	0.454	14.596%	0.535
Bilsthorpe Energy Centre - Carbon Calculations (Average) (October 2015)	Evidence given by the applicant's climate change witness [APP/SMO/6B]	34.10%	1.250	14.93%	0.547	19.17%	0.703
Waterbeach - Carbon Assessment (July 2018)	Table 2 - Waste Throughput cases (Base Case)	25.59%	0.938	10.59%	0.388	15.00%	0.550
	Average	**27.42%**	1.005	12.43%	**0.458**	14.99%	0.547

Note: Figures are rounded to the number of decimal places shown.

Calculating CO_2 per tonne of waste based on Environment Agency data sets

CO_2 released per tonne of waste processed can be calculated by dividing the total tonnes of CO_2 released by the total tonnes of waste incinerated. The estimated carbon percentage of the feedstock can be calculated by dividing the CO_2 per tonne by 3.667 (i.e. 44 ÷ 12, which represents the difference between the atomic weight of CO_2 and that of C). This approach will attribute all CO_2 released to the feedstock, whereas in reality a small proportion might derive from support fuel, but this will not have a significant impact on the result and for the purposes of the use of the information would actually result in a slightly more accurate figure for the direct fossil CO_2 released per tonne of waste treated.

Two primary data sources were used:

- 'Incineration Input & Capacity' worksheet from the 'Waste management 2016 in England: data tables' (Environment Agency, LIT 10671).[56]
- '2016 substances' worksheet from 'Pollution Inventory 2016 - Emissions to air, land, controlled waters and wastewater' (Environment Agency, Version 2).[57]

To verify the tonnes incinerated the following additional data source was used:

- Operator Annual Performance Reports, as reported by Tolvik on page 17 of 'UK Energy from Waste Statistics – 2016'.[58]

The 22 facilities included are those where the data was available from the Environment Agency and there were no significant discrepancies between the data reported by the EA and with other data sources (e.g. the tonnage reported in the Operator Annual Performance Reports).

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[56] Available from: https://www.gov.uk/government/publications/waste-management-for-england-2016
[57] Available from: https://data.gov.uk/dataset/cfd94301-a2f2-48a2-9915-e477ca6d8b7e/pollution-inventory
[58] Available from: http://www.tolvik.com/wp-content/uploads/UK-EfW-Statistics-2016-report-Tolvik-June-2017.pdf

Table 7: CO_2 per tonne based on extracts from Environment Agency 2016 data sets

Permit no	Operator	Site name	Tonnage incinerated in 2016	Tonnes of CO_2 released	CO_2 per tonne (calculated)	Feedstock carbon % (calculated)
NP3739PD	The Coventry & Solihull Waste Disposal Company Ltd	Coventry	282,849	216,611	0.766	20.89%
BS3042IM	Viridor Waste (Greater Manchester) Ltd	Bolton Thermal Recovery Facility	86,389	72,414	0.838	22.86%
WP3239SJ	Veolia ES Birmingham Ltd	Tyseley EFW Plant, Birmingham	351,208	316,087	0.900	24.55%
BM4082IY	Veolia ES Sheffield Limited	Sheffield Energy Recovery Facility, Sheffield	235,334	211,801	0.900	24.55%
XP3239GF	Veolia ES Shropshire Ltd	Battlefield EFW	94,421	84,979	0.900	24.55%
HP3431HK	Veolia ES Staffordshire Limited	Staffordshire Energy Recovery Facility	339,946	305,952	0.900	24.55%
BT7116IW	Lakeside Energy From Waste Limited	Slough	435,844	392,569	0.901	24.56%
BV8067IL	Veolia ES South Downs Ltd	Newhaven	233,013	210,304	0.903	24.61%
NP3738SY	South East London CHP Limited	Lewisham	448,235	407,966	0.910	24.82%
HP3538CR	Cyclerval (UK) Ltd	Exeter EFW	53,457	49,142	0.919	25.07%
JP3535CE	Avonmouth Bio Power Energy Ltd	Avonmouth Energy Facility	32428	31,149	0.961	26.20%
FP3134GU	Viridor Limited	Ardley EFW Plant	304,125	303,093	0.997	27.18%
BJ6178IX	SITA (Kirklees) Limited	Kirklees EFW, Huddersfield	127,510	127,510	1.000	27.27%
WP3438HZ	SITA Suffolk Ltd	SITA Suffolk EFW Plant	266,553	266,554	1.000	27.27%
YP3033BE	London Waste Ltd	Edmonton	547,721	581,019	1.061	28.93%
FP3739FS	FCC Linconshire Ltd	Lincolnshire EFW Facility	163,580	178,506	1.091	29.76%
AP3835SM	MES Environmental Limited	Wolverhampton	110,759	125,488	1.133	30.90%
BT4249IB	Newlincs Development Ltd	Grimsby	54,855	62,847	1.146	31.25%
QP3234SX	MES Environmental Limited	Stoke	182,969	215,633	1.179	32.14%
AP3435SD	MES Environmental Limited	Dudley, West Midlands	93,292	110,649	1.186	32.35%
RP3638CG	Viridor	Runcorn EFW Facility	867,715	1,074,092	1.238	33.76%
NP3638ZS	Viridor Peterborough Ltd	Viridor Peterborough Energy	82,702	103,999	1.258	34.30%
		Totals / Averages	5,394,905	5,448,364	1.010	**27.54%**

Note: Figures rounded to the number of decimal places shown. Contains Environment Agency information © Environment Agency and/or database right

Analysis of CO_2 per tonne incinerated

Based on the analysis above it is reasonable to assume that on average around 1 tonne of CO_2 is currently being released for each tonne of waste incinerated in the UK. It is also reasonable to assume that this tonne of CO_2 comprises around 0.458 tonnes of fossil CO_2 and around 0.542 tonnes of biogenic CO_2.

These figures are adopted to estimate the annual fossil CO_2 emitted in future years (2019 - 2049) because changes in feedstock composition are difficult to predict and because changes could go either way (i.e. the fossil CO_2 fraction could increase or decrease) depending on a number of market factors and legislative and policy drivers.

For example, it is understood that the Circular Economy Package requires that, by 31st December 2023, bio-waste is either collected separately or recycled at source. Increased separate collection of bio-waste could be expected to increase the proportion of waste that contains fossil carbon, whereas a reduction in the use of single-use plastics would increase the proportion of waste that is made up of biogenic carbon.

Furthermore, increased use of 'pre-treatment' processes, e.g. to turn waste into 'refuse derived fuels' ('RDF'), would result in a greater proportion of water being removed from the feedstock, which could be expected to increase the proportion of the feedstock which is carbon.

Sensitivity analysis of the impact on CO_2 emissions of different feedstock profiles is provided within this report (e.g. in Figure 2, and Table 5, and Annex C) for the default values of the Defra Carbon based modelling approach within the context of the evaluation of incineration relative to landfill.

As explained and discussed in the main body of the report, the estimate of 0.458 tonnes of fossil CO_2 per tonne of waste burned set out above and the estimate of 14,435,384 tonnes per annum of waste incineration capacity operational and under construction set out in the main body of the report are combined with Defra's prices for non-traded carbon to estimate the cost of fossil CO2 from incineration from this waste for a 30 year period (2019-2049). The calculations used to determine the cost to society of fossil CO2 from waste incineration for 2019-2049 are set out in Table 8 (overleaf).

Table 8: Cost to society of fossil CO_2 from waste incineration (2019-2049)

	Non-traded carbon price			Fossil CO_2 released by incineration			Cost to society of fossil CO_2 from incineration			Cost per tonne of waste		
	Low	Central	High	Tonnes of waste	Fossil CO_2 per tonne	Tonnes of fossil CO_2	Low	Central	High	Low	Central	High
2019	£33.54	£67.08	£100.62	14,435,384	0.458	6,611,406	£221,746,553	£443,493,106	£665,239,659	£15	£31	£46
2020	£34.04	£68.08	£102.12	14,435,384	0.458	6,611,406	£225,052,256	£450,104,512	£675,156,768	£16	£31	£47
2021	£34.61	£69.22	£103.83	14,435,384	0.458	6,611,406	£228,820,757	£457,641,514	£686,462,272	£16	£32	£48
2022	£35.18	£70.35	£105.53	14,435,384	0.458	6,611,406	£232,589,259	£465,112,403	£697,701,662	£16	£32	£48
2023	£35.74	£71.49	£107.23	14,435,384	0.458	6,611,406	£236,291,646	£472,649,406	£708,941,052	£16	£33	£49
2024	£36.31	£72.62	£108.93	14,435,384	0.458	6,611,406	£240,060,147	£480,120,294	£720,180,442	£17	£33	£50
2025	£36.88	£73.76	£110.64	14,435,384	0.458	6,611,406	£243,828,649	£487,657,297	£731,485,946	£17	£34	£51
2026	£37.45	£74.89	£112.34	14,435,384	0.458	6,611,406	£247,597,150	£495,128,186	£742,725,336	£17	£34	£51
2027	£38.01	£76.03	£114.04	14,435,384	0.458	6,611,406	£251,299,537	£502,665,188	£753,964,726	£17	£35	£52
2028	£38.58	£77.16	£115.74	14,435,384	0.458	6,611,406	£255,068,039	£510,136,077	£765,204,116	£18	£35	£53
2029	£39.15	£78.30	£117.44	14,435,384	0.458	6,611,406	£258,836,540	£517,673,080	£776,443,506	£18	£36	£54
2030	£39.72	£79.43	£119.15	14,435,384	0.458	6,611,406	£262,605,041	£525,143,968	£787,749,010	£18	£36	£55
2031	£43.40	£86.81	£130.21	14,435,384	0.458	6,611,406	£286,935,015	£573,936,144	£860,871,159	£20	£40	£60
2032	£47.09	£94.18	£141.27	14,435,384	0.458	6,611,406	£311,331,103	£622,662,205	£933,993,308	£22	£43	£65
2033	£50.78	£101.56	£152.34	14,435,384	0.458	6,611,406	£335,727,190	£671,454,380	£1,007,181,571	£23	£47	£70
2034	£54.47	£108.93	£163.40	14,435,384	0.458	6,611,406	£360,123,278	£720,180,442	£1,080,303,719	£25	£50	£75
2035	£58.15	£116.31	£174.46	14,435,384	0.458	6,611,406	£384,453,251	£768,972,617	£1,153,425,868	£27	£53	£80
2036	£61.84	£123.68	£185.53	14,435,384	0.458	6,611,406	£408,849,339	£817,698,678	£1,226,614,131	£28	£57	£85
2037	£65.53	£131.06	£196.59	14,435,384	0.458	6,611,406	£433,245,427	£866,490,854	£1,299,736,280	£30	£60	£90
2038	£69.22	£138.44	£207.65	14,435,384	0.458	6,611,406	£457,641,514	£915,283,029	£1,372,858,429	£32	£63	£95
2039	£72.91	£145.81	£218.72	14,435,384	0.458	6,611,406	£482,037,602	£964,009,090	£1,446,046,692	£33	£67	£100
2040	£76.59	£153.19	£229.78	14,435,384	0.458	6,611,406	£506,367,576	£1,012,801,266	£1,519,168,841	£35	£70	£105
2041	£80.28	£160.56	£240.84	14,435,384	0.458	6,611,406	£530,763,663	£1,061,527,327	£1,592,290,990	£37	£74	£110
2042	£83.97	£167.94	£251.91	14,435,384	0.458	6,611,406	£555,159,751	£1,110,319,502	£1,665,479,253	£38	£77	£115
2043	£87.66	£175.31	£262.97	14,435,384	0.458	6,611,406	£579,555,839	£1,159,045,563	£1,738,601,402	£40	£80	£120
2044	£91.34	£182.69	£274.03	14,435,384	0.458	6,611,406	£603,885,812	£1,207,837,739	£1,811,723,551	£42	£84	£126
2045	£95.03	£190.07	£285.10	14,435,384	0.458	6,611,406	£628,281,900	£1,256,629,914	£1,884,911,814	£44	£87	£131
2046	£98.72	£197.44	£296.16	14,435,384	0.458	6,611,406	£652,677,988	£1,305,355,975	£1,958,033,963	£45	£90	£136
2047	£102.41	£204.82	£307.23	14,435,384	0.458	6,611,406	£677,074,075	£1,354,148,151	£2,031,222,226	£47	£94	£141
2048	£106.10	£212.19	£318.29	14,435,384	0.458	6,611,406	£701,470,163	£1,402,874,212	£2,104,344,375	£49	£97	£146
2049	£109.78	£219.57	£329.35	14,435,384	0.458	6,611,406	£725,800,137	£1,451,666,387	£2,177,466,524	£50	£101	£151
			Total	447,496,904		**204,953,582**	£12,525,176,196	**£25,050,418,507**	£37,575,528,589			

ANNEX B: DATA USED TO CALCULATE INCINERATION CARBON INTENSITY

Minister of State (2008), UK incinerators

In answer to a Parliamentary Question from Stephen Gilbert MP, in January 2011 Greg Barker (then Minister of State for Climate Change) replied saying: *"Within the UK, incinerators which generate electricity from municipal solid waste (MSW) are commonly referred to as energy from waste (EfW) plant. In 2008, the latest year for which data are available, we estimate that EfW plant produce 0.54 kt carbon dioxide equivalent per GWh (equivalent to* ***0.54 kg per kWh****). This figure incorporates emissions of carbon dioxide, methane and nitrous oxide. It should be noted that there is a high level of uncertainty around this figure"*.[59]

'0.54 kg [CO_2e] per kWh' can also be expressed as **540gCO_2e/kWh**.

Eunomia (2006), electricity-only UK incinerators

Table 1 of 'A Changing Climate for Energy from Waste?' provides a fossil carbon intensity figure of 510gCO2e/kWh for electricity-only incinerators in 2006 and an estimate of **580gCO2e/kWh** for future electricity-only incinerators.[60]

Cory (2018), Riverside incinerator in 2015

The report entitled: 'Cory Riverside Energy: A Carbon Case' (Version 1.1 of which was published in January 2018) includes information about Cory's Riverside incinerator, a facility which has been running since 2011.[61]

Page 17 of the report states that, based on compositional analysis of the feedstock from 2015, Cory estimated that incinerating 700,138 tonnes of feedstock gave rise to the release of **317,914 tonnes of fossil CO_2** in 2015.

Page 18 of Cory's Riverside incinerator report states that in 2015 the facility treated 700,138 tonnes of waste, generated 574,385 MWh of electricity, and **exported 515,166 MWh of electricity to the grid**.

[59] Written Answers to Questions - Monday 17 January 2011, available from: https://publications.parliament.uk/pa/cm201011/cmhansrd/cm110117/text/110117w0001.htm#1101173000926
[60] A Changing Climate for Energy from Waste?, available from: https://friendsoftheearth.uk/sites/default/files/downloads/changing_climate.pdf
[61] Cory Riverside Energy: A Carbon Case, available from: https://www.coryenergy.com/wp-content/uploads/2018/01/Cory-Carbon-Report-v1.1.pdf

317,914 tonnes is equivalent to 317,914,000,000 grams and 515,166 MWh is equivalent to 515,166,000 kWh. Because 317,914,000,000 ÷ 515,166,000 = 617.1098248 it can be said that, according to the their report, in 2015 Cory's Riverside incinerator produced electricity with a fossil carbon intensity of **617gCO_2/kWh**.

Average carbon intensity of electricity generated by UK incinerators in 2017

One potential method of estimating the average fossil carbon intensity across all of the UK's incinerators is to divide the estimated average quantity of fossil CO_2 released per tonne of waste incinerated by the average quantity of electricity per tonne of waste incinerated. With the limitation that the two estimates might not be directly comparable, this report attempts to apply this approach.

The fossil CO_2 per tonne of waste can be said to be the 0.458 figure as set out in Annex A. This is equivalent to **458,000 grams (or 0.458 tonnes) of fossil CO_2** per tonne of waste.

For the average kWh per tonne of waste incinerated we turn to a Tolvik report which estimates this based on the Annual Performance Reports for 2017 provided to the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA) and Natural Resources Wales (NRW).[62]

According to page 6 of the Tolvik report, the 'Average Net kWh/tonne input' is **575 kWh** for 2017.

458,000gCO_2 ÷ 575kWh = 796.5217gCO_2/kWh, meaning that it can be estimated that **in 2017 UK incinerators generated electricity with an average fossil carbon intensity of 797gCO_2/kWh**.

Inquiry evidence (2015), Bilsthorpe Energy Centre

Evidence given by the applicant's climate change witness in October 2015 as part of the public inquiry into the planning application for the proposed Bilsthorpe Energy Centre provides information on estimated CO_2 and electricity output from a plasma arc gasification plant.[63]

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[62] Tolvik UK EfW Statistics 2017 report – June 2018, available from: http://www.tolvik.com/wp-content/uploads/Tolvik-UK-EfW-Statistics-2017.pdf

[63] APP/SMO/6B – Carbon Calculations, available from: http://www.nottinghamshire.gov.uk/media/109964/app-smo-6b.pdf

According to the 'average' case provided by the witness, the facility proposed for Bilsthorpe was expected to give rise to 67,095 tonnes of direct fossil CO_2e emissions per year and to export of 71,607.37 MWh of electricity. The 67,095 tonne figure included the GHG impact of the use of coke and limestone as part of the waste gasification process.

67,095 tonnes of fossil CO_2 is equivalent to 67,095,000,000 grams and 71,607.37 MWh of electricity is equivalent to 71,607,370 kWh.

67,095,000,000gCO_2 ÷ 71,607,370kWh = 936.984559gCO_2/kWh, meaning that according to the Bilsthorpe applicant's climate change witness, the energy that was to have been generated by the Bilsthorpe Energy Centre was estimated to have had an **average fossil carbon intensity of 937gCO_2/kWh**.

ANNEX C: RELATIVE NET CARBON IMPACTS OF INCINERATION COMPARED WITH LANDFILL

Use of Defra's Carbon based modelling approach

In order to compare the climate change impacts of incineration with sending the same waste directly to landfill, the approach that has been followed in this report is to apply Defra's model as set out in 'Energy recovery for residual waste: A carbon based modelling approach' to a modern, electricity-only, incinerator build in 2020. The results of this analysis is summarised in Figure 2 and Table 5, above.

Defra's Carbon based modelling approach document explains that the model was developed to consider *"...the carbon emissions from a tonne of mixed residual waste depending on whether that waste were to go to energy recovery or landfill..."*.[64] Details of the methodology and terminology are explained within Defra's document, and unless otherwise stated the assumptions adopted are the central or default assumptions of that report.

Choice of incinerator efficiency

An incinerator's climate change impact is affected by its thermal efficiency, which is to say the percentage of energy potential (calorific value) of the waste that is converted into electricity and exported to the grid.

'GCV efficiency' is a term used in the Defra report to describe the measure of efficiency followed in their model, and represents the overall energy recovery efficiency based on the Gross Calorific Value (GCV) of the waste. By way of explanation regarding why overall GCV efficiency was used by Defra, Paragraph 217 of the Defra document notes that: *"...due to the data sources available we have used the gross calorific value (or higher heating value)"*.

Paragraph 62 of Defra's document explains: *"All EfW efficiencies presented in the report have been calculated from the Gross CV (GCV) of the waste input. It is more usual to use net CV (NCV) to show efficiency, because this reflects the fact that the latent heat of condensation for water vapour is not utilised. For example, considering a high-performing electricity-only plant with a net CV efficiency of 30%. This equates to a gross CV efficiency of 25%"*.

[64] Energy recovery for residual waste – A carbon based modelling approach (February 2014), available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

Following the example provided in Defra's report, **UKWIN's evaluation adopts an overall GCV efficiency of 25%**, which according to the Carbon based modelling approach report represents a high-performing incinerator that equates to an overall NCV efficiency of 30%.

The 25% overall GCV efficiency adopted for this modelling by UKWIN is slightly higher than the efficiency claimed by Veolia for their current proposal for an incinerator in Hertfordshire, which according to Veolia's technical specification would have 24.6% GCV efficiency (and an NCV efficiency of 28.6%).[65] As such, 25% overall GCV efficiency could be said to represent an 'optimistic' assumption.

Choice of marginal emissions factor (MEF)

Proponents of waste incineration are prone to arguing that incineration can be relied upon to combat climate change because a portion of the energy generated from burning waste (the electricity that remains after use for the incineration process itself) can be fed into the electricity grid, thereby displacing other potential sources of electricity.

In order to examine these claims it is therefore important to compare the carbon intensity of the electricity exported to the grid by waste incineration with the carbon intensity of the electricity fed into the grid by the other sources that would be displaced by incineration.

The 2008 Climate Change Act *"established a legally binding target to reduce the UK's greenhouse gas emissions by at least 80% below base year levels by 2050, to be achieved through action at home and abroad"*.[66] The Government noted in 2012 that: *"Analysis published in the December 2011 Carbon Plan suggests that the most cost effective paths to deliver the 2050 target require the electricity sector to be largely decarbonised during the 2030s"*.[67]

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[65] See Table 7-1 ('Technical specifications of the Proposed Development') of the February 2017Energy Management Plan from the applicant's Environmental Permit (EP) Application (EPR/SP3038DY/A001) which sets out the Power exported to grid, the Net and Gross CVs of the waste, and the tonnes of waste per annum, from which the Gross and Net CV efficiencies are derived, available from: https://consult.environment-agency.gov.uk/psc/en11-0rf-veolia-es-hertfordshire-limited/supporting_documents/Energy%20management%20plan.pdf

[66] The Carbon Plan: Delivering our low carbon future (December 2011), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf

[67] Electricity System: Assessment of Future Challenges - Annex (August 2012), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48550/6099-elec-system-assess-future-chall-full.pdf

For the purposes of policy analysis and appraisal BEIS produces estimates of anticipated CO_2 emissions arising from both the future average electricity mix and long run marginal emissions factors (MEFs). The 'long run marginal' means the energy that would be displaced by reductions in energy usage or new base load energy capacity, and is therefore the figure to be used when assessing climate change impacts associated with incineration proposal. In 2017 BEIS explained that: *"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".*[68] These 'marginal emissions factors'[69] set out in BEIS's Data Table 1 are listed as follows:

Table 9: Extract from BEIS Data Table 1: 'Electricity emissions factors to 2100'

Year	Generation-based Long-run Marginal Emissions Factor	Generation-based Grid average
2010	357 gCO_2/kWh	459 gCO_2/kWh
2011	350 gCO_2/kWh	443 gCO_2/kWh
2012	343 gCO_2/kWh	485 gCO_2/kWh
2013	336 gCO_2/kWh	452 gCO_2/kWh
2014	328 gCO_2/kWh	401 gCO_2/kWh
2015	320 gCO_2/kWh	336 gCO_2/kWh
2016	311 gCO_2/kWh	255 gCO_2/kWh
2017	301 gCO_2/kWh	213 gCO_2/kWh
2018	291 gCO_2/kWh	205 gCO_2/kWh
2019	281 gCO_2/kWh	195 gCO_2/kWh
2020	**270 gCO_2/kWh**	181 gCO_2/kWh
2021	258 gCO_2/kWh	171 gCO_2/kWh
2021	258 gCO_2/kWh	171 gCO_2/kWh
2022	246 gCO_2/kWh	148 gCO_2/kWh
2023	233 gCO_2/kWh	144 gCO_2/kWh
2024	219 gCO_2/kWh	150 gCO_2/kWh
2025	205 gCO_2/kWh	141 gCO_2/kWh
2026	189 gCO_2/kWh	114 gCO_2/kWh
2027	173 gCO_2/kWh	119 gCO_2/kWh
2028	156 gCO_2/kWh	108 gCO_2/kWh
2029	138 gCO_2/kWh	96 gCO_2/kWh

[68] Paragraphs 3.31 and 3.32 of Valuation of Energy Use and Greenhouse Gas, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671205/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2017.pdf
[69] Table 1: Electricity emissions factors to 2100, available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/696677/Data_tables_1-19_supporting_the_toolkit_and_the_guidance_2017__180403_.xlsx

Defra's carbon based modelling, carried out in 2013, adopted an historic figure of 373gCO_2/kWh for the purpose of providing a default value for the carbon intensity of the marginal energy mix. This was based on CCGT, which was at that time broadly equivalent to the relevant marginal emissions factor (MEF). As a result of the decarbonisation of the electricity supply **the MEF to be used for an incinerator built in 2020 is 270gCO_2/kWh**, and this is what UKWIN has adopted for its assessment.

Rationale for using BEIS's MEF rather than CCGT

As set out above, in their Supplementary guidance to the HM Treasury Green Book on appraisal and evaluation of energy use and GHG emissions, BEIS explains that: *"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"*.[70]

The subsequent paragraph clarifies that a sustained 'change in grid electricity use' includes displacement from new incineration capacity, stating: "*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)…Modelling undertaken by BEIS has estimated these longer-term dynamics, and they are reflected in the marginal emissions factors"*. (**emphasis added**)

Use of the MEF as the correct counterfactual, instead of CCGT, 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 make it clear that whilst CCGT was an appropriate counterfactual to use in 2013 it does not remain appropriate for future years. This is because of the progress being made to decarbonise the UK's electricity supply. For reasons of simplicity, the initial version of the Government's Energy from Waste (EfW) Guide only mentioned CCGT rather than the MEF as the counterfactual for displaced electricity. Unfortunately, this was then misinterpreted by some individuals as meaning that CCGT would always be the appropriate comparator.

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[70] Paragraphs 3.31 and 3.32 of Valuation of Energy Use and Greenhouse Gas, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671205/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2017.pdf

In response to a query on the potential for this oversimplification to cause confusion, Defra stated in November 2013 that the only reason their 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 is essentially equivalent to CCGT, as this dominates the current calculation".* Defra's November 2013 letter went on to explain that: *"For specific calculations the DECC guidance is correct, long run marginal emissions factors should be used".*[71]

Indeed, 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".*[72]

As noted above, CCGT is no longer approximately the same as the marginal emissions factor and as such it is no longer appropriate to use CCGT as a proxy for the MEF, especially for a facility built in 2020. As such, UKWIN has made use of the MEF as advised by both BEIS and by the revised version of the EfW Guide for the purpose of assessing the relative net GHG impacts of incineration and landfill.

Approach to accounting for biogenic carbon sequestration

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

When comparing incineration with landfill, if one assumes that the release of biogenic carbon from an incinerator is 'carbon neutral' then it follows that avoiding the release of that biogenic carbon, through its sequestration in landfill, is a 'carbon benefit', and it is therefore necessary for the model to account for this benefit.

[71] 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: http://www.programmeofficers.co.uk/posl/documents/Gloucester/Proofs/GV/GV1-REB-A.pdf
[72] 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

As such, 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.

Rationale for accounting for biogenic sequestration in landfill

Comments in Defra's carbon based modelling approach document

Acknowledging the carbon benefit of biogenic carbon sequestration in landfill is consistent with the carbon based modelling approach report, which explains at Paragraphs 171-173 how:

> *"...not all of the biogenic material decomposes in landfill but it is all converted to CO2 in energy from waste. Landfill therefore acts as a partial carbon sink for the biogenic carbon. This is a potential additional benefit for landfill over energy from waste. There are two ways to account for this additional effect:*
>
> - *Estimate the amount of biogenic carbon sequestered and include the CO2 produced from the same amount of carbon in the EfW side of the model (or subtract it from the landfill side)*
> - *Include all carbon emissions, both biogenic and fossil on both sides of the model*
>
> *"While both approaches would address the issue of sequestered biogenic carbon the first would potentially be the better solution as it would avoid double counting carbon with other inventories".*

Comments by the IPCC

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories remain the current guidelines to be followed by the UK and other nations for GHG inventories. These guidelines acknowledge the GHG benefits of biogenic carbon sequestration in landfill. Chapter 3 of Volume 5 of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines state that: *"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)".*[73]

[73] Chapter 3 of Volume 5 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, available from: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html and https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

Comments by Eunomia

Eunomia is an environmental consultancy that has: *"advised Defra, Scottish Government, Welsh Government, Government of Ireland, the Environment Agency, OECD, UNEP, European Investment Bank and the European Commission on a range of waste-related issues"* since their incorporation in 2001.[74] Eunomia's estimates of anticipated residual waste infrastructure capacity were included in the Government's EfW Guide.[75]

Eunomia's 2006 report for Friends of the Earth entitled 'A Changing Climate for Energy from Waste?' states that: *"In a comparative analysis of different waste treatment technologies, the assumption that emissions of CO2 related to biogenic carbon should be ignored cannot be valid where the technologies deal with biogenic carbon in different ways. The atmosphere does not distinguish between those CO_2 molecules which are from biogenic sources and those which are not. Consequently, if one type of technology 'sequesters' some carbon over time, then this function needs to be acknowledged (it effectively negates the basis for distinguishing between biogenic and fossil sources of carbon on the basis that the one is 'short-cycle' and the other is 'long-cycle' – after all, how long is 'short' and long is 'long', and when could one period said to become the other?)".*[76]

Eunomia's 2010 report for the European Commission states: *"...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... ".*[77]

Recommendation 9 of Eunomia's 2015 report for Zero Waste Europe states that: *"All lifecycle studies engaged in comparative assessments of waste treatments should incorporate CO_2 emissions from non-fossil sources in their comparative assessment".*[78]

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[74] Residual Waste Infrastructure Review (12th Issue, Eunomia 2017), available from: http://www.eunomia.co.uk/reports-tools/residual-waste-infrastructure-review-12th-issue/

[75] See Paragraph 28 of Energy from waste: A guide to the debate (February 2014), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf

[76] A Changing Climate for Energy from Waste?, available from: https://friendsoftheearth.uk/sites/default/files/downloads/changing_climate.pdf

[77] Final Report - Assessment of the options to improve the management of bio-waste in the European Union, Annex F: Environmental assumptions, available from: http://ec.europa.eu/environment/waste/compost/pdf/ia_biowaste%20-%20ANNEX%20F%20-%20environmental%20assumptions.pdf

[78] Eunomia's 2015 report entitled 'The Potential Contribution of Waste Management to a Low Carbon Economy', available from: https://zerowasteeurope.eu/downloads/the-potential-contribution-of-waste-management-to-a-low-carbon-economy/

UKWIN's analysis uses the default values adopted by Defra for the carbon based modelling approach, but the actual level of biogenic carbon sequestration could be higher or lower than modelled. The precise impact of biogenic carbon sequestration will depend on various factors such as:

- the type of biodegradable waste being landfilled (e.g. higher lignin content will result in higher levels of sequestration);
- the operational management of the landfill over its lifetime;
- the extent of pre-treatment to stabilise waste prior to landfill; and
- the time period over which the assessment is made.

Feedstock composition profiles

Three feedstock composition profiles are used for UKWIN's analysis. The Base Case uses Defra's default composition, and two variations on these figures are also assessed to evaluate the relative net GHG impacts of feedstocks containing smaller proportions of plastic and smaller proportions of compostables respectively. Details of these feedstock profiles are set out in the 'comparing incineration with landfill' section of the main report above, with the waste composition percentages set out in Table 4. Some of the material in the feedstock profiles is recyclable but, in line with Defra's modelling approach, the net impact of incineration on recycling and composting falls outside the scope of UKWIN's relative net GHG model.

Waste throughput

It is assumed that **265,000 tonnes of waste will be treated per year at this typical incinerator.** The 265,000 tonnes per annum figure is derived from the input tonnage of the UK incineration plants that were operational for the whole of 2017. According to Tolvik, around 10,757,000 tonnes of waste was incinerated at the 40 plants that were operational throughout 2017.[79] This averages out to 268,925 tonnes (10,757,000 ÷ 40 = 268,925).

[79] Page 16 of http://www.tolvik.com/wp-content/uploads/Tolvik-UK-EfW-Statistics-2017.pdf ('total of 2017 Input (Ktpa)' minus the capacity in blue which represents facilities operational for only part of the year)

Table 10: Base Case - Data set and calculations for the incineration half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
	Proportion of 1 tonne of waste	**Calorific value MWh/t**	**Efficiency**	**Energy potential MWh**	**Prop. biogenic C**	**Mass of biogenic C**	**Mass of biogenic CO_2 released**	**Prop. fossil C**	**Mass of fossil C**	**Mass of fossil CO_2 released**	**Fossil CO_2 from electricity offset**	**Net fossil CO_2 from ERF**
				=(1)×(2)×(3)		=(1)×(5)	=(6)×44÷12		=(1)×(8)	=(9)×44÷12	(4)×0.270	(10)-(11)
Mixed Paper and Card	0.1514	3.5000	0.25	0.1325	0.3200	0.0484	0.1776	0	0	0.0	0.0358	-0.0358
Plastics	0.1348	7.0500	0.25	0.2376	0	0	0	0.5200	0.0701	0.2570	0.0641	0.1929
Textiles (and footwear)	0.0395	4.4400	0.25	0.0438	0.2000	0.0079	0.0290	0.2000	0.0079	0.0290	0.0118	0.0171
Miscellaneous combustibles	0.0590	4.3300	0.25	0.0639	0.1900	0.0112	0.0411	0.1900	0.0112	0.0411	0.0172	0.0239
Miscellaneous non-combustibles	0.0899	0.7800	0.25	0.0175	0.0400	0.0036	0.0132	0.0400	0.0036	0.0132	0.0047	0.0085
Food	0.3112	1.4700	0.25	0.1144	0.1400	0.0436	0.1597	0	0	0	0.0309	-0.0309
Garden	0.0311	1.8100	0.25	0.0141	0.1700	0.0053	0.0194	0	0	0	0.0038	-0.0038
Soil and other organic waste	0.0311	1.3300	0.25	0.0103	0.0700	0.0022	0.0080	0	0	0	0.0028	-0.0028
Glass	0.0537	0.4200	0.25	0.0056	0	0	0	0	0	0	0.0015	-0.0015
Metals, Other Non-biodegradable	0.0225	0	0.25	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0057	1.3300	0.25	0.0019	0	0	0	0.0700	0.0004	0.0015	0.0005	0.0010
Wood	0.0311	5.0800	0.25	0.0395	0.4400	0.0137	0.0502	0	0	0	0.0107	-0.0107
Sanitary / disposable nappies	0.0390	2.2200	0.25	0.0216	0.1500	0.0059	0.0215	0.0400	0.0016	0.0057	0.0058	-0.0001
TOTAL PER TONNE OF WASTE	1 Tonne			0.7028 MWh		0.1417 tC	0.5196 tCO_2		0.0948 tC	**0.3475 tCO_2**	**0.1897 tCO_2**	0.1577 tCO_2

Table 11: Base Case - Data set and calculations for the landfill half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
	Proportion of 1 tonne of waste	**Proportion of decom-posable C in 1 tonne of waste**	**Mass of decom-posable C in 1 tonne of waste**	**Mass of CH4**	**Mass of CO_2**	**Mass of methane captured**	**CO_2 from methane burned**	**Energy from methane burned**	**CO_2 offset from energy generated**	**Mass of methane oxidised**	**CO_2 from oxida-tion**	**Methane released**	**CO_2e of methane released**	**Net CO_2e emitted**
			=[1]×[2]	=[3]×0.5×16÷12	=[3]×0.5×44÷12	=[4]×0.75	=[6]×44÷16	=2.84×0.5×[6]	=0.270×[8]	=[4]×(1-0.75)×0.1	=[10]×44÷16	=[4]×(1-0.75-((1-0.75)×0.1))	=[12]×25	=[13]-[9]
Mixed Paper and Card	0.1514	0.1580	0.0239	0.0159	0.0439	0.0120	0.0329	0.0170	0.0046	0.0004	0.0011	0.0036	0.0897	0.0851
Plastics	0.1348	0	0	0	0	0	0	0	0	0	0	0	0	0
Textiles (and footwear)	0.0395	0.0670	0.0026	0.0018	0.0049	0.0013	0.0036	0.0019	0.0005	0	0.0001	0.0004	0.0099	0.0094
Miscellaneous combustibles	0.0590	0.0890	0.0053	0.0035	0.0096	0.0026	0.0072	0.0037	0.0010	0.0001	0.0002	0.0008	0.0197	0.0187
Miscellaneous non-combustibles	0.0899	0	0	0	0	0	0	0	0	0	0	0	0	0
Food	0.3112	0.0850	0.0265	0.0176	0.0485	0.0132	0.0364	0.0188	0.0051	0.0004	0.0012	0.0040	0.0992	0.0941
Garden	0.0311	0.0870	0.0027	0.0018	0.0050	0.0014	0.0037	0.0019	0.0005	0	0.0001	0.0004	0.0101	0.0096
Soil and other organic waste	0.0311	0.0030	0.0001	0.0001	0.0002	0	0.0001	0.0001	0	0	0	0	0.0003	0.0003
Glass	0.0537	0	0	0	0	0	0	0	0	0	0	0	0	0
Metals, Other Non-biodegradable	0.0225	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0057	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.0311	0.1250	0.0039	0.0026	0.0071	0.0019	0.0053	0.0028	0.0007	0.0001	0.0002	0.0006	0.0146	0.0138
Sanitary / disposable nappies	0.0390	0.0430	0.0017	0.0011	0.0031	0.0008	0.0023	0.0012	0.0003	0	0.0001	0.0003	0.0063	0.0060
TOTAL PER TONNE OF WASTE	**1 Tonne**		0.0666 tC	0.0444 tCH4	0.1222 tCO_2	0.0333 tCH4	0.0916 tCO_2	0.0473 MWh	**0.0128 tCO_2**	0.0011 tCO_2e	0.0031 tCO_2	0.0100 tCH4	**0.2499 tCO_2e**	0.2371 tCO_2e

Note: This does not account for the biogenic carbon sequestration benefit of landfill - see further calculations overleaf

Table 12: Base Case - Biogenic carbon sequestered in landfill

Column	[1]	[2]	[3]	[4]	[5]	[6]
	Proportion of 1 tonne of waste	Proportion decomposable C in 1 tonne of waste	Proportion biogenic C	Proportion sequestered biogenic C	Mass of sequestered biogenic C	Mass of sequestered biogenic CO_2e
	= [Landfill Table, Column 1]	= [Landfill Table Column 2]	= [Incineration Table, Column 5]	= [3] - [2]	= [1] × [4]	= [5] × 44÷12
Mixed Paper and Card	0.1514	0.1580	0.3200	0.1620	0.0245	0.0899
Plastics	0.1348	0.0000	0.0000	0.0000	0.0000	0.0000
Textiles	0.0395	0.0670	0.2000	0.1330	0.0053	0.0193
Miscellaneous combustibles	0.0590	0.0890	0.1900	0.1010	0.0060	0.0218
Misc non-combustibles	0.0899	0.0000	0.0400	0.0400	0.0036	0.0132
Food	0.3112	0.0850	0.1400	0.0550	0.0171	0.0628
Garden	0.0311	0.0870	0.1700	0.0830	0.0026	0.0095
Soil	0.0311	0.0030	0.0700	0.0670	0.0021	0.0076
Glass	0.0537	0.0000	0.0000	0.0000	0.0000	0.0000
Metals	0.0225	0.0000	0.0000	0.0000	0.0000	0.0000
Non-organic fines	0.0057	0.0000	0.0000	0.0000	0.0000	0.0000
Wood	0.0311	0.1250	0.4400	0.3150	0.0098	0.0359
Sanitary	0.0390	0.0430	0.1500	0.1070	0.0042	0.0153
TOTAL PER TONNE OF WASTE	1 Tonne				0.0751 tC	**0.2753 tCO2e**

Table 13: Base Case - Result formulas and calculations (Tonnes CO_2e)

		Incineration	Landfill	Relative net GHG impact of incineration
Direct emissions	**Formula**	[Incineration Table, Column 10] × Throughput	[Landfill Table, Column 13] × Throughput	[Incineration - Landfill]
	Calculation	0.3475 × 265,000 = **92,088**	0.2499 × 265,000 = **66,224**	92,088 - 66,224 = **25,864**
Electricity offset	**Formula**	[Incineration Table, Column 11] × Throughput × -1	[Landfill Table, Column 9] × Throughput × -1	[Incineration - Landfill]
	Calculation	0.1897 × 265,000 × -1 = **-50,271**	0.0128 × 265,000 × -1 = **-3,392**	-50,271 - (-3,392) = **-46,879**
Biogenic carbon sequestration	**Formula**		[Sequestration Table, Column 6] × Throughput × -1	[Incineration - Landfill]
	Calculation		0.2753 × 265,000 × -1 = **-72,955**	0 - (-72,955) = **72,955**
TOTAL	**Formula**	[Sum of above]	[Sum of above]	[Incineration - Landfill]
	Calculation	(92,088) + (-50,271) = **41,817**	(66,224) + (-3,392) + (-72,955) = **-10,123**	41,817 - (-10,123) = **51,940**

Table 14: Base Case - Results (Tonnes CO_2)

	Incineration	Landfill	Relative net
Direct emissions	92,088	66,224	25,864
Electricity offset	-50,271	-3,392	-46,879
Biogenic carbon sequestration		-72,955	72,955
TOTAL	41,817	-10,123	51,940

Table 15: Reduced Plastic - Data set and calculations for the incineration half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
	Proportion of 1 tonne of waste	Calorific value MWh/t	Efficiency	Energy potential MWh	Prop. biogenic C	Mass of biogenic C	Mass of biogenic CO_2 released	Prop. fossil C	Mass of fossil C	Mass of fossil CO_2 released	Fossil CO_2 from electricity offset	Net fossil CO_2 from ERF
				=(1)×(2)×(3)		=(1)×(5)	=(6)×44÷12		=(1)×(8)	=(9)×44÷12	(4)×0.270	(10)-(11)
Mixed Paper and Card	0.1632	3.5000	0.25	0.1428	0.3200	0.0522	0.1915	0	0	0	0.0386	-0.0386
Plastics	0.0674	7.0500	0.25	0.1188	0	0	0	0.5200	0.0350	0.1285	0.0321	0.0964
Textiles (and footwear)	0.0426	4.4400	0.25	0.0473	0.2000	0.0085	0.0312	0.2000	0.0085	0.0312	0.0128	0.0185
Miscellaneous combustibles	0.0636	4.3300	0.25	0.0688	0.1900	0.0121	0.0443	0.1900	0.0121	0.0443	0.0186	0.0257
Miscellaneous non-combustibles	0.0969	0.7800	0.25	0.0189	0.0400	0.0039	0.0142	0.0400	0.0039	0.0142	0.0051	0.0091
Food	0.3355	1.4700	0.25	0.1233	0.1400	0.0470	0.1722	0	0	0	0.0333	-0.0333
Garden	0.0335	1.8100	0.25	0.0152	0.1700	0.0057	0.0209	0	0	0	0.0041	-0.0041
Soil and other organic waste	0.0335	1.3300	0.25	0.0111	0.0700	0.0023	0.0086	0	0	0	0.0030	-0.0030
Glass	0.0579	0.4200	0.25	0.0061	0	0	0	0	0	0	0.0016	-0.0016
Metals, Other Non-biodegradable	0.0243	0	0.25	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0061	1.3300	0.25	0.0020	0	0	0	0.0700	0.0004	0.0016	0.0005	0.0010
Wood	0.0335	5.0800	0.25	0.0425	0.4400	0.0147	0.0540	0	0	0	0.0115	-0.0115
Sanitary / disposable nappies	0.0420	2.2200	0.25	0.0233	0.1500	0.0063	0.0231	0.0400	0.0017	0.0062	0.0063	-0.0001
TOTAL PER TONNE OF WASTE	1		0.25	0.6202		0.1528	0.5601		0.0616	0.2260	0.1674	0.0585

Table 16: Reduced Plastic - Data set and calculations for the landfill half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
	Proportion of 1 tonne of waste	Proportion of decom-posable C in 1 tonne of waste	Mass of decom-posable C in 1 tonne of waste	Mass of CH4	Mass of CO_2	Mass of methane captured	CO_2 from methane burned	Energy from methane burned	CO_2 offset from energy generated	Mass of methane oxidised	CO_2 from oxida-tion	Methane released	CO_2e of methane released	Net CO_2e emitted
			=[1]×[2]	=[3]×0.5×16÷12	=[3]×0.5×44÷12	=[4]×0.75	=[6]×44÷16	=2.84×0.5×[6]	=0.270×[8]	=[4]×(1-0.75)×0.1	=[10]×44÷16	=[4]×(1-0.75-((1-0.75)×0.1))	=[12]×25	=[13]-[9]
Mixed Paper and Card	0.1632	0.1580	0.0258	0.0172	0.0473	0.0129	0.0355	0.0183	0.0049	0.0004	0.0012	0.0039	0.0967	0.0918
Plastics	0.0674	0	0	0	0	0	0	0	0	0	0	0	0	0
Textiles (and footwear)	0.0426	0.0670	0.0029	0.0019	0.0052	0.0014	0.0039	0.0020	0.0005	0	0.0001	0.0004	0.0107	0.0102
Miscellaneous combustibles	0.0636	0.0890	0.0057	0.0038	0.0104	0.0028	0.0078	0.0040	0.0011	0.0001	0.0003	0.0008	0.0212	0.0201
Miscellaneous non-combustibles	0.0969	0	0	0	0	0	0	0	0	0	0	0	0	0
Food	0.3355	0.0850	0.0285	0.0190	0.0523	0.0143	0.0392	0.0202	0.0055	0.0005	0.0013	0.0043	0.1069	0.1015
Garden	0.0335	0.0870	0.0029	0.0019	0.0053	0.0015	0.0040	0.0021	0.0006	0	0.0001	0.0004	0.0109	0.0104
Soil and other organic waste	0.0335	0.0030	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0	0	0	0	0.0004	0.0004
Glass	0.0579	0	0	0	0	0	0	0	0	0	0	0	0	0
Metals, Other Non-biodegradable	0.0243	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0061	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.0335	0.1250	0.0042	0.0028	0.0077	0.0021	0.0058	0.0030	0.0008	0.0001	0.0002	0.0006	0.0157	0.0149
Sanitary / disposable nappies	0.0420	0.0430	0.0018	0.0012	0.0033	0.0009	0.0025	0.0013	0.0003	0	0.0001	0.0003	0.0068	0.0064
TOTAL PER TONNE OF WASTE	1		0.0718	0.0479	0.1317	0.0359	0.0988	0.0510	0.0138	0.0012	0.0033	0.0108	0.2693	0.2556

Note: This does not account for the biogenic carbon sequestration benefit of landfill - see further calculations overleaf

Table 17: Reduced Plastic - Biogenic carbon sequestered in landfill

Column	[1]	[2]	[3]	[4]	[5]	[6]
	Proportion of 1 tonne of waste	**Proportion decomposable C in 1 tonne of waste**	**Proportion biogenic C**	**Proportion sequestered biogenic C**	**Mass of sequestered biogenic C**	**Mass of sequestered biogenic CO_2e**
	= [Landfill Table, Column 1]	= [Landfill Table Column 2]	= [Incineration Table, Column 5]	= [3] - [2]	= [1] × [4]	= [5] × 44÷12
Mixed Paper and Card	0.1632	0.1580	0.3200	0.1620	0.0264	0.0969
Plastics	0.0674	0	0	0	0	0
Textiles	0.0426	0.0670	0.2000	0.1330	0.0057	0.0208
Miscellaneous combustibles	0.0636	0.0890	0.1900	0.1010	0.0064	0.0236
Misc non-combustibles	0.0969	0	0.0400	0.0400	0.0039	0.0142
Food	0.3355	0.0850	0.1400	0.0550	0.0185	0.0677
Garden	0.0335	0.0870	0.1700	0.0830	0.0028	0.0102
Soil	0.0335	0.0030	0.0700	0.0670	0.0022	0.0082
Glass	0.0579	0	0	0	0	0
Metals	0.0243	0	0	0	0	0
Non-organic fines	0.0061	0	0	0	0	0
Wood	0.0335	0.1250	0.4400	0.3150	0.0106	0.0387
Sanitary	0.0420	0.0430	0.1500	0.1070	0.0045	0.0165
TOTAL PER TONNE OF WASTE	1				**0.0809**	**0.2967**

Table 18: Reduced Plastic - Result formulas and calculations (Tonnes CO_2e)

		Incineration	Landfill	Relative net GHG impact of incineration
Direct emissions	Formula	[Incineration Table, Column 10] × Throughput	[Landfill Table, Column 13] × Throughput	[Incineration - Landfill]
	Calculation	0.226 × 265,000 = 59,890	0.2693 × 265,000 = 71,365	59,890 - 71,365 = -11,475
Electricity offset	Formula	[Incineration Table, Column 11] × Throughput × -1	[Landfill Table, Column 9] × Throughput × -1	[Incineration - Landfill]
	Calculation	0.1674 × 265,000 × -1 = -44,361	0.0138 × 265,000 × -1 = -3,657	-44,361 - (-3,657) = -40,704
Biogenic carbon sequestration	Formula		[Sequestration Table, Column 6] × Throughput × -1	[Incineration - Landfill]
	Calculation		0.2967 × 265,000 × -1 = -78,626	0 - (-78,626) = 78,626
TOTAL	Formula	[Sum of above]	[Sum of above]	[Incineration - Landfill]
	Calculation	(59,890) + (-44,361) = 15,529	(71,365) + (-3,657) + (-78,626) = -10,918	15,529 - (-10,918) = 26,447

Table 19: Reduced Plastic - Results (Tonnes CO_2)

	Incineration	Landfill	Relative net
Direct emissions	59,890	71,365	-11,475
Electricity offset	-44,361	-3,657	-40,704
Biogenic carbon sequestration		-78,626	78,626
TOTAL	15,529	-10,918	26,447

Table 20: Reduced Compostables - Data set and calculations for the incineration half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
	Proportion of 1 tonne of waste	Calorific value MWh/t	Efficiency	Energy potential MWh	Prop. biogenic C	Mass of biogenic C	Mass of biogenic CO_2 released	Prop. fossil C	Mass of fossil C	Mass of fossil CO_2 released	Fossil CO_2 from electricity offset	Net fossil CO_2 from ERF
				=(1)×(2)×(3)		=(1)×(5)	=(6)×44÷12		=(1)×(8)	=(9)×44÷12	(4)×0.270	(10)-(11)
Mixed Paper and Card	0.1964	3.5000	0.25	0.1719	0.3200	0.0628	0.2304	0	0	0	0.0464	-0.0464
Plastics	0.1750	7.0500	0.25	0.3084	0	0	0	0.5200	0.0910	0.3337	0.0833	0.2504
Textiles (and footwear)	0.0513	4.4400	0.25	0.0569	0.2000	0.0103	0.0376	0.2000	0.0103	0.0376	0.0154	0.0222
Miscellaneous combustibles	0.0766	4.3300	0.25	0.0829	0.1900	0.0146	0.0534	0.1900	0.0146	0.0534	0.0224	0.0310
Miscellaneous non-combustibles	0.1167	0.7800	0.25	0.0228	0.0400	0.0047	0.0171	0.0400	0.0047	0.0171	0.0061	0.0110
Food	0.1556	1.4700	0.25	0.0572	0.1400	0.0218	0.0799	0	0	0	0.0154	-0.0154
Garden	0.0155	1.8100	0.25	0.0070	0.1700	0.0026	0.0097	0	0	0	0.0019	-0.0019
Soil and other organic waste	0.0155	1.3300	0.25	0.0052	0.0700	0.0011	0.0040	0	0	0	0.0014	-0.0014
Glass	0.0697	0.4200	0.25	0.0073	0	0	0	0	0	0	0.0020	-0.0020
Metals, Other Non-biodegradable	0.0293	0	0.25	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0074	1.3300	0.25	0.0025	0	0	0	0.0700	0.0005	0.0019	0.0007	0.0012
Wood	0.0403	5.0800	0.25	0.0512	0.4400	0.0177	0.0650	0	0	0	0.0138	-0.0138
Sanitary / disp nappies	0.0507	2.2200	0.25	0.0281	0.1500	0.0076	0.0279	0.0400	0.0020	0.0074	0.0076	-0.0002
TOTAL PER TONNE OF WASTE	1		0.25	0.8014		0.1432	0.5250		0.1230	0.4511	0.2164	0.2347

Table 21: Reduced Compostables - Data set and calculations for the landfill half of the model (for one tonne of waste)

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]
	Proportion of 1 tonne of waste	Proportion of decom-posable C in 1 tonne of waste	Mass of decom-posable C in 1 tonne of waste	Mass of CH4	Mass of CO_2	Mass of methane captured	CO_2 from methane burned	Energy from methane burned	CO_2 offset from energy generated	Mass of methane oxidised	CO_2 from oxida-tion	Methane released	CO_2e of methane released	Net CO_2e emitted
			=[1]×[2]	=[3]×0.5×16÷12	=[3]×0.5×44÷12	=[4]×0.75	=[6]×44÷16	=2.84×0.5×[6]	=0.270×[8]	=[4]×(1-0.75)×0.1	=[10]×44÷16	=[4]×(1-0.75-((1-0.75)×0.1))	=[12]×25	=[13]-[9]
Mixed Paper and Card	0.1964	0.1580	0.0310	0.0207	0.0569	0.0155	0.0427	0.0220	0.0059	0.0005	0.0014	0.0047	0.1164	0.1104
Plastics	0.1750	0	0	0	0	0	0	0	0	0	0	0	0	0
Textiles (and footwear)	0.0513	0.0670	0.0034	0.0023	0.0063	0.0017	0.0047	0.0024	0.0007	0.0001	0.0002	0.0005	0.0129	0.0122
Miscellaneous combustibles	0.0766	0.0890	0.0068	0.0045	0.0125	0.0034	0.0094	0.0048	0.0013	0.0001	0.0003	0.0010	0.0256	0.0243
Miscellaneous non-combustibles	0.1167	0	0	0	0	0	0	0	0	0	0	0	0	0
Food	0.1556	0.0850	0.0132	0.0088	0.0242	0.0066	0.0182	0.0094	0.0025	0.0002	0.0006	0.0020	0.0496	0.0471
Garden	0.0155	0.0870	0.0013	0.0009	0.0025	0.0007	0.0019	0.0010	0.0003	0	0.0001	0.0002	0.0051	0.0048
Soil and other organic waste	0.0155	0.0030	0	0	0.0001	0	0.0001	0	0	0	0	0	0.0002	0.0002
Glass	0.0697	0	0	0	0	0	0	0	0	0	0	0	0	0
Metals, Other Non-biodegradable	0.0293	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-organic fines	0.0074	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.0403	0.1250	0.0050	0.0034	0.0092	0.0025	0.0069	0.0036	0.0010	0.0001	0.0002	0.0008	0.0189	0.0179
Sanitary / disp nappies	0.0507	0.0430	0.0022	0.0015	0.0040	0.0011	0.0030	0.0015	0.0004	0	0.0001	0.0003	0.0082	0.0078
TOTAL PER TONNE OF WASTE	1		0.0631	0.0421	0.1157	0.0316	0.0868	0.0448	0.0121	0.0011	0.0029	0.0095	0.2367	0.2246

Note: This does not account for the biogenic carbon sequestration benefit of landfill - see further calculations overleaf

Table 22: Reduced Compostables - Biogenic carbon sequestered in landfill

Column	[1]	[2]	[3]	[4]	[5]	[6]
	Proportion of 1 tonne of waste	Proportion decomposable C in 1 tonne of waste	Proportion biogenic C	Proportion sequestered biogenic C	Mass of sequestered biogenic C	Mass of sequestered biogenic CO_2e
	= [Landfill Table, Column 1]	= [Landfill Table Column 2]	= [Incineration Table, Column 5]	= [3] - [2]	= [1] × [4]	= [5] × 44÷12
Mixed Paper and Card	0.1964	0.1580	0.3200	0.1620	0.0318	0.1167
Plastics	0.1750	0.0000	0.0000	0.0000	0.0000	0.0000
Textiles	0.0513	0.0670	0.2000	0.1330	0.0068	0.0250
Miscellaneous combustibles	0.0766	0.0890	0.1900	0.1010	0.0077	0.0284
Misc non-combustibles	0.1167	0.0000	0.0400	0.0400	0.0047	0.0171
Food	0.1556	0.0850	0.1400	0.0550	0.0086	0.0314
Garden	0.0155	0.0870	0.1700	0.0830	0.0013	0.0047
Soil	0.0155	0.0030	0.0700	0.0670	0.0010	0.0038
Glass	0.0697	0.0000	0.0000	0.0000	0.0000	0.0000
Metals	0.0293	0.0000	0.0000	0.0000	0.0000	0.0000
Non-organic fines	0.0074	0.0000	0.0000	0.0000	0.0000	0.0000
Wood	0.0403	0.1250	0.4400	0.3150	0.0127	0.0465
Sanitary	0.0507	0.0430	0.1500	0.1070	0.0054	0.0199
TOTAL PER TONNE OF WASTE	1				**0.0800**	**0.2935**

Table 23: Reduced Compostables - Result formulas and calculations (Tonnes CO_2e)

		Incineration	Landfill	Relative net GHG impact of incineration
Direct emissions	**Formula**	[Incineration Table, Column 10] × Throughput	[Landfill Table, Column 13] × Throughput	[Incineration - Landfill]
	Calculation	0.4511 × 265,000 = 119,542	0.2367 × 265,000 = 62,726	119,542 - 62,726 = 56,816
Electricity offset	**Formula**	[Incineration Table, Column 11] × Throughput × -1	[Landfill Table, Column 9] × Throughput × -1	[Incineration - Landfill]
	Calculation	0.2164 × 265,000 × -1 = -57,346	0.0121 × 265,000 × -1 = -3,207	-57,346 - (-3,207) = -54,140
Biogenic carbon sequestration	**Formula**		[Sequestration Table, Column 6] × Throughput × -1	[Incineration - Landfill]
	Calculation		0.2935 × 265,000 × -1 = -77,778	0 - (-77,778) = 77,778
TOTAL	**Formula**	[Sum of above]	[Sum of above]	[Incineration - Landfill]
	Calculation	(119,542) + (-57,346) = 62,196	(62,726) + (-3,207) + (-77,778) = -18,259	62,196 - (-18,259) = 80,455

Table 24: Reduced Compostables - Results (Tonnes CO_2)

	Incineration	Landfill	Relative net
Direct emissions	119,542	62,726	56,816
Electricity offset	-57,346	-3,207	-54,140
Biogenic carbon sequestration		-77,778	77,778
TOTAL	62,196	-18,259	80,455