FICHTNER
Consulting Engineers Limited

Indaver Rivenhall

Carbon Assessment

1 Introduction

Indaver (the Client) is developing the Rivenhall Integrated Waste Management Facility at the former Rivenhall airfield near Braintree, Essex. The Facility is currently under construction and due to enter commissioning in 2025. This carbon assessment considers the carbon emissions associated with operation of the Combined Heat and Power (CHP) Plant (the Facility).

This report has been produced by Fichtner Consulting Engineers Ltd (Fichtner) in order to determine the expected carbon emissions from the operational phase of the Facility based on the design data for the Facility. The methodology utilised is in accordance with GHG Protocol guidance.

Scope 1 includes direct emissions from owned or controlled sources, and Scope 2 includes indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain[1]. Scope 3 emissions would include emissions from the transport of waste to the Facility or the removal of residues from the Facility.

For the purposes of this technical note only Scope 1 and 2 carbon emissions have been calculated. Scope 3 emissions have not been calculated due to uncertainties in the transport emissions associated with the transport of raw materials, waste and residues to/from the Facility.

2 Background

2.1 Waste composition

The assumed waste composition for waste to be processed within the Facility is made up of 70% municipal solid waste (MSW) and 30% is commercial and industrial (C&I) waste.

Waste composition data has been taken from different published sources:

- "National Municipal Waste Composition, England 2017", WRAP, January 2020
  - The Residual Municipal Waste composition from Table 3 has been used, as this is a mixture of household and commercial waste.
- "Composition analysis of Commercial and Industrial waste in Wales", WRAP Cymru, January 2020:
  - This report gives an estimate for C&I waste for 2017 and is an update of the previous 2007 report. We are not aware of a more recent report for English waste.

Waste composition will vary over time in line with government strategy, which aims to reduce the amount of both plastics and food waste in residual waste. The waste composition presented is based

[1] The Carbon Trust: *carbontrust.com/resources/briefing-what-are-scope-3-emissions*

on the current data above, with some adjustments to obtain a composition which best reflects the design NCV.

2.2 Comparator

The GHG protocol requires that emissions are calculated based on the direct emissions from the Facility. Therefore, the Scope 1 emissions are representative of the direct carbon emissions predicted from the Facility. However, this does not consider the change in carbon from alternative waste management solutions.

Currently, the UK does not have sufficient waste incineration capacity to process all residual waste arising domestically, and quite a lot of residual waste is disposed of in landfill. This position is also relevant on a more local scale, where landfill still has a role to play in current residual waste management practice in Essex, and to which the Facility will offer an alternative treatment for this residual waste. Alternatively, waste is shipped to Europe and overseas to older, less efficient waste incineration plants. Therefore, for the purposes of this technical note, it has been assumed that the comparator is landfill.

When waste which is disposed of in landfill, the biogenic carbon will degrade, resulting in the generation of landfill gas (LFG). LFG is comprised of methane and carbon dioxide, so has a significant carbon burden. Some of the methane in the LFG can be recovered and combusted in a gas engine to produce electricity.

Therefore, the comparator scenario would also produce Scope 1 and Scope 2 emissions. In Fichtner's experience, due to the efficiency of a waste incineration plant, net landfill emissions are greater than emissions from waste incineration. Therefore, EfW will provide a carbon benefit compared to landfill. This has been quantified this within the calculations provided.

The approach to use landfill as a baseline is supported by national guidance, specifically "*Energy from Waste: A Guide to the Debate*" and "*Energy recovery for residual waste – A carbon based modelling approach*", both published by DEFRA in 2014.

Further to the above, the draft Waste Management Plan for England (DEFRA, 2020) indicates government support for efficient energy recovery from residual waste, stating that "*energy from waste is generally the best management option for waste that cannot be reused or recycled in terms of environmental impact and getting value from the waste as a resource. It plays an important role in diverting waste from landfill*".

3 Carbon emissions

3.1 Facility

The combustion of waste generates direct emissions of carbon dioxide. It also produces emissions of nitrous oxide, which is a potent greenhouse gas. Methane may arise in minimal extents from the decomposition of waste remaining in the waste bunker; however, decomposition is actively avoided. Therefore, methane is not regarded to have relevant climate impacts in quantitative terms. These direct emissions are covered in Scope 1.

The design case for the Facility is a throughput of 571,040 tonnes per annum (tpa) of waste with a design point net calorific value (NCV) of 9.7 MJ/kg, assuming that the plant operates for approximately 8,000 hours a year.

Table 1: Waste characteristics

Carbon content (% mass)	Biocarbon (% carbon)	NCV (MJ/kg)	Waste throughput (tonnes/year)
25.38	56.82	9.70	571,040

Exporting energy to the grid and heat to local heat users offsets greenhouse gas emissions from the generation of power in other ways. These indirect emission savings are covered in Scope 2.

Appendix A provides detailed calculations for the carbon burdens and benefits associated with the Facility. Unless otherwise specified, all values presented are on an annual basis.

The Scope 1 emissions from the Facility are calculated to be 245,905 t CO_2e per annum. The carbon intensity is calculated as the tonnes of CO_2e produced per MWh. For Scope 1 emissions, this is 0.6921 tCO2e/MWh.

The Scope 2 emissions from the Facility are calculated to be -136,798 t CO_2e per annum, which is equivalent to a carbon intensity of -0.385 tCO2e/MWh. The value is negative because the CHP plant will offset alternative forms of energy generation.

3.2 Landfill

For waste which is disposed of in landfill, the biogenic carbon will degrade, resulting in the generation of landfill gas (LFG). LFG is comprised of methane and carbon dioxide, so has a significant carbon burden. Some of the methane in the LFG can be recovered and combusted in a gas engine to produce electricity.

Therefore, the comparator scenario would also produce Scope 1 (direct emissions of carbon and methane) and Scope 2 emissions (the electricity produced via methane combustion, which will offset alternative forms of energy generation).

The calculations of the emissions from landfill are calculated based on the same tonnage, composition and characteristics of waste as assumed for the Facility. Appendix A provides detail of the calculation of the carbon burdens and benefits associated with the landfill alternative. Unless otherwise specified, all values presented are on an annual basis.

The Scope 1 emissions from the Facility are calculated to be 232,603 t CO_2e per annum. The carbon intensity is calculated as the tonnes of CO_2e produced per MWh. For Scope 1 emissions, this is 0.6546 tCO2e/MWh.

The Scope 2 emissions from the Facility are calculated to be -36,686 t CO_2e per annum, which is equivalent to a carbon intensity of -0.103 tCO2e/MWh. The value is negative because the generation of electricity through the landfill gas engines will offset alternative forms of energy generation.

4 Conclusions

The Scope 1 and Scope 2 emissions are presented in Table 2. This also shows the combined Scope 1 and Scope 2 carbon emissions and the difference between carbon emissions from the Facility and the comparator.

Table 2: Carbon emissions summary

Source	**Carbon emissions (tonnes CO2 equivalent)**		
	Released (Scope 1)	**Offset (Scope 2)**	**Total Scope 1 and 2 emissions**
Facility	245,905	-136,798	109,108
Landfill	232,603	-36,686	195,916
Difference	**12,303**	**-100,111**	**-86,809**

As can be seen, when compared to the landfill, the Facility will result in a net carbon benefit of 86,809 tonnes CO2 equivalent per annum. It should be noted that this does not include for the export of heat from the Facility, which would further increase the carbon benefit of the Facility.

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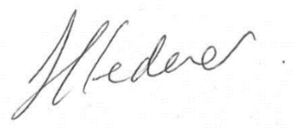

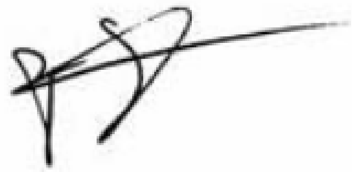

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Appendices

A Assumptions and detailed calculations

A.1 Facility

4.1.1 Direct emissions – Scope 1

The combustion of waste generates direct emissions of carbon dioxide, with the tonnes of carbon dioxide emitted determined from the carbon content of the waste.

For this assessment, only carbon emissions from fossil sources have been considered, as carbon emissions from the combustion of biogenic sources has a neutral carbon burden.

In accordance with Volume 5 of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, it has been assumed that 100% of the carbon in the fuel is converted to carbon dioxide through the combustion process.

The mass of fossil-derived carbon dioxide produced has been determined by multiplying the mass of fossil carbon in the fuel by the ratio of the molecular weights of carbon dioxide (44) and carbon (12) respectively as shown in the equation below (where Mr = molecular weight):

$$Mass\ of\ CO_2\ out = Mass\ of\ C\ in\ \times \frac{Mr\ CO_2}{Mr\ C}$$

The total fossil derived carbon emissions for the Facility are presented in Table 3.

Table 3: Fossil CO_2 emissions

Item	Unit	Facility
Fossil carbon in input waste	t C	62,582
Fossil derived carbon dioxide emissions	**t CO_2**	**229,468**

The process of recovering energy from waste results in the release of a small amount of nitrous oxide and methane, which both contribute to climate change. The impact of these emissions is reported as CO_2e emissions and has been calculated using the Global Warming Potential (GWP) multiplier. In this assessment the GWP for 100 years has been used.

Emissions of nitrous oxide and methane depend on combustion conditions. Nitrous oxide emissions also depend on flue gas treatment. Default emission factors from the IPCC have been used to determine the emissions of these gases, as shown in Table 4.

Table 4: N_2O and CH_4 assumptions

Item	Unit	Value	Source
N_2O default emissions factor	kg N_2O/TJ	4	IPCC Guidelines for Greenhouse Gas Inventories, Vol 2, Table 2.2 Default Emissions Factors for Stationary Combustion in the Energy Industries, Municipal Wastes (non-biomass) and Other Primary Solid Biomass
CH_4 default emissions factor	kg CH_4/TJ	30	
GWP – N_2O to CO_2	kg CO_2e/kg N_2O	298	IPCC Forth Assessment Report (AR4) 2007 (consistent with government guidance)

Item	Unit	Value	Source
GWP – CH_4 to CO_2	kg CO_2e/kg CH_4	25	IPCC Forth Assessment Report (AR4) 2007 (consistent with government guidance)

Nitrous oxide and methane emissions from both the biogenic and non-biogenic fractions are considered as a carbon burden. Both the biogenic and non-biogenic fractions of waste have the same default emissions factor. The emissions of nitrous oxide and methane and the equivalent carbon dioxide emissions for the Facility are presented in Table 5.

Table 5: N_2O and CH_4 emissions

Item	Unit	Facility
N_2O emissions	t N_2O	22.2
Equivalent CO_2 emissions	**t CO_2e**	**6,605**
CH_4 emissions	t CH_4	166.2
Equivalent CO_2 emissions	**t CO_2e**	**4,156**

Auxiliary burners will be installed for start-up and shutdown purposes, and to maintain the combustion temperature above 850°C. The auxiliary burners will burn gasoil and have a capacity of about 60% of boiler capacity; or approximately 110 MW_{th} combined capacity. Based on 10 start-ups a year with each period of start-up lasting 18 hours, it is assumed that the auxiliary burners will operate for up to 180 hours per annum.

Each MWh of gasoil releases approximately 0.27319[2] tonnes of carbon dioxide, so the emissions associated with auxiliary firing would be the energy required in MWh x 0.27318. The total direct equivalent carbon dioxide emissions for the combustion of waste in the Facility are presented in Table 6.

Table 6: Total equivalent CO_2 emissions from the combustion of waste

Item	Unit	Facility
CO_2 emissions	t CO_2	229,468
N_2O emissions	t CO_2e	6,605
CH_4 emissions	t CO_2e	4,156
Burner emissions	t CO_2e	5,676
Total emissions	**t CO_2e**	**245,905**

4.1.2 Grid offset – Scope 2

The Facility will generate electricity which will be exported to the grid. Sending electricity to the grid offsets the carbon burden of producing electricity using other methods. In the case of a waste incineration plant, such as the Facility, the displaced electricity would be the marginal source which is currently gas-fired power stations, for which the displacement factor is 0.385 t CO_2e/MWh[3]. DEFRAs *'Energy from Waste – A Guide to the Debate 2014'* (specifically, footnote 29 on page 21) states that "A gas fired power station (Combined Cycle Gas Turbine – CCGT) is a reasonable

[2] DEFRA – Greenhouse gas reporting: Conversion factors 2022 (based on net CV)

[3] DEFRA – Fuel Mix Disclosure Data Table – 01/04/2021 – 31/03/2022

comparator as this is the most likely technology if you wanted to build a new power station today". Therefore, the assessment of grid offset uses the current marginal technology (CCGT) as a comparator.

The construction of an EfW plant will have little or no effect on how nuclear, wind or solar plants operate when taking into account market realities, such as the phase-out of old nuclear plants and the planned construction of new plants, and the generous subsidies often associated with the development of wind and solar plants.

Current energy strategy uses nuclear power stations to operate as baseload stations run with relatively constant output over a daily and annual basis, with limited ability to ramp up and down in capacity to accommodate fluctuations in demand. Power supplied from existing nuclear power stations is relatively low in marginal cost and has the benefit of extremely low carbon dioxide emissions. Wind and solar plants also have very low marginal operating costs and are supported by subsidies in many cases. This means that they will run when there is sufficient wind or sun and that this operation will be unaffected by the operation of the Facility.

Combined cycle gas turbines (CCGTs) are the primary flexible electricity source. Since wind and solar are intermittent, with the electricity supplied varying from essentially zero (on still nights) to more than 16 GW (on windy or sunny days), CCGTs supply a variable amount of power. However, there are always some CCGTs running to provide power to the grid.

Gas engines, diesel engines and open cycle gas turbines also make a small contribution to the grid. These are mainly used to provide balancing services and to balance intermittent supplies. As they are more carbon intensive than CCGTs, it is more conservative to ignore these.

In addition, recent bidding of EfW plants into the capacity market mean that they are competing primarily with CCGTs, gas engines and diesel engines. It is therefore considered that CCGT is the correct comparator.

The amount of carbon dioxide offset by the electricity generated by the Facility is calculated by multiplying the net electricity generated by the grid displacement factor. Table 7 provides the electricity emissions factors used to calculate the grid displacement value, using the DERFA Fuel Mix Disclosure Table based on operational data from 2021-2022 and the calculated emissions saved based on an electric export of 49.9 MW (339,291 MWh).

The Facility is designed for the export of heat. The export of heat from the Facility will displace heat otherwise generated by other methods. Currently, the heat users from the Facility are not confirmed, therefore for the purpose of this calculation, the offset from heat has not been quantified. However, the export of heat from the Facility would provide further carbon savings.

Table 7: Grid Displacement

Value	Based on DERFA Fuel Mix Disclosure Tables
Conversion Factor for electricity offset (t CO_2e/MWh)	0.385
CO_2 offset through export of electricity (tonnes CO_2 p.a.)	136,798

The carbon intensity is calculated as the tonnes of CO_2e produced per MWh. As Scope 2 emissions are calculated from a carbon factor, the carbon intensity is equivalent to the carbon factor, i.e. -0.385 tCO2e/MWh.

A.2 Landfill

4.1.3 Direct emissions - Scope 1

The emissions associated with LFG can be split into:

1. carbon dioxide released in LFG;
2. methane released in LFG; and
3. methane captured and combusted in LFG engines and flares, producing carbon dioxide as a result of the combustion.

Since 1 and 3 result in the release of carbon dioxide derived from biogenic carbon in the waste, these should both be excluded from the calculation. Therefore, the focus of this calculation is the methane which is released to atmosphere, alongside the electricity displaced by generation in LFG engines. This is calculated as follows:

4. The biogenic carbon content of the waste is derived from the waste composition, refer to Table 1.
5. 50% of the degraded biogenic carbon is released and converted into LFG. The released carbon is referred to as the dissimilable decomposable organic carbon (DDOC) content.
   a. This assumes a sequestration rate of 50%, which is considered to be a conservative assumption and is in accordance with DEFRAs *'Energy from Waste – A Guide to the Debate'*.
   b. There is considerable uncertainty in literature surrounding the amount of biogenic carbon that is sequestered in landfill. The high sequestration used in this assessment (i.e. 50%), combined with the use of high landfill gas capture rates (assumed 68% capture) is considered to be conservative assumption. Therefore, it is not considered appropriate to give additional credit for sequestered carbon as this would result in an overly-conservative assessment.
      i. Although the DEFRA report "*Energy recovery for residual waste - A carbon based modelling approach*" considers the impact of sequestration on the carbon model, the report notes that there was considerable uncertainty surrounding the calculation and that further work is required.
      ii. Changing the level of sequestration impacts on both the amount of biogenic carbon that needs to be counted on the EfW side of the model, and the amount of methane emitted on the landfill side. The calculations are described as being "*particularly sensitive to sequestration levels, with any drop in assumed sequestration significantly favouring EfW over landfill*".
      iii. In addition, the report describes an additional complicating factor regarding the effect of sequestration assumptions on the LFG capture rate. The report indicates that the assumed LFG capture rates are based on a high sequestration rate, which may not be correct, and which are based on the higher end of the rates in literature. Should the sequestration rates be lower in reality, more LFG is generated than expected, resulting in lower capture rates and making the impact of landfill considerably worse. The approach used within the report (i.e., high sequestration percentage, high LFG capture rates and no additional credit for sequestered carbon), and also within this carbon assessment, is considered to be conservative, in that it will tend to favour landfill over EfW.
      iv. Therefore, it is considered that the report does not support the inclusion of credit for sequestered carbon within the assessment.

6. LFG is made up of 57% methane and 43% carbon dioxide, based on a detailed report carried out by Golder Associates for DEFRA[4].

   Opinion is divided as to whether to use an assumption of 50% or 57% for the methane content of landfill gas. The Golder Associates report reviewed an extensive dataset from UK landfill sites and calculated that a figure of 57% should be used, stating that this figure "is based on a substantive and representative data set, and is considered to be a very reliable calculation". This figure is then used throughout the Golder Associates report to derive the other figures. It is therefore considered that 57% is the correct figure to use within this carbon assessment. However, it is acknowledged by Golders that further review of published studies may be required to explain why 50% is more commonly used as an assumption in accordance with the IPCC (2006) default values.
7. Based on the same report, the analysis assumes a base of 68% of the LFG is captured and that 10% of the remaining 32% is oxidised to carbon dioxide as it passes through the landfill cover layer. The unoxidized LFG is then released to atmosphere. This is based on the estimated landfill gas collection efficiency for a subset of 43 large modern landfills as 68%. For all UK landfills, the figure would be 52%. Taking this into consideration, 68% has been used as the central figure: the landfill site in the comparison scenario is considered to represent a typical modern large UK landfill site.
8. Based on the same report, 90.9% of the captured LFG is used in gas engines to generate electricity, although 1.5% of this captured LFG passes through uncombusted and is released to atmosphere. The remainder is combusted in a flare. We have assumed that the flares fully combust the methane.
   a. The DEFRA report "*Energy recovery for residual waste - A carbon based modelling approach*" assumes that, over the life of a landfill site, about 50% of the landfill gas collected is used to generate electricity, with the remainder flared. In contrast to this, the Golder Associates report estimates that around 90.9% of the landfill gas would be used to generate electricity. This does not take account of sites which do not have gas engines, but should be representative of the 43 large, modern landfills for which the collection efficiency figure was derived. The Golder Associates report was produced after the DEFRA report and is more detailed, with a clearer evidence base. Therefore, we consider that the Golder Associates report supersedes the DEFRA report, and the assumption made for the amount of landfill gas used to generate electricity within the assessment is more conservative.
   b. In addition to the above, the DEFRA report uses an engine efficiency of 41%, based on the gross generation efficiency of new landfill gas engines. The Golder Associates report agrees with this figure for new engines, but takes account of parasitic loads and other losses to estimate a net export efficiency of 36%. Given that, for the Facility, we are using net electricity exported, it is reasonable to use the same type of efficiency for landfill gas engines.

Table 8 outlines the LFG assumptions and Table 9 shows the equivalent carbon emissions associated with landfill.

Table 8: LFG assumptions

Item	Value	Source
Calorific value of methane	50 MJ/kg	BEIS "Greenhouse gas reporting: conversion factors 2021"

[4] Review of Landfill Methane Emissions Modelling (WR1908), Golder Associates, November 2014

Item	Value	Source
DDOC content *(dissimilable decomposable carbon content, i.e. biogenic carbon which is converted to landfill gas)*	50%	Review of Landfill Methane Emissions Modelling (WR1908), Golder Associates (2014)
Carbon dioxide percentage of LFG	43%	
Methane percentage of LFG	57%	
LFG recovery efficiency	68%	
Oxidisation of landfill gas in cap	10%	
Fraction of recovered landfill gas used in engines	91%	
Methane slippage through landfill gas engine	1.5%	
Landfill gas engine efficiency	36%	
Molecular ratio of methane to carbon	1.33	Standard Values
Molecular ratio of carbon dioxide to methane	2.75	
Molecular ratio of carbon dioxide to carbon	3.67	
Global Warming Potential – methane to carbon dioxide	25	IPCC Fourth Assessment Report (AR4) 2007

Table 9: LFG emissions

Item	Unit	Value
Biogenic carbon	tonnes	82,364
Total DDOC content	tonnes p.a.	41,182
Landfill gas recovery efficiency	%	68%
Methane in LFG, of which:	tonnes p.a.	31,298
- Methane captured	tonnes p.a.	21,283
- Methane oxidised in landfill cap	tonnes p.a.	1,002
- Methane released to atmosphere directly	tonnes p.a.	9,014
Methane leakage through gas engines	tonnes p.a.	290
Total methane released to atmosphere	tonnes p.a.	9,304
CO_2e released to atmosphere	tonnes CO2e p.a.	232,603

The value for biogenic carbon in Table 9, is calculated by multiplying the annual tonnage of waste by the carbon content percentage of the waste, and then again by the percentage of that carbon which is derived from biogenic sources.

4.1.4 Grid offset – Scope 2

The methane in the LFG that has been recovered can be used to produce electricity. This electricity will offset grid production, and results in a carbon benefit of sending waste to landfill. The assumptions for the amount of LFG methane captured and used in a typical LFG engine are shown in Table 10.

Table 10: LFG grid offset assumptions

Item	Value	Source
Landfill gas recovery efficiency	68%	DEFRA Review of Landfill Methane Emissions Modelling (Nov 2014).
Methane captured used in gas engines	90.9%	DEFRA Review of Landfill Methane Emissions Modelling (Nov 2014)
Methane leakage through gas engines	1.5%	
Landfill gas engine efficiency	36%	
Methane net calorific value	50 MJ/kg	BEIS "Greenhouse gas reporting: conversion factors 2021"

The power produced by the LFG engines is based on the amount of methane, the heat content of methane and the engine efficiency, as per the assumptions in Table 10. The power generated by the LFG engines and the carbon dioxide offset are shown in Table 11.

Table 11: LFG grid offset

Item	Unit	Value
Landfill gas recovery efficiency	%	68%
UK Electricity conversion factor[5]	kg CO_2e/kWh	0.385
Methane captured, of which:	tonnes p.a.	21,283
- Methane flared	tonnes p.a.	1,934
- Methane leakage through gas engines	tonnes p.a.	290
- Methane used in gas engines	tonnes p.a.	19,058
Fuel input to gas engines	GJ	952,889
Power generated	MWh	95,289
Total CO_2e offset through grid displacement	t CO_2e p.a.	36,686

[5] Value taken from DEFRA – Fuel Mix Disclosure Data Table – 01/04/2021 – 31/03/2022