Appendix D.1 Carbon Assessment

FICHTNER
Consulting Engineers Limited

Riverside Optimisation Project

Cory Riverside Energy

Carbon Assessment - Technical Appendix

ENGINEERING CONSULTING

Document approval

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Document revision record

Revision no	Date	Details of revisions	Prepared by	Checked by
01	15/02/21	First Issue	SMO	SDR

Contents

1 Introduction

1.1 Background

As described in the Environmental Statement, Cory Riverside Energy Ltd ("Cory") operates the Riverside Resource Recovery Facility ("RRRF"). RRRF has recently been fitted internally with an upgraded operational control system that enables a more consistent level of operation. This technology enables RRRF to be operated more efficiently than its original design when first built.

Therefore, Cory is submitting an application to the Secretary of State for the Department of Business, Energy and Industrial Strategy to amend the section 36 consent and the deemed planning consent, so that the energy generation limit is increased from 72 MWe to 80.5 MWe and the maximum waste throughput is increased from 785,000 to 850,000 tpa. This is called the Riverside Optimisation Project, or "ROP".

Although the maximum permitted waste throughput is currently 785,000 tpa, operational data for RRRF indicates that it actually processes around 750,000 tpa. Therefore, for the purposes of this carbon assessment this throughput has been used as the base case.

1.2 Objective

The purpose of this Carbon Assessment is to determine the relative carbon impact of processing additional waste in the RRRF, compared to disposal in a landfill, as this is the most likely alternative destination for the waste. This assessment also considers the sensitivity of the results associated with changes in grid displacement factors and landfill gas recovery rates.

2 Conclusions

1. The carbon emissions have been calculated for RRRF as it currently operates and as it would operate in the future. This takes account of:
   a. carbon dioxide released from the combustion of fossil-fuel derived carbon in RRRF;
   b. releases of other greenhouse gases from the combustion of waste;
   c. combustion of gas oil in auxiliary burners;
   d. carbon dioxide emissions from the transport of waste and residues; and
   e. emissions offset from the export of electricity from RRRF.
2. The change in emissions following the implementation of ROP has been compared with the carbon emissions from sending the additional waste to a typical modern UK landfill site, taking account of:
   a. the release of methane in the fraction of landfill gas which is not captured; and
   b. emissions offset from the generation of electricity from landfill gas.
3. In the base case, the implementation of ROP is predicted to lead to a net reduction in greenhouse gas emissions of approximately 29,150 tonnes of CO_2-equivalent (CO_2e) per annum compared to the landfill counterfactual.
4. The emissions offset from the generation of electricity is based on the current marginal generation source, which is CCGTs. The sensitivity of this calculation to different grid displacement factors and different landfill gas recovery rates has also been considered. The lower figures used in the sensitivity analysis for grid displacement factor would only be relevant if RRRF were to displace other renewable sources of electricity. The results of the sensitivities for the base case provide a net reduction of greenhouse gas emissions within a range of 7,500 to 52,800 tonnes of CO_2e emissions per annum.

3 Calculations

3.1 RRRF

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 within the waste bunker; however, this will be actively avoided and methane is not regarded to have relevant climate impacts in quantitative terms from the operation of RRRF. In addition, combustion air is drawn from the bunker area. This means that any methane which does form from decomposition of waste within the bunker is drawn into the combustion chamber and burnt. As the methane would have arisen from biodegradable waste, any carbon dioxide produced by burning that methane will also be derived from biodegradable waste. Therefore, it has been excluded from the assessment.

Exporting energy to the grid offsets greenhouse gas emissions from the generation of power in other ways. In the case of RRRF, the displaced electricity will be the marginal source which is currently gas-fired power stations. It is considered that the optimisation of RRRF will not affect how wind, solar and nuclear plants operate. Therefore, the use of a gas-fired power station is considered a reasonable comparator when assessing the grid offset of RRRF. This is discussed in further detail in section 3.1.3.

The following sections provide detail of the calculation of the carbon burdens and benefits associated with RRRF. Unless otherwise specified, all values presented are on an annual basis. In all cases, the current and future operation of RRRF have been considered.

3.1.1 Waste Throughput and Composition

RRRF is designed to process waste with a range of NCV's in accordance with the firing diagram for RRRF. Therefore, the hourly throughput will vary in accordance with the NCV of waste that is processed. A lower NCV of waste is typically associated with a lower fossil carbon content; therefore, each tonne processed will have lower associated carbon emissions.

This assessment has been undertaken based on the design NCV and processing capacity of RRRF, which is currently 30.348 tph for each of the three lines and will increase to 34.597 tph following the implantation of ROP. It is assumed that the RRRF operates for 8,190 hours in a year, to give a future waste throughput of 850,000 tpa.

Table 1 below shows the characteristics of the assumed waste composition that are relevant to the Carbon Assessment.

Table 1: Waste characteristics

Case	Carbon content (% mass)	Biocarbon (% carbon)	NCV (MJ/kg)	Waste throughput (tpa)
Future	26.27	59.31	9.6	850,000
Current	26.27	59.31	9.6	745,605

Waste composition data has been taken from monitoring data from the RRRF which was published as part of a previous carbon emission assessment for the RRRF[1]. This waste has a NCV of 9.85 MJ/kg. Therefore, the NCV has been adjusted to 9.6 MJ/kg by removing a small quantity of plastics to reflect reductions in plastic usage. The sensitivity of the assessment to different waste compositions has been considered in section 4.3.

3.1.2 Direct Emissions

The combustion of waste generates direct emissions of carbon dioxide, with the tonnage determined using the carbon content of the waste.

Carbon from biogenic sources (e.g. paper and wood) has a neutral carbon burden; therefore, this Carbon Assessment only considers carbon dioxide emissions from fossil sources (e.g. plastics). The biogenic material in the residual waste processed at RRRF is considered to be 'waste' material. This means that there is no requirement to consider, for example, any land use implications in producing the biogenic material as, unlike energy crops which are grown for combustion, biogenic waste already exists.

The UK Government's document "Energy from Waste: A Guide to the Debate" states, in paragraph 40, *"Considering the energy from waste route, if our black bag of waste were to go to a typical combustion-based energy from waste plant, nearly all of the carbon in the waste would be converted to carbon dioxide and be released immediately into the atmosphere. Conventionally the biogenic carbon dioxide released is ignored in this type of carbon comparison as it is considered 'short cycle', i.e. it was only relatively recently absorbed by growing matter. In contrast, the carbon dioxide released by fossil-carbon containing waste was absorbed millions of years ago and would be newly released into the atmosphere if combusted in an energy from waste plant."* For landfill, paragraph 42 states *"Burning landfill gas produces biogenic carbon dioxide which, as for energy from waste, is considered short cycle."* Therefore, the carbon assessment is in line with government guidance for exactly this type of carbon assessment.

It has been assumed that all of the carbon in the waste fuel is converted to carbon dioxide in the combustion process as, according to Volume 5 of the Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, it can be assumed that waste incinerators have combustion efficiencies of close to 100%. The mass of fossil derived carbon dioxide produced is 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:

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

Where Mr = molecular weight. The total fossil derived carbon emissions are presented in Table 2.

Table 2: Fossil CO_2 emissions

Item	**Unit**	**Future**	**Current**
Fossil carbon in input waste	t C	90,857	79,699
Fossil derived carbon dioxide emissions	**t CO_2**	**333,143**	**292,229**

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[1] https://www.coryenergy.com/carbon-efficiency/less-carbon/

The process of recovering energy from waste releases a small amount of nitrous oxide and methane, which contribute to climate change. The impact of these emissions is reported as CO_2e emissions and is 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 are also influenced by flue gas treatment systems and the types of reagents used. These details are based on the final design of the ERF, which is not available at this stage. Therefore, default emission factors from the IPCC have been used to determine the emissions of these gases, as shown in Table 3.

Table 3: N_2O and CH_4 assumptions

Item	Unit	Value	Source
N_2O default emissions factor	kg N_2O/tonne waste	0.03823	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, using a NCV of 9.6 MJ/kg.
CH_4 default emissions factor	kg CH_4/tonne waste	0.28673	
GWP – N_2O to CO_2	kg CO_2e/kg N_2O	298	United Nations Framework for Climate Change Global Warming Potentials, from IPCC AR4 (2007).
GWP – CH_4 to CO_2	kg CO_2e/kg CH_4	25	

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. Table 4 shows the emissions of nitrous oxide and methane and the equivalent carbon dioxide emissions.

Table 4: N_2O and CH_4 emissions

Item	Unit	Future	Current
N_2O emissions	t N_2O	32.5	28.5
Equivalent CO_2 emissions	**t CO_2e**	**9,684**	**8,494**
CH_4 emissions	t CH_4	243.7	213.8
Equivalent CO_2 emissions	**t CO_2e**	**6,093**	**5,345**

RRRF is equipped with auxiliary burners which burn gasoil and have a capacity of about 60% of the boiler capacity, or 145.67 MWh. These would only be used for start-up and shutdown. It has been assumed that there would be 6 start-ups a year, which is a conservative assumption, and that the burners would operate for 18 hours total for start-up and shut down. Hence, the approximate total fuel consumption would be:

$$145.67 \times 6 \times 18 = 15{,}732\ MWh$$

Each MWh of gasoil releases 0.25[2] tonnes of carbon dioxide, so the emissions associated with auxiliary firing would be 15,732 x 0.25 = 3,933 t CO_2e.

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[2] DEFRA – Greenhouse gas reporting: Conversion factors 2019

Table 5 shows the total direct equivalent carbon dioxide emissions for the combustion of waste in the RRRF.

Table 5: Total equivalent CO_2 emissions from the combustion of waste

Item	Unit	Future	Current
CO_2 emissions	t CO_2	333,143	292,229
N_2O emissions	t CO_2e	9,727	8,532
CH_4 emissions	t CO_2e	6,120	5,368
Burner emissions	t CO_2e	3,933	3,933
Total emissions	**t CO_2e**	**352,923**	**310,062**

3.1.3 Grid Offset

Sending electricity to the grid offsets the carbon burden of producing electricity using other methods. In the case of an energy from waste plant, such as the RRRF, the displaced electricity would be the marginal source which is currently gas-fired power stations, for which the displacement factor is 0.371 t CO_2e/MWh[3]. Electricity generated by RRRF is exported to the National Grid.

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 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 as a comparator. In the recent decision letter on the Development Consent Order for the adjacent Riverside Energy Park (REP) (ref. EN010093, dated 9 April 2020), the Secretary of State said in paragraph 4.12 that "CCGT is the appropriate counterfactual against which the Development should be assessed." This supports the approach taken in this carbon assessment.

It is important to understand why this is the case. Cory considers that operating RRRF has and will have no effect on how nuclear, wind or solar plants operate. If a nuclear plant is built it will run all the time, as the marginal operating costs are low. Wind and solar plants run whenever they can, as their marginal operating costs are even lower and they are supported by generous subsidies in many cases which RRRF is not eligible to receive.

It is worth noting that energy from waste facilities have been bidding into the capacity market, where they are competing with, primarily, CCGTs, gas engines and diesel engines. The capacity market has developed over the last few years, with the first delivery year starting on 1 October 2017. The net effect is that electricity from energy from waste facilities, such as RRRF, is most likely to displace generation from CCGTs, gas engines and diesel engines. This means that CCGT is the correct comparator.

The Department for Business Energy and Industrial Strategy (DBEIS) publish fuel mix tables which identify the quantities of carbon dioxide equivalents from the combustion of different fuel types. The Fuel Mix Disclosure data table dated 01 April 2019 to 31 March 2020 states that carbon dioxide emissions from the combustion of natural gas to generate power are 371 g/kWh.

Therefore, for the purposes of this assessment, it is assumed that power generated by RRRF will displace power from a CCGT and that the carbon dioxide emissions from a CCGT power station is equivalent to 371 g/kWh (or 0.371 t/MWh).

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[3] DEFRA – Fuel Mix Disclosure Table – 01/04/2019 – 31/03/2020

It is acknowledged that the UK government has recently set a target which will require the UK to bring all greenhouse gas emissions to net zero by 2050. Taking this into consideration, in the future it is anticipated that the power which the ERF will generate will displace other forms of power generation, including renewable energy power stations. However, at this stage the mix of future generation capacity additions to the grid that might be displaced by the project is uncertain, and the emissions intensity of future displaced generation cannot be accurately quantified. Therefore, for the purposes of this assessment, it has been assumed that RRRF will displace a gas fired power station as this is considered a reasonable comparator.

The effect of changing the grid offset displacement factor has been considered as a sensitivity in Section 4.2.

RRRF also has the ability to export heat. We have excluded this from the assessment, as the optimisation programme does not change this ability.

The amount of carbon dioxide offset by the electricity generated by RRRF is calculated by multiplying the net electricity generated by the grid displacement factor.

In the base case, the RRRF generates around 72.3 MWe and exports around 65.73 MWe of power, giving a net electrical efficiency of 27.02%. Following implementation of ROP, RRRF will generate 83.93 MWe and export 76.64 MWe, giving a net electrical efficiency of 27.64%.

The carbon dioxide offset by electricity generation is counted as a carbon benefit and is shown in Table 6.

Table 6: RRRF electricity offset

Item	Unit	Future	Current
Net electricity export	MW	76.64	65.73
Net electricity exported	MWh	627,643	538,296
Total CO_2 offset through export of electricity	**tCO_2e p.a.**	**232,856**	**199,708**

3.2 Landfill

For waste which is disposed of in landfill, the biogenic carbon degrades and produces 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.

In this section, we have considered the emissions associated with the additional 104,392 tonnes of waste which would be diverted from landfill.

3.2.1 Emissions

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. This is calculated as follows:

1. The biogenic carbon in the waste comes from the waste composition, discussed in section 3.1.1 above.
2. 50% of the degraded biogenic carbon is released and converted into LFG. The released carbon is known as the degradable 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' (2014).
    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. Therefore, it is not considered appropriate to give additional credit for sequestered carbon as this would result in an overly conservative assessment.
3. LFG is made up of 57% methane and 43% carbon dioxide, based on a detailed report carried out by Golder Associates for DEFRA[4].
4. Based on the same report, the analysis assumes 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.
5. Based on the same guidance, 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.

Table 7 outlines the LFG assumptions and Table 8 shows the equivalent carbon emissions associated with landfill.

Table 7: LFG assumptions

Item	Value	Source
DDOC content	50%	DEFRA Review of Landfill Methane Emissions Modelling (WR1908) (2014)
CO_2 percentage of LFG	43%	
CH_4 percentage of LFG	57%	
LFG recovery efficiency	68%	
Molecular ratio of CH_4 to C	1.33	Standard Values
Molecular ratio of CO_2 to CH_4	2.75	
Molecular ratio of CO_2 to C	3.67	
Global Warming Potential – CH_4 to CO_2	25	United Nations Framework for Climate Change Global Warming Potentials

Table 8: LFG emissions

Item	Unit	Additional Waste Landfilled
Biogenic carbon	tonnes	16,267

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

Item	Unit	Additional Waste Landfilled
Total DDOC content (biogenic carbon not sequestered – degradable)	tonnes p.a.	8,133
Methane in LFG, of which:	tonnes p.a.	6,181
- Methane captured	tonnes p.a.	4,203
- Methane oxidised in landfill cap (capping material)	tonnes p.a.	198
- Methane released to atmosphere directly	tonnes p.a.	1,780
Methane leakage through LFG engines	tonnes p.a.	58
Total methane released to atmosphere	tonnes p.a.	1,838
CO_2e released to atmosphere	**tCO_2e p.a.**	**45,955**

The value for biogenic carbon in Table 8 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.

3.2.2 Grid Offset

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 as per section 3.1.3. The assumptions for the amount of LFG methane captured and used in a typical LFG engine are shown in Table 9.

Table 9: 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 LFG Engines	90.9%	
Methane leakage through LFG engines	1.5%	
LFG engine efficiency	36%	
Methane net calorific value	47 MJ/kg	Standard value

The power produced by combustion of LFG in an engine is based on the amount of methane in the LFG, the energy content of methane and the engine efficiency, as per the assumptions set out in Table 9. The power generated by the LFG engines and the carbon dioxide offset are shown in Table 10.

Table 10: LFG grid offset

Item	Unit	ERF – Base case
Methane captured, of which:	tonnes p.a.	4,203
- Methane flared	tonnes p.a.	336
- Methane leakage through LFG engines	tonnes p.a.	58
- Methane used in LFG engines	tonnes p.a.	3,809
Fuel input to LFG engines	GJ	190,450
Power generated	MWh	19,045
Total CO_2e offset through grid displacement	**t CO_2e p.a.**	**7,066**

3.3 Transport

The additional waste to be processed by RRRF would be transported to site by river. This is because there is no proposal to increase the current limit on waste deliveries by road. Similarly, the IBA would continue to be transported away from the site by river and so the only additional road transport would be for the removal of APC residues.

For the landfill base case, it is assumed that all of the additional waste which would be processed at the RRRF would otherwise be transported by road to landfill using articulated lorries, travelling 70km, and that these lorries would return empty.

Table 11: Transport Assumptions

Parameter	Unit	Value	Source
Articulated lorry load size	t	20	Operator information
Articulated Lorry CO2 Factor - 100% Loaded	kg CO2/km	0.96235	Department for Business , Energy and Industrial Strategy (BEIS) "Greenhouse gas reporting: conversion factors 2020"
Articulated Lorry CO2 Factor - 0% Loaded	kg CO2/km	0.64607	BEIS "Greenhouse gas reporting: conversion factors 2020"
Road transport distance, APCr	km	140	Distance to Brandon, Suffolk
River transport fuel consumption	l/t	1.6	RRRF Carbon report
GHG emission factor for marine gas oil	kg CO2e/litre	2.7754	BEIS "Greenhouse gas reporting: conversion factors 2020"

The carbon burden of transporting the waste is determined by calculating the total number of loads required and multiplying it by the transport distance to generate an annual one-way vehicle distance. This is multiplied by the respective empty and full carbon dioxide factor for HGVs to determine the overall burden of transport. It is recognised that this is conservative, as it may be possible to coordinate HGV movements to reduce the number of trips.

Table 12 – Transport calculations - landfill

Parameter	Unit	Additional waste
Waste throughput	t	104,392
Number of loads (20 t per load)		5,220
Total vehicle distance (70 km each way)	km	365,400
GHG emissions, transport to landfill	**t CO_2e**	**588**

Table 13 – Transport calculations - RRRF

Parameter	Unit	Additional waste
APCr transported by road	t	3,862
Number of loads (20 t per load)		194
Total vehicle distance (140 km each way)	km	27,160
GHG emissions	**t CO_2e**	**44**
Waste transported by river to RRRF	t	104,392
IBA transported by river from RRRF	t	25,054
Marine oil required (1.6 l/t transported)	l	207,113
GHG emissions	**t CO_2e**	**575**
Total GHG emissions for RRRF transport	**t CO_2e**	**619**

4 Results

4.1 Base Case

The results of the assessment are shown below. It can be seen that there is a net carbon benefit of **29,146 carbon dioxide equivalent emissions per annum** for the additional waste processed at RRRF.

Table 14: Summary

Parameter	Units	Change
Releases from LFG	t CO_2e	45,955
Transport of waste and outputs to landfill	t CO_2e	588
Offset of grid electricity from LFG engines	t CO_2e	-7,066
Total landfill emissions	**t CO_2e**	**39,477**
Transport of waste to and outputs from RRRF	t CO_2e	619
Offset of grid electricity with RRRF generation	t CO_2e	-33,148[5]
Emissions from RRRF	t CO_2e	42,861[6]
Total RRRF Emissions	**t CO_2e**	**10,331**
Net Benefit of additional waste processed at RRRF.	**t CO_2e**	**29,146**

Another way of expressing the benefit of the additional processing capacity at RRRF is to consider the additional power generated by recovering energy rather than sending the waste to landfill and calculating the effective net carbon emissions per MWh of additional electricity exported.

The effective net carbon emissions per MWh of additional electricity exported for RRRF is calculated as follows:

1. Additional power exported = 627,643 – 538,296 – 19,045 = 70,302 MWh
2. Net Carbon released = (42,861 + 619) – (45,955 + 588) = -3,064 tCO_2e
3. Effective carbon intensity = -3,064 ÷ 70,302 = -0.043 t CO_2e/MWh

Hence, it can be seen that the overall effect of the increased waste throughput at RRRF would be to generate an additional 70,302 MWh of power with an effective carbon intensity below zero.

4.2 Sensitivities

The two key assumptions in this Carbon Assessment are the grid displacement factor for electricity and the LFG capture rate.

- There is some debate over the type of power which would be displaced. It has been suggested by others that the long-run marginal generation-based emissions factor should be used. While the Applicant does not accept this position, the effect of varying this value is presented below by using the long-run marginal figures for 2021 and 2025[7] and the effect of using lower figures

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[5] Difference between 232,856 offset for the future case and 199,708 for the current case.

[6] Difference between 352,705 emissions for the future case and 309,844 for the current case.

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

has been considered, which would only be relevant if the RRRF were to displace other renewable sources of electricity.

- The Golders Associates report for DEFRA states that the collection efficiency for large, modern landfill sites was estimated to be 68% and the collection efficiency for the UK as a whole was estimated to be 52%. There have been suggestions in other guidance that a conservative figure of 75% should be used. The sensitivity of the results to this assumption has also been assessed.

Table 15 shows the estimated net benefit of processing additional waste in the RRRF, in tonnes of carbon dioxide equivalent emissions per annum, for different combinations of grid displacement factor and LFG capture rate.

It can be seen that there is a benefit for all LFG capture rate and grid displacement factor combinations.

Table 15: Sensitivity analysis

Grid Displacement Factor (t CO_2e/MWh)	**LFG Capture Rate**			
	75%	**68%**	**60%**	**52%**
0.371	18,832	**29,146**	40,933	52,720
0.258	11,110	21,202	32,736	44,269
0.205	7,488	17,476	28,891	40,306

We also note that we have used global warming potential figures from the IPCC fourth Assessment Report (2007), as these are used for national reporting. However, the figures were updated in the fifth Assessment Report (2013) from 298 to 265 for nitrous oxide and from 25 to 28 for methane. These could be considered to present the latest scientific view. Using these figures for GWP, the benefit of processing additional waste in RRRF increases by around 5,000 tCO_2e in the base case and by around 4,500 tCO_2e in the most conservative sensitivity case.

4.3 Changes in Waste

The actual waste to be processed in RRRF may change over time. Therefore, the effect of three different waste compositions has been considered:

1. REP Design waste – this has a NCV of 9 MJ/kg.
2. Reduced food – this is based on RRRF waste but with 50% of the putrescible waste removed to take account of a significant increase in separate collection of food and garden waste. The NCV in this scenario is 10.79 MJ/kg.
3. Future waste – this is also based on RRRF waste but with 50% plastics, 50% food and 20% metals removed to model a significant increase in source segregation. The NCV in this scenario is 9.56 MJ/kg.

The waste data for these three cases, along with the base case, is shown below. With different waste NCV, there are a number of different constraints on the plant capacity.

1. REP Design waste and Future Waste – As the NCV is lower, RRRF could process more waste but the processing capacity is limited by the planning limit of 785,000 tpa currently. This also means that the power generation in these cases is a little lower than in the base case.
2. Reduced food – As the NCV is higher, the processing capacity is limited by the thermal capacity.

Table 16: Waste Sensitivity inputs

	RRRF Design	REP Design	Reduced Food	Future Waste
Net Calorific Value (MJ/kg)	9.6	9.0	10.79	9.56
Carbon Content	26.27	25.18	28.65	26.49
Biocarbon content	59.31	64.58	54.05	64.92
Current Throughput (tpa)	745,605	785,000	663,237	748,917
Future Throughput (tpa)	850,000	850,000	756,096	850,000

Table 17: Waste Sensitivity results

Parameter	Units	RRRF Design	REP Design	Reduced Food	Future Waste
Releases from LFG	t CO_2e	45,955	29,865	40,622	49,119
Transport of waste and outputs to landfill	t CO_2e	588	366	523	569
Offset of grid electricity from LFG engines	t CO_2e	-7,066	-4,592	-6,246	-7,552
Total landfill emissions	**t CO_2e**	**39,477**	**25,639**	**34,899**	**42,136**
Transport of waste to and outputs from RRRF	t CO_2e	619	444	550	604
Offset of grid electricity with RRRF generation	t CO_2e	-33,148	-21,185	-33,148	-32,119
Emissions from RRRF	t CO_2e	42,861	22,396	46,775	36,325
Total RRRF Emissions	**t CO_2e**	**10,331**	**1,655**	**14,177**	**4,810**
Net Benefit of additional waste processed at RRRF	**t CO_2e**	**29,146**	**23,985**	**20,722**	**37,326**

It can be seen that there is a net benefit of processing additional waste in all cases.

4.4 Lifetime carbon benefit and Grid displacement sensitivity analysis

The benefits discussed within this assessment all relate to a single year. Within the analysis below, it is assumed that RRRF will continue to operate for a further 20 years. Therefore, the carbon benefits will accumulate over time; however, the annual benefits will also vary over time as a number of key assumptions will vary.

In this section, we have considered the lifetime benefits of ROP on an illustrative basis. We have varied a number of assumptions over time, described as follows:

1. The government's policy is to decarbonise grid electricity. The government has recently set a target to bring all greenhouse gas emissions to net zero by 2050. This means that the benefit of displacing electricity will reduce. As explained in section 3.1.3, it is considered that the correct comparator at present is CCGTs and that this will remain the case for some time. However, for

illustrative purposes we have used the long run marginal generation-based emission factors[8]. These are only relevant if the Facility were to displace other renewable sources of electricity, and are considerably more conservative, starting at 0.258 kg CO2e/kWh in 2021 and dropping to 0.03734 kg CO2e/kWh by 2040.

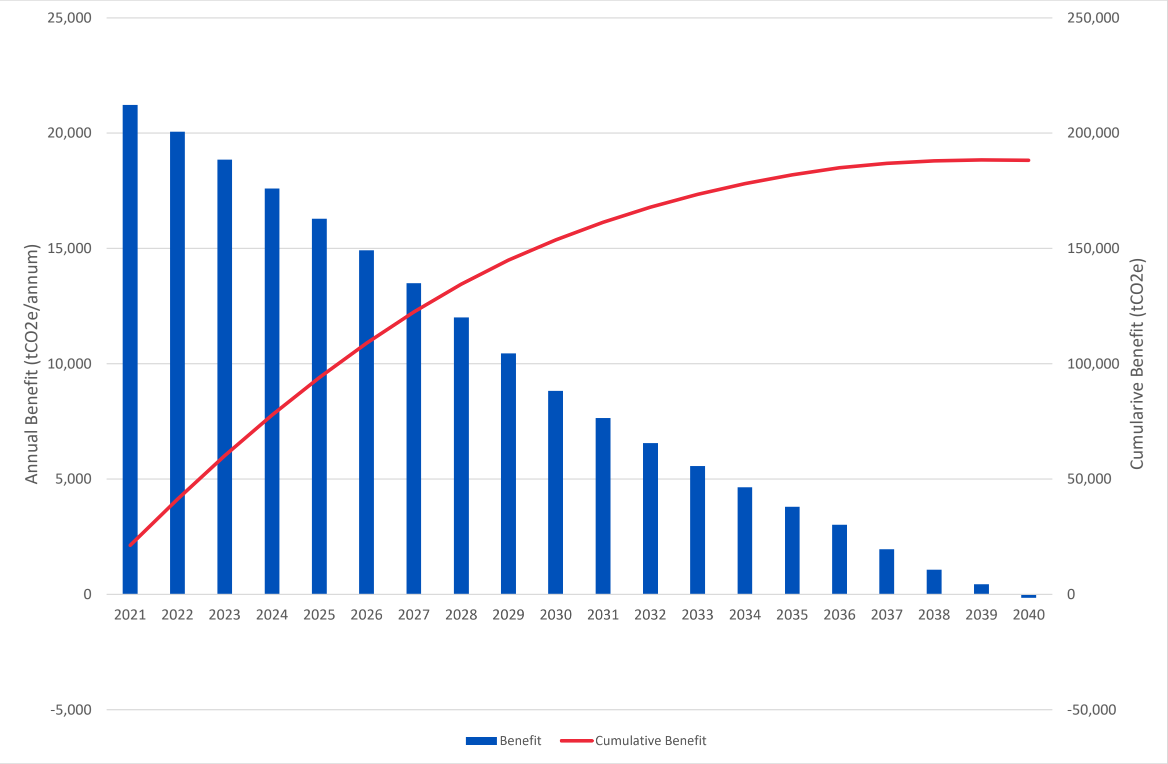
2. Waste composition will vary over time in line with government strategy, which aims to reduce the amount of both plastics and food waste in residual waste. Within the scenario below, a removal rate of approximately 2% per year for plastics (up to a maximum of 30%) and 3% per year for food waste (up to a maximum of 50%) is assumed.
3. LFG recovery rates may improve as older sites are closed. We have allowed for a 0.2% improvement per year, starting at 68% in 2021 and ending at 72% in 2040.

The net benefit of ROP each year compared to landfill, and the cumulative benefit of ROP over time, are illustrated in the figure below.

Applying these assumptions, the cumulative benefit of ROP over 20 years operation of RRRF is estimated to be approximately **188,000 tCO_2e**. In addition, the figures below indicate that ROP will continue to have an annual net benefit over landfill throughout its operational lifetime, with the exception of 2040.

The analysis is based on the conservative assumption that the Facility displaces power at the long run marginal rate (which the Applicant does not consider to be correct) and the actual benefit is expected to be higher.

Figure 1: Lifetime Assessment



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[8] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, BEIS, 2020

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