GP PLANNING LTD

APPENDICES TO PROOF OF EVIDENCE

MAUREEN DARRIE BSc (Hons) MRTPI

APPEAL BY BRITANIACREST RECYCLING LIMITED

PINS REF: APP/P3800/W/18/321965
LPA REF: WSCC/015/18/NH

OCTOBER 2019

APPENDICES PROOF OF EVIDENCE Appeal by Britaniacrest Recycling Ltd Land at former Wealden Brickworks PINS Ref – APP/P3800/W/18/3218965 LPA Ref – WSCC/015/18/NH		
Land at Wealden Brickworks	NI4H	H008-01

Revision	Comments	Author	Date
1	FINAL	MD	1st October 2019

APPENDIX A: Evaluation of the Climate Change Impacts of the Energy from Waste Plant Proposed for Wealden Brickworks, Horsham – Only Solutions September 2019

REPORT PREPARED FOR THE NO INCINERATOR 4 HORSHAM (NI4H) COMMUNITY GROUP BY ONLY SOLUTIONS LLP TO INFORM A PUBLIC INQUIRY

Appeal by Britaniacrest Recycling Ltd

Site Address: Former Wealden Brickworks, Langhurst Wood Road, Horsham, RH12 4QD

EVALUATION OF THE CLIMATE CHANGE IMPACTS OF THE ENERGY FROM WASTE PLANT PROPOSED FOR WEALDEN BRICKWORKS, HORSHAM

PINS Reference: APP/P3800/W/18/3218965

September 2019

TABLE OF CONTENTS

1. BACKGROUND, SUMMARY AND CONCLUSIONS

1. Only Solutions LLP is an environmental consultancy, comprising three partners with combined experience of more than four decades in the resources and waste management sector. Our clients include community-based groups, local authorities and national-level environmental, non-profit making organisation. This report has been prepared for the No Incinerator 4 Horsham (NI4H) community group by Messrs Josh and Shlomo Dowen.

2. Only Solutions has assessed the anticipated climate change impacts of the Energy from Waste (EfW) plant proposed by Britaniacrest Ltd (the Appellant) for Wealden Brickworks, Horsham.

3. This assessment is more comprehensive than the assessment set out in UKWIN's April 2018 objection on climate change grounds (which was also based on work undertaken by Only Solutions LLP).

4. This report adopts the same system boundary for calculating relative net greenhouse gas emissions as that adopted by the Appellant in terms of considering process emissions, transport emissions and avoided CO_2 emissions but not other elements outside of their boundary such as missed recycling opportunities.

5. This report addresses a number of deficiencies and inconsistencies observed in the Appellant's carbon assessment that impact upon the process emissions and/or the avoided CO_2 emissions, including:

   a) The Appellant's claimed waste feedstock composition being inconsistent with the Appellant's claimed level of energy export, which itself differs between the Appellant's two carbon assessments (21 MW) and the Appellant's Statement of Case (18 MW)[1] (which impacts upon both the process emissions and the avoided CO_2 emissions);

[1] Paragraph 5.3.6 of the Appellant's 2016 Carbon Assessment, which is included as Appendix 2.3 of Volume 3 of their Environmental Statement refers to: "…21 MW recovered as electricity and exported to the grid" whereas Paragraph 3.3 of the Appellant's Statement of Case refers to: "…approximately 18 MW would be available for export to the National Grid, with the remainder used by the facility itself". As shown in Table 21 below, the Appellant's claimed benefits with respect to displaced electricity are based on 21 MW rather than 18 MW in both their original 2016 Carbon Assessment and their August 2019 update.

b) The Appellant's claimed carbon savings from energy export being inconsistent with Government guidelines with respect to the correct counterfactual[2] to use in these circumstances (which impacts upon the avoided CO_2 emissions figures); and

c) The Appellant's failure to adequately account for the relative net greenhouse gas (GHG) impacts of biogenic carbon sequestration[3] in landfill (which impacts upon the avoided CO_2 emissions on the landfill side of the equation).

6. Paragraph 3.3 of the Appellant's Statement of Case claims that: *"The combustion of residual waste by the Proposed Development will generate an estimated 21 megawatts (MW) of electricity per annum. Of this, approximately 18 MW would be available for export to the National Grid, with the remainder used by the facility itself"*.

7. As such, Only Solutions' assessment adopts a primary feedstock composition profile that is consistent with the Appellant's claimed 18 MW of electrical export. However, the Appellant's waste composition profile set out in Table 1 of the Appellant's 2016 Carbon Assessment (to be found at Appendix 2.3 of the Appellant's Environmental Statement) would result in an electrical output of only around 13.65 MW (despite the fact that according to Paragraph 5.6.3 of their 2016 Carbon Assessment they claim that their assessment is based on *"…21 MW recovered as electricity and exported to the grid…"*).

8. This report sets out estimates of the direct fossil CO_2 emissions that would arise from the proposed EfW plant, the carbon intensity of the electricity that would be generated and the relative net GHG emissions of the proposal compared with sending the same waste (untreated) to landfill (taking account of additional climate change benefits claimed by the Appellant in relation to materials recovery and reduced traffic emissions).

9. In summary, the assessment concludes that **the EfW plant proposed for the former Wealden Brickworks would emit significant quantities of fossil CO_2, the energy generated would be high carbon**, and that, if it were allowed to go ahead, **the EfW plant would result in the release of more GHG emissions than sending the same waste directly to landfill**.

[2] In this context the term 'counterfactual' is used to mean the marginal emissions factor of the energy that would be displaced by electricity exported from the proposed incinerator and/or through landfill gas capture.
[3] In this context the term 'biogenic carbon sequestration' is used to mean the permanent storage of carbon with a biogenic origin (e.g. paper and card) in the ground, also known as a 'carbon sink'.

10. The direct emissions from the proposed EfW plant relate to the CO_2 which is released as part of the combustion process. 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 assessment converts the methane released from landfill into CO_2 equivalent (CO_2e).

11. As explained in more detail later in this report, based on a feedstock composition that is consistent with the Appellant's claimed 18 MW electrical output, it is estimated that **0.4511 tonnes of CO_2 of fossil origin (e.g. plastics) would be emitted per tonne of waste treated at the proposed EfW plant** (see Table 1 and Column 10 of Table 13, below)**.**

12. This equates to **81,198 tonnes of fossil CO_2 a year**, and **more than 2.4 million tonnes of direct fossil CO_2 emissions over 30 years of operation** (see Tables 1, 4 and 16, below).

13. The term 'carbon intensity' is used to describe the quantity of CO_{2e} released per unit of energy exported to the National Grid. This report focuses on fossil carbon intensity, i.e. the CO_2 released through the burning of fossil-based materials such as plastic. Knowing the fossil carbon intensity of the energy that would be generated by the EfW plant allows comparison with the fossil carbon intensity of other forms of electricity generation.

14. The assessment estimates that **the fossil carbon intensity of the proposed EfW plant would be 563 gCO_2e/kWh** (see Paragraph 46, below), which is <u>significantly higher than the conventional use of fossil fuel</u>, meaning **the electricity that would be exported from the proposed EfW plant would not be classified as 'low carbon'** using the NPPF Glossary definition of 'low carbon energy'.[4]

15. It should be noted that the fossil carbon intensity of the electricity exported from a typical Combined Cycle Gas Turbine (CCGT) is around 340 gCO_2e/kWh[5] and that BEIS' Marginal Emission Factor (MEF) for 2023 (the presumed year for the commencement of operation) has a carbon intensity of 223 gCO_2e/kWh[6].

[4] The definition of 'Renewable and low carbon energy' on page 71 of the NPPF (February 2019) states that: "…Low carbon technologies are those that can help reduce emissions (compared to conventional use of fossil fuels)"

[5] See page 5 of Valuation of Energy Use and Greenhouse Gas Background documentation, April 2019 available from:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794738/background-documentation-guidance-on-valuation-of-energy-use-and-greenhouse-gas-emissions.pdf

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

16. As such, **the electricity that would be generated by the proposed EfW plant would hamper efforts to decarbonise the electricity supply**.

17. The assessment also concludes that, even when the benefits that arise from the recovery of metals and IBA are taken into account, the proposed EfW plant is estimated to be **49,101 tonnes of CO_2e per year** **worse than sending the same waste to landfill**, which equates to the proposed EfW plant being more than 1.47 million tonnes of CO_2e worse than landfill over 30 years of operation (see Tables 4, 16, and 17, below).

18. Only Solutions' report sets out the rationale for the approaches adopted within our assessment, and the justification for key differences in assumptions and approaches compared with those adopted by the Appellant in their 2016 Carbon Assessment.

19. As summarised above, as part of explaining the rationale for the approach applied by Only Solutions, the report highlights a number of criticisms of the Appellant's 2016 and 2019 carbon assessments with respect to internal inconsistencies and to discrepancies with Government guidance and industry best practice.

20. Only Solutions also carried out sensitivity analysis on the impact of adopting the Default feedstock assumptions from Defra's Carbon Based Modelling report and the electricity generation displacement factor (known as a MEF or GHG Factor) adopted by the Appellant in Table 3b of their August 2019 Carbon Calculation Update (see Table 5, below). This **sensitivity analysis indicates that our report's conclusions are robust**.

21. Whilst the assessment has been made on the basis that the waste would otherwise go directly (untreated) to landfill, that is not to say that the discarded material might not otherwise be bio-stabilised prior to landfill or indeed that it might be reduced, re-used, recycled or composted. Therefore, the relative CO_2 impact of sending waste to the proposed EfW plant could be significantly worse than modelled.

2. CO_2 EMISSIONS FROM PROPOSED EFW PLANT

22. The quantity of CO_2 released by through combustion of waste depends on the amount of carbon that is burned, also known as the 'feedstock's carbon content'.

23. Burning one tonne of carbon produces 3.6667 tonnes of CO_2. This is because 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 (12 + (16 × 2) = 12 + 32 = 44). From this we know that the weight of CO_2 is 3.6667 times the weight of the carbon used to create it (44 ÷ 12 = 3.6667).

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

25. Columns 8 - 10 of Table 5 (*'Data set and calculations for the energy recovery half of the model'*) of Defra's Carbon Based Approach[7] provides values for the proportion of fossil carbon within each category of waste, and from this one can calculate direct CO_2 emissions for a given feedstock.

26. Defra's approach calculates this on a per-tonne basis,[8] and this can then be multiplied to determine the CO_2 emissions that would arise from burning 180,000 tonnes of waste i.e. the baseline assumed quantity of feedstock upon which the Appellant's 2016 and 2019 carbon assessments were carried out.

27. As explained further in Annex C of this report (*'Feedstock Profiles'*), two different feedstock profiles are used in Only Solutions' assessment. The primary feedstock profile has been formulated to reflect the Appellant's anticipated electrical export of 18 MW as set out in the Appellant's Statement of Case.

28. This feedstock profile can be described as a 'Reduced Compostables' profile because it halves the quantity of food, garden and soil waste (and proportionally increases other material) relative to the default composition from Defra's Carbon Based Modelling Approach report, in order to align with the Appellant's claimed level of electricity generation.

---

[7] Energy recovery for residual waste – A carbon based modelling approach - WR1910. Defra, February 2014. http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019

[8] Paragraph 3 of 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 …"

29. The proportions of feedstock by weight and their contribution to the MW of all three feedstock profiles are set out in Table 6 below, with further calculations included in Tables 21 and 22 of Annex I (*'Calculating Electricity Output (MW) of feedstock profiles'*). The 'Defra Default' feedstock composition is derived from Table 4 of Defra's Carbon Based Modelling Approach report.

30. Such a 'Reduced Compostables' variant of the default composition from Defra's Carbon Based Modelling Approach report also has the benefit of more closely reflecting current and anticipated increases in the separate collection of compostable waste, such as food waste, in line with the Government's December 2018 Resources and Waste Strategy.

31. The second feedstock profile, which is used for sensitivity analysis in this report, is the default composition from Defra's Carbon Based Modelling Approach report.

32. The Reduced Compostables waste feedstock profile has 0.12303 tonnes of carbon per tonne of waste (i.e. a carbon content of 12.3%, as it is rounded in Column 9 of Table 13, below) which results in the release of an estimated **0.4511 tonnes of CO_2 per tonne** of waste incinerated (0.12303 × 3.6667 = 0.04511 where the 0.12303 figure is provided in the bottom row of Column 9 of Table 13 below, the 3.6667 figure represents the difference in weight between carbon and CO2 and is equivalent to 44÷12, resulting in the 0.4511 figure which is set out in the bottom row of Column 10 of Table 13 below).

33. The fossil carbon content under the Defra Default waste feedstock profile is estimated to be 0.09476 tonnes of fossil carbon per tonne of waste (i.e. a carbon content of 9.48%, as set out in Column 9 of Table 8), which results in the release of an estimated **0.3475 tonnes of CO_2 per tonne** of waste incinerated (0.09476 × 3.6667 = 0.3475, with the 0.9476 being rounded to 0.0948 in the bottom row of Column 9 of Table 8 below, and 0.3475 being set out in Column 10 of the bottom row of Table 8).

34. For reasons explained in Annex C (*'Feedstock Profiles'*) below, the feedstock composition set out in Table 1 of the Appellant's 2016 Carbon Assessment (which is also used in the Appellant's August 2019 Updated Carbon Assessment) is not a useful basis for assessing the climate change impact of the proposal because there are significant discrepancies between the level of electricity generation that the Appellant claims within their Statement of Case and the level of electricity generation that was implied by their 2016 Feedstock Assumptions (associated with a previous planning application).

35. The quantity of electricity exported relates to the energy content in the waste (its 'calorific value' or 'CV') alongside the efficiency at which the incinerator can convert that energy into electricity, net of any electricity that is required to power the incineration process (known as the 'parasitic load').

36. The method used to determine the efficiency of the proposed EfW plant is set out in Annex B (*'Incinerator Efficiency'*), and the carbon intensity of what is being displaced per unit of electricity generated is explained in Annex D (*'Marginal Emissions Factor (MEF)'*).

37. The method used in this assessment to determine the quantity of energy contained within different types of waste is to use the Government's figures set out within Column 2 of Table 5 (*'Data set and calculations for the energy recovery half of the model'*) of Defra's Carbon-Based Modelling Approach report.

38. Based on BEIS' marginal emissions factor (MEF) for 2023, the earliest year that the proposed EfW plant is likely to be operational, one MWh of electricity from the Horsham incinerator would displace **0.233 tonnes of CO_2** that would be released from electricity generated by a mix of other means (see '*Table 7: BEIS Data Table 1 ('Electricity Emissions Factors To 2100'), Extract (March 2019)*', below).

39. Under the Reduced Compostables feedstock profile, **0.8014 MWh of electricity** is estimated to be exported to the grid (as per Column 4 of Table 13, below), and this would displace **0.1867 tonnes of CO_2** (0.8014 × 0.233 = 0.1867262).

40. Similarly, using the Defra Default feedstock profile, the Horsham EfW is estimated to displace, i.e. export, **0.7028 MWh of electricity to the grid for each tonne of waste incinerated** (as per Column 4 of Table 8, below). This means the Horsham EfW would displace **0.1637 tonnes of CO_2 per tonne of waste treated** (0.7028 × 0.233 = 0.1637524).

Table 1. Direct and net CO_2 based on Reduced Compostables feedstock profile

Value	Per tonne	Per year (×180,000)	Over 30 years (×30)
Tonnes of fossil CO_2 released by the EfW plant (Direct emissions)	0.4511	81,198	2,435,940
Fossil CO_2 from electricity offset (Displaced emissions)	-0.1867	-33,606	-1,008,180
Net fossil CO_2 released by EfW plant	0.2644	47,592	1,427,760

Table 2. Direct and net fossil CO_2 based on Defra Default feedstock profile

Value	Per tonne	Per year (×180,000)	Over 30 years (×30)
Tonnes of fossil CO_2 released by the EfW plant (Direct emissions)	0.3475	62,550	1,876,500
Fossil CO_2 from electricity offset (Displaced emissions)	-0.1637	-29,466	-883,980
Net fossil CO_2 released by EfW plant	0.1837	33,084	992,520

3. CARBON INTENSITY OF ENERGY GENERATED

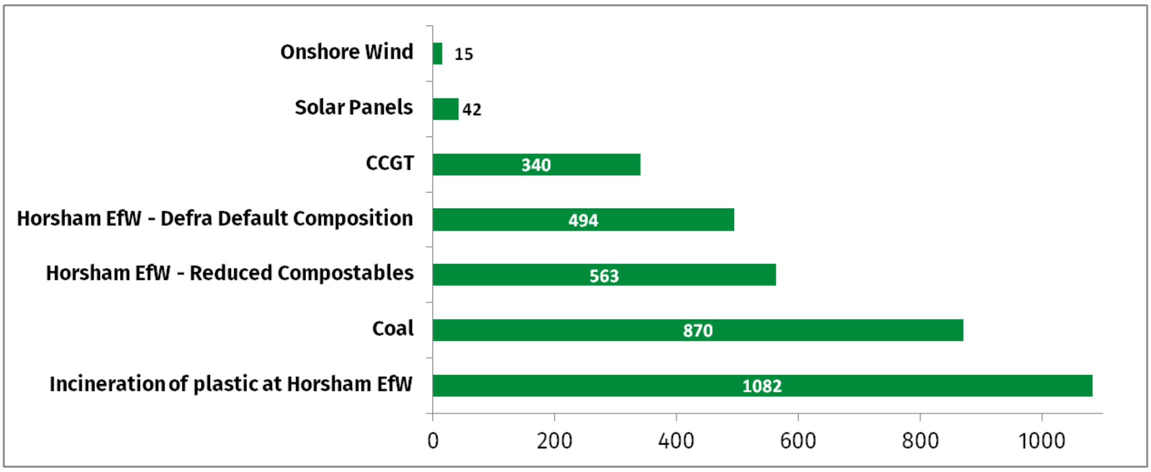
41. The term 'carbon intensity' is used to describe the quantity of CO_2 released per unit of energy exported to the grid.

42. This report focuses on fossil carbon intensity, i.e. the CO_2 released through the burning of fossil-based materials such as plastic.

43. To be consistent with the approach taken by the Appellant (e.g. as set out at Paragraph 3.6.3 of the Appellant's 2016 Carbon Assessment, included as Appendix 2.3 of the Appellant's Environmental Statement), this report does not focus on the additional CO_2 released through the burning of biogenic materials, such as food waste.

44. Knowing the fossil carbon intensity of the energy that would be generated by the EfW plant proposed for Horsham allows comparison with the fossil carbon intensity of other forms of energy generation, including energy generated through the conventional use of fossil fuel.

FIGURE 1. FOSSIL CARBON INTENSITY OF ELECTRICITY SOURCES (GCO2/KWH)



45. As set out above in Section 2 ('*CO_2 Emissions from Proposed EfW Plant*') above, using the Reduced Compostables feedstock profile it can be estimated that for each tonne of waste incinerated 0.4511 tonnes of fossil CO_2 would be released and 0.8014 MWh of electricity would be exported to the grid.

46. From this, it can be determined that the energy exported from the Horsham EfW plant would have a fossil carbon intensity of 0.563 tonnes of CO_2 per MWh of electricity (0.4511 ÷ 0.8014 = 0.5628899 (rounded up to 0.563), with 0.8014 and 0.4511 coming from the bottom row of columns 4 and 10 respectively of Table 13 below). This is equivalent to **563 gCO2e/kWh**.

47. Similarly, using the Defra Default feedstock profile it can be estimated that for every tonne of waste incinerated 0.3475 tonnes of fossil CO_2 is released (as per Column 10 of the bottom row of Table 8, below) and 0.7028 MWh of electricity is exported to the grid (as per Column 4 of Table 8, and Column 4 of Table 23, below).

48. From this, it can be determined that the energy exported from the Horsham EfW plant would have a fossil carbon intensity of 0.494 tonnes of CO_2 per MWh of electricity (0.3475 ÷ 0.7028 = 0.4944507, with 0.7028 and 0.3475 coming from the bottom row of columns 4 and 10 respectively of Table 8 below). This is equivalent to **494 gCO_2e/kWh**.

49. Based on the estimated year of commissioning, the BEIS marginal emissions factor used for comparison is the long-run marginal generation-based electricity emissions factor for 2023.[9]

50. This is explained in further detail in Annex D (*'Marginal Emissions Factor (MEF)'*). The long-run marginal generation-based electricity emissions factor for 2023 is 0.233 $kgCO_2/kWh$ which is equivalent to **233 gCO_2e/kWh**.

51. As set out above, the energy that would be exported by the EfW plant proposed for Horsham is estimated to have a carbon intensity of **563 gCO2e/kWh**, meaning that the energy would come with a significantly higher carbon intensity than the electricity it would be displacing, thus hampering efforts to decarbonise the electricity supply.

52. The National Planning Policy Framework (NPPF) states that: *"Low carbon technologies are those that can help reduce emissions (compared to conventional use of fossil fuels)"*.[10] (emphasis added)

53. Because the carbon intensity associated with the proposed EfW plant is significantly higher than the conventional use of fossil fuel **the energy that would be generated by the proposed EfW plant would not be classified as 'low carbon' using the NPPF Glossary definition of 'low carbon energy'**.

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

10 Pages 70 and 71 of the February 2019 version of the National Planning Policy Framework, available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/810197/NPPF_Feb_2019_revised.pdf

54. The conventional use of fossil fuel is associated with the use of gas in a typical Combined Cycle Gas Turbine (CCGT), which according to the Department for Business, Energy and Industrial Strategy (BEIS) has a carbon intensity of 0.340 $kgCO_2e/kWh$ which is equivalent to **340 gCO_2e/kWh**.[11]

55. As such, whether using the long-run marginal emissions factor (MEF) or the conventional use of fossil fuels as the comparator, the proposed facility would generate electricity with a high carbon intensity.

56. Electricity exported from the incineration of plastics at the proposed EfW can be estimated to have a carbon intensity of **1,082 gCO_2/KWh** (i.e. more than 1 tonne of CO_2 per kilowatt hour). This is significantly higher than the fossil carbon intensity of burning coal, which is 870 gCO_2/KWh.

57. The figure of 1,082 gCO_2/KWh for the incineration of plastic as shown within Figure 1 above is derived from data contained within Table 4 ('*Carbon content and calorific value by merged waste stream categories*') of the Defra Carbon Based Modelling Approach report.

58. The Calorific Value (CV) of plastic, expressed as MWh/t, is multiplied by 25%.

59. The 25% overall GCV (gross calorific value) efficiency figure is based on an optimistic assumption for the anticipated efficiency of the proposed Horsham EfW plant, and is equivalent to a 30% overall NCV (net calorific value) efficiency as explained in Annex B ('*Incinerator Efficiency*').

60. The carbon is converted into CO_2 by multiplying the figure by 3.6667 to take account of the additional weight of the added oxygen. The values are then converted into gCO_2/kWh.

61. Table 4 of the Defra Carbon Based Modelling Approach report provides the figure of 0.52 for the proportion of fossil carbon in plastic (in column 4), and a figure of 7.05 MWh/t for the calorific value for plastic (in column 6). Thus, if we assume 25% (0.25) conversion efficiency, it can be calculated that 1.7625 MWh is exported per tonne of plastic feedstock (because 7.05 × 0.25 = 1.7625), and 1.906684 tonnes of fossil CO2 is released per tonne of plastic feedstock (because 0.52 × 3.6667 = 1.906684).

[11] See page 5 of Valuation of Energy Use and Greenhouse Gas Background documentation, April 2019 available from:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794738/background-documentation-guidance-on-valuation-of-energy-use-and-greenhouse-gas-emissions.pdf

62. Therefore, the carbon intensity of the electricity exported from the incineration of plastics at the Horsham incinerator can be estimated to be 1.0818065 tonnes of fossil CO2 per MWh (because 1.906684 ÷ 1.7625 = 1.0818065), and this can be expressed as 1,082 gCO2/KWh.

63. 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 geothermal, hydropower, nuclear, solar, or wind.[12]

64. As such, based on the methodology used to assess the fossil carbon intensity from incinerators, the direct emissions arising from energy generated by genuinely low carbon sources such as wind and solar could be said to be **0gCO_2/kWh**.

65. It should be noted that the Only Solutions report excludes infrastructure (e.g. construction) emissions from the figures for emissions released by the proposed EfW plant, and indeed those emissions are also absent from both the Appellant's December 2016 Carbon Assessment and their August 2019 Carbon Calculation Update. However, in order to provide context regarding the relative carbon intensity of electricity generated by the proposed EfW plant compared with other forms of energy generation we have included the full life-cycle analysis (LCA) impact of these non-incineration electricity sources which consist of the 'infrastructure and supply chain emissions'.

66. 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 3. Emissions from low carbon sources, based on life-cycle analysis (LCA)

Technology	Infrastructure and 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*

[12] Table A.III.2 'Emissions of selected electricity supply technologies (gCO2eq/kWh)', page 1335 of the 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 IPPC, available from:
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf

67. As can be seen from the figures for wind, solar and geothermal in Table 3 above, these genuinely 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 taken of associated infrastructure and supply chain emissions.

68. As shown by the calculations carried out for this analysis, the energy that would be exported from the Horsham EfW plant would have a fossil carbon intensity of **563 gCO_2e/KWh**, far worse than the carbon intensity of 340 gCO2e/KWh associated with the conventional use of fossil fuels, and nearly two and a half times the MEF for 2023 (233 gCO2e/KWh), as set out in Table 7, below.

4. RELATIVE NET GHG EMISSIONS OF THE EFW COMPARED WITH LANDFILL

69. 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"*.[13]

70. 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..."*.[14]

71. Only Solutions' climate change assessment takes account of direct emissions, emissions displaced through electricity generation, and biogenic carbon 'sequestered' (stored) in landfill. This analysis uses the same emissions source category headings as those used by the Appellant and the same system boundary as that used by the Appellant, e.g. in Table 3 of their December 2016 Appendix 2.3 Carbon Assessment and Table 3b of their August 2019 Updated Carbon Assessment.

72. Further detail regarding the rationale for the approach applied by Only Solutions is set out in Annex A ('*Modelling Approach*'), Annex B ('*Incinerator Efficiency*'), Annex C ('*Feedstock Profiles*'), Annex D ('*Marginal Emissions Factor (MEF)*'), Annex E ('*Biogenic carbon sequestration*'), Annex F ('Materials Recovery Benefits'), Annex G ('Carbon Calculations'), and Annex H ('*Metal Recovery Calculations*').

[13] 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

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

73. To be consistent with the Appellant's chosen scope of impacts, for the purpose of comparing incineration with landfill, this assessment includes the Appellant's figures for transport emissions (which do not include staff travel) and for Incinerator Bottom Ash (IBA) aggregate. The benefits of metal recovery (from the IBA) are calculated using figures taken from, and the approach set out in, Section 5.3 of the Appellant's 2016 Carbon Assessment (included in the Appellant's Environmental Statement, Volume 3, Appendix 2.3) and applying these to the relevant feedstock composition profiles (see Annex F ('*Materials Recovery Benefits*') and Annex H ('*Metal Recovery Calculations*'), below).

74. The results of comparing the proposed incinerator with landfill are as follows:

Table 4. Relative net emissions from proposed EfW compared with landfill

Emissions Source	Appellant Figures for 'Proposed Facility Electricity only'[15]	Reduced Compostables feedstock profile [Table 16]	Defra Default Feedstock Profile [Table 11]	Cell in calculation table of Tables 16 and 11
Process	+50,955	+81,198	+62,550	Cell B1
Transport	-110	-110	-110	Cell B5
Avoided CO_2				
Displaced Electricity Generation	-42,940	-33,606	-29,466	Cell B2
Displaced Heat Generation	0	0	0	As per Appellant (electricity-only)
Materials Recovery	-37,684	-10,477	-7,953	Cell B4
Landfill Diversion	-76,505	+12,096	+6,552	Cell C6 × -1
Total	-106,284	**+49,101**	+31,573	Cell D6

75. Based on this analysis, even when account is taken of the release of methane from landfill (converted into CO_2e) and of the appellant's claimed benefits arising from increased material recovery and reduced transport emissions, sending waste to the proposed Horsham EfW facility is estimated to be 49,101 tonnes of CO_2e a year <u>worse</u> than sending the same waste to landfill. Over 30 years of operation this would equate to the EfW facility being more than 1.47 million tonnes of CO_2e worse than landfill.

[15] August 2019 Carbon Calculation Update. Table 3b: Summary of estimated emissions (tCO_2e per annum) - update to transport emission factor and electricity generation factor.

76. With the sensitivity analysis of the impact of using Defra's Default feedstock scenario, the adverse impact is reduced to being 31,454 tonnes of CO_2e per year worse than landfill, but the conclusion - that sending waste to the EfW proposed for Horsham would be worse in GHG terms than sending the same waste untreated to landfill - remains the same.

77. These estimates are based on the BEIS figure for displaced electricity (MEF or GHG Factor) of 0.233 kgCO_2e/KWh, whereas the Appellant in Table 3b of their August 2019 Updated Carbon Calculations uses a slightly higher figure of 0.2556 kgCO_2e/kWh which represents the *"Greenhouse Gas Reporting – Conversion Factors 2019"*.

78. As set out in Annex D (*'Marginal Emissions Factor (MEF)'*), Only Solutions prefers the 0.233 figure to the 0.2556 figure. Nevertheless, as set out in Table 5 below, using the 0.2556 figure does not alter the conclusions of Only Solutions' assessment.

Table 5. Relative net emissions from proposed EfW compared with landfill, with sensitivity based on Appellant 2019 Electricity MEF / GHG Factor

Emissions Source	Reduced Compostables feedstock profile [Table 16]	Defra Default Feedstock Profile [Table 11]
Process	+81,198	+62,550
Transport	-110	-110
Avoided CO_2		
Displaced Electricity Generation	**-36,864**	**-32,328**
Displaced Heat Generation	0	0
Materials Recovery	**12,294**	**6,750**
Landfill Diversion	+12,096	+6,552
Total	**+46,041**	**+28,790**
Difference	**-3,060**	**-2,664**

Technical Annexes

ANNEX A: MODELLING APPROACH

79. Determining the impacts of the EfW plant requires estimating various impacts with respect to both the plant proposed for Horsham and the relevant baseline comparators. For consistency and ease of comparison, our estimate of the relative net GHG impact of the proposed EfW plant compared to landfill adopts the same emissions source categories as those set out by the Appellant in Table 3 of their 2016 Carbon Assessment and in Tables 3a and 3b of their August 2019 Updated Carbon Calculations, i.e. Process Emissions, Displaced Electricity Generation, Materials Recovery and Landfill Diversion.

80. Paragraph 1 of Defra's Carbon Based Modelling Approach report, published in February 2014, explains that it was commissioned to identify the critical factors that affect the environmental case for energy from waste in comparison to landfill from a carbon perspective and the sensitivity of that case to those factors.

81. Paragraph 3 of 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 …"*. Details of the methodology and terminology used by Defra are explained within Defra's document.[16]

82. Where appropriate our analysis makes use of calculation formulas and waste parameters set out within the Defra Carbon Based Modelling Approach report, but we have adapted them as necessary to suit the purpose of this development-specific assessment as set out within the report.

83. The primary feedstock assumption is based on the Appellant's claim of 18 MW electricity export and 180,000 processing capacity.[17] The assessment takes account of: the Appellant's claimed benefits from reduced transport and IBA materials recovery; the latest BEIS figures for the displaced energy from the facility; and the impact of biogenic carbon sequestration in landfill.

84. As such, the assessment considers the relative impacts of the proposed facility relative to landfill, taking into account the Appellant's claimed benefits and system boundaries. This allows for the results from Only Solutions' assessment to be compared directly with the results from the Appellant's assessment.

[16] 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

[17] The Appellant's electrical export claims are stated in Paragraph 33 of the Appellant's Statement of Case and their anticipated capacity is stated in Paragraph 3.55 of the Appellant's Planning Supporting Statement.

ANNEX B: EFW EFFICIENCY

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

86. The Defra Report states that the model needs to consider a number of factors and confirms (at Paragraph 60) that the calorific value of the waste is how much (chemical) energy is stored in the waste per tonne that could potentially be converted into useful electrical or heat energy when burned.

87. '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.

88. 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)".*

89. 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%"*.

90. Following the example provided in Defra's report, Only Solutions' evaluation adopts an overall GCV efficiency of 25%, which according to the Carbon Based Modelling Approach report represents a high-performing plant that equates to an overall NCV efficiency of 30%.

91. A 30% NCV efficiency is higher than the efficiency claimed by the Appellant in their 2016 Carbon Assessment, where at Paragraph 5.3.6 they anticipated: *"[electricity] exported to the grid at a net [NCV] efficiency of 28.4%".*

92. The 30% NCV efficiency (which equates to 25% GCV efficiency) adopted for this modelling by Only Solutions is also higher than the efficiency claimed by Veolia for their proposal for an EfW plant at Rye House in Hertfordshire, which according to Veolia's technical specification would have had a 28.6% NCV efficiency (and a 24.6% GCV efficiency).[18]

93. As such, the level of overall efficiency adopted for this assessment is an optimistic assumption that assumes a higher level of efficiency than claimed by the Appellant, i.e. it represents a best case scenario for electricity-only mode.

94. Heat export is not considered in this assessment because this falls outside of what is being proposed in the planning application subject to this appeal and there is insufficient details regarding such a scheme.

95. However, as noted by the Appellant at Paragraph 5.3.7 of their 2016 Carbon Assessment, heat export can reduce electrical efficiency and there is *"uncertainty about potential demand for heat in CHP mode".*

96. As such, a facility operating in Combined Heat and Power (CHP) mode with a low level of heat output could be expected to perform worse in terms of overall efficiency and climate change impact than an electricity-only facility.

[18] See Table 7-1 ('Technical specifications of the Proposed Development') of the February 2017 Energy Management Plan from the Rye House 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. 'Total Fuel Input based on gross CV' is stated to be 982,16 MWh and 'Net electricity output in electricity-only mode' is stated to be 241,000 MWh, and as such the Veolia EfW plant has a claimed net GCV efficiency of 24.6% - because 241,600 ÷ 982,126 = 0.246 (rounded to three decimal places).

ANNEX C: FEEDSTOCK PROFILES

97. The following are the feedstock composition profiles that are used within this assessment, including those used to evaluate the relative net carbon impacts of the proposed EfW plant compared with landfill:

   a) The **Reduced Compostables feedstock profile**, which is the same as Defra's Default but with half the quantity of compostables (and a proportionate increase in other materials); and

   b) The **Defra Default feedstock profile**, which uses the default values from Column 1 of Tables 5 and 8 of Defra's Carbon Based Modelling report (as the values are expressed in that report as tonnes per tonne and can therefore be extrapolated into a percentage by weight).

98. The Reduced Compostables feedstock profile is a variant of the Defra Default that seeks to reflect anticipated increases in separate collection of compostable materials associated with changes in Local Authority collection practices and in line with the Government's December 2018 Resources and Waste Strategy ('Our Waste, Our Waste: A Strategy for England'), and to reconcile the Appellant's electricity export expectations with the energy input of the anticipated feedstock.

99. The Defra Default feedstock profile is used as for sensitivity testing because it is the base case adopted in Defra's Carbon Based Modelling Approach. Defra's Default was formulated to reflect the predicted English residual municipal waste composition data for 2011, and was used by DECC for the Greenhouse Gas Inventory (as explained at Paragraph 56 of the Carbon Based Modelling Approach report).

100. The Defra Default feedstock profile was not used as the primary feedstock profile for this analysis because it results in significantly lower levels of electrical output than set out in the Appellant's Statement of Case, and because it does not reflect historic and anticipated increases in the separate collection of compostables such as food waste.

101. The Government's December 2018 Resources and Waste Strategy sets out the Government's commitment to implement the separate bio-waste collection requirements of the Circular Economy Package. Specifically, the Strategy sets out a timeline (on Page 13 of the Strategy) which includes a reference to *"Transposition of the Circular Economy Package"* in 2019 and to *"Legislation for mandatory separate food waste collections"* from 2023.

102. The Circular Economy Package itself includes a requirement to separately collect bio-waste, including food waste, by the end of 2023.

103. Page 70 (Section 3.1.2) of the Resources and Waste Strategy sets out how, subject to consultation, the Government will ensure that every householder and appropriate business will be provided with a weekly separate food waste collection, and notes that the consultation also explores the prospect of the provision of free garden waste collections.

104. At Paragraph 3.3 of the Appellant's Statement of Case they state that: *"…approximately 18 MW would be available for export to the National Grid…"*

105. The Reduced Compostables feedstock profile is intended to reflect a feedstock mix that, based on Defra's assumptions for the energy content of the waste and the assumed level of efficiency of the EfW process (see Annex B, above), would provide a level of electricity export equivalent to that claimed by the Appellant in their Statement of Case.

106. As set out in Annex I ('*Calculating Electricity Output (MW) of Feedstock Profile*'), Only Solutions calculated the MW of electricity that would be generated from burning 180,000 tonnes at 25% Net GCV Efficiency for the feedstock set out in the Appellant's 2016 Carbon Assessment (Calculated in Table 22 below), for Defra's Default Feedstock Composition (set out in Table 23 below), and for the Reduced Compostables Feedstock Profile (set out in Table 24 below).

107. To convert MWh into MW the MW of exported electricity is divided by the hours of operation. We have adopted a figure of 8,000 hours of operation per annum because this is a standard assumption used for such assessment and because this was the assumption used by the Appellant for calculating displaced electricity generation in their 2016 and 2019 carbon assessments, as confirmed in Table 21 below.

108. The feedstock composition set out in Table 1 of the Appellant's 2016 Carbon Assessment (within Appendix 2.3 of their current planning application) includes an unusually high proportion of putrescibles which significantly reduces the calorific value of the feedstock.

109. A feedstock characterised by such a high proportion of putrescibles would be incompatible with the sort of C&I and MSW feedstock capable of generating the 18 MW of electricity for export envisioned within the Appellant's Statement of Case.

110. Furthermore, as noted in Footnote 31 of the Government's Energy from Waste Guide: *"Some wet wastes e.g. food are not particularly suitable for energy from waste"*. As such, one could anticipate operational difficulties from such a feedstock high-putrescibles feedstock which could require the use of high carbon support fuels.

111. The Appellant did not use precisely the same feedstock category headings as those used in Defra's Carbon Modelling Approach report, so a best fit exercise has been undertaken to match the Appellant's anticipated feedstock composition with the energy output figures set out in Defra's Carbon Based Modelling report.

112. The results of this best fit exercise is set out in Table 6, below:

Table 6: Feedstock composition profiles (based on 180,000 tonnes of waste input)

	Appellant's 2016 Carbon Assessment, Table 1 Waste Profile		Defra Default Waste Profile		Reduced Compostables Waste Profile	
	Waste Input	Energy Output	Waste Input	Energy Output	Waste Input	Energy Output
Mixed Paper and Card	13.96%	2.75 MW	15.14%	2.98 MW	19.64%	3.87 MW
Plastics	9.63%	3.82 MW	13.48%	5.35 MW	17.50%	6.94 MW
Textiles (and footwear)	2.11%	0.53 MW	3.95%	0.99 MW	5.13%	1.28 MW
Miscellaneous combustibles	9.87%	2.40 MW	5.90%	1.44 MW	7.66%	1.87 MW
Miscellaneous non-combustibles	6.12%	0.27 MW	8.99%	0.39 MW	11.67%	0.51 MW
Food	44.74%	3.70 MW	31.12%	2.57 MW	15.56%	1.29 MW
Garden	0.00%	0.00 MW	3.11%	0.32 MW	1.55%	0.16 MW
Soil and other organic waste	0.00%	0.00 MW	3.11%	0.23 MW	1.55%	0.12 MW
Glass	8.13%	0.19 MW	5.37%	0.13 MW	6.97%	0.16 MW
Metals, Other Non-biodegradable	5.46%	0.00 MW	2.25%	0.00 MW	2.93%	0.00 MW
Non-organic fines	0.00%	0.00 MW	0.57%	0.04 MW	0.74%	0.06 MW
Wood	0.00%	0.00 MW	3.11%	0.89 MW	4.03%	1.15 MW
Sanitary / disposable nappies	0.00%	0.00 MW	3.90%	0.49 MW	5.07%	0.63 MW
Total	**100%**	**13.65 MW**	**100%**	**15.81 MW**	**100%**	**18.03 MW**

113. Based on these assumptions, as set out in more detail within Annex I (Calculating Electricity Output (MW) of feedstock profiles):

a) As set out in Table 22, the **Appellant's 2016/2019 Carbon Assessment Composition** is estimated to result in the export of **13.65 MW** of electricity (i.e. 0.6068 MWh/t × 180,000 tonnes ÷ 8,000 hours = 13.653 MW);

b) As set out in Table 23, the **Defra Default feedstock profile** is estimated to result in the export of **15.81 MW** of electricity (i.e. 0.7028 MWh/t × 180,000 tonnes ÷ 8,000 hours = 15.813 MW); and

c) As set out in Table 24, the **Reduced Compostables feedstock profile** is estimated to result in the export of **18.03 MW** of electricity (i.e. 0.8014 MWh/t × 180,000 tonnes ÷ 8,000 hours = 18.0315 MW) - and this would align with the level of electricity export claimed by the Appellant in their Statement of Case.

114. The Appellant's Carbon Assessment Composition is not used for this analysis for several reasons, including because:

a) The level of putrescibles assumed within the Appellant's Carbon Assessment Composition is unusually high; and

b) Applying the Appellant's Carbon Assessment Composition would appear to result in a level of electricity export that would fall significantly below that anticipated by the Appellant in their Statement of Case (around 13.65 MW rather than the claimed 18 MW).

115. Taking these factors into account, it is clear that reliance on the Appellant's Carbon Assessment Composition would not provide a reasonable basis upon which to estimate the anticipated climate change impacts of the proposed EfW plant.

116. As such, for the purpose of this assessment, Only Solutions has adopted the Defra Default and the associated Reduced Compostables Profile.

117. The two feedstock composition profiles adopted for this assessment provide a sufficient range of potential feedstocks to produce a reasonable estimate of the potential climate change impacts of the proposal.

ANNEX D: MARGINAL EMISSIONS FACTOR (MEF)

118. 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*".[19]

119. As the Government noted in 2012: *"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"*.[20]

120. 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 the 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 proposals for new incineration capacity.

121. According to BEIS' April 2019 guidance: *"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. These emission factors will vary over time as there are different types of power plant generating electricity across the day and over time, each with different emissions factors…"*. [21]

122. The subsequent paragraph clarifies that a sustained 'change to the grid electricity supply' would include displacement from facilities such as the proposed EfW plant, stating: "*There are complex mechanisms that determine the effects of sustained but marginal changes to the grid electricity supply (from either <u>displacement with other generation</u> or a demand reduction)…sustained changes in consumption will result in changes to generation capacity – in terms of the timing, type, and amount of generation plant built and / or retired – as well as changes in generation levels. Modelling undertaken by BEIS has estimated these longer-term dynamics, and they are reflected in the marginal emissions factors". (<u>emphasis added</u>)*

[19] Box 1 of The Carbon Plan: Delivering our low carbon future (December 2011) on page 3, 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

[20] Paragraph 1.2 of 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

[21] Paragraphs 3.31 & 3.32 of Valuation of Energy Use and Greenhouse Gas (April 2019), available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794737/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal-2018.pdf

123. As explained in Footnote 20 of the Carbon Based Modelling Approach report: *"The marginal energy factor relates to the generation of an additional unit of grid electricity. There will be a range of different plants generating so the carbon intensity will be a mix of these. As this mixture will change with time so will the emissions factor. An alternative way of considering it is the carbon intensity of the plant you would build to deliver that same energy if you didn't use EfW…"*

124. As such, the Only Solutions has made use of the grid displacement factor as advised by BEIS for the purpose of assessing the relative net GHG impacts of incineration and landfill.

125. These grid displacement factors (also known as 'marginal emissions factors' or 'MEFs') as set out BEIS's Data Table 1 are listed overleaf:

Table 7: BEIS Data Table 1 ('Electricity Emissions Factors To 2100'), Extract (March 2019)

Year	Generation-based Long-run Marginal Emissions Factor
2023	233 gCO_2/kWh
2024	219 gCO_2/kWh
2025	205 gCO_2/kWh
2026	189 gCO_2/kWh
2027	173 gCO_2/kWh
2028	156 gCO_2/kWh
2029	138 gCO_2/kWh
2030	118 gCO_2/kWh
2031	105 gCO_2/kWh
2032	94 gCO_2/kWh
2033	84 gCO_2/kWh
2034	75 gCO_2/kWh
2035	66 gCO_2/kWh
2036	59 gCO_2/kWh
2037	53 gCO_2/kWh
2038	47 gCO_2/kWh
2039	42 gCO_2/kWh
2040	37 gCO_2/kWh
2041	36 gCO_2/kWh
2042	35 gCO_2/kWh
2043	34 gCO_2/kWh
2044	32 gCO_2/kWh
2045	31 gCO_2/kWh
2046	30 gCO_2/kWh
2047	29 gCO_2/kWh
2048	28 gCO_2/kWh
2049	26 gCO_2/kWh
2050	25 gCO_2/kWh

126. The Grid Displacement Factor that Only Solutions has adopted is that for 2023 (233 gCO_2/kWh, i.e. 0.233 tCO_2e/MWh), based on the year that we anticipate the facility to begin operations. However, if there are delays in the construction process and/or in the process of securing an Environmental Permit, then it is possible that a later year would be more accurate. Adopting a figure for a later commencement year, e.g. 2024, would result in the proposed facility faring even worse when compared with landfill.

ANNEX E: BIOGENIC CARBON SEQUESTRATION

127. When waste is burned at an energy from waste plant the carbon is converted into carbon dioxide (CO_2) and immediately released into the atmosphere.

128. However, when waste is landfilled a significant proportion of the carbon is 'sequestered', i.e. permanently or semi-permanently stored underground in what is known as a 'carbon sink'.

129. In line with Defra's Carbon Based Modelling Approach report and the EfW Guide to the debate, it is assumed that all of the fossil CO_2 is sequestered along with around half of the biogenic CO_2.[22]

130. 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.

131. The Appellant's 2016 and 2019 carbon assessments failed to follow best practice because the Appellant neither credits landfill with 'negative emissions' for this sequestered biogenic material nor includes the additional release of this biogenic carbon on the incineration side of the equation.

132. In effect, the Appellant's methodology does not actually model the relative net GHG impacts of incineration and landfill as it does not take account of one of a significant difference between these two forms of waste management.

133. For the purpose of Only Solutions' comparative analysis of incineration and landfill, all of the biogenic carbon which is assumed to be 'sequestered' (permanently stored) in landfill is attributed a 'carbon credit' in recognition of the environmental benefit of removing carbon from the cycle (as calculated in Tables 10 and 15 below).

134. This 'carbon credit' is represented in the calculations as a negative value emission. Each tonne of biogenic carbon sequestered in landfill is considered to prevent the release of 3.6667 tonnes of CO_2 that would otherwise be released into the atmosphere were the material to be combusted at an EfW plant.

[22] EfW Guide paragraph 42 and Carbon Based Modelling Approach report Paragraph 85.

135. As set out below, the approach adopted by Only Solutions is consistent with guidance from the Defra Carbon Based Modelling Approach report, IPCC guidelines, and the recommendations of industry professionals Eunomia.

136. The Appellant's failure to properly take into account biogenic carbon sequestration in their 2016 and 2019 carbon assessments represent a significant methodological failing in the approach that they adopted that seriously undermines the value of their carbon assessments.

137. Defra's Carbon Based Modelling Approach document explains, at Paragraphs 171-173, how: *"…the model assumes that 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:*

- *a) 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)*
- *b) Include all carbon emissions, both biogenic and fossil on both sides of the model*." (emphasis added)

138. The underlined portion of the above quote represents the approach adopted by Only Solutions, i.e. *"to estimate the amount of biogenic carbon sequestered and…subtract it from the landfill side"* of the equation.

139. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories remain the current guidelines to be followed for GHG inventories.

140. These guidelines acknowledge the GHG benefits of biogenic carbon sequestration in landfill, stating 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)".*[23]

[23] 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

141. Eunomia's 2006 report for Friends of the Earth states that: *"In a comparative analysis of different waste treatment technologies, the assumption that emissions of CO_2 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'…)"*.[24]

142. 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… ".*[25]

143. 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".*[26]

144. Similar views have also been expressed in the academic literature. As noted in Levasseur, Annie & Lesage, Pascal & Margni, Manuele & Samson, Réjean (2012) 'Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment' published in the Journal of Industrial Ecology: *"...not considering biogenic CO_2 can lead to biased conclusions. If a fraction of the biogenic carbon is assumed to be sequestered permanently, as was the case for the carbon sequestered…for 96.8% of the landfilled carbon, then the amount of biogenic carbon entering the product system is not equal to the amount leaving the system, which means that biogenic CO_2 emissions cannot be considered neutral"*.[27]

145. Only Solutions' 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.

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

[25] Section A.2 ('Biogenic CO_2 Emissions') of 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

[26] See Page 13 of 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/

[27] A version of this paper is available from: https://publications.polymtl.ca/706/1/2011_AnnieLevasseur.pdf

146. Bio-stabilisation of waste prior to landfill, for example, would significantly reduce the quantity of methane released and increase the quantity of biogenic material sequestered.

147. The method that Only Solutions has adopted to account for biogenic carbon sequestration is set out in further detail in the feedstock-specific calculations at Annex G, Tables 10 and 15.

ANNEX F: MATERIALS RECOVERY BENEFITS

148. Because Only Solutions is not investigating the potential disbenefits of the proposed facility with respect to recycling, e.g. disbenefits arising from the incineration of material that might otherwise have been recycled or composted, we could have excluded the Appellant's claimed metal recycling benefits from the scope of our assessment.

149. Metals can obviously be recovered without first being incinerated, and additional materials could be recovered prior to landfill, and as such an assessment of post-incineration activities could be accompanied by a more detailed assessment of the potential alternative fate of the feedstock, e.g. whether that material might otherwise be capable of being recycled or composted.

150. However, for comparison with the Appellant's 2016 and 2019 assessments - which include claimed benefits arising from recovering metal from the IBA (but not potential disbenefits from the incineration of material that could otherwise have been recycled or composted) - we have, in this regard, followed the same approach as that taken by the Appellant.

151. The analysis uses the Appellant's 119 tonnes of CO_2e per annum figure for the benefit of IBA aggregate, in combination with the respective metal recovery benefits for the different feedstocks (as set out in Tables 11, 16, 18, 19, and 20).

152. The analysis concludes that, even when the Appellant's benefits are scoped in and the disbenefits of incinerating recyclable and compostable material is scoped out, then based on either the Reduced Compostables or the Defra Default feedstock composition profiles **the EfW plant proposed for Horsham would be worse in climate change terms than sending the same material directly to landfill**.

ANNEX G: CARBON CALCULATIONS

Table 8: Defra Default - 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	Net GCV Efficiency [25%]	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)×0.233	(10)-(11)
Mixed Paper and Card	0.1514	3.5000	0.25	0.1325	0.3200	0.0484	0.1776	0	0	0.0	0.0309	-0.0309
Plastics	0.1348	7.0500	0.25	0.2376	0	0	0	0.5200	0.0701	0.2570	0.0554	0.2017
Textiles (and footwear)	0.0395	4.4400	0.25	0.0438	0.2000	0.0079	0.0290	0.2000	0.0079	0.0290	0.0102	0.0188
Miscellaneous combustibles	0.0590	4.3300	0.25	0.0639	0.1900	0.0112	0.0411	0.1900	0.0112	0.0411	0.0149	0.0262
Miscellaneous non-combustibles	0.0899	0.7800	0.25	0.0175	0.0400	0.0036	0.0132	0.0400	0.0036	0.0132	0.0041	0.0091
Food	0.3112	1.4700	0.25	0.1144	0.1400	0.0436	0.1597	0	0	0	0.0266	-0.0266
Garden	0.0311	1.8100	0.25	0.0141	0.1700	0.0053	0.0194	0	0	0	0.0033	-0.0033
Soil and other organic waste	0.0311	1.3300	0.25	0.0103	0.0700	0.0022	0.0080	0	0	0	0.0024	-0.0024
Glass	0.0537	0.4200	0.25	0.0056	0	0	0	0	0	0	0.0013	-0.0013
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	0.0004	0.0010
Wood	0.0311	5.0800	0.25	0.0395	0.4400	0.0137	0.0502	0	0	0	0.0092	-0.0092
Sanitary / disposable nappies	0.0390	2.2200	0.25	0.0216	0.1500	0.0059	0.0215	0.0400	0.0016	0.0057	0.0050	0.0007
TOTAL PER TONNE OF WASTE	1 Tonne			**0.7028 MWh**		0.1417 tC	0.5196 tCO_2		**0.0948 tC**	**0.3475 tCO_2**	**0.1637 tCO_2**	0.1837 tCO_2

Table 9: Defra Default - 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	0.0040	0.0004	0.0011	0.0036	0.0897	0.0857
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	0.0004	0	0.0001	0.0004	0.0099	0.0095
Miscellaneous combustibles	0.0590	0.0890	0.0053	0.0035	0.0096	0.0026	0.0072	0.0037	0.0009	0.0001	0.0002	0.0008	0.0197	0.0188
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	0.0044	0.0004	0.0012	0.0040	0.0992	0.0948
Garden	0.0311	0.0870	0.0027	0.0018	0.0050	0.0014	0.0037	0.0019	0.0004	0	0.0001	0.0004	0.0101	0.0097
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	0.0006	0.0001	0.0002	0.0006	0.0146	0.0139
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	**0.0110 tCO_2**	0.0011 tCO_2e	0.0031 tCO_2	0.0100 tCH4	**0.2499 tCO_2e**	0.2389 tCO_2e

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

Table 10: Defra Default - 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
	= [Table 8 Column 1]	= [Table 9 Column 2]	= [Table 8 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 11: Defra Default - Result formulas and calculations (Tonnes CO_2e)

			Incineration	Landfill	Relative net GHG impact of incineration
	A		B	C	D
1	Direct process emissions	**Formula**	[Table 8, Column 10] × Throughput	[Table 9, Column 13] × Throughput	[Incineration - Landfill]
		Calculation	0.3475 × 180,000 = **62,550**	0.2499 × 180,000 = **44,982**	62,550 - 44,982 = **17,568**
2	Electricity offset	**Formula**	[Table 8, Column 11] × Throughput × -1	[Table 9, Column 9] × Throughput × -1	[Incineration - Landfill]
		Calculation	0.1637 × 180,000 × -1 = **-29,466**	0.011 × 180,000 × -1 = **-1,980**	-29,466 - (-1,980) = **-27,486**
3	Biogenic carbon sequestration	**Formula**		[Table 10, Column 6] × Throughput × -1	[Incineration - Landfill]
		Calculation		0.2753 × 180,000 × -1 = **-49,554**	0 - (-49,554) = **49,554**
4	Benefits of Materials Recovery	**Formula**	[Appellant claimed IBA recovery benefits + Table 20 grand total]		[Incineration - Landfill]
		Calculation	119 + 7,953 × -1 = **-8,072**		-7,953 - 0 = **-8,072**
5	Benefits of Reduced Transport	**Formula**	[Appellant transport figure]		[Incineration - Landfill]
		Calculation	110 × -1 **= -110**		-110 - 0 = **-110**
6	TOTAL	**Formula**	[Sum of above]	[Sum of above]	[Incineration - Landfill]
		Calculation	(62,550) + (-29,466) + (-8,072) + (-110) = **24,902**	(44,982) + (-1,980) + (-49,554) = **-6,552**	24,902 - (-6,552) = **31,454**

Table 12: Defra Default - Results (Tonnes CO_2 per annum for 180,000 tpa)

	Incineration	Landfill	Relative net
Direct emissions	+62,550	+44,982	+17,568
Electricity offset	-29,466	-1,980	-27,486
Biogenic carbon sequestration		-49,554	+49,554
Benefits of Materials Recovery	-8,072		-8,072
Benefits of Reduced Transport	-110		-110
TOTAL	+24,902	-6,552	+31,454

Table 13: Reduced Compostables Feedstock Profile - 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)×0.233	(10)-(11)
Mixed Paper and Card	0.1964	3.5000	0.25	0.1719	0.3200	0.0628	0.2304	0	0	0	0.0400	-0.0400
Plastics	0.1750	7.0500	0.25	0.3084	0	0	0	0.5200	0.0910	0.3337	0.0719	0.2618
Textiles (and footwear)	0.0513	4.4400	0.25	0.0569	0.2000	0.0103	0.0376	0.2000	0.0103	0.0376	0.0133	0.0244
Miscellaneous combustibles	0.0766	4.3300	0.25	0.0829	0.1900	0.0146	0.0534	0.1900	0.0146	0.0534	0.0193	0.0340
Miscellaneous non-combustibles	0.1167	0.7800	0.25	0.0228	0.0400	0.0047	0.0171	0.0400	0.0047	0.0171	0.0053	0.0118
Food	0.1556	1.4700	0.25	0.0572	0.1400	0.0218	0.0799	0	0	0	0.0133	-0.0133
Garden	0.0155	1.8100	0.25	0.0070	0.1700	0.0026	0.0097	0	0	0	0.0016	-0.0016
Soil and other organic waste	0.0155	1.3300	0.25	0.0052	0.0700	0.0011	0.0040	0	0	0	0.0012	-0.0012
Glass	0.0697	0.4200	0.25	0.0073	0	0	0	0	0	0	0.0017	-0.0017
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	0.0006	0.0013
Wood	0.0403	5.0800	0.25	0.0512	0.4400	0.0177	0.0650	0	0	0	0.0119	-0.0119
Sanitary / disp nappies	0.0507	2.2200	0.25	0.0281	0.1500	0.0076	0.0279	0.0400	0.0020	0.0074	0.0066	0.0009
TOTAL PER TONNE OF WASTE	1		0.25	**0.8014**		0.1432	0.5250		**0.1230**	**0.4511**	0.1867	0.2644

Table 14: Reduced Compostables Feedstock Profile - 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	0.0051	0.0005	0.0014	0.0047	0.1164	0.1112
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	0.0006	0.0001	0.0002	0.0005	0.0129	0.0123
Miscellaneous combustibles	0.0766	0.0890	0.0068	0.0045	0.0125	0.0034	0.0094	0.0048	0.0011	0.0001	0.0003	0.0010	0.0256	0.0244
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	0.0022	0.0002	0.0006	0.0020	0.0496	0.0474
Garden	0.0155	0.0870	0.0013	0.0009	0.0025	0.0007	0.0019	0.0010	0.0002	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	0.0008	0.0001	0.0002	0.0008	0.0189	0.0181
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	0.0104	0.0011	0.0029	0.0095	0.2367	0.2263

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

Table 15: Reduced Compostables Profile - 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
	= [Table 14 Column 1]	= [Table 14 Column 2]	= [Table 13 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 16: Reduced Compostables Feedstock Profile - Result formulas and calculations (Tonnes CO_2e)

			Incineration	Landfill	Relative net GHG impact of incineration
	A		B	C	D
1	Direct process emissions	Formula	[Table 13, Column 10] × Throughput	[Table 14, Column 13] × Throughput	[Incineration - Landfill]
		Calculation	0.4511 × 180,000 = **81,198**	0.2367 × 180,000 = **42,606**	81,198 - 42,606 = **38,592**
2	Electricity offset	Formula	[Table 13, Column 11] × Throughput × -1	[Table 14, Column 9] × Throughput × -1	[Incineration - Landfill]
		Calculation	0.1867 × 180,000 × -1 = **-33,606**	0.0104 × 180,000 × -1 = **-1,872**	-33,606 - (-1,872) = **-31,734**
3	Biogenic carbon sequestration	Formula		[Table 15, Column 6] × Throughput × -1	[Incineration - Landfill]
		Calculation		0.2935 × 180,000 × -1 = **-52,830**	0 - (-52,830) = **52,830**
4	Benefits of Materials Recovery	Formula	[Appellant claimed IBA recovery benefits + Table 19 grand total]		[Incineration - Landfill]
		Calculation	119 + 10,358 × -1 = -**10,477**		-10,447 - 0 = -**10,477**
5	Benefits of Reduced Transport	Formula	[Appellant transport figure]		[Incineration - Landfill]
		Calculation	110 × -1 **=- 110**		-110 - 0 = -**110**
6	TOTAL	Formula	[Sum of above]	[Sum of above]	[Incineration - Landfill]
		Calculation	(81,198) + (-33,606) + (-10,477) + (-110) = **37,005**	(42,606) + (-1,872) + (-52,830) = **-12,096**	37,005 - (-12,096) = **49,101**

Table 17: Reduced Compostables Profile - Results (Tonnes CO_2 per annum for 180,000 tpa)

	Incineration	Landfill	Relative net
Direct emissions	+81,198	+42,606	+38,592
Electricity offset	-33,606	-1,872	-31,734
Biogenic carbon sequestration		-52,830	+52,830
Benefits of Materials Recovery	-10,477		-10,477
Benefits of Reduced Transport	-110		-110
TOTAL	**+37,005**	**-12,096**	**+49,101**

ANNEX H: METAL RECOVERY CALCULATIONS

Table 18: Calculation of metal ratios

	Ferrous	Non-ferrous	Total
Kt arising in UK (Defra Table 3)	719	186	905
Expressed as a %age of the Total	79.45%	20.55%	100.00%

Table 19: Metal recovery benefits for reduced compostables feedstock

		Unit	Ferrous	Non-ferrous	Calculation / Source
1	Total tonnes	Tonnes of waste	180,000		Appellant (Paragraph 3.55 of Planning Supporting Statement)
2	% metals	% of waste	2.93%		Composition (Table 6)
3	Total metals	Tonnes of waste	5,274		Row 1 × Row 2
4	%ages of Ferrous/Non-ferrous	% of waste	79.45%	20.55%	Defra Table 3 (see Table 18 above for calculation)
5	Tonnes of Ferrous/Non-ferrous input	Tonnes of waste	4,190	1,084	Row 3 × Row 4
6	% remaining in IBA (output)	% of waste	80%	60%	Appellant (Paragraph 5.3.1 of 2016 Carbon Assessment, included in ES Vol 3 Appendix 2.3)
7	Remaining metals	Tonnes of waste	3,352	650	Row 5 × Row 6
8	Avoided emissions (tCO_2/t)	% of waste	0.705	12.3	Appellant (Table 2: Emissions avoided through material recovery of 2016 Carbon Assessment, included in ES Vol 3 Appendix 2.3)
9	Total savings	Tonnes of CO_{2e}	2,363	7,995	Row 7 × Row 8
10	**Grand total**	**Tonnes of CO_{2e}**	**10,358**		**Ferrous + Non Ferrous**

Table 20: Metal recovery benefits for Defra default feedstock

		Unit	Ferrous	Non-ferrous	Calculation / Source
1	Total tonnes	Tonnes of waste	180,000		Appellant (Paragraph 3.55 of Planning Supporting Statement)
2	% metals	% of waste	2.25%		Composition (Table 6)
3	Total metals	Tonnes of waste	4,050		Row 1 × Row 2
4	%ages of Ferrous/Non-ferrous	% of waste	79.45%	20.55%	Defra Table 3 (see Table 18 above for calculation)
5	Tonnes of Ferrous/Non-ferrous input	Tonnes of waste	3,218	832	Row 3 × Row 4
6	% remaining in IBA (output)	% of waste	80%	60%	Appellant (Paragraph 5.3.1 of 2016 Carbon Assessment, included in ES Vol 3 Appendix 2.3)
7	Remaining metals	Tonnes of waste	2,574	499	Row 5 × Row 6
8	Avoided emissions (tCO_2/t)	% of waste	0.705	12.3	Appellant (Table 2: Emissions avoided through material recovery of 2016 Carbon Assessment, included in ES Vol 3 Appendix 2.3)
9	Total savings	Tonnes of CO_{2e}	1,815	6,138	Row 7 × Row 8
10	**Grand total**	**Tonnes of CO_{2e}**	**7,953**		**Ferrous + Non Ferrous**

ANNEX I: CALCULATING ELECTRICITY OUTPUT (MW) OF FEEDSTOCK PROFILES

Table 21: Appellant's August 2019 Table 3b assumed hours of operation and MW output

		Value	Unit	Source / Calculation
1	Displaced Electricity Generation	42,940	Tonnes of CO_2	Appellant's August 2019 Carbon Update - Table 3b (Converted to positive number)
2	GHG Factor (MEF)	0.2556	Tonnes of CO_2 per MWh	Appellant's August 2019 Carbon Update - Table 3b, Footnote 2 (Converted to tCO_2/MWh)
3	MWh	167,997	MWh per annum	(Row 1) ÷ (Row 2) = 42,940 ÷ 0.2556 = 167,997 MWh
4	Hours per annum	8,000	Hours per annum	Standard industry figure
5	MW output	21	MW	(Row 3) ÷ (Row 4) = 167,997 ÷ 8,000 = 21 MW

Table 22: MW Calculation for Appellant's Composition from 2016 Carbon Assessment

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Proportion of 1 tonne of waste	Calorific value MWh/t	Net GCV Thermal Efficiency	Energy potential MWh per tonne	Tonnes processed per annum	Hours of operation per annum	MW electrical output
				=(1)×(2)×(3)			=((4)×(5))÷(6)
Mixed Paper and Card	0.1396	3.5000	0.25	0.1221	180,000 tonnes	8,000 hours	2.75
Plastics	0.0963	7.0500		0.1697			3.82
Textiles (and footwear)	0.0211	4.4400		0.0234			0.53
Miscellaneous combustibles	0.0987	4.3300		0.1068			2.40
Miscellaneous non-combustibles	0.0612	0.7800		0.0119			0.27
Food	0.4474	1.4700		0.1644			3.70
Garden	0.0000	1.8100		0.0000			0.00
Soil and other organic waste	0.0000	1.3300		0.0000			0.00
Glass	0.0813	0.4200		0.0085			0.19
Metals, Other Non-biodegradable	0.0546	0		0.0000			0.00
Non-organic fines	0.0000	1.3300		0.0000			0.00
Wood	0.0000	5.0800		0.0000			0.00
Sanitary / disp nappies	0.0000	2.2200		0.0000			0.00
GRAND TOTAL	1 Tonne			0.6068 MWh/t			**13.65 MW**

Table 23: MW Calculation for Defra Default Feedstock Composition

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Proportion of 1 tonne of waste	Calorific value MWh/t	Net GCV Thermal Efficiency	Energy potential MWh per tonne	Tonnes processed per annum	Hours of operation per annum	MW electrical output
				=(1)×(2)×(3)			=((4)×(5))÷(6)
Mixed Paper and Card	0.1514	3.5000	0.25	0.1325	180,000 tonnes	8,000 hours	2.98
Plastics	0.1348	7.0500		0.2376			5.35
Textiles (and footwear)	0.0395	4.4400		0.0438			0.99
Miscellaneous combustibles	0.0590	4.3300		0.0639			1.44
Miscellaneous non-combustibles	0.0899	0.7800		0.0175			0.39
Food	0.3112	1.4700		0.1144			2.57
Garden	0.0311	1.8100		0.0141			0.32
Soil and other organic waste	0.0311	1.3300		0.0103			0.23
Glass	0.0537	0.4200		0.0056			0.13
Metals, Other Non-biodegradable	0.0225	0		0			0.00
Non-organic fines	0.0057	1.3300		0.0019			0.04
Wood	0.0311	5.0800		0.0395			0.89
Sanitary / disp nappies	0.0390	2.2200		0.0216			0.49
GRAND TOTAL	1 Tonne			**0.7028 MWh/t**			**15.81 MW**

Table 24: MW Calculation for Reduced Compostables Feedstock Composition

Column	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Proportion of 1 tonne of waste	Calorific value MWh/t	Net GCV Thermal Efficiency	Energy potential MWh per tonne	Tonnes processed per annum	Hours of operation per annum	MW electrical output
				=(1)×(2)×(3)			=((4)×(5))÷(6)
Mixed Paper and Card	0.1964	3.5000	0.25	0.1719	180,000 tonnes	8,000 hours	3.87
Plastics	0.1750	7.0500		0.3084			6.94
Textiles (and footwear)	0.0513	4.4400		0.0569			1.28
Miscellaneous combustibles	0.0766	4.3300		0.0829			1.87
Miscellaneous non-combustibles	0.1167	0.7800		0.0228			0.51
Food	0.1556	1.4700		0.0572			1.29
Garden	0.0155	1.8100		0.0070			0.16
Soil and other organic waste	0.0155	1.3300		0.0052			0.12
Glass	0.0697	0.4200		0.0073			0.16
Metals, Other Non-biodegradable	0.0293	0		0			0.00
Non-organic fines	0.0074	1.3300		0.0025			0.06
Wood	0.0403	5.0800		0.0512			1.15
Sanitary / disp nappies	0.0507	2.2200		0.0281			0.63
GRAND TOTAL	1 Tonne			**0.8014 MWh/t**			**18.03 MW**

- **A1:Excerpts from Valuation of Energy Use and Greenhouse Gas Background documentation (April 2019)**

Department for
Business, Energy
& Industrial Strategy

VALUATION OF ENERGY USE AND GREENHOUSE GAS

Background documentation

April 2019

2.3 Emissions Factors for Electricity

Unlike other fuels, the emissions associated with a unit of grid electricity can vary greatly depending on the source of electricity generation. It is also important to distinguish between the average and (long-run) marginal electricity emissions factors. Whereas the average emissions factors should be used to account for emissions for the purposes of emissions footprinting, the marginal emissions factor should be used for analysing sustained *changes* in energy consumption for the purposes of cost-benefit analysis, including policy appraisal. Note that these are emissions factors per unit of electricity consumed (that, is they reflect the emissions from primary fuel use in order to deliver the electricity consumed), taking account of transmission and distribution losses post production.

- The average emissions factor is used for reporting emissions associated with electricity use and for calculating the emissions coverage of policies / sectors.
- The marginal emissions factor is used to estimate the change in UK electricity sector emissions associated with policies that lead to sustained marginal changes in the consumption of electricity.

2.3.1 Long-run Marginal Emissions Factors for Electricity

The marginal electricity emissions factor is intended to reflect the change in emissions that would result from a small but sustained change in electricity consumption. The change in electricity consumption is assumed to be constant throughout the day and year (i.e. no differentiation is made between peak and non-peak. Figures are an average for each year).

The marginal plant(s) refers to what energy source(s) we expect to increase or decrease when there are marginal but sustained changes to energy demand or supply. The marginal emissions factor allows us to conduct policy analysis relative to a baseline that includes implemented, adopted and planned policies and in which sufficient plant is built to meet projected demand. Table 2.1 below summarises the technology assumptions behind the marginal emissions factor series.

The calculations are based on the assumption that, until very recently, a Combined Cycle Gas Turbine (CCGT) plant was the long-run marginal electricity generation plant on the basis that it was both relatively cheap and quick to build. Therefore, the marginal emissions factor in 2010 reflects that of a typical CCGT plant (0.34 kgCO2e/kWh before taking into account distribution and transmission losses). However, going forward there are reasons to think that this may not remain the case, particularly given the policies in place to incentivise low carbon electricity generation.

Illustrative demand reduction scenarios have been modelled in BEIS using the Dynamic Dispatch Model (DDM)[6] to examine the impact of a change in electricity consumption on capital build and generation. The model predicts that CCGT plant will form a significant part of the marginal impacts, but that going forward in time, there are impacts on other plant, including low carbon technologies.

In order not to draw overly precise conclusions from the modelling of an inherently uncertain future, the results of the demand reduction modelling have been used to inform a profile of

[6] Further information on the BEIS dynamic dispatch model may be found here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48383/5425-decc-dynamic-dispatch-model-ddm.pdf

emissions factors between the CCGT plant in 2010, and the marginal emissions factor modelled in 2030. A moving average of the results suggests broadly an increasing rate of decline in the emissions factors over this period.

In the longer run, uncertainties increase even further. Given that it is very difficult to identify what the marginal impacts would be, a pragmatic approach of using the projected average grid emissions factor from 2040 onwards is taken. Between 2031 and 2040 an interpolation has been used. For modelling purposes, emissions factors are assumed to remain constant beyond 2050.

In projecting the long-run average emissions factor, MARKAL modelling[7] carried out in July 2009 has been used to derive an expected long-run average electricity emissions factor over the 2040-2050 period. The model predicts that by 2040, the average electricity emissions factor is 0.05kg/KWh. This then falls to 0.03kg/kW by 2050[8].

Table 2.1: Marginal electricity emissions factor estimation methodology

Period	Marginal Emissions Factor
2010	CCGT
2011–2029	Mix of technologies, found via exponential interpolation between 2010 and 2029
2030	Modelled marginal emission factor (through the Dynamic Dispatch Model (DDM), based on a series of demand reduction scenarios)
2031-2039	Constant annual percentage change between marginal emissions factor in 2030 and average emissions factor in 2040
2040-2049	Average emissions Factor
2050 onwards	Flatlined/Constant Emissions Factor

[7] Please visit http://www.iea-etsap.org/web/index.asp for further information on the MARKAL model.
[8] DECC (2009) Analytical Annex to the Low Carbon Transition Plan. We have used the modelling run which looked to decarbonise the economy by 80% by 2050 and included the Renewable Energy Strategy (RES) policies in the baseline. The average electricity emissions are broadly similar for all MARKAL modelling runs with stringent climate change targets.

- **A2:Energy recovery for residual waste - A carbon based modelling approach (February 2014)**

www.gov.uk/defra

Department for Environment Food & Rural Affairs

Energy recovery for residual waste

A carbon based modelling approach

February 2014

This document/publication is also available on our website at:

Any enquiries regarding this document/publication should be sent to us at:

efw@defra.gsi.gov.uk

PB 14131

WR1910

Contents

1. Summary

1. This analysis set out to identify the critical factors that affect the environmental case for energy from waste (EfW) in comparison to landfill from a carbon perspective and the sensitivity of that case to those factors. In particular the aim was to examine the influences that the biogenic carbon content of the waste and the thermal efficiency of the EfW process have on the relative benefits of EfW and landfill.

2. It is recognised that there are a wide range of other practical, environmental and economic factors that need to be considered in assessing the benefits of different waste management approaches and that carbon cannot be the sole consideration. However, as the relative carbon impacts are often used as justification for adopting different approaches it is important to understand how they vary in the context of this wider decision process. The intention is to identify the key factors necessary to maximise the benefits of EfW over landfill in carbon terms in line with the hierarchy rather than indicate a preferred management route for waste of a certain composition.

3. A model was developed that considered the carbon emissions from a tonne of mixed residual waste depending on whether that waste were to go to energy recovery or landfill.

4. Energy from waste was considered to produce emissions from combustion of all the carbon in the waste and to produce energy related to the calorific value of that waste. The net energy generated (total energy reduced by the modelled net efficiency) was assumed to offset fossil emissions from an alternative generating source (the baseline being electricity only generation and the alternative source being the marginal generation mix). It did not directly account for any carbon left in the ash or the potential carbon benefits of metal recycling. These would be additional carbon benefits for EfW. Similarly nitrous oxide (N_2O) emissions have not been included in the calculation which would be a small disbenefit. If desired these factors could be accounted for by creating an 'apparent net efficiency' of a plant.

5. Landfill was considered to produce no gaseous[1] emissions from fossil waste and a proportion of the biogenic carbon was also assumed to be sequestered. The remaining biogenic carbon was assumed to decompose to form landfill gas made up of 50:50 (by volume) CO_2 and methane. This gas was assumed to be either released into the atmosphere or converted to CO_2 through: being captured and used to generate energy, which was assumed to offset the same fossil source as EfW; flared with no energy offset; or oxidised in the cap. CO_2 from these processes was assumed to be all biogenic. Methane released into the atmosphere was converted into carbon dioxide equivalents for direct comparison with EfW emissions.

[1] There are some non-gaseous emissions from the fossil component of the waste, particularly leachate.

6. The model was used to identify the ‘balance’ or point between energy from waste and landfill for a given composition of waste - the overall net efficiency of EfW plant required for a tonne of waste going to EfW to have the same carbon impact as that same tonne of waste going to landfill.
7. This balance point was examined for a range of theoretical waste compositions. It was found there was a very good, slightly non-linear, correlation (R^2 >0.99) between the biogenic carbon content of the waste and minimum efficiency of EfW plant required to match landfill. This allowed the sensitivity to underlying assumptions to be examined using a limited range of example compositions.
8. The sensitivity of the model output to the input assumptions was tested. As might be expected it was found to be highly sensitive to the marginal energy mix used to calculate carbon offset from generation and the level of landfill gas capture. It was sensitive to other parameters but these two were clearly the key factors.
9. Decreasing the carbon intensity of the background electrical energy mix was found to increase the biogenic content of waste required for a plant operating at a given efficiency, or alternatively increase the minimum efficiency of plant required to operate with a waste of a specific biogenic content. The sensitivity diminished with increasing biogenic content and there is a limiting value of biogenic content beyond which EfW is always superior to landfill in carbon terms regardless of efficiency (although high efficiency should still always be favoured for resource efficiency and economic reasons).
10. The limiting value of biogenic content was found to be dependent on the level of landfill gas capture. High capture rate required higher biogenic content for EfW to be superior to landfill. For a plant of given efficiency, increasing the level of landfill gas capture again led to a higher biogenic content being required for EfW to be superior. The marginal impact of a change was greatest at high capture rates. For a given biogenic content, increasing capture level increased the minimum efficiency of plant required.
11. Covariance of the two parameters showed there is no complex interaction between them.
12. Three scenarios were developed for electricity only EfW to look at the sensitivity of carbon outcomes to different assumptions over time. The carbon intensity of the offset energy was varied in line with DECC predictions for the marginal energy mix, which see a decarbonisation towards 2030, this was kept the same across the scenarios. The three scenarios were then developed based on the initial level of methane released from landfill as dictated by the capture rate. High methane (50% capture), central (60% capture) and low methane (75% capture). In all three scenarios the level of capture was modelled to increase asymptotically over time towards 80%.
13. Under all three scenarios, in the long term (by 2050), a high proportion of biogenic content (in the region of >70%) was required for electricity only generation. This could only be achieved by pre-treating the waste or much greater fossil plastics collection and recycling than is currently seen.

14. The average annual CO_2 savings over the plant lifetime for an EfW plant using waste with biogenic content of 61% were calculated for electricity only plants with efficiency ranging from 15% to 30%. For this comparison a 100 year window was considered, assuming the same waste was going to either management option for the first 25 years and that emissions from EfW would occur only during this period (planned plant lifetime) while during the overall 100 year period all potential emissions from landfill would occur.
15. In all scenarios there was an apparent cut off point beyond which an electricity only plant would have a lifetime carbon disbenefit. This occurred later and at lower efficiencies the lower the assumed methane capture rate.
16. Similarly there were cut off points where, despite overall lifetime benefits, at the end of the plant’s lifetime it would be a net carbon emitter relative to landfill and therefore there would be a carbon disbenefit in extending its life. These transitions happened earlier and at higher efficiencies than the overall lifetime disbenefits.
17. The nature of this analysis means that some net emissions in later years are being offset by earlier carbon savings. This means that while a 25 year plant lifetime might be valid, extension beyond this may not. An analysis of net emissions relative to landfill shows that higher biogenic content is required to extend a plant’s life beyond 25 years.
18. By convention biogenic carbon has been ignored in the modelling, however, some biogenic carbon that would be released in energy recovery is sequestered in landfill. We have modelled an approach that aims to reflect this sequestered component.
19. Including sequestered carbon significantly increases the efficiency of plant required for a given biogenic content. This conclusion is highly sensitive to the level of sequestration assumed. Reducing the assumed level of sequestration results in a significant drop in the biogenic content required for a given efficiency. This is due to its impact on three interlinked parameters – increasing the amount of methane assumed released from landfill; reducing the amount of biogenic carbon from EfW that should be counted; and reducing the apparent landfill gas capture rate. All of which favours EfW over landfill.
20. Comparison with other energy outputs gives different results due to the differing carbon intensity of the energy source being offset.
21. The carbon intensity of heat depends on the fuel source being displaced - oil or gas. In both cases this is lower than the current marginal electricity mix, however, unlike electricity it is expected to decarbonise much more slowly.
22. While earlier carbon benefits may be lower, heat continues to provide these for the lifetime of the plant.
23. As the model accounts for all of the carbon produced against electricity generation any additional heat use is ‘carbon free’. As such it was found that relatively little additional heat use (through combined heat and power) was sufficient to offset any disbenefits from later years of electricity production.

Giving overall lifetime benefits under all but the most challenging set of assumptions for EfW.

24. Transport fuels likewise offset higher carbon intensity fuel sources. Therefore transport fuels form waste can potentially provide lifetime carbon benefits with lower overall efficiencies/biogenic content than electricity alone provided the energy use during production is properly accounted for.

2. Aims

25. To develop a simple model that allows variation of the critical factors and assumptions which impact on the carbon based environmental case for using energy from waste, relative to the alternative of landfill, for residual waste.

26. Identify the balance point for this choice and understand how it is reliant on underlying assumptions.

27. Help determine what factors may need to be considered in order to ensure recovery of energy from residual waste remains environmentally superior to landfill (i.e. in line with the hierarchy) in the long term.

28. Other drivers such as practicality, economics or fuel security are important in determining the overall case for waste treatment choices, this model will not take these into consideration.

3. Introduction

29. It is recognised that there are a wide range of practical, economic and environmental factors that need to be considered in assessing the benefits of different waste management approaches. The carbon case is just one of the considerations in this decision making process but is an important one that tends to dominate the environmental case for energy from waste relative to landfill. Carbon will therefore be the focus of this report.

30. The carbon case for energy from waste being superior to landfill is based on the premise that the climate change impact, in terms of CO_2 equivalents, of producing energy from the waste is less than the potential impact from methane emitted if the waste were to go to landfill. The model can therefore be thought of as being in two parts:

- the potential carbon impact of producing energy from waste
- the potential carbon impact of landfilling that same waste

31. If the latter is greater then there is a carbon case that the waste should go to energy recovery rather than landfill and vice versa. The difference between the two halves of the model for a given set of circumstances determines which is the better choice in terms of greenhouse gas emissions. There are of course a number of other environmental issues to be taken into account when selecting between the two routes - some of which may tip the balance in the opposite direction depending on the relative magnitude of the carbon case and these other factors.

32. The discussion that follows considers energy recovery only from residual waste. For this purpose, residual waste is considered to be waste which cannot be beneficially recycled (or reused) for economic, environmental or practical reasons. We recognise that the ultimate goal is to minimise residual waste and that as a function of this, waste volumes and composition may change over time, but this does not fundamentally impact on the analysis below, although it may impact on the case for building residual waste infrastructure.

33. Although the model could potentially apply to residual waste of any type, our primary consideration is in relation to municipal solid waste (MSW) as the majority of plants in the UK currently burn this type of waste, or RDF derived from it. For ease we will refer to this type of waste as 'black bag' in reference to how it has been historically collected from households in the UK. However, in reality we are considering all residual municipal solid waste[2] however sourced.

34. A typical black bag of residual MSW will contain a mixture of different things, such as paper, food, plastic, clothes, glass and metal. Some of these wastes, e.g. food, will originally have come from biological sources, i.e. plants, and the carbon stored in them is known as biogenic carbon. Some of the waste materials, e.g. plastics[3], will have been made from fossil fuels such as oil and the carbon stored in them is known as 'fossil carbon'. Some of the wastes, e.g. clothes, will contain a mixture of biogenic and fossil carbon (e.g. cotton/polyester mixes), while other wastes will contain little or no actual carbon (e.g. metals). We need to understand if the carbon in the waste is biogenic or fossil in origin for two reasons: (i) they behave differently in landfill (plastic does not generally decompose) and (ii) biogenic and fossil carbon are counted differently in terms of how they are calculated to contribute to global warming[4]. Of the waste in our typical black bag, currently[5] somewhere between one half and two thirds of the carbon in waste is of biogenic origin.

35. 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[6] 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[7] 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.

36. The energy from waste plant will generate some energy (in addition to whatever it uses to run itself). This energy substitutes for energy that would otherwise

---

[2] We are also considering the current broad EU definition of MSW to include household and household like C&I waste.

[3] A small but increasing proportion of plastics are being made from biogenic sources. The model could in future be adapted to account for these releasing biogenic rather than fossil carbon in EfW and the likelihood of their decay to produce methane in landfill. However, as the output of the model depends on total biogenic carbon rather than its specific source this does not affect the conclusions. For simplicity where we refer to plastic this should be assumed to be fossil plastic.

[4] The atmosphere cannot distinguish between CO_2 released from a biogenic source versus a fossil source. However, in terms of considering overall climate impacts it is important they are accounted for and treated differently to avoid double counting. The IPCC have agreed conventions for doing this which are applied here.

[5] The composition of waste changes over time as consumption patterns, reuse, recycling and separate collection practices change.

[6] <3% would remain in the ash.

[7] In this context 'relatively recently' is considered to be decades (or for wood centuries) as opposed to the millennia which fossil materials have been locked underground.

need to be generated[8], thereby saving any fossil carbon dioxide that would have been released by that alternative generating source. This means that in our comparison some of the fossil carbon dioxide released by the energy from waste plant can be offset by the saving from the alternative generating source, reducing the overall impact. The more efficiently the energy from waste plant converts the waste to useful energy, the greater the carbon dioxide being offset and the lower the net emissions.

37. Alternatively, considering the landfill route, all the fossil carbon stays in the ground and doesn't break down. The fossil carbon is sequestered, as is potentially up to half of the biogenic carbon depending on the exact conditions in the landfill. However, some of the biogenic material does break down with the carbon converted to a mixture of carbon dioxide and methane, known as landfill gas. A large proportion of this landfill gas would be captured and burned, generating energy and offsetting alternative generation emissions. Burning landfill gas produces biogenic carbon dioxide which, as for energy from waste, is considered short cycle. Crucially however, some of the methane would escape into the atmosphere. As a very potent greenhouse gas even a relatively small amount of methane can have dramatic effect and be equivalent to a much larger amount of carbon dioxide (methane is around 25 stronger than CO_2 as a greenhouse gas[9]).

38. The carbon (equivalent) emissions from the two different routes are summarised in Diagram 1 below.

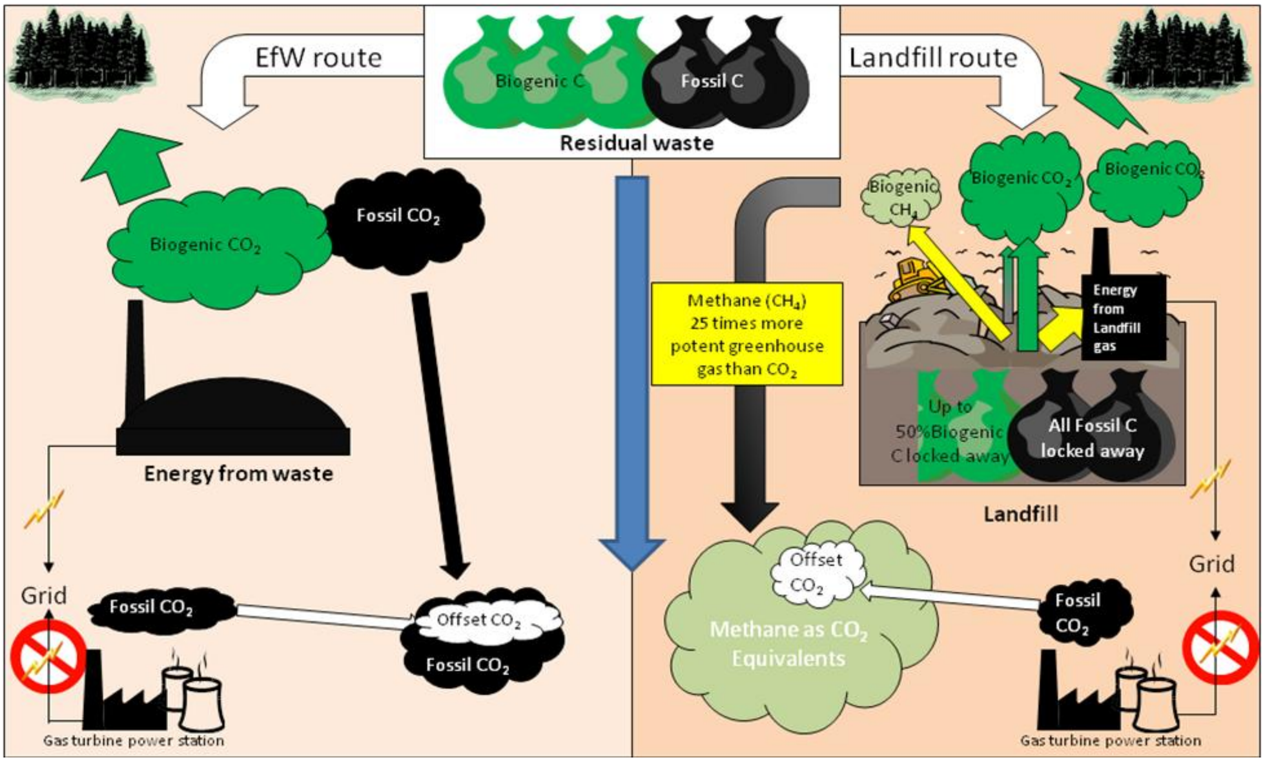
39. Crucially the negative carbon impacts of energy from waste come from the fossil component of the waste, while those from landfill originate from the biogenic material. Hence the relative proportions of fossil and biogenic material will have an important impact on which route is better and result in a balance point where the theoretical emissions are equal. The other key factor is clearly the carbon impacts of the energy being offset. The benefits of offsetting high carbon fossil energy will be greater than offsetting low carbon renewable energy.

40. This can be illustrated by considering the extreme cases. An energy from waste plant burning 100% fossil material, releasing its fossil CO_2, and offsetting only renewable energy would produce more CO_2 equivalents than landfilling the same 100% fossil waste where all the carbon would be locked away (i.e. zero emissions). Similarly an energy from waste plant burning 100% biomass producing only biogenic CO_2, which is conventionally discounted, while also offsetting a high fossil carbon generating source would clearly be better than that same biomass producing methane in landfill.

[8] The amount of energy offset is determined by what is considered to be the marginal energy mix at the time.

[9] The very latest update from IPCC has revised this value up to 34 times (http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_All.pdf). The majority of the modelling was conducted with the earlier figure of 25. This does have some impact on the numeric output of the model but does not dramatically affect the conclusions. The sensitivity of the model to this factor is discussed below.

Diagram 1. Emissions routes from landfill and EfW



41. This illustrates that if you could perfectly separate residual waste (that by definition cannot be beneficially recycled) into biogenic and fossil components, you would aim to recover energy from the biogenic component and landfill or otherwise sequester the fossil component[10]. In reality this is not possible hence the need to understand the impact of mixed waste.

42. A number of issues complicate both sides of the model but the fundamental point remains that residual waste is generally a mixture of biogenic and fossil. Therefore the balance of these components and the efficacy of how they are treated will determine whether energy recovery or landfill is the most appropriate solution for the waste.

43. Metal recovered and recycled from bottom ash can significantly add to the environmental benefits of EfW. It is beyond the scope of this model to consider this especially as, while it is commonplace, it is not necessarily always done. This should perhaps be considered as an additional route by which the balance point can be shifted.

44. Equally, both landfill and EfW emit greenhouse gases other than CO_2 and methane e.g. N_2O, again these have not been considered in this model and are more suited to detailed lifecycle analysis. The simplifications used mean that

[10] This is assuming there were not mechanisms which allowed environmentally sound recovery of the embedded carbon in the fossil component at the molecular level e.g. through depolymerisation (i.e. making new polymers from the waste was less carbon intensive than using virgin materials). There would then be the separate issue of whether this is recovery or 'molecular recycling'.

the values identified in the model should be considered illustrative rather than definitive. However, it would be expected that the trends demonstrated by the model would be maintained and it is from these that conclusions may be drawn.

4. Model development

45. As discussed above the model consists of an energy recovery side and a landfill side, with the overall output being determined by the balance of the two.

4.1. Assumptions

46. In developing the model we have had to make a number of assumptions. The rationale for these is described in the method below but they are listed here for ease.

47. For each waste material *stream* that make up the overall composition we have used values from the “Carbon Balances[11]” report and assumed constant:

- proportion biogenic carbon
- proportion fossil carbon
- calorific value

48. For wastes with a biogenic content:

- proportion of dissimible decomposable carbon (DDOC) – the proportion of the waste which is carbon that will actually decompose to landfill gas is taken from MelMod[12]
- all gases released from landfill are biogenic in origin

49. Default values for variables

- Carbon intensity of marginal energy mix: 0.373t/MWh (equivalent to CCGT)
- Landfill gas capture rate: 75%
- Waste composition: 2011 figures from MelMod, gives 61% biogenic

50. Fixed input values

- Proportion of methane in landfill gas: 50%
- Calorific value of methane: 50MJ/t = 13.89MWh/t
- Efficiency of landfill gas engine: 41%
- Proportion of methane oxidised in the cap: 10%

[11] Fisher K, Collins M, Aumônier S and Gregory B (2006), Carbon Balances and Energy Impacts of the Management of UK Wastes *Defra R&D Project WRT 237* Final Report, Table A1.61

[12] Brown K, Conchie S, Leech A (2012) MELMod-UK (Methane Emissions from Landfills Model - UK) 2012v1.1

- Proportion of landfill gas used in energy generation (not flared): 50%
- Equivalent warming potential of 1t of methane: 25 CO_2eq

51. In addition to these numerical assumptions it has been necessary to make a number of simplifications in order to keep the model manageable. The assumptions are listed in Table 1 below along with their potential impact on application of the model to the real world.

Table 1. Assumptions

Assumption	Implication
Metal recycling from EfW incinerator bottom ash is not occurring (this does occur in the majority of plants but to different levels).	The impact will be to underestimate the carbon benefits of EfW where recycling does occur. Recycling of metal from IBA can have a significant impact on the global warming impacts of EfW. For example, Burnley and Coleman (2012) estimated that recovering aluminium from IBA doubled the reduction in greenhouse gas emissions of the EfW system. Taking account of these impacts would have the effect of moving the “balance point” in favour of EfW.
The volumes of N_2O and other emissions have a negligible greenhouse impact relative to CO_2.	The impact will be to underestimate the negative impact of EfW. Detailed results data in the WRATE model indicates that with a typical UK residual waste composition approximately 4.5% of total direct greenhouse gas emissions from EfW are attributable to N_2O and there are no significant N_2O emissions from landfill. Taking these into account would move the balance point in favour of landfill.
All carbon is converted to CO_2 in EfW.	This will overestimate emissions as up to 3% of carbon can remain in the ash.
The carbon impacts of ash handling (negative from transport or positive from recycling to aggregate) are not considered.	The impact will depend on handling method.
The same total volume of CO_2 equivalents released will have the same impact regardless of the timescale over which release occurs.	Landfill emits CO_2e of methane over a much longer period of time than EfW releases CO_2 so this is likely to overestimate the relative impact of landfill.

4.2. Composition of waste

52. The key commonality between both sides of the model is the composition and mass of waste involved. The composition of the waste is one of the key variables to be examined, and the dependency on mass was removed by basing the calculations on 1 tonne of waste. Like-for-like composition was compared between the two sides of the model.

53. Care needs to be taken if considering refuse derived fuels. Comparing the relative benefits of burning or landfilling the fuel itself then the model is valid. However, comparing the fate of 1 tonne of residual waste where it undergoes some further separation to create the refuse derived fuel before burning, the loss of mass needs to be considered along with any carbon benefits of additional recycling. This requires a more life cycle approach and is beyond the scope of this model.

54. One tonne of waste does not have a constant carbon content as it varies depending upon the waste components. The relative proportions of biogenic and fossil carbon also depend upon the waste components, as do other important factors such as the calorific value.

55. One of the difficulties in developing this model was finding data sources that provide all of the information required in a single place based on a single set of assumptions and analysis. Unfortunately this was not possible and as a result, key data on composition, carbon content and calorific values had to be taken from two different sources. While the data where comparisons can be made between the two sources seem relatively self consistent, this is recognised as a weakness in the model.

56. For a simple model it is necessary to consider some average values of waste composition. Defra uses a model called MelMod to consider the potential carbon impacts of waste management. This model is also used by DECC for the Greenhouse Gas Inventory, so for consistency, average compositional data was taken from this model. The base case used was for predicted residual municipal waste in England 2011, though to a degree the starting point does not matter as one of the key purposes of the model is to enable variation of these components.

57. Unfortunately MelMod does not include information on the carbon content and calorific value of fossil waste components so a different data source was required for this information. This is provided by the report "Carbon Balances and Energy, Impacts of the Management of UK Wastes December 2006 (Annex A Table A1.26)[13]". While this is a relatively old report it is unlikely the

---

[13] Fisher K, Collins M, Aumônier S and Gregory B (2006), Carbon Balances and Energy Impacts of the Management of UK Wastes *Defra R&D Project WRT 237* Final Report, Table A1.61

http://www.fcrn.org.uk/sites/default/files/ERM_Carbon_balances_and_energy_impacts_of_waste.pdf
Original source material: AEA Technology, National Household Waste Analysis Programme NHWAP (1992/3), Phase 2 Volume 2. Department of Environment 1995.

carbon content and calorific values of the individual materials has changed significantly.

Table 2. Baseline residual waste composition

Waste stream	Predicted residual waste for England 2011 kt	Proportion of total residual waste	Proportion of total residual waste revised categories
Paper	1459.89	0.104	
Card	680.91	0.049	
Mixed Paper and Card	0.00	0.000	0.153
Plastics	1751.87	0.125	0.125
Textiles (and footwear)	567.17	0.041	0.045
Miscellaneous combustibles	593.48	0.042	0.063
Miscellaneous non-combustibles	1278.05	0.091	0.091
Food	4318.42	0.308	0.308
Garden	423.27	0.030	0.030
Soil and other organic waste	478.49	0.034	0.034
Glass	665.37	0.048	0.048
Metals, White Goods and Other Non-biodeg Products	228.62	0.016	0.016
Non-organic fines	207.93	0.015	0.015
Wood	373.77	0.027	0.027
Sanitary / disposable nappies	628.80	0.045	0.045
Furniture	285.34	0.020	
Mattresses	62.63	0.004	
Bulky household items	0.00	0.000	
	0.00	0.000	
Total	14004.00	1.000	1

58. To effectively utilise data from both reports some of the waste stream categorisations needed to be merged to provide a single set. The changes implied by this are set out below, and the revised compositional data shown in the final column of the table above.

- Paper and card are considered under a single mixed heading
- Furniture is included under miscellaneous combustible
- Mattresses have been added to textiles[14]

---

[14] While it is recognised that a major component of the weight will be metal the major combustible component will be textile.

4.3. Energy recovery model

59. The energy recovery model needs to consider a number of factors:

Calorific value of the waste

60. The calorific value of the waste is how much (chemical) energy is stored in the waste per tonne that could potentially be converted into useful electrical or heat energy when burned. Waste such as plastic has a high calorific value whereas other wastes such as kitchen waste that is very wet have much lower values. This is due to the water adding significantly to the weight while adding nothing in energy terms. Energy is used to convert all the water to steam during combustion. The data available uses gross calorific value (higher heating value). More details on comparison of gross and net calorific values can be found in **Annex 1**.

The efficiency of conversion of that calorific value into energy

61. In reality, not all of the energy stored in the waste can be practically realised. Each step in the system of burning waste, using the resultant heat to make steam and using this steam to drive a turbine results in significant loss of energy. The efficiency of conversion takes account of this. For the purpose of the model the efficiency is considered to be the proportion of the energy stored in the waste that actually gets converted into energy (heat and/or electricity) useable outside of the plant i.e. net of any parasitic loads[15]. It important to know how much useable energy is generated, as this energy can be considered to substitute for energy that would have been generated using other means.

Energy (EfW) = mass of waste x calorific value x efficiency

62. 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%. The difference that this makes is set out in more detail in **Annex 1**, together with information as to how an approximate conversion could be made between plant efficiencies calculated using NCV and GCV. Any comparison between the model and real plants needs to be based on efficiencies also calculated using gross CV (higher heating value).

63. This report and the model consider a wide range of potential plant efficiencies that would have lower net greenhouse gas emissions than landfill. However, in

[15] Parasitic load will primarily be the energy required to run the plant, but the concept could also easily be extended to include, for example, the energy required in a pre-treatment step for example to produce RDF.

reality EfW facilities will have to meet Best Available Techniques (BAT) derived on a case by case basis from the European BAT Reference Document (BREF Note) which covers the detailed technical requirements and which was published in 2006. Work on an update is not planned to start until 2014[16].

64. In 2009, the Environment Agency published guidance[17] for waste incineration based on the IPPC Directive. This has not been updated for the Environmental Permitting Directive. Whilst the efficiency figures apparently required are not particularly onerous for new build, there are several factors to consider including that BAT has to apply to existing as well as new plants. The Environment Agency sets out indicative BAT.

65. Importantly, recent planning inquiries have shown that for electricity only, a plant that is not classified as recovery (R1 status[18]) is unlikely to receive planning permission.

66. An efficiency of approximately 25.5%[19] is required to be classified as recovery (R1). The recovery of energy from waste is limited by boiler temperatures, steam pressures etc. to a potential maximum efficiency of approximately 33%, so there is a very narrow band of realistic efficiency values. If a higher thermal efficiency is required, useful heat will have to be provided, either alone or as combined heat and power (CHP), and the actual efficiency will be dependent on the heat load.

67. Therefore, while it is necessary for the model to include a wide range of theoretical efficiencies, in reality the window of attainable efficiencies in electricity only generation mode is quite narrow.

CO_2 offset through generation

68. 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[20] in line with HMT Green Book[21] guidance on appraisal

---

[16] http://eippcb.jrc.ec.europa.eu/reference
[17] How to comply with your environmental permit Additional guidance for: The Incineration of Waste (EPR 5.01); Environment Agency, March 2009.
[18] European Union, (2008), Waste Framework Directive https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/218586/l_31220081122en00030030.pdf
[19] Based on net CV and equivalent to approximately 21.4% efficiency based on gross CV using the conversion factor calculated in Annex 1.
[20] The marginal energy factor relates to the generation of an additional unit of grid electricity. There will be a range of different plants generating so the carbon intensity will be a mix of these. As this mixture will change with time so will the emissions factor. An alternative way of considering it is the carbon intensity of the plant you would build to deliver that same energy if you didn't use EfW. Currently this is approximately the same as CCGT hence its use as the baseline value, however, this factor should only be used as a guide - use of the marginal factor is the correct approach for detailed analysis.
[21] The Green Book: Appraisal and evaluation in central government https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent and supplementary DECC guidance: Valuation of energy use and greenhouse gas

and evaluation. This is currently approximately equivalent to combined cycle gas turbine (CCGT) using natural gas so this has been taken as the baseline value. However, this 'marginal energy' mix is expected to vary over time and is therefore one of the variable parameters in the model. Generating the energy from waste offsets the amount of CO_2 that would have been emitted by a CCGT to generate an equivalent amount of energy.

Fossil CO_2 offset (CCGT) = Energy produced (EfW) x CO_2 emitted per unit energy (CCGT)

69. Estimates of the CO_2 emitted per unit energy from CCGT vary. For the purposes of this model we use the value used by DECC of 373 kg/MWh or 0.373 t/MWh [22].

The Fossil CO_2 Emitted as a Result of Energy Recovery

70. Assuming the waste is fully combusted, all of the carbon in the waste would be converted to CO_2. The fossil CO_2 emitted is therefore directly proportional to the amount of fossil carbon in the waste and similarly for the biogenic CO_2. The factor of 44/12 is used to account for the relative atomic masses of carbon (C=12) and molecular mass of CO_2 (C=12, O=16, 12+(2x16)=44).

Fossil CO_2 (EfW) = mass of waste x proportion fossil C in waste x 44/12

71. The net fossil CO_2 emitted from EfW is therefore CO_2 emitted by the energy from waste plant minus the CO_2 emitted by a CCGT power station in order to produce the same useable energy.

Net fossil CO_2 = Fossil CO_2 (EfW) – Fossil CO_2 offset (CCGT)

The Biogenic CO_2 Emitted as a Result of Energy Recovery

72. Although this is conventionally omitted we wanted to be able to understand the impact of including it. As above,

Biogenic CO_2 (EfW) = mass of waste x proportion biogenic C in waste x 44/12

73. The values used in the model for calorific value and carbon content of different waste streams are summarised in Table 3 below as extracted from the Carbon Balances report.

emissions for appraisal https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[22] http://www.decc.gov.uk/en/content/cms/about/ec_social_res/iag_guidance/iag_guidance.aspx

Table 3. Waste composition data from the Carbon Balances report

	Total UK arisings (2003/4) kt	Proportion of total arisings	Proportion of waste fraction biogenic C by mass	Proportion of waste fraction fossil C by mass	Gross Calorific value MJ/kg
Paper and card	6462	0.18	0.32		12.6
Plastic film	969	0.03		0.48	23.6
Dense plastic	1313	0.04		0.55	26.7
Textiles	876	0.02	0.2	0.2	16
Absorbent hygiene products	807	0.02	0.15	0.04	8
Wood	1070	0.03	0.44		18.3
Other combustibles	771	0.02	0.19	0.19	15.6
Non-combustible	4262	0.12	0.035	0.035	2.8
Glass	2291	0.06	0.003		1.5
Ferrous metal	719	0.02			0
Non-ferrous metal	186	0.01			0
Kitchen waste	6095	0.17	0.14		5.3
Green waste	6282	0.18	0.17		6.5
Fine material	1395	0.04	0.07	0.07	4.8
WEEE	1394	0.04		0.16	7.6
Hazardous	374	0.01		0.3	12.4
Total	35266	1			

74. The categories used in this paper did not perfectly match those in the MelMod model. To achieve consistency, the following changes were made:

- Plastic film and dense plastic were merged into a single category with the carbon content and calorific values being a weighted average based on the arisings.
- The 'fines' category were split with the value for biogenic fines being assigned to the soils and other organic waste category and the fossil portion to non-organic fines.

75. Finally, a conversion factor of 1000/3600 [23] is applied to the calorific value to give it in megawatt hours per tonne of waste (MWh/t).

76. The final dataset used in the model is shown in Table 4 below.

[23] 1 tonne = 1000kg, 1MWh = 3600MJ

Table 4. Carbon content and calorific value by merged waste stream categories

Merged categories	Previous categories	Proportion biogenic C	Proportion fossil C	Calorific value MJ/kg	Calorific value MWh/t
Mixed Paper and Card	Paper, card	0.32		12.6	3.50
Plastics	Plastic film, Dense plastic		0.52	25.38	7.05
Textiles (and footwear)	Textiles	0.2	0.2	16	4.44
Miscellaneous combustibles	Other combustables	0.19	0.19	15.6	4.33
Miscellaneous non-combustibles	Non-combustable	0.035	0.035	2.8	0.78
Food	Kitchen waste	0.14		5.3	1.47
Garden	Green waste	0.17		6.5	1.81
Soil and other organic waste	Fine material (biogenic portion)	0.07		4.8	1.33
Glass	Glass	0.003		1.5	0.42
Metals, White Goods and Other Non-biodeg Products	Ferrous metal, Non-ferrous metal,				0.00
Non-organic fines	Fine material (fossil portion)		0.07	4.8	1.33
Wood	Wood	0.44		18.3	5.08
Sanitary / disposable nappies	Absorbant hygiene products	0.15	0.04	8	2.22

77. The calculation for the EfW half of the model, based on a theoretical 100% efficient plant, is shown in the table below. By varying the efficiency value in column (3) we can consider the balance for a range of plants

Table 5. Data set and calculations for the energy recovery half of the model

Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Prop. 1t	Calorific value MWh/t	Efficiency	Energy potential MWh =(1)x(2)x(3)	Prop. biogenic C	Mass of biogenic C =(1)x(5)	Mass of biogenic CO_2 released =(6)x44/12	Prop. fossil C	Mass of fossil C =(1)x(8)	Mass of fossil CO_2 released =(9)x44/12	Fossil CO_2 from CCGT offset =(4)x0.373	Net fossil CO_2 from EfW =(10)-(11)
Mixed Paper and Card	0.15	3.50	*1.00	0.54	0.32	0.05	0.18	0.00	0.00	0.00	0.20	-0.20
Plastics	0.13	7.05	*1.00	0.88	0.00	0.00	0.00	0.52	0.07	0.24	0.33	-0.09
Textiles (and footwear)	0.04	4.44	*1.00	0.20	0.20	0.01	0.03	0.20	0.01	0.03	0.07	-0.04
Miscellaneous combustibles	0.06	4.33	*1.00	0.27	0.19	0.01	0.04	0.19	0.01	0.04	0.10	-0.06
Miscellaneous non-combustibles	0.09	0.78	*1.00	0.07	0.04	0.00	0.01	0.04	0.00	0.01	0.03	-0.01
Food	0.31	1.47	*1.00	0.45	0.14	0.04	0.16	0.00	0.00	0.00	0.17	-0.17
Garden	0.03	1.81	*1.00	0.05	0.17	0.01	0.02	0.00	0.00	0.00	0.02	-0.02
Soil and other organic waste	0.03	1.33	*1.00	0.05	0.07	0.00	0.01	0.00	0.00	0.00	0.02	-0.02
Glass	0.05	0.42	*1.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	-0.01
Metals, Other Non-biodeg	0.02	0.00	*1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-organic fines	0.01	1.33	*1.00	0.02	0.00	0.00	0.00	0.07	0.00	0.00	0.01	0.00
Wood	0.03	5.08	*1.00	0.14	0.44	0.01	0.04	0.00	0.00	0.00	0.05	-0.05
Sanitary / disp nappies	0.04	2.22	*1.00	0.10	0.15	0.01	0.02	0.04	0.00	0.01	0.04	-0.03
Total	1.00			2.79		0.14	0.52		0.09	0.34	1.04	-0.70

*efficiency is included to be a potential variable in the calculation. It is set at the hypothetical value of 1 by default for the purpose of setting up the model, however, this is not intended to represent a realistic maximum for the actual value attainable.

78. The figures used for the model give the average calorific value of the mixed residual waste to be 2.79MWh/t, which is equivalent to around 10MJ/kg. The total percentage C in the waste is 23%. 61% of the carbon is biogenic in origin as therefore is the same proportion of the CO_2 emitted. All of these values are within the ranges commonly identified for mixed municipal waste.

79. Notably, if the biogenic proportion by simple mass balance of the waste, assigned by reference to the waste category (i.e. food 100% biogenic, textiles 50% biogenic 50% fossil etc) rather than a measure of the actual carbon content, then the apparent biogenic content of the waste would be much higher at around 67%. Understanding these differences is important when it comes to assessing the renewable energy potential. Calorific value and therefore energy produced is highly correlated to carbon content. A carbon-based measure of biogenic content would give a good indication of renewable energy potential, whereas a category based input measure would overestimate renewable energy potential.

80. The calorific value is slightly higher than some generally used, while the biogenic proportion is lower. This is self consistent as the fossil wastes such as plastics tend to have higher calorific values than the biogenic streams which have higher water content and correspondingly lower calorific values. The actual values determined for the example composition used to set up the model are unimportant, as one of the purposes of the model is to vary that composition and examine the effect.

81. From these figures it can also be concluded that for this composition of waste an overall conversion efficiency of greater than 33% (=100 x 0.34/1.04) would ensure that the EfW plant emitted less fossil CO_2 than CCGT generating the same energy. To emit less CO_2 overall, including biogenic, would require a conversion efficiency of 83% (=100 x ((0.52+0.34)/1.04)). The latter efficiency is probably not obtainable. However, effective use of CHP or ACT could easily reach the former, potentially making EfW with CHP as a power source sustainable compared to other fossil generation, without the need for offsetting landfill emissions (for this composition).

4.4. Landfill model

82. As with the energy recovery model, the landfill model needs to consider a number of factors:

- the proportion of carbon in the waste that actually degrades to give landfill gas
- the relative proportions of CO_2 and methane in landfill gas
- the level of landfill gas capture
- the quantity of energy generated from the methane in landfill gas and how much energy this would offset from an alternative fossil source
- the amount of methane naturally oxidised in the landfill
- the amount of methane released into the atmosphere
- the potency of methane as a greenhouse gas compared to CO_2

83. Conventionally, biogenic CO_2 emissions are disregarded. However, if these are included in the energy recovery part of the model, they should also be included in the landfill part.

84. All of the carbon contained within the fossil portion of waste can be considered to be locked away in landfill, as fossil-based plastics take a very long time to degrade. As a result, it is assumed it does not result in release of greenhouse gases. Biological processes within the landfill will degrade the biogenic portion of the waste. However, not all of the carbon in this biogenic portion will degrade to form CO_2 or methane and some, like the fossil carbon, will become locked away. The proportion of degradable carbon varies by material. This has been assessed for the development of the MelMod model. Values from MelMod have been used in this model and are summarised in Table 6 below.

Table 6. Data set from MelMod

	Proportion of waste that is biogenic C	Proportion of waste that is decomposable C	Proportion of waste in 1t	Mass of biogenic C in 1t	Mass of decomposable C in 1 t
Mixed Paper and Card	0.32	0.158	0.15	0.049	0.024
Plastics		0	0.13	0.000	0.000
Textiles (and footwear)	0.2	0.0667	0.04	0.009	0.003
Miscellaneous combustibles	0.19	0.0889	0.06	0.012	0.006
Miscellaneous non-combustibles	0.035	0	0.09	0.003	0.000
Food	0.14	0.0849	0.31	0.043	0.026
Garden	0.17	0.0872	0.03	0.005	0.003
Soil and other organic waste	0.07	0.0025	0.03	0.002	0.000
Glass		0	0.05	0.000	0.000
Metals, White Goods and Other Non-biodeg Products		0	0.02	0.000	0.000
Non-organic fines		0	0.01	0.000	0.000
Wood	0.44	0.1253	0.03	0.012	0.003
Sanitary / disposable nappies	0.15	0.043	0.04	0.007	0.002
Total			1.00	0.142	0.067

85. As can be seen from the table, under the assumptions in the MelMod model a significant proportion (just over 50%) of the biogenic carbon in the waste is not considered to be decomposable and therefore remains locked in the landfill.

Methane produced

86. Landfill gas produced by decomposition of biogenic waste is a mixture of methane and carbon dioxide. The proportions of each will be dependent upon the exact biological processes being undergone but a reasonable assumption would be that landfill gas is approximate 1:1 mix by volume.

87. In terms of this model this means that the decomposable proportion of the biogenic waste decomposes by a range of processes to give a mixture of CO_2 and methane. The mass balance of the different decomposition routes results in a 1:1 mixture by volume of CO_2 and methane. When differing molecular masses and densities are taken into account this means that the proportion of decomposable biogenic carbon by mass that becomes methane is also around 50%, the remainder is released as biogenic CO_2.

Table 7. Potential contribution to landfill gas by waste stream

	Mass of decomposable C in 1 t	Potential mass of CH_4 from decomposition =Mass of C x 0.5 x 16/12	Potential mass of CO_2 from decomposition =mass of C x 0.5 x 44/12
Mixed Paper and Card	0.024	0.016	0.044
Plastics	0.000	0	0
Textiles (and footwear)	0.003	0.0020	0.0055
Miscellaneous combustibles	0.006	0.0037	0.010
Miscellaneous non-combustibles	0.000	0	0
Food	0.026	0.017	0.048
Garden	0.003	0.0018	0.0048
Soil and other organic waste	0.000	0.000005	0.00016
Glass	0.000	0	0
Metals, White Goods and Other Non-biodeg Products	0.000	0	0
Non-organic fines	0.000	0	0
Wood	0.003	0.0022	0.0061
Sanitary / disposable nappies	0.002	0.0013	0.0035
Total	0.067	0.044	0.12

Methane released

88. It is assumed that all the CO_2 released in this way will find its way into the atmosphere, where it counts as biogenic CO_2 and is generally discounted in calculations. The methane can undergo a number of different fates, standard assumptions are:

- 75%[24] of the landfill gas, and therefore 75% of methane by mass is captured and burned. Of the gas captured around 50% is used to generate energy, the remainder is flared
- of the remaining 25%, 10% will be oxidised to CO_2 before it can be released into the atmosphere - this is equivalent to 2.5% of the overall methane
- the remaining 22.5% of methane is released into the atmosphere

89. For the purposes of the model these are the baseline figures used, however the model is designed in such a way that the proportion of landfill gas captured can be varied with a consequential impact on the amount of methane released into the atmosphere.

Methane released = tot. methane x (1-prop. methane captured) x (1-prop. methane oxidised)

90. For 1 tonne of methane using the baseline figures above

Methane released = 1 x (1-0.75)*(1-0.1)

= 1 x 0.25 x 0.9

=0.225

i.e. 22.5%

91. As with the CO_2 produced as part of the landfill gas, CO_2 produced from combustion of methane captured as landfill gas or natural oxidation is assumed to be released into the atmosphere and counted as biogenic short cycle $CO_{2.}$ Therefore it is not included in calculations unless biogenic emissions are being specifically considered.

Energy from landfill gas

92. The methane captured as landfill gas is assumed to be combusted to produce energy or flared. The amount of energy produced will depend upon the calorific value of the gas and the efficiency of conversion to usable energy.

93. For the purposes of the model the methane in landfill gas is assumed to have calorific value of 50MJ/kg with an electrical conversion efficiency of 41%. Over the lifetime around 50% of this will be flared with the remainder used for energy generation:

Energy (landfill) = mass of methane x proportion used for generation x calorific value x efficiency

[24] This is the estimated lifetime capture rate. The value of 75% is that currently used by Government for Greenhouse Gas Inventory and other purposes. A further discussion on landfill gas capture rate can be found in **0**.The sensitivity of the model to this value is examined later.

94. This gives a generating capacity of 2.8MWh per tonne of methane.

Carbon offset from generation

95. It is assumed that the source of energy being replaced is the same as for the EfW side of the model, i.e. the marginal energy mix. As noted above the baseline value is taken as being approximately equivalent to combined cycle gas turbine (CCGT) using natural gas. Generating the energy from waste offsets the amount CO_2 that would have been emitted by a CCGT to generate an equivalent amount of energy. As with the EfW side of the model this is considered to be a key variable.

$$tCO_2 \text{ offset (CCGT)} = \text{Energy produced (landfill)} \times CO_2 \text{ emitted per unit energy (CCGT)}$$

CO_2 Equivalents released

96. The 22.5% of the methane remaining is assumed to be released into the atmosphere where it acts as a greenhouse gas. The relative potency of methane as a greenhouse gas is a matter of some debate. For some time it has been considered to be 21 times more potent than CO_2, however, more recently 25 times has become the more accepted figure based on the IPCC estimates. For the purposes of the model the default is the most recent assessment, 25, although this can be varied to assess the sensitivity. The methane emissions can therefore be converted into equivalent tonnes of CO_2 (CO_2e) by multiplying the tonnes of methane by 25.

$$tCO_2e = \text{t methane} \times 25$$

Net landfill emissions as CO_2e

97. The net CO_2 emissions from landfill can therefore be calculated as:

$$CO_2e \text{ (landfill)} = tCO_2e \text{ (methane)} - tCO_2 \text{ (CCGT)}$$

Or, if all biogenic emissions are counted:

$$CO_2e \text{ (landfill)} = tCO_2e \text{ (methane)} - tCO_2 \text{ (CCGT)} + tCO_2 \text{ (oxidation)} + tCO_2 \text{ (combustion)} + tCO_2 \text{ (decomposition)}$$

98. Based on these calculations the data for this composition of residual waste is shown in Table 8 below.

Table 8. Data and calculations for the baseline landfill component of the model

Column number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Prop. 1t	Proportion decomposable C	Mass of decomposable C in 1 t (1) x (2)	Mass of CH_4 (3) x 0.5 x 16/12	Mass of CO_2 (3) x 0.5 x 44/12	Mass of methane captured (4) x 0.75	CO_2 from methane burned (6) x 44/16	Energy from methane burned 2.84 x 0.5 x(6)	CO_2 offset from energy generated 0.382 x (8)	Mass of methane oxidised (4) x (1-0.75) x 0.1	CO_2 from oxidation (10) x 44/16	Methane released (4) x (1 -0.75 -((1-0.75) x 0.1))	CO_2e of methane (12) x 25x	Net CO_2e emitted (13)-(9)
Mixed Paper and Card	0.15	0.158	0.0242	0.0161	0.044	0.0121	0.0332	0.034	0.0132	0.00040	0.00111	0.0036	0.091	0.077
Plastics	0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Textiles (and footwear)	0.04	0.067	0.0030	0.0020	0.005	0.0015	0.0041	0.004	0.0016	0.00005	0.00014	0.0004	0.011	0.010
Miscellaneous combustibles	0.06	0.089	0.0056	0.0037	0.010	0.0028	0.0077	0.008	0.0030	0.00009	0.00026	0.0008	0.021	0.018
Miscellaneous non-combustibles	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Food	0.31	0.085	0.0262	0.0175	0.048	0.0131	0.0360	0.037	0.0143	0.00044	0.00120	0.0039	0.098	0.084
Garden	0.03	0.087	0.0026	0.0018	0.005	0.0013	0.0036	0.004	0.0014	0.00004	0.00012	0.0004	0.010	0.008

Column number	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Prop. 1t	Proportion decomposable C	Mass of decomposable C in 1 t (1) x (2)	Mass of CH_4 (3) x 0.5 x 16/12	Mass of CO_2 (3) x 0.5 x 44/12	Mass of methane captured (4) x 0.75	CO_2 from methane burned (6) x 44/16	Energy from methane burned 2.84 x 0.5 x(6)	CO_2 offset from energy generated 0.382 x (8)	Mass of methane oxidised (4) x (1-0.75) x 0.1	CO_2 from oxidation (10) x 44/16	Methane released (4) x (1 -0.75 -((1-0.75) x 0.1))	CO_2e of methane (12) x 25x	Net CO_2e emitted (13)-(9)
Soil and other organic waste	0.03	0.003	0.0001	0.0001	0.0	0.0	0.0001	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glass	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Metals, Other Non-biodeg Products	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-organic fines	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.03	0.125	0.0033	0.0022	0.006	0.0017	0.0046	0.005	0.0018	0.00006	0.00015	0.0005	0.013	0.011
Sanitary / disp. nappies	0.04	0.043	0.0019	0.0013	0.004	0.0010	0.0027	0.003	0.0011	0.00003	0.00009	0.0003	0.007	0.006
Total	1		0.0669	0.0446	0.123	0.0335	0.0920	0.096	0.0365	0.00112	0.00307	0.0100	0.251	0.214

99. The one component missing in the landfill model is time. Whereas all the CO_2 from an energy from waste plant is emitted immediately at the time of combustion the methane released from landfill appears in the atmosphere over an extended period of time. This is particularly challenging to model and beyond the scope of this work. This model therefore compares only the total CO_2e emissions and assumes the same equivalent volume emitted from either source will have the same long term impact. This is a simplification but one that is often necessarily used.

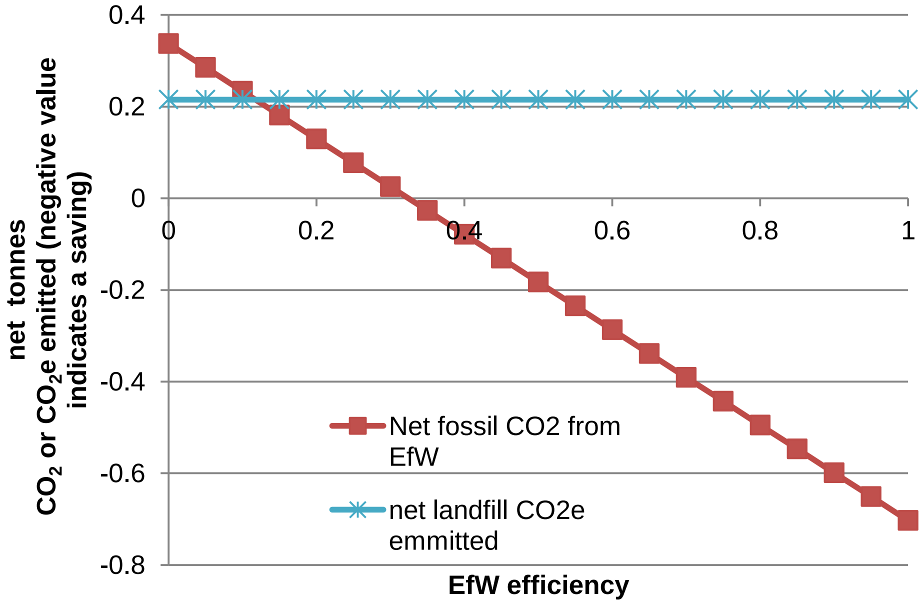
5. The combined model

100. In its simplest form the combined model is the difference between the two components. For the waste composition above the net fossil CO_2 emissions from EfW are -0.73tCO_2 (minus indicates a saving) and those from landfill are 0.215 tCO_2e so for the overall EfW process there is a saving of -0.73-0.215 = -0.945 tCO_2e indicating a significant carbon saving from EfW compared to landfill, as one would expect in the hypothetical case of 100% efficient EfW. In reality EfW efficiencies are much lower than this and thus the balance of carbon savings is more subtle and sensitive to some of the key parameters being modelled here.

101. Of greater interest is the balance point in terms of efficiency at which EfW becomes the same as landfill. This will be dependent on the composition of the waste. At a constant composition it can be determined by applying a linear reduction to the efficiency of energy production. This reduces the CO_2 offset from alternative sources so the overall net impact becomes the same as landfill i.e. in this example at what efficiency is the net impact of EfW equal to the emissions of 0.215tCO_2e from landfill. For this composition and assumption set it turns out this would require a net efficiency of 11.7%, about half that of a typical moving grate incinerator.

102. The next step is to examine the sensitivity of the model to different input parameters and assumptions and the efficiency required to deliver the environmental benefits across a range of different waste compositions.

Chart 1. Variation in CO_2e emissions from EfW and landfill with EfW plant efficiency for the same tonne of waste



5.1. Sensitivity analysis

103. There are a number of different assumptions underpinning the model so it is important to understand how varying these affect the model outputs.

104. The impact of different assumptions is also likely to be different depending of on the composition of the waste as factors such as landfill gas capture rate would be expected to be much more important for high biogenic content. To examine this three different theoretical waste compositions were developed for use in the model, set out in Table 9 below. The compositions were developed using simple manipulation of the proportions of the primary biogenic waste streams to give a linear change in biogenic content rather than to exemplify any particular real world composition. The compositions were:

- the baseline composition discussed above with around 60% biogenic content
- a composition containing around 50% biogenic content developed by halving the mass of paper, food, garden waste and wood in the baseline composition and then normalising the new proportions back to 1 tonne
- a composition containing around 40% biogenic content similarly developed by reducing paper, food, garden waste and wood to 25% of the levels in the baseline composition and then normalising the new proportions back to 1 tonne

Table 9. Sample compositions for sensitivity analysis

	Composition approx 60% biogenic	Composition approx 50% biogenic	Composition approx 40% biogenic
Mixed Paper and Card	15.3%	10.6%	6.3%
Plastics	12.5%	17.3%	20.5%
Textiles (and footwear)	4.5%	6.2%	7.4%
Miscellaneous combustibles	6.3%	8.7%	10.3%
Miscellaneous non-combustibles	9.1%	12.6%	14.9%
Food	30.8%	21.3%	12.6%
Garden	3.0%	2.1%	1.2%
Soil and other organic waste	3.4%	2.4%	5.6%
Glass	4.8%	6.6%	7.8%
Metals, White Goods and Other Non-biodeg Products	1.6%	2.3%	2.7%
Non-organic fines	1.5%	2.1%	2.4%
Wood	2.7%	1.8%	1.1%
Sanitary / disposable nappies	4.5%	6.2%	7.3%
Total	100.0%	100.0%	100.0%
Actual % of C of biogenic origin	60.7%	48.5%	39.7%
Total Carbon	23.4%	24.7%	25.0%
CV MWh/t	2.79	3.01	3.11

105. The parameters being examined and key data ranges are set out in Table 10 below. Each parameter is independently varied for each of the three compositions. The output measure is the minimum net efficiency required for EfW to be better than landfill based on EfW fossil only emissions.

106. The ranges were selected to include the likely extremes for each of the variables and also to include an appropriate number of intermediate points. This means that some of the ranges tested are quite large, for example landfill gas capture, where a broad range of figures are quoted in the literature while others are quite small e.g. the potency of methane as a greenhouse gas.

107. The results of the analysis are summarised in Table 11 below in relation to the sensitivity to the changes of the net efficiency of EfW required to be better than landfill.

Table 10. Parameters being independently varied for sensitivity analysis

Parameter being independently varied	Reason for likely variance	Range examined (baseline in bold)	Rationale for range selection
Carbon intensity of displaced energy source	The marginal energy source may change over time	**0.373**, 0.300,0.250, 0.200, 0.150 t/MWh	Background/marginal energy mix expected to reduce in carbon intensity over time
Proportion of decomposable C going to methane	Essentially varying the composition of landfill gas	0.4, **0.5**, 0.6	Values quoted tend to be in the range 40-60% methane
Proportion of methane captured	Landfill gas capture estimates vary significantly depending on the age and type of landfill	0.85, 0.8, **0.75**, 0.7, 0.65, 0.6, 0.55, 0.5, 0.45, 0.40	Baseline estimate of 75% is considered towards likely maximum so range weighted to lower values
Efficiency of landfill gas engine	Range of different engines exist	0.51, **0.41**, 0.31	10% either side of baseline
Proportion of landfill gas used in generation (not flared)	Range of estimates exist for energy use /flaring rate	0.7, **0.5**, 0.3	20% either side of baseline
Proportion of methane oxidised	Range of values exist	0.2, 0.15, **0.1**, 0.05	
Global warming potential of methane	Range of values quoted in literature	**25,** 23, 21	From latest value of 25 to previous estimates of 23 and 21
Calorific value of waste	Different estimates exist	Carbon balances WRATE model	
C content of waste	Different estimates exist	Carbon balances WRATE model	

Table 11. Outcome of sensitivity analysis for each of the parameters varied

Parameter varied	Change applied (% variation cf baseline)	Difference in net EfW efficiency required between extremes (% change cf baseline)			Comments
		At 60%	At 50%	At 40%	
Carbon intensity of displaced energy source	0.373 to 0.15 t/MWh (60%)	0.12 (+105%)	0.35 (+134%)	0.51 (+141%)	**Highly sensitive**. At low biogenic content decreasing the carbon intensity of the energy mix significantly increases the efficiency of EfW required. At high biogenic content decreasing marginal carbon intensity also increases the efficiency required but to a smaller extent.
Proportion of decomposable C going to methane	0.4 to 0.6 (40%)	-0.083 (-22%)	-0.061 (-13%)	-0.044 (-8%)	**Sensitive** at high biogenic. Increasing the proportion of carbon decomposing to methane reduces the EfW efficiency required with the greatest impact with higher biogenic content.
Proportion of methane captured	0.85-0.4 (60%)	-0.45 (-387%)	-0.34 (-129%)	-0.25 (-67%)	**Highly sensitive.** Reducing the proportion of landfill gas captured significantly reduces the efficiency of EfW required. Most sensitive at high biogenic content.
Efficiency of landfill gas engine	0.51-0.31 (50%)	-0.017 (-4%)	-0.012 (-2.5%)	-0.009 (-1.6%)	**Insensitive**. Slight reduction if the landfill gas engine is less efficient. Within the likely range the model is insensitive.
Proportion of landfill gas used in generation	0.7-0.3 (80%)	-0.027 (-6.5%)	-0.020 (-4%)	-0.015 (-2.5%)	**Insensitive**. Slight reduction if less landfill gas is used for generation (more flared). Within the likely range the model is insensitive

Parameter varied	Change applied (% variation cf baseline)	Difference in net EfW efficiency required between extremes (% change cf baseline)			Comments
		At 60%	At 50%	At 40%	
Proportion of methane oxidised	0.2-0.05 (150%)	-0.04 (-10%)	-0.03 (-6%)	-0.022 (-4%)	**Insensitive.** Slight reduction in EfW efficiency required if less of the methane is oxidised
Global warming potential of methane	25-21 (16%)	0.039 (-9%)	0.029 (-6%)	0.021 (-4%)	**More sensitive at high biogenic content.** Increase in EfW efficiency required if the warming potential of methane is assumed to be lower
Calorific value of waste	Carbon balances - WRATE	0.022 (5%)	0.041 (8%)	0.051 (9%)	**More sensitive at low biogenic content**. Slight increase at high biogenic content and greater increase at low biogenic content. This is consistent with WRATE data having slightly higher calorific values for food and garden waste and lower for plastics
C content of waste	Carbon balances - WRATE	-0.01 (-2.5%)	-0.013 (-2.5%)	0.015 (-2.5%)	**Insensitive**. The values only differ marginally between the two data sets

108. The analysis above shows that the key factors in determining the environmental benefits of EfW in terms of the relationship between the efficiency of the EfW plant and the biogenic content of the waste are the background marginal energy mix being offset and the amount of methane being released from landfill (driven by the level of capture and amount produced).

109. Factors such as the exact data set used to represent the calorific value of the waste and carbon make up or efficiency of energy generation from landfill are much more marginal – within the range of variation between the data sets available. Therefore while potentially having an impact on marginal cases it is reasonable to adopt a consistent set of these parameters. For all subsequent analysis we will use the baseline values set out above.

5.2. Varying the composition of waste

110. One of the key aims in developing this model was to understand how varying the composition of the waste input to EfW impacted on the environmental case.

111. As illustrated in the sensitively analysis above the model allows variation in the various components of the waste. This is done by making a change to the mass of a type of waste in the reference composition and then normalising the new composition back to 1 tonne. The example of halving the food waste going to EfW is illustrated in Table 12 below.

Table 12. Example change in relative composition of 1 tonne of waste by altering the absolute amount of a waste stream

	Reference composition	Composition with mass of food waste halved	Revised composition of 1 tonne
Mixed Paper and Card	0.1528	0.1528	0.1807
Plastics	0.1250	0.1250	0.1479
Textiles (and footwear)	0.0449	0.0449	0.0531
Miscellaneous combustibles	0.0627	0.0627	0.0741
Miscellaneous non-combustibles	0.0912	0.0912	0.1078
Food	0.3083	0.1541	0.1822
Garden	0.0302	0.0302	0.0357
Soil and other organic waste	0.0341	0.0341	0.0403
Glass	0.0475	0.0475	0.0561
Metals, White Goods and Other Non-biodeg Products	0.0163	0.0163	0.0193
Non-organic fines	0.0148	0.0148	0.0175
Wood	0.0266	0.0266	0.0315
Sanitary / disposable nappies	0.0449	0.0449	0.0530
Total mass	1	0.8458	1
% C of biogenic origin	60.73		56.75
Calorific value MWh/t	2.79		3.03

112. As can be seen the halving of the total mass of food waste results in less than halving the proportion of food waste in a typical 1 tonne mixture but also an increase

in the proportion of all the other components. The overall number of tonnes of waste available will of course be reduced. This has an impact on the biogenic carbon content and the calorific value of the waste. The former goes down as a purely biogenic source is being removed while the latter goes up as the calorific value of food waste is relatively low due to the high water content.

113. In order to examine the impact of changing composition on the model a range of example compositions were developed. A number of these are somewhat arbitrary, designed to examine how the model performs across the full range of values rather than to reflect possible real world compositions[25], for example a linear reduction in waste with a biogenic component. Others were based on potentially more realistic impacts of policy such as removing food waste, or reduced wood waste, or waste of certain types to EfW increasing due to landfill bans. Also included were the two extremes of no biogenic waste and 100% biogenic waste. These are summarised in Table 13.

Table 13. Example compositions modelled

Composition	Proportion of C in the waste that is biogenic (%)	CV (MWh/t)	EfW net efficiency required to be better than landfill
Baseline	60.73	2.79	0.12
80%* of baseline biogenic waste	56.7	2.90	0.16
60%* of baseline biogenic waste	51.1	3.07	0.22
40%* of baseline biogenic waste	42.7	3.36	0.31
20%* of baseline biogenic waste	28.5	3.94	0.46
No biogenic waste	0	5.77	0.72
No fossil waste	100	2.02	-0.39
No food	51.8	3.38	0.24
No food, no garden waste	50.54	3.44	0.25
No garden, 20% food, 20% wood	50.33	3.22	0.24
No textiles	61.6	2.71	0.10
No inert non combustible material (glass, metal etc)	61.0	3.19	0.11
No plastics	84.1	2.18	-0.16
20% paper/card, 50% plastics, 30% food, 10% garden, textiles, glass and metal (good recycling area)	53.9	2.85	0.22
Plastic and paper with contaminants of food at 10% (RDF from an MBT process)	45.0	4.73	0.28
No wood	58.7	2.73	0.13
Double wood (e.g. if landfill restriction)	62.6	2.85	0.10

[25] It is relatively straightforward to develop new compositions for the purposes of theoretical modelling. The ability to do so in terms of real world interventions is much more limited. The composition of residual waste is dictated by the composition of arisings and the collection, reuse and recycling systems it is subject to. Introduction of new regimes such as separate collection of plastic or the use of MBT type processes could be used to manipulate the composition but they would be unlikely to deliver some of the more extreme example compositions being modelled.

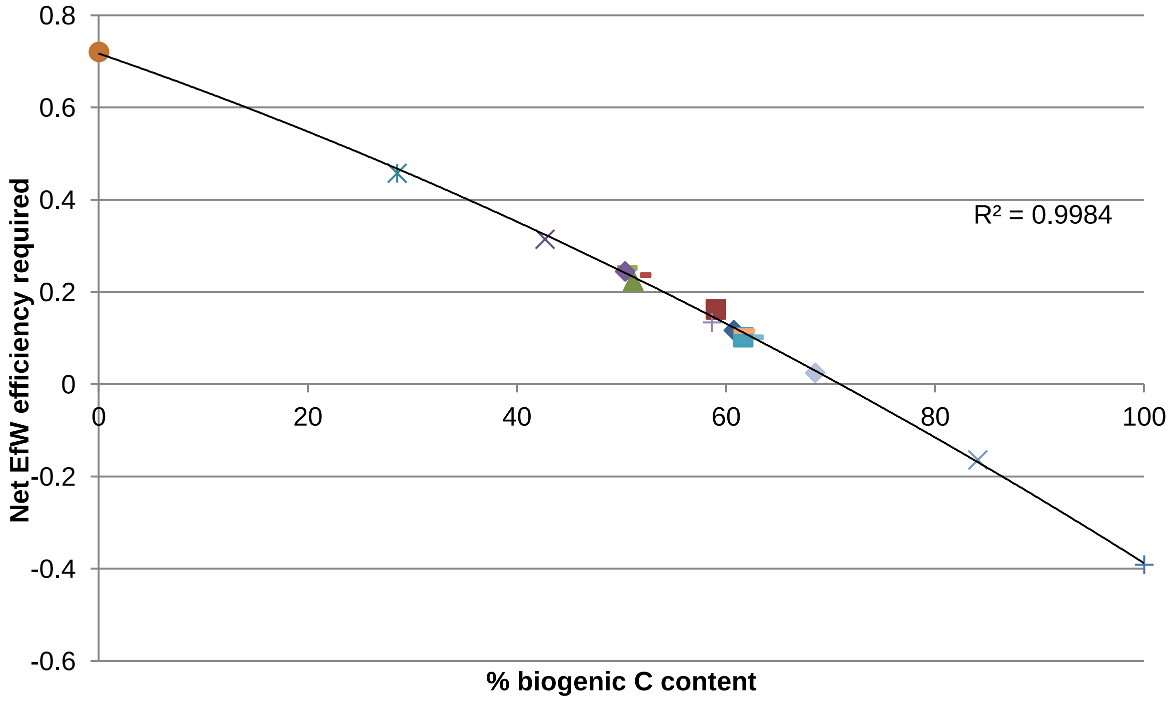
Composition	Proportion of C in the waste that is biogenic (%)	CV (MWh/t)	EfW net efficiency required to be better than landfill
Double wood and double textiles	61.7	2.91	0.12
Reducing each component by a randomly generated percentage	68.5	2.55	0.025

*all wastes with a mix of biogenic and fossil e.g. textiles were included in the reduction

114. The different compositions resulted in a wide range of biogenic content, CV and efficiencies required for EfW to be better than landfill. For a couple of compositions the model produces a negative value for the efficiency of the plant required. This is because for these compositions the mass of fossil carbon emitted from the EfW plant is less than the carbon equivalents emitted by landfill without needing to take into account the energy generated offsetting other sources. In theory combustion of waste with these compositions without energy recovery would be environmentally justifiable on carbon grounds but would clearly be a waste of a valuable energy source and thus highly undesirable.

115. The biogenic composition has been plotted against the minimum net efficiency required for EfW to be better than landfill. Across the range of compositions it is clear that the model produces a highly correlated relationship, albeit slightly non-linear.

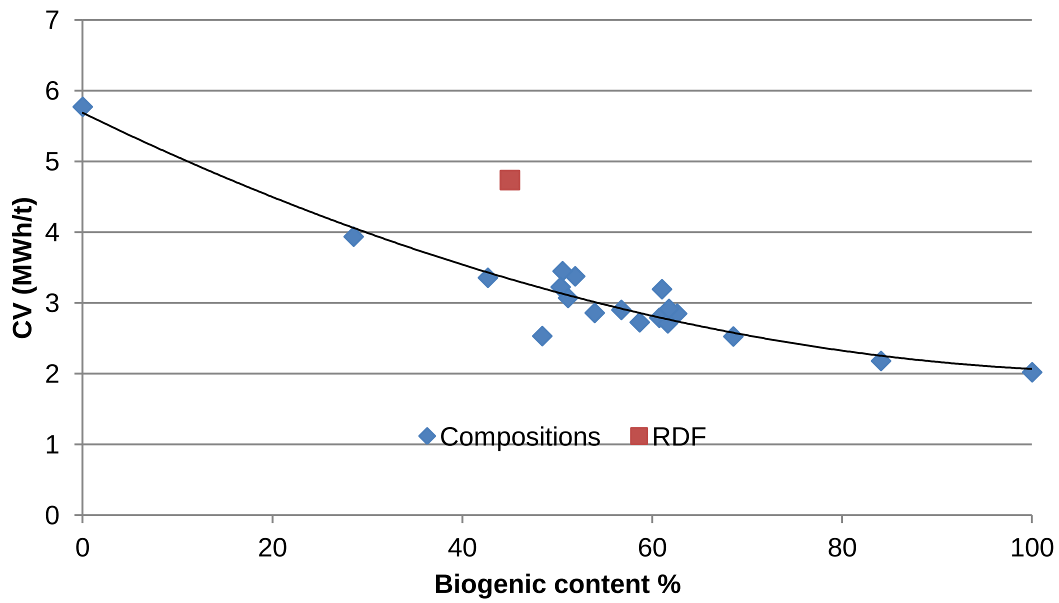
Chart 2. Net efficiency of EfW required as a function of biogenic C content of a range of waste compositions



116. There is some deviation from the trend albeit relatively small for certain compositions of wastes particularly where food is significantly reduced relative to other waste types, tending to give a slightly higher than expected efficiency requirement for the biological content. This is probably due to food having the highest proportion of decomposable carbon of all the waste types and therefore having a proportionally greater impact on methane emissions relative to its calorific value. However, even with these variations the correlation is still very good (R^2 = 0.99). Notably the randomly generated composition also falls on the trend line.

117. A plot of calorific value against biogenic content (Chart 3) also produces a reasonably consistent trend with one notable outlier relating to the composition designed to mimic a paper/plastic RDF. This is due to most biogenic wastes having relatively high moisture content and therefore relatively low calorific value, paper being the exception.

Chart 3. Calorific value of waste as a function of biogenic content of a range of waste compositions



118. The level of consistency in the trends produced by the model means that general conclusions regarding the impact of changes in key variables such as the rate of landfill gas capture can be reliably examined using a relatively small range of example compositions. To this end the first ten compositions in the table above have been used to examine the impact on the trend of changes to key variables in more detail. These compositions were chosen to give a good range of variation in biogenic content as well as a few example compositions that might appear slightly off the trend where food in particular has been reduced.

5.3. Changing the marginal electricity mix

119. One of the variables that showed significant sensitivity across a range of reasonable values was the marginal energy mix in terms of its carbon intensity (tCO_2/MWh). Up to now we have used the comparator of CCGT to estimate the CO_2 offset from

energy generation. More correctly we should use the marginal energy mix which represents the carbon intensity of generating an additional kW of electricity. Currently this is comparable to CCGT as this is the marginal technology, however, as renewable energy and nuclear make a greater contribution to the marginal energy mix this will change and the result will be a significant drop in the carbon intensity of the marginal energy mix.

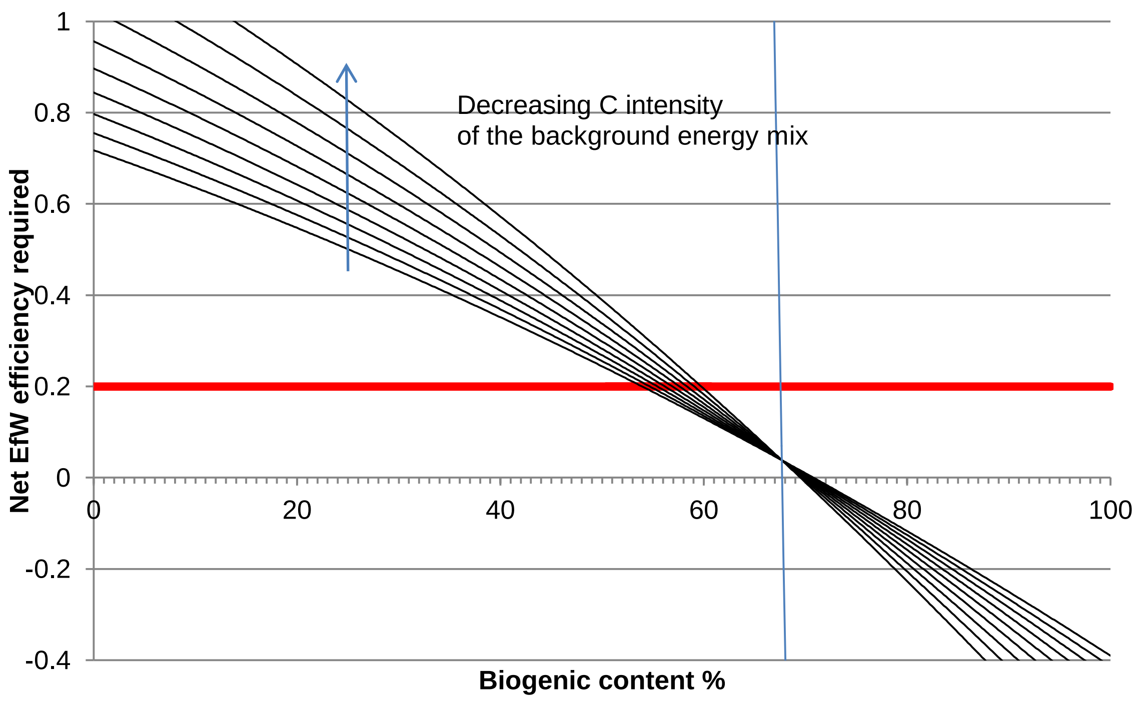
120. The impact of changing this marginal carbon intensity on the efficiency required from EfW was examined using a range of different values set out in Table 14 and the range of compositions outlined above. All other starting parameters were the same as the baseline model.

Table 14. Changing the C intensity of offset energy

Proportion of baseline C intensity	C intensity t/MWh
1	0.373
0.95	0.354
0.9	0.336
0.85	0.317
0.8	0.298
0.75	0.280
0.7	0.261
0.65	0.242
0.6	0.224
0.001 (equivalent to 0 – to avoid Div0 errors, all non-fossil)	0.00037

121. The output from the model for these different values is shown in Chart 4 below.

Chart 4. Impact of changing energy offset on the efficiency of EfW as a function of biogenic C content of a range of waste compositions



122. As expected the efficiency of EfW plant required varies as the marginal electricity carbon intensity changes. As can be seen from Chart 4 there is a static point where the efficiency required is independent of the marginal electricity carbon intensity. This will be the biogenic content at which the energy offset by EfW is the same as the energy offset by generation from landfill gas. Taking the extreme value of zero carbon intensity of the marginal electricity mix the trendline appears vertical at the static point (blue line), which for this set of baseline assumptions occurs at a biogenic content of around 68%.

123. For compositions with a biogenic content to the left of this point (lower than 68%) decreasing the marginal electricity carbon intensity increases the efficiency of energy from waste plant required to outperform landfill whereas for compositions to the right (greater than 68%) the opposite is true.

124. Under this set of assumptions, considering an EfW plant with a net efficiency of 20% (red line) it can be seen that, with the current carbon intensity of CCGT at 0.373t/MWh, waste with a biogenic content of greater than around 54% would be better going to EfW than landfill. But as the marginal electricity carbon intensity reduces, the minimum biogenic content required increases to e.g. 60% at a marginal electricity C intensity of 0.224t/MWh (60% of current). At a zero marginal electricity C intensity this would reach the 68% biogenic content limit.

125. A plant with 60% efficiency would be able to deal with lower biogenic content waste, around 14% with a marginal electricity mix of 0.373t/MWh, but this will be much more sensitive to changes in the marginal electricity mix moving to around 39% biogenic content at a marginal electricity C intensity of 0.224t/MWh (60% of the current value). However, it will be subject to the same limiting value of 68% biogenic content and except at this extreme will always be able to accept lower biogenic content waste than a lower efficiency plant.

126. The static point is above zero efficiency (around 0.025). To the right of this point as the carbon intensity decreases the biogenic content required for EfW to be better than landfill also decreases. The maximum biogenic content required is therefore around 71% at the current marginal electricity C intensity of 0.373t/MWh. Using this baseline set of assumptions EfW will always be better than landfill regardless of marginal electricity mix or EfW plant efficiency for waste compositions of above 71% biogenic content.

127. The slope of the trendline is dependent on the marginal energy mix being offset. As there is inherently a static point for the composition where the energy from EfW matches that from landfill the trendline ‘rotates’ around this point as the background intensity decreases. The lower the background carbon intensity the steeper the line. The lower the biogenic content of the waste then the net EfW efficiency required to favour EfW over landfill will be much more sensitive to changes in the comparative marginal energy mix.

128. This example considered electricity only. There will be a similar marginal energy mix for heat and transport fuels. While the absolute values will be different the expected trend would be the same – as the marginal energy carbon intensity decreases the minimum efficiency required for EfW to outperform landfill will increase.

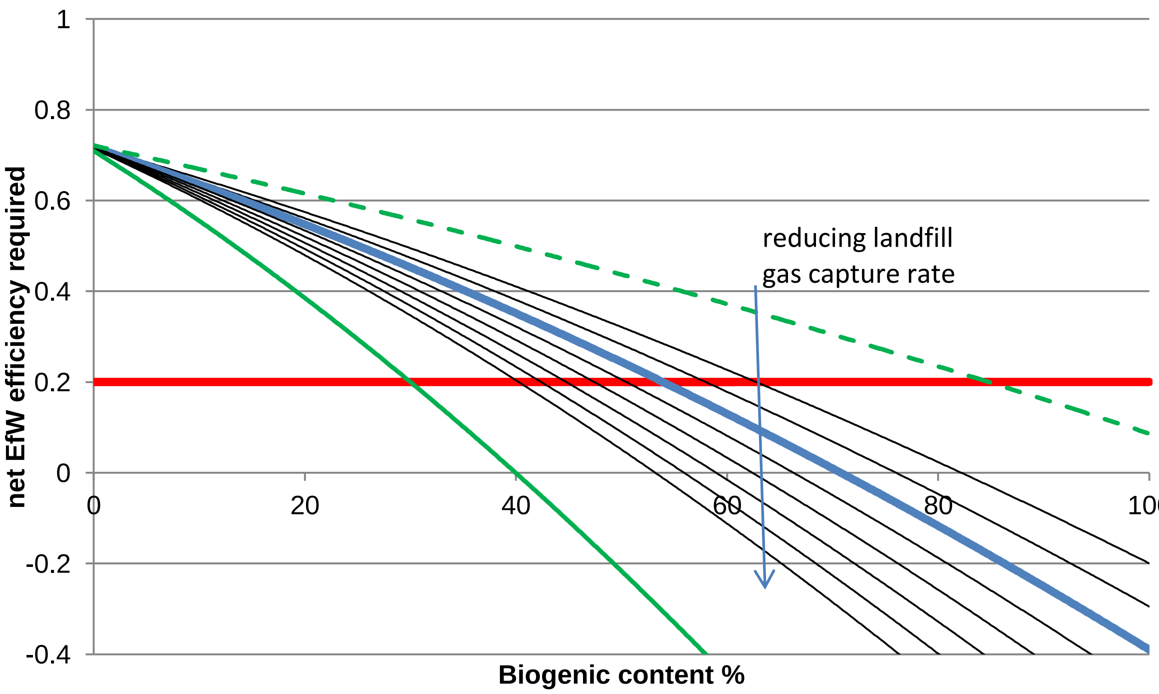
129. The other factor which can affect the slope of the trendline is the position of the static point. This will be a function of methane emissions from landfill.

5.4. Changing methane emissions from landfill

130. There are a number of different factors than can alter the level of emissions from landfill and their impact: the amount of landfill gas captured, oxidation rate and potency of methane as a greenhouse gas are the primary ones. Of these the proportion of methane captured had the greatest impact across the likely range of values in the sensitivity analysis. Estimates of landfill gas capture are discussed in more detail in **Annex 2.** Methane emissions from landfill are very dependent on the technology put in place to prevent them, which in itself will be related to how old the landfill is. Global estimates for emissions from UK landfill will incorporate a whole range of sites, ages and capture technologies many of which will be less efficient than current best practice. For this model we are considering the fate of a tonne of waste being disposed of today. We therefore need to use a capture level consistent with current best practice.

131. The baseline figure for landfill gas capture used in the model is 75% estimated lifetime capture. The percentage of landfill gas captured for flaring or energy generation in the model was varied from 85% down to 50% in 5% steps for the same range of compositions used above. The model output is shown in Chart 5 .

Chart 5. Impact of changing landfill gas capture on the efficiency of EfW as a function of biogenic C content of a range of waste compositions



132. The chart shows that as the proportion of landfill gas captured is reduced the steepness of the curve increases. There is a static point at zero biogenic content as there would be no landfill gas produced. Elsewhere for a given biogenic content a

lower net EfW efficiency is required to outperform landfill as the proportion of landfill gas captured decreases. The baseline value of 75% capture is represented by the thick blue line.

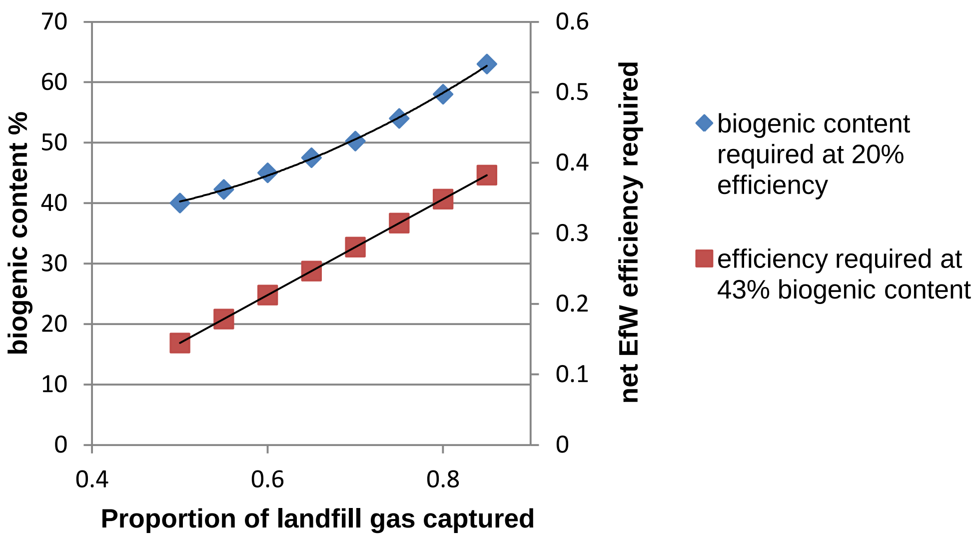
133. Considering an EfW plant with net efficiency of 20% (red line). At 85% landfill gas capture a minimum biogenic content of 63% would be required falling to 54% at the baseline value of 75% capture and 40% biogenic content at a landfill gas capture proportion of 50% (assuming all other background parameters remain constant).

134. At a 100% capture rate, represented by the dashed green line, a biogenic content of greater than 85% would be required. This value will be independent of all other parameters relating to landfill gas production such as warming potential etc. as no methane is released. It will be dependent on factors relating to the EfW plant such as background energy mix and not those which affect generation from landfill.

135. At 0% capture rate, represented by the solid green line, a biogenic content of more than 30% would be required for a 20% efficient plant. This value is highly dependent on other parameters relating to methane release such as warming potential.

136. For a given biogenic content the change in efficiency required with changing landfill gas capture is reasonably linear (Chart 6). Given the static point at zero biogenic content this means that for a given efficiency the rate of change in biogenic content required increases as captured proportion increases. So a change of 5% capture rate from 80 to 85% has a much greater impact on the biogenic content required than a step from 50% to 55%.

Chart 6. Variation in minimum biogenic content required at for a 20% efficient EfW plant and efficiency of plant required at 43% biogenic content with proportion of landfill gas captured

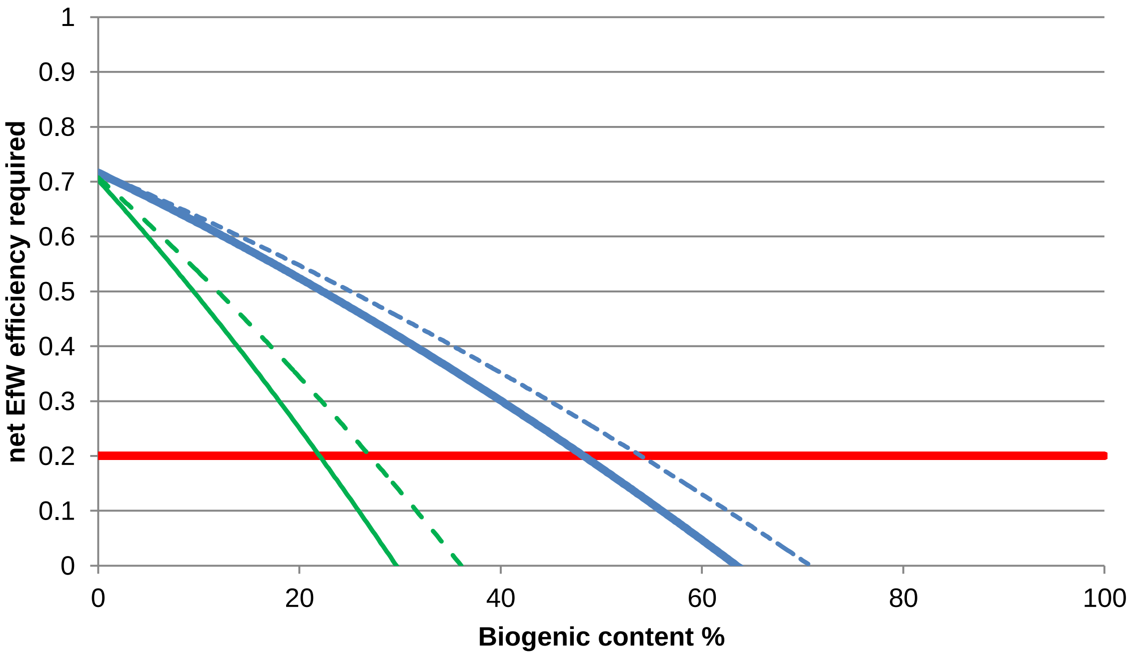


137. Clearly uncertainty in the proportion of landfill gas captured is most important when it is in relation to very high levels of capture.

138. Another key parameter is the potency of methane as a greenhouse gas. The baseline model uses a value of 25. The very latest value recommended by the IPPC for the 100 year warming potential is 34 but this is not yet widely adopted. The impact of this change on the above analysis can be seen in Chart 7 below where solid lines

represent a value of 34 and dotted lines a value of 25 for the baseline and zero capture scenarios. A 100% capture rate has been omitted as the line is the same as before – with no methane emitted it is independent of potency.

Chart 7. Impact of changing global warming potential of methane form 25 (dotted lines) to 34 (solid lines) for the 75% and zero capture scenarios



139. For a given efficiency e.g. 20% the impact of using the higher potency is a reduction of around 5% in the biogenic content required at both the baseline 75% level and the zero capture point. For a given biogenic content the effect is much greater at low capture rates than high, with the greatest impact at the highest biogenic content. This is as expected as these compositions would generate the most methane. As noted in the sensitivity analysis overall the impact of changing the methane potency is not that great compared to other factors.

5.5. Combining key variables – background energy mix and methane capture

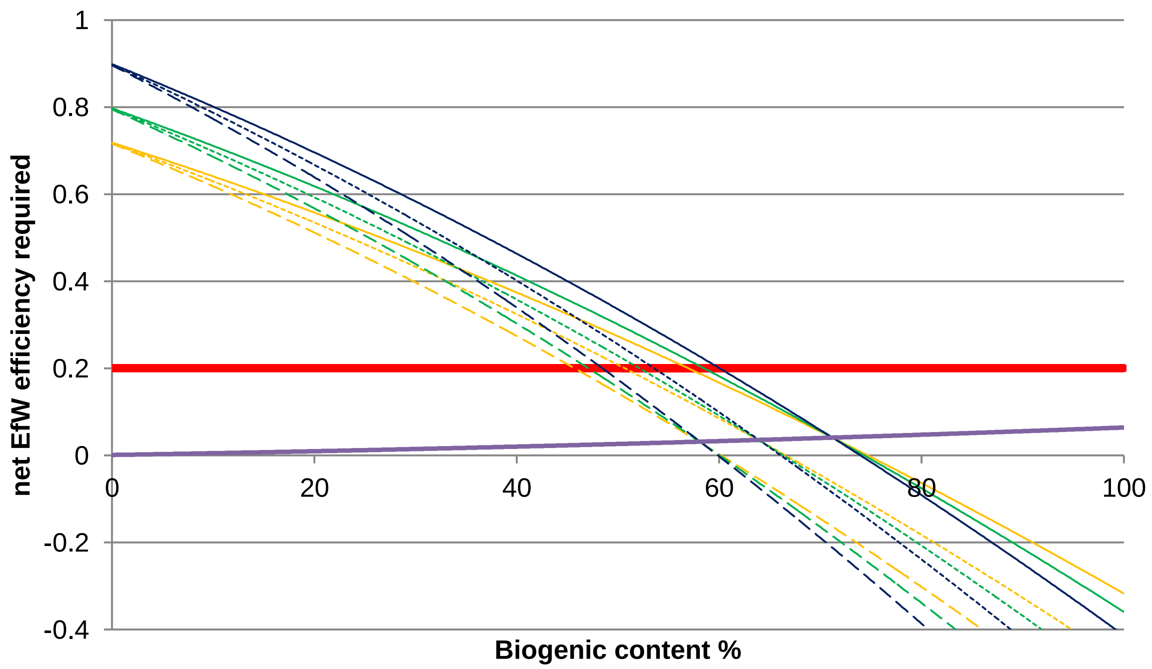
140. Clearly the two factors, energy offset and landfill gas capture, considered above could act in combination so it is important to understand the impact of this covariance. The model was used to examine 3 different levels of landfill gas capture alongside 3 different levels of background energy carbon intensity to give nine different scenarios. These are set out in Table 15 below. The same range of compositions used previously was modelled.

Table 15. Scenarios modelled using different levels of landfill gas capture and carbon intensity

Proportion of landfill gas captured	Background energy carbon intensity
0.75	0.373
0.75	0.336 (90% baseline)
0.75	0.298 (80% baseline)
0.65	0.373
0.65	0.336
0.65	0.298
0.55	0.373
0.55	0.336
0.55	0.298

141. The model output is shown in Chart 8 below.

Chart 8. Model output for the nine scenarios in Table 15



142. As can be seen from Chart 8 for each value of landfill gas capture (indicated by the same line weight) there is a ‘set’ of trendlines associated with changing the background energy intensity, each with its own unique static point. As the proportion of landfill gas captured increases these static points move to higher biogenic content levels along the line (purple) relating to what would be seen with a very high background energy intensity[26]. Equally for a given background energy intensity

[26] The increase in EfW efficiency required with increasing biogenic content in the very high background energy mix scenario (represented by the purple line in Chart 8) is due to the drop in CV of the waste with increasing biogenic content (Chart 3). With lower energy content in the fuel a higher efficiency of EfW plant is required to match the energy from landfill gas to give the ‘energy neutral’ static point.

(indicated by colour) there is a static point associated with each set of landfill gas capture values.

143. This analysis indicates that there is no additional complex interaction between the two key sensitivities in the model and that scenarios could be sensibly developed based on choosing specific sets of assumptions without concern that outliers could accidentally be selected.

144. As these key parameters are varied the model output is changing in a consistent and readily explicable manner which gives us confidence in the output and that the model can be used for more detailed analysis.

6. Modelling electricity only EfW

6.1. Scenarios for future impacts on electricity only EfW

145. The above analysis has considered a number of different parameters that could be changed for analysis of the impact of biogenic content on the carbon case for EfW. Some of the factors such as the background energy mix and the level of landfill gas capture may change over time. EfW plants have a long lifetime so it is important that these factors are considered for the end of the plant lifetime as well as the start.

146. The degree to which landfill gas is captured is hotly debated with significant variation depending on the phase of operational life of the landfill. Government has historically used an assumption of 75% capture. This would seem to be an optimistic figure at the upper end of any estimates which can range as low as 20%. 50-60% lifetime capture rate might be a more realistic with an assumption that this will improve with new technology over time to deliver the more optimistic value[27].

147. The marginal energy mix is also predicted to change over time. For electricity only generation DECC have made estimates of how this is expected to change up to 2050. There is a relatively slow decline up to 2025. However, beyond this point the marginal energy mix is expected to drop more significantly, and rapidly, to 2040 as renewable and nuclear energy become a greater proportion of the energy mix. Heat use will have its own separate marginal energy mix. For simplicity in the scenarios below we have considered an electricity only plant.

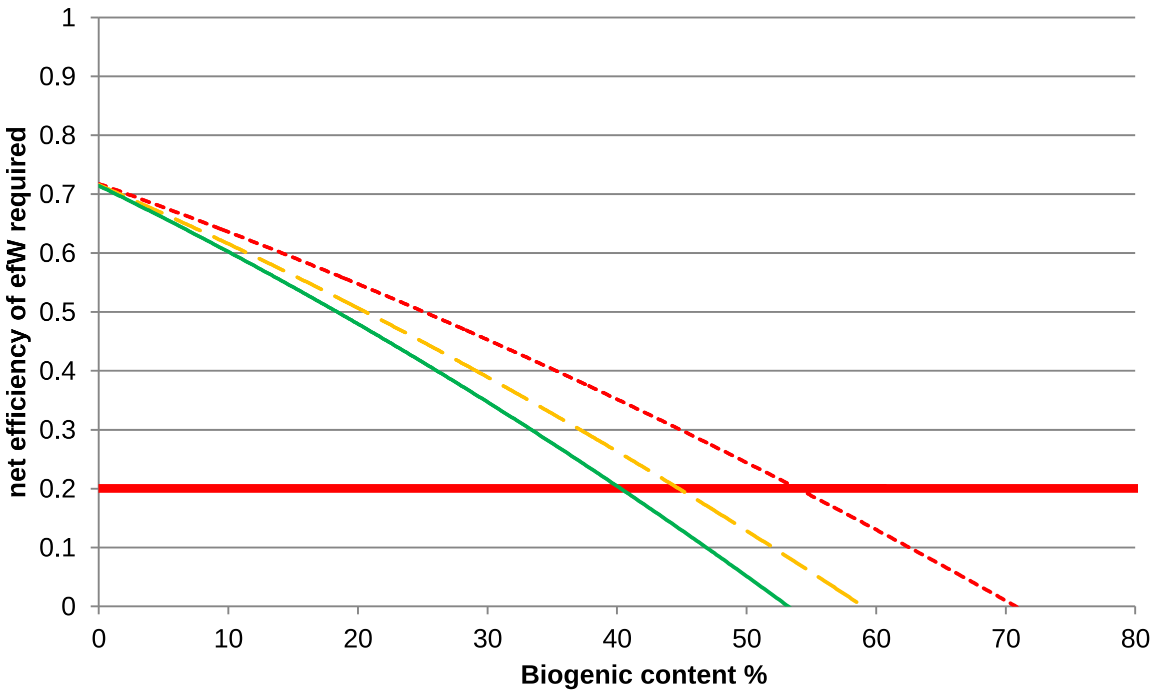
[27] The level of landfill gas capture is one of the most debated issues in this area. The Eunomia report: “A Changing Climate for Energy from Waste? Final report to Friends of the Earth”, May 2006; remarks that “there is very little by way of field measurements to substantiate the use of the high gas captures [75%] being posited in Defra” and notes “Dutch field measurements give figures between 10-55% for instantaneous gas capture rates, and average rates of around 25%, whilst default figures for reporting to IPCC are likely to be specified at around 20%”. The report itself uses a baseline value of 50%. The source of the biogenic content of waste data used in the model: ERM (2006) Carbon Balances and Energy Impacts of the Management of UK Wastes, Defra R&D project WRT 237 December 2006 uses the value of 75% but their modelling also indicates that adoption of a longer timeframe results in a lifetime capture rate dropping to 59%. Other reports similarly provide a range of values. We have selected the range for the three scenarios based on the above quoted figures (rounding the 59% to 60%).

148. Based on these factors we have modelled three different scenarios.

Low methane case – 75% landfill gas capture
Central case – using the 60% landfill gas capture
High methane case – using 50% landfill capture

149. The three scenarios were input into the model and the variation in minimum EfW efficiency required with biogenic content plotted with a background energy mix of 0.373t/MWh (Chart 9).

Chart 9. Model output for Low (red, small dotted line), Central (yellow, large dashed line) and High Methane (green solid line) scenarios with baseline marginal energy mix



150. All three scenarios give the same efficiency at zero biogenic content as the background energy mix is the same. As expected the rate of landfill gas capture has a significant effect. Under the low landfill emissions scenario a 20% efficient EfW plant should burn waste with a biogenic content of at least 54% for the central scenario this drops to 45% and to 40% for the high methane scenario.

151. These scenarios give a snapshot of the required efficiency/biogenic content balance. Clearly for an EfW plant with a 25+year lifetime we need to consider how this balance changes over time. With improving technology we might expect landfill gas capture rates to move towards the more optimistic emissions figure and we have already demonstrated that changing the marginal energy mix will also have a dramatic effect. Figures for the marginal energy mix are taken from DECC's IAG toolkit[28]. Levels of

[28] https://www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal

landfill gas capture are based on a transition to a long term capture rate of 80% by 2100 with a reducing rate of improvement over time[29].

Table 16. Modelled scenarios changing landfill gas capture rate and marginal energy mix over time

Year	Marginal electrical energy mix C intensity (t/MWh)	Landfill gas capture		
		Scenario 1 (low methane)	Scenario 2 (central)	Scenario 3 (high methane)
2010	0.3564	75%	60%	50%
2015	0.3192	76%	64%	56%
2020	0.2674	77%	67%	61%
2025	0.1950	77%	70%	65%
2030	0.0954	78%	72%	68%
2035	0.0673	78%	73%	70%
2040	0.0482	79%	75%	72%
2045	0.0277	79%	76%	74%
2050	0.0227	79%	77%	75%

152. The outputs from the three models are shown below (Chart 10-0). In all cases in the period up to 2025, while the assumed carbon intensity of the marginal background energy mix drops relatively slowly, the changes are dominated by capture rate with the impact greatest at the lowest efficiencies of EfW plant. As the carbon intensity of the background mix changes, dropping dramatically from 2025 through to 2045 the lines steepen to such a point that the biogenic content required becomes independent of efficiency of EfW plant, dependent essentially on the level of landfill gas capture. By 2050 the difference between scenarios is marginal as they approach the assumed capture limit.

[29] There is insufficient information to give an accurate profile for the rate of landfill gas capture. The modelled profile is based on 80% lifetime capture as a long term limit. The starting capture rate is increased each 5 year step by 20% of the difference between the previous value and this long term limit. This gives a profile where improvements are greatest in the early years and then gradually level off as marginal benefits become harder to achieve. Capture rate in year x = rate in year x-5 + (0.2*(rate in year 2100 -rate in year x-5))

Chart 10. Model output low methane scenario

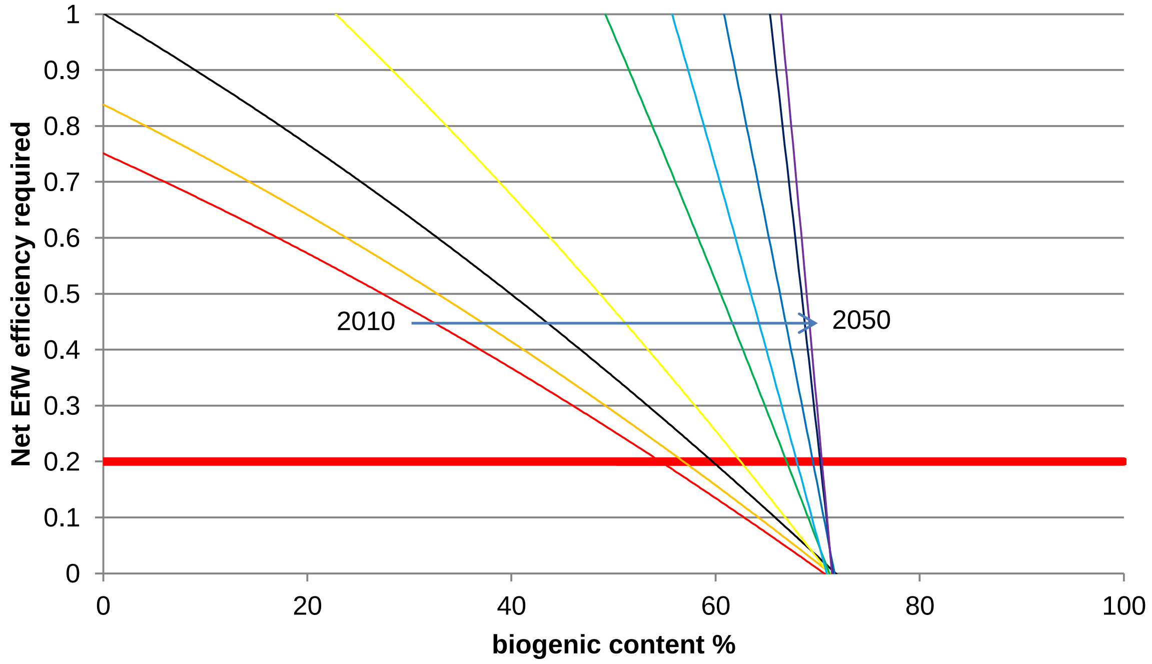


Chart 11. Model output central methane scenario

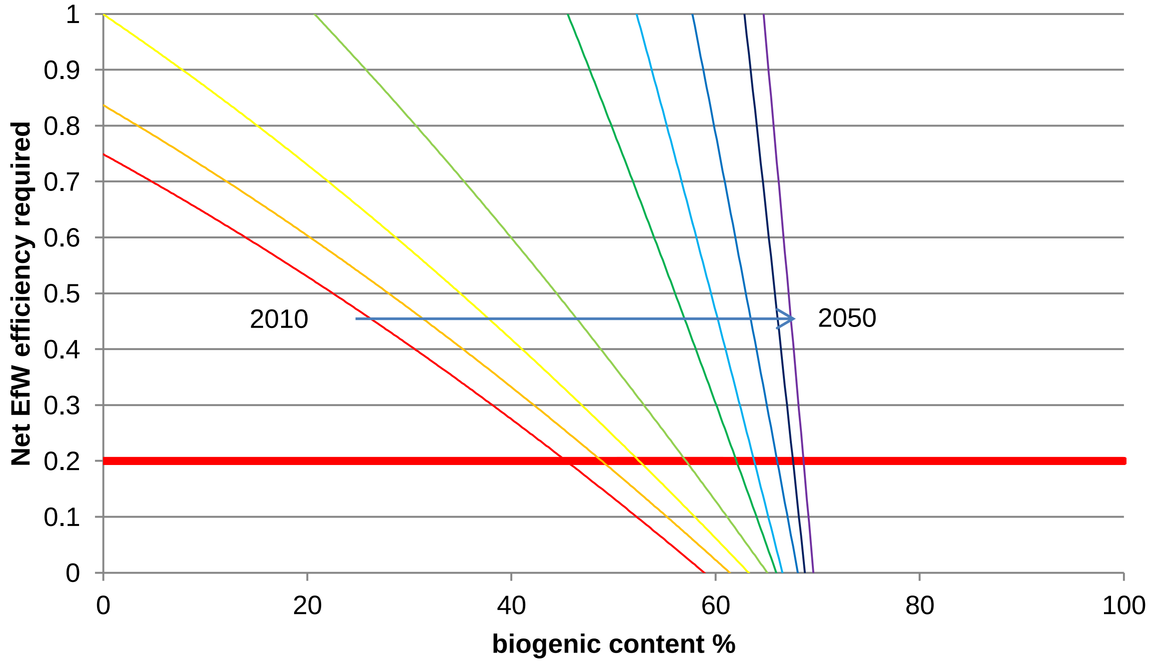
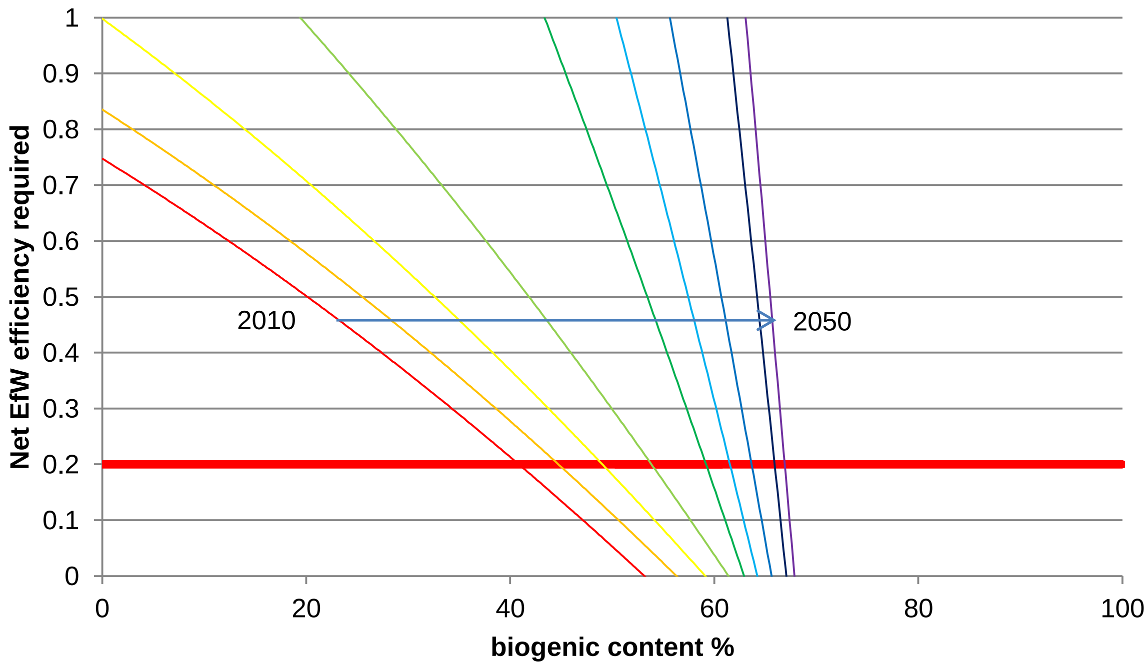


Chart 12. Model output high methane scenario



153. Based on these scenarios, in the very long term electricity only EfW will need to use feedstocks with relatively high biogenic content to be environmentally sustainable from the carbon balance viewpoint. Efficiency of the plant will be irrelevant in terms of determining the biogenic content of the fuel but more efficient plants will of course remain critical in maximising the energy extracted from the waste and the overall economic and environmental case.

154. Based on these scenarios the model indicates that even under the low methane set of assumptions EfW based on waste with a biogenic content of greater than 72% will deliver an environmental benefit throughout the lifetime of the plant. It is important to note that this does not imply that a plant utilising waste with a lower biogenic content for some or indeed all of its life cannot be a more environmentally sound solution than landfill, this is discussed further in the section below.

6.2. Impact over the plant lifetime

155. Energy from waste plants are constructed based upon a return on investment over the lifetime of the plant i.e. in order to make them financially viable they need to operate for a number of years, a 25 year period would be a typical planned lifetime. Landfill is also a long term commitment; in this case the damaging gases are potentially released over tens of years. The year by year balance of emissions will be different depending on the period being considered. Emissions from the energy from waste plant will be essentially constant (with short term fluctuations) for the lifetime of the plant (assuming constant biogenic content) whereas those from landfill will rise to a peak and then tail off, the exact shape of the curve being impacted by the timing and level of any capture.

156. Considering a hypothetical composition of waste such that the same amount of waste being managed in either EfW or landfill over a 25 year period gives the same total CO_2e emissions over a 100 year period. Chart 13 (EfW) and Chart 14 (landfill) below illustrate the 5 yearly and cumulative emissions for the different treatment routes. The cumulative emissions at the end of the period are the same (red line) but the EfW plant would clearly be emitting more in the early years (blue bars) but would be emitting nothing in later years, assuming the plant ceases operation after 25 years.

Chart 13. Illustrative phasing of emissions from an EfW plant

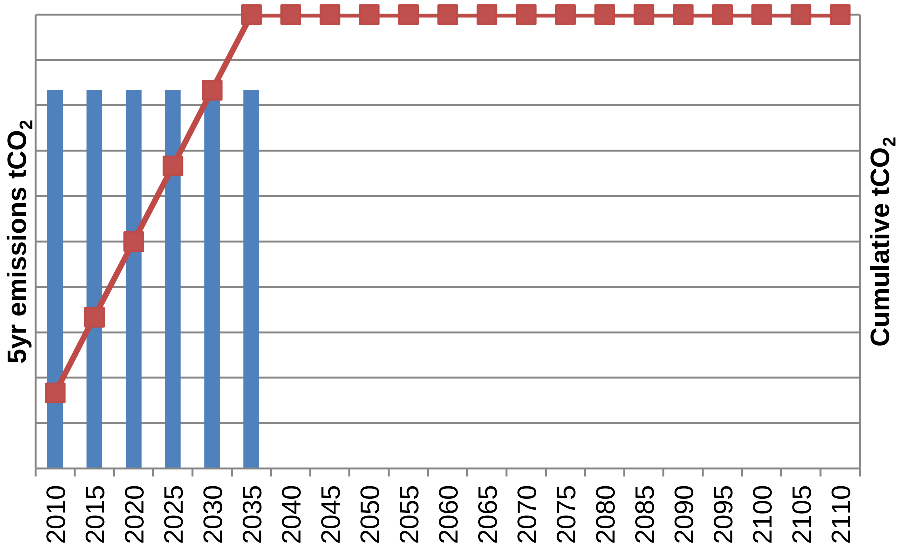
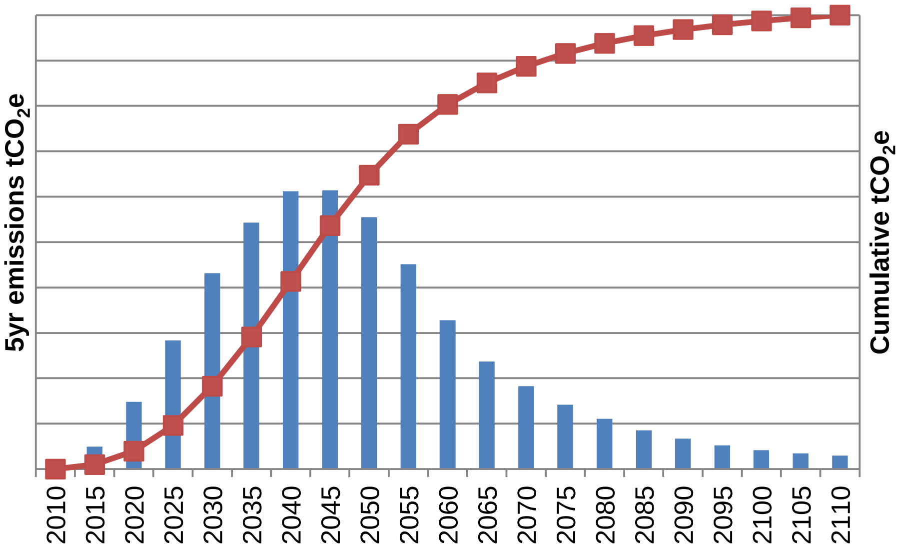


Chart 14. Illustrative phasing for emissions from landfill



157. How to treat this time dependency is one of the key difficulties for analysing the relative impacts of the two approaches. In economic terms there is a well used approach to account for this time dependency, a discount rate is applied with the costs of later emissions being valued less than immediate emissions. However, the discount rate to be applied is a matter of much debate.

158. In environmental terms, which are what this analysis considers, it is even more difficult. There is as yet no ‘discount rate’ for CO_2 or its warming potential. An

alternative approach is therefore to look at the total emissions over an extended period. The assumption here is that providing there is no environmental tipping point during the period then the warming potential and therefore relative environmental impact depends on the cumulative total of gases released over the entire period. In this approach using the examples shown in the graphs above EfW and landfill have been modelled with assumptions to give the same overall impact in CO_2eq terms, whereas, by comparison on a year by year basis they differ markedly.

159. This long timescale approach can be applied to the scenarios outlined above for a number of compositions with different biogenic contents. We will consider total emissions over a 100 year period, based on the following assumptions:

- All of the methane that will be released from landfill will have been released by the end of this period – 100 years is a standard assumption for this in many climate models
- The biogenic content of the waste will remain broadly the same over time – while it is expected that waste composition will change plants will often only be able to operate within a given range of calorific value, this in turn may lead to the requirement for a relatively constant composition developed from mixing different waste sources.
- The Energy from waste plant will be operated for the lifetime required to give the planned return on capital investment, this 'planned lifetime[30]' is assumed to be 25 years – if a plant cannot operate for the full time to recoup the investment then it will not be built .

160. There is the possibility that a plant will continue to be utilised beyond the planned lifetime if EfW was considered to be the best option at that point. However, if EfW was no longer sustainable then it is assumed it will cease to run. It is important to recognise that the plant needs to run for this period in order to be built, so even if EfW becomes the less desirable option during the plant's life we should assume it will continue to be operated until this return on investment point is reached. Whether this is desirable will depend on the overall environmental balance over the plant's lifetime. Hence it is important for both the landfill and EfW sides of the model to consider the total impact over the lifetime of the infrastructure.

161. There is the additional issue of which comparators are fixed over the lifetime of the plant and which are varied. Clearly there will always be the option to send the waste to landfill rather than EfW so landfill effects, such as capture rate, should vary over the course of the plant's lifetime. The issue of comparative energy mix is more difficult. There are two options, either the marginal energy mix is varied throughout the plants lifetime or it is set at the level at which the plant started operation. The former is more consistent with it being a waste management tool that happens to produce energy, the latter with considering it as an energy generation plant, i.e. if you need the energy you will have to build some form of power plant at that point in time be it the EfW plant or the marginal energy plant, therefore the marginal plant at the time of initiation is what you are offsetting for the lifetime of the plant. In the analysis below we have assumed the former which will make it more challenging for EfW to maintain primacy over landfill.

[30] For municipal waste plants this planned lifetime will be linked to the duration of the local authority waste contract – often 20-25 years.

Modelled net carbon benefits over 25 year plant lifetime

162. From the charts above for a biogenic content of around 75% or greater EfW would always seem to be the better solution, across all three scenarios. We have therefore considered the impact of a lower biogenic content on a range of different efficiencies and plant construction dates. The net CO_2 emissions were calculated every five years from 2010 to 2050 against a background of varying marginal emissions factors for electricity. Values for intermediate years were estimated assuming linear change between data points. Using this data the average net tCO_2eq per tonne of waste for a plant operating over a given period was calculated. For plants that were operating before 2010 it is assumed net emissions were the same as 2010 for previous operating years. The results are summarised below in Table 17 (low methane), Table 18 (central) and Table 19 (high methane).

163. The red shaded cells indicate combinations of efficiency and plant where over the lifetime of the plant the average net CO_2eq emissions would be greater than those from landfill (positive value).

164. Under all of the scenarios there is a threshold beyond which a new plant would have carbon disbenefits versus landfill. This is understandably closely linked to the decarbonisation of the marginal energy mix. The efficiency and year at which this threshold appears is dependent on the level of landfill gas capture, with higher capture rates reducing the primacy of EfW over landfill earlier for a given efficiency of plant.

165. The orange shading indicates plants that over their lifetime produce a positive benefit (negative value in the table) but at the end of their planned life would be giving net emissions relative to landfill for a tonne of waste. For such plants extending operation beyond the planned lifetime may not be the best environmental outcome. Unshaded plants on the other hand still have net benefits at the end of their planned life and therefore it may be beneficial to have their lifetime extended.

Table 17. High capture Low methane scenario (75% initial capture)

	Average net t CO_2eq emissions from 1t of waste with 61% biogenic content over the period						
Plant efficiency	Existing plant 1995-2020	Existing plant 2000-2025	Existing plant 2005-2030	Existing plant 2010-2035	New plant 2015-2040	New plant 2020-2045	New plant 2025-2050
30%	-0.167	-0.141	-0.102	-0.055	-0.009	0.034	0.068
25%	-0.118	-0.097	-0.064	-0.025	0.014	0.050	0.078
20%	-0.070	-0.053	-0.026	0.005	0.037	0.065	0.088
15%	-0.021	-0.008	0.012	0.036	0.060	0.081	0.098

Table 18. Central methane scenario (60% initial capture)

	Average net t CO_2eq emissions from 1t of waste with 61% biogenic content over the period						
Plant efficiency	Existing plant 1995-2020	Existing plant 2000-2025	Existing plant 2005-2030	Existing plant 2010-2035	New plant 2015-2040	New plant 2020-2045	New plant 2025-2050
30%	-0.312	-0.273	-0.216	-0.149	-0.083	-0.025	0.022
25%	-0.263	-0.228	-0.178	-0.119	-0.060	-0.009	0.032
20%	-0.215	-0.184	-0.140	-0.088	-0.038	0.007	0.042
15%	-0.166	-0.139	-0.102	-0.058	-0.015	0.022	0.052

Table 19. Low capture High methane scenario (50% initial capture)

	Average net t CO_2eq emissions from 1t of waste with 61% biogenic content over the period						
Plant efficiency	Existing plant 1995-2020	Existing plant 2000-2025	Existing plant 2005-2030	Existing plant 2010-2035	New plant 2015-2040	New plant 2020-2045	New plant 2025-2050
30%	-0.408	-0.359	-0.291	-0.210	-0.132	-0.064	-0.009
25%	-0.359	-0.315	-0.253	-0.180	-0.109	-0.048	0.001
20%	-0.311	-0.270	-0.215	-0.150	-0.086	-0.032	0.011
15%	-0.262	-0.226	-0.176	-0.119	-0.063	-0.017	0.021

166. Under all scenarios existing plants with a higher efficiency have a potentially longer operational lifetime, and based on this set of assumptions and biogenic content any plant commissioned after 2015 by the end of its planned life may have reached a point where it would not be environmentally beneficial to extend its life.

167. These assessments are very dependent on the underlying assumptions. Increasing the biogenic content of the waste being used will essentially extend the beneficial lifetime of the plant as will any use of heat, which would both increase the efficiency and change the marginal energy mix being offset. Metal recycling from bottom ash and ash recycling would similarly benefit EfW over landfill and shift the balance point.

Composition required to sustain benefits over plant lifetime

168. The above approach looks at the environmental benefits of a plant based upon a specific biogenic content. An alternative approach is to examine the minimum biogenic content over a plant's lifetime required to be a zero net emitter when compared to the alternative of the waste going to landfill.

169. To achieve this a function was introduced to alter the proportion of all fossil containing wastes in the composition and this was optimised using a 'what if' tool to give a zero net CO_2 benefit over a 25 year plant lifetime. The corresponding biogenic content was noted. The results are summarised for the central scenario in the table below.

Table 20. Central methane scenario (60% initial capture) minimum lifetime biogenic content required

	Minimum lifetime biogenic content required %						
Plant efficiency	Existing plant 1995-2020	Existing plant 2000-2025	Existing plant 2005-2030	Existing plant 2010-2035	New plant 2015-2040	New plant 2020-2045	New plant 2025-2050
30%	40.19	42.46	45.98	50.31	54.8	58.93	62.39
25%	43.47	45.51	48.63	52.46	56.44	60.08	63.12
20%	46.71	48.54	51.26	54.59	58.06	61.22	63.85
15%	49.93	51.53	53.87	56.71	59.68	62.35	64.57

170. Cells shaded green indicate where the lifetime biogenic content required is less than the 50% currently used for deeming of Renewables Obligation Certificates (ROCs). Orange indicates where the content falls in the 60-68% range currently considered likely for mixed municipal waste. This indicates that for the central set of assumptions all plants are viable for municipal waste with a biogenic content at the top end of the commonly used range. As might be expected the low methane scenario required higher biogenic content than the central scenario for a given plant while conversely the high methane scenario required lower biogenic content.

171. Once the plant reaches the end of its 25 year life it needs to still be providing a carbon benefit for that life to be extended. The minimum biogenic content to extend a plant's lifetime to a given year is shown in the table below. Higher biogenic content is required to justify extending a plant's lifetime beyond the initial 25 years under this set of assumptions.

Table 21. Central methane scenario (60% initial capture) Minimum biogenic content required to extend plant life beyond initial 25yr lifetime

	Minimum biogenic content required to extend plant lifetime beyond initial 25 year period %						
Plant efficiency	Existing plant 1995-2020	Existing plant 2000-2025	Existing plant 2005-2030	Existing plant 2010-2035	New plant 2015-2040	New plant 2020-2045	New plant 2025-2050
30%	47.12	52.86	59.67	61.93	64.53	66.48	67.61
25%	49.77	54.84	60.63	62.61	65.03	66.77	67.85
20%	52.4	56.8	61.59	63.29	65.53	67.06	68.09
15%	55.01	58.75	62.55	63.97	66.02	67.34	68.33

6.3. Treatment of biogenic CO_2

172. So far this analysis has ignored biogenic CO_2 emissions based on the assumption that it is short cycle and therefore has no net global warming impact. Impacts from factors such as changes in land use to grow the original plants are accounted for in overall carbon inventories elsewhere and are conventionally not considered as part of waste management or energy generation.

173. However, the model assumes that not all of the biogenic material decomposes in landfill but it is all converted to CO_2 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.

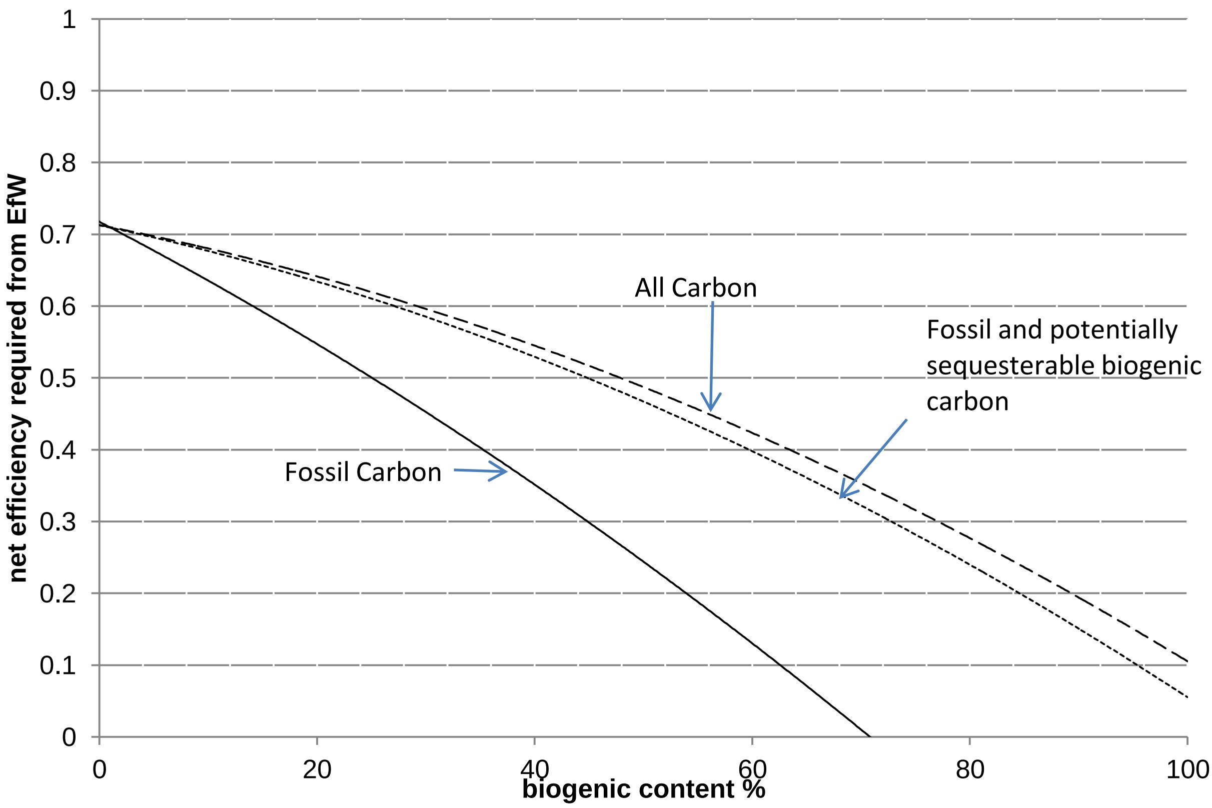
174. There are two ways to account for this additional effect:

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

175. 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.

176. Both approaches were examined in the model using the baseline set of assumptions (equivalent to the high capture low methane scenario) and the results are shown in Chart 15 below.

Chart 15. Net efficiency of EfW plant required with different biogenic content of waste considering EfW emissions of: only fossil carbon (solid line), fossil and potentially sequesterable biogenic carbon (dotted line) and all carbon (dashed line)



177. It can be seen from Chart 15 that both approaches deliver a very similar change with, as expected, EfW becoming more disfavoured relative to landfill with the greatest change at high biogenic content of the waste. Taking into account sequestered biogenic carbon in landfill will require greater EfW efficiency and/or biogenic content.

178. The similarity between the two approaches is unsurprising as biogenic carbon which is not sequestered in landfill or converted to methane becomes CO_2, as it would in EfW, so for that aspect the two sides of the model cancel out. The slight difference is due to the need for EfW to compensate for the CO_2 offset by electricity generation

from landfill gas when all emissions are considered. The small difference indicates how relatively small a contribution this energy makes to the overall balance. Given this similarity it may be better to consider only the sequestered biogenic C to avoid double counting with other inventories.

179. A range of different values exist in the literature for the amount of biogenic carbon that is sequestered in landfill. The baseline assumptions used in this model result in a very high level of sequestration, around 53% for the baseline composition. The outcome will be sensitive to the level of sequestration in two ways. Reducing the level of sequestration will require less biogenic carbon to be included in the EfW side of the model and will also result in more methane being emitted from the landfill side. Both factors will favour EfW over landfill. To examine the sensitivity of the model to changes in sequestration the baseline proportion of decomposable carbon in each waste type was increased by 50%. This changed the overall proportion of sequestered biogenic carbon from 53% to 29.5%. The values used are summarised in Table 22 below.

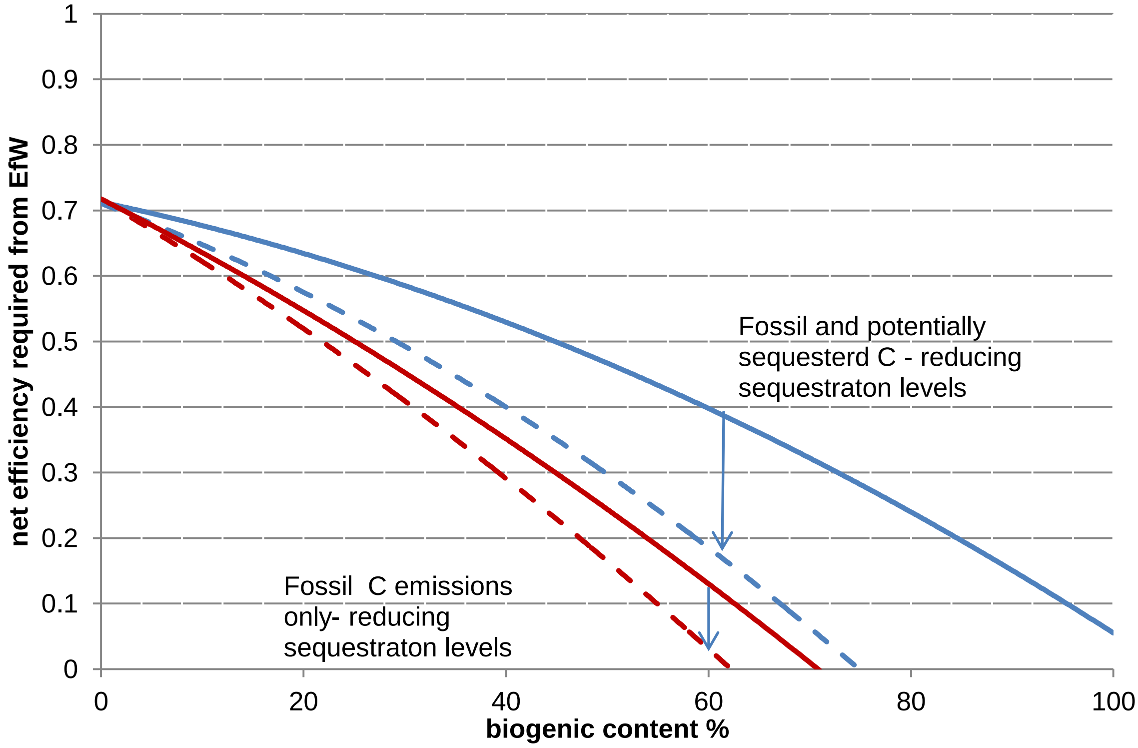
Table 22. Changes in modelled sequestration levels for each component by increasing the proportion of biogenic C considered sequesterable

Material	High sequestration % (model baseline)	Reduced sequestration %
Mixed Paper and Card	50.63	25.94
Plastics		
Textiles (and footwear)	66.65	49.98
Miscellaneous combustibles	53.21	29.82
Miscellaneous non-combustibles	100	100
Food	39.36	9.04
Garden	48.71	23.06
Soil and other organic waste	96.43	94.64
Glass	100	100
Metals, White Goods and Other Non-biodeg Products		
Non-organic fines		
Wood	71.52	57.28
Sanitary / disposable nappies	71.33	57
Total	53.00	29.50

180. By taking this approach materials which already have a high proportion of decomposable carbon are most greatly affected, i.e. Food, Paper and garden waste.

181. The impact of these changes on the model outputs is shown in Chart 16 below.

Chart 16. Impact of reducing the assumed level of carbon that decomposes on model outputs for fossil emissions (red) and fossil and potentially sequestered biogenic C (blue). Baseline model (solid line) and reduced sequestration (dashed line)



182. As noted above, 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. As a consequence changing the sequestration level impacts not only when considering both fossil and sequestered carbon but also when considering fossil carbon alone.

183. In the example above for the baseline composition (61% biogenic) reducing the amount of sequestration of biogenic carbon from 50% to 30% results in a drop of 10% in the efficicncy required if just considering fossil carbon and 20% if considering both fossil and sequestered biogenic carbon.

184. There is an additional complicating factor regarding the assumptions around sequestration levels. The proportion of landfill gas captured is difficult to measure directly so assumed levels have previously been derived from a combination of measurement of the amount of landfill gas captured as a proportion of the amount modelled as being produced. However, the modelling for this also contains assumptions on sequestration, Therefore any lowering in the sequestration assumptions will also inherently reduce the assumed level of landfill gas capture. This interaction has not been captured in the above analysis. As a result the scenarios outlined above will be particularly sensitive to sequestration levels with any drop in assumed sequestration significantly favouring EfW over landfill. Given all of these interactions there is a high degree of uncertainty and further work is required.

7. The impact of utilising heat

185. All of the above analysis considers an EfW plant operating in electricity only mode. However, most plants have the potential to operate in combined heat and power (CHP) mode.

186. Use of heat has two important impacts on the above analysis

- It significantly increases the net efficiency of the EfW plant
- It changes the marginal energy mix being offset

187. Heat is expected to decarbonise more slowly than electricity therefore in the long term it will have a higher marginal energy mix than electricity. For example a recent technical report for the Committee on Climate Change assumes a carbon intensity of 246gCO_2/kWh for oil heating and 183gCO_2/kWh for gas[31] up to 2050

188. As the marginal energy mix for heat is predicted to be maintained over the period up to 2050 only changes in the landfill gas capture rate impact on the minimum biogenic content/efficiency required from an EfW plant. This was modelled for the central scenario offsetting gas (Chart 17) or oil (Chart 18) heating.

189. If the heat source being offset is a gas fired boiler then in 2050 for the baseline composition a heat efficiency of 30% is required. If the heat source being offset is an oil fired boiler then an efficiency of only 20% is required. Both of these are easily achievable.

190. In reality it is much more likely that a plant will operate in CHP mode producing both power and electricity. Based on the baseline composition and central scenario in 2050 a plant generating electricity with 20% efficiency in 2050 will have net CO_2 emissions of 0.325tCO_2 per tonne of waste relative to landfill emissions of 0.229tCO_2 giving a net disbenefit of 0.096tCO_2 per tonne of waste. However, all of the carbon emissions from the plant have been counted against the electricity generation, this assumes the heat is just wasted. Using this heat in addition to electricity doesn't produce any additional CO_2 (the same waste is being burned) therefore any additional heat produced can be counted as 'carbon free' energy. This energy can offset fossil sources generating elsewhere.

191. With a marginal carbon intensity for gas heating of 0.183tCO_2/MWh this means the plant would need to generate an additional 0.52MWh of heat energy per tonne of waste to offset the electricity emissions. This is equivalent to producing heat at less than 20% efficiency which is easily achievable.

[31] Decarbonising Heat in buildings:2030-2050 Technical annex p143
http://archive.theccc.org.uk/aws/IA&S/Element%20Energy%20-%20Decarbonising%20heat%20to%202050%20-%20Annex.pdf

Chart 17. Model output for central scenario offsetting gas fired heating 2010-2050

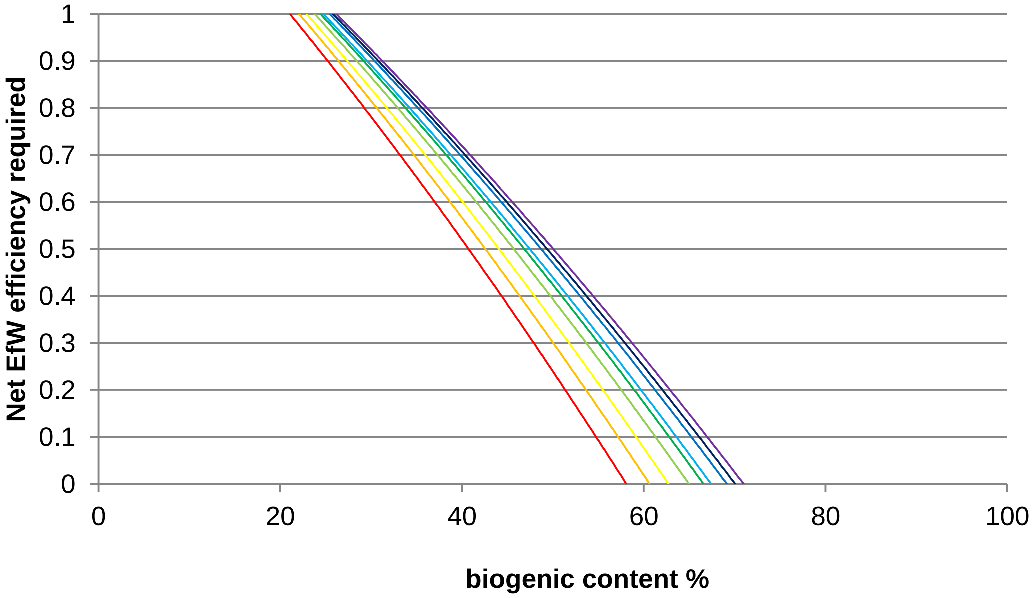
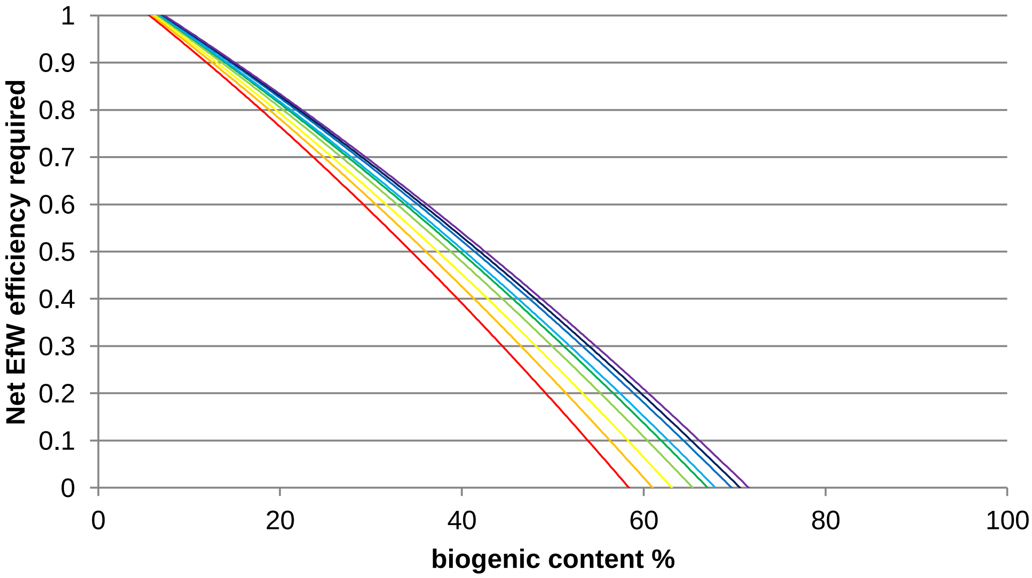


Chart 18. Model output for central scenario offsetting oil fired heating 2010-2050



192. There is a trade off between electricity and heat. The z ratio, additional heat energy supplied per unit electrical energy foregone, for Energy from Waste CHP should be in the range 4-5 i.e. for every additional 4MWh of heat 1MWh of electricity is lost. So in the above example the plant operating at 20% electrical efficiency in CHP mode might actually operate closer to 25% efficiency in electricity only mode (where it would still be a net CO_2 emitter).

193. Alternatively, considering the lifetime emissions as above, a plant constructed in 2025 delivering 20% electrical efficiency would need to produce an average additional 0.18MWh to offset the 0.032tCO_2 average net emissions per tonne of waste, equivalent to using heat at less than 7% additional heat efficiency. Alternatively the plant could use the heat for some of its lifetime at a higher level.

194. If circumstances permitted, the most beneficial approach would be to operate in CHP mode optimised for power while the marginal electricity carbon intensity was high, and switch to optimising for heat output once the marginal electricity intensity dropped below that of heat. In reality the availability of heat customers will constrain the availability of this approach.

195. If the plant is a gasifier producing a syngas, which is used to drive a gas engine or gas turbine, electrical efficiencies may be higher, enabling such plants to operate in electricity only mode for their whole lifetime. However, there would still be significantly greater benefits from operating in CHP mode and also using the waste heat. Unlike with steam based generation there is no trade off between heat and electricity and very high total efficiencies may be attainable.

196. However, gasifiers producing syngas generally require a prepared fuel such as RDF/SRF. Manufacturing this fuel has a disbenefit in terms of the energy consumed during the processing and the generation of a residue that has to be landfilled. There will be additional benefits from any recyclates recovered during the fuel manufacture process and fuel could potentially be manipulated to ensure sufficient biogenic content in line with the arguments above. Further work is necessary to determine the overall CO_2 balance of a full scale commercially operating gasifier. Experience in the UK of full scale gasifiers treating wastes is limited and their potential has yet to be fully demonstrated.

8. Other energy outputs

197. In the case of gasification technology producing syngas there is the potential to deliver other energy outputs such as gas to grid or transport fuels. Although as noted above this potential has yet to be fully demonstrated on a commercial scale in the UK.

198. In these processes it becomes more difficult to calculate the overall net efficiency of the process as this needs to consider the energy losses in production, transportation and use of the fuel.

199. However, domestic boilers or internal combustion engines in cars are highly efficient in terms of turning their fuel into heat or useful work. Therefore even with production losses the overall process could be highly efficient.

200. Taking the example of transport fuels. The EU average lifecycle emissions value for fossil fuels is 88.3 grams CO_2e/MJ, equivalent to 0.318tCO_2/MWh. However, this is likely to rise over time as oil (at the margin) will increasingly be sourced from higher GHG intensity pathways (e.g. tar sands, oil shale).

201. Assuming the emissions value remains static under the central scenario, baseline composition, in 2050 an overall process efficiency of less than 20% will be sufficient to be better than landfill. Even under the most challenging scenario for EfW, high capture (low methane) and an assumption of high sequestration an overall process efficiency of 50% would be sufficient.

9. Discussion

202. As with all modelling the results should be used with a suitable degree of caution. The scenarios have been developed to understand likely trends and should not be considered predictions. There are uncertainties in many of the assumptions and while the model's sensitivity to these has been examined one should avoid placing too much weight on exact figures but rather focus on the general trends they exemplify.

203. Using conventional analysis (disregarding biogenic carbon) the model indicates a good carbon case for continuing to include EfW as a key part of the hierarchy. However, as time goes on this case will get progressively worse for electricity only generation as the carbon intensity of the marginal energy mix decreases and if technology for landfill gas capture improves.

204. The model supports the conclusion that existing plants can and should continue to operate as a better solution than landfill. However, once that plant reaches the end of its planned life (assumed to be 25 years) then a detailed analysis should be conducted to determine whether extending its life is the best environmental option as the model indicates there is a significant likelihood that, from a carbon perspective at least, this will not be the case. Modifying processes to use fuel with a higher proportion biogenic material and with increased efficiency throughout the lifetime of a plant, for example through greater use of heat, will improve its overall environmental performance and may help extend its environmentally beneficial operational lifetime. In particular even relatively little use of heat can significantly improve the lifetime benefits of a plant.

205. New plants commencing operation will minimise the risks of becoming environmentally unsound by adopting higher efficiency processes, not just producing electricity but also heat and/or using high biogenic content fuels.

206. This will potentially require a degree of pre-processing of black bag waste to raise the biogenic content of the fuel through removal of fossil based plastics. However, the energy cost of any such processes will need to be included in the calculation of the net efficiency.

207. An alternative approach would be to adopt collection and recycling regimes that remove more of the fossil plastic from the residual waste which will both decrease the overall volume of residual waste and increase the relative biogenic content of that which remains. Where separate collections of organic waste for AD or composting have been shown to have lifecycle benefits over EfW these should not be abandoned in order to feed the need for biogenic waste of an EfW solution.

208. How high a biogenic content is required is very dependent on the level of landfill gas capture and more research is required to estimate this in a manner which decouples estimates from modelled values of carbon sequestration. This work is ongoing.

209. Including an element of sequestered biogenic carbon in the analysis has a significant impact on the conclusions, dramatically reducing the benefit of EfW over landfill, or alternatively significantly increasing the biogenic content required in the waste for a given plant. However, it also significantly increases the uncertainty in the model as it becomes highly sensitive to the assumed sequestration levels. The baseline assumptions used in the model assume a very high level of sequestration (around

50%) which could be considered to be an upper limit. On this basis all new plants would need to operate with some degree of refined fuel, where significant fossil plastic recycling occurs resulting in high biogenic content residual waste and/or with significant use of heat.

210. Much more work is required to understand the levels of sequestration present in landfill to remove the uncertainty and develop policy decisions on this basis.

211. However, based on the modelling presented above, a new plant operating on fuels with greater than 90% biogenic carbon would maintain overall environmental benefits even under the low emissions scenario and modelling including biogenic carbon sequestration. This is the threshold above which energy from waste already qualifies to be considered as biomass under incentive schemes.

212. The uncertainty in the modelling does not preclude the development of energy from waste facilities, there are significant energy security and other drivers for developing these, in the short term they will almost certainly provide carbon benefits. Longer term dis-benefits could be addressed by modifying processes, fuels or appropriately pricing the carbon they produce.

213. While we have used the term ‘balance point’ to indicate where the modelled carbon case switches between favouring EfW and landfill in reality there is a large zone of uncertainty either side of this point where impacts may be only marginal in either direction. In this zone it could be said that the carbon case is equivocal and other considerations should dominate. The carbon case being set out here is just one of the factors that needs to be considered in determining the best treatment route for waste.

214. To move to a position where the carbon case for EfW is less equivocal and minimise risk of dibenefits the modelling indicates that:

- High efficiency solutions should be preferred, beyond that obtainable with mass burn incineration electricity only, for plants commissioned beyond 2015.
- Use of heat provides the simplest route to ensuring continued primacy of EfW over landfill.
- The biogenic content of the waste should be maintained as high as possible through the removal of fossil plastics for recycling.
- The biogenic content of the waste needs to be understood and monitored in relation to the technology being used.
- Increasing the biogenic content of the waste fuel and the process efficiency of a plant during its lifetime will help ensure it continues to provide a carbon benefit.
- Mixed residual waste may need pre-processing to achieve the biogenic content required. The parasitic load required to do this should be included in efficiency calculations.
- It should not be assumed that extending the operational life of existing infrastructure is the best environmental option.

215. The modelling does not directly address the question of whether AD or composting of source segregated food waste is superior in environmental performance to EfW, this

is beyond the scope. However, in line with the hierarchy, high biogenic content in residual waste fuels needs to be driven by greater removal of fossil plastics rather than additional biogenic material.

Annex 1. Comparison of thermal efficiencies using gross and net calorific values

216. The thermal efficiency of a power-only EfW is defined as

$$\text{power exported to grid/energy content of the waste} \times 100\%$$

217. The energy content of the waste is given by the calorific value of the waste. Most European sources (including WRATE) use the net calorific value (or lower heating value) here. However, due to the data sources available we have used the gross calorific value (or higher heating value). To compare our results with values given in the literature there is a need to make a correction.

218. The standard formula for converting gross to net CV is

$$\text{Net CV} = \text{Gross CV} – 0.212H\text{-}0.0245M\text{-}0.008O$$

219. Where CVs are in MJ kg^{-1} and H, M and O represent the percentage hydrogen, moisture and oxygen in the waste respectively.

220. So, a plant efficiency quoted in net CV terms needs to be corrected as follows to be directly comparable with our figures.

$$\text{Gross CV efficiency} = \text{net CV efficiency} \times \text{net CV/gross CV}$$

221. Clearly, this correction factor will be a function of the waste composition, but if we take the NHWAP CV and chemical composition data and the category composition data from Table 2, we can determine an approximate value as shown below.

Table 23. Composition and calorific values (Composition adjusted to remove minor fractions not included in NHWAP)

Material	Composition (%)	Gross CV (MJ kg-1)	Net CV (MJ kg-1)
Paper and card	16.21	12.58	10.75
Dense plastics	6.67	27.90	26.74
Film plastics	6.67	23.56	21.24
Textiles	4.77	15.94	14.34
Misc combustibles	6.67	15.57	13.93
Misc non-combustibles	9.64	2.63	2.53
Food	32.84	5.35	3.39
Garden	3.18	6.50	4.58
Glass	5.30	0	0
Metals	1.69	0	0
Nappies/sanpro	4.77	7.95	5.39
Fines	1.59	5.02	3.46
Overall CV	100	9.95	8.37

222. Therefore the conversion factor is

$$\text{Gross CV efficiency} = \text{net CV efficiency} \times 8.37/9.95$$

$$\text{Gross CV efficiency} = \text{net CV efficiency} \times 0.84$$

Annex 2. Landfill gas capture

223. The assumed rate of landfill gas recovery or rather the methane emissions that result from a particular assumed rate is crucial to the impact of landfills on global climate change.

224. Environment Agency recommended models[32] predict more than 99.5% of landfill gas will have been produced over 150 years, using probabilistic modelling and the 50th percentile. The Environment Agency best practice requirements for landfill gas collection are '*An active gas extraction system to achieve the maximum practicable collection efficiency. The annual collection efficiency for methane should be compared against a value of 85 per cent. The operator or regulator may use this simple assessment to trigger further investigation. This collection efficiency should be achieved in that part of the landfill where gas collection must be taking place (i.e. the capped areas of the site)*'.

225. In 2006, ERM reported to Defra[33] that modelling the active collection phase at 85% recovery gives an overall (150 year) recovery figure of 75%.

226. 'Gas collection efficiency is set at 75% over a 100 year period in Scenarios A-B to replicate the approach of the spreadsheet modelling performed elsewhere in this study. In Scenarios C-D, gas collection efficiency is set at 85% when gas can be actively managed at the landfill. This excludes the stage of filling a landfill cell, and the period post closure when gas cannot be collected and combusted. The 85% value is the Environment Agency's expectation of a landfill operator in a current design of landfill. The gas collection efficiency during the active gas management period in earlier decades for previous landfill designs are (sic) significantly less than this. Scenarios A-B are compared with Scenarios C-D to demonstrate that the 75% overall collection efficiency is justified in a model representing the effect seen in the population of all current UK landfills (as modelled in the study core scenarios)'.

227. The modelling for the Defra report was carried out using GasSim, the same model used for the landfill emissions modelling in WRATE.

228. According to the Environment Agency[34] gaseous emissions from landfills can arise from a wide range of sources including:

- freshly deposited wastes;
- uncapped wastes;
- caps or temporary cover materials;
- intrusive engineering work and excavation;
- leachate and the infrastructure for leachate collection and treatment;
- cracks, gaps, fissures and along the edges of the site capping;
- lateral migration through surrounding geology;

[32] A computerised model developed for the Environment Agency by Golder Associates.
[33] Carbon Balances and Energy Impacts of the Management of UK Wastes, Defra R&D Project WRT 237, Final Report, December 2006, Environmental Resources Management Limited
[34] Landfill Guidance Note 3, Environment Agency Guidance on the management of landfill gas.

- landfill gas flares and engines (utilisation plant);
- emissions through leakages in gas collection and distribution pipework, e.g. poorly sealed; and
- balanced collection wells in which gas pressure exceeds the available suction.

229. The problem is that there are too many unknowns. First, the percentage of methane in the gas will change with time. More importantly, even on the best run sites, some methane will be emitted before an effective collection and recovery system is installed. The problem is compounded when considering lifetime emissions, as overall recovery rates as high as 75% depend on continuing maintenance of the extraction system for decades after the economic incentive has ceased.

230. In 2007, Lefebvre et al reported at the Landfill Symposium in Sardinia that they had sampled different closed landfills and that the closed landfills studied lost 90% of their degradable carbon in ten years, suggesting almost total decomposition in 15 years[35].

231. Barlaz et al[36] reviewed the available literature and then calculated temporally adjusted recovery rates based on the likely rate of gas production at the time.

232. The temporally adjusted rates varied according to the decay rate but were between 55% and 91%.

233. More recently, Defra has funded research looking at surface emissions from different landfill sites[37]. This work was led by the National Physical Laboratory (NPL) and used various techniques, including a long-path laser to estimate surface methane emissions. Unfortunately, the report does not give any figures on the proportion of gas collected. However, the methane flows estimated from concentrations detected above the site show that there are significant flows from areas with active gas management.

234. Spokas, Bogner, Chanton et al looked at the overall methane balance on several sites[38]. The researchers studied four landfill sites in France, recorded recovery rates and calculated emissions to produce an overall methane mass balance. The results showed relatively low surface fluxes and oxidation rates up to 50%. The authors report that '*The results of these studies were used as the basis for guidelines by the French environment agency (ADEME) for default values for percent recovery: 35% for an operating cell with an active landfill gas (LFG) recovery system, 65% for a temporary covered cell with an active LFG recovery system, 85% for a cell with clay final cover and active LFG recovery, and 90% for a cell with a geomembrane final cover and active LFG recovery.*'

---

[35] X. Lefebvre, S. Pommier, A. Åkerman, G. Barina and A. Budka (2007), Analysis of the Waste Mass Degradation Degree in the Context of Functional Stability of Closed Landfills, Eleventh International Waste Management and Landfill Symposium, Sardinia.

[36] Barlaz MA, Chanton JP, Green B, Controls on landfill gas collection efficiency: instantaneous and lifetime performance. Department of Civil, Construction, and Environmental Engineering, North Carolina State University, Raleigh, NC 27695- 7908.

[37] F Innocenti, R A Robinson, T D Gardiner, J Tompkins, S Smith (2011), WR1125 - Measurements of Methane Emissions and Surface Methane Oxidation at Landfills. NPL, Analytical Science Division. D Lowry and R Fisher, Royal Holloway, University of London. Defra.

[38] K. Spokas, J. Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan, I. Hebe (2006), Waste Management, Volume 26, Issue 5, 2006, Pages 516-525

235. Thus, these figures show reasonable agreement with the Environment Agency best practice guide for 85% recovery from covered cells with full gas extraction and therefore potentially with an overall best practice recovery rate of 75%.

236. The most authoritative study comparing the recovery rates used by individual European countries was published in 2010[39]. This examined in detail the greenhouse gas emissions returns on landfills for nine European countries submitted to the European Environment Agency.

237. The study shows that the reported landfill gas capture rates vary widely between countries. The authors report that recovery rates of 70% are possible in individual cells but are unlikely to be replicated across the entire landfill population in a country. The UK recovery rates reported were the highest in the nine countries examined. Achieving them depends on achieving best practice and not encountering any of the problems that can decrease the amount collected, increase surface leakage etc., the overall effect of which is to make the 75% lifetime recovery rate the likely maximum under current best practice.

[39] Sustainable Landfill Foundation and Solagro (2010), Waste landfilling in Europe, European Environment Agency.

- **A3:Excerpts from Annex III - Technology-specific Cost and Performance Parameters**

ANNEX

III

Technology-specific Cost and Performance Parameters

Editor:
Steffen Schlömer (Germany)

Lead Authors:
Thomas Bruckner (Germany), Lew Fulton (USA), Edgar Hertwich (Austria/Norway), Alan McKinnon (UK/Germany), Daniel Perczyk (Argentina), Joyashree Roy (India), Roberto Schaeffer (Brazil), Steffen Schlömer (Germany), Ralph Sims (New Zealand), Pete Smith (UK), Ryan Wiser (USA)

Contributing Authors:
Gesine Hänsel (Germany), David de Jager (Netherlands), Maarten Neelis (China)

This annex should be cited as:

Schlömer S., T. Bruckner, L. Fulton, E. Hertwich, A. McKinnon, D. Perczyk, J. Roy, R. Schaeffer, R. Sims, P. Smith, and R. Wiser, 2014: Annex III: Technology-specific cost and performance parameters. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Table A.III.2 | Emissions of selected electricity supply technologies (gCO_2eq/kWh)[i]

Options	Direct emissions	Infrastructure & supply chain emissions	Biogenic CO_2 emissions and albedo effect	Methane emissions	Lifecycle emissions (incl. albedo effect)
	Min/Median/Max	Typical values			Min/Median/Max
Currently Commercially Available Technologies					
Coal—PC	670/760/870	*9.6*	*0*	*47*	**740/820/910**
Gas—Combined Cycle	350/370/490	*1.6*	*0*	*91*	**410/490/650**
Biomass—cofiring	n.a. [ii]	–	–	–	**620/740/890**[iii]
Biomass—dedicated	n.a. [ii]	*210*	*27*	*0*	**130/230/420**[iv]
Geothermal	0	*45*	*0*	*0*	**6.0/38/79**
Hydropower	0	*19*	*0*	*88*	**1.0/24/2200**
Nuclear	0	*18*	*0*	*0*	**3.7/12/110**
Concentrated Solar Power	0	*29*	*0*	*0*	**8.8/27/63**
Solar PV—rooftop	0	*42*	*0*	*0*	**26/41/60**
Solar PV—utility	0	*66*	*0*	*0*	**18/48/180**
Wind onshore	0	*15*	*0*	*0*	**7.0/11/56**
Wind offshore	0	*17*	*0*	*0*	**8.0/12/35**
Pre-commercial Technologies					
CCS—Coal—Oxyfuel	14/76/110	*17*	*0*	*67*	**100/160/200**
CCS—Coal—PC	95/120/140	*28*	*0*	*68*	**190/220/250**
CCS—Coal—IGCC	100/120/150	*9.9*	*0*	*62*	**170/200/230**
CCS—Gas—Combined Cycle	30/57/98	*8.9*	*0*	*110*	**94/170/340**
Ocean	0	*17*	*0*	*0*	**5.6/17/28**

Notes:

i For a comprehensive discussion of methodological issues and underlying literature sources see Annex II, Section A.II.9.3. Note that input data are included in normal font type, output data resulting from data conversions are bolded, and intermediate outputs are italicized.

ii Direct emissions from biomass combustion at the power plant are positive and significant, but should be seen in connection with the CO_2 absorbed by growing plants. They can be derived from the chemical carbon content of biomass and the power plant efficiency. For a comprehensive discussion see Chapter 11, Section 11.13. For co-firing, carbon content of coal and relative fuel shares need to be considered.

iii Indirect emissions for co-firing are based on relative fuel shares of biomass from dedicated energy crops and residues (5-20%) and coal (80-95%).

iv Lifecycle emissions from biomass are for dedicated energy crops and crop residues. Lifecycle emissions of electricity based on other types of biomass are given in Chapter 7, Figure 7.6. For a comprehensive discussion see Chapter 11, Section 11.13.4. For a description of methodological issues see Annex II of this report.

- **A4:Excerpts from Government Review of Waste Policy in England 2011**

Government Review of Waste Policy in England 2011

defra
Department for Environment Food and Rural Affairs

Energy Recovery

Summary

Government supports efficient energy recovery from residual waste which can deliver environmental benefits, reduce carbon impacts and provide economic opportunities. Our aim is to get the most energy out of waste, not to get the most waste into energy recovery. Anaerobic digestion offers a positive solution to food waste. We will work to remove barriers to other energy from waste technologies by ensuring information is available and readily understood. In particular we will:

- Work with industry to implement our joint Anaerobic Digestion Strategy;
- Overcome barriers to development of markets for outputs from energy from waste;
- Identify and communicate the full range of recovery technologies available and their relative merits – right fuel, right place and right time;
- Publish a guide to the full range of energy from waste technologies available to help all involved make decisions based on their specific requirements;
- Provide the necessary framework to address market failures in delivering the most sustainable solutions, while remaining technology neutral;
- Work to identify commercially viable routes by which communities can realise benefits from hosting recovery infrastructure to help support community acceptance;
- Ensure the correct blend of incentives are in place to support the development of recovery infrastructure as a renewable energy source;
- Support the development of effective fuel monitoring and sampling systems to allow the renewable content of mixed wastes to be accurately measured; and
- Ensure that waste management legislation does not have unintended consequences on the development of the energy recovery industry.

207 The government supports energy from waste as a waste recovery method through a range of technologies, and believes there is potential for the sector to grow further. At present, we cannot prevent, re-use or recycle all of our waste. However, some of our residual waste has value in the form of recoverable energy and other by-products, such as soil conditioners. Through effective prevention, re-use and recycling, residual waste will eventually become a finite and diminishing resource; but we need to deal with this waste effectively for the foreseeable future.

208 The benefits of recovery include preventing some of the negative greenhouse gas impacts of waste in landfill. Preventing these emissions offers a considerable climate change benefit, with the energy generated from the biodegradable fraction of this waste also offsetting fossil fuel power generation, and contributing towards our renewable energy targets. Even energy from the non-biodegradable component, whilst suffering from the negative climate impacts of other fossil fuels, has additional advantages in terms of providing comparative fuel security, provided it can be recovered efficiently.

209 The revised Waste Framework Directive allows for deviation from the waste hierarchy where it can be clearly demonstrated there is a better environmental outcome from doing so, which may be the case for energy recovery from certain waste streams. Conversely, 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.

210 Energy from waste covers a range of complementary processes which recover additional value from the waste, some of which extract the energy directly while others convert residual waste into different types of fuel for later use. We need to understand how different technologies can work together and with the different feedstocks available.

Did you know?

In 2009 enough electricity was generated from biodegradable municipal waste to supply all the households in Leeds.

211 We will need to have sufficient infrastructure in place to support increasingly efficient recovery that is flexible enough to adapt to changing feedstocks over time. As we recycle more, we need to understand how we can adapt to recover the best value from what is left, while delivering the best environmental outcomes. We are aiming to get the most energy out of the residual waste, rather than to get the most waste into energy recovery.

212 Our overarching goals are to ensure that:

- Recovery of energy from waste and its place in the waste hierarchy is understood and valued by households, businesses and the public sector in the same way as re-use and recycling.
- Energy is recovered in a variety of ways, using the best technology available for the circumstances. The resulting electricity, heat, fuel or other products are seen as commodities with real economic value. Where necessary incentives and regulation are aligned to reflect this value.
- Recovery of energy from waste makes an important contribution to the UK's renewable energy targets, minimising waste to landfill and helping to meet UK carbon budgets.

- **A5:Excerpts from Appeal Ref 2224529 – Former Ravenhead Glass Warehouse, Lock Street, St Helens (August 2015)**

The Planning Inspectorate

Appeal Decision

Hearing held on 21 and 22 January and 17 June 2015

Site visits made on 21 and 22 January 2015

by M Middleton BA(Econ) DipTP DipMgmt MRTPI

an Inspector appointed by the Secretary of State for Communities and Local Government

Decision date: 3 August 2015

Appeal Ref: APP/H4315/A/14/2224529
Former Ravenhead Glass Warehouse and other land, Lock Street, St Helens, WA9 1HS

- The appeal is made under section 78 of the Town and Country Planning Act 1990 against a refusal to grant planning permission.
- The appeal is made by Brian Moore against the decision of St. Helens Metropolitan Borough Council.
- The application Ref P/2013/0475, dated 7 May 2013, was refused by notice dated 31 March 2014.
- The development proposed was change of use of warehouse building and installation of plant and machinery, including 39 m high flue, to form a 10.6 MW energy from waste plant that will be powered by refuse derived fuel, together with the relocation of the existing materials reclamation and waste recycling facility to accept non-hazardous waste, currently located on Merton Street, to the application site and demolition of the existing materials and waste recycling facility.

Application

1. The application form describes the proposal as written above. During early discussions between the Applicant and the Council, it became apparent that following the relocation of the waste recycling facility from Merton Street to Lock Street, he would wish to redevelop the Merton Street site for industrial purposes but did not have any detailed proposals. With the Applicant's agreement, the Council therefore amended the application description, considering it to be a hybrid application and added 'outline permission for industrial development of the Merton Street site' to the above description.

2. This description was used in the report to the Council's Planning Committee and was the basis of its determination. I have also considered the appeal on this basis, determining it as a hybrid appeal for three constituent parts of an overall proposal; these being the relocation of a waste recycling facility from Merton Street to Lock Street, the installation of an energy from waste plant at Lock Street to treat the waste from the relocated waste recycling facility and other refuse derived fuel (RDF) and the redevelopment of the vacated site on Merton Street for industrial purposes.

Decision

3. The appeal is dismissed insofar as it relates to the installation of plant and machinery, including 39 m high flue, to form a 10.6 MW energy from waste plant that will be powered by refuse derived fuel.

of north Cheshire is closer to this facility than most of Merseyside and the western part of Greater Manchester is close by.

23. Both the Appellant and the Council consulted Ineos Chlor about their imminent capacity at Runconn. The Email to the Council, which is dated January 2015 says that there was 50,000 tonnes pa of spare capacity that Viridor has control over. Whether that would or could be available to other waste suppliers is not clear. The correspondence also says that phase 2 has a capacity of about 425,000 tonnes pa but nothing is said about the extent to which this is committed. The communication received by the Appellant suggests that there may be an opportunity for 30,000 tonnes at a gate fee of £85/tonne. Without sight of the letter from the Appellant to Ineos Chlor and therefore the context of its reply, one cannot conclude that there is only 30,000 tonnes of spare capacity overall at Runcorn. Nor can one conclude that there is currently 475,000 tonnes pa of uncommitted capacity as the Council's evidence implies. In my experience it is most unlikely that the capital expenditure involved in such a project as phase 2 would be committed without significant medium term commitment from RDF suppliers.

24. The Appellant has shown interest from potential RDF suppliers that could deliver over 280,000 tonnes pa of non hazardous waste to a new EfW plant at Lock Street. Whilst not all of this may be forthcoming, as most of the suppliers already supply the existing facility, it seems probable that the Appellant could source the 150,000 tonnes pa required to efficiently operate the proposed EfW plant.

25. It is a fact of life that EfW capacity at Merseyside is used to process RDF from other parts of the region. Despite the duty to cooperate there is no available information as to the extent of this and thereby no conclusive evidence that there is in fact sufficient EfW capacity at Merseyside and Halton to meet the sub-region's future requirements.

26. Nevertheless, this site is not proposed in the WP. Despite the weaknesses in the Council's case, the Appellant has not clearly demonstrated that existing operational and consented capacity cannot be accessed to meet the identified need. The proposal is therefore contrary to WP Policy WM14. Furthermore the National Planning Policy for Waste (NPPfW) expects applicants to demonstrate the quantitative or market need for new waste management facilities where proposals are not consistent with an up to date LP. I conclude that the overall need for the proposal has not been clearly demonstrated.

Carbon Output

27. National Planning policy for Waste (NPPfW) expects applicants to demonstrate that waste disposal facilities, not in line with the LP, will not undermine the objectives of the LP by prejudicing the movement of waste up the Waste Hierarchy. The WP has the vision of waste as a resource that is moved up the Waste Hierarchy and an objective of all new waste management facilities contributing to reductions in greenhouse gas emissions.

28. Energy from Waste[1] points out that such waste infrastructure has a long life (normally 20-30 years) and that steps should be taken at the start to ensure that systems drive waste up the Waste Hierarchy and do not constrain it. In

[1] Energy from Waste, a guide to the debate: Department of Energy and Climate Change, 2014

consequence new infrastructure, particularly where there is not clear evidence of a need for additional capacity, needs to contribute to recovery and not disposal. It seeks to maximise the benefits of energy generation and points out that to comply with the Waste Framework Directive the process needs to constitute recovery.

29. The WP policies that require proposals to demonstrate that facilities would not prejudice the movement of waste up the waste hierarchy and would contribute to waste recovery rather than disposal are clearly in accordance with this advice. Whilst the attainment of R1 status is not a mandatory process by which planning proposals should be considered, it is nevertheless a method of demonstrating whether or not a proposal is recovery or disposal.

30. In certain circumstances 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 will have a positive effect on overall carbon emissions. Additionally, it is consequently now generally accepted that EfW plants need to provide heat as well as electricity to be considered to be a waste recovery operation.

31. Despite the opportunity provided by the adjournment, the Appeal proposal does not include a detailed specification of the type of gasification technology to be used. Other than indications from potential users in the area, there is also no evidence to demonstrate that the supply of heat, from whatever system is installed, to these users would be commercially viable. Whilst conflicting with the evidence from UKWIN, the Appellant's evidence nevertheless suggests that electrical generation from the plant alone would not enable it to meet R1 status. Consequently the plant would need to recover and facilitate the use of waste heat to realistically be considered as a recovery facility.

32. The proposal alleges that the EfW plant will provide heat for local businesses and I have no reason to doubt that there are genuine potential customers in the area. However, whilst I accept that it is not reasonable to expect applicants to demonstrate a definite commitment from heat end users at this stage, in the absence of more detailed operational and financial information, it is not possible to make a judgement on the plant's potential to perform in this context. Additionally, there is no suggested condition to ensure that the necessary infrastructure, to enable any heat produced by the plant to be readily exported, would be provided. This does not inspire confidence in the Appellant's alleged desire to export heat from the site. As the Appellant points out, "Guidance on the Application of the Waste Hierarchy[2]" makes it clear that all energy recovery technologies come higher in the waste hierarchy than disposal. However, there is no evidence to suggest that the material to be treated by the proposal would otherwise be disposed of by landfill.

33. Whilst some of the material would be diverted from transportation to the continent and would contribute to greenhouse gas reductions in this respect, a substantial amount would not. There is no evidence as to the nature of the disposal of this material at the present time or indeed whether any of it would be diverted from existing EfW plants in the region. Notwithstanding the carbon savings that would result from the Appellant's existing output of RDF not being transported to the Continent, I therefore conclude that the proposal's carbon output has not been demonstrated to be such that the proposal would be a

[2] Department for the Environment, Food and Rural Affairs 2011

waste recovery operation that would clearly drive the treatment of waste up the Waste Hierarchy. Consequently the proposal does not meet the requirements of WP Policies WM12 and WM13.

Environmental quality

34. The representations from the general public clearly demonstrate that there is substantial local concern about the traffic implications of the proposal, particularly its impact on Merton Bank Road, and environmental issues associated with the operation of the existing waste recycling facility on Merton Street.

35. The Appellant points out that the anticipated maximum of 622 heavy goods vehicle movements per week from the Lock Street site are substantially less than was indicated when planning permission was applied for and granted for the Merton Street operation. That estimate was 1648. Even when the anticipated HGV traffic generated by the redeveloped Merton Street is added in (the Highway Authority anticipate less than 30 per week), there would still be a substantial reduction. However, the application maximum is unlikely to be the experienced HGV traffic output of the Merton Street operation. Observations on my site visit suggest that it is currently working at operational capacity. However, it appears to be operating with difficulty and with a throughput that is about half of that consented. This suggests, in the absence of any data, that its HGV generation is substantially less than that indicated in the original planning application. Whilst the appeal proposal would not have vehicles visiting the site to collect material for despatch to the Continent, I nevertheless consider that there would be an increase in HGV's visiting the appeal proposal when compared to the actual number visiting the existing operation.

36. However, both sites are within a sizeable industrial area that must overall already generate a significant number of HGV movements. As the Highway Authority points out, the Lock Street site was traditionally used as a warehouse facility and could be so used again. Given the nature of the site and its buildings, the HGV traffic generated by such operations is likely to be significantly greater than that from the appeal proposal.

37. Merton Bank Road is a district distributor road that connects Lock Street and Merton Street to the A58, which is a primary route. There is undoubtedly congestion at the junction of these two roads, particularly at peak periods. However, in the absence of any evidence on vehicular flows it is impossible to conclude that the appeal proposal would materially worsen this situation. There was also no evidence of accidents before the Hearing.

38. The nature of this part of Merton Bank Road is now largely industrial but there are a number of residential properties behind front gardens on the western side and a school on the eastern side. Parked cars in association with these could assist the creation of congestion if HGV's are trying to overtake. However, if this is a major problem then traffic regulations may be able to resolve it. There is also ample space along Merton Bank Road to widen the carriageway in order to provide dedicated residents and school car parking if parking seriously impedes the free flow of traffic and highway improvements can be justified. Similarly the junction capacity could be increased if the alleged rat running to avoid it is significant or queuing traffic is producing unacceptable air quality, noise or vibration.

- **A6:Excerpts from Environmental Permit Application SP3038DY (February 2017)**

Rye House Energy Recovery Facility,

Hoddesdon, Hertfordshire

Environmental Permit Application EPR/SP3038DY/A001

Energy Management Plan

February 2017

Prepared for

7. Proposed Development Assessment

7.1 Proposed Development – Operational Parameters

The Proposed Development is a two line mass burn process with the capacity to accept a maximum of 350,000 tonnes of municipal waste per annum. The Proposed Development is anticipated to have an annual availability of circa 8,000 hours per annum, accounting for annual maintenance and plant failure down-time.

The plant will be designed to be of sufficiently high gross efficiency to achieve R1 status when in power-only mode. Viability of future heat off-take must be assessed carefully against R1 criteria, ensuring that sufficient heat is supplied through an efficient heat network, with parasitic and distribution losses low enough to retain R1 energy recovery status in CHP mode.

The key technical specifications of the Proposed Development are summarised in the table below.

Table 7-1 Technical specifications of the Proposed Development

Technical Specification[11]	Value
Municipal Waste (tonnes)[12]	320,000
NCV waste (based on design data) (MJ/kg)	9.5
GCV waste (MJ/kg)	11
Total Fuel Input (based on gross CV) (MWh)	982,126
Gross electrical output (MW_e) in electrical-only mode	33.5
Parasitic Load (MW_e)	3.3
Net electricity export (MW_e) in electrical-only mode	30.2
Maximum useful heat (MW_{th})	25
Gross electrical output (MWh) in electrical-only mode	268,000
Net electricity export (MWh) in electrical-only mode	241,600
Gross electrical output (MWh) in CHP mode	218,800
Net electricity export (MWh) in CHP mode	191,600
Annual recoverable heat output from the steam turbine (MWh) in CHP mode	200,000
Z ratio assumed[13].	4

Steam generated from the waste combustion process is fed in a steam turbine at a mass flow rate of 35 kg/s, temperature of 433°C and pressure of 65 bar. The steam turbine plant is a condensing turbine with 3 uncontrolled extraction points:

- Deaerator and air preheater at the first and second extraction point; and
- Low pressure heater at the third extraction point.

The steam extracted from the steam turbine expansion process presents the following conditions:

- Mass flow rate: 29kg/sec,
- Temperature: 42°C,
- Pressure: 80 mbar

The turbine will have the capacity to generate 33.5 MW_e of gross electricity under electricity-only mode. The net electricity output is expected to be 30.2 MW_e. The remaining electricity will be used on-site to support the operation of the Proposed Development (3.3 MW_e). Due to the scale of the ERF being less than 300 MW_e, there is no requirement under EA guidance to design the facility to be Carbon Capture Ready (CCR).

[11] Data provided by Veolia
[12] Assuming 8,000 hours per annum of waste treatment operations
[13] The Z ratio provides an estimation of the loss in electrical power generated when heat is exported before full steam turbine expansion to serve heat loads. Data provided by Veolia.

- **A7:Excerpts from Valuation of Energy Use and Greenhouse Gas (April 2019)**

Department for
Business, Energy
& Industrial Strategy

VALUATION OF ENERGY USE AND GREENHOUSE GAS

Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government

April 2019

Table 3.1[16]: Factors for converting greenhouse gases to their equivalent in carbon dioxide

Greenhouse Gas	Global warming potential per unit mass (relative to CO_2)
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
HFC – 134a	1,430
HFC – 143a	4,470
Sulphur hexafluoride	22,800
Carbon Dioxide as Carbon[17]	3.67

3.28 The GHG emissions associated with the use of energy may be estimated by applying a fuel-specific emissions factor. By multiplying the energy use (measured in kWh) by an emissions factor (measured in $kgCO_2e/kWh$), one obtains the quantity of GHG emissions produced, measured in terms of the equivalent mass of carbon dioxide emissions ($kgCO_2e$).

3.29 In order to quantify changes in GHG emissions resulting from changes in energy use, net changes in energy use should first be quantified, making sure to include the impact that any rebound effect may have (see paragraph 3.8). Marginal emissions factors are then applied to these energy use changes as demonstrated in Box 3.4.

Box 3.4 Converting changes in fuel use to GHG emissions

$$\Delta \boldsymbol{C}_{it} = \Delta(\boldsymbol{EU})_{it} \times \boldsymbol{M}_{it}$$

$\Delta \boldsymbol{C}_{it}$ = *Change in emissions from fuel i in year t* ($kgCO_2e$)

$\Delta(\boldsymbol{EU})_{it}$ = *Change in use of fuel i in year t* (kWh)

$\boldsymbol{M}_{it}$ = *Year t marginal emissions factor* ($kgCO_2e/kWh$)

3.30 For estimating changes in emissions from changes in **direct fuel** use, such as burning coal or gas, analysts should use the emissions factors found in **data tables 2a and 2b**. The marginal emissions factor is assumed to be constant across different levels of supply / demand (i.e. the average and marginal emissions factors are identical), and also over time. While there are minor variations in the emissions produced from these fuels over time resulting from differences in the average chemical composition, it is reasonable to assume that this variation is insignificant for appraisal purposes.

3.31 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**. These emission factors will vary over time as there are different types of

[16] The conversion factors incorporate GWP values for a 100 year time horizon relevant to reporting under UNFCCC, as published by the IPCC in its Fourth Assessment Report Revised GWP values have since been published by the IPCC in the Fifth Assessment Report (2013) Current UNFCCC Guidelines on Reporting and Review are that the figures in the Fourth Assessment Review should be used in the emission inventory carbon budgets and for international reporting.

[17] Prior to 2007, figures for changes in GHG emissions were presented in terms of carbon (C). Any such figures should be converted into units of CO_2e using the conventional conversion factor of 44/12 (e.g. 1 tonne of C emissions is equivalent to 1 x (44/12) = 3.67 tonnes of CO_2e).

power plant generating electricity across the day and over time, each with different emissions factors. An example of the calculation is presented in Box 3.5.

Box 3.5 Using emissions factors to convert electricity use changes into GHG emissions changes

An energy efficiency programme which reduces the use of electricity by households is being considered. Electricity consumption is predicted to be cut by 10GWh (10 million kWh) relative to the "do nothing" option in each year between 2018 and 2038. The calculations below demonstrate how this change in energy use is multiplied by the appropriate marginal emissions factor (see data table 1) to derive the change in emissions.

	Change in electricity use	**Marginal emissions factor (Table 1) - Domestic Households**		**Change in emissions**
	GWh	**$kgCO_2e$ /kWh**	**tCO_2e /GWh (see Annex B)**	**tCO_2e**
2018	-10	0.32	319	-3191
2019	-10	0.31	308	-3077
…	…	…	…	…
2036	-10	0.06	65	-649
2037	-10	0.06	58	-578
2038	-10	0.05	52	-515

3.32 There are complex mechanisms that determine the effects of sustained but marginal changes to the grid electricity supply (from either displacement with other generation or a demand reduction). A small reduction in grid electricity consumption will be met through a reduction in supply from a small subset of plant, rather than through an equal drop across all generation plant. Very temporary changes in consumption will likely only result in short run changes to generation levels, rather than changes in capacity. However, sustained changes in consumption will result in changes to generation capacity – in terms of the timing, type, and amount of generation plant built and / or retired – as well as changes in generation levels. Modelling undertaken by BEIS has estimated these longer-term dynamics, and they are reflected in the marginal emissions factors. Further information may be found in chapter 2 of the background documentation accompanying this guidance.

- **A8:Excerpts from Energy from waste A guide to the debate (February 2014)**

www.gov.uk/defra

Department
for Environment
Food & Rural Affairs

Energy from waste

A guide to the debate

February 2014 (revised edition)

DEPARTMENT OF
ENERGY
& CLIMATE CHANGE

overall impact. The more efficiently the energy from waste plant converts the waste to useful energy, the greater the carbon dioxide being offset and the lower the net emissions.

42. Alternatively, considering the landfill route, all the fossil carbon stays in the ground and doesn't break down. The fossil carbon is sequestered, as is potentially up to half of the biogenic carbon depending on the exact conditions in the landfill. However, some of the biogenic material does break down with the carbon converted to a mixture of carbon dioxide and methane, known as landfill gas. A large proportion of this landfill gas would be captured and burnt, generating energy and offsetting power station emissions. Burning landfill gas produces biogenic carbon dioxide which, as for energy from waste, is considered short cycle. Crucially however, some of the methane would escape into the atmosphere. As a very potent greenhouse gas even a relatively small amount of methane can have dramatic effect and be equivalent to a much larger amount of carbon dioxide.

43. For our average current black bag of waste, once the energy offset is taken into account, the net carbon dioxide equivalents from the methane released from landfill would be greater than the net carbon dioxide released from a typical energy from waste plant. All of this means that for this example, energy recovery from residual waste has a lower greenhouse gas impact than landfill. It would therefore be considered higher than landfill in the waste hierarchy and the preferred option for managing residual waste in terms of minimising potential climate change impact.

44. These arguments are of course simplified and whilst these are the key issues, in reality there are many more factors being balanced than those outlined above[30]. There is significant debate on how a number of issues are handled that mean it is important to consider things on a case by case basis. These include: changing biogenic content of residual waste over time; how the biogenic carbon dioxide is counted; the fact that not all the biogenic material breaks down in landfill; the level of landfill gas capture; the impact of recycling metals from ash generated by energy from waste; the impact of pre-treatments on stabilising waste and how to allow for the fact that the landfill gas is released over many years.

45. However, even when these factors are taken into consideration, in carbon terms, currently energy from waste is generally a better management route than landfill for residual waste. While it is important to remember this will always be case specific and may change over time, two rules apply:
    - the more efficient the energy from waste plant is at turning waste into energy, the greater the carbon offset from conventional power generation and the lower the net emissions from energy from waste;
    - the proportion and type[31] of biogenic content of the waste is key – high biogenic content makes energy from waste inherently better and landfill inherently worse.

[30] Recent modelling work has considered the impact of a number of these factors. The implications of this work are discussed in more detail in chapter 5 and the modelling can be found at http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=19019&FromSearch=Y&Publisher=1&SearchText=wr1910&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

[31] Some wet wastes e.g. food are not particularly suitable for energy from waste.

46. Energy from waste will therefore be a better environmental solution than landfill provided the waste being used has the right biogenic content and a plant is efficient at turning that waste into useable energy. The life of the plant is usually 25-30 years and the biogenic content of the waste will change in that period. It is also possible to treat waste to increase biogenic content e.g. removing plastics. Ensuring that the waste and efficiency of plant are sufficiently matched for the entire life of an energy from waste plant is key to the debate over whether energy from waste is the most appropriate management option. It may be that the plant itself can be updated, upgraded or refurbished to keep pace with the changing nature of the waste. To understand fully the relative benefits of energy from waste against other solutions a full life cycle assessment (see below) for the specific circumstances will be required. The Waste Resource Action Programme (WRAP) have developed an interactive guide[32] which provides information to help decision making for the development of energy from waste facilities.

Recovery or disposal – the meaning of R1

47. As described above the Waste Framework Directive (WFD) sets out the waste hierarchy and enshrines it in law. It requires that a waste management route defined as recovery should be used ahead of an alternative that is classified as disposal. Exceptions can be made (see below) but this general principle makes it important to know whether a process is considered recovery or disposal.

48. Historically the Waste Framework Directives have included annexes which set out lists of what are considered to be recovery or disposal operations. Each is given a number and a letter: R for recovery, D for disposal. In the current directive the classifications of particular relevance to energy from waste are:
    - R1 – Use principally as a fuel or other means to generate energy
    - D10 – Incineration on land

49. What this means is that where waste is burnt as a fuel to generate energy it can potentially be considered a recovery operation (R1) but where the purpose of incineration is to get rid of waste, it is considered D10 and hence disposal. All municipal waste incinerators were and are deemed as disposal activities (D10) unless and until they are shown to meet the requirements of R1. This is why the term R1 often crops up in the debate about how good an energy from waste plant might be and how it compares to other options.

50. For municipal solid waste, which includes all the waste collected from households, the EU has gone further by defining what it considers to be sufficient for recovery status under R1. The WFD includes a formula relating to the efficiency of the combustion plant. A municipal waste combustion plant can only be considered to be a recovery operation under R1 if it generates energy *and* the plant meets the efficiency thresholds calculated using the R1 formula[33].

[32] http://www.wrap.org.uk/content/energy-waste-development-guidance-0
[33] The R1 formula calculates the energy efficiency of the municipal solid waste incinerator and expresses it as a factor. This is based on the total energy produced by the plant as a proportion of the energy of the fuel (both traditional fuels and waste) which is incinerated in the plant. It can only be considered recovery if the value of this factor is above a certain threshold. It is important to note that the calculated value arrived at via the R1 formula is not the same as power plant efficiency which is typically expressed as a percentage.

51. This helps ensure that all plants which want to be classed as recovery in the EU will meet a minimum standard of environmental performance. As waste can only cross national boundaries for recovery not disposal it also ensures only the more environmentally sound plants can compete internationally for waste derived fuel.

52. The requirement to apply the R1 formula means that lower efficiency municipal energy from waste plants are classed as disposal (D10) even if they are generating useable energy. However, with the right combination of overall efficiency and biogenic content in the waste, an energy from waste plant which does not qualify for R1 status may still be a better environmental option than landfill. Similarly, in line with the right fuel, right technology argument set out above, a plant meeting the R1 formula does not in itself necessarily mean it is the best solution for all waste streams.

53. R1 status is not mandatory for energy from waste plant[34] and will not be part of an environmental permit. Irrespective of whether the plant is classed as a Recovery (R1) plant or Disposal (D10) plant, operation under the Environmental Permitting Regulations requires that plants recover as much energy as practicable[35].

54. The distinction between having R1 status or having a plant being classified as a disposal facility is important for planning purposes and in the application of the proximity principle. It is therefore important that operators strive towards demonstrating that energy from waste is a recovery operation according to the WFD definitions. Interested operators should contact the relevant competent authority[36] who, based on an application from the operator, will assess whether or not a municipal solid waste combustion facility meets or exceeds the threshold and can be considered a recovery operation.

Waste exports for energy recovery

55. The UK has a long-standing policy of self-sufficiency for waste disposal and the UK Plan for Shipments of Waste[37] prohibits the export of waste for disposal. Waste may be exported for recovery, which can have advantages over managing it within the UK. For example if current lack of appropriate infrastructure means the alternative UK treatment route is more costly or environmentally worse.

56. Although exports of waste for recovery from the UK are generally permitted, in line with EU law, the export of mixed municipal waste[38] (in other words “black-bag waste”) for recovery is not allowed unless it has undergone some form of pre-treatment. Such

---

Environment Agency guidance on R1 can be found at https://publications.environment-agency.gov.uk/ms/C7xJLZ

[34] Although Wales require any plant that is part-funded by the Welsh Government should at least comply with an R1 factor of 0.65.

[35] The Environment Agency will shortly be publishing guidance on its requirements for CHP readiness under environmental permitting.

[36] The Environment Agency in England and Wales, the Scottish Environment Protection Agency in Scotland and the Northern Ireland Environment Agency for Northern Ireland.

[37] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69546/pb13770-waste-shipments.pdf

[38] coded 20 03 01 in the European Waste Catalogue

- **A9:Excerpts from 2006 IPCC Guidelines for National Greenhouse Gas Inventories**

CHAPTER 3

SOLID WASTE DISPOSAL

BOX 3.2 (CONTINUED)

Plume measurements are designed to measure the emissions from an entire SWDS by measuring the difference in CH_4 flux in a transect screen downwind and upwind from the SWDS. Emissions might be assessed comparing increase in CH_4 concentrations with tracer concentrations (e.g., from a known amount of N_2O or SF_6 released on the SWDS) or using a dispersion model. Variations of this method are used around the world by Czepiel *et al*. (1996), Savanne *et al*. (1997), Galle *et al*., (1999) and Hensen and Scharff (2001). The advantage of the method is its accuracy and its possibility to measure emissions from the entire SWDS, this being very effective to cope with spatial variation. However, the method is very expensive and normally only applied for one or a few specific days. Therefore the result seems to be not representative for the annual average emissions from the site (Scharff *et al*., 2003). For this reason Scharff *et al*. (2003) developed a stationary version of the mobile plume measurement (SPM) for plume measurements around a SWDS for longer times.

At this moment (2006), there is no scientific agreement on what methodology is preferred to obtain annual average emissions from an entire SWDS. Intercomparisons of methods are performed by Savanne *et al*. (1995) and Scharff *et al*. (2003) and the conclusion is more or less that no single method can deal with spatial and temporal variability and is yet affordable. According to Scharff *et al*. (2003) the mass-balance method and the static plume method are the best candidates for further development and validation. However there has been little scientific discussion on this conclusion at the moment of writing of the *Guidelines*.

3.4 CARBON STORED IN SWDS

Some carbon will be stored over long time periods in SWDS. Wood and paper decay very slowly and accumulate in the SWDS (long-term storage). Carbon fractions in other waste types decay over varying time periods (see Half-life under Section 3.2.3.)

The amount of carbon stored in the SWDS can be estimated using the FOD model (see Annex 3A.1). The long-term storage of carbon in paper and cardboard, wood, garden and park waste is of special interest as the changes in carbon stock in waste originating from harvested wood products which is reported in the AFOLU volume (see Chapter 12, Harvested Wood Products). The FOD model of this Volume provides these estimates as a by-product. The *waste composition* option calculates the long-term stored carbon from wood, paper and cardboard, and garden and park waste in the SWDS, as this is simply the portion of the DOC that is not lost through decay (the equations to estimate the amount are given in Annex 3A.1). When using *the bulk waste* option it is necessary to estimate the appropriate portion of DOC originating from harvested wood products in the total DOC of the waste, before finding the amounts of long-term stored carbon. When country-specific estimates are not available, the IPCC default fractions of paper and cardboard, wood, and garden and park waste can be used.

The long-term stored carbon in SWDS is reported as an information item in the Waste sector. The reported value for waste derived from harvested wood products (paper and cardboard, wood and garden and park waste) is equal to the variable 1B, $\Delta C_{HWP\ SWDS\ DC}$, i.e., the carbon stock change of HWP from domestic consumption disposed into SWDS of the reporting country used in Chapter 12, Harvested Wood Products, of the AFOLU Volume. This parameter as well as the annual CH_4 emissions from disposal of HWP in the country can be estimated with the FOD model (see sheet HWP in the spreadsheet).

3.5 COMPLETENESS

Previous versions of the *IPCC Guidelines* have focused on emissions from MSW disposal sites, although inventory compilers were encouraged to consider emissions from other waste types. However, it is now recognised that there is often a significant contribution to emissions from other waste types. The *2006 Guidelines* therefore provide default data and methodology for estimating the generation and DOC content of the following waste types:

- Municipal Solid Waste (MSW) – the default definition and composition is given in Chapter 2,
- Sewage sludge (from both municipal and industrial sewage treatment),
- Industrial solid waste (including waste from wood and paper industries and construction and demolition waste, which may be largely inert materials, but also include wood as a source of DDOCm),

- **A10:Excerpts from A Changing Climate for Energy from Waste (2006)** eunomia

research & consulting

A Changing Climate for Energy from Waste?

Final Report for Friends of the Earth

Author:

Dr Dominic Hogg

03/05/2006

methane, which can be used to generate energy, far from being a problem, potentially becomes a virtue.

It is interesting to note, therefore, that the most recent studies being carried out on behalf of government propose levels of landfill gas release to the atmosphere of 15% or so. At these levels of capture, if one could believe them, the generation of methane might be something to be encouraged, not to be seen as problematic.

Given that the statement that 'energy from waste incineration is good for climate change' might not necessarily be true, it is interesting to see how incineration compares in a comparative analysis with other residual waste treatment technologies.

These and other issues are explored in what follows.

3.1 Methodological Issues

Before embarking on the analysis, it is worth teasing out some of the key methodological issues regarding the relative performance of waste management technologies as regards climate change. These are discussed in more detail in Annex 2.

1. In a comparative analysis of different waste treatment technologies, the assumption that emissions of CO_2 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?);[17]
2. The timing of emissions of GHGs is important in understanding impacts. There is a clear difference, from the point of view of impacts and from the perspective of policy, between a process which emits all associated GHGs after one hour, and one that emits the same GHGs in one day after fifty years;
3. For these reasons – that the time profile of emissions is important – conventional life cycle analysis is unhelpful. Conventional lifecycle analysis determines (somewhat arbitrarily) a cut-off time and counts all emissions occurring before that cut-off, and none that occur after it. Those that occur before are treated equally, irrespective of whether they appear in the first second, or in the last second before the cut-off point.
4. The correct approach would be to allocate emissions to different years and understand the contribution of GHGs to climate change through understanding their contribution over time. This implies use appropriate application of discounting. Though the appropriate rate of discount is still under discussion (and has a bearing upon the social costs of carbon calculated), we have followed the approach recommended by the Treasury in the Green Book. Such an approach

[17] Further explanation of the approach is given also in Eunomia et al (2002) *Economic Analysis of Options for Managing Biodegradable Municipal Waste*, Final Report to DG Environment, European Commission.

- **A11:Excerpts from Assessment of the options to improve the management of bio-waste in the European Union (2010)**

ARCADIS
Infrastructure, environment, facilities

Imagine the result

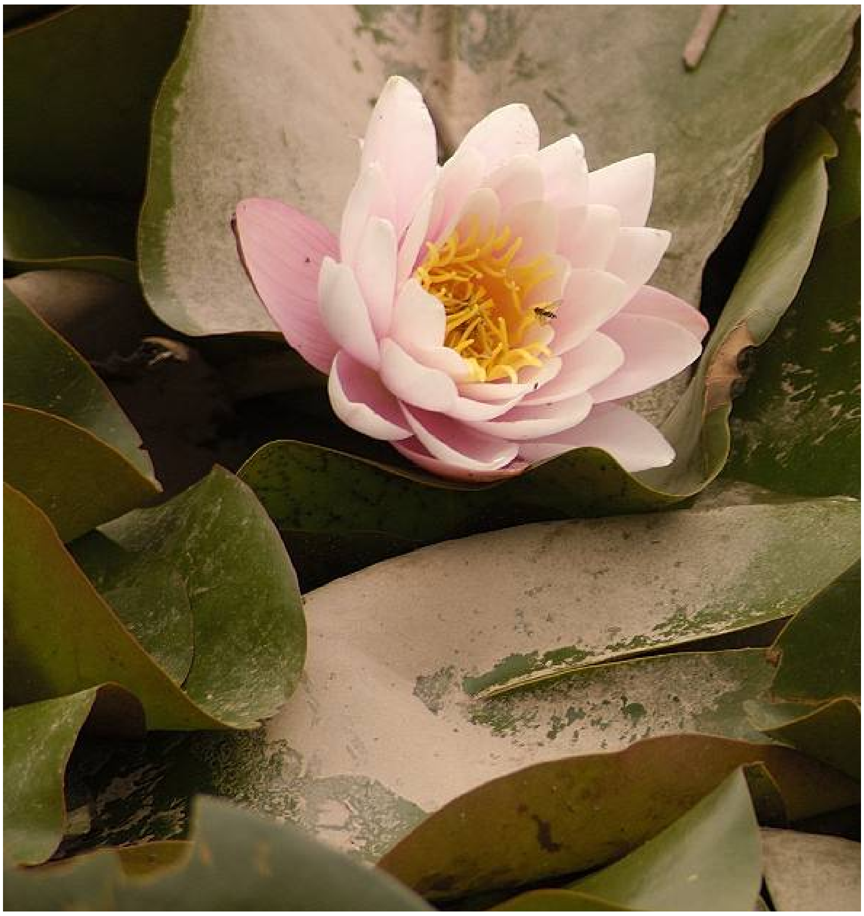
eunomia
research & consulting

FINAL REPORT

ASSESSMENT OF THE OPTIONS TO IMPROVE THE MANAGEMENT OF BIO-WASTE IN THE EUROPEAN UNION
ANNEX F: Environmental assumptions

STUDY CONTRACT NR 07.0307/2008/517621/ETU/G4

EUROPEAN COMMISSION DG ENVIRONMENT
ARCADIS Project number – 11/004759 | Version B | 12-02-2010



CLIENT	**European Commission Directorate-General Environment** **Mr. Bartosz Zambrzycki** **Unit G.4 – BU – 5 05/118** **B-1049 Brussels**

ASSESSMENT OF THE OPTIONS TO IMPROVE THE MANAGEMENT OF BIO-WASTE IN THE EUROPEAN UNION

ARCADIS
Infrastructuur, milieu, gebouwen

CONSULTANTS	**ARCADIS Belgium nv** **Clara Snellingsstraat 27** **2100 Deurne** **Belgium** **EUNOMIA** **Research & Consulting** **62 Queen square** **Bristol, BS1 4JZ** **United Kingdom**
Contact	**Laurent Franckx**
Telephone	**+32 3 328 62 73**
Telefax	**+32 3 328 62 87**
E-mail	**l.franckx @arcadisbelgium.be**
Website	**www.arcadisbelgium.be**

Revision				
Version	Date	Remark		
Final	30/11/2009			
Issued by				
Department	Function	Name	Signature	Date
ARCADIS, Strategic Policy Advice	Team leader and senior economist	Laurent Franckx		
ARCADIS, Strategic Policy Advice	Senior waste specialist	Mike Van Acoleyen		
Eunomia		Dr Dominic Hogg		
Eunomia		Dr Adrian Gibbs		
Eunomia		Tim Elliott		
Eunomia		Chris Sherrington		
Eunomia		Ann Ballinger		
Eunomia		Siobhan O’Brien		
Eunomia		Debbie Lister		
Eunomia		Catherine Beswick		
Verified by				
Department	Function	Name	Signature	Date
Approval by client				
Department	Function	Name	Signature	Date

TABLE OF CONTENTS

A Generic Assumptions

A.1 Time

Time is an important factor when considering emissions modelling. Whilst incineration of biowaste results in an immediate release of CO_2, for example, composting biowaste with subsequent application to land results in at least partial sequestration of the organic carbon, with gradual release of CO_2 over an extended time period.[1]

If the overarching aim of any assessment is to determine the relative impacts of different technologies on climate change, and there is general consensus on the immediacy of the climate change issue, then the pace of release of greenhouse gases over time becomes an essential factor for consideration. In other words, the ability to sequester (or store) non-fossil carbon and effectively 'buy time' in terms of climate change is valuable. The importance of time-limited carbon sequestration was highlighted to the EU in a report by AEA Technology:[2]

> *However, for almost all treatment options, not all of the carbon released from organic materials during the treatment process is returned to the atmosphere; some remains in the 'residue' from the treatment process. This raises the issue of how this carbon should be accounted for, when comparing the treatment options in terms of climate change. If the carbon is sequestered in a form which is unavailable to the natural carbon cycle over a sufficiently long time period, then it could be argued that a 'sink' for carbon has been created and the treatment options should receive a carbon credit for this. The two main routes for carbon storage in waste management are in landfills (where the anaerobic conditions inhibit the decomposition of certain types of waste, particularly woody materials) and in compost applied to soil (where a proportion of the carbon becomes converted to very stable humic substances which can persist for hundreds of years). The permanency of such sinks is difficult to assess, and depends on the time scale used to define permanent. Available data suggests that 'woody' type materials in landfill may have only partially degraded over a one hundred year time scale, but degradation rates over a 500 year period are not known*.

LCA studies typically define a moment in time and aggregate all emissions occurring until that point in time. Such analyses have been criticised as not being a reliable indicator of the contribution of waste treatments to climate change because they ignore, to a certain degree, the dimension of time.[3]

For processes whose profile of emissions varies in time, this raises the following questions:

- Do emissions in all years count equally, or should a form of discounting be applied in such analyses? and;
- What is the justification for drawing the cut off in time in one year as opposed to another?

---

[1] G. Finnveden, J. Johansson, P. Lind and A. Moberg (2000) *Life Cycle Assessments of Energy from Solid Waste*, FMS: Stockholm

[2] AEA (2001) *Waste Management Options and Climate Change – Final report to the European Commission, DG Environment*

[3] Eunomia (2006) A Changing Climate for Energy from Waste? Final Report for Friends of the Earth, April 2006

In other words, 'doesn't time matter?' Given the discussion presented above regarding time-limited sequestration of non-fossil carbon, time evidently does matter, or at least should be considered in a comprehensive analysis.

Approach Taken in the Current Study

For the purposes of the present study we have applied the declining discount rate proposed by the UK's HM Treasury Green Book, as presented in Table A-1. The Green Book recommends using a discount rate of 3.5%. However, for projects with impacts exceeding thirty years, it recommends that a declining schedule of discount rates should be used rather a single, constant discount rate.

Table A-1: The declining long-term discount rate, as recommended in the Treasury Green Book

Period of years	0-30	31-75	76-125	126-200	201-300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

A.2 Biogenic CO_2 Emissions

A key issue in the assessment of GHG emissions from waste treatment technologies is whether or not non-fossil CO_2 (otherwise known as biogenic CO_2) should be included.

Under international GHG accounting methods developed by the Intergovernmental Panel on Climate Change (IPCC), non-fossil CO_2 is considered to be part of the natural carbon balance and therefore not a contributor to atmospheric concentrations of CO_2.[4] The rationale behind the IPCC's decision is that non-fossil carbon was originally removed from the atmosphere via photosynthesis, and under natural conditions, it would eventually cycle back to the atmosphere as CO_2 due to degradation processes. Climate change, however, is attributed to anthropogenic emissions, which impact this natural carbon cycle.

As regards waste, the Guidelines from IPCC state that the following should be reported: [5]

> *Total emissions from solid waste disposal on land, wastewater, waste incineration and any other waste management activity. Any CO_2 emissions from fossil-based products (incineration or decomposition) should be accounted for here but see note on double counting under Section 2 "Reporting the National Inventory." CO_2 from organic waste handling and decay should not be included.*

Specifically regarding waste incineration, the same guidelines state that reporting should include:

> *Incineration of waste, not including waste-to-energy facilities. Emissions from waste burnt for energy are reported under the Energy Module, 1 A. Emissions from burning of agricultural wastes should be reported under Section 4. All non-CO_2 greenhouse gases from incineration should be reported here as well as CO_2 from non-biological waste.*

Given the above, then it is worth reporting what is set out regarding energy. The following are to be reported:

---

[4] Intergovernmental Panel on Climate Change. *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3, Pg. 6.28, (Paris France 1997).

[5] Understanding the Common Reporting Framework, in IPCC (u.d.) Revised 1996 IPCC Reporting Guidelines for National Greenhouse Gas Inventories, Reporting Instructions (Volume 1), Hadley Centre, Bracknell

Total emissions of all greenhouse gases from all fuel combustion activities as described further below. CO_2 emissions from combustion of biomass fuels are not included in totals for the energy sector. They may not be net emissions if the biomass is sustainably produced. If biomass is harvested at an unsustainable rate (that is, faster than annual regrowth), net CO_2 emissions will appear as a loss of biomass stocks in the Land-Use Change and Forestry module. Other greenhouse gases from biomass fuel combustion are considered net emissions and are reported under Energy. (Sum of I A 1 to I A 5). Incineration of waste for waste-to-energy facilities should be reported here and not under Section 6C. Emissions based upon fuel for use on ships or aircraft engaged in international transport (1 A 3 a i and 1 A 3 d i) should, as far as possible, not be included in national totals but reported separately.

Methane (CH_4) is also derived primarily from non-fossil carbon during degradation processes. However, CH_4 emissions from landfills are counted within GHG inventories. The rationale provided by the IPCC can be described as follows:[6]

CH_4 emissions from landfills are counted - even though the source of carbon is primarily biogenic, CH_4 would not be emitted were it not for the human activity of landfilling the waste, which creates anaerobic conditions conducive to CH_4 formation.

Currently, convention appears to be shaped by IPCC's approach to dealing with non-fossil carbon in the reporting of Greenhouse Gas Inventories by different countries.

The crucial point here is that for the purposes of IPCC reporting, non-fossil CO_2 from incineration is effectively not reported – an approach also recommended by the French waste management industry.[7] Although it could be argued that this convention of ignoring non-fossil CO_2 is appropriate within the inventory context, it has perhaps erroneously been applied to comparative assessments between waste management processes.[8]

Whatever the merits or otherwise of not reporting biogenic CO_2 for the purpose of national inventories, in comparative assessments between processes, it cannot be valid to ignore biogenic CO_2 if the different processes deal with biogenic CO_2 in different ways. Given that different processes often deal with non-fossil CO_2 in different ways, and that the atmosphere does not distinguish between molecules of greenhouse gas depending on their origin, the omission of non-fossil CO_2 from analyses appears dubious. The need to include biogenic CO_2 is well recognized by some of those involved in life-cycle assessments, such as Finnveden *et al.*:[9]

The practise to disregard biotic CO_2-emissions can lead to erroneous results (Dobson 1998). Let us consider an example to illustrate this. Let us compare incineration and landfilling of a hypothetical product consisting of only cellulose. When incinerated, nearly 100 % of the carbon is emitted as CO_2. However, in the inventory, this emission is often disregarded as noted above. If the product is landfilled, approximately 70 % of the material is expected to be degraded and emitted during a short time period, mainly as CO_2 and CH_4 (Finnveden et al. 1995) (The short time period is here defined as the surveyable time period). Again the

---

[6] USEPA (2004) *Greenhouse Gas Emission Factors for Municipal Waste Combustion and Other Practices*

[7] L'Entreprises pour L'Environnement, *Protocol for the quantification of greenhouse gas emissions from waste management activities*, September 2006, Nanterre, France

[8] For example, ERM (2006) *Carbon Balances and Energy Impacts of the Management of UK Wastes*, Final Report for Defra, December 2006

[9] G. Finnveden, J. Johansson, P. Lind and A. Moberg (2000) *Life Cycle Assessments of Energy from Solid Waste*, FMS: Stockholm

> *emitted CO_2 is normally disregarded, although the CH_4-emissions are noted. During the surveyable time period, 30 % of the carbon is expected to be trapped in the landfill. There is thus a difference between the landfilling and the incineration alternatives in this respect, in the incineration case all carbon is emitted, whereas in the landfilling case some of the carbon is trapped. This difference is however not noted, since the CO_2-emissions are disregarded and this is in principle a mistake. Additionally, the biological carbon emitted as CH_4 in the landfilling case is noted and will discredit this option. It could be argued that a part of the global warming potential, corresponding to the potential of the same amount of biological carbon in CO_2, should be subtracted from the landfilling inventory.*

Recent articles published in both the International Journal of Life Cycle Assessment and Science also recommend the same approach as that taken by Finnveden et al.[10]

The IPCC Guideline regarding emissions related to energy requires further analysis in the context of refuse-derived fuels (RDF). If the biomass portion of RDF is included under the definition of 'biomass fuels', then whether or not CO_2 emissions should be included (for inventory purposes) would appear to depend on the sustainability of the production of that biomass. Considering the heterogeneous mix of biological material contributing to the biomass portion of waste, the task of determining what is or is not sustainably produced would be extremely difficult. Should a comparison of the GHG intensity of waste management processes relative to traditional fossil fuel generation be undertaken, this might be a worthy approach.

In the IPCC Guidelines, in theory, this would not be of significance if one was confident that the reporting of inventories under the Agriculture, Forestry and Other Land Use (AFOLU) Section took adequate account of all the effects of waste-related activities on changes in soil carbon, carbon in the existing forest stock, etc. Using, as a convention, the assumption that the non-fossil CO_2 is unimportant risks, however, ignoring the matter of the potential significance of changing the rate of flux of CO_2 from non-fossil sources into the atmosphere. Clearly, burning biomass leads to the immediate release of CO_2. However, composting biomass leads to the production of compost which, on application to soil, increases the carbon stock, and releases the carbon over an extended period of time.[11]

Approach Taken in the Current Study

The current study includes all biogenic CO_2 emissions from waste management processes. Our approach to the biogenic CO_2 emissions resulting from wood combustion (where wood is used as a renewable energy source) is discussed in Section A.4.4.2.

[10] See, for example: Rabl A, Benoist A, Dron D, Peuportier B, Spadaro J V and Zoughaib A (2007) How to Account for CO_2 Emissions from Biomass in an LCA, *Int J LCA*, 12(5) p 281; Searchinger T D, Hamburg S P, Melillo J, Chameides W, Havlik P, Kammen D M, Likens G E, Lubowski R N, Obersteiner M, Oppenheimer M, Robertson G P, Schlesinger W H and Tilman G D (2009) Fixing a Critical Climate Accounting Error, *Science*, 326, pp527-528

[11] See E. Favoino and D. Hogg (2008) The Potential Role of Compost in Reducing Greenhouse Gases, *Waste Management Research,* 2008; pp. 26; 61

- **A12:Excerpts from Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment (2012)**

RESEARCH AND ANALYSIS

Biogenic Carbon and Temporary Storage Addressed with Dynamic Life Cycle Assessment

Annie Levasseur, Pascal Lesage, Manuele Margni and Réjean Samson

Key words:
carbon footprint
carbon storage
climate change
global warming
industrial ecology
time

Summary

A growing tendency in policy making and carbon footprint estimation gives value to temporary carbon storage in biomass products or to delayed greenhouse gas (GHG) emissions. Some life cycle-based methods, such as the British publicly available specification (PAS) 2050 or the recently published European Commission's *International Reference Life Cycle Data System (ILCD) Handbook*, address this issue. This article shows the importance of consistent consideration of biogenic carbon and timing of GHG emissions in life cycle assessment (LCA) and carbon footprint analysis. We use a fictitious case study assessing the life cycle of a wooden chair for four end-of-life scenarios to compare different approaches: traditional LCA with and without consideration of biogenic carbon, the PAS 2050 and *ILCD Handbook* methods, and a dynamic LCA approach. Reliable results require accounting for the timing of every GHG emission, including biogenic carbon flows, as soon as a benefit is given for temporarily storing carbon or delaying GHG emissions. The conclusions of a comparative LCA can change depending on the time horizon chosen for the analysis. The dynamic LCA approach allows for a consistent assessment of the impact, through time, of all GHG emissions (positive) and sequestration (negative). The dynamic LCA is also a valuable approach for decision makers who have to understand the sensitivity of the conclusions to the chosen time horizon.

Introduction

Over the last few years there has been growing concern about the lack of consideration for temporal aspects of greenhouse gas (GHG) emissions in life cycle assessment (LCA) and carbon footprint analysis. Two different factors explain this concern: (1) an increasing will in policies and carbon footprint methods to give value to temporary carbon storage, and (2) the inconsistency in time frames when assessing the impact of GHG emissions, even when adopting global warming potentials (GWPs) with a fixed time horizon. Another topical issue regarding the assessment of GHG emissions is the consideration of biogenic carbon, for which there is no consensus among different methods. Using a fictitious case study comparing different approaches, the objective of this article is to show that the results of a life cycle GHG assessment are sensitive to the assumptions regarding the timing of emissions and the consideration of biogenic carbon, and that dynamic LCA is the preferred approach to address these issues consistently.

Address correspondence to: Annie Levasseur, CIRAIG, Department of Chemical Engineering, École Polytechnique de Montréal, P.O. Box 6079, Centre-ville, Montréal, Québec, H3C 3A7, Canada. *E-mail:* annie.levasseur@polymtl.ca

DOI: 10.1111/j.1530-9290.2012.00503.x

Volume 00, Number 00

Table 3 Comparison of the results obtained with five different approaches for 100- and 500- year time horizons (in kg CO_2-eq)

	100 years				*500 years*			
Method	*Incineration*	*Landfill*	*Refurbishment*	*Energy recovery*	*Incineration*	*Landfill*	*Refurbishment*	*Energy recovery*
LCA_{dyn}	5.6	1.2	**−3.0**	1.8	−1.2	**−16.3**	−8.6	−12.3
$LCA_{without}$	2.3	5.5	2.7	**−10.3**	2.2	2.9	1.5	**−10.2**
LCA_{with}	−2.6	**−17.5**	−8.6	−15.1	−2.7	**−20.0**	−10.0	−15.1
$LCA_{PAS2050}$	−6.9	**−13.5**	−11.3	−4.1	N/A	N/A	N/A	N/A
LCA_{ILCD}	−11.8	**−20.2**	−14.7	−17.9	N/A	N/A	N/A	N/A

Notes: LCA categories refer to dynamic LCA, traditional LCA without and with biogenic CO_2, PAS 2050, and the *ILCD Handbook* method, respectively. kg CO_2-eq = kilograms carbon dioxide equivalent.

The PAS 2050 specification ($LCA_{PAS2050}$) does not assess biogenic CO_2 emissions, but instead assumes that an equivalent amount of CO_2 has been sequestered in the recent past. A credit, represented by a negative emission, is given for any delayed emission (fossil or biogenic). This credit is proportional to the fraction of the 100-year time period following a product's formation during which its emissions will be in the atmosphere. The results show that, according to the PAS 2050, the landfill scenario is better than the others because of permanent carbon sequestration. The landfill scenario is also preferred according to the *ILCD Handbook* method (LCA_{ILCD}). The major difference between these two is that the ILCD method considers biogenic CO_2 emissions in the calculations, while the PAS 2050 does not.

The three major differences between the PAS 2050 and *ILCD Handbook* on the one hand and dynamic LCA on the other hand are (1) the choice of a time horizon, which is fixed at 100 years for the PAS 2050 and *ILCD Handbook*, but remains adaptable for the dynamic LCA approach; (2) the temporal distribution of the sequestration, which is only accounted for in the dynamic LCA approach; and (3) the individual assessment of delayed emissions of all GHGs other than CO_2 using so-called dynamic characterization factors; in the PAS 2050 and *ILCD Handbook* a proxy is used by multiplying each GHG by its respective GWP_{100} before calculating the credit. The results in table 3 show that these differences can lead to opposite conclusions. Indeed, the best scenario according to both carbon footprint methods (PAS 2050 and ILCD) is not the same as that identified when using the dynamic LCA approach. Because it assesses the specific radiative forcing impact of every GHG flow (positive and negative emissions of any type of GHG from fossil and biogenic sources) on a consistent time frame, and because it allows decision makers analyzing the sensitivity of the conclusions to choose a time horizon, dynamic LCA is considered a preferable approach.

When to Account for the Sequestration of Carbon in Growing Trees

The results of the first case study show that the choice to consider biogenic carbon or its temporal distribution can significantly change the LCA results. Using dynamic LCA for the assessment of products containing biogenic carbon also raises the issue of temporal boundaries. The dynamic LCA conducted on one chair built at year 1 and burned at its end of life 50 years later shows very different results depending on whether the sequestration is assumed to occur before or after the chair is built (see figure 2).

For a time horizon of 100 years, the "before" scenario has a cumulative radiative forcing benefit (negative value) three times higher than the impact (positive value) of the "after" scenario. For a time horizon of 500 years, both scenarios have a negative cumulative radiative forcing; the "before" scenario has 4.3 times more forcing than the "after" scenario.

The methods that have been proposed to-date to account for temporary carbon storage (PAS 2050 and *ILCD Handbook*) do not consider the timing of the sequestration. The end-of-life biogenic CO_2 emissions have a zero impact (emissions − sequestration = 0), and a credit is given for storage related to the ratio of the storage time over the chosen time horizon. This gives a net negative impact. The results of the dynamic LCA show that the impact is very sensitive to the dynamics of the carbon sequestration (carbon balance curve) and to its timing (before or after the product is manufactured).

For the "after" scenario of this case study, it takes 270 years after the chair is built before the cumulative radiative forcing becomes negative, and it does so because we consider that a part of the sequestered carbon is permanently held in the soil. In the case where no carbon is sequestered in the soil, the impact would never become negative.

Because these results are very different for the "before" and "after" scenarios, the setting of an initial temporal boundary is both critical and informed by two opposing viewpoints. Choosing the "before" scenario means that one assumed the trees were grown to be used as a raw material. Choosing the "after" scenario means that one considers that nature provides some resources that can be used as raw materials; because wood is a renewable resource, a tree can be planted to replace the one that is cut.

Conclusion

There is currently no consensus regarding how to treat biogenic CO_2 in LCA. In this article we showed that not considering biogenic CO_2 can lead to biased conclusions. If a fraction of the biogenic carbon is assumed to be sequestered

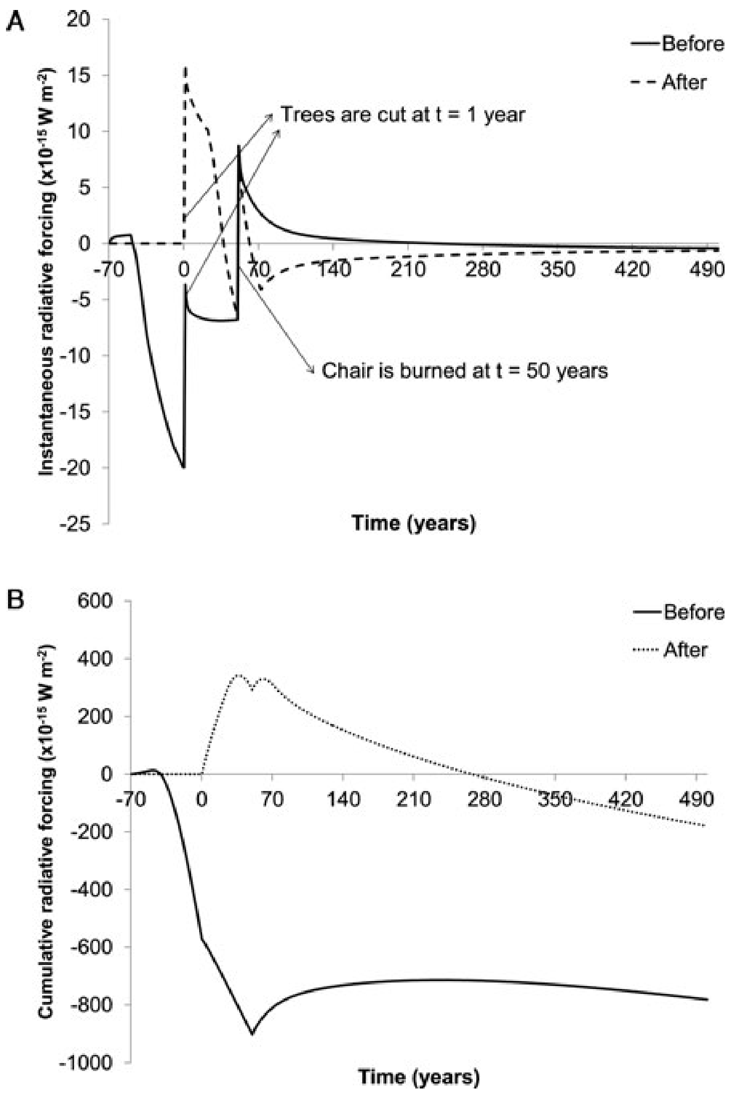


Figure 2 Instantaneous (a) and cumulative (b) radiative forcing determined using dynamic LCA, caused by one wooden chair for the incineration scenario with a sensitivity analysis done based on the timing of the sequestration (i.e., whether it occurs before or after the chair is built). W = watts.

permanently, as was the case for the carbon sequestered in the soil of the boreal forest or for 96.8% of the landfilled carbon, then the amount of biogenic carbon entering the product system is not equal to the amount leaving the system, which means that biogenic CO_2 emissions cannot be considered neutral. Also, as soon as a benefit is given for temporarily storing carbon, even if the total amount of biogenic carbon entering the product system is equal to the amount leaving the system, then it becomes important to account for the timing of every CO_2 flow that occurs in the life cycle inventory. Methodological inconsistencies otherwise lead to unreliable results. The dynamic LCA approach allows the consistent assessment of the impact, through time, of every GHG emission and sequestration, avoiding the necessity to artificially tag carbon flows as biogenic or fossil in origin.

Dynamic LCA also allows sensitivity testing of the results by time horizon. On an infinite time basis, there is no benefit to temporarily storing carbon or to delaying GHG emissions. Giving value to temporary climate mitigation is made possible by defining a time horizon beyond which we do not consider impacts, or by discounting, similar to what is done in economic decision making (Levasseur et al. 2012a).

The use of a discount rate to increase the importance of short-term emissions is still a controversial issue (Hellweg et al. 2003; Nordhaus 2007; O'Hare et al. 2009; Stern 2007), and is more a policy-based question than a scientific one, as is the choice of time horizon (Fearnside 2002; Moura-Costa and Wilson 2000). Given the debate concerning discounting and the fact that carbon footprint calculation methods do not use this type of time preference, we have decided to present the results without any discounting. However, it is possible for decision makers to apply a discount rate to annual dynamic LCA results like those presented in figure 1.

Choosing a finite time horizon for results analysis also provides a weight to time itself, and is a particular case (or a hidden

APPENDIX B: Extracts from West Sussex Waste Local Plan Sustainability Appraisal Report, March 2013

Appendix B

Extract from West Sussex Waste Local Plan Sustainability Appraisal Report, March 2013

1.1.1 The SA objectives, targets and indicators are set out at Appendix E of the SA. In respect of my evidence the following indicators and SA outcomes are relevant:

- B: To protect and, where possible, enhance the amenity of users of the PROW and other users of the countryside including transport networks
- G: To protect and, where possible, enhance landscape and townscape character.
- P: To reduce the emissions of greenhouse gases and promote the use of renewable and lower carbon energy sources.

1.1.2 The interpretation., decision making criteria and assumptions, draft indicator (s) and target (if applicable are set out below and then applied to each policy and each site therein.

B: To protect and, where possible, enhance the amenity of users of the PROW and other users of the countryside including transport networks.	Would the option/policy/site be likely to impact on PROW or other users of the countryside including road and rail users, for example, by blocking PROW, increased traffic in the area, or by affecting public views? Would the option/policy/site reduce the tranquillity of the area, specific consideration to protected landscapes?	Number of PROW diversions Number of PROW stopped up Number of new PROW opened Proportion of land classed as tranquil.	All Public Rights of Way must remain open and available for public use at all times unless the Local Authority has undertaken the relevant legal procedure. Planning permission alone does not allow the right of way to be obstructed or moved in any way.

G: To protect and, where possible, enhance landscape and townscape character.	Would the option/policy/site help enable protection of landscape (particularly AONB and SNDP) and townscape character?	Number/extent (area) of planning consents issued on greenfield land outside defined urban areas by type. Percentage of land classified as tranquil. Number of planning consents in AONB and SDNP by type.	None identified

P: To reduce the emissions of greenhouse gases and promote the use of renewable and lower carbon energy sources.	Would the option/policy/site affect carbon dioxide and methane emissions production in the county? E.g. reduce the quantity of biologically active waste landfilled? Would the options/policy/site encourage and increase production/use of renewable or lower carbon energy supplies?	Greenhouse Gas emissions (Mt) Greenhouse gas emissions from landfill (tonnes). Number of new waste facilities in West Sussex generating energy from waste. Energy from renewable and low-carbon sources.	International: Kyoto protocol: cut greenhouse gas emissions by 12.5% below 1990 levels by 2008-2012 National: Climate Change Act 2008: to cut emissions of green house gas emissions by 80% below 1990 levels by 2050. 15% of energy from renewable sources by 2020. Regional: To achieve 895MW by 2016 and 1130MW by 2020.

1.1.3 SA objectives, the relevant mitigation/enhancement and commentary for the policy (found at page 317 of the SA) are extracted below.

Policy W10: Strategic Waste Site Allocations

(a) The following sites are allocated for waste management facilities and are acceptable, in principle, for the development of proposals for the transfer, recycling, and/or treatment of waste (including the recycling of inert waste):
- Site north of Wastewater Treatment Works, Ford (Inset Map 1);
- Hobbs Barn, near Climping (Inset Map 2);
- Fuel Depot, Bognor Road, Chichester (Inset Map 3);
- Brookhurst Wood, near Horsham (Inset Map 4); and
- Land west of Wastewater Treatment Works, Goddards Green (Inset Map 5).

(b) The following site is allocated for non-inert landfill and is acceptable, in principle, for that purpose:
- Extension to Brookhurst Wood Landfill Site, near Horsham (Inset Map 4).

(c) The development of a site allocated under (a)-(b) must take place in accordance with the policies of this Plan and satisfactorily address the 'development principles' for that site identified in the supporting text to this policy.

(d) The sites allocated under (a)-(b) will be safeguarded from any development either on or adjoining the sites that would prevent or prejudice their development (in whole or in part) for the allocated waste management use or uses.

	Policy W10				
Appraisal Objective	Short-term	Medium-term	Long-term	**Mitigation/Enhancement**	**Commentary**
A: To protect and, where possible, enhance the health, well-being and amenity of residents and neighbouring land-uses	N	N	N	Policy should be applied alongside development management policies.	Sites have been selected as optimal sites and are dispersed justifies neutral impact. Site preferable to others.
B: To protect and, where possible, enhance the amenity of users of the PROW and other users of the countryside including transport networks	N	N	N	As above	As above
G: To protect and, where possible, enhance landscape and townscape character	-	N	N	Should be applied alongside Policy W11: Character.	Sites have been assessed in terms of their landscape impact and their dispersal means than cumulative impacts are minimised. Negative score given in the short term with neutral in the medium and long term as mitigation measures are established. Potential cumulative impact on views from the SDNP from Site North of WWTW (Ford) and Fuel Depot (Chichester) if tall stacks proposed.
P: To reduce the emission of greenhouse gases and promote the use of renewable and lower carbon energy sources.	+	+	+	Should be applied alongside Policy W12: High Quality Development.	Cumulative effect of sites would mean that more waste would be diverted from landfill therefore reducing methane emissions. Sites could also offer opportunity for renewable or lower carbon energy.

1.1.4 The Brookhurst Wood site was appraised in two parts (the built waste facility where the Appeal proposals would be located) and an extension to the landfill (land to the north). The assessment begins at page 359 of the SA:

Horsham District - Brookhurst Wood, near Warnham (Built Waste Facility)					
Appraisal Objective	Short-term effects 0-5yrs	Medium-term effects 6-25	Long-term effects 25 yrs	**Mitigation/ Enhancement**	**Commentary**
B: To protect and, where possible, enhance the amenity of users of the PROW and other users of the countryside including transport networks	-	N	N	Assume that development management principles and policies in Plan are applied. Protection/mitigation of PRoW.	Construction impacts may give rise to negative effects due to noise and views. Improved landscaping would reduce impact on public views in the medium term. In the long term the effects are unknown as the building/use may remain or the site could become derelict.
G: To protect and, where possible, enhance landscape and townscape character	+	+	N	Site currently has adequate screening, however new facilities may require additional landscaping/screening.	There are no landscape designations. Development of the site represents an opportunity to improve the appearance of/or replace the existing derelict buildings. In the long term the effects are unknown as the building/use may remain or the site could become derelict.
P: To reduce the emission of greenhouse gases and promote the use of renewable and lower carbon energy sources.	+	+	+	Appropriate mitigation and controls may be necessary through the development management/waste regulation processes.	In the medium to long term, the effects would be positive as the site is located close to waste arisings and reducing overall waste miles travelled. The close proximity of the site to potential users of energy produced (if EfW technology built) does offer potential benefits.
Assessment Summary	The site is well-located to manage waste due to its proximity to waste arisings in the north of the county, close to the Lorry Route Network and it has potential to move waste by rail (subject to viability assessment). Although there would be some negative impacts in the short term during the construction period, development of the site is considered to bring overall benefits in the medium to long term as it would benefit from co-location of other waste facilities and replace existing derelict buildings. Transport assessment at application stage should assess impacts on residents of Langhurstwood Road, particularly due to potential cumulative impacts from other waste uses. Routing should also be via the south and impacts on the A264 and junction 11 of M23 need to be considered. There are industrial buildings on the site therefore an industrial archaeological impact assessment required at application stage. The site is adjacent to SSSI, Ancient Woodland and there may be protected specifies (Great Crested Newts) which would require survey and mitigation. Site should not exceed critical load of site limits in terms of air quality and consideration given to lorry routing to avoid impacts. Habitat Regulation Assessment concludes that there is no scope for pathways connecting European sites. The potential for risk of birdstrike in lieu of the Gatwick airport bird circle requires a comprehensive bird management plan.				

APPENDIX C: AL 14, SASEA Assessment Table

Appendix C

AL 14, SASEA Assessment Table

AL14 – Warnham and Wealden Brickworks, Horsham

SA/ SEA Objective	Summary of effects	Short term	Medium term	Long term
1 Access to Affordable Homes	Site not identified for housing provision	😐	😐	😐
2 Access to services and facilities	Site would provide waste disposal facility	😐	☺	☺
3 Reduce crime and fear of crime	Effects uncertain	?	?	?
4 Conserve & Enhance land and townscape character	Proposal would be redevelopment of an existing site, but new uses could have a further impact on the land and townscape	😐?	😐?	😐?
5 Conserve and enhance biodiversity	Site involves redevelopment of existing site and effects on biodiversity likely to be small	😐?	😐?	😐?
6 Conserve and enhance historical environment	Site is close to ancient monument. Unlikely it would be affected, but further work may be beneficial	☹?	☹?	☹?
7 Maintain high quality environment in terms of air soil and water quality	Although development could help clean up existing contamination on site, but harm air quality / water quality through burning of landfill gas and waste uses	☹?	☹?	☹?
8 Reduce car journeys and promote alternative means of transport	Site is in a relatively remote condition and would probably result in increased car journeys for those employed at the site	☹	☹	☹
9 To reduce the risk of flooding	Site is already brownfield and runoff unlikely to increase significantly as a result of new development	😐	😐	😐
10 Efficient land use by prioritising brownfield land	Site would result in re-use of brownfield land	☺	☺	☺
11 Reduce waste and maximise recycling	Site would include facilities for recycling and recovery of waste	☺	☺	☺
12 Ensure energy and water consumption is as efficient as possible	Site would require use of energy and water use, but effects depend on amount required and whether energy is supplied from power plant on site	?	?	?
13 Reduce greenhouse gases by encouraging provision and use of renewable energy	Development would retain power plant which burns methane. This is a worse greenhouse gas than CO2 which would be produced as a result	😐	☺	☺
14 Maintain overall high and stable economy	Redevelopment of the site is likely to be beneficial to the economy by providing employment land, and jobs during construction phase	☺	☺	☺
15 Enhance areas of inequalities in economy including rural areas	Site is in a rural location and could help economy in this area. Most employees will probably live in Horsham	☺?	☺?	☺?
16 Maintain and enhance vitality and viability of Horsham town and other village centres	Site is outside town or village centres	😐	😐	😐

Assessment of significance: This site would have some impact if increased traffic to the site, but relatively limited at the site is already in use and would use the same footprint

☺☺	The option provides a strong **positive** effect towards the SA/SEA objective
☺	The option provides a **positive** effect towards the SA/SEA objective
😐	This option has **no effect** on the SA/SEA objective
☹	The option provides a **negative** effect towards the SA/SEA objective
☹☹	The option provides a strong **negative** effect towards the SA/SEA objective
?	The effects on this objective are uncertain

Note: the key is found at page 84 of the SASEA

APPENDIX D: Analysis of Representations

No Incinerator 4 Horsham Community Group

Website: ni4h.org

Email: NoIncinerator4Horsham@gmail.com

PUBLIC PERCEPTION ANALYSIS

PREPARED BY

NO INCINERATOR 4 HORSHAM COMMUNITY GROUP

TO INFORM A PUBLIC INQUIRY

PINS Reference: APP/P3800/W/18/3218965

WSCC Reference: WSCC/015/18/NH

September 2019

Contents

1. Introduction to NI4H

1.1 No Incinerator for Horsham Community Group (NI4H) is a voluntary group formed in 2016 by local residents to raise awareness and campaign against the proposal for a large-scale incinerator in Horsham to import waste from a wide area across the Southern Counties.

1.2 NI4H had Rule 6 status imposed on the Group at the Pre-Inquiry Meeting on 6th June 2019.

1.3 NI4H has engaged with members of the public through organising two petitions, holding public meetings and exhibitions, through fundraising events, the media and social media. Whilst acknowledging these are not formal tools in the planning process, NI4H asks the Planning Inspector to note the 4,532 members of the public at planning application stage, and 2,031 members of the public (so far) at planning appeal stage, who have signed NI4H petitions and feel very strongly that this planning appeal should be dismissed.

1.4 Representatives of NI4H spent several days at the Swindon Public Inquiry in January and February 2019 and saw how their Community Group was labelled 'Project Fear' by the Appellant's barrister, though there appeared to be no evidence of this. So NI4H has taken great care over website content, press releases, social media publicity, newsletters, printed material and discussions with the public.

1.5 NI4H has spent many hours reviewing evidence in the public domain, including the comments made by members of the public at planning and appeal stages.

2. Six Reasons for Refusal Survey

2.1 When West Sussex County Council reviewed the six reasons for refusal, NI4H drafted a Reasons for Refusal Survey to find out which reasons are important to the public.

2.2 The survey listed the Council's six reasons for refusal of the planning application and asked: Which ones are most important to you? Please tick or give each of them a score:
1 = very important, 2 = important, 3 = not very important

2.3 14 completed surveys were returned. The results are presented in the following chart.

Reasons for Refusal Survey Results

Reason for Refusal	Very Important	Important	Not very important
It has not been demonstrated that the facility is needed to maintain net self-sufficiency to manage the transfer, recycling and treatment of waste generated within West Sussex	5	5	3
The development would have an unacceptable impact on landscape and visual amenity of the area	7	5	1
The development would have an unacceptable impact on highway capacity	6	4	2
The development would have an unacceptable impact on residential amenity	7	2	2
The development would have an unacceptable impact on public health	12	0	2
The development, along with other existing, allocated and permitted development, including the North of Horsham development, would result in adverse cumulative impacts	10	2	1

2.5 The most important reason listed was 'The development would have an unacceptable impact on public health' closely followed by 'The development, along with other existing, allocated and permitted development, including the North of Horsham development, would result in adverse cumulative impacts'.

3. Public Perception Analysis

3.1 With limited resources NI4H was not able to extend the survey to a larger number of people, and so analysed in more detail the 'object' comments sent to the Council at Planning Stage and to the Planning Inspector at Appeal Stage.

3.2 NI4H compiled a spreadsheet using the Council's six reasons for refusal plus a seventh reason 'The development would have unacceptable environmental impacts' subdivided into: Reduce/Recycle, Air Pollution, Noise Pollution and Light Pollution.

3.3 The public comments were carefully read and recorded on the spreadsheets with a number 1 added to the relevant columns for each appropriate mention in the comments. This tally record was made by one person to give consistency in determining the reasons expressed in each submission or representation.

3.4 Comments like “I don’t want my children near this” could infer unacceptable impact on Public Health, but unless health related concerns were mentioned in the comments, they were not scored as such.

3.5 NI4H conducted a statistical analysis using AutoSum to calculate the total number of each response and calculated the percentages.

4. Third-Party Representations Sent to Council at Planning Stage

4.1 NI4H has noted 1,284 representations received by the Council are on the Planning Portal. 148 individually listed in Public Comments (all these were analysed) and 1,136 listed in ‘Representation emails and on-line received 15 March – 10 May 2018’ the first 150 of which were analysed. A total of 298 submissions, 23.2% were analysed.

4.2 1,272 (93%) objected to the appeal, 12 (7%) supported the appeal.

5. Third-Party Representations Sent to Planning Inspector at Appeal Stage

5.1 262 submissions are recorded on the Third-Party Representations sent to PINS List – Part 1, Part 2a and Part2b of which: 250 (95%) objected to the appeal, 12 (5%) supported the appeal.

5.2 One or more of these environmental impacts were mentioned in 212 submissions, 85%: reduce/recycle, air pollution, noise pollution and light pollution.

6. Examples of Public Perception of Harm Comments

6.1 Here is a selection from the 1,546 comments objection comments which represent the concerns expressed by many local residents.

6.2 Looking down from areas like Tower Hill; a person can see the black steeple of St. Mary's church on the South of town, and the pale steeple of what used to be St. Mark's church in the North. It's currently a beautiful picture which speaks of tranquillity and our local history. Please don't let it be ruined.

6.3 I feel it is unsafe now to walk or cycle from my house as a result of the 700+ HGV vehicle movements at a speed which is not suitable in my view on what is a rural country road. I leave and come home when it is dark and am often put at risk walking down Mercer Road and Langhurst Wood Road. Walkers and cyclists are being dismissed as road users.

6.4 The 95m stack and the enormous plume will be visible from our garden and road. This will be a constant reminder of the risks of living so near it and will devalue our property, which currently has rural, residential views.

6.5 What evidence do you have that this facility will not be a Public Health concern?

6.6 Born and bred in Horsham we do not wish ourselves, our children and grand-children to be endangered by breathing in invisible toxins from this proposed facility.

6.7 It doesn't matter what precautions are taken, we do not have a good enough understanding of the emissions to be able to guarantee peoples safety. At one point smoking was good for you and diesel cars were better than petrol !

6.8 My child suffers with Asthma and to hear we are going to enhance Horsham with pollution and potentially toxic frightens me. There will be more cases of our younger generation with breathing difficulties, a study did show that living near a busy road increased children with having asthma, goodness knows what an incinerator will do!

6.10 The community should work together in reducing waste, recycling and reusing!

6.11 As residents in the town, we are not even allowed to have a bonfire these days, then why is a massive chimney chucking out smoke from dusk to dawn, even being considered as safe!

6.12 There is insufficient study into the distribution of pollutants once leaving the stack. Effects of aircraft vortex have not been modelled nor has the fact that the Warnham area sits within a geographic 'bowl' which effectively traps air. This is frequently experienced with the odours emanating from the Landfill and MBT sites especially where weather conditions conspire to trap smells affecting local residents.

6.13 One assumes that the thin 95m chimney will have to be cable stayed in some manner – where will the tie down point be and can they fit it on the site? There is no mention of high pitched whine when wind blows around these cables.

6.14 Permanently lit with red aviation lights a permanent hazard for aircraft and helicopters.

6.16 Light pollution will affect local residents and wildlife, including breeding Red Kites and Bat colonies.

6.17 Turbulence created by aircraft may drive the fine particulate emissions from the chimney down to the ground. Increased air traffic movements will exacerbate this issue.

6.18 Local farmland, where both crops and livestock are grown for human consumption, Warnham Nature reserve is within very close proximity.

6.19 With increased pollution comes irreversible impact on bird life, insect life and all flora and fauna in the vicinity. Our neighbours and our home is also host to endangered swifts, honey bees and barn owls to name a few. We have a very special ecosystem in this area growing elderflower, blackberries and apples, rearing ducks and chickens and of course the local deer. We need to preserve all this for the future.

6.20 Too close to housing, existing and new schools.

6.21 I also worry about the prospect of a fire at such a plant and its proximity to the MBT, landfill and the areas of woodland. Movement in and out of flammable chemicals or hazardous/ contaminated material from site, adds to the risks/ health hazards if a fire were to occur.

6.22 There is insufficient evidence to allay resident's concerns about need, highway capacity, public health and the cumulative impact that development may have on the future residents.

7. Conclusion

Peter Catchpole who has been West Sussex County Councillor for Holbrook since 2005 and is Chairman of Ni4H said:

“The response from the residents of Horsham in overwhelmingly objecting to the development of this incinerator in North Horsham is by far the largest reaction to any planning application I have seen in my 14 years as County Councillor for Holbrook. They are rightly concerned about their future wellbeing and that of future generations if an incinerator comes to this area. This overwhelming NO vote is democracy at work and should be given the authority it deserves and fully respected.”

8. Statistical Analysis of Object Comments at Horsham Incinerator Planning and Appeal Stages

1	2	3	4	5	6	7			
Need	Landscape and Visual Impact	Highway Capacity	Residential Amenity	Public Health	Cumulative Impact	Environmental Impact			
						Reduce Recycle	Air Pollution	Noise Pollution	Light Pollution
PLANNING STAGE									
130	190	197	144	139	79	138	235	115	125
44%	64%	66%	48%	47%	27%	46%	79%	39%	42%
APPEAL STAGE									
93	150	153	134	172	139	103	173	47	43
37%	60%	61%	54%	69%	56%	41%	69%	19%	17%

APPENDIX E: Extract from the Encyclopaedia of Planning Law, Public Concerns about Safety

Appendix E

Extract from the Encyclopaedia of Planning Law
Public concerns about safety:
P70.39

Public concern, as opposed to actual evidence of threats to public safety, can be a material consideration with respect to planning decisions. In ***Newport*** *BC v Secretary of State for Wales [1998] Env. L.R. 174* the Court of Appeal allowed the local planning authority's appeal against a decision on the part of the Secretary of State awarding costs against it following an appeal on the basis that the authority had acted unreasonably in taking into account the public perception of danger emanating from a chemical waste treatment plant which was unsupported by evidence. The court held that it was a material error of law to conclude that a genuinely held public perception of danger which was unfounded could never amount to a valid ground for refusal.

That decision was applied in *Trevett v Secretary of State for Transport, Local Government and the Regions [2002] EWHC 2696 (Admin)*, a challenge to a decision made on appeal under s.78 of the 1990 Act to grant planning permission for three telecommunications masts at three sites near Stroud in Gloucestershire. The claimant lived close to one of the masts and was concerned about the potential health effects of the development on children attending the local primary school and her own children when they visited her from America. The court (Sullivan J, as he then was) dismissed the appeal on the basis that the inspector had been entitled to place the weight that he did on the professional views of national and international organisations to the effect that TETRA stations (as were in issue in this case) did not pose a greater risk to health than mobile phone stations. In reaching this conclusion, however, he had properly followed the **Newport** approach and had recognised that the perceived adverse effects on health of the public could justify a refusal of planning permission.

It should be noted that as at the time of this decision Planning Policy Guidance note 8: Telecommunications remained extant. Paragraph 97 of that document confirmed that health considerations and public concern can in principle be material considerations in determining applications for planning permission. The guidance in PPG8 has now been replaced by that to be found in s.5 of the National Planning Policy Framework, where there is no reference to health considerations or public concern as comprising material planning considerations. Paragraph 97 of PPG8 simply reflected the existing law, however, which remains unchanged.

The issue of the relevance of public concern to planning also arose in *West Midlands Probation Committee v Secretary of State for the Environment, Transport and the Regions (1998) 76 P. & C. R. 589*. This case concerned an appeal by the West Midlands Probation Committee against the dismissal of its appeal against a refusal of planning permission for an extension to a bail and probation hostel, the inspector having found that the extension would be likely to increase significantly the disturbance caused to nearby residents. The Court of Appeal dismissed the appeal.

The following propositions may be suggested on the basis of the case law:

(a)
public safety is clearly capable of being a material consideration in determining planning applications;

(b)
so too are any potential physical externalities: this is the basis of the *West Midlands Probation Committee* case. The concerns held by residents were justified concerns because of a history of disturbing behaviour, and the Court of Appeal was unwilling to distinguish the impact of this conduct upon the use of adjoining land from the impact of, e.g. polluting discharges by way of smoke or fumes, or unneighbourly uses: "There can be no assumption that the use of the land as a bail and probation hostel will not interfere with the reasonable use of adjoining land when the evidence is that it does";

(c)
public opposition per se is not a material consideration (per Aldous LJ in ***Newport***), even though it may be a powerful background consideration in a democratically based planning system;

(d)
the fact that fears and concerns are held by members of the public may itself constitute a material consideration, if:

(i)
they relate to a matter (e.g. public safety, interference with reasonable use of adjoining land) which is itself a material consideration; or

(ii)
they are objectively justified (as in *West Midlands Probation Committee*). If the proposed development would introduce or increase a risk of danger, that must be a factor to be assessed and weighed in the balance; or

(iii)
if the fact that they exist, even if baseless, may itself have land-use consequences. For example, in the *Broadland* case, it was conceded that the officers had been wrong to advise the Council that increased car trips resulting from parents' concerns about the safety of their children was not a material consideration;

(e)
whether such fears and concerns must be dismissed if they are shown to be baseless is less clear, not least because this may not always be as sharp a distinction as that terminology suggests. Differences over safety, for example, usually boil down to the acceptability of different degrees of risk, rather than a clear conclusion that the fear is either justified or baseless. The primary task of the decision maker in such a case must be to determine the acceptability of the risk. That seems to be the approach adopted by Glidewell LJ in *Gateshead MBC v Secretary of State for the Environment [1994] 1 P.L.R. 85* at 95, who said:

"Public concern is, of course, and must be recognised by the Secretary of State to be, a material consideration for him to take into account. But if in the end that public concern is not justified, it cannot be conclusive. If it were, no industrial development—indeed very little development of any kind—would ever be permitted.;"

(f)

however, the majority in ***Newport*** seem to go further than this, and to accept that even fears that have been shown to be unjustified may continue to be a material consideration: "local fears which are not, in fact, justified can rank as part of the human factor [per Lord Scarman in *Westminster City Council v Great Portland Estates plc*] and can be given direct effect as an exceptional or special circumstance."

Two points may be worth recording on that proposition:

(i)

that there is a very thin line between unjustified local fears and pure prejudice, including discrimination on racial or other unlawful grounds; and

(ii)

it must follow, if unjustified local fear is capable of being a material consideration, that it could on its own justify a departure from the development plan and justify a refusal of permission. This approach is clearly contrary to the approach taken by Glidewell L.J. in the Court of Appeal in *Gateshead* (above).

(g)

Although presented in ***Newport*** as a distinction of principle, there is good reason in practice to regard it as one of degree, because:

(i)

the issue at stake in ***Newport*** was not whether unjustified public fears were to be permitted to influence the planning decision, but whether the authority had acted unreasonably, in the context of an application for an award of costs against them, in citing, as a reason for refusing planning permission, that: "(4) The proposed development is perceived by the local community to be contrary to the public interest generally and to their interests in particular";

(ii)

hence the matter was being considered at a stage that was one remove from the other cases cited above;

(iii)

a matter may constitute a material consideration without being conclusive of the issue. It is a matter wholly for the decision-maker what weight to accord to any material consideration, and in practice there may be little difference between the weight attached to a consideration which is material but peripheral, and one which is not material at all;

(iv)

even if a matter is found to have been material, but has been ignored by the decision-maker, the broad discretion of the court on a statutory appeal (against a decision of the Secretary of State) or a judicial review application (against a decision of a local planning authority) means that the decision is not necessarily invalid, and it is for the court to consider whether, had it been taken into account, there is a real possibility that it would have made a difference to the decision (*Broadland*, on judicial review, applying the principles summarised for statutory appeals by Glidewell L.J. in *Bolton MBC v Secretary of State for the Environment (1990) 61 P. & C.R. 343* at 353);

(v)

the consistent approach of the courts to material considerations has been to avoid establishing a priori distinctions between matters which are, and those which are not, material considerations. Ever since *Stringer v Ministry of Housing and Local Government [1971] 1 All E.R. 64* the approach has been inclusive rather than exclusive, so as to allow the real distinctions to be drawn by decision makers in weighing the evidence, rather than by courts in drawing fine distinctions affecting the validity of decisions.

Health concerns have become a significant issue surrounding the erection of telecommunications masts, and their intensification of use by the addition of further equipment. Specific guidance is given in PPG8, where paras.97 and 98 of the appendix provide:

"97.

Health considerations and public concern can in principle be material considerations in determining applications for planning permission and prior approval. Whether such matters are material in a particular case is ultimately a matter for the courts. It is for the decision-maker (usually the local planning authority) to determine what weight to attach to such considerations in any particular case.

98.

However, it is the Government's firm view that the planning system is not the place for determining health safeguards. It remains Central Government's responsibility to decide what measures are necessary to protect public health. In the Government's view, if a proposed mobile phone base station meets the ICNIRP guidelines for public exposure it should not be necessary for a local planning authority, in processing an application for planning permission or prior approval, to consider further the health aspects and concerns about them."

These paragraphs formed the subject of the decision of the Court of Appeal in *T Mobile UK Ltd v First Secretary of State [2004] EWCA Civ 1763* (Pill, Mummery and Laws L.JJ.; 12th November 2004) in which an appeal proposal, which complied with ICNIRP guidelines, was dismissed by an Inspector purportedly in accordance with the above policy (in particular, para.97). The court held that this was an erroneous approach. It would be open to the decision-maker to identify some exceptional circumstance whereby, despite compliance with your ICNIRP guidelines, health concerns should constitute a material consideration justifying refusal. But such a course would amount to a departure from policy, to be recognised as such: see also *Alan Cox v Secretary of State for Communities and Local Government, North Hertfordshire DC and T-Mobile (UK) Ltd [2010] EWHC 104 (Admin)*; see also *Alan Cox v Secretary of State for Communities and Local Government, North Hertfordshire DC and T-Mobile (UK) Ltd [2010] EWHC 104 (Admin)*.

GPP

GP PLANNING LTD

GP PLANNING LTD

Mr Christian Smith DipTP MRTPI MCMI
Miss Maureen Darrie BSc (Hons) MRTPI

Registered in England
Number 6019666

Registered Office:
iCon Innovation Centre, Eastern Way,
Daventry, Northamptonshire, NN11 0QB