Department for Transport

# Annex B: Supporting Recycled Carbon Fuels through the Renewable Transport Fuel Obligation

## Summary of Analysis

Department for Transport
Great Minster House
33 Horseferry Road
London
SW1P 4DR



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Any enquiries regarding this publication should be sent to us at www.gov.uk/government/organisations/department-for-transport

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# 1. Introduction

## Policy context

The Department for Transport is currently developing proposals to support recycled carbon fuels (RCFs) under the Renewable Transport Fuel Obligation (RTFO). In the government response to our 2021 consultation, we committed to undertake further analysis to inform our policy position as part of a commitment to consult again on the detailed technical aspects of the policy. This Annex gives an overview of some of the key analysis, undertaken with the support of technical consultants - NNFCC.

## Analysis undertaken

This document contains three chapters, each summarising different aspect of the analysis undertaken. In each case, the key assumptions and methodology are set out, followed by an overview of the analysis results.

### Assessing the impact of counterfactual fates on the overall GHG intensity of RCFs

To inform proposals concerning feedstock eligibility and the choice of counterfactual for the greenhouse gas (GHG) emissions methodology, we have analysed the impact of different counterfactual fates and variation within each fate based on different assumptions on the net GHG emissions from RCFs. Four different counterfactuals were modelled and it was identified that energy from waste (electricity only) results in the lowest emissions, with the addition of heat export (combined heat and power) or carbon capture and storage (CCS) both resulting in a reduction in the net carbon savings. The process heat counterfactual results in the greatest overall RCF emissions, although this is highly variable depending on the replacement fuel.

### Assessing how the GHG intensity of RCFs may change over time

To inform proposals for the GHG emission savings threshold, we have analysed how the emissions associated with RCFs might evolve over time as the UK electricity grid decarbonises. We modelled three different emission scenarios for the years 2025 to 2035. The proposed options for setting the emissions saving threshold were then overlaid.

## Assessing the impact of different reward rates

To inform proposals for the reward rate, we modelled the effective reward per tonne of feedstock for three scenarios: high productivity, low productivity and mid-range. The effective reward was modelled for two different reward rates: 1 dRTFC per litre and 0.5 dRTFC per litre. This data was then compared to typical gate fees and prices for recyclable plastic.

# 2. Assessing the impact of counterfactual fates on the overall GHG intensity of RCFs

## Key assumptions and methodology

We modelled the greenhouse gas emissions across four different counterfactuals each with three different scenarios (high, mid-range and low emissions). These scenarios are described below and summarised in Table 1 and the results presented in Figure 1 and inform the proposals set out in Chapter 3 of the main consultation document.

In each case, emissions were calculated following the GHG emissions methodology that has been put forward for RCFs which takes account of production emissions (including transport, distribution and processing) as well as counterfactual emissions. The aim of this analysis was to ascertain the effect of the counterfactual on overall carbon intensity, so the emissions associated with production emissions were held at 15 gCO2e/MJ in line with the 2019 E4Tech report. Where electricity generation is displaced, the 2025 grid intensity projection was used following the Treasury Green Book figures. No carbon capture and storage (CCS) in the RCF use case was included.

| Counterfactual | High emissions scenario | Mid-range scenario | Low emissions scenario |
|---|---|---|---|
| Energy from waste (electricity only) | 40% RCF conversion efficiency | 50% RCF conversion efficiency | 60% RCF conversion efficiency |
| Energy from waste, combined heat and power (CHP) | 100% CHP deployment | 16% CHP deployment | 5% CHP deployment |
| Process heat | Replacement fuel 100% coal | Replacement fuel 88.5% coal, 3.2% gas and 8% biomass | Replacement fuel 50% natural gas and 50% biomass |
| Energy from waste, electricity, with CCS | 90% CCS deployment | 50% CCS deployment | 10% CCS deployment |

**Table 1** Main assumptions for the analysis presented in Figure 1. All scenarios follow the same assumption regarding RCF conversion efficiency as in the EfW (electricity only) counterfactual scenario**.**

### Energy from waste electricity

The energy from waste (electricity only) counterfactual assumes that the counterfactual use is incineration in an energy from waste plant with no heat recovery, only electricity generation. The variability between the three scenarios is driven by differences in the conversion efficiency to RCF – a lower conversion efficiency to RCF leads to greater feedstock consumption per MJ of finished fuel produced and therefore greater counterfactual emissions. The conversion efficiency for the low emissions scenario was chosen to be 60% based on the figure used in the 2019 E4Tech report while lower conversion efficiencies of 40% and 50% were chosen for the high and mid-range scenarios respectively, in line with reasonable expectations given current state of the art in conversion technologies. The conversion efficiency in the counterfactual was assumed to be 22% in line with the consultation proposals.

### Energy from waste, combined heat and power (CHP)

The energy from waste (combined heat and power) counterfactual takes the same assumptions as for energy from waste (electricity only) but with additional useful heat export taken into account in addition to electricity. The efficiency of conversion to heat is assumed to be 13%[1] and it is assumed that this is entirely replaced with natural gas with a carbon intensity of 66.03 $gCO_2e/MJ$ fuel[2]. Additional variability is generated (on top of the variations in RCF conversion efficiency carried over from the energy from waste electricity scenario) through variation in the proportion of CHP deployment. In the low emissions scenario, this is assumed to be 5% compared to 100% in the high emissions scenario. The mid-range scenario was taken as 16% in line with the E4Tech 2019 report.

### Process heat

In the process heat counterfactual, there is no electricity production with all the feedstock being used to produce process heat in an industrial facility such as a cement kiln. In line with typical industry figures, the efficiency of conversion to heat in the counterfactual use is assumed to be 75%[3] and the same conversion efficiencies to RCF are carried over from the other scenarios (40%, 50% and 60%). A significant determinant of the counterfactual emissions for process heat uses is the replacement fuel mix, for which three different scenarios were modelled. For the high emissions scenario it is assumed to be 100% coal while in the low emissions scenario it is assumed to be to 50% biomass and 50% natural gas. In the mid-range scenario, we take the fuel mix used in the 2019 E4Tech report of 88.5% coal, 8% biomass and 3.2% natural gas. Natural gas was assumed to have a carbon intensity of 66.03 $gCO_2e/MJ$ fuel, coal of 110.10 $gCO_2e/MJ$ fuel, and biomass of zero.[4]

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[1] This is the figure used in the 2019 E4Tech report.
[2] Source: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021
[3] Cement kiln conversion efficiencies are typically in the range of 70-80%: https://cembureau.eu/media/oyahklgk/12042-ecra-energy-performance-cement-kilns-2017-10-15.pdf
[4] Source: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2021

### Energy from waste, electricity, with CCS

The energy from waste (electricity, with CCS) counterfactual uses the same assumptions as the energy from waste electricity only counterfactual but with an added factor for displaced CCS that would have taken place in the counterfactual use. The same conversion efficiencies to RCF are carried over from the other scenarios (40%, 50% and 60%). The maximum $CO_2$ available for CCS is assumed to be 92.473 $gCO2/MJ_{feedstock}$[5] and the average proportion of carbon captured in the counterfactual is assumed to be 90%, 50% and 10% in the high, mid-range and low emissions scenarios, respectively.'

**Question B1: Do you agree or disagree that the assumptions made in modelling the RCF counterfactual emissions are reasonable? Please give reasoning for your answer.**

## Results

Figure 1 shows that the counterfactual scenario has a significant bearing on the overall GHG emissions. In all cases, lower conversion efficiency to RCF significantly increases the counterfactual emissions per MJ of fuel produced. The emissions associated with replacing EfW (electricity only) are relatively low in countries like the UK where a significant proportion of the replacement generation capacity is likely to be renewable. On the other hand, where EfW plants also export heat they are more efficient, and any lost heat utility is likely to be replaced by fossil fuels like natural gas. Similarly, feedstock diverted from process heat applications is likely to be at least partially replaced with fossil fuels such as natural gas or coal resulting in substantially higher emissions.

In the medium-term, carbon capture and storage (CCS) is expected to be applied to some waste treatment routes such as EfW plants which would make the comparative GHG saving from RCF use more marginal. However, small GHG savings are still realised relative to the 94gCO2e/MJ fossil fuel comparator even with a 90% CCS deployment in the counterfactual. Furthermore, it is also possible that CCS could also be deployed at RCF production plants. This is not included in the analysis presented here which assumes that there is no CCS utilised during RCF production, but if it were deployed it could significantly improve the relative GHG performance of the RCF route.

The data and analysis presented in Figure 1 is subject to high uncertainty due to limited real-world data. The results are also highly dependent on assumptions around the level of deployment of technologies like CHP and CCS in the EfW fleet, and what replacement fuels are used in the case of process heat counterfactuals.

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[5] This is calculated based on combustion emissions of 1683 kgCO2/tonne feedstock and a LHV of 18.2 MJ/kg (based on figures from the 2019 E4Tech report).

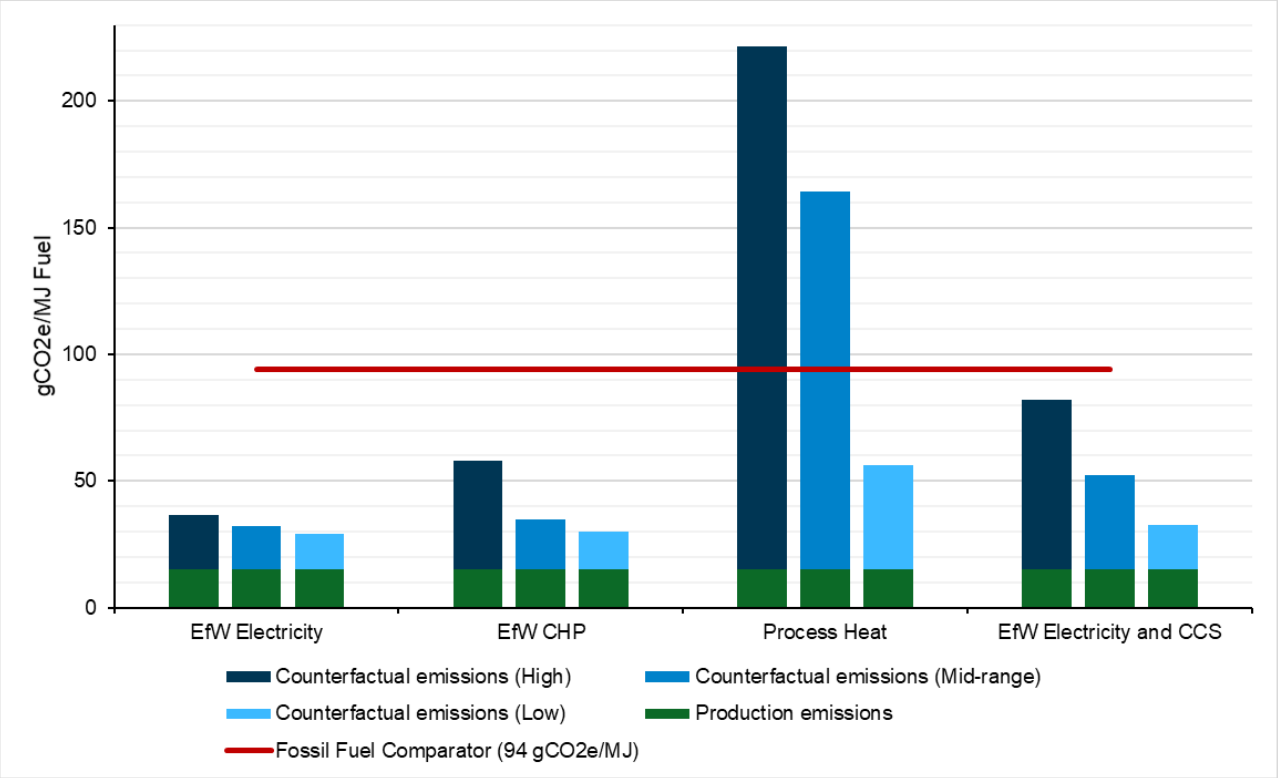


**Figure 1** Indicative GHG emissions for RCFs following different end-of-life scenarios. Where electricity generation is displaced, the 2025 grid intensity projection is used following the Treasury Green Book figures.

# 3. Assessing how the GHG intensity of RCFs may change over time

## Key assumptions and methodology

To inform decisions concerning the GHG emissions saving threshold (see Chapter 3 of the main consultation document), we modelled how the GHG emission savings might vary over time. This analysis assumed an electricity from waste (electricity only) counterfactual and modelled three scenarios for each year:

- **Low emissions:** 60% RCF conversion efficiency and 10gCO2e/MJ production emissions.
- **Mid-range emissions:** 50% RCF conversion efficiency and 15gCO2e/MJ production emissions.
- **High emissions:** 40% RCF conversion efficiency and 20gCO2e/MJ production emissions.

The electricity grid carbon intensity was varied over time using Treasury green book figures to project the average carbon intensity of the grid over time with the year increased by three years to account for the fact that actual grid emissions factors are only available at a three year delay – for example, in January 2022, the most recent factors published by BEIS were the 2021 reporting factors which are based on data for 2019.

The supply chain emissions are also likely to decrease over time as any process electricity they utilise will reduce substantially in carbon intensity. This variability is reflected in the different supply chain emissions scenarios modelled.

**Question B2: Do you agree or disagree that the assumptions made in modelling the how the GHG emissions from RCFs will change of time are reasonable? Please give reasoning for your answer.**

## Results

The overall results of this analysis are shown in Table 2 and Figure 2. Figure 3 and Figure 4 illustrate the effect of the two options for the RCF GHG emission savings threshold proposed in the consultation.

Option 2 involves the previously proposed "stepped" approach, whereby the threshold becomes more stringent in two steps from 55 to 60% and from 60 to 65%. To inform the date at which these steps in the threshold should occur, Figure 2 was overlayed with three horizontal lines showing the maximum permissible RCF carbon intensity for a 55%, 60% and 65% saving threshold relative to the fossil fuel comparator of 94 gCO2e/MJ. This is shown in Figure 3.

| Year | Low emissions (supply chain + counterfactual) | Medium emissions (supply chain + counterfactual) | High emissions (supply chain + counterfactual) |
|---|---|---|---|
| 2024 | 27.26 (10 + 17.26) | 35.71 (15 + 20.71) | 45.89 (20 + 25.89) |
| 2025 | 26.13 (10 + 16.13) | 34.36 (15 + 19.36) | 44.20 (20 + 24.20) |
| 2026 | 25.51 (10 + 15.51) | 33.61 (15 + 18.61) | 43.26 (20 + 23.26) |
| 2027 | 26.88 (10 + 16.88) | 35.26 (15 + 20.26) | 45.32 (20 + 25.32) |
| 2028 | 24.26 (10 + 14.26) | 32.11 (15 + 17.11) | 41.38 (20 + 21.38) |
| 2029 | 20.50 (10 + 10.50) | 27.61 (15 + 12.61) | 35.76 (20 + 15.76) |
| 2030 | 18.75 (10 + 8.75) | 25.50 (15 + 10.50) | 33.13 (20 + 13.13) |
| 2031 | 18.13 (10 + 8.13) | 24.75 (15 + 9.75) | 32.19 (20 + 12.19) |
| 2032 | 17.50 (10 + 7.50) | 24.00 (15 + 9.00) | 31.25 (20 + 11.25) |
| 2033 | 16.00 (10 + 6.00) | 22.20 (15 + 7.20) | 29.00 (20 + 9.00) |
| 2034 | 14.75 (10 + 4.75) | 20.70 (15 + 5.70) | 27.13 (20 + 7.13) |
| 2035 | 14.13 (10 + 4.13) | 19.95 (15 + 4.95) | 26.19 (20 + 6.19) |

**Table 2** Indicative RCF GHG emissions trajectory based on Treasury green book grid decarbonisation projections. All figures in gCO2e/MJ fuel.

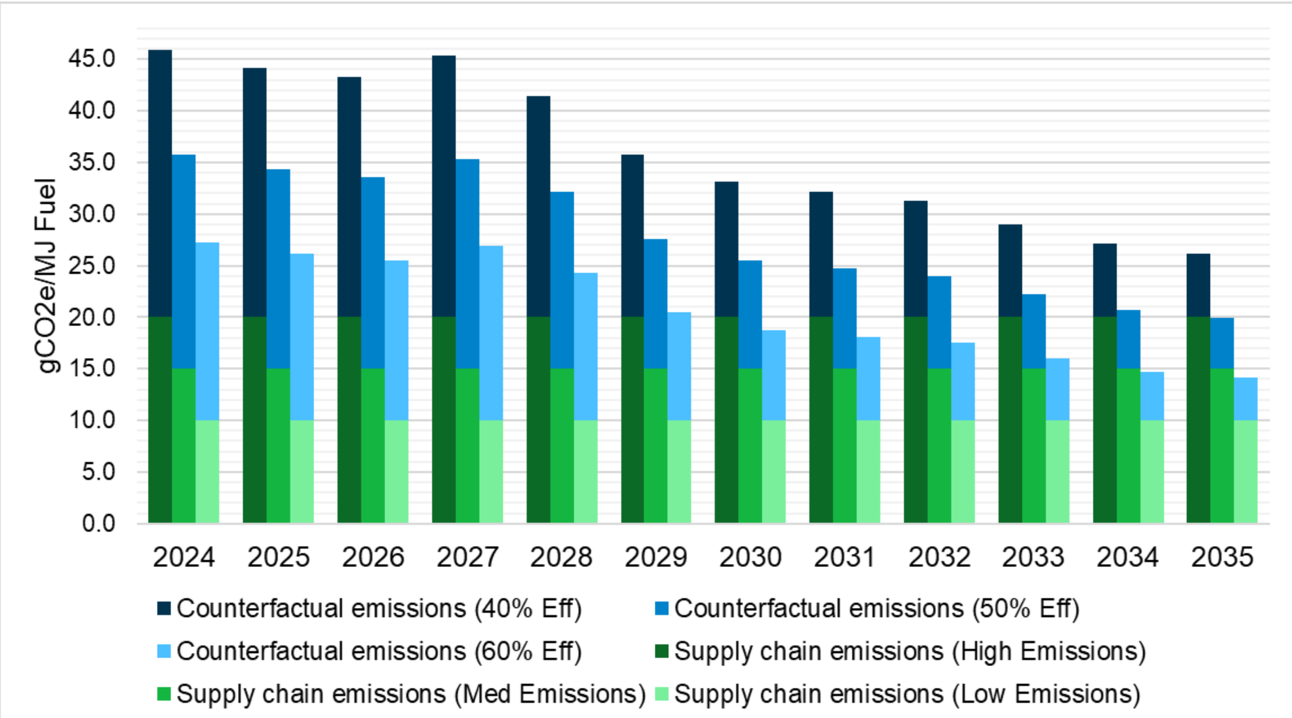


**Figure 2** Indicative RCF GHG emissions trajectory based on Treasury green book grid decarbonisation projections.

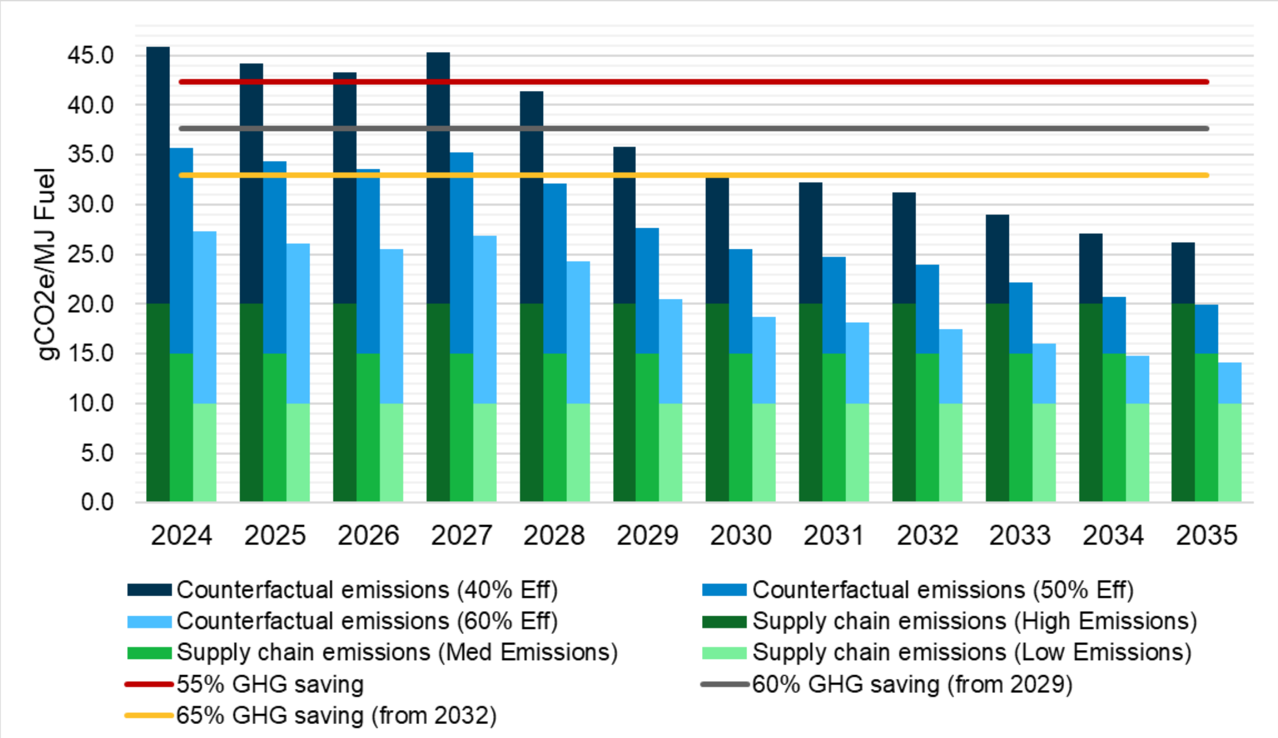


**Figure 3** Indicative RCF GHG emissions trajectory from Figure 2 with emissions saving thresholds from Option 2 overlaid.

Option 1 proposes a GHG threshold linked to the actual grid intensity, following the methodology outlined in the box below. To illustrate how this might work assuming the grid emissions evolve as projected in the Treasury Green Book figures, the effective maximum carbon intensity was calculated for each year and overlaid on Figure 2, as shown in Figure 4.

### GHG emissions saving threshold linked to UK grid intensity

The maximum carbon intensity could be expressed as follows:

$$CI_{max,y} = (1 - Threshold_{baseline}) \times FFC + \frac{Ef_e}{Ef_{RCF}} \times E_{e,y}$$

The emission savings threshold percentage can then be calculated as follows:

$$GHG\ Threshold = \frac{FFC - CI_{max,y}}{FFC}$$

Where:

- $CI_{max,i}$ = the maximum permissible carbon intensity for RCFs supplied in year y ($gCO_2e/MJ$)
- $Threshold_{baseline}$ = the baseline threshold that RCF producers are required to meet (%)

- FFC = the fossil fuel comparator for the relevant year ($gCO_2e/MJ$)
- $Ef_e$ = Standard efficiency of conversion in the counterfactual use (%)
- $Ef_{RCF}$ = Standard efficiency of conversion to RCF (%)
- $E_e$ = Emission factor of the UK electricity grid applicable to year y - the most recent available figure at the start of that year ($gCO_2e/MJ$)

The proposed standard figures are as follows:

- $Threshold_{baseline}$ = 75%
- FFC = 94 $gCO_2e/MJ$
- $Ef_e$ = 22%
- $Ef_{RCF}$ = 50%

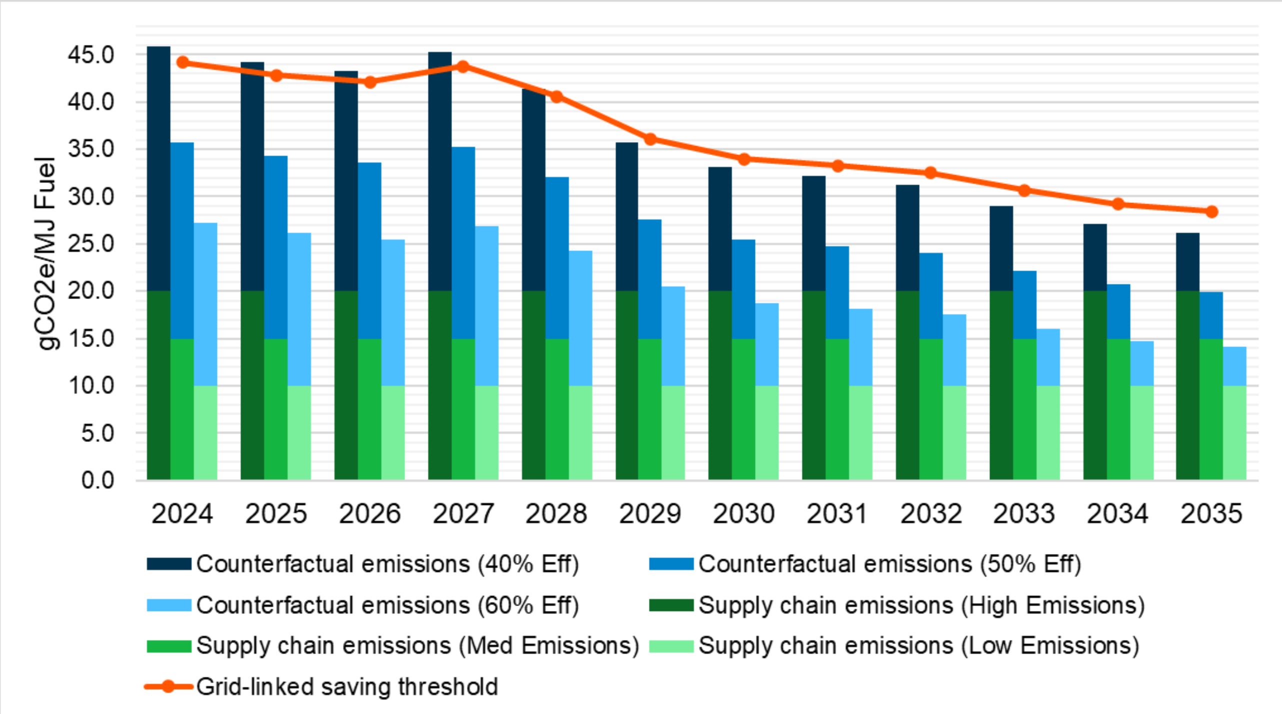


**Figure 4** Indicative RCF GHG emissions trajectory with the maximum GHG intensity implied by the Option 1 overlaid. Note that in this option the emissions saving threshold would be responsive to the latest available GHG emissions factors and so will not necessarily exactly follow the trajectory shown.

# 4. Assessing the impact of different reward rates

## Key assumptions and methodology

To inform the reward rate proposals in Chapter 4 of the main consultation document, we undertook analysis to determine the incentive per tonne of feedstock for different RCF reward rates, modelled over a range of scenarios.

We assumed that the fuel produced is diesel with a density of 0.85 kg/l and a low heating value of 42.793[6] and investigated two different reward rates: 0.5 dRTFC per litre and 1 dRTFC per litre. To account for inherent uncertainties in these calculations, we modelled three scenarios for each reward rate:

- **High productivity scenario:** Assumes a market price of 80p per dRTFC (current buyout price), a waste energy content of 36.6 MJ/kg (appropriate for segregated plastic waste[7]) and an efficiency of conversion to RCF of 60%.
- **Mid-range scenario:** Assumes a market price of 60p per dRTFC, a waste energy content of 18.2 MJ/kg (appropriate for residual waste[8]) and an efficiency of conversion to RCF of 50%.
- **Low productivity scenario:** Assumes a market price of 40p per dRTFC, a waste energy content of 9.12 MJ/kg (appropriate for unsorted municipal solid waste[9]) and an efficiency of conversion to RCF of 40%.

The RCF incentive rate per tonne of waste feedstock was then calculated using the equation in the box below. For comparison, gate fee data was derived from data published by WRAP and typical recyclable plastic price ranges were sourced from S&P Platts.

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[6] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

[7] https://www.gov.uk/government/publications/greenhouse-gas-emissions-created-by-producing-fuels-from-fossil-wastes-and-residues

[8] https://www.gov.uk/government/publications/greenhouse-gas-emissions-created-by-producing-fuels-from-fossil-wastes-and-residues

[9] https://www.tolvik.com/wp-content/uploads/2021/05/Tolvik-UK-EfW-Statistics-2020-Report_Published-May-2021.pdf

### Equation for calculating reward rate incentive

The RCR incentive rate per tonne of feedstock is calculated using the following equation:

$$\text{Incentive} = \frac{P_{RTFC} \times RR_{RCF}}{D_{RCF}} \times Y_{RCF} \left[\frac{\text{tonne RCF}}{\text{tonne feedstock}}\right]$$

Where:

- $P_{RCF}$ = The estimated market price per dRTFC
- $RR_{RCF}$ = The number of RTFCs awarded per litre equivalent of eligible RCF
- $Y_{RCF}$ = The RCF yield per tonne of feedstock
- $D_{RCF}$ = The density of the RCF fuel, assumed to be the density of diesel, 0.85 kg/l

The RCF yield (per tonne of feedstock) is calculated as follows:

$$Y_{RCF} \left[\frac{\text{tonne RCF}}{\text{tonne feedstock}}\right] = \frac{LHV_{Feedstock}}{LHV_{RCF}} \times Y_{RCF} \left[\frac{\text{MJ RCF}}{\text{MJ feedstock}}\right]$$

Where:

- $LHV_{Feedstock}$ = The assumed lower heating value (LHV) of the feedstock.
- $LHV_{RCF}$ = The assumed LHV of the RCF fuel, assumed to be the value for diesel of 42.793 MJ/kg.

**Question B3: Do you agree or disagree that the assumptions made in modelling the impact of different RCF reward rates are reasonable? Please give reasoning for your answer.**

## Results

The analysis compares the 0.5 and 1 dRTFC per litre reward rates to relevant gate fees and prices for recyclable plastics. The results of this analysis are given in Table 3. For the two RCF reward rates the mid-range scenario result is quoted with the high and low productivity scenarios reflected in the range shown in brackets. The incentive per tonne of feedstock is highly variable depending on the energy content of the feedstock, the yield and the market price of dRTFCs. In all cases modelled, the incentive compares favourably to typical gate fees charged at waste processing centres. At the higher level of reward, the incentive could start to approach a price comparable to difficult to recycle plastic.

| Aspect | Value per tonne of waste feedstock |
|---|---|
| RCF incentive at 0.5 dRTFCs per litre | £75.05 (£20.06-£241.49) |
| RCF incentive at 1 dRTFCs per litre | £150.05 (£40.12-£482.98) |
| Gate fee: Material recovery facility | £43 |
| Gate fee: Energy from waste facility | £93 |

| Aspect | Value per tonne of waste feedstock |
|---|---|
| Gate fee: landfill | £116 |
| Price of high value recyclable plastic | £595-£765 |
| Price of low value recyclable plastic | £255-£340 |

**Table 3** Indicative incentive at 0.5 and 1 dRTFCs reward rate. Typical gate fees and prices for recyclable plastic are provided for context.