

Determining the renewability of co-processed fuels

Final report



Determining the renewability of co-processed fuels

Final report

By: Matthias Schimmel, Gemma Toop, Sacha Alberici, Michele Koper (Ecofys)

Date: 9 April 2018

Project number: BIENL15839

© Ecofys 2018 by order of: European Commission, DG Energy

Table of contents

1	Introduction	1
1.1	Background and goal of this study	1
1.2	Data sources	2
1.3	How to read this report	2
2	What is co-processing?	4
3	Existing European Commission guidance	6
4	Options to quantify renewable fuel content	8
4.1	Assessment criteria	9
4.2	Mass balance based methods	10
4.3	Energy content method	16
4.4	¹⁴ C analysis	20
5	Discussion	24
	Annex: Stakeholders consulted	28
	References	29

1 Introduction

1.1 Background and goal of this study

Biofuels play an important role in the EU's effort to reduce greenhouse gas (GHG) emissions in transport. The average share of energy from renewable sources in transport increased from 1.4% in 2004 to 6.7% in 2015. Among the EU Member States, the relative share of renewable energy in transport fuel consumption ranged from highs of 24% in Sweden and 22% in Finland to less than 2% in Spain, Greece and Estonia.¹ The increasing use of biofuels is mostly driven by the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD). Under the RED, the EU aims to have 10% of transport fuel from renewable sources such as biofuels by 2020. The FQD includes a target for fossil fuel suppliers to reduce life cycle GHG emissions by at least 6% by 2020. Co-processing of biogenic material with fossil fuels and the processing of mixed feedstocks may help to further increase the use of renewable fuels within the EU.

To report the biofuel content (i.e. the renewable share) of the outputs when biogenic and fossil components are co-processed, a robust, consistent and transparent methodology is needed. There are several processes for which such a methodology could be relevant. For example, facilities where biomass and fossil inputs are co-processed, or facilities where mixed fossil and waste feedstocks (e.g. municipal wastes or waste tyres) are processed. It is essential that any proposed methodology is technology neutral, so that it can be flexibly applied to different types of installations. This will facilitate its application in the market by relevant stakeholders, and furthermore help to ensure that it is "future proof" to the extent that this is possible.

In 2015, the Commission included high-level guidance on how to report the biogenic content of co-processed fuel in the FQD Implementing Directive, and the proposed RED II includes additional high-level principles. However, further detail is needed to ensure that a consistent approach is taken across Member States and voluntary schemes. Amongst the Member States, the UK and German governments have issued guidance on co-processing. Additionally, some voluntary schemes have developed guidance on this issue (namely ISCC and KZR), although this guidance is not currently recognised by the Commission with respect to compliance with the RED and FQD.

The goal of this study is to describe options for a detailed methodology that can robustly determine the share of renewable energy in cases where biomass is co-processed with fossil fuels or where mixed feedstocks are processed, and the advantages and disadvantages of the different methodology options available. Note that the aim is not necessarily to report the actual physical content of the fuel(s), rather to ensure that the biogenic fuel reported is based on a robust methodology that can be transparently and consistently applied and verified.

Also note that the methodologies described do not concern how sustainability characteristics for different biogenic feedstocks are allocated to outputs. This has conceptual parallels, but is a separate question. Sustainability characteristics should be allocated following the mass balance rules detailed in Article 18(1) of the RED and Communication (2010/C) 160/01.

¹ Eurostat. (2017). *Renewable energy statistics*. http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics

1.2 Data sources

This study is primarily based on a review of published guidance on co-processing. We complemented this with targeted interviews with the authors of the guidance, as well as representatives from a selection of companies actively undertaking co-processing. A list of stakeholders interviewed is included in the Annex, as well as a list of references to key documents.

It is our understanding that the UK and Germany are the only Member States to have published operational guidance on co-processing to date. Specifically, the UK Department for Transport (DfT) published the *Renewable Transport Fuel Obligation (RTFO) Guidance Part 1* in April 2017, which details how the amount of renewable fuel produced in co-processing can be calculated.² In Germany, the *Thirty-seventh Ordinance on the Implementation of the Federal Pollution Control Act* includes provisions for co-processed biogenic oils to be eligible under the Biofuel Quota Regulations.³

Two voluntary schemes have also developed guidance (note that the guidance is not currently recognised by the Commission). In November 2016, the *International Sustainability & Carbon Certification (ISCC)* system released guidance for the certification of co-processing,⁴ which describes three methodologies to calculate the biogenic output. The *System of Certification of Biofuels and Bioliquids (KZR INiG System)*⁵ has also published guidance, putting forward one methodology to calculate the renewability of co-processed fuels.

Outside Europe, the California Air Resources Board (CARB) who administer the Low Carbon Fuel Standard Program (LCFS)⁶, has done significant research into this topic and is in the process of drafting guidance on co-processing that will apply under the LCFS.⁷ In the latest draft discussion paper, published in November 2017, two approaches to low carbon fuel quantification are put forward. Earlier draft papers included additional approaches, which are still being further investigated by CARB.

1.3 How to read this report

This report describes the methodology options identified to calculate the share of renewable energy in cases where biomass is co-processed with fossil fuels. Section 2 introduces the concept of co-processing. Section 3 describes

² Department for Transport. (2017). RTFO guidance part 1: process guidance year 10. Section 2.11 – 2.19. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604591/rtfo-guidance-part-1-process-guidance-year-10.pdf

³ Thirty-seventh Ordinance on the Implementation of the Federal Pollution Control Act (Ordinance on the allocation of electricity-based fuels and co-processed biogenic oils to the greenhouse gas quota). https://www.gesetze-im-internet.de/bimschv_37/BJNR119500017.html#BJNR119500017BJNG000300000

⁴ ISCC. (2016). ISCC 203-01 Guidance for the certification of co-processing. https://www.iscc-system.org/wp-content/uploads/2017/02/ISCC-Guidance-Documents-203-01_Co-processing-requirements.pdf

⁵ KZR. (2017). Guidelines for the determination of the lifecycle per unit values of GHG emissions for biofuels, Section 3rd issue. http://www.kzr.inig.eu/file/repository/System_KZR_INIG_8_ver_3_EN_04052017.pdf

⁶ The LCFS is a programme to promote low carbon fuels in California. The programme is open to either fossil or renewable fuel to calculate and report its lifecycle GHG emissions, as long as the emissions are lower than normal fossil fuel.

⁷ California Air Resources Board. (2017). Co-processing of low carbon feedstocks in petroleum refineries – Draft discussion paper. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/053017draft_discussion_paper_coprocessing.pdf

⁸ California Air Resources Board. (2017). 2018 LCFS Preliminary Draft Regulatory Amendment Text. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/110617presentation.pdf

existing European Commission guidance relating to co-processing. Section 4 details the different methodology options identified on how to calculate the biogenic share of co-processed fuels as well as their pros and cons and section 5 brings together the findings of this study. An overview of stakeholders consulted for this report is included in the Annex.

2 What is co-processing?

Co-processing refers to the simultaneous transformation of biogenic feedstocks and intermediate petroleum distillates such as vacuum gas oil (VGO) in existing petroleum refinery process units to produce finished fuels. It involves cracking, hydrogenation, or other reformation of semi-processed biogenic oils in combination with petroleum intermediates to obtain diesel, gasoline, kerosene, naphtha, LPG, or any other hydrocarbon fuels. Semi-processed biogenic feedstocks that have been identified as likely to be suitable for co-processing include pyrolysis oil, triglycerides such as virgin vegetable oils (e.g. rapeseed oil), algae based oils, used cooking oil and fat-based oils (e.g. animal fat). In addition, lignin and sugars may be co-processed in existing refineries. The addition of denaturant or other auxiliaries to fossil refinery processing are not regarded as co-processing.

Co-processing of bio-based inputs and fossil inputs results in mixed outputs with the same chemical properties. However, there are several properties that tend to differ between the biogenic and fossil origin materials, such as:

- Biogenic feedstocks have lower hydrogen and sulphur content compared to fossil feedstocks and they typically have an abundance of oxygen which is converted to CO, CO₂, and water in fluid catalytic cracking (FCC) or hydrotreating process units.
- During co-processing in FCC units, biogenic feedstocks, especially pyrolysis oil, tend to preferentially precipitate as coke on the catalyst, compared to petroleum feeds.
- There is also a tendency for biogenic feedstocks to produce additional mixed C₄s (mixtures of hydrocarbons consisting of four carbon atoms) when compared to fossil feedstocks. This alters the mass and volume ratios of liquid fuels and emissions produced from the unit when compared to processing 100% fossil feedstocks.

Robust methods are needed to quantify the renewable fuel fractions of the outputs produced.

Refineries are typically large and complex installations, but generally, the system boundary for the simultaneous processing of bio-based feedstocks and fossil feedstocks is the mineral oil refinery as depicted in Figure 1.

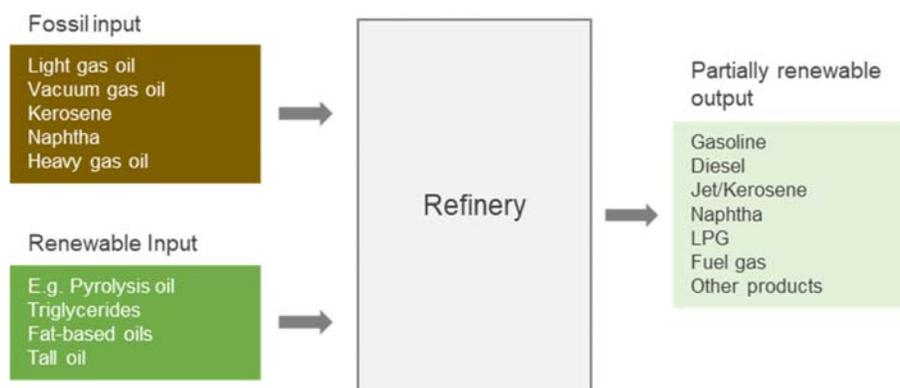


Figure 1: Example of co-processing of fossil and renewable feedstocks in a refinery

Refining processes that could potentially be used for co-processing include fluid catalytic cracking (FCC), hydrotreating, and hydrocracking, as described in Box 1.

Box 1: Co-processing application in refineries

FCC is a chemical process that uses a catalyst to create smaller molecules from larger molecules (hydrocarbon fractions of petroleum crude oil) to make more valuable gasoline and distillate fuels. Today, it is an important and widely used process in petroleum refineries to primarily produce additional gasoline in the refining process. Cracking of petroleum hydrocarbons was originally done by thermal cracking. This has been almost completely replaced by catalytic cracking because it produces more gasoline with a higher-octane rating. It also produces by-product gases that have more carbon-carbon double bonds.

Hydrotreating is an established refinery process to reduce sulphur, aromatics, nitrogen, oxygen and metals while enhancing the combustion quality, cetane number, density and smoke point of distillates. The process is done for medium distillates like heavy naphtha, kerosene and diesel through hydrodesulphurisation reactors. It is also done for VGO to prepare the feedstock for FCC and hydrocracking units. The growing demand for transportation fuels and the shift toward diesel over the last decade mean that hydrotreating has become an increasingly important refinery process in recent years.

A *hydrocracking* unit takes gas oil, which is heavier and has a higher boiling range than distillate fuel oil, and cracks the heavy molecules into distillate and gasoline in the presence of hydrogen, high temperatures, high pressure and a catalyst. The hydrocracker upgrades low-quality heavy gas oils from the atmospheric or vacuum distillation tower, the fluid catalytic cracker, and the coking units into high-quality, clean-burning jet fuel, diesel, and gasoline. In addition to the liquid products hydrocracking yields light gases that can be used as fuel for the refinery or as petrochemical feedstock.

Co-processing has recently received attention due to its potential to provide low carbon renewable fuels at economically competitive prices by using existing refining, transport and storage infrastructure. Co-processed fuels may also increase the supply of so-called “drop-in” biofuels to the market as they inherently contain both fossil and biofuel content, so they are not subject to the same biofuel blend limits as more conventional bioethanol or FAME biodiesel. Apart from being considered as a key technology that may enable higher share of renewable transportation fuels, additional benefits have been reported for co-processing. For example, the process achieves a higher energy content and cetane number, thus, an overall improved fuel quality in contrast to conventional bio component blending.

Today, co-processing is already carried out by several companies across Europe, e.g. Preem in Sweden, Neste in Finland and Repsol in Spain. It is our understanding that to date most co-processed fuel has been sold within the country of processing and not traded across borders, and so the method for reporting the biogenic content of fuel has been discussed directly with the respective Member State. However, this situation is likely to change as co-processing increases and therefore there is a need for a robust methodology accepted at the EU level. A similar challenge in reporting the biogenic content of a fuel occurs when mixed feedstocks are processed to biofuel, such as municipal solid waste (MSW) or waste tyres that are a mixture of biogenic and fossil content within a single feedstock.

3 Existing European Commission guidance

The RED and FQD include mandatory sustainability criteria that biofuels must meet to be counted towards the target in either Directive. Both Directives apply in their current form until the end of 2020. The core sustainability criteria and GHG methodology are the same in each Directive, although the respective Directives – and especially the 2015 amendments, the ILUC Directive and the FQD Implementing Directive – differ in the details on certain aspects.

The FQD Implementing Directive (Directive (EU)2015/652) includes a high level but legally binding principle on how to determine the quantity of biofuel (i.e. renewable share) when co-processing biogenic and fossil content within Annex I on the GHG calculation methodology, the relevant extract of which is included in Box 2 below.

The key points are that the quantity of biofuel is determined according to the energy balance and efficiency of the co-processing process. As is already the case, if there are multiple biofuels processed, the quantity and type of each biofuel needs to be reported to Member States and any biofuel that does not meet the sustainability criteria would be counted as fossil fuel.

Box 2: Directive (EU)2015/652⁹, Annex I Method for the calculation and reporting of the life cycle GHG intensity of fuels and energy by suppliers, Part 1, paragraph 3(c)(ii) (emphasis added for the purpose of this report)

(ii) Simultaneous co-processing of fossil fuels and biofuels

Processing includes any modification during the life cycle of a fuel or energy supplied causing a change to the molecular structure of the product. The addition of denaturant does not fall under this processing. The quantity of biofuels co-processed with fuels from non-biological origin reflects the post-processing state of the biofuel. **The quantity of the co-processed biofuel is determined according to the energy balance and efficiency of the co-processing process** as set out in point 17 of Part C of Annex IV to Directive 98/70/EC.¹⁰

Where multiple biofuels are blended with fossil fuels, the quantity and type of each biofuel is taken into account in the calculation and reported by suppliers to the Member States. The quantity of biofuel supplied that does not meet the sustainability criteria referred to in Article 7b(1) of Directive 98/70/EC is counted as fossil fuel.

E85 petrol-ethanol blend shall be calculated as a separate fuel for the purpose of Article 6 of Regulation (EC) No 443/2009 of the European Parliament and of the Council (3).

If quantities are not collected pursuant to Regulation (EC) No 684/2009, Member States shall collect equivalent data in accordance with a nationally established excise duty reporting scheme.

⁹ Directive (EU)2015/652: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0652&from=EN>

¹⁰ Point 17 of Part C of Annex IV relates to the GHG calculation methodology: "Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity)."

At the end of 2016, the Commission published the draft proposal for the update to the RED to cover the period 2021 to 2030. (Note that the FQD target is not currently proposed to continue beyond 2020.) This RED II proposal is under negotiation at the time of writing, so no final text is available. However, the Commission proposal text (see Box 3) includes two important principles: 1. the amount of biofuel in the product shall be established applying adequate conversion factors to the biomass input, and 2. if the process yields more than one product, all products stemming from the process shall be assumed to contain the same share of biofuel.

Box 3: Proposed REDII text (emphasis added for the purpose of this report)

Article 25 Mainstreaming renewable energy in the transport sector

3 (b) **When biomass is processed with fossil fuels in a common process, the amount of biofuel in the product shall be established applying adequate conversion factors to the biomass input.** In case the process yields more than one product, **all products stemming from the process shall be assumed to contain the same share of biofuel.** The same rules shall apply for the purposes of Article 27(1).

6. The Commission is empowered to adopt delegated acts in accordance with Article 32 to further specify the methodology referred to in paragraph 3(b) of this Article to determine the share of biofuel resulting from biomass being processed with fossil fuels in a common process, to specify the methodology for assessing greenhouse gas emission savings from renewable liquid and gaseous transport fuels of non-biological origin and waste-based fossil fuels and to determine minimum greenhouse gas emission savings required for these fuels for the purpose of paragraph 1.

Article 27 Verification of compliance with the sustainability and greenhouse gas emissions saving criteria for biofuels, and bioliquids and biomass fuels

1. Where biofuels, and bioliquids and biomass fuels are to be taken into account for the purposes referred to in Articles 23 and 25 and in points (a), (b) and (c) of Article 1726(1), Member States shall require economic operators to show that the sustainability and greenhouse gas emissions saving criteria set out in Article 26(2) to (5) (7) have been fulfilled. For that purpose they shall require economic operators to use a mass balance system which: [...]

(b) allows consignments of raw material with differing energy content to be mixed for the purpose of further processing, provided that the size of consignments is adjusted according to their energy content;

In summary, the key principles are:

1. The quantity of the co-processed biofuel is determined according to the energy balance and efficiency of the co-processing process (FQD)
2. Where multiple biofuels are blended with fossil fuels, the quantity and type of each biofuel is taken into account in the calculation and reported by suppliers to the Member States (FQD)
3. The amount of biofuel in the product shall be established applying adequate conversion factors to the biomass input (proposed RED II)
4. If the process yields more than one product, all products stemming from the process shall be assumed to contain the same share of biofuel (proposed RED II)

4 Options to quantify renewable fuel content

Co-processing fuel or processing mixed biogenic and fossil feedstocks does not produce discrete volumes that are renewable or fossil. Therefore, to determine how much of the fuel is biogenic, the volume of the finished fuel must be administratively quantified into notional *non-renewable* and *renewable* portions for the purpose of reporting to Member States and counting towards renewable energy targets. Any quantification method must be robust, transparent, verifiable and easily replicable.

The following approaches have been identified (terminology differs between existing guidance):

1. *Mass balance* based on:
 - i. *Observed yields*
 - ii. *Carbon/total mass balance*
2. *Energy content*
3. *¹⁴C analysis (carbon dating)*

Mass balance methods and the energy content approach refer to administrative calculation methods based on *chemical reactions* in the refining unit. They require measurements to be taken prior to the start of the process and thereafter, i.e. monitoring of input and output mass or energy content. By contrast, ¹⁴C analysis is a post reaction analysis that determines the actual *physical composition* of the finished fuel.

Table 1 provides an overview of the quantification methods recommended in the guidance documents reviewed for this study. Of the documents considered, the ISCC guidance allows the largest number of methodology options, including a mass balance approach, the energy content approach and ¹⁴C analysis. The KZR scheme allows the energy content method. The UK DfT also recommends the energy content method, however, is open to other methods if suppliers make a case and DfT deems the method appropriate. In Germany, obligated parties are required to provide evidence of the renewability of co-processed fuels using ¹⁴C analysis, following the specific methodology in the DIN 51637 standard¹¹. The latest draft version of the CARB guidelines recommends using mass balance methods. Other methods are being further evaluated by CARB, including the energy content method and the suitability of ¹⁴C analysis, particularly at low blend percentages of renewable feedstock. CARB is currently conducting tests of the ¹⁴C method on samples of co-processed fuel to test the accuracy and reproducibility of the method at a range of bioenergy contents.

¹¹ DIN 51637:2014-02, Liquid petroleum products - Determination of the bio-based hydrocarbon content in diesel fuels and middle distillates using liquid scintillation method.

Table 1: Overview of methodologies recommended by guidance documents

	Mass balance	Energy content	¹⁴ C analysis
UK		✓	
Germany			✓
ISCC	✓	✓	
KZR		✓	
California	✓ (Observed yields & carbon mass)	(Included in draft guidance)	(Included in draft guidance - Under evaluation)

4.1 Assessment criteria

To assist the Commission in better comparing the different methodology options, we scored each against several criteria which have been grouped into three broader categories:

- **Costs**, relating to equipment needed to carry out the measurements, staff and resources needed to carry out the measurements, ease of integration into existing processes, how much effort is required to put the methodology into practice.
- **Monitoring, reporting and verification (MRV)**, relating to the ease of monitoring and replicating the method, whether the results can be easily reported and verified.
- **Technology**, relating to whether the outcomes of the measurements are consistent, whether they accurately reflect the physical outcomes of the process, whether the method can be applied by all Member States, whether the methodology is applicable to different processes with various shares of biogenic material and whether the results are readily available.

Each method is assessed against the criteria and give a score using a traffic light assessment (see Figure 2).

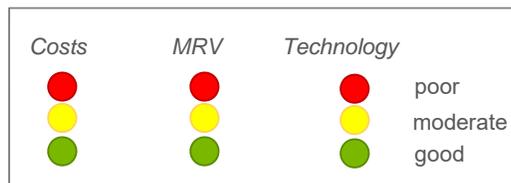


Figure 2: Traffic light assessment for criteria

4.2 Mass balance based methods

A mass balance approach is predicated on the conservation of mass principle. In any system, the total mass of inputs should equal the total mass of outputs. A mass balance method does not directly measure the renewable fuel content of products, instead a reasonable method of allocation is applied to indirectly and conservatively determine the renewable fractions of fuel products after a mass balance analysis is performed. This section describes three variations of the mass balance method, all of which are based on calculations related to the chemistry of the process:

1. Mass balance approach based on *Observed yields* compares the hydrocarbon yields of co-processing to baseline processing with only fossil or only biogenic feedstocks
2. Mass balance approach that also takes into account CO, CO₂ and H₂O:
 - a) The *Carbon mass balance* method takes into consideration the amounts of CO and CO₂ produced during co-processing, and adjusts the mass of biogenic feedstock to exclude the mass of biogenic feedstock that ends up as CO and CO₂
 - b) The *Total mass balance* approach measures changes in the carbon content and also H₂O

The CARB propose mass balance approaches based on observed yields or carbon mass balance. Total mass balance was also included in the draft CARB paper, but removed from the latest version, although we understand that they are still examining all options. ISCC's approach b) is called "Determination through the efficiency of a process and thus the losses". We understand this to be a mass balance approach. The ISCC approach b) suggests using 100% bio feedstock as the baseline, but it is not explicitly detailed on whether the mass balance should also take into account gases (CO, CO₂) and water.

4.2.1 Mass balance based on Observed yields

This approach does not attempt to directly measure the amounts of renewable fuel output produced. Instead it estimates the amount of renewable fuel produced based on observing the changes in total yield when comparing co-processing scenarios to baseline scenarios with 100% fossil (no biogenic feedstock) processed and thereby calculating a "Yield factor" that can be applied. The approach could equally be applied taking 100% biogenic feedstock as the baseline, but we have illustrated the fossil baseline approach.

Figure 3 provides an example of a baseline scenario where 100kg of fossil feedstock is processed in a refinery unit yielding 90kg of finished fuel, e.g. Diesel, gasoline, kerosene etc. In the co-processing scenario, 10kg of renewable feedstock is added to the process which increases the total yield to 97kg. The increase in yield of 7kg can be fully labelled as "renewable". The yield factor of 7.2% (i.e. 7/97) can be applied to all outputs to calculate the kg renewable fuel.

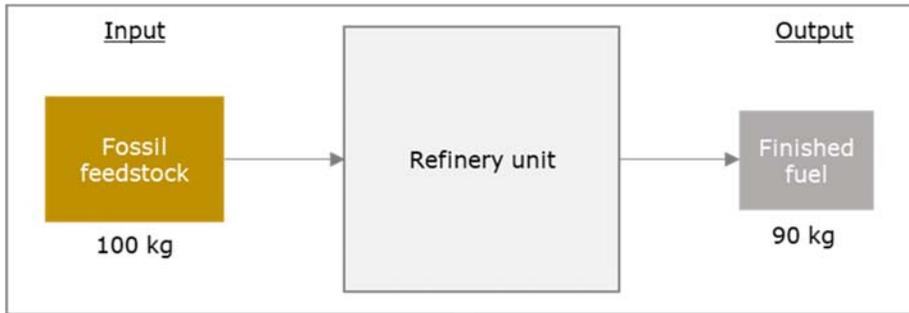


Figure 3: Baseline fossil only scenario (illustrative purposes only)

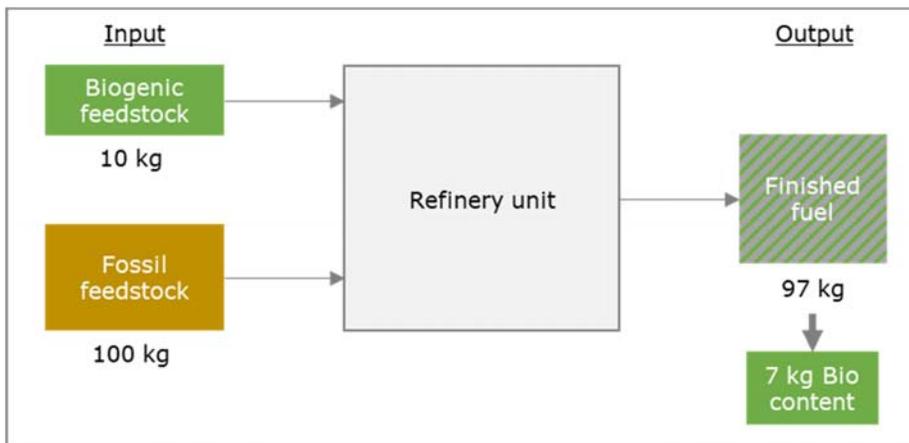


Figure 4: Co-processing scenario with renewable and fossil feedstocks (illustrative purposes only)

If this calculation is undertaken for the total mass of inputs and outputs (as illustrated in Figure 3 and Figure 4), then the same share of biogenic material would be allocated to each output. Alternatively, the calculation could be done for all the individual hydrocarbon outputs (as illustrated in Figure 5 and Figure 6). This is a more complex calculation (noting that there may be many more than two different hydrocarbon outputs from a refinery) and could mean that the bio-share allocation to each product is different, but this may better reflect the physical content of the outputs. This calculation approach could therefore benefit specific installations, although the costs and benefits will be specific to the individual installation. In this specific illustrative example, a yield factor of 4.8% (i.e. 2/42) would be applied to calculate the biogenic kg of petrol-based outputs and 9.1% (i.e. 5/55) applied to calculate the biogenic kg of diesel-based outputs.

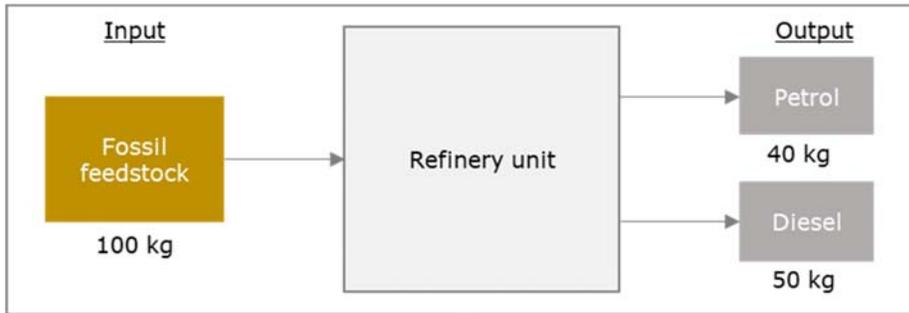


Figure 5: Baseline fossil scenario considering all hydrocarbon outputs (illustrative purposes only)

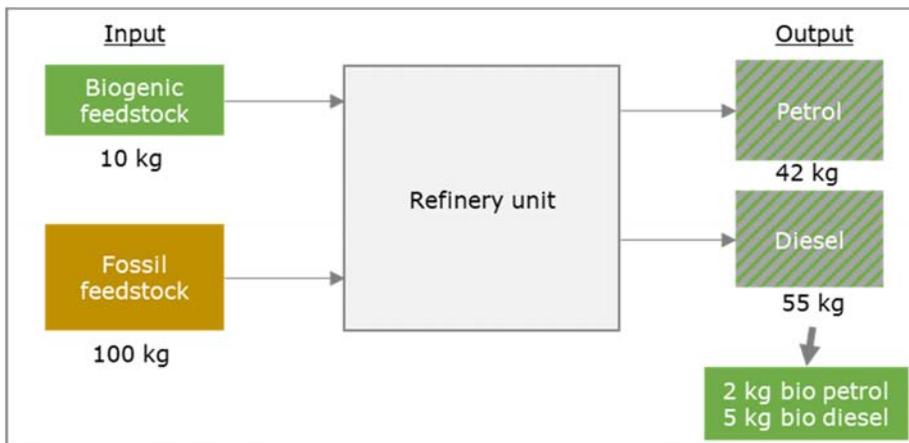


Figure 6: Co-processing scenario considering all hydrocarbon outputs (illustrative purposes only)

MRV considerations

Refineries can be very complex and defining the system boundary for the mass balance is a crucial step to ensure the approach is transparent, replicable and therefore verifiable, and that the calculations can be undertaken in a practical way. The biogenic share needs to be allocated to the final (fuel) outputs so the mass balance analysis needs to be performed at the level where *inputs* and *final fuel outputs* can be determined. Any steps/sub-processes in between can in principle be represented as a “black box”. As an alternative, the mass balance needs to be performed on the unit where co-processing occurs and then continued through the refinery in any downstream processing units. What is essential for the calculation is that the mass of the biogenic and fossil inputs and the mass of the total (hydrocarbon) fuel outputs can be determined.

The baseline scenario can be calculated once. However, if the input feedstocks change regularly and the relationship between the mass of biogenic input and the mass of biogenic output is not linear, the yield factor may need to be recalculated regularly, which could be burdensome.

The baseline and comparison calculations could be done for a specific unit in the refinery, or for a defined volume of fuel such as a storage tank, or over a defined period of time (e.g. a day, week, month or 3-month period). As long as the baseline and comparison scenarios have the same set-up (in terms of system boundary, whether conducted for

separate products or the total output mass etc) and are conducted consistently, this should not impact the overall result. For verification purposes, the approach (often called Fuel, Measurement and Sampling, or FMS, approach) should be defined and documented and consistently implemented.

Stoichiometric calculations/theoretical modelling could also be used to verify that observed yields do not exceed maximum theoretical yields. If the observed yields exceed theoretical limits, adjustments may need to be suggested.

Advantages and Disadvantages

Criteria	Advantages	Disadvantages	Scoring
Costs	<ul style="list-style-type: none"> No or limited investments in equipment needed (dedicated meters and testing equipment needed to measure mass of all inputs and outputs) Can be easily integrated into current refining processes Limited staff needed to carry out measurements (partly automatable) 	<ul style="list-style-type: none"> Each unit is unique (from a chemistry perspective) and must be adjusted with specific yield factor calculations if the upstream composition and/or downstream yield of the co-processed output(s) significantly changes → potential <i>administrative burden</i> 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ○ ● </div> <div> <p>Measurements of input and output mass should be relatively simple to integrate into current processes</p> </div> </div>
MRV	<ul style="list-style-type: none"> The results are readily available No CO, CO₂ and H₂O output measurements required 	<ul style="list-style-type: none"> Defining system boundary can be challenging Refineries will need to keep records of mass outputs (each unit will be reporting actual yields) → <i>extensive record keeping</i> 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>If the input feedstocks change regularly and the relationship between the % bio input and the % bio output is not linear, the yield factor may need to be recalculated regularly, which could be burdensome</p> </div> </div>
Technology	<ul style="list-style-type: none"> The method yields consistent outcomes based on the chemical processes in the processing unit The method can be applied across all Member States The methodology is applicable to different 	<ul style="list-style-type: none"> Potentially technical calculation which requires monitoring of mass of outputs. May require additional monitoring if this is not already done 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ○ ● </div> <div> <p>Monitoring mass is easily accessible technology</p> </div> </div>

Criteria	Advantages	Disadvantages	Scoring
	technologies using any share of biogenic feedstock		

4.2.2 Carbon/total mass balance methods

Carbon mass balance

The carbon mass balance approach is similar to the approach above but takes into consideration the amounts of CO and CO₂ produced during co-processing, and adjusts the mass of biogenic feedstock to exclude the mass of biogenic feedstock that ends up as CO and CO₂. The carbon content lost from the biogenic feedstock can be estimated by considering the mass difference of these components between the fossil only baseline and co-processing. If the production of CO and CO₂ in the fossil only baseline is shown to be negligible, then all carbon content produced from co-processing can be assumed to come from the biogenic feedstock. The difference between the fossil only baseline and the co-processing situation is used to calculate the yield factor to determine the renewable share of the finished fuel.

Total mass balance

The total mass balanced approach, which was discussed in an early draft paper by the CARB, is almost identical to the carbon mass balance method except that it also takes into consideration H₂O losses. Any H₂O introduced externally as steam is excluded to only account for water from the biogenic feedstock and petroleum intermediate.

MRV considerations

MRV considerations are the same as for the mass balance approach based on observed yields, but the monitoring is more complex as the output records need to include records of gases and water (in the case of the total mass balance approach). In the context of a refinery, there should be sufficient monitoring equipment already in place to monitor water and gases, but of course there may be some efforts to ensure that the monitoring is set up and integrated into the renewable energy reporting in an efficient way.

Carbon mass balance should be based on elemental composition of feedstock inputs and output liquid streams and composition analysis of gaseous products. Records of measurement data and calculations should be kept for each particular blend percentage separately. For gaseous species, analysis using a Gas Chromatograph (GC) or equivalent may need to be used. The CARB suggests that economic operators should include continuous commercial production data for a minimum of three months both *prior* and *after* initiation of co-processing in the

report to the authorities. It is furthermore suggested that a minimum of 50 GC traces are provided over these periods to quantify the gaseous components produced for the carbon balance analysis.¹²

Advantages and Disadvantages

Criteria	Advantages	Disadvantages	Scoring
Costs	<ul style="list-style-type: none"> • No or limited investments in equipment needed (dedicated meters and testing equipment needed to measure mass of all inputs and outputs, <u>including gases and water</u>) • Should be easily integrated into current refining process • Limited staff needed to carry out measurements 	<ul style="list-style-type: none"> • Each unit is unique (from a chemistry perspective) and must be adjusted with specific yield calculations if the composition and/or yield of the co-processed output (s) significantly changes → potential <i>administrative burden</i> 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>Same as for observed yields approach, but additional cost of measuring gases (and water). Could be significant if gases are not already monitored</p> </div> </div>
MRV	<ul style="list-style-type: none"> • The results are readily available 	<ul style="list-style-type: none"> • CO, CO₂ and H₂O (in case of Total mass balance) measurements required • Defining system boundary can be challenging • Refineries will need to keep records of mass outputs (each unit will be reporting actual yields) → <i>extensive record keeping</i> 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>Same as for observed yields approach. If the input feedstocks change regularly and the relationship between the % bio input and the % bio output is not linear, the yield factor may need to be recalculated regularly, which could be burdensome</p> </div> </div>

¹² California Air Resources Board. (2017). Draft Guidance - Low Carbon Fuel Standard (LCFS) Guidance 17-03. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/10162017_guidance.pdf

Criteria	Advantages	Disadvantages	Scoring
Technology	<ul style="list-style-type: none"> • Method yields consistent outcomes based on the chemical processes in the processing unit • Method can be applied across all Member States • Method is applicable to different technologies using any share of biogenic feedstock 	<ul style="list-style-type: none"> • More complex calculation (than observed yields) • May require additional equipment and monitoring if this is not already done 	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>Monitoring mass is easily accessible technology. May require additional techniques to monitor gases and water (as steam)</p> </div> </div>

4.3 Energy content method

In this approach, the calculation of the biogenic output is based on energetic weighted ratios of biogenic and fossil inputs. Biogenic materials have a lower energy content (calorific value) than fossil materials, because of the higher oxygen and water content. For example, fossil VGO has an energy content of about 42 MJ/kg, whereas raw bio pyrolysis oil typically has an energy content of about 20 MJ/kg (noting that pyrolysis oil has a particularly high oxygen content).

The energy content approach assumes that the *share* of biogenic content in the inputs is equal to the *share* of biogenic content of the outputs, *on an energy content basis*. The biogenic share of the total input material is calculated based on the lower heating values (LHV) of the different raw material inputs¹³ and this factor is applied to the outputs to calculate the biogenic output. The method could in theory be done on a higher heating value (HHV) basis, but bioenergy calculations are typically conducted on an LHV basis – including the RED GHG calculations. The main difference between the two is that HHV includes the latent heat of vaporisation of the water content.

The bio-content of the co-processed fuel is determined based upon the percentage (bio yield factor) of all the feedstock inputs to the production process that are of renewable origin, as detailed in equation 1.

$$\beta = \frac{\text{Total MJ of renewable feedstocks}}{\text{Total MJ of all feedstocks}} = \frac{\sum(Q_{b_{in}i} * LHV_{b_{in}i})}{\sum(Q_{b_{in}j} * LHV_{in}j)}$$

where:

- β: bio yield factor
- Q_{b_{in}i}: mass of ith biomass directed to conversion process; expressed in mass unit;
- LHV_{b_{in}i}: lower heating value of ith biomass directed to conversion process, expressed as energy unit per mass unit;
- Q_{b_{in}j}: quantity of jth stream (of both biological and fossil origins) introduced into the process, expressed in mass units;

¹³ It would seem logical for these feedstocks to do the calculation on the basis of the feedstock 'as received' (e.g. virgin oils), as opposed to a dry matter basis. However, the most important is that the data is on a consistent basis for all biogenic feedstocks.

LHV_{inj}: lower heating value of jth stream (of both biological and fossil origins) expressed as energy unit per mass unit.

Equation 1: Calculation of the bio-fraction of inputs (equation adapted from the DfT and KZR approaches)

The amount of renewable fuel output is then calculated using equation 2 below, where the energy within each feedstock in MJ is the amount of feedstock over a given period (or in a specific container / processing unit) multiplied by the respective feedstock LHV. During daily operations, the bio yield factor can be applied to the outgoing products to calculate the biogenic output.

$$MJ \text{ of renewable fuel} = \beta * \text{Total MJ of fuel produced}$$

Equation 2: Calculation of renewable energy content in the finished fuel

A potential issue with this approach is that it looks at the energy content of feedstock *inputs* to a process and does not therefore reflect what actually happens in the processing unit. CARB noted that, when compared to fossil feedstocks, biogenic feedstocks in particular produce CO and CO₂ during co-processing owing to their high oxygen content¹⁴. Therefore, not all of the input material ends up in the finished fuel, which could mean that the renewability of the finished product is slightly overstated on a structural basis when using the energy content method, depending on the feedstock. In addition, for some processes, this may lead to a result that is less close to the physical fuel content than the mass balance approach. For example, KZR discussed an example where the production of propane is up to five times higher when co-processing than when processing fossil only feedstocks. Applying a single conversion factor based on the energy content of the inputs does not reflect the true yield of (bio-)propane. For some Member States with a significant LPG market (e.g. Poland), this could be considered a disadvantage of this approach.

To apply this approach to a feedstock that is a mix of biogenic and fossil fractions, the component parts should be treated as two separate feedstocks (one wholly renewable, one wholly no-renewable), each with their own LHV (MJ/kg). For example, 10 tonnes of MSW should be treated as 6 tonnes of biogenic MSW with a LHV of 12 MJ/kg, and 4 tonnes of fossil MSW with a LHV of 18 MJ/kg (indicative values only), which on its own would produce a partial biofuel that is $(6*12)/(6*12+4*18) = 50\%$ renewable. Each co-product from the fuel production process will be assigned the same renewable percentage as the main product. The determined bio-yield factor can be applied in daily operations for varying amounts of bio-inputs.

MRV considerations

Once the bio-yield factor is calculated, the amount of renewable fuel can easily be calculated by multiplying it by the total amount of fuel produced. If the type of feedstock or the percentage of biogenic input changes, the bio-yield factor may need to be recalculated.

¹⁴ The impact is greatest for pyrolysis oil which can have an oxygen content of up to 50%.

The bio-yield calculation is based on inputs only and would logically be done for a defined period of time (e.g. a day, week, month or 3-month period).

Advantages and Disadvantages

Criteria	Advantages	Disadvantages	Scoring
Costs	<ul style="list-style-type: none"> No or limited investments in equipment needed (measurements of energy content of inputs and outputs required). Calorific values can be used which are within a certain standard range and/or would be stated on technical paperwork or invoices Can be easily integrated into current refining process Limited staff needed to carry out measurements 		 <p>Fuel companies should already have good understanding of energy content of materials. Need to know energy contents already for RED targets and GHG calculations. Calorific values can be used</p>
MRV	<ul style="list-style-type: none"> Consistency with RED targets and GHG calculation/allocation that are already based on energy content Data requirements and administrative burden are minimal as only the weight fraction of biogenic feedstock and its energy content has to be reported Result does not depend on process conditions 		 <p>Depends on how often bio-yield factor has to be recalculated</p>
Technology	<ul style="list-style-type: none"> Simple calculation method Ease of performing mass balance Minimising the impact of measurement errors 	<ul style="list-style-type: none"> Only looks at energy content of feedstock inputs and does not reflect what happens in the processing unit. Could slightly overstate 	 <p>Monitoring energy contents of inputs and outputs should not be challenging</p>

Criteria	Advantages	Disadvantages	Scoring
		<p>the renewable content as biogenic feedstocks produce more CO and CO₂ in processing than the fossil equivalent</p>	

4.4 ¹⁴C analysis

The fraction of biogenic components within co-processed fuels can also be determined by measuring their ¹⁴C activity. Analysis of ¹⁴C (also referred to as carbon dating or radiocarbon analysis) is an established approach to determine the age of artefacts based on the rate of decay of the isotope ¹⁴C, as compared to ¹²C. It can be used to determine the physical percentage fraction of biogenic materials in bio/fossil mixtures because biogenic material is much younger than fossil material and so the types of material contain very different ratios of ¹⁴C:¹²C. While the biogenic component reflects the modern atmospheric ¹⁴C activity, no ¹⁴C is present in fossil fuels (oil, coal). Therefore, the biogenic fraction of any material of interest is proportional to its ¹⁴C content. Samples of *finished fuels* can be analysed post-reaction to determine the amount of biogenic-sourced carbon in the fuel. This approach would work equally for co-processed fuels or fuels produced from mixed feedstocks. (Note that there is not necessarily any need to test input materials when using this approach as the actual physical renewability of the finished fuel is being directly measured.)

Several established techniques can be applied for ¹⁴C activity measurement. Radiometric measurement techniques are based on counting ¹⁴C decay rate by gas proportional counters (GPC) or liquid scintillation counters (LSC), while the accelerator mass spectrometry (AMS) technique directly counts the number of ¹²C, ¹³C and ¹⁴C atoms. GPC is not commercially available nor very sensitive, thus, has been replaced by either LSC or AMS. It will not be detailed further in this report.

1. Liquid Scintillation Counters (LSC)¹⁵

Radiometric dating measures the radiation produced from the decay of ¹⁴C. Within LSC, three main sub-methods exist: 1) LSC-benzene, 2) LSC-CO₂, and 3) LSC-direct. LSC-benzene is the most accurate sub-method, but involves a complex and time-consuming sample preparation due to the required benzene synthesis. As such, it is also correspondingly the most expensive LSC sub-method. LSC-CO₂ is quicker, but less accurate. LSC-direct is a relatively simple technique based on shining light through a material which does not require any sample preparation procedure. Unlike the other two sub-methods LSC-direct only works for liquid fuels. Also, the level of accuracy is lower compared to the other techniques, especially when detecting very low percentages of biogenic material. For fuels having less than 2% bio-content the accuracy drops. The 95% confidence error at 5% biogenic feedstock is only 0.17% and at 50% biogenic feedstock it is 0.6%. The main drawback associated with this method is the variable quenching¹⁶ due to different colours of liquids. Coloured liquids decrease the sensitivity because some of the light is absorbed. (Oils produced from common feedstocks such as rape seed, sunflower, soybean or animal fat, are typically varying intensities of yellow in colour.) An advanced counter can be used to compensate for this automatically – but may be slightly less accurate. LSC-direct is most appropriate for fuels such as petrol or diesel, but does not work for heavier fractions (e.g. bitumen) or solid feedstocks such as MSW.

¹⁵ Krajcar Bronić. I. et al. (2017).

¹⁶ Quenching is the loss of counts due to sample characteristics.

2. Accelerated Mass Spectrometry (AMS)

AMS counts the atoms of ^{14}C and ^{12}C in a given sample, determining the ^{14}C to ^{12}C ratio directly. The main advantages of the AMS technique are the smaller sample size needed than for the radiometric techniques (as little as several mg of a sample, depending on the type of a sample) and higher precision. However, the AMS analysis is more expensive, so not all laboratories are likely to be able to purchase the AMS machine. In the application of bio-based product analysis, sample size is not typically a limiting factor, but samples frequently exhibit heterogenic compositions. There is extensive instrumentation involved as well as complicated chemistry in the preparation of samples before measurement.

The physical measurement of fuel could be interesting especially for economic operators in cases where the biogenic material is not physically proportionately allocated to outputs. For example, in the pyrolysis of tyres, it can be shown that the biogenic component goes preferentially to the pyrolysis oil and the fossil component goes preferentially to the carbon black output. In such cases, companies may favour an approach whereby they can measure and report the physical biogenic content of the output fuels.

MRV considerations

The ^{14}C measurement would be conducted on finished fuels. The measurement would have to be taken for a representative physical sample of the finished fuel, such as from a full storage tank. Note unlike the other administrative methods, this is a physical measurement, so would have to be taken for a physical sample and cannot be calculated over a period of time.

The measurement would need to be repeated if the co-processing conditions change (e.g. different bio-based inputs or different shares of inputs, or potentially different reaction conditions such as different temperatures). This means, that regular measurements of all storage tanks would not necessarily be required if the feedstocks and reaction conditions remained the same. Potentially therefore in the medium term, for some facilities, a series of measurements could be taken initially to prove the biogenic content of the outputs and the same biogenic output could be assumed on an ongoing basis. However, further periodic testing is likely to always be needed and further investigation is needed in the short term to understand the relationships between inputs and outputs with different feedstocks and reaction conditions. For a company who regularly changes the bio-based inputs and/or reaction conditions, regular ^{14}C analysis would likely have to be done on an ongoing basis. This could, for example, be done on a batch-by-batch or storage tank basis.

Physical sampling of fuel is already required for the purposes of certifying fuel quality. Making the equipment and facilities available for ^{14}C testing to be done alongside this physical testing, could minimise the additional efforts needed to use this approach.

Advantages and Disadvantages

Criteria	Advantages	Disadvantages	Scoring
Costs	<ul style="list-style-type: none"> Upfront investment in equipment & training for in-house LSC analysis reasonable in the context of an overall refinery (~100,000€¹⁷) 	<ul style="list-style-type: none"> Analysis unlikely to be feasible in-house for smaller installations Estimated 500 - 1,000€ per external LSC analysis Other ¹⁴C methods more expensive and unlikely to be feasible in-house 	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>LSC not expensive in the context of a refinery, although could be for smaller installation processing mixed feedstocks</p> <p>AMS is more expensive and time consuming</p> </div> </div>
MRV	<ul style="list-style-type: none"> Established methodology recognised by ASTM D6866¹⁸ and CEN/TS 16640¹⁹ standards Method based on accurate physical measurement In-house analysis possible: results after 10 hours Could be conducted alongside existing physical testing for fuel quality standards 	<ul style="list-style-type: none"> External analysis: Receiving results can take several weeks 	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>Batch by batch or storage tank level. Can't do over time period because physical measurement</p> <p>Harder if feedstock changes, ok if doing once to prove that bio ends up preferentially in one product over another</p> </div> </div>
Technology	<ul style="list-style-type: none"> All techniques suitable for high bio-concentrations Post reaction analysis allows for exact determination of the physical biogenic fraction Routine analysis by using LSC method 	<ul style="list-style-type: none"> LSC not accurate in low concentrations (below 1-2%) LSC works best for clear liquids such as petrol or diesel. Further calibration is required if used for non-clear liquids If LSC is not suitable, other techniques are 	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> ○ ● ○ </div> <div> <p>LSC is viable and accessible. If it is not suitable, other techniques are more expensive and time consuming and not always available</p> </div> </div>

¹⁷ Neste Oil, November 2017, personal communication

¹⁸ ASTM international. (2016). D6866 - 16 - Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.

¹⁹ CEN/TS 16640. (2017). Bio-based products - Determination of the bio based carbon content of products using the radiocarbon method.

Criteria	Advantages	Disadvantages	Scoring
	(analysis duration 10 hours)	more expensive and time consuming. Not all member states have testing laboratories capable of performing ¹⁴ C analysis ²⁰	

²⁰ Rogowska D. 15. November 2017. Interview

5 Discussion

- Several methods have been identified to determine the renewable share of the outputs from co-processing or processing of feedstocks that are a mixture of biogenic and fossil origin material. The mass balance and energy content methods offer an **administrative** way to report the renewable share of outputs and ensure that the renewable share can be reported robustly and verifiably on a consistent basis. The ¹⁴C method offers the possibility to measure the **actual physical biogenic content** of the outputs.
- Note that the aim is not necessarily to report the actual physical content of the fuel(s), rather to ensure that the biogenic fuel reported is based on a robust methodology that can be transparently and consistently applied and verified. Being able to report the physical bioenergy content will be favourable for some specific applications and less favourable for others. There are examples of processes where it can be shown that the biogenic content does physically end up preferentially in one type of output over another.
- Also note that the methodologies described do not concern how sustainability characteristics for different biogenic feedstocks are allocated to outputs. There are conceptual parallels, but this is a separate question. Sustainability characteristics should be allocated following the mass balance rules detailed in Article 18(1) of the RED and Communication (2010/C) 160/01. Any system to apportion renewability needs to work alongside the mass balance system to allocate sustainability characteristics so that sustainability characteristics are allocated transparently and robustly to the renewable portion of the outputs.
- The administrative methods identified to determine the renewable share of outputs are based on either the **mass balance** or **energy content** of inputs and outputs. The physical measurement method identified is based on measuring the **ratio of ¹²C to ¹⁴C isotopes** of carbon in the outputs. Other physical measurement methods may become available in the future but none were identified at this point.
 - The **mass balance approach** has three possible variations. It is based on the conservation of mass principle, whereby the total mass of inputs equals the total mass of outputs. One variant (Observed yields) compares the mass of outputs in a baseline scenario with 100% fossil to the mass of outputs with a percentage of biogenic input to calculate a yield factor that can be applied. The other two variants (Carbon mass balance and Total mass balance) take a similar approach but also take into account gases (CO and CO₂) and in the case of Total, also H₂O produced in the process.
 - This methodology can work, just requiring measurement of the mass of inputs and outputs which in most cases will be known. However, the calculation can become quite complex, which can increase the risk of error when calculating or verifying.
 - The methodology can be done for the total mass of inputs and outputs and the same share of biogenic material would be allocated to each output. Alternatively, the calculation could be done for all the individual hydrocarbon outputs. This is a more complex calculation and could mean that the bio-share allocation to each product is different, but this may better reflect the physical content of the outputs. This calculation approach could therefore benefit specific installations.
 - There is an outstanding question how sensitive this calculated yield factor would be to different feedstock inputs and whether the factor would be linear as the percentage of biogenic content changes, and therefore how often it would need to be calculated. This may be different for different processes and has an influence on the practicality of the approach for certain applications.
 - All three mass balance approaches are considered possible, but it is not clear what the benefits of the carbon or total mass balances approaches would be over the simpler observed yield approach.
 - The **energy content approach** calculates the biogenic energy content share (LHV basis) of the inputs and applies this percentage equally to all outputs of the process.

- This methodology is relatively simple and aligns well with several elements of the RED (targets and GHG calculations) which are also calculated on an energy content basis. The calculation requires knowledge of the energy content of the component inputs and outputs of the process, which fuel companies would know.
 - The Yield factor can be calculated for physical batches or storage tanks or over a defined period of time.
 - A potential issue with this approach is that it looks at the energy content of feedstock *inputs* to a process and does not therefore reflect what actually happens in the processing unit. For some processes, this may lead to a result that is less close to the physical fuel content than the mass balance approach. In particular, as compared to fossil feedstocks, biogenic feedstocks produce CO and CO₂ during co-processing owing to their high oxygen content. Therefore, not all of the input renewable carbon ends up in the finished fuel, which could mean that the renewability of the finished fuel is slightly overstated using this approach.
- **¹⁴C analysis** provides an accurate determination of the physical biogenic content of the output fuel. Because biogenic content is so much younger than fossil content, the relatively simple techniques can be used to measure the biogenic content. The equipment can be purchased to enable in-house testing, which can be a viable option, especially in the context of a large refinery which would also have the in-house skills for such analysis. Physical sampling of fuel is already required for the purposes of certifying fuel quality, so aligning ¹⁴C testing with this process could minimise the additional efforts required. However, results of the ¹⁴C analysis can still take several weeks and the simpler liquid scintillation counter (LSC) testing approach has lower accuracy than other ¹⁴C techniques, meaning it may be unsuitable for very low biogenic blends. It is also best suited for testing clear liquids, such as petrol/diesel, but therefore less suitable for heavier fractions or feedstocks such as MSW. Importantly, not all Member States currently have external laboratories with the capability to perform ¹⁴C analysis.
- Both administrative approaches appear to be viable, although the different approaches can lead to differences in the result. The impact will depend on the specific process, so different approaches may be favoured by different economic operators. The mass balance approach could be used to allocate the renewable share proportionately to calculate a yield factor for each type of outputs. The energy content approach allocates the renewable share proportionately to all outputs. For co-processing, this broadly reflects the actual situation and is transparent and defensible to stakeholders.
- However, for some processes this may not reflect the physical content of the output. For example, in the pyrolysis of tyres, it can be shown that the biogenic component goes preferentially to the pyrolysis oil and the fossil component goes preferentially to the carbon black output. In such cases, companies may favour an approach whereby they can measure the physical biogenic content of the output fuels.
- Note that there is a fundamental difference between administratively allocating renewability to outputs and physically measuring the renewability of outputs. In a mass balance approach – as permitted by Article 18(1) of the RED – the characteristics of the physical fuel would, by definition, not necessarily match the characteristics that are recorded administratively *for an individual sample*. Care should therefore be taken if the two types of approach are used in combination. However, at a refinery site, there should not be a large discrepancy between the administrative and physical measurement approaches because refineries will – in general – take in single feedstock virgin or waste materials that are both administratively and physically 100% renewable, and co-process those with fossil fuels to produce a finished fuel. Co-processing refineries today will generally buy in single feedstock oils, so there is a low likelihood of mixing upstream. Further fuel blending downstream (before the excise duty point) is also unlikely as in most cases, the excise duty point will be at the refinery because they produce finished fuels ready for the market. However, if any of these conditions are not the case in a particular situation, then there could be a discrepancy between reporting renewability based on an administrative approach and a physical measurement approach. If physical (¹⁴C) measurement was required for co-processed fuels – and only for co-processed fuels – then this would mean that co-processed biofuels could not be mixed with other fuels downstream from the refinery (and before the excise duty point) as such mixing would alter the renewable energy content.

- From the perspective of the current legislation, the FQD is only in place until 2020 and the REDII is under negotiation, so the rules on co-processing could in theory be changed. Nevertheless, reflecting on the principles included in the existing documents is useful (see end of section 3). Only the energy content method really considers the energy content and efficiency of the process (as described in the first principle), but all options comply with the other principles and we would consider all options to be in line with the intended "spirit" of the EC guidance.
- It seems reasonable to allow the renewability to be allocated proportionally across all output products and this can be done with the mass balance and energy content approaches. The ¹⁴C method allows facilities to report the actual physical content of their fuel. This will be favourable for some facilities and less favourable for others. If the simpler ¹⁴C approaches can be implemented at a reasonable cost and integrated efficiently into, for example, the existing physical sampling regime for finished fuels, this could become a viable option for all fuels, especially from larger installations such as refineries. If a company can physically demonstrate that their process leads to a different allocation than the administrative approaches would result in, then they would have a clear interest in reporting based on the physical content of the fuel and it would seem justifiable to permit this approach. For example, a physical measurement approach could be used to inform or verify the actual physical outputs of a particular process, so a more appropriate "conversion factor" could be used in one of the administrative approaches, e.g. to inform which outputs the biogenic material actually ends up in. However, allowing companies a free choice in which approach to use to allocate renewability would allow "cherry picking", so further guidance on when to use which method is advised.
- Beyond these methodologies, the flexibility to allocate renewability across different outputs is largely a political choice.
 - Allowing complete flexibility contravenes the proposed REDII text and is seen as unacceptable by some stakeholders because this would clearly allow companies to preferentially allocate renewable material into the markets where they can get the highest value (i.e. road or air transport fuel markets). However, some refinery operators we spoke to indicated that they would value this flexibility because it would enable them to maximise the value of processing biogenic material as they could allocate all the biogenic material into products where that is valued most, i.e. transport fuel, as opposed to e.g. carbon black or heavier refining fractions such as bitumen. These parties argue that such flexibility would make the market more attractive and so would stimulate processing of biogenic material.
 - A compromise position could be to allow the flexibility to allocate renewability *within* products. This is an approach apparently permitted in the UK DfT guidance (the guidance does not explicitly disallow this and personal communication confirmed that this level of flexibility is allowed in the UK). This means that the same renewable share has to be allocated to all products of the process (e.g. kerosene, petrol, diesel etc) but within a product, the company can flexibly allocate the renewable portion. So, for example, some diesel can be sold to company A with 100% biogenic and some to company B as 0% biogenic, as long as overall diesel output has the same bio-share as the other outputs. DfT do not allow allocation across fuel types (as described in the previous bullet point) as it would allow refineries to shift the renewability to fuels which receive higher incentives.
- MRV considerations:
 - For the purposes of verification, any economic operator undertaking co-processing should define and document a consistent fuel, measurement and sampling approach. The complexity will depend on the process and how often feedstock types and biogenic feedstock shares are expected to change.
 - In line with the RED sustainability criteria, it would be logical to incorporate verification of the renewable share of output fuel into the (normally) annual sustainability verification cycle.
 - Refineries can be very complex and defining the system boundary for the mass balance is a crucial step to ensure the approach is transparent, replicable and therefore verifiable, and that the calculations can be undertaken in a practical way.

- For the mass balance approach, the calculations are based on *baseline and comparison inputs and outputs* could be done for a specific unit in the refinery, or for a defined volume of fuel such as a storage tank, or over a defined period of time (e.g. a day, week, month or 3-month period).
- For the energy content approach, the bio-yield calculation is based on *inputs only* and would logically be done over a defined period of time.
- The ¹⁴C method would be conducted on *finished fuels*. The measurement would have to be taken for a representative physical sample of the finished fuel and could perhaps be best aligned with the current physical sampling for fuel quality standards. Measurements are likely to need to be conducted on a tank-by-tank basis. Note unlike the other administrative methods, it is a physical measurement, so would have to be taken for a physical sample and cannot be calculated over a period of time.
- In contrast to the administrative approaches, the ¹⁴C approach measures the outputs only. Therefore, there could be a discrepancy between the measured outputs of a process with the input material (from an administrative perspective) if the upstream supply chain has involved mixing of different feedstock streams and has used a mass balance approach to the chain of custody which means that the physical inputs differ from the administrative inputs. However, as explained above, refineries today will generally buy in single feedstock oils, which would be 100% renewable material, and fossil oils, which are 100% fossil, so the renewable share going into the refinery should be the same both physically and administratively. As with any processing facility, an appropriate conversion factor would need to be applied when allocating sustainability characteristics to the outputs to reflect any losses in the processing step. Further fuel blending downstream (before the excise duty point) is considered unlikely as in most cases, the excise duty point will be at the refinery because they produce finished fuels.

Annex: Stakeholders consulted

The project team would like to thank the following people for their insights:

- Tom Reid, UK Department for Transport
- Thomas Weber, Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit / Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
- Anil Baral, California Air Resources Board
- Anil Prabhu, California Air Resources Board
- Andreas Feige, ISCC
- Delfina Rogowska, KZR INiG System
- Sari Kuusisto, Neste Oyi
- Timo Haatainen, Neste Oyi
- Seppo Loikkanen, Neste Oyi
- Linda Werner, Preem AB
- Sören Erkisson, Preem AB
- Eva Lind Grennfelt, Preem AB

References

37. Bundesimmissionsschutzverordnung (2017): Verordnung zur Anrechnung von strombasierten Kraftstoffen und mitverarbeiteten biogenen Ölen auf die Treibhausgasquote / Ordinance on the on the allocation of electricity-based fuels and co-processed biogenic oils to the greenhouse gas quota

COM. (2017). Biofuels. <https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels>

COM(2016)0767 Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast) – “REDII” <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29>

California Air Resources Board. (2017). 2018 LCFS Preliminary Draft Regulatory Amendment Text. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/110617presentation.pdf

California Air Resources Board. (2017). Co-processing of low carbon feedstocks in petroleum refineries – Draft discussion paper. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/053017draft_discussion_paper_coprocessing.pdf

California Air Resources Board. (2017). Draft Guidance - Low Carbon Fuel Standard (LCFS) Guidance 17-03. https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/10162017_guidance.pdf

Department for Transport. (2017). RTFO guidance part 1: process guidance year 10. Section 2.11 – 2.19. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604591/rtfo-guidance-part-1-process-guidance-year-10.pdf

Deutsche Industrie Norm (German Standard) 51637 (2014). Liquid petroleum products – Determination of the bio-based hydrocarbon content in diesel fuels and middle distillates using liquid scintillation method

Directive (EU)2015/652, Annex I Method for the calculation and reporting of the life cycle GHG intensity of fuels and energy by suppliers, Part 1, paragraph 3(c)(ii) - “FQD Implementing Directive“ <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0652&from=EN>

Eurostat. (2017). *Renewable energy statistics*. http://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics

ISCC. (2016). ISCC 203-01 Guidance for the certification of co-processing. https://www.iscc-system.org/wp-content/uploads/2017/02/ISCC-Guidance-Document-203-01_Co-processing-requirements.pdf

Krajcar Bronić. I. et al. (2017). Determination of biogenic component in liquid fuels by the 14C direct LSC method by using quenching properties of modern liquids for calibration, Radiation Physics and Chemistry 137, pages 248-253

KZR. (2017). Guidelines for the determination of the lifecycle per unit values of GHG emissions for biofuels, Section 3rd issue. http://www.kzr.inig.eu/file/repository/System_KZR_INIG_8_ver_3_EN_04052017.pdf

