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Renewables Obligation: Biodiesel and Fossil Derived Bioliquids guidance

Guidance

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Overview:

This document provides generating stations using fossil derived bioliquids with guidance on the legislative requirements of the Renewables Obligation (RO). It is an updated version of the guidance published in April 2011.

Context

The Government's aim is that renewable energy will make an increasing contribution to energy supplies in the UK, with renewable energy playing a key role in the wider Climate Change Programme.

The Renewables Obligation (RO), the Renewables Obligation (Scotland) (ROS) and the Northern Ireland Renewables Obligation (NIRO) are designed to incentivise renewable generation into the electricity generation market. These schemes were introduced by the then Department of Trade and Industry (now the Department of Energy and Climate Change), the Scottish Executive and the Department of Enterprise, Trade and Investment respectively and are administered by the Gas and Electricity Markets Authority (the Authority), whose day-to-day functions are performed by Ofgem. The schemes are provided for in secondary legislation.

The first Renewables Obligation Order came into force in April 2002, as did the first Renewables Obligation (Scotland) Order. The first Renewables Obligation Order (Northern Ireland) came into force in April 2005. All three Orders have been subject to regular review. The Orders place an obligation on licensed electricity suppliers in England and Wales, Scotland, and Northern Ireland respectively to source an increasing proportion of electricity from renewable sources. Suppliers meet their obligations by presenting sufficient Renewables Obligation Certificates (ROCs) to cover their obligations. Where suppliers do not have sufficient ROCs to meet their obligation, they must pay an equivalent amount into a fund, the proceeds of which are paid back on a pro-rata basis to those suppliers that have presented ROCs.

The EU introduced in 2009 a comprehensive and binding sustainability scheme. Under the European Renewable Energy Directive (RED), operators using bioliquids must meet specified sustainability criteria to be eligible for incentive schemes from national governments. The Department for Energy and Climate Change (DECC) transposed the requirements of the RED in the Renewables Obligation (Amendment) Order 2011 for England and Wales.

This guidance has been produced in light of the eligibility of Fossil Derived Bioliquids under the Renewables Obligation. As ROCs are only issued for the biomass content of any fuel used, it will be necessary for generating stations using such fuels to determine the proportion of the fuel that has come from biomass.

Associated documents

Readers should be aware of the following documents which support this publication. These documents are available on our website at www.ofgem.gov.uk/ro:

- Renewables Obligation: Fuel Measurement and Sampling guidance 2013
- Fuel Measurement and Sampling questionnaires
- Renewables Obligation: Guidance for Generators 2013
- Renewables Obligation: Sustainability criteria for bioliquids guidance

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Executive Summary

This document provides guidance to generating stations using fossil derived biodiesel and other fossil derived bioliquids (FDBLs) that wish to benefit from the Renewables Obligation (RO). It sets out the definition of a FDBL and the 2013 amendments to the Renewables Obligation Order 2009 (as amended in 2013), the Renewables Obligation (Scotland) Order 2009 (as amended in 2013) and the Renewables Obligation Order (Northern Ireland) 2009 (as amended in 2013) (the Orders). This document also outlines the level of support available for the use of such FDBLs and an example methodology of how generating stations could calculate the fossil fuel component of fossil derived biodiesel each month.

Ofgem[1], as the administrator of the RO, agrees the method generating stations use to determine the fossil fuel content of the fuel used through the submission and approval of Fuel Measurement and Sampling (FMS) procedures. The example methodology given in this guidance document relates to biodiesel produced using fossil derived methanol, as this is expected to be the most commonly used FBDL.

FDBLs include biodiesel produced using fossil derived methanol but do not include biodiesel produced using non-fossil derived alcohols e.g. bioethanol.Generating stations using other FDBLs e.g. hydrotreated vegetable oils, can put forward proposals for determining the fossil fuel content to Ofgem (as can generating stations using biodiesel who wish to use a different methodology than that outlined in chapter 4). This will be considered on a case by case basis. Uncontaminated vegetable oils or other bioliquids that use no fossil fuel in their production are not covered by this guidance document. This includes biodiesel produced using bioethanol. For further information on FMS procedures please refer to the Renewables Obligation: Fuel Measurement and Sampling (FMS) guidance document.

This document relates to generation which occurs on or after 1 April 2013 (or 1 May 2013 under the NIRO). The document does not profess to anticipate every scenario which may arise. Where a scenario arises which is not addressed in these procedures, we will adopt an approach consistent with the relevant legislation. Any separate guidance published in addition to this document will be available from our website. This is a guidance document only. It is not intended to provide comprehensive legal advice on how the Orders should be interpreted.

[1] Ofgem is the Office of the Gas and Electricity Markets Authority.

1. Introduction

Chapter Summary

Explanation of why we have produced this guidance and how it fits with other RO guidance documents produced by Ofgem.

1.1. This guidance explains how biodiesel generating stations can determine the fossil fuel and renewable content of biodiesel and other Fossil Derived Bioliquids.

1.2. This guidance applies to England & Wales, Scotland and Northern Ireland. Unless apparent from the context, where used in this document, the term "RO" refers to the Renewables Obligation, the Renewables Obligation (Scotland) and the Northern Ireland Renewables Obligation. Similarly, the term "the Orders" is used to describe the Renewables Obligation Order 2009 (as amended in 2010, 2011 and 2013), The Renewables Obligation Order (Scotland) 2009 (as amended in 2010, 2011 and 2013) and The Renewables Obligation Order (Northern Ireland) 2009 (as amended in 2010, 2011 and 2013). The term "ROCs" refers to Renewable Obligation Certificates (ROCs), Scottish Renewables Obligation Certificates (SROCs) and Northern Ireland Renewable Obligation Certificates (NIROCs). The use of 'Ofgem', 'us', 'our' and 'we' are used interchangeably when referring to the exercise of the Authority's powers and functions under the Orders. The "Authority" is the Gas and Electricity Markets Authority.

1.3. The term "the Act" refers to the Electricity Act 1989. This is the primary legislation from which the RO and ROS were borne. Subsequent changes made via the Energy Act 2008 have given the Government the enabling powers to introduce the differential rewards that have fundamentally changed the ROC reward structure. The 2011 amendment to the Renewables Obligation Order 2009 introduces FDBLs as eligible for ROCs.

The nature of the legislation

1.4. Some areas of the legislation are prescriptive, others give us discretion. Where the legislation is prescriptive, this guidance is intended to help generating stations understand what we require. Where the legislation gives us discretion, the document gives guidance as to how we will generally exercise that discretion. It also explains what we need, practically, from generating stations, to enable them to meet these requirements.

Our role under the Renewables Obligation

1.5. Where the RO Order and the ROS Order detail Ofgem's powers and functions in respect of the Renewables Obligation in England and Wales and in Scotland respectively. Those functions include:

- Accrediting generating stations as being capable of generating electricity from eligible renewable energy sources.
- Issuing Renewable Obligation Certificates (ROCs) and Scottish Renewable Obligation Certificates (SROCs).
- Establishing and maintaining a register of ROCs and SROCs.
- Revoking ROCs and SROCs where necessary.
- Monitoring compliance with the requirements of the Orders.
- Calculating annually the buy-out price resulting from adjustments made to reflect changes in the RPI.
- Receiving buy-out payments and redistributing the buy-out fund.
- Receiving late payments and redistributing the late payment fund.
- Publishing an annual report on the operation of and compliance with the requirements of the Orders.
- Forwarding to the Secretary of State a summary of the sustainability information submitted during each obligation period.

1.6. We cannot act beyond the scope of the powers laid down in the Orders. For example, we have no remit over the operation or regulation of the ROC market itself. Amendments to the relevant legislation in respect of the Renewables Obligation are a matter for the Secretary of State, Scottish Ministers and the Secretary of State for Northern Ireland.

1.7. By virtue of section 121 of the Energy Act 2004, the Authority and the Utility Regulator Northern Ireland (UREGNI) can enter into an arrangement for the Authority to act on behalf of UREGNI in respect of the NIRO. This arrangement is facilitated by an Agency Services Agreement (ASA) with UREGNI. Under this agreement, Ofgem is required to carry out the administrative process relevant in respect of the functions listed above on behalf of UREGNI. However, UREGNI retains the statutory responsibility for administering the NIRO.

The purpose of this guidance document

1.8. To determine the number of ROCs a generating station is eligible for on a monthly basis, fuelled generating stations need to distinguish between the amount of biomass and the amount of fossil fuel used to generate electricity. These amounts have to be expressed as energy contributions, based on GCV. We agree how generating stations will calculate the biomass and fossil fuel content through the approval of a generating station’s fuel measurement and sampling procedures.

1.9. Our FMS guidance sets out the eligibility for different biomass related fuels under the RO and examples of how generating stations using such fuels could demonstrate the biomass to fossil fuel content on a monthly basis.

1.10. FDBLs are specifically defined within the RO. The most common of these fuels is expected to be biodiesel. Fossil derived energy is an integral part of the combustion of FDBLs due to the process involved in their production. The contribution to overall energy content of this fossil derived energy must be calculated as this is not eligible for certificate issue. It can however, be complex to determine this fossil derived contribution to the overall energy content.

1.11. This guidance is intended to be read alongside the FMS guidance. It focuses specifically on FDBLs and sets out:

- What is classified as a FDBL (section 2.7);
- The number of ROCs FDBLs are eligible for (section 2.13); and
- An example methodology that generating stations using biodiesel may use to form the basis of their FMS procedure (chapter 4).

1.12. The purpose of this document is to focus on the FMS procedures for FDBL fuels. Operators of generating stations using such fuels will also be required to meet other RO requirements. For example, the sustainability criteria set out in the EU Renewable Energy Directive (RED). Guidance on these criteria and how to demonstrate that they have been met is given in our Renewables Obligation: Sustainability Criteria for Bioliquids guidance. More general guidance on the eligibility of a generating station is provided in our Renewables Obligation: Guidance for generators document.

1.13. This is a guidance document only. The onus lies with the operator of a generating station to ensure that it is aware of the requirements of the Orders. It is not intended to provide comprehensive advice on how the Orders should be interpreted.

Terminology

1.14. When discussing the different components of biodiesel the terminology can become confusing. To differentiate between the various elements, we have used the following terms:

- Biodiesel – includes all elements of the biodiesel fuel used in generating electricity.
- Fatty Acid Methyl Ester (FAME) mixture – includes all FAME compounds present in the biodiesel. This only applies only to biodiesel produced using methanol.
- FAME compound – refers to a FAME which includes a particular FAD e.g. 14:0.
- Fatty Acid Derivative (FAD) – refers to the fatty acid part of the FAME i.e. the biomass part of it.
- Methoxy group – refers to the part of the FAME derived from methanol i.e. the fossil fuel element where fossil fuel derived methanol has been used in the production process.

Queries

1.15. All queries in relation to our functions under the Orders should be emailed to renewable@ofgem.gov.uk. Written queries should be sent to the address on the front of this document clearly marked for the attention of the Renewables and CHP Administrator.

1.16. Any queries regarding future changes to the renewables obligation for England and Wales and wider policy should be directed to the Department for Energy and Climate Change (DECC). Contact details can be found at www.decc.goc.uk. For the ROS and NIRO, contact details can be found at www.scotland.gov.uk and www.detini.gov.uk.

2. Eligibility

Chapter Summary

Provides background to the introduction of eligibility for FDBLs and a summary of the RO provisions.

Background

2.1. Under the Renewables Obligation, generating stations can claim ROCs for eligible renewable generation. In the case of FDBLs, since April 2011, this has included the non-fossil fuel content of these bioliquids. However, these were not eligible before this date.

2.2. In 2008, it was identified that one of the reagents used to produce biodiesel, methanol, was frequently obtained from the methane within natural gas (a fossil fuel). The use of methanol directly produced from natural gas implied that these fuels could be seen as being indirectly derived from a fossil fuel.

2.3. After obtaining independent expert technical advice on the manufacturing process used to create these fuels, we undertook consultation in September 2008. Our conclusion from the consultation was that the presence of this fossil fuel in the biodiesel manufacturing process meant that it was a fossil fuel as defined in the RO Order 2006 (amended), which was effective at the time. As the whole fuel was considered a fossil fuel, it was not possible to claim ROCs for any part of the biodiesel. This meant if biodiesel and other FDBLs were to be eligible for ROCs, a change to the legislation was necessary.

The introduction of FDBLs into the RO

2.4. In June 2008 the EU RED was published. It contains requirements to be fulfilled by each EU Member State in relation to renewable energy, including the 2020 renewable energy targets. In particular, there are a number of sustainability requirements relating to the use of biofuels and bioliquids, which refer specifically to their treatment under Member State support schemes. In the UK this includes the RO.

2.5. Transposition of these requirements into the RO resulted in the following:

- To be eligible for support any energy produced from a bioliquid must meet the sustainability criteria laid out in the RO; and
- Any bioliquid that meets the sustainability criteria cannot be excluded from support on sustainability grounds.

2.6. The second of these changes meant that bioliquids manufactured from chemicals of fossil fuel origin, e.g. biodiesel, must be eligible for support under the RO, unless there are reasons for excluding it unrelated to sustainability. As a result, the UK Government introduced eligibility for FDBLs into the RO in April 2011.

2.7. A FDBL is defined in the RO Order 2011 as follows:

- Bioliquid produced directly or indirectly from –
- (a) coal,
- (b) lignite,
- (c) natural gas (within the meaning of the Energy Act 1976 (a)),
- (d) crude liquid petroleum, or
- (e) petroleum products (within the meaning of the Energy Act 1976);

2.8. The fossil fuel used in the production process can either be purely fossil fuel e.g. natural gas or a product derived originally from fossil fuel e.g. methanol. The legislation provides no minimum requirement for the proportion of the FDBL that comes from renewable sources.

2.9. Table 1 below provides a list of examples of FDBLs.

Table 1: Examples of bioliquids used for electricity generation

Fuel	**FDBL?**	**Fossil element used in production process**
Biodiesel produced using fossil derived methanol	Yes	Methanol
Hydrotreated Vegetable Oil	Yes	Hydrogen
Glycerol	Possibly*	Methanol
Renewable diesel via Fischer-Tropsch synthesis	Yes	Hydrogen
Renewable diesel produced from Pyrolysis oil using the hydrodeoxyggenation process	Yes	Hydrogen

**In the case of glycerol it will be determined on a case by case basis whether it is fossil fuel derived.*

2.10. Bioliquids that do not include fossil fuel in the production process (e.g. uncontaminated vegetable oils or biodiesel produced using bioethanol) are not classified as FDBLs. For guidance on these materials and associated fuel measurement and sampling procedures, please refer to our FMS guidance.

2.11. Schedule 2 of the RO Order sets out the number of ROCs that should be awarded on generation by various fuelled and non-fuelled technologies. The legislation also states[2] that electricity generated in a way which is not described in Schedule 2 should realise 1 ROC per MWh. Upon its introduction into the Order in 2011, FDBLs were supported in accordance with Article 27(5), as none of the existing bands outlined in Schedule 2 provided support for FDBLs.

2.12. From 1 April 2013 (or 1 May under the NIRO) fuels which are fossil derived bioliquids (FDBLs) also meet the definition of biomass.[3] As such, from 1 April 2013 (or 1 May under the NIRO), generating stations using FDBLs are eligible to claim the same level of support as other bioliquids.

2.13. The level of support will be determined based on the fuel mix and technology within the month of generation.

2.14. The operator of the generating station will still need to determine to our satisfaction what proportion of the FDBL is derived from fossil fuel. Additionally, they must continue demonstrating that the FDBL meets the required sustainability criteria to be eligible for ROCs.

[3] The amended definition can be found in Article 4 of the Orders

3. Agreeing FMS procedures

Chapter Summary

Sets out further information on the fuel measurement and sampling (FMS) procedures. Generating stations using FDBLs must agree with Ofgem to claim ROCs under the Orders.

3.1. A FMS procedure is the general term we use to describe the agreed procedures for the measurement and sampling of fuels at each generating station. This is done to determine the amount of fuel used in a month, the energy content of the fuel and the level of any fossil fuel derived contamination present in compliance with the Orders. Whilst the term FMS procedure usually refers to the physical measurement and sampling processes, it may also refer to the provision of documentary evidence.

3.2. As with other fuels, generating stations using FDBLs will need to agree FMS procedures with Ofgem in advance of being accredited and issued with ROCs. As part of the process the generating stations will need to demonstrate to Ofgem's satisfaction how they will determine the proportion of the FDBL that is derived from fossil fuel.

3.3. An example methodology of how generating stations using biodiesel would be able to demonstrate the biomass proportion is given in Chapter 4. Generating stations using other FDBLs can put forward proposals for determining the fossil derived energy content to Ofgem. This process is also required for generating stations using biodiesel who wish to use a different methodology than that outlined in Chapter 4.

Fuel measurement and sampling

3.4. We can only issue ROCs for electricity generated from renewable sources in a given month. Articles 25 and 26 of the Orders set out how to calculate the amount of electricity generated from renewable sources, and in the case of a generating station fuelled partly by fossil fuel and/or waste and partly by another fuel or fuels, the amount of electricity generated from the fossil fuel fraction needs to be determined.

3.5. The amount of electricity is determined according to the energy content attributable to the fossil and non-fossil derived fraction of each of the fuels used in a particular month. It is due to this calculation that generating stations of fuelled stations need to propose and agree FMS procedures with us, describing how they will obtain the values required for the ROC calculations.

Accurate and reliable information

3.6. The operator of a generating station using FDBLs has an obligation under the Orders to ensure that the information provided to Ofgem which is relevant to the issuing of ROCs is accurate and reliable. We will work with the generating station as closely as possible to ensure that a procedure meets this requirement, but the onus for the design of suitable procedures ultimately lies with the operator.

A case-by-case approach

3.7. We recognise that no two generating stations are identical, and that different generating stations can use different combinations and volumes of fuels, drawn from different sources. For these reasons, our approach is always to agree FMS procedures on a case-by-case basis, according to the specific setup and conditions at each generating station.

The timeframe for agreeing FMS procedures

3.8. There is no set timeframe for the agreement of FMS procedures. Our aim is to agree procedures that will enable generating stations to meet the requirements of the legislation in respect of the fuel measurement, sampling and energy contents. . Given that the complexity of FMS procedures will vary greatly from one station to the next, we do not have set timeframes for the agreement of procedures, although clearly we aim to work closely with generating stations to make the process as efficient as possible.

The format of an FMS procedure

3.9. All procedures should be submitted using the appropriate FMS questionnaires. A range of questionnaires are available on our website[4]. Accompanying documentation can be provided alongside the FMS questionnaire if necessary. If the operator is unsure which questionnaire to complete they should contact the Renewables and CHP team on 0207 901 7310.

3.10. For more information on FMS, including general principles and their link to data submissions, please refer to our FMS guidance.

[4] http://www.ofgem.gov.uk/Sustainability/Environment/RenewablObl/FuelledStations/Pages/FS.aspx

4. Calculating the fossil fuel content of biodiesel

Chapter Summary

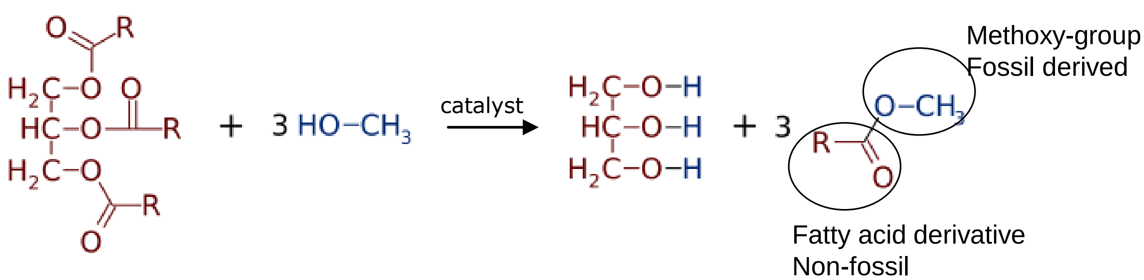
Sets out a methodology operators may wish to use to determine the fossil fuel and biomass energy content of biodiesel.

Background information

4.1. This chapter focuses on a methodology for determining the relative biomass and fossil fuel energy contents in biodiesel which is produced using fossil derived methanol. The use of fossil derived methanol in the production of biodiesel means that the fossil fuel and biomass aspects within the biodiesel are chemically bonded. Figure 1, below, shows the chemical reaction that occurs in the typical biodiesel manufacturing process.

Figure 1: The chemical reaction in the production of biodiesel.

Vegetable oil /Animal Fat | **Methanol** | **Glycerol** | **Fatty Acid Methyl Ester**



Key: The **brown** part of the FAME shown in the diagram comes from the vegetable oil or animal fat. The **blue** part comes from the fossil derived methanol. The R in the above diagram refers to hydrocarbon chains of varying lengths.

4.2. Vegetable oils or animal fats are reacted with methanol in the presence of catalysts to form glycerol and a Fatty Acid Methyl Ester (FAME). The FAME is the desired component of biodiesel and the glycerol is separated as a separate by-product.

4.3. This leads to four issues which make the energy contribution of biomass in biodiesel difficult to determine:

- The vegetable oil/animal fat component of the biodiesel (the fatty acid derivative) is chemically bonded to the methanol derived component (methoxy group). This means it is not possible to separately measure the energy content of the fossil fuel and biomass within the biodiesel.
- The length of the hydrocarbon chains within the vegetable oil or animal fat vary as they are not uniform substances. This means it is not possible to simply determine the fossil fuel content in one FAME compound and apply it to all FAME compounds in the biodiesel;
- There are two main products from the process, glycerol and FAME, both taking differing amounts of energy from the methanol and biomass. This means it is not easy to determine what proportion of the reactants end up in the mix of FAME compounds without considering the mix of fatty acid derivatives making up the FAME compounds; and
- There are residual elements within the biodiesel e.g. residual methanol as a result of the production process.

4.4. To address these challenges, we have put forward an example methodology for calculating the energy content of biodiesel attributable to fossil fuel that a generating station can use in their FMS procedures. This is based on determining the fatty acid derivatives within the biodiesel, the bond energies within the fatty acid derivatives and using standard GCVs to account for the residual elements in the biodiesel. Where this approach is utilised the operator is still required to detail the associated procedures to collect the necessary input data as part of their FMS documentation.

The example methodology

4.5. An example methodology is included in this guidance to provide operators with an indication (rather than a prescriptive guide) as to how the fossil fuel derived energy content of biodiesel can be calculated. It does not preclude operators from proposing alternative procedures to determine the fossil derived contribution to the energy content of biodiesel, to Ofgem for consideration.

4.6. We recognise that sampling can be costly, especially for smaller generating stations. However, we are only able to issue ROCs to electricity generated by renewable sources. As a result, we have adopted a two-tier approach to the example methodology. This enables operators to choose between two options:

4.7. Minimal Sampling (Option 1): This allows for minimal sampling information but uses conservative estimates of the renewable content based on the biodiesel quality standard EN14214:2008 and a default fatty acid composition. Conservative values which can be used are found in the appendices to this document.

4.8. Full Sampling (Option 2): Where full sampling is undertaken and the results of samples analysed are used to determine the renewable content. Where sampling and analysis are undertaken the details of this will have to be outlined to Ofgem in the form of FMS procedures. This is in order to demonstrate they will provide accurate and reliable results.

4.9. Much of the information required comes from fundamental thermodynamics and this is explained further in the appendices. Either conservative default values or figures obtained from sampling can be used for:

- The fatty acid derivative composition of the FAME mixture.
- The proportion of fossil derived residues.
- The proportion of FAME in the biodiesel.

4.10. Default values and sampling options for this information are provided in this document.

4.11. Option 1 requires less sampling than Option 2, as it relies on conservative default figures. Therefore, Option 1 could potentially result in a lower qualifying percentage than Option 2. Apart from using one of these options, operators can also propose to Ofgem an alternative methodology to accurately determine the biomass content of biodiesel. These will be reviewed for suitability on a case by case basis.

4.12. The information requirements under Options 1 and 2 are set out below. This is followed by a step by step explanation of the calculations to be undertaken, including a worked example.

Overview of the key steps of the example methodology

4.13. Figure 2, below, provides an overview of the calculation methodology. It identifies where information is required either as a result of sampling or default values, depending on the option chosen by the operator. The terminology used to refer to the different elements within biodiesel and calculations are explained in chapter 1.

Figure 2: An overview of the calculation and information requirements for determining the biomass contribution in fossil-derived biodiesel.

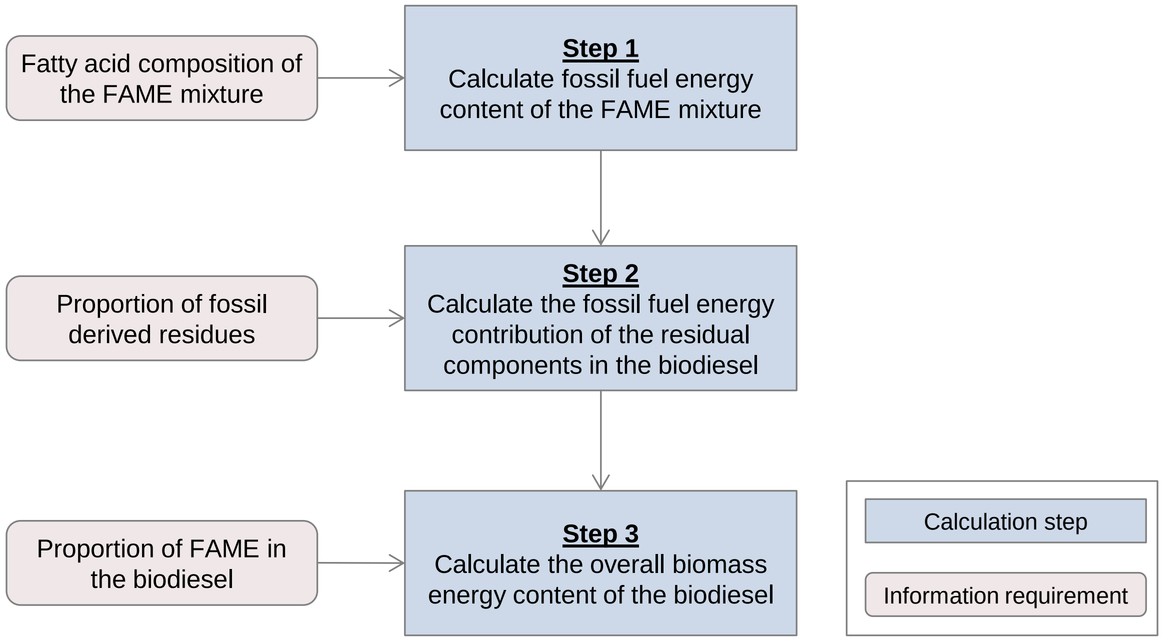


Table 2: Summary of sampling options

	Minimal sampling (Option 1)	**Full sampling (Option 2)**
Determining the fatty acid derivative (FAD) composition of the FAME mixture.	If the vegetable oil/animal fat used to make the biodiesel is known then the default values listed in Appendix 1, for the FAD composition of the biodiesel can be used. If the vegetable oil/animal fat is not listed in Appendix 1 a default value can be proposed to Ofgem based on appropriate evidence.	Direct measurement of the FAD composition of the biodiesel can be used e.g. using a mass spectrometer and gas chromatography. You will need to propose a procedure for how this is undertaken to Ofgem.
Calculating the proportion of fossil fuel derived residues.	If the fuel meets the EN14214:2008 standard then the maximum percentage proportion and standard energy contents of potential fossil fuel derived components can be used. These	The biodiesel used at the generating station during the month can be sampled for the breakdown of the FAME compounds comprising FAD. The standard energy contents (GCV values) for the

	are given in Appendix 4.	fossil fuel derived components given in Appendix 2 can then be used.
Calculating the proportion of FAME in biodiesel	If the fuel meets the EN14214:2008 standard then the minimum FAME content given in Appendix 4 can be used.	The biodiesel used at the generating station during the month can be sampled to determine the minimum FAME content.

4.14. Further information on both the minimal and full sampling approaches for each of these sampling and calculation steps is provided below.

Determining the Fatty Acid Derivative (FAD) composition of the FAME mixture

Option 1 - minimal sampling with conservative estimates

4.15. The FAD composition, also referred to as mass share, will generally vary within a range according to the vegetable oil or animal fat used to produce the biodiesel. Appendix 1 details conservative FAD compositions of palm oil, soybean, rapeseed, sunflower and tallow. If operators are using biodiesel from any of these feedstocks they can use these figures for the FAD composition of their biodiesel.

4.16. If the production facility uses a feedstock that is not listed, then a conservative FAD composition can be proposed to Ofgem. It is likely that where the feedstock is a waste e.g. used cooking oil, it will not be possible to estimate the composition and so the testing method under Option 2 would be required.

4.17. Documentation required by Ofgem is likely to include:

- Evidence of fuel supply from the production facility to the generating station e.g. a fuel supply contract or formal letter from the fuel supplier. This should name the feedstock used to produce the biodiesel used.
- Details of the sources of the FAD composition if the feedstock is one not listed in this document.

Option 2 - full sampling

4.18. Samples of the fuel can be taken at the generating station and the FAD composition can be tested by means of e.g. mass spectrometry or gas chromatography. Procedures for extracting samples and how these are tested will form part of FMS procedures which will need to be agreed with Ofgem. Documentation required on a monthly basis will include:

- A spreadsheet containing the sample results.
- Copies of the sampling results e.g. a lab report.

Calculating the proportion of fossil fuel derived residues

Option 1 - minimal sampling with conservative estimates

4.19. EN 14214:2008 is the European biodiesel standard commonly used to demonstrate the quality of biodiesel. It provides a lower and upper limit to the different components that exist within biodiesel, which have to be met for the fuel to comply with the standard. The components that could be derived from fossil fuel are:

- Carbon residue remnant.
- Methanol.
- Glycerol (up to 3 H atoms per molecule of glycerol).
- Other additives.

4.20. Carbon residue remnant is an impurity in the biodiesel that can result from any point in the production process, for example, it could be from tractor fumes on the vegetable crop. If using minimal sampling operators must assume that the upper limit of each of the above elements is reached and is derived from fossil fuel.

4.21. Appendix 4 shows the EN14214:2008 standard and the upper limit values of each of the components listed above. We have also added a column to provide standard gross calorific values (GCVs) that can be assumed for each of the components above. The relatively small GCV for glycerol reflects the fossil derived hydrogen. A GCV for fossil diesel is assumed for the "other additives" column. This is in line with a conservative approach assuming that any residue that is unallocated is derived from fossil fuel.

Option 2 - full sampling

4.22. Operators may choose to undertake sampling themselves. As with all FMS procedures, this needs to be representative of the biodiesel consumed within the month and procedures will need to be agreed with Ofgem for how this is undertaken. Sampling should provide the levels of the following fossil fuel components:

- Carbon residue remnant.
- Methanol.
- Glycerol (up to 3 H atoms per molecule of glycerol).

- Other additives/miscellaneous[5].

4.23. As in Option 1 we expect that the GCV of the components will be standard GCVs as specified in Appendix 4.

4.24. Documentation required on a monthly basis will include:

- A spreadsheet containing the sample results.
- Copies of the sampling results e.g. a lab report.
- Any other evidence that bio-methanol or bio-hydrogen has been used instead of fossil fuel derived reagents.

Calculating the proportion of FAME in the biodiesel

Option 1 - minimal sampling with conservative estimates

4.25. To meet the European biodiesel standard EN 14214:2008, a biodiesel needs to have a minimum FAME content of 96.5%. If an operator uses biodiesel that meets the EN14214:2008 standard, then as a conservative estimate, the ester content of 96.5% can be assumed for that biodiesel.

4.26. Documentation required by Ofgem is likely to include:

- Evidence of fuel supplier(s) supplying the generating station with biodiesel e.g. fuel contract or formal letter from the supplier.
- Evidence that the biodiesel meets the EN 14214:2008 standard on a monthly basis e.g. copy of certifications, production facility sampling results.
- Procedures should also be agreed with Ofgem to demonstrate that no contamination of the biodiesel would occur during transportation.
- Option 2 – full sampling.

4.27. If using full sampling operators will need to undertake sampling of the fuel(s) used at the generating station for the FAME content of the biodiesel consumed within the month. The samples analysed should be representative of the fuel used in the month, and the sample results averaged to give an overall sampling result for the month. For more information on sampling see our FMS guidance.

4.28. Documentation required on a monthly basis will include:

- A spreadsheet containing the sample results.

[5] If not explicitly stated within test results 'Other additives / miscellaneous' can be calculated as one minus the FAME, carbon residue remnant, methanol and glycerol contents.

- Copies of the sampling results e.g. a lab report.

4.29. An explanation of how the results from these calculations and tests is utilised to calculate the fossil fuel derived contamination percentage, and therefore biomass qualifying percentage, of the fuel is provided on the following page.

Example Calculation

4.30. The calculation to determine the biomass content in the biodiesel that is eligible for ROC is composed of three steps.

4.31. **Step 1: Calculating the fossil fuel energy content of the FAME mixture.** This is necessary to take account of the presence of energy derived from the methoxy group (fossil fuel element) chemically bonded to the FAD (biomass component) in the FAME molecule.

- **Step 2: Calculating the fossil fuel energy contribution of the residual components in biodiesel.** This is necessary to take account of any residual components within the biodiesel e.g. methanol, glyceride, glycerols, which are fossil fuel derived and contribute to the energy content of the fuel.
- **Step 3: Calculating the overall biomass energy content of the biodiesel.** Calculating the overall biomass content of the biodiesel brings together the fossil fuel element calculated in the FAME mixture and the residual fossil fuel elements to create an overall qualifying percentage for the biomass contribution that is eligible for ROC issue.

4.32. A worked example for how the calculations in steps 1-3 can be undertaken is now provided.

4.33. Step 1: Calculating the fossil fuel energy content of the FAME mixture.

4.34. The fossil fuel energy content within the FAME mixture is dependent on the fossil fuel energy content of each FAME compound and the proportion of each FAD within the FAME mixture.

4.35. We have calculated the fossil fuel energy content of a range of FADs likely to be present in biodiesel using fundamental thermodynamics. These proportions are given in Appendix 2 with an explanation of how these proportions are arrived at in Appendix 5.

4.36. The proportion of each FAD within the FAME is also required (mass share). Either the default value relevant to your feedstock as given in Appendix 1, or your sampling results as discussed in the information requirements above can be used depending on whether you are using Option one (minimal sampling) or Option two (full sampling).

4.37. To calculate the fossil fuel contribution of each FAME compound multiply the fossil fuel energy content of the FAME compound by the mass share of that FAD within the FAME mixture. Then sum the fossil fuel contribution of each FAME compound to determine the share of fossil fuel in the FAME mixture.

4.38. Only the mass share of the FAD need be taken into account as the mass of the methoxy group is already incorporated in the fossil fuel energy content calculation of the FAME compound.

$$fossil\ fuel\ energy\ content\ of\ FAME\ mixture = \sum_{i=1}^{n} fossil\ fuel\ energy\ content\ of\ FAME\ x\ mass\ share\ of\ FAD\ in\ feedstock\,(\%)$$

$[where\ n = number\ of\ FAD\ types]$

<u>Example 1 – Step 1</u>

This example uses the rapeseed default values given in Appendix 1.

Table 1 – Mass and fossil fuel energy share of FAME in rapeseed

FAME compound comprising FAD	Fossil fuel energy content of FAME (%)	Mass share of FAD in feedstock (%)
12:0	5.64	0
14:0	4.86	1.5
16:0	4.27	6
16:1	4.32	0
17:0	4.03	0
18:0	3.81	1
18:1	3.85	51.5
18:2	3.88	30
18:3	3.92	10

Fossil fuel energy content of FAME mixture = ((4.86 x 1.5) + (4.27 x 6) + (3.81 x 1) + (3.85 x 51.5) + (3.88 x 30) + (3.92 x 10)) = 390.6.
390.6 / 100 = 3.91%

Step 2: Calculating the fossil fuel energy contribution of the residual components in biodiesel

4.39. The information requirements for the proportion of fossil derived residues identify four potential fossil fuel residual components within biodiesel. This step explains how to take account of these residual components.

4.40. To determine the percentage energy contribution that each component makes to the biodiesel, it is necessary to know the energy content of the biodiesel as a whole. If the GCV of the fuel is known as a result of sampling, then this GCV should be used. Procedures for how a sample is extracted for GCV analysis will need to be agreed with Ofgem. If the GCV of the fuel is not known, the GCV of the FAME mixture, as the major component of the biodiesel, can be used as an approximation for the energy content of the biodiesel as a whole. To calculate the GCV of the FAME mixture use the calculation set out in step 2a. The proportion of each component can then be determined as set out in Step 2b.

Step 2a: Calculate the GCV of the FAME mixture (if GCV unknown)

4.41. The GCV of the FAME mixture depends on the GCV of each FAME compound present in the FAME and the proportion of each FAD in the FAME.

4.42. **Table 3** shows our calculated GCV of each FAME compound based on fundamental thermodynamics (an expanded table including more FADs is given in Appendix 2). For an explanation of how these figures were arrived at, see Appendix 5.

Table 3 – GCV of each FAME compound

FAME compound comprising FAD	GCV of FAME compound (MJ/kg)
12:0	38.0
14:0	39.0
16:0	39.8
16:1	39.7
17:0	40.1

18:0	40.4
18:1	40.3
18:2	40.2
18:3	40.1

4.43. For the proportion of each FAD within the FAME mixture you can either use the default value relevant to your feedstock as given in Appendix 1 for Option one (minimal sampling). If a GCV value, produced from testing, is available for the FAME mixture it will be expected that this would be used in preference to this calculation method.

4.44. To calculate the GCV of the FAME mixture the energy contribution of each FAME compound first needs to be determined. This is calculated by multiplying the GCV of each FAME compound by the percentage share of the FAD within the FAME. The contribution of each FAME compound is then summed to reach the total GCV of the FAME mixture.

$$GCV\ of\ FAME\ mixture = \sum_{i=1}^{n} GCV\ of\ FAME\ compound\ x\ mass\ share\ of\ FAD\ in\ feedstock$$

$$[where\ n = number\ of\ FAD\ types]$$

Example 2 - Step 2a

This example uses the rapeseed default values in Appendix 1.Table 2 - mass distribution of FADs from rapeseed

FAME compound comprising FAD	GCV of FAME compound MJ/kg	Mass share of FAD in feedstock (%)
12:0	38.0	0
14:0	39.0	1.5
16:0	39.8	6
16:1	39.7	0
17:0	40.1	0
18:0	40.4	1
18:1	40.3	51.5
18:2	40.2	30
18:3	40.1	10

GCV of FAME = (39.0 x 1.5) + (39.8 x 6) + (40.4 x 1) + (40.3 x 51.5) + (40.2 x 30) + (40.1 x 10) = 4020.
4020 / 100 = 40.2MJ/kg

Step 2b: Calculate the energy content contributions of residual fossil fuel components

4.45. The energy contribution of the components is dependent on the proportion by mass of that component in the biodiesel, the energy content of that component and the energy content of the biodiesel as a whole. The GCV of the biodiesel from sampling results, or if this is not utilised, the outcome of Step 2a can be used for the energy content of biodiesel as a whole.

4.46. Either the default values given in Appendix 4 or sampling results as discussed in the information requirements above can be used to determine the proportion by mass of each component. As the GCVs of the components cannot be measured, standard GCVs can be used; these are provided in Appendix 4 and discussed further in the information requirements above.

4.47. To work out the energy contribution of a residual component the proportion by mass of the component is multiplied by the GCV of the component to determine its energy contribution. This is then divided by the GCV of the biodiesel to get a percentage contribution.

$$\textit{energy contribution of component} = \frac{\textit{proportion of component in biodiesel x GCV of component}}{\textit{GCV of biodiesel}}$$

Example 3 – Step 2b

This example uses the default proportion of residual methanol (0.2) and standard GCV for methanol (22.6 MJ / Kg) as given in Appendix 4.

Energy contribution of residual methanol = (0.002 x 22.6)/40.2 =0.11%

Repeating this calculation for each of the residual fossil fuel components using the figures in appendix 4 gives the following results: carbon residue remnant (0.24%), glycerol (0.02%) and other additives (4.17%).

Step 3: Calculate the overall biomass energy content of the biodiesel

4.48. Step 3a shows how to calculate the fossil fuel energy contribution to the biodiesel as a whole. This fossil fuel energy content comes from the methoxy group within the FAME compounds that make up the FAME mixture. This can then be added to the fossil fuel contribution of each component to give an overall fossil fuel and biomass proportion of the biodiesel in step 3b. The percentage fossil fuel contamination figure is entered on the Renewables & CHP Register IT system each month as it is not eligible for ROC issue.

Step 3a: the fossil fuel energy content of biodiesel from the FAME mixture

4.49. The fossil fuel content within the FAME mixture as a proportion of the fossil fuel content in the biodiesel is dependent on:

- The fossil fuel energy content of the FAME mixture.
- The proportion of FAME in the biodiesel.

4.50. The first of these is calculated in step 1. For the proportion of FAME in the biodiesel you can either use the default value of 96.5% or the results of sampling as discussed above in the information requirements.

4.51. The fossil fuel energy content attributable to the FAME mixture is simply a multiple of the proportion of FAME in the biodiesel and the proportion of fossil fuel content in the FAME mixture.

$$\textit{fossil fuel energy content attributable to FAME mixture} \\ = \textit{proportion of FAME in biodiesel} \times \textit{fossil fuel energy content in FAME mixture}$$

Example 4 – Step 3a

> This example uses the outcome of example 1 for the average fossil fuel content of the FAME mixture (3.91%) and the minimum FAME content from the EN14214:2008 biodiesel stand given in Appendix 4 (96.5%).
>
> Fossil fuel energy content attributable to rapeseed FAME = 3.91% x 96.5% = 3.77%.

Step 3b: biomass energy content of biodiesel

4.52. To determine the overall fossil fuel energy content of the biodiesel, expressed as a percentage, add the fossil fuel energy content from the FAME mixture to the fossil fuel energy content of the components. This can then be subtracted from 100 to give a biomass energy contribution to the biodiesel.

$$\boldsymbol{fossil\ fuel\ energy\ content\ of\ biodiesel} = fossil\ fuel\ energy\ content\ attributable\ to\ FAME\ mixture + \sum_{i=1}^{n} fossil\ fuel\ energy\ content\ of\ each\ potential\ fossil\ fuel\ component$$

$$[Where\ n = number\ of\ fossil\ fuel\ components]$$

$$\boldsymbol{biomass\ energy\ content\ of\ biodiesel} = 100 - fossil\ fuel\ energy\ content\ of\ biodiesel$$

Example 5 – Step 3b

> This example uses the outputs of examples 3 Step 2b (0.24%, 0.11%, 0.02% and 4.17%) and 4 (3.77%) for the fossil fuel content of the FAME and the fossil fuel content of the components
>
> **Fossil fuel energy content of rapeseed biodiesel (%)** = 3.77 + 0.24 + 0.11 + 0.02 + 4.17 = 8.09%. This is the contamination value which would be stated within your fuel submission on the Renewables and CHP register.
>
> **Biomass energy content of rapeseed biodiesel** = 100% – 8.09%= 91.91%

Appendices

Index

Appendix 1 – Default values for fatty acid derivative (FAD) composition

Table A1: A breakdown of FAD compositions by mass according to the least favourable share

	FAD composition by mass share (carbon chain length : number of double bonds)								
	12:0[6]	**14:0**	**16:0**	**16:1**	**17:0**	**18:0**	**18:1**	**18:2**	**18:3**
Palm	2.4	46.3	6.3	0	0	37	8	0	0
Soybean	0	0	11	0	0	2.4	23.1	53	10.5
Rapeseed	0	1.5	6	0	0	1	51.5	30	10
Sunflower	0	0	6.5	0	0	1.3	23.5	68.7	0
Tallow	0	4	27	4	0	13	48	4	0

[6] Fatty acid 12:0 is not included in the EN14103:2008 standard (Determination of Esters), however, because this table shows the worst case scenario, in the case of palm oil, a small amount is assumed to come from fatty acid 12:0.

Appendix 2 – FAME energy values

Table A2: the energy content and fossil fuel content in FAME compounds comprising different fatty acid derivatives

FAME compound comprising FAD	GCV of FAME (MJ/kg)	Fossil fuel energy share in FAME (%)
6:0	32.5	10.85
8:0	35.0	8.30
10:0	36.7	6.72
12:0	38.0	5.64
14:0	39.0	4.86
16:0	39.8	4.27
16:1	39.7	4.32
17:0	40.1	4.03
18:0	40.4	3.81
18:1	40.3	3.85
18:2	40.2	3.88
18:3	40.1	3.92
20:0	40.9	3.44
20:1	40.8	3.47
20:2	40.8	3.50
20:3	40.7	3.53
22:0	41.4	3.13
22:1	41.3	3.16
22:2	41.2	3.18
22:3	41.1	3.21
24:0	41.8	2.88
24:1	41.7	2.90
24:2	41.6	2.92
24:3	41.5	2.94

Appendix 3 – Default values for the biomass energy content of FAME

Table A3: Default values for different biodiesel feedstocks based on FAD compositions according to the least favourable share

	Mass (kg)	Mass share (%)	Energy content (MJ/kg)	Energy share (%)
Palm	234.0	88.29	42.9	95.63
Methoxy group	31.0	11.71	14.8	4.37
Soy	260.7	89.36	43.2	96.08
Methoxy group	31.0	10.64	14.8	3.92
Rapeseed	261.5	89.39	43.2	96.10
Methoxy group	31.0	10.61	14.8	3.90
Sunflower	262.0	89.41	43.2	96.10
Methoxy group	31.0	10.59	14.8	3.90
Tallow	254.1	89.11	43.1	95.98
Methoxy group	31.0	10.89	14.8	4.02

Appendix 4 – Specifications in EN14214:2008 standard and standard GCVs for residual elements

Property	Units	Lower limit	Upper limit	Test-Method	Potentially fossil fuel*	Energy content (MJ/kg)
FAME content	% (m/m)	96.5	-	EN 14103	Partially	
Density at 15°C	kg/m^3	860	900	EN ISO 3675/EN ISO 12185	n/a	
Viscosity at 40°C	mm^2/s	3.5	5.0	EN ISO 3104	n/a	
Flash point	°C	>101	-	EN ISO 2719/EN ISO 3679	n/a	
Sulphur content	mg/kg	-	10	EN ISO 20846/EN ISO 20884	n/a	
Carbon residue remnant (at 10% distillation)	%(m/m)	-	0.3	EN ISO 10370	Yes	32.7
Cetane number	-	51	-	EN ISO 5165	n/a	
Sulfated ash content	%(m/m)	-	0.02	ISO 3987	n/a	
Water content	mg/kg	-	500	EN ISO 12937	No	
Total contamination	mg/kg	-	24	EN 12662	n/a	
Copper band corrosion (3 hours at 50°C)	rating	Class 1	Class 1	EN ISO 2160	n/a	
Oxyidation stability, 110°C	hours	6	-	prEN 15751/EN 14112	n/a	
Acid value	mg KOH/g	-	0.5	EN14104	n/a	
Iodine value	-	-	120	EN14111	n/a	
Linolenic Acid Methylester	%(m/m)	-	12	EN14103	Already accounted for**	
Polyunsaturated (>=4 double bonds) Methyles	%(m/m)	-	1	EN14103	Already accounted for**	

ter						
Methanol content	%(m/m)	-	0.2	EN14110I	Yes	22.6
Monoglyceride content	%(m/m)	-	0.8	EN14105	No	
Diglyceride content	%(m/m)	-	0.2	EN14105	No	
Triglyceride content	%(m/m)	-	0.2	EN14105	No	
Free glycerol	%(m/m)	-	0.02	EN14105/EN14106	n/a	
Total glycerol	%(m/m)	-	0.25	EN14105	Yes	3.29
Group 1 metals (Na+K)	mg/kg	-	5	EN14108/EN14109/EN14538	n/a	
Group 11 metals (Ca+MG)	mg/kg	-	5	EN14538	n/a	
Other additives	%(m/m)		3.5		Yes	47.85

*where n/a is entered the property does not have an energy content
** these esters are accounted for in the FAME content specified in the first row

Appendix 5 – Calculation of GCV and fossil fuel energy share of FAME compounds

5.1. The calculation to determine the GCV and fossil fuel content of each FAME compound is split into four steps:

- **Step 1: Calculate the proportion by mass of biomass and fossil fuel in the FAME compound** - this is necessary to apportion the energy from biomass and fossil fuel that can be expected in a particular unit of mass.
- **Step 2: Calculate the bond energies of biomass and fossil fuel in the FAME compound** - this is necessary to understand where the energy in the FAME compound has come from so that it can be attributed to biomass or fossil fuel.
- **Step 3**: **Calculate the GCV of the FAME compound** – this is calculated from the bond energies according to the proportion by mass of biomass and fossil fuel and is used in the calculation in Chapter 4 and presented in Appendix 2.
- **Step 4**: **Calculate the proportion by energy content of biomass and fossil fuel in the FAME compound** - this uses the GCVs of the biomass and fossil fuel to calculate the proportion of biomass and fossil fuel given in Chapter 4 and Appendix 2.

The calculation for each of these steps is given below.

Step 1: Calculate the proportion by mass of biomass and fossil fuel in the FAME compound

5.2. This step begins with a calculation of the atomic mass of the biomass and fossil fuel in the FAD and methoxy group within each FAME compound in step 1a. Step 1b then uses the mass of the FAD and methoxy group to reach the relative proportions of the biomass and fossil fuel by mass within the FAME compound.

Step 1a: Molecular mass of FAD

5.3. The molecular mass of the FAD is calculated by multiplying the number of each type of atom by the atomic mass of the atom, then summing the mass calculated across all the types of atoms contained in the FAD.

5.4. Table 7 shows the number of each type of atom in the FAD within each FAME compound.

$$\textit{molecular mass of the the FAD} = \sum_{i=1}^{n} \textit{number of atoms in the the FAD x atomic mass}$$

$[\textit{where } n = \textit{number of atom types}]$

This step also needs to be repeated for the methoxy group.

Table A4 – the number of atoms present in FADs commonly found in biodiesel

Fatty acid derivative	Carbon atoms	Hydrogen atoms	Oxygen atoms
Methoxy group	1	3	1
12:0	12	23	1
14:0	14	27	1
16:0	16	31	1
16:1	16	29	1
17:0	17	33	1
18:0	18	35	1
18:1	18	33	1
18:2	18	31	1
18:3	18	29	1

Fatty acid derivative	Carbon atoms	Hydrogen atoms	Oxygen atoms
Atomic mass	12	1	16

Example A

This example uses the makeup of FAD 14:0 and atomic mass of each atom as given in the table above.

Mass of biomass in FAD 14:0 = (14 x 12) + (27 x 1) + (1 x 16) = 211 [kg/kmol]

Step 1b; calculate the relative proportion of biomass and fossil fuel by mass

5.5. This step uses the mass of the FAD and the methoxy group calculated in the Step 1a to determine the relative proportions of biomass to fossil fuel by mass. The percentage mass of biomass is the mass of the FAD divided by the combined mass of the FAD and methoxy group multiplied by 100. The percentage mass of the methoxy group can then be calculated by deducting the percentage mass of the FAD from 100.

$$\textit{Percentage mass of biomass} = 100\ x\ \frac{\textit{mass of FAD}}{\textit{mass of FAD} + \textit{mass of methoxy group}}$$

$$\textit{Percentage mass of methoxy group} = 100 - \textit{percentage of mass of FAD}$$

<u>Example B</u>

This example uses the mass of fatty acid derivative 14:0 as calculated in example A and the mass of the methoxy group which can be calculated as in step 1a

Mass of the FAD = 211 [kg/kmol]
Mass of the methoxy group = 31 [kg/kmol]

Percentage mass of the FAD = 100 x (211/(211 + 31)) = 87.19%

Percentage mass of methoxy group = 100 - 87.19=12.81%

Step 2: Calculate the bond energies of biomass and fossil fuel in the FAD

5.6. Steps 2a and 2b calculate the energy required breaking the bonds in the FAD and the energy released when forming the products of combustion. The difference between the two gives the overall energy content of the biomass and fossil fuel in the FAME compound in step 2c. A correction factor is then applied in step 2d to account for the difference between theoretical bond energies and experimental bond energies. Step 2e then calculates the energy content of the biomass and fossil fuel in the FAME compound.

Step 2a: calculate the total input energy required for combustion of FAD

5.7. The total input energy required to combust the FAD is the energy within each bond multiplied by the number of that type of bond. The bond energies for each FAD are then summed separately. The calculation also takes into account the energy required to break the bonds in oxygen molecules needed for combustion.

$$\textit{total input energy needed for combustion of FAD} = \sum_{i=1}^{n} \textit{number of bonds x bond energy}$$

$[\textit{where } n = \textit{number of bond types in FAD or oxygen}]$

Example C

The example uses FAD 14:0.

Table 3: Bonds within FAD 14:0 and oxygen required for combustion

Bond type	Number of bonds	Bond energy (MJ/kmol)
C-C	13	346
C-H	27	411
C=O	1	799
O=O	20.25	498
C=C	0	611

Total input energy = (13 x 346) + (27 x 411) + (1 x 799) + (20.25 x 498)= 26478.5 [MJ/kmol]

Step 2b - calculate the total energy released from combustion of FAD

5.8. This is the same calculation as 2a but is performed on the products of combustion of the FAD, namely carbon dioxide and water.

$$\textit{total energy released on combustion of the FAD} = \sum_{i=1}^{n} \textit{number of bonds in products of combustion x bond energy}$$

$\textit{where } n = \textit{number of bond types in FAD}$]

Example D

The example uses FAD 14:0

Table 4: bonds within combustion products of FAD 14:0

Bond type	Number of bonds	Bond energy MJ/kmol
C=O	28	799
H-O	27	459

Energy released on combustion = (28 x 799) + (27 x 459) = 34,765 [MJ/kmol]

Step 2c - calculate net energy released from each FAD

5.9. This simply deducts the total input energy from the energy released on combustion to give the energy content of the FAD.

$$\textbf{Theoretical biomass energy content of FAD} = \text{total energy released from FAD on combustion} - \text{total input energy required for combustion of FAD}$$

<u>Example E</u>

This example uses the calculated input- energy used and energy released in examples C and D for fatty acid derivative 14:0 Energy content in FAD 14:0 = 34,765 – 26,478.5 = 8,286.5 MJ/kmol

Step 2d - apply correction factor

5.10. The theoretical bond energy is multiplied by the correction factor of 1/0.923 (1.0834) to make it comparable with bond energies seen through experimentation.

$$\textbf{corrected energy content of FAD} = \text{theoretical energy content of FAD} \times \text{correction factor}$$

<u>Example F</u>

The example uses the energy content of the FAD 14:0 as calculated in example D and the correction factor given above. Corrected energy content of biomass portion of FAD 14:0 = 8,286.5 x 1.0834 = 8,977.8 MJ/kmol

Step 2e: calculate the energy content of the biomass and fossil fuel in the FAME compound

5.11. This divides the corrected energy content of the FAD by the molecular mass calculated in step 1a to provide an energy content of the biomass in MJ/kg.

$$\textbf{energy content of FAD} = \frac{\text{corrected energy content of FAD}}{\text{molecular mass of FAD}}$$

Example G

This example uses the corrected energy content of FAD 14:0 calculated in example F and the molecular mass of FAD 14:0 calculated in Example A.

Energy content of biomass = 8,977.8/211 = 42.5MJ/kg

Step 3: calculate the GCV of the FAME compound

5.12. To calculate the energy from the biomass in 1 kg of FAME compound, the energy content of the FAD is multiplied by the mass share of the FAD in the FAME. The same is performed to calculate the energy from fossil fuel. The energy from biomass and fossil fuel can then be added together to get a GCV of the FAME compound.

5.13. The energy content of the FAD is as calculated in Step 2. The energy content of the methoxy group to be used is 14.8MJ/kg. This is calculated from the bond energies in the methoxy group. In addition, we have incorporated the bond energy of the C-O bond between the methoxy group and the FAD.

$$\textit{energy from FAD in FAME compound} = \textit{percentage mass of FAD x energy content of FAD}$$

$$\textit{energy from methoxy group in FAME compound} = \textit{percentage mass of methoxy group in FAME compound x energy content of methoxy group}$$

$$\textit{GCV of FAME compound} = \textit{energy from FAD in FAME compound} + \textit{energy from methoxy group in FAME compound}$$

Example H

This example uses the energy content of FAD 14:0 calculated in example G and the energy content of the methoxy group calculated as 14.8 MJ/kg. It also uses the mass share of the FAD and methoxy group in the FAME compound calculated in example B

Energy from FAD 14:0 = 0.8719 x 42.5 = 37.1 MJ/kg
Energy from methoxy group = 0.12817 x 14.8 = 1.9 MJ/kg

GCV of FAME compound = 37.1 + 1.9 = 39.0 MJ/kg

Step 4: calculate the proportion of biomass to fossil fuel energy in the FAME compound

5.14. The energy from the FAD is divided by the GCV of the FAME compound and multiplied by 100 to give the percentage of biomass within the FAME compound. This can then be deducted from 100 to give the percentage of fossil fuel within the FAME compound.

$$\textit{percentage of biomass energy} = 100\ x\ \frac{\textit{energy from FAD}}{\textit{GCV of the FAME compound}}$$

$$\textit{percentage of fossil fuel energy} = 100 - \textit{percentage of biomass energy}$$

<u>Example I</u>

This example uses the energy in FAD 14:0 and the GCV of the FAME compound comprising FAD 14:0 calculated in example H.

Proportion of biomass energy in FAME compound comprising FAD 14:0 = 100 x (37.1/39.0) = 95.14%*

Proportion of fossil fuel energy in FAME compound comprising FAD 14:0 = 100 - 95.13 = 4.86%*

*Note: the percentages presented are slightly different to those calculated from the preceding numbers due to rounding.

Appendix 6 - Glossary

D

DECC	The Department of Energy and Climate Change

E

EN	European Norm (Standard)

F

FAD	Fatty Acid Derivative
FAME	Fatty Acid Methyl Ester (main component of biodiesel)
FDBL	Fossil-Derived Bioliquid
FMS	Fuel Measurement and Sampling

G

GCV	Gross Calorific Value
GHG	Greenhouse Gas

K

Kg	Kilogram
Kmol	Kilomole

M

MJ	Megajoule

O

OFGEM	Office of Gas and Electricity Markets

R

RED	Renewable Energy Directive
RO	Renewables Obligation
ROC	Renewables Obligation Certificate

Appendix 7 - Definitions

Biodiesel means fuel suitable for use in diesel engines produced from vegetable oils or animal fat and alcohol e.g. methanol. If made from methanol it is primarily made up of a mixture of Fatty Acid Methyl Ester (FAME) compounds.

Bioliquid has the meaning as per Electricity Act 1989 and means liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass.

Carbon residue remnant means the tendency for carbon deposits to form within a fuel. These can exist as an impurity in the biodiesel and can result from any point in the biodiesel production process, for example, it could be from tractor fumes on the vegetable crop.

FAME compound refers to a particular FAME compound which includes a particular FAD e.g. 14:0. This only applies only to biodiesel produced using methanol.

FAME mixture includes all FAME compounds present in the biodiesel. This only applies only to biodiesel produced using methanol.

Fatty Acid Derivative (FAD) refers to the fatty acid part of the FAME e.g. the biomass part of it. A particular FAD can be specified by the number of carbon atoms and double bonds it contains e.g. 14:0 has 14 carbon atoms and no double bonds.

Glycerides mean esters formed from the reaction of glycerol with fatty acids (from vegetable oil or animal fat). These can be mono, di or tri glycerides. Triglycerides are the main components of vegetable oils or animal fats.

Glycerol (also known as glycerine) means a product of the biodiesel making process which can also be used as a fuel.

Methanol means an alcohol generally produced from natural gas and often used in the production of biodiesel.

Methoxy group means the part of the FAME derived from methanol e.g. the fossil fuel part where fossil fuel derived methanol has been used in the production process.