ofgem e-serve Making a positive difference for energy consumers

Renewables Obligation: Biodiesel and fossil-derived bioliquids guidance

Guidance

Publication date: December 2015

Team: Fuelling & Sustainability, Renewable Electricity

Tel: 0207 901 7310

Email: fuellingandsustainability@ofgem.gov.uk

Overview:

This document gives guidance to generating stations using fossil-derived bioliquids. It covers the legislative requirements of the Renewables Obligation (RO) in England, Wales, Scotland and Northern Ireland. It is effective from 1 December 2015.

Context

The Renewables Obligation, the Renewables Obligation (Scotland) and the Northern Ireland Renewables Obligation incentivise large-scale renewable electricity generation in the UK. They help the UK meet its target of 15 per cent of energy to be sourced renewably by 2020. The schemes are administered by the Gas and Electricity Markets Authority (the Authority), whose day-to-day functions are done by Ofgem. The Orders put an obligation on licensed electricity suppliers in England and Wales, Scotland and Northern Ireland to source an increasing proportion of electricity from renewable sources.

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 reviewed regularly. The Orders put an obligation on licensed electricity suppliers in England and Wales, Scotland, and Northern Ireland to get an increasing proportion of electricity from renewable sources. Suppliers meet their obligations by presenting sufficient Renewables Obligation Certificates (ROCs) to cover their obligations. If suppliers do not have enough ROCs to meet their obligation, they must pay an equivalent amount into a fund, the proceeds of which are paid back pro rata to those suppliers that have presented ROCs.

This guidance has been produced following the introduction of support for fossil-derived bioliquids under the Renewables Obligation. This guidance applies to England & Wales, Scotland and Northern Ireland. As ROCs are only issued for the biomass content of any fuel used, generating stations using such fuels will have to determine the proportion of the fuel that has come from biomass. This guidance explains how biodiesel generating stations can determine the fossil fuel and renewable derived content of biodiesel and other fossil-derived bioliquids.

The document does not profess to anticipate every scenario which may arise. If a scenario arises which is not addressed here, we will handle it in a way that is consistent with legislation. Any separate guidance published in addition to this document will be available from our website. 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 legal advice on how the Orders should be interpreted.

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
- Fuel Measurement and Sampling questionnaires
- Renewables Obligation: Guidance for Generators
- Renewables Obligation: Sustainability criteria
- Renewables Obligation: Sustainability Reporting Guidance

Contents

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). This document also outlines the definition of a FDBL, the level of support available for the use of FDBLs and an example of how generating stations could calculate the fossil fuel component of fossil-derived biodiesel each month.

Ofgem, as the administrator of the RO, agrees the method that generating stations use to determine the fossil fuel content of the fuel burnt in a month. Generators must submit proposed Fuel Measurement and Sampling (FMS) procedures to Ofgem to review and approve. The example in this guidance document relates to biodiesel produced using fossil-derived methanol, as we expect this to be the most commonly used FBDL. Alternative methodologies may be proposed to Ofgem.

FDBL includes biodiesel produced using fossil-derived methanol but does not include biodiesel produced using non-fossil-derived alcohols, eg bioethanol. Generating stations using other FDBLs eg hydro-treated vegetable oils can put forward proposals for determining the fossil fuel content to Ofgem. We will consider these case by case. Uncontaminated vegetable oils or other bioliquids that use no fossil fuel in their production are not covered by this document. This includes biodiesel produced using bioethanol.

1. Introduction

Chapter Summary

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

The nature of the legislation

1.1. The term "the Orders" is used to describe the Renewables Obligation Order 2015 (RO), The Renewables Obligation Order (Scotland) 2009 (as amended in 2010, 2011, 2013, 2014 and 2015) (ROS) and The Renewables Obligation Order (Northern Ireland) 2009 (as amended in 2010, 2011, 2013 and 2014) (NIRO).

1.2. Some areas of the legislation are prescriptive, others give us discretion. Where the legislation is prescriptive, this guidance helps generating stations understand what we require. Where the legislation gives us discretion, the document shows how we will generally exercise this discretion. It also explains what we need from generating stations to meet the requirements of the legislation.

Our role under the Renewables Obligation

1.3. Here is a list of Ofgem's powers and functions as stated in the Orders:

- Accrediting generating stations as capable of generating electricity from eligible renewable energy sources.
- Issuing Renewables Obligation Certificates (ROCs)[1].
- Establishing and maintaining a register of ROCs.
- Revoking ROCs 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 Retail Price Index.
- 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.

[1] The term "ROCs" refers to Renewable Obligation Certificates, Scottish Renewables Obligation Certificates (SROCs) and Northern Ireland Renewable Obligation Certificates (NIROCs).

- Sending the Secretary of State a summary of the sustainability information submitted during each obligation period.

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

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

The purpose of this guidance document

1.6. This guidance explains how biodiesel generating stations can determine the fossil fuel and renewable derived content of their fossil-derived bioliquids. The purpose of this document is to focus on the Fuel Measurement and Sampling (FMS) procedures for FDBL fuels.

1.7. To determine the number of ROCs a generating station is eligible for month by month, fuelled generating stations need to distinguish between the amount of biomass and the amount of fossil fuel used to generate electricity. These amounts must be expressed as energy contributions, resulting from the Gross Calorific Value. We agree how generating stations will calculate the biomass and fossil fuel content by approving a generating station's fuel measurement and sampling procedures.

1.8. 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.

1.9. 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 because of 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 ROC issue. It can however be complex to determine this fossil-derived contribution to the overall energy content.

1.10. This guidance document should be read alongside the FMS guidance, and answers specific questions on FDBLs.

- What is classified as a FDBL (section 2.7)?
- How many ROCs are FDBLs eligible for (section 2.12)?

- How do I account for biodiesel in my FMS methodology and procedures (chapter 4)?

1.11. Operators of generating stations using FDBLs must also meet other RO requirements, such as the sustainability criteria in the European Union Renewable Energy Directive. Our Renewables Obligation: Sustainability Criteria Guidance shows how to meet these criteria and evidence that they have been met. There is more general guidance on the eligibility of a generating station in our Renewables Obligation: Guidance for generators document.

Terminology

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

- **Biodiesel** means fuel suitable for use in diesel engines produced from vegetable oils or animal fat and alcohol, eg methanol. If made from methanol it primarily contains a mixture of Fatty Acid Methyl Ester (FAME) compounds.
- **Bioliquid** We use the same definition as the Electricity Act 1989: liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass.
- **FAME compound** refers to a particular FAME compound which includes a particular biomass-derived FAD group, eg 14:0. This only applies to biodiesel produced using methanol.
- **FAME mixture** includes all FAME compounds present in the biodiesel. This only applies to biodiesel produced using methanol.
- **Fatty Acid Derivative (FAD)** refers to the fatty acid part of the FAME compound, ie 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.
- **Fatty Acid Methyl Ester (FAME)** refers to a chemical compound that is made up of a biomass (-R-CO) and fossil fuel derived ($-O-CH_3$) group.
- **Methanol** means an alcohol generally produced from natural gas and often used in the production of biodiesel.
- **Methoxy group** refers to the part of the FAME compound derived from methanol, ie the fossil fuel element where fossil fuel derived methanol has been used in the production process.

Queries

1.13. Please email any queries about what Ofgem does to renewable@ofgem.gov.uk, or post them to the address on the front of this document. Mark them for the attention of the Renewables and CHP Administrator.

1.14. Please direct any queries about future changes to the renewables obligation for England and Wales and wider policy to the Department for Energy and Climate Change (DECC). Contact details are at www.decc.goc.uk. For the ROS and NIRO, visit www.scotland.gov.uk and www.detini.gov.uk respectively.

2. Eligibility

Chapter Summary

Provides background to the introduction of eligibility for fossil-derived bioliquids and a summary of the Renewables Obligation provisions.

Background

2.1. Under the Renewables Obligation (RO), generating stations can claim Renewables Obligation Certificates (ROCs) for eligible renewable generation. Since April 2011, fossil-derived bioliquids (FDBLs) have been eligible for ROCs on their non-fossil fuel energy content. But FDBLs were not eligible before this date.

2.2. One of the reagents used to produce biodiesel, methanol, is often 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 we got independent expert technical advice on the manufacturing process used to create these fuels, we carried out a consultation in September 2008. The conclusion from this 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 needed.

The introduction of FDBLs into the RO

2.4. In June 2008, the European Union Renewable Energy Directive was published. It contains renewable energy requirements to be fulfilled by each European Union Member State, including the 2020 renewable energy targets. In particular, there are many 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. Making these requirements part of the RO resulted in the following:

- To be eligible for support, any energy produced from a bioliquid must meet the sustainability criteria in the RO
- 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, eg biodiesel, must be eligible for support under the RO, unless the reasons for excluding it are 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 Orders as:

> "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 eg natural gas, or a product derived originally from fossil fuel eg methanol. The legislation provides no minimum requirement for the proportion of the FDBL that comes from renewable sources.

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

Table 1: Examples of FDBLs used for electricity generation

Fuel	**Fossil element used in production process**
Biodiesel produced using fossil-derived methanol	Methanol
Hydro-treated vegetable oil	Hydrogen
Renewable diesel via Fischer-Tropsch synthesis	Hydrogen
Renewable diesel produced from Pyrolysis oil using the hydrodeoxygenation process	Hydrogen

2.10. Bioliquids that do not include fossil fuel in the production process (eg uncontaminated vegetable oils or biodiesel produced using bioethanol) are not classified as FDBLs. For guidance on this, please refer to our FMS guidance.

2.11. The Orders[2] shows the number of ROCs that should be awarded on generation by various fuelled and non-fuelled technologies. The legislation also states[3] that

[2] Schedule 5 of the ROO, Schedule 2 of the ROS and NIRO Orders
[3] Article 33(8) of the ROO, Article 27(9) of the ROS and Article 25(5) of the NIRO Orders

electricity generated in a way which is not described in the relevant Schedule should realise 1 ROC per MWh. When they were introduced into the Orders in 2011, FDBLs were supported in accordance with Article 33(8) of the ROO, as none of the existing bands outlined in Schedule 5 provided support for FDBLs.

2.12. From 1 April 2013 (or 1 May under the Northern Ireland Renewables Obligation) fuels which are FDBLs also meet the definition of biomass[4]. As such, from 1 April 2013 (or 1 May under the NIRO), generating stations using FDBLs are eligible to claim the same 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 demonstrate that the biogenic portion of the FDBL meets the required sustainability criteria to be eligible for ROCs.

[4] Article 3 of the ROO, Article 4 of the ROS and NIRO Orders

3. Agreeing FMS procedures

Chapter Summary

Further information on the fuel measurement and sampling procedures. Generating stations using fossil-derived bioliquids must agree procedures with Ofgem to claim Renewables Obligation Certificates under the Orders.

Fuel measurement and sampling

3.1. A fuel measurement and sampling (FMS) procedure is the general term we use to describe the agreed procedures for the measurement and sampling of fuels at a 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 fossil-derived bioliquids (FDBLs) will need to agree FMS procedures with Ofgem before being accredited and issued with Renewable Obligation Certificates (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. In chapter 4, there is an example of how generating stations using biodiesel can demonstrate the biomass proportion of the fuel. Generating stations using other FDBLs can put forward proposals for determining the fossil-derived energy content to Ofgem. Alternative proposals can also be submitted for operators of generating stations using biodiesel who wish to use a different methodology than that outlined in chapter 4.

3.4. We can only issue ROCs for electricity generated from renewable sources in a given month. The Orders[5] show how to calculate the amount of electricity generated from renewable sources. 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 should be determined. The amount of electricity is determined according to the energy content of the fossil and biogenic fraction of each of the fuels used in a particular month. Operators of fuelled stations need to propose and agree FMS procedures with us, describing how they will get the values required for the ROC calculations.

3.5. We can only issue ROCs based on information provided to us which we consider is accurate and reliable. We will work with the generating station as closely as possible

[5] Articles 29 and 30 of the ROO, Articles 25 and 26 of the ROS and Articles 23 and 24 of the NIRO Orders

to do this, but the onus for the design of suitable FMS procedures ultimately lies with the operator.

The format of FMS procedures

3.6. 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 case-by-case, according to the specific setup and conditions at each generating station.

3.7. There is no set timeframe for agreeing FMS procedures, because the complexity of FMS procedures will vary greatly from one station to the next. Our aim is to agree procedures that will enable generating stations to meet the requirements of the legislation for fuel measurement and sampling to determine the energy content of fuels. We will work closely with generating stations to make the process as efficient as possible.

3.8. All procedures should be submitted using the appropriate FMS questionnaires. A range of questionnaires are available on our website[6]. Accompanying documentation can be provided alongside the FMS questionnaire if necessary. If you are unsure which questionnaire to complete, contact the Fuelling and Sustainability team at FuellingandSustainability@Ofgem.gov.uk (or call 0207 901 7310).

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

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

4. Calculating the fossil fuel content of biodiesel

Chapter Summary

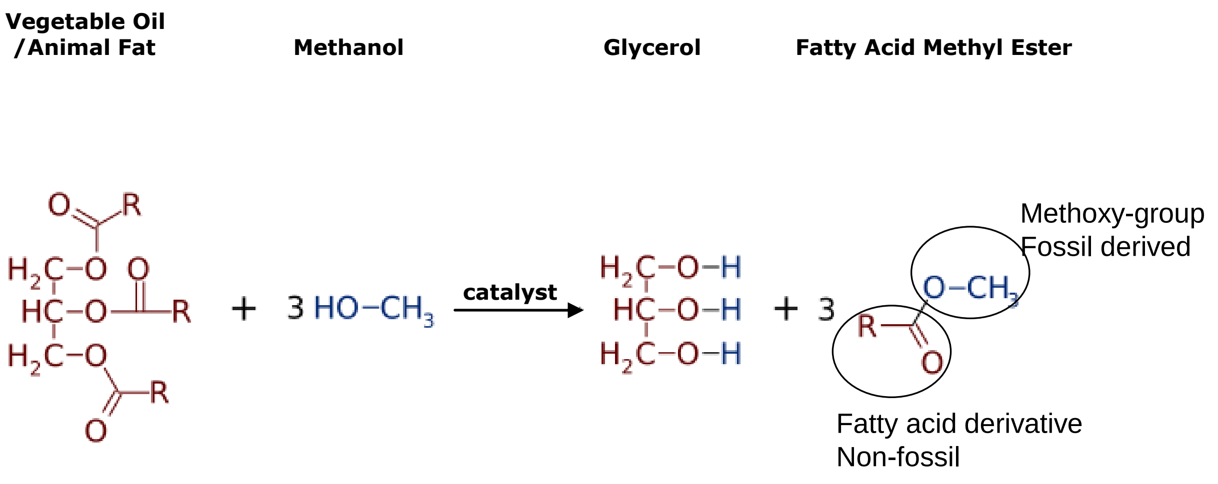
Describes a methodology operators may wish to use to determine the fossil fuel and biomass energy content of biodiesel.

Background information

4.1. This chapter focuses on a methodology for determining the relative biomass and fossil fuel energy content in biodiesel 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.

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 by-product.

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



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.

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

- The vegetable oil or animal fat component of the biodiesel – the fatty acid derivative (FAD) – 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 relative 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 FADs making up the FAME compounds.
- There may be residual elements within the biodiesel, eg 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 its FMS procedures. This is based on determining the FADs within the biodiesel, the bond energies within the FADs and using standard Gross Calorific Values (GCVs) to account for the residual elements in the biodiesel. Where this approach is used the operator is still required to detail the 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) 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 Renewables Obligation Certificates (ROCs) to electricity generated by renewable sources. As a result, we have adopted a two-tier approach to the example methodology. This allows operators to choose between two options:

- **Minimal Sampling (Option 1):** This allows for minimal sampling information but uses conservative estimates of the biogenic content based on the biodiesel quality standard EN14214:2012 and a default fatty acid composition. Conservative values which can be used are found in the appendices to this document.

- **Full Sampling (Option 2):** When fuel is sampled and analysed, the test results can be used to determine the biogenic content of the FDBL. Details of the sampling and analysis must be outlined to Ofgem in the form of FMS procedures. This is necessary to demonstrate the sampling procedures will provide accurate and reliable results.

4.7. 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 FAD composition of each FAME component in the biodiesel.
- The proportion of FAME in the biodiesel.
- The proportion of fossil-derived residues in the biodiesel.

4.8. Option 1 requires less sampling than Option 2, as it relies on conservative default figures (provided in this document). 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 alternative methodologies to accurately determine the biomass content of biodiesel. We will review these case-by-case.

4.9. The information requirements under Options 1 and 2 are below. This is followed by a step-by-step explanation of each methodology. In chapter 5 there is an explanation of how the results from these steps are used to determine the fossil fuel-derived contamination percentage, and therefore biomass qualifying percentage

Overview of the key steps of the example methodology

4.10. Figure 2 and Table 2 below give an overview of the two options described above. they identifies where information is required either as a result of sampling or default values, depending on which Option is 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.

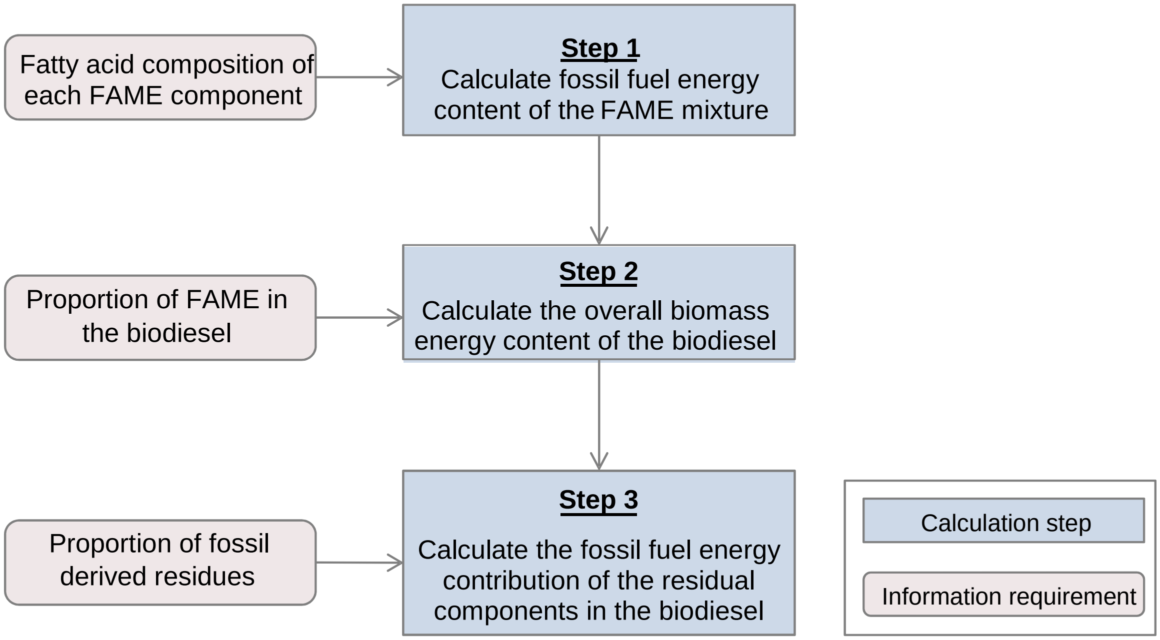


Table 2: Summary of sampling options

	Minimal sampling (Option 1)	**Full sampling (Option 2)**
Determining the FAD composition of each FAME component in 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 evidence.	Direct measurement of the FAD composition of the biodiesel can be used eg using a mass spectrometer and gas chromatography. You will need to demonstrate to Ofgem how you plan to do this.
Calculating the proportion of FAME in biodiesel	If the fuel meets the EN14214:2012 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.

Calculating the proportion of fossil fuel-derived residues.	If the fuel meets the EN14214:2012 standard, then the maximum percentage proportion and standard energy contents of potential fossil fuel-derived components can be used. These are given in Appendix 4.	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 fossil fuel-derived components given in Appendix 2 can then be used.

4.11. The next sections give more information on both the minimal and full sampling approaches for each of the sampling and calculation steps.

Option 1: minimal sampling with conservative estimates

4.12. If an operator does not wish to sample and instead wants to use conservative estimates to calculate the required elements in Table 2, they should use this three-step process.

Step 1: Determining the FAD composition of each FAME component in the FAME mixture

4.13. The FAD composition (also referred to as mass share) of FAME compounds 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.

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

4.15. The documents we need in support of the FAD composition will probably include:

- Evidence of fuel supply from the biodiesel production facility to the generating station, eg a fuel supply contract or formal letter from the fuel supplier. This should name the feedstock used to produce the biodiesel.
- Details of the sources of the FAD composition if the feedstock is not one listed in Appendix 1.

Step 2: Calculating the proportion of FAME in the biodiesel

4.16. EN 14214:2012 is the European biodiesel standard commonly used to demonstrate the quality of biodiesel. The standard is outlined in Appendix 4. To meet the standard, a biodiesel needs to have a minimum FAME content of 96.5%. If an operator uses biodiesel that meets EN14214:2012 standards, then the FAME content of 96.5% can be assumed for that biodiesel.

4.17. The documents we need are likely to include:

- Evidence of fuel supplier(s) supplying the generating station with biodiesel eg a fuel contract or formal letter from the supplier.
- Evidence that the biodiesel meets the EN 14214:2012 standard on a monthly basis, eg copy of certifications or production facility sampling results.

4.18. Procedures should also be agreed with Ofgem to demonstrate that no contamination of the biodiesel occurs during fuel transportation.

Step 3: Calculating the proportion of fossil fuel-derived residues

4.19. The European biodiesel standard EN 14214:2012 provides a lower and upper limit to the different components in biodiesel, which have to be met for the fuel to comply with the standard.

4.20. The limits are given in the table in Appendix 4 and we have added a column to provide standard GCVs that can be assumed for each relevant component.

4.21. Unless evidence is presented for the composition of the residue, we will conservatively assume that any unallocated residue (ie that is not FAME) is derived from fossil fuel and is considered under the “other additives” column. A GCV for fossil diesel is assumed for "other additives".

Option 2: full sampling

4.22. If an operator wants to sample the FDBL themselves to provide the required elements in Table 2, they should use the following three-step sampling process. As with all FMS procedures, sampling needs to represent the biodiesel consumed within the month and they should agree with us how to do this. For more information on sampling, see our FMS guidance.

Step 1: Determining the FAD composition of each FAME compound in the FAME mixture

4.23. Fuel samples can be taken at the generating station and the FAD composition tested, for example by mass spectrometry or gas chromatography. Procedures for extracting samples and how these are tested will form part of FMS procedures which should be agreed with Ofgem. Documents required monthly are likely to include:

- A spreadsheet containing the sample results.
- Copies of the sampling results, eg a lab report.

Step 2: Calculating the proportion of FAME in the biodiesel

4.24. If using full sampling, operators will need to sample the fuel(s) used at the generating station for the FAME content of the biodiesel consumed within the month. The samples analysed should represent the fuel used in the month. The sample results should be averaged to give an overall sampling result for the month. We would normally expect a weighted average to be used based on the proportion of each fuel used in the month.

4.25. Documents required each month are likely to include:

- A spreadsheet containing the sample results.
- Copies of the sampling results, eg a lab report.

Step 3: Calculating the proportion of fossil fuel-derived residues

4.26. Sampling should provide the levels of fossil fuel or fossil fuel-derived components, for instance:

- Methanol
- Other additives/miscellaneous[7].

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

4.28. Glycerol is not considered a fossil fuel-derived component because the net contribution to the GCV of the fossil fuel-derived Oxygen-Hydrogen bond is zero (the bond is broken and reformed in a water molecule). If sampling indicates the presence of glycerol, the quantity of glycerol contamination in the biodiesel can be considered as a renewable proportion of the FDBL.

4.29. Documents required each month are likely to include:

- A spreadsheet with the sample results.

[7] If not explicitly stated within test results 'Other additives / miscellaneous' can be calculated as one minus the percentage sum of FAME + methanol

- Copies of the sampling results, eg a lab report.
- Any other evidence that bio-methanol or bio-hydrogen has been used instead of fossil fuel-derived reagents.

5. Calculating the Biomass content of FAME

Chapter Summary

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

Background information

5.1. Once the Fatty Acid Methyl Ester (FAME) and fossil fuel composition of the biodiesel have been determined (through either Option 1 or Option 2 described in the previous chapter) the energy content of the FAME and fossil fuel can be calculated.

5.2. There are three steps to calculating the biomass content in the biodiesel that is eligible to claim Renewables Obligation Certificates (ROCs):

- **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 fossil fuel methoxy group chemically bonded to the biomass Fatty Acid Derivative (FAD) 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 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.

5.3. There following sections provide a worked example for doing the calculations in steps 1-3.

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

5.4. The fossil fuel energy content within the FAME mixture depends on the fossil fuel energy content of each FAME compound and the relative proportion of each FAME compound within the FAME mixture.

5.5. Using fundamental thermodynamics, we have calculated the fossil fuel energy content of a range of FAME compounds likely to be present in biodiesel. These proportions are given in Appendix 2 with an explanation of how these proportions are arrived at in Appendix 5.

5.6. The proportion of each FAD within the feedstock's FAME mixture is also required (as a mass share). Either the default value relevant to the feedstock as given in Appendix 1, or the sampling results as discussed in the information requirements above can be used depending on whether you are using Option 1 (minimal sampling) or Option 2 (full sampling).

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

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

$$[where\ n = number\ of\ FADs\ in\ feedstock\ from\ appendix\ 1\ or\ from\ lab\ analysis]$$

Example 1 – Step 1

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 (ordered by FAD)	Fossil fuel energy content of FAME compound (%)	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 = (5.64% x 0%) + (4.86% x 1.5%) + (4.27% x 6%) + (4.32% x 0%) + (4.03% x 0%) + (3.81% x 1%) + (3.85% x 51.5%) + (3.88% x 30%) + (3.92% x 10%)

Percentage fossil fuel energy content of FAME mixture = 3.91 %

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

5.8. This step explains how to take account of the energy content of the fossil-derived residues present in the biodiesel.

5.9. To determine the percentage energy contribution that each residue makes to the biodiesel, it is necessary to know the energy content of the biodiesel as a whole. If the Gross Calorific Value (GCV) of the fuel is known as a result of sampling, then this GCV should be used. Please agree with us how a sample is extracted for GCV analysis.

5.10. 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 in Step 2a below. The proportion of each component can then be determined as in Step 2b. If a GCV value produced from testing is available for the FAME mixture, this GCV value should be used in preference to the GCV value from the approximate calculation method described above.

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

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

5.12. Table 3 shows our calculated GCV of each FAME compound based on fundamental thermodynamics (an expanded table 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 that is comprised of FAD group x:y	GCV of FAME compound (MJ/kg)
12:0	38.0
14:0	39.0
16:0	39.8
16:1	39.6
17:0	40.1
18:0	40.4
18:1	40.3
18:2	40.1
18:3	40.0

5.13. For the proportion of each FAME compound within the FAME mixture, you can either use the default value relevant to your feedstock as given in Appendix 1 for Option 1, or the results of sampling for Option 2.

5.14. To calculate the GCV of the FAME mixture, you should first work out the energy contribution of each FAME compound. This is calculated by multiplying the GCV of each FAME compound by the percentage share of the FAD within the FAME mixture. The GCV contribution of each FAME compound is then summed to reach the total GCV of the FAME mixture.

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

$$[where\ n = number\ of\ FADs\ in\ feedstock\ from\ appendix\ 1\ or\ from\ lab\ analysis]$$

Example 2 - Step 2a

This example uses the rapeseed default values in Appendix 1. Table A1 - mass distribution of FADs from rapeseed

FAME compound (ordered by FAD)	GCV of FAME compound (MJ/kg)	Mass share of FAD (%)
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 = (38.0 x 0%) + (39.0 x 1.5%) + (39.8 x 6%) + (39.7 x 0%) + (40.1 x 0%) + (40.4 x 1%) + (40.3 x 51.5%) + (40.2 x 30%) + (40.1 x 10%)

GCV of FAME = 40.2 MJ/kg

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

5.15. 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 the outcome of Step 2a can be used for the energy content of biodiesel as a whole.

5.16. 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 in Appendix 4 and discussed further in the information requirements above.

5.17. 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.

$$\textbf{energy contribution of component} = \frac{\text{proportion of component in biodiesel} \times GCV \text{ of component}}{GCV \text{ of biodiesel}}$$

<u>Example 3 – Step 2b</u>

This example assumes no sampling has been carried out and uses the default proportion of residual fossil fuel components (3.5%) and a standard GCV for fossil diesel (47.9 MJ/kg) as given in Appendix 4. Energy contribution of residual components = (3.5% x 47.9)/40.2 = 4.17%

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

5.18. Step 3a below shows how to calculate the fossil fuel energy contribution to the biodiesel as a whole. This fossil fuel energy content comes from both the methoxy group within the FAME compounds that make up the FAME mixture and the fossil fuel contribution of each contamination component in the biodiesel. An overall fossil fuel and biomass proportion of the biodiesel is calculated in step 3b. The total percentage of 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

5.19. 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 mixture in the biodiesel.

5.20. The fossil fuel energy content of the FAME mixture is calculated in step 1. For the proportion of FAME in the biodiesel you can either use the default value of 96.5% (if your fuel meets the standard EN14214:2012) or the results of sampling as in the information requirements above.

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

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

Example 4 – Step 3a

This example uses the outcome of example 1 for the average fossil fuel energy content of the FAME mixture in rapeseed oil (3.91%) and the minimum FAME mixture content from the EN14214:2012 biodiesel standard given in Appendix 4 (96.5%).

Fossil fuel energy content attributable to rapeseed FAME mixture = 3.91% x 96.5%

Fossil fuel energy content attributable to rapeseed FAME mixture = 3.77%.

Step 3b: biomass energy content of biodiesel

5.22. 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 other components. This can then be subtracted from 100 to give a biomass energy contribution to the biodiesel.

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

$$\% \ \textbf{\textit{biomass energy content of biodiesel}} = 100\% - \% \ \textit{fossil fuel energy content of biodiesel}$$

[where n = number of fossil fuel components]

<u>Example 5 – Step 3b</u>

This example uses the outputs of example 3 (0.11% and 3.63%) and example 4 (3.77%) for the fossil fuel content of the FAME and the fossil fuel content of the components (glycerol is excluded from the fossil fuel percentage as it is considered biogenic).

Fossil fuel energy content of rapeseed biodiesel (%) = 0.11% + 3.63% + 3.77% = <u>7.51%</u> (*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% – 7.51% = 92.49%

Appendices

Index

Appendix 1 – Default Fatty Acid Derivative (FAD) composition values

Table A1: A breakdown of Fatty Acid Derivative (FAD) compositions by mass according to the least favourable share in commonly used vegetable oils/ animal fats

	FAD composition by mass share (%) (carbon chain length : number of double bonds)								
	12:0[8]	**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	37.0	8.0	0	0
Soybean	0	0	11.0	0	0	2.4	23.1	53.0	10.5
Rapeseed	0	1.5	6.0	0	0	1.0	51.5	30.0	10.0
Sunflower	0	0	6.5	0	0	1.3	23.5	68.7	0
Tallow	0	4.0	27	4.0	0	13.0	48.0	4.0	0

[8] 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 – Fatty Acid Methyl Ester (FAME) energy values

Table A2: The energy content and fossil fuel derived energy content in Fatty Acid Methyl Ester (FAME) compounds derived from different Fatty Acid Derivatives (FADs).

FAD component in FAME compound	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	39.6	4.32
17:0	40.1	4.03
18:0	40.4	3.81
18:1	40.3	3.85
18:2	40.1	3.89
18:3	40.0	3.93
20:0	40.9	3.44
20:1	40.8	3.47
20:2	40.7	3.50
20:3	40.6	3.53
22:0	41.4	3.13
22:1	41.3	3.16
22:2	41.2	3.19
22:3	41.0	3.21
24:0	41.7	2.88
24:1	41.6	2.90
24:2	41.5	2.92
24:3	41.4	2.94

Appendix 3 – Default values for the biomass energy content of Fatty Acid Methyl Ester

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

	Mass (kg)	Mass share (%)	Energy content (MJ/kg)	Energy share (%)
Palm	237.1	88.44	42.9	95.69
Methoxy group	31.0	11.56	14.8	4.31
Soy	260.7	89.37	43.1	96.08
Methoxy group	31.0	10.63	14.8	3.92
Rapeseed	261.7	89.41	43.2	96.10
Methoxy group	31.0	10.59	14.8	3.90
Sunflower	262.0	89.42	43.1	96.10
Methoxy group	31.0	10.58	14.8	3.90
Tallow	254.9	89.16	43.2	96.00
Methoxy group	31.0	10.84	14.8	4.00

Appendix 4 – Specifications in EN14214:2012 standard and standard Gross Calorific Values for residual components

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 EN ISO 13032	N/A	
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	
Oxidation stability, 110°C	hours	8	-	EN 15751 EN 14112	N/A	
Acid value	mg KOH/g	-	0.5	EN14104	N/A	
Iodine value	-	-	120	EN14111 EN 16300	N/A	
Linolenic Acid Methylester	%(m/m)	-	12	EN 14103	Already accounted for**	
Polyunsaturated (≥4 double bonds) methyl esters	%(m/m)	-	1	EN 15779	Already accounted for**	
Methanol content	%(m/m)	-	0.2	EN 14110	Yes	22.6
Monoglyceride content	%(m/m)	-	0.7	EN 14105	No	
Diglyceride content	%(m/m)	-	0.2	EN 14105	No	
Triglyceride content	%(m/m)	-	0.2	EN 14105	No	
Free glycerol	%(m/m)	-	0.02	EN 14105 EN 14106	N/A	
Total glycerol	%(m/m)	-	0.25	EN 14105	No	
Group 1 metals (Na+K)	mg/kg	-	5	EN 14108 EN 14109 EN 14538	N/A	
Group 11 metals (Ca+MG)	mg/kg	-	5	EN 14538	N/A	
Phosphorus content	mg/kg	-	4	EN 14107 FprEN 16294	N/A	
Other additives	%(m/m)		3.5		Yes	47.9

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

Appendix 5 – Calculation of Gross Calorific Values (GCV) and fossil fuel energy share of Fatty Acid Methyl Ester (FAME) compounds

A5.1. 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 (as 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 component and fossil fuel component to calculate the proportion of biomass and fossil fuel given in Chapter 4 and Appendix 2.

A5.2. The calculations for each of these steps are given below.

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

A5.3. 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

A5.4. 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.

A5.5. Table 7 shows the number of each type of atom in the FAD within each FAME compound. The same steps have been completed for the methoxy group (first row in Table A4).

Table A4 – the number of atoms present in methoxy group and 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

Example A

Atom type	Carbon	Hydrogen	Oxygen
Atomic mass	12	1	16

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

Mass of FAD 14:0 = (14 x 12) + (27 x 1) + (1 x 16)

Mass of FAD 14:0 = 211 kg/kmol

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

A5.6. This step uses the mass of the FAD and the methoxy group calculated in 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.

$$\textbf{percentage mass of biomass} = 100 \times \frac{\textit{mass of FAD}}{\textit{mass of FAD} + \textit{mass of methoxy group}}$$

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

Example B

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 FAD (biomass) = 211 kg/kmol
Mass of the methoxy group (fossil fuel) = 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 FAME compound

A5.7. Steps 2a and 2b calculate the energy required to break the bonds in the FAME and the energy released when forming the products of combustion. The difference between the two gives the net energy content of the biomass and fossil fuel in the FAME compound (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 net specific energy of the biomass and fossil fuel in the FAME compound.

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

A5.8. 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.

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

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

Example C

The example uses FAD 14:0.

Table 2: 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)

Total input energy = 26478.5 MJ/kmol

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

A5.9. This is the same calculation as 2a but is performed on the products of combustion of the FAD: carbon dioxide and water.

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

[where n = number of bond types in FAD]

Example D

The example uses FAD 14:0

Table 3: 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)

Energy released on combustion = 34,765 MJ/kmol

Step 2c - calculate net energy released from the FAD

A5.10. This simply deducts the total input energy from the energy released on combustion to give the net energy content of the FAD.

$$\textit{theoretical biomass energy content of FAD} = \textit{total energy released from FAD on combustion} - \textit{total input energy required for combustion of FAD}$$

Example E

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

Step 2d - apply correction factor

A5.11. The theoretical bond energy is multiplied by the correction factor of 1/0.923 (1.0834) to make it comparable with results observed through experimentation.

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

Example F

> 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 in FAD 14:0** = 8,286.5 x 1.0834
>
> **Corrected energy content in FAD 14:0** = 8,977.6 MJ/kmol

Step 2e: calculate the GCV of the FAD

A5.12. This step divides the corrected energy content of the FAD by the molecular mass calculated in step 1a to provide the GCV of the biomass in the FAME compound (MJ/kg).

$$\textbf{GCV of FAD} = \frac{\textit{corrected energy content of FAD}}{\textit{molecualr mass of FAD}}$$

<u>Example G</u>

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.

GCV of FAD = 8,977.6/211

GCV of FAD = 42.5 MJ/kg

Step 3: Calculate the GCV of the FAME compound

A5.13. To calculate the energy from the biomass in 1 kg of FAME compound, the GCV of the FAD is multiplied by the mass share of the FAD in the FAME compound. The same calculation is performed to calculate the energy from fossil fuel (the methoxy group) in the FAME compound. The energy from biomass and fossil fuel can then be added together to get an overall GCV of the FAME compound.

A5.14. The energy content of the FAD is as calculated in step 2. The GCV of the methoxy group to be used is 14.8 MJ/kg. This is calculated from the bond energies in the methoxy group and the ester C-O bond between the methoxy group and the FAD (348 MJ/kmol).

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

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

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

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 = 87.19% x 42.5 = 37.1 MJ/kg
Energy from methoxy group = 12.81% 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

A5.15. 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.

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

$$percentage\ of\ fossil\ fuel\ energy = 100 - percentage\ of\ biomass\ energy$$

Example I

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 FAD 14:0 = 100 x (37.1/39.0)
= 95.14%*

Proportion of fossil fuel energy in FAD 14:0 = 100 - 95.14
= 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)
EU	European Union

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

N

NIRO	Northern Ireland Renewables Obligation

O

Ofgem	Office of Gas and Electricity Markets

R

RED	Renewable Energy Directive
RO	Renewables Obligation
ROC	Renewables Obligation Certificate
ROS	Renewables Obligation Scotland