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Supergen Bioenergy Hub

Fuel Standards Summary

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Supergen Bioenergy Hub

Resources

Pre-treatment and conversion

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Introduction

This document aims to provide a comprehensive overview of the standards relating to fuel use in the UK. It can be used to gain an initial insight into which regulations must be considered when developing bio-based alternatives and the potential composition limits to meet current fuel quality specifications. This report has focussed on the fuel quality and composition specification. It must be noted that the complete standards contain further, strict requirements such as testing method and frequency for each composition requirement and reporting requirements. This is in addition to the requirements given in the appendices and therefore complete standards should be used to ensure compliance. Additional sustainability requirements fall outside the scope of this report but their existence in other standards must be acknowledged and adhered to. Standards are regularly updated and continue to evolve as more fuel and biofuel options are developed. Users should check the publishing body website for most up to date issues and to ensure standard status is current.

Table 1 gives an overview of the relevant standards for each fuel subgroup. These will be addressed in more detail in the relevant sections. Full names are given in the references section below. Full copies can be purchased online through BSOL (British Standards Online), ASTM (American Society of Testing and Materials) and ISO (International Organization for Standardization).

Table 1 - Overview of relevant standards

Fuel	Standards (abbreviated titles)
Aviation Fuels	DEF STAN 91-091 Turbine Fuel, Kerosene Type, Jet A- 1; F-35; AVTUR ASTM D1655 - 19a Standard Specification for Aviation Turbine Fuels ASTM D7566 – 20a Aviation Turbine Fuel with Synthesized Hydrocarbons ASTM D6615 Jet B Wide-Cut Aviation Turbine Fuel
Automotive Fuels	BS EN 590:2013+A1:2017 Diesel. Requirements and test methods BS EN 228:2012+A1:2017 Unleaded petrol. Requirements and tests EN 15940:2016 Automotive fuels. Paraffinic diesel fuel from synthesis or hydrotreatment EN 589:2018 Automotive fuels. LPG ASTM D975 Standard Specification for Diesel Fuel
Marine Fuels	BS ISO 8217:2017 Petroleum products. Specifications of marine fuels ISO 8216-1:2017 Petroleum products. Part 1: Categories of marine fuels
Hydrogen	ISO 14687-2:2012 Hydrogen fuel. PEM fuel cell applications for road vehicles ISO 14687-3:2014 Hydrogen fuel. PEM fuel cell applications for stationary appliances ISO 14687:2019 Hydrogen fuel quality - Product specification
General Biofuels	Hydrocarbon Oil Duties Act (HODA) 1979 BS EN14214:2012+A2:2019 Fatty acid methyl esters (FAME) for use in diesel engines and heating applications. Requirements and test methods BS EN 15376: 2014 Ethanol as a blending component for petrol. Requirements and test methods BS EN 15940:2016+A1:2018 Automotive fuels. Paraffinic diesel fuel from synthesis or hydrotreatment. ISO 9162:2013 Petroleum products. Liquefied petroleum gases. ISO 16861:2015 Petroleum products. Specifications of dimethyl ether (DME)
Gas Grid	Gas Safety (Management) Regulations 1996 GS(M)R

Aviation Fuels

DEF STAN 91-091, ASTM D1655-19a, D7566-20a and D6615-15a define the acceptable additives for use in civil operated aircraft internationally. The typical fuels used in civil aviation are Jet A and Jet A-1 with the former usually only available in the USA and the latter widely available outside the USA. DEF STAN 91-091 applies to UK civil jet fuel, although initially developed as a military fuel specification. DEF STAN 91-091 is largely similar to D1655 except for a small number of areas in which it is more stringent. A third grade of jet fuel, Jet B, is the lightest of the three conventional jet fuels, with the lowest freezing temperature of -62˚C. It can be used as an alternative to Jet A-1, however it has a higher flammability making it more difficult to handle. Demand for Jet B is only significant in cold weather climates where better cold weather performance is important. Specifications for Jet B can be found in Table 6 (Appendix A) and ASTM D6615.

The aviation sector continues to play a leading role in driving the development of drop-in biofuels. To be produced in the required volumes for this sector, a co-processing strategy will need to be adopted. However, unless an ASTM standard has been approved for co-processing jet fuel, it will not meet specifications which currently allow 5% vol insertion of vegetable oil with middle distillates in hydroprocessing[1].

DEF STAN 91-091

This standard allows for synthetic jet fuel components derived from non-petroleum sources on a case by case basis, dependent on the initial raw material and production process. The standard was initially developed for fuels derived solely from petroleum sources. A desire to produce renewable jet fuels has led to a widening in interest in both processes and feedstocks. Typically, approval of new fuel components are progressed via ASTM Task Forces and approved as Annexes in ASTM D7566. Tables 3 to 5 in Appendix A outline the composition requirements to meet Def Stan 91-091. Full test requirements and methods, including for the original SASOL (South African Synthetic Oil Limited) approvals and fuels derived from co-hydroprocessed fatty acid esters and fatty acids, should be found in the complete standard. The use of SASOL's unblended coal-to-liquids synthetic jet fuel is approved for commercial use on all types of turbine aircraft[2]. Blends conforming to D7566 are permitted citing this standard as the reference for synthetic jet fuel. Compliance requires the listing of volume percentage of synthetic components, and fuel

[1] IEA Bioenergy. 2019. Task 39 – Drop in Biofuels – The key role that co-processing will play in its production.

traceability requirements that go beyond those in D7566[2]

ASTM D1655 – 19a

Jet A and Jet A-1 represent two grades of kerosene fuel that differ in freezing point. These specifications have evolved primarily as a performance specification rather than a compositional specification. Consequently, it is impossible to define the exact composition of Jet A/A-1. Table 7 in Appendix A lists the detailed requirements the aviation turbine fuel must conform to such as freezing point, viscosity, sulphur content and aromatic content.

Co-processing

It is acceptable to co-process some feedstocks with conventional hydrocarbons under certain conditions. This would produce co-hydroprocessed hydrocarbon synthetic kerosene. The feedstocks must not exceed 5% (by volume) of the process streams in the refinery. The allowable feedstocks for co-processing are mono-, di- and triglycerides free fatty acids, and fatty acid esters. Extended requirements for such fuels (filter pressure drop, viscosity at -40°C, freezing point and unconverted esters and fatty acids content) are given in Table 8, Appendix A.

ASTM D7566 – 20a

This standard covers the manufacture of aviation fuel that consists of conventional and synthetic blending components for use in civil operated engines and aircrafts. It should be noted that fuel approved to meet the requirements of this specification shall also be regarded as meeting the requirements of D1655 and duplicate testing is not required. Requirements are mostly as in Table 4 (D1655-19a) with differences given in Table 9, Appendix A.

Blending Limits

Conventional blending components of Jet A or Jet A-1 with synthetic blending limits are given in Table 2. These limits ensure the appropriate level of safety and compatibility with the aircraft systems, mainly due to levels of aromatics, and meet the density requirements of ASTM D1655[3]. Detailed batch requirements for the synthetic compounds can be found in Tables 10 to 16, Appendix A.

Military Fuels

There are several jet fuel standards to meet military interests including a high flash point fuel for use on aircraft carriers, a wide cut fuel, or a main grade military equivalent of Jet A-1. In the UK these standards are DEF STAN 91-86 (F-44), DEF STAN 91-88 (F-40) and DEF STAN 91-87 (F-34) respectively. Complications can arise with shared distributions systems that can cause trace contamination and operational problems. Standards contain requirements for fuel handling in the distribution chain, in addition to specification and test requirements.

[2] IATA. 2015. IATA Guidance Material for Sustainable Aviation Fuel Management.

[3] GAMA. 2018. Business Aviation Guide: To the Use of Sustainable Alternative Jet Fuel.

Table 2 - Blending limits for aviation turbine fuels

Blending Component	Max % (V/V)
Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosine (FT-SPK)	50
Synthesized Paraffinic Kerosine from Hydroprocessed Esters and Fatty Acids (HEFA SPK)	50
Synthesized Iso-Paraffins from Hydroprocessed Fermented Sugars (HFS SIP)*	10
Synthesized paraffinic kerosene plus aromatics (SPK/A)	50
Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK)**	50
Catalytic Hydrothermolysis Jet (CHJ)	50
Synthesized paraffinic kerosine from hydroprocessed hydrocarbons, esters and fatty acids (HC-HEFA SPK)	10

** also known as Direct Sugars to Hydrocarbons producing Synthetic Iso-Paraffins (SIP)*

*** synthetic blending components shall be comprised of hydroprocessed synthesized paraffinic kerosene wholly derived from ethanol or isobutanol*

Automotive Fuels

The standard specifications of diesel and petrol in the EU are EN 590 and EN 228 respectively. The former allows renewable contributions of up to 7% biodiesel (B7), and in 2013 the maximum level of ethanol permitted in petrol increased from 5% (E5) to 10% (E10) by volume. E5 is supplied alongside E10 for use in vehicles that are not compatible with the higher ethanol blend. In the EU in 2016, 75% of petrol sold was E5, and 9.5% was E10. Of diesel sold, 83.4% was B7 while 16.6% was B+ (which contains more than 7% biodiesel), meaning all diesel sold contained some biodiesel[4]. In the UK, E5 fuel is currently available with a consultation for the introduction of E10 running from March to May 2020. EN 15940 and EN 589 give the requirements for paraffinic diesel fuel and LPG (Liquified Petroleum Gas) as automotive fuel, respectively.

It should be noted that high incentives have been introduced for suppliers to produce development 'drop-in fuels'. These will be renewable transport fuels that can be blended at higher rates than conventional biodiesel or bioethanol, meeting specifications in EN 590 and EN228. Feedstocks will not necessarily be bio-based and may include waste tyres, waste wood or refuse derived fuels[5]. The Renewable Energy Directive states that greenhouse gas emission savings from the use of biofuels, bioliquids and biomass fuels in the transport sector shall be at least 60% in installations in operation before 5 October 2015 and 65% from 1 January 2021.

EN 590

This standard specifies the requirements and test methods for marketed and delivered automotive diesel fuels, full details of which can be found in Table 17, Appendix B. It includes cetane number, density, and sulphur and manganese content amongst other properties. There are different requirements for arctic or severe weather climates which can be found in the complete standard.

Other Components

Diesel fuel may contain up to 7.0% (V/V) of FAME complying with EN 14214:2012+A1:2014 (see below). Limits for FAME do not apply to other (non-petroleum derived) hydrocarbons such as Hydrotreated Vegetable Oil (HVO), Gas to Liquid (GTL) or Biomass to Liquid (BTL) derived hydrocarbons, since these paraffinic diesel compounds are allowed in any proportions provided that the final blend complies with the requirements of EN 590. The co-processing of renewable feedstock at refineries is also allowed provided the final fuel meets these requirements.

[4] EEA. 2017. Fuel quality in the EU in 2016. Fuel quality monitoring under the Fuel Quality Directive.

[5] Department for Transport. 2020. RTFO Guidance Part One. Process Guidance

EN 228

This standard specifies two types of unleaded petrol, one with a maximum oxygen content of 3.7% (m/m) and maximum ethanol content of 10.0 % (V/V) and one type that is intended for older vehicles (max oxygen of 2.7%) that are not warranted to use petrol with a high biofuel content. Tables 18 and 19 in Appendix B give the full requirements for each fuel respectively including but not limited to; research octane number, motor octane number and sulphur, oxygen and oxygenate content. Where a property is not listed in Table 19, it is unchanged from Table 18. Additionally, it must be noted that compounds containing phosphorous shall not be added to unleaded petrol (in order to protect catalyst systems). The volatility classes for both fuels can be found in the complete standard.

Bio-components

Unleaded petrol may contain up to 10.0% (V/V) of ethanol complying with EN 15376 (see below). When ethanol is used as a blending component, it may contain denaturants if required by EU and national regulations; these are permitted provided they do not cause harmful side effects to vehicles and fuel distribution systems. A traceable record of biological origin is recommended. Limits given in Tables 18 and 19 do not apply to other hydrocarbons, such as synthetic hydrocarbons and other renewable hydrocarbons, since these components are allowed in any proportion provided that the final blend complies with the requirements of EN 228. The co-processing of renewable feedstock at refineries is also allowed provided that the final fuel meets these requirements.

EN 15940

This is a specification for automotive paraffinic diesel fuels and therefore applies to HVO (Hydrotreated Vegetable Oil) and XTL (synthetic diesel fuel including: Biomass to Liquid, Gas to Liquid and Coal to Liquid). Paraffinic diesel fuel does not always meet the requirements of standard EN590 and therefore two classes have been identified, with one showing improved ignition quality compared to automotive diesel fuel meeting EN 590. Table 20, Appendix B gives the requirements for class A (high cetane) and class B (normal cetane). Paraffinic diesel fuel may contain up to 7.0% (v/v) FAME complying with EN 14214. Paraffinic diesel fuel is also used as a blending component in automotive diesel and in that case does not have to meet EN15940 requirements.

EN 589

EN 589 gives the requirements and test methods for LPG as an automotive fuel, given in Table 21, Appendix B. LPG is defined as low pressure liquified gas consisting predominantly of propane and butanes with small proportions of propene, butenes, and pentanes/pentenes. BioLPG is chemically equivalent and presents a non-intrusive ‘drop-in’ solution to decarbonisation targets. It should be noted that the UK committee voted against the approval of this standard as it references ASTM D6667-14 for the testing of total volatile sulphur in LPG. EN 589:2018 is current and under review.

ASTM D975

ASTM Standards apply to the US whilst the EN standards covered previously apply to the UK. ASTM D975 covers seven grades of diesel fuel oils suitable for various types of engines. Grade No. 1-D S15, Grade No. 1-D S500 and Grade No. 1-D S5000 are special-purpose, light middle distillate fuels for use in diesel engine applications requiring maximum sulphur concentrations of 15, 500 and 5000 ppm respectively and higher volatility than their Grade No. 2 counterpart. Grade No. 2-D S15, Grade No. 2-D S500, Grade No. 2-D S5000 are general-purpose, middle distillate fuels for use in diesel engine applications requiring maximum sulphur concentrations of 15, 500 and 5000 ppm sulphur respectively. They are especially suitable for use in applications with conditions of varying speed and load. Grade No. 4-D is a heavy distillate fuel, or a blend of distillate and residual oil, for use in low- and medium-speed diesel engines in applications involving predominantly constant speed and load. Detailed requirements for all seven grades can be found in Table 22, Appendix B.

Marine Fuels

Fuels used in international maritime transport are regulated by the International Maritime Organisation (IMO). From January 2020 the IMO reduced the limit on sulphur in fuel oil from 3.5% (m/m) to 0.5% (m/m). This will significantly reduce the amount of sulphur oxide emanating from ships and aims to achieve major health and environmental benefits. One opportunity to reach this is to more widely consider distillate marine fuels containing FAME. This will bring specific complications with regards to storage and handling that must be considered including: a tendency to oxidation and long-term storage issues, risk of microbial growth and FAME material deposition on exposed surfaces such as filter elements. Within the UK the specific requirements for marine fuels are set out in BS ISO 8217:2017.

IMO Regulations 2020

IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. They are responsible for setting and implementing a regulatory framework for the industry. To significantly reduce the amount of sulphur oxides emanating from ships, the International Maritime Organization (IMO) has set a global limit for sulphur in fuel oil onboard ships of 0.5 % m/m (mass by mass) by 2020. One method to achieve this is to consider bio-derived fuels and blends of bio-derived fuels with petroleum products as alternate energy sources. Further information can be found at www.imo.org.

ISO 8217

This standard gives the requirements for marine fuels prior to conventional onboard treatments. It considers the increasing demands of environmental legislation and incorporates a diverse range of fuel categories of distillate and residual fuels. The status of this standard is current and under review. Seven categories of distillate fuels and six categories of residual fuels are specified which are defined in ISO 8216. The DF grades include up to 7.0 %(v/v) FAME that is in accordance with EN 14214. Requirements including, but not limited to: viscosity, density, flash point, hydrogen sulphide content and specific energy are given for each fuel category and should be found in the complete standard.

Hydrogen Fuels

Hydrogen has the potential to decarbonise electricity generation, transport and heat. It can be generated by steam reforming of natural gas, electrolysis of water, gasification, extraction of 'bio-hydrogen' from biogas and as a by-product of larger industrial chemical processes[6]. Each method may introduce its impurities, and international standards are required to define the minimum quality requirements, but they do not currently apply to all production methods. Currently, silicon levels are not addressed within ISO 14687:2019 which states, "Biological sources of hydrogen can contain additional constituents (e.g. siloxanes or mercury) that can affect the performance of the various applications, particularly PEM fuel cells. However, these are not included in most of the following specifications due to insufficient information". This would need to be included if the standards were to extend to biological sources of hydrogen.

ISO 14687

With recent progress in PEM (proton exchange membrane) fuel cell technology, it became necessary to reconsider tolerances of hydrogen impurities for the PEM fuel cells which were previously specified in ISO 14687-2:2012 and ISO 14687-3:2014. This revision has been in the form of standard ISO 14687:2019. The grade D and grade E of this standard is intended to apply to PEM fuel cells for road vehicles and stationary appliances respectively. This is a rapidly developing area, and it has been noted that standards may need to be further reviewed in the future according to technological progress.

The classification of fuels, according to the ISO standards, shall be as follows:

- Type I (grades A, B, C, D and E): gaseous hydrogen and hydrogen-based fuels
- Type II (grades C and D): liquid hydrogen
- Type III: slush hydrogen

The requirements for hydrogen fuel vary dependent on application. Tables 23 to 25, Appendix C give the minimum quality characteristics for hydrogen fuel as distributed for use in vehicular, stationary and all other applications. These characteristics include hydrogen fuel index, oxygen, nitrogen and argon content amongst other properties.

The following subcategories are used to specify the requirements of different stationary applications (Table 24):

- Type I, grade E, category 1: hydrogen-based fuel: high efficiency/low power applications

[6] NPL. 2017. Energy transition: measurement needs within the hydrogen industry.

- Type I, grade E, category 2: hydrogen-based fuel: high power applications
- Type I, grade E, category 3: gaseous hydrogen: high power/high efficiency applications

The following subcategories are used to specify the requirements for other applications (Table 25):

- *Type I, grade A*: gaseous hydrogen - internal combustion engines for transportation, residential/commercial combustion appliances
- *Type I, grade B:* gaseous hydrogen - industrial fuel for power generation and heat generation except PEM fuel cell applications
- *Type I, grade C:* gaseous hydrogen - aircraft and space-vehicle ground support systems except PEM fuel cell applications
- *Type II, grade C:* liquid hydrogen - aircraft and space-vehicle on-board propulsion and electrical energy requirements, off-road vehicles
- *Type III*: slush hydrogen - aircraft and space-vehicle on-board propulsion

General Biofuels

The two most widely used types of biofuels are ethanol and biodiesel. The use of biodiesel as a low blend component, blends up to B7, in transport fuel is covered under EN 590. Most biodiesel in use consists of fatty acid methyl esters (FAME) which are produced by the transesterification of plant oils with methanol[7]. The requirements for FAME are covered under EN 14214.

Ethanol is a renewable fuel that can be made from plant starches and sugars. It can be blended with gasoline to increase octane. The most common blends of ethanol are E5 and E10 (the maximum blend allowed under EN 228). Ethanol used for this purpose shall conform to EN 15376. Standards ISO 9162 and ISO 16861 give the requirements for LPG and DME (dimethyl ether). The Bio-alternatives to these fuels are chemically indistinct and can be easily blended with existing supply to present a 'drop-in' alternative.

HODA

The Hydrocarbon Oil Duties Act (HODA) consolidates the enactments related to exercising duties on hydrocarbon oil, petrol substitutes, power methylated spirits and road fuel gas. Whilst much of this lies outside the scope and purpose of this report it does offer descriptions for fuels to be considered as biodiesel (2AA) or bioethanol (2AB).

2AA: In this act biodiesel means diesel quality liquid fuel:

(a) That is produced from biomass or waste cooking oil
(b) The ester content of which is not less than 96.5% by weight, and
(c) The sulphur content of which does not exceed 0.005% by weight

In subsection (1):
(i) "Diesel quality" means capable of being used for the same purposes as heavy oil;
(ii) "Liquid" does not include any substance that is gaseous at a temperature of 15°C and under a pressure of 1013.25 millibars;
(iii) "Biomass" means vegetable and animal substances constituting the biodegradable fraction of:
Products, wastes and residues from agriculture, forestry and related activities, or
Industrial and municipal waste.

2AB: In this Act "bioethanol" means a liquid fuel:
(a) Consisting of ethanol produced from biomass, and
(b) Capable of being used for the same purposes as light oil.
In subsection (1):
(ii) and (iii) as above

[7] Sherkhanov, S., Korman, T, P., Clarke, S, G., Bowie, J, U., 2016. Production of FAME biodiesel in E. coli by direct methylation with an insect enzyme. *Sci Rep.* **6**(24239).

EN 14214

This standard details the requirements for fatty acid methyl esters (FAME) for use in automotive diesel engines and heating applications. The characteristics, such as FAME content, density, flash point and methanol and sulphur content are given in Table 26, Appendix D. Biodiesels produced using other alcohols (for example ethanol) are not covered by this standard. When used for heating purposes, either at 100% or as a blend component, FAME shall have a minimum net calorific value of 35MJ/kg determined by DIN 51900-2 or DIN51900-3.

EN 15376

This standard details the requirements for ethanol used as a blending component for automotive fuel for petrol given in Table 27, Appendix D. It includes composition requirements such as ethanol, higher saturated mono-alcohols, methanol and water content amongst other properties and composition limits. The composition of any denaturant(s) is at the discretion of national authorities and should not be in contradiction with EN 228 requirements.

ISO 9162

ISO 9162 gives the required characteristics for liquefied petroleum gases and is intended to apply to international transfers of commercial propane and butane, Table 28 Appendix D. Bio-propane and bio-butane will be molecularly identical to the fossil equivalent and should conform to the standards associated with LPG supply and usage.

ISO 16861

This standard covers DME for use as a transport fuel or a heating fuel. BioDME is a gas at ambient temperature but relatively easily liquified at low pressure, like bioLPG. Up to 20% bioDME could be blended with bioLPG with no modifications needed to the boiler or fuel storage and handling system[8]. Blends above this may require further adaptations. Requirements for DME can be found in Table 29, Appendix D.

[8] NNFCC, 2019. Evidence gathering for off-grid bioliquid heating options.

Gas Grid

The standard for quality of gas in the gas grid is the Gas Safety (Management) Regulations GS(M)R which applies to the supply of natural gas (mainly methane) through pipes to domestic and other consumers. This covers gas composition, safe management of gas flow, emergency supply arrangements and arrangements for gas escapes and incidents.

Biogas produced from anaerobic digestion contains a lower methane percentage than natural gas. For injection into the grid this is upgraded, and methane content is enriched up to 98% and impurities such as carbon dioxide, which can reduce the calorific value of the gas, are removed. Once removed the biomethane must be blended with a gas with a higher energy content than natural gas (mostly propane) to reach the calorific value stipulated by the local gas distributor (about 39.5MJ/m^3)[9]. The Gas Calculation of Thermal Energy Regulations (GCOTER) dictate the necessary calculations and definitions required to ensure that the flow-weighted average calorific value requirements are being met[10]. A biomethane network entry facility (BNEF) is required to ensure the biomethane is compliant with the regulations of GSM(R), (GCOTER) and the network entry agreement.

The UK currently has no specification for hydrogen injected into the grid with the UK currently permitting 0.1%vol hydrogen in the network despite formerly distributing town gas with 40-60% vol hydrogen. The evidence base suggests that blending should be feasible at between 10-20% vol hydrogen that would equate to 15-29TWh pa of decarbonized heat[11]. The Institute of Gas Engineers and Managers (IGEM) is seeking to change the specification of gas that is permitted for use under the GS(M)R to allow for increased use of imported gas and low carbon alternatives such as hydrogen[12].

GS(M)R

Table 30, Appendix E gives detailed requirements for the content and characteristics of the gas. This includes sulphur, oxygen and hydrogen content, Wobbe Number (WN), incomplete combustion factor (ICF) and soot index amongst other properties and is valid for all cases other than an emergency. In the case of emergency prevention, this changes to allow a WN ≥46.50 MJ/m^3 and ≤52.85 MJ/m^3 and an ICF ≤1.49.

[9] Flogas. The Propane Enrichment of Biomethane – The Future of Energy Supply
[10] Northern Gas Networks. 2015. Biomethane: A Producer's handbook.
[11] 2018. Cadent. Gas NIC Submission: HyDeploy2 Full Submission. Available from: https://www.ofgem.gov.uk/publications-and-updates/gas-nic-submission-cadent-hydeploy2
[12] IGEM. Gas Quality Working Group. Available from: https://www.igem.org.uk/technical-services/gas-quality-working-group/

Registry

REACH Registration

REACH is a regulation of the European Union that was adopted to improve the protection of human health and the environment from risks posed by chemicals, and to increase competitiveness of the EU chemicals industry. REACH applies to all chemical substances, from industry to day-to-day life, that are imported or manufactured in quantities of 1 tonne or more per year. The regulation places the burden of proof on companies who must identify and manage the risks related to the substances they manufacture and market in the EU. REACH establishes procedures for collecting and assessing information on the properties and hazards of substances which could then be banned if risks are viewed as unmanageable.

An overview of the REACH registration process is given below:

1. Pre-registration.
2. Registration. This includes gathering and evaluating data, identifying gaps and preparing technical dossiers and chemical safety reports
3. Evaluation. ECHA (European Chemicals Agency) will conduct completeness checks and full evaluations
4. Authorisation. Substances identified as very high concern will be subject to authorisation
5. Restriction. Substances shall not be manufactured, placed on market or used unless they comply with the conditions of restriction (if applicable).

The Ministry of Defence (MOD) is committed to complying with the REACH regulation but where necessary in the interest of defence, can seek an exemption from the Secretary of State. In these cases, the MOD will introduce internal standards.

CAS Registry

CAS (Chemical Abstracts Service) registry is the most authoritative collection of disclosed chemical substance information. Each substance is assigned a unique identification number which links to a wealth of information about that specific substance. CAS numbers identify the chemical but not specific concentration or mixture. This makes it easier for regulatory bodies despite the large number of synonyms and trade names in use. The CAS number for bioethanol will be the same as ethanol. To obtain a CAS registry number, application forms and an associated fee must be submitted to the CAS Inventory Expert Service or the Chemist Consultation Service.

Conclusions

This report has given a brief overview of the key standards and composition requirements that will apply when developing bio-based fuel alternatives. In some cases, current regulations do not fully extend to biofuels (ISO 14687). In the case of aviation fuels, a new process must undergo a lengthy approval process to be recognised by D7566. However, the explored regulations do highlight the minimum quality requirements which would have to be met, although it is accepted that biofuels may have to go further still, for example with additional composition limits such as silicon.

Detailed requirements have been given in the relevant appendices, and test methods can be found through the full standards linked in Table 1. It must also be noted that additional sustainability requirements, outside the scope of this report, will apply to any bio-based fuel alternatives. Standards are regularly updated and publishing body websites should be checked to ensure this document references the most up to date issue.

Standards referenced

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BS EN 228:2012+A1:2017 Automotive fuels. Unleaded petrol. Requirements and test methods. BSI, 2017. London: BSI. https://shop.bsigroup.com/ProductDetail/?pid=000000000030242771

BS EN 15940:2016+A1:2018 Automotive fuels. Paraffinic diesel fuel from synthesis or hydrotreatment. Requirements and test methods. BSI, 2018. London: BSI. https://shop.bsigroup.com/ProductDetail?pid=000000000030393612

BS EN 589:2018. Automotive Fuels. LPG. Requirements and test methods. BSI, 2018. London: BSI. https://shop.bsigroup.com/ProductDetail?pid=000000000030347788

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BS ISO 8217:2017. Petroleum products — Fuels (class F) — Specifications of marine fuels. ISO, 2017. London: BSI. https://www.iso.org/standard/64247.html

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Appendix A – Aviation Fuels

Table 3 - Def Stan 91-091 Abbreviated table of requirements

Property	Unit	Min	Max
Total acidity	mg KOH/g		0.015
Aromatic hydrocarbon types			
Aromatics	% (v/v)		25.0
Or total aromatics	% (v/v)		26.5
Sulphur, total	% (m/m)		0.30
Sulphur, mercaptan	% (m/m)		0.0030
Doctor test		Doctor Negative	
Distillation temperature:			
10% recovery	°C		205.0
End point	°C		300.0
Distillation residue	% (v/v)		1.5
Distillation loss	% (v/v)		1.5
Flash point	°C	38.0	
Density at 15°C	Kg/m^3	775.0	840.0
Freezing point	°C		-47.0
Viscosity at -20°C	mm^2/s		8.000
Smoke point	mm	25.0	
Or Smoke point and	mm	18.00	
naphthalenes	%(v/v)		3.00
Specific energy	MJ/kg	42.8	
Copper strip corrosion	Class		1
Test temperature tube rating	°C	260	
Existent gum	Mg/100ml		7
Microseparometer, at Point of Manufacture:			
MSEP without SDA	Rating	85	
MSEP with SDA	Rating	70	
Electrical conductivity	pS/m	50	600
Lubricity: Wear scar diameter	mm		0.85

Sasol semi-synthetic jet fuels

- Aromatic content 8.0% ≤ 25.0% by volume (IP156) and 8.4% ≤ 26.5% by volume (IP436) with analysis at point of manufacture
- The amount of synthetic fuel in the final blend shall not exceed 50% by volume
- If used in combination with the Sasol HN1, the final synthetic blend shall contain at least 25% IPK by volume. IPK blends shall meet requirements in table 4

Table 4 - Batch Requirements for HN1/IPK Blend (Def Stan 91-091)

Property	**Unit**	**Min**	**Max**
Test temperature	°C	325	
Tube rating visual		Less than 3. No Peacock (P) or Abnormal (A)	
Pressure differential	mmHg		25
Freezing point	°C		-40.0
Specific energy	MJ/kg	42.80	
Aromatics	% (v/v)		7.0
Or Total Aromatics	% (v/v)		7.4

Sasol fully synthetic jet fuels

- Aromatic content 8.0% ≤ 25.0% by volume (IP156) and 8.4% ≤ 26.5% by volume (IP436) with analysis at point of manufacture
- The flash point shall be no greater than 50°C
- The boiling point distribution shall have a minimum slope defined by T50-T10 ≥ 10°C and T90-T10 ≥ 40°C (IP123 / ASTM D86)

Co-processing

- The co-processing refinery units shall not exceed 5 percent by volume of mono-, di-, and triglycerides, free fatty acids and fatty acid esters in feedstock volume, with the balance being conventional sources. (Table 5)

Table 5 - Extended Requirements of Aviation Turbine Fuels Containing Co-hydroprocessed Fatty Acid Esters and Fatty Acids (Def Stan 91-091)

Property	**Unit**	**Min**	**Max**
Test temperature	°C	280	
Pressure differential	mmHg		25
Freezing point	°C		-47.0
Viscosity at minus 40°C	mm^2/s		12.0
Unconverted fatty acid esters and fatty acids	mg/kg		15

Table 6 - Detailed requirements for Jet B aviation fuel D6615-15a (US based)

Property	Unit	Minimum	Maximum
Aromatics, one of the following	% (v/v)		
(1) aromatics*			25
(2) aromatics**			26.5
Sulphur, mercaptan	% (m/m)		0.003
Sulphur, total	% (m/m)		0.30
Distillation temperature	°C		
20% recovered, temp		90	145
50% recovered, temp		110	190
90% recovered, temp			245
Distillation residue	%		1.5
Distillation loss	%		1.5
Density at 15°C	kg/m^3	751	802
Vapour pressure, 38°C	kPa	14	21
Freezing point	°C		-50
Viscosity at -20°C	mm^2/s		8.0
Net heat of combustion	MJ/kg	42.8	
One of the following:			
(1) smoke point	mm	25.0	
(2) smoke point and naphthalenes	mm and	18.0	
	vol, %		3.0
Copper strip, 2h at 100°C			No. 1
Filter pressure drop	mm Hg		25
Existent gum	mg/100mL		7
Microseparometer rating			
(1) without electrical conductivity additive		85	
(2) with electrical conductivity additive		70	
Antioxidants (one from list below)	mg/L		24.0
N,N-disalicylidene-1,2-propane diamine	mg/L		
(1) on initial blending			2.0
(2) after field re-blending cumulative concentration			5.7
Fuel system icing inhibitor	% (v/v)	0.10	
Diethylene glycol monomethyl ether	% (v/v)		0.15
Electrical conductivity improver	mg/L		
(2) Stadis 450			
On initial blending			3
After field reblending, cumulative concentration			5

Leak detection additive	mg/kg	1
Corrosion inhibitor, one of the following:	mg/L	
(1) HiTEC 580		23
(2) Octel DCI-4A		23
(3) Nalco 5403		23

* Test method: D1319

** Test method: D6379

Antioxidants

- 2,6 ditertiary-butyl phenol
- 2,6 ditertiary-butyl-4-methyl phenol
- 2,4 dimethyl-6-tertiary-butyl-phenol
- 75 % minimum, 2,6 ditertiary-butyl phenol plus
  25 % maximum mixed tertiary and tritertiary butyl-phenols
- 55 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus
  15 % minimum 2,6 ditertiary-butyl-4-methyl phenol,
- remainder as monomethyl and dimethyl tertiary-butyl phenols
- 72 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus
  28 % maximum monomethyl and dimethyl-tertiary-butyl-phenols

Table 7 - Detailed requirements of aviation turbine fuels D1655 – 19a (US based)

Property	Unit	Minimum	Maximum
Acidity	mg KOH/g		0.10
Aromatics, one of the following	% (v/v)		
(1) aromatics*			25
(2) aromatics**			26.5
Sulphur, mercaptan	% (m/m)		0.003
Sulphur, total	% (m/m)		0.30
Distillation temperature 10%	°C		
Recovered, temp			205
Final boiling point, temp			300
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	775	840
Freezing point	°C		-40 JetA -47 Jet A-1
Viscosity at -20°C	mm^2/s		8.0
Net heat of combustion	MJ/kg	42.8	
One of the following:			
(1) smoke point	mm	25.0	
(2) smoke point and naphthalenes	mm and vol, %	18.0	 3.0
Copper strip, 2h at 100°C			No. 1
Filter pressure drop	mm Hg		25
Existent gum	mg/100mL		7
Microseparometer rating			
(1) without electrical conductivity additive		85	
(2) with electrical conductivity additive		70	
Antioxidants (one from list below)	mg/L		24.0
N,N-disalicylidene-1,2-propane diamine	mg/L		
(1) on initial blending			2.0
(2) after field re-blending cumulative concentration			5.7
Fuel system icing inhibitor	% (v/v)	0.07	
Diethylene glycol monomethyl ether	% (v/v)		0.15
Electrical conductivity improver, one of the following:	mg/L		
(1) AvGuard SDA			
On initial blending			3

After field re-blending, cumulative concentration		5
(2) Stadis 450l, m		
On initial blending		3
After field reblending, cumulative concentration		5
Leak detection additive	mg/kg	1
Corrosion inhibitor, one of the following:	mg/L	
(1) HiTEC 580		23
(2) Innospec DCI-4A		23
(3) Nalco 5403		23
Fatty acid methyl ester (FAME)	mg/kg	50
Pipeline drag reduction additive (DRA)	µg/L	72

* Test method: D1319/IP 156

** Test method: D6379/IP 436

Antioxidants

- 2,6 ditertiary-butyl phenol
- 2,6 ditertiary-butyl-4-methyl phenol
- 2,4 dimethyl-6-tertiary-butyl-phenol
- 75 % minimum, 2,6 ditertiary-butyl phenol plus
  25 % maximum mixed tertiary and tritertiary butyl-phenols
- 55 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus
  15 % minimum 2,6 ditertiary-butyl-4-methyl phenol,
- remainder as monomethyl and dimethyl tertiary-butyl phenols
- 72 % minimum 2,4 dimethyl-6-tertiary-butyl phenol plus
  28 % maximum monomethyl and dimethyl-tertiary-butyl-phenols

Table 8 - Extended requirements of aviation turbine fuels containing co-hydroprocessed Esters and Fatty Acids

Property	Unit		Jet A or Jet A-1
Filter pressure drop	mm Hg	max	25
Viscosity at -40°C	mm^2/s	max	12.0
Freezing point	°C	max	
Unconverted esters and fatty acids	mg/kg	max	15

Table 9 – Requirement variations for conformance with ASTM D7566 (US based)

Property	Unit		Jet A or Jet A-1
Aromatics	% V/V	min	8* 8.4**
Viscosity at -40°C	mm^2/s	max	12
Distillation T50-T10	°C	min	15
T90-T10			40
Lubricity	mm	max	0.85

* Test method: D1319 or IP156

** Test method: D6379/IP436

Aviation batch requirements for use as synthetic blending component in aviation turbine fuels

FT SPK

Table 10 - Detailed batch requirements for Fischer-Tropsch Hydroprocessed SPK

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T90-T10	°C	22	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	730	770
Freezing point	°C		-40
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
Cycloparaffins	% (m/m)		15
Aromatics	% (m/m)		0.5
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

HEFA SPK

Table 11 - Detailed batch requirements for SPK from hydroprocessed esters and fatty acids

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T90-T10	°C	22	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	730	772
Freezing point	°C		-40
Existent gum	mg/100mL		7
FAME	mg/kg		<5
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
Cycloparaffins	% (m/m)		15
Aromatics	% (m/m)		0.5
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

SIP

Table 12 - Detailed batch requirements for SIP from hydroprocessed fermented sugars

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		250
Final boiling point	°C		255
T90-T10	°C		5
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	100	
Density at 15°C	kg/m^3	765	780
Freezing point	°C		-60
Existent gum	mg/100mL		7
Microseparometer rating without electrical conductivity additive		85	
Thermal stability (2.5h at control temp)	°C	355	
Filter pressure drop	mm Hg		25
Net heat of combustion	MJ/kg	43.5	
Antioxidant additives	mg/LH	17	24
Saturated hydrocarbons, mass percent	% (m/m)	98	
Farnesane, mass percent		97	
Hexahydrofarnesol	% (m/m)		1.5
Olefins	$mgBr_2/100$ g		300
Aromatics	% (m/m)		0.5
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		2
Metals	ppm		0.1 per metal
Halogens	mg/kg		1 per halogen

SPK/A

Table 13 - Detailed batch requirements for SPK/A

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Aromatics	% (v/v)		20* 21.2**
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T90-T10	°C	22	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	755	800
Freezing point	°C		-40
Existent gum	mg/100mL		4
MSEP		90	
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
Cycloparaffins	% (m/m)		15
Aromatics	% (m/m)		20
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

* Test method D1319/IP 156

** Test method D6379/IP 436

ATJ-SPK

Table 14 - Detailed batch requirements for Alcohol-to-Jet (ATJ-SPK)

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T90-T10	°C	21	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	730	770
Freezing point	°C		-40
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
Cycloparaffins	% (m/m)		15
Aromatics	% (m/m)		0.5
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

CHJ

Table 15 - Detailed batch requirements for CHJ from fatty acid esters and fatty acids

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T50-T10	°C	15	
T90-T10	°C	40	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	775	840
Freezing point	°C		-40
Existent gum	mg/100mL		7
FAME	mg/kg		<5
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
One of the following:			
(1) aromatics, volume percent	% (v/v)	8	20
(2) aromatics, mass percent	% (m/m)	8.4	21.2
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

HC-HEFA SPK

Table 16 - Detailed batch requirements for SPK from hydroprocessed hydrocarbons, esters and fatty acids

Property	Unit	Minimum	Maximum
Acidity, total	mg KOH/mg		0.015
Distillation temperature, 10% recovered	°C		205
Final boiling point	°C		300
T90-T10	°C	22	
Distillation residue	%		1.5
Distillation loss	%		1.5
Flash point	°C	38	
Density at 15°C	kg/m^3	730	800
Freezing point	°C		-40
Smoke point	mm	25.0	
Existent gum	mg/100mL		7
FAME	mg/kg		<5
Thermal stability (2.5h at control temp)	°C	325	
Filter pressure drop	mm Hg		25
Antioxidant additives	mg/L	17	24
Cycloparaffins	% (m/m)		50
Aromatics	% (m/m)		0.5
Carbon and hydrogen	% (m/m)	99.5	
Nitrogen	mg/kg		2
Water	mg/kg		75
Sulphur	mg/kg		15
Metals	mg/kg		0.1 per metal
Halogens	mg/kg		1

Appendix B – Automotive Fuels

Table 17 – Requirements for automotive diesel fuel (EN 590)

Property	Unit	Minimum	Maximum
Cetane number		51.0	
Cetane index		46.0	
Density at 15°C	kg/m^3	820.0	845.0
Polycyclic aromatic hydrocarbons	% (m/m)		8.0
Sulphur content	mg/kg		10.0
Manganese content	mg/l		2.0
Flash point	°C	Above 55.0	
Carbon residue (on 10% distillation residue)	% (m/m)		0.30
Ash content	% (m/m)		0.010
Water content	% (m/m)		0.020
Total contamination	mg/kg		24
Copper strip corrosion	rating	class 1	
FAME content	% (V/V)		7.0
Oxidation stability	g/m^3		25
	h	20	
Lubricity, wear scar diameter at 60°C	µm		460
Viscosity at 40°C	mm^2/s	2.000	4.500
Distillation			
Recovered at 250°c	% (V/V)		<65
Recovered at 350°c	% (V/V)	85	
95% (v/v) recovered at	°C		360

Table 18 - Requirements for unleaded petrol with maximum oxygen content of 3.7% (m/m) (EN 228)

Property	Unit	Minimum	Maximum
Research octane number, RON		95.0	
Motor octane number, MON		85.0	
Lead content	mg/l		5.0
Density at 15°C	kg/m^3	720.0	775.0
Sulphur content	mg/kg		10.0
Manganese content	mg/l		2.0
Oxidation stability	minutes	360	
Existent gum content	mg/100ml		5
Copper strip corrosion	rating	class 1	
Hydrocarbon type content	% (V/V)		
Olefins			18.0
Aromatics			35.0
Benzene content	% (V/V)		1.00
Oxygen content	% (m/m)		3.7
Oxygenates content	% (V/V)		
- methanol			3.0
- ethanol			10.0
- iso-propyl alcohol			12.0
- iso-butyl alcohol			15.0
- tert-butyl alcohol			15.0
- ethers (5 or more C atoms)			22.0
- other oxygenates			15.0

Table 19 - Requirements for unleaded petrol with maximum oxygen content of 2.7% (m/m) (EN 228)

Property	Unit	Minimum	Maximum
Oxygen content	% (m/m)		2.7
Oxygenates content	% (V/V)		
- methanol			3.0
- ethanol			5.0
- Iso-propyl alcohol - iso-butyl alcohol - tert-butyl alcohol - ethers (5 or more C atoms) - other oxygenates		Volume blending restricted to 2.7% (m/m) maximum oxygen content	

Table 20 – Generally applicable requirements for paraffinic diesel fuel from synthesis or hydrotreatment (EN 15940)

Property	**Unit**	**Class A**	**Class B**
Cetane number		Min 70.0	Min 51.0
Density at 15°C	kg/m^3	765.0-800.0	780.0-810.0
Flash point	°C	Above 55.0	Above 55.0
Viscosity at 40°C	mm^2/s	2000-4500	2000-4500
Distillation	%	<65	<65
Recovered at 250°C	% (v/v)	Min 85	Min 85
Recovered at 350°C	% (v/v)	Max 360.0	Max 360.0
95% recovered at	°C		
Lubricity, wear scar diameter at 60°C	µm	Max 460	Max 460
FAME content	% (v/v)	Max 7.0	Max 7.0
Manganese content	mg/l	Max 2.0	Max 2.0
Total aromatics content	% (m/m)	Max 1.1	Max 1.1
Sulphur content	mg/kg	Max 5.0	Max 5.0
Carbon residue (on 10% distillation residue)	% (m/m)	Max 0.30	Max 0.030
Ash content	% (m/m)	Max 0.010	Max 0.010
Water content	% (m/m)	Max 0.020	Max 0.020
Total contamination	mg/kg	Max 24	Max 24
Copper strip corrosion (3h at 50°C)	rating	class 1	class 1
Oxidation stability	g/m^3	Max 25	Max 25
	h	Min 20.0	Min 20.0

Table 21 – Composition requirements for automotive LPG (EN 589)

Property	Unit	Minimum	Maximum
Motor octane number, MON		89.0	
Total dienes content	% (m/m)		0.5
1,3 Butadiene	% (m/m)		0.10
Propane content	% (m/m)		
until 2022-04-30		20	
until 2022-05-01		30	
Hydrogen sulphide		negative	
Total sulphur content	mg/kg		30
Copper strip corrosion (1h at 40°C)	rating	class 1	
Evaporation residue	mg/kg		60
Vapour pressure, gauge at 40°C	kPa		1550
Vapour pressure, gauge, min 150kPa at a temperature of:	°C		
for grade A			-10
for grade B			-5
for grade C			0
for grade D			+10
for grade E			+20
Water content		pass	
Odour		unpleasant and distinctive at 20% LFL	

Table 22 - Detailed requirements for diesel fuel types (ASTM D975 – US based)

Property	**Grade**						
	No. 1-D S15	No. 1-D S500	No. 1-D S5000	No. 2-D S15	No. 2-D S500	No. 2-D S5000	No. 4-D
Flash point, °C, min	38	38	38	52	52	52	55
Water and sediment, % volume, max	0.05	0.05	0.05	0.05	0.05	0.05	0.50
Distillation temperature, °C 90%, % volume recovered min max	- 288	- 288	- 288	282 338	282 338	282 338	- -
Kinematic viscosity, mm^2/S at 40°C min max	1.3 2.4	1.3 2.4	1.3 2.4	1.9 4.1	1.9 4.1	1.9 4.1	5.5 24.0
Ash percent mass, max	0.01	0.01	0.01	0.01	0.01	0.01	0.10
Sulphur, ppm (µg/g) max percent, max	15*	0.05**	0.50**	15*	0.05**	0.50**	2.00**
Copper strip corrosion rating, max	No 3	No 3	No 3	No 3	No 3	No 3	-
Cetane number, min	40	40	40	40	40	40	30
One of the following: (i) cetane index, min (ii) aromatically, percent volume, max	40 35	40 35	- -	40 35	40 35	- -	- -
Ramsbottom carbon residue on 10 % distillation residue, percent mass, max	0.15	0.15	0.15	0.35	0.35	0.35	-
Lubricity, HFRR @ 60 °C, micron, max	520	520	520	520	520	520	-
Conductivity, pS/m or Conductivity Units (C.U.), min	25	25	25	25	25	25	-

* Test method: D5453

** Test method: D2622

Appendix C – Hydrogen Fuels

Table 23 - Fuel quality specification for PEM fuel cell road vehicle application (ISO 14687)

Constituents (assay)	Unit		Type I, Type II Grade D
Hydrogen fuel index	mole fraction (%)	minimum	99.97
Total non-hydrogen gases	µmol/mol	maximum	300
Water	µmol/mol	maximum	5
Total hydrocarbons except methane	µmol/mol	maximum	2
Methane	µmol/mol	maximum	100
Oxygen	µmol/mol	maximum	5
Helium	µmol/mol	maximum	300
Nitrogen	µmol/mol	maximum	300
Argon	µmol/mol	maximum	300
Carbon dioxide	µmol/mol	maximum	2
Carbon monoxide	µmol/mol	maximum	0.2
Total sulphur compounds	µmol/mol	maximum	0.004
Formaldehyde	µmol/mol	maximum	0.2
Formic acid	µmol/mol	maximum	0.2
Ammonia	µmol/mol	maximum	0.1
Halogenated compounds	µmol/mol	maximum	0.05
Maximum particle concentrations	mg/kg	maximum	1

Table 24 - Fuel quality specification for PEM fuel cell stationary applications (ISO 14687)

Constituents (assay)	**Type I, grade E**		
	Category 1	**Category 2**	**Category 3**
Hydrogen fuel index (max mole fraction)	50%	50%	99.9%
Total non-hydrogen gases (max mole fraction)	50%	50%	0.1%
Water	Non-condensing at any ambient conditions		
Maximum concentration of individual contaminants			
Total hydrocarbons except methane	10 µmol/mol	2 µmol/mol	2 µmol/mol
Methane	5%	1%	100 µmol/mol
Oxygen	200 µmol/mol	200 µmol/mol	50 µmol/mol
Sum of Nitrogen, Argon and Helium (mole fraction)	50%	50%	0.1%
Carbon dioxide	Included in total non-hydrogen gases		2 µmol/mol
Carbon monoxide	10 µmol/mol	10 µmol/mol	0.2 µmol/mol
Total sulphur compounds	0.004 µmol/mol	0.004 µmol/mol	0.004 µmol/mol
Formaldehyde	3.0 µmol/mol	0.2 µmol/mol	0.2 µmol/mol
Formic acid	10 µmol/mol	0.2 µmol/mol	0.2 µmol/mol
Ammonia	0.1 µmol/mol	0.1 µmol/mol	0.1 µmol/mol
Halogenated compounds	0.05 µmol/mol	0.05 µmol/mol	0.05 µmol/mol
Maximum particle concentrations	1 mg/kg	1 mg/kg	1 mg/kg
Maximum particle diameter	75 µm	75 µm	75 µm

Table 25 - Fuel quality specification for applications other than PEM fuel cell road vehicles and stationary applications (ISO 14687)

Constituents (assay)	**Type I**			**Type II**	**Type III**
	Grade A	**Grade B**	**Grade C**	**Grade C**	
Hydrogen fuel index (min mole fraction)	98.0%	99.90%	99.995%	99.995%	99.995 %
Para-hydrogen (min mole fraction)	NS	NS	NS	95.0%	95.0%
Impurities (max content)					
Total gases	20,000 µmol/mol	1000 µmol/mol	50 µmol/mol	50 µmol/mol	
Water (mole fraction)	Non-condensing at all ambient conditions		c	c	
Total hydrocarbon	100 µmol/mol	Non-condensing at any ambient conditions	c	c	
Oxygen	b	100 µmol/mol	d	d	
Argon	b		d	d	
Nitrogen	b	400 µmol/mol	c	c	
Helium			39 µmol/mol	39 µmol/mol	
Carbon dioxide			e	e	
Carbon monoxide	1 µmol/mol		e	e	
Mercury		0.004 µmol/mol			
Sulphur	2.0 µmol/mol	10 µmol/mol			
Permanent particulates	g	f	f	f	
Density					f

b – combined water, oxygen, nitrogen and argon: maximum mole fraction of 1.9% (19,000 µmol/mol)

c – combined nitrogen, water and hydrocarbon: maximum 9 µmol/mol

d – combined oxygen and argon: maximum 1 µmol/mol

e – total CO2 and CO: maximum 1 µmol/mol

f – to be agreed between the supplier and the customer

g – the hydrogen shall not contain dust, sand, dirt, gums, oils or other substances in an amount sufficient to damage fuelling station equipment or the vehicle (engine) being fuelled.

Appendix D – General Biofuels

Table 26 - Generally applicable requirements and limits for FAME (EN 14214)

Property	Unit	Minimum	Maximum
FAME content	% (m/m)	96.5	
Density at 15°C	kg/m^3	860	900
Viscosity at 40°C	mm^2/s	3.50	5.00
Flash point	°C	101	
Cetane number		51	
Copper strip corrosion (3h at 50°C)	Rating	Class 1	
Oxidation stability (at 110°C)	h	8.0	
Acid value	mg KOH/g		0.50
Iodine value	g iodine/100g		120
Linolenic acid methyl ester	% (m/m)		12.0
Polyunsaturated methyl esters	% (m/m)		1.00
Methanol content	% (m/m)		0.20
Monoglyceride content	% (m/m)		0.70
Diglyceride content	% (m/m)		0.20
Triglyceride content	% (m/m)		0.20
Free glycerol	% (m/m)		0.02
Total glycerol	% (m/m)		0.25
Water content	% (m/m)		0.050
Total contamination	mg/kg		24
Sulphated ash content	% (m/m)		0.02
Sulphur content	mg/kg		10.0
Group I metals	mg/kg		5.0
Group II metals	mg/kg		5.0
Phosphorus content	mg/kg		4.0

Table 27 – Generally applicable requirements for undenatured ethanol (EN 15376)

Property	Unit	Minimum	Maximum
Ethanol + higher saturated alcohols content	% (m/m)	98.7	
Higher saturated (C3-C5) mono-alcohols content	% (m/m)		2.0
Methanol content	% (m/m)		1.0
Water content	% (m/m)		0.300
Total acidity	% (m/m)		0.007
Electrical conductivity	µS/cm		2.5
Appearance		clear and colourless	
Inorganic chloride content	mg/kg		1.5
Sulphate content	mg/kg		3.0
Copper content	mg/kg		0.100
Phosphorous content	mg/l		0.15
Involatile material content	mg/100ml		10
Sulphur content	mg/kg		10.0

Table 28 – Specifications for liquefied petroleum gases (ISO 9162)

Property	Unit	commercial propane	Commercial butane
Density at 15°C	kg/m^3	report	report
Gauge vapour pressure at 40°C	kPa	max1550	max 520
Volatility	% (molar)		
C_2 hydrocarbons		report	-
C_4 hydrocarbons		max 7.5	-
C_5 hydrocarbons		max 0.2	max 2.5
Unsaturated hydrocarbons	% (molar)	report	report
Dienes	% (molar)	max 0.5	max 0.5
Evaporation reside	mg/kg	max 60	max 60
Corrosiveness to copper		max 1	max 1
Sulphur	mg/kg	max 50	max 50
Hydrogen sulphide		Pass	Pass
Free water content		None	None

Table 29 – Specifications for dimethyl ether before addition of additives (ISO 16861)

Property	Unit	Minimum	Maximum
DME purity	mass %	98.5	
Methanol	mass %		0.050
Water	mass %		0.030
Hydrocarbons (up to C_4)	mass %		1.00
Carbon dioxide (CO_2)	mass %		0.10
Carbon monoxide (CO)	mass %		0.010
Methyl formate	mass %		0.050
Ethyl methyl ether	mass %		0.20
Evaporation residues	mass %		0.0070
Total sulphur	mg/kg		3.0

Appendix E – Gas Grid

Table 30 - Requirements for gas under normal conditions, GS(M)R

Property	Value
Hydrogen sulphide content	≤5 mg/m^3
Total sulphur content	≤50 mg/m^3
Hydrogen content	≤0.1% (molar)
Oxygen content	≤0.2% (molar)
Impurities	Shall not contain solid or liquid material which may interfere with integrity or operation of pipes or appliances which a consumer could reasonably be expected to operate
Hydrocarbon dewpoint and water dewpoint	Shall be at such levels that they do not interfere with the integrity or operation of pipes or appliances which a consumer could reasonably be expected to operate
Wobbe number (WN)	≥ 47.20 MJ/m^3 and ≤51.41 MJ/m^3
Incomplete combustion factor (ICF)	≤0.48
Soot index (SI)	≤0.60

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