

# Supergen Bioenergy Hub Fuel Standards Summary

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## Reference

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

## 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<sup>1</sup>.

### 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<sup>2</sup>. 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

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<sup>1</sup> 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<sup>2</sup>

### 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<sup>3</sup>. 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.

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<sup>2</sup> IATA. 2015. IATA Guidance Material for Sustainable Aviation Fuel Management.

<sup>3</sup> 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<sup>4</sup>. 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<sup>5</sup>. 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.

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<sup>4</sup> EEA. 2017. Fuel quality in the EU in 2016. Fuel quality monitoring under the Fuel Quality Directive.

<sup>5</sup> 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](http://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<sup>6</sup>. 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

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<sup>6</sup> 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<sup>7</sup>. 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

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<sup>7</sup> Sherkhonov, 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<sup>8</sup>. Blends above this may require further adaptations. Requirements for DME can be found in Table 29, Appendix D.

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<sup>8</sup> NNFFCC, 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<sup>3</sup>)<sup>9</sup>. 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<sup>10</sup>. 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<sup>11</sup>. 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<sup>12</sup>.

### 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  $\geq 46.50$  MJ/m<sup>3</sup> and  $\leq 52.85$  MJ/m<sup>3</sup> and an ICF  $\leq 1.49$ .

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<sup>9</sup> Flogas. The Propane Enrichment of Biomethane – The Future of Energy Supply

<sup>10</sup> Northern Gas Networks. 2015. Biomethane: A Producer's handbook.

<sup>11</sup> 2018. Cadent. Gas NIC Submission: HyDeploy2 Full Submission. Available from:

<https://www.ofgem.gov.uk/publications-and-updates/gas-nic-submission-cadent-hydeploy2>

<sup>12</sup> 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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**ASTM D1655-19a**, Standard Specification for Aviation Turbine Fuels. ASTM, 2019. West Conshohocken, PA: ASTM. <https://www.astm.org/Standards/D1655.htm>

**ASTM D7566-20a**, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. West Conshohocken, ASTM, 2019. PA: ASTM. <https://www.astm.org/Standards/D7566.htm>

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<http://www.legislation.gov.uk/uksi/1996/551/contents>

## 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 <sup>3</sup>  | 775.0           | 840.0  |
| Freezing point                             | °C                 |                 | -47.0  |
| Viscosity at -20°C                         | mm <sup>2</sup> /s |                 | 8.000  |
| Smoke point                                | mm                 | 25.0            |        |
| Or Smoke point and naphthalenes            | mm                 | 18.00           |        |
|  | %(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  $8.0\% \leq 25.0\%$  by volume (IP156) and  $8.4\% \leq 26.5\%$  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  $8.0\% \leq 25.0\%$  by volume (IP156) and  $8.4\% \leq 26.5\%$  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  $T_{50}-T_{10} \geq 10^{\circ}\text{C}$  and  $T_{90}-T_{10} \geq 40^{\circ}\text{C}$  (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 <sup>2</sup> /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 <sup>3</sup>  | 751     | 802     |
| Vapour pressure, 38°C                                | kPa                | 14      | 21      |
| Freezing point                                       | °C                 |         | -50     |
| Viscosity at -20°C                                   | mm <sup>2</sup> /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<br>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)            | 0.10    |         |
| 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%<br>Recovered, temp            | °C                 |         | 205                     |
| Final boiling point, temp                                  |                    |         | 300                     |
| Distillation residue                                       | %                  |         | 1.5                     |
| Distillation loss  | %                  |         | 1.5                     |
| Flash point  | °C                 | 38      |                         |
| Density at 15°C  | kg/m <sup>3</sup>  | 775     | 840                     |
| Freezing point   | °C                 |         | -40 JetA<br>-47 Jet A-1 |
| Viscosity at -20°C   | mm <sup>2</sup> /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<br>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<br>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<br>concentration    |                    |         | 5.7                     |
| Fuel system icing inhibitor                                | % (v/v)            | 0.07    |                         |
| Diethylene glycol monomethyl ether                         | % (v/v)            |         | 0.15                    |
| Electrical conductivity improver, one of<br>the following: | mg/L               |         |                         |
| (1) AvGuard SDA<br>On initial blending                     |                    |         | 3                       |

|   |       |    |
|---|-------|----|
| After field re-blending, cumulative concentration<br>(2) Stadis 450I, m |       | 5  |
| 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 <sup>2</sup> /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 <sup>2</sup> /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 <sup>3</sup> | 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 <sup>3</sup> | 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 <sup>3</sup>        | 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 <sub>2</sub> /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*<br>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 <sup>3</sup> | 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 <sup>3</sup> | 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 <sup>3</sup> | 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 <sup>3</sup> | 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 <sup>3</sup>  | 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 <sup>3</sup>   |            | 25      |
|  | h                  | 20         |         |
| Lubricity, wear scar diameter at 60°C        | µm                 |            | 460     |
| Viscosity at 40°C                            | mm <sup>2</sup> /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 <sup>3</sup> | 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         |         | Volume blending restricted to 2.7% (m/m) maximum oxygen content |         |
| - iso-butyl alcohol          |         |   |         |
| - tert-butyl alcohol         |         |   |         |
| - ethers (5 or more C atoms) |         |   |         |
| - other oxygenates           |         |   |         |

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 <sup>3</sup>  | 765.0-800.0 | 780.0-810.0 |
| Flash point                                  | °C                 | Above 55.0  | Above 55.0  |
| Viscosity at 40°C                            | mm <sup>2</sup> /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 <sup>3</sup>   | Max 25      | Max 25      |
|  | h                  | Min 20.0    | Min 20.0    |

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

| <b>Property</b>   | <b>Unit</b> | <b>Minimum</b>                        | <b>Maximum</b> |
|---|-------------|---------------------------------------|----------------|
| 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                      | -           | -            | -             | 282         | 282          | 282           | -       |
| min   | 288         | 288          | 288           | 338         | 338          | 338           | -       |
| max   |             |              |               |             |              |               |         |
| Kinematic viscosity, mm <sup>2</sup> /S at 40°C                           |             |              |               |             |              |               |         |
| min   | 1.3         | 1.3          | 1.3           | 1.9         | 1.9          | 1.9           | 5.5     |
| max   | 2.4         | 2.4          | 2.4           | 4.1         | 4.1          | 4.1           | 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   | 15*         | 0.05**       | 0.50**        | 15*         | 0.05**       | 0.50**        | 2.00**  |
| percent, max  |             |              |               |             |              |               |         |
| 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   | 40          | 40           | -             | 40          | 40           | -             | -       |
| (ii) aromatically, percent volume, max                                    | 35          | 35           | -             | 35          | 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)

| <b>Constituents<br/>(assay)</b>   | <b>Unit</b>       |         | <b>Type I, Type II<br/>Grade D</b> |
|-----------------------------------|-------------------|---------|------------------------------------|
| 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)

| <b>Constituents<br/>(assay)</b>                   | <b>Type I, grade E</b>                   |                   |                   |
|---|--|-------------------|-------------------|
|   | <b>Category 1</b>                        | <b>Category 2</b> | <b>Category 3</b> |
| 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<br>(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 $\mu\text{mol/mol}$               | 1000 $\mu\text{mol/mol}$                 | 50 $\mu\text{mol/mol}$ | 50 $\mu\text{mol/mol}$ |          |
| Water (mole fraction)                   | Non-condensing at all ambient conditions |  | c                      | c                      |          |
| Total hydrocarbon                       | 100 $\mu\text{mol/mol}$                  | Non-condensing at any ambient conditions | c                      | c                      |          |
| Oxygen                                  | b  | 100 $\mu\text{mol/mol}$                  | d                      | d                      |          |
| Argon                                   | b  |  | d                      | d                      |          |
| Nitrogen                                | b  | 400 $\mu\text{mol/mol}$                  | c                      | c                      |          |
| Helium                                  |  |  | 39 $\mu\text{mol/mol}$ | 39 $\mu\text{mol/mol}$ |          |
| Carbon dioxide                          |  |  | e                      | e                      |          |
| Carbon monoxide                         | 1 $\mu\text{mol/mol}$                    |  | e                      | e                      |          |
| Mercury                                 |  | 0.004 $\mu\text{mol/mol}$                |                        |                        |          |
| Sulphur                                 | 2.0 $\mu\text{mol/mol}$                  | 10 $\mu\text{mol/mol}$                   |                        |                        |          |
| Permanent particulates                  | g  | f  | f                      | f                      |          |
| Density                                 |  |  |                        |                        | f        |

b – combined water, oxygen, nitrogen and argon: maximum mole fraction of 1.9% (19,000  $\mu\text{mol/mol}$ )

c – combined nitrogen, water and hydrocarbon: maximum 9  $\mu\text{mol/mol}$

d – combined oxygen and argon: maximum 1  $\mu\text{mol/mol}$

e – total CO<sub>2</sub> and CO: maximum 1  $\mu\text{mol/mol}$

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 <sup>3</sup>  | 860     | 900     |
| Viscosity at 40°C                   | mm <sup>2</sup> /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 <sup>3</sup> | report             | report            |
| Gauge vapour pressure at 40°C | kPa               | max1550            | max 520           |
| Volatility                    | % (molar)         |                    |                   |
| C <sub>2</sub> hydrocarbons   |                   | report             | -                 |
| C <sub>4</sub> hydrocarbons   |                   | max 7.5            | -                 |
| C <sub>5</sub> hydrocarbons   |                   | max 0.2            | max 2.5           |
| Unsaturated hydrocarbons      | % (molar)         | report             | report            |
| Dienes                        | % (molar)         | max 0.5            | max 0.5           |
| Evaporation residue           | 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)

| <b>Property</b>                      | <b>Unit</b> | <b>Minimum</b> | <b>Maximum</b> |
|--------------------------------------|-------------|----------------|----------------|
| DME purity                           | mass %      | 98.5           |                |
| Methanol                             | mass %      |                | 0.050          |
| Water                                | mass %      |                | 0.030          |
| Hydrocarbons (up to C <sub>4</sub> ) | mass %      |                | 1.00           |
| Carbon dioxide (CO <sub>2</sub> )    | 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

| <b>Property</b>                         | <b>Value</b>   |
|---|--|
| Hydrogen sulphide content               | $\leq 5 \text{ mg/m}^3$  |
| Total sulphur content                   | $\leq 50 \text{ mg/m}^3$   |
| Hydrogen content                        | $\leq 0.1\%$ (molar)   |
| Oxygen content                          | $\leq 0.2\%$ (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)                       | $\geq 47.20 \text{ MJ/m}^3$ and $\leq 51.41 \text{ MJ/m}^3$  |
| Incomplete combustion factor (ICF)      | $\leq 0.48$  |
| Soot index (SI)                         | $\leq 0.60$  |

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[www.supergen-bioenergy.net](http://www.supergen-bioenergy.net)

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