Neste Renewable Diesel Handbook

NESTE

The only way is forward

Foreword

This booklet provides information on Neste Renewable Diesel, in Europe classified as a Hydrotreated Vegetable Oil (HVO), and its use in diesel engines. The booklet's potential readership consists of, e.g., fuel and exhaust emission professionals in oil companies, automotive and engine industry representatives, fuel blenders and users, research facilities, and people preparing fuel standards and regulations.

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This booklet will be updated periodically when enough new or additional information has become available.

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Neste Corporation

Disclaimer

Contents

General

The common acronym “HVO” comes from the terms “Hydrotreated Vegetable Oil” or “Hydrogenated Vegetable Oil”. They originate from the time before 2010 when only vegetable oils were used as feedstocks. Today HVO is increasingly produced from waste and residue fat fractions coming from the food industry, as well as from non-food grade vegetable oil fractions. Thus “HVO” and “Hydrotreated Vegetable Oil” are no longer accurate terms describing the origin of the fuel. However, those terms cannot be changed easily since they are common in the European regulation, fuel standards, and biofuel quality recommendations set by automotive companies. According to several chemistry experts, “Hydrotreated” referring to fuel processing is preferable over “Hydrogenated”, as the latter is commonly linked to the manufacturing of margarine.

Neste Corporation calls its own HVO product “Neste Renewable Diesel” or “Neste MY Renewable Diesel™”. “Renewable Paraffinic Diesel” has also been commonly used, as it is chemically a proper definition for product quality. However, this term also covers Biomass-to-Liquid (BTL) fuels made by Fischer-Tropsch synthesis and, therefore, does not define the feedstock and process used to produce “HVO”. Also the terms “HDRD”, i.e. “Hydrogenation Derived Renewable Diesel”, “Non Ester Renewable Diesel”, “Renewable Hydrocarbon Diesel”, and “HBD”, i.e. “Hydro-generated Biodiesel”, have been used especially in North America and the Far East. The European EN 15940 standard uses the term “Paraffinic Diesel Fuel from Hydrotreatment”. This handbook refers to isomerized, good cold operability and high cetane number (above 70) products meeting EN 15940 Class A requirements. In this document, “HVO”, “Neste Renewable Diesel”, “NRD” and “renewable diesel” are used to refer to such products.

The hydrotreatment of vegetable oils as well as suitable waste and residue fat fractions through patented the NEXBTL™ process to produce HVO is an already mature commercial scale manufacturing process. It is based on oil refining know-how and is used for the production of biofuels for diesel engines. In the process, hydrogen is used to remove oxygen from, for example, triglyceride vegetable oil molecules and to split the triglyceride into three separate chains, thus creating hydrocarbons that are similar to existing diesel fuel components (Figure 1). This allows blending in any desired ratio without any concerns regarding fuel quality.

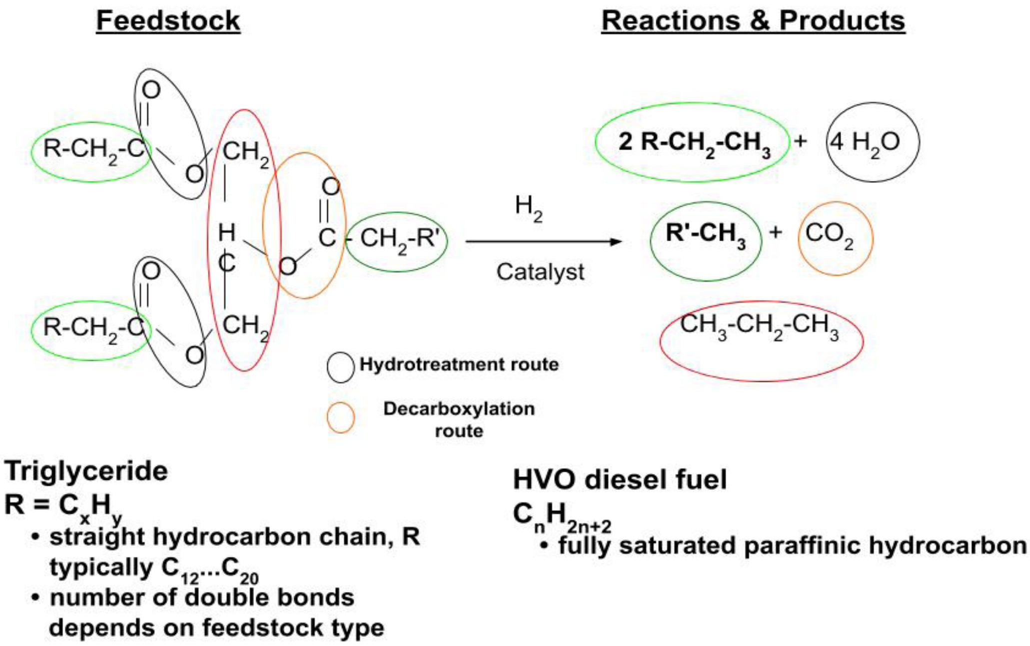


Figure 1. Chemical formation and composition of HVO.

Neste spends 70% of all its R&D investments in pursuit of suitable new raw materials, especially waste and residues. With year-on-year increases, the supply of Neste Renewable Diesel from waste and residue material reached 80% in 2019; thus the use of such raw materials by Neste is very remarkable already today. The aim of the company's current efforts is focused on the utilization of lower quality waste and residue materials, as well as on the development of promising new raw materials, such as algae and microbial oils.

Traditional biodiesel is produced from vegetable oils by an esterification process. The products are called Fatty Acid Methyl Esters (FAME or "biodiesel"). Other acronyms are also used, such as Rape Seed Methyl Ester (RME), Soybean Methyl Ester (SME), Palm Oil Methyl Ester (PME), or Used Cooking Oils Methyl Ester (UCOME), depending on the used feedstock. A very simplified scheme of the esterification used for the production of biodiesel and the hydrotreatment used for the production of renewable diesel is depicted in Figure 2 below. Neste Renewable Diesel is produced through the hydrotreatment route, a complex industrial process that needs high pressure and temperature.

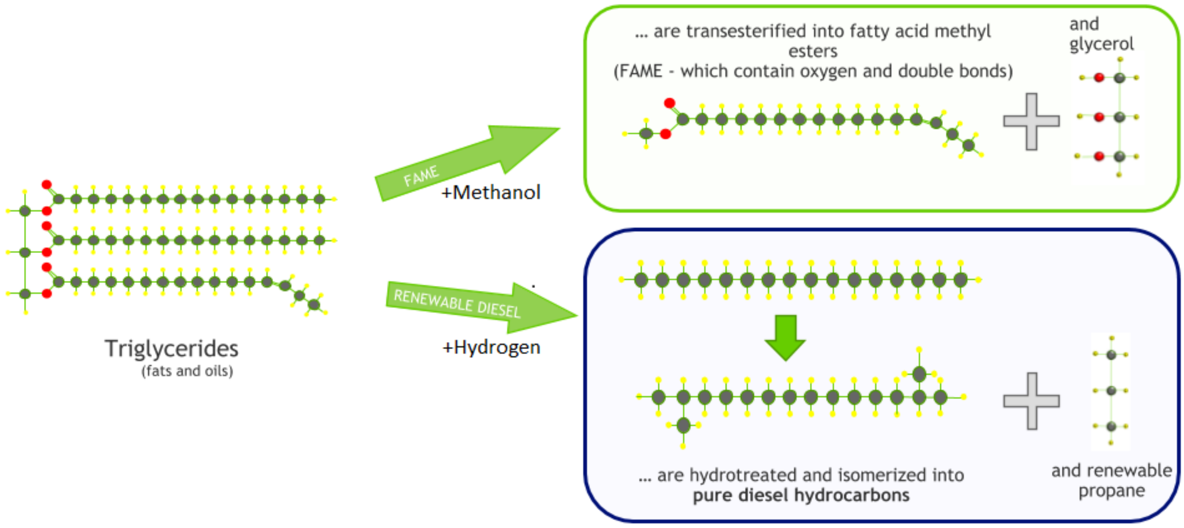


Figure 2. Simplified scheme of esterification and hydrotreatment processes for biofuel production.

HVO is a mixture of straight chain and branched paraffins – the simplest type of hydrocarbon molecules from the clean and complete combustion point of view. Typical carbon numbers are C15...C18. Paraffins exist also in fossil diesel fuels, which additionally contain significant amounts of aromatics and naphthenes. Aromatics are not favourable for clean combustion. HVO is practically free of aromatics and its properties are quite similar to Gas-to-Liquid (GTL) and BTL diesel fuels made by Fischer Tropsch synthesis from natural gas and gasified biomass. At least the companies presented in Table 1 have developed stand-alone HVO production processes and products.

Table 1. Examples of HVO production processes and product names.

Company	Technology	Product names
Neste	NEXBTL™	Neste MY Renewable Diesel™
Axens IFP	Vegan®	
Honeywell UOP/ ENI	Ecofining™	Green Diesel
Haldor Topsoe	HydroFlex™	UPM BioVerno

The following description provides an overview of the NEXBTL™ production process and the products of the NEXBTL™ process. The process is usually optimized for diesel fuel yield. In addition to diesel fuel, small amounts of renewable gasoline components and gases, like propane and isoalkane, are formed as side products. Renewable gasoline components can be blended into gasoline where they provide a high bioenergy value but suffer from low octane numbers compared to, for example, ethanol. Biopropane can be used in cars and other applications using Liquefied Petroleum Gas (LPG); it can also be used as renewable process energy at the production site, reducing the carbon footprint of products from the NEXBTL™ process. Isoalkane can be used as a raw material in a wide range of chemical applications, e.g. paints and coatings. The NEXBTL™ process includes an isomerization unit for improving cold properties even down to arctic diesel fuel grades. The NEXBTL™ process also enables the production of renewable jet fuel.

Fuel specifications

Neste Renewable Diesel, HVO

- Meets the requirements of EN 15940 for paraffinic diesel fuels
- Allowed as a blending component in EN 590 B7 diesel fuel without any fixed maximum percentage
- Labelled with "XTL" at retail points, according to EN 16942
- Does not meet EN 14214 standard for FAME due to totally different chemical composition
- Fulfils ASTM D975 requirements

EN standards in Europe

Fuel standards as well as standards for fuel-related analytical methods are developed, updated and approved by CEN, the European Committee for Standardization. CEN committees and working groups consist of fuel and automotive vehicle experts nominated by national standardization bodies. Preparing and approving standards take place outside any political setting and is carried out by experts with no direct legislative mandate. In some cases, the European Commission has asked CEN to prepare a standard. CEN includes members also from non-EU countries.

Because of a standard's preparation and approval procedure, it is a voluntary fuel quality agreement to be used for fuel production and commerce. It defines properties that are important for the operability, durability and tailpipe emissions of vehicles. In principle, such properties must be satisfied at retail points where vehicles are refuelled, but, in practice, they are controlled at the level of fuel manufacturing and bulk sales. However, authorities in some countries have decided that fuel sold has to meet standards set by national legislation.

Standards are updated frequently, which means that it is always recommended to verify the latest edition with a supplier of standards in order to be sure of the requirements in force. Amendments marked "A1" and corrections "AC" are also possible, and they need to be checked before any standard is used for formal purposes.

Standards do not take into consideration whether the carbon's origin in the fuel is fossil or renewable, since it technically does not matter for the engine or tailpipe emission measurements.

Emission-related diesel fuel properties are mandated in Annex II of the Fuel Quality Directive 2009/30/EC ("FQD"). These mandatory requirements are copied into EN fuel standards as such.

EN 15940 paraffinic diesel fuel standard

The EN 15940:2016 + A1:2018 + AC:2019 standard covers hydrotreated paraffinic renewable diesel fuel and synthetic Fischer-Tropsch products GTL, BTL and Coal-to-Liquid (CTL). In the future e-fuels might also be covered with this standard. Before publishing EN 15940, paraffinic diesel fuel was specified by CEN Technical Specification TS 15940:2012 and CEN Workshop Agreement CWA 15940:2009.

EN 15940 covers paraffinic diesel fuel used as such in vehicles, and it defines fuel properties at retail points. It does not take into consideration whether the fuel's origin is fossil or renewable since that part of the fuel supply chain is regulated only in fuel and feedstock directives.

Paraffinic diesel is used very commonly also as a blending component in diesel fuel. In that case, it does not have to meet EN 15940 requirements since composition and properties of diesel fuel blends are defined in the respective diesel fuel standards like EN 590 and EN 16734 (details in paragraph 5.4. of EN 590 and EN 16734). Blending is mentioned also in EN 15940 paragraph “Introduction”.

In many cases, the abbreviation “XTL/HVO” is used for paraffinic fuels. XTL is a term used to describe synthetic GTL, CTL and BTL Fischer-Tropsch production paths. Since there are no practical methods for measuring paraffinic content, the paraffinic nature is proven by limiting aromatic content to practically zero. Nominally, fuel’s paraffinic purity is min. 98.5 wt-% “without any intentional adding of non-paraffinic material other than additives or markers” since 100.0% purity cannot be verified from a fuel sample because of inaccuracy of analytical methods.

EN 15940 has two main fuel grades: High cetane class A (min. 70) and normal cetane class B (min. 51). Neste Renewable Diesel meets the EN 15940 class A. Neste Renewable Diesel as such also meets the European diesel fuel standard EN 590 in all respects, except density, which is below the lower limit. The American diesel fuel standard ASTM D975 and Canadian CGSB-3.517 are met as such, since they do not limit density of the fuel.

EN 15940 states “Paraffinic diesel fuel is not validated for all vehicles, consult vehicle manufacturer before use”. Even though paraffinic diesel should not cause any risks in engines or vehicles, Euro 6 and Euro VI exhaust regulations may formally require that vehicle manufacturers need to give an allowance to use paraffinic diesel.

Ester type biodiesel (FAME) standard EN 14214 is not valid for Neste Renewable Diesel, since Neste Renewable Diesel consists of hydrocarbons only. Originally, CWA 15940 did not allow FAME, but nowadays 7 vol-% FAME is allowed as a blending component in EN 15940 paraffinic diesel fuel.

EN 590 “B7” diesel fuel standard

EN 590

- Defines properties of “B7” diesel fuel sold at retail
- Does not take any position on how and from what feedstock fuel is processed
- Limits the use of FAME to max. 7 vol-%
- Allows blending of HVO without any limit and without pump labelling

Diesel fuel standard EN 590:2013 + A1:2017 defines properties of “B7” diesel fuel sold at retail points. It allows maximum 7.0 vol-% of FAME (biodiesel, ester, 1st generation biodiesel) as a blending component.

EN 590 does not take any position on the type of feedstock used to produce fuel components or on the way such components are processed and blended. The only requirement is that the final fuel meets the defined technical requirements. All suitable hydrocarbon-type blending components, such as straight run gas oils or kerosenes, various types of cracked gas oils or kerosenes, GTL diesel fuels, hydrotreated vegetable oils and animal fats (HVO), BTL fuels as well as co-processing of fossil and renewable feedstocks, can be used. It does not matter whether the components to be blended are handled only inside a specific refinery site or whether they are traded as bulk batches between fuel suppliers before the final blending. The allowance of HVO is especially mentioned in EN 590 paragraph 5.4 “Other (bio) components”. HVO belongs to the group of hydrocarbons that are miscible with a hydrocarbon matrix of a fuel blend, and, therefore, the use of HVO as a blending component does not need to be regulated further through technical standards. This means that HVO, such as Neste Renewable Diesel, can be used as a blending component in diesel fuel without any fixed maximum percentage value. In practice, the limiting factor is the minimum density set by EN 590, which is usually met at tens of percentages of HVO. Labelling “B7” refers only to the maximum FAME content and not to HVO content.

The maximum amount and quality of FAME (EN 14214) are defined by EN 590, since FAME has different chemistry, properties, and levels of impurities compared to hydrocarbons. These requirements in EN 590 are not applicable to any other biocomponent than FAME. In the same way, Annex II of the FQD requires FAME to comply with EN 14214. For example, the presence of phosphorus, which may be harmful to vehicles’ exhaust aftertreatment systems, can only originate from FAME. It is more convenient to control phosphorus content at a robust level from neat FAME before blending than to measure phosphorus from all diesel fuels using accurate analytical methods after FAME has been diluted by 93% of phosphorous-free hydrocarbon fuel. The same applies for aging and decomposition during storage, which is different for hydrocarbon fuels and esters. As a consequence, different requirements apply to neat FAME (EN 14214), fuels containing 2 to 7 vol-% FAME, and hydrocarbon fuels without FAME.

In addition, the analytical method EN 14078 for measuring the biofuel content of diesel fuel is valid only for FAME. This means that the amount of HVO in diesel fuel has to be shown by audit trail and mass balance from the fuel blending. If an audit trail is contested, a radioisotope carbon ^{14}C method can be used for estimating the biofuel content (ASTM D6866, EN 16640 or DIN 51637). Unfortunately, these methods are too laborious for routine fuel quality control.

EN 16734 “B10” diesel fuel standard

EN 16734:2016 + A1:2018 is a standard for diesel fuels allowing maximum 10.0 vol-% FAME. It is equal with EN 590 except that the allowed FAME content is higher. This means that the use of HVO is allowed without any fixed limits and without specific labelling for HVO, provided that the final blend complies with EN 16734. B10 can be sold if a national decision allowing more than 7% FAME is made according to Fuel Quality Directive 2009/30/EC Article 4(1).

EN 16709 “B20” and “B30” diesel fuel standard

The EN 16709:2015 + A1:2018 standard defines requirements for diesel fuels containing 14.0…20.0 vol-% (B20) or 24.0…30.0 vol-% (B30) FAME. B20 and B30 can be used only in dedicated fleets, since fuels do not meet the density requirement maximum 845 kg/m^3 set by the Fuel Quality Directive 2009/30/EC Annex II for market fuels. HVO is not separately mentioned in EN 16709. However, B20 and B30 should be manufactured by adding FAME into EN 590 diesel fuel. Since HVO is already allowed in EN 590 diesel fuel, B20 and B30 are also allowed to contain HVO without any specified limit or labelling.

HVO versus EN 14214 FAME standard

Since HVO consists of paraffinic hydrocarbons, it cannot meet the requirements set by EN 14214:2013 + A2:2019, which is a standard developed and valid only for methyl ester chemistry type biodiesel, namely FAME. As a matter of fact, HVO meets EN 590, except the requirement for minimum density. EN 15940 Class A specifies a density range of 765 … 800 kg/m^3, which is considerably lower than FAME’s density range of 860 … 900 kg/m^3 defined by EN 14214. This shows that properties of HVO and FAME are so far from each other that they cannot be covered by the same standard. Because of this, attempts to require that all biocomponents meet EN 14214 are technically impossible and discriminatory.

EN 16942 standard for identification of vehicle compatibility

Neste Renewable Diesel, HVO

- Paraffinic diesel fuels are identified with the "XTL" label in dispensing pumps when sold neat
- The label is "B7" when sold as a blend fulfilling the EN590 standard

Fuels have to be labelled at retail points according to directive 2014/94/EU on the deployment of alternative fuels infrastructure "AFID" article 7(2). In practice, labelling is covered by the standard EN 16942:2016. It defines the label "XTL" to be used for paraffinic diesel fuel at dispensing pumps and filling nozzles when it is sold as such, in practice meeting EN 15940. Correspondingly, "XTL" shall be visible near a vehicle's fuel filler cap or flap in order to show that a vehicle is compatible to run with paraffinic diesel fuel (Figure 3). This means that when the same "XTL" label is found both on a vehicle and at a fuel dispenser, customers can be sure that the vehicle is formally accepted for the fuel. However, labelling came into force in October 2018, so vehicles registered before that usually do not have the "XTL" label, even though they might be formally accepted to run with EN 15940 paraffinic diesel fuel.

Labelling does not make a difference whether the fuel is fossil (GTL, CTL) or renewable (HVO, BTL, "Renewable diesel"), since, from the point of view of vehicle operation and durability, the fuel's feedstock does not matter. The label "HVO/XTL" could not be accepted, since the small label doesn't have room for so many letters in an adequately visible font size. So, Neste Renewable Diesel is labelled with "XTL" at refuelling pumps and in new vehicles that are formally accepted to run with it.

For the common EN 590 diesel fuel, the label is "B7", and it is used also for EN 590 fuel containing no FAME and using only HVO as a renewable content, because, in principle, all vehicles are compatible and labelled with "B7". This may cause confusion, but it can be clarified by using additional information at fuel refuelling points, e.g. "Does not contain FAME". The use of HVO as a blending component in diesel fuels does not have any effect on labelling, since, from the point of view of engine and vehicle operation and emissions, there are no issues or risks to be taken into account. Higher FAME content fuels have to be labelled correspondingly with "B10", "B20" and "B30" at refuelling points as well as in vehicles designed and certified to run with those FAME contents.

Figure 3. Examples of fuel labelling according to EN 16942 a) – b) in fuel tanks of trucks and c) in dispensers and pistols at retail points. “XTL” in the vehicle means that paraffinic diesel including renewable diesel fuel is formally accepted.

ASTM D975 diesel fuel standard in the USA

ASTM D975-20 is a fuel standard in the United States for diesel fuels suitable for various types of diesel engines. There are seven different grades in this standard, and Neste Renewable Diesel fulfils No. 2-D Grade requirements with max. 15 mg/kg sulphur.

Worldwide Fuel Charter (WWFC)

HVO, paraffinic renewable diesel

- is a recommended biocomponent, according to the WWFC

The Worldwide Fuel Charter (WWFC) is a recommendation published by automotive companies for fuel qualities to be used with different vehicle emission requirements. The WWFC also includes justifications for each parameter required. The 6th edition (2019) of the WWFC can be downloaded from https://www.acea.be/uploads/publications/WWFC_19_gasoline_diesel.pdf.

The WWFC pays attention to challenges related to the use of FAME, and recommends using HVO as a biocomponent. The Category 5 diesel fuel for “Markets with highly advanced requirements for emission control (including GHG) and fuel efficiency” does not allow the use of FAME as a blending component at all, but it does allow the use of HVO (page 60 – 61 in the 6th edition of the WWFC). More technical background for FAME use can be found on pages 81 – 83 of the 6th edition of the WWFC and for HVO use on page 84.

Legislative fuel composition requirements in Europe

Neste Renewable Diesel

- Meets compositional requirements set by the FQD 2009/30/EC Annex II for diesel fuels
- May be blended into diesel fuel without any fixed limit or labelling at retail pumps because of its hydrocarbon nature, according to the FQD 2009/30/EC recital 33
- Energy content is defined in directive RED II 2018/2001/EU Annex III
- Typical and default greenhouse gas values are defined in directive RED II 2018/2001/EU Annex V
- FQD 98/70/EC requires free circulation of fuels: Neste Renewable Diesel or any fuel shall not be discouraged, if it complies with specifications
- RED II and the FQD define feedstock issues and properties of final fuels, but not production processes

The following paragraphs present a detailed account of how HVO has been treated in the European Union directives. It is important to note that directives do not set any limits on how fuels or fuel components are processed, which means that a fuel company is free to choose between HVO, FAME, co-processing, GTL, or any other technically suitable production process. The regulation only sets limits regarding sustainability issues of feedstock, amount of bioenergy, greenhouse gas emissions, and quality of the final fuel when it is related to tailpipe emissions or technical compatibility with vehicles.

Directives of the European Union

The Fuel Quality Directive 98/70/EC with remarkable amendments by Directive 2009/30/EC lays down in Article 1(a) the fuel requirements that are related to health, environment and engine technology. Further, Article 1(b) determines targets for the reduction of greenhouse gas emissions for fuels, expressed in gCO_{2eq}/MJ fuel's calorific value at retail points.

The regulatory technical requirements for diesel fuel are related to the minimum cetane number and the maximum density, 95% distillation point, polyaromatics, sulphur and FAME content. When FAME is used in blending, it must comply with the EN 14214 standard (FQD Article 4(1) and Annex II) and the final fuel must fulfil the EN 590 specification. The use of biocomponents in diesel fuel was not limited by legislation until the amendment brought by Directive 2009/30/EC, which limited the use of FAME to maximum 7 vol-%. This limitation is justified by the technical properties of FAME (recital 33), mainly with respect to engine and vehicle operability and durability (recital 31).

According to Article 2(9) of the FQD, this Directive applies to biofuels within the meaning of Directive 2009/28/EC "RED". However, RED has been replaced by Directive 2018/2001 "RED II", and the FQD has not yet been updated to refer to the new RED II. The FQD update is beginning in 2020, and it might come into force around 2024, since there will be numerous legislative issues within the European Union before agreement on the update.

Both RED and RED II define biofuels on the basis of their feedstock path and sustainability requirements without any requirements as to how the final fuel has been produced or as to their chemical composition. Furthermore, all types of energy from renewable sources must be taken into account in the calculation of the share of energy from renewable sources used in each Member State.

In this respect, the FQD specifically provides that the use of biofuels other than FAME in diesel fuel is not limited. Hydrotreated vegetable oil is explicitly mentioned as one of the unlimited diesel-like hydrocarbon biofuels (Recital 33). As a matter of fact, even in its pure state, HVO meets all the diesel fuel specifications set forth in Annex II of the FQD and HVO is also considered to originate fully from renewable sources.

It follows from footnote 3 of Annex II of the FQD that the requirements set out in EN 14214 only apply to FAME. Also, the analytical method contained in EN 14078 (Annex II) for measuring the biofuel content of diesel fuel is valid only for FAME. This means that the amount of HVO used in diesel fuel has to be shown by audit trail and mass balance from fuel blending, which is defined in the FQD Article 7c (1). If an audit trail is contested, the biofuel content can be estimated by the radioisotope carbon ^{14}C method.

Greenhouse gas emission values are defined by the FQD Annex IV and the RED II Annex V. HVO from several production pathways is mentioned besides biodiesel (FAME) in both directives. The same applies to energy content, which is determined in Annex III of the RED II as regards hydrotreated vegetable oil.

As a result, HVO is explicitly mentioned by both the RED II and the FQD, which allow HVO to be marketed in exactly the same way as FAME, provided that such biofuels meet the sustainability and greenhouse gas emission requirements. It is only the FAME that has a technical based blending limit of max. 7 vol-% and that is subject to the quality requirements described in EN 14214.

Legislative requirements for free markets

Article 34 TFEU ("Treaty on the Functioning of the European Union") and the free movement clause in Article 5 of Directive 98/70/EC preclude Member States from prohibiting, restricting or preventing the placing on the market of fuels that comply with the requirements of that Directive (as amended). This means that a Member State may not limit the use of Renewable Diesel as a biocomponent in diesel fuel, provided that Renewable Diesel satisfies the greenhouse gas and sustainability requirements set forth in the RED II and the FQD, and provided that the final diesel fuel complies with the limits imposed by Annex II of the FQD as regards cetane, density, distillation, polyaromatics, sulphur and FAME. In this respect, the European Court of Justice has consistently held that Member States are not allowed to impose additional requirements on the product specifications that have been fully harmonized at the EU level.

The RED II and the FQD do not require diesel fuel to meet the EN 590 specifications. The FQD only refers to EN 590 in relation to the test methods in order to ensure that fuel producers and regulators use the same laboratory methods for monitoring compliance with the requirements set by Article 8(1) and Annex II of FQD. As a result, Member States cannot make the marketing of Renewable Diesel or of any other diesel fuel conditional upon it satisfying EN 590 specifications. In any event, it should be noted that technical standards, such as EN 590, are not compulsory, as explicitly stated in Article 1(4) of Directive 98/34/EC laying down a procedure for the provision of information in the field of technical standards and regulations. This is further confirmed in the Commission's Guide to the implementation of directives based on the New Global Approaches, according to which "the application of harmonized standards, which give a presumption of conformity, remains voluntary […]. Thus, the product may be manufactured directly on the basis of the essential requirements [contained in the relevant Directive]".

Case: Fuel taxation in Finland

Fuel taxation in Finland

- Based on energy content (MJ/l), Well-To-Wheels CO_2 and locally harmful tailpipe emissions
- Promotes paraffinic diesel fuels (HVO, GTL, BTL) because of their lower tailpipe emissions and biofuels made from waste or cellulosic feedstock (double counting)

Fuel taxation in Finland (Act 1399/2010 with its amendments, e.g. 1554/2019) promotes the use of renewable and clean combusting fuels. Taxes are based on energy content, greenhouse gas emissions, and tailpipe emissions. In addition to those, a security of supply levy is charged (Table 2).

Table 2. Diesel fuel taxes in Finland from August 2020, euro cents per litre without value added tax (Act 1554/2019). Taxes of ethanol diesel fuel (ED95) for dedicated engines are also presented for reference.

	Energy tax (c/l)	CO_2 tax (c/l)	Security of supply levy (c/l)	Total (c/l)	Difference to diesel fuel (c/l)
Fossil diesel fuel	34.57	24.56	0.35	59.48	
Double-counted renewable paraffinic diesel (e.g. HVO from waste, BTL)	27.65	0.00	0.35	28.00	- 31.48
Double-counted biodiesel (e.g. FAME from waste)	31.69	0.00	0.35	32.04	- 27.44
Double-counted ethanol diesel (e.g. ED95)	16.23	1.42	0.35	18.00	

The CO_2 tax is 77 euros per ton of CO_2. Here CO_2 is the CO_2 formed in the final combustion using the Well-To-Wheels (WTW) approach, which is common for biofuels. For practical reasons, the energy tax is converted to cents per litre of fuel to be paid. Renewable fuels that meet sustainability and GHG-criteria of Directive 2009/28/EC RED are entitled to a 50% reduction in CO_2 tax. Fuels that meet the double counting criteria of waste- or cellulosic-based feedstock are free of CO_2 tax. Renewable fuels that do not meet criteria set by RED are taxed like fossil fuels. However, the updating of regulations is ongoing in 2020, and criteria for the double counting will be replaced with new sustainability criteria.

Paraffinic diesel fuel is defined in Finnish Act 181/2016 by parameters set by FQD 2009/30/EC by choosing limit values that make a clear difference between paraffinic and common diesel fuel: cetane number min. 51, density 765...810 g/l, total aromatics max. 1.1 wt-%, sulphur max. 5 mg/kg and 95% distillation max. 360 °C. Tax of the EN 590 market diesel fuel is calculated based on blending percentages of fossil and renewable parts. However, when renewable paraffinic diesel fuel is sold as such, the tax is 33 c/l instead of the 28 c/l mentioned in the table, since EU Tax regulations set a 33 c/l minimum tax for diesel fuel.

Fuel properties

Neste Renewable Diesel

- One of the highest heating values among current biofuels
- Severe winter and arctic grades available, thanks to the isomerization process
- Usable either as 100% HVO fuel or as a “drop in” blending component within diesel fuel
- High quality component that can be used to enhance the properties of the final diesel blend

Neste Renewable Diesel (NRD) contains only n- and i-paraffins and can be used within XTL/HVO validated vehicles as is or blended as “drop in fuel” without a “blending wall” set by vehicle technology or limitations by fuel logistics. The properties of NRD have many more similarities with high quality sulphur free fossil diesel fuel than with FAME, which is a well-known biocomponent to oil companies. Moreover, the properties of Neste Renewable Diesel are very similar to the synthetic GTL diesel fuel, which has been considered to be the best diesel fuel regarding engines and tailpipe emissions. Thus, NRD offers the same compositional benefits as GTL but with remarkably lower greenhouse emissions. Neste Renewable Diesel can be evaluated with the same analytical methods as used with fossil fuels. Table 3 presents typical properties for NRD, and limits in the EN 15940, EN 590 and ASTM D975 standards.

Table 3. Typical properties of pure Neste Renewable Diesel and how it relates to EN 15940, EN 590 and ASTM D975 standards (typical values only as guidance, not binding the supplier).

Property		Neste Renewable Diesel Typical values	EN 15940:2016 + A1:2018 + AC:2019 Class A	EN 590:2013 + A1:2017	ASTM D975-20 2-D
Appearance at +25 °C		Clear & Bright			
Cetane number		> 70	≥ 70	≥ 51.0	≥ 40
Cetane index		No requirement (calculating formula invalid)	No requirement (calculating formula invalid)	≥ 46.0	≥ 40
Density at +15 °C	kg/m³	780	765.0…800.0	820.0…845.0 ≥ 800.0 *	No requirements
Total aromatics	% (m/m)	Below detection limit	≤1.1	Not regulated by EN 590	≤ 35
Polyaromatics	% (m/m)	Below detection limit	Not regulated by EN 15940	≤ 8.0	
Sulphur	mg/kg	≤ 5.0	≤ 5.0	≤ 10.0	≤ 15
FAME-content	% (V/V)	0	≤ 7.0	≤ 7.0	≤ 5.0
Flash point	°C	> 70	> 55.0	> 55.0	≥ 52
Carbon residue on 10% distillation residue	% (m/m)	< 0.1	≤ 0.30	≤ 0.30	≤ 0.35
Ash	% (m/m)	< 0.001	≤ 0.010	≤ 0.010	≤ 0.01
Water	% (m/m)	< 0.010	≤ 0.020	≤ 0.020	
Total contamination	mg/kg	< 12	≤ 24	≤ 24	
Water and sediment	% (V/V)	< 0.01			≤ 0.05
Copper corrosion		Class 1a	Class 1	Class 1	Class 3
Oxidation stability	g/m³ h	< 2 Not relevant since no FAME	≤ 25 ≥ 20 **	≤ 25 ≥ 20 **	
Lubricity HFRR at 60 °C	µm	< 460 *** ≈ 650 ****	≤ 460	≤ 460	≤ 520
Viscosity at 40 °C	mm²/s	3	2.000…4.500	2.000…4.500 1.200…4.000 *	1.9…4.1
Initial boiling point	°C	200	Report		
Evaporated at 250 °C	% (V/V)	5	< 65	< 65	
Evaporated at 350 °C	% (V/V)	> 97	≥ 85	≥ 85	
Distillation 90% (V/V)	°C				282…338
Distillation 95% (V/V)	°C	295	≤ 360.0	≤ 360.0	
Cloud point	°C	Severe winter grades available	As in EN 590	≤ –10*…≤ –34*	
CFPP	°C	Close to cloud point		≤ +5…≤ –44*	
Antistatic additive		Added			
Conductivity	pS/m	≥ 50*****			≥ 25

*) Severe winter and arctic grades
**) Additional requirement if contains above 2 % (V/V) FAME. Method that applies in this case is Rancimat, EN15751
***) Including lubricity additive when delivered to be used as such in vehicles that are validated for EN 15940 fuel
****) If delivered without lubricity additive to be used as a blending component, preference is to add lubricity additive into the final blend
*****) Including electrical conductivity additive

Density and energy content

Neste Renewable Diesel

- Lower density (780 kg/m3) compared to common European diesel fuels (800...845 kg/m^3)
- Higher energy content compared to FAME, both in MJ/kg and MJ/l
- Less Neste Renewable Diesel in mass and volume is needed to fulfil a given biomandate when compared to FAME

When compared to standard diesel fuel with ~13.5 wt-% of hydrogen, Neste Renewable Diesel has higher heating value per mass due to the higher hydrogen content of ~15.2 wt-%.The energy content of NRD also is higher compared to FAME, both per litre and per kg; as a consequence, a slightly smaller blending ratio is needed to meet the same bioenergy mandate. When NRD and ethanol are compared, the volumetric benefit of Neste Renewable Diesel is significant since the heating value of HVO is 44 MJ/kg, and for ethanol it is only 27 MJ/kg. This means that a remarkably lower amount of HVO in tons or cubic meters is needed to meet the same national biomandate compared to ethanol in case there is a combined biomandate for gasoline and diesel (Table 4).

Table 4. Energy content (heating values, lower calorific values) of diesel fuel and some neat biofuels defined by RED II Annex III (rounded to integers as in RED II).

	By weight (MJ/kg)	Compared to diesel fuel by MJ/kg	Compared to FAME by MJ/kg	By volume (MJ/l)	Compared to diesel fuel by MJ/l	Compared to FAME by MJ/l
Diesel fuel	43			36		
HVO	44	+2.2%	+19%	34	–5.6%	+3%
BTL	44	+2.2%	+19%	34	–5.6%	+3%
FAME	37	–14%		33	–8.3%	
Ethanol	27	–37%	–27%	21	–42%	–36%

Fuel density has traditionally been an important factor, as it affects the maximum power output and volumetric fuel consumption of engines. The heating value of various fossil diesel fuel grades is quite constant per mass when they are inside a certain range of aromatic content. However, heating value per volume is decreased as a function of density. With a lower volumetric heating value, the engine gets less energy in with a full throttle and needs more fuel in order to provide the same energy output at part loads. Because the energy content of NRD is higher per mass, the effect of lower density is partially compensated (Table 5).

Table 5. Typical densities and typical calorimetric heating values. In this comparison, analytically measured heating values have been used (instead of the rounded ones used by RED II) for reporting bioenergy to authorities, since engines run according to precise actual heating values.

	Unit	EN 590 B0 summer grade diesel	Neste Renewable Diesel	FAME
Density	kg/m^3	835	~780	~880
Heating value difference to diesel fuel	MJ/kg	43.1	44.1 +2.3%	37.2 –13.7%
Heating value difference to diesel fuel	MJ/l	36.0	34.4 –4.4%	32.7 –9.2%
Heating value, 7 vol-% blend	MJ/l		35.9	35.8
Heating value, 10 vol-% blend	MJ/l		35.8	35.7
Heating value, 30 vol-% blend	MJ/l		35.5	35.0

The lower density of Neste Renewable Diesel results from the paraffinic nature and the low final boiling point. The lower density often offers additional benefits when NRD is used as a blending component in diesel fuel production, because it may allow the use of heavier fractions used otherwise in lower profit products. When blending different components, density changes linearly.

Distillation

Neste Renewable Diesel

- Distillation range is within a similar range typical of European summer grade diesel fuel
- Lower final boiling point compared to FAME

Distillation curves represent the amount of a fuel sample that is evaporated in atmospheric pressure at each temperature when increasing the temperature gradually. The distillation characteristics illustrate how the fuel evaporates when it is sprayed into the combustion chamber of a diesel engine. Some fractions with low boiling temperatures are needed for engine start-up, while fractions with boiling temperatures that are too high may not combust completely and result in engine deposits and an increase in tailpipe emissions. A typical boiling range of a European summer grade diesel fuel is from ~180 °C (356 °F) to ~360 °C (680 °F). The distillation range of Neste Renewable Diesel is within that range, while FAME contains significantly heavier compounds (Figure 4).

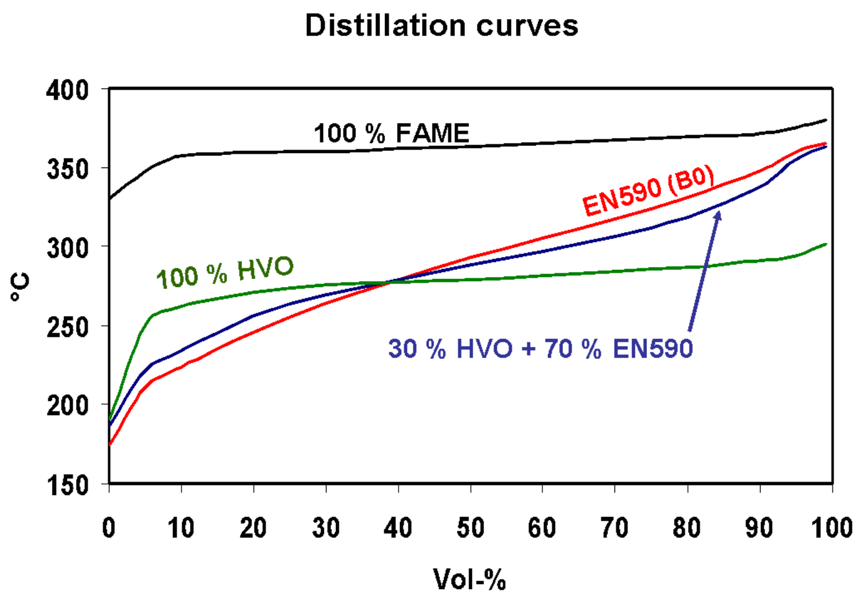


Figure 4. Distillation curves (EN ISO 3405) of a typical diesel fuel without any biocomponents (fuel meets EN 590), FAME, NRD (i.e. HVO), and diesel fuel containing 30 vol-% NRD (HVO).

Cold properties

Neste Renewable Diesel

- Severe winter grades can be produced through a patented isomerization process that allows for high biomandate blending ratios all year round
- CFPP is practically the same as the cloud point, and cold operability characteristics are generated by adjusting the cloud point
- No risk for impurity precipitation at temperatures above the cloud point
- Density is the same, regardless of the cloud point

Fit-for-purpose around the year is an essential requirement for diesel fuels. The cold properties of traditional fossil fuels are generated in conventional oil refining, where the oil is distilled to lighter and narrower fractions to achieve the desired cloud point. In the case of Neste Renewable Diesel, this is achieved through a patented process, where the feedstock is first converted to n-paraffins via hydrotreatment process and then to i-paraffins via isomerization process. During isomerization the melting point of n-paraffins, for example +28 °C for C18, can be adjusted down to -40 °C (-40 °F) to meet the requirements within the most severe arctic climate grades. Isomerization of Neste Renewable Diesel has a negligible effect on density, since the process changes the structure of the molecules keeping the distillation curve practically the same. The viscosity of Neste Renewable Diesel at -15 °C (5 °F) is about 15 mm^2/s, which is about the same as of fossil diesel fuels, and only half of FAME's viscosity at the same temperature.

The feedstock does not limit the cold properties of NRD as it does in the case of FAME. This means that a high biomandate content can be met all year round without compromising cold operability of vehicles or having trouble with fuel logistics. Cold properties are commonly described by cloud point (CP), cold filter plugging point (CFPP) and pour point (PP). The latter two (CFPP and PP) can be adjusted with cold flow additives in many diesel grades. However, due to the narrow distillation range and carbon chain distribution (C15...C18) of paraffinic hydrocarbons in Neste Renewable Diesel, only minor improvements can be achieved with cold flow additives. When Neste Renewable Diesel is blended with diesel components, it is recommended to confirm the cold properties of the final blend.

During extended storage periods, neat Neste Renewable Diesel and its blends behave similar to fossil diesel fuels. Neste Renewable Diesel does not contain any harmful impurities, such as saturated monoglycerides in FAME, and therefore it is not prone to precipitation at temperatures above the cloud point which could result in operability problems. NRD blends behave similar to fossil diesel, and some precipitation of paraffins originating either from the fossil part or Neste Renewable Diesel may take place if the blend is stored below the cloud point for a long period. It is always recommended to store all diesel fuels above the cloud point.

The cold operability of Neste Renewable Diesel and EN 590 (B0) blends containing 10, 30 and 50 vol-% of Neste Renewable Diesel has been studied in laboratories by running diesel cars in a climate chamber (Figure 5) and by using a cold test rig consisting of a complete fuel system of a passenger car built in a deep-freezer. The published results show that the tested Neste Renewable Diesel and its blends operate as expected in severe winter conditions. [Nylund *et al.* 2011] No cold operability problems have been observed in long-term field use either, as later discussed in the Performance in engines chapter.

Figure 5. Testing of cold properties with diesel cars in a climate chamber.

Cetane number

Neste Renewable Diesel

- Very high cetane number: 70...95
- When blended into diesel fuel, the cetane number changes quite linearly according to the blending ratio

The cetane number of most paraffinic diesel fuels is very high, typically over 70, because of their nature as a mixture of n- and isoparaffins. The higher cetane number improves the combustion quality, which can have a positive effect on fuel consumption. Therefore, the difference in fuel consumption between Neste Renewable Diesel and fossil diesel is usually smaller than the difference between the volume based heating values (MJ/l) presented in tables 4 and 5.

When Neste Renewable Diesel is used as a blending component, the cetane number and the blending quantity have a quite linear correlation (Figure 6). Traditionally, 2-ethyl hexyl nitrate additive has been used to improve the lower cetane number of fossil diesel, but the effect is only limited. According to automotive companies, additive use is not as beneficial for real engine performance as a naturally increased cetane number obtained by blending with high cetane paraffinic diesel fuels. Therefore, the use of NRD as a blending component is a good way to increase the cetane number – either to get the blend to meet the specification limit or to produce premium diesel fuel grades.

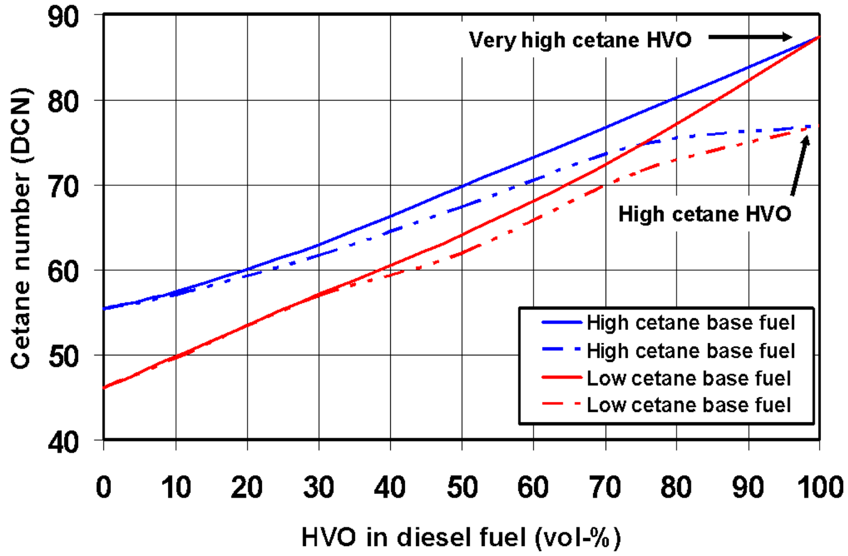


Figure 6. Cetane number of two different Neste renewable fuels (HVO: high and very high cetane) blended with two different diesel fuels (low and high cetane).

The cetane number of Neste Renewable Diesel can be measured with two different methods, as described in EN 15940: cetane engine (EN ISO 5165) and derived cetane number (DCN, EN 15195). When determining precision data for the cetane number, it is noted that the DCN is the most precise method for paraffinic diesels. The cetane number precision data for high cetane paraffinic diesel, as Neste Renewable Diesel, is explained separately in EN 15940 Annex B. The formula of the cetane index is designed only for conventional diesel fuels, which means that the cetane index is not applicable for neat Neste Renewable Diesel.

Stability

Neste Renewable Diesel

- Stability is good and comparable to fossil diesel
- Does not have similar storage stability challenges as FAME, and therefore NRD does not require a “best before” date

The stability of Neste Renewable Diesel is similar to conventional fossil diesel, which means that there is no need to apply a “use before” date [Hartikka *et al.* 2013]. For the sake of comparison, a maximum storage time of 6 months has been defined for neat FAME and FAME blends in Guidelines for handling and blending FAME, published by Concawe [Engelen, B. *et al.* 2009].

The long-term oxidation stability of Neste Renewable Diesel remains on a steady level over at least fifteen years (Table 6). Therefore, there are no risks if vehicles or stationary engines with Neste Renewable Diesel in their fuel tanks are out of use for extended periods. This is especially beneficial for, e.g., mobile homes used seasonally, vehicles parked in dealers’ yards, seasonal agricultural machinery, boats, and emergency generator sets. Also plug-in hybrid cars and even fuel efficient diesel vehicles may suffer if low stability fuels are used in normal day-to-day use and refuelling periods are longer.

Table 6. Long-term oxidation stability results for Neste Renewable Diesel. The samples are without antioxidants and storage has taken place at ambient temperature.

Sampling year	Batch 1 ENISO 12205 (g/m³)	Batch 2 ENISO 12205 (g/m³)
2005	3	2
2006	2	-
2010	<1	<1
2013	1	-
2015	<1	2
2018	<1	1
2020	2	2

Since Neste Renewable Diesel consists of only hydrocarbons, the traditional stability methods used for fossil diesel fuel are applicable, while the methods developed for FAME do not apply. In particular, the "Rancimat" method EN 15751 designed for neat FAME and diesel fuel containing more than 2 vol-% FAME is not valid for NRD or diesel fuel containing only NRD as a biocomponent.

Sulphur content

Neste Renewable Diesel

- The sulphur content is < 1 mg/kg, but, due to possible contaminants within normal diesel logistics, the specification is set to ≤ 5.0 mg/kg
- Can be used in blends to reduce the sulphur content of the final diesel fuel

The sulphur content of Neste Renewable Diesel coming from the production process is less than 1 mg/kg. Therefore, NRD can be used in blending to reduce the sulphur content of the final blend to meet the specification, if the sulphur content of the other blending component is above the specification limit. Due to possible contaminants within normal diesel fuel logistics, the sulphur content within the Neste Renewable Diesel fuel specification is set to ≤ 5.0 mg/kg, which is in line with the EN 15940 standard. This meets the requirements set by the most modern exhaust aftertreatment systems.

Ash and metal content

Neste Renewable Diesel

- The ash content is < 0.001% and thus does not cause excess burden for modern exhaust aftertreatment systems

The ash content of Neste Renewable Diesel is very low, < 0.001%, because feedstock-originated metals, like P, Ca and Mg, are removed in a pretreatment unit, resulting in an ash content well below practical detection limits of analytical methods (<1 mg/kg). Therefore, Neste Renewable Diesel offers at least as long lifetime as high quality fossil diesel fuel for modern exhaust aftertreatment systems.

Filterability

Neste Renewable Diesel

- No filter blocking problems as observed with FAME
- Filter blocking tendency value is usually around 1.0...1.1

Filter blocking issues are widely recognized in several European countries due to widespread use of FAME. These issues have not been observed with Neste Renewable Diesel. Traditionally, total contamination (EN 12662) has been used to detect solid particulates, but not other contaminants causing filter blocking. Filter blocking tendency (FBT) IP 387 was implemented for detection of blocking above the cloud point, while CFPP measures it below the cloud point. While the EN 590 specification does not limit FBT, the recommendation of the Worldwide Fuel Charter is below 1.6. The UK has set the limit to a maximum of 2.52; the FBT of Neste Renewable Diesel is usually around 1.0…1.1. Applying an FBT limit has not completely solved the encountered field issues with FAME.

Water content

Neste Renewable Diesel

- Low tendency to incorporate dissolved water
- No additional measures in fuel logistics required when compared to fossil diesel fuels

Neste Renewable Diesel and fossil diesel have low water solubility, due to the non-polar nature of hydrocarbons and the polar nature of water molecules (Figure 7). The small difference between NRD and fossil fuel can be caused by the aromatic content of fossil fuel. If a small amount of water has been absorbed into NRD, it separates similarly as water separates from fossil diesel fuels. As a consequence, the water issues do not require any additional measures in fuel logistics when comparing Neste Renewable Diesel to fossil diesel fuels. When storing Neste Renewable Diesel, the same kind of housekeeping is recommended as for fossil diesel. The difference is clear when a comparison is made with FAME, which has a polar nature and can dissolve significant amounts of water (Figure 7). Increased water content enables microbial growth and, therefore, FAME is more prone to microbial contaminations.

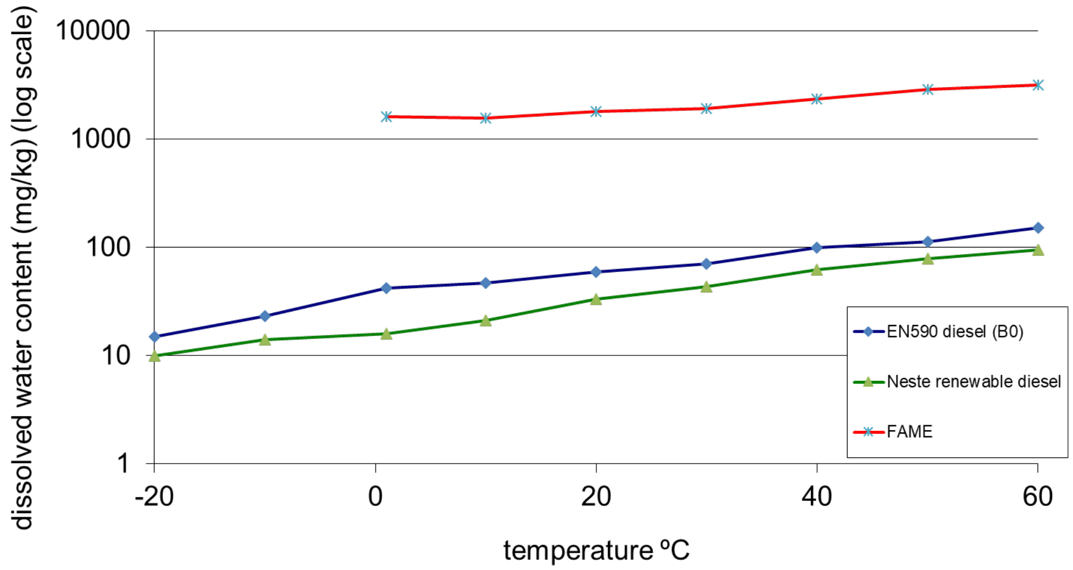


Figure 7. Water absorption properties of EN 590 diesel, Neste Renewable Diesel and FAME were demonstrated with laboratory experiments under a wide temperature range and excess amount of supplemented water.

Microbial growth

Neste Renewable Diesel

- Due to the low water dissolving property, the risk of microbial growth is similar to fossil diesel and no additional precautions are needed

Microbes can grow in all types of diesel fuels if free water is present; higher temperatures (~+30 °C) increase this tendency. Because Neste Renewable Diesel as such or as a blending component dissolves water poorly, no additional precautions are needed when compared to fossil diesel; the high water content of FAME makes it predisposed to microbial growth. When considering diesel fuels in general, good maintenance, cleaning and dewatering of containers and tanks regularly is essential to avoid contaminations. Microbial growth may cause issues with long storage periods in marine use and fuel stations, but also automotive vehicles can suffer from filter blocking caused by microbes.

Appearance and odour

Neste Renewable Diesel

- Clear and bright above the cloud point; paraffins may crystallize below the cloud point

Neste Renewable Diesel is clear, bright and odourless with an almost water-like colour at temperatures above the cloud point (Figure 8). It does not contain any impurities prone to precipitate at temperatures above the cloud point; below the cloud point, paraffins cause cloudiness and crystallized paraffins may settle during an extended storage period, which is a known phenomenon also for fossil fuels. Neste Renewable Diesel does not have an unpleasant diesel fuel type odour.

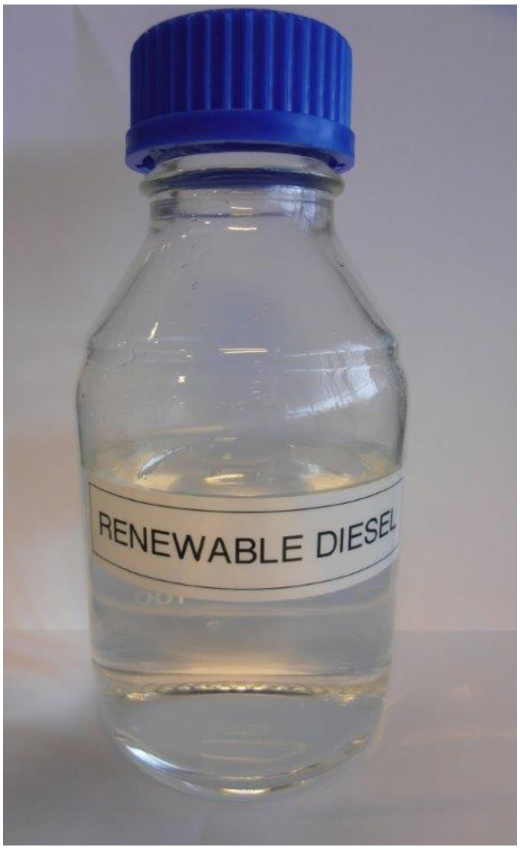


Figure 8. Appearance of Neste Renewable Diesel.

Lubricity

Neste Renewable Diesel

- Requires a lubricity additive in the same way as sulphur free diesel fuels and GTL
- Generally, similar types of lubricity additives can be used in fossil diesel fuel and Neste Renewable Diesel

The lubricity of neat Neste Renewable Diesel corresponds to that of sulphur-free fossil diesel and GTL diesel fuels. It is essential that all of these types of fuels contain a lubricity additive in order to meet the HFRR (High Frequency Reciprocating Rig) specification (<460 µm in EN590 and EN15940, <520 µm in ASTM D975) for protecting fuel injection equipment and high-pressure pumps against wear. Lubricity additives generally used in fossil diesel fuels also function in Neste Renewable Diesel. Additives representing neutral chemistry are recommended, because they do not affect the acid number of the diesel fuel, which could predispose the fuel to salt formation and instability. When pure NRD is used, the additive dosing rate is typically about the same as in arctic grade fossil diesel fuels. When used either neat or blended with other diesel fuels, the lubricity of the fuel always has to be checked and a lubricity additive used when needed. In commercial fuels, the HFRR is typically clearly better than <460 µm.

In addition to the specified HFRR tests, lubricity has been evaluated with several 1,000-hour fuel system component durability tests using both the distributor pump and the modern common rail systems. For the tests, Neste Renewable Diesel batches were treated with a minimum dosing rate of lubricity additives to be at the borderline of acceptance, i.e. as close to the <460 µm HFRR limit as possible. After the tests, all the internal parts of the tested pumps were in good condition, and the overall rating of both pumps was pass. Distributor pumps are no longer used in new engines, but since they were known to be sensitive to fuel lubricity, passing the pump test gives additional confidence over HFRR on the lubricity of NRD treated with a lubricity additive. In addition, no field issues have been reported when using Neste Renewable Diesel fulfilling HFRR according to the EN 15940 specification.

Fuel injection system suppliers have indicated that for some paraffinic diesel fuels extra lubricity evaluation methods would be needed to secure lubricity to a sufficient level, even though paraffinic diesel fuels have been successfully used without lubricity issues for well over 12 years in captive fleets (EN 15940 Annex A). Fuel injection system suppliers are suggesting the SLBOCLE (Scuffing Load Ball On Cylinder Lubricity Evaluator) method with a minimum limit of 3500 g. There have been studies regarding the lubricity of paraffinic fuels with both methods: HFRR and SLBOCLE. The main conclusion of the published studies [Lehto *et al.* 2014; Kuronen *et al.* 2015] is that the SLBOCLE method is so inaccurate that it cannot be taken on as a part of a specification.

Compatibility with materials

Neste Renewable Diesel

- Similar compatibility with materials as fossil diesel
- Lack of aromatics may predispose the shrinking of elastomers; therefore, avoidance of significant changes in fuel composition is recommended

Neste Renewable Diesel may be considered as having the same compatibility as conventional diesel towards parts and materials, such as seals, hoses, diaphragms, dry couplers, base swivel joints and mechanical seals of pumps. Likewise, construction materials containing carbon and stainless steel and suitable for conventional diesel fuel can be used with NRD. The use of both welded and riveted tanks is acceptable. Tanks may have internal floating roofs made of aluminium, and nitrogen blanketing can be used.

Neste Renewable Diesel is compatible with nitriles (NBR, Nitrile Butyl Rubber), fluoroelastomer (FKM), PTFE (polytetrafluoroethylene), vinyl ester resins, and epoxy resins. In principle, the lack of aromatic compounds may shrink elastomers that have already been swollen due to aromatic or FAME containing fuels, but no fuel leakages have been observed during 12 years of usage in the field. Generally speaking, significant changes within liquid composition may cause the swelling or shrinking of elastomers, especially within older seals. Special attention should be given to NBR seals, which may be more sensitive to leakage if they are first exposed to high FAME content and thereafter low paraffinic content.

Neste Renewable Diesel as blending component

Neste Renewable Diesel

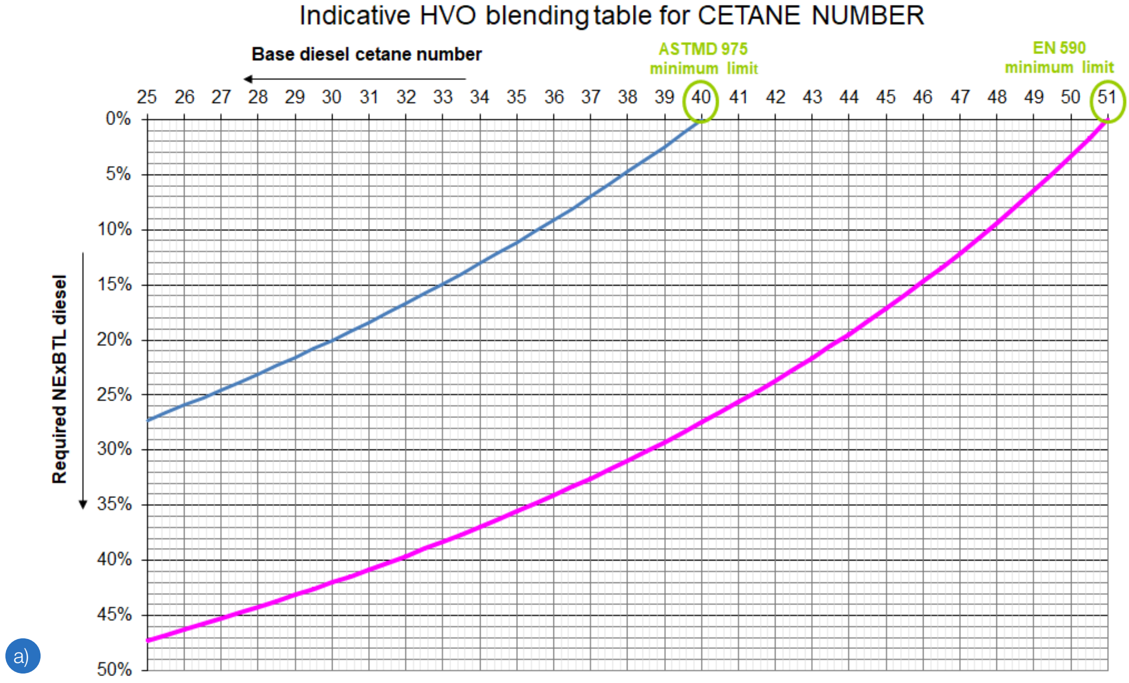
- Preserves and even improves the properties of the final diesel fuel blend
- Benefits depend on the blending ratio
- Minimum density specified in EN 590 limits the maximum amount of NRD that can be blended in the final fuel
- Can be blended in all ratios with ASTM D975 fuel, due to the absence of density limitations
- Some attention needed if FAME and renewable diesel are blended, especially regarding the precipitation of FAME originated impurities
- Blends well with GTL fuels

Blending properties with diesel fuel

Because Neste Renewable Diesel contains only n- and i-paraffins, it can be blended into diesel fuels as a “drop in fuel” without a “blending wall” set by vehicle technology or limitations by fuel logistics. Also the Fuel Quality Directive 2009/30/EC, recital 33, states that no limit is required for diesel-like hydrocarbon biofuels and hydrotreated vegetable oil. Regarding the actual blending procedure, the same considerations need to be taken into account as when two fossil diesels are blended together, such as temperature and density of the fuels. Compatibility with commonly used additives (lubricity, conductivity etc.), current logistics and practices, excellent storage stability and low tendency to pick up and dissolve water make Neste Renewable Diesel a convenient blending component.

In practice, the maximum amount of Neste Renewable Diesel to be blended is limited by the lower density limit in EN 590, which often limits the blending to ~30-50% of Neste Renewable Diesel. In blending recipes, the density behaves linearly; therefore, even more could be added if the density of the base diesel fuel is over 845 kg/m^3. This allows the usage of slightly heavier distillation fractions, which would otherwise be directed into lower profit products, such as heating gas oil. In the American ASTM D975, there is no limit for density – so there are no limits for adding Neste Renewable Diesel from that point of view.

Neste Renewable Diesel is a valuable component for oil refineries, since it can be used to enhance many of the properties of base diesel fuel. It is aromatic free and can be used to dilute aromatic content of the final blend. The sulphur content of NRD is low and, consequently, it can be used to reduce the sulphur content of the final blend. The high cetane number increases the final cetane number (Figure 9a), and the relatively low final boiling point of NRD can be advantageous to reduce the final boiling points of the blend as well (Figure 9b). The cold properties of Neste Renewable Diesel are good due to the isomerization step and can be used to benefit the cold operability of the final blend. Thus, if the base fuel does not meet regulatory requirements, for example, density being above 845 kg/m^3, the cetane number below 51 or polyaromatics above 8% as set by the FQD, the effect of adding Neste Renewable Diesel is practically linear on the values to be corrected by blending.



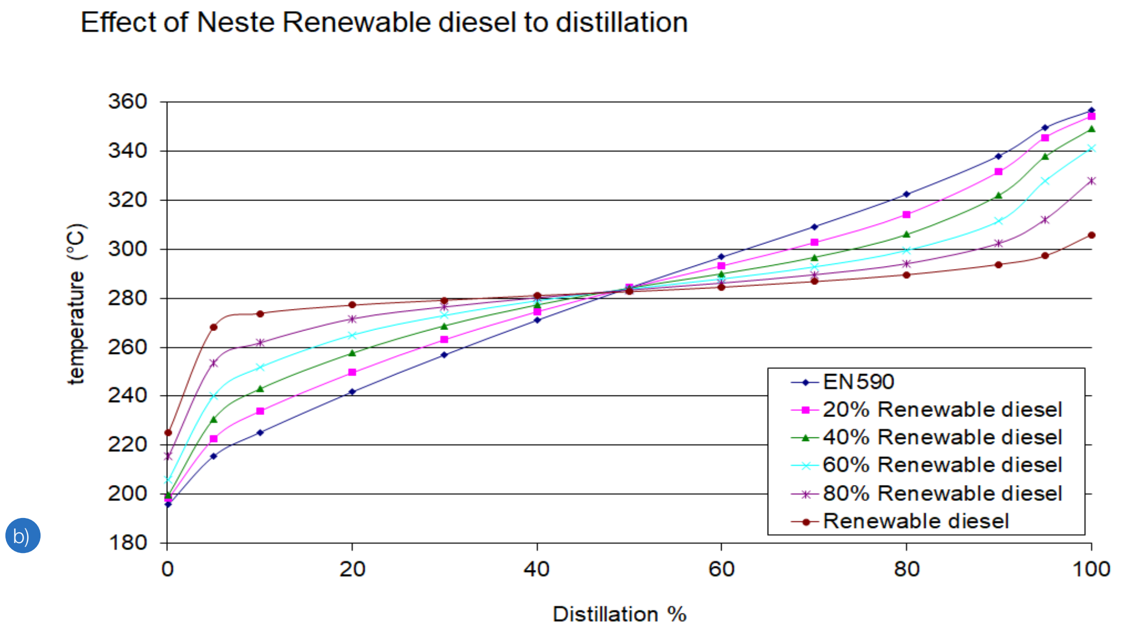


Figure 9. a) The amount of HVO (with cetane number 80) which is required to upgrade the base diesel fuel to meet the cetane number requirements of EN 590 or ASTMD 975 standards and b) behaviour of distillation properties in Neste Renewable Diesel fuel blends.

Storage and blending of Neste Renewable Diesel with FAME

Since Neste Renewable Diesel is fully paraffinic, it is not as good of a solvent as fossil diesel fuels containing usually 15...30% total aromatics, with the exception of the lower aromatic content diesel fuels used in Sweden and California, for example. The poor solvent properties of NRD increase the risk of precipitation of possible impurities of FAME, which even within fossil fuels can precipitate at temperatures above the cloud point. Thus, the better the diesel fuel (lower aromatics), the higher the risk for precipitation; therefore, the quality of FAME becomes an even more important factor in order to avoid problems.

EN 15940 allows max. 7% FAME content, but the quality of FAME is an important factor; poor quality may result in problems, even at lower concentrations. The precipitation risk of FAME's impurities increases with higher blending content. Concawe has given a recommendation for EN 590 diesel's SMG (saturated monoglyceride) content [Engelen *et al.* 2009], as does Annex C in the FAME standard EN 14214, and these recommendations can be applied also when blending FAME with Neste Renewable Diesel. In addition, the Swedish diesel fuel quality Environmental class 1 (MK1) and NRD behave similarly when blending with FAME and, therefore, the same maximum SMG levels in the final blend, i.e. 20 mg/l, can be applied to both.

When blending FAME and NRD, blending temperatures should be well above the cloud points of both FAME and NRD. The precipitation risk decreases at higher temperatures. The remarkable difference in densities between FAME and Neste Renewable Diesel also need to be taken into account in blending. It is recommended that long-term storage of the neat components take place in separate tanks and that the blending of the final fuel take place only just before use. Blending FAME in NRD will have an impact on the final fuel colour, as shown in Figure 10.

In practice, the same tank might be used for FAME and renewable diesel due to limited tank capacity. In this case, it is recommended to perform a normal quality change procedure when changing between different products. (See the Logistics section for more information.)

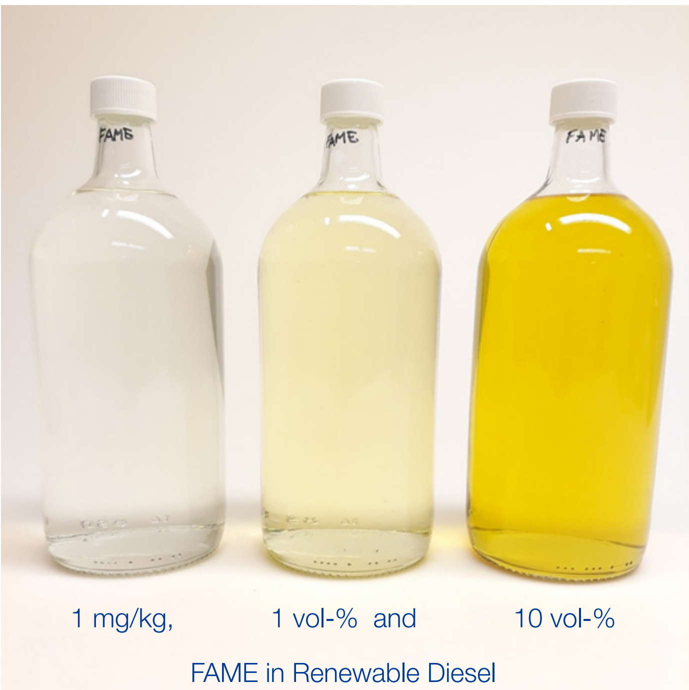


Figure 10. Appearance of 1 mg/kg, 1 vol-% and 10 vol-% of FAME in Neste Renewable Diesel.

Blending of GTL and Neste Renewable Diesel

In some urban areas, the use of neat GTL diesel fuel has been considered in order to reduce locally harmful tailpipe emissions and dependence on crude oil. If the addition of a biocomponent is also required, renewable diesel fits perfectly for blending into GTL. Both GTL and NRD are paraffinic diesel fuels, and thus the final blend fulfils the requirements of EN 15940.

Measurement of Neste Renewable Diesel content in diesel fuel

Neste Renewable Diesel

- Reporting of bioenergy content is based on bookkeeping of mass balance
- Can be detected by ^{14}C isotope methods
- Cannot be detected by routine analytical methods used for FAME or ethanol detection

Both Neste Renewable Diesel and fossil diesel fuels consists of paraffinic hydrocarbons; due to this chemical similarity, the amount of renewable diesel in a fuel blend cannot be analyzed with conventional analytical methods used to detect chemically different components, such as FAME (in diesel) or ethanol (in gasoline). Neste Renewable Diesel content in a fuel blend can be determined by ^{14}C isotope method or a radiocarbon dating method, the same used for archeological studies. These methods are based on a fixed ratio of stable ^{12}C and decaying ^{14}C carbon isotopes in the atmosphere that can be found in all living plants and animals. When these organisms stop their growth, the amount of ^{14}C isotopes begins to decline gradually, with a half-life of 5,730 years. Therefore, fossil diesel no longer contains ^{14}C isotope and the proportion of newer organic material can be detected. The principles of determining the bio-based content in fuels can be found from the standards ASTM D6866 or EN 16640.

Two commonly accepted methods for biogenic content analysis are Accelerator Mass Spectrometry (AMS) and Liquid Scintillation Counting (LSC). Both methods, AMS and LSC, are able to confirm if paraffins are bio-based (renewable diesel or BTL) or fossil (GTL or CTL) with a practical detection limit of 1 wt-% or less of bio carbon content in liquid fuels. AMS is the more accurate of the two methods, but, due to limited availability, the external service prices are typically more expensive and turnaround times can be longer. LSC is typically cheaper, more accessible and easier for the performing laboratory, but not as accurate as AMS nor as sensitive. The AMS method is suggested for measuring lower biogenic content (0-2 wt-%) in a fuel blend. If a sample contains both FAME and renewable diesel, the amount of FAME is first measured with the traditional infrared method and subtracted from the total biocontent to find out the renewable diesel content. Some further calculations are needed to convert the ^{14}C results between vol-%, wt-% or bioenergy-% units, depending on what is needed in each case.

Both the AMS and LSC methods are available at several commercial and custom laboratories. When selecting external service providers, as a rule of thumb the laboratory should be asked and required to stick to one of the international standards mentioned. This guarantees, to an extent, that the methods used are more comparable to those of other laboratories and thus the results are more reliable. As a secondary guideline, it is recommended to use a laboratory with ISO 17025 accreditation. However, especially in the more niche field of AMS, there are few accredited laboratories and, therefore, it may not always be possible.

As an internal quality control method, Neste is currently using the Direct LSC method described in standard DIN 51637. This is the easiest LSC method to use, but it has to be validated for each separate sample type, as the method is not universal in the same sense as the other LSC or AMS methods. The Direct LSC method works very well when dealing with known samples (i.e. quality control of production), but it is suboptimal for measuring unknown samples; thus it is advisable to use other methods for this type of work.

Since ^{14}C methods are not yet part of routine laboratory practices at oil companies or with the authorities, the content of renewable diesel shall be based on the seller's declaration and bookkeeping of the blending procedures. ^{14}C methods can be used in cases where the audit trail approach is contested or the biocontent needs to be otherwise determined. This approach is already mentioned in the EN 228:2012 standard in order to make a difference between fossil and renewable ethanol in gasoline. The European Custom Administration has noticed this challenge, and Round Robin tests with the methods are already in progress.

Production and logistics

Ways to use Neste Renewable Diesel

Neste Renewable Diesel can be used:

- To fulfil the biomandate without the 7% blending wall set for FAME in EN590
- To replace ASTM D975 diesel as such
- For upgrading diesel to meet premium retail fuel requirements
- For reducing locally harmful tailpipe emission and greenhouse gasses in dedicated fleets, like city busses

There are four principal ways to use renewable diesel fuel:

- By using it as a neat 100% product in all diesel vehicles, such as buses, delivery vans, trucks, taxis, passenger cars and non-road machinery, including locomotives and boats, in order to reduce GHG emissions of the operations. Additionally, this will reduce the local emissions of older vehicles, especially from the highest emitters. The use of neat Neste Renewable Diesel remarkably reduces the carbon footprint of the vehicle, and also improves the function of the exhaust aftertreatment device, due to lower engine-out particulate and nitrogen oxides (NO_x) emissions, and the negligible ash content compared to fossil diesel. This is also a convenient way to use 100% biofuel in cases where it is required by local policy makers or company profiles. There are already multiple OEMs who have accepted using 100% paraffinic fuels, i.e. EN 15940 fuels. ASTM D975 diesel can be directly replaced with renewable diesel. Extra benefits of the Neste Renewable Diesel can be achieved by optimizing calibration of the engine's fuel injection system, as described in the chapter "Optimizing engines for HVO".
- By adding the required percentage into diesel fuel in order to meet the local bioenergy mandate. For this purpose, renewable diesel can be used in addition to the max. 7% FAME in EN 590, or as such without a blending wall. Renewable diesel can be used alone to fulfil the biomandate all year round without the challenges related to cold operability, engine oil dilution or storage stability.
- By adding tens of percents into diesel fuel in order to upgrade the final fuel to meet EN 590 or ASTM D975 or to prepare a premium diesel fuel in order to achieve reduced exhaust emissions and better overall performance. By blending with Neste Renewable Diesel, the aromatic content and density are reduced and, at the same time, the cetane number is increased. Also cold properties can be adjusted with renewable diesel, as it has superior cold properties. Likewise, renewable diesel can be added without any detrimental effects on the final boiling area. If the target is that the final blend meets, e.g., FQD and EN 590 specifications or ASTM D975, the fossil part can be originally out of specification and renewable diesel can be used to finalize the final blend. Additionally, Neste Renewable Diesel introduces biocontent to the final blend to fulfil the local bioenergy mandate. For retail marketing, fuel can be produced to meet, e.g., the highest Worldwide Fuel Charter (WWFC) requirements, which are the toughest ones set by the automotive industry for premium fuels [Hartikka *et al.* 2013]. So renewable diesel as a blending component offers new economic benefits for refineries and fuel blenders.
- By using Neste Renewable Diesel in order to reach a high biocontent level within EN 590 or ASTM D975 without separate engine validation. For example, in cases where a fleet operator decides to increase the biocontent to 30%, Neste Renewable Diesel can be added to meet the FQD and EN 590, while if the same biocontent is made by FAME, engines have to be validated and accepted separately for EN 16709 B30 fuel.

Logistics

Neste Renewable Diesel and blends

- Behave like traditional fossil diesel fuel
- No additional issues related to storage stability, water separation and microbiological growth
- No additional material compatibility issues

Neste Renewable Diesel can be handled similarly to fossil diesel fuel. It can be mixed with diesel in any ratio, and there is no risk of precipitation or phase separation. Water solubility and storage stability properties of renewable diesel are so similar to fossil diesel fuels that no extra precautions are needed in pipelines, tank farms, tanker trucks or service stations. Well-known practices used for fossil diesel fuels apply also for blends containing renewable diesel, and for renewable diesel as such. Because of these similarities, the same equipment as for fossil diesel can also be used for leak detection [Gordji, 2014].

As discussed in detail in the Properties section, NRD has low water dissolving properties. Consequently, the probability of microbial growth in Neste Renewable Diesel is low, so no extra precautions regarding microbiological growth or storage stability are required compared to fossil diesel. However, general good storage tank maintenance and housekeeping is recommended. Storage tanks should be kept free of water, and tanks should have provisions for water draining on a scheduled basis. There are two reasons for this: water promotes corrosion, and microbiological growth can occur at the fuel-water interface.

For a real-life, long-term storage test, neat renewable diesel was left for 8 months in the refuelling storage tank of a bus operator after a large field test of several years was completed. The fuel was clear and free from microbiological growth after the additional storage time [Nylund *et al.* 2011]. Moreover, Neste has stored Neste Renewable Diesel from the first production batches for more than 15 years and has monitored the quality regularly. The product has maintained its quality over the years, as shown in Table 6.

When one wants to start using their fuel storage for storing Neste Renewable Diesel after having stored diesel fuels with a FAME content over 7%, it is recommended to empty, clean and dry the tank. If it is not possible to clean the tank, the leftover FAME must be kept to a minimum. When using a storage tank in which conventional diesel has been stored previously, there is no need for such precaution when switching to Neste Renewable Diesel.

The flash point of HVO is regulated to above +55 °C (131 °F) in the paraffinic diesel standard EN 15940, meaning that it can be stored and transported like standard diesel fuel. The natural electrical conductivity of HVO is low and comparable to sulphur-free diesel fuels. An antistatic additive is used in Neste Renewable Diesel in order to allow high pumping velocities in pipelines and loading racks. Neste Renewable Diesel can be transported in multiproduct pipeline systems, as it is essentially similar to diesel fuel.

As a neat 100% product, Neste Renewable Diesel is considered as an energy-rich fuel. From January 1, 2019, Neste Renewable Diesel is to be carried subject to Annex I of MARPOL (International Convention for the Prevention of Pollution from Ships). The UN proper shipping name is “UN1202 DIESEL FUEL”. Also blends of Neste Renewable Diesel and fossil diesel are carried according to Annex I.

Custom codes

Neste Renewable Diesel

- is treated similarly to fossil diesel fuel in regards to customs tariff classification purposes
- is classified under the CN code 2710 19 43, whether in pure form or as a blend with fossil diesel fuel

Neste Renewable Diesel is, for customs tariff classification purposes, treated similarly to fossil diesel fuel. This is due to note 2 of Chapter 27 of the Harmonized System (HS) Nomenclature, which reads:

References in heading 2710 to 'petroleum oils and oils obtained from bituminous minerals' include not only petroleum oils and oils obtained from bituminous minerals but also similar oils, as well as those consisting mainly of mixed unsaturated hydrocarbons, obtained by any process, provided that the weight of the non-aromatic constituents exceeds that of the aromatic constituents.

Explanatory notes to the Combined Nomenclature of the European Union provide a more detailed definition of the similar oils referred to in note 2 of Chapter 27 of the HS. The definition reads (page 124 of OJ C119/2019, published 29 March 2019):

> *The expression 'similar oils' includes, among others, the following mixtures of hydrocarbons:*
>
> – *synthetic paraffinic diesel fuels, in particular 'Hydrotreated Vegetable Oils' (HVO) and 'Gas to Liquid Fuels',*
> – *products from renewable sources resulting from the following processes: 'Biomass to Liquid Fuels' or 'Biogas to Liquid Fuels',*
> – *products from the co-processing of renewable feedstock at refineries with petroleum feedstock.*
>
> *The following definitions as regards the production of 'similar oils' apply:*
>
> – *'Hydrotreating' means the thermochemical conversion of triglycerides with hydrogen to produce alkanes; it refers to fuel processing. Sources for triglycerides are, in general, fats and oils, suitable waste, residue fat fractions and fat originating from algae.*
> – *'Gas to Liquid Fuels', 'Biomass to Liquid Fuels' and 'Biogas to Liquid Fuels' mean the conversion of gas into liquid fuels by the Fischer-Tropsch process or equivalent processes. In the case of 'Biomass to Liquid Fuels' there is a prior step, converting the biomass into gas.*

In accordance with the above notes, Neste Renewable Diesel is classified under the CN code 2710 19 43, whether in pure form or as a blend with fossil diesel fuel.

The TARIC subclassification of the blend depends on the blending ratio, as indicated in Table 7 below.

Table 7. CN and TARIC codes.

Gas oils / Sulphur content max. 0.001% by weight	**CN code (export and intra-EU)**	**TARIC code (import)**
- Neat HVO and blends with > 20% of HVO - Blends with max. 20% of HVO	2710 19 43 2710 19 43	2710 19 43 29 2710 19 43 30

Sustainability

Renewable energy and sustainability criteria

EU

Renewable Energy Directive II

- Gives default GHG values for some of the biofuel pathways to help fuel producers calculate the GHG emissions of the entire life cycle of fuel
- Obligates Member States to have a minimum of 14% of the energy consumed in road and rail transport originated from renewable sources by 2030
- Individual Member States may have even more challenging requirements

The European directive promoting the use of renewable energy ("RED", directive 2009/28/EC) requires that at least 10% of the energy used in the transport sector has to originate from renewable sources by 2020. In RED II (2018/2001/EU), each Member State is obligated to have a minimum of 14% of the energy consumed in road and rail transport as renewable energy by 2030. The Member States must update their legislation accordingly by the end of June 2021. In addition, the directive regulating fuel quality and environmental impacts ("FQD", directive 2009/30/EC) demands a 6% reduction in fuel greenhouse gases (GHG) by 2020. The requirement of 6% will continue after 2020. In addition, individual Member States may have even more challenging requirements. For example, Finland will increase the share of biofuels used in road transport to a minimum 30% by 2029, the major reason for which is the "Non-ETS sectors" (ETS, emissions trading system) greenhouse gas reduction regulation 2018/842/EU.

The RED and FQD have common sustainability and GHG emission criteria that bioliquids used in transport must comply with. In RED II, some of these criteria are the same as in the original RED and FQD, but some are new or rewritten. All sustainable renewable energy sources are taken into account in the fuel supplier obligation. Biofuel needs to be traced to its origin, for example, where the raw material has been cultivated. Waste and residue raw materials are traced to their collection point of origin. Additionally, there are bans that restrict biofuel raw material from areas like primary or highly biodiverse forests, wetlands, peatlands and nature protection areas. There are caps restricting the use of some raw materials.

The life cycle GHG emissions need to be assessed for all product steps: cultivation, raw material transport, all processing steps, fuel transport, distribution and final use of the fuel. It's called the Well-To-Wheels approach in the life cycle assessment (LCA). The sum of all product chain steps is compared to the sum of the fossil fuel production steps and the result is the GHG savings. RED II has tightened the GHG saving limit criteria for biofuel production in new production sites:

- at least 50% on or before 5.10.2015,
- at least 60% from 5.10.20.15-31.12.2020
- at least 65% after 1.1.2021.

The RED, RED II and FQD give default GHG values for some of the biofuel pathways to help fuel producers with complicated GHG calculations. There are examples in Table 8. However, the directives give fuel producers the possibility to use partly default values or to calculate the biofuel pathway emissions with actual raw material, process and transport values on their own. Biofuel producers are required to have third party (e.g. ISCC certificate) verification of compliance with the sustainability and greenhouse gas emissions saving criteria annually.

Table 8. Examples of default greenhouse gas savings defined by RED II.

	Default savings
HVO from rape seed oil	47%
HVO from sunflower	54%
HVO from soybean	51%
HVO from palm oil, methane capture at oil mill	49%
HVO from waste cooking oil	83%
HVO from animal fats from rendering	77%

Neste Renewable Diesel reduces greenhouse gas emissions by 50–90%. The actual GHG savings from Neste Renewable Diesel, based on waste and residue raw materials, such as used cooking oil, is on average 90%. Further details can be found here:

https://www.neste.com/en/corporate-info/sustainability/cleaner-solutions/products-carbon-footprint

The greenhouse gas calculation methodology established in RED, RED II and FQD, sets fuel in use emissions as zero because of carbon dioxide sequestration. This means that the differences in engine efficiency between the various biofuels are not reflected in the final results. The total environmental benefit could be assessed by taking into account the total efficiency of the engine and fuel type combination. In this case, the comparisons would be made in terms of grams CO_2eq/passenger-km or grams CO_2eq/ton-km for trucks, rather than grams CO_2eq/MJ fuel used, as is currently done in the directives.

Diesel engines are clearly more efficient than spark-ignited engines, which means lower fuel consumption for diesel. Although Well-To-Tank greenhouse gas values of, for example, sugar beet ethanol are low per MJ of ethanol's calorific value, even a current HVO can be better on a Well-To-Wheels basis because of the diesel engine's better efficiency (Figure 11). JEC WTW GHG calculation methodology differs from EU legislation methodology, e.g. the allocation method is different and biofuel CO_2 sequestration is taken into account in Well-To-Tank (WTT) part.

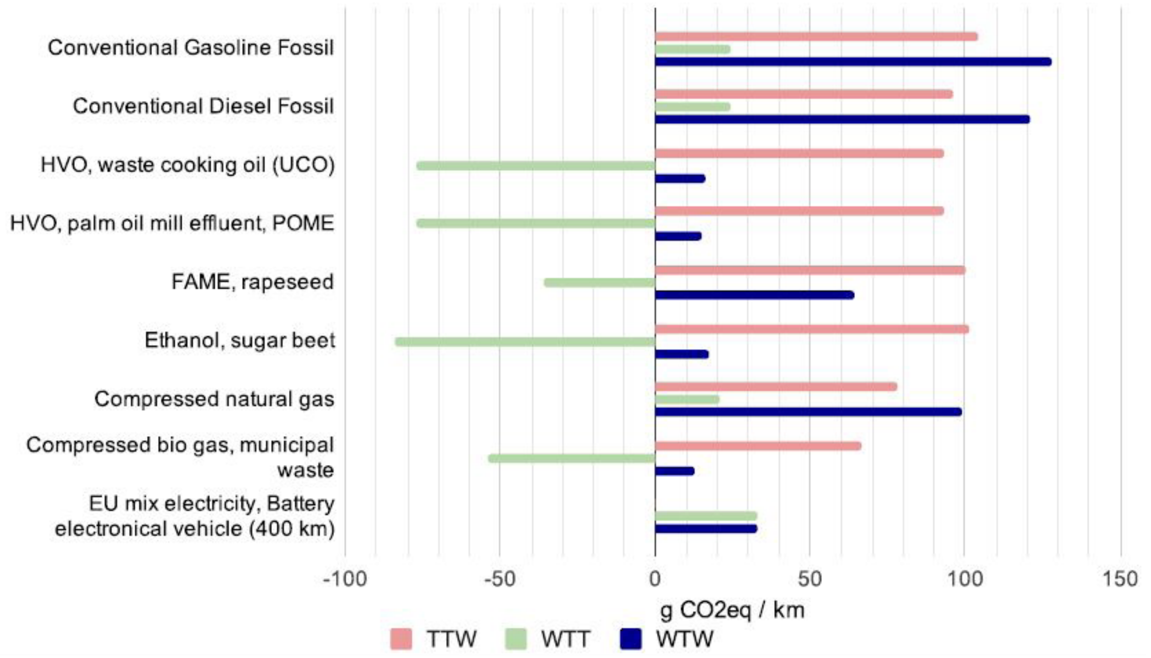


Figure 11. Well-To-Wheels greenhouse gas emissions of a typical midsize class car, 2025+ as emissions/km. WTT means Well-To-Tank (emissions from fuel production chain) and TTW means Tank-To-Wheels (tailpipe emissions). In the JEC WTW methodology, carbon sequestration is taken into account in the WTT part. WTW is the sum of WTT and TTW. [Prussi *et al.* 2020]

North America

United States

Renewable Fuel Standard

- Obligates certain parties to use a specific volume of renewable fuel
- Qualifies Neste Renewable Diesel as renewable fuel or biomass-based diesel in the Renewable Fuel Standard
- Actual fuel legislation varies in different states

The Renewable Fuel Standard (RFS) program in the United States requires obligated parties to use a certain volume of renewable fuel. The obligated parties are refiners or importers of gasoline and/or diesel fuel, and compliance is achieved either by blending renewable fuels into transportation fuel or by obtaining credits, named Renewable Identification Numbers (RINs), to meet an EPA-specified Renewable Volume Obligation (RVO).

Under the RFS, each fuel type is assigned a “D-code” that identifies the renewable fuel type based on the feedstock, fuel type, energy inputs, and GHG reduction thresholds.

The four renewable fuel categories and their corresponding D-codes under the RFS are:

- Cellulosic biofuel, D3 or D7 for cellulosic diesel
- Biomass-based diesel, D4
- Advanced biofuel, D5
- Renewable fuel, D6

Standard renewable fuel must meet a 20% GHG reduction and biomass-based diesel a 50% reduction against a 2005 conventional baseline. Depending on the current feedstock, Neste Renewable Diesel qualifies as renewable fuel or biomass-based diesel. Biomass-based diesel can also be used to fulfil the advanced biofuel volume obligation.

North America Renewable Fuel Legislation varies in different states. Legislation is in change in many states. California has a separate Low Carbon Fuel Standard (LCFS) regulation, in addition to the RFS. The goal of the LCFS is to reduce the carbon intensity of transportation fuel pool used in California by at least 20% by 2030. Fuels below the standard carbon intensity generate credits. The biofuel pathways are raw material- and production site-specific and must be accepted by the authority. The new pathways are certified by third party verifiers and California Air Resources Board and, from 2021, the pathways are annually verified by third party verifiers. Many states have or will have their own LCFS regulations – Oregon is one example. The base model is often from the California LCFS, but the sustainability regulations change from state to state.

Canada

Canadian Federal Fuel Standard

- Under a renewing process and provincial policies have a significant role in the roadmap

The Canadian Federal Fuel Standard (CFS) is currently being renewed. Canada has had a federal mandate requiring 5% of the national gasoline pool to be renewable since 2010, and the federal mandate was extended in 2011 to include a 2% blending requirement for renewable diesel or FAME. Renewable diesel offers an alternative to fulfil the different blend mandates, and GHG emissions depend on feedstock and provincial sustainability requirements.

The provincial policies are also significant, as they have often been the forerunners of what has eventually been developed at the federal level. There is the same type of LCFS program in British Columbia as in California. In Alberta, there is a minimum 25% reduction of GHG emissions; in Ontario, the mandate is an average of 4 vol-% blend in diesel with a 70% reduction in carbon intensity. Quebec is considering a new provincial biofuel mandate.

Health, safety and environmental properties

Neste Renewable Diesel

- Registered under the REACH regulation
- Well-known practices for handling and safety precautions of diesel fuels apply

The normal precautions for personal safety must be followed, as described in the Safety Data Sheet of the product. Neste Renewable Diesel's health and environmental properties have been subject to a thorough testing program in order to comply with the EU REACH regulation. Neste Renewable Diesel as such is biodegradable according to OECD test guideline 301 B. Under the EU's hazard classification system, CLP, Neste Renewable Diesel as such is classified as hazardous only if swallowed and enters airways (aspiration). The aspiration hazard is a characteristic for all low viscosity hydrocarbons, both fossil and renewable. Repeated exposure may cause skin dryness or cracking. The odour of Neste Renewable Diesel is very weak and of a paraffinic nature without the typical odour of diesel fuel. Neste Renewable Diesel as such is practically insoluble in water. When Neste Renewable Diesel is blended into diesel fuel, well-known practices used for diesel fuel apply.

Performance in engines

Neste Renewable Diesel

- No modifications to vehicles required
- Same torque and maximum power as with fossil diesel fuel in modern engines
- No cold operability issues with severe winter grades
- Low tendency to form deposits in fuel injection system and fuel injectors
- No engine oil dilution issues or chemical incompatibilities with engine oil
- Possibility to design more fuel-efficient low-emission diesel engines (“diesel-FFV-vehicles”)
- Supported in Worldwide Fuel Charter published by automotive and engine manufacturers

Some decades ago, diesel engines were used mainly in robust commercial applications, like trucks, buses, and non-road applications. Today, diesel engines are common also in passenger cars, where customer requirements for convenience are high. More stringent emissions legislation has led to sophisticated engines, fuel injection systems, and exhaust aftertreatment designs in both on-road and non-road applications. Fuel properties and quality are integral parts of the proper operation and durability of the engines and exhaust systems. From this point of view, the addition of bio-components should lead to an enhanced fuel quality rather than deteriorated properties. Better ignition characteristics, viscosity, heating value, oxidation stability, and proper distillation behaviour are some of the essential properties for improved engine operation and durability of engines.

Good ignition characteristics of diesel fuels improve cold start performance. The cetane number of the fuel defines its ignition quality. A number of modern engines can benefit from a higher cetane number when starting in very cold climates. The smoothness of operation, misfiring, smoke emissions, noise, and ease of starting are all dependent on the ignition quality of the fuel. As discussed in detail in the Properties section, the cetane number of Neste Renewable Diesel is very high, above 70, because of its chemical composition, a mixture of n- and isoparaffins.

Fuel economy is related to the heating value of the fuel. Although the heating value of Neste Renewable Diesel per volume is lower, the heating value per mass is higher due to the increased hydrogen content compared to standard diesel fuel. Noteworthy is also that the energy content of NRD is higher compared to FAME, both per litre and per kg. Besides heating value, fuel viscosity is an essential parameter since it affects the atomization; the viscosity of Neste Renewable Diesel is well within the EN15940 and EN590 specification limits.

To avoid excessive wear, fuel must have a minimum level of lubricity. The use of fuels with poor lubricity can increase fuel pump and injector wear and, at the extreme, cause a total failure. Hydrotreated fuels have typically poor natural lubricity. However, this is easily resolved by treating the fuel with a lubricity additive.

Malfunction can be caused by soluble gums or insoluble organic particulates formed by unstable diesel fuels. Both gums and particulates may contribute to injector deposits, and particulates can clog fuel filters. The oxidation stability of NRD is on a very good level and, as a consequence, it has a low tendency to form deposits in the fuel injection system and fuel injectors.

In a nutshell, HVO offers improved performance in terms of operation, emissions, and durability, due to a higher cetane number than conventional diesel, a reasonable distillation range without high boiling fractions, a very high heating value, proper viscosity and good oxidation stability.

Fuel quality

- Is defined by specifications
- Neste Renewable Diesel is a high quality product and can be used to enhance several properties in the final fuel blend
- Modern engines and new emission control systems require very high quality fuels

Vehicle owners are used to high-quality ultra-low sulphur or sulphur-free hydrocarbon-type diesel fuels, which are practically free of ash, heavy hydrocarbon fractions, and unstable components. For engines and emission control systems, this has enabled longer lifetimes, less maintenance, and extended oil-change intervals compared to the situation decades ago.

In addition to the requirements set by legislation and fuel standards, "fit for purpose" has risen as an essential requirement for fuels. Thus the addition of biofuels should not cause fuel quality problems from the point of view of cold operability, engine cleanliness or durability of emission control systems. Fuel requirements are, in fact, becoming more stringent due to the extending mileage durability requirements for emission control systems and the more stringent requirements for exhaust emissions, fuel economy and on-board diagnostics (Table 9).

Table 9. Comparison of sulphur-free fossil fuel and NRD in regards to fuel effects on operation, reliability, and need for maintenance of vehicles. A more detailed description of fuel properties can be found in Table 3.

Property	Sulphur-free fossil diesel fuel	Neste Renewable Diesel in a blend or as neat	Importance for vehicle technology and vehicle owner
Distillation range	Reasonable	Better than in fossil fuels due to lower final boiling point (FBP)	Lower engine oil dilution Lower risk for degraded lubrication Long engine oil change intervals
Cetane number	Reasonable	Excellent	Rapid cold start Lower exhaust emissions Less noise
Chemical composition	Hydrocarbon	Hydrocarbon	Low engine oil aging Low engine oil thickening Low material compatibility issues
Carbon/hydrogen ratio	Traditional	Better than in fossil fuels	Enhanced combustion Lower engine out CO_2
Oxidation stability	Good	Good	Low deposit formation in fuel system Low fuel injector fouling No acid formation in fuel No "best before date" needed
Ash, S, P, metals	Practically zero	Practically zero	High exhaust catalyst performance Long lifetime for particulate filter
Cold properties	As needed 0…–34 °C	As needed 0…–34 °C	Fit for purpose even in arctic winters
Solubility of water	Low	Low	Low risk of water contamination in logistics
Corrosion protection	Good with corrosion inhibitor additive	Good with corrosion inhibitor additive	Low risk for troubles if some water condensates in fuel tanks

Tailpipe emissions

Neste Renewable Diesel

- Reduces engine out NO_x, particulate (also nanosize), CO, HC, PAH, aldehyde and mutagenic emissions
- Reduces cold start smoke and emissions in winter conditions
- Effects seen already at 10...30% blending ratios
- Ash-free combustion offers a long lifetime for particulate filters

When Neste Renewable Diesel was blended with standard diesel fuel to produce a premium EN 590 diesel fuel, Neste Renewable Diesel (representing some tens of percents of the blend) offered the following benefits regarding exhaust emissions of passenger cars [Nylund *et al.* 2011]:

- Nitrogen oxides (NO_x) 0…-10%
- Hydrocarbons (HC) -10…-30%
- Particulate mass 0…-10%
- Carbon monoxide (CO) -20…-40%
- Less polyaromatic hydrocarbons (PAH)
- Less aldehydes, benzene and 1,3-butadiene
- Less mutagenic activity
- Faster and easier cold start, less cold start smoke
- Less engine noise after a cold start

This excellence of Neste Renewable Diesel is based on it being practically free of aromatics, polyaromatics, olefins, sulphur, and high boiling fractions. Also its cetane number is very high. The properties were compared against EN 590 reference fuel (Table 3).

In many areas of the world, the standard diesel fuel in use may contain more sulphur and aromatics than what EN 590 allows. When compared to those lower-quality fuels, the benefits resulting from Neste Renewable Diesel use are even more significant. The resulting reduction in exhaust emissions leads to better local air quality. This is especially important in many downtown areas where air quality is still a significant challenge, even though standard fuels and vehicle technologies have developed over the last few decades. Also some special working environments, such as mines or construction sites of tunnels, may be challenging with regards to tailpipe emissions. Neste Renewable Diesel offers remarkable benefits over standard diesel fuels or non-road fuels within such environments.

Comprehensive exhaust emission tests have been performed with more than 36 trucks and buses or their engines, and several passenger cars in vehicle and engine test beds. These tests consisted of transient tests simulating real driving conditions, artificial driving cycles and included acceleration. The results were collected from several research reports published together with various partners in the past fifteen years. A summary of the results is shown in Figure 12, which highlights significant reduction of particulate mass, carbon monoxide (CO) and hydrocarbons (HC). It is also important to note that, with Neste Renewable Diesel, the nitrogen oxides (NO_x) decrease or remain unchanged, while the use of FAME typically increases NO_x tailpipe emissions. [Hartikka *et al.* 2012.]

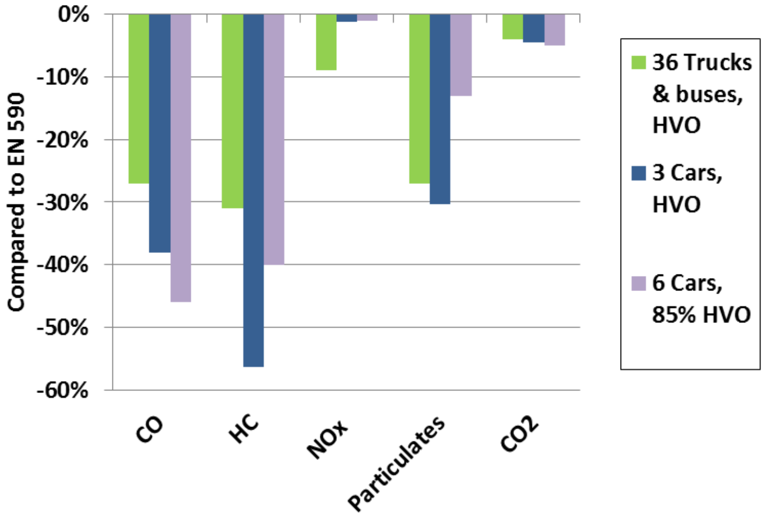


Figure 12. Average effect of neat and almost neat (85%) Neste Renewable Diesel (HVO) on tailpipe emissions in EURO II to EURO VI vehicles compared to a sulphur-free EN 590 diesel fuel.

The CO_2 of all these vehicle and engine measurements is based on the measured tailpipe values without distinguishing the origin of the carbon. So, this CO_2 corresponds only to the Tank-To-Wheels part of a life cycle assessment without assuming renewable CO_2 to be absorbed back by growing plants. The reduced CO_2 from the tailpipe is achieved by the higher hydrogen to carbon ratio of Neste Renewable Diesel compared to common fossil diesel fuel. Many studies have also shown slightly better (~ +1%) engine efficiency with Neste Renewable Diesel, but, due to the measurement accuracy, these results are only indicative.

Use of Neste Renewable Diesel reduces also several unregulated exhaust emissions:

- Polyaromatic hydrocarbons (PAH)
- Aldehydes
- Mutagenicity
- Particulate number (PN)

In addition, many stakeholders have been worried about nanoparticles due to their adverse health effects. Test results have shown that Neste Renewable Diesel reduces the number of particulates in all size classes (Figure 13). The size distribution of particulates is quite similar; however, the overall mass is significantly decreased with Neste Renewable Diesel. [Nylund *et al.* 2011.]

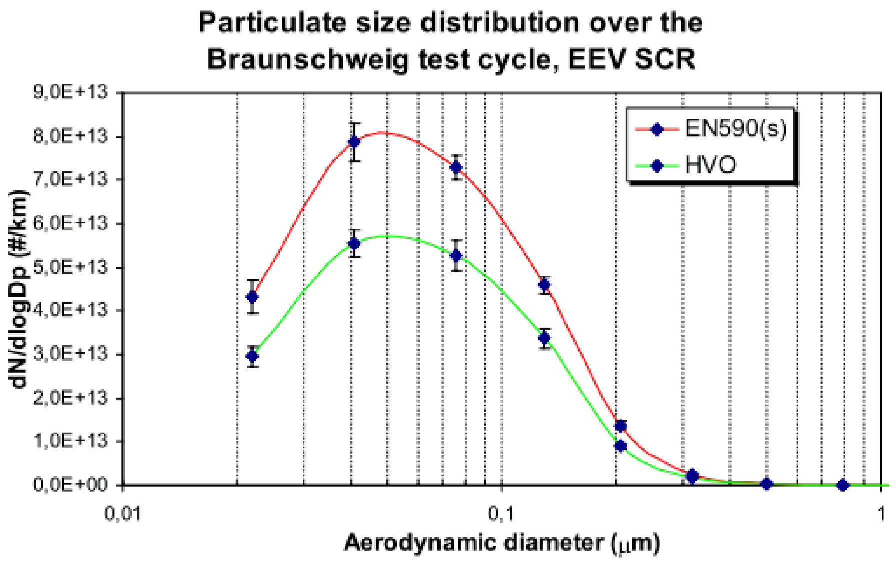


Figure 13. Example of particulate size distribution with summer-grade EN 590 fossil diesel fuel and neat Neste Renewable Diesel (HVO) in a Euro V/EEV city bus [Nylund *et al.* 2011].

In some cases, the observed differences in emission behaviour between individual engines have been significant. Some truck or bus types showed a reduction of particulate mass of up to 47% together with a negligible or even slight increase of NO_x, while in some engines NO_x is reduced more, up to 14%, and particulate emissions less. In any case, Neste Renewable Diesel moves a well-known NO_x particulate emission trade-off-curve of the base engine towards the origin, which is a desired effect for every engine designer (Figure 14). The total effect of Neste Renewable Diesel depends then on the engine's fuel injection and exhaust gas recirculation (EGR) control strategy.

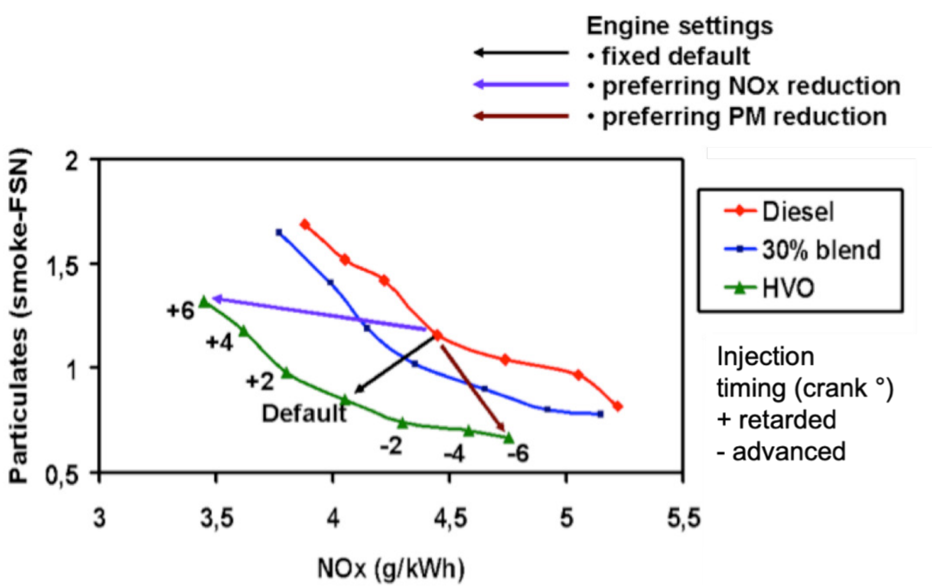
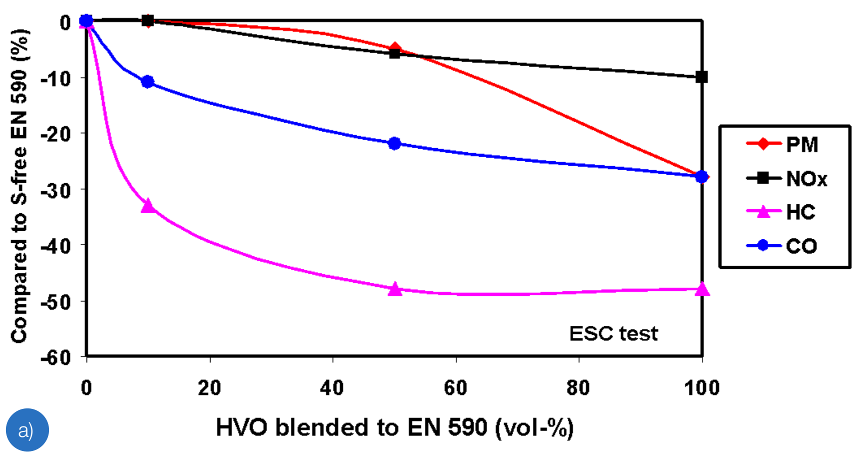


Figure 14. NO_x particulate emission trade-off curves of diesel fuel, diesel fuel with 30% Neste Renewable Diesel (HVO) and neat Neste Renewable Diesel (HVO) measured with a modern direct injection heavy-duty engine without an exhaust aftertreatment system, common rail fuel injection with different fuel injection advance settings [Aatola *et al.* 2008].

When Neste Renewable Diesel is used as a blending component, particulate and NO_x emissions reduce parallel with increasing HVO content in the blend (Figure 15 a and b). Typically, already quite a small blending percentage of Neste Renewable Diesel reduces regulated emissions, especially HC and CO. When an engine is not equipped with an exhaust aftertreatment system, the key benefit of Neste Renewable Diesel is that the fuel significantly reduces NO_x and particulate emissions, which are the Achilles heel of diesel engines, in addition to the unregulated emissions mentioned above. However, since modern engines are equipped with exhaust aftertreatment systems, the reduction of these tailpipe emissions is either slight or negligible when comparing NRD and regular fossil diesel. [Kuronen *et al.* 2007.]



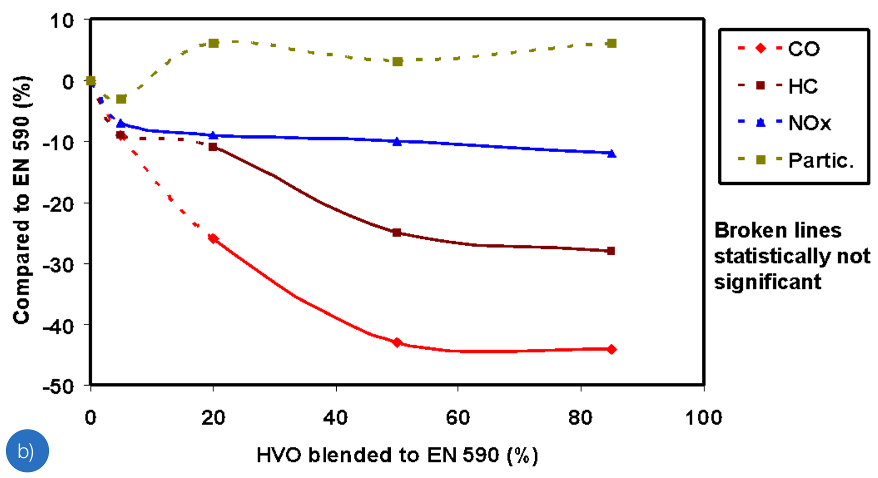


Figure 15. Effect of Neste Renewable Diesel (HVO) blending ratio on a) emissions of a Euro 4 truck engine with EGR but without any aftertreatment [Kuronen *et al.* 2007], and b) emissions of a car with common rail fuel injection, EGR, and oxidation catalyst but without a particulate filter, resulting a clear reduction of NO_x but particulate emissions were practically unchanged.

In cold conditions (-7 °C, -20 °C), the effect of neat Neste Renewable Diesel and 30% blends on reducing CO, HC, and particulate emissions of cars was remarkable, up to -70...-90%. As a matter of fact, emissions of HVO at -20 °C (-4 °F) were about the same as those of standard diesel fuel at +23 °C (73.4 °F) [Nylund *et al.* 2011]. This is a significant advantage since emissions are normally higher in colder conditions. Reductions of this magnitude can have an immediate effect on ambient air quality in downtown areas during cold seasons.

Figure 16 represents the particulate matter (PM) vs. NO_x emissions from city buses on a realistic city driving cycle starting from model year 1996 (Euro II) to 2013 (Euro VI). In older heavy-duty vehicles (Euro II to Euro IV) HVO typically reduces NO_x and particulate emission by 10% and 20-40%, respectively. However, in vehicles manufactured in 2013 and later (Euro VI vehicles), the NO_x and particulate emissions are extremely low, and thus, in practice, the effect of HVO becomes negligible.

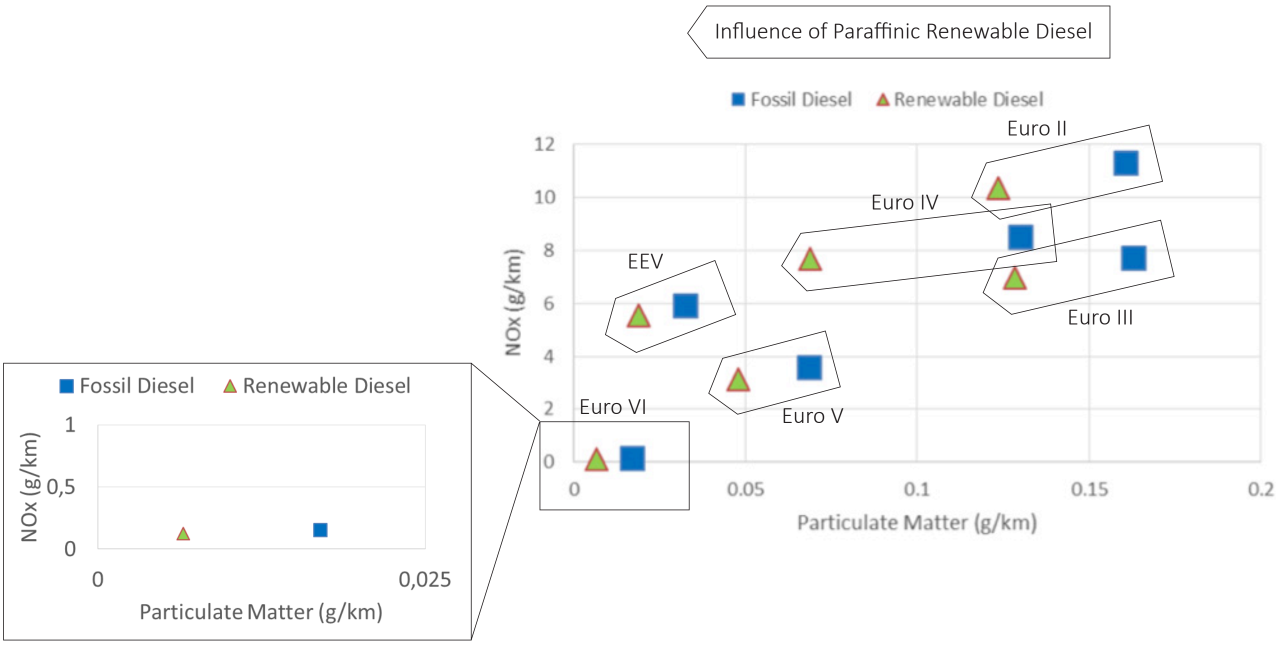


Figure 16. Average influence of paraffinic renewable diesel on exhaust emissions of city buses on a realistic city driving cycle starting from model year 1996 (Euro II) to 2013 (Euro VI).

Practically all new diesel cars and heavy-duty vehicles today are equipped with a particulate filter (DPF, diesel particulate filter) that reduces particulate emissions effectively. The lower engine-out particulate emissions resulting from the use of Neste Renewable Diesel offer benefits also to the users of these vehicles since exhaust back-pressure is lower and there is no need to clean the filter as often when using the so-called regeneration phase [Kopperoinen *et al.* 2008]. This can lead to slightly lower fuel consumption with Neste Renewable Diesel compared to other fuels, if the control system of the particulate filter is able to detect actual soot build up according to the fuel quality used. The lifetime of DPF is also longer because Neste Renewable Diesel is practically free of ash-forming components. Similar conclusions have also been drawn in a field trial on heavy-duty fleets, carried out by the city of Knoxville, which is discussed in detail in the Field Trials section.

Spread in emissions of passenger cars seems to largely depend on the type of fuel injection system, engine calibration and exhaust aftertreatment system. The strategy for controlling EGR is assumed to have a remarkable effect on NO_x emissions. These factors were not taken into account in the tests, since the tests were made using factory engine mappings. As a result, the biggest benefits of paraffinic fuels used as such or in high concentrations can be achieved if cars can be designed in the future to detect fuel quality or combustion and then optimize engine parameters on-line (HVO dedicated engine optimization discussed in detail in the Optimizing Engines for HVO section).

Fuel consumption

Neste Renewable Diesel

- Fuel consumption with fossil based diesel, FAME, and Neste Renewable Diesel are practically in line with their calorific heating values (MJ/l)
- Fuel consumption slightly lower with Neste Renewable Diesel blends compared to FAME blends at the same bioenergy level
- Fuel consumption with neat Neste Renewable Diesel about 3% higher than with summer grade fossil fuel and about 5% lower than with neat FAME

The fuel property having the largest effect on volumetric fuel consumption is the heating value that is normally expressed in MJ/litre. Fuel consumption measurements made in test bed engines, chassis dynamometer, and vehicles in real traffic are associated with high uncertainty. Therefore, the heating value that can be measured more precisely is a better way to describe fuel consumption. Traditionally, before biofuels, fuel density has been the factor having the greatest effect on volumetric fuel consumption since the quantity of fuel injected into an engine is metered by volume. This means that more fuel volume is needed for a low-density fuel in order to provide the same energy output as from a high-density fuel. Neste Renewable Diesel's density is clearly lower than that of standard diesel fuels, due to the paraffinic nature. However, NRD's heating value per mass (MJ/kg) is higher because of its paraffinic nature and higher hydrogen content, as discussed in the Properties section and as shown in Tables 4 and 5. Therefore, the higher heating value per mass of NRD partly compensates for the effect of lower density on heating value per volume. Moreover, the heating value of Neste Renewable Diesel is clearly higher than FAME per mass since it does not contain oxygen like FAME (Tables 4 and 5). The high density of FAME partially compensates for the difference, but, even after compensation, Neste Renewable Diesel's heating value per volume is better. When taking all the aspects into account, slightly less Neste Renewable Diesel is needed in a diesel fuel to meet the same bioenergy mandate compared to FAME (Table 10).

Table 10. Energy content of neat fuels and blends containing 14.0% bioenergy as an example (14% energy is the EU level RED II 2030 mandate).

Fuel	Bioenergy (%)	Heating value (MJ/l)
Fossil diesel fuel, summer grade	0	36.0
100% HVO	100	34.4
100% FAME	100	32.7
Diesel incl. 14.7 vol-% HVO	14.0	35.8
Diesel incl. 15.4 vol-% FAME	14.0	35.5

Heavy-duty vehicle tests showed an average increase of about 3% in volumetric fuel consumption with neat Neste Renewable Diesel compared to ultra-low sulphur diesel (density 828 kg/m^3) fuel [Karavalakis *et al.* 2015]. Previously, also varying test results influenced by test cycles, test vehicles, and used reference fuel have been published. One of these earlier studies discovered a slight tendency (0.5%) towards a lower energy consumption in MJ/km and better engine efficiency with neat HVO [Nylund *et al.* 2011], while passenger car tests with neat Neste Renewable Diesel showed an average increase of about 3% in volumetric fuel consumption compared to fossil summer grade diesel fuel [Nylund *et al.* 2011]. The used reference fuel in the experiments was completely fossil based. Nowadays, also EN590 fuels often contain biobased components, which reduces the differences between neat NRD and the reference fuel. If fuel consumption of neat FAME and neat Neste Renewable Diesel are compared, volumetric consumption of FAME would be about 5% higher based on the differences in heating values.

A recent test carried out in a multi-cylinder Euro 6 diesel engine reported an increase of only 1.5% fuel consumption with Neste Renewable Diesel compared to fossil based diesel, whereas a plausible decrease of 2% in fuel consumption was reported with the dedicated engine calibration for renewable diesel, recommended in the same study. [Bharadwaj *et al.* 2017.] Detailed information on this is provided in the Optimizing Engines for HVO section, where also the volumetric fuel consumption with HVO used as a drop-in and with dedicated calibration is discussed. The fossil diesel used in these tests [Bharadwaj *et al.* 2017] has a density of 830 kg/m^3 and is EN 590 diesel containing 7 vol-% of FAME. With the HVO dedicated calibration, the thermodynamic efficiency improvement with HVO is high enough to yield an improvement of approximately 2% in volumetric fuel consumption, despite its lower density compared to the reference fossil diesel.

Engine power and torque

Neste Renewable Diesel

- Similar maximum power and acceleration time as with fossil diesel in modern vehicles (common rail fuel injection)
- Slightly lower performance with older engines due to lower volumetric heating value

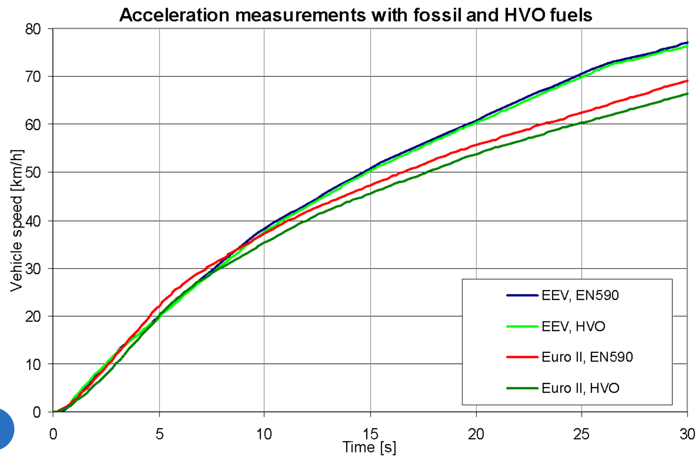
In modern engines, the amount of fuel injected into the combustion chamber is controlled by the energizing time of the fuel injector and fuel pressure. The engine control unit calculates the right signal length and timing for the requested engine load and speed conditions. Thus the maximum power output of the engine is related to the efficiency of the engine, injector energizing time, fuel pressure, and energy content of the fuel. In some modern common rail injection systems, it has been seen that with the same indicated injection duration, more paraffinic fuel is actually injected. With this type of injection system, Neste Renewable Diesel produces the same engine power and torque as EN 590 diesel. The maximum power of the engine can be even higher, if compared to winter grade diesel [Sugiyama *et al.* 2011].

In older injection systems (in-line pump, distributor pump, pump-line-nozzle, pump injector), the volume of fuel injected is almost equal with Neste Renewable Diesel and EN 590 diesel. Thus the maximum power is reduced by some 3-5% with neat NRD because of the lower volumetric energy content compared to EN 590 diesel. The slightly better engine efficiency with Neste Renewable Diesel cannot compensate for the lower volumetric energy content [Sugiyama *et al.* 2011].

In-house passenger car tests have shown no measurable differences in power output with neat Neste Renewable Diesel compared to summer grade diesel fuel. Since differences in vehicle performance are negligible between neat NRD and diesel fuel in modern vehicles, Neste Renewable Diesel does not have any noticeable effects when it is used as a blending component.

Similar conclusions have been drawn when using NRD in bus fleets. Figure 17 represents the acceleration and traction power for two buses, an older Euro II certified bus and a newer EEV certified bus. In the case of the older bus, reaching 50 km/h with HVO takes 5% less time with NRD in comparison with summer grade diesel, and traction power at 50 km/h is 6% less with NRD in comparison with summer-grade diesel. However, in the case of the EEV bus, equipped with a common-rail injection system, the differences in both acceleration and traction power are negligible.

a)



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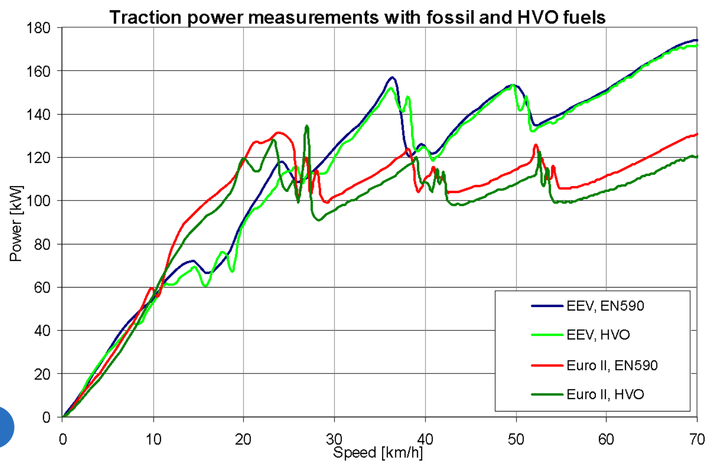
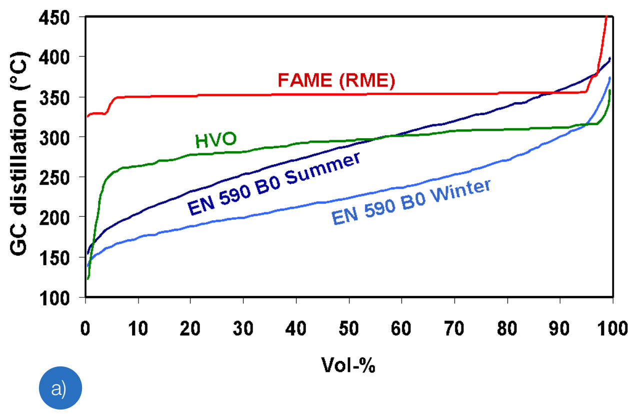


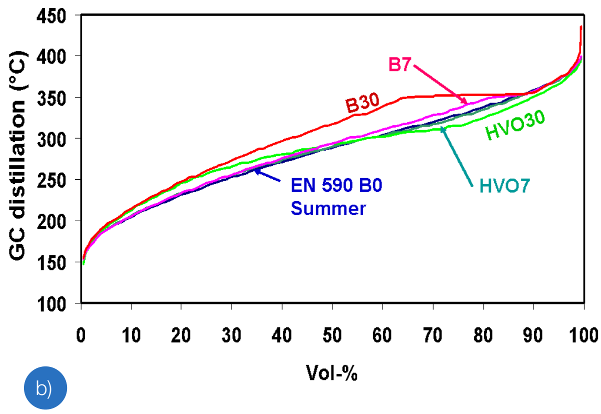
Figure 17. a) Acceleration performance, and b) traction power of Euro II and EEV city buses in a dynamometer. The Euro II bus was equipped with an in-line injection pump representing old technology, and the EEV bus with a modern common rail fuel injection system [Nylund *et al.* 2011].

Neste Renewable Diesel

- Better engine oil condition due to reasonable distillation range and hydrocarbon type chemistry
- Higher cetane number decreases oil dilution in cold starts and low load conditions

A distillation curve shows how much of a fuel sample is evaporated at each temperature when the temperature is increased gradually. In this case, gas chromatographic (GC) distillation was used in order to see the heavy boiling fractions clearly (Figure 18), which may not be the case with the common atmospheric distillation (as seen in Figure 4 in the Properties section). Distillation characteristics have an effect on how fuel is evaporated when it is sprayed into the combustion chamber. Fractions boiling at too high temperatures may not burn completely or they may wet the cylinder walls. Neste Renewable Diesel is well within the recommended range of diesel fuels, while FAME boils at remarkably higher temperatures. Thus, the evaporation behaviour of NRD is similar to fossil diesel and significantly better in comparison with FAME. Neste Renewable Diesel does not cause any drawbacks on oil dilution either. The differences are mainly attributed to the volatility properties of fuel rather than other physical properties, such as viscosity and density. Also, the high cetane number of NRD compared to fossil diesel and FAME attributes to the reduced oil dilution in the cold start and low load conditions.





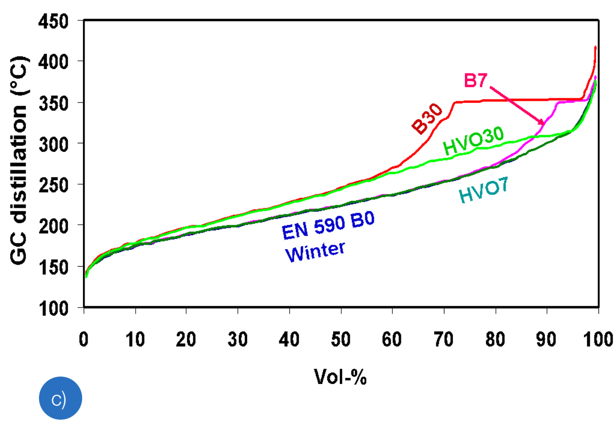


Figure 18. GC distillations a) of typical diesel fuels without biocomponents (meeting EN 590), neat FAME and neat Neste Renewable Diesel (HVO), b) of summer grade fuel and its blends with biocomponents, and c) of winter grade fuel and its blends with biocomponents (B30 may not be suitable fuel also because of cold operability). In b) and c), the numbers show vol-% of bio added. Note that in a-c) the temperature scale of GC distillation is different from atmospheric distillation, which is commonly used for diesel fuels.

The fuel content in engine oil (oil dilution) was tested with accelerated simulation and the results are presented in Figure 19. It can be seen that fossil diesel and renewable diesel/fossil diesel blends (70/30 vol-%) show similar results. This difference is negligible in comparison with the uncertainty of the experiments (~0.4%). Fuel content in the oil is much higher for FAME when compared to Neste Renewable Diesel. As stated above, this is due to the better evaporation behaviour of NRD in comparison with FAME.

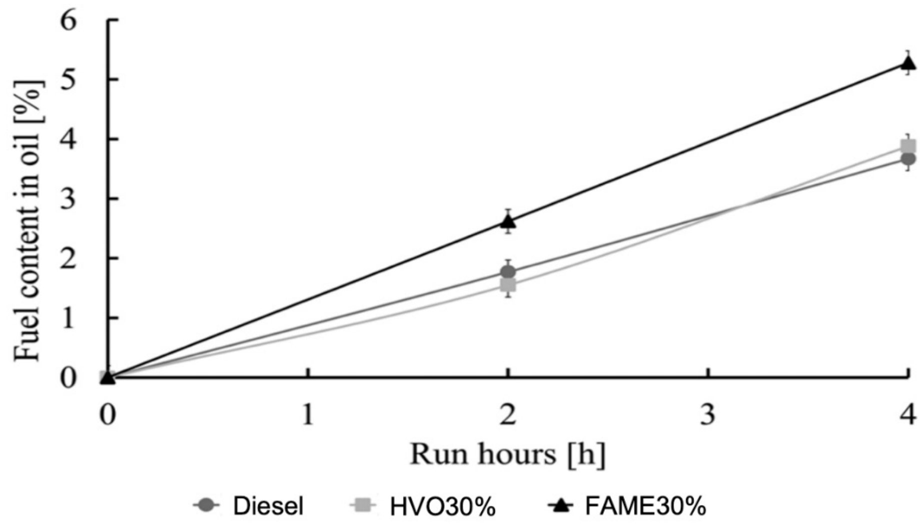


Figure 19. Fuel content in engine oil. The optical research engine was operated with regeneration mode for 4h [Hulkkonen *et al.* 2016].

Regeneration of diesel particulate filters

A new challenge has arisen with modern vehicles with diesel particulate filters (DPF). They need to be periodically cleaned, i.e. “regenerated”. In the majority of applications, DPF regeneration is achieved by injecting extra fuel into the engine to raise the temperature of the exhaust, triggering regeneration. A significant disadvantage associated with active regeneration is the dilution of the engine oil caused by a small amount of diesel during the post-injection cycles, where fuel is injected into the cylinder after the regular combustion. A thin layer of fuel can build up on the cylinder walls, leading to premature engine wear, and drivers are warned to consider shorter oil service intervals. The reduction of this extra DPF-related fuel consumption, which leads to oil dilution, strongly depends on thermal soot oxidation temperature.

Apart from operating parameters, fuel’s chemical composition also relates to the type of particulate emissions, which is associated with the regeneration of DPF and the combustion of trapped PM in the DPF. Comparison of particulate emission related parameters for fossil based diesel, biodiesel (FAME) and NRD indicates that filter smoke number (FSN) and indicated specific particulate matter (ISPM) are around 78% reduced with neat FAME (RME) than fossil based diesel (B0). The FSN value and ISPM are around 50% lower with HVO in comparison with fossil based diesel. The reduction in the particle number emission follows a similar trend as mass emission (Figure 20a).

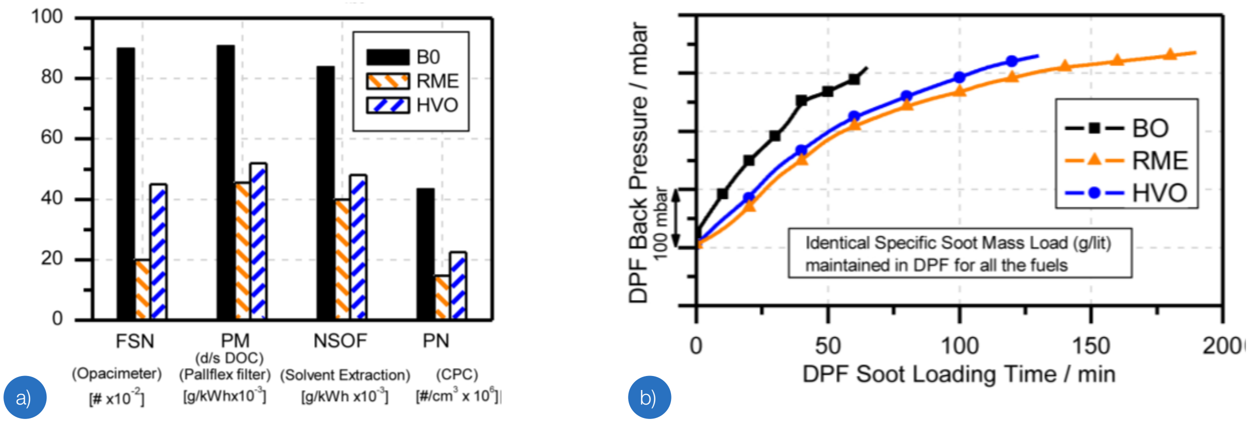


Figure 20. a) Particulate mass and number emissions of fossil based diesel (B0), biodiesel (RME), and HVO (NRD) in a single-cylinder diesel research engine at similar operating points. b) DPF loading behaviour for fossil based diesel (B0), biodiesel (RME), and HVO (NRD) in a single-cylinder diesel research engine at similar operating points. [Bhardwaj *et al.* 2014].

The type of formed PM from biodiesel and non-oxygenated fuels (HVO and fossil based diesel) differs chemically. The total PM formed from NRD and fossil based diesel contains 5% soluble organic fractions (SOF), whereas the PM from FAME contains 12% SOF. The higher amount of SOF in FAME provides reactive hydrocarbons to be oxidized catalytically in DPF. In FAME, about 40% of the total PM is oxidized due to the presence of these SOF. Hence, the FSN from fossil based diesel, FAME, and NRD directly relates with the non-soluble organic fractions (NSOF), which is lower for NRD than for B0 fossil diesel, and FAME has the least amount of NSOF, consequently the least FSN too.

For typical DPFs, active regeneration is required when the pressure drop exceeds a threshold, typically 5 to 7 kPa. At the identical Soot Mass Load, the backpressure of NRD and biodiesel increases at a much slower rate than that of fossil based diesel. This is because of the lower PM emissions from these fuels, and this leads to an enhanced DPF regeneration interval (Figure 20b). Also, in a previous study [Kopperoinen *et al.* 2011], the DPF regeneration frequency of HVO and fossil based diesel were compared in a passenger car where regeneration is assisted by post-injection of fuel into cylinders. The passenger car used in the test was equipped with a Euro 4, turbocharged direct injection diesel engine. The results indicate that the use of 100% NRD decreases engine out particulate emissions. This has a clear effect on the soot accumulation rate and exhaust back-pressure build-up in a particulate filter (DPF). Therefore, the increase of exhaust backpressure is slower with pure NRD in comparison with diesel, enabling longer DPF regeneration frequency. The lowest soot accumulation rate was found with pure NRD as a fuel. Also, the use of 10% FAME in diesel fuel reduced the soot accumulation rate, whereas 30% of HVO in diesel fuel behaved like fossil diesel fuel.

The most commonly used active DPF regeneration occurs at ~550-600 °C, whereas the typical diesel engine exhaust temperature falls within the 200-500 °C range. A fuel penalty occurs when the exhaust temperature is increased. Also, the needed high temperature and, consequently, a high thermal stress for the regeneration can cause cracking or melting of ceramic DPF. Therefore, the lower soot-oxidation temperature is beneficial [Park *et al.* 2010]. Thermogravimetric analysis (TGA) of the soot formed from the combustion of all three fuels reveals that the soot from NRD and FAME oxidizes at lower temperatures compared to soot from B0 fossil diesel. At TGA10% (an indication of DPF-Light-off), FAME soot oxidizes at 42 °C lower and NRD soot oxidizes at 52 °C lower than fossil diesel based soot. At TGA90% (indication for completion of regeneration event), the complete oxidation of biodiesel and HVO soot shifted to ~55 °C lower than fossil diesel soot. Overall, soot samples from FAME and NRD show a ~50 °C lower oxidation temperature compared to fossil based diesel fuel (Figure 21).

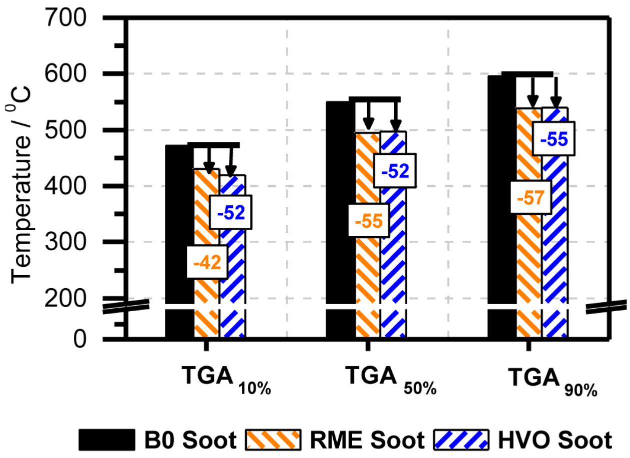


Figure 21. TGA Soot oxidation temperatures for the different fuels derived from the measured TGA traces [Bhardwaj *et al.* 2014].

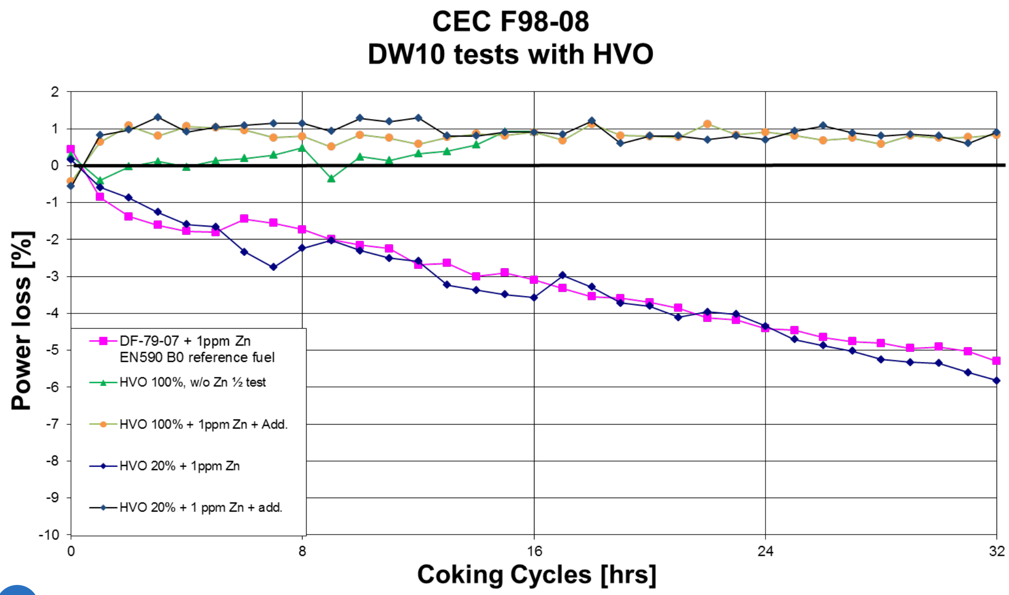
Injector Fouling

Neste Renewable Diesel

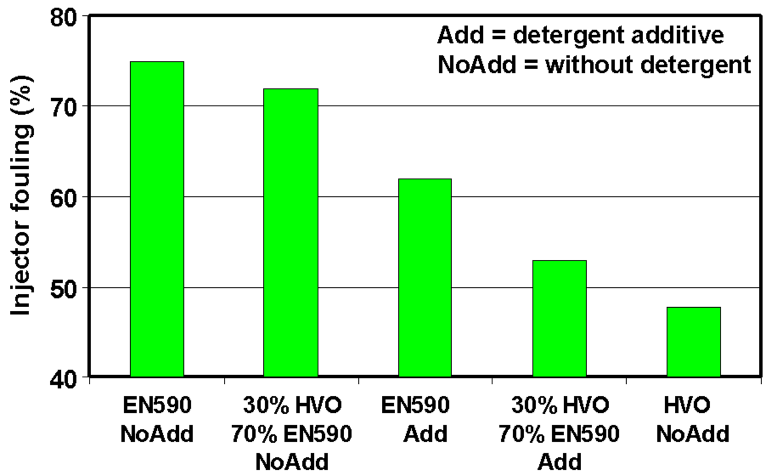
- Low tendency for injector fouling as neat and in diesel fuel blends
- Same detergent additives suitable as for standard diesel fuels

Deposit formation in fuel injectors of engines is a phenomenon that should be limited in order to keep engine power output and exhaust emissions constant over the entire lifetime of a vehicle. Injector fouling of NRD has been tested with a Peugeot DW10 Common rail direct injection engine and Peugeot XUD9 indirect injection engine.

The DW10 test is based on the CEC F-98-08 test method, which represents Euro 5 standard fuel injection equipment with a maximum injection pressure of 1600 bar. The test is used to research and demonstrate the propensity of some fuels to provoke fuel injector fouling by injector deposits in modern engines, and also to demonstrate the ability of fuel additives to prevent or control these deposits. The test fuel can be doped with 1 ppm of zinc to speed up injector fouling to an abnormal rate but still maintaining accomplishable test duration. The method measures injector fouling directly from engine power, and lower power loss means cleaner injectors. Without the Zn addition, NRD showed clean injectors, and NRD combined with an effective detergent showed clean injectors also with Zn doping. Neste Renewable Diesel blend (20%) behaved like EN 590 B0 (DF-79-07 reference fuel) (Figure 22a).



a)



b)

Figure 22. Injector fouling tests a) with DW10 engine [Neste Engine Laboratory tests], and b) with XUD engine where lower values are better [Neste Engine Laboratory tests]. The fuels used for the tests included EN590 diesel fuel and HVO (Neste Renewable Diesel).

The XUD9 test is based on a widely used old CEC F-23 test method, which has been modified according to some engine updates. For that reason, the numerical scale of the results is not binding; but, in any case, a lower value means cleaner injectors. Neste Renewable Diesel showed cleaner injectors than a high quality standard diesel fuel, both as such and as a 30% blend (Figure 22b).

Performance additive packages containing, for example, detergent, corrosion inhibitor, and antifoam agents are commonly used in high quality diesel fuels. Although Neste Renewable Diesel performs well in injector fouling tests (XUD9), an additive package at least for corrosion protection shall be considered for cases where some water condensates in fuel logistics or vehicle fuel systems.

Sodium (Na) contamination in diesel fuel has been suspected to cause harmful internal deposits in fuel injectors. Neste Renewable Diesel should not have such negative effects, since the sodium content has been below the detection limit of analytical methods in all measurements.

Auxiliary heaters

Neste Renewable Diesel

- Functions well in fuel burning auxiliary heaters, due to excellent cold properties
- Due to efficient burning, heaters remain cleaner compared to deposits caused by fossil diesel

Neste Renewable Diesel operates in fuel burning auxiliary heaters as well as or even better than fossil diesel. Contrary to FAME, NRD does not have any problems with cold properties; therefore, it operates without trouble also in cold conditions.

A test with Webasto auxiliary heaters was conducted in 2013 in Finland. Deposit build-up in the combustion chamber was assessed. A test cycle consisting of a 10-minute heating period and a 50-minute cooling period was used. The cycle was run consecutively for 21 hours, after which the heater was pulled apart and the combustion chamber examined. The difference between commercial fossil EN 590 diesel and 100% Neste Renewable Diesel was clear (Figure 23). Even after this relatively short test, the combustion chamber of the fossil diesel heater had some deposits clearly visible, while the Neste Renewable Diesel heater was practically clean.

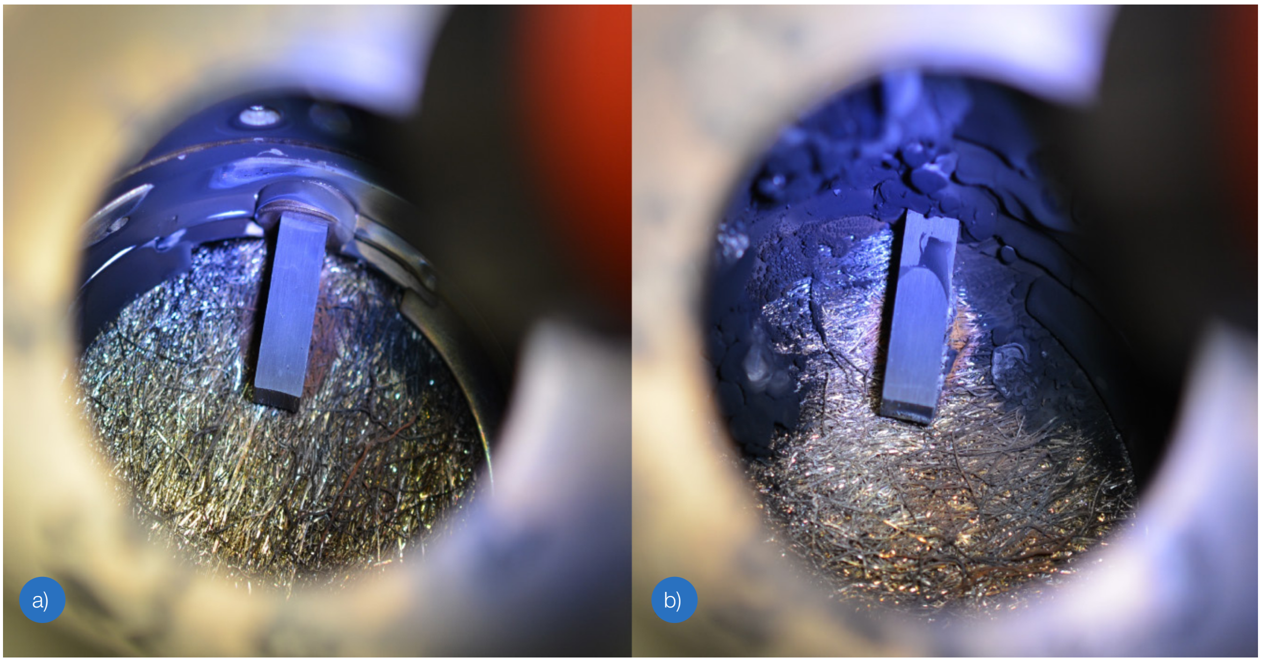


Figure 23. Combustion chambers of Webasto auxiliary heaters after the 21-hour test. A heater using 100% Neste Renewable Diesel on the left a) and a heater using fossil EN 590 diesel on the right b).

Burning renewable diesel will create a light blue flame instead of the yellow flame observed with conventional diesel. This is because the combustion is more complete with NRD. However, in some very rare cases with heaters/burners (home heating or vehicle heating), visual flame sensors can have trouble recognizing blue flames. Most burner suppliers have already upgraded their system to cope with this issue and offer a repair kit for older models.

Optimizing engines for HVO

Neste Renewable Diesel

- Benefits for CO_2 emissions and savings in mass fuel consumption can be achieved through advanced fuel injection timing
- Engine and exhaust aftertreatment optimization for HVO can further decrease NO_x and particulate emissions

Diesel engines today have been designed for fuel fulfilling the EN 590 diesel standard in Europe or relevant standards on other continents. There has not been a major need for diesel engines that can adapt to fuel composition like gasoline-FFV vehicles. Now that high quality paraffinic diesel fuels fulfilling EN 15940, such as HVO and GTL, are available, users would benefit from optimized engine calibrations based on fuel quality.

Diesel engines run without operability problems with neat Neste Renewable Diesel; however, additional benefits are obtained if engines are optimized for Neste Renewable Diesel or high amounts of Neste Renewable Diesel in the fuel. The reason for this is the fact that NRD gives more freedom under the NO_x - HC/CO emission trade-off, NO_x - particulate emission trade-off, and NO_x - efficiency trade-off phenomena, which are well-known challenges for engine designers (see Figure 24). The high cetane number of Neste Renewable Diesel leads to a higher degree of completeness of combustion, which in turn provides inherently higher thermodynamic efficiency. This is helpful for the cold start cycle and provides the flexibility to use EGR at cold start low loads. The absence of aromatics in NRD leads to a significant reduction in PM, which provides freedom of calibration space for higher EGRs and thus a better optimization of rail-pressure and centre of combustion is feasible. The observed load-dependent behaviour of soot, HC and CO emissions versus NO_x indicates that for NRD, a dedicated EGR strategy differing from that of fossil diesel could be beneficial.

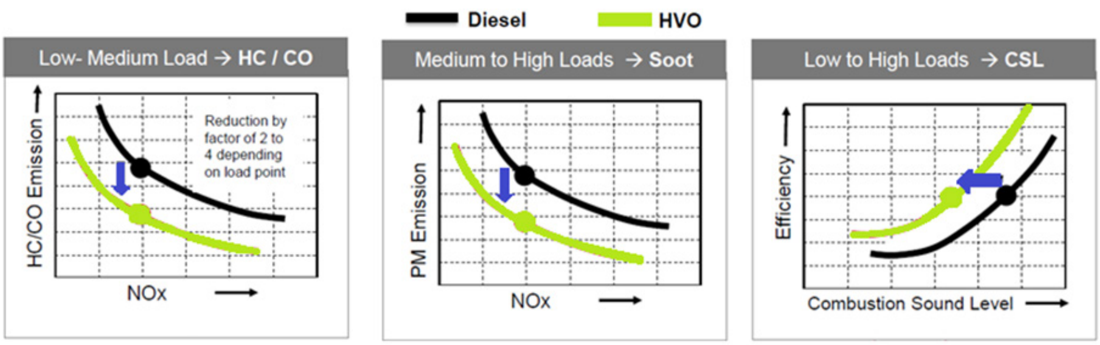


Figure 24. Trade-offs of Soot, HC, CO and efficiency versus NO_x emissions for NRD and fossil based diesel [Bharadwaj *et al.* 2017].

The control of EGR is also essential for reducing NO_x, as well as optimizing urea feed for SCR catalysts according to the real need. Several studies show the development potential for optimizing the engine, fuel, and exhaust aftertreatment together. With this approach, "Diesel-FFV" vehicles could be designed as well as FFV-cars today, adapting themselves automatically to gasoline, 85% ethanol, or any mixture of these fuels. Another possibility could be to change engine mapping if vehicles are used by dedicated fleets, which use only neat Neste Renewable Diesel as an alternative fuel.

The effect of injection timing on engine emissions and fuel consumption with HVO and its blend have been previously investigated [Aatola *et al.* 2008] in a common rail heavy-duty diesel engine. Studies were conducted by changing engine software settings in a heavy-duty engine (Table 11, previously in Figure 14). With the default engine settings, the results were in line with other tests made on heavy-duty engines. With advanced fuel injection timing fuel consumption can be reduced remarkably, up to 6...8% by mass, if NO_x reduction is carried out in an aftertreatment device. The reduced fuel consumption means smaller Well-To-Wheels CO_2 emissions. With retarded timing, NO_x can be reduced remarkably, but, in this case, fuel consumption will be increased. Preliminary studies show that even greater benefits can be obtained if the amount of EGR is optimized for Neste Renewable Diesel (HVO).

Table 11. Effect of Neste Renewable Diesel (HVO) on emissions and fuel consumption using different injection timing settings in a heavy-duty engine without EGR and aftertreatment. Reference is EN 590 diesel fuel. [Aatola *et al.* 2008].

Injection timing	Default	Advanced	Remarkably advanced	Retarded
NO_x	–6%	0%	+4%	–16%
Smoke	–35%	–37%	–32%	–32%
Fuel consumption (mass)	–3%	–6%	–8%	0%
Fuel consumption (volume)	+5%	+2%	0%	+8%

Recent work [Omari *et al.* 2017 & Bharadwaj *et al.* 2017] focusing on the NRD calibration in a four-cylinder Euro 6 diesel engine suggests that at lower loads, higher fractions of low-pressure EGR in combination with lower fuel injection pressures are favourable for improved efficiency. At moderate and towards higher loads, the higher cetane number of HVO and its lower propensity to form soot allow several modifications without exceeding NO_x emissions and combustion noise levels. These modifications include advancing of the centre of combustion, an increase in rail pressure, lowering of the pilot injection quantity, and a reduction of the pilot offset from the main injection. (Figure 25)

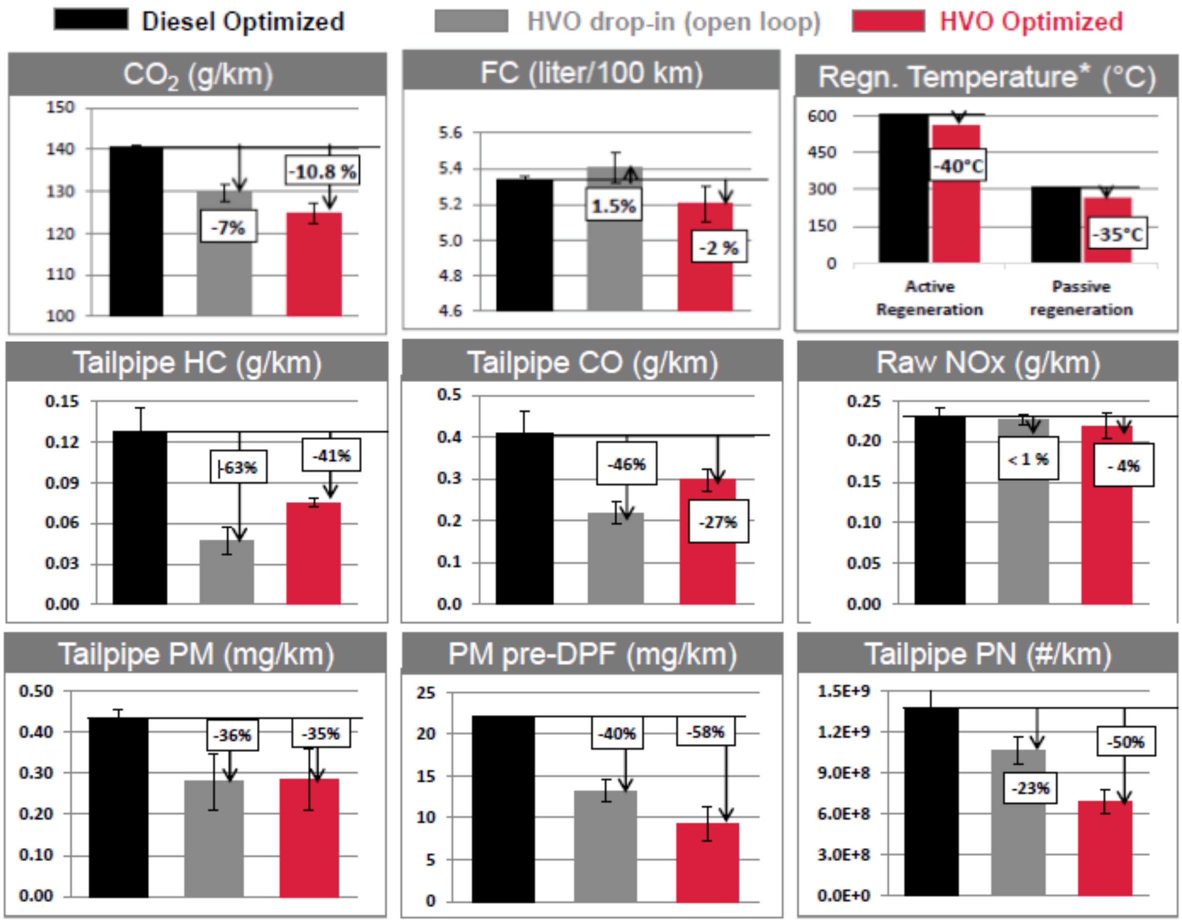


Figure 25. Emissions & performance validation at Chassis dynamometer Cold WLTC with drop-in and optimized calibration using a Euro 6 demonstrator.

The optimization results at constant raw NO_x and noise levels indicate that the overall Tank-To-Wheel CO_2 benefits of NRD amount to up to ~10.8% compared to the conventional diesel fuel (containing 7 vol-% FAME). About 3.5% CO_2 benefit is caused by the lower carbon content of NRD, and the remaining 7.3% CO_2 benefits are realized due to more efficient combustion resulting from the dedicated calibration optimization for NRD. NRD shows an increase in thermodynamic efficiency. However, due to the lower density, the volumetric fuel consumption was observed to increase for NRD drop-in by 1.5%. With optimized engine calibration, volumetric fuel consumption is decreased by 2% in comparison with baseline diesel. Moreover, compared to conventional diesel fuel, the emissions of HC, CO, and PM are significantly lower with NRD drop-in as well as with NRD optimized. PM is reduced mainly due to the zero aromatic content in NRD, thus leading to lower PM accumulation in DPF and, consequently, to a longer DPF regeneration interval. PM emissions pre-DPF are further reduced, leading to the almost doubling of the DPF regeneration interval in comparison with diesel. Due to their reactive microstructure, typically, the soot particles emitted from NRD oxidize at lower temperatures as compared to baseline diesel soot. Thus, due to the extended DPF regeneration intervals and the needed lower temperatures, several negative impacts of DPF regeneration, such as elevated fuel consumption and oil dilution, are reduced with the recommended engine calibration for NRD.

Field trials

Neste Renewable Diesel

- All year-round trials in many countries, including severe winter conditions
- Up to 300 vehicles and even more than 300,000 km/vehicle

Extensive field trials have been carried out with Neste Renewable Diesel in Finland, Sweden, Germany, Canada, and the USA. The fuel has performed excellently in these trials, both at 100% content and a variety of blending ratios. The trial uses of the fuel have not resulted in any operability issues or need for extra maintenance regarding fuel filters, fuel systems, fuel hoses, seals in fuel systems, engines or exhaust aftertreatment devices. The same applies to fuel logistics: the trial uses did not reveal any differences compared to fossil diesel fuel use regarding water, microbiological growth, storage stability and material issues.

About 300 buses were driving in the Helsinki area from 2007 to 2010 with Neste Renewable Diesel all year round down to ambient temperatures below -25 ºC (-13 °F). Most of the buses used a fuel blend containing up to 30% of Neste Renewable Diesel in EN 590 fuel, while 11 buses ran with NRD as such. The goal of this project was to improve the quality of the urban air and to promote advanced biofuels in public transport. Both old and modern buses from several manufacturers representing Euro II to EEV emission levels were included in the test fleet as well as some retrofit exhaust aftertreatment systems. A total of 50 million kilometres were run with the fuel blend and 1.5 million kilometres with the neat Neste Renewable Diesel. This means, on average, 170,000 km/bus, with some of them driving clearly more in this test. In total, 22,000,000 litres of blend fuel and 1,000,000 litres of neat NRD were consumed. There was no need for any extra maintenance compared to standard diesel fuel use. Analyses of used engine oils did not show any differences compared to running with standard diesel fuel. After the test was completed, the neat Neste Renewable Diesel was left in a refuelling storage tank for 8 months; after the storage time, the fuel remained clear and free of microbiological growth. [Nylund *et al.* 2011]

A year-round field trial in Germany started in 2008 with 10 Mercedes-Benz trucks and 4 Mercedes-Benz buses. They ran on 100% NRD for more than 3 million kilometres in total and over 200,000 km/vehicle on average. This trial was scheduled to last for three years in total and ended in 2011. Both field trial tests have also included numerous exhaust emission measurements.

A trial with 75 vehicles using 2% Neste Renewable Diesel during the winter and 5% during the summer was conducted in an arctic environment at temperatures down to -44 °C (-47.2 °F) in Alberta, Canada, between 2006 and 2009. Federal and provincial governments together with Shell Canada sponsored the tests. Neste Renewable Diesel blend operated without any problems.

In Finland, a field trial with neat Neste Renewable Diesel started during spring 2010 with more than 60 passenger cars. The fleet consisted of various vehicle brands and different engine and injection system technologies. The objective was to prove the suitability of neat NRD for severe winter conditions and various driving conditions. Some of the vehicles underwent periodic additional check-ups for more detailed investigations. During this field trial more than 200,000 litres of neat Neste Renewable Diesel was consumed, and the cars travelled more than two million kilometres. No fuel-related issues arose during the field trial. This field trial was successfully concluded at the end of 2014.

In Germany, under the project Diesel Regenerative [Krahl 2011], two fleets of passenger cars ran more than 200,000 km with Neste Renewable Diesel blended with 2% and 7% RME over the course of a year without any fuel-related driver complaints. All vehicles were tested for regulated emissions at the beginning and end of the project period. The more extensive assessment of the non-regulated emissions was only carried out on three vehicles of emission standards Euro 3, Euro 5 and Euro 6. Engine oil samples were taken from all vehicles and analyzed over the test period. In sum, emissions reductions for hydrocarbons, carbon monoxide and particulate matter were comparable to EN 590 B5 fossil diesel fuel. However, the nitrogen oxide values were slightly elevated.

In 2011, a field trial with two new 60 tonne Scania 500R tanker trucks was started in Finland. The trucks had a 15.8 litre V8 Euro 5 engine with Scania PDE high-pressure unit injectors. One truck was running on 100% Neste Renewable Diesel and the other on normal commercial EN 590 (B0) diesel fuel. Approximately 300,000 km were driven with both trucks until the spring of 2013. The injectors were then bench-tested and dismantled. There were no differences in performance or wear between the two vehicles. During the trial, no repairs or replacement parts were needed for the fuel system.

From 2011 to 2013, a durability field test was conducted in Finland. A model year 2011 Volvo V60 2.0 used as a driving school car (mostly city driving) was run on neat Neste Renewable Diesel fuel for 100,000 km. After the test, the engine with oxidation catalyst, particulate filter, fuel system and fuel tank were disassembled and each part analyzed to understand the long-term effects of HVO. The conclusion was that none of the analyzed parts showed any negative impact. Also, the oil dilution was analyzed in each service; it was concluded that Neste Renewable Diesel fuel does not cause high oil dilution.

In 2017, the city of Knoxville, USA, performed an extensive field trial using Neste Renewable Diesel in five of its heavy-duty fleets. The fleets of the City of Knoxville include Freightliner M2 Medium-duty trucks with the Cummins ISC diesel engine. For this field trial, 5 vehicles with model years ranging from 2009 to 2016 were chosen and the selected vehicles were continuously used in all other departments, ranging from fire, police and public service utilizing the Knoxville site. The main monitored parameters were fuel mileage and number of DPF regeneration events. Totally, 28,390 litres of Neste Renewable Diesel was consumed in these tests. The city of Knoxville reported that after collecting the data for two months it was observed that there are no side effects from using Neste Renewable Diesel. No reportable issues with the performance of the vehicles, nor any fuel system related issues were observed, and NRD can be used as a drop-in fuel since in their tests it was randomly mixed with diesel during refuelling without any boundary conditions of mixing. Also, an additional test was performed by storing the Neste Renewable Diesel in a freezer for a week in order to ensure its non-gelling characteristics at lower temperatures. One of the observed benefits of renewable diesel includes the reduction of DPF regeneration events. Normally with the fossil diesel, the city of Knoxville reports forced regeneration every week for some of its trucks; in two months, not a single truck running on renewable diesel was brought to the shop for the forced regeneration. One unforeseen observed positive effect was that the knuckle boom operators did not experience irritation in their eyes from the exhaust while operating the equipment of the truck. This alone is a proof that the engine is definitely burning cleaner. Another noted benefit was that no infrastructure change was needed for the fuel site tank. This is a huge benefit, especially compared to FAME, which would require the fuel site tank to be emptied and cleaned before and after.

Statements made by the automotive and engine manufacturer industry

Automotive and fuel injection system companies

- Prefer advanced paraffinic biocomponents, such as Neste Renewable Diesel
- HVO supported by Worldwide Fuel Charter (WWFC) in order to avoid concerns associated with FAME

The Worldwide Fuel Charter (WWFC) is a recommendation published by automotive companies about fuel qualities to be used with different vehicle emission requirements. The WWFC also includes justifications for each parameter required. The 6th edition (2019) of the WWFC can be downloaded from https://www.acea.be/uploads/publications/WWFC_19_gasoline_diesel.pdf

The WWFC pays attention to the challenges related to the use of FAME and recommends using HVO as a biocomponent. The Category 5 diesel fuel for "Markets with highly advanced requirements for emission control (including GHG) and fuel efficiency" does not at all allow the use of FAME as a blending component, but does allow the use of HVO (pages 60 – 61 in the 6th edition of WWFC). HVO is fully allowed without any blending limit in all fuel categories if the final fuel blend meets the limits of each category. More technical background for HVO use can be found from the 6th edition of the WWFC, page 84, and for FAME, pages 81 – 83.

The European Automobile Manufacturers Association ACEA reported in April 2010: "Political support and appropriate policy tools are needed now to encourage the development and wider market access to new and more sustainable 'drop-in' advanced biofuels that could increase the biocontent in road transport fuels, e.g. HVO, BTL, cellulosic (or advanced) ethanol." Bosch, Continental, Delphi, Denso and Stanadyne, all manufacturers of diesel fuel injection systems, noted in September 2009: "The FIE manufacturers support the use of bioparaffins obtained by hydro-treatment or co-processing of plant oil. Due to their paraffinic nature and high fuel and transport system compatibility, bioparaffins are also well-suited for blends with biogenic portions above 7%."

For European heavy-duty vehicles, the latest Euro VI emission limits were introduced by Regulation (EC) 595/2009, with technical details specified in Regulation (EC) 582/2011. The new emission limits became effective from 2014 onwards for all new registrations. The Euro VI emission limits are comparable in stringency to the US 2010 standards. Regulation (EC) 582/2011 introduced also requirements on universal fuel range type-approval. If the manufacturer permits the engine to operate on a fuel not fulfilling the EN 590 CEN standard, the manufacturer must demonstrate the capability of the parent engine to meet the Euro VI emission and in-service conformity requirements on the fuel declared.

Today numerous truck and bus engine manufacturers, e.g. Caterpillar, Cummins, DAF, Daimler, Iveco, MAN, Steyr, Scania and Volvo, have formally accepted the use of paraffinic renewable diesel (EN 15940) as such in their engines in Europe. The same applies for non-road engines, like Agco, Caterpillar, Deere and Hitachi. For cars and vans, Citroen, Ford, Mercedes-Benz, Peugeot, Renault, Volvo and VW have given their acceptance to use paraffinic renewable diesel for some models. However, the engine or vehicle supplier should be asked to update the situation case by case, since the list of formally accepted vehicles is constantly updating, and since some manufacturers have given acceptance also for older engines already in use. The formal acceptance is clearly easier in the USA compared to Europe: Since Neste Renewable Diesel meets standard ASTM D975 2-D for traditional diesel fuel, separate acceptance is not needed at all, and all diesels sold on that market are formally allowed to use paraffinic diesel fuel as such.

Market experience

Neste Renewable Diesel

- Sales of neat and blended Neste Renewable Diesel are increasing globally – to private customers and to fleets
- Available at thousands of service stations
- No modifications to fuel logistics or service stations required with blends or neat product

Finland

Since 2007, service stations in Finland have been selling EN 590 diesel fuel containing Neste Renewable Diesel in order to fulfil the national biomandate. The blending and sales have been carried out in severe winter conditions as well. The highest blending ratios have been around 50%. This kind of fuel has been used in cars, vans, trucks and buses, and, in minor amounts, in non-road mobile machinery. Today, there are approximately 1,700 service stations selling this blend.

There is an increasing number of customers who are reducing their GHG emissions while demanding premium quality diesel. As a consequence, more and more EN 590 diesel dispensing pumps are being replaced with neat Neste Renewable Diesel dispensing pumps. The number of service stations selling neat NRD has grown from four in 2010 to more than one hundred in 2020. This has been used mainly in passenger vehicles. Since 2008, neat NRD has also been delivered into storage tanks of some bus fleets and hauliers for use in city buses and trucks.

The biomandate in Finland is counted from the total sales of bioenergy in traffic fuels per calendar year. This means that an oil company is able to choose between different biocontents and biocomponents in gasoline and diesel fuel. In principle, an oil company could cover the mandate by selling only fossil gasoline and a lot of Neste Renewable Diesel in diesel fuel, or by selling only a lot of E85 and fossil diesel.

All of the Neste Renewable Diesel blend and neat Neste Renewable Diesel deliveries have taken place all year round, including in severe winters. The vehicles, including the ones driving with neat Neste Renewable Diesel, have been standard vehicles without any modifications. No technical modifications have been made to pipelines, storage tanks, tanker trucks or service stations. Experience shows that Neste Renewable Diesel blends have behaved similarly to fossil fuels in terms of corrosion, storage stability, microbiological growth, water separation, elastomeric materials, delivery pump filters etc. that could appear in the logistic chain.

USA, Sweden and other countries

Renewable Diesel has been delivered from Neste's Porvoo, Rotterdam and Singapore plants to many customers in Europe – from northern to southern Europe – and to North America for use as such. NRD is especially used by customers that are aware and keen on bioenergy or reduced tailpipe emissions, or in order to meet biomandates and generate premium diesel fuels.

The west coast of the United States presents an example of the increasing use of Neste MY Renewable Diesel (see the Neste MY Renewable diesel brand section below). Ambitious targets for CO_2 savings, legislated by programs such as California's Low Carbon Fuel Standard and Oregon's Clean Fuels Program, have encouraged increasing numbers of public and private fleets to switch to NRD in their operations. There is also an ever-expanding network of Neste cardlock locations in these states to provide more access and options for operators seeking renewable diesel. In the future, it is expected that the State of Washington and a coalition of northeast states will follow suit with similar programs to help reduce carbon emissions and expand renewable diesel consumption.

In Sweden, the use of Neste Renewable Diesel has been increasing rapidly. NRD has been used as a biocomponent there since 2013 and sold as a neat 100% product since 2014. The Neste MY Renewable Diesel brand was launched in Sweden in late summer 2018 (see the Neste MY Renewable diesel brand section below). Prior to that, NRD was sold to fleets like hauliers and bus companies as a 100% product. Also fuel distributors are selling 100% Neste Renewable Diesel fuel both at their stations and to fleet markets to support the ambition of customers to move away from fossil fuels. In addition to the 100% market, NRD is used as a blending component in the regular Swedish Environmental Class 1 (MK1) diesel along with fossil diesel and RME to fulfil the local ambitious GHG mandate. The blending ratio of Neste Renewable Diesel varies but can be as high as 35%. The blending takes place all year round, meaning that NRD is blended with diesel also during the severe winter months. This kind of blend is sold today at thousands of stations. This blended diesel fuel has been used in e.g. cars, vans, trucks and buses without additional hurdles.

The experience of more than 15 years has proven that Neste Renewable Diesel as such or in blends meets user expectations. It is a safe, sustainable and high-quality fuel option that can be used without requiring any changes to fuel logistics or vehicles. Therefore, the interest in use of Neste Renewable Diesel as a 100% product has grown tremendously in the last 5-10 years around the world. In countries like the Netherlands, the UK, Germany, Estonia, Lithuania, Latvia, France, Japan, New Zealand and in many others, companies and individuals are already using or implementing it.

Neste MY Renewable Diesel brand

In order to offer sustainable solutions to its customers, Neste launched the Neste MY Renewable Diesel brand in Finland in 2017. In doing so, the user knows that they are getting a product with all the benefits that an HVO fuel product can bring and the insurance of Neste's stable and premium quality and compliance with EN 15940 and ASTM D975. Neste understands that the market for blending components still exists but has witnessed an increase in the interest for the neat product. In 2020, Neste MY Renewable Diesel is available in Finland, Sweden, the USA, the Netherlands, Estonia, Lithuania and Latvia.

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Acronyms

AMS	Accelerated Mass Spectrometry
ASTM	International organization for standardization (previously American Society for Testing and Materials)
BTL	Biomass-to-Liquid fuel made from biomass by Fischer-Tropsch synthesis
Bx	x = maximum allowed FAME content in diesel fuel
CEC	Co-ordinating European Council (for engine etc. test methods)
CEN	European Committee for Standardization
CFPP	Cold Filter Plugging Point
CN code	Combined Nomenclature for customs and trade statistics
CO	Carbon monoxide (tailpipe emission)
CO_2	Carbon Dioxide (direct tailpipe emission or Well-To-Wheels emission)
CTL	Coal-to-Liquid fuel made from coal by Fischer-Tropsch synthesis
CWA	CEN Workshop Agreement (possible 1st step for preparing a standard)
DCN	Derived Cetane Number
DPF	Diesel Particulate Filter
ED95	Fuel for modified diesel engines containing 95% ethanol and additives
EEV	Enhanced Environmental Friendly Vehicle
EGR	Exhaust Gas Recirculation
EN	European Standard prepared by CEN
FAME	Fatty Acid Methyl Ester (biodiesel)
FBP	Final Boiling Point
FBT	Filter Blocking Tendency
FFV	Flexible Fuel Vehicle
FIE	Fuel Injection Equipment
FKM	Fluoroelastomer
FQD	Fuel Quality Directive, directive 2009/30/EC
FSN	Filter Smoke Number
GC	Gas Chromatography
GTL	Gas-to-Liquid fuel made from natural gas by Fischer-Tropsch synthesis
HBD	Hydro-generated Biodiesel
HC	Hydrocarbons (tailpipe emission)
HDRD	Hydrogenation Derived Renewable Diesel
HFRR	High Frequency Reciprocating Rig (device for measuring fuel lubricity)
HS	Harmonized System
HVO	Hydrotreated Vegetable Oil
ISPM	Indicated Specific Particulate Matter

JEC	Collaboration between the European Commission's Joint Research Centre, EUCAR and Concawe
LSC	Liquid Scintillation Counting
LPG	Liquefied Petroleum Gas
MARPOL	International Convention for Prevention of Pollution from Ships
NBR	Nitrile Butyl Rubber
NEXBTLTM	Neste's brand and trademark for HVO process
NO_x	Nitrogen oxides (tailpipe emission)
NSOF	Non-Soluble Organic Fractions
PAH	Polycyclic Aromatic Hydrocarbons (tailpipe emission)
PM	Particulate Matter (tailpipe emission)
PN	Particulate Number
PME	Palm oil Methyl Ester (biodiesel)
PTFE	Polytetrafluoroethylene
REACH	European Community Regulation on chemicals and their safe use
RED	Renewable Energy Directive, directive 2009/28/EC
RED II	Revised Renewable Energy Directive, directive 2018/2001/EU
RME	Rapeseed Methyl Ester (biodiesel)
SLBOCLE	Scuffing Load Ball On Cylinder Lubricity Evaluator
SME	Soybean Methyl Ester (biodiesel)
SMG	Saturated Monoglycerides (impurities from FAME)
TM	Trademark
TS	CEN Technical Specification (possible 2nd step for preparing a standard)
TWW	Tank-To-Wheels
WTT	Well-To-Tank
WTW	Well-To-Wheels
XTL	BTL, CTL and GTL fuels made by Fischer-Tropsch synthesis