KNOWLEDGE GUIDE

Version 2.0

Shell

GTL Fuel

SYNTHETIC TECHNOLOGY FOR CLEANER AIR*

*Shell GTL Fuel burns more cleanly and so produces lower local emissions compared to conventional crude oil-derived diesel.

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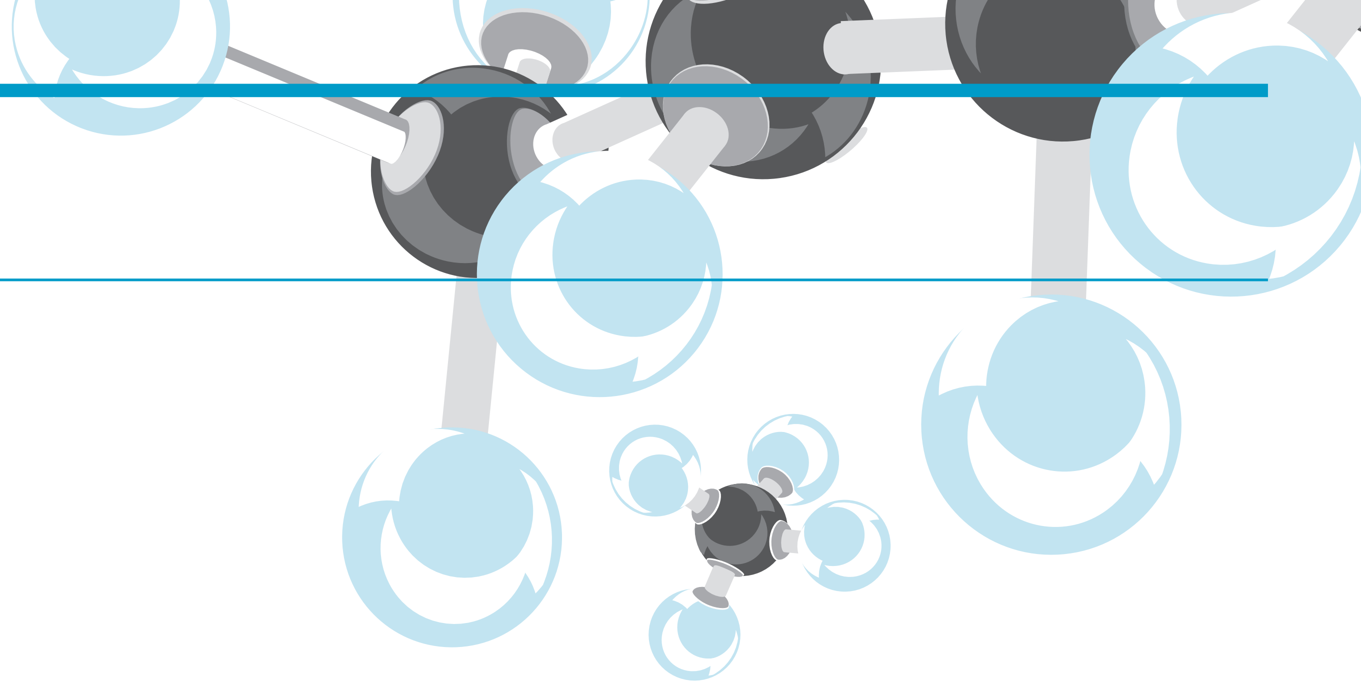

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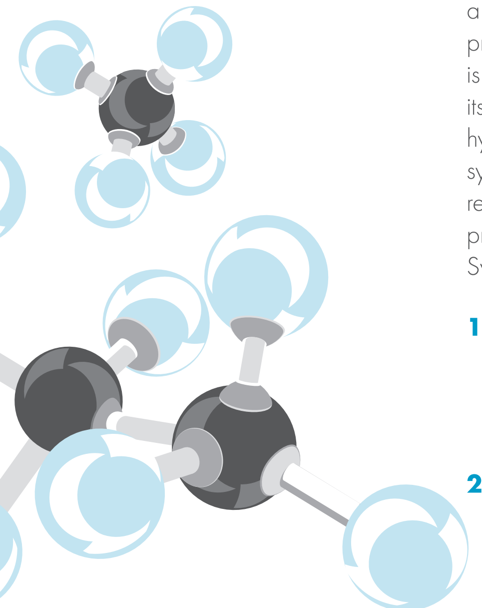
SHELL GTL FUEL SCIENTIST

Executive Summary

This guide summarises Shell's extensive knowledge of and experience with Shell GTL (Gas-to-Liquids) Fuel when used in a range of conventional diesel vehicles. In this guide, "Shell GTL Fuel" means 100% GTL fuel which is branded and marketed under the Shell name.



Shell GTL Fuel is an innovative synthetic fuel produced from natural gas that can help to reduce local emissions in conventional diesel vehicles.

Shell GTL Fuel contains lower levels of aromatics, poly-aromatics, olefins, sulphur and nitrogen than conventional diesel. This very high purity means that it is colourless and almost odourless.

It contains only molecules found in conventional diesel, and consists almost exclusively of straight chain normal-paraffins and branched iso-paraffins. Due to this unique composition, Shell GTL Fuel has a very high cetane number and burns more cleanly, and can produce lower local vehicle emissions compared to conventional crude oil-derived diesel. In addition, because GTL products are derived from natural gas, rather than crude oil, they can help to diversify supplies to the liquid fuel market.

Production Process

Shell GTL Fuel is produced by a Gas-to-Liquids (GTL) process, which uses natural gas as a feedstock. The core chemistry of the GTL process was developed in the 1920s, and is known as the Fischer-Tropsch process after its inventors. In essence, it synthesises higher hydrocarbons from a carbon source, via synthesis gas (CO and H_2), using catalysed reactions. The Shell GTL Fuel production process, known as the Shell Middle Distillate Synthesis (SMDS), contains three key steps:

1. Gasification
Synthesis gas (CO and H_2) is manufactured from natural gas by partial oxidation

2. Synthesis
The synthesis gas is converted into liquid hydrocarbons using a low temperature Fischer-Tropsch process, yielding a 'synthetic crude'.

3. Hydrocracking/Conversion to Products
The synthetic crude is further processed and fractionated into high quality paraffinic products, such as transportation fuels, aviation fuels and feedstocks.

Production Plants

Shell implemented the SMDS process in the world's first commercial scale GTL plant, which opened in 1993 in Bintulu, Malaysia. Bintulu now produces 14,700 barrels per day of GTL products. The experience gained at Bintulu has been critical to the success of Shell's second commercial GTL plant, known as Pearl, which is in Qatar and developed in partnership with Qatar Petroleum. Pearl, the world's largest GTL plant, is a fully integrated upstream/downstream project. It has the capacity to produce 140,000 barrels per day of GTL products as well as 120,000 barrels of oil equivalent a day of gas processing products.

The product slate at Pearl consists of GTL gasoil, GTL naphtha, GTL kerosene, GTL normal paraffins and GTL base oils. Shell GTL Fuel is derived primarily from the 'gasoil' cut, which has similar properties to conventional diesel.

Ease of Use

In general, Shell GTL Fuel can be packaged, transported and stored using the same equipment, materials, and procedures as conventional diesel. Diesel vehicles can also be run on Shell GTL Fuel without engine or exhaust system modifications, which means that Shell GTL Fuel can be considered as a drop-in replacement for conventional diesel, allowing seamless introduction without investment in new vehicles or refuelling infrastructure.

Product Characteristics

Shell GTL Fuel is a premium quality product. Although it has broadly similar physical characteristics to conventional diesel, it has a much higher cetane number, higher mass calorific value, lower sulphur and aromatics, and a lower density [1]. Shell GTL Fuel is almost entirely paraffinic, and comprises hydrocarbon molecules of essentially only two types, normal-paraffins and iso-paraffins. It is essentially free from the unsaturated molecules, such as olefins (alkenes) and aromatics, which are present in conventional fuels. These unique properties enable more efficient combustion and lower vehicle local emissions.

Shell GTL Fuel can meet the needs of most temperate and cold climates. Its Cold Filter Plugging Point (CFPP) is typically in the range of -9°C to -20°C, depending on the requirements of the climate. Lower CFPP batches have also been produced.

Successful Worldwide Experience

Over the past decade, Shell has conducted many field trials of Shell GTL Fuel in major cities around the world. These vehicle trials have tested the performance of Shell GTL Fuel over many months of real "on the road" conditions. The trials showed that the switchover from conventional diesel was easy and that vehicle performance was maintained. They have also helped to raise the awareness of GTL fuel amongst governments, automotive manufacturers and the general public in Europe, the USA and Asia.

Key Benefits

Through all these tests and trials a large amount of local emissions data has been collected, covering a wide range of the vehicles, engines and after-treatment systems on the road today. Collectively, the local emissions tests have shown that Shell GTL Fuel can provide significant percentage local emissions benefits compared to conventional diesel. Moreover, these have remained similar on a percentage basis over a range of engine and vehicle technologies. Therefore, the use of 100% Shell GTL Fuel in light- and heavy-duty applications, both on- and off-road, can be an attractive solution for helping to reduce local emissions and to improve local air quality.

As well as yielding local emissions benefits, Shell GTL Fuel is non-toxic, odourless, readily biodegradable and has a low hazard rating. These characteristics further enhance its credentials and make Shell GTL Fuel intrinsically safer to transport, handle and use than conventional diesel. Since 2006, Shell has embarked on the global registration of Shell GTL Fuel using a new CAS number and product descriptor to differentiate this from crude oil-derived products. This enables the hazard properties of Shell GTL Fuel to be recognised thereby creating opportunities to promote its use in operational areas where 'safer' (i.e. less hazardous) products are desirable. In addition to these benefits, Shell GTL Fuel has been shown to give engine noise benefits in some situations, due to its high cetane number.

SHELL GTL FUEL TRIAL VEHICLE IN CHINA

Helping to Improve Local Air Quality

A number of emissions tests have been performed in real engines and vehicles under controlled conditions by Shell and collaborative partners, which confirm the benefits of using 100% Shell GTL Fuel. Measurements on engine test beds using standard test cycles have shown that 100% Shell GTL Fuel can give local emissions benefits in both heavy-duty and light-duty diesel engines as compared to conventional diesel. These measurements have been supplemented by testing vehicles on chassis dynamometers, using application-based cycles. Emissions tests commissioned in support of the customer field trials have mirrored the local emissions reductions seen in the collected database of dedicated emissions studies.

Availability of Shell GTL Fuel

Shell is currently marketing 100% Shell GTL Fuel in Germany and The Netherlands. It can be implemented as a drop-in replacement for conventional diesel, helping to reduce local emissions immediately, without the need for investment in new vehicles or refuelling infrastructure.

2.

GTL Background - A Historical Perspective

Shell GTL Fuel is a product of a Gas-to-Liquids (GTL) process, which uses natural gas as a feedstock.

The GTL process is the most commercially developed of a group of technologies, known collectively as 'Anything'-to-Liquids (XTL).

XTL processes can be used to create liquid hydrocarbons from a variety of carbon feedstocks. The core chemistry of these processes, the Fischer-Tropsch synthesis, is well proven and has been in development for nearly a century. In essence, Fischer-Tropsch uses catalytic reactions to synthesise complex hydrocarbons from simpler organic molecules. The products of XTL processes are mainly middle distillates, including transportation fuels. This means that the application of XTL technology offers diversification of the liquid fuel supply, to supplement crude oil-derived fuels. The following is a brief timeline of key events in the history of GTL technology.

- **1922 -** German scientists, Franz Fischer and Hans Tropsch, discover the synthesis step core to the GTL process.
- **1945 -** Fischer-Tropsch (F-T) was used in Germany during the Second World War to produce approximately 1600 barrels per day of liquid transportation fuels from coal (CTL).
- **1955 -** South Africa began using the F-T process in 1955, using coal as feedstock. The country has no domestic oil, but has large coal reserves, making CTL an attractive option for reducing dependence on liquid fuel imports.

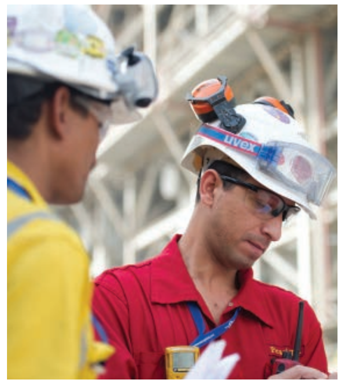
GTL PILOT PLANT, AMSTERDAM

- **1973 -** Shell took the F-T process that converts gas (and other feedstocks) to liquids and further developed it at the Amsterdam laboratory.
- **1983 -** Shell built a pilot plant in Amsterdam for larger scale tests on paraffin synthesis and conversion to make GTL products.
- **1992 -** PetroSA, Republic of South Africa's national oil company opened a GTL plant, using high temperature Fischer-Tropsch at Mossel Bay in 1992, which now has capacity of 45,000 barrels per day of GTL products. The products of this plant are mostly gasoline, rather than diesel components.
- **1993 -** Shell opened the world's first commercial low-temperature Fischer-Tropsch plant at Bintulu, Malaysia, designed to produce 12,500 barrels per day of high quality GTL products.
- **2001 -** Sasol announced an agreement to build their first GTL plant, Oryx, in Qatar.
- **2003 -** Technical improvements raised the production capacity at Bintulu to 14,700 barrels per day.
- **2005 -** Chevron announced GTL plant in Escravos, Nigeria.
- **2006 -** Pearl GTL project (Shell and Qatar Petroleum) was approved by The Government of the State of Qatar, and was planned to be 10 times the size of the Bintulu facility.
- **2007 -** Sasol's Oryx plant opened in Qatar, which currently produces 34,000 barrels per day of GTL products.

2.

GTL Background - A Historical Perspective

- **2012 -** Full-scale production at Pearl GTL commenced, with 140,000 barrels per day of high quality GTL products.
- **2012 -** Sasol began the construction of the Oltin Yo'l GTL plant in Uzbekistan. It will produce 38,000 barrels per day of GTL products.
- **2012 -** Sasol commenced the front-end engineering and design phase of a GTL plant in Louisiana, USA. It is expected to produce 96,000 barrels per day of GTL products.
- **2012 -** Sasol conducted a feasibility study into constructing a GTL plant in Alberta, Canada. It is also expected to produce 96,000 barrels per day of GTL products.
- **2012 -** Shell conducted a feasibility study into GTL production in the USA, on a similar scale to Pearl GTL.
- **2014 -** Chevron and the Nigeria National Petroleum Corporation (NNPC) start up the Escravos GTL plant in Nigeria, capable of producing 33,000 barrels per day of GTL products.

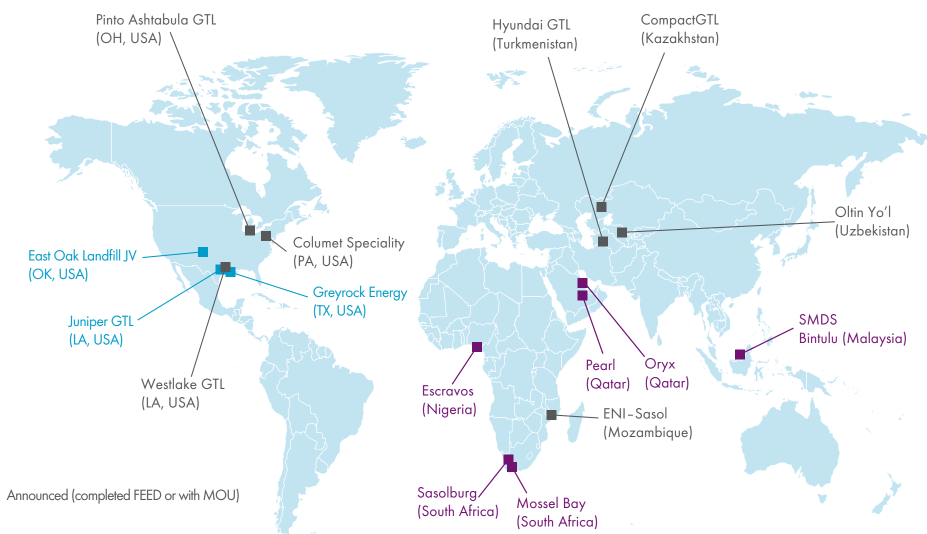


PEARL GTL, QATAR

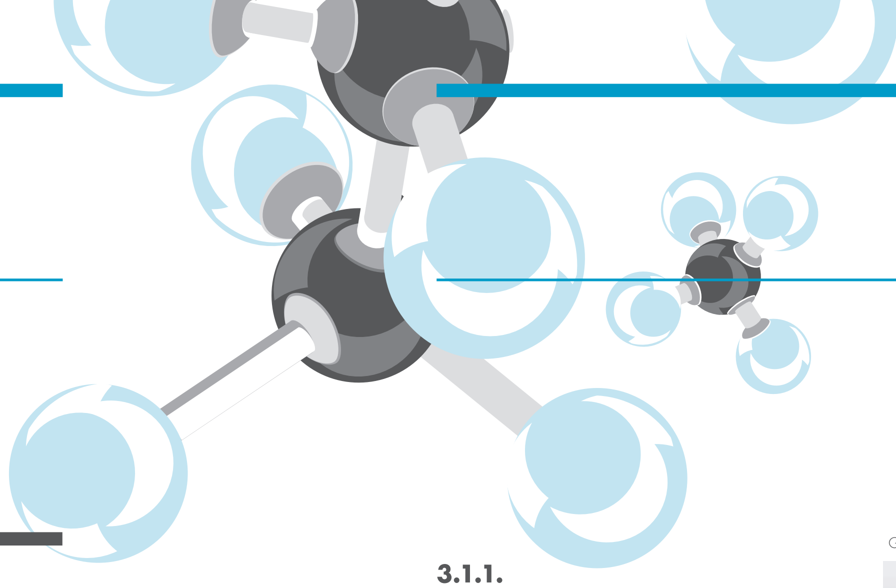
GTL is an expanding technology, with many new projects being announced in the recent years. Shell continues to assess opportunities for new GTL plants in the future. The figure below shows the activities of Shell and selected others, covering both operational and announced projects. These announced projects have been divided into two classes, pre and post final investment decision (FID).

Figure 1.

World GTL Plants Schematic - Current and Future Announced



Source: Public sources data as of May 2015. Locations and size are for illustration only. Only projects that have either FEED (Front end engineering design) completed or at least a MOU (Memorandum of understanding) in place are listed.



3.

GTL Production

This section describes the Shell GTL Fuel production process and gives an overview of Shell's two main GTL plants - Bintulu and Pearl GTL.

3.1.
Shell Middle Distillate Synthesis (SMDS)

The basis of GTL technology was developed in the 1920s, and is known as the Fischer-Tropsch process, after its inventors.

In essence, the process synthesises higher hydrocarbons from a carbon source, via synthesis gas (CO and H_2), using catalytic reactions. Shell's GTL production process, known as the Shell Middle Distillate Synthesis (SMDS), comprises three key steps:

1. Gasification
Synthesis gas (CO and H_2) is manufactured from natural gas by partial oxidation.

2. Synthesis
The synthesis gas is converted into liquid hydrocarbons using a low temperature Fischer-Tropsch process, yielding a 'synthetic crude'.

3. Hydrocracking/Conversion to Products
The synthetic crude is further processed and fractionated into high quality paraffinic products, such as transportation fuels, aviation fuels and feedstocks.

GTL facilities are complex plants, like a giant chemistry set, that first combine, then break up and rearrange chains of atoms. Chains of different lengths have different properties, and so they make a range of GTL products.

Figure 2.

Schematic of Typical Process Line-Up in a Shell GTL Plant

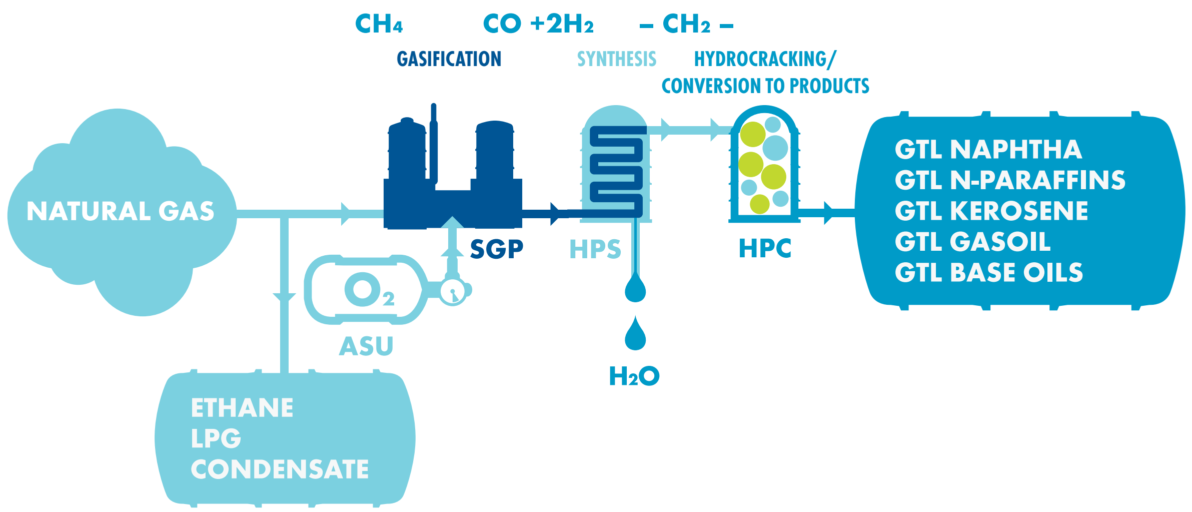


Figure 2. Schematic of Typical Process Line-Up in a Shell GTL Plant

3.

GTL Production

3.1.1.
Gasification

The Shell Gasification Process (SGP) was first developed in the 1950s, primarily with the objective of gasifying heavy residues. During the process, methane is partially oxidised to produce synthesis gas (or syngas), a mixture of carbon monoxide and hydrogen. The oxygen for the SGP is produced in an Air Separation Unit (ASU). The reaction producing syngas can be represented as:

$$CH_4 + \tfrac{1}{2}O_2 \rightarrow CO + 2H_2$$

The process is operated at 1300 to 1500°C and pressures of up to 70bar. The H_2/CO ratio of the SGP gas requires little adjustment to yield the Shell GTL product slate, giving high overall process efficiency.

3.1.2.
Synthesis

At the heart of the GTL process is the Fischer-Tropsch synthesis, in which hydrocarbon molecules are 'grown', with the aid of a catalyst. The syngas passes through a Heavy Paraffin Synthesis (HPS) reactor, in which it is contacted with a proprietary Fischer-Tropsch catalyst, at elevated temperature and pressure. The proprietary catalysts used in the SMDS process have been developed by CRI/Criterion Inc., the global catalyst technology company used by the Shell Group. The product of the HPS process is a waxy mixture containing significant quantities of long-chain normal alkanes (linear paraffins, C1-C100+), which are solid at room temperature, and at present, unsuitable for use as transport fuel. The F-T reaction can be characterised as:

$$(2n+1)H_2 + nCO \rightarrow C_nH_{(2n+2)} + nH_2O$$

GTL WAX FROM HPS

The Fischer-Tropsch reaction can be carried out under a variety of conditions depending on the feedstock and the desired product slate. Shell uses a low temperature Fischer-Tropsch process at Pearl and Bintulu, which is performed at 210-260°C and employs a cobalt catalyst, developed by CRI/Criterion Inc. The conditions and catalyst used in the SMDS process maximises the yield of highly paraffinic middle distillates, which are suitable for use as liquid transport fuels. The Fischer-Tropsch process produces water as the only by-product.

By contrast, the high temperature Fischer-Tropsch process which is used extensively in Coal-to-Liquids (CTL) is carried out at 310-340°C over an iron catalyst. The high temperature Fischer-Tropsch process yields light products rich in olefins and aromatics, which are more suited to gasoline and chemical feedstock production.

3.1.3.
Hydrocracking/ Conversion to Products

The Heavy Paraffin Conversion (HPC) reactor is used to fine-tune the unique properties of the Shell GTL products. The bulk of the HPS product is fed to the HPC reactor, in which it is contacted with hydrogen in the presence of another Shell proprietary catalyst. The waxy part of the HPS product is selectively hydrocracked to the desired middle distillate products. Simultaneously the product is hydroisomerised to increase branching, thus improving the cold flow properties. Any unsaturated molecules formed in the cracking processes are hydrogenated to paraffins. The HPC product is subsequently separated in a conventional fractional distillation column where it is separated into a number of end-product fractions, as will be discussed in the next section.

PEARL GTL, QATAR

3.

GTL Production

The SMDS process yields several GTL products, one of which is GTL gasoil, from which Shell GTL Fuel is produced.

3.2.
Products of the SMDS Process

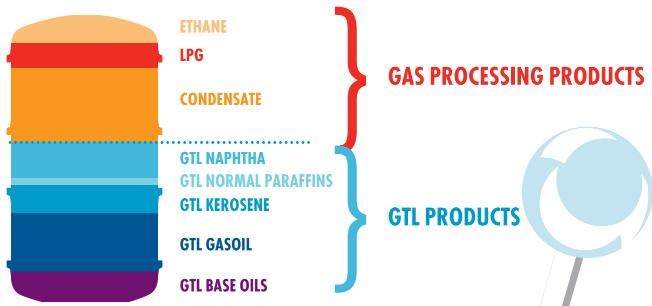
Separated refinery or GTL products are known as 'cuts' or 'fractions'.

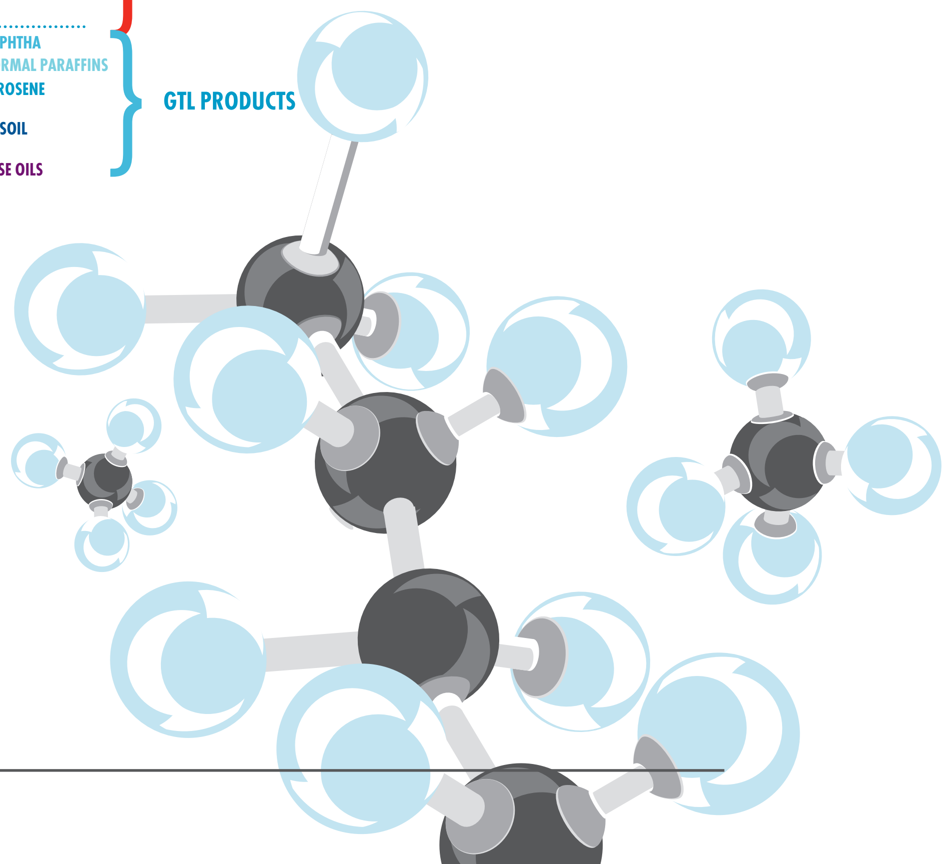
Each GTL cut has different physical properties, which make them suitable for specific applications. The relative amounts of these various cuts from a specific GTL process is defined as the 'product slate'. Shell GTL Fuel is derived from the 'gasoil' cut of the product slate.

The product slate varies depending on the GTL production conditions i.e. the temperature of the reactor and the type of catalyst used. The SMDS process, using low temperature Fischer-Tropsch with a cobalt catalyst, maximises the yield of middle distillates and increases the paraffinic nature of the products, making them highly suitable for use in a variety of fuel products. The products from the SMDS process can be separated into two main classes, gas processing products, and GTL products.

Figure 3.

Pearl GTL 'Product Slate'





3.

GTL Production

3.2.1.
Gas Processing Products

The gas processing products are mainly taken directly from the gas feed (Figure 2), but some Ethane and LPG will also be produced during the SMDS process.

- Ethane can be processed into ethylene and used to make plastics.
- LPG consists mainly of propane and butane and can be used as a fuel.
- Condensate is primarily used in petrochemical refineries.

3.2.2.
GTL Products

The SMDS process makes it possible to use natural gas, rather than crude oil, as the raw material for a range of valuable liquid products. These include cleaner-burning fuels for use in road transport and aviation, and materials that go into making chemicals and lubricants.

- At the lighter end of the product slate, GTL naphtha is an alternative high quality feedstock for chemical manufacturing and a building block for the plastics industry. It offers superior yields of ethylene/ propylene and lower feedstock costs than conventional naphtha.

- GTL normal paraffins is a premium alternative feedstock for detergent production. Detergent manufacturing companies usually extract conventional normal paraffin from oil-based kerosene; the GTL process offers a suitable feedstock directly.

GTL PRODUCTS

- GTL kerosene is an alternative to conventional oil-based kerosene. It can be used for heating and lighting, but its primary use is expected to be in aviation. GTL kerosene can be blended at up to 50% in conventional Jet A-1 (GTL Jet Fuel).

- GTL gasoil can be used as an alternative fuel in conventional diesel engines ("Shell GTL Fuel") or blended with conventional refinery diesel.

- Finally, heavy components such as GTL base oils are suitable for use in high quality oils and lubricants.

GTL products can be classified as UVCB[1] substances, and they are similar to crude-oil derived products such as naphtha, kerosene, gasoil and lubricating base oils. GTL products contain negligible amounts of aromatics, sulphur and nitrogen compounds compared to crude-oil derived products, when they leave the production process.

[1] "UVCB substances": Substances of Unknown or Variable composition, Complex reaction products or Biological materials. (REACH Technical Guidance for identification and naming of substances).

Pearl GTL was constructed in Ras Laffan, Qatar in 2010 and is now the world's largest source of GTL products.

3.3.
Process Development

The SMDS process was developed at Shell Technology Centre, Amsterdam.

The development was a multi-disciplinary project with early involvement of all areas of expertise from basic and exploratory, to engineering, catalyst and process development. This cooperation has not only led to the successful commercialisation of Bintulu and subsequently Pearl, but has also resulted in over 3,500 patents and numerous publications.

After almost 40 years of GTL research and commercial operation, Shell has enhanced the SMDS processes extensively, particularly the catalysts produced by CRI/Criterion. These have been considerably improved by experience gained from the world's first commercial scale GTL plant in Bintulu, Malaysia. The improvements have led to more efficient synthesis and reduced unit capital expenditure, allowing greater volumes of fuel and other products to be produced, more cost effectively. This valuable experience and evolution of the SMDS process has enabled the success of the Pearl GTL project. Shell's two commercial GTL plants are described in more detail in the next section.

SHELL TECHNOLOGY CENTRE AMSTERDAM

3.
GTL Production

3.4.
Shell's Commercial GTL Plants

3.4.1.
Bintulu GTL

Shell opened its first GTL plant in Bintulu, Malaysia in 1993. At that time Bintulu was the world's first commercial scale low temperature Fischer-Tropsch GTL plant, initially producing 12,500 barrels per day of GTL products. The project was the culmination of over 30 years of research and development by Shell. Bintulu is still in operation today, and now produces 14,700 barrels per day of premium GTL products, allowed by advances in Shell GTL technology. Bintulu can produce up to 4,000 barrels per day of Shell GTL Fuel for use worldwide. These limited volumes have been used by Shell as a component in premium retail products such as Shell Pura Diesel (marketed in Thailand) and Shell V-Power Diesel.

BINTULU, MALAYSIA

3.4.2.
Pearl GTL

Pearl GTL was constructed in Ras Laffan, Qatar in 2010 and is now the world's largest source of GTL products. Pearl GTL is a fully integrated upstream/downstream project and is the largest energy project within the borders of Qatar as well as the largest equity investment on a single project made to-date by Shell. Construction of the plant began in 2006 and the majority of the work was completed by the end of 2010. In March 2011, the plant started receiving gas from the Qatar North field. Production from the Pearl GTL began in June 2011 and the first commercial shipment was made on 13th June 2011. The plant was ramped up to reach full capacity in late 2012.

Pearl GTL produces 140,000 barrels per day of GTL products - gasoil, naphtha, kerosene, normal paraffin and lubricants base oils, as well as 120,000 barrels of oil equivalent a day of ethane, liquefied petroleum gas (LPG) and condensate. Pearl produces approximately 50,000 barrels per day of GTL gasoil for use worldwide. Given this substantial availability of GTL gasoil, Shell has begun marketing Shell GTL Fuel to commercial customers in the Netherlands and Germany.

PEARL GTL, QATAR

4.

Characteristics and Performance of Shell GTL Fuel

Shell GTL Fuel has an exceptionally high cetane number (up to 30 numbers higher than conventional diesel).

Shell GTL Fuel is a premium quality innovative synthetic fuel, for use in diesel engines.

It has broadly similar physical characteristics to crude oil-derived diesel, but with a much higher cetane number, a higher mass calorific value, lower levels of sulphur and aromatics and a lower density.

The fuel is almost entirely paraffinic, and comprises hydrocarbon molecules of essentially only two variants, normal-paraffins and iso-paraffins. It is essentially free from unsaturated molecules, such as olefins (alkenes) and aromatics that are present in conventional fuels, enabling more efficient combustion, and lower local emissions. This section describes 100% Shell GTL Fuel in mostly descriptive terms. Section 8 illustrates how the product compares to quantitative limits in conventional diesel and paraffinic diesel specifications.

4.1. Summary of Key Properties

The key differences in the properties of Shell GTL Fuel compared to conventional diesel are summarised in Table 1 below.

Table 1.

Qualitative Summary of Key Shell GTL Fuel Performance-Related Properties

Property	Shell GTL Fuel compared to conventional diesel	Implications for application in a diesel vehicle
Cetane number	Very high	• Lower local emissions (PM, NOx, CO, HC) • Less engine noise (in some vehicles)
Mass energy content (MJ/kg)	High	• Enhanced combustion
Density	Low	• Lower than the minimum density requirement of European diesel specification (EN 590) • Potentially higher volumetric fuel consumption • Lower local emissions
Sulphur content	Very low (almost zero)	• Lower PM and SOx emissions[2] • Potential benefits for sulphur sensitive aftertreatment[2]
Aromatic content	Very low (almost zero)	• Lower local emissions • "Non toxic" and "readily biodegradable"
Cold Flow Properties	Similar	• Able to meet the specifications for winter grade fuels in temperate Europe (and elsewhere)

[2] Diminishing effect in regions with already very low (<10/15ppm) sulphur specifications

4.

Characteristics and Performance of Shell GTL Fuel

4.2. Appearance and Odour

The appearance of Shell GTL Fuel is clear and bright. It is almost water-like in colour and there is no characteristic diesel fuel type odour, due to the lack of sulphur and aromatics.

ODOUR TESTING

4.3. Cetane Number

The cetane number of a fuel is a measure of combustion quality.

In particular, it relates to the ignition delay of the combustion process, which is the time taken between the start of fuel injection and the start of combustion. A higher cetane diesel fuel has a shorter ignition delay, which can yield a number of other associated benefits.

Shell GTL Fuel is almost entirely paraffinic and is essentially free from unsaturated molecules, such as olefins (alkenes) and aromatics that are present in conventional fuels. This means that Shell GTL Fuel combusts very well under compression, giving it an exceptionally high cetane number, typically in the range of 74-80 compared to 51-57 for conventional diesel. The high cetane number and paraffinic nature of Shell GTL Fuel can help to yield a number of performance benefits:

i) Lower local emissions (PM, NOx, CO, HC) (see Section 5)

ii) Less engine noise and smoother operation in some situations (see Section 7.4)

Emissions benefits can be predicted by the European Program on Emissions, Fuels and Engine Technologies (EPEFE) equations, in which cetane is a key parameter[3] [2].

4.4. Mass Energy Content (Calorific Value)

The mass energy content of diesel fuel is usually described by its net calorific value or lower heating value, which give an indication as to the energy delivered per unit mass of fuel (MJ/kg).

As a result of its paraffinic nature, Shell GTL Fuel has a higher net calorific value than conventional diesel (GTL: 44.0 MJ/kg vs EN 590: 42.9 MJ/kg).

4.5. Density

The density of a diesel fuel is its mass per unit volume. The higher the density, the heavier the material and the greater its energy content per litre.

As a consequence of the chemical composition, Shell GTL Fuel has a lower density than conventional crude oil-based diesel. The low density has several implications for both the handling and end-use of Shell GTL Fuel:

i) 100% Shell GTL Fuel does not meet the minimum density requirement (820 kg/m3) of the European diesel specification (EN 590). However, Shell GTL Fuel does meet the full requirements of the US ASTM D975 diesel, the European Fuels Quality Directive (2009/30/EC) and the Japanese JIS K 2204 diesel specification, which have no lower density limit.

ii) Volumetric fuel consumption in a vehicle (e.g. in litres per 100km) may be somewhat higher with Shell GTL Fuel compared to conventional diesel because the lower density (GTL typically: 774-782 kg/m3 vs EN 590: 820-845 kg/m3) is only partially offset by the higher calorific value (see values above). It is difficult to forecast the exact fuel economy parity or dis-benefit for a given vehicle or fleet because there are many other factors that can affect the fuel economy, such as: driver behavior and style, driving conditions, drive cycle, quality of the lubricant and inflation of tyres.

iii) The lower density of Shell GTL Fuel can also help to reduce local emissions. Local emissions benefits for Shell GTL Fuel are described in Section 5.

[3] Vehicles tested up to Euro II

4.

Characteristics and Performance of Shell GTL Fuel

4.6. Sulphur content

Sulphur is a natural component of refinery fuel; however it can negatively affect both exhaust emissions (PM and SOx) and aftertreatment systems.

In the context of modern engine systems low sulphur levels (e.g. 50ppm and 10ppm specifications) are seen as the enabler for advanced aftertreatment systems, e.g. the catalysts within particulate traps would be poisoned at higher sulphur levels. For older technology systems tolerant to higher sulphur fuels, the relevance of sulphur content is its direct effect on particulate matter (PM) emissions by contributing a sulphate fraction to the PM weight. For these reasons strict sulphur limits have been imposed on fuel suppliers. The U.S. Environmental Protection Agency (EPA) limited the sulphur content of on-road diesel fuel to <15mg/kg starting in 2006 (Ultra-Low Sulphur Diesel Fuel). Elsewhere, since 2009, the European Union has limited diesel sulphur content to <10mg/kg and Japan also limited sulphur to <10mg/kg in 2007.

The sulphur content of Shell GTL Fuel coming directly from the production process is practically zero (<1.0mg/kg). However, since it is used in the normal diesel fuel logistics system, <5.0 mg/kg sulphur is the limit defined in the Shell GTL Fuel product supply specification, to account for possible contaminants introduced through conventional fuel. This conservative limit meets the requirements of the most modern (and envisaged future) exhaust aftertreatment systems. That said, much of the sulphur contacting aftertreatment systems now originates from engine oil rather than fuel, so lower sulphur content in the fuel may have little benefit on aftertreatment systems. Near-zero levels of sulphur in Shell GTL Fuel mean that emissions of sulphur oxides (SOx) and sulphate particulates from diesel vehicles running on Shell GTL Fuel are negligible, however the benefits when compared to modern fuels in developed regions, with already very low sulphur levels (<10mg/kg), are likely to be small.

COLOUR COMPARISON BETWEEN GTL (LEFT) AND DIESEL (RIGHT)

4.

Characteristics and Performance of Shell GTL Fuel

4.7. Performance at Low Temperatures (Cold Flow Properties)

At low temperatures, the free flow of diesel fuel may be impeded by the blocking of fuel lines and filters by particles of paraffin wax that precipitate out of solution as the fuel cools.

'Cold flow properties' is a collective term for a number of parameters which define how effectively the fuel will flow in a diesel fuel system, at low temperature. The precipitation of solid wax in a cooled fuel is accompanied by a change in the appearance of the fuel, which turns from clear to cloudy at the so-called 'Cloud Point' temperature. Other cold flow properties include the temperature at which filters similar to those used in fuel systems become clogged (cold filter plugging point - CFPP) and the temperature at which the fuel ceases to pour (pour point - PP). It is the CFPP which is regulated under European specification for automotive diesel.

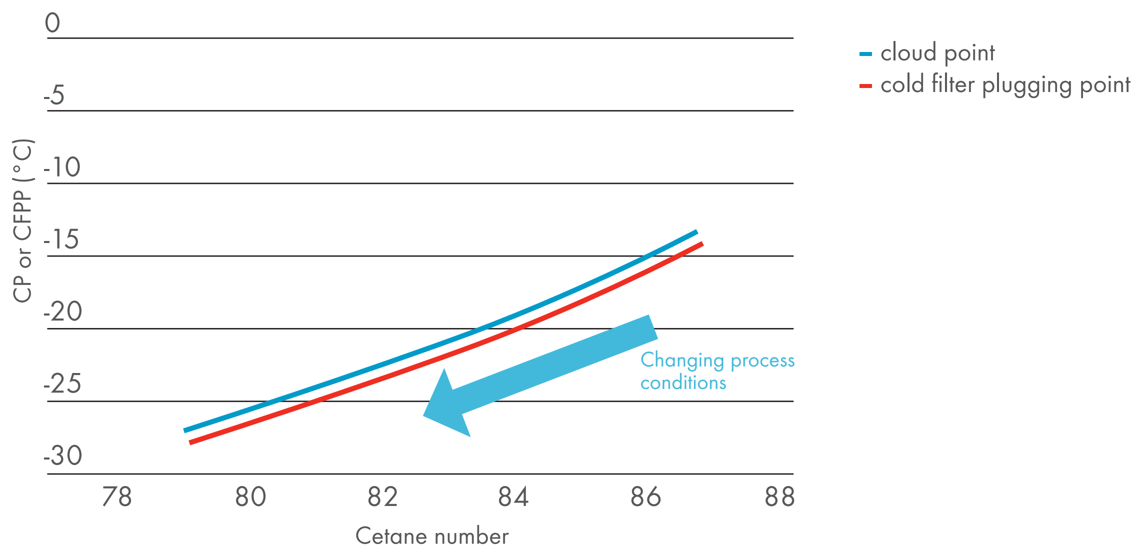
In conventional oil refining, the required cold properties are obtained by blending different refinery streams in order to meet specific cold flow requirements. Additional help comes from cold flow additives, which can decrease the CFPP of the fuel. Tests with cold flow additives from different suppliers have shown that additives used in conventional diesel can also give satisfactory performance in Shell GTL Fuel. Whilst Shell GTL Fuel does contain n-paraffins, which have inherently poor cold flow properties, the iso-paraffins predominate, ensuring good cold flow. Moreover, through fine tuning of the production process, even higher levels of iso-paraffins can be introduced, thus further improving the cold flow to suit more demanding markets.

A potential drawback with replacing n-paraffins with iso-paraffins, is an associated decrease in cetane number. However, the iso-paraffins in Shell GTL Fuel have limited and short side chains, enabling it to have both high cetane number and good cold flow. This means that there is only a mild fall-off of cetane number, with significantly improved cold flow, as emphasised in Figure 4 [3].

The CFPP of Shell GTL Fuel can be tailored to meet the requirements of the climate in a particular country. Typically, the CFPP of Shell GTL Fuel is from -9°C to -20°C (untreated with cold flow additive), but lower CFPP batches have also been produced. Shell GTL Fuel is therefore able to meet specifications for winter grade fuels in Europe, ensuring fitness for purpose in this area. Moreover, even 'winter grade' type Shell GTL Fuel has a high cetane number when compared to conventional diesel.

Figure 4.

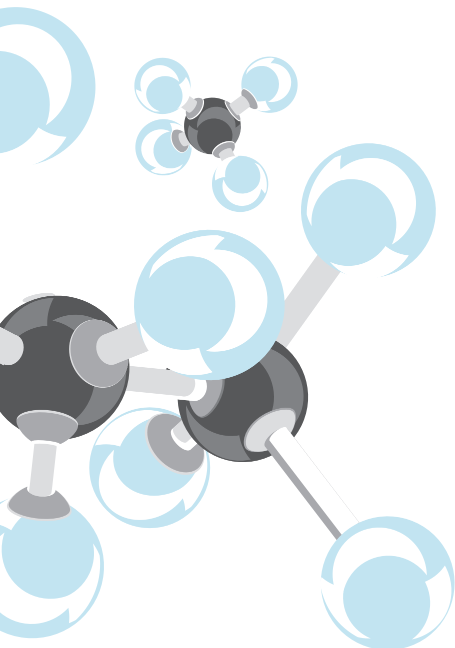
Shell GTL Fuel Cold Flow/Cetane Number Trade-Off



4.

Characteristics and Performance of Shell GTL Fuel

Shell GTL Fuel is treated with a lubricity additive therefore it adequately meets both ASTM D975 and EN 590 HFRR lubricity specifications.



4.8. Lubricity

The lubricity of a fuel is its ability to reduce friction between solid surfaces.

Some moving parts of diesel fuel pumps and injectors are protected from wear by lubrication from the fuel. To avoid excessive wear, the fuel must have a certain level of lubricity. In international specifications (EN 590, ASTM D975) diesel lubricity is expressed as a 'Mean wear scar diameter', measured in micrometres, in an apparatus called a High Frequency Reciprocating Rig (HFRR). A maximum HFRR value is specified (460μm in EN 590, 520μm in ASTM D975).

The lubrication of modern low-sulphur diesel fuel is improved significantly through: i) the addition of Fatty Acid Methyl Ester (FAME) as a biocomponent, which has high natural lubricity ii) the use of lubricity improver (LI) additives. GTL Gasoil falls into the same category as highly processed diesel, in that it has little natural lubrication, and so it must also be treated with LI additives. Conventional LI additives have been found to be equally effective in reducing the HFRR value of Shell GTL Fuel. Shell GTL Fuel is supplied already treated with an LI additive therefore it adequately meets ASTM D975 and EN 590 HFRR lubricity specification.

SHELL GTL FUEL SCIENTIST

One of the main global suppliers of diesel fuel injection equipment (FIE), Delphi Diesel Systems, has been working with Shell Global Solutions to study the effect of paraffinic diesel on the durability of modern common-rail fuel injection hardware.

The conclusions of the joint program stated that in a series of rig and engine tests, Shell GTL Fuel performed no worse and in some respects better than conventional diesel. In particular, the lubricity of Shell GTL Fuel was improved by addition of lubricity additives or FAME, with minimal wear under a wide range of operating conditions and temperatures. No deposits or lacquer were produced on fuel injection system components, even under relatively severe operating conditions [4].

4.

Characteristics and Performance of Shell GTL Fuel

4.9. Viscosity

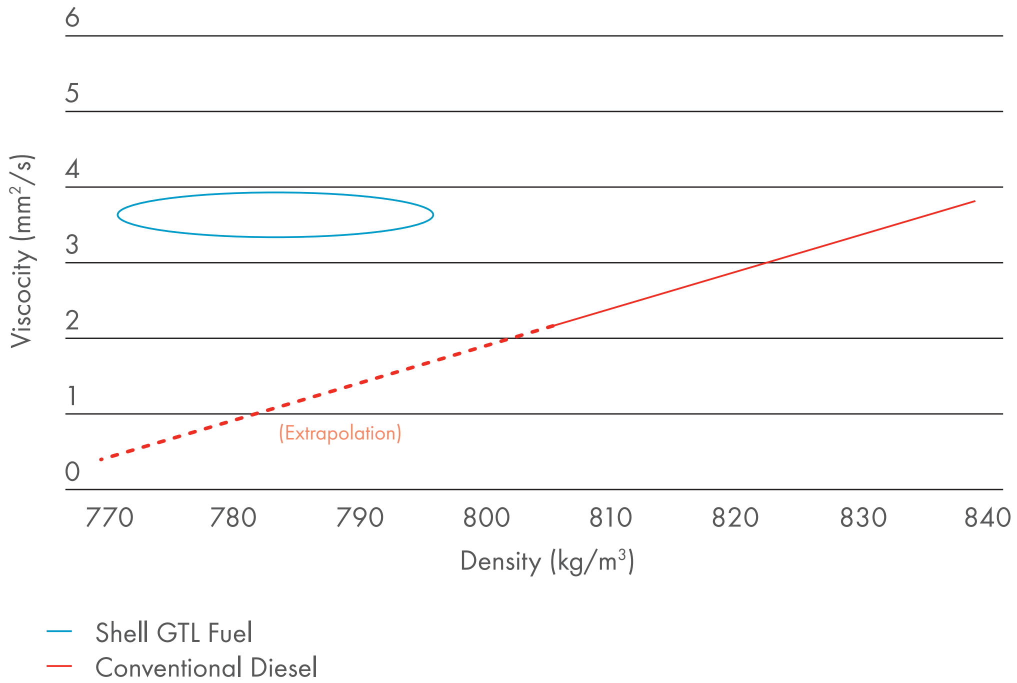
Viscosity of Shell GTL Fuel is broadly similar to the range of viscosities encountered in conventional diesel.

It might be expected that the low density of paraffinic diesel would be reflected in a low viscosity, but this is not the case in practice, due to its chemical composition. Shell GTL Fuel breaks the conventional density/viscosity correlation of conventional diesel fuels, having relatively high viscosity when compared to conventional diesel of an equal density, as shown in Figure 5.

Viscosity of Shell GTL Fuel is broadly similar to the range of viscosities encountered in conventional diesel. Both meet the required geographic specifications, e.g. in Europe EN 590 Vk40: 2.0 – 4.5 mm^2/s.

Figure 5.

Density/Viscosity Correlation of Diesel Fuels



Viscosity of Shell GTL Fuel is broadly similar to the range of viscosities encountered in conventional diesel.

SHELL GTL FUEL VISCOSITY (LEFT)

4.

Characteristics and Performance of Shell GTL Fuel

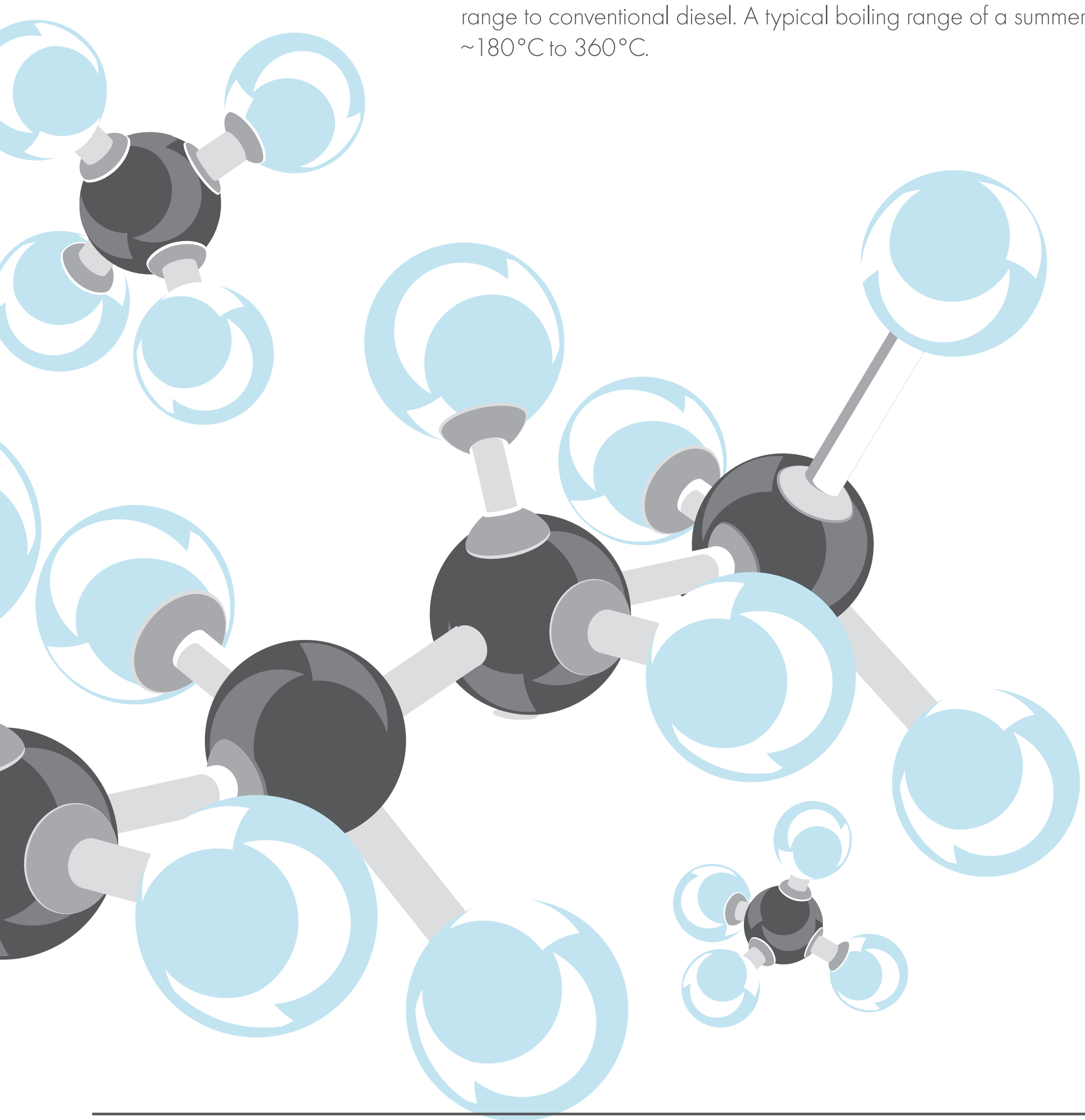
DISTILLATION AT SHELL TECHNOLOGY CENTRE AMSTERDAM

4.10. Distillation

The distillation characteristics of a fuel describe how it evaporates when the temperature is gradually increased.

This is important for understanding how the fuel vaporises when it is sprayed into the combustion chamber of a diesel engine. Some fractions boiling at low temperatures are needed for satisfactory engine start-up, while fractions boiling at excessively high temperatures may not combust completely, forming engine deposits and increasing tailpipe emissions.

As with conventional diesel fuels, there is a reasonable relation between the boiling range and the carbon chain length distribution. Paraffins in the middle distillate range typically have between 9 and 25 carbon atoms per molecule. Shell GTL Fuel distils over a similar temperature range to conventional diesel. A typical boiling range of a summer grade diesel fuel is from ~180°C to 360°C.



5.

Shell GTL Fuel Local Emissions Benefits

Worsening air quality is a concern for many large cities around the world today. Many congested urban areas fail to meet local air quality standards and emissions from vehicles can be a key contributor to the problem.

The application of 100% Shell GTL Fuel in diesel vehicles, for example in public transport, has the potential to improve local air quality through reductions in local emissions.

This chapter explains:

- The types of emissions and how they are formed
- Who regulates emissions
- How Shell GTL Fuel can help to reduce local emissions and improve local air quality

CONGESTED CITY

5.1. Regulated Emissions

When hydrocarbon fuel is burned in a diesel engine, the vast majority of the combustion products are water vapour and carbon dioxide (a greenhouse gas). These predominate in the exhaust gases alongside nitrogen (derived from the air intake), all of which are benign.

However, incomplete combustion, high combustion temperatures, and contaminants in the fuel lead to the formation of small amounts of other gases, which are pollutants and can affect air quality. These pollutants include oxides of nitrogen (NOx), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), oxides of sulphur[4] (SOx) as well as other low-level substances.

5.1.1. Oxides of Nitrogen (NOx)

At the high temperatures encountered in a diesel combustion chamber nitrogen combines with oxygen to form a mixture of NO and NO_2. The emissions of NO, NO_2 and N_2O are regulated collectively as NOx. The reason that NOx is regulated is primarily because it can form photochemical smog in the presence of hydrocarbons and sunlight. It is also, along with SOx, a major precursor to acidic deposition (acid rain) [5].

5.1.2. Particulate Matter (PM)

PM is a complex mixture of extremely small particles and liquid droplets. The basic fractions of PM from diesel combustion are elemental carbon, heavy hydrocarbons derived from the fuel and lubricating oil, and hydrated sulphuric acid derived from the fuel sulphur. PM emissions are mainly the result of the non-uniform[5] nature of diesel combustion. PM can cause adverse health effects, particularly to the respiratory system and it also contributes to photochemical smog [5].

5.1.3. Carbon Monoxide (CO)

CO is generated primarily by combustion processes, through the incomplete combustion of the hydrocarbon fuel. Carbon monoxide is colourless, odourless, and tasteless, but highly toxic [5].

5.1.4. Hydrocarbons (HC)

The main source of vehicle HC emissions is from unburned fuel. They can form photochemical smog in the presence of NOx and sunlight [5]. The toxicity of hydrocarbons depends on their structure. Most hydrocarbons are non-toxic at low concentrations, however some monocyclic and polycyclic aromatic hydrocarbons (PAH) are suspected or known carcinogens.

[4] Not currently regulated
[5] Fuel-rich and oxygen deficient regions in combustion chamber

5.

Shell GTL Fuel Local Emissions Benefits

VISUALISATION OF SOOT BENEFITS. CONVENTIONAL DIESEL (LEFT) AND SHELL GTL FUEL (RIGHT)

5.1.5.
Oxides of Sulphur (SOx)

SOx is produced by the combustion of sulphur-containing fuel and to some extent, contributions from the lubricating oil. It is a moderate lung irritant and along with NOx, it is a major precursor to acidic deposition (acid rain). SOx is not regulated in emissions legislation, however, it is controlled through sulphur limits imposed on fuels, which have become ever stricter in recent years [6].

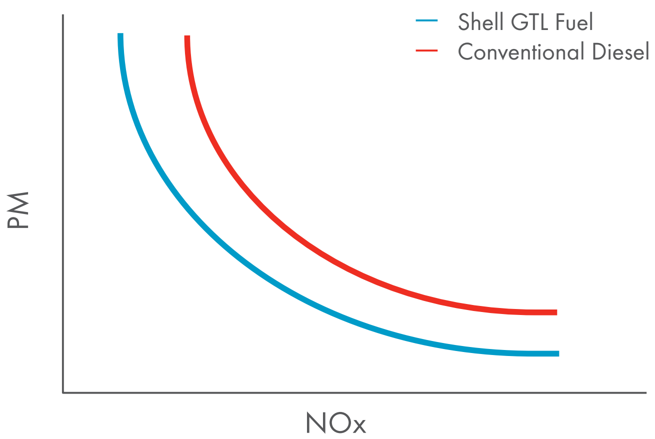
5.1.6.
Key Local Emissions in Diesel Engines

Diesel engines are designed to run lean (i.e. with excess oxygen). A consequence of this is that carbon monoxide (CO) and unburned hydrocarbons (HC) emissions are very low, but PM and NOx emissions are relatively high. This means that for diesel vehicles, levels of PM and NOx emitted are of particular importance with respect to legislative regulations.

Diesel NOx and PM emissions are generally linked through the nature of diesel combustion. Efforts to reduce PM by increasing combustion efficiency lead to higher combustion temperatures, and thus, higher NOx emissions. Lowering NOx formation by lowering the combustion temperature leads to less complete combustion and, thus, higher PM emissions. These effects give rise to the so called PM/NOx trade-off. The challenge for diesel engine designers is to reduce emissions of NOx and PM simultaneously. The unique properties of GTL fuels provide the key to do just this.

Figure 6. PM/NOx Trade-Off Curve

Shell GTL Fuel vs. Conventional Diesel



5.

Shell GTL Fuel Local Emissions Benefits

5.2.
Current Emissions Regulations

In response to the negative effect on air quality of road transport, legislators have imposed limits on emissions of potentially harmful pollutants.

5.2.1.
Heavy-Duty On-Road

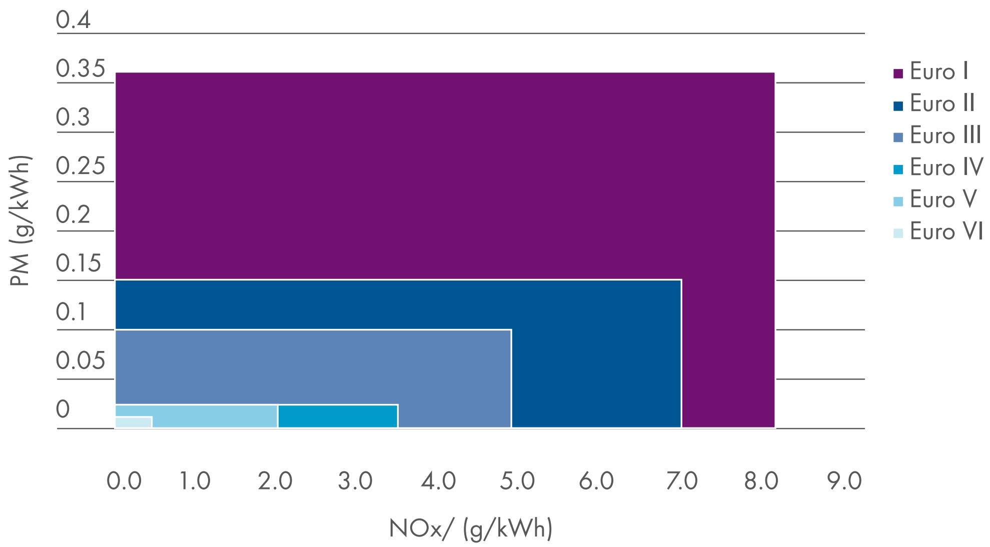
Heavy-duty diesel engines and vehicles are often not manufactured by the same company. In addition, vehicle manufacturers often use engines from several different suppliers. To simplify the qualification process, regulatory agencies have elected to apply heavy-duty diesel emission standards to engines rather than vehicles.

5.2.1.1.
Europe

European emission standards[6] define the acceptable limits for for exhaust emissions of new engines in vehicles sold in EU member states. The emission standards are defined in a series of European Union directives, staging the progressive introduction of increasingly stringent standards. For heavy-duty diesel engines, these commenced with Euro I for vehicles built after 1992, Euro II for vehicles built after 1996, progressing to Euro VI for vehicles built after January 2013. Figure 7 shows the progressive reduction in allowed levels of PM and NOx in new engines over time.

Figure 7.

Heavy-Duty NOx/PM Emissions Limits Euro I to VI
* ESC test cycle limits, Euro I PM limit for >85kW (for ≤85kW, PM limit is 0.612g/kWh) [7]



[6] For full details of the European emissions standards see Appendix 1

5.

Shell GTL Fuel Local Emissions Benefits

For heavy-duty engines, European legislation currently sets limits on the emissions of nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO) and hydrocarbons (HC).

For heavy-duty engines, European legislation currently sets limits on the emissions of nitrogen oxides (NOx), particulate matter (PM), (and in recent legislation the related particulate number, PN), carbon monoxide (CO) and hydrocarbons (HC). Levels of exhaust emissions are highly dependent on engine operating conditions. Standardised test cycles have be developed representing typical operating conditions. In such cycles exhaust emissions are measured while the engine is operated according to specified speed-time or speed-load conditions on an engine test bed. Each Euro level has a designated test cycle or combination of cycles and as time has moved on, test cycles have changed to be more representative of typical driving. In Europe, tests cycles have evolved from the R-49 steady state cycle (Euro I-II), to the ESC (European Stationary Cycle) and ETC (European Transient Cycle) (Euro III-V) to most recently, the WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonised Transient Cycle) (Euro VI). New vehicles cannot be sold in the EU if their engines do not meet the relevant limits, but new standards do not apply retrospectively to older vehicles already on the road.

Although new emissions limits have been phased in every few years over the last decade in Europe, it takes time for new vehicles to significantly penetrate the market (Figure 8). This means that there is a delay between European Government implementing stricter new limits, and cleaner, new vehicles becoming the norm on the road. Thus, stricter local emissions legislation can take time to improve local air quality.

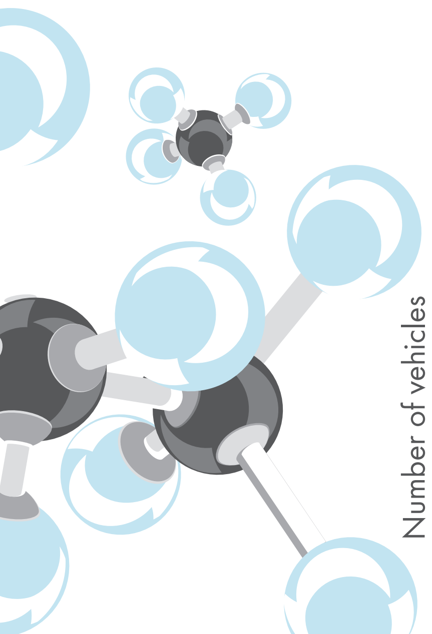
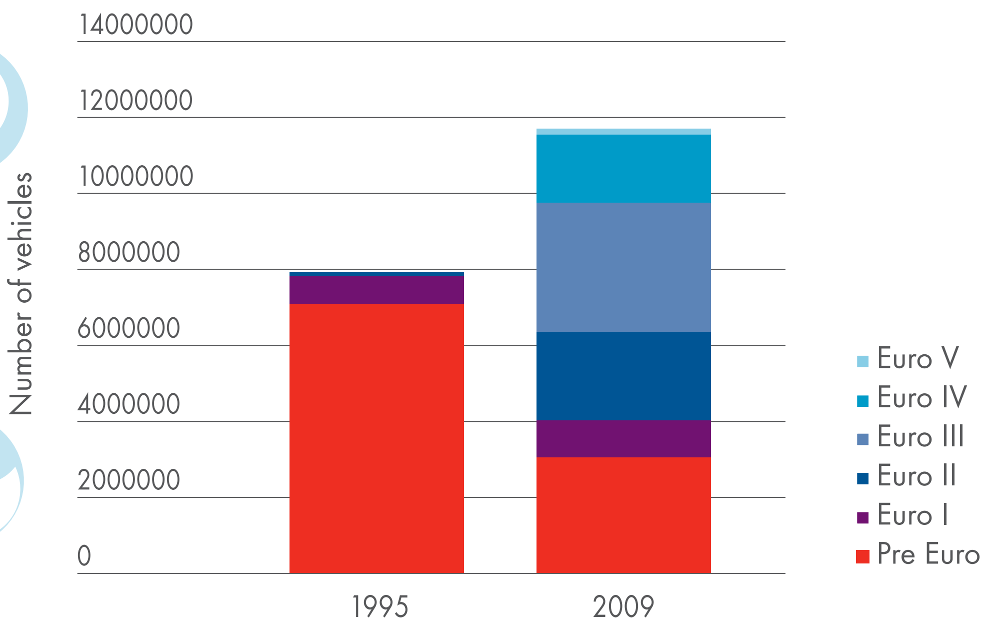


Figure 8.

Estimated Euro Norm Penetration in the EU 27: Heavy Duty Vehicles [8]



5.2.1.2.
US

Emission standards for engines and vehicles sold in the US are established by the Environmental Protection Agency (EPA). The authority of the EPA to regulate vehicle emissions and air quality in general is based on the Clean Air Act, which was most recently amended in 1990. The relevant standard for a new vehicle is determined by the year in which the vehicle was made, and is phased towards more stringent limits as in European legislation.

As well as Federal emissions standards set by the EPA, to which all states must abide by, some states have stricter emissions policies, for example, the emissions standards set by the California Air Resources Board (CARB). Historically, CARB standards have been more stringent than the EPA requirements, but their structure is similar to that of the federal legislation.

5.2.1.3.
Worldwide Summary

PM and NOx are the key emissions in terms of meeting legislation for heavy-duty diesel vehicles. Table 2 lists the U.S. Federal, European, and Japanese standards for NOx and PM emissions from heavy-duty engines from 1994 onwards. Many other countries have chosen to adopt some form of these standards although they are often one or two levels behind.

Emissions units are gram/kWh (EU, Japan) or gram/bhp-hr (US). A larger engine generates an increased mass of exhaust gas; hence a higher absolute amount of emissions compared to a smaller engine, but it also delivers more energy. Expressing emissions as a mass per unit of energy delivered by the engine (g/kWh or g/bhp-hr) allows the use of a single standard for engines of all sizes.

Table 2.

Heavy-Duty Diesel Engine Emission Limits for NOx and PM

Year	US Federal		European Union		Japan	
	NOx (g/bhp-hr)*	PM (g/bhp-hr)*	NOx (g/kWh)	PM (g/kWh)	NOx (g/kWh)	PM (g/kWh)
1992 (Euro I)	-	-	8.0	0.36	-	-
1994	5.0	0.10	"	"	7.8	0.95
1996 (Euro II)	"	"	7.0	0.25	"	"
1998	4.0	0.10	"	0.15	"	"
1999	"	"	"	"	4.5	0.25
2000 (Euro III)	"	"	5.0	0.10**	"	"
2002	2.5	0.10	"	"	"	"
2005 (Euro IV)	"	"	3.5	0.02**	3.0	0.10
2007	0.2	0.01	"	"	"	"
2008 (Euro V)	"	"	2.0	0.02**	"	"
2013 (Euro VI)	"	"	0.4	0.01**	"	"

Due to differences in test cycles, it is not appropriate to compare limits directly between different regulatory agencies
*1.00g/bhp-hr = 1.34g/kWh
** European PM standards reported under European Stationary Cycle (ESC) pre-2001, European Transient Cycle (ETC) thereafter

PM and NOx are the key emissions in terms of meeting legislation for heavy-duty diesel vehicles.

5.2.2.
Light-Duty On-Road

Light-duty diesel emissions regulations are broadly similar to those for heavy-duty vehicles; however one key difference is that emissions limits apply to vehicles, rather than engines. This is because the manufacturer of the vehicle is usually the manufacturer of the engine as well, which is not necessarily the case for heavy-duty vehicles. Emissions certification is carried out on a chassis dynamometer, and measured in units of mass of pollutant per distance travelled (g/km), rather than mass of pollutant per unit of energy (g/kWh). Full European light-duty emissions limits can be found in Appendix 1.

5.2.3.
Heavy Duty Off-Road: Marine

For marine applications different emissions regulations exist for both maritime and inland waterway use.

5.2.3.1.
Maritime

In the maritime sector, sulphur limits have fallen over the years. For example in the North Sea, English Channel and Baltic Sea Emission Control Area (ECA), the International Maritime Organization (IMO) now limits sulphur content to 0.1% since 1st January 2015.

MARPOL Annex VI legislation limits NOx as well as sulphur oxide emissions. Under this legislation, Shell GTL Fuel meets the requirements set out in MARPOL Annex VI Reg. 18.3.1, as it is an ISO 8217 fuel. Consequently Shell GTL Fuel does not require further NOx testing[7] (this is required of certain other types of fuels per paragraph 18.3.2).

5.2.3.2.
European Inland Waterways

The European Fuels Quality Directive (2009/30/EC, amending 97/70/EC) limits sulphur in diesel used for inland waterways to 10 ppm since January 2011.

The Central Commission for the Navigation of the Rhine (CCNR) and the EU issued emissions limits for new inland waterway engines in 2007, referred to as 'CCNR 2' as well as 'stage IIIA' requirements [9]. Prior to this regulation was CCNR1, the first inland waterway legislation which was introduced in 2003. Note, some engines are referred to as CCNR0, which is pre-legislation, and therefore are non-regulated engines with no limitations on emissions.

Emissions limits depend on power, and are outlined in Tables 3 and 4.

THE KROONBORG, AN OFFSHORE SERVICE VESSEL, USING SHELL GTL FUEL

[7] It may be possible for a ship to use Shell GTL Fuel to help lower the NOx emission in order to meet the stricter Tier III emissions requirements. If this is the case, emissions certification could require Shell GTL Fuel for Tier III compliance testing as it would be part of the NOx reduction measures.

5.
Shell GTL Fuel Local Emissions Benefits

Table 3.

CCNR2 Emissions Limits

Net power (P) (kW)	Carbon monoxide (CO) (g/kWh)	Hydrocarbons (HC) (g/kWh)	Oxides of nitrogen (NOx) (g/kWh)	Particulates (PT) (g/kWh)
130 < P < 560	3.5	1.0	6.0	0.2
75 < P < 130	5.0	1.0	6.0	0.3
37 < P < 75	5.0	1.3	7.0	0.4
18 < P < 37	5.5	1.5	8.0	0.8

Table 4.

Stage IIIA Emissions Limits

Category: swept volume/net power (SV/P) (litres per cylinder/kW)	Carbon monoxide (CO) (g/kWh)	Sum of hydrocarbons and oxides of nitrogen (HC+NOx) (g/kWh)	Particulates (PT) (g/kWh)
V1:1 SV<0,9 and P≥37 kW	3.5	7.5	0.40
V1:2 0,9≤SV<1,2	5.0	7.2	0.30
V1:3 1,2≤SV<2,5	5.0	7.2	0.20
V1:4 2,5≤SV<5	5.0	7.2	0.20
V2:1 5≤SV<15	5.0	7.8	0.27
V2:2 15≤SV<20 and P<3300 kW	5.0	8.7	0.50
V2:3 15≤SV<20 and P≥3300 kW	5.0	9.8	0.50
V2:4 20≤SV<25	5.0	9.8	0.50
V2:5 25≤SV<30	5.0	11.0	0.50

New legislation is currently being developed by the EU and Commission for Navigation on the Rhine (CCNR) for both new and existing vessels. The EU requirements for emissions from new vessels have been tightening. The European Commission adopted the Non-Road Mobile Machinery Directive (NRMM) on 25 September 2014, setting out Stage V emissions requirements, which come into effect 2018-2021[10].

5.2.4.
Heavy Duty Off-Road: Other

Additional emissions standards exist for other off-road applications such as railroad, construction etc. These standards are somewhat complex as they cover a variety engine types with different power ranges. However, there is some degree of unification offered by the NRMM directive, see reference [10].

5.

Shell GTL Fuel Local Emissions Benefits

5.3. Local Emissions and Air Quality

There is an increasing focus on vehicle exhaust emissions and their impact on local air quality.

However, over time, ever stricter emissions limits have led to significantly cleaner vehicles (as illustrated by Figure 7), so in absolute terms, the emissions benefits from cleaner-burning fuels are diminishing. Nevertheless, air quality still remains worse than permitted standards in many cities. Governments and commercial fleet owners are under significant pressure to reduce their local emissions.

SHELL GTL FUEL BUS TRIAL IN SHANGHAI, CHINA

5.4. Reducing Local Emissions of Vehicle Fleets

Compliance with modern emissions regulations has been achieved through a combination of advanced engine and aftertreatment technology in new vehicles.

The deployment of these modern technologies into fleets may take some time as it requires large capital investment in new vehicles.

The drop-in use of Shell GTL Fuel is attractive from two viewpoints i) there is the ability for immediate local emissions reductions, and ii) particularly in older fleets, one can begin to improve the overall local emissions of a fleet for a significantly smaller capital investment than buying new vehicles. Using Shell GTL Fuel requires no investment in vehicle or re-fuelling infrastructure, which is not the case with some other clean alternative fuels and technologies (e.g. diesel particulate filters – DPF, compressed natural gas – CNG, liquefied natural gas – LNG).

A number of Shell in-house studies and collaborative research programmes have demonstrated the local emissions benefits arising from the implementation of Shell GTL Fuel. The magnitude of these benefits varies according to a number of factors; the age and type of engine, the aftertreatment technology used, the current diesel fuel being replaced, as well as the demands of the specific application. The following section describes the extensive emissions testing programmes undertaken by Shell and the local emissions benefits that have been observed.

5.

Shell GTL Fuel Local Emissions Benefits

5.5. Shell GTL Fuel Emissions Test Results Summary

Controlled laboratory tests have been conducted to confirm the local emissions benefits that can be expected from Shell GTL Fuel.

A large amount of local emissions data has now been collected predominantly on engine test beds, but also on chassis dynamometers. The data covers an extensive range of vehicles, engines and aftertreatment systems that are on the road today. All data presented in this section has undergone full statistical analysis, and the benefits are statistically significant to >95% unless indicated otherwise.

Presenting local emissions benefits as 'percentage benefits when compared to conventional diesel' is a convenient way of communicating the potential local emissions reductions of Shell GTL Fuel to stakeholders. This is particularly useful in the frequently encountered case where a fleet has vehicles of various ages and therefore large variations in absolute local emissions levels. Extensive testing has shown that the percentage local emissions benefit is relatively consistent over a range of vehicle types and ages.

It is important to note that percentage benefits have been obtained from emissions tests performed using European legislated test cycles, under carefully-controlled laboratory conditions. These test cycles aim to be representative of 'normal' driving in Europe. However, actual vehicle types and driving conditions encountered 'on the road' may be different from this, so there can be no guarantee that the same magnitude of benefits will always be obtained in all real applications in the field. Nevertheless, the percentage benefits are believed to be good indicators of the magnitude of potential benefits that may be obtainable in real vehicle fleets.

5.5.1. Heavy-Duty Vehicles

Heavy-duty vehicles are an application well suited to 100% Shell GTL Fuel primarily because they are often operated in home-based fleets, and so can be refuelled from a central location. They also consume large amounts of fuel, and hence produce significant amounts of pollutants when compared to their light-duty equivalents. This means that any fuel-related local emissions reduction has the potential to result in larger net local air quality benefits.

Shell in-house studies and collaborative field trials on heavy-duty vehicles have shown that, in percentage terms, Shell GTL Fuel local emissions benefits are relatively constant, even in increasingly modern technologies. Most tests have shown a benefit in the region of 10-20% for NOx, PM, CO and HC. However, there are variations in the magnitude of percentage benefits within each technology (Euro level) due to differences in the following factors:

- Engine design and calibration
- Aftertreatment presence and type
- Characteristics of the drive cycle and reference fuels

Shell and others have conducted controlled laboratory studies to confirm the local emissions benefits that can be expected from Shell GTL Fuel.

SHELL GTL FUEL BUS TRIAL, GERMANY

Shell GTL Fuel Local Emissions Benefits

SHELL GTL FUEL BUS TRIAL IN LONDON, UK

Shell GTL Fuel gives substantial percentage local emissions benefits, even with modern Euro V technology.

The following sections summarise the results from the emissions tests that Shell has conducted, from Euro I to Euro VI. All of the emissions tests employ a test cycle relevant to the Euro level of the engine tested. Properties of reference diesel fuels used in these tests complied with associated Euro level of the engines. All data presented in this section have undergone full statistical analysis, and are statistically significant to the ≥95% confidence interval unless indicated otherwise. See Appendix 1 for full details of heavy-duty emissions percentage benefits as well as information on the vehicles and test cycles used.

5.5.1.1. Summary of Heavy-Duty Local Emissions Percentage Benefits - Euro I to VI

A large amount of local emissions data has now been collected, particularly in modern Euro VI engines. This covers an appreciable range of vehicles, engines and aftertreatment systems on the road today.

Shell GTL Fuel gives substantial percentage local emissions benefits, even with modern Euro V technology.

Table 5.

Heavy-Duty Percentage Local Emissions Benefits compared to Conventional Diesel

	% Benefit when compared to Conventional EN 590 Diesel			
	PM	NOx	HC	CO
Euro I	18	16	13	22
Euro II	18	15	23	5
Euro III	10 to 34	5 to 19	<9*	12 to 20
Euro IV	31 to 38	5 to 16	10 to 28	9
Euro V	23 to 33	5 to 37	19 to 23**	8 to 22
Euro VI	Absolute levels close to the limit of detection therefore no significant benefit seen			

* Not statistically significant at the ≥95% confidence interval (Estimate of upper bound of benefit)
** Not at standard test temperature (5°C and 40°C not 23°C)
All values given are statistically significant ≥95% unless indicated. Ranges correspond to maximum and minimum statistically significant benefits measured in engines at that Euro level.
A complete breakdown of the engines tested and percentage local emissions benefits recorded are available in Appendix 2.

Table 5 shows that there is good agreement in the percentage local emissions benefits over the range of technologies studied. Shell GTL Fuel can still give substantial percentage local emissions benefits, even with modern Euro V technology. Moreover, in percentage terms, these benefits appear to have remained relatively uniform over time, even with ever cleaner vehicle technology. When assessing the benefits of each regulated emission individually it is noted that:

- A large PM percentage benefit has been measured in nearly all of the engines tested, from Euro I to Euro V
- There can be a large variation in percentage benefits within each age of technology (Euro level). Some vehicles yield much larger percentage local emissions benefits than others. However, on a fleet average basis, then the NOx percentage benefits remain relatively constant over time, even in modern vehicle technologies

Shell GTL Fuel Local Emissions Benefits

- Shell GTL Fuel has given consistent percentage benefits for HC and CO emissions, however in modern engines, the absolute emissions levels are very low (typically <10% of Euro Limits), so the benefits from some tests are not statistically significant.

SHELL GTL FUEL CAR TRIAL IN LONDON, UK

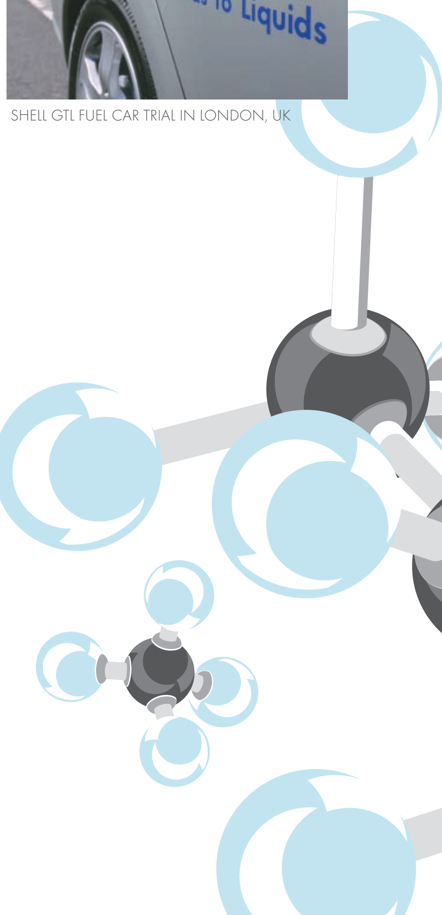
5.5.1.2. Euro VI

Euro VI engines are more advanced compared to earlier Euro levels and include on board diagnostics. Therefore in addition to the usual emissions measurements, operability studies were also conducted. Moreover, there are difficulties with collecting data from Euro VI vehicles due to the emissions measurements being very low and close to the limit of detection of the methods used.

Results from a recent Euro VI VDL bus test show no statistically significant differences between EN590 diesel and Shell GTL Fuel in the regulated tailpipe emissions: THC (Total Hydrocarbons), CO, NOx and PN (Particulate Number, a new measurement for Euro VI). This similarity between the fuels is due to the fact that the emissions levels are already very low in modern vehicles with efficient aftertreatment technology. Shell GTL Fuel did however give significantly lower engine-out emissions in THC, CO, NOx and soot, compared to EN 590 diesel. This may potentially lead to benefits such as less stress on the catalyst, maintenance advantages and a longer lifetime for the aftertreatment system.

In an on-road test a Mercedes Actros 1851 Euro VI truck operated on Shell GTL Fuel for 2 days. The driver reported no unusual vehicle behaviour, no warning lights on the dashboard and the truck operated as expected. On return to homebase, the driver did a cold start on the next morning (around 0°C) and commented that the cold engine idle was smoother as compared to regular diesel fuel, without the thick cloud of smoke just after engine start.

Finally, during a Shell GTL Fuel trial with a German bus company, a Euro VI bus (Daimler Citaro G C2) was successfully operated on the road with GTL Fuel without any problems, such as on board diagnostic (OBD) warning lights, occurring.



Considering the limited Euro VI experiences described above together with third party data, the preliminary results indicate that Shell GTL Fuel can be used in Euro VI engines without technical problems, and without exceeding regulated emissions requirements.

5.5.2. Light-Duty Vehicles

Light-duty emissions tests are less expensive than their heavy-duty counterparts, mainly because the vehicles and test equipment are more readily available, less expensive and easier to set up. This allows for the possibility of testing a wider range of vehicle makes at each technology (Euro) level. This, coupled with more consistent levels of percentage benefits, means that, unlike with heavy-duty emissions tests, percentage benefits from light-duty tests can be averaged to produce a mean representative of that technology and also offers the possibility of calculating 'fleet averages'. In general, light-duty percentage benefits are larger in all local emissions apart from NOx.

5.5.2.1.
Summary of Light-Duty Local Emissions Percentage Benefits - Euro 1 to 4

Table 6.

Light-Duty Percentage Local Emissions Benefits Compared to Conventional Diesel

% Benefit when compared to Conventional EN 590 Diesel				
	PM	NOx	HC	CO
Euro 1	42	10	45	40
Euro 2	39	5	63	53
Euro 3	41	5	62	75
Euro 4*	14 to 20	-6 to 2	66 to 77	73 to 83

All values given are statistically significant at the ≥95% confidence interval
* Ranges arise from comparing against two different reference diesel fuels (differing in density), correspond to maximum and minimum statistically significant benefits measured. Full details of the vehicles tested that have been tested are available in Appendix 2

Table 6 shows that there is relatively good consistency in the local emissions benefits from Euro 1 to Euro 4. When assessing the benefits of each regulated emission individually it is noted that:

- Shell GTL Fuel has provided large HC and CO emissions benefits compared to diesel in all light-duty vehicle technologies tested including the modern Euro 3/4 engines
- PM emissions benefits have also been substantial and still apparent in Euro 4 vehicles, although smaller
- NOx emissions benefits have been smaller as compared to the other emissions and essentially no real benefits were measurable in Euro 4 vehicle technology.

5.6.
Overview of Marine Emissions Tests

Emissions measurements have been conducted on inland ships (Novamente and Invado), a high-power main propulsion engine (MTU bench engine test) and marine auxiliary engines (on-board the Dr Wagemaker ferry and PonPower bench engine test) operating on Shell GTL fuel.

Running on Shell GTL Fuel has shown emissions benefits across all of the regulated emissions (PM, NOx, HC, and CO) in all of the engines tested with the exception of the MS Invado ship where no CO benefits were seen. In general, the inland marine emissions reductions (for each species) are similar to those from heavy-duty on-road engines, in both percentage reduction and range (with the exception of the PM reduction which was slightly higher than with the heavy-duty engines in testing).

The table below summarises the 5 tests and gives the emissions reduction ranges found for ship engines when operating on GTL [11].

5.
Shell GTL Fuel Local Emissions Benefits

Table 7.

Marine Percentage Local Emissions Benefits Compared to Conventional Diesel

Approximate % Benefit when compared to diesel				
	PM	NOx	HC	CO
Inland Waterway Engines: CCNR0, CCNR1 & US EPA Marine Tier 2	15 to 60	6 to 13	10 to 50	0 to 15

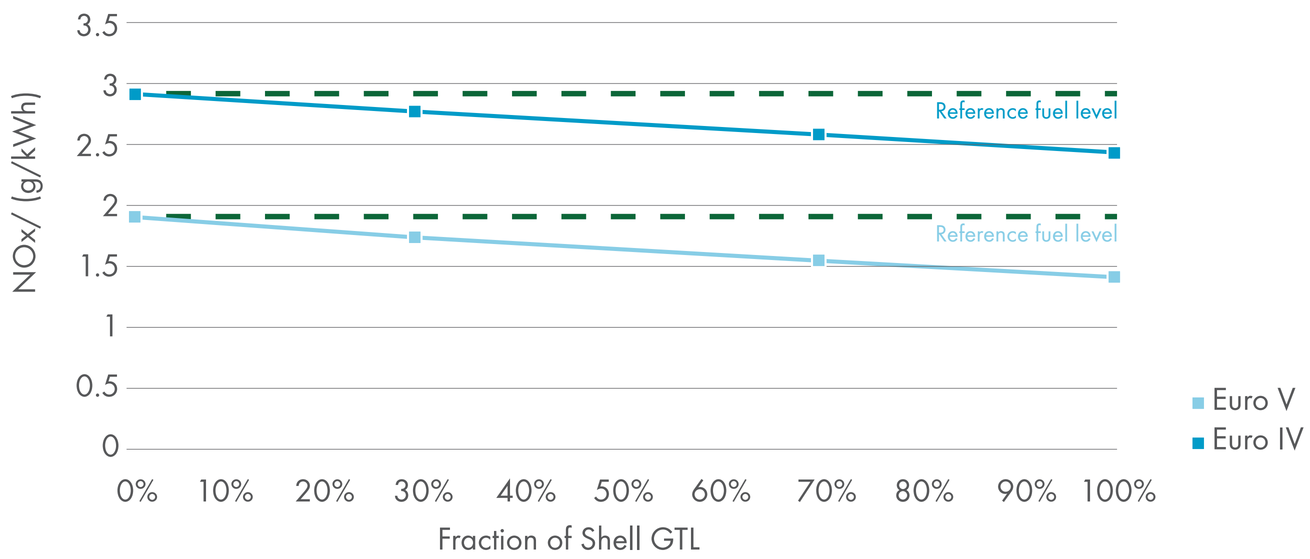
It should be noted that compared to heavy-duty and light-duty engine testing, there have been fewer tests with inland marine vessels, the measurements are mostly conducted with different types of Caterpillar engines, and the data have not been statistically analysed.

5.7.
Blend Emissions

Blends of Shell GTL Fuel with conventional diesel can also achieve significant emissions benefits. Experiments with heavy-duty engines have shown that emissions levels are a linear function of Shell GTL Fuel content for PM and NOx emissions. For example, blends of 25% GTL/75% diesel would have 25% of the emissions benefits of 100% GTL, see Figure 9. There have been tentative signs that HC and CO emissions will also act linearly with Shell GTL Fuel blends in heavy-duty engines, however, no statistically significant results have been produced due to the low absolute levels of these emissions [12].

Figure 9.

NOx Benefits of 100% GTL and Blends in ULSD for Prototype Euro IV and Euro V Heavy-Duty Diesel Engines, Both with Aftertreatment



For light-duty, NO_x emissions are also a linear function of Shell GTL Fuel content. However, PM, HC and CO emissions show a strong non-linear reduction in emissions versus Shell GTL Fuel content, i.e. at low levels of Shell GTL Fuel, the emissions reduction is larger than would be expected based on linear blending predictions. Thus, a large percentage of the emissions benefits can be achieved for a relatively low level of Shell GTL Fuel in the blends [3].

On a Well-to-Wheels (WtW) basis the total greenhouse gas emissions for GTL products are broadly comparable with the equivalent quantity of products from conventional refining.

5.8. Greenhouse Gas Emissions and CO_2

Greenhouse gas (GHG) emissions are of global concern in terms of global warming and Shell may have to account for the emissions intensity of GHG products, even in regions where GHG emissions are not regulated. For GTL products, the most significant emissions are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which may be emitted at any stage of the life cycle: gas production and transport, gas processing and conversion to GTL, transport and distribution, and end use (combustion).

Shell uses the Life Cycle or Well-to-Wheels (WtW) method for comparing GHG emissions, in line with industry practice. On a WtW basis, some GTL products have higher intensity than their conventional equivalents and some lower but the total emissions are broadly comparable with the equivalent quantity of products from conventional refining. Differences in assumptions and methodologies can lead to variations in the results.

The European Union is the only region that regulates the WtW intensity of GTL gasoil as a transport fuel. The European Commission has reviewed the GHG intensity for various fuels on a WtW basis. The updated Fuels Quality Directive [13] includes the use of a single industry average greenhouse gas intensity value for diesel that will also apply for GTL gasoil volumes. It also references a WtW intensity for GTL that is broadly in line with refinery diesel (94.3 gCO_2eq/MJ for GTL vs. 95.1 gCO_2eq/MJ for diesel). Note that this is a notional intensity for generic GTL fuel and does not represent the actual intensity of GTL fuel produced by Shell, also note that other regulatory regimes may adopt different intensity values.

Certain municipalities and legislations reference Tank-to-Wheels CO_2 emissions (TtW) and many fleet operators report or are regulated on them. It is generally assumed that combustion of GTL gasoil in engines produces similar CH_4 and N_2O emissions to conventional diesel fuel, however, CO_2 emissions are lower for GTL than for diesel. Tank-to-Wheels emissions from Shell GTL Fuel have typically been measured at 4% to 5% lower than conventional crude-derived diesel. This lower TtW emission value for Shell GTL Fuel derives from a combination of two factors. Firstly, the hydrocarbons of Shell GTL Fuel have a higher specific energy content (net calorific value), therefore less mass is required to generate the same amount of energy as diesel. Secondly, the Shell GTL Fuel contains less carbon by mass (Hydrogen-Carbon ratio of 2.1 as compared to 1.85 with diesel) which shifts the ratio of combustion products from CO_2 towards water.

5.9. Summary

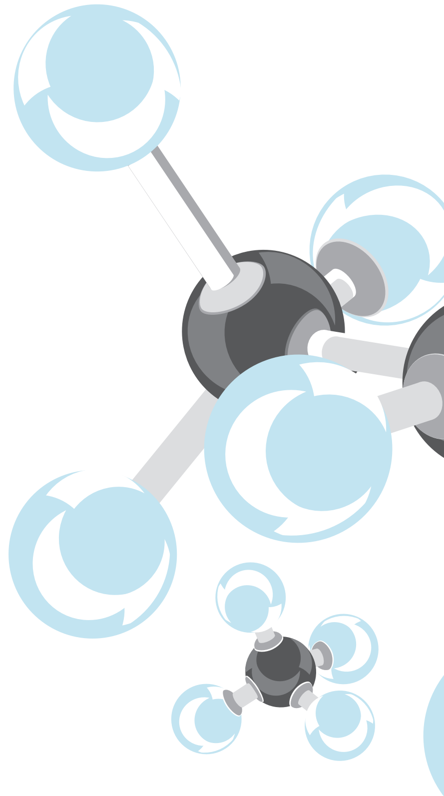
The tests results show that the use of Shell GTL Fuel can provide significant local emissions benefits in both heavy-duty and light-duty vehicles.

The emissions benefits are achieved as soon as Shell GTL Fuel is used (i.e. an instantaneous or 'drop-in' benefit) and are potentially achievable with any diesel engine. By implementing Shell GTL Fuel, a fleet manager could therefore gain a local emissions advantage immediately, without investment in new, cleaner vehicles or new re-fuelling infrastructure.

The emissions benefits of using Shell GTL Fuel are particularly relevant in older vehicles, where the higher absolute level of emissions results in the reduction being the most significant, which could lead to significant local air quality improvements. For developing nations, where older diesel engines are still present, use of Shell GTL Fuel could yield large air quality benefits, particularly in inner cities.

The use of Shell GTL Fuel in modern engine technologies still results in large percentage benefits; however these may not have such a significant impact on air quality, as absolute local emissions levels are already very low. National and city governments still put fleet owners under pressure to reduce local emissions levels, regardless of the age of their fleet. Therefore, percentage benefits in modern vehicles can still be important for fleet managers.

In terms of GHG emissions, the WtW value for Shell GTL Fuel is broadly in line with refinery diesel. The TtW value however, is typically 4-5% lower than conventional diesel due to a combination of the higher energy content and lower Carbon content of Shell GTL Fuel.



EMISSIONS TESTING

6.

Shell GTL Fuel Field Trials

This section is a summary of Shell trials and customer experience with Shell GTL Fuel for over 10 years, covering more than 1 million kilometres, and ranging from Smart cars in Singapore to buses in The Netherlands.

Shell GTL Fuel can be used in applications relevant for conventional diesel to help to provide immediate local emissions reductions.

Vehicle trials provide the means to validate the performance of 100% Shell GTL Fuel under many months of real "on the road" conditions.

Shell has conducted many field trials on Shell GTL Fuel in major cities around the world. These trials have helped to raise the awareness of GTL fuels amongst governments, automotive manufacturers and the general public in Europe, USA and Asia (Figure 10). Most of the trials are from home-based commercial vehicle fleets, such as public buses or taxis which can be re-fuelled from a central location.

The focus of the trials was on vehicle operability of engines running on Shell GTL Fuel under real world 'on-road' conditions. However, in some, well-controlled emissions tests were also performed to complement those cited in Section 5.

This section provides a summary of Shell trials and customer experience with Shell GTL Fuel for over 10 years, covering more than 1 million kilometres, and ranging from Smart cars in Singapore to buses in The Netherlands. The information is taken from Shell internal reports, press releases, university reports and reports by trial participants. Please note the benefits for a given vehicle or fleet are subject to many other factors that can affect the results, such as: driver behavior and style, driving conditions, drive cycle, quality of the lubricant and inflation of tyres.

AMSTERDAM, VAN KEULEN SWITCHES THEIR HEAVY DUTY DIESEL FLEET TO SHELL GTL FUEL

6.

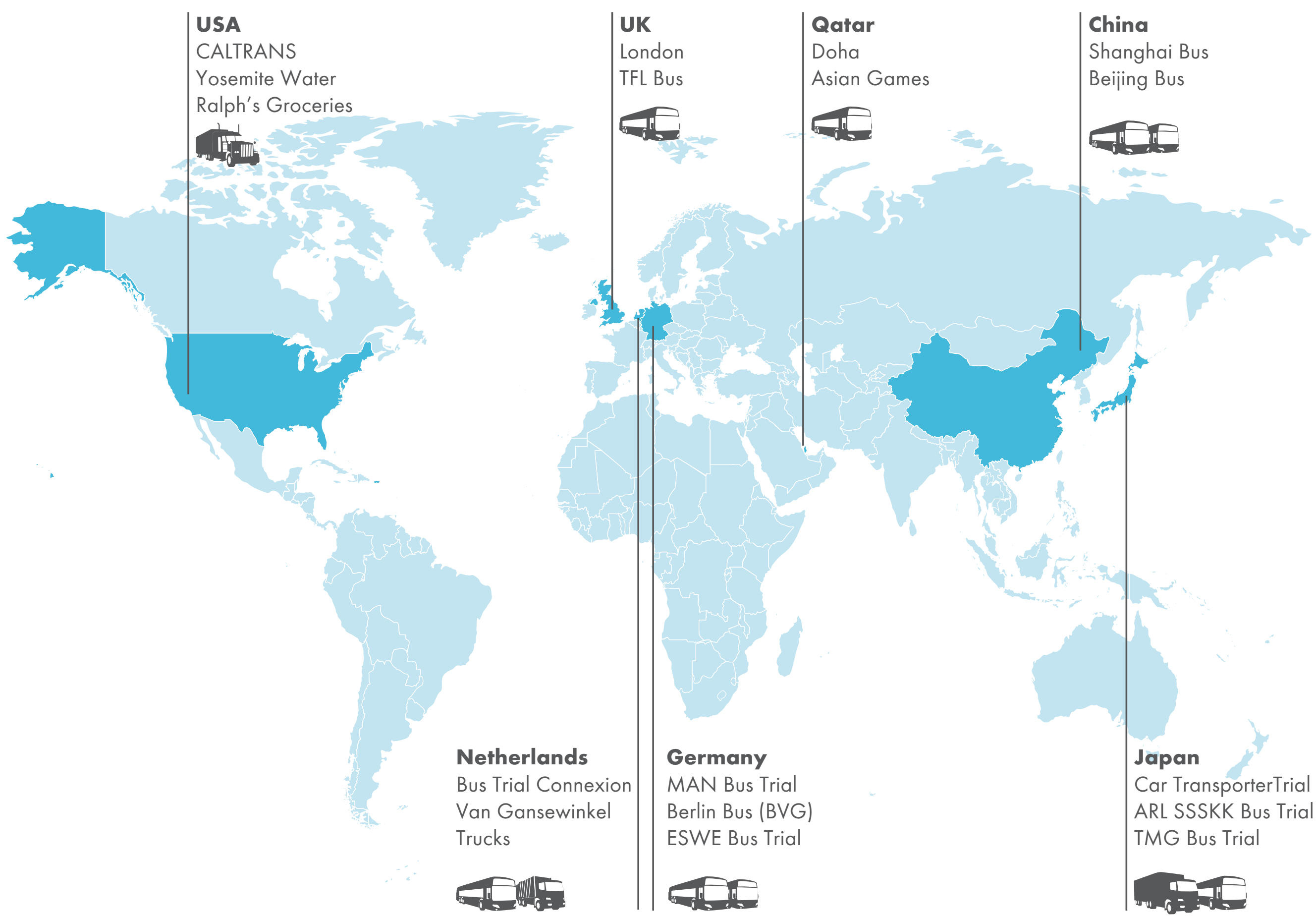
Shell GTL Fuel Field Trials

6.1. Heavy-Duty Vehicles

Figure 10.

Examples of Worldwide Shell GTL Fuel Heavy Duty Field Trials

Public buses are an application well suited for the use of 100% Shell GTL Fuel, as they are often operated in home-based fleets, and can be re-fuelled from a central depot. They also consume large amounts of fuel and so produce a relatively large mass of pollutant for the distance travelled, and so any local emissions reduction can result in a larger local air quality benefit. A large number of Shell GTL Fuel field trials have been conducted with public buses, trucks and other heavy-duty vehicles around the world. These are summarised in Table 8.



6.

Shell GTL Fuel Field Trials

Table 8.

Summary of 100% Shell GTL Fuel Heavy-Duty Trials

Year/ Month	Location	Trial Name	Partner	Number of Vehicles	Total Trial Distance	Vehicle Manufacturer
2002 April - May	California, USA	CALTRANS	California Dept of Transportation	69 Trucks	Not recorded 30,000 litres of GTL used	Various
2003 July - September	London, UK	London Bus Trial	London General	1 Bus	5,000 km	EvoBus Euro III with Daimler Chrysler engine
2003 - 2004 December - August	Los Angeles, USA	Yosemite Waters Trial	Yosemite Waters, National Renewable Energy Laboratory (NREL)	3 Trucks	57,000 km	Navistar International HD trucks
2005 - 2006	Hamburg, Germany	MAN Bus Trial	Hochbahn HVV	2 Buses	10,000 km	MAN 7000 city bus
2005 February - September	California, USA	Ralph's Groceries	Ralph's Groceries, US DOE	2 Trucks	Est. 20,000 km	Cummins engines
2006 - 2007 December - February	Doha, Qatar	Doha Asian Games (DAG)	Qatar Petroleum, Shell/Sasol Chevron	20 Buses	Not Recorded	10 King Long media buses and 10 Mercedes school buses
2006 - 2007 November - May	Shanghai, China	Shanghai Euro II Bus Trial	Shanghai Ba-shi First Bus Public Traffic Co.	4 Buses	105,000 km	Yuchai Euro II bus
2007 June - November	Shanghai, China	Shanghai Euro III Bus Trial	Shanghai Ba-shi First Bus Public Traffic Co.	2 Buses	41,000 km	Yuchai Euro III bus
2007 May - August	Beijing, China	Beijing China III Bus Trial	Beijing Public Transport Holdings Ltd.	4 Buses	70,000 km	Xiamen Jinlong United Auto Industry Limited with a Cummins engine
2007 May - November	Delft, The Netherlands	Delft Connexxion Bus Trial	Connexxion Bus Company	7 Buses	Est. 300,000 km	MAN VIAbus
2007 - 2008 December - February	Japan	Car Transporter Trial	Showa Shell Sekiyu K.K., Toyota	2 Trucks	33,000 km	Hino HD truck Euro III

6.

Shell GTL Fuel Field Trials

Table 8. continued

Summary of 100% Shell GTL Fuel Heavy-Duty Trials

Year/ Month	Location	Trial Name	Partner	Number of Vehicles	Total Trial Distance	Vehicle Manufacturer
2007 - 2009 December - March	Japan	ARL SSSKK Commuter Bus Trial	Showa Shell Sekiyu K.K.	1 Bus	23,000 km	Hino Liesse II
2008 July	London, UK	London TfL	Transport for London (TfL)	3 Buses	Emissions only	Volvo Euro III, Enviro Euro IV, Dart Euro III
2009 - 2010 February - January	Tokyo,	Japan TMG Bus Trial	Tokyo Metropolitan Government (TMG)	2 Buses	1,500 km	Hino Hybrid
2010 July - November	Vlaardingen and Rotterdam, The Netherlands	Van Gansewinkel Trial	Van Gansewinkel	7 Refuse Trucks	Not Recorded	DAF Euro III, DAF Euro V, Volvo Euro III, Volvo Euro V, Sennebogen
2012 May	Berlin, Germany	BVG Bus Test	Berliner Verkehrsbetriebe (BVG)	1 Bus	Not Recorded	MAN A39 DD Euro IV
2012 - 2013 May - April	Wiesbaden, Germany	ESWE Bus Trial	ESWE Verkehr Wiesbaden	12 Buses	Est. 720,000 km on completion in April 2013	EvoBus O 530 Euro III and MAN A21 EEV

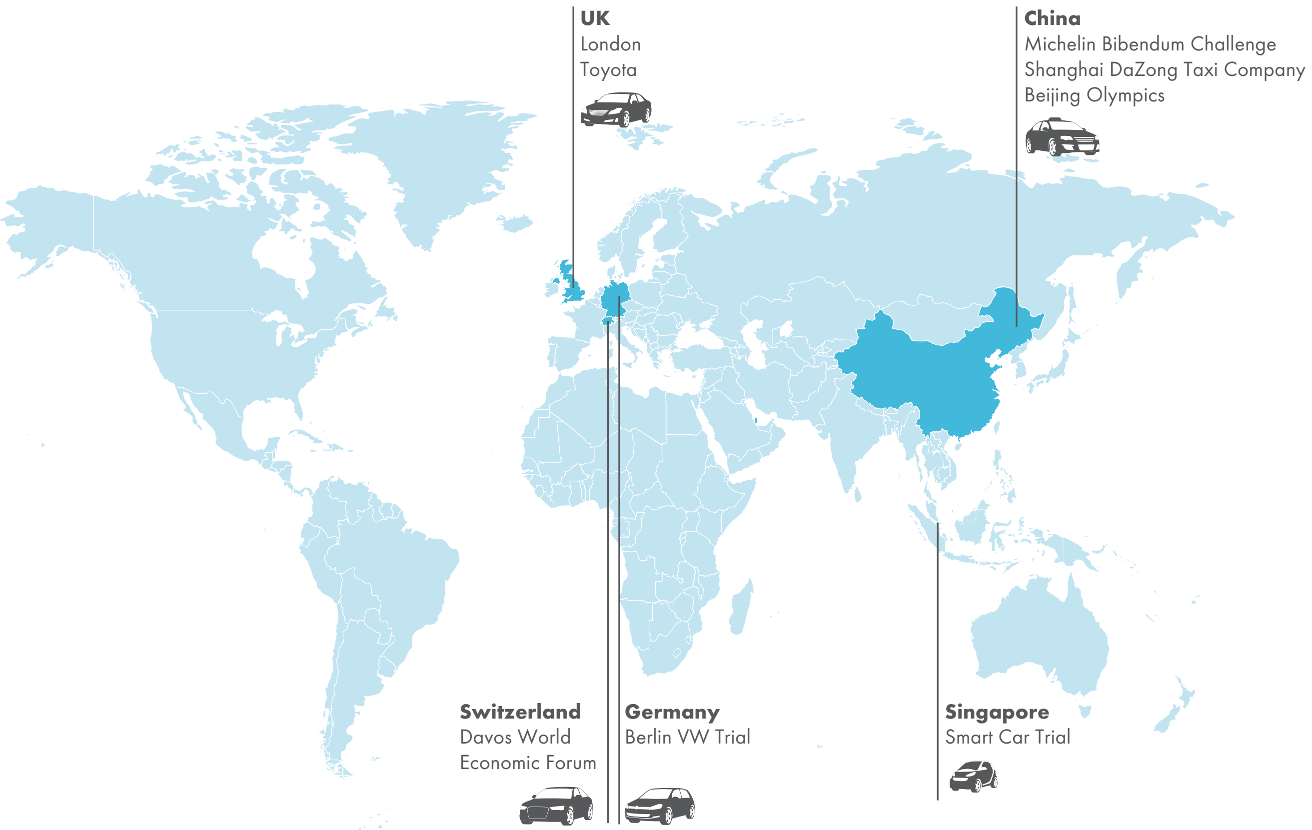
The heavy-duty trials have demonstrated that Shell GTL Fuel can be used directly in these vehicles without any technical modification. There were no fuel-related problems such as fuel leaks, increased wear or any maintenance issues discovered in any of the trials. In addition, customer experience with Shell GTL Fuel has been very positive throughout, with drivers commenting on the lack of unpleasant odour and exhaust smoke, and driveability comparable to conventional diesel.

In addition to validating the performance of Shell GTL Fuel under many months of real "on the road" conditions, the associated emissions tests have shown local emissions benefits compared to conventional crude oil-based diesel. The associated local emissions tests are summarised in Appendix 2, Table 21. It is apparent from the trial emissions results and the Shell heavy-duty tests (Table 5), that there is good agreement in the data when it is assessed on a 'percentage benefit' basis. This confirms the ability for Shell GTL Fuel to help to reduce local emissions in heavy-duty vehicles, even under strenuous application specific cycles.

6.2.
Light-Duty Vehicles

Figure 11.

Examples of Worldwide Shell GTL Fuel Light-Duty Field Trials



Light-duty vehicles such as taxi fleets, operating in inner cities, are another well suited application for 100% Shell GTL Fuel as they can be refuelled from a single location, as with bus fleets. Vehicles in light-duty fleets have also been shown to give large local emissions percentage benefits when using Shell GTL Fuel. Shell has conducted a wide range of light-duty vehicle trials some with associated emissions measurements. The light-duty trials are summarised in Table 9.

6.
Shell GTL Fuel Field Trials

Table 9.

Summary of 100% Shell GTL Fuel Light-Duty Trials

Year/Month	Location	Trial Name	Partner	Number of Vehicles	Total Trial Distance	Vehicle Manufacturer
2003 May - September	Berlin, Germany	Berlin VW Trial	Welfare Organisations	25 Cars	>220,000 km	VW Golf Euro 3
2004 July - September	London, UK	London Toyota Trial	Welfare Organisations	10 Cars	Not recorded	Toyota Avensis Euro 4
2005 - 2006 October - June	Shanghai, China	Shanghai Taxi	Shanghai DaZong Taxi Company	8 cars	600,000 km	VW Passat Euro 3
2004 October	Shanghai, China	Michelin Bibendum Challenge	Audi	2 Cars	Not recorded	Audi A8 and A2 TDI Euro 4
2008 January	Davos, Switzerland	Davos World Economic Forum	World Economic Forum, Audi	80 Cars	Not Recorded	Audi A2 TDI, A6 TDI & A8 TDI
2008 July - September	Beijing, China	Beijing Olympics	VW	35 Cars	Not recorded 100 tonnes of GTL used	VW 5 Tiguan, 10 Magotan, 20 Passat
2008 - 2009 August - July	Singapore	Singapore Smart Car Trial	Mercedes-Benz (Smart)	2 Cars	Not Recorded	MB Smart Cdi

Over the large number of light-duty trials, no fuel-related problems were reported. Furthermore, no issues were observed when changing from diesel to Shell GTL Fuel or when changing back from Shell GTL Fuel to diesel after the trials. The trials also displayed that Shell GTL Fuel can be used in modern diesel vehicles without any material compatibility issues (Section 9.2.2).

The associated emissions tests are summarised in Appendix 2, Table 24. It is apparent from all of the emissions data that there is good agreement when it is compared to other emissions tests (Table 6) on a 'percentage benefits' basis. This confirms the ability for Shell GTL Fuel to help reduce local emissions in light-duty vehicles, even under strenuous application-specific cycles.

6.

Shell GTL Fuel Field Trials

6.3.
Off-Road Vehicles

The engine technology in off-road vehicles tends to be less sophisticated than that in on-road. Furthermore, the fuel specifications are less stringent and therefore the possibility for seeing emissions benefits with GTL is potentially greater. A number of off-road Shell GTL Fuel trials have been carried out in Europe in the areas of construction, rail and inland marine. The table below describes the trials which we are able to disclose; other trials have been conducted confidentially.

Table 10.

Summary of 100% Shell GTL Fuel Off-Road Trials

Year/Month	Location	Trial Name	Partner	Number of Vehicles	Engine Manufacturer
2007 - 2008 July - February	Den Helder – Texel, The Netherlands	TESO Marine Trial	TESO	1 Auxiliary power unit onboard a large ferry	Caterpillar 3408C
2012 February	Rijn kanaal, Amsterdam, The Netherlands	DB Schenker Rail Trial	Reederij P. Kooij	1 Canal boat	DAF 825
2012 October	Geleen, The Netherlands	DB Schenker Rail Trial	DB Schenker	4 Shunting Locomotives and 3 Shunting Robots	Ohrenstein & Koppel and Windhoff (respectively)
2012 - 2013 December - August	Amsterdam, The Netherlands	Hitachi Storage Stability Trial	Hitachi Construction Machinery Europe	1 Demonstration machine	Hitachi ZX210-5B
2013 February - May	Mysen, Norway	Hitachi Cold Weather Operability Trial	Hitachi Construction Machinery Europe and NASTA	2 Earth-moving excavator machines	Hitachi ZX470LCH-5B
2013 November	River Rhine, The Netherlands/ Germany	INVADO Marine Trial	Vidol Marine	1 Propulsion engine onboard an inland waterway ship	Caterpillar 3512B DITA, CCNR0
2013 December	Vuile Gat, The Netherlands	NOVAMENTE Marine Trial	Novamente Shipping B.V. and Vidol Marine	1 Propulsion engine onboard an inland waterway ship	Caterpillar 3512B, CCNR1
2014 - 2015 July - August	Kassel, Germany	Deutsche Bahn Rail Trial	Deutsche Bahn	4 Shunting Locomotives	DB 294 powered by MTU 8V4000 R 41

The off-road trials have shown that Shell GTL Fuel can be used effectively as a 'drop-in' fuel in a wide range of applications under different operating conditions. As well as verifying that Shell GTL Fuel is fit for purpose with no fuel-related problems reported, a number of other aspects were seen: The trials conducted with Hitachi Construction Machinery Europe demonstrated that Shell GTL Fuel remained stable despite the demanding cold conditions and storage for an extended period of time. Furthermore, the rail trial with DB Schenker resulted in maintenance advantages, where filter regeneration of soot filters is no longer required due to the cleaner burning of Shell GTL Fuel. Finally some of the marine trials (Novamente, Invado and TESO) provided an opportunity for emissions tests. A summary of these results is given in section 5.6.

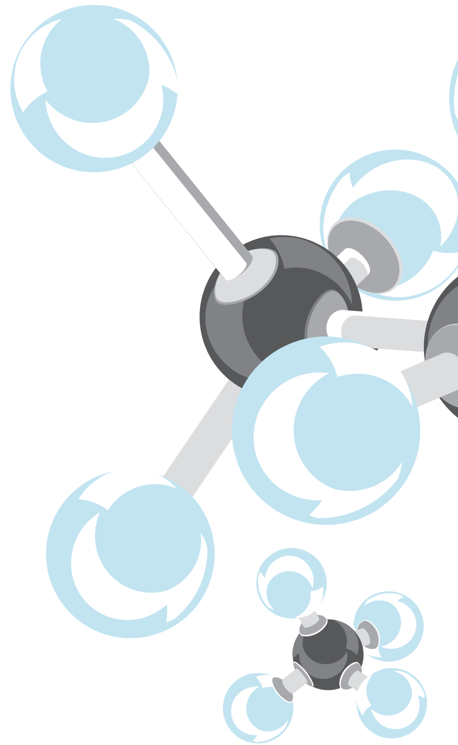
6.4.
Conclusions – Implications for Durability

GTL field trials have been happening for over 10 years and have covered more than 1 million kilometres in both on- and off-road applications. The trials have investigated the use of Shell GTL Fuel in a range of operations: heavy-duty vehicles such as trucks and buses (Euro I to VI), light-duty vehicles such as passenger cars (Euro 1 to 4), some inland waterway ship engines (CCNR 0 and CCNR 1), construction machines and rail engines.

These trials have demonstrated that the switching of the vehicles to 100% Shell GTL Fuel was practically seamless across a wide range of vehicles with different engine technologies. For heavy-duty vehicles, in the ESWE trial each bus covered an average of 60 thousand km on Shell GTL Fuel, and for light-duty vehicles in the Shanghai taxi trial each VW Passat did 80 thousand km. One of the trucks in the Yosemite water trial ran for an extended period of 1½ years. There have been no fuel-related operational issues or failures in engines noted in this >1 million km [8].

Substantial local emissions benefits were also seen in the associated emissions tests. These 'application specific' benefits are in broad agreement with the percentage benefits from the legislated cycle measurements summarised in Table 5 and Table 6. On the basis of extensive laboratory testing and trials, 100% Shell GTL Fuel can be considered as a drop-in replacement for conventional diesel, helping to give immediate reductions in local emissions, without the need for new vehicles or refuelling infrastructure.

Additionally, various OEMs have made statements to endorse Shell GTL Fuel's durability (see section 8.4 for full details).



[8] In marine systems there is an expectation of older hardware than in on-road vehicles, so more monitoring of elastomers may be required and these may need to be changed if appropriate. See section 9.2.2.

7.

Additional Environmental Benefits of Shell GTL Fuel

This section provides an overview of some of the additional environmental benefits of using Shell GTL Fuel compared to conventional diesel.

The composition of Shell GTL Fuel, particularly the low aromatic content, suggests that it is likely to be more benign, biodegradable and pose less environmental hazards than conventional diesel.

As an example, a key concern with any fuel is the environmental damage or other adverse effects which may occur in the event of a spill or leak during transport, storage or handling.

From an environmental perspective to minimise the risks, it is desirable to have fuels that are not persistent (P), will not bioaccummulate (B) in living organisms and are non-toxic (T) to organisms. These are commonly referred to as PBT criteria. As part of the global registration process the PBT and hazard profile of Shell GTL Fuel has been assessed by undertaking a range of ecotoxicity, biodegradability and toxicological studies. These studies have confirmed that, as anticipated on the basis of its composition, Shell GTL fuel is "readily biodegradable" and nontoxic to a range of organisms [14]. The key points are that:

- Currently Shell GTL Fuel is not classified as PBT or dangerous to the environment
- The only toxicological classifications for Shell GTL Fuel (which are also in common with conventional diesel) are related to its aspiration hazard (may cause lung damage if swallowed) and skin 'defatting' (repeated exposure may cause skin dryness or cracking).

SHELL GTL FUEL CAR TRIAL IN THE NETHERLANDS

These points have been substantiated during the global notification of Shell GTL Fuel as a new substance. The data generated on Shell GTL Fuel can be used to demonstrate that it is less hazardous than conventional diesel.

A detailed account of the environmental and hazardous properties of Shell GTL Fuel can be found in the Chemical Safety Report (CSR) which has been submitted to the European Chemicals Agency (ECHA) as part of the EU REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) requirements [15].

An overview of some of the additional environmental benefits of Shell GTL Fuel is discussed below.

7.

Additional Environmental Benefits of Shell GTL Fuel

7.1. Biodegradability

The biodegradability of a substance describes its readiness to be broken down by bacteria or other biological means.

As a general rule, the biodegradability of hydrocarbons increases in the order: aromatic hydrocarbons < cycloalkanes < branched alkanes < alkanes [16]. Shell GTL Fuel has a negligible aromatic content (<0.05%m.) and contains a high proportion of linear alkanes. In contrast, low sulphur diesel contains approx. 26-30%m. aromatics and Swedish Class I ULSD (ultra low sulphur diesel), ~5%m. Therefore, purely from its composition, Shell GTL Fuel would be expected to have a higher biodegradability than conventional crude oil-based diesel fuels. Shell has performed tests to confirm this. These tests are described below.

'Ready' biodegradability tests are stringent screening tests, which are used to assess whether a substance can be rapidly and extensively biodegraded in the environment. The 'ready' biodegradability of Shell GTL Fuel was determined both at 100% and when blended with ULSD. These tests are defined in European Union legislation for classifying substances. In OECD 301 F, the pass level for 'ready' biodegradability is 60% ThOD (theoretical oxygen deficit) which must be reached 10 days after biodegradation has first achieved 10% ThOD (so-called '10 day time window').

From the biodegradation studies it was determined that Shell GTL Fuel can be described as 'readily' biodegradable according to EU legislation.

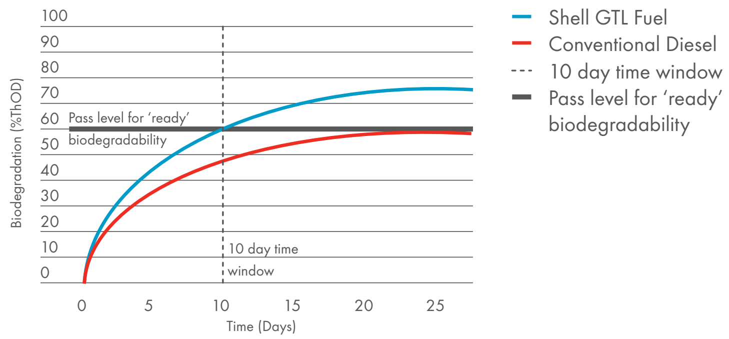
Although all of the samples tested were biodegraded by ≥60% ThOD by the end of the test, only Shell GTL Fuel met the '10 day time window' pass criterion. In addition, Shell GTL Fuel was biodegraded by around 15% ThOD more than ULSD. Although the variability in 'ready' biodegradability tests is relatively high, a difference of ≥15% ThOD is significant [16].

In addition to the aquatic studies, there are OECD 307 soil degradation studies which provide further evidence that the GTL Fuel degrades more rapidly than Zero Sulphur Diesel. Furthermore, analysis of the soil after completion of one of the soil studies has demonstrated that no components of the GTL Fuel remained in the soil at detectable concentrations [15].

From the biodegradation studies it was determined that Shell GTL Fuel can be described as 'readily' biodegradable according to EU legislation.

Figure 12.

'Ready' Biodegradability Tests



7.

Additional Environmental Benefits of Shell GTL Fuel

Data from ecotoxicological and biodegradation tests indicate that Shell GTL Fuel has considerable benefits over conventional diesel.

7.2. Ecotoxicity

The ecotoxicity of a substance is the potential effect it may have on the natural biochemistry, physiology, behavior and interactions of the living organisms that comprise the ecosystem.

There is an expectation based on its composition that Shell GTL Fuel would be less toxic to aquatic organisms than conventional diesel, including zero sulphur diesel (ZSD). Shell has performed tests to confirm this theory. This is summarised below.

The acute toxicity to key species was determined for 100% Shell GTL Fuel and blends with ULSD. The chosen species are widely used in aquatic toxicology as representative of important groups of aquatic organisms. These tests are defined by European Union legislation for classifying substances. After initial studies on invertebrates, a freshwater fish and aquatic organisms study was conducted to generate further data on the environmental effects of Shell GTL Fuel. The EU base set of organisms currently comprises fish, Daphnia and algae. Additional chronic (longer term) aquatic toxicity studies including fish early life stage and Daphnia reproduction tests have also shown that Shell GTL Fuel does not have significant toxicity. The test methods used were OECD Test Guideline 201 (Alga, Growth Inhibition Test), OECD Test Guideline 202 (Daphnia Acute Immobilisation Test) and OECD Test Guideline 203 (Fish, Acute Toxicity Test). Test results are expressed as No Observable Effect Level (NOEL), meaning the level of substance that can be introduced without affecting mortality rate.

No toxicity or adverse effects were observed in any of the species tested with Shell GTL Fuel. The aquatic toxicity studies demonstrate that Shell GTL Fuel was non-toxic (NOEL >1000 mg/l) to fish, Daphnia and algae. Consequently, Shell GTL Fuel is classified as 'not harmful' to aquatic organisms on the basis of the European Union Criteria [17].

From the lack of aquatic toxicity it can be inferred that Shell GTL Fuel would also have a lower toxicity to terrestrial organisms in the event of a spill when compared to conventional diesel. This view is supported by studies of the effects of several hydrocarbons on earthworms and plants [17]. As with aquatic organisms, in these studies the rank order of toxicity of the hydrocarbons was that aromatics were more toxic than cycloalkanes, which in turn were more toxic than branched alkanes, which were more toxic than linear alkanes. Consequently it is anticipated that virtually eliminating aromatics would significantly decrease the toxicity to terrestrial organisms. This view has been endorsed by a range of both terrestrial (earthworm and plant), sediment (Chironomids and Lumbriculus) and avian (Japanese Quail) studies. Details of these studies are provided in the Chemical Safety Report. The lack of significant toxicity in the majority of these studies provides further reassurance that the GTL Fuel has a low potential to cause adverse environmental effects making it an ideal fuel to use in environmentally sensitive areas (i.e. forestry or where there is potential for spills to occur on water) [15].

Data from ecotoxicological and biodegradation tests indicate that Shell GTL Fuel has considerable benefits over conventional diesel. Shell GTL Fuel was determined to be 'readily' biodegradable and non-toxic to aquatic organisms, according to the European Union's definitions. The lack of aquatic toxicity and ready biodegradability, coupled with its ability for reduced local emissions indicate that Shell GTL Fuel would be a suitable fuel for use in sensitive environmental areas [14].

7.

Additional Environmental Benefits of Shell GTL Fuel

7.3. Safety Benefits

In addition to the positive biodegradability and ecotoxicity results described in sections 7.1 and 7.2, there are other safety benefits for Shell GTL Fuel.

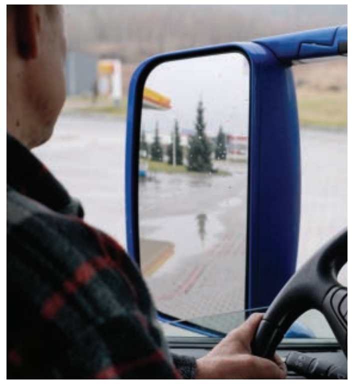
The handling and use of Shell GTL Fuel presents reduced health risks compared to conventional fuels due to its paraffinic nature and the fact it is virtually aromatics- and sulphur-free. The hazardous properties of Shell GTL Fuel have been rigorously studied and it is classified as less harmful than conventional diesel across a range of aspects listed below (in Figure 13). Workers are therefore subject to less health risks if they use Shell GTL Fuel, with the normal precautions taken to minimize exposure.

Focusing on one aspect, the reduced odour, this seems to be particularly noticed and liked by customers: "If I took a blindfold test with two identical machines using different test fuels, I would be able to identify Shell GTL Fuel, [in part] because it doesn't smell."

Figure 13.

Reduced health risks when handling Shell GTL Fuel

[9] For full details of the European emissions standards see Appendix 1



HEAVY-DUTY TRUCK USING SHELL GTL FUEL

There can be a considerable reduction in combustion noise from the use of Shell GTL Fuel compared to conventional diesel (1-4dB).

7.4. Engine Noise

The noise produced by a diesel engine is a combination of combustion noise and mechanical noise. Fuel properties can affect combustion noise directly. In a diesel engine, fuel ignites spontaneously shortly after injection begins.

During this delay, the fuel vaporises and mixes with the air in the combustion chamber. Combustion of this mixture causes a rapid heat release and a rapid rise of combustion chamber pressure. The rapid rise in pressure is responsible for the diesel knocking noise that can be audible in some diesel engines.

Increasing the cetane number of the fuel shortens the ignition delay thus reducing diesel knock intensity. On the basis of the higher cetane number of Shell GTL Fuel, it is expected that the combustion noise will be reduced compared to conventional diesel. Shell has performed a number of tests to investigate the reduction in combustion noise, as well as overall vehicle noise from the use of Shell GTL Fuel. Tests have measured noise from engines on engine test beds, as well as from inside and outside of the vehicle, on both chassis dynamometers and 'on-the-road'. The level at which humans can detect noise differences is 1-3dBA, so any noise reduction should be compared to this level.

7.4.1. Noise Tests on an Engine Test Bed

- Noise tests on a light-duty 4-cylinder Toyota engine at constant speed (2000rpm) showed large reductions in engine noise through the use of Shell GTL Fuel when compared to conventional diesel. The test found that the high cetane number fuel can reduce combustion noise by around 4dB [18].
- During a trial with Pon Power, a distributor for Caterpillar, noise measurements were made on a Caterpillar 8 cylinder 3408 engine. These tests showed a smaller 1-2dB reduction in engine noise when using Shell GTL Fuel compared to conventional diesel.

The above tests confirm that the high cetane number of Shell GTL Fuel can reduce combustion noise in an engine. A reduction in overall vehicle noise is likely to be attractive to fleet customers. In this context, noise tests have also been performed on heavy and light-duty vehicles on chassis dynamometers, in the laboratory and on the road, in an attempt to quantify this effect.

7.4.2. Noise Tests on a Chassis Dynamometer

- Tests using Shell GTL Fuel in a Cummins Enviro 200 bus on a chassis dynamometer found that there were benefits compared to ZSD in several locations on the bus. There were statistically significant benefits next to the engine at various engine speeds, but these were found to be below the level of human detection (< 1dB).
- In Groningen, noise measurements were made on road sweepers and utility tool carriers from the municipal vehicle fleet. The vehicles were initially tested running on diesel fuel, followed by three months operation on Shell GTL Fuel before final testing. At the end of the three month period the noise measurements have been repeated under conditions as close as possible to the measurements three months before.

There was some variation in the reduction of the engine sound pressure level measured with operation on Shell GTL Fuel, depending on the engine and operation conditions (e.g. engine revolutions per minute). However, an average benefit of between 2 and 3dB was achieved when running on Shell GTL Fuel compared to conventional diesel. The greatest benefit was a reduction of 8dB, achieved by one of the RAVO sweepers operating on Shell GTL Fuel at an engine speed of 1500rpm[10].

- Shell GTL Fuel was also tested in three different types of ROTEB service vehicles on a chassis dynamometer: a tool carrier, a sweeping machine and a refuse collection vehicle, which are all operated in the Rotterdam municipality. The measurements were made using a handheld sound level meter over various engine speeds.

  Measurements on the tool carrier gave small noise differences across a range of engine speeds, with an average reduction of 0.42dB for operation Shell GTL Fuel compared to conventional diesel. For the sweeping machine and refuse collection vehicle, there were considerable average reductions with operation on Shell GTL Fuel of 1.0 and 2.6dB, respectively. The biggest reduction seen was 6dB with the refuse collection vehicle operating on Shell GTL Fuel at 1200rpm[11].

7.4.3. Noise Tests 'On-The-Road'

Tests were made on a DAF CF85 heavy-duty truck and a DAF CF75 waste collection truck on a noise test track, according to ISO 10844. In addition to measurements made as the vehicle was driven past a microphone, sound measurements were taken from various locations near to the engines to see where the noise reduction was most significant. For both vehicles, measurements were taken at varying engine speeds; i) idle at stand still ii) governed engine speed at stand still and iii) wide open throttle from idle to governed speed in first gear. The study yielded the following observations:

- Measurements correlate well between the heavy-duty truck and the waste collection truck.
- Under certain conditions there was a significant reduction in noise by using Shell GTL Fuel compared to conventional diesel, under other conditions, the difference was not significant, or was masked. The effect of Shell GTL Fuel on the noise emission is most clear when the engine is running at low engine speed and low engine load. Under these conditions, the difference in noise was found to be 1-2dB in overall noise level.
- When running on Shell GTL Fuel, the high frequency diesel knocking noise is reduced and the engine sounds smoother. The largest noise reduction is found in the frequency bands between 630-2500Hz[12], in these bands, the difference can be up to 5dB.
- When running at higher engine speeds, the differences in noise emissions are much less. This can perhaps be explained by higher mechanical noise which is more prevalent at higher engine speeds.

7.4.4. Conclusions

- Shell's research shows that there can be a considerable reduction in combustion noise of 1-4dB from the use of Shell GTL Fuel compared to conventional diesel.
- This can result in a substantial decrease in overall vehicle noise, of 1-2dB, at low engine speeds, but with smaller reductions at higher engine speeds, possibly due to increased mechanical noise in diesel engines at higher speed. Noise benefits however seem to be highly vehicle dependant - some vehicles respond well to Shell GTL Fuel whereas others show no effect.
- Customers have made favourable comments about lower noise from vehicles running on Shell GTL Fuel. This can be important for vehicles operating in cities where noise is an issue. Furthermore lower noise may be especially attractive for customers who wish to operate their vehicles outside of normal daytime hours.

[10/11] Note that these results are merely indications of noise reduction levels with operation on Shell GTL Fuel as no statistical analysis was conducted and only a few vehicles were tested.

[12] Human hearing range typically 20-20,000Hz

8.

Specifications and Regulations Governing Shell GTL Fuel

Automotive diesel specifications in Europe (EN 590) and the USA (ASTM D975) aim to ensure that all diesel fuel sold in these regions is of a satisfactory quality.

Fuel specifications are important to ensure that the characteristics of all diesel fuels give satisfactory performance and reliable operation in diesel vehicles.

These specifications prescribe properties for diesel by setting limits on their values. These limits are decided by representatives from the refining industry and vehicle and engine manufacturers, as well as other interested parties. While specifications are used by the industry, national regulators may use other limits to set legal requirements; for instance, the European Fuels Quality Directive's Annex II describes the parameters of what diesel fuels are legal to sell in the EU.

The properties are measured using standard test methods which are stated as part of the specification documents. European (EN 590) and US (ASTM D975) automotive diesel specifications have been in place for some time, and aim to ensure that all fuel sold in these regions is of a satisfactory quality.

GTL fuels (diesel cut) have only recently become commercially available in large volumes, nevertheless, progress has been made to create similar specifications that cover GTL fuel as well as other 'paraffinic diesels' (BTL, CTL, HVO - hydrotreated vegetable oil). The aim of these specifications is to replicate the reassurances provided by conventional diesel specifications and so they follow a similar format. These dedicated specifications may also allow fuels labelled as 'paraffinic diesel' to be recognised as high quality fuels which can help to provide significant local emissions reductions and other benefits.

FUEL DISPATCH

8.

Specifications and Regulations Governing Shell GTL Fuel

8.1. Government Specifications

8.1.1. Europe

In Europe, transport fuel specifications are developed by the European Committee for Standardisation (CEN). These specifications are also used extensively in Asia and elsewhere, with modifications to fit local supply, crude source, and regulations.

The fuel standard EN 590 is a fuel quality agreement used for fuel manufacturing and commerce. It defines properties that are important for operability, durability and tailpipe emissions of diesel vehicles. EN 590 does not define the type of hydrocarbon feedstock to be used to produce fuel components or on the way such components are processed and blended. Shell GTL Fuel meets all of the requirements of EN 590, apart from density, which is below the lower limit.

In terms of fuel sales, member states independently prescribe which fuels can be marketed in their geographical reach. The European diesel requirements are determined by the Fuels Quality Directive Annex II [19]. This Directive states the requirements for diesel fuel sold in the European Union, as per the table below. Note that Shell GTL Fuel meets all the requirements of this regulation, which has no minimum density requirement. European member states may impose stricter requirements. For example Germany allows only EN 590 compliant fuels to be sold as diesel; EN 590 imposes additional specifications that are not part of the Fuels Quality Directive, including a density minimum. In the Netherlands non-EN 590 fuels can be sold, so long as they are not labelled as EN 590 diesel.

Table 11.

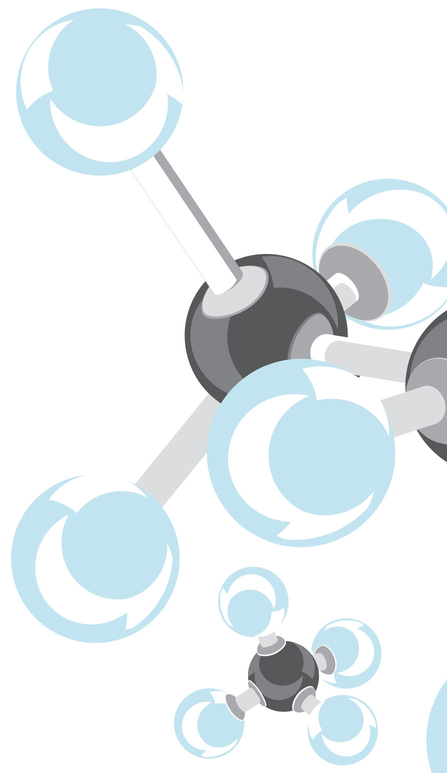
Required Parameters in the Fuels Quality Directive

Parameter	Unit	Citerion	Limits
Cetane number		Minimum	51.0
Density at 15 °C	kg/m^3	Maximum	845.0
Distillation: 95 % (v/v) recovered at	°C	Maximum	360.0
Polycyclic aromatic hydrocarbons	%m/m	Maximum	8.0
Sulphur content	mg/kg	Maximum	10.0
FAME content - EN 14078	%v/v	Maximum	7.0

The specification covering Shell GTL Fuel has evolved through several stages: a CEN Customer Workshop Agreement in 2009 (CWA 15940), through to a CEN Technical Specification in 2013 (TS 15940) and finally to a CEN preliminary EN 15940 specification (prEN 15940) which is currently employed in 2015.

CEN prEN 15940 was constructed in a similar manner to the EN 590 specification, by a CEN group comprising representatives of OEMs (original equipment manufacturers), fuel suppliers, and other interested parties. The specification (Table 12) covers paraffinic diesel fuels, which can comprise synthetic Fischer-Tropsch products GTL, BTL and CTL, as well as HVO (hydrotreated vegetable oil). With the exception of the density value, all measurement parameters for prEN 15940 and their values are identical to, or even better than EN 590. This includes FAME level where blends of B0 to B7 are allowed. Shell GTL Fuel is covered by the 'Class A' section of the specification due to its superior cetane quality.

The current specification governing Shell GTL Fuel (as of 2015) is prEN 15940 (a CEN preliminary EN specification), which is closely aligned with EN 590.



8.

Specifications and Regulations Governing Shell GTL Fuel

Table 12.

Properties Specified in prEN 15940 Class A Compared to EN590

			CEN prEN 15940 Class A: 2015		Diesel fuel EN 590: 2013	
Property	**Unit**	**Test Method**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Cetane number		EN ISO 5165 EN 15195	70.0	-	51.0	-
Density at 15 °C	kg/m³	EN ISO 3675 EN ISO 12185	765.0	800.0	820.0	845.0
Total aromatics content	% (m/m)	EN 12916 SIS 155116	-	1.0	-	-
Polycyclic aromatic hydrocarbons content	% (m/m)	EN 12916	-	-	-	8.0
Sulphur content	mg/kg	EN ISO 20846 EN ISO 20884	-	5.0	-	10.0
Flash point	°C	EN ISO 2719	>55[a]	-	>55	-
Carbon residue (on 10% distillation residue)	% (m/m)	EN ISO 10370	-	0.30	-	0.30
Ash content	% (m/m)	EN ISO 6245	-	0.010	-	0.010
Water content	mg/kg	EN ISO 12937	-	200	-	200
Total contamination	mg/kg	EN 12662	-	24	-	24
Copper strip corrosion (3h at 50 °C)		EN ISO 2160	Class 1		Class 1	
Oxidation stability	g/m³	EN ISO 12205	-	25	-	25
Oxidation stability	hrs	EN 15751[c]	20	-	20	-
FAME content	% (V/V)	EN 14078	-	7.0[b]	-	7.0
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C	μm	EN ISO 12156-1	-	460	-	460
Viscosity at 40 °C	mm²/s	EN ISO 3104	2.00	4.50	2.00	4.50
Distillation 95% (V/V) recovered at	°C	EN ISO 3405	-	360	-	360
Distillation % (V/V) recovered at 250 °C	% (V/V)	EN ISO 3405	-	<65	-	<65
Distillation % (V/V) recovered at 350 °C	% (V/V)	EN ISO 3405	85	-	85	-

a) Shell GTL Fuel Marine has a flashpoint minimum >61 - b) Shell GTL Fuel and Shell GTL Fuel Marine are typically FAME-free
c) When diesel fuel contains more than 2 % (V/V) FAME, oxidation stability as determined by EN 15751 is the requirement
Note: This table defines Class A of the prEN 15940 specification. Class B accommodates paraffinic diesels which have a lower minimum cetane number (51) and higher density (min: 780 kg/m³ and max: 810 kg/m³), that are made from other processes such as Conversion of Olefins to Distillates (COD).

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Specifications and Regulations Governing Shell GTL Fuel

Table 13.

EN 590 and prEN 15940 Climate-Dependent Requirements (Temperate Regions)

Property	**Unit**	**Limits**					
Class		A	B	C	D	E	F
CFPP	°C	5	0	-5	-10	-15	-20

*Note: EN 590 also has Arctic Grades with CFPPs down to -44 °C (Classes 0 to 4)


SHELL GTL FUEL SAMPLE

Cold Filter Plugging Points (CFPPs) in prEN 15940 are the same as the conventional diesel specification, EN 590. Shell GTL Fuel can be supplied to suit requirements of these country specific requirements. To summarise, Shell GTL Fuel meets all criteria of the prEN 15940 specification for paraffinic diesel fuels. This Technical Specification is currently being progressed to a formal EN standard.

8.1.2.
USA (ASTM)

Diesel fuel specifications in the USA are similar, but not identical, to those in the European Union. US transport fuel specifications are decided by ASTM International (formerly American Society for Testing and Materials). Shell GTL Fuel meets ASTM D975, which does not specify a density requirement and so it can be sold as diesel fuel in the USA.

8.1.3.
Japan

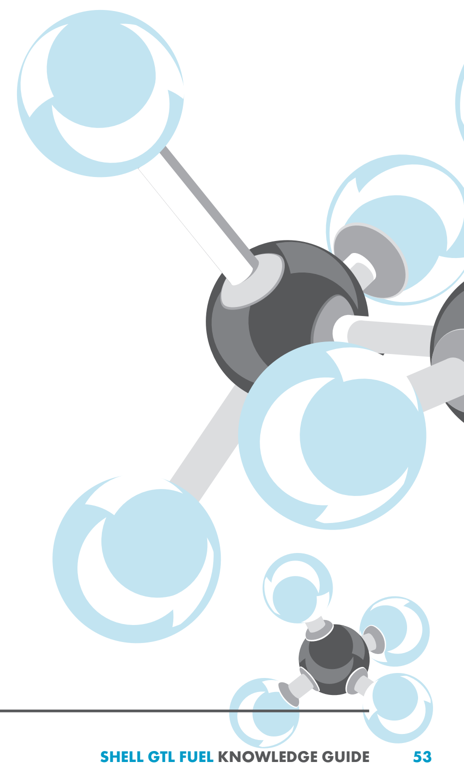
Shell GTL Fuel meets all aspects of the Japanese JIS K 2204 diesel standard, as it only specifies a maximum density (860 kg/m³) and not a minimum density requirement.

8.1.4.
Other Countries

In general, the emissions and fuel standards of other countries are based on European, U.S. or Japanese regulations.

8.1.5.
Marine

Shell GTL Fuel is able to meet all of the specifications in the ISO 8217 marine fuel standard. Shell GTL Fuel Marine is a subcategory of Shell GTL Fuel with the same properties but with a higher minimum flashpoint (>61 °C) and with red dye in accordance with Dutch tax policies for use in marine applications.



Air quality has become such an important issue that some governments are willing to allow tax incentives for fuels which reduce local emissions.

8.2.
Tax Incentives

Air quality is such an important issue that some governments are willing to allow tax incentives for low emitting fuels such as Shell GTL Fuel. An example of one such country where these incentives are implemented is Finland, which is summarised below.

Fuel taxation in Finland (Act 1443/2011) 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. The taxation promotes paraffinic diesel fuels (HVO, GTL, BTL) because of their lower tailpipe emissions.

The result is calculated on a cents per litre of fuel basis and subtracted from the total energy tax for diesel (30.70c/l).

Table 14.

Diesel Fuel Taxes in Finland from January 2015

Product	Energy Content Tax (€ c/l)	Carbon Dioxide Tax (€ c/l)	Strategic Stockpile fee (€ c/l)	Total (€ c/l)	Difference to diesel fuel (€ c/l)
Diesel oil	31.65	18.61	0.35	50.61	-
Paraffinic diesel oil [e.g. GTL, BTL, HVO]	24.89	17.58	0.35	42.82	-7.79

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Specifications and Regulations
Governing Shell GTL Fuel

8.3.
Product Registration

From a regulatory (product registration) perspective Shell GTL Fuel was initially assigned to the same descriptors as conventional diesel.

However, this created problems with classification and labelling and differentiation of Shell GTL Fuel from conventional diesel. The subject was discussed with the UK Health and Safety Executive in 2005 who recommended that the issue was referred to the EU Technical Committee of New and Existing Substances (TCNES) to ask for endorsement of an approach to obtain unique product descriptors for GTL products.

Under this proposal the GTL products previously marketed under alkanes, C12-C26 and CAS No 90622-53-0 would be covered by the new CAS name and descriptor Distillates (Fischer-Tropsch) C8 - C26 -Branched and Linear CAS No 848301-67-7. The proposal was endorsed by the TCNES (Technical Committee for New and Existing Substances) and since 2006 Shell has embarked on the global registration of Shell GTL Fuel using the new CAS number and product descriptor.

TECHNICAL STAFF WORKING ON THE PEARL GTL PROJECT

8.

Specifications and Regulations Governing Shell GTL Fuel

8.

Specifications and Regulations Governing Shell GTL Fuel

8.4. External Support for Shell GTL Fuel

Shell has conducted a significant number of road trials with Shell GTL Fuel globally in partnership with major automotive industry players and policy makers, as discussed in Section 6.

These Shell on-road trials have covered both light- and heavy-duty engines and have been run in collaboration with vehicle operators. The trials have extended over many months, over thousands of kilometres and have concluded without vehicle durability or fuel-related problems. This comprehensive evaluation program helps to conclude that it is possible to use Shell GTL Fuel in existing diesel engines without modification or harm. Moreover, they have raised awareness of Shell GTL Fuel worldwide. In addition to these trials, some Original Equipment Manufacturers (OEMs) and policy makers have gone further in their support of Shell GTL Fuel, as is discussed below.

8.4.1. OEM Statements

The following industry leaders have made positive statements regarding the use of Shell GTL Fuel in their engine systems.

8.4.1.1. Delphi

One of the main global suppliers of diesel fuel injection equipment (FIE), Delphi Diesel Systems, has recently been working with the appropriate research team within Shell to study the effect of paraffinic diesel on the durability of modern common-rail fuel injection hardware. The conclusions of the joint program stated that in a series of rig and engine tests, Shell GTL Fuel performed no worse and in some respects better than conventional diesel. In particular, the lubricity of Shell GTL Fuel was improved by addition of lubricity additives or FAME, with minimal wear under a wide range of operating conditions and temperatures. No deposits or lacquer were produced on fuel injection system components, even under relatively severe operating conditions [4].

8.4.1.2. Caterpillar

A major manufacturer of engine systems, Caterpillar, has included a statement on the use of paraffinic fuels in its manual: '"If a renewable or alternative fuels fulfills the performance requirements described in Cat Fuels Specification, the latest version of "ASTM D975", the latest version of "EN 590", or the latest version of

FUEL RETAIL STATION

the paraffinic fuel specification "CEN TS 15940" (which defines quality requirements for Gas to Liquids (GTL), Biomass to Liquids (BTL), and hydrotreated vegetable oil (HVO), then this fuel or a blend of this fuel (blended with appropriate diesel fuel) can be used as a direct replacement of petroleum diesel in Cat engines. Consult with the fuel supplier and with your Cat dealer to ensure that the cold-weather performance of the fuel is appropriate to the expected ambient temperatures at the operation sites and to ensure elastomer compatibility. Certain elastomers used in older engines (such as engines manufactured up to the early 1990s) may not be compatible with the new alternative fuels' [20].

8.4.2. European Union Support

The European Union acknowledges and encourages the use of paraffinic fuels (GTL, BTL and HVO) for air quality improvements.

8.4.2.1. Parliament

European Parliament has released an official position statement recommending Synthetic Fuels:
In the Resolution on "Conventional Energy Sources and Energy Technology", The European Parliament "calls on the Commission to support synthetic fuels technology, in view of its potential to reinforce security of energy supply and reduce emissions from the road transport sector in Europe".

In the Resolution "A Road Map for renewable energy in Europe", The European Parliament "calls the Commission to submit measures to promote other alternative fuels that will help to cut emissions from the transport sector, in line with the Action Plan for alternative fuels submitted in 2001, and examine the possibility of promoting synthetic fuels which can help to diversify energy supply, improve air quality and reduce CO_2 emissions" [21].

8.4.2.2. Alliance for Synthetic Fuels in Europe (ASFE)

Within the EU, a trade association of OEMs and fuel producers was set up in 2006 to support synthetic fuels. They are known collectively as the Alliance for Synthetic Fuels in Europe (ASFE). ASFE members are working together to promote alternative fuel options in order to significantly reduce environmental impact and help diversify the EU energy mix through improved energy efficiency and cleaner fuels. Since its founding, ASFE has continued to get positive feedback from European politicians about the role of paraffinic fuels in European policy objectives.

8.4.2.3. Clean Power for Transport

In 2014 the European Union published the Clean Power for Transport directive (formally Directive 2014/94/EU on the deployment of alternative fuels infrastructure) [22]. This directive defines 'alternative fuels' as those 'which serve, at least partly, as a substitute for fossil oil sources in the energy supply to transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector.' They explicitly include 'synthetic and paraffinic fuels', which encompasses Fischer-Tropsch diesels such as Shell GTL Fuel.

It has been proposed that European Member States should consider the following, among others, for such synthetic and paraffinic fuels:

- 'Availability of tax incentives to promote means of transport using alternative fuels and the relevant infrastructure
- Use of public procurement in support of alternative fuels, including joint procurement
- Demand-side non-financial incentives, for example preferential access to restricted areas, parking policy and dedicated lanes'

8.4.2.4. Clean Vehicle Directive

This directive (formally Directive 2009/33/EC on the Promotion of Clean and Energy Efficient Road Transport Vehicles) aims for a broad market introduction of environmentally-friendly vehicles. It requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in all purchases of road transport vehicles, as covered by the public procurement directives and the public service regulation.

It states that 'these lifetime impacts of vehicles shall include energy consumption, CO_2 emissions and emissions of the regulated pollutants of NOx, NMHC (non-methane hydrocarbons) and particulate matter. Purchasers may also consider other environmental impacts' [23].

Costs for emissions in road transport (in 2007 prices) per Table 2 of the Annex [24] are:

CO_2:	0.03 to 0.04 EUR/kg
NOx:	0.0044 EUR/g
NMHC:	0.001 EUR/g
Particulate Matter:	0.087 EUR/g

8.4.3. Awards

Shell GTL Fuel has been acknowledged publicly for its lower emissions by various certification organizations.

8.4.3.1. Lean and Green Certification

On the 8th October 2013, Shell GTL Fuel was awarded with the official 'Lean and Green' certificate for the Netherlands within the Connekt program of Lean and Green. This certificate is given to organisations which 'show that they are actively engaged in making their logistics and mobility process more sustainable.'

8.4.3.2. Marine Green Award

The Green Award Scheme gives harbor fee reductions in a rapidly increasing number of Dutch, European and global river sea ports, including Rotterdam. In 2014 a customer, Mr. A.G.W. Holthaus of Novamente Shipping B.V., won the Green Silver Award, 'mostly for using Shell GTL Fuel Marine as an alternative for diesel.' The Novamente ship has a CCNR1 engine but by using Shell GTL Fuel, it achieved CCNR2 emissions levels which are much more stringent, allowing it to earn the Green Award.

LEAN AND GREEN

GREEN AWARD

8.

Specifications and Regulations Governing Shell GTL Fuel

8.

Specifications and Regulations Governing Shell GTL Fuel

8.4.4. Third Party Joint Studies

Shell has collaborated with third parties to verify their in-house results and assess the potential impact of GTL Fuels on urban air quality.

8.4.4.1. TNO

With respect to Shell GTL Fuel as a replacement for regular diesel fuel (EN590), TNO conducted a study which reviewed the potential advantages for a range of both new and existing commercial diesel vehicles, inland ships and non-road mobile machinery [11].

The following key conclusions were made:

- Shell GTL Fuel shows a reduction in all regulated pollutant emissions (NOx, PM, CO and HC). Test results showed variations between test programs, as can be expected due to differences between engines.
- The pollutant emissions of existing fleets can be reduced significantly by the application of GTL. The reduction is instantaneous and can be seen as an alternative to replacement by newer or cleaner vehicles, ships or machines, or it can serve as a complementary measure.
- In absolute sense, the emissions reductions are the largest when GTL is used for relative higher polluting engines such as use in older vehicles, ships or mobile machinery.

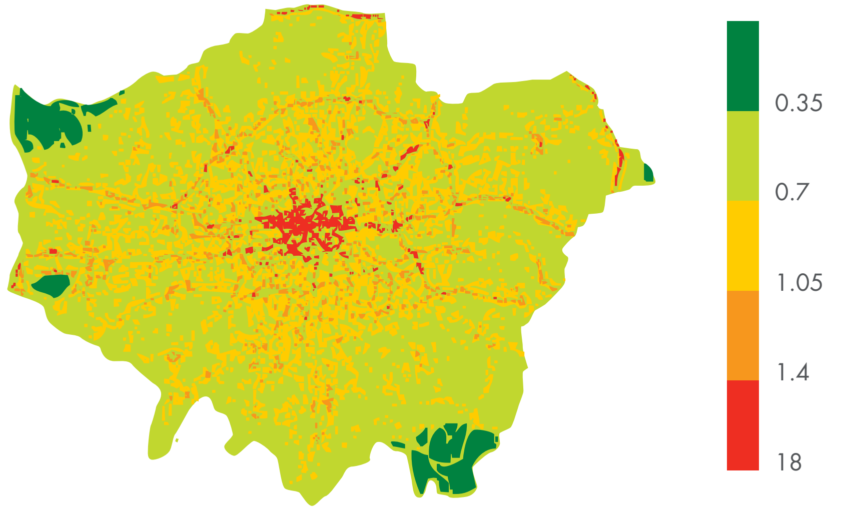
8.4.4.2. Kings College Study on London Air Quality

Between 2007 and 2009 Shell collaborated with King's College Environmental Research Group, and using the London Atmospheric Emissions Inventory (LAEI) and London Air Quality Toolkit model (LAQT), assessed the potential impact on air quality of switching most diesel fleets in London to Shell GTL Fuel. Specifically, the study asked: Can GTL have an influence on the 'non-attainment' of Air Quality standards. Where 'non-attainment' refers to areas of London where air quality exceeds one or more EU limit values in a specific year (more details can be found on the DEFRA site http://uk-air.defra.gov.uk/assets/documents/National_air_quality_objectives.pdf) [25].

The project simulated fuelling 5 of London's 7 vehicle classes, with Shell GTL Fuel, assessing total emissions from vehicles and other sources before and after the GTL scenario, and using the LAQT model to produce NO_2 and PM concentration difference maps of London (Figure 14).

Figure 14.

NO_2 annual mean concentration reductions in London (μg m^{-3}) based on 100% GTL benefits in 2010



Red = reduction range 1.4 to 18 μg m^{-3} (cf. magnitude of 40 μg m^{-3} target)

The Air Quality annual mean targets for PM_{10} and NO_2 are 40 μg m^{-3} and the target for $PM_{2.5}$ is 25 μg m^{-3}. The PM_{10} daily exceedance limit is 50 μg m^{-3}, which is not to be exceeded more than 35 times a year. These targets were used, along with the reduction in air quality concentrations, shown on the maps, to identify areas where the air quality limits would have been met, both with and without the use of Shell GTL Fuel. Areas where the air quality limits are not met are called 'air quality exceedance areas' and are outlined in the table below. The model suggests that the use of Shell GTL Fuel can reduce Air Quality exceedance areas by 19 to 39%.

Table 15.

Air Quality Exceedance areas (km^2)

Pollutant (2015)	Base Case (Diesel)	GTL Scenario	% Change
$PM_{2.5}$ annual mean	0.73	0.44	-39%
PM_{10} exceedance days	0.57	0.39	-32%
NO_2 annual mean	64	52	-19%

8.4.4.3 ASFE Brussels Case Study

In 2013, an ASFE study modelled the air quality in Brussels in order to understand the potential impact of a switch to paraffinic fuels. According to a government analysis of the Belgian car fleet, the total annual diesel PM emissions from transport in Brussels is almost 350 tonnes. ASFE has estimated that if all diesel vehicles in Brussels (passenger and heavy duty) switched to paraffinic fuels, there could be a PM reduction of approximately 129 tonnes each year. This value corresponds to taking 64,000 of the most polluting cars (categories Euro 1 & 2) off the road [26].

9.

Shell GTL Fuel Storage and Handling

Storage and handling procedures for Shell GTL Fuel are based on those for conventional diesel fuel.

In general, Shell GTL Fuel can be packaged, transported and stored using the same equipment, materials and procedures that are used for conventional diesel fuel.

Specifically Shell GTL Fuel can be stored in the same tanks, refuelling can be carried out using the same pumps and the refuelling time is also the same as for conventional diesel.

Moreover, the more benign nature of Shell GTL Fuel means that it is generally less hazardous to health, safety and the environment than conventional diesel (Section 7). In particular, Shell GTL Fuel can be transported without the 'class 3 flammable liquid' dangerous goods label that conventional diesel often requires. Nevertheless, the handling, transportation, storage, use and disposal of petroleum products are regulated in most parts of the world and the Shell Group takes its responsibilities in these matters seriously.

9.1. Differences Between Shell GTL Fuel and Conventional Diesel

Certain specific properties of Shell GTL Fuel differ from conventional diesel and therefore mean that particular attention should be paid to supplier recommendations (i.e. data provided in Materials Safety Data Sheet - MSDS). In this context, in the storage and handling of Shell GTL Fuel the following properties should be monitored:

- Low density and different thermal expansion coefficient - effects on dispensing meters
- Low aromatics - possible effect on old nitrile rubber seals in equipment exposed previously to aromatic containing streams
- Low levels of contaminates - precautions to ensure this is maintained during storage and handling

Storage and handling procedures for Shell GTL Fuel are based on those for conventional diesel fuel. GTL fuel is mainly paraffinic, making it generally more benign than conventional diesel fuel; this means that procedures for diesel are usually sufficient when using Shell GTL Fuel. It is important, however, to appreciate that national and international rules and regulations must be followed when storing and handling Shell GTL Fuel. In this respect, the properties of interest are discussed in detail below; some such as conductivity have important safety implications.

9.

Shell GTL Fuel Storage and Handling

9.2. The Implications of These Differences to Conventional Diesel

9.2.1. Low Density and Different Thermal Expansion Coefficient - Effects on Dispensing Meters

Meters for measuring Shell GTL Fuel volumes need to be calibrated. The coefficient of thermal expansion of a fuel is needed in order to compensate for density changes with temperature when loading and receiving products. Dispensing meters used for Shell GTL Fuel will need to be calibrated to compensate for its different thermal expansion coefficient. Adhering to local calibration regulations for diesel fuel will ensure that the correct volume of Shell GTL Fuel is dispensed.

9.2.2. Elastomer Material Compatibility

From laboratory testing and extensive vehicle trials, it can be concluded that Shell GTL Fuel is generally more benign than conventional diesel towards elastomers commonly used in rubber seals and hoses in fuel handling systems. This can be attributed to the lower aromatic content of Shell GTL Fuel, which reduces interactions with elastomers. When used in combination with advanced seal materials such as fluorocarbon elastomers (Viton), trouble-free operation in new vehicles can be assured. However, for some older vehicles, fitted with seals made from nitrile rubber that have been aged through prolonged exposure to conventional diesel fuel, there is a small risk of fuel leakage. This effect is not unique to Shell GTL Fuel and may occur when changes are made between fuels with different compositions.

When switching older vehicles to Shell GTL Fuel, elastomeric material which has contact with the fuel should be monitored for signs of leakage. In marine systems there is an expectation that the vessels/hardware could be older than on-road vehicles, so more monitoring may be required. If leakage occurs, elastomeric material (e.g. seals and fuel carrying hoses) should be replaced as appropriate.

9.2.3. Precautions to Avoid Contamination

The logistical arrangements for using Shell GTL Fuel will differ by location, but will usually involve pipelines, pumps, valves and hoses that are shared with other products and not dedicated to paraffinic diesel use. Arrangements need to be in place to ensure that cross-contamination from multi-product facilities is minimised, in order to maintain the highly clean nature of Shell GTL Fuel.

9.2.4. Flash Point

The flash point is the lowest temperature at which a sufficient proportion of fuel can vaporise to form an ignitable mixture in air. The flash point is often used as a descriptive characteristic of liquid fuels and is used to assess the potential fire hazards of fuels. The flash point of Shell GTL Fuel is comparable to conventional diesel. Both EN 590 (diesel) and prEN 15940 (GTL) specify that the Flash Point should be at least 55°C. Shell GTL Fuel is well within these legislative limits, above 60°C.

Generally, a flash point of >60°C is considered not to require a dangerous goods classification. Because the flash point of diesel varies either side of this cut point, diesel is considered to be a dangerous goods 'class 3 flammable liquid' (UN 1202) under EU, Australian and US Department of Transportation regulations.

As Shell GTL Fuel is consistently above the 60°C threshold and has been shown not to sustain combustion, it does not have to carry the 'class 3 flammable liquid' label. Note, some GTL gasoils on the market have lower flash points and may have to bear this transport safety label. Shell GTL Fuel Marine, which is sold for marine applications, has a flash point above 60°C, which is required for use on inland waterways in Europe.

9.2.5. Conductivity

Electrical conductivity is another important factor in the safe handling and transportation of liquid fuels. Static electric charges can be generated when fuel is pumped from one tank to another (in a refinery, terminal, or fuelling station), particularly when it is pumped through a filter. Normally, this charge is quickly dissipated and does not pose a problem. However, if the conductivity of the fuel is low, the fuel may act as an insulator allowing a significant amount of charge to accumulate. In many installations, including Shell refineries and terminals, minimum conductivity levels are prescribed for diesel products prior to distribution by ship, rail car or road tanker to prevent build-up of static electricity.

Shell GTL Fuel, in common with other highly processed fuels (such as ZSD, HVO), has a very low natural electrical conductivity. The low conductivity is due to the absence of polar chemical compounds that typically act as electrical charge carriers. The conductivity of highly processed diesel fuels can easily be readily increased by the addition of a Static Dissipater Additive (SDA) or conductivity improver. These additives have been found to work well in Shell GTL Fuel and are routinely added to improve conductivity.

9.

Shell GTL Fuel Storage and Handling

PEARL GTL STORAGE FACILITY, QATAR

9.2.6.
Low Temperature Storage

The cold flow properties of a diesel fuel need to be suitable for the market where it is to be supplied. Cold flow properties such as cloud point, cold filter plugging point and pour point need to be considered in cold climates when storing Shell GTL Fuel in tanks. Tank and line heating may need to be considered during storage at very low temperatures.

During long term storage, Shell GTL Fuel behaves similarly to conventional diesel. Shell GTL Fuel has extremely low contaminant levels, so there is no risk of precipitation at temperatures above the cloud point. As with traditional diesel fuels, some precipitation of long chain paraffins may take place if the temperature is below the cloud point for a long period.

9.2.7.
Storage Stability

Issues with storage stability have traditionally been related to gum and sludge formation. However, with modern ultra-low or zero sulphur fuels, the concerns are more likely to relate to oxidation stability.

The molecular structure of GTL Fuel (mostly paraffinic hydrocarbons) indicates that GTL Fuel will have excellent storage stability with respect to both oxidation and microbial growth.

This good oxidation stability is due to the paraffinic nature of GTL fuel, where paraffins are the hydrocarbon class that is most stable to oxidation. Furthermore, GTL has a lower propensity to solubilise metals which catalyse oxidation reactions and may be present in storage/handling systems. We have seen this excellent oxidation stability in both tests and long term storage trials.

Shell GTL Fuel shows a low propensity to microbial growth due to its superior water shedding ability (paraffinic nature) which enables the drop-out of free water suspended in the fuel and little time for microbes to grow at the suspended water-fuel interface. Shell GTL Fuel has experienced at least equivalent resistance to microbial growth when compared to conventional diesel (B0). If microbial growth does occur, GTL can be treated using the same biocides that are used to treat conventional diesel.

This good oxidation stability depends upon no contamination with catalytic metals such as copper, zinc and rust. Microbial growth should be prevented through limiting exposure to water and oxygen. Therefore Shell GTL Fuel, like other zero sulphur diesel, needs to be stored and handled in good conditions to ensure optimum stability.

9.3.
Availability

Shell launched Shell GTL Fuel during 2012 in the Netherlands and the Rhine area in Germany. Shell is currently exploring making Shell GTL Fuel available in additional locations in the future.

Acronyms

ASTM	American Society for Testing and Materials (now ASTM International)
BTL	Biomass-to-Liquids
CARB	California Air Resources Board
CAS	Chemical Abstracts Service
CEN	European Committee for Standardisation
CFPP	Cold Filter Plugging Point
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CP	Cloud Point
CTL	Coal-to-Liquids
DI	Direct Injection
DPF	Diesel Particulate Filter
EGR	Exhaust Gas Recirculation
ESC	European Stationary Cycle (European Steady State Cycle)
ETC	European Transient Cycle
FAME	Fatty Acid Methyl Ester
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GTL	Gas-to-Liquids
HC	Hydrocarbon
HFRR	High Frequency Reciprocating Rig
HVO	Hydrotreated Vegetable Oil
IDI	Indirect Injection
LSD	Low Sulphur Diesel (<500mg S/kg in EU)
NMHC	Non-Methane Hydrocarbons
NOx	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PM	Particulate Matter
SCR	Selective Catalytic Reduction
SMDS	Shell Middle Distillate Synthesis
SOx	Sulphur Oxides
THC	Total Hydrocarbons
ThOD	Theoretical Oxygen Demand
ULSD	Ultra Low Sulphur Diesel (<50mg S/kg in EU)
WHTC	World Harmonized Transient Cycle
WHSC	World Harmonized Stationary Cycle (World Harmonized Steady State Cycle)
XTL	'Anything' (Gas/Biomass/Coal)-to-Liquids
ZSD	Zero Sulphur Diesel (<10mg S/kg in EU)

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[8] http://www.eea.europa.eu/data-and-maps/indicators/proportion-of-vehicle-fleet-meeting/proportion-of-vehicle-fleet-meeting-4; TERM 34 Figure 2:. Estimated share of pre Euro/conventional and Euro I-V heavy-duty vehicles, buses and coaches and conventional and 97/24/EC mopeds and motorcycles in 30 EEA member countries 1995 and 2009

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European Diesel Emissions Standards

Table 16.

Heavy-Duty Diesel Emissions Standards (Steady State Cycles)

Stage	Year	Test Cycle	CO	HC	NOx	PM
			g/kWh			
Euro I	1992	R-49	4.5	1.1	8.0	0.36*
Euro II	1996	R-49	4.0	1.1	7.0	0.25**
Euro III	2000	ESC***	2.1	0.66	5.0	0.10
Euro IV	2005	ESC	1.5	0.46	3.5	0.02
Euro V	2008	ESC	1.5	0.46	2.0	0.02
Euro VI	2013	WHSC	1.5	0.13	0.4	0.01

*>85kW Engines (≤ 85 kW PM limit is 0.612g/kWh)
**Changed to 0.15g/kWh in 1998
***Also requires ELR (European Load Response) smoke test from Euro III onwards

Table 17.

Heavy-Duty Diesel Emissions Standards (Transient Cycles)

Stage	Year	Test Cycle	CO	*NMHC	NOx	PM
			g/kWh			
Euro III	2000	ETC	5.45	0.78	5.0	0.16
Euro IV	2005	ETC	4.0	0.55	3.5	0.03
Euro V	2008	ETC	4.0	0.55	2.0	0.03
Euro VI	2013	WHTC	4.0	0.16**	0.46	0.01

* Non-Methane Hydrocarbons - also CH_4 limits for natural gas vehicles
**THC for diesel

Table 18.

Light-Duty Diesel Emissions Standards

Stage	Year	Test Cycle	CO	HC+NOx	NOx	PM
			g/km			
Euro 1	1992	ECE+EUDC	2.72	0.97	-	0.14
Euro 2 (IDI)	1996	ECE+EUDC	1.0	0.70	-	0.08
Euro 2 (DI)*	1996	ECE+EUDC	1.0	0.90	-	0.10
Euro 3	2000	NEDC	0.64	0.56	0.50	0.05
Euro 4	2005	NEDC	0.50	0.30	0.25	0.025
Euro 5	2009	NEDC	0.50	0.23	0.18	0.005
Euro 6	2014	NEDC	0.50	0.17	0.08	0.005

*until 30.09.1999 (after that date DI engines must meet the IDI limits)

Tables are adapted from source [7].

Appendix 2

Emissions Tests - Additional Details

The emissions tests were performed by Shell and collaborative partners. [3] [12] [27] [28] [29]

A2.1. Heavy-Duty

A2.1.1. Dedicated Emissions Tests

This section give full details of the heavy duty vehicles tested (Table 19) and the corresponding percentage local emissions benefits measured (Table 20), as summarised in Section 5.

Table 19.

Heavy-Duty Tests - Summary of Vehicles Tested

Ref	Euro Level	OEM	Model	Engine	Aftertreatment
A	Euro I	Mercedes-Benz	OM366	6L	None
B	Euro II	Mercedes-Benz	OM366	6L	None
C	Euro III	-	-	11L	None
D	Euro III	-	-	6L	None
E	Euro IV	Scania	DC12	10.6L	EGR and DPF
F	Euro IV	MAN	D2066	10.5L	Measured pre-aftertreatment[13]
G	Euro V	Scania	DC12	11.7L	SCR
H*	Euro V	Scania	R400	12.7L	EGR (no DPF or SCR)
I**	Euro V	Scania	R400	12.7L	EGR (no DPF or SCR)
J	Euro V	Mercedes-Benz	Actros 1846 LS	12.0L	SCR
K	Euro V	Volvo	FH 480	12.8L	SCR
L	Euro V	MAN	TGX 440	10.5L	SCR
M	Euro V	Mercedes-Benz	Actros 1846 LS	12.0L	SCR
N	Euro V	Volvo	FH 480	12.8L	SCR
O	Euro V	MAN	TGX 440	10.5L	SCR

*Tests performed at non-ambient temperature (5°C)
** Tests performed at non-ambient temperature (40°C)

The emissions tests were performed by Shell and collaborative partners.

[13] Separate test work has shown that Shell GTL Fuel percentage benefits on the same engine post-aftertreatment are at least as large, if not larger than benefits pre-aftertreatment. This meant that even though test B measured emissions pre-aftertreatment, it was seen as appropriate to compare the percentage benefits to other tests, because benefits would be as large, if not larger had the benefits been measured post-aftertreatment.

Appendix 2

Table 20.

Heavy-Duty Tests - Percentage Emissions Benefits

This table show percentage local emissions benefits from all of the heavy duty emission tests, which are summarised in Table 5.

Ref	Euro Level	Test Cycle	Reference Diesel Sulphur Specification	% Emissions benefit compared to EN 590 Diesel			
				PM	NOx	HC	CO
A	Euro I	R49	<400mg/kg	18	16	13	22
B	Euro II	R49	<400mg/kg	18	15	23	5
C	Euro III	ESC	<400mg/kg	34	5	ND	9
D	Euro III	ESC	<400mg/kg	10	19	9	20
E	Euro IV	ESC	50mg/kg	38	17	28	ND
F	Euro IV	ETC	10mg/kg	31	5	10	9
G	Euro V	ESC	50mg/kg	23	26	ND	ND
H*	Euro V	WHTC	10mg/kg	32	10	23	8
I**	Euro V	WHTC	10mg/kg	31	11	19	14
J	Euro V	ETC	10mg/kg	22	13	ND	16
K	Euro V	ETC	10mg/kg	33	11	ND	22
L	Euro V	ETC	10mg/kg	26	5	ND	14
M	Euro V	ESC	10mg/kg	26	32	ND	8
N	Euro V	ESC	10mg/kg	25	37	ND	17
O	Euro V	ESC	10mg/kg	25	18	ND	9

Not statistically significant at the ≥95% confidence interval

*Tests performed at non-ambient temperature (5°C)
** Tests performed at non-ambient temperature (40°C)
ND = no data - absolute emissions levels so low that attempted measurements were at the noise level due to the intrinsically low emissions and contaminated ambient air

A2.1.2.
Emissions Tests Associated with Trials

This table show percentage emissions benefits from all of the heavy duty emissions tests associated with the trials.

Table 21.

Heavy-Duty Trials - Percentage Local Emissions Benefits

Euro Level	Trial Name	Test Cycle	Reference Diesel Sulphur Specification	% Benefit Compared to Conventional Diesel				
				PM	NOx	HC	CO	CO_2
Euro II	Shanghai[14]	R-49	<350mg/kg	35	15	-8	13	4
Euro II	Van Gansewinkel[15]	CARB Refuse Cycle	10mg/kg	18	2	16	12	1
Euro III	Van Gansewinkel[16]	CARB Refuse Cycle	10mg/kg	19	8	4	37	3
Euro III	*London Bus[16]	London Millbrook bus cycle (MLTB)	<50mg/kg	20 (15)	4 (0)	20 (28)	12 (0)	3 (2)
Euro III	Shanghai[14]	ESC	<350mg/kg	40	3	18	8	3
Euro III	Beijing[17]	ESC	<350mg/kg	33	5	19	20	ND
Euro III	Delft	Connexxion[16]	Dutch Urban Bus cycle <10mg/kg	15	12	17	3	3
Euro III	*London TfL[16]	London Millbrook bus cycle	<10mg/kg	9 (16)	12	11	-9	4
Euro III	*London TfL[16]	London Millbrook bus cycle	<10mg/kg	-23 (23)	3	-13	-6.5	4
US 2001 (Similar to Euro III)	Yosemite Waters[18]	NYCB/CSHVR cycle	2mg/kg	33/23	8/13	69/58	10/-1	ND
US 2002 (Similar to Euro III)	Ralph's Groceries[18]	NYComp	2mg/kg	18	6	ND	ND	ND
Euro IV	*London TfL[16]	London Millbrook bus cycle	<10mg/kg	22 (10)	13	3	11	4
Euro V	Van Gansewinkel[15]	CARB Refuse Cycle	10mg/kg	0	5	13	72	0

*(Pre-aftertreatment)
Not statistically significant at the ≥95% confidence interval
No statistical analysis

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A2.2. Light-Duty

A2.2.1.
Dedicated Emissions Tests

This section gives full details of the light duty emissions tests summarised in Section 5.

Table 22.

Light-duty Tests - Summary of Vehicles Tested

Ref	Euro Level	OEM	Model	Engine	Aftertreatment
A	Euro 1	Ford	Transit	2.5L (IDI)	None
B	Euro 1	Ford	Orion	1.8L (IDI)	None
C	Euro 1	Peugeot	605	2.1L (IDI)	None
D	Euro 1	Renault	21	2.1L (IDI)	None
E	Euro 2	Audi	80	1.9L (DI)	Oxicat
F	Euro 2	Audi	100	2.5L (DI)	Oxicat
G	Euro 2	Volkswagen	Golf	1.9L (IDI)	Oxicat
H	Euro 2	Ford	Orion	1.8L (IDI)	None
I	Euro 3	Mercedes-Benz	C220 CDI	2.2L (DI)	Oxicat
J	Euro 3	Volkswagen	Bora Combi	1.9L (DI)	Oxicat
K	Euro 3	Citroen	Xantia HDI	2.0L (DI)	Oxicat
L	Euro 3	Ford	Focus	1.8L (DI)	Oxicat
M	Euro 3	Citroen	Xantia HDI	1.9L (DI)	Oxicat
N	Euro 4	Toyota	Avensis	2.0L (DI)	Oxicat
O	Euro 4	Honda	Civic	2.2L (DI)	Oxicat
P	Euro 4	Ford	Focus	1.8L (DI)	Oxicat
Q	Euro 4	Peugeot	407	2.0L (DI)	Oxicat + DPF

Given large amount of light-duty emissions data, and consistency of percentage local emissions benefits, they are given as means for all of the vehicles tested at that Euro Level. The emissions tests were performed by Shell and collaborative partners.

Appendix 2

Table 23.

Light-Duty Tests - Percentage Local Emissions Benefits

Ref	Euro Level	Test Cycle	Reference Diesel Sulphur Value	% Emissions Benefit Compared to EN 590 Diesel			
				PM	NOx	HC	CO
A, B, C, D	Euro 1	ECE+EUDC	400mg/kg	42	10	45	40
E, F, G, H	Euro 2	ECE+EUDC	400mg/kg	39	5	63	53
I, J, K, L, M	Euro 3	NEDC	400mg/kg	41	5	62	75
N, O, P, Q	Euro 4	NEDC	10mg/kg	14 to 20*	6 to 2*	66 to 77*	73 to 83*

* Ranges arise from comparing against two different reference diesel fuels (differing in density)

Appendix 2

A2.2.2. Emissions Tests Associated with Trials

This table show percentage local emissions benefits from all of the light duty emissions tests associated with the trials.

Table 24.

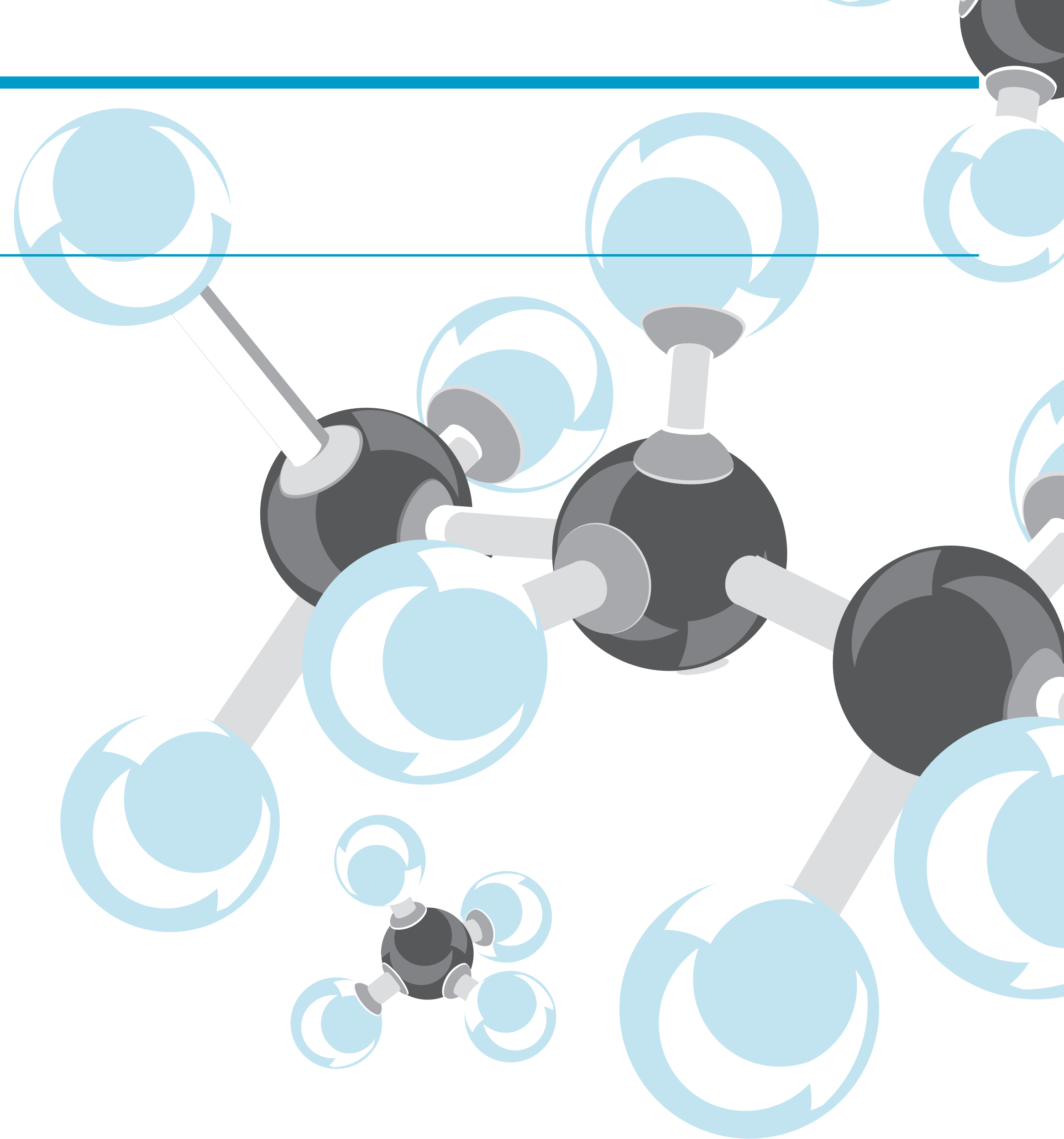
Light-Duty Trials - Percentage Local Emissions Benefits

Euro Level	Trial Name	Test Cycle	Reference Diesel Sulphur Specification	% Benefit Compared to Diesel				
				PM	NOx	HC	CO	CO_2
Euro 3	Berlin VW[19]	ECE+EUDC	10mg/kg	26	6	63	91	4
Euro 3	Shanghai Taxis[20]	NEDC	350mg/kg	42	6	68	57	2
Euro 4	London Toyota[21]	ECE+EUDC	10mg/kg	25	5	73	94	4
Euro 4	Michelin Bibendum Challenge[22] (A2)	ECE+EUDC	10mg/kg	38	5	57	82	4
Euro 4	Michelin Bibendum Challenge[22] (A8)	ECE+EUDC	10mg/kg	36	2	63	90	4

Not statistically significant at the ≥95% confidence interval
No statistical analysis

[19] Volkswagen/2003
[20] Tongji University/2006
[21] Toyota/2004
[22] On-board measurements/2004

Your Notes



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