Whitepaper

TESTING OF HVO IN *mtu* ENGINES FOR RAIL APPLICATIONS

Rolls-Royce has approved synthetic paraffinic diesel fuel/ renewable diesel (hydrogenated vegetable oil or HVO) compliant with standard EN 15940 for use in ***mtu*** Series 4000, 1800 (EU V and EU IIIA/IIIB) and 1600 diesel engines in rail applications. This white paper provides a detailed summary of the comparative tests performed on ***mtu*** diesel engines with standard diesel fuel and HVO-100.

Rolls-Royce Power Systems, with headquarters in Friedrichshafen, employs more than 10,500 people. Its ***mtu***-brand high-speed engines and drive systems power ships, heavy land and rail vehicles, and defense vehicles and are also used in the oil and gas industry. Its engine portfolio also includes diesel and gas systems and battery solutions for safety-critical applications, continuous power generation, Combined Heat and Power modules, and microgrids. Climate-friendly technologies from Rolls-Royce Power Systems are helping to drive the energy transition.

Since 1924, Rolls-Royce has put more than 20,000 engines and drive systems into service on the tracks. More than half of all railcars in

Authors:
Steffen Mors, Stephan Nase, Dr. Günter Zitzler

A Rolls-Royce solution

Europe are powered by ***mtu*** engines, making Rolls-Royce one of the top four drive suppliers for locomotives worldwide.
mtu drive systems used in mainline and multi-purpose locomotives, high-speed trains and local rail transport are technologically optimized for heavy-duty use under the most varying operating conditions and set the standard in terms of performance, robustness and low exhaust emissions. They are in service across all continents, proving their outstanding capabilities day in and day out, not only in passenger transport and on long-haul passenger routes, but in heavy freight trains, HSTs, industrial locomotives and shunting operations.

Thanks to their low weight, compactness, smooth running and low noise emissions, ***mtu*** engines are the preferred drives for rail vehicles. Rounding off the engine portfolio for rail applications is the ***mtu*** PowerPack, a compact propulsion system which besides the engine and transmission contains all sub-systems required for powering the rail vehicle such as the cooling and exhaust gas aftertreatment systems. Rolls-Royce Power Systems also offers an especially eco-friendly version of this drive solution in the form of the ***mtu*** Hybrid PowerPack which combines the benefits of battery and diesel power on trains.

Executive summary

The tests performed using HVO in *mtu* engines were evaluated on the basis of the following criteria:

— Engine performance
— Exhaust emissions (using diesel as per EN 590 and HVO-100 as per EN 15940)
— Comparative fuel consumption
— Long-term use of HVO in the field

All tests so far have shown no differences in performance between operation with HVO-100 and operation with fossil diesel (EN 590), while engine emissions – especially particulate emissions – were lower. The representative tests were carried out on two ***mtu*** engines: 12V4000R84 and 12V1600R91 for rail applications.

The tests with HVO-100 showed:

— **A decrease in CO_2, and particulate (PM) emissions**
— **Full performance capabilities**
— **Lower fuel consumption**

NOx emissions:

In general, synthetic fuels do not significantly influence NOx emissions on engines equipped with exhaust gas aftertreatment. This is confirmed by the measurement results shown below.

Comparison of fuels

Comparative testing of performance and emissions was carried out using distilled diesel fuel and HVO-100. The diesel fuel complied with DIN 590 (B7) and the HVO-100 fuel with EN 15940 Class B.

Key figures	Meas. Unit	EN 590	EN 15940 Class B	Neste MY Renewable Diesel (EN15940) Fuel sample
Cetan number	–	min. 51	min. 51	65,6
Cetan index	–	min. 46	na	92,2
Density at 15°C	kg/m³	820-845	780-810	780
Sulfur	ppm	max. 10	max. 5	<5
Total aromatics	m %	na	max. 1,1	na
Flashpoint	°C	min. 55	min. 55	74
Viscosity at 40 °C	mm²/s	2,0-4,5	2,0-4,5	2,9
FAME content	Vol %	max. 7	max. 7	0
Oxidation stability (Rancimat)	h	min. 20	min. 20	na
Oxidation stability	g/m³	max. 25	max. 25	na
Lubricity at 60° (HFRR value)	µm	max. 460	max. 400	360
Total contamination	mg/kg	max. 24	max. 24	<12
Water content	mg/kg	max. 200	max. 200	85
Water + Sediment	Vol %	na	na	na

Fuel specifications state ranges, maximums and minimums for various fuel characteristics. The tolerance ranges for individual fuel characteristics can be found in the applicable Fluids and Lubricants Specifications.

Test results

Extensive measurements at the test stand and in the field were carried out on Series 4000 and 1600 rail engines. Furthermore, long-term trials on rail vehicles powered by 16V4000R84 and 12V1600R70 units were carried out under real-life conditions. All results were consistently positive and confirmed the advantages of using synthetic paraffinic fuels. The representative results for Series 4000RX4 EU V and Series 1600 RX1 EU V units are shown below. The comparative values for each engine type were determined at an engine test bench.

Fuel consumption

Specific fuel consumption figures for the 12V1600R91 unit at a rated speed of 1900 rpm are compared below. A specific fuel consumption reduction of 2 % was measured on the Series 1600 unit when run on synthetic fuel (HVO-100).

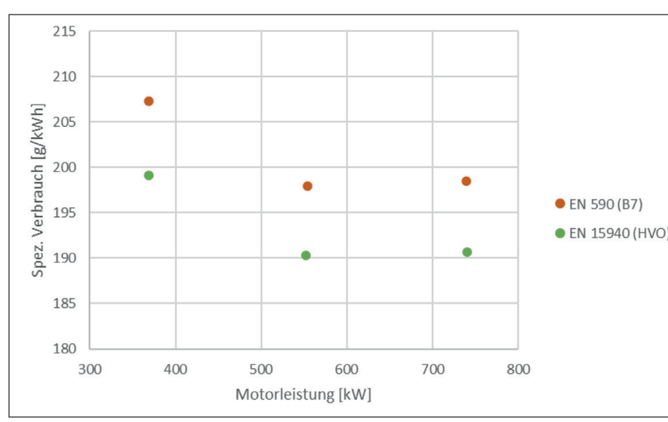

Figure 1:
Specific fuel consumption 12V1600R91

Similar results were measured on the 12V4000R84 unit. The following graph shows specific fuel consumption at individual measuring points on the full load curve. Here as well, a reduction of 2 % in specific fuel consumption was measured.

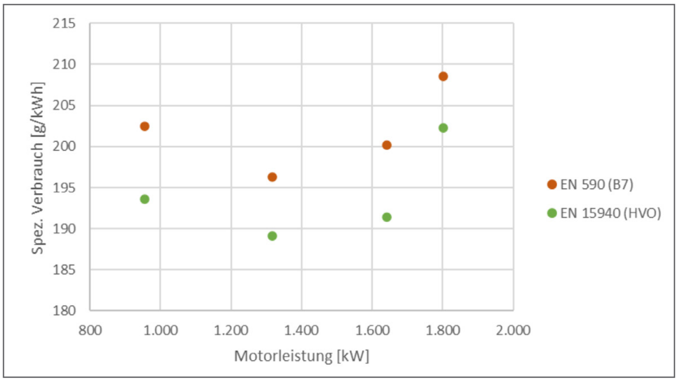

Figure 2:
Specific fuel consumption on the 12V4000R84 unit

NOx comparison

In general, synthetic fuels do not significantly affect NOx emissions on engines equipped with exhaust gas aftertreatment. This is due to the type of regulation and sensor deployed in the engine system which principally regulate NOx emissions downstream of the exhaust gas aftertreatment system. This finding is confirmed by the measurement results for Series 1600 Stage V as shown in Fig. 3. The difference between synthetic and diesel fuels in terms of nitrogen oxide emissions is no greater than the sensor tolerance range.

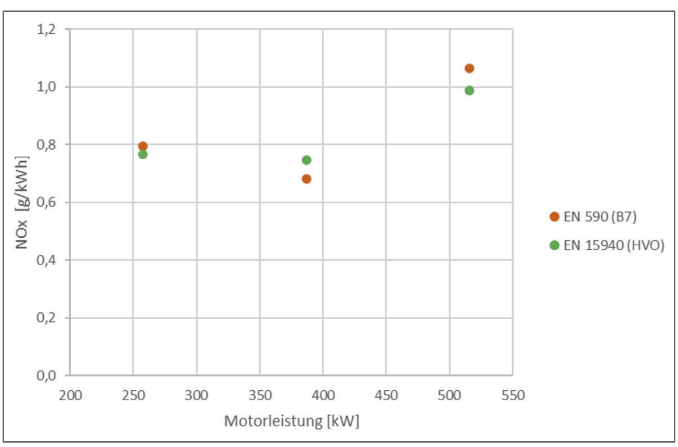

Figure 3:
NOx emissions on a 12V1600R91 unit

The test results for the 12V4000R84 unit also show that the NOx level with HVO-100 fuel is comparable to that of commercially available diesel fuel (EN590).

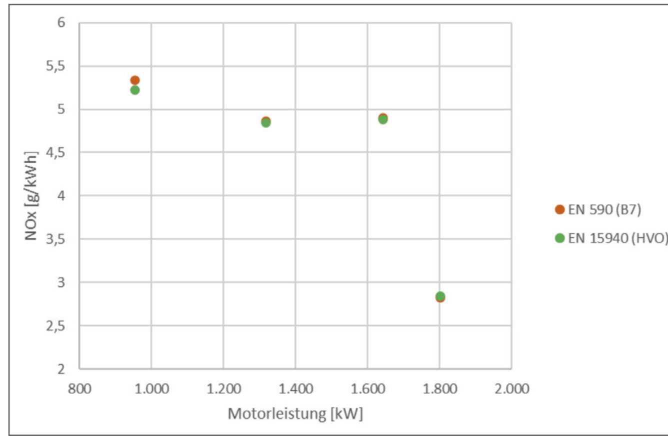

Figure 4:
NOx emissions on a 12V4000R84 unit

CO_2 comparison

The advantages of HVO are clean combustion with a reduction in CO_2 emissions of up to 90 % (depending on the production process and source material)* compared to fossil diesel fuel. As HVO fuel is produced using renewable raw materials, some of which is waste, its production, transport and combustion generate greenhouse gas quantities roughly equal to the amount previously absorbed during the growth of the plants used for biomass.

A further benefit is the reduction in CO_2 when synthetic fuels are combusted in the engine. The following graph shows the measurement points of the 12V1600R91 unit at a rated speed of 1900 rpm (Fig. 5) and of the 12V4000R84 unit over the full load curve (Fig. 6). A CO_2 reduction of 4 % was measured at the individual power nodes

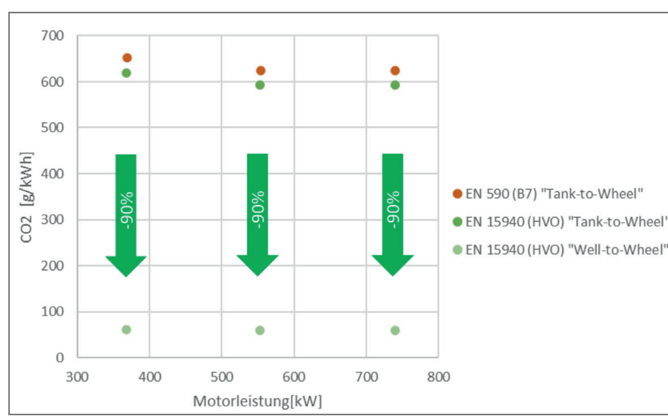

Figure 5:
CO_2 emissions on a 12V1600R91 unit

* Leading European manufacturers of HVO-100 fuels have determined a reduction in greenhouse gas emissions (CO_2 equivalent) of up to 90 % compared to fossil diesel over the product lifecycle. Implemented was the calculation method for lifecycle emissions and emission reductions set out in the EU Renewable Energy Directive II (2018/2001/EU, “RED II”).

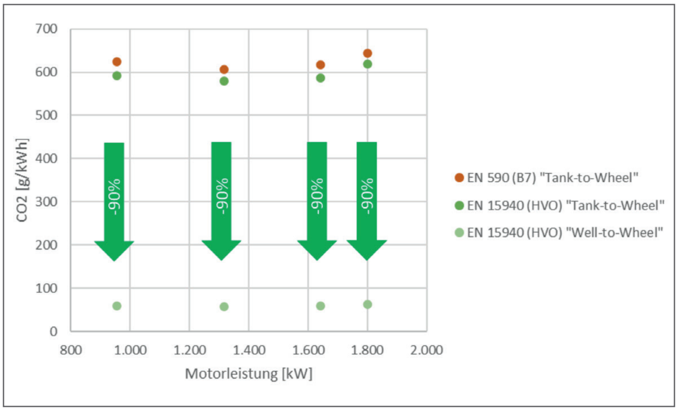

Figure 6:
CO_2 emissions on a 12V4000R84 unit

Particulate Matter (PM) comparison

A significant reduction in PM emissions could be observed during operation with HVO fuel. Upstream of the DPF, particulate emissions decreased by 30-40 % depending on the load point. When using synthetic fuels, generation of particulate emissions slows down very significantly as rated speed and power is approached. On engines with downstream filter systems, the particulate level is generally very low. The effects produced by clean combustion of synthetic fuels diminish significantly on engines without a downstream exhaust aftertreatment system, as is normally the case with EU Stage III A units.

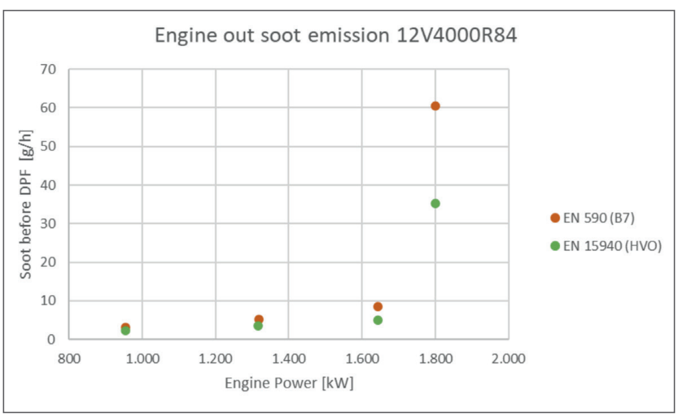

Figure 7:
Soot emissions upstream of the DPF on a 12V4000R84 unit

Field testing

Testing HVO-100 fuels on numerous rail engines under real-life conditions has shown the following:

— It is not necessary to modify maintenance intervals (e.g. to shorten oil change intervals as is the case with FAME fuels)
— There was no negative effect on rail vehicle performance.
— There was no negative effect on the rail vehicle range.
— Modification of the engine or rail vehicle is not required (genuine drop-in fuel).

Conclusion

Using HVO as a drop-in fuel resulted in a comparable engine performance in the applications tested. HVO fuel is therefore approved for use in ***mtu*** Series 4000, 1800 (EU V, EU IIIB, EU IIIA) and 1600 engines for rail applications. The tests showed that the engine performance parameters as per the nameplate could be equally achieved using synthetic fuels complying with the EN 15940 standard.

The tests also demonstrated the following advantages of HVO fuel over distilled diesel fuel:
— Lower PM and CO_2 emissions at nearly all load points
— Consistent performance

The use of paraffinic fuels complying with the EN 15940 standard – today in the form of HVO-100 or based in the future on other raw material sources such as municipal waste, plastic waste or agricultural and forestry residues and in the longer term eFuels– enables an immediate reduction in CO_2 emissions of up to 90 % (with HVO-100) or of up to 100 % with eFuels based on regeneratively produced hydrogen when available in the future.

Unlike other available alternatives, no modifications are required to engine, vehicle or infrastructure. Furthermore, since the volumetric energy densities of HVO and diesel fuel are at a similarly high level, operating procedures can be retained without restrictions in terms of performance capabilities, robustness, range, train payloads and refueling times. Established processes and infrastructures relating to e.g. fuel supply and vehicle maintenance can likewise be retained.

When converting fuel storage facilities from fossil diesel to HVO-100, it must be ensured that the tank is cleaned beforehand and that the fuel requirements specified in the valid Fluids and Lubricants Specifications are complied with when procuring the fuel.

Further information on HVO and references can be found here:
mtu ENGINES FUELED by HVO ALMOST CLIMATE-NEUTRAL (mtu-solutions.com)

Rolls-Royce Power Systems
www.mtu-solutions.com