Eni HVO fuel vs commercial EN590 Diesel emissions comparison on OHW engine dyno bench

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Abstract
A comparison between generic EN590 diesel fuel and an innovative Eni HVO fuel from renewable feedstocks is carried out on a heavy-duty powertrain (for off highway applications) installed on a dyno bench. The exhaust gas emissions as well as particle emissions are measured during different operating conditions and a combination of dynamic cycles (NRTC std) and static working points (NRSC std). Direct emissions, from tailpipe as well as engine out take points, result in a comparable level of different emission species (NO_x, CO, HC, PN) but, taking in account the entire "Well to Wheel" production process, it becomes clear that the CO_2eq emitted by the HVO fueled engine is circa 75% lower than std B7 Diesel fuel with the planed path to further increase to circa 83% difference by using only waste and residues feedstock. Finally, a study of possible calibration optimization is presented with the target to further improve the emission results of HVO fuel by fine tuning the engine combustion parameters.

Introduction
During the last few years there has been a strong push in Europe to control and reduce all substances harmful to the human being, following historical agreements that led to the "Kyoto protocol" [1]. In Europe have been issued numerous directives contemplated in the so-called "Fit for 55" CO_2 emission reduction proposal [2], the first step of which is the CO_2 reduction of the 13% by 2030 to reach carbon neutrality by 2050 (Figure 1).
In this scenario, it is highlighted the need not only to envisage vehicles developments and total new-generation Powertrains (Electrification, H_2, etc.), but also the need to find solutions for the actual vehicle fleet and special applications where liquid fuel is, from a technical point of view, mandatory (Aeronautics, Navals, etc.). An easy and directly applicable solution could be using plant-based HVO fuel, in the whole life cycle of which the "wheel-to-wheel" CO_2 emission is strongly reduced if compared to the equivalent fossil fuel one. (EN590 diesel).
CO_2eq emissions depend on the feedstock used for HVO production and on the raw materials, classified as Waste & Residues (advanced or double counting), allow the highest GHG reduction.
Average values of CO_2eq emissions, calculated on all Eni productions of 2021 and on the only Waste & Residues-derived raw materials, are reported in Table 1.

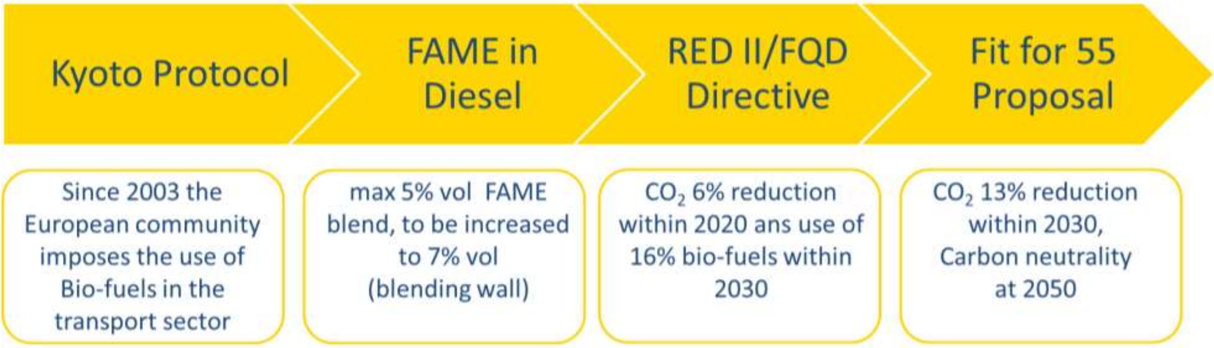

Figure 1. Evolution of antipollution directives

The reference diesel it's a standard "typical" diesel with a 5.8%vol FAME concentration (median value calculated from 300 commercial diesel samples taken in 2021 at Italian points of sale). CO_2eq emissions were calculated starting from the following values of carbon intensity:

- Fossil (94.2%vol) = 95 gCO_2eq/MJ (source: FQD)
- FAME (5.8%vol) = 14.95 gCO_2eq/MJ (source: in the absence of other official data, the weighted average of the carbon intensity of FAME purchased by Eni in 2021 was used - figure reported to GSE)

	Average CO_2eq emissions Well to Wheel – gCO_2/MJ
HVO diesel (ecofining ™) [3] - average value for all posts worked in 2021	21.4 (24% of commercial diesel)
HVO diesel (ecofining ™) – average value for the only Waste & Residues posts worked in 2021	14.38 (16% of commercial diesel)
Commercial diesel	90.7

Table 1. Average values of CO_2eq emissions

NRTC [4]: results of dynamic tests

The results of the test at the dynamometric bench were derived using an NRTC (Non-Road Transient Cycle) load profile, as per European regulations for the determination of emissions from internal combustion engines. The European NRTC cycle is a sum of mini-cycles representative of the various applications of off highway heavy duty engines in order to include an average load for each Powertrain under consideration.

Therefore, based on this type of NRTC load profile, we have the following plot which relates the "engine out" emission of the engine under consideration using either an EN590 commercial diesel fuel or Eni's HVO fuel (Figure 2):

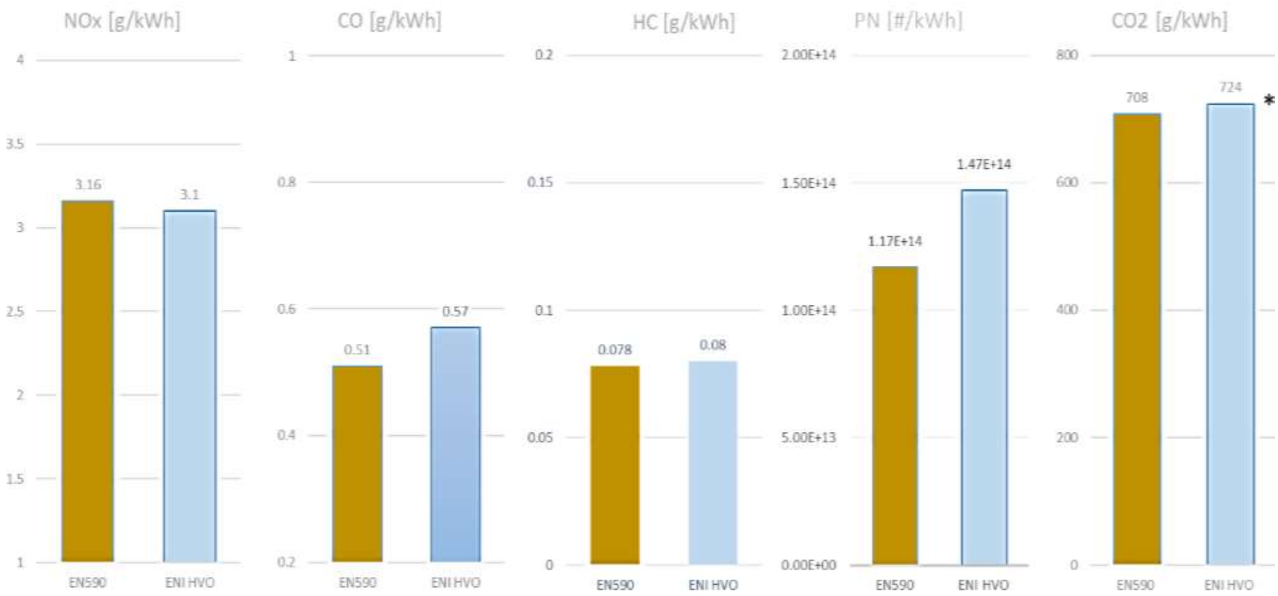

Figure 2. NRTC engine out emissions

* The total amount of CO_2 emitted by using HVO fuel, considering the entire life cycle of bio-based fuel according to the "Well to Wheel" methodology, is indeed much lower, reaching a value of 24% in the case of current HVO production and 16% in the case of using bio-based waste and residues. Therefore, the real CO_2 emission value is to be assumed to be 174 g/kWh, which can become 116 g/kWh in the case of new-generation HVO (waste and residue).

In (Table 2) is shown the overall difference in values of CO_2eq (on the entire “Well to Wheel” life cycle) for the HVO diesel (produced nowadays) and HVO W&R diesel (2nd gen produced by residuals and waste products). The gap, calculated in this way, is much bigger between traditional fuel (B7) and the new HVO biofuel (about 75%). This gap gets even bigger if we consider the latest-generation HVO biofuels produced by waste products and residuals (About 84%).

CO_2eq	g/MJ	gCO_2/kg	gCO_2/g	CO_2/kWh	Diff%
B7	90.7	3872.43	3.87	828.70	
HVO	21.4	933.47	0.93	205.36	-75.22
HVO W&R	14.38	627.26	0.63	138.00	-83.35

Table 2. NRTC engine out CO_2eq emissions

Always by using the NRTC profile we can compare the emissions at the “tailpipe” exhaust of the entire combustion gas management system, in the case of using EN590 diesel and using HVO, with the limits imposed by the current European Stage V norm for emissions of “off highway” vehicles and machinery. Indeed, (Figure 3) below enhances the fact that the measured emissions of the different species are far below the maximum regulatory limits for this Powertrain class (which is already subjected to a pre-ageing of approximately 4000h of operation representative of typical and severe working conditions). In particular, we have the specific and following observations:

- NO_x: Combustion of HVO fuel generates, under these fixed boundary conditions, less Nitrogen Oxides than the EN590 diesel standard, remaining approximately below 25% of the legal limit.
- CO: Carbon Monoxide emission using HVO are comparable to the std diesel and, as expected, both values are here below the allowed limits.
- HC: as far as it’s concerned the unburnt hydrocarbons, we notice an increase of the emitted quantities of the Powertrain with HVO compared to commercial diesel, probably because of the different external working conditions, even if they are still below the legal limits.
- PARTICULATE: particulate matter emissions in both test conditions obviously resulted low (and below the limits), witnessing the invariance of using different types of fuel as well as the efficiency of the filtering system (DPF) used by the Powertrain.

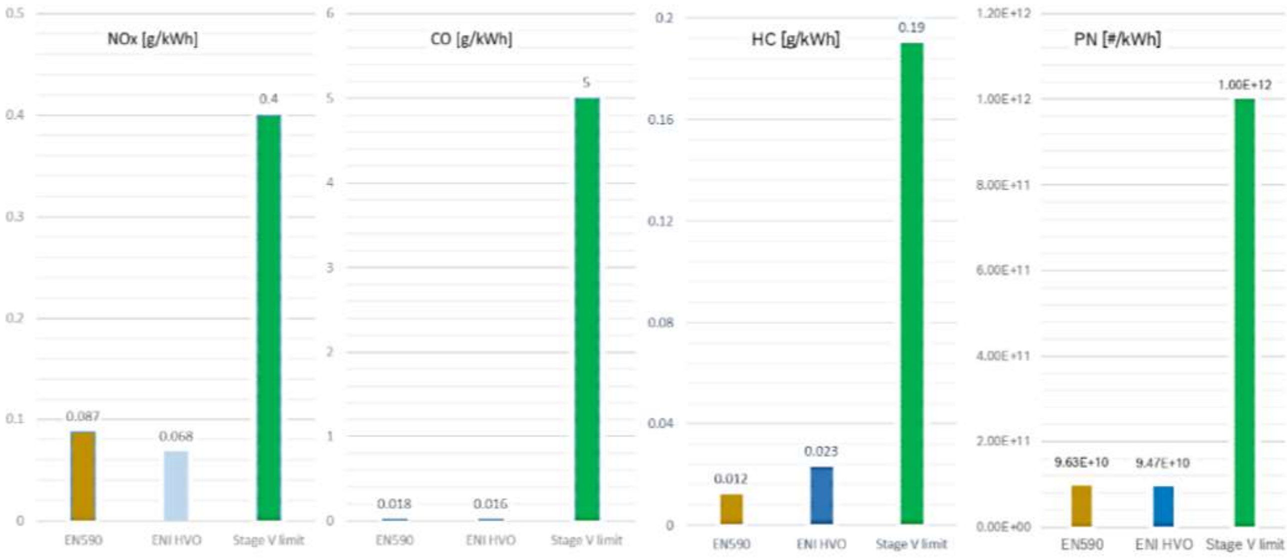

Figure 3. NRTC Tailpipe emissions vs Stage V limits

NRTC: sensitivity to the calibration variations

The (figure 4) below compare the “engine out” emission results using std EN590 diesel (in Brown) and HVO diesel (in Blue) in an NRTC cycle but varying the following emission parameters:

- SOI: "Start of main Injection" which represents the moment in which the main injection in the injections pattern (defined at each specific working point) occurs and is taken as a reference from other injection parameters. This parameter is varied from -2° to + 2° (crankshaft rotation angle) from the standard calibration.
- EGR: "Exhaust Gas Recirculation" which represents, in this specific application, the amount of recirculation of the exhaust gases in the combustion chamber thanks to the synergic intervention of the EGR high pressure valve and Throttle vale, after the appropriate cooling of the hot gases. This parameter is varied in a range from -10% to +10% (filling of the combustion chamber) from the standard calibration.

It can be noticed in particular the evolution of CO_2 emissions in [g/kWh] (in the upper trio) and NO_x in [g/kWh] (lower trio) in function of the EGR variations (horizontal axis) in the various SOI calibrations.

- CO_2 Graphs: particular deviations are not observed as the calibration varies, although it can be noticed a minimum increase pattern as the injection delay increases, due to a slight lower combustion efficiency. The difference between HVO and EN590 is definitely minimum but constant.
- NO_x Graphs: visible overlapping of results between EN590 and HVO. There is clearly an evident dependence (reduction) of NO_x emissions as the recirculation of the (O_2-poor) flue gas increases, and an even more evident reduction as the injection delay increases due to the lower combustion temperatures thus obtained.

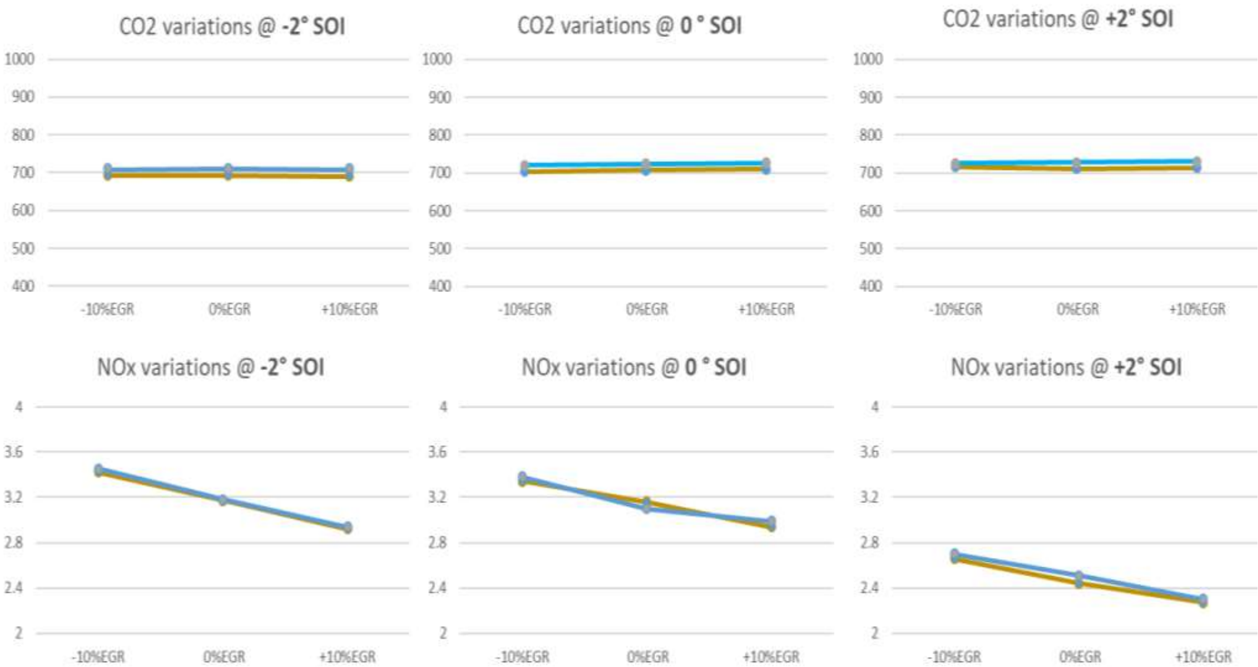

Figure 4. NRTC Engine out calibration variation for CO_2 and NO_x [g/kWh]

Conclusion

In this work commercial diesel fuel EN590 and Eni HVO diesel were compared analyzing pollutant emissions at the 'engine out', but also at the "tailpipe" exhaust outlet, during a NRTC operating cycle, by performing different engine calibrations (both EGR and SOI) using an off-highway engine 4-cyl (3.6 l, 105 kWh, 550 Nm). In addition, the same calibration variations were applied in a fixed-point cycle NRSC in order to evaluate their effect and to establish the opportunity of other calibration optimizations. Results can be collected in the following points:

- NRTC Cycle: comparable CO_2 values for both fuels were measured at the engine out. Similarly, we can register minimum variations for NO_x, CO, and HC emissions.
- NRTC Cycle: the biggest contribution to the overall "Well-to-Wheel" CO_2 reduction is consequently related to the productive process and, in particular, to the origin of raw materials necessary to obtain HVO. In fact, it is expected that the final CO_2eq emission value using HVO diesel (as currently produced), instead of commercial EN590 diesel (containing up to 7% biodiesel), implies a reduction of three quarters of the CO_2eq emissions due to transport considering the entire Well to Wheel process. Moreover, it is highlighted how the usage of waste materials or biological residues can further improve the overall emission gaining a CO_2eq reduction up to 83% of the current amount using commercial diesel, as shown in the (Table 3).
- NRTC Cycle: Exhaust emissions (tailpipe) for both fuels are comparable in their behaviour in the relevant points examined and below the limits of the Stage V standard.
- NRSC [4] Cycle: variations of SOI and EGR parameters on CO_2 emissions have a limited impact even when HVO and EV590 are compared. However, there is a possibility to obtain a better specific calibration for HVO to optimize emissions.
- NRSC: the influence of the variations of SOI and EGR parameters on NO_x, CO, HC and, especially, Particulate emissions is clearly visible, however in this case the optimal calibration seems pretty close, hence the margin of improvement is narrow.
- Finally, a rapid introduction of the considered Eni HVO fuel in the market appears to be possible for the considered parameters without adaptation of the calibration and application. Thus, the examined HVO drop in fuel represents a simple possibility to directly contribute to decreasing CO_2-emission especially on existing stock of ICE vehicles.

References

[1] Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), http://unfccc.int/resource/docs/convkp/kpeng.pdf
[2] "Fit for 55" proposal by EU commission, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4754
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[4] Non-Road Transient Cycle, Non-Road Steady Cycle (ISO 8178), https://dieselnet.com/standards/cycles/nrtc.php https://dieselnet.com/standards/cycles/iso8178.php