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Executive Summary

In the frame of the joint research project “Robust and Efficient Processes and Technologies for Drop-In Renewable Fuels for Road Transport” (REDIFUEL), the potential of novel bio-fuels in reducing the Well-to-Wheel CO_2 emissions from heavy-duty transportation is investigated. In such an analysis, the Tank-to-Wheel CO_2 emissions during vehicle real duty operation have a significant contribution in the overall Well-to-Wheel CO_2 emissions formation. In the present study, the Tank-to-Wheel CO_2 emissions formation of a class 5 long-haul truck is analyzed through dedicated vehicle simulations. For this purpose, a mean value powertrain simulation frame capable of real time simulation is set up. For the investigation of the Tank-to-Wheel CO_2 emissions reduction potential of the REDIFUEL blends in comparison to the fossil diesel B0 fuel, a methodology for the transfer of trends in fuel efficiency and CO_2 emissions observed through the fuels comparison on the single cylinder engine to the multi-cylinder engine simulation domain is described. The CO_2 emissions results are analyzed in the VECTO long-haul cycle for a heavy-duty truck with a gross vehicle weight of up to 40 t. In the last part of the study, an estimation of the overall Tank-to-Wheel CO_2 emissions reduction potential in a heavy-duty truck fleet powered solely by REDIFUEL blends in 2030 is conducted by considering forecasts and projection for future powertrain efficiency improvement technologies for heavy-duty trucks operated under long-haul conditions. A 21 % CO_2 emissions reduction for the fuel blend of 60 vol% B0 / 40 vol% $RF_{A30P070}$ and a 22 % using the fully renewable blend of 93 vol% $RF_{A30P070}$ / 7 vol% UCOME in respect to the 2018 fossil diesel baseline have been identified.

Contents

Tables:

1 Introduction

In this part of the project, the impact of the REDIFUEL blends on the Tank-to-Wheel (TtW) CO_2 emissions is studied through dedicated vehicle simulations. At first, the generic vehicle simulation approach is presented. This includes the summary of the main specifications of the considered vehicle, the selection of the relevant real-duty cycle for the CO_2 emissions evaluation as well as the assumptions met for the definition of a heavy-duty (HD) trucks virtual fleet. As next, the approach and the assumptions for the integration of the renewable fuel in the vehicle simulation environment are described. For the simulations, a validated mean value engine model is used. The CO_2 emissions results of the fossil diesel B0 and the REDIFUEL blends are analysed in detail. In the last part of the work, the FEV Europe GmbH projections of future technologies trends in HD diesel powertrain development for long-haul operation are summarized. Based on these projections, an overall TtW CO_2 emissions reduction estimation in the 2030 horizon can be realized for future HD trucks that use the REDIFUEL blends, 40 vol% $RF_{A30P070}$ diesel and 93 vol% $RF_{A30P070}$ / 7 vol% UCOME, as fuel.

2 Methods

In this chapter, the individual research methods and the necessary steps for the vehicle simulations are being thoroughly described. At first, the generic vehicle simulation approach as well as the main powertrain specifications of the investigated HD truck are summarized. Next, the approach and the assumptions for the integration of the REDIFUEL blends combustion efficiency characteristics in the mean value simulation are described.

2.1 CONSIDERED HD VEHICLE AND GENERIC VEHICLE SIMULATION APPROACH

The simulated HD truck is based on the FEV N3 class HD tractor demonstrator. The truck has a 4x2 axle configuration, with maximum allowed laden mass above 16 t and engine power above 165 kW. The vehicle belongs to the subgroup 5 long-haul (5-LH) category according to the VECTO CO_2 regulation [1]. The emissions classification of this truck follows the EU VI-C standards. The vehicle’s exhaust aftertreatment system consists of a DOC (diesel oxidation catalyst), DPF (diesel particulate filter) and a SCR (selective catalytic reduction). In Table 1 the main specifications of the considered vehicle are summarized.

Table 1: HD truck specifications

Parameter	Unit	Value
Engine power	kW	350
Engine displacement	L	12.8
Exhaust gas recirculation	-	High Pressure Cooled
Axle configuration	-	4 x 2
Transmission	-	12 Gears AMT
Gross vehicle weight (N3 class)	t	40
Curb weight (Empty tractor + trailer)	t	14.5 t
Exhaust aftertreatment system	-	DOC – DPF – SCR
Type approval	-	EU VI-C

In Figure 1 and Figure 2, the powertrain and exhaust aftertreatment system (EATS) layout of the considered truck are respectively depicted.

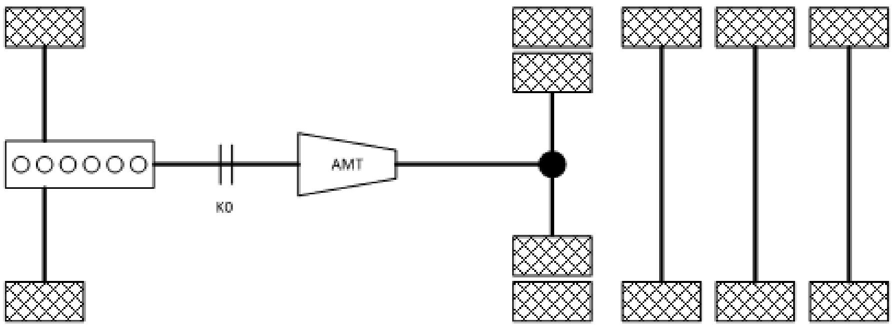

Figure 1: HD truck powertrain layout

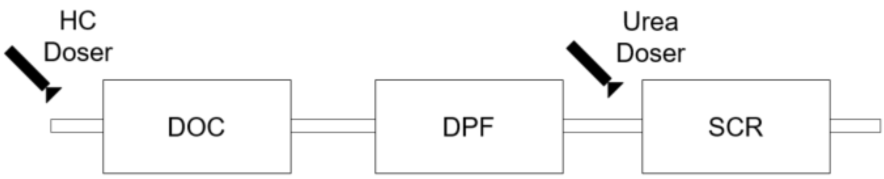

Figure 2: HD Truck EU VI-C EATS layout

For this vehicle subgroup, the CO_2 emissions regulatory cycles for newly manufactured vehicles as defined by the VECTO regulation [1] are the VECTO long-haul and the VECTO regional delivery (RD). However, as shown in Figure 3 around 95 % of the subgroup 5 HD trucks operate under long-haul conditions, while only 5 % of these trucks operate under regional delivery conditions. Thus, the long-haul operation gains automatically more importance for this vehicle subgroup and is therefore put on focus in this study. The considered cycle for the CO_2 emissions analysis for B0 and REDIFUEL blends is depicted in Figure 4.

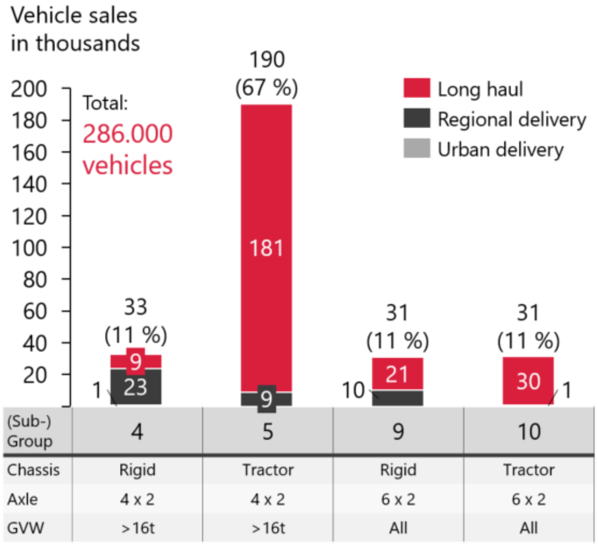

Figure 3: Share of vehicles sales of the CO_2 regulated subgroup in EU in 2018 [2]

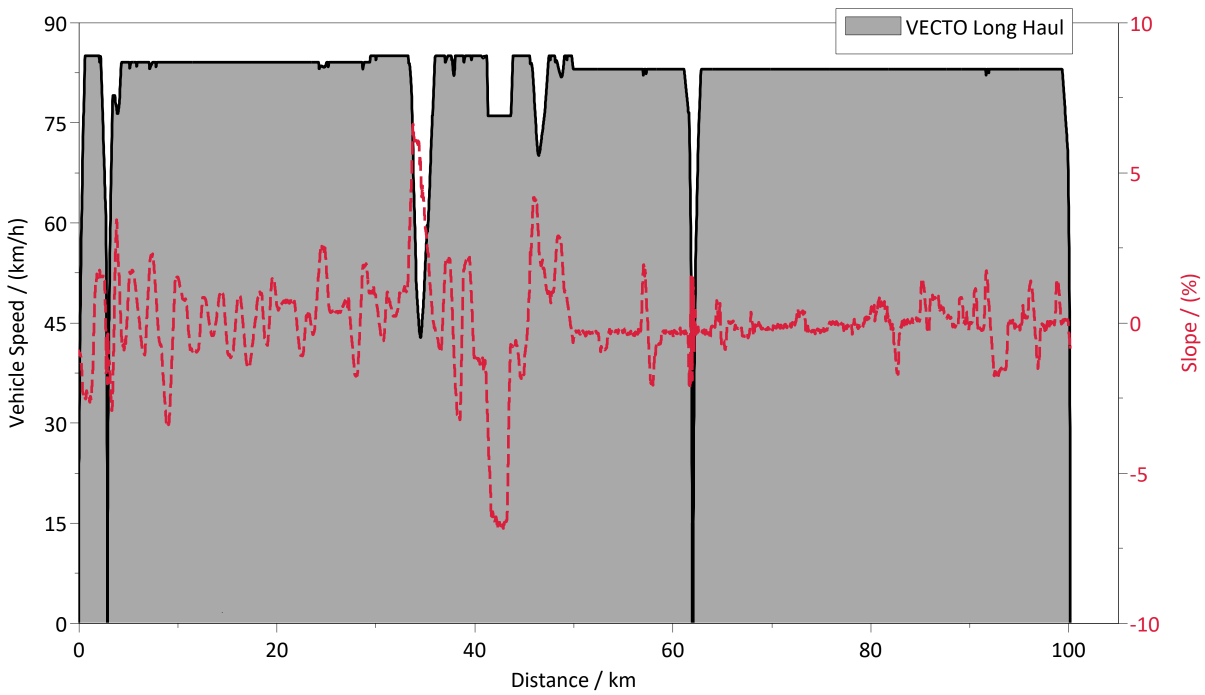

Figure 4: VECTO Long-Haul cycle [3]

The considered average yearly payload that is assumed for the simulations and the analysis is 8.8 t, resulting in a total vehicle mass of 23 t, see Table 2. The annual-averaged payload value has been identified for the life cycle assessment by the project partner VUB.

Table 2: Vehicle overall mass for the regulated payloads

Vehicle Subgroup	Average yearly payload / t	Average yearly vehicle total mass / t
5-LH	8.8	23

In Figure 5, a schematic explanation of the simulation toolchain is depicted.

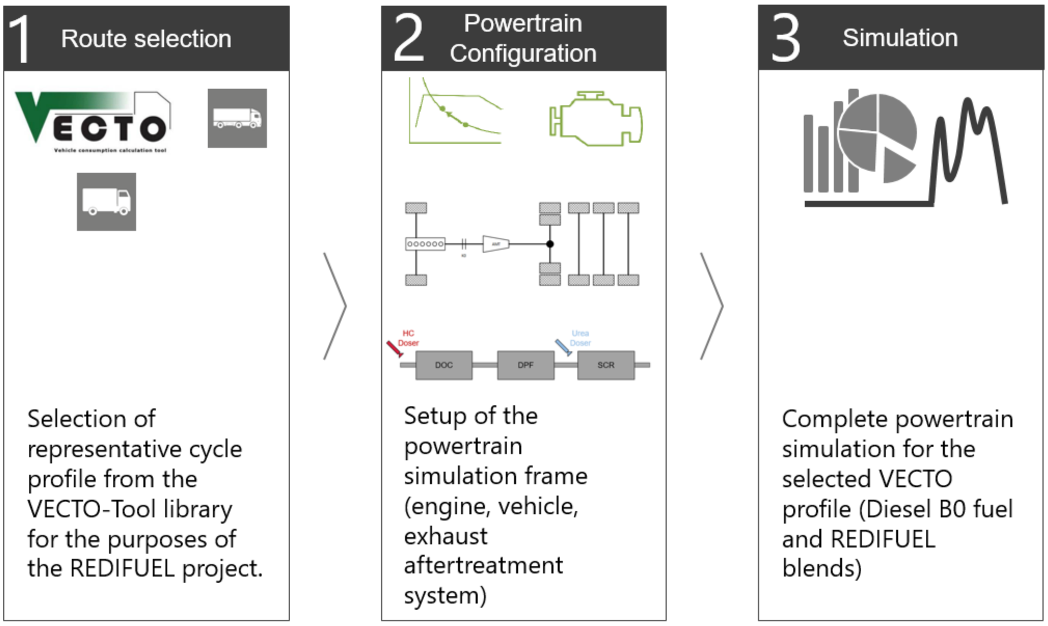

Figure 5: Schematic explanation of the vehicle simulation toolchain

2.2 APPROACH FOR THE SCE MEASUREMENTS INTEGRATION IN THE VEHICLE SIMULATION ENVIRONMENT

For the estimation of the CO_2 emissions reduction potential through the usage of the REDIFUEL blends, a method for the correction of the fossil diesel fuel results based on findings and trends shown on the single cylinder engine (SCE) had to be established. In the diagram depicted in Figure 6, the individual steps for the correction of the fossil diesel B0 fuel results based on the trends obtained by comparing the SCE measurements with REDIFUEL blends measurements are shown.

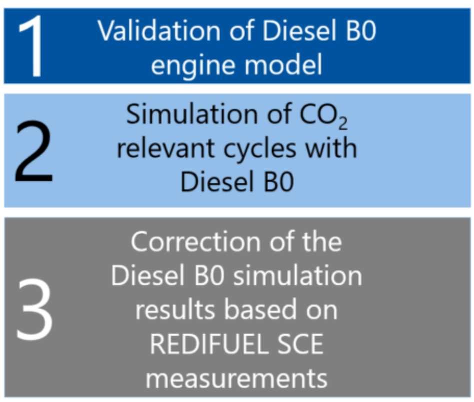

Figure 6: Approach for the integration of the REDIFUEL blends combustion efficiency characteristics in the complete vehicle simulation environment

For the decision on the most appropriate correction approach of the B0 simulation results, different scenarios have been investigated. It has been concluded that the correction of the final simulation result of the validated B0 engine model, i.e. the model output, is the most adequate for the purposes of this research study. The main reason for this is the predominance of the stationary operation of the truck at cruising conditions, see Figure 7. This allows the very good prediction of the overall CO_2 emission performance in the whole cycle, by only optimizing the engine operation at the cruising conditions engine operating area. In Figure 7, the engine operating points' distribution in the VECTO long-haul cycle is analyzed for the VECTO regulation relevant payloads, namely 2.6 t and 19.3 t [1].

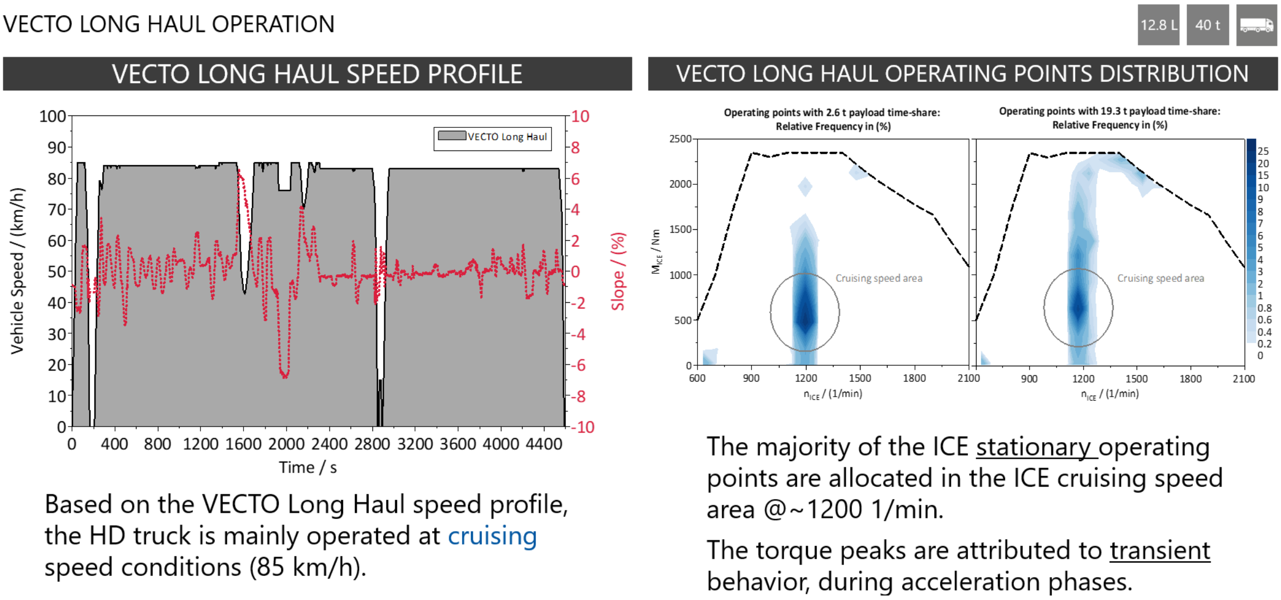

Figure 7: VECTO long-haul cycle analysis

For the B0 baseline model correction and the simulation of the Tank-to-Wheel CO_2 emissions of the REDIFUEL blends, one constant correction factor for the blend 40 vol% $RF_{A30P070}$in diesel and a second for the blend 93 vol% $RF_{A30P070}$ / 7 vol% UCOME have been applied. The factors were derived by comparing the SCE engine-out measurements of these blends with B0 diesel at cruising point operating conditions, see Figure 8. The correction factor is applied to the simulated cumulative CO_2 emission result for B0. For the blend 60 vol% B0 / 40 vol% $RF_{A30P070}$ the considered CO_2 emissions reduction factor in respect to the baseline B0 reference is 2.5 % and for the 93 vol% $RF_{A30P070}$ / 7 vol% UCOME blend 4.5 % as shown in Figure 8.

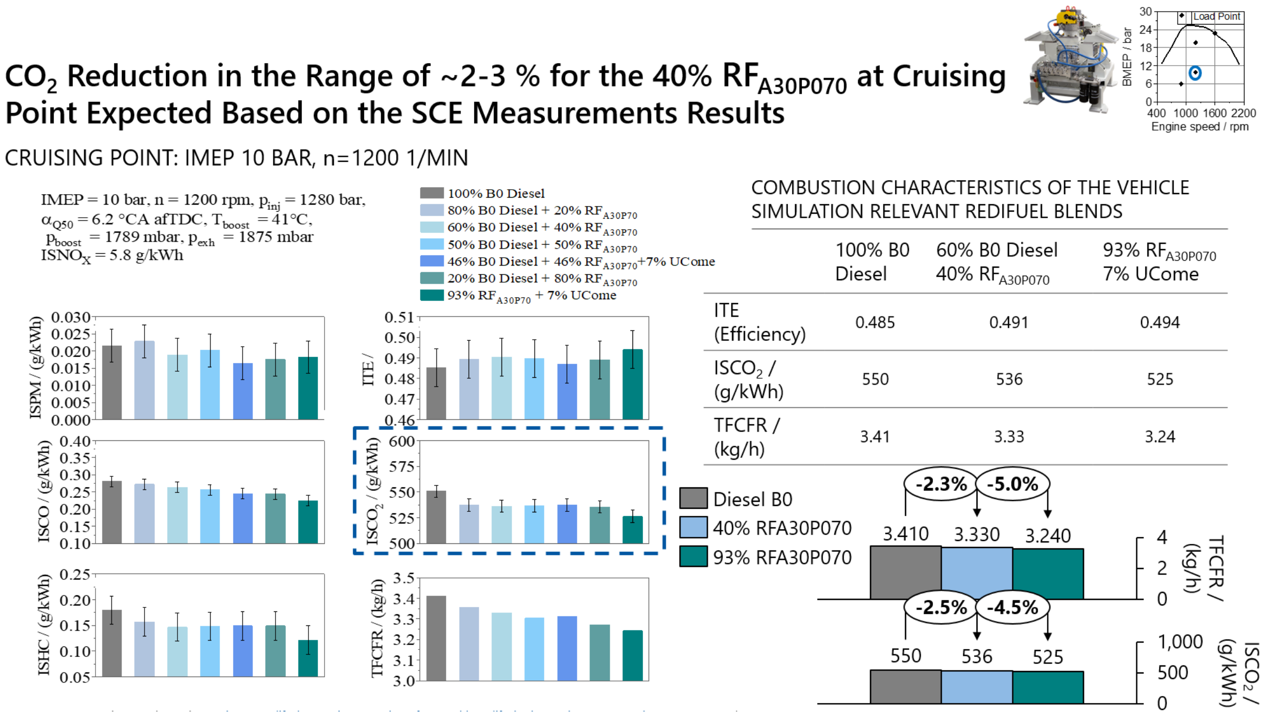

Figure 8: Comparison of REDIFUEL blends combustion efficiency properties at cruising operating conditions [4-6]

3 Results

3.1 VEHICLE AND FLEET SIMULATION OF FUEL EFFICIENCY AND CO_2 EMISSIONS IN EXISTING HD VEHICLE FLEETS

The assumed HD trucks fleet consists of around 180,000 5-LH trucks, see Figure 3. As first step, a complete powertrain simulation with B0 has been conducted to estimate mostly accurately the actual diesel baseline fuel consumption and CO_2 emissions of a 2018 subgroup 5-LH classified vehicle with 8.8 t yearly average payload. The results are shown in Figure 9.

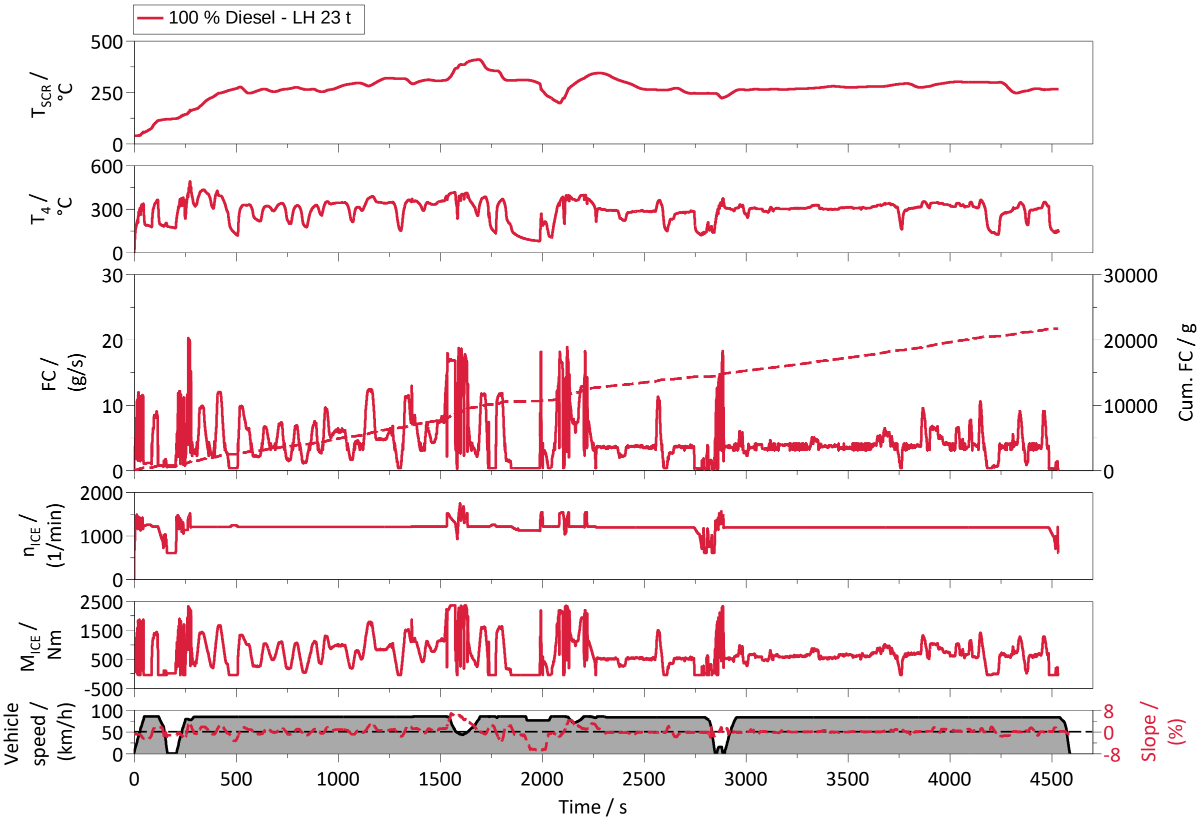

Figure 9: B0 diesel simulation results in VECTO cycles

As next, the CO_2 emissions for each individual fuel have been estimated based on the B0 results and with the assumptions for corrections described in chapter 2.2. For the B0 CO_2 emissions results estimation from the fuel consumption 0.835 g/l fuel density and 2670 $gCO_2/(kgFuel)$ carbon content have been considered. Since the REDIFUEL blends are Drop-In capable, it is assumed for the simulation to have a similar engine-out NO_x level with this of the B0. Thus, the focus in the present study is put on the CO_2 emissions only. The CO_2 emissions results are summarized in Figure 10.

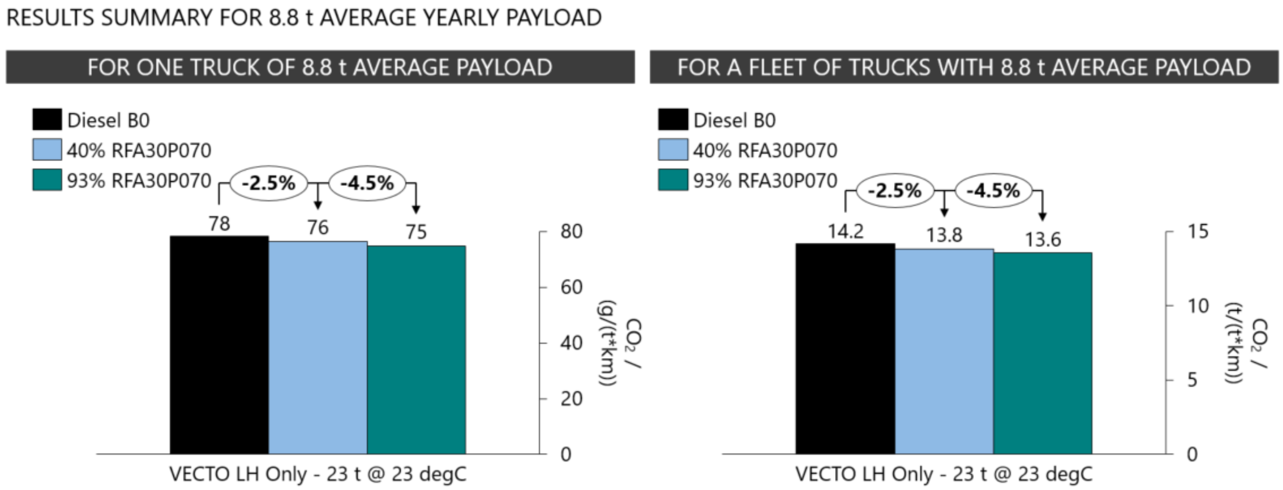

Figure 10: Summary of Tank-to-Wheel CO_2 emissions results for the investigated 5-LH truck with 8.8 t payload - Comparison of Diesel B0 with the REDIFUEL blends 60 vol% B0 / 40 vol% $RF_{A30P070}$ and 93 vol% $RF_{A30P070}$ / 7 vol% UCOME

3.2 VEHICLE AND FLEET SIMULATION OF FUEL EFFICIENCY AND CO_2 EMISSIONS IN FUTURE HD VEHICLE FLEETS

In the last part of the results section, projections for future technologies trends in the HD diesel powertrain of long-haul trucks based on FEVs forecasts are considered. Based on the forecasts, the diesel internal combustion engine vehicles will remain the predominant vehicle category in the market in both scenarios, with a penetration of more than 85 % being expected for this category. Simultaneously, different powertrain fuel efficiency measures, including vehicle aerodynamic drag reduction, rolling resistance reduction and electrification, are expected to contribute to an overall CO_2 emissions reduction of around 19 % until 2030 compared to the 2018 baseline. These trends are summarized in Figure 11.

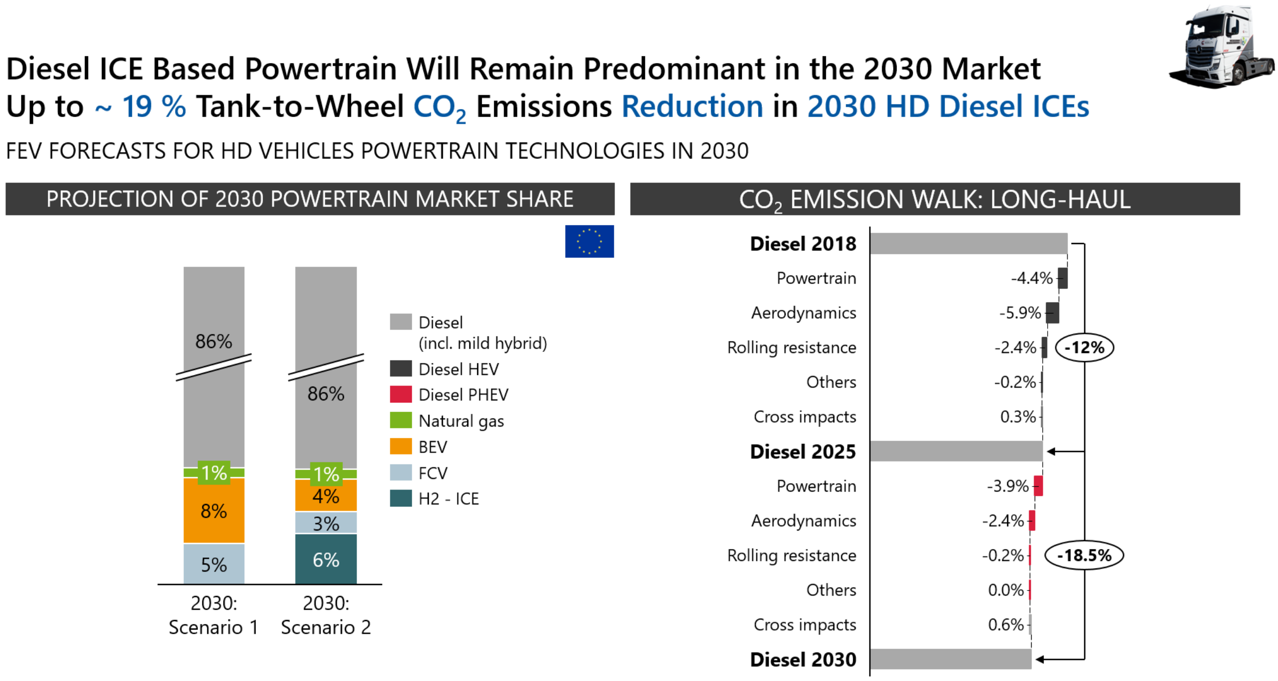

Figure 11: 2018-2030 technologies trends in the HD diesel powertrain of long-haul trucks [2]

Based on the trends shown above, an estimation of the overall CO_2 emissions reduction potential of future 5-LH HD fleets in the long-haul operation was conducted. Two scenarios have been evaluated for the 2030 vehicle fleet: 1) 2030 powertrain with 40 vol% $RF_{A30P070}$in diesel blend and 2) 2030 powertrain with 93 vol% $RF_{A30P070}$ / 7 vol% UCOME blend. The results are summarized in Figure 12.

Summary of Tank-To-Wheel CO_2 Emissions for the 5-LH Subgroup Truck
Comparison Diesel B0 with 40% RFA30P070 and 93% RFA30P070

RESULTS SUMMARY FOR 8.8 t AVERAGE YEARLY PAYLOAD

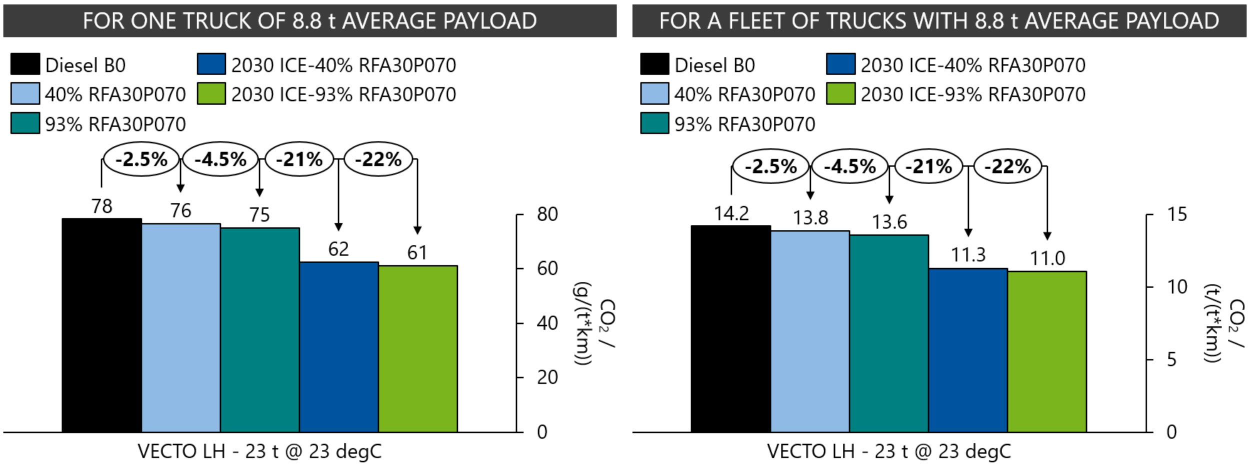

Figure 12: Summary of Tank-to-Wheel CO_2 emissions results for the investigated 5-LH subgroup truck with 8.8 t payload by considering future technologies trends in HD diesel powertrain of long-haul trucks - Comparison of B0 diesel with the 60 vol% B0 / 40 vol% $RF_{A30P070}$ and 93 vol% $RF_{A30P070}$ / 7 vol% UCOME blends

4 Discussion and Conclusions

The REDIFUEL blends showed a considerable decrease of Tank-to-Wheel CO_2 emissions that can have a significant contribution in the 2030 target of 30 % CO_2 emissions reduction in the HD on-road sector compared to the 2018 baseline fleet emissions. This is attributed to the lower carbon content as indicated through the theoretical carbon mass flow rate (TFCFR) shown in Figure 8 [4-6]. As general trend, an increase in RF_{A30P70} share leads to a direct reduction in indicated specific carbon dioxide ($ISCO_2$) emissions and thus lower tailpipe CO_2 emissions. However, the greatest benefits in terms of CO_2 emissions reduction for REDIFUEL is expected thanks to its renewable nature, which can lead to an overall Well-to-Wheel (WtW) CO_2 emissions reduction proportional to its share in the blend. Based on the simulation results an up to 21 % CO_2 emissions reduction for the 60 vol% B0 / 40 vol% $RF_{A30P070}$ blend and a 22 % with 93 vol% $RF_{A30P070}$ / 7 vol% UCOME in respect to the 2018 fossil B0 diesel baseline have been identified for the 2030 powertrain. These are translated to 2.9 tCO_2/(t*km) and 3.1 tCO_2/(t*km) less TtW CO_2 emissions per year for the 60 vol% B0 / 40 vol% $RF_{A30P070}$ blend and the 93 vol% $RF_{A30P070}$ / 7 vol% UCOME respectively in comparison to the 2018 fossil B0 baseline.

5 Deviations from Annex 1

There are no deviations with respect to the description of work.

6 References

[1] REGULATION (EU) 2019/1242 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 June 2019

[2] FEV Webinars, Future Truck Series June-July 2020, “Heavy duty on-road powertrain concepts to achieve 2025 and 2030 CO_2 regulations”; Webpage: https://www.fev.com/de/aktuelles/webinare/aufzeichnungen.html and https://fev-live.com/ack/wp-content/uploads/sites/5/2020/10/Future-Truck-Series_1st_Session_GHG_Trends_and_Legislation.pdf, Accessed on 09-07-2021

[3] VECTO Tool, Webpage: https://ec.europa.eu/clima/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/vehicle-energy-consumption-calculation-tool-vecto_en, Accessed on: 01-03-2022

[4] Yadav et. al, Renewable Drop-In Fuels as Immediate Measure to Reduce CO_2-Emissions of Heavy-Duty Applications, ATZ live, Internationaler Motorkongress 2020

[5] REDIFUEL: Robust and Efficient processes and technologies for Drop In renewable FUELs for road transport, Achieved Results, Webpage: https://redifuel.eu/engine-screening-of-renewable-redifuel-mixtures-jan-2020-month-16-36/, Accessed on: 01-03-2022

[6] Deppenkemper, K.; Yadav, J.: REDIFUEL – D3.7 – Report on Emission and Efficiency Impact on Existing Engines. EU Horizon2020 Grand Agreement No. 817612 – REDIFUEL, Brussels, (2021).

7 Acknowledgement

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6 - OWI – OWI Science for Fuels gGmbH - DE
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8 Risk register

Risk No.	WP	What is the risk?	Probability of risk occurrence[1]	Effect of risk[2]	Solutions to overcome the risk
1	3.4	Possible engine damage (rebuild / repair not possible in time)	2	1	Procurement of spare parts, spare cylinder head; definition of engine shut-down limitations
2	3.4	Lead time of ordered components too long	2	2	Regular (monthly) alignment of delivery time plan with suppliers

[1] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

[2] Effect when risk occurs: 1 = high, 2 = medium, 3 = Low