On-Board CO_2 Capture - an innovative approach

Décio Magioli Maia
Valéria Said de Barros Pimentel
Ricardo Almeida Barbosa de Sá
Instituto Nacional de Tecnologia - INT

Jadson Cláudio Belchior
Geison Voga Pereira
Universidade Federal de Minas Gerais - UFMG

ABSTRACT

The article describes the development of an onboard CO_2 capture system aimed at reducing emissions from heavy-duty diesel vehicles. A real-world driving emission testing cycle (RDE) was developed, suitable for the requirements of relevant standards and legislation, using a truck adapted to working conditions with the developed adsorbent material and the local characteristics of the vehicle manufacturer. Vehicle adaptations included the development of a reactor for encapsulating the adsorbent material without pressure drop, and the integration of a monitoring system for RDE testing. A series of RDE tests were conducted without the adsorption reactor, using blends of diesel, biodiesel, and green diesel (Hydrotreated Vegetable Oil - HVO) at different percentages, with no statistical difference observed. The tests measured CO, CO2, THC, NMHC, CH4, and NOx emissions, and with the reactor, the system's capacity to adsorb CO_2 was evaluated. The results showed excellent CO_2 capture. Tests with capture only during the urban cycle demonstrated that CO_2 capture was even more significant, indicating higher effectiveness in this cycle due to the lower temperature exposure of the adsorbent material. This project was carried out in partnership with INT, UFMG, a vehicle manufacturer, and the FUNDEP - ROTA 2030 program.

INTRODUCTION

In the 1st National Inventory of Atmospheric Emissions [1], projections indicated that by the end of the year 2020, the road transport sector could emit about 60% more than in 2009, which would represent a total of around 270 million tons of CO_2.

According to the National Energy Balance [2], the year 2023 broke the record for fossil fuel consumption for transport, accounting for 71% of total energy consumption of fossil diesel oil. Although this did not meet the 2011 projections, it still reached 217 Mt CO_2-eq. The emissions related to diesel oil consumption were not higher thanks to the share of biodiesel in its composition, which increased by 19.2%. This can be explained by the increase in the biodiesel blend percentage to 12% (B12) starting in April 2023. As a result of these developments, Brazil's transportation sector achieved an energy matrix composed of 22.5% renewable sources in 2023, compared to 22% the previous year [2].

An increase in biomass energy consumption is expected, due to the progressive rise in biodiesel content blended with petroleum diesel, the increase in anhydrous ethanol content in gasoline C, improvements in production efficiency, and innovations in the development of new biofuels such as green diesel [3].

However, much remains to be done, as the projection for 2030 indicates an approximately 21% increase in CO_2 emissions associated with the energy matrix [2].

Therefore, the use of a fuel that improves combustion efficiency and contains higher renewable content becomes essential.

In this context, HVO – hydrotreated vegetable oil – emerges as a promising alternative. It is a synthetic liquid biofuel that can be blended with diesel, and it is free of aromatics, oxygen, and sulfur. Composed of linear-chain paraffinic hydrocarbons, it is produced through catalytic hydrotreatment of triglyceride, based biomass [4]. It falls under the green diesel category and is already being used internationally, including in ternary blends.

Unlike common issues reported with biodiesel-diesel blends such as physicochemical degradation, oxidation, water contamination, sludge and resin formation, and consequent engine damage, HVO blends lead to reduction in bench emissions of CO and HC, in addition to reducing NOx [5], when compared to diesel-biodiesel blends alone.

The need to reduce emissions also drives regulatory programs to gradually lower allowable emission limits over time, with compliance verified through standardized laboratory tests.

EURO VI Standards [6] reduced the limits for particulate matter and nitrogen oxides (NOx) by approximately 90% compared to EURO III standards. However, they did not improve urban air pollution as much as expected [7]. Various studies showed that vehicles approved in laboratories were emitting between 7 to 40 times more NOx on the streets than the regulatory limit [8,9,10]. To address this issue, since 2017, Europe has added a *Real Driving Emission* (RDE) test to the vehicle approval process, requiring vehicles to meet emission limits while driving on actual roads using portable measuring systems.

The RDE test represents real-world driving conditions far better than laboratory tests, and the procedure is more robust against vehicle calibration tactics meant to comply only during standardized lab testing (cycle beating), as well as against fraudulent practices [10].

However, for the RDE procedure to be effectively applied to the Brazilian context, it must be adapted to the specific characteristics of Brazilian cities. To be more effective and meet local needs, it should be enhanced through some adaptations or minor adjustments that do not compromise the method but rather align it more closely with our reality [11].

The Brazilian standard equivalent to EURO VI, called PROCONVE P8 (Program for the Control of Air Pollution by Motor Vehicles – Phase 8 for heavy vehicles) [12], has been in effect since 2023 for commercial motor vehicles (buses and trucks), requiring RDE testing as a complement to laboratory tests.

Thus, identifying a ternary blend of two renewable fuels (biodiesel and HVO) with diesel has become highly relevant, aiming to increase the renewable share in the fuel mix and reduce vehicular emissions. However, this should occur without compromising vehicle performance, which can be affected by increased biodiesel content, potentially causing filter clogging, higher fuel consumption, increased engine component wear, and premature aging of the catalytic system.

In addition to identifying a ternary blend (diesel, biodiesel and HVO), it is important to conduct tests under real driving conditions (RDE), adapted to the realities of Brazilian cities.

To further reduce CO_2 emissions, studies have been proposed aiming to lower these emissions through processes involving solid sorbents, which are typically in the form of metal oxides and hydroxides, among which calcium and magnesium stand out. CO_2 interacts with the surface of these oxides through a reaction known as carbonation [13]. The addition of magnesium oxide to calcium oxide increases the specific surface area through the formation of mesopores, which reduces sintering and prolongs the high efficiency of the sorbent [14].

The results of this study showed a reduction in CO_2 emissions from heavy-duty vehicles through experiments using ternary blends, increasing the share of renewable sources in fossil fuel, along with the development of an onboard CO_2 capture system with high mitigation potential. The data were obtained from RDE tests adapted to the specific characteristics of Brazilian cities. This approach, spanning from biofuel composition to emission mitigation, is unprecedented in terms of its impact on the performance of heavy-duty vehicle engines.

STUDY OF STANDARDS AND LEGISLATION – METHODOLOGY DEFINITION

RDE test methodology was developed to identify vehicle emissions under real traffic conditions. The duration of the RDE test is based on the World Harmonized Transient Driving Cycle (WHTC), which is performed on a chassis dynamometer. This cycle simulates real-world operating conditions and is divided into three segments lasting 600 seconds each [15]. The first segment simulates an urban route, the second a rural route, and the third a highway route.

The RDE route and consequently the urban, rural, and highway segments is directly related to the type of vehicle. In this project, the vehicle used was a truck certified under the PROCONVE P7 phase, with a payload capacity of 5,263 kg, which classifies it as an N2 category vehicle (Table 1).

The American [16,17,18], European [15,19] and Brazilian [20,21,22,23] legislations were analyzed and compared. This comparison revealed that Brazilian legislation is strongly based on European standards. Therefore, the research focused on the similarities between Brazilian and European legislation in order to implement a customized RDE methodology adapted to local conditions and vehicle characteristics, as detailed in the Appendix.

RDE CYCLE USED

For the development of this project, a heavy-duty diesel truck was used, as described in Table 1 below:

Table 1. Technical Vehicle Information

VEHICLE INFORMATION	
Category	N2
Year of manufactory	2018
WEIGHTS AND CAPACITIES	
Curb Weight	2737 kg
Gross Vehicle Weight rating (GWRT)	8000 kg

Payload capacity (payload body)	5263 kg
ENGINE	
Type	Euro V, 3.0-liter, twin-turbo charged with intercooler and EGR (Exhaust Gas Recirculation)
Number do Cylinders	04 in-line
Number of valves	16
Maximum Power - cv @ rpm	170 cv @ 3.500rpm
Maximum Torque - kgf.m (N.m)@rpm	40,8 kgf.m (400N.m) @1.500-2.200 rpm
Electronic Fuel Injection	Bosch – Common Rail -1.800 bar
Fuel	Diesel

A portable onboard emissions measurement system (OBS-ONE) was installed on the truck. The OBS-ONE is designed for certifying engines/vehicles under real-world road conditions, in compliance with the specifications of CONAMA Resolution No. 490 [22]. It measures emissions concentrations (CO, CO_2, THC, NO_x, NO_2), air-fuel ratio, exhaust flow rate, GPS data, ambient conditions (temperature, humidity, pressure), and calculates emissions mass.

Test planning followed Regulation (EU) 2016/1718 [24], which defines the RDE test requirements, including vehicle preparation and test route conditions. The test was conducted using standard B10 S10 diesel, with the vehicle loaded at 3,000 kg, equivalent to 57% of its gross payload capacity, as shown in Figures 1 and 2. The regulation also specifies route characteristics, detailing the proportions of acceleration, deceleration, cruising, idle time, and overall test length.

Figure 1. Elevated Exhaust

Figure 2. Exhaust with expansion pipe and loading

By analyzing all experimental results related to work performed and CO_2 emissions, the proposed cycle was adjusted to best represent actual conditions while complying with regulatory requirements and ensuring equipment safety.

The final route totaled 186.09 km over 3h42 min29s, resulting in a work ratio (kWh) of 6.8 compared to the certified engine test value. The route was distributed as 48.9% urban, 22.6% rural and 28.5% highway, generating approximately 630.7 g/kWh and a fuel consumption of 6.2 km/L.

Exhaust gas temperatures were also mapped at the engine outlet, as shown in Figure 3.

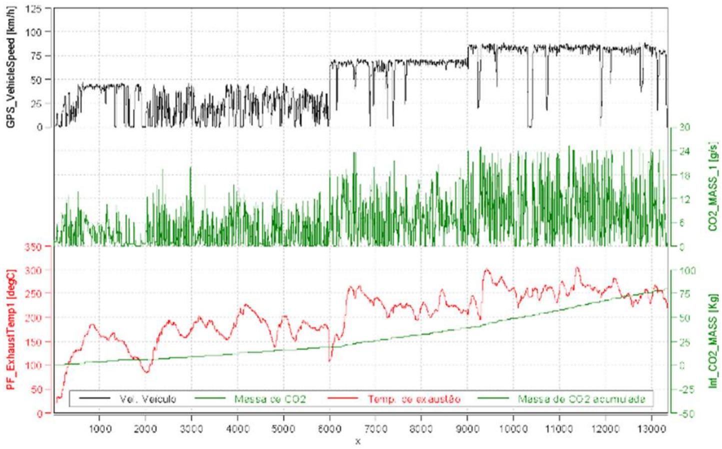

Figure 3. Exhaust Gas Temperature

Due to the high exhaust gas temperatures observed, an expansion pipe was installed (see Figure 2) to reduce temperatures closer to 120°C, considered ideal for maximum CO_2 capture efficiency by adsorbent material.

REACTOR DEVELOPMENT

Initial studies by UFMG supported the design of a prototype used in lab tests to define the geometry of the encapsulator (reactor) and the adsorption material load for the initial phase, as illustrated in Figure 4.

Figure 4. Initial encapsulator

Preliminary tests showed that packing the material directly in the full exhaust flow caused excessive pressure drop, preventing the engine from reaching its maximum torque and power.

The INT team, working closely with the truck manufacturer and UFMG, developed a basic design for installing a CO_2 absorption reactor on the truck's exhaust system. Based on this, the manufacturer fabricated a prototype pipe section to house the reactor, which was then installed on the vehicle, as shown in Figures 5 to 7.

Figure 5. Designed encapsulator (reactor)

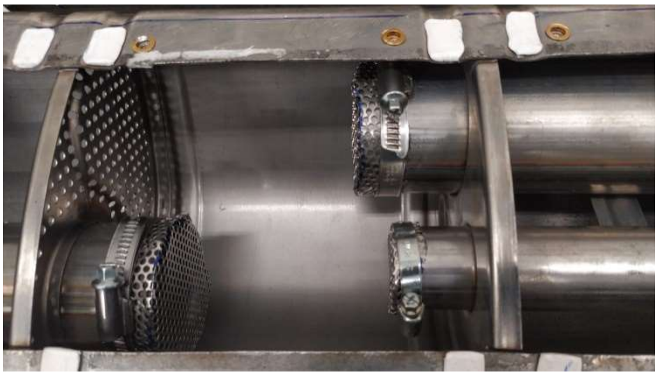

Figure 6. Internal detail of encapsulator

Figure 7. Truck with reactor installed

With this setup, the system reached the target temperature range of 120°C to 150°C at the entrance of the added pipe section—mostly during the urban cycle. During rural and highway cycles, exhaust gas temperatures exceeded optimal levels, resulting in low CO_2 capture in those segments and over the complete test.

The initial road tests aimed to assess whether the vibration would cause the adsorbent material to fragment during RDE emissions testing. After the tests, the material was sent to UFMG for further analysis, including checking for fragmentation critical for optimizing the formulation used in subsequent CO_2 adsorption tests.

For the tests measuring RDE emissions, efforts were made to maximize the use of UFMG's developed adsorbent material by using one or both chambers of the reactor, as shown in Figure 5. However, when both chambers were filled, excessive pressure drop again compromised engine performance. The decision was made to fully load only one chamber, as shown in Figure 8, totaling about 3 kg of compacted material. Testing with the three fuels was then initiated.

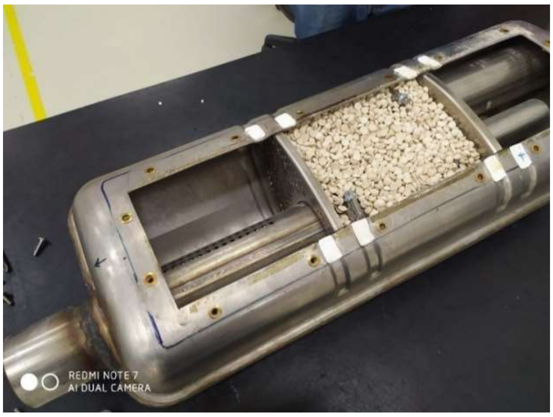

Figure 8. Reactor filled in one chamber

TESTS PERFORMED AND RESULTS OBTAINED

Throughout the project, the following fuels were evaluated:

A → diesel oil + 10% biodiesel – B10 (reference)

B → diesel oil + 15% biodiesel – B15

C→ diesel oil + 15% biodiesel + 5% HVO – B15HVO5

The RDE tests were divided into two stages:

1. To evaluate the differences between the three fuels in terms of pollutant emissions (CO, CO_2, THC, NMHC, CH_4, NOx) and FUEL CONSUMPTION, without the carbon capture system installed on the truck; and
2. To evaluate the effectiveness of the capture system (reactor and adsorbent material) regarding the retention of CO_2 emitted by the truck's exhaust system.

The RDE tests were carried out for mixtures A, B, and C, with at least three repetitions to ensure statistical validation. Whenever anomalies or events raised doubts about their influence on the results, the RDE tests were excluded following an outlier analysis of the response variables studied: CO_2, CO, THC, NOx, NMHC, CH_4, and FUEL CONSUMPTION.

The results showed no statistically significant difference among the evaluated fuels for all pollutants, as exemplified in Figure 9 for CO_2.

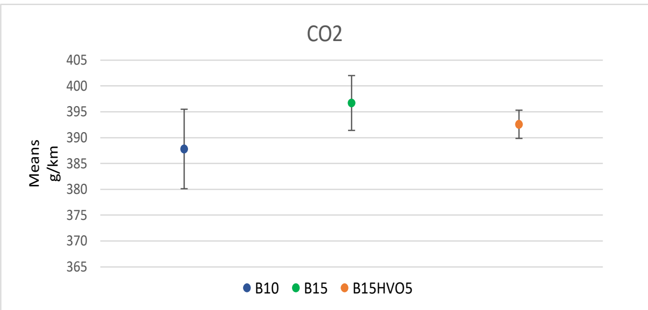

Figure 9. Means and Confidence Intervals for CO_2 results

Regarding the evaluation of the CO_2 capture system, comparative tests were carried out using fuel C (B15HVO5), WITH and WITHOUT the capture system installed on the truck. The choice of fuel C aimed to investigate the possible effect of capturing CO_2 present in exhaust emissions, resulting from the combustion of diesel oil mixtures with 20% renewables (15% biodiesel and 5% HVO).

The RDE tests, performed WITH and WITHOUT CO_2 capture throughout the complete cycle, resulted in an excellent 7.7% CO_2 capture, as shown in Table 2 and Figure 10, demonstrating good efficiency of the reactor/adsorbent material system used in the process.

Table 2. Summary of statistical results

	B15HVO5 WITH X WITHOUT CAPTURE (RDE FULL TEST)	B15HVO5 WITH CAPTURE (ONLY URBAN) X WITHOUT CAPTURE (RDE FULL TEST)
CO	NO DIF	---
CO2	**7,7% <**	---
URBAN CO2	---	**17,2%<**
THC	NO DIF	---
CH4	NO DIF	---
NMHC	NO DIF	---
NOx	NO DIF	---

No DIF - without significant statistical difference

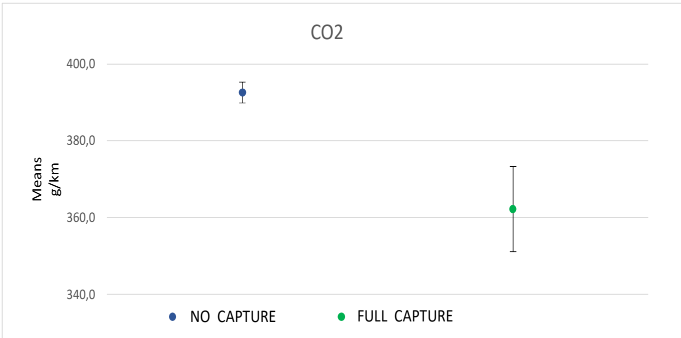

Figure 10. Means and Confidence Intervals of CO_2 results for tests WITH and WITHOUT CO_2 capture

The same tests, with capture performed only during the urban cycle, showed that CO_2 capture was even more significant at 17.2%, highlighting that it was more effective in the urban cycle due to the lower exhaust gas temperatures, close to 120°C, which is optimal for the adsorbent material's performance.

This finding suggests the possibility of improving the results with the development of new reactor designs featuring cooling systems and/or temperature controls to maintain the temperature closer to 120°C throughout the entire test.

STATISTICAL ANALYSIS

The statistical treatment was applied in four stages. First, a sweep for possible outliers was conducted across all RDE tests performed for each fuel. This analysis guided the exclusion of trials with the aim of selecting the three valid trials used in the next stage.

Next, an evaluation of the Normality and Homogeneity of the data was carried out to verify the feasibility of applying parametric tests. For this purpose, the assumptions of normality and homogeneity of variances were tested for each numerical variable.

Based on the results, the hypothesis of normality was rejected for the variables "THC," "NMHC," and "Fuel Consumption." Similarly, the homogeneity of variances hypothesis was rejected for the variables "THC" and "Fuel Consumption." In these cases, non-parametric statistical analysis is recommended.

The first two stages guided the next two stages, applying Non-Parametric Statistics (Kruskal-Wallis Test) to the variables THC, NMHC and Fuel Consumption, and Parametric Statistics (Analysis of Variance – ANOVA) to the other variables CO, CO_2, CH4 and NOx, with emphasis on the CO_2 variable, the main focus of this study.

In the application of the statistical technique of Analysis of Variance – ANOVA, a significance level α (alpha) of 95% (2σ) was adopted.

CONCLUSION

The results presented herein demonstrate that the performance of fuels in real driving condition emission tests (RDE), the results showed no statistically significant differences in pollutant emissions (CO, CO_2, THC, NMHC, CH4 and NOx) or in fuel consumption among the three fuels evaluated (B10, B15, and B15HVO5).

The tests performed with CO_2 capture during the full RDE cycle resulted in an excellent 7.7% CO_2 capture rate, demonstrating good efficiency of the adsorbent material used in the process. The same tests, when compared to CO_2 emissions with capture performed only during the urban driving cycle, showed an even more significant capture of 17.2%, due to the lower temperature, close to 120°C, to which the adsorbent material was exposed. This finding suggests the potential for improved results through the development of new cooled reactor designs and/or temperature control systems to maintain it closer to the recommended 120°C throughout the test.

Consequently, for every 100,000 km driven, current emissions are around 40 tons of CO2. By applying the system developed in this project, about 3 tons of CO_2 per 100,000 km driven per truck could be prevented from being released into the atmosphere a significant amount, especially when compared to the use of biofuels, where CO_2 is only partially recovered by flora in the lifecycle. In this case, the CO_2 is captured and can be used as a raw material for various products.

Despite the differences found, it can be concluded that the adsorption mechanism and the adsorbent material proved to be quite efficient, indicating potential for improvement and implementation of the technology in future projects, such as designing a cooled reactor system that maintains the exhaust gas temperature at around 120°C, increasing the quantity of adsorbent material in a higher-capacity reactor, and also verifying the material's saturation rate to define the replacement interval.

Additionally, it will be important to develop a regeneration process for the adsorbent material, as well as optimal methods to convert the captured CO_2 in to products beneficial to society.

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CONTACT INFORMATION

For further information regarding this article, please find the contact details of the main author below:

Eng. Decio Magioli Maia
National Institute of Technology – INT
e-mail: decio.maia@int.gov.br
tel: +55 (21) 981215461

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APPENDIX

Appendix 1 - Comparative spreadsheet Brazil X European Union x Adapted Procedure - RDE Tests

Location	Brazil	European Union	Adapted Procedure
Certifying Entities	National Environment Council (CONAMA), Brazilian Institute of Environment and Renewable Natural Resources (IBAMA)	European Commission (EC) and United Nations Economic Commission for Europe (UNECE)	-
Program / Fase	PROCONVE P8	EURO VI	-
Gaseous Pollutants Analyzed	Total Hydrocarbons (THC), Non-Methane Hydrocarbons (NMHC), Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Particulate Matter (PM), Methane (CH4), Ammonia (NH3)	Total Hydrocarbons (THC), Non-Methane Hydrocarbons (NMHC), Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Particulate Matter (PM), Methane (CH4), Ammonia (NH3)	Total Hydrocarbons (THC), Non-Methane Hydrocarbons (NMHC), Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Particulate Matter (PM), Methane (CH4), Ammonia (NH3)
Rules / Regulations / Documents Used	Normative Instruction No. 20/2020 (DOU) CONAMA Resolution No. 490/2018 (UNECE) No. 49 ABNT NBR ISO 16185	CE (UE) 595/2009 CE (UE) 582/2011 CE (UE) 2017/2400 Diretiva 2007/46/CE CE (UE) 2016/427 CE (UE) 2016/1718 CE (UE) 2019/1242 (UNECE) nº 49	Normative Instruction No. 20/2020 (DOU) CONAMA Resolution No. 490/2018 (UNECE) No. 49.06 step C ABNT NBR ISO 16185
Vehicle Condition and Operation for Testing	At least one vehicle equipped with a master engine (sample size) representing each driving interval, as defined in Article 6 of CONAMA Resolution No. 490/2018, plus one urban bus; to meet the requirements outlined in paragraphs 1 and 2 of Article 14 of CONAMA Resolution No. 490/2018, a minimum of three vehicles tested per engine family (sample size) will be required to achieve the approval criterion of the Emissions Verification Cycle During the Vehicle's Useful Life (ISC). There is no need for these vehicles to be equipped with the master configuration of the family (19) (Art. 14 R.CONAMA 490/2018).	The selected engines and vehicles must be used and registered within the European Union. The vehicle should have been in service for at least 25,000 km. The OBD system should be monitored to verify the proper functioning of the engine. All anomaly indications and diagnostic trouble codes should be recorded in the OBD system memory, with any necessary repairs carried out. It is recommended that the vehicles operate under normal daytime traffic conditions..	At least one vehicle equipped with a master engine (sample size) representing each driving interval, as defined in Article 6 of CONAMA Resolution No. 490/2018, plus one urban bus; to meet the requirements outlined in paragraphs 1 and 2 of Article 14 of CONAMA Resolution No. 490/2018, a minimum of three vehicles tested per engine family (sample size) will be required to achieve the approval criterion of the Emissions Verification Cycle During the Vehicle's Useful Life (ISC). There is no need for these vehicles to be equipped with the master configuration of the family (19) (Art. 14 R.CONAMA 490/2018).
PEMS Installation	The electrical power supplied to the PEMS must come from an external power unit and not from a source that draws energy directly or indirectly from the vehicle's engine being tested. The installation of the PEMS equipment should not influence the vehicle's emissions or performance. Whenever possible, the PEMS should be mounted in a way that minimizes the impact of elements such as ambient temperature changes, ambient pressure variations, electromagnetic radiation, mechanical shocks and vibrations, and environmental hydrocarbons. The mounting must follow the manufacturer's instructions for the PEMS.		
Samples	The planned tests should be conducted using B7 reference diesel fuel (7% v/v biodiesel), in accordance with ANP Resolution No. 764 of 2018, or commercial diesel fuel, according to the current specifications set by ANP, at the discretion of the manufacturer and/or importer. Mileage accumulation should be done exclusively with commercial diesel fuel. The fuel temperature must follow the manufacturer's recommendations. Fuel samples should be collected. The lubricating oil must be specified by the manufacturer and be representative of the lubricating oil available on the market; the specifications of the lubricating oil used for the test should be recorded and presented with the test results. Lubricating oil samples should also be collected (Art. 12 CONAMA 490/2018).	The fuel must meet the specifications issued by the manufacturer. The test fuel should be a commercial fuel covered by Directive 98/70/EC and relevant CEN standards, or a reference fuel as specified in Annex IX of Regulation (EU) 582/2011. Fuel samples should be collected. For exhaust after-treatment systems that use a reagent to reduce emissions, the reagent must be commercial and conform to the engine manufacturer's specifications. A sample of the reagent should be collected, and it should not be frozen.	The tests will be conducted using the following fuels: B10 (Commercial) B15 B15 + HVO5
Initial Conditions	The sampling of emissions, measurement of exhaust parameters, and recording of engine and ambient data should begin before starting the engine. The data evaluation should start after the engine coolant temperature has reached 343 K (70 °C) for the first time, or after the coolant temperature has stabilized within ±2 K over a 5-minute period, whichever occurs first, but never more than 20 minutes after engine startup.		
Dynamic Conditions	Dynamic conditions include the effects of road inclines/declines, headwinds, driving dynamics (accelerations and decelerations), and auxiliary systems on the energy consumption and emissions of the test vehicle. The verification of the normality of dynamic conditions should be carried out after the test is completed, using the recorded PEMS data.		

Appendix 1 (cont.) - Comparative spreadsheet Brazil X European Union x Adapted Procedure - RDE Tests

Location			Brazil			European Union			Adapted Procedure
Test	Categories		N1	N2	N3	N1	N2	N3	N2
	Maximum Load		Up to 3,5 ton	Between 3.5 and 12 tons.	Above 12 ton	Up to 3,5 ton	Between 3.5 and 12 tons.	Above 12 ton	Between 3.5 and 12 tons.
	Vehicle Useful Mass		The payload of the vehicle should correspond to 50-60% of the vehicle's maximum load. (p. 8, EU R2016/1718).						55% and 100% load
	Duration		Greater than 5 times the work during the WHTC cycle or 5 times the mass of CO_2 released during the WHTC cycle.			Between 4 and 8 times the work performed during the WHTC cycle or 4 to 8 times the CO_2 emitted during the WHTC cycle (page 3, EU 2018/932).			Greater than 5 times the work during the ETC cycle or 5 times the mass of CO_2 released during the ETC cycle.
	Trip Composition	Urban	(8)			34% of the total distance (EU 2016/1718)	45% of the total distance (EU 2016/1718)	30% of the total distance (EU 2018/932)	45% of the total distance (76,5km)
		Rural	(8)			33% of the total distance (EU 2016/1718)	25% of the total distance (EU 2016/1718)	25% of the total distance (EU 2018/932)	25% of the total distance (42,5km)
		Highway	(8)			33% of the total distance (EU 2016/1718)	30% of the total distance (EU 2016/1718)	45 % of the total distance (EU 2018/932)	30% of the total distance (51km)
	Average Speed	Urban	(8)			15 to 30 km/h (EU 2016/1718)	15 to 30 km/h (EU 2016/1718)	15 to 30 km/h (EU 2016/1718)	-
		Rural	(8)			60 to 90km/h (EU 2016/1718)	45 to 70km/h (EU 2016/1718)	45 to 70km/h (EU 2016/1718)	-
		Highway	(8)			> 90 km/h (EU 2016/1718)	> 70 km/h (EU 2016/1718)	> 70 km/h (EU 2016/1718)	-
	Speed Limit	Urban	(8)			maximum 50 km/h (EU 2016/1718)	maximum 50 km/h (EU 2016/1718)	maximum 50 km/h (7) (EU 2016/1718)	maximum 50 km/h
		Rural	(8)			maximum 90 km/h (EU 2016/1718)	maximum 75 km/h (EU 2016/1718)	maximum 75 km/h (EU 2016/1718)	minimum 50km/h and maximum 75 km/h
		Highway	(8)			-	-	-	minimum 75km/h
	Ambient Temperature		A Temperatura mínima deve ser de -7°C e a máxima deve repeitar a equação : T=-0,4514*(101,3-pb)+38(°C) onde pb é a pressão atmosférica.						The minimum permitted temperature is -7°C and the maximum is 33°C
	Altitude		Abaixo de 1600 metros acima do nível do mar(Pressão mínima de 82,5kPa)						Approximately 1000 meters above sea level
	Altitude Difference		(8)			—	—	—	-
	Cumulative Altitude Gain		(8)			—	—	—	-
Data Analysis Method			Moving Average Window (MAW)			Moving Average Window (MAW) Power Binning (PB)			Moving Average Window (MAW)
WHTC Emissions Limit	CO(g/kWh)		4			4			Record
	THC(g/kWh)		0,16			0,16			
	NH3(ppm)		10			-			
	Nox(g/kWh)		0,46			0,46			
	PM(g/kWh)		0,01			0,01			
	PN(#/kWh)		6,0 x 10^11			6,0*10^11			

(1) Includes urban stops. Stopping periods, defined as periods where vehicle speed is less than 1 km/h, must represent 6% to 30% of the operating time under urban conditions. Urban driving must include several stopping periods of 10 s or more. However, each stopping period cannot exceed 300 consecutive seconds; otherwise, the trip will be considered invalid. The average speed (including stops) during cold start periods, as defined in Annex D, point 4, must also be between 15 and 40 km/h.

(2) The route must be selected such that the test is not interrupted and data are continuously recorded, in order to achieve the minimum defined test duration.

Appendix 1 (cont.) – Comparative spreadsheet at Brazil x European Union x Adapted Procedure – RDE Tests

(3) The maximum payload is the difference between the technically permissible maximum laden mass of the vehicle and the mass of the vehicle in running order, as specified in Annex I of Directive 2007/46/EC.

(4) In addition to the In-Service Conformity (ISC) sample selection criteria provided in Annex 8 of UNECE Regulation No. 49, the following criteria must also be met: a) For passenger vehicles with a Gross Vehicle Weight (GVW) less than or equal to 5 tonnes, vehicles with mileage equal to or less than 160,000 km and with a service life equal to or less than five years shall be selected; b) For vehicles with a GVW between 3.856 tonnes and 16 tonnes, and for passenger vehicles with a GVW between 5 tonnes and 7.5 tonnes, vehicles with mileage equal to or less than 300,000 km and with a service life equal to or less than six years shall be selected; c) For vehicles with a GVW greater than 16 tonnes, and for passenger vehicles with a GVW greater than 7.5 tonnes, vehicles with mileage equal to or less than 700,000 km and with a service life equal to or less than seven years shall be selected; d) For light commercial vehicles with a GVW between 3.5 tonnes and 3.856 tonnes, whose engine is derived from a parent engine type-approved for a heavy-duty vehicle, the mileage range must follow the criteria applied to the parent engine from which it is derived.

(5) As provided in § 3 of Art. 12 of CONAMA Resolution No. 490, of November 16, 2018, the parameters to be verified in real-driving emissions (RDE) tests, such as test distance and duration, the percentage of urban, rural, and motorway driving, maximum speed, average speed, idle periods, road gradient, relative positive acceleration, cold start, and fuel, shall be approved by IBAMA.

(6) When evaluating the results obtained using the Moving Average Window (MAW), at least 50% of the windows must have more than 15% of the maximum engine power; otherwise, the test must be considered void and needs to be repeated.

(7) The urban, rural, and motorway shares can be determined based on geographical coordinates (via a map), or by the first acceleration method. The trip composition is defined for the categories below (by "approximately," the target value of ± 5% is understood):
a) For M1 and N1 vehicles, the trip shall consist of approximately 34% urban driving, 33% rural driving, and 33% motorway driving;
b) For N2, M2, and M3 vehicles, the trip shall consist of approximately 45% urban driving, 25% rural driving, and 30% motorway driving. M2 and M3 vehicles of classes I, II, or A, as defined in UNECE Regulation No. 107, shall be tested with approximately 70% urban driving and 30% rural driving;
c) For N3 vehicles, the trip shall consist of approximately 30% urban driving, 25% rural driving, and 45% motorway driving.
For the purpose of assessing trip composition, the duration of the share shall be calculated from the moment the coolant temperature first reaches 343 K (70 °C), or after the coolant temperature has stabilized within ± 2 K over a 5-minute period, whichever occurs first, but no later than 15 minutes after engine start. The driving period until the coolant reaches the temperature of 343 K (70 °C) shall consist of urban driving. Categories M1, M2, M3, N1, N2, and N3 are classified according to Annex II of Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007, as per the table below (GVW = Gross Vehicle Weight):

(8) As provided in § 3 of Art. 12 of CONAMA Resolution No. 490, of November 16, 2018, the parameters to be verified in real-driving emissions (RDE) tests, such as test distance and duration, the percentage of urban, rural, and motorway driving, maximum speed, average speed, idle periods, road gradient, relative positive acceleration, cold start, and fuel, shall be approved by IBAMA.

Directive 70/156/EC, as amended by Directive 2007/46/EC

Category	Description	Sub-category	Number of Persons	Mass Limit	
M	Carriage of Passengers Min. 4 wheels PC	M1	Up to 9 Persons	GVW ≤ 3.500 kg [1]	
		M2	Over 9 Persons	GVW ≤ 5.000 kg	
		M3		5.000 kg < GVW	
N	Carriage of Goods Min. 4 wheels	N1 CL 1	N.A.	Max GVW ≤ 3.500 kg	RM ≤ 1.305 kg
		N1 CL 2			1.305 kg < RM ≤ 1.760 kg
		N1 CL 3			1.760 kg < RM ≤ 3.500 kg
		N2		3.500 kg < GVW ≤ 12.000 kg	
		N3		12.000 kg < GVW	

[1] Until Euro 4: Two subgroups: M1 with GVW ≤ 2.500 kg and M1 with 2.500 kg < GVW ≤ 3.500 kg