RDE Assessment of a Flex-Fuel 1.0L PFI Vehicle for PROCONVE L8 Emission Standards

Raphael Montemor
AVL South America, Powertrain Engineering

Maurilio Cassiani
Murilo Jara
Vinicius Vicente
Vincent Bigliardi
AVL South America, Powertrain Engineering

ABSTRACT

Brazilian PROCONVE L8 legislation introduces in 2025 the Real Driving Emissions (RDE) evaluation as a new vehicle type-approval criterion in addition to the traditional FTP75 based evaluation. Reduction of legal emission limits and RDE's dynamic driving, including extended temperature ranges, introduce a new perspective regarding engine and aftertreatment technologies, with adoption of high-end solutions ultimately leading to an increase in overall powertrain cost.

Traditionally, the Brazilian market is known for the dominance of low-cost vehicles in segments A and B (EU classification), in which Port Fuel Injection (PFI) flex-fuel (any blend of Gasoline E022 and Ethanol E100) 1.0L engines are commonly present. Therefore, the advanced engine and aftertreatment technologies successfully introduced in the USA and EU focusing on reduction of pollutant emission levels may reduce vehicle cost competitiveness, and their application on local market vehicles demands a detailed assessment.

In the proposed study, AVL South America tech center in Brazil evaluates a 1.0L PFI vehicle compliant with PROCONVE L7 legislation level, subject to the updated PROCONVE L8 laboratory evaluation criteria, and several RDE scenarios through homologated and benchmark routes. In addition, optimized engine calibration will be assessed focusing on the challenges identified to achieve the more stringent pollutant emission levels.

INTRODUCTION

The analysis of atmospheric emission sources shows internal combustion engines (ICE) have become the main source of air pollution in inner city areas [1]. Emission policies have evolved since the 1960s through increasingly tighter standards to reduce environmental pollution caused by motor vehicles.

The upcoming PROCONVE L8 [2] ("L8" from now on in this article), introduces the concept of emission bins, instead one single limit. Eight different bin levels are defined, and a vehicle is compliant with a certain bin in case all pollutant limits of that defined bin are met [3]. Additionally, L8 also defines the limit for corporate level emissions, regardless of the vehicle category. This allows automakers to define strategies according to their portfolio. It also establishes the generation and use of emission credits [4].

In association with pollutant limits reduction, some studies have indicated a considerable difference between real driving emissions and standardized laboratory type-approval cycles [5]. To reduce this gap, the L8 emission legislation introduces a new type-approval test and with that, new challenges for engine and emission control development arise. It is proposed, that from 2025 onwards, all vehicles must comply with emission limits under real driving test conditions, which most likely requires public road testing with portable emission measurement systems (PEMS).

Real driving emissions testing has been implemented as a European type-approval parameter since the EU6c emission legislation in 09/2017. A laboratory type-approval cycle is designed to represent typical driving behavior under a defined load spectrum and reproducible laboratory conditions, therefore leading to a reproducible load range. As RDE testing offers a large variety of conditions to be covered with emission optimized settings, the driving style has significant influence on resulting emissions, and a wide ambient temperature range must be covered with an unconditioned vehicle [6].

A valid RDE measurement also needs to comply with several boundary conditions. For instance, prior to test start, the vehicle must be preconditioned and soaked for a defined period. Ambient conditions, trip duration, length and vehicle velocity, distribution of urban, rural and highway routes are some of defined trip requirements. Additionally, to ensure a minimum trip correlation with laboratory type-approval cycles, a CO2 moving average window method is used. If real driving CO2 emissions differ significantly from the laboratory cycle, a correction factor is applied.

RDE boundary conditions raise new challenges for ICE emissions control development in Brazil. Unlike the standard type-approval laboratory cycle, for which the vehicle is soaked at a temperature between 20 and 30ºC; in real driving emissions testing, vehicles are submitted to varying ambient temperatures, which requires an optimized calibration of operating conditions, such as ethanol cold starts, for a wider temperature range.

RDE also raises challenges for repeatability analysis, as emissions evaluation under real road conditions add uncontrollable factors such as driving style, environmental temperature, and complex traffic conditions. To increase the efficiency of the vehicle development process and reduce the risk of unexpected costs, it is necessary to transfer part of on-road activities to a more controlled environment. For this effect, a street route can be transferred as velocity and road gradient profiles to a vehicle chassis dyno and evaluated, which allows development engineers to easily manipulate ambient parameters and quickly evaluate optimization proposals.

With emission requirements and testing methods becoming more stringent, increasing efforts on engine optimization and adoption of high-end pollutant aftertreatment solutions have become focal points. In a cost sensitive market as Brazil, the total cost of ownership is a major competitive advantage, thus each automaker must optimize its existing portfolio with minimum cost impact.

Among the top selling vehicles in Brazil, are A and B-segment vehicles, generally equipped with PFI flex-fuel 1.0L engines [7]. In this study, a B-segment vehicle is evaluated regarding current and future emissions legislation, considering upcoming pollutant calculation changes and testing methods. An extensive demonstration of real driving emissions challenges and critical maneuvers will be assessed and described focusing on cost effective solutions for extending existing powertrain life cycles.

A real driving emissions optimization methodology will be described and applied to the reference vehicle to achieve L8 compliance levels with existing powertrain – optimization will be focused on engine and aftertreatment system calibration. The most relevant calibration topics for achieving the purpose of this work are detailed to obtain a greater understanding of their principle of operation and their importance for meeting more restrictive emissions.

VEHICLE CHARACTERISTICS

A vehicle, representative of the Brazilian market, was selected for FTP75 and RDE emissions analysis under the upcoming L8 legislation limits. This reference vehicle complies with the current PROCONVE L7 limits (Table 1), and its main characteristics are presented below:

- B-segment light passenger vehicle (EU classification)
- 1000cm³, PFI, flex-fuel, naturally aspirated ICE
- Variable valve timing
- Fuel heating system

During this study, two distinct vehicles were utilized – a stabilized (3.000 km) and an aged (160.000 km) vehicle.

Table 1. L6 vs L7 vs L8 legislation targets.

PROCONVE limits for passenger car [g/km]					
Level	NMHC	NOx	CO	HCHO	PM
L5	0,1	0,12	2,0	0,020	0,050
L6		0,08	1,3	0,020	0,025
L7	0,08 (NMOG+NOx)		1,0	0,015	0,006
L8	Based on BIN level – Table 4				

Source: Resolution 492, December 20th, 2018 [1]

BOUNDARY CONDITIONS

FTP75 testing was conducted in accordance with the ABNT NBR 6601 [8] standards, with updated Maximum Incremental Reactivity (MIR) values for Non-Methane Organic Gas (NMOG) calculation, and updated Deterioration Factor (DF) for NMOG+NOx, as proposed by the IBAMA-IN21, 2021 normative instruction [9].

RDE testing was executed on a chassis-dyno simulation of the homologated AVL South America RDE route and validated to ensure the resulting data's transparency. For RDE testing and soaking, ambient temperatures of 10, 15, 23, 35 and 40°C were utilized, and coast-down coefficients were recalculated considering additional masses of the PEMS equipment and the homologation agent. As required by the ABNT NBR 17011, 2022 standard [10], air conditioning and headlights were active during RDE testing.

STANDARD RDE ROUTE

RDE IN BRAZIL - Starting by 2022, according to the current L7 legislation, RDE testing for fleet monitoring purposes became a mandatory parameter for vehicle homologation [1]. The RDE testing procedure currently applied in Brazil originates from European legislation, adapted for local conditions, yet keeping similarities to reduce adaptation efforts of post-processing tools and related software [11].

RDE NORMATIVE ABNT NBR 17011 - Table 2 summarizes the characteristics from RDE requirements and the homologated AVL RDE route.

Table 2. RDE requirements vs AVL RDE.

Parameter	RDE Brazil	RDE AVL
Altitude Moderate	0-1000m	720-820m
Altitude Extended	1000-1300m	-
Cumulated positive altitude gain	600-1,200 m/100km	891m
Ambient temperature moderate	15-35°C	-
Ambient temperature extended	10-15°C and 35-40°C	-
Trip share – Urban	Urban 55-75%	59%
Trip share – Rural	Rural 25-45%	41%
Trip duration	60 – 120min	77min

Source: Author / ABNT NBR 17011, 2022 [10]

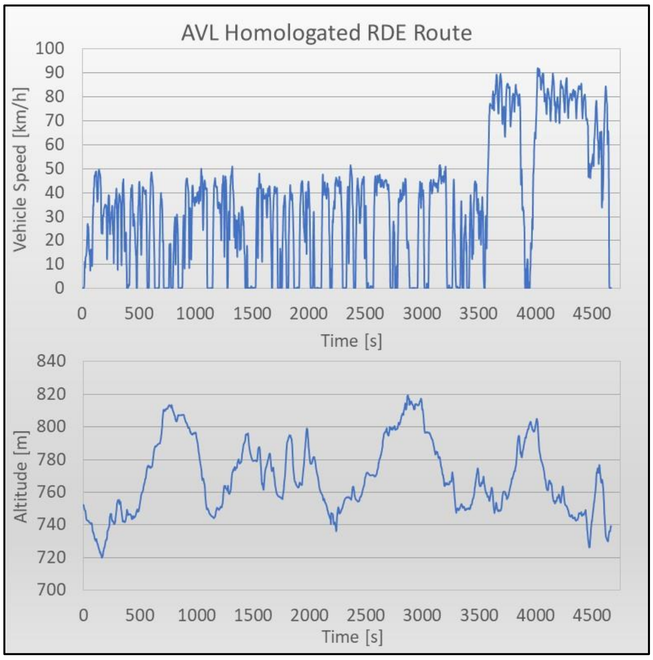

Figure 1. AVL standard-RDE speed and altitude profiles.
Source: Author

AVL RDE ROUTE - Main characteristics as shown in Figure 1 - consists mostly of 50 km/h streets in its urban section as shown in Figure 2, containing traffic lights, crossings, and crosswalks. Intrinsic to the Guarulhos city, the aforementioned characteristic results in dynamic behavior at low speeds, since below 50 km/h vehicle braking and acceleration maneuvers are highly present, as for example in accelerations resulting from traffic lights exits or transposing speed bumps. Although the above characteristics are a sample of the natural urban driving pattern, parameters such as route dynamics and especially CO2 emissions may reach undesirable values [15], and attention should be paid during the execution of the test. On the other hand, the rural section comprises entirely of roads with 90 km/h speed limit, which naturally leads parameters such as driving dynamics and CO2 emissions to the lower threshold.

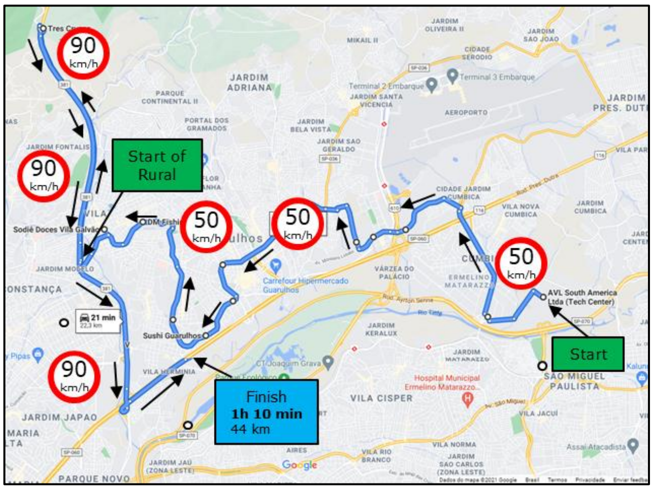

Figure 2. AVL standard-RDE route details.
Source: Author

The AVL RDE route was submitted to the regulatory agency CETESB (Companhia Ambiental do Estado de São Paulo) for evaluation and has been approved, making it not only representative for development purposes, but also qualifying it for vehicle homologation processes.

SEVERE RDE CYCLE

RDE tests aim to expose the vehicle under evaluation to real traffic conditions through a previously homologated route and in accordance with the legal provisions. Due to the topographic and demographic characteristics of each region, as well as the driving characteristics of the test driver, critical characteristics of the vehicle under analysis may jeopardize the pollutant emission performance. An RDE cycle capable of exposing vehicle weaknesses is necessary for the development of a robust product in terms of pollutant emission regardless the test route characteristics.

AVL's SEVERE RDE CYCLE – Given the universe of possible maneuvers and driving characteristics of a vehicle, several emission modes can be identified. Aiming to visit as many critical maneuvers as possible, AVL developed a chassis-dyno cycle for emission evaluation and development based on known effects, such as: Aggressive cold-start phase, full-load, catalyst breakthrough, high engine speed, etc. The proposed cycle has characteristics as shown in Figure 3 and is fully compliant with the RDE legislation [10], except for the vehicle-specific CO2 Mean Average Window (MAW).

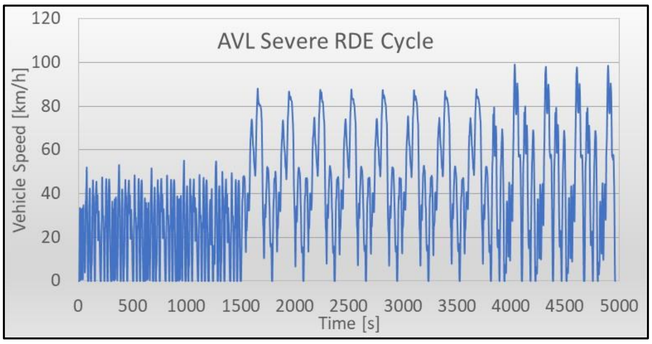

Figure 3. AVL's Severe-RDE cycle.
Source: Author

L8 CORPORATE EMISSION LEVELS – BIN LEVEL

Starting by 2025, the L8 legislation introduces emissions assessment based on manufacturer's corporate weighted average, which must be less than or equal to thresholds set in stages [1], as shown in Table 3.

Table 3. L8 BIN timeline

Emission Limit for Corporation Level		
Implementation Date	**Corporation Fleet Level**	**RDE CF**
01/01/2025	50	2,0
01/01/2027	40	1,5
01/01/2029	30	1,5

Source: Resolution 492, December 20th, 2018 [1]

Similar to the previous legislations in Brazil, the evaluation and determination of vehicle's emission level uses data collected from FTP75 laboratory tests, with the reference fuels A22H0 (Gasoline E022) and EHR (Hydrated Ethanol E100). The following pollutants are analyzed and compared to the limits proposed by legislation: NMOG + NOx, CO, PM, and Aldehydes. Emission data added by its respective deterioration factors (DF), or emission data from aged 160.000 km vehicle are confronted to the Table 4 to determine its BIN level.

Table 4. L8 pollutant emission vs BIN level

BIN Level	NMOG+NOx [mg/km]	PM [mg/km]	CO [mg/km]	Aldehydes [mg/km]
80	80	6	1000	15
70	70	4	600	10
60	60	4	600	10
50	50	4	600	10
40	40	4	500	10
30	30	3	500	8
20	20	2	400	8
0	0	0	0	0

Source: Resolution 492, December 20th, 2018 [1]

UPDATED MIR – The NMOG is defined as total emission of NMHC, ethanol, formaldehyde, and acetaldehyde, weighted by their O3 formation potential [12]. Upcoming L8 legislation imposes new MIR values for NMOG calculation in 2 steps [9], as shown in Table 5.

Table 5. L8 MIR values

	NONMHC			NMOGA22
MIR	A22	A11H50	EHR	A22
Before	4,70	3,93	3,16	4,86
01/01/2025	3,69	4,63	4,82	3,91
01/01/2028	3,69	4,63	5,57	3,91

Source: IBAMA – Normative Instruction 21, 2021 [9]

The updated MIR values for NMOG calculation impose an additional challenge for achieving compliant pollutant emission levels, as it increases NMOG levels by up to 37% in the tested vehicle, as demonstrated in Figure 4.

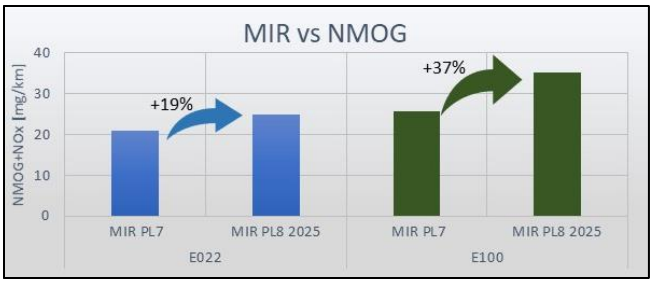

Figure 4. Influence of MIR on NMOG calculation.
Source: Author

FTP75 EMISSION CICLE RESULTS

The first step in evaluating a vehicle against the requirements of L8 legislation is to perform FTP75 tests (Figure 5) and evaluate emission results considering each pollutant DF factor, or the results from an aged 160.000 km vehicle.

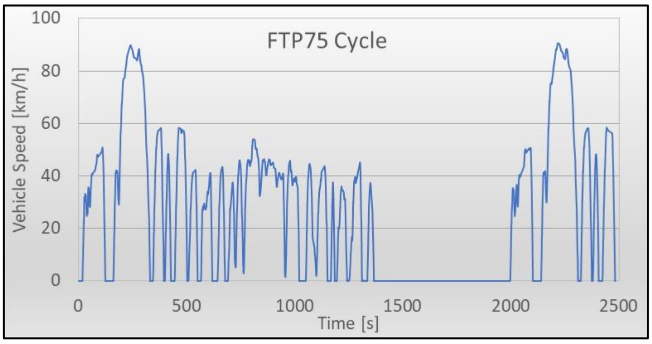

Figure 5. FTP75 emission cycle – speed profile.
Source: ABNT NBR 6601 [8]

Therefore, a stabilized vehicle with 3.000 km was used for data collection, following the usual procedure for emissions type-approval according to ABNT NBR 6601 [8]. Additionally, a second vehicle with 160.000 km driven on public roads was tested to evaluate the vehicle classification in both possibilities according to the L8 legislation. Results in Figure 6.

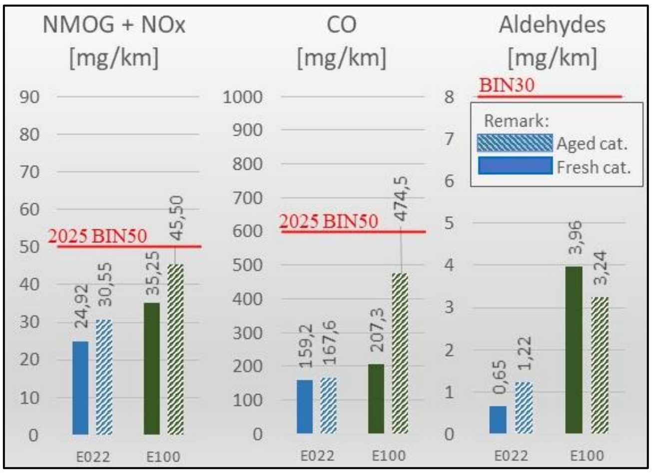

Figure 6. FTP75 results – Fresh and aged configurations. Source: Author

The analysis of pollutant emissions shows that for both fuels, NMOG+NOX is the determinant element for BIN selection. Therefore, the vehicle can be characterized as BIN40 if considered the stabilized 3000 km vehicle data added by the normative DFs [1], or characterized as BIN50 if considered the aged 160.000 km vehicle and aftertreatment system data. Although a significant increase of CO emissions from E100 testing was observed in the aged vehicle, CO remains below the BIN30 and BIN40 targets (500 mg/km) and will not undergo further investigation.

As a consequence of the strong attractive forces between ethanol molecules, the vapor pressure of ethanol is very low. This translates into low volatility, which can be assessed by a fuel's dry vapor pressure equivalent (RVP, or DVPE), as demonstrated in Figure 7 for different gasoline and ethanol blends [13]. Ethanol's low volatility, especially at lower temperatures, results in a natural tendency of higher hydrocarbon emissions, and has significant impact on PFI engines, in which fuel puddle formation on intake ports has significant role in mixture formation during engine start and after-start phases [14].

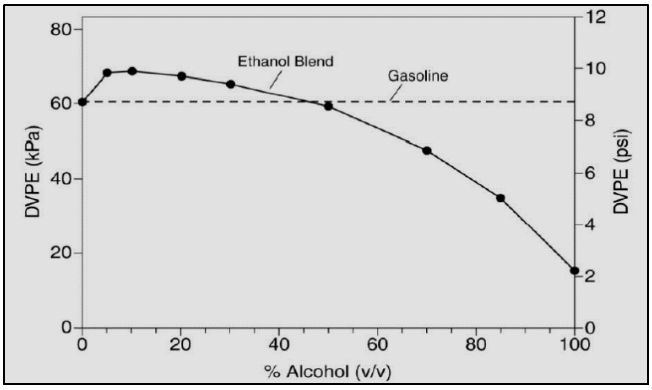

Figure 7. DVPE values for different gasoline/ethanol blends. Source: Adapted from McCORMICK and YANOWITZ, 2012 [13]

RDE EVALUATION

STANDARD RDE ROUTE - RDE tests are characterized by the non-repeatability among tests due to external and uncontrollable factors such as traffic, traffic lights, ambient conditions, etc., resulting in different emission data. Such a characteristic is not desired during emission development, and an RDE cycle on a chassis dynamometer was developed to achieve the desired repeatability. This cycle is a precise approximation of the real RDE test, taking into account the additional inertia and coast-down of the RDE equipment and the route gradients, resulting in emission values similar to the real RDE test used as baseline data.

RDE tests with temperatures from 10 to 40°C were performed in order to understand vehicle behavior within the temperature range of laboratory tests – from 20 to 30°C - and at extended temperatures unmonitored in previous legislations. Temperature values in the ranges from 10 to 15°C and 35 to 40°C are corrected and have their emission values divided by 1,6 according to ABNT NBR 17011 [10]. The data obtained from the tests are shown in Figure 8.

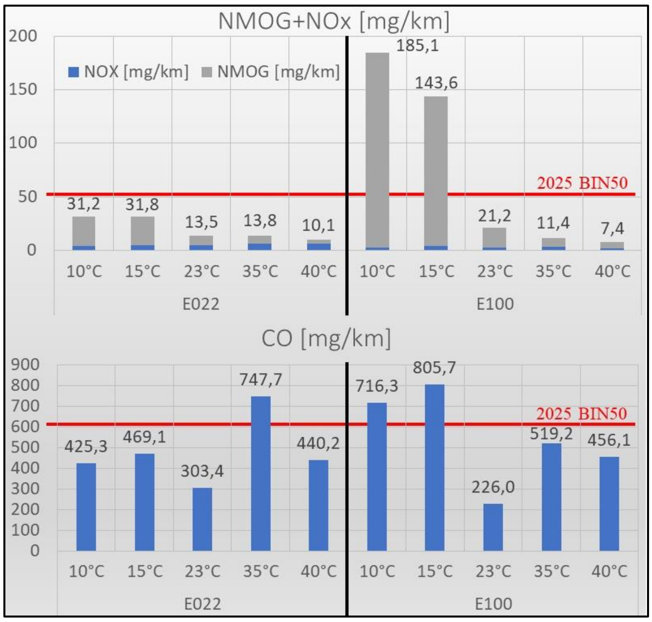

Figure 8. Baseline standard-RDE emission level. Source: Author

The RDE tests at 23°C with both fuels presented the lowest values of CO emissions, which can be explained by the greater effort normally employed in the calibration of emissions at laboratory temperature (20 – 30°C). On the other hand, emission data from tests below 20°C and above 30°C results in significant increase of both pollutants, with great emphasis on NMOG values in the tests with E100 at 15 - 10°C. There is also a trend of CO emission results at 10 - 40°C to be lower when compared to results at 15 - 35°C, which is explained by the aforementioned correction factor of 1,6.

MANEUVER IDENTIFICATION - The in-depth analysis of the emission data from the previously mentioned tests allows the identification of critical events and maneuvers, which can be grouped according to their relevance in pollutant emission, RDE test region, engine operation point, among others. For the mentioned analysis, the NOx data will be excluded due to the low relevance in the emission result for the vehicle in question as observed in Figure 8, and the NMOG will be replaced by THC for being a value measured in real time along the emission test.

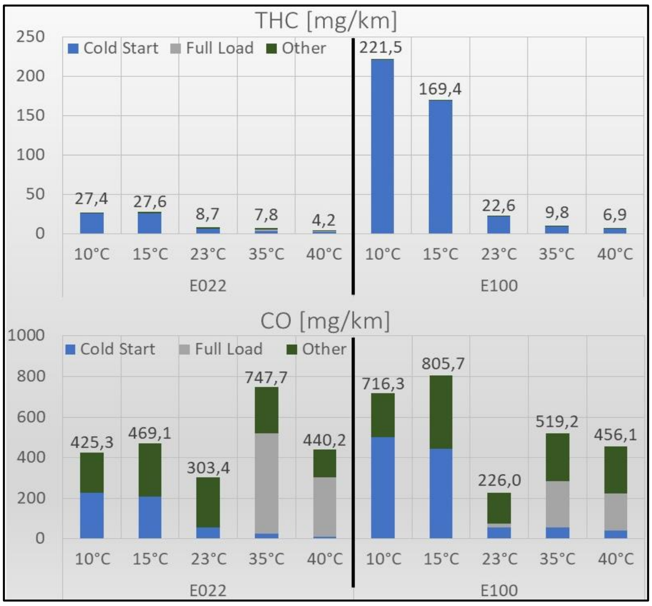

Figure 9. Discrete emission from standard-RDE cycle. Source: Author

The maneuvers were grouped as in Figure 9:

Cold Start – Blue bar. Time frame comprising the emission of pollutants in the first 5min or until the coolant reaches 70°C. The emission of pollutants during this section of the test results mostly from the enrichment for engine start and during the warm-up phase. Both CO and THC pollutants were significantly increased especially in the E100 tests due to the usual enrichment at low temperature starts.

Full Load – Grey bar. Traditionally, fuel enrichment during full load events is implemented to naturally aspirated engines with the primary objective of increasing the output torque [16]. The high ambient temperature tests led to full load events due to reduced engine's air-charge, reduced ignition advance especially with E022 and increased power consumption from HVAC.

Other – Pollutant emissions from other, less significant events were grouped and will not be explored in this study.

SEVERE RDE CYCLE - Additional RDE tests were performed using the AVL's severe development cycle to identify any additional pollutant emission occurrence apart from those identified in the standard RDE tests. Due to the highly dynamic nature, relying on several full-load accelerations up to maximum engine speed and challenges not commonly encountered in urban driving, the development cycle should not be evaluated against the legal emission limits, but used as a development tool. The results are shown in Figure 10:

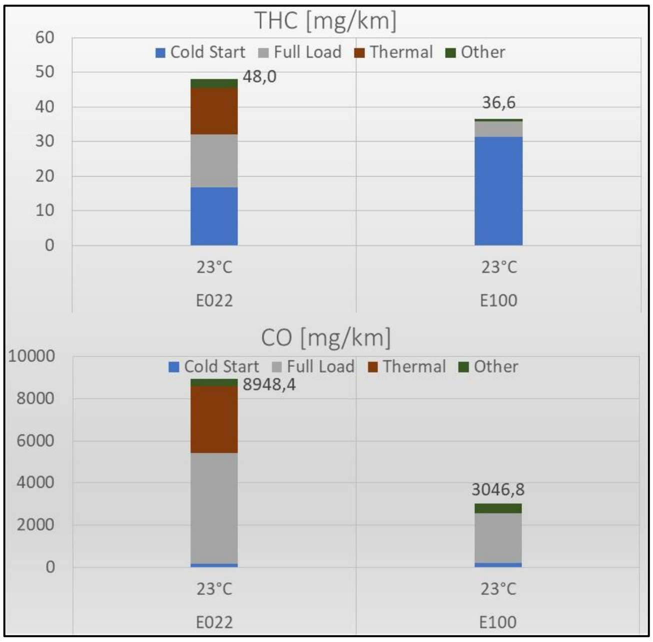

Figure 10. Emission from severe-RDE cycle.
Source: Author

Pollutant emission data from the severe RDE AVL cycle demonstrated that in addition to full-load, thermal protection of exhaust and after-treatment components results in even more pronounced fuel enrichment, resulting in significant CO and THC emission events especially with E022. The enrichment demand for exhaust temperature control is a hardware characteristic composed of several factors such as: maximum temperature supported by each section of the exhaust system, presence of a cooled exhaust manifold that promotes gas temperature reduction [14], combustion characteristics, among others.

EMISSION OPTIMIZATION

RDE test results from type-approval route and also the AVL severe development cycle have shown emissions increasing mostly due to excess fuel from low-temperature engine start events with E100, from full-load enrichment events, and as exposed in the AVL development cycle, from enrichment for thermal protection of exhaust and after-treatment components.

Cold-start optimization – In general, cold E100 starts result in a large excess of fuel over a long period. This artifice has been commonly used in vehicles to date to ensure satisfactory engine cranking and operation regardless of lifespan, production deviations, fuel quality, aggressive maneuvering, etc. The start and warm-up optimization effort will be focused on ethanol at 10°C and 15°C as it is the most challenging fuel due to the aforementioned vaporization characteristics at low temperatures.

The reduction of engine start and after-start fuel mass in PFI engines has as a major challenge the control of the fuel puddle on the intake port once vaporization rate is greatly influenced by the intake manifold pressure. The presence of fuel heating systems enables further reduction of fuel mass at cranking and warm-up since it reduces the dependence of intake manifold pressure on vaporization and mixture preparation [17] [18]. Additional factors such as injection phase and torque reserve for rapid catalyst heating were assumed already optimized and therefore not reviewed in this study.

Full-load lambda – Although more present in RDE tests with E022 due to the lower engine torque availability resulting from the delayed ignition advance, full-load enrichment has a major influence on CO emissions for both fuels [16]. Figure 11 illustrates CO and THC emission events resulting from full-load and thermal protection fuel enrichment requests - CO is much more sensitive to short enrichment events compared to THC.

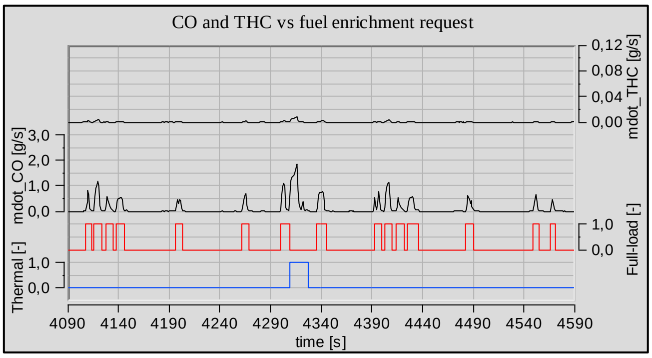

Figure 11. CO and THC vs fuel enrichment request.
Source: Author

During standard Otto engine operation, a stoichiometric air-fuel mixture is desired for best tradeoff among gross emissions and conversion efficiency of the three-way catalyst [14]. Lambda values around λ=0.90, or 10% fuel enrichment, promote torque increase of up to 1.5%, excluding other factors that may further enhance the torque benefit [14]. Generally, the transition between emission lambda and power lambda occurs by acceleration pedal position and will be disabled for next emission tests focusing on CO reduction.

OPTIMIZATION RESULTS

STANDARD RDE ROUTE – Optimizing low-temperature engine start with E100 and disabling full-load enrichment brought significant improvement for both THC and CO pollutants, as illustrated in Figure 12.

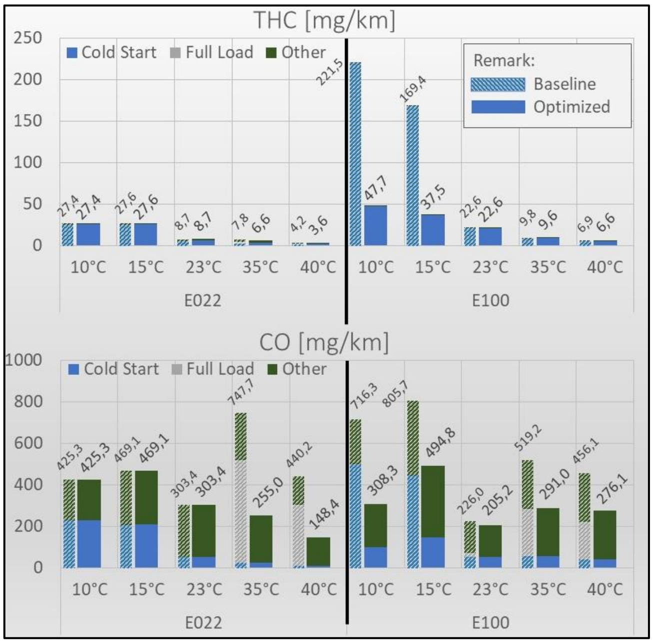

Figure 12. Baseline and optimized standard-RDE emission. Source: Author

The absence of full-load enrichment reduced CO emissions for both fuels in 35°C and 40°C tests, with greater reduction with E022 - up to 66.3% - in which fuel enrichment often occurred in baseline tests given the aforementioned degraded combustion characteristics. Virtually, thermal protection enrichment events were not observed in standard RDE tests, given the natural moderate dynamicity of the test, which does not demand high engine speeds. Furthermore, optimization of engine start brought significant THC and CO reduction for 10°C and 15°C tests with E100. There is also potential for further emissions reduction at cold-start with additional optimization of transient fuel at low temperatures - those not explored in the present study.

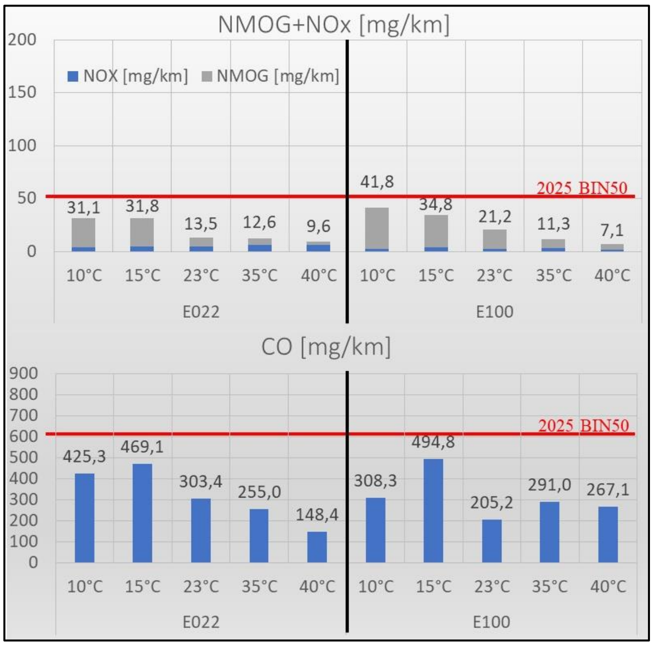

Figure 13. Optimized standard-RDE emissions vs L8 limits. Source: Author

Final emission data from the proposed optimizations results in pollutant levels within L8 limits for 2025 even considering CF = 1, as shown in Figure 13.

Although significant reduction in emissions of organic species with E100 are observed, those still represent the largest share of NMOG+NOx at low temperatures, which indicates room for optimization of engine start enrichment for both fuels. The CO emission also has higher values at low temperatures, however with influence of other factors (such as transient fuel and catalyst purge) as shown in figure 12, which were not explored in this study.

SEVERE RDE CYCLE – Tests were run at laboratory temperature to identify pollutant emission events other than cold-start. The main identified sources of emission are full-load and component protection enrichments, as in Figure 14.

The CO emission, which had already been exposed as a critical point by the severe RDE cycle, reduced significantly in both fuels after disabling full-load enrichment. Nevertheless, CO value for E022 is still far beyond the legal limit for L8 2025 (even though this test does not aim at reaching legislation targets) as consequence of thermal protection enrichment, which was slightly extended to the points where previously the full-load enrichment was already sufficient for exhaust temperature control. The CO reduction with E100 fuel, in relative terms, was more significant - 72.8% - given the fact that full-load fuel enrichment was the major driver for CO emission.

THC emission was reduced mainly on E022 - 35.2%. Baseline testing with E100 already resulted in very low influence of full-load enrichment on the emission of this pollutant, thus no further emission reduction was achieved after optimization.

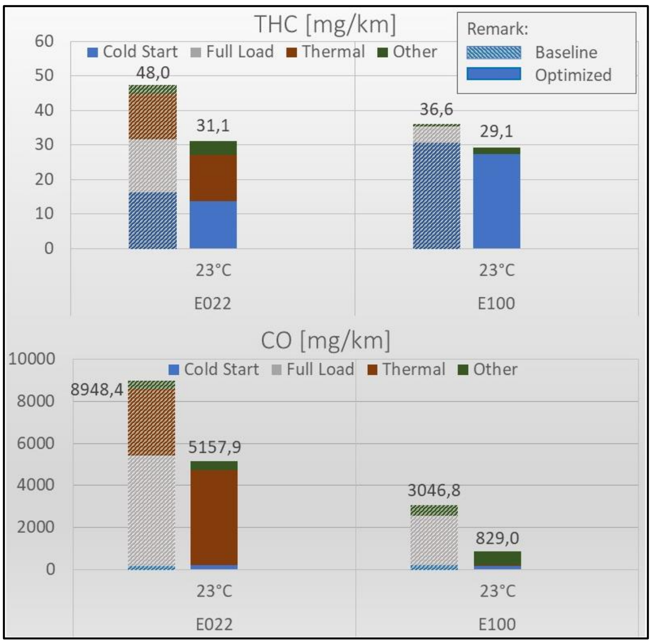

Figure 14. Optimized severe-RDE emissions. Source: Author

CONCLUSION

As a result of the upcoming emission legislation for light-duty vehicles - PROCONVE L8 - to be in force as of 2025, a 1.0L PFI vehicle representative of the Brazilian market was evaluated against the more stringent exhaust pollutant emission targets, and calibration optimizations were proposed as solutions to the identified challenges. The main features of the new legislation, which has the addition of RDE tests for type approval, were examined in order to support the analysis and conclusions.

The evaluation of a 1.0L PFI, L7 level vehicle demonstrated the possibility of achieving pollutant targets for L8 level BIN50 in both the FTP75 and homologated RDE route at various temperatures with engine calibration enhancements only, thus reducing development costs and prolonging the viability of current hardware. In contrast, when considering the aged vehicle and aftertreatment system, the proximity of test results to the emission limits suggests aftertreatment system evolution in order to ensure emission performance robustness. Furthermore, the evaluation of severe RDE cycle demonstrated hardware limitations which may lead to a possible increase on pollutant emissions when subjected to dynamic driving behavior.

As next steps, further evaluation of hardware characteristics and possible solutions shall be performed to comply with FTP75 and RDE emission targets for future BIN40 and BIN30 emission levels.

REFERENCES

(1) Zhu Q. et al. *Study on Real Road Driving Emission Characteristics of Light-Duty Gasoline Vehicles.* Tianjin, 2021.

(2) Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente (CONAMA). *Resolution 492, December 20th, 2018. Establishment of PROCONVE L7 and PROCONVE L8 vehicle pollution control phases.* Diário Oficial da União. Brasília, DF, Ed. 246, dec. 24, 2018.

(3) Neves Guilherme et al. *Incremental Cost of Emission Reduction Technologies for A- and B-Segment Vehicles Equipped with PFI/TGDI Flex Fuel 1.0L Engines to Meet Brazilian Emissions Standard PROCONVE L8.* AEA - Brazilian Society of Automotive Engineering - SIMEA 2021. Sao Paulo, 2021.

(4) CETESB (2018). *Análise da proposta de Resolução CONAMA para as novas fases de controle de veículos leves do Proconve (L7 e L8) aprovada em reunião Plenária do CONAMA em 28 de novembro de 2018.* São Paulo: CETESB.

(5) Johnson TV. *Review of vehicular emissions trends.* SAE Tech Paper, 2015-01-0993

(6) Vidmar K. et al. *Real Driving Emissions – A Challenge for GDI Engines?* 8. Internationalen Forums Abgas- und Partikelemissionen. Ludwigsburg, Germany, 2014.

(7) FENABRAVE. *Modelos mais emplacados acumulado Abril 2022, ed. 232, 2022.*

(8) ABNT - Associação Brasileira de Normas Técnicas. *ABNT NBR 6601: Light duty road vehicles — Determination of hydrocarbons, carbon monoxide, nitrogen oxide, carbon dioxide and particulate material on exhaust gas*. São Paulo: ABNT. 2021. 63 p.

(9) Ministério do Meio Ambiente. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA). *Instrução Normativa nº 21, December 10th, 2021. Alteration of MIR values for NMOG emissions calculation on light passenger vehicle emissions testing*. Diário Oficial da União. Brasília, DF, ano 235, dec. 15, 2021.

(10) ABNT - Associação Brasileira de Normas Técnicas. ABNT NBR 17011: Light duty road vehicles - Determination of non-organic methane, hydrocarbon, carbon monoxide, nitrogen oxide and carbon dioxide on exhaust gases in real driving. São Paulo: ABNT. 2022. 99 p.

(11) FORCETTO, Andre Luiz Silva et al. *Development of the RDE Brazilian procedure: Biofuels, urban pollution, and regulations*. SSRN, São Paulo, Brasil, mar. 24, 2022 DOI: https://doi.org/https://dx.doi.org/10.2139/ssrn.4065323. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4065323. Accessed in: mai. 12, 2022.

(12) SLUDER, C. Scott; WEST, Brian H. NMOG Emissions Characterizations and Estimation for Vehicles Using Ethanol-Blended Fuels. SAE International Journal of Fuels and Lubricants, SAE International, v. 5, n. 2, p. 721-732, Apr 2012. Work presented at the 2012 SAE World Congress & Exhibition, Detroit Michigan, United States, 2012.

(13) MCCORMICK, R. L.; Yanowitz, J. *Discussion Document - Effect of Ethanol Blending on Gasoline RVP*. Colorado: National Renewable Energy Laboratory, 2012.

(14) HEYWOOD, J. B. *Internal Combustion Engine Fundamentals*. 2. ed. New York: McGraw-Hill Education, v. 1, 2018.

(15) ENGELMANN, Danilo et al. *Real Driving Emissions in Extended Driving Conditions.* Energies, 2021, *14*(21), 7310

(16) BAUMGARTEN, Henning et al. *New lambda = 1 gasoline powertrains new technologies and their interaction with connected and autonomous driving*. 30th International AVL Conference “Engine & Environment”, June 7th - 8th, 2018, Graz, Austria

(17) KABASIN, Daniel et al. *Heated Injectors for Ethanol Cold Starts*. SAE International Journal of Fuels and Lubricants, [s. l.], v. 2, feb. 11, 2009.

(18) VOLPATO, Orlando et al. *Heated Injector Cold Start System for Flex-Fuel Motorcycles*. SAE Brasil Congress 2010, São Paulo, out. 2010. Work presented at the 19th SAE Brasil Congress and Exhibit, São Paulo, 2010.

CONTACTS

Raphael Montemor
Powertrain Development Engineer at AVL South America
mailto: Raphael.Montemor@avl.com

Maurilio Cassiani
Powertrain Development Skill Team Leader at AVL South America
mailto: Maurilio.Cassiani@avl.com

Murilo Jara
Powertrain Development Intern at AVL South America
mailto: Murilo.Jara@avl.com

Vinicius Vicente
Powertrain Development Project Leader at AVL South America
mailto: Vinicius.Vicente@avl.com

Vincent Bigliardi
Department Manager at AVL South America
mailto: Vincent.Bigliardi@avl.com