Technological trends to lower emission for Flexfuel vehicles.

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ABSTRACT

Recent advances in automotive technology have opened up new pathways for reducing emissions in FlexFuel vehicles. The emerging emission roadmap leverages multiple strategies—including enhanced combustion techniques, sophisticated after-treatment systems, and innovative electrification methods—to achieve stringent emission targets cost-effectively. By integrating these diverse technological avenues, future FlexFuel vehicles could potentially attain near-zero impact emissions, where tailpipe emissions would be in average same as local ambient air emission level.

This article examines each of these trends, exploring how dedicated development across these areas can be synchronized to not only meet environmental regulations but also provide a competitive edge in performance and sustainability for the automotive industry.

INTRODUCTION

The definition of the vehicle after-treatment system is no longer solely guided by increasingly stringent emissions legislations and on-board diagnostic (OBD) system requirements. The right cost of ownership over product life is a major competitive advantage, which can only be achieved through optimized integration of the after-treatment system with the powertrain definition in early stages of development.

In a cost sensitive market like Brazil, such integration is even more decisive, especially for the automaker's with A- and B-segment vehicles, which are the top sellers and generally equipped with a PFI (Port Fuel Injection, also known as Indirect Injection) flex fuel 1.0L engine, even though in recent years the market has observed the introduction of TGDI (Turbocharged Gasoline Direct Injection) flex fuel 1.0L engine in these segment vehicles.

The forecast provided by [2] is that TGDI engines will increase their share in the Brazilian market, overcoming PFI engines in 2028, as shown in Figure 1. This high market share for TGDI engines will be mainly leveraged by A- and B- segment vehicles, likely to be equipped with a TGDI flex fuel 1.0L engine.

Such low engine displacement TGDI technology will continuously increase its share due to increasingly stringent future emissions targets and ROTA 2030, Brazilian automotive program based on fuel efficiency, safety and R&D (Research and Development). In Brazil most of the engines are flex-fuel, which is a technology that allows the engine to run on either gasoline or ethanol, or in any blend in-between.

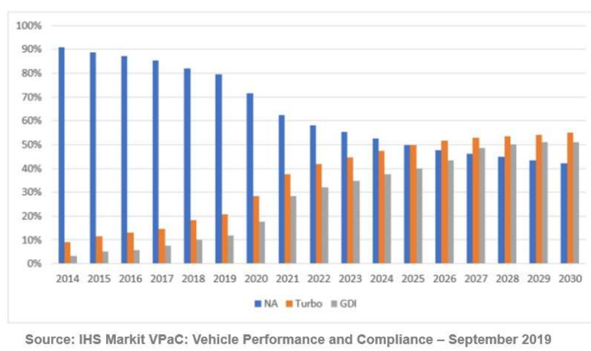

Figure 1. Market share increase forecast for TGDI engines in the Brazilian market [3].

The current phase of pollutant emission control for light vehicles in Brazil, namely PROCONVE L8 or shortly PL8, is implemented, since January 2025 as a first step with more stringent targets for upcoming steps in 2027 and upfront.

These upcoming phases will require emission reduction technologies compatible with low-cost Brazilian market context. This paper provides an overview of these key technologies, divided into 3 different categories:

- Combustion optimization leverages.
- After treatment leverages.
- Electrification leverages

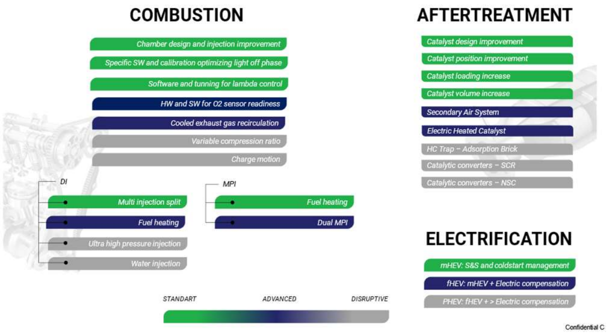

Figure 2: AEA Group of Technology Tendencies Low Emissions Roadmap [Author]

Additionally, as illustrated in Figure 2, these technologies can be classified based on their development maturity, ranging from mainstream technologies, which are already well-established and widely implemented, to advanced technologies, which still require further refinement and developments to enable their application.

Next, a brief overview of the emission regulations in Brazil will be presented. Subsequently, the technologies in each category that will enable compliance with emission targets will be detailed.

BRAZILIAN EMISSION LEGISLATION

Historically, the pollutant emission control for light vehicles in Brazil has always been based on the legislation applied in the USA. It presents several adaptations, both in terms of implementation time, procedures and limits, mainly due to specificities, such as higher ethanol content in gasoline [4].

The current PL8 regulation sets stricter emission limits, especially for NMOG (Non-Methane Organic Gases), which besides NMHC also includes the organic gases ethanol and aldehydes. Specific NMOG calculation for PL8 considers photochemical reactivity adjustment coefficients to account for different ozone formation potential between gasoline and ethanol fuels. CO (Carbon Monoxide) and HCHO (aldehydes) are further reduced for PL8, and PM (Particulate Matter) is now regulated exclusively for GDI (Gasoline Direct Injection) engines.

Beyond the stricter emission limits mentioned above, PL8 also introduces the concept of a single emission limit at the corporate level, regardless of the vehicle category. This allows automakers to strategize emission compliance based on their portfolios. It also establishes the generation and use of emission credits.

RDE (Real Driving Emission), currently in monitoring phase, will be part of PL8 legislation with different CF (Conformity Factor) for each step:

- CF=2 for PL8 Step 1 effective January 2025.
- CF=1.5 for PL8 Step 2 effective 2027.

For RDE testing, only CO, NOx, THC (Total Hydrocarbons) and CO_2 (Carbon Dioxide) will be measured.

Figure 3 summarizes the exhaust and evaporative emissions limits for passenger vehicles for Brazilian (PL6, PL7, PL8), American (Tier 3) and European (Euro 6) legislations. It is important to note that even with similar levels of NMOG + NOx between PL7 and US Tier 3 Bin125 (as for PL8, Bin is related to emission level; in this case 125 refers to NMOG + NOx = 125 mg / mi), these standards are not directly comparable in relation to technological solutions due to different fuels.

While the Brazilian standard uses E22, E61 and E100 as reference fuels, the American standard adopts E10. The number refers to the percentage of ethanol in volume that is mixed with gasoline. NMOG + NOx is the most critical limit to be met for PL8. This is mainly due to ethanol, which has the hydroxyl functional group (-OH), in addition to the low vapor pressure that makes it difficult to burn in cold conditions.

					Exhaust					Evaporative			
	Legislation	Level	Date	Cycle	NMOG+NOx (mg/km)*	PM (mg/km)	CO (mg/km)	HCHO (mg/km)	RDE	D+HS** (number of tests / h per test)	D+HS** (g/test)	D+HS** (g/total)	Refueling Onboard (mg/l)
Brazil	PL6	-	2014-2022	FTP-75	130	-	1300	20	No	1/2	1,5	1,5	-
	PL7	-	2022-2025	FTP-75	80	6	1000	15	Monitor	2/24	0,5	1	50
	PL8	80	2025-	FTP-75	80	6	1000	15	Yes	2/24	0,5	1	50
	PL8	70	2025-	FTP-75	70	4	600	10	Yes	2/24	0,5	1	50
	PL8	60	2025-	FTP-75	60	4	600	10	Yes	2/24	0,5	1	50
	PL8	50	2025-	FTP-75	50	4	600	10	Yes	2/24	0,5	1	50
	PL8	40	2025-	FTP-75	40	4	500	10	Yes	2/24	0,5	1	50
	PL8	30	2025-	FTP-75	30	3	500	8	Yes	2/24	0,5	1	50
	PL8	20	2025-	FTP-75	20	2	400	8	Yes	2/24	0,5	1	50
	PL8	0	2025-	FTP-75	0	0	0	0	Yes	2/24	0,5	1	50
US	Tier 3	Bin 160	2017-2025	FTP-75	99,4	1,9	2609,8	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 125	2017-2025	FTP-75	77,7	1,9	1304,9	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 70	2017-2025	FTP-75	43,5	1,9	1056,3	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 50	2017-2025	FTP-75	31,1	1,9	1056,3	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 30	2017-2025	FTP-75	18,6	1,9	621,4	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 20	2017-2025	FTP-75	12,4	1,9	621,4	2,5	No	3/24	0,3	0,9	53
	Tier 3	Bin 0	2017-2025	FTP-75	0	0	0	0	No	3/24	0,3	0,9	53
EU	Euro 6	-	2014-2025	WLTC	138	4,5	1000	-	Yes	1/48	2	2	-

* For PL6 and Euro 6 NMOG + NOx is estimated from NMHC and NOx individual limits
Obs: NMHC = NMOG for comparison purpose
** Diurnal + Hot Soak (D+HS) test has specificities between Brazil, US and EU standards.
Obs: limits are presented in this format for comparison purpose only.

Figure 3. Light vehicle exhaust and evaporative emissions limits for Brazilian, US and EU legislations.

Figure 4 shows the evolution of corporate limits over time for the US Tier 3 and PL8, which establishes a gradual reduction every 2 years, with values to be reviewed according to global technologies and international experiences in force at the time.

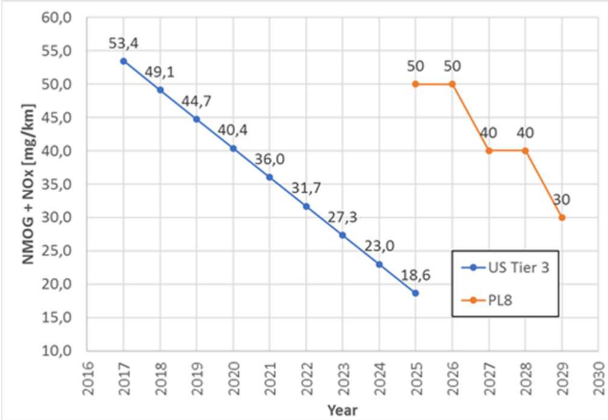

Figure 4. Emissions corporate level, considering NMOG + NOX, for US Tier 3 and PL8.

Currently FlexFuel engines are meeting BIN 50 in average to fit inside PL8 step1 corporate fleet emission limit. As corporate limit will reduce to BIN 40 for PL8 step2 in 2027, optimizations will be required to meet this new target.

Additionally, more efforts will be needed to reach the lowest emission level possible in the future, aiming at a zero-impact emission level, where tailpipe emissions would approximate local ambient air quality.

COMBUSTION OPTIMIZATION LEVERAGES

Currently, there are technologies aimed at optimizing emissions in combustion engines, while others still require further development for full implementation.

Ethanol fuel has some characteristics that makes its cold operation more challenging when compared to gasoline. The main ones are related to its composition, a simple molecule with a well-defined evaporation point, and its low vapor pressure, mainly during cold phase.

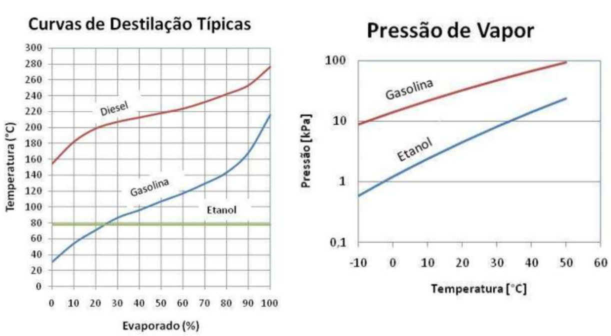

Figure 5: Distillation and vapor pressure curves for gasoline and ethanol (8)

The low vapor pressure of ethanol can be increased by heating the fuel, thus resulting in a more favorable air-fuel mixture likely to have more robust combustion. 1st generation fuel heating systems, currently on market, has as main objective to enable cold start with ethanol and to improve the driveability at those temperatures, typically below 20°C, which are non-relevant emission for Brazilian emissions legislation. 2nd generation systems will extend its operation to emission relevant temperatures above 20°C during engine start and its warm-up phase, thus resulting in lower HC and CO emissions, in sync with PL8 limits. The most common systems have heating elements in the fuel rail, such as the one from Bosch presented in 6, or directly in the injector nozzle, a solution implemented by Delphi and shown in 7.

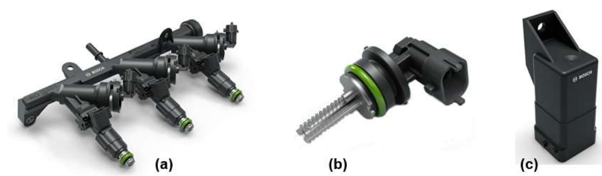

Figure 6: Fuel heating system by fuel rail from Bosch – (a) fuel rail; (b) heating element; (c) HCU (Heating Control Unit)

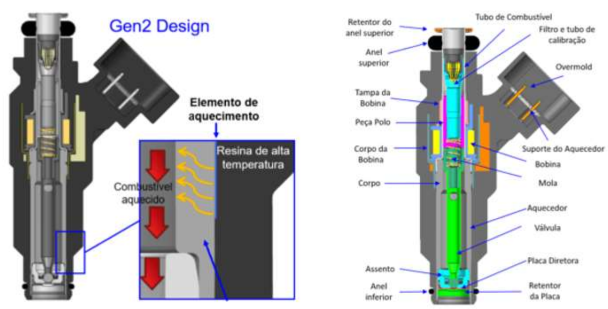

Figure 7: Fuel heating system by injector nozzle from Delphi

CHAMBER DESIGN AND INJECTION IMPROVEMENT – The chamber design and injection system enhancements aim to optimize air charge into cylinder and fuel vaporization, using tumble and swirl to fill cylinders with the best mixture possible of air and fuel. Proper injector spray targeting is a key factor to ensure good vaporization, minimizing droplet size while reducing fuel contact with metal surfaces to prevent losses.

For PFI injectors, the goal is to position them to be as close as possible to intake valve, directing the spray to avoid contact with air intake tube. Meanwhile, TGDI injectors are desired to have central spray, targeting the fuel to the middle of the cylinder avoiding contact with the cylinder walls and piston top.

SPECIFIC SW AND CALIBRATION OPTIMIZING LIGHT OFF PHASE – This approach focuses on optimizing injection timing and duration to enhance fuel vaporization and combustion efficiency, especially when using pure ethanol. Targeting the optimal injection strategy—injecting ethanol during open valve timing for PFI engines and employing multiple injections for TGDI engines—is key to limiting NMOG emissions during the start and cold phases.

SOFTWARE AND TUNING FOR LAMBDA CONTROL – This leverage seeks to reduce emissions during the start and cold phases by applying dedicated software strategies and calibration settings that rapidly drive the engine to reach a lambda (air-to-fuel ratio) of 1. Achieving this balance as quickly as possible after start-up helps minimize the period of fuel enrichment when emissions are typically higher.

HW AND SW FOR O2 SENSOR READINESS – Optimizing both hardware and software for O2 sensor readiness aims to minimize the open-loop phase post-start by reaching a lambda of 1 via closed-loop operation as quickly as possible. This involves designing O2 sensors to heat up very rapidly—ideally with water droplet protection—and fine-tuning software to accelerate sensor readiness.

Today's state in the FlexFuel engine market is around 8 seconds, and ongoing studies suggest that pre-heating O2 sensors before engine start could further reduce this time.

COOLED EXHAUST GAS RECIRCULATION (EGR) – Cooled Exhaust Gas Recirculation (EGR) is a sophisticated technology primarily designed to reduce nitrogen oxide (NOx) emissions by lowering the peak combustion temperature within the engine's cylinders. In FlexFuel applications, this system must be viewed as an advanced leverage that works best when integrated with complementary technologies.

By coupling cooled EGR with optimized injection strategies, precision calibration, and other emission control techniques, FlexFuel engines can achieve enhanced combustion stability, improved efficiency, and significantly reduced pollutant outputs.

VARIABLE COMPRESSION RATIO – Variable compression ratio (VCR) technology allows FlexFuel engines to adjust the combustion chamber's compression ratio. This adaptability optimizes engine efficiency and performance by matching the compression pressure to the fuel's combustion characteristics, whether it's gasoline, ethanol, or their blends.

By fine-tuning the compression ratio, FlexFuel engines can enhance thermal efficiency and reduce emissions, making them more responsive to varying driving conditions. Despite the challenges in mechanical complexity and cost, VCR represents a promising advancement for improving performance and environmental standards in flexible fuel applications.

CHARGE MOTION – Charge motion is essential for achieving efficient and uniform combustion in flex fuel engines by creating swirling and tumbling movements that improve the mixing of air and fuel. This enhanced turbulence helps ensure consistent combustion regardless of the fuel blend (gasoline, ethanol, or their mixtures), resulting in faster flame propagation, improved thermal efficiency, and reduced emissions.

Engine components such as intake geometry, valve timing, and combustion chamber design are typically optimized to fine-tune this charge motion, effectively compensating for the variability in fuel properties and ensuring that the engine performs reliably under different operating conditions.

FUEL HEATING – Fuel heating is already a mainstream technique for PFI FlexFuel engines and shows potential for extension to TGDI FlexFuel engines. It assists in better fuel vaporization during cold starts, thereby reducing NMOG emissions when using pure ethanol (E100).

DUAL INJECTOR (MPI) – The dual injector system for MPI has proven effective in markets such as Europe and the USA. While its application to FlexFuel engines is feasible, it is considered an advanced technology, making widespread adoption unlikely in the near future.

MULTI INJECTION SPLIT (DI) – Already applied in TGDI engines (with up to three injections), this approach could see further improvements with additional injection splits. In some cases, PFI engines might also benefit from split injections during the cold phase to improve performance and emissions.

ULTRA HIGH PRESSURE INJECTION (DI) – Ultra high pressure injection is considered a disruptive technology. Currently, high pressure injection is limited to 200 bar when using pure ethanol due to durability constraints. However, ongoing developments aim to increase this pressure to 350 bar, further enhancing fuel vaporization during startup and cold phases.

WATER INJECTION (DI) – Another disruptive technology with potential future applications for FlexFuel engines. Already utilized in other markets for gasoline applications, this approach is effective in reducing NOx emissions under high-temperature operating conditions.

In conclusion these leverages are considered to enhance better fuel vaporization, combustion flame propagation and/or lambda control. Efficiency of each leverage depends on base engine characteristics.

AFTER TREATMENT LEVERAGES

For otto cycles engines TWC (Three-Way Catalyst) is the standard after-treatment system for controlling emissions. It receives this name due to its capability of controlling THC, CO and NOx. Main parameters and components are described for better understanding the process of selecting a TWC. The catalyst position in the exhaust is very important for emission control. More stringent THC and CO emissions require CC (Close-Coupled) catalyst, which is integrated to the exhaust manifold to allow it to faster achieve operating temperature for maximum conversion. UF (Under-Floor) catalysts are used as buffer for further emission reduction. TWC itself is composed of substrate, a cylinder with honeycomb structure that is defined by its material, volume, CSPI (Cells Per Square Inch), thickness between cells. Such substrate is impregnated with PGM (Platinum Group Metals), commonly palladium (Pd) and rhodium (Rh), which will be responsible for the catalytic conversions. Then a metallic housing is bounded to the substrate through a mantle that has several functions, as sealing, thermal insulation, fixation and mechanical protection against impact. A heat shield provides extra thermal insulation to keep catalyst at the proper operating temperature.

The fundamental disadvantage of conventional TWC is that it requires exhaust heat produced by combustion by products to achieve operational temperature. Meanwhile it can only partially reduce emission on cold phase, which is generally responsible for more than 80% of total emissions over cycle. As countermeasure some technologies were developed to faster warm-up the catalyst, such as SAI (Secondary Air Injection), which injects air in the exhaust to have post-combustion requiring extra fuel, and EHC (Electrically Heated Catalyst), which utilizes electrical power for heating.

The three-way catalyst is a component widely used to control exhaust emissions from gasoline engines. It is a catalyst due to its properties, which increases the speed of a chemical reaction, participates in it, but is not consumed as a reagent or product. And it is so called three-way for being able to convert 3 pollutants that are regulated, directly or indirectly, by emissions legislations: HC, CO and NOx.

Catalytic agents are precious metals that are part of the PGM group, composed by ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt). Automotive applications, however, mainly use Pt, Pd and Rh due to their remarkable resistance to corrosion and oxidation at high temperatures.

Currently most automotive applications have reduced or eliminated the use of Pt, replacing it by Pd for the oxidation of HC and CO. The reduction of NOx, in turn, is performed by Rh. The global chemical reactions are shown by Equations 1, 2 and 3.

$$HC + O_2 \rightarrow CO_2 + H_2O \tag{1}$$

$$CO + {}^1\!/_2\, O_2 \rightarrow CO_2 \tag{2}$$

$$NO_x + CO \rightarrow CO_2 + {}^1\!/_2\, N_2 \tag{3}$$

This means that HC, CO and NOx are controlled through the three-way catalyst, which at its maximum efficiency consumes the above-mentioned pollutants (chemical reaction reagents) to produce CO_2, H_2O (water) and N_2 (nitrogen), as illustrated in Figure 8. The substrate is generally honeycomb shaped and is defined by CPSI and the wall thickness of adjacent cells. PGM is impregnated in each cell to maximize the useful area for catalytic reactions.

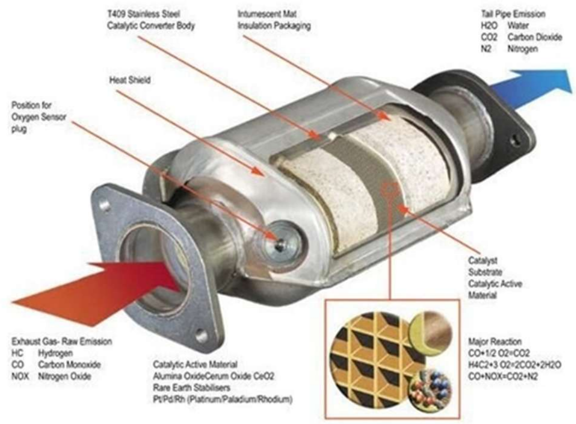

Figure 8. Three-way catalyst working principles and main components.

For the catalytic conversion to be maximized, it is necessary that the catalyst operates at an appropriate temperature and that the air-fuel mixture is controlled in a narrow band around stoichiometric ratio. Figure 6 shows the impact of catalyst aging on the light-off temperature, at which the catalyst presents 50% conversion efficiency, in this case to CO. Catalyst aging can occur due to different phenomena, such as, for example, a mechanical impact that detaches the mantle between substrate and encapsulation or the agglutination of PGM by thermal stress, thus reducing the useful area. Catalyst aging requires longer time and higher temperatures to reach the light-off temperature.

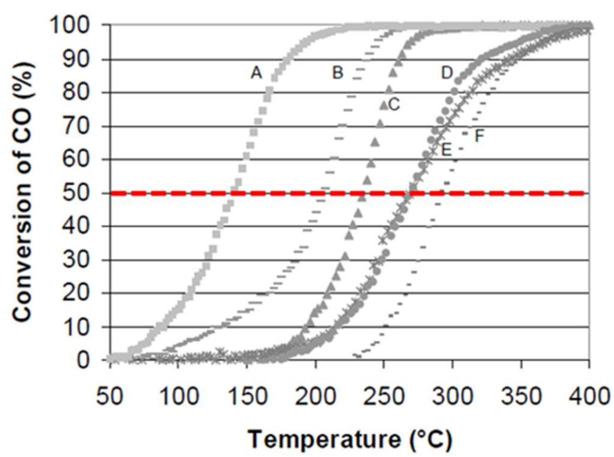

Figure 6. Comparison of the light-off curves of CO after the reductive and oxidative ageings: A) H_2 (Hydrogen)/800°C/3h-aged; B) air/800°C/3h-aged; C) H_2/1000°C/3h-aged; D) H_2/1200°C/3h-

aged; E) air/1000°C/3h-aged, and F) air/1200°C/3h-aged; lean reaction conditions; adapted from [5].

Figure 9 shows the conversion efficiency of HC, CO and NOx as function of air-fuel ratio, as well as the operating range for optimum conversion efficiency of the 3 gases. Such range is typically between $\lambda = 1 \pm 2\%$.

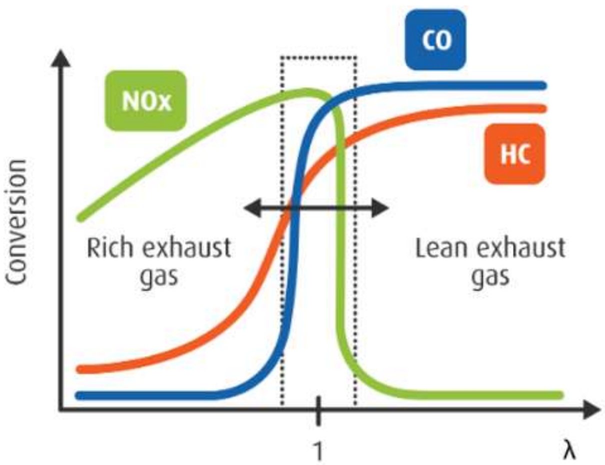

Figure 9. Characteristic curves of HC, CO and NOx conversion as function of λ [6].

Below are key strategies available to optimize aftertreatment efficiency, primarily by accelerating catalyst light-off.

CATALYST DESIGN IMPROVEMENT – This leverage consists in optimizing the catalyst's design for rapid heating (porosity, number of cells/ft3, shape, etc…). The goal is to achieve a fast transfer of heat into the ceramic substrate.

CATALYST POSITION IMPROVEMENT – This strategy aims to enhance catalyst performance by optimizing its placement for quick heating. Positioning the catalyst as close to the exhaust valves as possible — ideally integrated with the manifold — can significantly improve thermal efficiency.

CATALYST LOADING INCREASE – By increasing the catalyst loading, the system can achieve better efficiency after the light-off phase. However, this approach may require additional measures to reduce NMOG emissions during the cold phase, especially when using pure ethanol.

CATALYST VOLUME INCREASE – Expanding the catalyst volume enhances its oxygen storage capacity, thereby improving efficiency post-light-off. Like increasing loading, this strategy needs to be paired with extra measures to mitigate NMOG emissions during the cold phase, particularly with pure ethanol.

SECONDARY AIR SYSTEM – Already proven effective in markets such as Europe and the USA for gasoline applications, the secondary air system can be adapted for FlexFuel vehicles. To further reduce NMOG emissions during the cold phase — particularly with pure ethanol, where late combustions are used to heat the catalyst.

This leverage is considered as advanced for FlexFuel vehicles and should be applied in some applications, probably coupled with other leverages.

ELECTRIC HEATED CATALYST – This method employs electrical resistance to heat the catalyst, reducing the light-off time. Its effectiveness in other markets suggests it is well-suited for addressing NMOG emissions during the cold phase with pure ethanol.

Its efficiency depends on the available electrical energy and exhaust airflow during engine start and cold conditions. Combining it with additional strategies, such as a secondary air system to boost airflow before engine start, can enhance overall performance.

HC TRAP: ADSORPTION BRICK – Designed to treat hydrocarbon (HC) emissions through a dedicated converter, this strategy is considered disruptive for FlexFuel vehicles.

CATALYTIC CONVERTERS: SCR AND NSC – These disruptive technologies are considered highly relevant but still disruptive for FlexFuel vehicles.

ELECTRIFICATION LEVERAGES

Electrification is increasingly being integrated into FlexFuel vehicles to improve fuel efficiency and optimize emissions. Each electrification architecture offers unique advantages

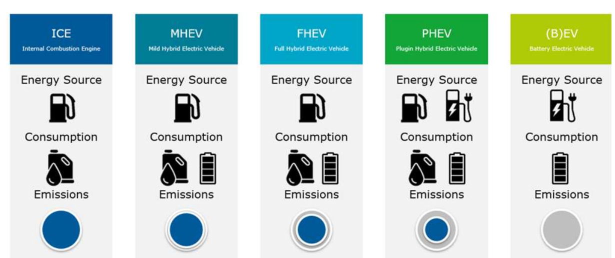

Figure *10*. Comparison of Electrification architectures.

MHEV: BSG, STOP & START AND COLDSTART MANAGEMENT – Mild Hybrid Electric Vehicle (mHEV) architecture is currently the most prevalent electrification solution in the FlexFuel market. By replacing the combustion engine during start-up and cold phases with electrical devices, mHEVs effectively reduce emissions.

Additionally, combining this setup with an Electric Heater Catalyst (EHC) can ensure a quicker catalyst light-off before the combustion engine starts, further minimizing emissions.

FHEV: MHEV + ELECTRIC COMPENSATION – Full Hybrid architecture is growing inside FlexFuel vehicles market share and can be used to reduce emission during start and cold phase using electrical devices instead of combustion engine. Due to higher electrical power available, this leverage is considered more efficient to reduce emission compared to mild Hybrid leverages.

In fHEVs, electrical devices substitute the combustion engine during start-up and cold phases, providing superior emission reduction. Certain configurations, like the Serial Hybrid architecture, can further enhance these benefits. For example, when using pure ethanol, the electric motor can support the engine start—eliminating emissions during the cranking phase—and, if paired with an EHC, can ensure a prompt catalyst light-off.

PHEV: FHEV + > ELECTRIC COMPENSATION – Plug-in Hybrid Electric Vehicles (PHEVs) build upon fHEV technology by offering even more electrical power through plug charging. This increased capacity allows for greater electric compensation compared to standard full hybrids, leading to further reductions in emissions, thus is the best electrification architecture to reach Zero Impact emission level.

CONCLUSION

The roadmap for reducing emissions in FlexFuel vehicles harnesses a wide range of strategies—ranging from advancements in combustion methods and state-of-the-art after-treatment systems to electrified architectures.

Leverages can be separated into 3 different packages:

- Standard tech package for BIN30
- Advanced tech package for BIN20
- Disruptive tech package for Zero Impact Emission

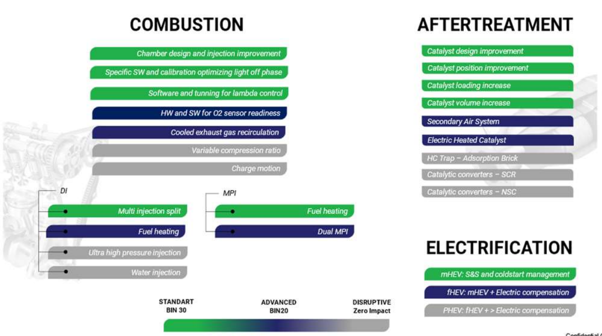

Figure 11: AEA Group of Technology Tendencies Low Emissions Roadmap (with emission level) [Author]

To effectively meet emission targets, a dedicated and well-coordinated development program must be implemented for each technological leverage. Moreover, the integration of these diverse strategies will be essential for achieving cost-effective solutions that drive down emissions to almost negligible levels. By smartly combining these advances, there is a promising potential to achieve a near-zero emission status.

This convergence of technologies not only marks a significant step forward for environmental sustainability in the automotive sector but also sets a benchmark for future innovations in emission control.

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DEFINITIONS/ABBREVIATIONS

A- Segment (Vehicle): Also known as city car or mini compact; smallest category of vehicles.

AT: Automatic Transmission

B- Segment (Vehicle): Also known supermini or subcompact; next larger category of vehicle when compared to A- segment vehicle.

BMS: Battery Management System

BRL: Brazilian currency, real

CC: Close-Coupled

CF: Conformity Factor for RDE

CO: Carbon Monoxide

CO_2: Carbon Dioxide

CV: Catalyst Volume

ECU: Engine Control Unit

EGR: Exhaust Gas Recirculation

EHC: Electrically Heated Catalyst

EPA: Environmental Protection Agency

EU: European Union

Exx: gasoline with xx percent of ethanol in volume

Flex Fuel: technology that allows the engine to run on either gasoline or ethanol, or in any blend in-between

FTP-75: Federal Test Procedure Number 75

GDI: Gasoline Direct Injection

H_2: Hydrogen

H_2O: Water

HC: Hydrocarbons

HCHO: Aldehydes

HEGO: Heated Exhaust Gas Oxygen sensor

ICE: Internal Combustion Engine

Ir: Iridium

LV: Light Vehicle

MT: Manual Transmission

N_2: Nitrogen

NMHC: Non-Methane Hydrocarbons

NMOG: Non-Methane Organic Gases

NOx: Nitrogen Oxides

OSC: Oxygen Storage Capacity

OBD: On-Board Diagnostic

OBD-Br2+: On-Board Diagnostic Brazil Phase 2+

OBD-Br3: On-Board Diagnostic Brazil Phase 3

OH: Hydroxyl Functional Group

ORVR: Onboard Refueling Vapor Recovery

Os: Osmium

Pd: Palladium

PFI: Port Fuel Injection

PGM: Platinum Group Metals

PL8 Level 50: Level is related to emission level; in this case 50 refers to NMOG + NOx = 50 mg / km

PM: Particulate Matter

PROCONVE: Motor Vehicles Air Pollution Control Program in Brazil

PROCONVE L6, PL6: Brazilian Emissions Standard for Light Vehicles Phase 6

PROCONVE L7, PL7: Brazilian Emissions Standard for Light Vehicles Phase 7

PROCONVE L8, PL8: Brazilian Emissions Standard for Light Vehicles Phase 8

Pt: Platinum

RDE: Real Driving Emission

R&D: Research and Development

Rh: Rhodium

RIA: Regulatory Impact Analysis

ROTA 2030: Brazilian automotive program based on fuel efficiency, safety and Research and Development

Ru: Ruthenium

SAI: Secondary Air Injection

SHED: Sealed Housing for Evaporative Determination

SVR: Swept Volume Ratio

TGDI: Turbocharged Gasoline Direct Injection

THC: Total Hydrocarbons

TRL: Technological Readiness Level

TSP: Thermal Shock Protection

TWC: Three-Way Catalyst

UEGO: Universal Exhaust Gas Oxygen sensor

UF: Under-Floor

USA: United States of America

USD: US Dollars

US Tier 3: United States National Vehicle Emissions and Fuel Standards Phase 3

US Tier 3 Bin125: Bin is related to emission level; in this case 125 refers to NMOG + NOx = 125 mg / mi

Vd: Engine Displacement

VVT: Variable Valve Timing