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ENERGY EFFICIENCY AND GASEOUS EMISSIONS IN THE AUTOMOTIVE INDUSTRY - COMPREHENSIVE ANALYSIS OF TECHNOLOGICAL ALTERNATIVES FOR FUTURE MOBILITY

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Abstract. *The transport sector contributes to greenhouse gas and harmful emissions. For this reason, emission control programs were introduced in markets with greater commercialization of vehicles and more recently energy efficiency programs, encouraging the reduction of fuel consumption. In Brazil, based on the experiences of previous programs and other countries, it is possible to predict the technological path for medium and long term for powertrain and chassis to support the targets achievements, taking into account local investment and infrastructure constraints. There are still several points of improvement on legislation to guarantee its effectiveness, such as introduction of inspection and maintenance programs for vehicles in use, control of the number of particles from combustion for light vehicles equipped with direct injection and study about the brake and tire emissions. Increase fuel RON to improve fleet fuel consumption and the performance of flex fuel vehicles, introduction of HVO, as a complementary solution to Biodiesel above 15% mixing and the definition of energy efficiency goals for light vehicles after 2022 based on the need for GHG reduction including well to wheel concept, to guarantee the technological competitiveness of the Brazilian vehicle and for heavy vehicles the definition of goal based on European experience.*

Keywords: *Energy Efficiency, Vehicle Emissions, Biofuels, Automotive Technology, GHG Emissions.*

1. INTRODUCTION

The automotive market is an important pillar in the world economy, data from OICA (Organization Internationale des Constructeurs d'Automobiles), indicate that sales of vehicles has grown steadily from 65,923,794 units in 2005 to 93,856,388 in 2016, 30% growth in 12 years. (IPCC,2014).

The transport sector's share of greenhouse gas (GHG) emissions is around 14% globally, due to the burning of fossil fuels, which has generated the need to define automotive legislation to control and reduce these emissions, with a focus on reducing the impact of this sector on global warming.

In the same way that the transport sector makes a significant contribution to increase the GHG emissions, it also contributes considerably to harmful gaseous emissions. Such emissions come from the fuel burning process and have also been the focus of attention and theme for public policies, especially in large centers, where the concentration of these pollutants has a direct impact on public health and consequently on the economy.

The need for an increasing contribution from the transport sector, with a focus on reducing greenhouse gas emissions, demands the development of technological alternatives capable of increasing the energy efficiency of vehicles and finding ways for long-term sustainable transportation, at cost as accessible as possible. Therefore the motivation of this paper is to explore the technological paths that the automotive industry can follow in order to mitigate the impact on global warming and contribute to the construction of sustainable mobility.

The objective of this paper is to indicate the technological routes for mobility focusing at the reduction of local and GHG emissions, indicating the technological development trends to meet the goals of the Brazilian programs ROTA2030 and PROCONVE, and also possible future complementation in the existing programs, aiming at the predictability of actions, taking into account the analysis of the main energy efficiency and gaseous emissions programs at a global level and the technologies used so far to achieve the established goals.

The methodology adopted in this paper was a comprehensive bibliographic review of the global legislation on gaseous emissions and energy efficiency, as well as the available technologies to guarantee the achievement of the established goals, carrying out an analysis focused on the Brazilian application.

Based on this analysis, this paper makes recommendations for the next stages of Brazilian automotive legislation, whether for emissions or energy efficiency, with indications of possible measures to be adopted with a focus on equalizing Brazilian programs to international ones, with the objective of reducing the technological gap between Brazil and the most developed countries on these themes.

Scenarios of possible technological routes were also indicated in this paper, based on the measures adopted in other countries with similar goals and also previous experiences of Brazilian automotive legislation.

2. OVERVIEW – CURRENT BRAZILIAN VEHICLE ENERGY EFFICIENCY AND EMISSION CONTROL PROGRAMS.

One of the biggest sources of urban pollution are vehicles equipped with Otto and Diesel engines. These vehicular emissions are formed through the process of burning fuel during the operation of internal combustion engines.

Legislation to control local and GHG emissions has been implemented in recent years on all continents, as shown in the Fig.1, indicating that the industry has a great challenge to achieve these objectives, however being possible through the application of new powertrain or chassis technologies.

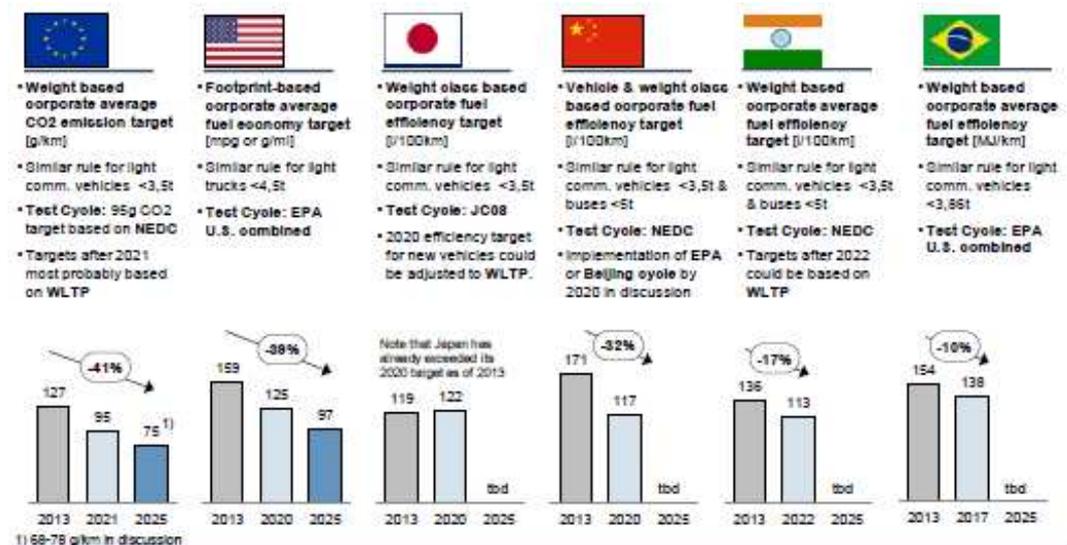


Figure 1. CO2 Emissions Limit and Energy Consumption for Passenger Vehicles. (ICCT, 2019).

About powertrain technologies, improvements were performed in the last years on combustion engines with increased thermal efficiency through the reduction of thermal and friction losses and application of lighter materials (Samaras, Z. Voutisis, I. 2005). Electric motors and especially batteries, becoming more competitive in terms of cost in relation to the combustion engine, supporting the sales increase of vehicles with these technologies (Schilick, T. et al, 2016). For transmissions, the application of double-clutch, continuously variable transmission (CVT) and transmission systems optimized to keep the engine as long as possible in maximum efficiency regimes, should be the most used technologies in the coming years.

About chassis technologies to reduce the vehicle resistive power, such as aerodynamic drag and friction to the ground, mass reduction with the application of lighter and more resistant materials should lead the technological advances, emphasizing that the vehicle safety requirements will also be taken into consideration when choosing new technologies.

With the introduction of legislation to improve energy efficiency in Brazil, to meet the energy efficiency goals defined by INOVAR AUTO, vehicle manufacturers, based on the average values of their fleets, at the time 2.07MJ / km for reference vehicle with mass of 1121kg and also the need to achieve at least 12% improvement in efficiency, defined

their strategies seeking technologies with the best trade-off between cost & % reduction in consumption, focusing on meet the goals without considerably increasing the costs in modern vehicles.

As reference, the Fig.2 shows the incremental cost ratio in vehicles according technology introduction.

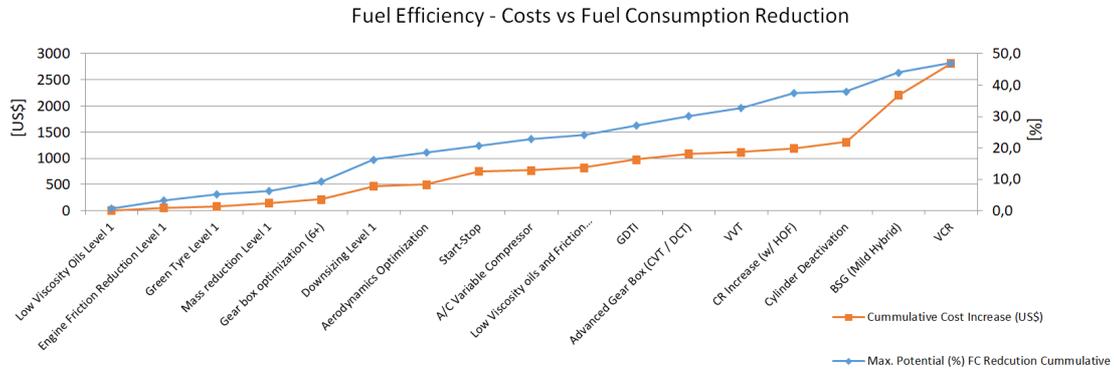


Figure 2. Comparison of energy consumption versus incremental cost according technology (Board on Energy and Environmental Systems, 2015)

Comparing the energy efficiency of models sold in December 2014 in Brazil with vehicles sold in September 2017, as shown in the Fig.3, it is possible to observe the positive effect of the INOVAR-AUTO program in improving the efficiency of vehicles, especially in the lighter ones.

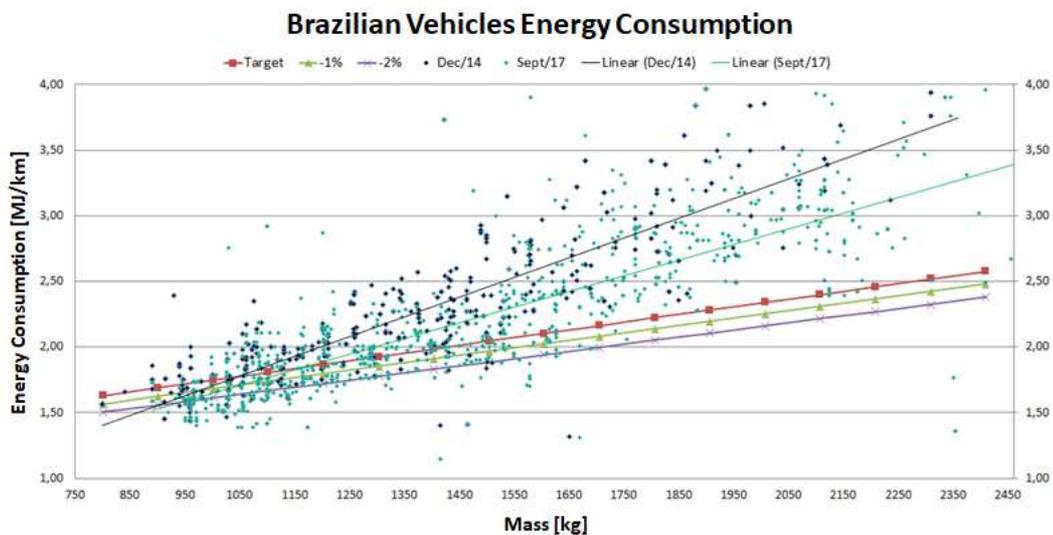


Figure 3. Comparison of energy consumption in Brazilian models Dec/14 and Sep/17 (CONPET Database, 2018)

Based on the CONPET data, it is possible to verify that the most efficient models, received mostly the following technologies with low cost of introduction according Figure 2.

- Low viscosity oils with a focus on reducing hydrodynamic friction.
- Green tires to reduce rolling resistance.
- Vehicle mass reduction.
- Variable valve timing and 4 valves per cylinder.
- Increase in specific power through the introduction of turbo engines and direct injection.
- Changes in transmission (increase in the number of gears or CVT).
- Electric steering pump.
- Gear shift indicator.
- Tire pressure monitoring.
- Start-Stop systems

About harmful emissions, in particular, in the last phase of emissions for light vehicles PROCONVE L6 it was necessary to introduce new technologies to meet the emission reductions of carbon monoxide (CO), nitrogen oxide (NOx) and from cold start as well, as follow:

- New materials for after-treatment systems.
- Adoption of fuel heating systems to assist in the engine cold start with a focus on reducing hydrocarbon emissions.
- Application of an additional oxygen probe to the exhaust, to support the mixture control.
- Optimization in the on-board diagnostic system (OBDDR2), which assists in controlling the operation of the devices mentioned above, ensuring the maintenance of the emission levels during the use of the vehicle.
- Improvements in the fuel specification, especially for commercial gasoline, also received a significant reduction in the amount of sulfur from 800ppm to 50ppm, which contributes significantly to avoid degradation of the catalyst system, ensuring the maintenance of emission levels.

For heavy vehicles, the introduction of PROCONVE P7, equivalent to the European EURO-V, also introduced new technologies such as:

- After treatment systems, such as Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF) and Selective Catalyst Reduction (SCR).
- Adoption of a gas recirculation system (EGR) in some applications as a measure to reduce NOx.
- Improvements in commercial diesel oil, with a reduction in the level of sulfur, which contributes to the formation of particulate matter and the introduction of higher levels of mixture of Biodiesel to commercial diesel, with the objective of reducing particulate material and (GHG) greenhouse gases.

Therefore, the introduction of these technologies allowed the complete and successful implementation of the last phase of PROCONVE and INOVAR AUTO.

3. FUTURE OVERVIEW – NEXT PHASE OF THE BRAZILIAN EMISSIONS AND ENERGY EFFICIENCY PROGRAMS.

To meet the next stage of ROTA2030 for light vehicles, scheduled for 2022, automakers will need more efficient vehicles, as the weighted corporate average should improve by at least 11%, compared to the goal established in INOVAR-AUTO. This will require expanding the application of existing technologies, such as:

- Direct injection turbocharged engines.
- Three-cylinder engines (downsizing).
- Start-Stop systems.
- CVT or more geared transmissions with a focus on downspeed.
- Reduction in mass of the best-selling vehicles.
- Adoption of off-cycle technologies, such as the variable air conditioning compressor.
- Aerodynamic optimization.
- Eco credits (increase in the compression rate to benefit Ethanol and introduction of hybrid / electric vehicles)

About energy efficiency for heavy vehicles, there was no prediction for targets for this vehicle class before the entry of ROTA2030, however, there was always great market attention regarding fuel consumption, as it has a direct impact on the vehicle's operating cost.

Starting from ROTA2030, limits will be defined for heavy vehicles, which should come into force in 2032. Such limits will be based on the energy consumption of commercial vehicles sold from 2022 onwards with the technology to meet the PROCONVE P8, equivalent to EUROVI and goals between 20% up to 30% improvement in efficiency compared to MY2022 should be established, and it is possible to meet them as there are technologies to support the real range of up to 43% efficiency increase compared to current vehicles, as shown in the Fig.4.

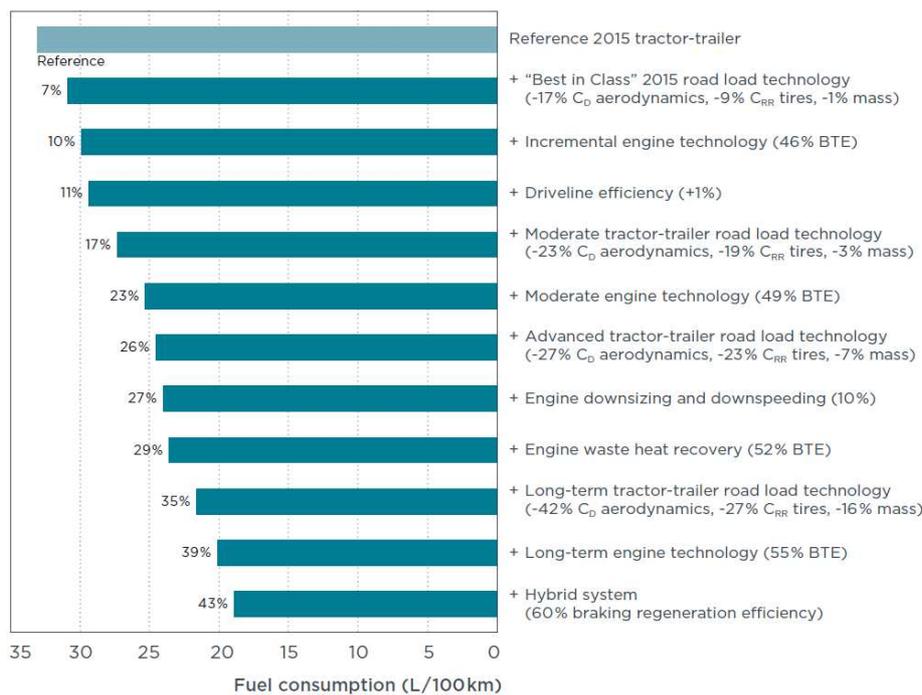


Figure 4. Potential to reduce fuel consumption with new technologies in an implement truck application (ICCT, 2017)

To meet the next stages of gaseous emissions legislation for commercial vehicles, one of the evident needs is the introduction of the technology called extended SCR, which is an integrated system of DOC, DPF and SCR in a single component, ensuring the optimization of costs and product efficiency. For some more critical applications in terms of NO_x emission, the exhaust gas recirculation (EGR) technology integrated with the gas cooling system (cooler) should also be implemented.

With all these devices to support the reduction of local emissions, the OBD system will undergo evolution in this new phase, carrying out the continuous diagnosis of the operation of these technologies, ensuring the maintenance of emission levels.

For light vehicles, the introduction of three-way catalysts with increment of precious materials making the systems more efficient, the introduction of gasoline particulate filters (GPF) for vehicles equipped with direct injection systems, fuel heating systems to reduce emissions at cold start and the introduction of evaporation absorption systems during vehicle refueling, will be the main technologies introduced to meet the next stages of emissions legislation.

4. SUGGESTIONS FOR THE FUTURE AUTOMOTIVE LEGISLATION STEPS.

4.1 Light Vehicles

For local gaseous emissions control programs, this paper recommends special attention to the control of the number of particles for direct injection gasoline engines, since the L7 and L8 standards only contemplate the mass control of particulate matter in [mg/km]. However, the number of particles is important especially for extremely small particles such as PM₁₀ and PM_{2.5}, very common in these types of engines.

There is also a need to improve gasoline, especially at the level of octane number as an enabling element for better performance of flex fuel vehicles, to allow the introduction of new technologies such as downsizing and to improve the energy consumption of vehicles in use. Studies indicate that increasing the research octane number (RON) rating from 92 to 98 may allow the compression ratio to increase by 1.5: 1 and still improve consumption by 4.7% for naturally aspirated vehicles and up to 6.9% for turbocharged vehicles. (Chow, E. 2013.)

It is also necessary to reduce non-methane organic gases (NMOG) emissions by reducing Total Aldehydes (HCO) through the control of unburned hydrocarbon emissions, with the introduction of cold start technologies, as the large emission of these gases reside in the cold phase of catalyst operation. (Souza, R. 2013)

About the contribution of the transport sector to the reduction of greenhouse gas emissions, the introduction of the well-to-wheel concept, controlling CO₂ emissions from the production of the fuel to its use, will be an alternative to contribute to the growth in the use of biofuels.

During the production process of a fuel, there are several stages that emit CO₂, being the collection and transportation of raw material, the production and distribution of fuel and, finally, the burning to move the vehicles as can be seen in the Fig.5. In the case of biofuel, a large part of this CO₂ emitted is captured in the process of growth of the raw material, a process that is not possible in fossil fuels, so biofuels have a great advantage regarding the environmental aspect, especially in mitigating the effects of GHG in global warming.

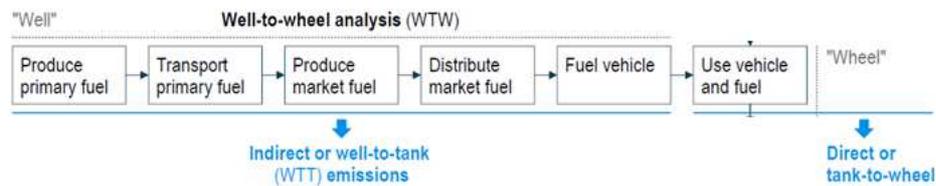


Figure 5. Well to Wheel Concept. (Roland Berger, 2018)

It is possible to observe in figure 6 the comparison of different technologies and fuels applied in a conventional passenger vehicle in terms of CO_{2eq} emission. The basis is the vehicle fueled with fossil gasoline, which has the biggest CO_{2eq} emissions. The vehicle fueled with renewable fuel has such low emissions as the electric vehicle with the European electric power generation base in 2030, or even a hydrogen fuel cell vehicle. The biofuel has a great advantage, since biofuel is fully applicable in vehicles fueled with fossil fuel, requiring only small adaptations, already known and applied in the market, as compared with the need to implement new and expensive technologies, demonstrating the great potential of Brazilian biofuels.

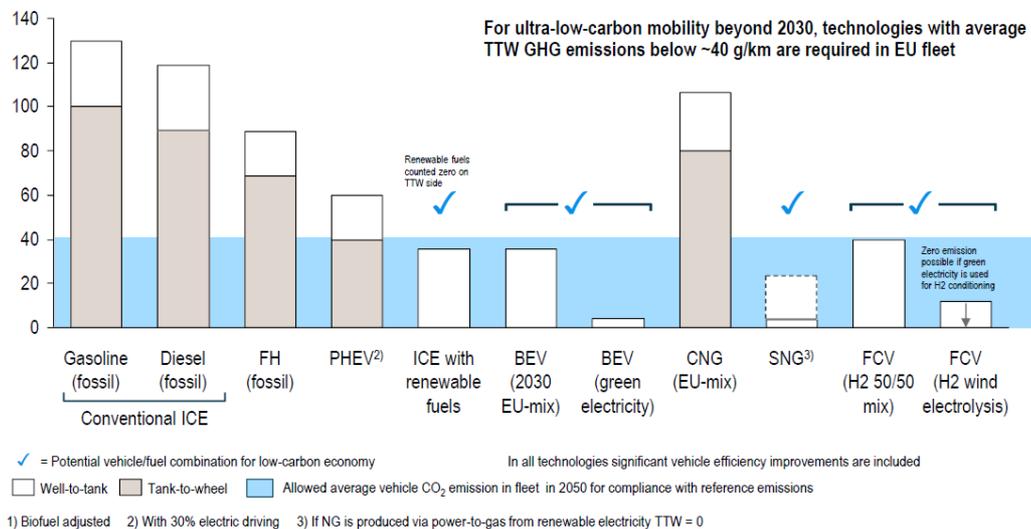


Figure 6. CO_{2eq} emissions from different technologies and fuels. (Roland Berger, 2018)

4.2 Commercial Vehicles

The improvement in fuels, especially a renewable alternative with greater resistance to oxidation in relation to Biodiesel, should be a measure explored to support the reduction of GHG. In this sense, hydrotreated vegetable oil (HVO) fuel is an applicable alternative. In addition to energy efficiency targets, it is important to consider setting CO₂ emission targets from well to wheel, same concept proposed for light vehicle, connecting the ROTA2030 program with RENOVABIO, supporting to effectively reduce greenhouse gas emissions and decreased dependence on fossil fuels.

At the engine technology, it is possible to observe that there is still room for improvement in the field of friction reduction and mechanical losses, especially in the set of accessories, but the technology with the greatest potential

related to the combustion engine is the use of exhaust energy through technologies such as turbo-compounding and waste heat recovery systems.

In relation to transmissions, the integration with electric motors in hybrid systems can generate a considerable increase in efficiency at the level of up to 8%, but it is in the aerodynamic parameters that the greatest opportunities are, since improvements in tires reducing the rolling resistance and aerodynamic optimizations can bring consumption reductions of up to 9%.

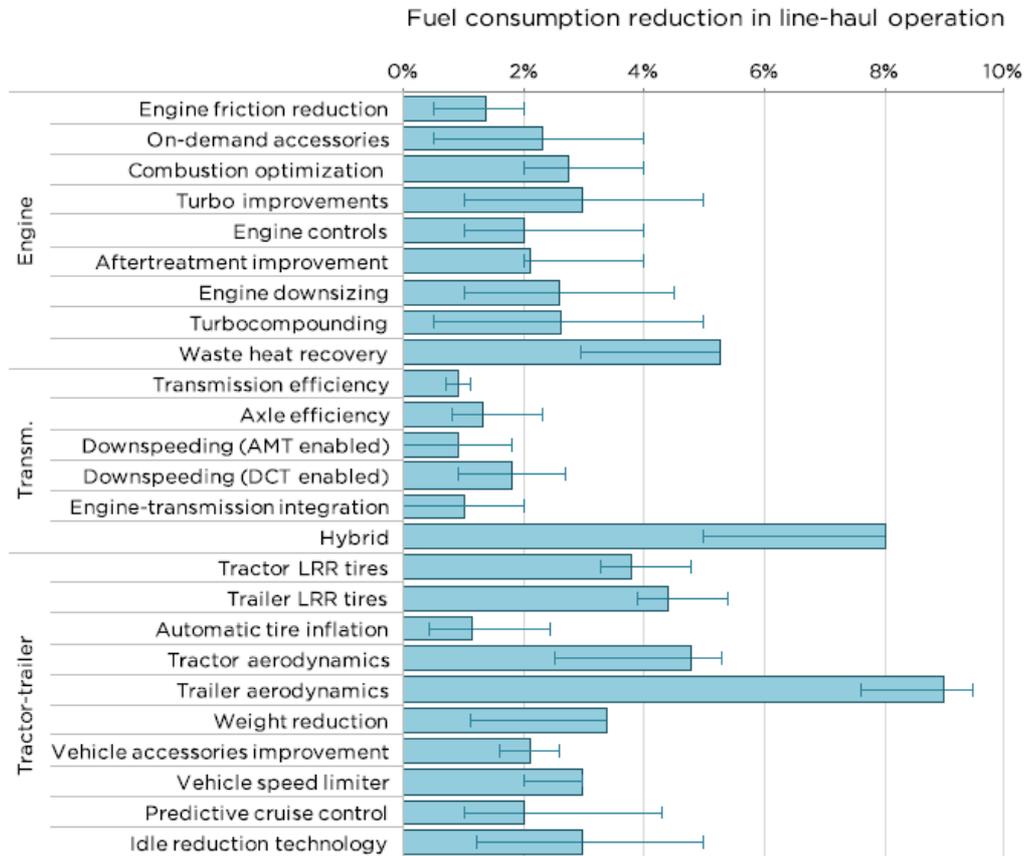


Figure 7. Commercial vehicle technologies for fuel efficiency (ICCT, 2017)

The implementation of technologies to increase energy efficiency shown in the Fig.7 for commercial vehicles goes beyond environmental issues, since the reduction of fuel consumption has a great impact on operating costs, which at the end of the transport chain, helps to reduce the costs of transported products.

4.3 Technologies for Urban Applications – Brazil Future Vision

The adoption of a single technological route for all transport segments is something that does not make sense, as the technological application depends on the regional conditions of resources availability, and in particular on the environmental and economic needs of each segment.

For urban transport, the subway stands out for its ability to unite strategic points of the city with the shortest distance between routes and avoiding the creation of traffic jams, but the cost per meter of the initial investment is very high. There are other alternatives already implemented such as bus corridors that need less investment; in this segment the adoption of buses for public transport powered by hybrid systems with biofuel is an environmentally adequate solution and with a possible introduction cost in the medium term.

Purely electric buses, whether the existing trolleybuses, as in the city of São Paulo, or even electric ones using batteries or fuel cells, are also an adequate solution for reducing local emissions in large Brazilian cities, which associated with the low CO_{2eq} emission of Brazilian energy matrix, can also collaborate with the reduction of GHG emissions.

Commercial and passenger utility vehicles, which carry out short daily journeys (<200 km), can also adopt hybrid technologies powered by biofuel, battery powered or fuel cell, as it will contribute in the same way as city buses to the reduction local emissions.

Especially for urban applications, in order to reduce the impacts of local emissions on public health, it is recommended to adopt an inspection and maintenance program for vehicles in use, as recent experience with the adoption of these programs in the city of São Paulo, demonstrated the reducing the environmental impact of vehicles while the program was active. Results showed that vehicles from the first year of use need to be inspected, as they are susceptible to wide variations in emissions in the event of problems, increasing emissions from ten to twenty times higher than normal. (Branco, G. 2013).

In the Figure 8, it is possible to observe the clear benefits of the inspection in guaranteeing the conformity of vehicles to their emission levels. This example refers to the results of the I/M program of São Paulo city, showing the average emissions of approved vehicles, disapproved vehicles and of these re-inspected after maintenance, being approved accordingly.

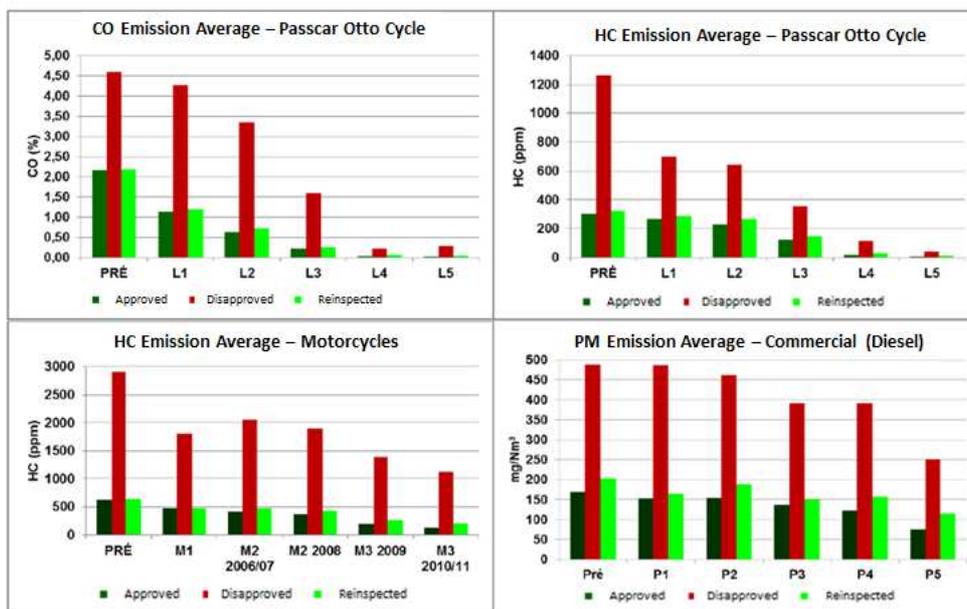


Figure 8. Average vehicle emissions by technology, type and inspection result (Branco, G, 2013)

4.4 Technologies for Long Distance Applications - Brazil Future Vision.

For road applications with a focus on long distances, conventional combustion systems are cost-effective associated with the availability of supply infrastructure and there are no problems associated with local emissions, due to the low demographic density around the highways and also a short residence time vehicle in the same location.

In this segment, the greatest contribution can be associated only with the reduction of GHG. In this case the expansion of the offer of biofuel, as already indicated in this work, is the best way for sustainable transport, since the adoption of electric vehicles will require major investments in recharge infrastructure, and it is estimated an average cost to build the network in the range between US \$ 1,000.00 to US \$ 2,000.00 per vehicle (EPE, 2018).

5. CONCLUSIONS

GHG emissions between the period from 1950 to 2011 quadrupled from the period from 1750 to 1950, indicating that the changes related to economic growth in the last decades have a direct impact on these emissions and as a consequence, the increase in the combined temperature of the oceans and continents .

Local emissions also contribute to the reduction of quality of life in large cities, in particular emissions of Particulate Material, Nitrogen Oxides and gases reactive to the formation of Ozone.

The transport sector has a significant contribution to local and GHG emissions, so there is a great effort in the implementation of automotive legislation with considerable advances in the last decades, guaranteeing the technological evolution of vehicles at each new stage, enabling significant reductions of these emissions through the implementation of new technologies for vehicles or fuels.

In particular, the last phase of Brazilian automotive legislation significantly changed the model adopted for short predictability, since with the definition of ROTA2030 and the last phase of PROCONVE, there was a definition of a long-term vision, ensuring planning for the government in the field of infrastructure and for industry with the development and introduction of new technologies. However, it is still necessary to create integration between the programs PROCONVE, ROTA2030 and RENOVABIO, reducing the technological distance of Brazilian vehicles in relation to developed countries and in particular adding value technologies related to biofuel.

These programs indicated above are focused on new vehicles. However, there are no current vehicle inspection and maintenance programs (I/M) in use in large centers, considerably reducing the effectiveness of new technologies in contributing to the reduction of local emissions. Therefore, this paper recommends the adoption of these programs with the objective of guaranteeing the benefits derived from technologies in improving air quality, benefiting society, resulting in the reduction of public health expenses, reverting to the subsidy of these programs.

This paper also recommends the inclusion of particle numbers emission control from combustion for light vehicles equipped with direct injection technology, based on European legislation and elaboration of studies on the impact of particles from the wear of the brake and tire system, as this emission contributes considerably to the drop in air quality.

In relation to fuels, for Otto cycle vehicles, it is recommended to introduce high-octane fuels, with a RON level close to 100 due to the significant improvement in performance under field conditions, enabling new technologies and reducing fleet consumption.

For Diesel cycle vehicles, to ensure the continuous introduction of a renewable matrix to replace fossil, HVO can be implemented as a complement to Biodiesel at levels above 15% of mixture, as it is a drop-in fuel for fossil Diesel not requiring investments in fleet vehicles retrofit.

To support the reduction of greenhouse gases, through the wide application of biofuels, this work recommends the introduction of the concept of analysis of CO₂ emissions from well to wheel, considering the production, transport and use of fuels, with goals established in 2027 on new phase of ROTA2030.

In relation to energy efficiency targets in heavy vehicles, it is recommended to apply the European concept, setting a 2032 goal of reducing consumption by 30% in relation to the consumption reported for heavy vehicles in 2022, which is a possible goal to be achieved with technologies available for the engine, transmission and aerodynamic optimizations.

For light vehicles, the adoption of a new target in 2027 with a reduction in consumption of -11% compared to 2022 will guarantee the continued introduction of new technologies supporting the competitiveness of the Brazilian vehicle.

Finally, the introduction of new technologies must be in accordance with the needs imposed by legislation, taking into account the cost of application and needs of each segment.

The analysis separating vehicles that operate in large centers of those that operate over long distances, taking into account the existing infrastructure and the availability of alternatives such as biofuel, will ensure the sustainable and affordable transportation for society.

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