TECHNICAL DOCUMENT

Programa Clima y Aire limpio en Ciudades de América Latina

PROPOSAL FOR AN INSPECTION AND CONTROL SYSTEM FOR THE EURO V AND EURO VI FLEET FOR COLOMBIA

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Proposal for an Inspection and Control System for the Euro V and Euro VI Fleet for Colombia

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Content

1 Background

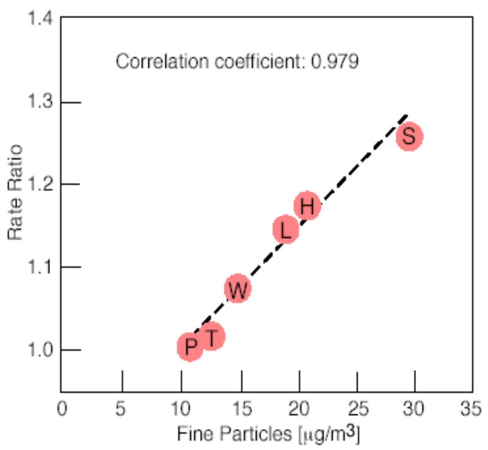
1.1 Ultrafine particulate emissions and public health

Particles are minute liquid or solid fragments dispersed in a gas medium. They are harmful depending on their ability to enter the human respiratory tract, which is in turn related to their size and their residence time in the environment (before being deposited on the ground). In the case of solid particles emitted by diesel engines, these have both properties since, due to their size of around 100 nm, they are breathable and can reside for several days or even weeks in the atmosphere, with a sedimentation speed of $8.6*10^{-3}$ cm/s.

With regard to health effects, two aspects are also considered critical: the half-life of particles in the lungs and their toxicity whether they contain toxic substances and/or accumulate them on their surface. In the case of diesel particles, both aspects are met, as they do not dissolve in the body and, given their large size, they also carry other toxic substances from the engine such as Polycyclic Aromatic Hydrocarbons (PAHs).

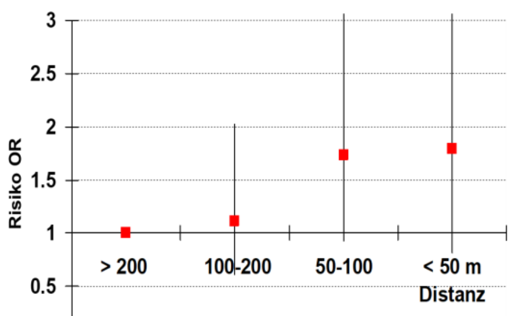
Thus, the incidence of these particles in respiratory diseases, in the origin of various types of cancer and in heart attacks, has been sufficiently documented by the scientific community, both toxicologically (effects on the human body) and epidemiologically (population health statistics). The effects of particles on mortality (Dockery 1993) and heart attacks (Hoffmann 2006) are shown below.

Figure 1: Correlation between mortality and particle concentration.



Source: Dockery 1993

Figure 2: Risk of heart attack in relation to distance from home to road



Source: Hoffmann 2006

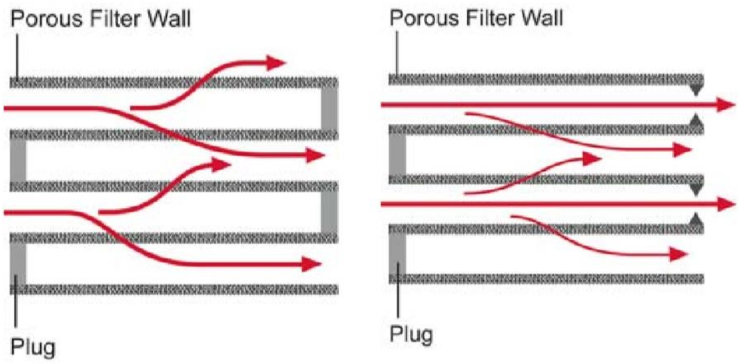
As for their impact on climate change, diesel particles are formed by black carbon (soot), which is a greenhouse product classified as second only to carbon dioxide (CO2) in terms of its contribution to global warming and consequently, glacier retreat.

1.2 Particulate filters and vehicle technology

Diesel Particulate Filters (DPFs) are devices that capture particulate matter from diesel engines and have been shown to be the most effective in controlling these emissions, measured either in mass (reduces approximately 90% of the particulate matter mass) or in number (reduces around 99% of the amount of particulate matter emitted).

DPFs retain the particulate matter that travels in the exhaust gases, making them pass through a porous substrate. Particle retention occurs through the contact of the particles with the filter surface, by means of the surface tensions that adhere the particle to the substrate walls. When all the exhaust gases are forced through the porous substrate, it is considered a closed filter ("full-flow filter"), whereas when there is a fraction of the flow that can pass directly into the atmosphere without being filtered, it is known as an open filter ("partial-flow filter").

Figure 3: Diagram of a closed filter ("full-flow filter") and an open filter ("partial-flow filter")



Source: SAE 2009-01-1087, Mayer *et al*

For open filters, the fraction of gases passing through the porous substrate depends on at least two parameters: the engine operating conditions (torque and rpm) and the accumulation of particles preventing the gases to pass through the pores of the substrate (substrate loading). Therefore, the fraction of filtered gases, and the total efficiency of the open filter are higher as long as the substrate is kept clean or a higher exhaust gas speed does not force the release of a larger fraction of unfiltered exhaust gases. In practice it has been shown that the efficiency of open filters deteriorates with use, reducing efficiency by 30%[1].

In addition to the porous substrate, a DPF must have a regeneration system that allows the combustion of the retained particles, and an electronic control unit that records the backpressure and the temperature of the exhaust gases.

The increasingly stringent mass emission standards for particulate matter (PM) and particle number (PN) for diesel engines have made it necessary to incorporate DPF systems in vehicles. This is the case of the Euro VI standard for heavy-duty vehicles and Euro 6 for light-duty vehicles, which set particle number (PN) limits, and have required the use of closed DPF systems. These DPF systems can also be factory-fitted on lower standard engines (e.g. Euro V engines), achieving emission levels in PM and PN equivalent to Euro VI, although in this case there are no further reductions in nitrogen oxide (NOx) emissions.

The new Volvo articulated and bi-articulated diesel Transmilenio buses, with DH12E340 EUV CRT engine, are certified for emissions according to Euro V protocols and limits, which were submitted by the Colombian counterpart and which were reviewed[2]. In the engine specifications stated in the test report, one of the components of the emissions after-treatment system is a DPF system with a catalytic

[1] SAE 2009-01-1087, Mayer et al.

[2] Test Report: Heavy Duty Emissions (Euro V), Vehicle Certification Agency, United Kingdom. Report Number T41 3973 01, 11/12/2018.

converter, which technically corresponds to a CRT (Continuous Regeneration Trap) type system. This is confirmed in the Volvo document attached to the test report (Job No. BSU446973), specifically in section 2.2.5. This system is described in attachments 1a and 1b of the same document as a variant incorporated into the engine before the SCR (Selective Catalytic Reduction) system. Finally, the Service Manual, provided by Volvo for this engine, specifically states that this is a "wall-flow" filter (see page 2 of the Manual).

In the Test Report we can see the following results:

Table 1: Results of the European Transition Cycle (ETC) tests

DF	CO	NMHC	CH4	NOx	PT	NH3
Mult	1,3	1	1,20	1	1,0	-
Emissions Diesel engine	CO (g/kWh)	NMHC (g/kWh)	CH4 (g/kWh)	NOx (g/kWh)	PT (g/kWh)	NH3 (ppm)
Measured with regeneration	Results from periodic regeneration event, if applicable					
Measured without regeneration	0,008	0,0100		1,035	0,0026	0,700
Measured/Weighted	0,008	0,0100		1,035	0,0026	0,70
Calculated with DF	0,01	0,010		1,04	0,003	0,7
Limit (Row B2)	4,0	0,55		2,0	0,03	25
% Limit	0%	2%		52%	9%	3%

Note: CF: correction factor for emissions measured in new engine due to deterioration, **Measured** refers to the emissions measured in the cycle, **Measured with regeneration** is the emissions measured without considering an additional cycle or protocol to measure the effects of DPF regeneration (not required in systems with continuous regeneration), **Calculated with DF** refers to the emissions including correction for deterioration, **Limit (Row B2)** is the emission limit values for Euro V.

Source: Test Report of DH12E340 EUV CRT engine, information provided by the counterpart

Table 2: Test results in the European Stationary Cycle (ESC)

DF	CO	THC	NOx	PT	NH3
Mult	1,54	1,0	1,0	1,0	-
Emissions	CO (g/kWh)	THC (g/kWh)	NOx (g/kWh)	PT (g/kWh)	NH3 (ppm)
Measured	0,008	0,0070	1,110	0,0043	2,30
Calculated with DF	0,01	0,007	1,11	0,004	2,3
Limit (Row B2)	1,5	0,46	2,0	0,02	25
% Limit	1%	2%	56%	21%	9%

Note: **Mult** is the correction factor for emissions measured in new engine due to deterioration, **Measured** refers to the emissions measured in the cycle, **Calculated with DF** is the emissions including correction for deterioration, **Limit (Row B2)** is the emission limit values for Euro V.

Source: Test Report of DH12E340 EUV CRT engine, information provided by the counterpart

As presented in the tables above, based on emissions certification in accordance with the European legislation protocols for a Euro V standard, the emissions of the DH12E340 EUV CRT engine, with a factory-fitted DPF, show significant reductions with respect to the emissions limit, which can be attributed to the built-in CRT system, in the following pollutants:

Table 3: % reduction from the Euro V limit

European Transient Cycle (ETC)		
Carbon monoxide (CO)	Non-methane hydrocarbons (NMHC)	Particulate matter (mass)
99.80%	98.18%	91.33%
European Stationary Cycle (ESC)		
Carbon monoxide (CO)	Total Carbon Hydrocarbons (THC)	Particulate matter (mass)
99.47%	98.48%	78.50%

Source: Own elaboration

These reductions consider the calculated value without a deterioration factor, although for the deterioration factors recorded, there are no significant changes when considering the corrected value. It does not correspond to the DPF efficiency as the final emissions are compared against the Euro V emission limit and not against the gross engine emissions before the DPF.

1.3 Retrofit experiences in LA

1.3.1 The program in Santiago de Chile

The concept for the Santiago de Chile DPF Program was developed in close cooperation between the Ministry of the Environment, the Centre for Vehicle Control and Certification (which belongs to the Ministry of Transport and Telecommunications), the Public Transport System of Santiago de Chile (Transantiago) and a Swiss Consulting Team (on behalf of the Swiss Agency for Development and Cooperation). This consisted of three main components:

- DPF retrofit pilot program
- Local certification of DPF
- Implementation of DPF

In addition to these three main components, two other factors were decisive for the success of the program:

- Capacity building and know-how transfer and
- Public-private partnership with international manufacturers of DPFs

Pilot program

To demonstrate the DPF system performance in the local Chilean context with its bus types, operation mode, maintenance conditions and routes, in 2004 a pilot project was carried out with twelve buses operating in representative conditions.

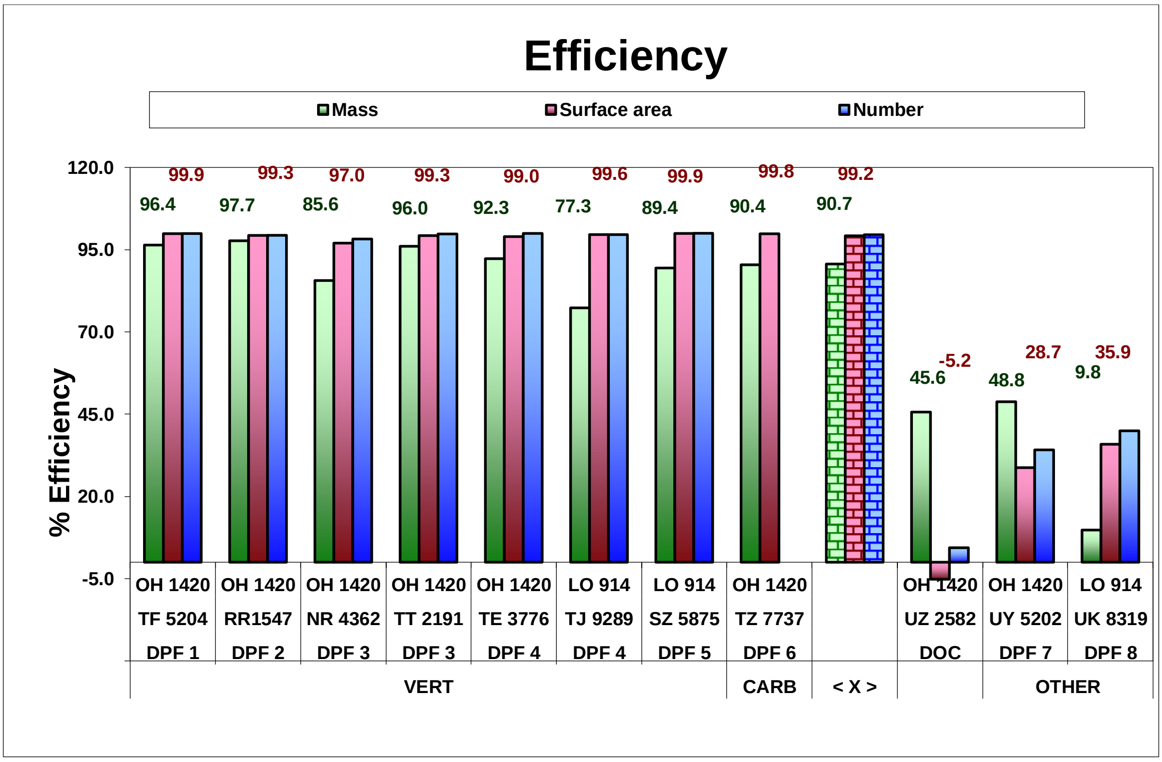
Nine buses were retrofitted with an internationally homologated DPF system (VERT- or CARB-certified), two buses with a non-homologated DPF system, and one bus was equipped with a diesel oxidation catalyst (DOC).

For two months these systems were tested for filtration efficiency and endurance. The pilot fleet was monitored for operational factors, such as exhaust gas opacity, gas emissions, noise, lubricant and fuel consumption, exhaust gas temperature and DPF backpressure.

All DPF or DOC providers, who participated in the pilot tests at their own expense, were informed of the testing criteria. The filtration efficiency had to be over 70% (in particle mass), and no deterioration of filtration efficiency should occur between the first measurement (at the beginning) and the second one (at the end of the two-month test phase). Furthermore, no increase in noise was allowed when replacing the original vehicle muffler with a DPF; therefore, noise was also measured with instruments in accordance with local legislation. All participants were aware that only those systems which meet these criteria would be locally certified to compete in the subsequent retrofit implementation phase.

As part of the pilot program, the best available technology (BAT) for measuring nanoparticles was introduced, using particle number (PN) measurement methods. These techniques were applied in parallel with the conventional gravimetric methods.

Figure 4: Results of the PN measurements in the Santiago de Chile pilot program



Fuente: A. Reinoso - Retrofit Program for the Santiago Bus Fleet: Pilot Project Results. 9 ETH Conference.

The retrofit pilot program in Santiago de Chile showed that good DPFs, also in the local Chilean context, achieve filtration efficiencies of over 70% (based on particle mass measurements) and over 97% (based on particle number measurements) for ultrafine particles.

It also showed that international certification guarantees the quality of DPFs and that DOCs have very low efficiency in reducing particulate emissions. This finding becomes even more significant if one compares not only the filtration efficiency, but also the percentage of the particles coming out after the DPF (penetration), which is the relevant measure for air pollution. Based on particle number counting, the following average values resulted from the pilot program.

Table 4

N°	Type of system	Certification	Filtration efficiency	Particle emission
1-9	Good DPF	Certified	99.5%	0.5%
10-11	Poor DPF	Not Certified	37.0%	73.0%
12	DOC	Not Certified	4.4%	95.6%

Source: Own elaboration from "The Santiago de Chile Diesel Particle Filter Program for Buses of Public Urban Transport". Swiss Agency for Development and Cooperation SDC.

Based on the pilot experience, in August 2004 the Chilean authorities published the Supreme Decree No. 65, which established the local certification scheme for DPFs. In order to qualify for the retrofit, DPFs had to undergo this procedure. Only DPFs that have already been internationally approved (by VERT or CARB) can perform local certification.

To date, 25 DPF systems have been locally certified and are published on the official filter list of 3CV of the Ministry of Transport.

As mentioned above, the introduction of the Transantiago public transport system offered the opportunity to implement a DPF retrofit program as an 'incremental' element with a view to environmental benefits. But obviously, being only a complement of the overall Transantiago system, the DPF implementation program had to adapt its strategy to Transantiago, particularly to its concession scheme.

Originally, Transantiago's concession scheme included:

- Mandatory DPF retrofit of old Euro I and Euro II buses,
- Voluntary DPF installation on newly acquired Euro III buses to obtain an extension of the concession period as an economic incentive.

In September 2009, the Supreme Decree No. 130 of 2001 on emission standards for new buses operating in the metropolitan area was amended. This meant that all new buses had to comply with Euro III plus a DPF system, with a filtration efficiency of at least 80% (measured as particle mass).

Consequently, DPF implementation followed these three schemes, as indicated below.

Table 5: Results of the DPF implementation in the Transantiago fleet

Year	Increase in the number of buses with DPF	Mode of installation	Reason for implementation
2005	110 Euro III	New buses, equipped in factory	Incentive
2010	+564 Euro III	Retrofit of used buses	Incentive
2010-2012	+2.025	New buses, equipped in factory	Mandatory emission standard
2012	+500	Retrofit of used buses	Incentive

Source: Prepared by the authors based on the "The Santiago de Chile Diesel Particle Filter Program for Buses of Public Urban Transport". Swiss Agency for Development and Cooperation SDC.

1.3.2 Other initiatives

The mechanism for retrofitting vehicles to reduce pollutant emissions has been a strategy proposed since the beginning of the 21st century in several first world countries, especially for regulating emissions in-service vehicles. In Latin America, one of the most notable experiences with this type of management tool was the Integrated Program for the Reduction of Pollutant Emissions program[3] (*Programa Integral para la Reducción de Emisiones Contamsinantes,* PIREC) developed by the Mexican Ministry of the Environment, which promoted the certification of generic replacement catalytic converters for vehicles with Otto cycle engines, as well as the installation of emission retrofitting kits for units which were not factory-fitted, especially taxis.

At the same time, the California Air Resources Board (CARB) developed an emission reduction device and system certification program for diesel vehicles, that included three levels of pollutant emission reduction, and considered the simultaneous control of two toxic substances emitted by diesel cycle engines: NOX and PM, classifying them by reduction ranges: up to 50% reduction, between 50% and 75% reduction, and higher than 75% reduction[4].

Based on these experiences, the former Corporation for Air Improvement in Quito, Ecuador (CORPAIRE), carried out research between 2006 and 2008 with the aim of locally type approving devices or systems with CARB certification level 2 or higher and also with VERT[5] certified devices.

The results of the studies developed in Ecuador were based on the fact that the fuel to be used in the vehicles should be the same as that sold in the country to date, with a sulphur content regulated by law that can reach up to 500 ppm based on particle mass. Furthermore, vehicles should operate under normal environmental conditions of the city, i.e. at 3000 meters above sea level. Under these premises, 8 different types of devices were tested, including DOC, DPF and water-in-fuel microemulsions. The DPF-type devices, even those with partial flow, were damaged during the tests, while the water-fuel microemulsion and the DOC-type devices were able to normally exceed the set test periods of more than 10,000 km. It should be noted that the vehicles used during the test were regular public transport units and that the engine maintenance was certified by a thorough monitoring program. For this reason, the city of Quito decided to retrofit its mass transport units (90 Volvo B10M articulated buses) with DOC devices, which have operated for 10 years without reporting any problems but have achieved particulate matter reductions of less than 10%, although with visible smoke (opacity) reductions of around 40%. To date, water-in-fuel microemulsion has not been used due to a lack of a legal framework for modifying fuel at the shipping and loading terminals, even though its use generated results equivalent to those reported by CARB for the microemulsion certified within its program and sold in the United States under the name PuriNOx®.

1.4 Fleet inspection models in Latin America

Overall, in Latin America, experiences in controlling pollutant emissions from in-service vehicle fleets have progressively shifted towards what is known as the Centralized Inspection system, in which a legally authorized operator performs a systematic test of all vehicle systems that are related to road safety, as well as the pollutant emissions they generate.

This type of systems currently offers high levels of reliability, insofar as specific performance standards have been developed, such as ISO/IEC 17020, and also due to the high level of automation of the

[3] Reference: http://cofemersimir.gob.mx/expediente/19759/mir/42467/anexo/3419392

[4] Reference: https://ww3.arb.ca.gov/diesel/verdev/vt/cvt.htm

[5] Reference: https://www.vert-dpf.eu/j3/images/pdf/article/48/VERT-Filter-Liste-Stand-November-2018.pdf. VERT is a Swiss NGO dedicated to the certification of post-combustion devices for particulate matter emission reduction.

integrated control systems. As a result, measurement results are increasingly tamper resistant, while vehicle technical inspection lines have become increasingly automated, which has led to a sustained reduction in inspection times, along with an improvement in the performance of each individual test.

As far as emission control is concerned, control systems are still grouped into two large blocks, depending on the type of vehicle power plant or more specifically, on the thermodynamic cycle under which each engine is designed, i.e. Otto or Diesel.

This characteristic of toxic emission control is due to the substantial difference in the concentrations of toxins present in the exhaust emissions of each type of engine, linked to a greater extent to the air-fuel ratio that each one uses and to a lesser extent to the type of fuel used.

Testing of vehicles with Otto cycle engines

The predominant equipment for controlling emissions in Otto cycle engines continues to be the gas tester with NDIR (Non Dispersive InfraRed) chamber and electrochemical cells, which allows the volumetric concentration (identical to the molar concentration) of the pollutants present in the exhaust gases to be measured along with the gases concerning combustion quality (CO_2 and O_2).

This type of equipment is used both for tests with the engine at idle and without acceleration (idle test) as well as at high RPM. This is known as the Two Speed Idle test and provides a better evaluation of the engine condition and its emission control systems, especially the catalytic converter. This equipment must usually be accredited under the OIML R99 standard and for those that perform mandatory emission control, they should be of Class 1 or higher. However, due to their high acceptance, this equipment can usually be accredited by North American metrological authorities, especially the BAR (Bureau of Automotive Repairs).

An evolution of the emission control system for Otto cycle vehicles is the dynamic testing protocols, of which the most commonly accepted is the ASM (Acceleration Simulation Mode) developed by the California Air Resources Board (CARB) as an alternative to the IM240 protocol developed by the EPA. Its purpose is to achieve results that are correlated with the laboratory certification protocols (FTP75) but at an affordable cost for vehicle inspection facilities.

Figure 1: ASM test equipment

Source: Taxmexa - Mexico

The advantage of dynamic emission testing protocols is that a fifth toxic gas (NOX - Nitrogen Oxides) is tested, which is formed when the engine is under load. Through this process, more accurate results can be obtained from the operation of the three-way catalytic converters, which can fail in the reduction channel and still continue to operate in the oxidation channel, generating incremental NOX values. However, due to the cost and operational requirements for implementing this testing methodology (both the gas testers and dynamometer need to be calibrated several times a day, generating almost twice as much time as a routine inspection), it has only been introduced in two Latin American countries (Mexico and Chile) and is restricted to certain regions with high urban and vehicle concentration.

Testing vehicles with diesel cycle engines

Historically, the biggest concern about emissions from diesel cycle engines has been the amount of solid particulate matter (soot) they emit. This is due to the basic operating condition (mixture with a high excess of air) and the fact that the internal combustion produced is a deflagration[6] unlike the usual explosion of Otto engines.

As a result, diesel engines were associated with significant visible smoke emissions from their exhaust systems, which were later correlated with epidemiological effects, especially chronic lung diseases. For this reason, international certification bodies and environmental authorities globally have focused on increasingly reducing the amount of particulate matter emitted by such engines, which has generated a consequent reduction in the amount of visible smoke emitted. Furthermore, different regulations in

[6] Deflagration: Fast and progressive combustion without explosion, which generates a uniform flame front that embraces the piston head but generates colder areas at the back of the piston.

Europe and North America have set increasingly lower values for the total mass of particulate matter emitted by diesel engines.

However, since the first decade of the 21st century, studies conducted by various European academic institutions and non-governmental organizations, highlighted the presence of non-visible particulate matter produced by state-of-the-art diesel engines, which immediately raised an alert among health researchers, who found significant relationships between this "ultrafine particulate matter" (currently called nanoparticles) and serious conditions such as cancer and mutagenic diseases.

This ultrafine particulate matter does not contribute significantly to the total mass of emitted particulate matter, as its size (and consequently its weight) is more than 1000 times smaller than the largest particles recorded in the emitted PM mass measurement systems.

On the other hand, this characteristic of the ultrafine particulate matter adds to the fact that its size is usually below the wavelength of visible light, so for all practical purposes, this type of particle cannot be detected by optical mechanisms.

This situation has generated concern at the international level, because the methods commonly used for the measurement and control of particulate matter emitted by diesel engines do not seem to be appropriate to the changing conditions of the industry or to the health protection requirements of populations potentially exposed to them.

The common method of measuring toxic emissions from diesel cycle engines is by using smoke meters, which are governed by Beer Lambert's law and can measure the degree of blackening of the visible smoke emitted by the engines, under a condition called "Free Acceleration Test". It consists of several rapid accelerations where the engine is run at full throttle.

Modern diesel cycle engines no longer emit visible smoke, so the degree of toxicity of their emissions cannot be determined by measuring opacity nor can the condition of their emission control systems, especially after combustion, be objectively evaluated.

1.5 EURO VI, a new challenge for inspections

As mentioned in section 1.2 of the report, the adoption of stringent emissions standards in international legislation has led to the implementation of aftertreatment systems, which are also becoming increasingly competitive and efficient for controlling NOx and particulate matter, in particular. In fact, emissions from existing modern engines are now more sensitive to failures in these aftertreatment systems, with a high impact on vehicle emissions. As a result, the stability of engine emissions is now more dependent on the deterioration of these systems, and while in the past the deterioration of diesel engines could affect their emissions by 20 to 50%, today a failure in a diesel engine aftertreatment system can increase emissions by 2 to 3 orders of magnitude.

Table 6: Evolution of Emission Control Systems and Aftertreatment Systems

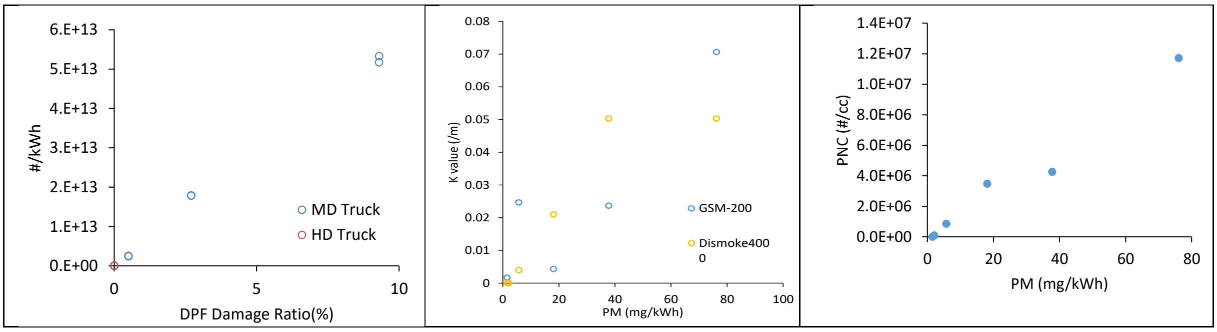
STANDARD	EMISSION CONTROL SYSTEMS
EU III	• DOC+EGR - without DPF; mechanical injection • DOC, without EGR; electronic injection • no DOC, no EGR; electronic injection
EU IV	• DOC+SCR - without DPF; electronic injection • DOC, EGR + open filter; electronic injection
EU V	• DOC+SCR - no DPF; electronic injection

EU VI	• DOC, SCR + DPF; electronic injection • DOC, SCR+EGR+DPF; electronic injection

Source: Prepared by the authors

A study by Yamada et al (NTSEL-2015) showed that with 0.5% damage to the DPF surface, the emissions from a Euro VI engine can exceed the Particle Number (PN) emission limit. However, it was not possible to detect this level of damage with a smoke meter. Nevertheless, the PN testing is capable of detecting damage even at low idle speed. With 100% damage to the DPF the emissions exceeded the PN limit by 40,000 times.

Figure 5: Emissions in terms of DPF damage ratio



Source: Yamada et al (NTSEL-2015)

However, the major reduction in atmospheric particle number concentrations achieved by the new DPF systems[7], and the high impact of these emission control systems, increased the need for control, especially since the introduction of the Euro 6/VI standard in Europe. One solution is defining control mechanisms, such as periodic technical inspections (called PTIs in Europe), which allows the testing, detection and repair of highly polluting vehicles due to failure in their control systems. As a result, OBD strategies have been replaced by inspection strategies, given the difficulties in monitoring particulate matter and the automotive industry's perceived mistrust of OBD.

The strategy proposed based on several studies aims at measuring PN as a substitute for opacity, which, given its high sensitivity in measurements, can detect failures in the DPF with idle tests. These have shown good correlation with the emissions measured in cycles on chassis dynamometers used in emissions certification (NEDC)[8].

At present, several European countries have already prepared a certification protocol for the new PN instruments, which adhere to the same measurement principle as those required for certification (PMP protocols) and incorporate the necessary improvements and construction requirements specific to on-site equipment.

A final document is now available as an *international recommendation* for a particle number counter that was initially prepared by the Netherlands Metrology Institute (NMi), as part of an international

[7] Results measured in Switzerland by Hüglin revealed an annual reduction rate of 11.6% in black carbon from traffic between 2008 and 2018 (Effects of Traffic Related Abatement Policies on Swiss Air Quality Trends). Proc. 21st ETH-Conference on Combustion Generated Nanoparticles, June 19th - 22nd, Zurich, Switzerland 2017 http://nanoparticles.ch/archive/2017_Hueglin_FO.pdf)

[8] Kadijk, G., Elstgeest, M., Ligterink, N.E., van der Mark, P.J.: Investigation into a periodic technical inspection (PTI) test method to check for presence and proper functioning of diesel particulate filters in light-duty diesel vehicles - part 2. Report TNO 2017 R10530, (2017)

NPTI working group[9]. The members who participated in this working group were Switzerland (VERT), Germany, Belgium, the Netherlands, the European Commission (JRC) and about eight manufacturers of particle counters, the Netherlands Metrology Institute (NMI), the German Metrology Institute (PTB), the Netherlands Vehicle Authority (RDW), the Dutch research organisation (TNO) and others. In addition, this paper was proposed to the OIML by Germany.

Several manufacturers have already developed particle counter equipment that meets these requirements. Some examples of equipment available or under development are the NPET (from TSI) or a recent equipment from SENSORS (http://www.sensors-inc.com/Products/SEMTECH/CPN) or the Nanomet3 from Testo (https://www.testo.com/de-CH/produkte/nanoparticle).

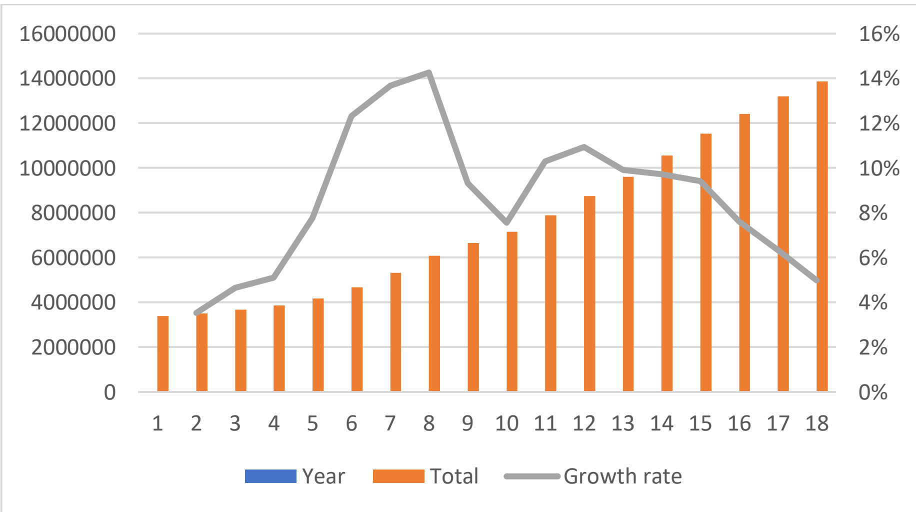
With regard to the measurement procedure, a simple and quick procedure should be considered. In this regard, we can rely on the experience of Switzerland in measuring PN at maximum RPM for construction machinery, and experiences in the Netherlands and Chile with the application of idle measurement. The latter has proven to be much simpler and provides very good results in detecting malfunctioning systems.

Regarding the limit to be used for qualifying malfunctioning vehicles, the most absolute recommendation is that it should be below 10^6 #/cm^3. However, a more specific value can be defined based on local testing of fleet behaviour.

1.6 Discussion of the Colombian vehicle fleet (Euro VI)

Colombia's vehicle fleet has grown steadily over the last 15 years. According to data from the Ministry of Transport´s National Single Transport Registry (*Registro Único Nacional de Tránsito* – RUNT), its growth rate was lowest in 2002 with 4% and highest in 2008 with 14%. From then on it has stabilized around 6% per year. As of July 2019, there are 14,957,654 registered vehicles[10].

Figure 6 Vehicle fleet in Colombia



Source: Prepared by the authors based on RUNT data.

[9] Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements. Annex 4.
[10] https://www.runt.com.co

One aspect that differentiates Colombia from other national registries in the Region is the number of motorcycles in the vehicle fleet. Around 58% of the fleet is made up of this type of motor vehicle, generating all the negative externalities that are widely known in the context of urban mobility.

Given the historical trends, Colombia will close the present administration with nearly 15 million motor vehicles. The annual number of vehicles registered is around 800,000.

For the purpose of the study, the annual increase in heavy-duty vehicles (minibuses, buses, trucks, tractors and dump trucks) should be defined. Most of these vehicles should be powered by diesel engines, which, under the expected trends and policies, should have EURO V and/or, ideally, EURO VI systems. With the official 2018 data, it is estimated that this vehicle segment will reach 530,000 motor vehicles. Although the segment represents 2% of new additions, the current inspection technology does not keep up with the new technology (smoke meters). In the case of light-duty vehicles, this increases at a rate of 220,000 vehicles per year. In this case, the parameter measured as an indicator of pollution (Carbon Monoxide - CO) and the efficiency parameters (CO_2 and O_2) will also meet the appropriate values, especially because of the pollution control systems. There is still a discussion as to whether Colombia will implement a NOx emissions control that requires infrastructure with load measurements or particle number measurements as explained below.

At the conurbation level, half of the vehicle fleet is concentrated in five cities: Bogota, Medellin, Cali, Bucaramanga and Barranquilla[11]. It is important to note that 25% corresponds to Bogota[12].

1.7 Discussion of Bogota's public transport fleet

As mentioned above, Bogota has 25% of Colombia's vehicle fleet. The ratio of motorcycles to 4-wheeled vehicles is different from the national average. Motorcycles only account for 28% of the fleet and cars, 43%. Most of the motorcycles in Colombia are heavily concentrated in tropical cities.

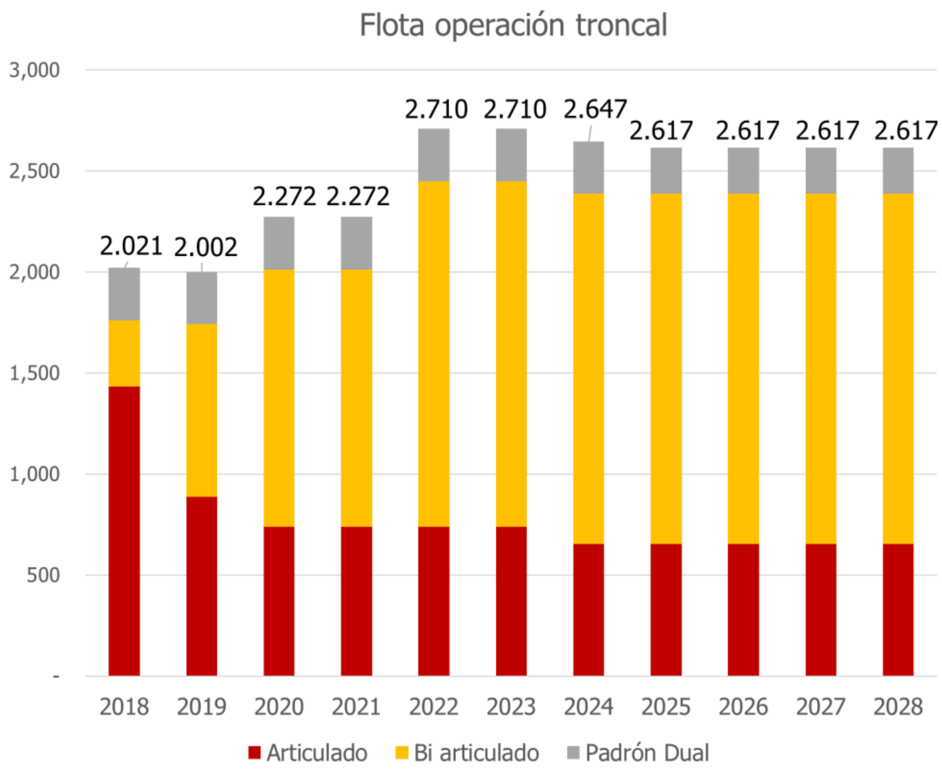
Heavy-duty vehicles including potentially diesel-powered minibuses account for 5.3%, with a volume of no more than 180,000 units. If we apply the national annual growth rate to this value, we have an annual increase of 3,600 vehicles which would require new inspection systems.

Transmilenio has initiated the process of renewing its fleet. The first stage of renewal involved removing 1152 articulated buses and 10 bi-articulated buses from service to make way for the introduction of 458 articulated buses and 925 bi-articulated buses[13]. The buses that were put into service were compressed natural gas-powered (EURO VI) articulated buses and diesel-powered bi-articulated buses (EURO V + DPF).

The fleet composition for trunk routes would be distributed as shown in Figure 10 until 2028 according to the Transmilenio scheme.

[11] Asociación Nacional de Movilidad Sostenible, with 2017 data.
[12] Includes: Bogota, Cota, Mosquera, La Calera, Cajica, Sibate, Funza, Chia, Facatitiva and Soacha
[13] Transminelio S.A. **Renewal of the TransMilenio fleet, Phase I and II.**

Figure 7: Composition of the Transmilenio Fleet



Source: Transmilenio S.A.

Translation of text in Figure 7:

- Flota operacional troncal: Bus fleet for trunk routes
- Articulado: Articulated
- Bi articulado: Bi-articulated
- Padrón Dual: Dual buses

This fleet composition and the technological upgrade will depend on electric mobility developments. There is no doubt that part of the fleet will be electric, but one part will certainly be EURO VI. Therefore, it is uncertain how many vehicles will be needed for the new inspection systems, in addition to the 1383 newly registered vehicles.

As for trucks, there is strong social and public pressure to reduce particulate matter pollution, particularly from this sector, since according to Bogota's emissions inventory, they contribute about 43% (measured in particle mass) against only 9.8% from the SITP (Bogota's Integrated Transportation System), as shown in Table 8

Table 7: Percentage of PM_{10} emissions from mobile sources in 2010, 2012, 2014 and 2016

Participación emisiones de PM_{10} Fuentes Móviles (%)				
Categoría	**2010**	**2012**	**2014**	**2016**
1. Vehículos privados	1,80%	3,80%	3,80%	2,74%
2. Camperos y Camionetas	1,20%	10,20%	11,00%	10,13%
3. Camiones	33,30%	36,40%	39,90%	43,60%
4. TPC	39,30%	36,20%	13,80%	13,62%
5. SITP (Servicio Zonal y Troncal)	2,60%	3,90%	9,00%	9,80%
6. Taxi	1,00%	0,30%	0,20%	0,25%
7. Motocicletas	20,80%	7,40%	7,40%	9,05%
8. Transporte Especial	NA	2,00%	14,80%	10,13%
9. Otros	NA	NA	NA	0,66%
Totales	**100%**	**100%**	**100%**	**100%**

Source: Bogota Emission Inventories - District Environmental Secretariat

Translation of text in Table 7:
Participación emisiones de PM10 Fuentes Móviles (%): Share of PM10 emissions from mobile sources
Categoría: Category
1.Vehículos privados: Private vehicles
2.Camperos y camionetas: Campers and vans
3.Camiones: Trucks
4.TPC: Collective Public Transport
5.SITP (Servicio Zonal y Troncal): SITP (Trunk and Zonal service)
6.Taxi: Taxi
7. Motocicletas: Motorcycles
8.Transporte Especial: Special Transport
9.Otros: Others
Totales: Total

According to RUNT´s 2017 report, the volume of trucks in the city reached 87,260 motor vehicles in addition to those registered in other cities of Colombia that have an interdistrict flow and that regularly run through the city. This is a potential niche for technological renewal that will most likely be EURO VI instead of electric. By adopting an aggressive renewal policy, we could consider the incorporation of at least 10% of the fleet, which would represent 8,700 motor vehicles.

1.8 Type approval procedures in Latin America (Ecuador, Chile and Colombia).

Regulated emission limits in Colombia

Based on the information provided to the consulting team, it appears that Colombia does not have an official vehicle type approval program for pollutant emissions from vehicles entering the country. Resolution 910 of the Ministry of the Environment, Housing and Territorial Development sets forth certain limits that must be observed by both in-service vehicles and new units entering the vehicle fleet; however, it does not meet the administrative requirements to become a vehicle type-approval system.

Resolution 910 cited above establishes what is known in Colombia as the "self-certification" mechanism, i.e. the importer or assembler of the vehicle must issue a certification stating the emission values reported by an independent laboratory endorsed by IDEAM[14]; however, in a vehicle type

[14] Resolution 910 - IDEAM

approval system, it must be consistent with the global accreditation system. Therefore, the authorized laboratories should be those accredited under ISO 17025 and included in the laboratory register held by ONAC (Colombia's National Accreditation Agency).

On the other hand, Law 1972 of July 18, 2019, establishes that as of January 1, 2023 all vehicles with diesel cycle engines must comply with maximum emissions limits corresponding to Euro VI technologies, equivalent or higher. However, it does not specify the administrative control procedure either. Therefore, compliance with Resolution 910, i.e. self-certification of the importer or assembler, would be expected, although the document does not state this either.

Ecuadorian type approval system[15]

By way of a comparative example, reference is made to Ecuador's vehicle type approval system, which is set out in Technical Regulations INEN 017 (pollutant emissions) and 034 (safety elements). This system is currently only on paper, but it establishes the mechanisms for validating the documents that the brand's sales representative must file with the control body (National Traffic Agency) in order to obtain the vehicle's type-approval certificate, which is an essential document for marketing and registering the vehicle in the country.

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The vehicle type approval system is based on the international accreditation system and requires an ISO 17025 accredited laboratory to issue the "Test Report".

The National Traffic Agency also has auditing capacity and can therefore revoke type approval documents and/or establish additional requirements if there are concerns about the accuracy of the results stated in the documents or about the values that the vehicles actually emit.

Chilean type approval system[16]

In the case of Chile, vehicle type approval is carried out by the Ministry of Transport and Telecommunications, through the Vehicle Control and Certification Centre (*Centro de Control y Certificación Vehicular,* 3CV). It consists of a technical analysis of light and medium-duty motor vehicles and motorcycles, which are either prototypes or production vehicles to be sold in the country.

This test includes checking the level of emissions from exhaust gases and hydrocarbon evaporation, and verifying compliance with safety, dimensional and functional requirements, including systems and components. For each model approved through this procedure, 3CV issues a Type Approval Certificate that indicates the model (make) in question with its main specifications. This certificate is valid as long as it does not change with respect to the prototype that was the subject of the approval.

In turn, manufacturers, shipping companies, importers or their representatives must issue individual certificates for each vehicle they sell corresponding to the tariff headings of the approved model. The vehicle covered by a valid Individual Type Approval Certificate (*Certificado de Homologación Individual*,

[15] Applicable reference standards: https://www.ant.gob.ec/index.php/descargable/category/56-homologacion-vehicular

[16] Adapted from: https://www.mtt.gob.cl/archivos/5609

CHI) is exempt from technical and exhaust gas inspections in order to obtain a vehicle registration certificate during the period of validity of the certificate.

The technical and exhaust gas inspections must be carried out no less than twenty-four nor more than thirty-six months from the month in which the document was issued and as appropriate according to the last digit of the plate.

However, the Chilean regulatory framework establishes a type approval system for light and medium-duty vehicles and motorcycles, while heavy-duty vehicles are certified locally through 3CV's own laboratories (hence providing a special system for testing this type of unit).

1.9 Analysis of the international recommendation on fuel quality

The Worldwide Fuel Charter was first established in 1998 to promote greater understanding of the fuel quality needs of motor vehicle technologies and to harmonise fuel quality worldwide in accordance with vehicle needs, with particular attention to new technologies for reducing pollutant emissions.

It provides recommended fuel specifications for a range of gasoline and diesel fuel grades for use with engines designed for different levels of emission control. It also provides a full explanation of the various aspects of fuel quality and its effects on vehicle emissions.

The Worldwide Fuel Charter is developed and published by the Worldwide Fuel Charter Committee, made up by representatives of the European Automobile Manufacturers´ Association (ACEA), the American Automobile Manufacturers Association (AAMA), the Japan Automobile Manufacturers Association (JAMA) and the Truck and Engine Manufacturers Association (EMA), with associate members from most other countries where automobiles are manufactured, and with the support of the Organization of Motor Vehicle Manufacturers (OICA).

Over the years, this document has become the best and most complete reference on fuel quality at the international level, and therefore any country with specific fuel quality improvement goals linked to sustained vehicle emission reduction programs should consider it a key reference.

Considering the emission reduction technology specifications that the Colombian vehicle fleet currently has and those that would come into effect on January 1, 2023 (EURO VI), the fuel quality required by these vehicles would correspond to the highest specification contained in the international recommendation shown in the following table[17]:

Table 8: Recommended diesel fuel quality specification for markets with highly advanced emission control and/or fuel efficiency requirements. It includes aftertreatment systems for particulate matter and NOX (SCRT).

Parameter	Unit	Limit	
		Minimum	Maximum
Cetane number		55	
Cetane number		55 (52)(1)	
Density @ 15°C	kg/m³	820(2)	840
Viscosity @ 40°C	mm²/s	2(3)	4
Sulphur	mg/kg(4)		10

[17] Reference to the fifth edition of the Worldwide Fuel Charter, 2013: http://www.oica.net/wp-content/uploads//WWFC5-2013-Final-single-page-correction2.pdf

Parameter	Unit	Limit	
		Minimum	**Maximum**
Trace metals[(5)]	mg/kg		1 or non-detectable, whichever is lower
Total Aromatics	Mass percentage		15
PAH (di+, tri+)	Mass percentage		2
T90[(6)]	°C		320
T95[(6)]	°C		340
Final boiling point	°C		350
Flash point	°C	55	
Carbon residue	Mass percentage		0,2
CFPP or LTFT or CP	°C		Equal to or lower than the lowest expected ambient temperature[(7)]
Water	mg/kg		200
Oxidation stability	g/m3		25
Foam volume	ml		100
Foam vanishing time	seconds		15
Biological growth[(8)]		No growth	
FAME		Non-detectable	
Other biofuels[(9)]			
Ethanol/Methanol	% by volume	Non-detectable[(10)]	
TAN (Total Acid Number)	mg KOH/g		0,08
Ferrous corrosion			Light rusting
Copper corrosion	Rating		Class 1
Ash	Mass percentage		0,001[(11)]
Particulate contamination, total	See test method		10
Particulate contamination, size distribution	Code rating		18/16/13 by ISO 4406
Appearance		Clean and bright; no free water or particulates	
Injector cleanliness (method 1)	% of air flow loss		85
Injector cleanliness (method 2)	% of power loss		2
Lubricity (HFRR wear scar diameter @ 60°C)	Micron		400

Source: Worldwide Fuel Charter; 5th Edition; 2013.

Notes:

(1) Cetane Index is acceptable instead of Cetane Number if a standardized engine to determine the Cetane Number is unavailable and cetane improvers are not used. When cetane improvers are used, the estimated Cetane Number must be greater than or equal to the specified value and the Cetane Index must be greater than or equal to the number in parenthesis.

(2) May relax minimum limit to 800 kg/m3 when ambient temperatures are below -30°C. For environmental purposes, a minimum of 815 kg/m3 can be adopted.

(3) May relax minimum limit to 1.5 mm^2/s when ambient temperatures are below -30°C or to 1.3 mm^2/s when ambient temperatures are below -40°C.

(4) The unit mg/kg is often expressed as ppm.

(5) Examples of trace metals include, but are not limited to, Cu, Fe, Mn, Na, P, Pb, Si and Zn. Another undesirable element is Cl. No trace metal should exceed 1 mg/kg. No intentional addition of metal-based additives is allowed.
(6) Compliance with either T90 or T95 is required..
(7) If compliance is demonstrated by meeting CFPP, then it must be no more than 10°C less than cloud point.
(8) Alternative test methods, with appropriate limits for "no biological growth," can be used.
(9) Other biofuels include HVO and BTL. Blending level must allow the finished fuel to meet all the required specifications.
(10) At or below detection limit of the test method used..
(11) Limit and test method are under review to assure DPF endurance. The use of the most developed laboratory ASTM methods for each parameter is recommended.

As can be seen, high specification fuel for emission control systems with advanced aftertreatment suggests not using biofuels in blending with the base fuel.

Fatty acid methyl esters (FAME), also known as biodiesel, are increasingly used to extend or replace diesel fuel. Such use has been largely driven by efforts in many countries to exploit agricultural products and/or to reduce dependence on oil-based products, especially linked to greenhouse gas emission mitigation strategies also called "carbon neutrality".

Several different oils may be used to make biodiesel, e.g. rapeseed, sunflower, palm, soy, cooking oils, animal fats and others. These oils must be reacted with an alcohol to form ester compounds before they can be used as biodiesel fuel. Unprocessed vegetable oils, animal fats and non-esterified fatty acids cannot be used as fuel for internal combustion engines due to their very low cetane level, inadequate cold flow properties, high injector fouling tendency and high kinematics viscosity level. Historically, methanol has been the alcohol most used to esterify the fatty acids, and the resulting product is called fatty acid methyl ester (FAME).

Research is underway to allow the use of ethanol as a reactive alcohol in which case the product is called fatty acid ethyl ester (FAEE).

The European standards organization, CEN, has published a FAME standard (EN 14214) that establishes specifications for biodiesel use as either: (i) a final fuel in engines designed or adapted for biodiesel use; or (ii) a blending material for conventional diesel fuel. Similarly, ASTM International has set specifications for neat biodiesel (ASTM D 6751) but only for use as a blending component, not as a final fuel

Generally, biodiesel is believed to enhance the lubricity of conventional diesel fuel and reduce exhaust gas particulate matter. At the same time, engine and vehicle manufacturers have concerns about introducing biodiesel into the marketplace, especially at higher levels, specifically:

- Biodiesel may be less stable than conventional diesel fuel, so precautions are needed to avoid problems linked to the presence of oxidation products in the fuel. Some fuel injection equipment data suggest such problems may be exacerbated when biodiesel is blended with ultra-low sulphur diesel fuels.
- Biodiesel requires special care at low temperatures to avoid an excessive rise in viscosity and loss of fluidity. Additives may be required to alleviate these problems.
- Being hygroscopic, biodiesel fuels require special handling to prevent high water content and the consequent risk of corrosion and microbial growth
- Deposit formation in the fuel injection system may be higher with biodiesel blends than with conventional diesel fuel, so detergent additive treatments are advised.
- At low ambient temperatures, FAME may produce precipitated solids above the cloud point, which can cause filterability problems.
- Biodiesel may negatively impact natural and nitrile rubber seals in fuel systems. Also, metals such as brass, bronze, copper, lead and zinc may oxidize from contact with biodiesel, thereby

creating sediments, which is why it is not recommended for older engines that have these materials.

- Transitioning from conventional diesel fuel to biodiesel blends may significantly increase tank sediments due to biodiesel's higher polarity, and these sediments may plug fuel filters. Thus, fuel system parts must be specially chosen for their compatibility with biodiesel (manufacturer certifications).
- Neat (100%) biodiesel fuel and high concentration biodiesel blends have demonstrated an increase in NOx exhaust emission levels.
- Biodiesel fuel that comes into contact with the vehicle's shell may be able to dissolve the paint coatings used to protect external surfaces.

Biodiesel (FAME) inherently has poor oxidation stability due to the nature of its chemical composition. Most FAMEs contain carbon-to-carbon double bonds in its chemical construction that are easily oxidized after production and during the storage and use of the fuel. Such oxidation reactions are why precautions must be taken, such as the use of oxidation stability enhancing additives like BHT, when blending and distributing biodiesel fuels.

To secure the quality of biodiesel blended fuel, additional oxidation stability criteria are being introduced into finished fuel specifications in some regions. The European standard for B7 requires a 20 hour minimum induction period by the modified Rancimat method (See EN 590). As part of a compulsory standard for B5, Japan requires either a delta TAN maximum of 0.12 mg KOH/g[18] or a minimum of 65 minutes by the PetroOXY method. The growth in acid value is reported as delta TAN.

The current European limit is believed to be inadequate to prevent corrosion in metal parts such as vehicle fuel tanks, however. Given ongoing questions about the adequacy of various methods and limits, Europe and Japan are working to harmonize the oxidation stability test method by introducing the PetroOXY method. The goal of the investigation is to shorten the test duration and improve repeatability of the results. This research may lead to future revisions in the oxidation criterion and test method for biodiesel blended fuels.

In contrast to the above, the Colombian Ministries of Agriculture and Rural Development, Mines and Energy, and Environment and Sustainable Development have issued Resolution No. 4-0666 dated 20 August 2019, which establishes the blending of 12% biodiesel for fuel used in vehicle engines in some areas of the country, including large metropolitan areas, as of 1 September this year, which could have an impact on the undesirable effects listed above.

For these reasons, we suggest that the National Government of Colombia officially inform the sales representatives of diesel engine vehicles regarding the decision to change the quality of the fuel mentioned above, and at the same time, that these sales representatives be asked to issue certificates that their vehicles will be able to operate normally with the regulated concentration of biodiesel (B12), without this affecting the manufacturer's warranties for new vehicles to be sold in the country.

The Biodiesel Handling and Use Guide[19] has been included as Annex 1 to this document. This guide is particularly indicated for the use of high specification vehicles in emission control systems and equipped with aftertreatment devices (SCR and CRT), prior to the use of fuels that contain significant amounts of biodiesel in their composition. Authorities are advised to use this document as a reference and issue a similar one for Colombia, in order to guide users in the proper use of fuel.

[18] The delta TAN method measures the acid value before and after ageing according to ASTM D2274 (@ 115°C)
[19] https://www.afdc.energy.gov/uploads/publication/biodiesel_handling_use_guide.pdf

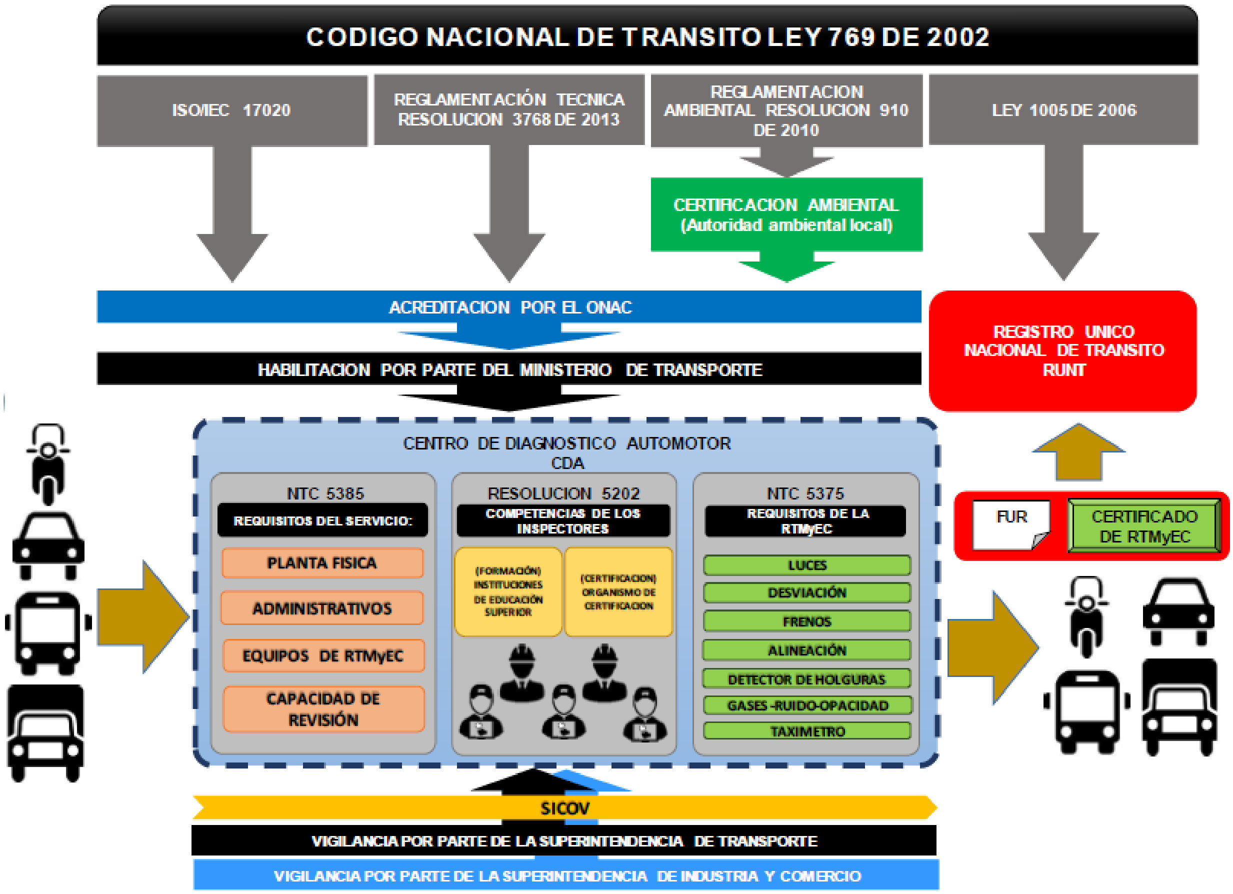
2 The Colombian System of Automotive Diagnostic Centers

2.1 Institutional framework of Automotive Diagnostic Centers (CDAs)

The Colombian national system of Automotive Diagnostic Centers (Technical-Mechanical and Pollutant Emissions Inspection System) was established by Law 769 of 2002 (National Traffic Code) and is extensively outlined in Resolution 3768 of 2013 of the Ministry of Transport.

As for its organizational structure, the CDA system follows a non-centralized model, also known as liberal authorization, whereby the relevant regulatory body (Ministry of Transport) sets the operational standards and requirements that technical inspection facilities must meet and authorizes their operation, but does not limit their number or type, since it is considered a private equity project, similar to any other business or economic venture.

Figure 2: Legal and institutional framework of the Colombian Pollutant Emissions and Mechanical and Technical Inspection System.



Source: The Pollutant Emissions and Mechanical and Technical Inspection System; National Association of Vehicle Diagnostic Centres; 2019.

Translation of text in Figure 2

CÓDIGO NACIONAL DE TRÁNSITO – LEY 769 DE 2002: NATIONAL TRAFFIC CODE - LAW 769 OF 2002
ISO/IEC 17020: ISO/IEC 17020
REGLAMENTACIÓN TÉCNICA RESOLUCIÓN…: TECHNICAL REGULATION – RESOLUTION 3768 OF 2013
REGLAMENTACIÓN AMBIENTAL RESOLUCIÓN…: ENVIRONMENTAL REGULATION – RESOLUTION 910 OF 2010
LEY 1005: LAW 1005 OF 2006
CERTIFICACIÓN AMBIENTAL: ENVIRONMENTAL CERTIFICATION (Local environmental authority)
ACREDITACIÓN POR EL ONAC: ONAC ACCREDITATION
HABILITACIÓN POR PARTE DEL MINISTERIO DE TRANSPORTE: AUTHORIZATION BY MINISTRY OF TRANSPORT
REGISTRO ÚNICO NACIONAL DE TRÁNSITO (RUNT): NATIONAL SINGLE TRANSIT REGISTRY (RUNT)
CENTRO DE DIAGNÓSTICO AUTOMOTOR (CDA): AUTOMOTIVE DIAGNOSTIC CENTER (CDA)
REQUISITOS DEL SERVICIO: SERVICE REQUIREMENTS

PLANTA FÍSICA: PHYSICAL FACILITY
ADMINISTRATIVOS: ADMINISTRATIVE
EQUIPOS DE RTMyEC: MECHANICAL-TECHNICAL INSPECTION EQUIPMENT
CAPACIDAD DE REVISIÓN: INSPECTION CAPABILITY
RESOLUCIÓN 5202: RESOLUTION 5202
COMPETENCIA DE LOS INSPECTORES: INSPECTORS´ COMPETENCE
(FORMACIÓN)…: (TRAINING) HIGHER EDUCATION INSTITUTES
(CERTIFICACIÓN)…: (CERTIFICATION) CERTIFICATION BODIES
NTC 5375: NTC 5375
REQUISITOS DE LA RTMyEC: MECHANICAL-TECHNICAL INSPECTION REQUIREMENTS
LUCES: LIGHTS
DESVIACIÓN: AXIS DEVIATION
FRENOS: BRAKES
ALINEACIÓN: ALIGNMENT
DETECTOR DE HOLGURAS: PLAY DETECTOR
GASES-RUIDO-OPACIDAD: GASES-NOISE-OPACITY
TAXIMETRO: TAXIMETER
CERTIFICADO DE RTMyEC: MECHANICAL-TECHNICAL INSPECTION CERTIFICATE
VIGILANCIA POR PARTE DE LA SUPERINTENDENCIA DE TRANSPORTE: OVERSIGHT BY THE TRANSPORT SUPERINTENDENCE
VIGILANCIA POR PARTE DE LA SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO: OVERSIGHT BY THE INDUSTRY AND TRADE SUPERINTENDENCE

However, as can be seen in Figure 2, Colombia's Mechanical-Technical and Pollutant Emissions Inspection system is based on a series of additional regulations to the one already mentioned, which make it considerably complex, since it involves several control authorities. Thus, CDAs must be accredited under the ISO/IEC 17020 standard, whose official version in Colombia must be issued by ICONTEC. On the other hand, the agency that verifies and issues the accreditation is the National Accreditation Organization of Colombia (*Organismo Nacional de Acreditación*, ONAC), based on the International Accreditation System's mandate and powers. Additionally, these entities must comply with the Environmental Regulations contained in Resolution 910 of 2010 of the Ministry of the Environment, which is implemented through both departmental and municipal or metropolitan authorities, as in the case of Valle de Aburra or the Capital District. Finally, the CDAs must comply with the requirements established in Law 1005 of 2006, which creates the National Single Transit Registry (RUNT). Even though the RUNT is a private body, like the CDAs, it has the specific competences of a national transportation authority, since it is bound to it by a concession contract.

The institutional framework of the CDAs in Colombia is one of the most complex in Latin America, making it very difficult to oversee and implement policies through them. This can generate conflicts between authorities and lack of coordination in the implementation process as mentioned by the stakeholders contacted by the consulting team during the field visit in Bogota.

2.2 Characteristics of the system

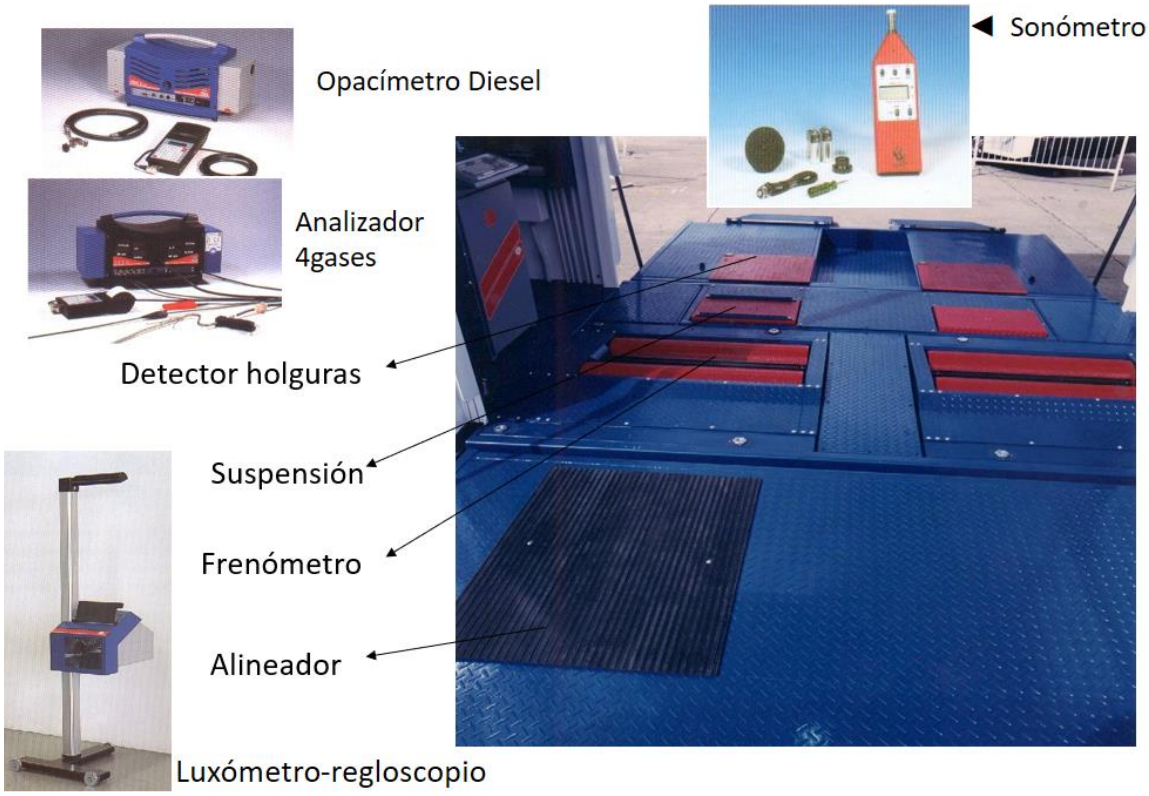
Colombia's PTI system (locally known as the Technical-Mechanical and Pollutant Emission Inspection), is based on the model known internationally as "Decentralised Inspection" in which each vehicle inspection station acts autonomously, regulated by a set of technical standards and specific legislation under the control of different local and national authorities.

In this regard, the Colombian model has similarities to the model implemented in Peru and in certain states of the Mexican Union, while it differs from that implemented in Ecuador, Chile, Argentina and Costa Rica, which follow the so-called "Centralised inspection" approach, in which the system is managed by a single local authority and is often implemented through a concession contract or public-private partnership.

The PTI is a comprehensive system that performs diagnostic tests on various vehicle systems in a single location as well as several sequential measurements. These tests regularly follow local technical regulations and are generally based on international recommendations and/or standards, focusing on emissions, lights, brakes, suspension, alignment, underbody and bodywork, noise, among others.

In general, an integrated computerised mechatronics line comprises the equipment shown in Figure 3.

Figure 3: Setting up an integrated computerised mechatronic inspection system..



Source: Roberto Custode Archive.

Translation of text in Figure 3:
Opacímetro diesel: Diesel opacimeter
Sonómetro: Sound meter
Analizador gases: Gas tester
Detector holguras: Play detector
Suspensión: Suspension bench
Frenómetro: Brake meter
Alineador: Aligner
Luxómetro-regloscopio: Light meter-beamsetter

In this setup, all equipment is managed by a single computer platform, which not only activates each module, but also collects the readings of the measurement performed by each instrument and integrates them into a single database or output file platform, for storage and post-processing. Several brands of equipment are currently available in the international market, all of which are accredited members of the International Motor Vehicle Inspection Committee (CITA)[20].

[20] International Motor Vehicle Inspection Committee - CITA: https://citainsp.org/

2.3 Upgrading the inspection system in Colombia

Despite the above, a parallel system to the CDAs exists in practice, which is implemented by several autonomous authorities, primarily linked to the area of pollutant emissions[21]. It is not known whether this similarity is due to an unresolved overlapping of powers by environmental municipal, metropolitan, departmental, regional and national authorities, but in practice it generates redundant control over controlled vehicle units, especially those belonging to the public transportation systems of Colombia's most populated cities.

As a result, there is a risk that the authorities involved will disrupt the mechanisms for the operational control of vehicle emissions, which could have a potential negative impact on the effectiveness of inspection actions and duplicate efforts. This in turn weakens the capacity of the inspection authorities to respond to the regulated parties and consequently their ability to reduce the environmental impact caused by in-service vehicles.

Therefore, considering that the CDA system is already in its twelfth year of implementation, possible scenarios to improve its management model must be considered, focusing particularly on improving its intervention capacity so it can evolve based on state-of-the-art operational management of PTI systems.

On the one hand, systems based on the "Centralised Technical Inspection" are currently the most effective in terms of performance, efficiency and feedback of the process, because they have a single fully competent licensing or regulatory authority. This implementation mechanism allows coordination among several sectoral authorities, but also harmonizes roles, moving from a scenario of overlapping competences (interference) to one of operational coordination and collaboration (synergy).

The basic requirement of this type of control and management system is that implementation and inspection should rest on a single authority while there should be an unambiguous inspection mechanism between the PTI operators and their management authorities. On the other hand, it will be the local control authorities themselves (licensing bodies) who will have to respond and engage with the national control authorities.

In practice, this means that the system should not be based on facilitating and promoting MSMEs, but rather on the most effective design for the provision of a public service, in which the PTI operator is merely the control instrument required by the authority and not its justification. Therefore, the number of operators, stations and lines required is based on the demand and is controlled through a two-way computer link between the control body and its licensed operator. In this way direct administrative actions can be taken instead of having to go through complex legal procedures.

Upgrading the Colombian system will certainly require changing and improving the control and inspection legislation, both at the technical and regulatory levels, which will result in better quality interventions. However, if this mechanism is considered too complex and unfeasible in the short term, the procedures for interagency coordination among operational control bodies (CDAs) must be redesigned, since there are significant opportunities for improving their current mechanisms of interaction with a positive impact on the users of the system, environmental quality and road safety.

[21] This parallel system to the CDAs, described in this paragraph, was verified by the consulting team during its field visits, where it became evident that inspection on public roads and in the Transmilenio bus yards was carried out by the District Secretary of the Environment of Bogota (a similar action is known to have been taken by the Metropolitan Environmental Authority of the Aburra Valley), limiting its action to pollutant emissions (area of competence). This similarity has also been discussed in section 2 of this document which addresses the legal-institutional framework of the CDA system.

2.4 Roadside inspection in Bogota

The procedure for inspecting road vehicles in the city of Bogota, documented during the consultants visit, has significant opportunities for improvement, both in the technological upgrade of information processing systems as well as in the use of instruments for this procedure.

Figure 4: Smoke meter of the District Secretary of the Environment of Bogota, connected to a public transport unit.

Source: Archive of the consulting team

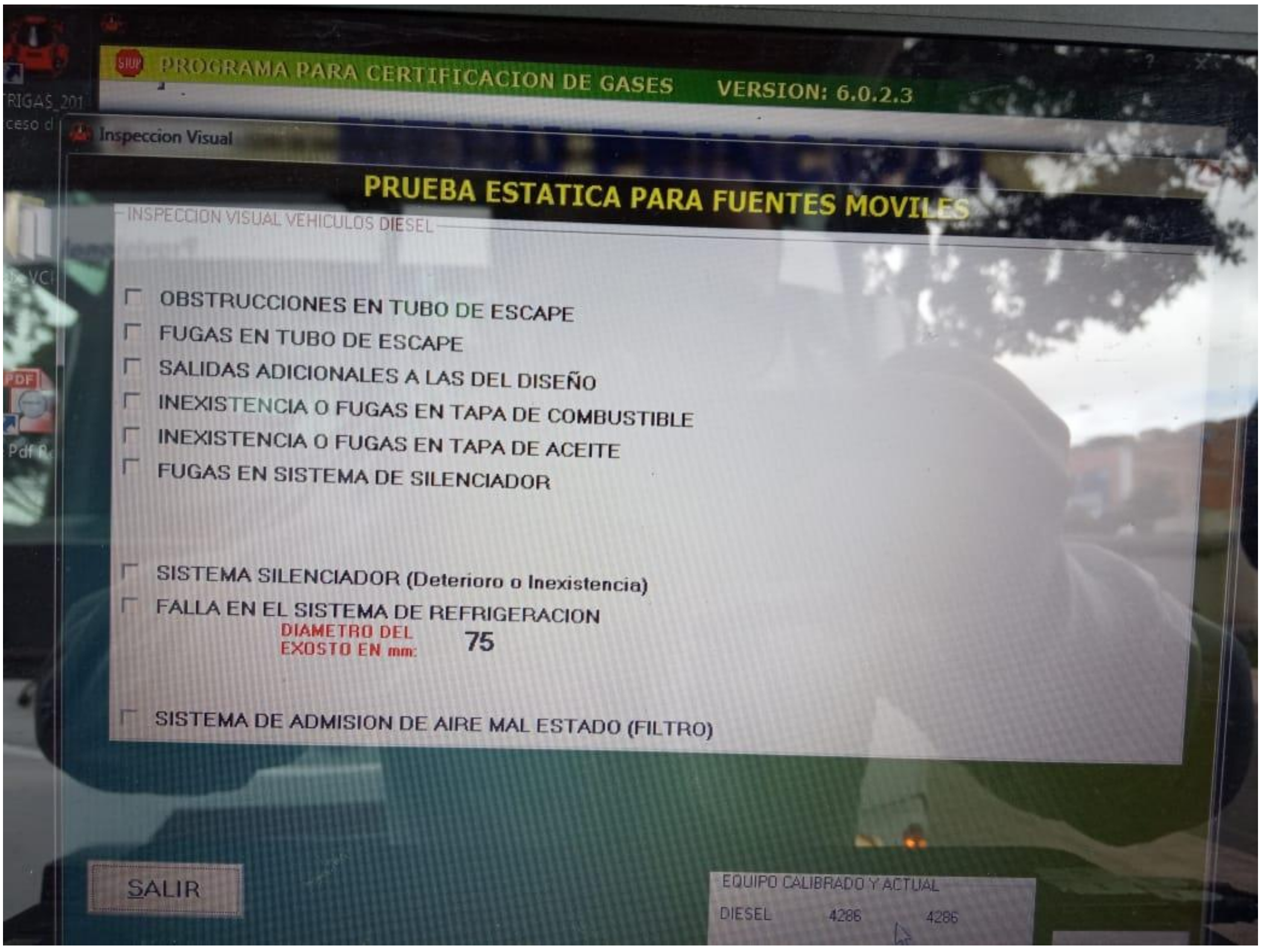
One of the main issues noted during the inspection procedure is that the operational testing takes considerable time since all the data contained in the registration card of the vehicle being tested need to be manually entered into the mobile inspection unit's computer, resulting in a high possibility of error and a substantial waiting time (almost 10 minutes). Subsequently, all the procedures established under the NTC 4231, NTC 4983 and NTC 5365 standards are carried out, depending on whether it is an Otto or Diesel cycle engine and the type of unit.

Some of these procedures should not be performed on the roadside, such as checking the oil temperature in the crankcase, testing opacity levels at 0 and 100%, among others. All this makes the process even slower and generates significant delays and inefficiency in the process. This roadside inspection process is not well accepted by the population as it is not a quick roadside inspection.[22]

[22] From the information gathered, only 8 to 10 units per checkpoint can be tested during the working day (data subject to verification).

It should also be noted that the computerised control system used by the mobile roadside inspection unit lacks connectivity with the centralised systems of the inspection authority and must therefore be downloaded manually in order to be processed and stored in a timely manner.

Figure 5: Pre-operational testing requirements for roadside inspections



Source: Archive of the consulting team

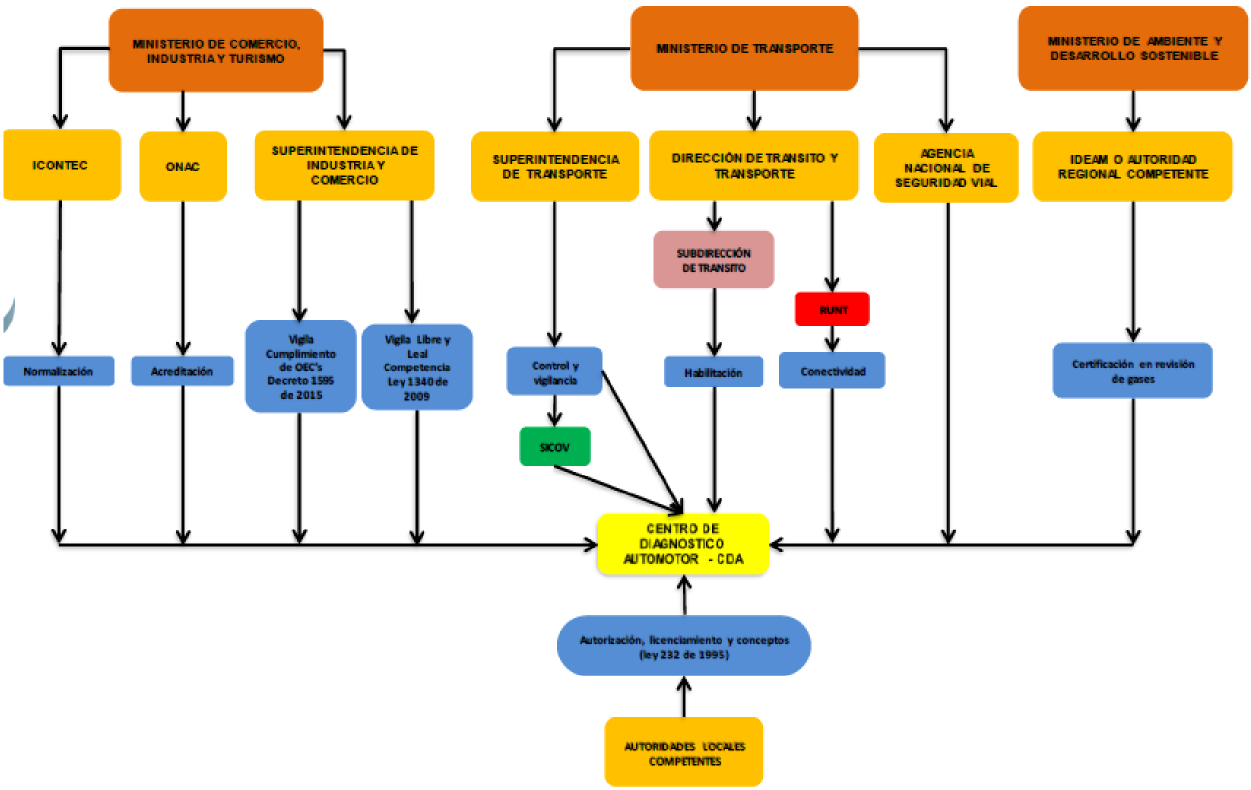
Figure 6: Explanation of the roadside inspection system

Source: Archive of the consulting team

2.5 Institutional framework of the system

The Periodic Technical Inspection system in Colombia involves a large number of bodies, which have joint responsibility for the control, regulation and inspection of facilities as well as for the execution of roadside policies.

Figure 8: Institutional scheme of the Colombian Technical-Mechanical and Pollutant Emissions Inspection.



Source: Revisión Técnico Mecánica y de Emisiones Contaminantes; Asociación Nacional de Centros de Diagnóstico Automotor; 2019.

Translation of text from Figure 8

MINISTERIO DE COMERCIO, INDUSTRIA Y TURISMO: MINISTRY OF TRADE, INDUSTRY AND TOURISM
MINISTERIO DE TRANSPORTE: MINISTRY OF TRANSPORT
MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE: MINISTRY OF THE ENVIRONMENT AND SUSTAINABLE DEVELOPMENT
SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO: INDUSTRY AND TRADE SUPERINTENDENCE
DIRECCIÓN DE TRÁNSITO Y TRANSPORTE: TRAFFIC AND TRANSPORT DIRECTORATE
AGENCIA NACIONAL DE SEGURIDAD VIAL: NATIONAL ROAD SAFETY AGENCY
IDEAM O AUTORIDAD REGIONAL COMPETENTE: IDEAM OR REGIONAL COMPETENT AUTHORITY
SUBDIRRECIÓN DE TRÁNSITO: TRANSIT DIVISION
Normalización: Standardisation
Acreditación: Accreditation
Vigila cumplimiento de OEC´s… : Oversees OEC compliance (Decree 1595 of 2015)
Vigila libre y leal competencia: Oversees free and fair competition (Law 1340 of 2009)
Control y vigilancia: Control and surveillance
Habilitación: Authorisation
RUNT: RUNT
Conectividad: Connectivity
Certificación en revisión de gases: Gas inspection certification
CENTRO DE DIAGNÓSTICO AUTOMOTOR – CDA: AUTOMOTIVE DIAGNOSTIC CENTER – CDA
Autorización, licenciamiento y conceptos: Authorization, licencing and concepts (Law 232 of 1995)
AUTORIDADES LOCALES COMPETENTES: LOCAL COMPETENT AUTHORITIES

This somehow interferes with policy implementation, especially controls related to emission testing from mobile units with advanced aftertreatment systems, such as DPF and/or SCR.

The experience of countries with a longer history of periodic technical inspection shows that the coordination between authorities should be at the core of the PTI process, so that inspection stations are not affected or confused by certain aspects of the PTI.

In addition, it must be recognized that in the near future a differentiated emission control system for diesel vehicles will be necessary, since the smoke meters currently used are not suitable for testing this type of vehicles. This opens up a new challenge concerning the regulatory framework for vehicle inspection, since a new set of regulations will have to be drafted to make it enforceable in practice.

2.6 Current procedures and filing of infraction notices

The infraction notices issued by the mobile roadside control and inspection units are processed legally and issued locally, but there is no online and real time electronic backup. This renders the system susceptible to errors both in data entry and filing of records, thus making it somewhat vulnerable.

Therefore, the platform needs to be upgraded in line with technological developments in management of traffic control, transport and land-based mobile source emissions. This does not necessarily mean changing the type of equipment to be used, but rather upgrading the computer systems that support it.

In this regard, international experiences show that the greatest effectiveness is achieved by streamlining procedures and using computerised registration data systems, possibly through advanced information methodologies, such as RFID/NFC identifiers, among others. This not only makes the procedure very efficient, but also highly reliable, minimizing the risk of inconsistencies in report processing, and ensuring that they are resolved to the satisfaction of the control authorities.

2.7 Upgrading the roadside inspection system

Today, virtually all inspection systems are based on centralised, interconnected, web-service platforms that interact with various databases and inspection systems. This means that, to a greater or lesser extent, roadside inspection equipment must have data transmission and interconnection capacity which does not currently exist.

The technological upgrade of modern inspection platforms relies mainly on their ability to manage information online (interconnection), mostly through web connectivity technology and mobile communication networks that are now locally available in most Colombian cities. These platforms provide quality bidirectional transmission of support information required for managing operations. At the same time, by substantially increasing the number of units tested, it is possible to achieve greater effectiveness and efficiency during inspections.

However, this technological upgrade of the management platforms is insufficient unless the legal and regulatory framework is updated in a way that is consistent with the inspection to be performed and with its physical and human components, in order to ensure adequate coordination.

As an example, even if the management platform is upgraded and enhanced, inspection and control will not be efficient if unnecessary or ineffective testing procedures are maintained, such as measuring the oil temperature in the crankcase by inserting a thermocouple probe through the oil level measuring spigot line, because this procedure, in addition to being risky, takes a long time and is not relevant for the final test.

3 Colombian standard for opacity measurement

3.1 The international SAE J 1667 standard

The SAE J 1667 standard dates from the mid-1990s and was developed by the Society of Automotive Engineers of America (SAE), to measure visible smoke from heavy-duty diesel vehicles, which ideally have overhead exhaust systems, This is why the equipment referred to in this standard is known as "open-chamber" or "full- flow" equipment, i.e. systems where the exhaust is located in the middle of the equipment's light transmitter and receiver and the smoke plume passes through them, generating a measurement.

Figure 7: SAE J 1667 smoke meter (full-flow to open-chamber)

Source: http://www.eiseverywhere.com

This standard also provides for a smoke plume sampling system (although it does not describe nor specify a partial-flow or external closed-chamber equipment), but within the same dimensional and development concepts of a full-flow equipment. This is why most equipment under this standard have the same characteristics as the one shown in Figure 7.

The main feature of this type of equipment is the complex way of correcting the measurements made, which are affected by recalculations due to external factors such as ambient temperature and humidity, barometric pressure of the measurement site, dry and wet bulb temperature of the measurement site, wind speed, among others Similarly, the equipment must correct the measurements according to a second-order filtering algorithm to adjust the measurement response to 0.5 seconds. The standard itself, however, indicates that the adjustment equations should not be used when having air densities below 0.908 kg/m^3, which are not uncommon during hot days in cities at high altitude, so such devices should be avoided under these conditions. It also suggests avoiding the use of the correction equations when temperatures above 32°C are reached in locations below 412 meters above sea level, since systematic effects of deviation from the proposed corrections have been found.

While these advanced features have the primary purpose of providing the user and the inspection authority with a highly reproducible and reliable measurement over time, they often generate lower measurements than closed-chamber partial-flow smoke meters (ISO 11614) – which generally report peak opacity values rather than corrected values – making their results not comparable.

On the other hand, it should be noted that the SAE J 1667 standard is designed to measure opacity in heavy-duty vehicles and buses but does not apply to light-duty diesel vehicles, which are very common in Latin America, especially those of European origin, and medium and light-duty vehicles (pickup trucks and vans), which somehow hinders their use in the region.

Opacimeters that meet the SAE J 1667 standard are commonly used in the United States and Canada, but have not become popular in the Latin American region, presumably because of the regulatory requirement for uniform exhaust pipe diameter, a situation that is uncommon in the Region, given the adaptations that are usually required with respect to the original manufacturer's vehicle configurations.

3.2 ISO 11614

The first version of ISO 11614 dates to 1999 and was developed by the International Organization for Standardization (ISO) to evaluate the degree of opacity of exhaust gas from light and heavy-duty vehicles equipped with diesel engines. In addition to open-chamber or full-flow equipment, this standard specifies "closed-chamber" or "partial-flow" equipment, which consists of instruments that take a sample of the exhaust gas flow from the vehicles tested and force it through a chamber under controlled conditions and known dimensions, where both the light transmitter and receiver are found.

It should be noted that ISO 11614 does not make the distinction indicated in SAE J 1667 with regards to the type of vehicles to be tested. Specifically, the scope of the recommendation does not exclude medium and light-duty vehicles. For this reason, its implementation is considerably more general and applicable to Latin American countries.

Since the ISO 11614 does not propose correcting the measurement for weather conditions, nor does it suggest using the sophisticated response correction algorithms established by the equivalent SAE, the testing is usually focused on establishing peak opacity values. In this regard, even though their results are less replicable, they can also be considered more correlative and comparable, as they are not significantly affected by external factors, but rather limited to immediate results.

Figure 8: Partial-flow (closed-chamber) smoke meter certified under ISO 11614

Source: https://koeng.page.tl/Opacity-Meter.htm

These are the reasons most Latin American countries rather use this standard to make their results comparable instead of the one issued by the SAE. However, the trend of high opacity values in high-altitude cities is a regional constant, which is not necessarily due to one smoke measurement methodology or another, but rather to an external factor resulting from the change in engine operating conditions when they are at sea level or high-altitude locations (over 1500 meters above sea level).

3.3 The Colombian Standard

The consulting team does not have information on those responsible for drafting Colombian Technical Standard NTC 4231[23]; however, this standard outlines several aspects inherent to both ISO 11614 and SAE J 1667. The objective is to compile the best design and operating practices for both standards, summarizing them in a partial flow measurement kit. Nevertheless, it should be noted that the two standards are not compatible in many aspects and that other Latin American countries have widely adopted the ISO 11614 standard. Thus, the historical results of the tests performed in Colombia are not comparable with those of other countries, since they appear to use different regulatory systems.

Additionally, the NTC standard establishes several metrological certification requirements that may not be possible to meet locally, such as checking the second-order response filtering algorithm, the wavelength of the green LED light bulb, and the response of interferometric systems (physical and electrical response of the receiver), among others. In this regard, an exhaustive description would not be useful.

In view of the above, it is advisable that countries that use technology developed and certified in industrialised nations request metrological certifications from the countries of origin of the equipment and create a procedure for standardizing requirements, rather than depending on the translation and transcription of regulatory requirements that cannot be verified locally.

3.4 Recommendations for updating regulations

Given that the other South American countries where emission control on diesel vehicles is performed using the free acceleration opacity test commonly follow the ISO 11614 standard, its adaptation and

[23] Testing procedures and characteristics of partial-flow equipment necessary to measure smoke emissions from diesel-powered mobile sources. Free acceleration method

direct use in Colombia should be considered, and SAE J 1667 should be regarded only as an international benchmark not applicable to Colombian´s situation.

Consequently, the bodies responsible for inspecting and regulating pollutant emissions from motor vehicles must examine the possibility of revising everything set forth in their regulations. The transcription of metrological standards that cannot be verified in the country could be replaced with technical and administrative systems for type approval and international certification with respect to the country of origin of the instruments.

As an example of this need, we must also consider the fact that the opacity measurement equipment found at both the CDAs and roadside (inspection) checkpoints were partial-flow and closed-chamber instruments, which are not certified under SAE J 1667 (although said standard does not expressly exclude them). However, it is impossible to determine their type without knowing in detail the corrections their software makes or the sensors they use to make such corrections.

4 Alternatives for inspecting the new fleet in Bogota

4.1 Background on inspection of the new fleet

Currently, based on the information available on the new Transmilenio fleet discussed in section 1.2, as well as the information presented in section 1.5 regarding the state of the art of emission testing on engines with DPFs, we can recommend that the PN testing be incorporated into the fleet inspection procedures using equipment that meets the corresponding certification requirements .

In this regard, the consulting team from CALAC+ was able to learn about three particular experiences which included roadside vehicle emission testing by the SDA, emission control performed by the SDA in the Transmilenio bus yard, and emission and safety testing at Automotive Diagnostic Centers (CDA).

Random roadside emission testing is a very effective method used in Chile, among other countries, since vehicles are inspected under their actual operating conditions and emitting exhaust gas. A field measurement was performed using a PN counter (TSI-NPET Model 3795) on 400 Transantiago buses with DPF. The purpose of the program was to determine the specifications of the equipment, test procedure and PN testing limit of heavy-duty vehicles after DPF. Measurements were taken at low idle speed and at maximum RPM, along with the traditional smoke measurement (free acceleration). The conclusions were:

- PN testing was much more sensitive, instrumentally, than smoke measurement.
- A recommendable limit for detecting a malfunctioning DPF was $2.2x10^5$ $\#/cm^3$, measured at idle speed.
- Measurement at idling turned out to be the simplest, most effective procedure for detecting malfunctioning DPFs.
- The free acceleration test shows difficulties in some modern vehicles, particularly when the vehicle computer unit does not allow you to perform free acceleration and when the acceleration process (3 times at least) is not exactly the same (either voluntarily or due to human error).

In practice, each measurement took 2 to 4 minutes, and the measurements were taken in a simple manner.

Notwithstanding what was discussed during the visit with the environmental and transport authorities, it might be difficult to implement this type of inspection on the Transmilenio buses due to the current operating conditions. This is primarily due to the system's capacity problems.

An alternative may be PN emission control in bus yards, using the SDA’s current inspection system for measuring bus opacity. That is, taking advantage of the time buses are parked and out of service or arriving or leaving. The disadvantage compared to roadside inspection is that the selection of buses may no longer be random and under actual operating conditions.

Using this method, a practical PN testing exercise was carried out on July 31 in a Transmilenio bus yard. Measurements were taken by SDA technicians using Nanomet3 equipment, which operates under the PMP testing methodology required for PN testing. On that occasion, measurements were taken of four buses at low idle speed, with the following results.

Table 9: Results of Transmilenio bus measurements using Nanomet3 (Meeting minutes - 126PG01-PR08-M2 – SDA)

Vehicle No.	Type	Make	Technology	Result [#/cm³]
FVK 733	Bi-articulated	VOLVO	Euro V diesel + DPF	900
FVK 863	Bi-articulated	SCANIA	Euro VI gas	2,000
ESO 170	Bi-articulated	VOLVO	Euro V diesel	35,000
FVK 403	Articulated	VOLVO	Euro V diesel + DPF	40,000

Source:

An assessment of DPF systems in Euro V diesel + DPF buses is of particular interest. According to international experiences in PN measurement (Chile and Switzerland), a reference value of 250,000 [#/cm³] is adequate to identify malfunctioning DPF systems. In this regard, DPF filters in FVK 733 and FVK 403 buses showed good performance. However, the CALAC+ consulting team was surprised to find soot at the end of the tail pipe of both diesel buses (mainly in the FVK 403 bus). It should be noted that, considering the high efficiency of closed filters in vehicles with factory-fitted DPF, there should be no soot in the tail pipe, unless at some time the bus was in operation without the filter[24] or if the filter was damaged in a way that allowed soot to pass into the tail pipe. Lastly, in tests at maximum RPM, which were performed at the same time, unusual PN concentrations reaching 700,000 [#/cm³] were found in the FVK 403 bus. It is important to point out that the Swiss recommendation of 250,000 [#/cm³] for detecting filters with malfunctioning DPFs is also for measurements at maximum RPM. In this regard, the following is recommended:

- Visually examine the DPF filter module for the presence of soot in the exhaust gas. This is an unmistakable sign of filter damage.
- Continue with PN testing in Euro V + DPF buses and generate a historical record of their emissions.

Lastly, in relation to the implementation of a PN test at the CDAs, work is being done in Europe, particularly in the Netherlands, to implement such a standard, considering the following steps:

Step 1: Introduction of a PN test for vehicles with DPF at the vehicle authority's inspection facility (2019).

Step 2: Introduction of a PN test for vehicles with DPF during police roadside inspections.

Step 3: Introduction of a mandatory PN test in the periodic technical inspection (PTI) of all diesel vehicles with DPF (2021).

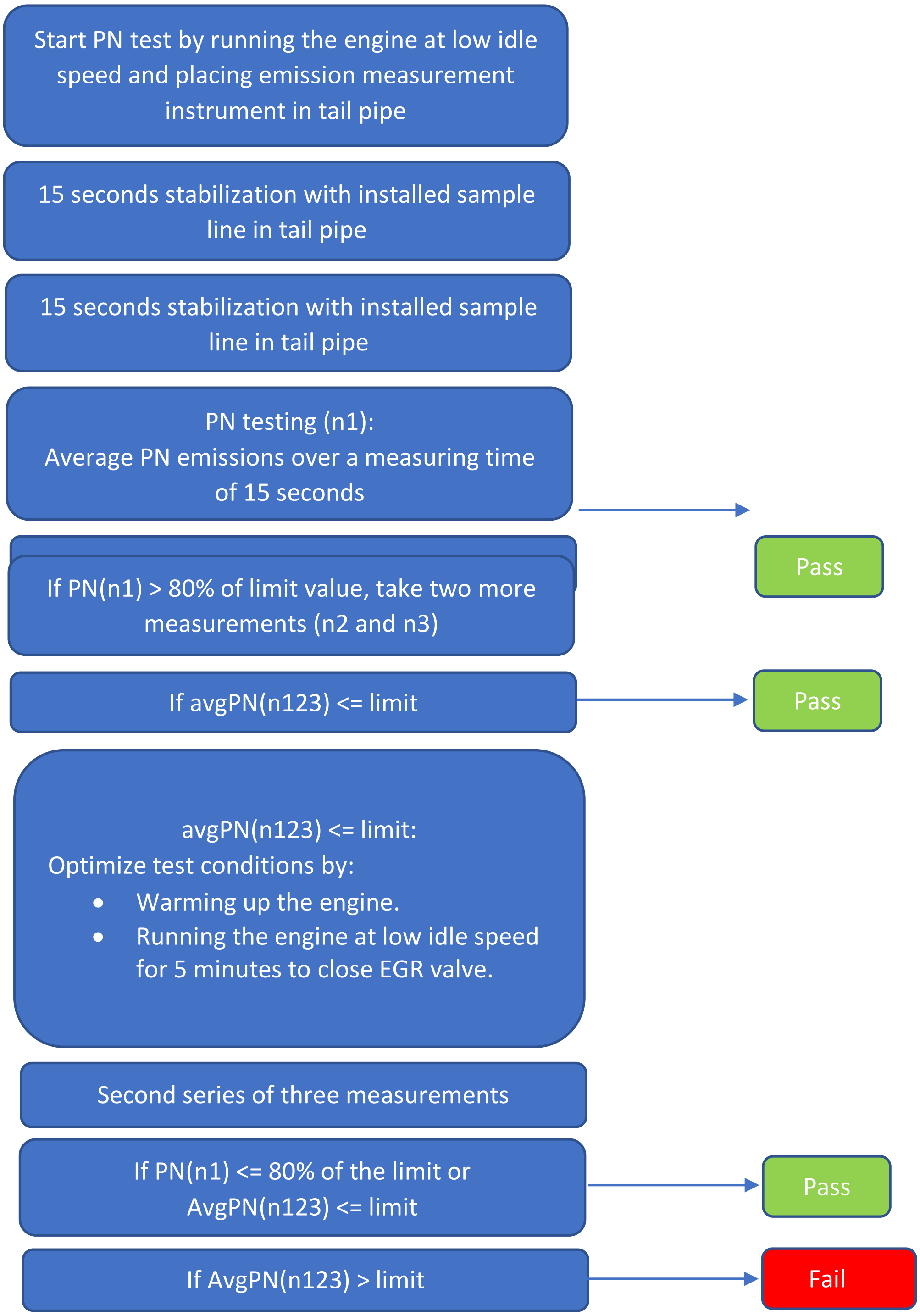
The International Recommendation drafted by the NPTI Working Group (Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements) will be used as the protocol for equipment certification. Basically:

- It is applicable to diesel and gasoline engines.
- The instrument contains a sampling system, volatile particle remover (VPR), and a counter.
- The VPR has over 95% efficiency.

[24] It is worth mentioning that in the case of the Euro III + DPF buses built for Santiago, Chile, it was necessary to bring them from Brazil by land without having the DPF installed, due to the sulphur values in diesel fuel in the countries of transit. This caused the tail pipes to blacken.

- The particle size for calibration verification and linearity is 55 +/- 1 nm.
- Measurement range: 0 – 5,000,000 #/cm^3.
- Measurement accuracy: +/- 25%.
- The stabilization time (T10 – T90) of the particle counter is under 15 seconds (including sampling line).
- Measurement frequency is at least 1 Hz.

As a measurement procedure, the Netherlands has proposed a protocol that can be summarized as follows:



In any case, incorporating this new inspection method in the CDAs is all the more justified with the introduction of the new Euro VI standards for new vehicles – expected to be in place by 2023 – than for the new Euro V + DPF buses. Therefore, appropriate changes must be made to the respective testing equipment and protocols.

4.2 Alternative 1. CDAs as the basis for a new inspection system

As seen in this report, modern internal combustion engines have increasingly efficient and complex exhaust aftertreatment systems. This means a small group of malfunctioning vehicles accounts for a large percentage of total emissions. The role of periodic technical inspection has been raised internationally in order to avoid the environmental impact this entails.

The majority of the CDAs in Colombia have been in operation for more than 10 years, which is why both their functional structure and their legal and institutional framework are not the most appropriate for testing vehicles equipped with the latest technology in post-combustion devices for reducing pollutant emissions (PM and NO_X). Additionally, the existing stations do not have the necessary equipment for measuring nanoparticle emissions and thus, it is not physically possible for them to measure emissions from vehicles equipped with DPF.

However, their legal framework meets the regulatory needs of the inspection process for in-service vehicles, although the exemption periods for inspecting new units are excessively long. Therefore, in practice, inspection will not be mandatory for the first units of this type until 2025[25], if said legal framework is used and the provisions of Law 1972 of 2019 are taken into consideration.

Based on the above, and going beyond the Transmilenio fleet, a control strategy for the Colombian Euro VI/Euro 6 fleet as a whole should take into account that the introduction of new inspection methods, such as PN testing, at the CDAs would only apply to new vehicles that will gradually be incorporated into the PTI system starting in 2025. Therefore, a plan needs to be defined for the gradual introduction of new testing devices in the CDA system. This is possible through the establishment of centres specializing in this type of technologies, with the necessary equipment and technical capacity. Discussion of measurement equipment, testing protocol and limits to be considered should begin as soon as possible and should be aligned with the state of the art discussed in Europe.

Considering the implications of this type of inspection on the environmental impacts of the new technology, the discussion of the advantages and disadvantages of a decentralized inspection system, such as the one in Colombia, versus a centralized one, is a substantial part of the benefits offered by the new technologies.

Lastly, the main comparative advantage of the CDA system in terms of verifying emissions from advanced technology vehicles would be its IT platform for backing up information. However, this data is not sent directly to the environmental authority, but rather it is replicated by the designated vehicle registration body (RUNT).

[25] *"…New public service vehicles, as well as motorcycles and the like, will be subject to their first technical and mechanical and pollutant emissions inspection when they are two (2) years old, calculated from the registration date." (SIC)* Text taken from article 52 of Law 769 of 2002, modified by article 12 of Law 1383 of 2010 and by article 202 of Decree 019 of 2012.

4.3 Alternative 2. Self-inspection of buses by operators

A short-term alternative could be that the units equipped with modern post-combustion emissions control systems are tested directly by the operators at their main stations using nanoparticle counters, since this test can be widely used, taken directly to the unit's operation areas and performed quickly and safely.

According to the consultants, the diagnosis of emission control systems is key in the design of an operator´s maintenance policy of modern fleets, which should aim not only at the diagnosis of emission control systems but also of the engine. Particularly because aftertreatment systems may mask potential flaws in injection systems, filters, etc. In this regard, new periodic inspection and testing methods should play a leading role in an operator's maintenance policies, through systematic self-testing.

However, as an inspection option, this alternative will always be challenged by the clear conflict of interest that an operator has when performing a self-test, since replacing the filter element of a post-combustion emissions control system (the only viable alternative for correcting high nanoparticles values in the exhaust gas) is very costly, and the operator will want to avoid this.

Additionally, this option goes against the basic principle of ISO 17020, which is to avoid conflicts of interest with the certification body, especially in relation to the mandatory testing of aspects regulated by the competent authority.

Notwithstanding the above, as observed during the consultants' field visit to the Transmilenio bus yard, the operational inspection of the pollutant emissions generated by the units is carried out directly by personnel from the District Secretariat of the Environment, using their own equipment. From the point of view of the transport fleet operator (Transmilenio), this option does not represent a conflict of interest and falls within the logic of auditing the operating contracts of each company that owns buses and has been hired to provide services within the system, as the inspection is carried out by a legally differentiated body with its own institutional objectives and competencies. However, from the point of view of the national authority and the user (the general public), this option may give rise to objections derived from the conflict of interests resulting from the fact that the inspection body, the regulatory authority and the fleet operator all belong to the same entity: The Mayor's Office of Bogotá.

This type of analysis, concerning the point of view of the regulator, the authority, the regulated entity and the public are not minor aspects and are in fact analysed in depth by ISO 17020. This is a globally accepted standard for determining the validity of an inspection body criteria which should verify that a product, good or service conforms to a standard. This standard classifies inspection bodies into three categories:

a) *Third-party Inspection Body (Type A)* – Definition that applies to inspection bodies that require the highest level of objectivity and independence in their judgement, as their measurements, protocols and metrological traceability chains have legal consequences, generally related to obtaining or ratifying permits, as well as imposing eventual fines and sanctions for failure to comply with the regulations.
b) *Related Inspection Body (Type B)* - They are separate and identifiable entities, with their own legal status, that provide external control services, but they belong to an organization that develops products or provides services in an area related to the object of control and its inspection services.
c) *Self-inspection Body (Type C)* – Typically associated with areas within an organization, which do not have administrative or legal independence and that primarily provide services within it. Entities of this type usually carry out quality inspections of products or services provided by the organization as a whole.

From a legal standpoint, an inspection body whose technical action or decision has legal consequences that may affect the organization and are based on public legislation can only be third parties, as independence of judgement is a basic element for judging the actions of a regulated entity.

In view of the foregoing and for the matter at hand, regarding the actions of the operating entity known as Transmilenio and its inspection body for compliance with pollutant emission standards, if the assessment to be made by the District Secretariat for the Environment (evidently within Type B of the inspection bodies defined by standard 17020) will be limited to determining compliance with the parameters regulated by signed contracts between the operator and the transportation companies hired, their actions do not lack objectivity. Therefore, their assessment can be admitted with no potential for legal objections. However, if inspections made by this body (Type B) could have legal consequences based on national and/or local public legislation, its actions may be challenged and could not be sustainable over time. In that case, a type A inspection body may be needed in the medium term.

4.4 Alternative 3. Building a new inspection model for the EURO VI fleet

In the medium term, a new vehicle inspection system must be created including nanoparticle counters for all types of in-service vehicles with post-combustion PM emission control systems.

In this regard, an alternative for restructuring the current mandatory vehicle emissions control system for units equipped with nanoparticle reduction after-treatment systems (DPF) can be considered.

This new system should have a centralized design for existing CDAs, based on private concessions awarded to a limited number of companies that manage the system for a period of time sufficient to obtain a return on their investment in new equipment and procedures. In addition, the current emission control system developed by the SDA, both on the road and in the Transmilenio bus yards, can be considered as an additional level of control under the normal operation conditions of the fleet. This system is closer to the "on-board" or "off-cycle" measurement trend, which prevents users, operators or even the CDAs themselves from tampering with the tests.

Therefore, considering that this type of vehicle inspection will be required as of 2023 in accordance with Law 1972 of 2019, a specific reform of the legal bodies responsible for vehicle emission testing in Colombia should be considered. This reform should provide for the participation of organizations specializing in nanoparticle testing, which may have to be accredited under standard 17020 and which can provide the service in the main stations of public and commercial vehicle fleets as well as at the CDAs.[26]

4.5 Recommendations on procedure and equipment required

As mentioned in section 4.1, there are currently specifications for testing instruments, test protocols and standards that are being implemented mainly in European Union countries such as the Netherlands, Germany or Switzerland. It is recommended to consider these as a basis for the new inspection system in Colombia, as follows:

[26] Consultant's note: This alternative should be based on a new operating model for the CDAs, which would consider this option based on a new legal-technical-administrative framework, representing the evolution of the current system and which should be studied and designed by the Colombian Government as soon as possible, given the age of its current system and the experience gathered in its operation.

- They must first be applied to the Euro VI/Euro 6 diesel vehicle fleet. In the future, the same or very similar protocols may be extended to gasoline vehicles with a GPF system[27].
- A PN tester should be used that follows the International Recommendation made by the NPTI working group (Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements).
- As a test procedure, measure PN emissions at the exhaust with the engine running at idle (see section 4.1).
- Collect field data on PN emission testing in diesel and gasoline vehicles, to generate historical information for developing a maximum emissions limit according to the fleet conditions. This would range from 220,000 to 1,000,000 [#/cm^3], in line with international recommendations.
- Participation in the regional working group (Chile, Peru, Mexico and Colombia) on PN emissions, testing protocols and implementation is recommended in order to produce a single standard that will help generate economies of scale and standardize policies at the regional level, taking into account aspects specific to the Region such as high-altitude cities.
- Acquiring a nanoparticle counter of the type required by a PTI station is recommended and should be used to collect statistically validated information from the fleet that currently has post-combustion devices in order to evaluate whether the regulatory limit proposed in Europe for establishing the performance of nanoparticle filtering systems should be applied.

[27] Consultant's note: Because of the PN Type Approval standards for gasoline vehicles with direct injection, particulate filters have also been installed in gasoline vehicles, in this case GPF (Gasoline Particulate Filter).

4.6 Matrix of alternatives and weighting based on expert judgment

- For inspection of the Transmilenio fleet

	RELIABILITY OF RESULTS	SPEED OF IMPLEMENTATION	COST TO USERS	MODERNIZATION OF PROCESSES	TOTAL
Use of existing CDAs	5/10	10/10	10/10	2/10	27
Self-inspection by operators	2/10	10/10	10/10	2/10	24
Creation of a new, centralized inspection model	10/10	2/10	10/10	10/10	**32**
Reinforcement of current inspections by the SDA in the bus yard, based on contractual regulations	10/10	10/10	10/10	10/10	**40**

- For inspection of the EuroVI/Euro6 fleet

	RELIABILITY OF RESULTS	SPEED OF IMPLEMENTATION	COST TO USERS	MODERNIZATION OF PROCESSES	TOTAL
Use of existing CDAs	5/10	10/10	5/10	2/10	22
Creation of a new inspection model	10/10	2/10	10/10	10/10	**32**
Reinforcement of current roadside inspections by the SDA[28]	10/10	10/10	10/10	10/10	**40**

Reliability	**Implementation Time**	**Cost**	**Modernization of Processes**
1 – Unreliable 10- Very reliable	1- Very slow 10- Very short term	1 – No cost variation 10 – Very costly	1 – Does not contribute to modernization 10 – Contributes significantly to modernization

Finally, the recommended model aims at creating a new centralized CDA system based on inspections performed by the SDA in the bus yards (on its own or outsourced to take measurements in the yards) and upgrading roadside inspections.

[28] This quick and necessary implementation mechanism should not be considered as contrary to the Technical-Mechanical and Pollutant Emissions Inspection system, but rather complementary to it. In this regard, it can be implemented in the short term, but it must continue to operate together with a centralized inspection system (advanced Periodic Technical Inspection Centres, with PM emissions testing capability and dynamic inspection protocols) in order to provide a comprehensive system in accordance with national emissions standards.

5 Conclusions and recommendations

- This is a good time for the Colombian CDA system to reformulate its operating structure. At the same time, there are significant opportunities for improvement and evolution of its management model, as well as its legal and regulatory framework. It is also advisable to consider updating the mechatronic tools used to carry out their work. It is therefore recommended that the necessary processes be initiated to review and discuss the technical standards related to their management, making use of existing stakeholder forums in the country, such as technical roundtables or multidisciplinary working groups.
- Updating NTC 4231 needs to be reconsidered, based on regional experience in the use of smoke measurement equipment. In this regard, the implementation of a conformity assessment (type approval) system is suggested. It should be based on a legal-technical-administrative mechanism for recognizing metrological certificates issued at the origin, rather than the transcription of regulatory technical specifications that cannot be validated by national metrological bodies.
- Notwithstanding the above, and considering the deadlines required by the regulation to implement the Euro VI emission standards for the new fleet entering Colombia, it is necessary to align the standard for measuring vehicle emissions, both on the road and in the yard, as well as at the CDAs, with the new PN measurement replacing the smoke test. The equipment certification protocol to be followed would be the International Recommendation drafted by the NPTI working group (Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements); the test procedure would be that established for PN testing in the Netherlands (see section 4.1), and the limit would be defined between 220,000 and 1,000,000 [#/cm3], based on the collection and analysis of local measurements.
- Plans should be made for the short-term upgrade of the information technology platform and mechanism to support roadside control and inspection of existing vehicles. The consulting team findings show that there are several opportunities for improving this mechanism, which could include the implementation of a public-private partnership controlled and regulated by local and/or national environmental authorities.
- The soundest, best developed periodic technical inspection systems in the Latin American region are those that bring together an adequate institutional arrangement, an appropriate legal framework, and a single designated authority. In this type of operational model, inspection must be seen as a public service rather than a productive enterprise, prioritizing the quality of user service, its accuracy and reliability. It is recommended that this approach be considered when planning for the Colombian Technical and Safety Inspection system.
- At present, the quality of fuel provided for diesel engine vehicles in Colombia is possibly one of the best in the Latin American region, which makes it possible to introduce vehicle fleets with state-of-the-art post-combustion emission treatment systems. However, it is recommended that the Colombian Government carefully consider the introduction of blends with biodiesel content higher than 5%, as the global automotive industry has not yet fully accepted the quality of this fuel. If the need for an increase remains, or if it is proposed in the future, the Colombian Government should request the vehicle brand representatives to issue certifications of the type of fuel that their units are capable of using, without this having an effect on the warranty. Likewise, consumers should be widely informed about the introduction of this fuel and should check with their vehicle manufacturer's dealer what precautions they should take when using it.
- Dynamic emission control systems are currently a growing trend worldwide. Therefore, the Ministry of the Environment should consider this system during the studies and designs prior

to upgrading the CDA system. One of the best experiences in this field is the ASM system implemented in Chile's PRT program, which should be analysed and adapted to the Colombian context.

- Based on the findings of the consulting team during the field visit, it is concluded that the most advisable approach for implementing an emissions control and inspection system for the new vehicle fleet with advanced emissions control systems would be contracting the service, probably through a delegation agreement or a public-private partnership (concession). This would allow the authority to remain neutral with respect to the results since it is a stakeholder and thus cannot carry out the inspection independently. At the same time, it enables the designee to carry out the inspection according to its capacities and operating mechanisms. This procedure should be developed through detailed studies on the precontractual model to be used, following the regulations and technical specifications required.
- In relation to the additional inspection the SDA currently performs in the Transmilenio bus yards, or on the road for the fleet in general, the consulting team considers it very effective to know the actual operating conditions of the fleet and to cross-check the quality of the measurements taken at the CDAs. Therefore, this method should be continued and reinforced, incorporating it into the general control and inspection model described above. In particular, for adequate inspection of the new Transmilenio fleets with DPF technologies, we believe that inspections in the bus yard should be the natural choice for the early implementation of PN testing, instead of the opacity test. This will allow to quickly focus on the fleet that is currently equipped with the new post-treatment systems, without excluding the need to evolve towards a centralized CDA system, which would include the suggested PN tests.
- Lastly, regarding the results of the PN measurement taken in Transmilenio buses, specifically in the FVK 403 bus, we recommend monitoring and verifying the emission level in free acceleration and if levels remain above 700,000 [#/cm^3], an expert technical analysis should be made to determine the cause of this unusual behaviour that may fail to guarantee adequate performance and emission levels consistent with the technology acquired.

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