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BRIEFING

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DEFICIENCIES IN THE BRAZILIAN PROCONVE P-7 AND THE CASE FOR P-8 STANDARDS

SUMMARY

This paper highlights implementation and compliance issues with PROCONVE P-7 (Euro V-equivalent) standards for heavy-duty vehicles (HDVs) in Brazil, and identifies policy pathways to overcome these issues. Because Brazil is the first developing country to adopt Euro V-equivalent standards for HDVs, this paper also provides lessons learned for other developing countries on the Euro pathway.[1]

In January 2012, Brazil implemented the PROCONVE P-7 emission standards for heavy-duty vehicles to replace the previous P-5 standards (Euro III-equivalent). The P-7 standards were designed to be equivalent to Euro V standards, introduced in Europe in 2008, and lowered limits on emissions of local air pollutants, including carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), and particulate matter (PM).

The aftertreatment technologies that manufacturers install on vehicles to meet these limits require the use of ultra low sulfur diesel fuel (ULSD), and often an additional diesel exhaust fluid composed of 32.5% urea and 67.5% water. This mixture is known as DEF in the U.S., AdBlue in Europe, and ARLA-32 in Brazil. Prior to implementing the PROCONVE

1 This document was edited from its original version to include corrections in P-7 and OBD requirements.

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P-7 standards, ULSD and ARLA-32 were not available in Brazil, but through coordinated efforts the challenges around ensuring availability were ultimately overcome.

In contrast to developed countries that allow only one grade of on-road diesel, namely ULSD, Brazil opted to provide two grades of diesel outside of metropolitan centers: ULSD in sufficient quantity required by P-7 vehicles, and a higher sulfur diesel (500-ppm) for the older fleet. While this was a cost saving approach that allowed for a faster implementation of P-7 standards, it increases the risk of improperly fueling P-7 vehicles with 500-ppm diesel.

However, other issues also have arisen with the implementation of the new standards. Regulatory loopholes allowed manufacturers to forego OBD monitoring strategies for ARLA-32 quality and consumption rates, thus enabling a fraction of truck drivers using defeat strategies to avoid using ARLA-32 adequately, leading to much higher NO_x emissions and poorer air quality. As a result, NO_x emissions will be more than 36% higher than designed in 2030, and thus will continue to pose a threat to public health. Furthermore, the P-7 standards have the same flaws as the Euro V standards do in Europe, which result in significantly higher off-cycle NO_x emissions in urban areas. Finally, even after the P-7 regulations were implemented in January 2012, older vehicles not meeting the standards were still available for sale until June 2012, thus significantly limiting the P-7 benefits during the first year of implementation.

The most effective option for rectifying these issues is to quickly advance to the next PROCONVE P-8 phase, align it with Euro VI standards, and ensure there are no regulatory loopholes. These standards require much tighter limits on NO_x, PM, and HC, and better control of in-use emissions through a combination of more advanced on-board diagnostics (OBD) requirements; more representative test cycles, including a cold start requirement; and in-use conformity requirements. Euro VI's lower emission limits and changes in test cycles in practice require more advanced selective catalytic reduction (SCR) catalysts and the adoption of diesel particulate filter (DPF) technology. In addition, this paper also addresses near-term measures to rectify the inadequate use of ARLA-32, specifically amending P-7 regulations, requiring manufacturers to recall vehicles or void warranty provisions, and improving roadside enforcement.

BACKGROUND

In 2012 Brazil implemented PROCONVE P-7 (Euro V-equivalent) standards for heavy-duty vehicles, including heavy-duty trucks and buses. Prior to 2012, Brazil's heavy-duty fleet consisted largely of PROCONVE P-5 (Euro III) and P-4 (Euro II) vehicles, with some older Euro I and uncontrolled trucks still in use (Figure 1).

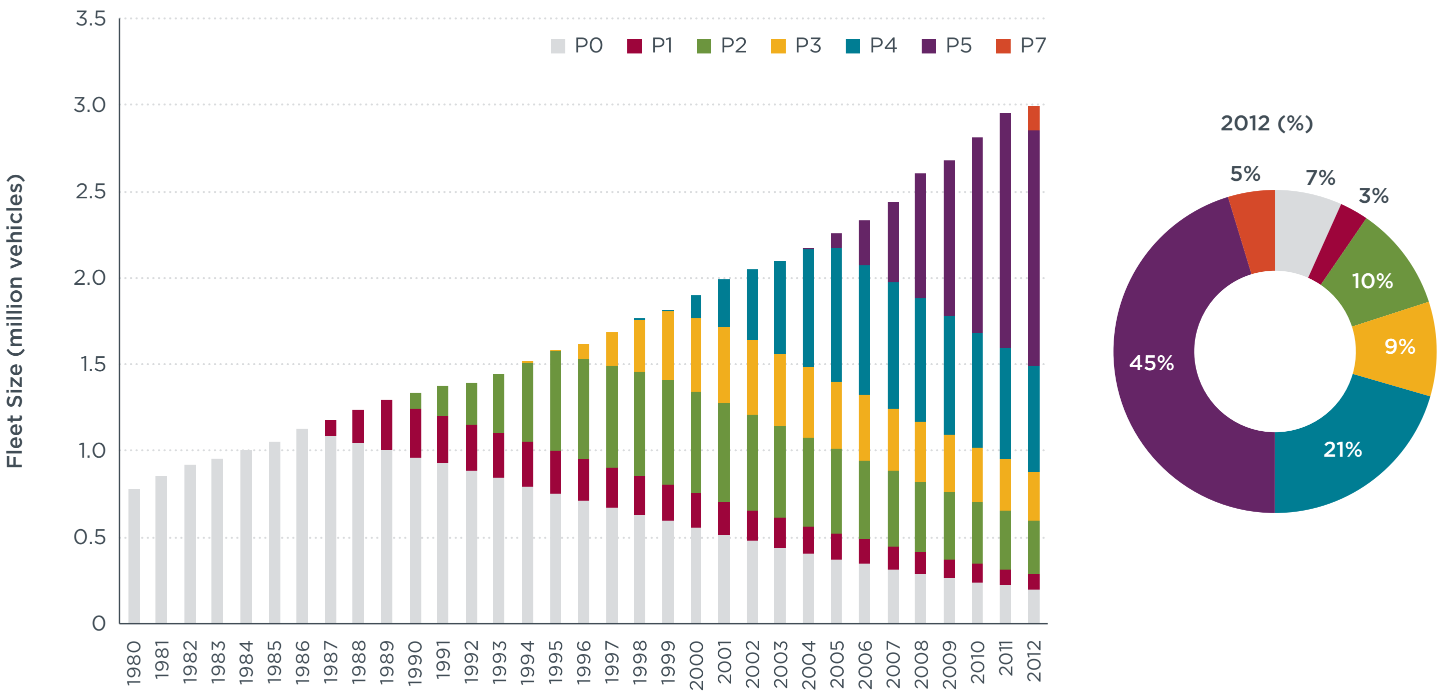

Figure 1. Estimates of diesel fleet by PROCONVE phase[2]

The PROCONVE program has achieved significant reductions in vehicle emissions in Brazil. The program for HDVs was first implemented between 1987 and 1989 as phase P-1, but limits for gaseous pollutants and particulate matter were not required until 1994 for buses and 1996 for trucks. Since then, more stringent standards roughly consistent with the European standards have been implemented. The current P-7 emission limits are 86% and 95% lower than the first limits of NO_x and PM, respectively (Table 1).

2 Source: Ministério do Meio Ambiente [Ministry of the Environment] (2013).

Table 1. Brazil and EU emission standards for HD diesel engines

PROCONVE Standard***	Euro Equivalent	Test Cycle	CO	HC	NO_x	PM	NMHC	CH_4	PN (n°/kWh)
			(g/kWh)						
P-1 (1989)	—	NBR 7026/7027	Only smoke index						
P-2 (1996)	—	R-49	11.2	2.45	14.40	0.60	—	—	—
P-3 (2000)	Euro I (1991)	R-49	4.9 4.5*	1.23 1.1*	9.0 8.0*	0.40 0.36*	—	—	—
P-4 (2002)	Euro II (1996)	R-49	4.0	1.1	7.0	0.15	—	—	—
P-5 (2006)	Euro III (2000)	ESC/ELR	2.1	0.66	5.0	0.10 0.13**	—	—	—
		ETC	5.45	-	5.0	0.16 0.21**	0.78	1.6	—
P-6 (skipped)	Euro IV (2005)	ESC/ELR	1.5	0.46	3.5	0.02	—	—	—
		ETC	4.0	-	3.5	0.03	0.55	1.1	—
P-7 (2012)	Euro V (2008)	ESC/ELR	1.5	0.46	2.0	0.02	—	—	—
		ETC	4.0	-	2.0	0.03	0.55	1.1	—
P-8 (TBD)	Euro VI (2014)	WHSC	1.5	0.13	0.4	0.01	—	—	8.0×10^{11}
		WHTC	4.0	-	0.46	0.01	0.16	0.5	6.0×10^{11}

* Indicates values for corresponding Euro standard.
** For engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}.
*** Years indicate full implementation of standards for all HDV types.

Despite the progress by PROCONVE, air pollution in major metropolitan areas in the state of São Paulo is still considerably above levels recommended by the World Health Organization (WHO, 2005). Figure 2 illustrates the range of PM concentrations for the metropolitan São Paulo region (RMSP), the areas close to the Port of Santos (Baixada Santista) and other areas located within the interior of the state of São Paulo (Companhia Ambiental do Estado de São Paulo, 2014). Not only did many cities in São Paulo exceed Brazil's air quality standards (AQS) for PM_{10}, but no city met the WHO guidelines. A similar trend is observed with all other monitored pollutants.

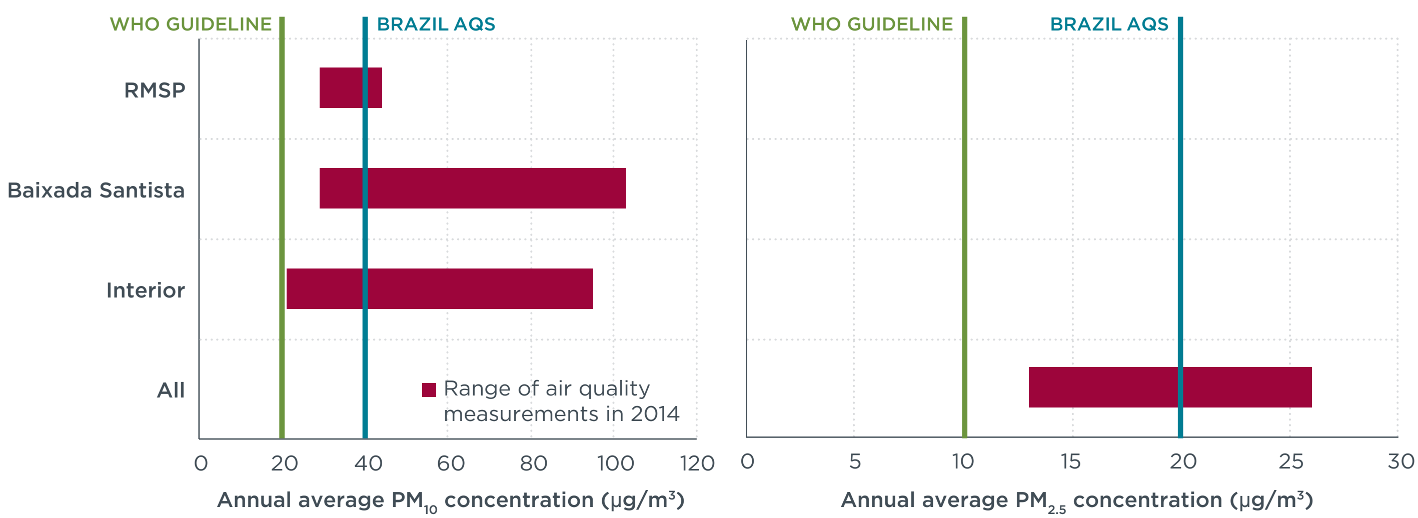

Figure 2. Air quality in the state of São Paulo (2014)

To mitigate air quality problems and offset the increase in vehicle activity, future phases of PROCONVE are necessary. The P-7 phase was adopted to solve some of these air quality problems. The limit values for the key pollutants of concern, NO_x and PM, are 60% and 80% lower than P-5 limits, respectively. Unfortunately, phase P-7 is not working as designed. As a result, noncompliant P-7 vehicles (labeled as P-7 noncompliant in Figure 3) could be emitting NO_x at rates higher than the limits of previous P-5 standards (see next section). And although P-7 standards do result in dramatic reductions in PM emissions by mass, emissions of the smallest particles–which also are those most damaging to human health–are not controlled.

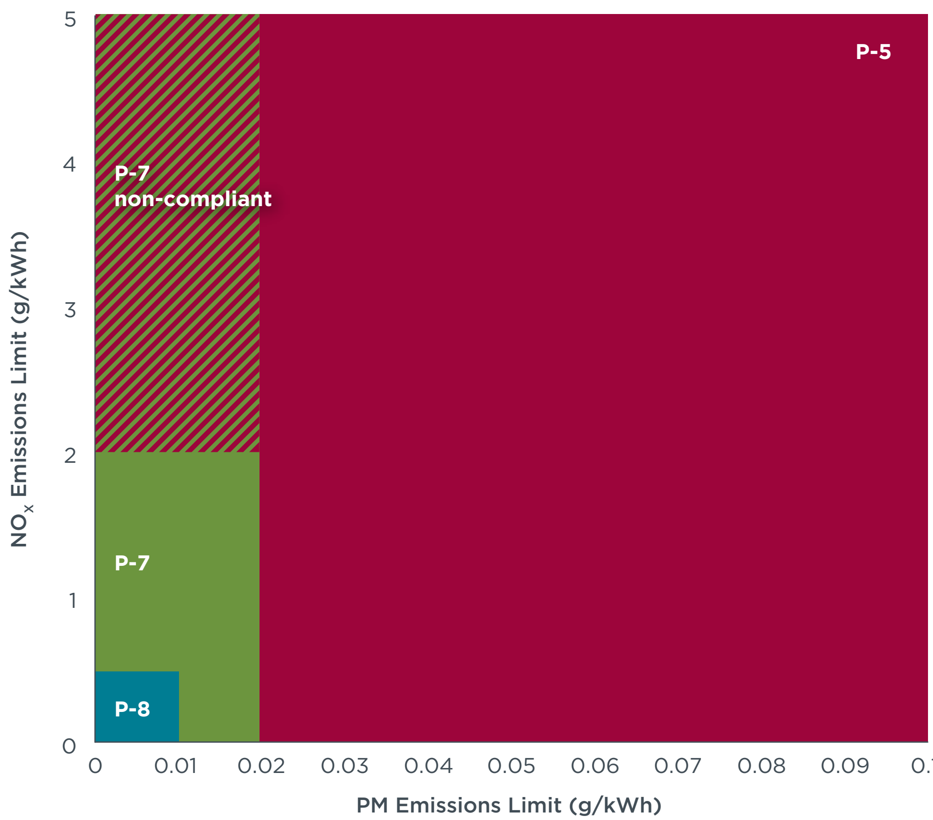

Figure 3. Change in emission limits by PROCONVE phase

P-7 ADOPTION AND IMPLEMENTATION

Brazil was set to implement PROCONVE P-6, the Euro IV equivalent, in 2009, but lack of ULSD–a requirement for the proper functioning of emissions aftertreatment systems–prevented the standard from being implemented on time. As a compromise to the implementation delay, automakers and the regulatory agencies agreed to skip PROCONVE P-6 and implement the Euro V-equivalent PROCONVE P-7 in 2012. Euro V standards have slightly lower NO_x emission limits than Euro IV standards, but the costs and vehicle technologies required to meet both sets of standards are essentially identical.

To comply with resolution 403 of November 11, 2008, passed by Brazil's national environmental council (CONAMA) implementing the P-7 standards, Brazil's national petroleum agency, Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP), developed a plan for nationwide distribution of ULSD to new P-7 vehicles, initially with the supply of S50 (50-ppm diesel) by January 1, 2012, and to be replaced by S10 (10-ppm diesel) by January 1, 2013. This plan was implemented concurrently with the gradual phase-in of ULSD fuel for public buses in metropolitan regions (Figure 4).

Currently there are two grades of diesel being sold in Brazil, namely S10 diesel in all metropolitan regions and in selected stations nationwide to supply P-7 vehicles, and S500 (500-ppm diesel) in the rest of the country. In other words, although S10 is available nationwide, S500 diesel continues to be sold outside of metropolitan regions. However, S1800 (1,800-ppm diesel) is still available for off-road equipment, which is not illustrated in the figure.

Metropolitan Regions	Municipalities	Segment	1/1/09	5/1/09	8/1/09	1/1/10	1/1/11	1/1/12	1/1/13	1/1/14
—	Sao Paulo, Rio de Janeiro	Public transport	S50						S10	
Recife, Fortaleza, Belem	—	All	S500							
—	Curitiba	Public transport								
Sao Paulo	—	Public transport								
—	Belo Horizonte, Salvador, Porto Alegre	Public transport								
Campinas, Baixada Santista, SJ Campos, Rio de Janeiro	—	Public transport								
All	All	New P7 vehicles						S50		
Others	Others	Others	S1800							S500

Figure 4. ULSD implementation timeline in Brazil

Petrobras, the largest oil refiner and distributor in Brazil, committed to produce or import ULSD in sufficient quantity to meet the expected demand from new P-7 vehicles. In order to ensure sufficient ULSD supply for P-7 vehicles, they set a premium markup on the price of ULSD over regular diesel.[3] Petrobrás and other suppliers have overcome many logistical challenges to ensure the ULSD provision was effective. These include effectively segregating different grades of fuel to avoid contamination of lower sulfur fuels, distributing the clean fuels to stations throughout the country, and communicating where clean fuels can be found. The total number of stations offering ULSD increased from 4,225 in 2012 to 18,900 in 2014, out of a total of 38,893 stations throughout the country. The ULSD share of total diesel sales increased from 9% to 27% in the same period, with just 2.7% nonconformity with respect to ULSD quality (Souza, 2015, and Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2015).

3 The premium markup varied between 1% and 8%, depending on the month and region, with an average of about 6% (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, 2015).

In addition to ULSD, P-7 vehicles that use selective catalytic reduction (SCR) also require a liquid reductant additive, sold as ARLA-32 in Brazil, for the NO_x aftertreatment systems to function. ARLA-32 is a mixture of 32.5% urea in water, by weight, and has been available throughout Brazil since 2012. Because the incentives for ARLA-32 production, as well as technical specification for product quality and packaging, fell beyond ANP's scope, commercialization of ARLA-32 was left to the market. Despite uncertainties and concerns about the availability of ARLA-32 prior to the implementation of P-7, the product was made available by private companies who saw the opportunity to establish the production and distribution infrastructure for ARLA-32.

While the success of the ULSD and ARLA-32 distribution network was immediately apparent, other implementation issues hindered the effectiveness of the regulation. For example, although P-7 standards were officially in place starting in January 2012, older trucks meeting the Euro III standards continued to be sold until June 2012, sometimes at a discount. As a result, only about half met the P-7 standard (Braga, 2012). Not only did this result in an additional 40,000 Euro III vehicles on the road, but it also meant that more ULSD and ARLA-32 was available in early 2012 than was needed. In addition to a significant number of P-5 vehicles being sold in the first year the P-7 standard was implemented, other implementation issues also arose, namely the inadequate use of ARLA-32, and off-cycle NO_x emissions in urban areas as a consequence of the already recognized deficiencies of the Euro V standard.

INADEQUATE USE OF ARLA-32

To meet the P-7 standard for NO_x, many manufacturers use an aftertreatment technology known as SCR.[4] This technology requires precise dosing of the reagent urea, sold in Brazil as ARLA-32, which enables the catalyst to convert NO_x and urea to more benign gases, namely nitrogen, carbon dioxide, and water. When driven without ARLA-32, a truck that normally would meet the P-7 standards could instead emit at levels much above the regulatory NO_x limit of 2 g/kWh. Vehicle tests conducted by Petrobras' research arm, CENPES, indicated that NO_x emissions in the absence of ARLA-32 were on the order of 5.2 g/kWh (Cordeiro, 2015). However, such tests were conducted at constant speed and likely without load, and thus the use of a realistic driving cycle and load would likely increase this value. Data gathered during testing of SCR-equipped trucks under operating conditions in which no urea is injected (i.e., due to low exhaust temperatures) show that during these periods NO_x emissions range from 4.0 to 10 g/kWh (Muncrief, 2015). In other words, trucks without ARLA-32 could be emitting NO_x at rates that are five times greater than the regulatory limit. In order to ensure that drivers use urea, the Euro V regulations in Europe require the use of driver inducements and other fail-safe mechanisms that limit engine torque if the sensors indicate any tampering or problems with the urea supply.

However, not long after new P-7 trucks started to be sold, anecdotal evidence of inadequate use of ARLA-32 began to surface. Although a truck only consumes about 3%-5% as much ARLA-32 per mile as it does diesel (Cummins Inc., 2015), and a liter of ARLA-32 typically costs about as much as a liter of diesel fuel, this can still be a noticeable cost, and drivers have an economic disincentive to use ARLA-32.

4 Some manufacturers opted for using exhaust gas recirculation (EGR), especially in light- and medium-heavy duty trucks.

As early as November 2012 there were stories in the media suggesting numerous ways to trick the system, such as using water instead of ARLA-32, removing the emission control fuse, or installing electronic modules. In early 2013, electronic ARLA-32 emulators were readily available online, easily found with a Google search (Emulador ARLA-32, 2015). By September 2015, ARLA-32 sales were about 32% lower than expected, suggesting that a large fraction of drivers were finding ways to defeat the on-board diagnostics (OBD) and avoid using ARLA-32 (Figure 5). This was supported by numerous news articles and interviews with drivers, who openly confirmed regularly using the aforementioned defeat strategies (Grupo Globo, 2014).

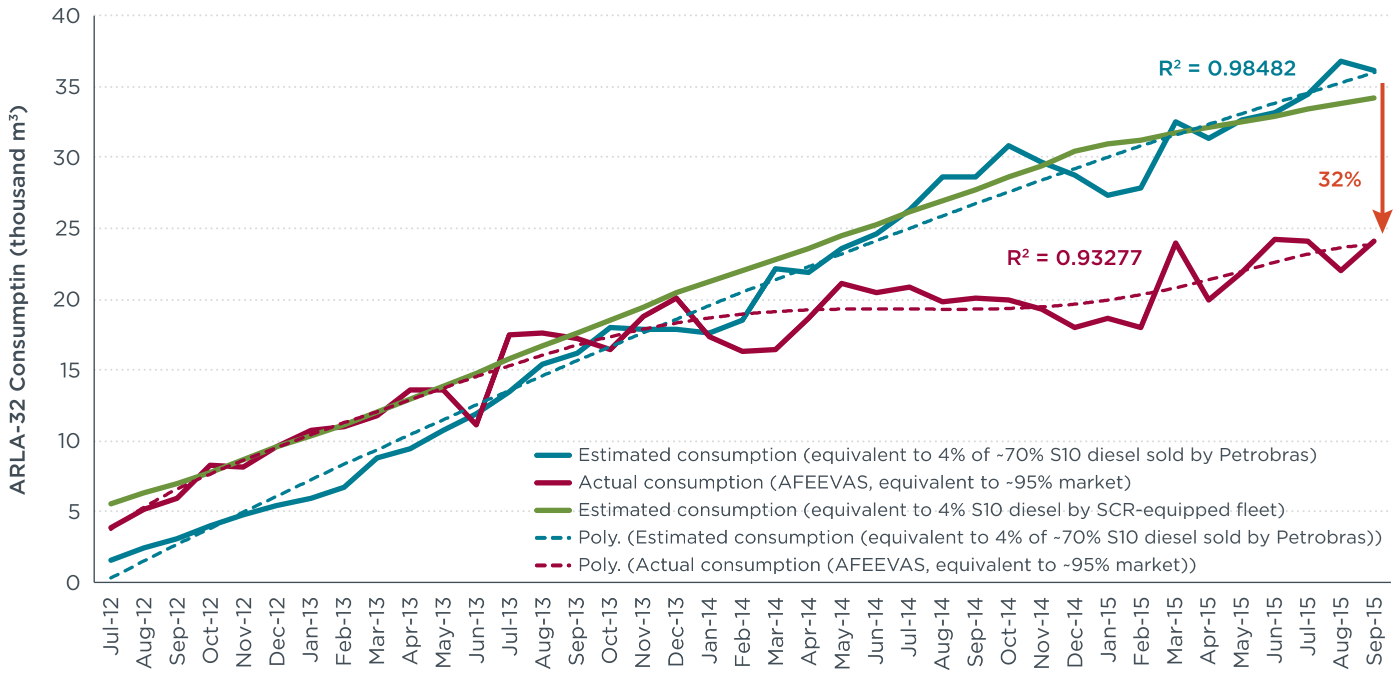

Figure 5. Estimated versus actual ARLA-32 consumption (thousand m^3)[5]

REGULATORY DEFICIENCIES

This level of urea avoidance is unheard of in other countries that have implemented comparable standards. In addition to insufficient enforcement, the root causes for the inadequate use of ARLA-32 are deficiencies in the type-approval process, and loopholes in the actual regulation. When the P-7 regulations were drafted and adopted, Brazilian regulators closely followed the Euro V emission standards, but failed to adequately include the driver inducements and other fail-safe mechanisms that are part of the Euro V regulations in order to ensure adequate use of ARLA-32.

Driving a vehicle equipped with SCR in the absence of urea or using urea of poor quality, or water, would invariably result in high NO_x emissions during the period of improper operation. Thus, governmental agencies have incorporated safeguards into the regulations for proper operation of reagent-based NO_x control systems. These

5 Data provided by Associação dos Fabricantes de Equipamento para Controle de Emissões Veiculares da América do Sul (AFEEVAS) specifically for use in this publication.

systems alert the driver and prompt correction of malfunctions of the SCR system, even preventing vehicle operation under conditions of high NO_x emissions.

The system of driver warnings and inducements are part of the special measures for proper operation of NO_x control systems under the original Euro IV, V and VI standards. Three types of events can initiate the activation of the driver warning and inducement system: (1) low urea level, (2) incorrect fluid in urea tank, and (3) SCR faults attributable to incorrect dosage rates or tampering.

The warning and inducement system is structured according to three levels of progressive severity. First, the warning system will alert the driver that there is a low level of urea or urea of incorrect quality; second, if the urea deficiency or quality issue persists, warnings will be followed by a low-level action, in the form of a reduction in truck performance, aimed at encouraging the driver to refill the urea tank. The driver will suffer a performance penalty initiated by the electronic control module (ECM), resulting in a loss of vehicle speed or engine power (torque). Ultimately, if the detected issue persists and is not corrected, the ECM will immobilize the vehicle. It is important to note that before the vehicle experiences low-level penalties or immobilization, there are ample driver/operator reminders and warnings for corrective action. For example, drivers will see dashboard lights to remind them to add urea and will be alerted if there is incorrect fluid in the urea tank.

The OBD system is related to the driver warning and inducement system, but its scope is wider with differing actions. OBD feeds on the same signals that are used to activate driver warnings and inducements, specifically urea quantity, quality, and consumption, but it does not actively engage until the emission malfunction is activated (i.e., when a malfunction that leads to exceeding an emission limit has been detected). The driver and inducement system, on the other hand, is proactive and activates well before the NO_x emission threshold has been exceeded. OBD monitors all emission control systems in the vehicle, of which the SCR system is one component.

To ensure that the driver warning and inducement system can accurately detect whether urea is being used properly, the Euro V regulations require either the direct monitoring of NO_x levels or monitoring of urea level, consumption, and quality. Brazil's P-7 requirements are very similar to those in the Euro V regulations, but the OBD rule in Brazil is considerably lacking when it comes to urea monitoring (Posada & Bandivadekar, 2015). Instead of requiring that all three parameters listed above be monitored, the OBD regulations in Brazil include only urea levels. As a result, even if Brazilian HDV manufacturers included strategies for monitoring urea consumption and quality, either by direct measurement or inference, the OBD would only trigger inducement if there is noncompliance with urea levels (and not with urea consumption or quality). Thus noncompliance with P-7 trucks is much easier than with Euro V vehicles sold in Europe. Note that SCR systems for Euro IV, Euro V and PROCONVE P-7 vehicles typically do not require NO_x sensors as part of the control strategy. Rather they rely entirely on inferred NO_x emissions from engine signals (i.e., open loop systems).

If the OBD monitors only fluid levels in the urea tank and activate the inducement system only when those levels are too low, it is clear how many drivers are able to defeat the fail-safe systems and avoid using urea with a variety of techniques. Figure 6 illustrates how the presence, or absence, of these monitoring strategy requirements and inducement can prevent, or allow, drivers to avoid complying with the requirement to use urea. A green dot indicates that the OBD monitoring strategy does not exist (and thus does not detect an issue), while a red dot indicates that the OBD monitoring strategy exists and would detect foul play and trigger the driver inducement to comply with urea requirements.

Defeat Pathway	OBD monitoring strategies		Inducement Triggered
	ARLA-32 Level	ARLA-32 Consumption*/Quality or Direct NO_x monitoring	
EURO V			
Disrupt signal from sensors	🟢	🟢	→ NO
Use an alternate fluid	🟢	🔴	→ YES
Loop outflow back into tank	🟢	🔴	→ YES
Use no fluid	🔴	🔴	→ YES
P-7			
Disrupt signal from sensors	🟢	🟢	→ NO
Use an alternate fluid	🟢	N/A	→ NO
Loop outflow back into tank	🟢	N/A	→ NO
Use no fluid	🔴	N/A	→ YES**

🟢 Monitoring strategy does not indicate malfunction; 🔴 Monitoring strategy indicates malfunction; N/A Monitoring strategy not available
* Consumption may be inferred, not directly measured.
**If system is reset within 48 hours of malfunction being detected, inducement will not be triggered.

Figure 6. Comparison of defeat pathways in Euro V and P-7 regulations

As shown in Figure 6, the presence of emulators to disrupt sensor signals would fool the system not only in Brazil, but also in other countries. In other words, no regulation is completely foolproof to foresee the use of all defeat devices. If an OBD monitoring strategy for urea quality is not present in P-7 applications, any other liquid would not trigger a malfunction, allowing drivers to use agricultural urea, water, or any other liquid in place of ARLA-32. Furthermore, if the OBD only notifies the system when levels are too low, rather than if ARLA-32 is being consumed, interrupting the connection by installing an electronic emulator device, breaking off the sensor, or other means would prevent a signal from being sent, and so the system would not trigger the inducement. Alternatively, if an issue is detected and the warning light goes on, the OBD does not save the fault code unless it persists for 48 hours. That means unplugging the battery on Euro V and PROCONVE P-7 vehicles will erase the fault codes and reset the OBD, as this type of OBD systems lack permanent code storing.

The effect of this regulatory loophole within PROCONVE P-7 can have significant effects on NO_x emissions. As highlighted in this paper, the absence of urea could increase NO_x emissions up to 10 g/kWh based on real-world testing, considerably above the regulatory limit of 2 g/kWh.

OFF-CYCLE NO_x EMISSIONS IN URBAN AREAS

In addition to increased NO_x emissions from inadequate use of ARLA-32, Brazilian trucks and buses operating in urban areas are likely emitting NO_x at much higher levels than certification limits because of off-cycle NO_x emissions, thus resulting in greater exposure of the population to NO_2 and ground-level ozone. Around the world, even when operated with adequate urea quality and dosing, Euro IV and V trucks driving at low speed in urban settings have been found to emit NO_x at much higher rates than the limits set by their respective standards, due to exhaust temperatures being too low to activate the SCR system. The root cause for higher off-cycle NO_x emissions is the fact that the Euro IV and V certification protocols are not sufficient to ensure that manufacturers control NO_x in the most challenging, low-temperature exhaust conditions (Lowell & Kamakaté, 2012). To meet Euro IV and V standards manufacturers typically use vanadium catalysts in the SCR system. This inexpensive catalyst has an optimum operating temperature of around 300-450 °C. However, with a cold start, or when stopping frequently as in urban areas, exhaust temperatures do not reach this temperature, leading to ineffective catalytic reduction and overall increased NO_x emissions.

Besides having more stringent emission limits, certification for Euro VI standards must be demonstrated over a much more challenging test cycle, including a cold start and low-speed driving conditions (Muncrief, 2015). As a result, Euro VI standards effectively force manufacturers to use more expensive copper-zeolite catalysts, which are effective in temperatures as low as 225 °C. Figure 7 illustrates test data of Euro IV, V, and VI certified heavy-duty vehicles from tests performed in 2013-2014 in a chassis dynamometer test cell at the VTT Technical Research Centre of Finland. NO_x emissions for all 210 samples are plotted as NO_x emissions, in g/kWh, versus average vehicle speed, in km/h. The Euro IV, V, and VI certification levels are indicated for reference. Although emissions for many Euro IV and V vehicles are much above certification levels, especially at lower average speeds observed in urban conditions, emissions for Euro VI vehicles remained below certification levels under most conditions. These tests confirm that new Euro VI certification protocols are indeed effective at mitigating off-cycle NO_x emissions in real-world conditions.

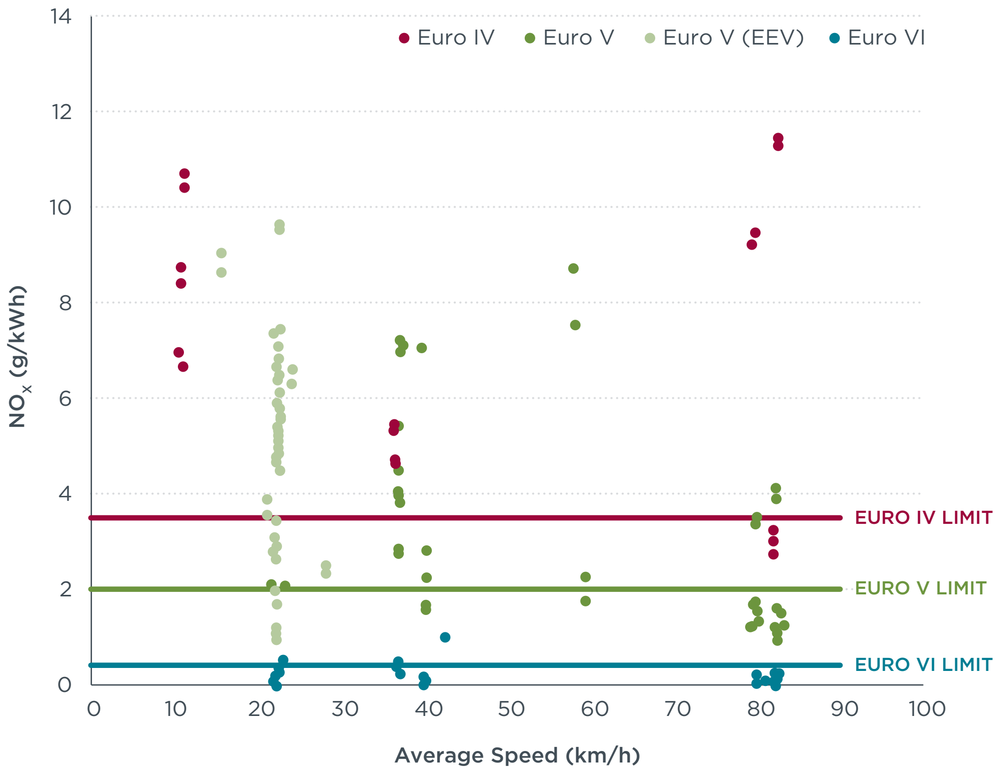

Figure 7. Euro IV, V, VI NO_x emissions versus average vehicle speed (Muncrief, 2015)[6]

IN-USE CONFORMITY

In addition to flaws in the development of P-7 regulations (i.e., lack of requirements for ARLA-32 consumption and quality monitoring), another root cause of the widespread inadequate use of ARLA-32 is the fact that Euro IV and V regulations are particularly weak with respect to in-use conformity requirements. These ensure that emissions are effectively controlled under a full range of in-use driving conditions, not just under conditions similar to the certification test cycle. In addition, in-use conformity requirements provide a means and a legal basis for the certification authority to require a manufacturer to address excessive in-use emission levels or risk revocation of its type approval (Lowell & Kamakaté, 2012). Ideally, in-use conformity language should also specifically prohibit “defeat devices” and require testing to confirm that in-use conformity requirements are met.

The Euro VI emissions legislation requires verification of in-use conformity of heavy-duty engines, also known as In Service Conformity (ISC) requirements (European Commission, 2011). These include limits — defined as conformity factors — of 1.5 times the emission limit for NO_x, CO, HC (for compression ignition engines), and CH_4 (for spark ignition engines).

While stronger enforcement measures are certainly necessary for the near-term environmental performance of P-7 regulations, a medium-term solution is moving to a stronger PROCONVE phase consistent with Euro VI requirements. Not only does Euro

6 Euro V data also include a special category called Enhanced Environmentally Friendly Vehicle (EEV), which has the same NO_x emission limits and test protocols but requires lower PM emissions than Euro V.

VI have more stringent emission limits, but it is based on a certification procedure that more closely resembles real-world driving conditions, especially in urban areas, and contains stronger in-use conformity language.

EFFECTS OF P-7 PROBLEMS ON NO_X EMISSIONS

The implementation problems highlighted in this paper — inadequate use of ARLA-32, off-cycle NO_x emissions in urban areas, and sales of P-5/Euro III vehicles in the first year of implementation of P-7 standards — have serious consequences on PROCONVE P-7's ability to control NO_x in Brazil. Figure 8 illustrates the effects of different levels of compliance to P-7 standards on nationwide NO_x emissions from heavy-duty vehicles. The following scenarios are considered:

- **P-7 full compliance:** New diesel heavy-duty vehicles meet P-7 (Euro V) requirements and are supplied with S10 diesel and appropriate levels of ARLA-32.
- **P-7 partial compliance:** Same as "full compliance" scenario, but only 66% of vehicle-kilometers traveled (VKT) are supplied with appropriate levels of ARLA-32. The remaining vehicles are assumed to emit NO_x at levels equivalent to the previous P-5 standard (Euro III-equivalent).
- **P-8:** New diesel heavy-duty vehicles meet P-8 (Euro VI) requirements starting in 2018 and continue to use S10 diesel and appropriate levels of ARLA-32.

The effects of possible off-cycle NO_x emissions in urban areas are not quantified due to lack of real-world emissions measurements in Brazil. All scenarios already take into account that only half the vehicles sold in 2012 met P-7 requirements. In other words, all emission variations in these scenarios are due to the inadequate use of ARLA-32.

P-8 standards would reduce NO_x emissions by 87% in 2048 relative to a P-7 scenario with full compliance, equivalent to cumulative reductions of 12 million tons of NO_x through 2048. The cumulative NO_x benefits of P-8 standards would be 18 million tons if P-7 vehicles were in partial compliance with standards.

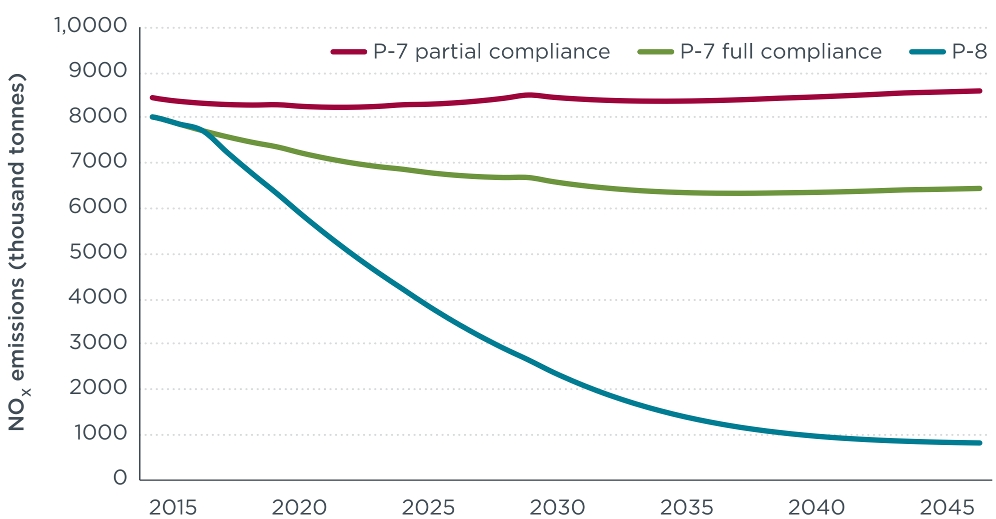

Figure 8. Effects of P-7 implementation problems on NO_x emissions

RECOMMENDED POLICY PATHWAY

As previously highlighted, the PROCONVE P-7 phase is likely not resulting in its intended NO_x benefits. First, the adaptation of Euro V protocol requirements to Brazil allows many defeat pathways that avoid adequate use of ARLA-32 without any practical consequences on engine torque limitations. This is reflected in national consumption of ARLA-32, which is much lower than forecast. Second, flaws in the original Euro V regulatory design allowed for much higher real-world NO_x emissions than intended, a problem that has been demonstrated by comprehensive testing conducted in Europe. Finally, widespread sales of P-5/Euro III trucks in 2012 meant that the effective implementation of P-7 standards started only six months (July 2012) after its original date (January 2012). As a result of these implementation problems, NO_x emissions will be much higher than designed, and thus continue to pose a threat to public health.

Although there are a number of near-term measures to ameliorate the problem, the most effective action to control NO_x emissions is to immediately advance to the next PROCONVE phase while aligning with Euro VI standards. This will not only result in much lower emission rates of NO_x, PM, and HC, but it will also close the P-7 regulatory loopholes while better controlling NO_x emissions in urban areas.

NEAR-TERM MEASURES

A number of near-term measures could be taken to address P-7 implementation problems:

» **Require manufacturers to recall vehicles or void warranty provisions.** Although manufacturers are complying with P-7 test procedures, they likely failed to include OBD monitoring strategies to ensure adequate use of ARLA-32 and effective NO_x control in real-world conditions. As a result, Brazilian regulators could place the onus on manufacturers to produce or fix vehicles whose aftertreatment systems, driver inducements, or fail-safe mechanisms do not operate effectively in real-world conditions. Some effective options for enforcing emission standard compliance in the United States have included the authority to recall and repair noncompliant vehicles and engines at the manufacturer's expense and the ability to levy fines for the use of "defeat devices." Alternatively, certification authorities could require that manufacturers recall noncompliant vehicles, and void the manufacturer warranty. One advantage of this measure is that it would affect existing P-7 vehicles already in operation.

» **Amend the P-7 regulation.** The most immediate and direct action for preventing inadequate use of ARLA-32 would be to amend P-7 protocol requirements to include all Euro V requirements for OBD monitoring systems, and more specifically to require either ARLA-32 consumption and quality monitoring. The addition of a cold start requirement and the adoption of the world harmonized transient cycle (WHTC), which better reflects vehicle operations in low-speed/load conditions, would ensure better compliance to test limits in urban areas. Finally, in-use conformity requirements equivalent to those in the Euro VI regulations alongside penalties for in-use non-compliance, would substantially ensure better compliance. The Euro-standard legislation requires member states to set penalties that are "effective, proportionate, and dissuasive" and to "take all measures necessary to ensure that they are enforced." (European Commission, 2011). This measure would affect new vehicles only.

- **Improve roadside enforcement.** Ensuring adequate use of ARLA-32 and verifying the use of defeat strategies on vehicles with roadside testing could catch noncompliant vehicles, and imposing heavy fines could serve as a disincentive for broader noncompliance. On-road enforcement could be complemented by remote sensing to identify repeated offenses from the same vehicle and flag those vehicles for roadside inspection. This measure would also affect the existing fleet.

EURO VI ADOPTION

In addition to these near-term measures, the adoption of Euro VI standards would not only resolve the inadequate use of ARLA-32 and urban off-cycle NO_x emissions, it would also strengthen emission limits. The Euro VI standard brings a series of advantages over its predecessor standard, making it the most effective option in the medium term:

- **More stringent emission limits.** The Euro VI standards require manufacturers to reduce NO_x emissions by 80% and PM emissions by 50% compared to Euro V, essentially ensuring the use of diesel particulate filters (DPF). When compared to a noncompliant P-7 vehicle, Euro VI standards could reduce NO_x emissions by more than 90%. In addition, Euro VI standards include limits for particle number to strengthen the control of fine particles.
- **More advanced OBD requirements.** Euro VI standards introduce many OBD improvements over previous generations, including more stringent OBD threshold values and type approval based on the WHTC; the adoption of in-use performance ratios, which indicate how often the conditions subject to monitoring occurred and how frequently the monitoring was conducted; and additional monitoring requirements for EGR flow, EGR cooling system, boost, and fuel injection systems (Posada & Bandivadekar, 2015).
- **More representative test cycles.** The WHTC certification test cycle used in Euro VI resembles real-world driving much more closely than the ESC and ELR cycles used in the Euro III through V regulations. This change in certification test cycles, including cold starts and low-speed driving, effectively forces manufacturers to use better catalysts (e.g., copper-zeolites versus vanadium), resulting in more similar emission rates between in-use and homologated vehicles.
- **In-use conformity requirements.** Euro VI standards have specific in-use conformity language, which specifies that emissions must be effectively limited under all in-use operating conditions, not just in those that resemble test conditions. Euro VI also tightens the in-use not-to-exceed limit to 1.5 times the WHTC on-cycle test limit, and requires in-use vehicle testing to demonstrate compliance. This essentially puts the onus on manufacturers to produce vehicles that comply with emission limits not only on test conditions but also on a wide variety of in-use conditions.

An upcoming cost-benefit analysis of P-8 standards, as an equivalent to Euro VI, indicates that economic benefits, specifically savings associated with a reduction in health impacts, outweigh costs by a ratio of 11:1 (Miller & Façanha, 2015). This is consistent with equivalent analyses of Euro VI standards in other countries, such as Mexico with a benefit-cost ratio of 11:1 (Miller, Blumberg, & Sharpe, 2014), U.S. with a benefit-cost ratio of 16:1 (U.S. EPA, 2000), and India with a benefit-cost ratio of 8:1 (Bansal & Bandivadekar, 2013).

In order to ensure a successful Euro VI implementation, however, S500 diesel would need to be phased out entirely. The catalysts used in Euro VI vehicles are highly sensitive to sulfur, and phasing out S500 diesel is the most effective way to eliminate any risk of misfueling. Fortunately, Petrobrás has already demonstrated its ability to effectively transition the country's diesel supply by providing ULSD nationwide, so there should be no concerns about fuel availability.

The problems highlighted in this paper indicate why Brazil should quickly advance to the next PROCONVE P-8 phase and align with Euro VI requirements. While several near-term options are available for addressing some of the issues currently present, none of them are sufficient on their own. Requiring vehicles to meet Euro VI emission standards and ensuring real-world compliance through in-use testing is the only measure that can effectively ensure adequate use of ARLA-32 by restoring the full set of OBD requirements while simultaneously overcoming the challenge of ineffective NO_x controls in urban areas.

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