White paper

NPTI – the New Periodic Technical Inspection emission test procedure for vehicles with emission control systems.

This white paper addresses the need for new emission test procedures in Periodic Technical Inspections (PTI). These new test procedures are needed to secure the long term emission performance of modern light and heavy-duty road vehicles with particle filters (DPF or GPF) and catalytic emission control. A simple Particulate Number (PN) PTI test at low idle speed is proposed. Governments are requested to develop the final PTI test procedures.

Diesel engines without a particulate filter emit toxic substances from which solid particles in the lung penetrating size range of 10-500 nm are by far the most dangerous substance. Solid particles in this size range are responsible for 450'000 premature death in Europe, 45 % by heart attacks, 35% by strokes and the rest by cancer [10] [11]. In order to reduce this particulate emission DPFs play a major role because they have a very high efficiency.

Euro 5+6/VI diesel vehicles have for the first time implemented Best Available Technology (BAT) for all road vehicles. Diesel Particle Filters (DPF) eliminate this particle emission more than 99%. In the EU more than 100 million of these vehicles with such powerful filters have been sold. So the problem is solved if theses filters operate properly. Experience however has shown that this new technology can fail by aging, poisoning or manipulation – control and repair or in other terms inspection and maintenance are absolutely needed to detect and correct failures. This is why highest priority is required for DPF control. But also for other elements of the new emission control technology to reduce NOx, HC and CO we need NPTI focused on the properties and weaknesses of these new elements to guarantee emission stability over vehicle life.

The current PTI emission test for petrol vehicles is very suitable. However there are no suitable PTI emission test procedures for modern diesel vehicles in place. Their Lean NOx Traps (LNT) and Selective Catalytic NOx-Reduction (SCR) catalysts, diesel particulate filters (DPFs) and other technologies reduce NOx and particulate emissions more than 95%. Due to these extremely effective technologies with their high performances the current Euro 6/VI emission levels are possible and air pollution can be reduced. Moreover the long term vehicle emission performance is defined in durability requirements (LD-vehicles 160.000 km and HD-vehicles up to 700.000 km).

In order to secure the long term emission performance of catalysts and filters regular maintenance and periodic technical inspections are needed. The current PTI smoke emission test for diesel vehicles is not suitable to judge the emission performance of DPFs. Therefore new reliable, simple and affordable PTI test procedures (NPTI) must be developed and implemented in current vehicle emission legislation.

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Background:

In 2016 several Swiss, German and Dutch governmental organizations, metrological institutes, scientists and equipment manufacturers recognized the need for new PTI emission tests and formed an informal technical working group. This white paper describes the need and possibilities for a new PTI emission test procedure (NPTI) and is meant to inform policy makers of national and European authorities, equipment manufacturers, type approval authorities and PTI service providers.

The **objectives** of this white paper are:

- Creation of awareness of the need of new emission test procedures in the PTI.
- Informing stakeholders about the current shortcomings of PTI emission testing.
- Showing a pathway to realistic and reliable options for new PTI emission tests.
- Inviting stakeholders to give input to this development.

This white paper deals with four questions:

1. What has been changed in the configuration of modern on-road vehicles in the last decades?
2. What is the quality of the emission tests in current European PTIs?
3. Which NPTI emission tests must be developed?
4. How can NPTI emission tests be implemented in current legislation?

1. What has been changed in the configuration of modern on-road vehicles in the last decades and what is needed to secure their exhaust emissions?

From 1990 to 2016 the European exhaust emission limit values (Euro standards) of vehicles have been decreased 90-97%. In Table 1 and Figure 1 the decreasing trend of emission limit values (PM and NOx) and applied technologies for diesel light-duty vehicles are shown. In Table 2 and Figure 2 the decreasing trend of emission limit values (PM and NOx) and applied technologies for heavy-duty vehicles are shown.

Table 1: European PM and NOx Type Approval emission limit values for Light-Duty diesel passenger cars and applied emission reduction technologies

		Limit value			
		NOx	PM	PN	Applied emission reduction technologies
		[mg/km]	[mg/km]	[#/km]	
Euro 1	1993	970	140	-	-
Euro 2	1996	700	80	-	-
Euro 3	2000	500	50	-	DOC
Euro 4	2005	250	25	-	EGR+DOC
Euro 5a	2009	180	5.0	-	Cooled EGR + DOC + DPF
Euro 5b	2011	180	4.5	6×10^{11}	Cooled EGR + DOC + DPF
Euro 6	2016	80	4.5	6×10^{11}	Cooled EGR + DOC + DPF + LNT/SCR

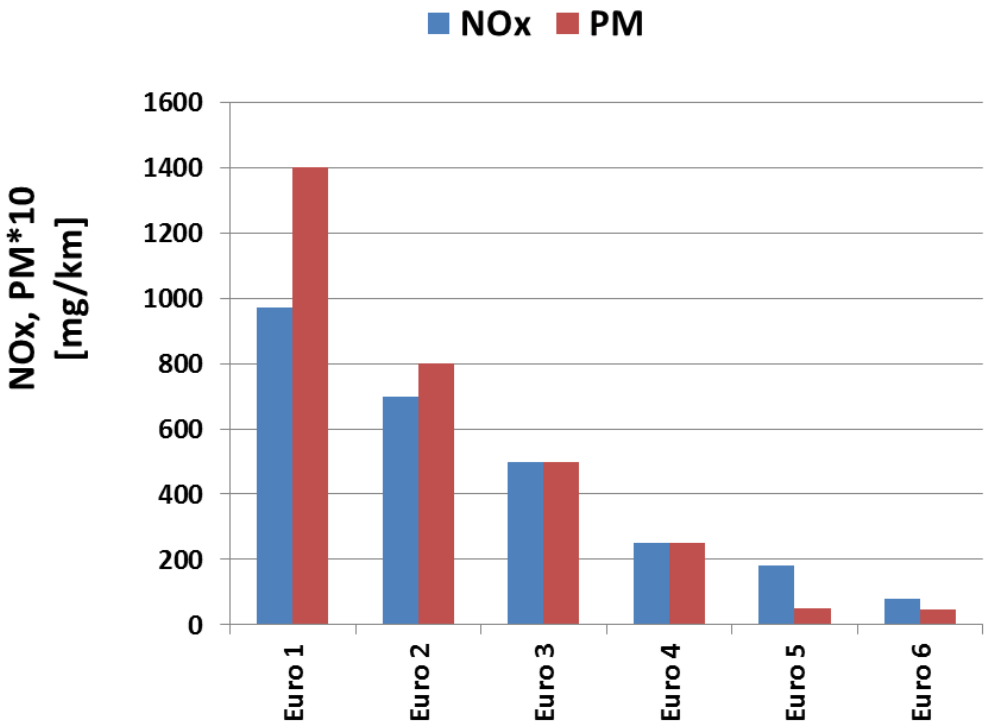

Figure 1: European PM and NOx Type Approval emission limit values for Light-Duty diesel vehicles

Table 2: European PM and NOx Type Approval emission limit values for Heavy-Duty vehicles and applied emission reduction technologies

		limit [g/kWh]			
		NOx	PM	PN	Applied emission reduction technologies
		[g/kWh]	[g/kWh]	[#/kWh]	
Euro I	1992	8.0	0.36	--	-
Euro II	1996	7.0	0.15	-	-
Euro III	2000	5.0	0.10	-	-
Euro IV	2005	3.5	0.02	-	Cooled EGR/SCR
Euro V	2008	2.0	0.02	-	Cooled EGR+DOC+SCR
Euro VI	2014	0.46	0.01	6×10^{11}	Cooled EGR+DOC+DPF+SCR

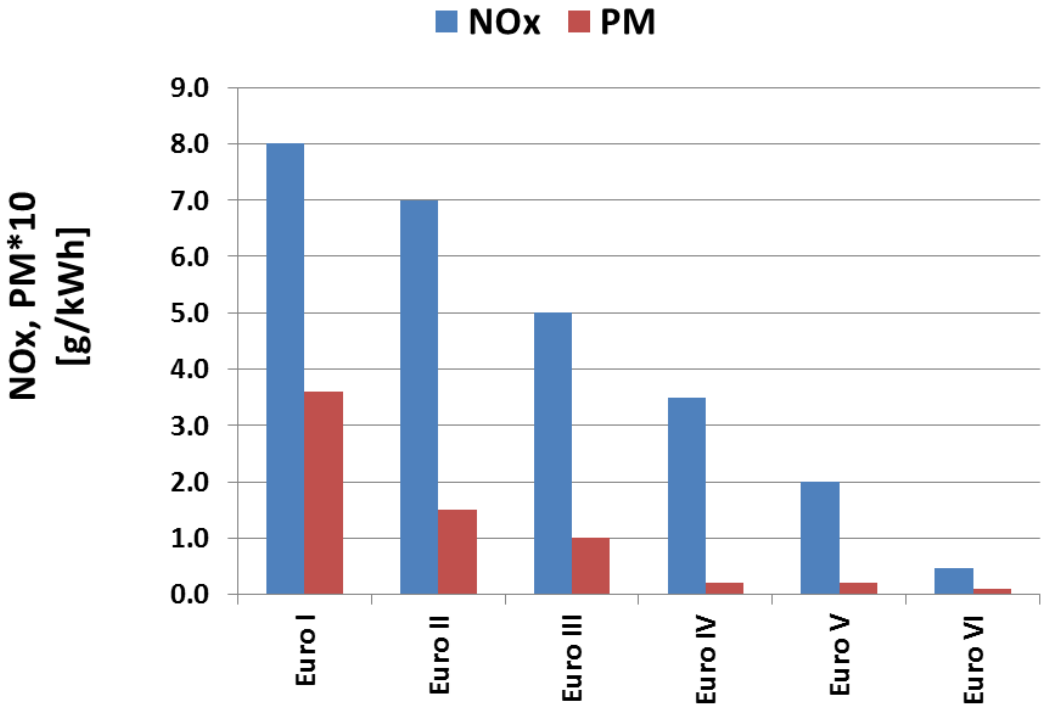

Figure 2: European PM and NOx Type Approval emission limit values for Heavy-Duty vehicles

From Euro 3/Euro IV onwards application of emission reduction technologies or so-called exhaust aftertreatment systems was needed to meet the newest emission standards. The development and availability of exhaust aftertreatment systems such as Particle Filters (DPF, CRT), Oxidation Catalysts (DOC, ASC), Selective Catalytic NOx-Reduction (SCR), and Lean NOx Traps (LNT) allowed the emission limits for CO, THC, NOx and PM to be further decreased and a much more sensitive emission limit for solid particle number (PN) to be introduced. Consequently the emission levels of modern vehicles are mainly determined by the performance of their exhaust aftertreatment systems. Hence the performance of these systems should be checked properly in PTIs.

Currently there are no suitable PTI vehicle tests available for checking the proper functioning of exhaust aftertreatment systems[1].

[1] For DPF there is a PN-based control system in Switzerland for construction machines since 2015. There is also a PN-instrument specification in force in Switzerland for PTI of construction machines.

The stability of the real world emission of a diesel engine cannot be guaranteed over the lifetime of the engine. However, these emissions are essential for air quality and public health. Apart from the effects of wear, aging and damage of emission control hardware and software elements, also various kinds of manipulation have been observed. It is known that services for tampering with emission control systems are being offered to the market. Unfortunately the legally required application of electronic onboard OBD control and current PTIs turned out to be insufficient. Independent 100% periodic inspection with suitable PTI emission tests ought to be mandatory to guarantee the proper functioning of Particle Filters (DPF), Oxidation Catalysts (DOC, ASC), Selective Catalytic NOx-Reduction (SCR), Lean NOx Traps (LNT) and other emission control systems of modern combustion engines.

2. What is the quality of the emission tests in the current European Periodic Technical Inspections?

The European Directive 2014/45/EC describes the PTI nuisance test procedures in chapter 8.

For petrol vehicles the current PTI emission test contains an exhaust gas analysis at low idle engine speed in which four gases are measured (CO_2, CO, THC and O_2). The quality of this exhaust gas mixture is calculated on the basis of these gases and expressed in a lambda value. Lambda should be between 0.97 and 1.03. In fact the air-fuel ratio at idle operation is checked. This is a very simple test in a restricted area of the engine map. Fortunately the emission performance of most petrol vehicles is good because the concept of the three-way catalyst is very robust and stable. A further improvement of the PTI can be achieved by implementation of a NOx and PN test (for Gasoline Particulate Filters).

For Euro 6/VI diesel vehicles the current PTI emission test procedure contains an opacity measurement in a free acceleration smoke emission test which has a very bad correlation with the PM/PN-emission of the vehicle. In this free acceleration test the current light duty opacity limit value is 0.7 m^{-1}. Most diesel vehicles can even pass this test without DPF because the opacity value of the engine-out exhaust flow is even lower than 0.7 m^{-1}. Removal of DPFs is therefore not detected. Lowering the limit value is not an option because current PTI opacity meters have an accuracy of +/- 0.3 m^{-1} and are not suitable to measure low smoke emission levels. The Swiss Federal Institute of Metrology reported that transmission smoke meters and opacimeters reach the limit of their capabilities as the measurement principles become less sensitive at smaller particle sizes and lower concentrations. They concluded that opacimeters are not suitable for the current generation of diesel engines that meet Euro 5 and 6 standards [8] [9]. NOx and PN emissions are not even measured in the PTI. Consequently there is a tremendous need for development of a new PTI test procedure which offers the possibility to judge the emission performance of a modern diesel vehicle.

EOBD tests: Besides the opacity test, most vehicles are primarily checked in the PTI by reading the Electronic On-Board Diagnostic system (EOBD) which might report certain fault codes. EOBD systems monitor the technical status of hardware (sensors and actuators) and monitor some engine behavior with software. In case of a malfunction, fault codes are generated which mostly result in a blinking sign on the dashboard and fault codes stored in the memory of the Electronic Control Unit (ECU). Due to a lack of sensors EOBD systems are not able to monitor and control all emissions. Current vehicles have NOx sensors but PM or PN sensors are not available yet. Future vehicles should

contain appropriate sensors and control strategies securing real world emission levels. Consequently EOBD does not secure emissions of modern vehicles and the emission performance of current vehicles must be monitored in PTIs.

It can be concluded that the todays PTI emission test of petrol vehicles satisfies but it can be expanded with a NOx and PN test. The current PTI emission test of diesel vehicles with aftertreatment systems is not appropriate. For these vehicles there is a huge need for suitable PTI emission test procedures which are based on PM/PN and NOx emissions.

3. Which New PTI emission tests must be developed?

Following the example of the Swiss PTI methodology for construction machines[2], the New PTI emission test procedure for diesel engines should consist of several modular tests for determination of CO, THC, NOx and PM/PN emission performances of a vehicle and should correlate with a type approval emission test procedure. Due to the very different nature of the various aftertreatment systems, which reduce the specific chemical components, a series of different emission tests are needed. These tests might be executed separately and independently.

Particularly three different tests must be developed, these are:

- DPF test
- SCR/LNT test
- DOC test

DPF test: The PM/PN emission of current diesel vehicles is mainly determined by the filtration efficiency of a DPF which is for a well operating closed DPF more than 99.5%. This technical concept with its passive filtration nature has a fairly constant filtration efficiency. In order to determine the condition of a DPF in the PTI one should be able to measure a DPF efficiency loss of 1 to 10%.

Currently the PTI only prescribes a smoke emission test which is very insensitive. In Figure 3 an example of a cracked DPF of a light-duty diesel vehicle is shown. The PTI smoke emission of this vehicle is 0.30 m^{-1} which is below its type approval limit value of 0.51 m^{-1}. The Conformity factor of the smoke emission (CF_{smoke}) is 0.6. When tested on the NEDC this vehicle had a PM emission of 5.2 mg/km (CF_{PM} = 1.0) and a PN emission of 1.9 * 10^{13} #/km (CF_{PN} = 32)[3]. On the basis of the PM and PN emissions in the NEDC the vehicle fails but the same vehicle passes on the basis of the PTI smoke emission test result. These three CF's of the same vehicle with very deviating values (0.6 to 32) show the need for better PTI emission test procedures. The current smoke emission test procedure is not designed for such low emission levels and the smoke meter has insufficient screening performance. Significantly more reliable results can be achieved for low emissions by the solid particle number (PN) measurement method, which is so sensitive that it can measure emissions more than 100 times

[2] Verordnung des EJPD über Abgasmessmittel für Verbrennungsmotoren1 (VAMV), 941242

[3] This Euro 5a vehicle has no Type Approval PN limit value but a similar Euro 5b vehicle with a cracked DPF and a PN limit value of 6 * 10^{11} #/km has a similar PN emission.

lower than the lowest level of any PM test (around 1 mg/km) and also verify the correct performance of aftertreatment systems [7].

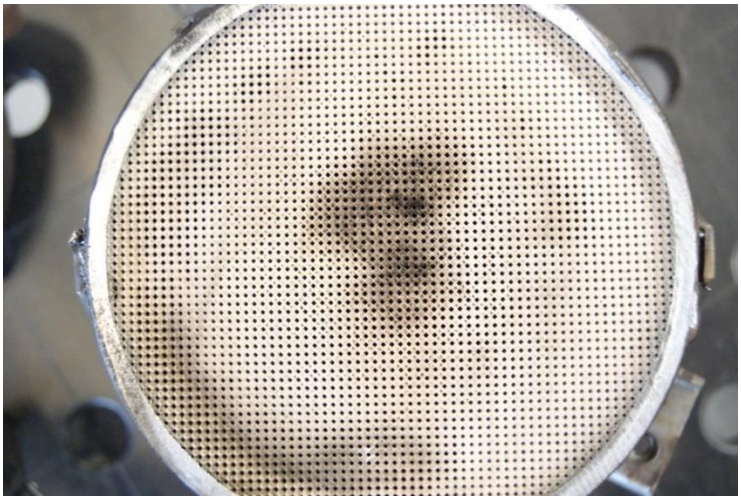

Figure 3: Backside of a cracked DPF of a Euro 5a diesel vehicle @ 160,200 km.

New PTI PN test procedure at low idle speed for diesel vehicles with a DPF:

On behalf of the Dutch Ministry of Infrastructure and The Environment TNO has developed a new very simple and short (< 30 seconds) PTI PN emission test procedure for light-duty diesel vehicles with a DPF which can be performed at low idle speed [1] which is similar to current gasoline PTI tests. Emission tests of three different vehicles have shown a good correlation of PN emissions at low idle speed and the PN emissions in NEDC tests, see Figure 4.

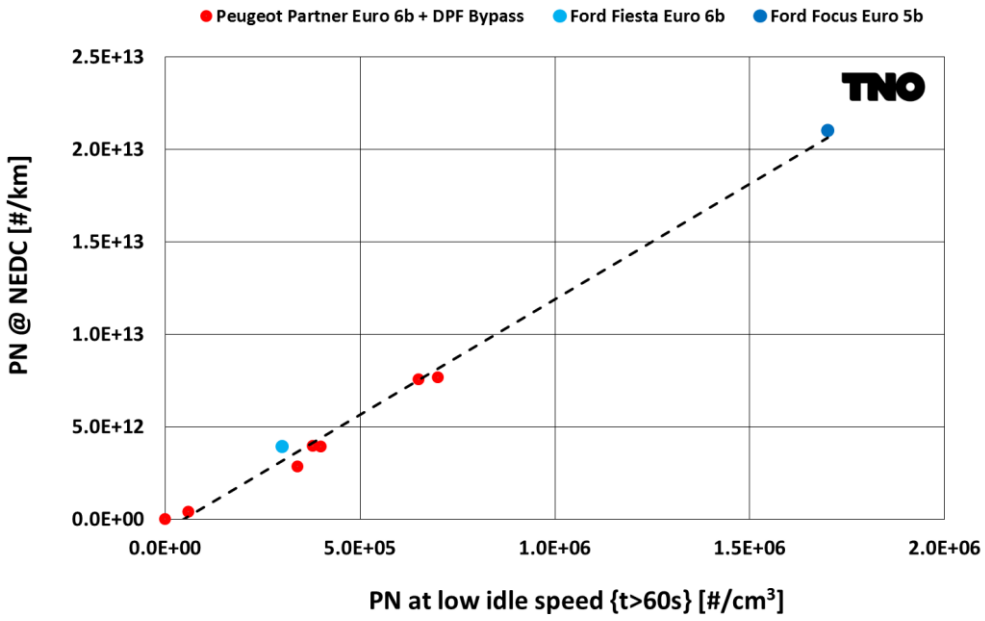

Figure 4: PN emissions at low idle speed and on the NEDC test of 3 different diesel vehicles with (cracked) DPF or variable bypass.

In order to build a new PTI PN emission test procedure, in 2017 scientists and test equipment manufacturers of the NPTI working group have defined new specifications of simple PTI-PN testers. Prototypes of these PN-testers are available and should be validated with the PMP-PN emissions test in future projects.

The authors are convinced that suitable and effective solutions for a new PTI PN emission test procedure can be developed within two years. In general PTI tests must be executable, reproducible, easy to handle, affordable and applicable for all vehicle types of a certain category. The procedure contains a description of an emission test, a specification of the test conditions and test equipment as well as pass/fail criteria.

SCR/LNT test:

In Figure 5 an example of an exhaust line with SCR catalyst and AdBlue injection system is shown. AdBlue is a mixture of water and urea and is injected upfront the hot SCR catalyst. Due to the thermal energy of the exhaust gas urea is converted to ammonia which reacts in the SCR catalytic convertor with NOx to harmless elements. An SCR PTI test must determine the functionality of the SCR catalyst.

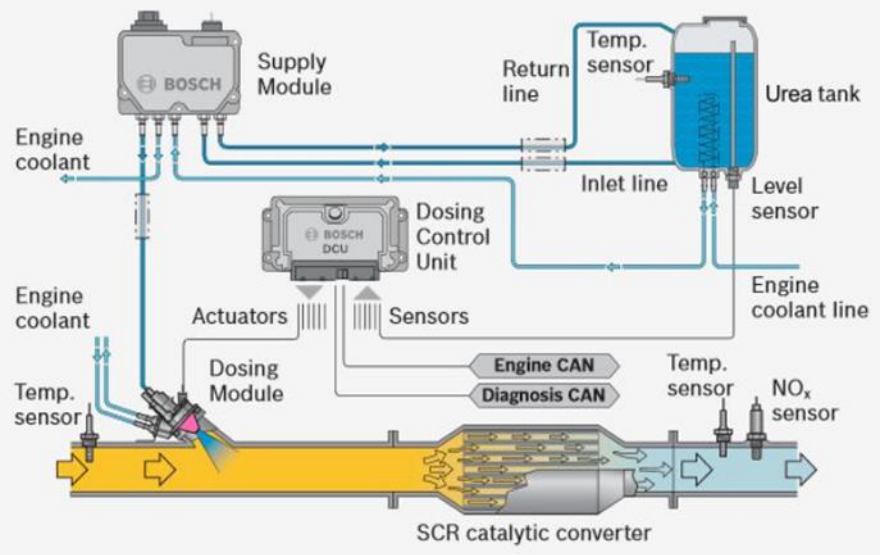

Figure 5: Diesel exhaust line with SCR system. Schematic of Bosch Denoxtronic 2.2 urea injection system (Source: Bosch)

Lean NOx traps (LNT) store NOx molecules. The LNT is periodically regenerated by offering some HC & CO to the LNT. This is governed by dedicated engine controls. Due to the very low NOx concentrations and low exhaust temperature at low idle speed it is expected that LNTs can be checked in specific PTI tests but these PTI tests must be developed.

First attempts for a NOx PTI-test: In general the NOx emission of a modern diesel vehicle fluctuates over the engine map and is very dynamic because the applied NOx reduction technologies (EGR, LNT and SCR) are actively controlled. Currently the Swiss VERT Association [2] and AFHB develop a first version of a dedicated PTI test procedure for vehicles with modern aftertreatment systems. For this

determination of the NOx emission performance the engine should be tested on a simple chassis dynamometer.

For the NPTI SCR/LNT test it is expected that a more advanced and a simple NOx emission test procedure can be developed with simple NOx testers or automotive NOx sensors.

The CO and THC emissions of a vehicle are mainly determined by the quality of the combustion and the performance of an oxidation catalyst. Currently the Swiss VERT Association [2] and AFHB develop a first version of a dedicated PTI test procedure for vehicles with modern aftertreatment systems. For determination of the performance of DOCs the engine should be tested on a simple chassis dynamometer.

4. How can new PTI emission tests be implemented in current legislation?

Current PTI test procedures, as specified in UNECE Regulation 24 for the free acceleration smoke emission test for LD and HD diesel vehicles and UNECE Regulation 83 (Type II test) for petrol vehicles, are no longer suitable for detecting relevant levels of malfunctioning or tampering in modern vehicles with advanced emission control systems.

It is known that possible losses in filtration efficiency or removal of DPF's significantly affect real-world PM and PN emissions [3]. In first Dutch studies [4] [5] at least 21 of the 355 assessed Dutch vehicles with a DPF (6%) showed elevated smoke emissions with a k-value higher than 0,3 m^{-1}.

This white paper addresses the need to start up discussions about development and implementation of improved NPTI tests in the legislative frameworks, and indicates some promising options.

PTI tests at low idle speed can be added to UNECE R83 as a type II test or as part of the WLTP.

References:

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Abbreviations:

ASC Ammonia Slip Catalyst

CO Carbon Monoxide

CRT Continuous Regenerating Trap

DOC Diesel Oxidation Catalyst

DPF Diesel Particulate Filter

ECU Electronic Control Unit.

EOBD Electronic On Board Diagnosis

GPF Gasoline Particulate Filter

HD Heavy Duty

LD Light Duty

LNT Lean NOx Trap

NO_x Nitrogen Oxides (NOx = NO + NO_2)

NPTI New Periodic Technical Inspection

PM Particulate Matter

PN Particulate Number

PTI Periodic Technical Inspection

SCR Selective Catalytic Reduction

THC Total Hydro Carbons

WLTP World harmonized Light-Duty Test Procedure