TFTEI informal background document on reduction techniques for mobile sources and the review of annex VIII of the Gothenburg Protocol

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List of abbreviations and acronyms

ACEA	European Automobile Manufacturers' Association
AGP	Amended Gothenburg Protocol
AGVES	Advisory Group on Vehicle Emission Standards
BAT	Best Available Technique
BEV	Battery Electric Vehicle
BTL	Biomass To Liquid
CADC	Common Artemis Driving Cycles
CH_4	Methane
CH_2O	Formaldehyde
CF	Conformity Factor
CI	Compression Ignition
CLOVE	Consortium for Ultra-Low Vehicles Emissions
CNG	Compressed Natural Gas
CO	Carbon monoxide
DI	Direct Injection
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particle Filter
EC	European Commission
EGR	Exhaust Gas Recirculation
EHC	Electrically Heated Catalyst
ELR	European Load Response
ELV	Emission Limit Value
ER-EV	Extended-Range Electric Vehicles
ESC	European Steady-State Cycle
EtOH	Ethanol
EU	European Union
FCEV	Fuel Cell Electric Vehicle
GDI	Gasoline Direct Injection
GHG	Greenhouse gas
GP	Gothenburg Protocol
GPF	Gasoline Particle Filter
GTL	Gas to Liquid
GVW	Gross Vehicle Weight
H_2	Hydrogen

HC	Hydrocarbon
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicles
HFO	Heavy Fuel Oil
HVO	Hydrotreating of Vegetable Oil
IC	Internal Combustion
ICCT	International Council of Clean Transportation
INTERREG	Funding program from the European Union
ISC-FCM	In-Situ Combustion – Fuel Consumption Meter
IWA	Inland Waterland Auxiliary
IWP	Inland Waterland Vessel direct or indirect Propulsion
JRC	Joint Research Centre
LAT/Auth	Laboratory of Applied Thermodynamics of the University of Thessaloniki
LCV	Light Commercial Vehicle
LDV	Light Duty Vehicle
LNG	Liquefied Natural Gas
LNT	Lean-NOx Trap
LPG	Liquefied Petroleum Gas
LRTAP	Long-range Transboundary Air Pollution
LSFO	Low Sulphur Fuel Oil
MtOH	Methanol
N_2	Nitrogen
N_2O	Nitrous Oxide
NEDC	New European Driving Cycle
NEE	Non-Exhaust Emissions
NH_3	Ammonia
NMHC	Non methanic hydrocarbons
NMOG	Non-Methanic Organic Gases
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NRMM	Non-road Mobile Machinery
NYCC	New York City Cycle
OBD	On-Board Diagnostic
OC	Organic Carbon
PC	Passenger Car

PEMFC	Proton-exchange membrane fuel cells
PEMS	Portable Emission Measurement System
PHEV	Plug-In Hybrid Electric Vehicles
PM	Particulate Matter
PN	Particle Number
POC	Particle Oxidation Catalyst
PTL	Power to Liquid
RDE	Rear Driving Emissions
RLL	Locomotives
RLR	Railcars
RNG	Renewable Natural Gas
RW	Reference Weight
SCR	Selective Catalytic Reduction
SI	Spark-ignition
SOx	Sulphur Oxides
SPN	Suspended Particles number
TWC	Three-way catalyst
UFP	Ultra Fine Particles
UK	United Kingdom
UN	United Nations
UNECE	United Nations Economic Commission for Europe
US	United States
VOC	Volatile Organic Compounds
WHSC	World Heavy Duty Steady State Cycle
WHTC	World Heavy Duty Transient Cycle
WLTC	Worldwide harmonized Light vehicles Test Cycles
WMTC	Worldwide harmonized Motorcycle emissions Certification/Test procedure

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Executive Summary

The Decision 2019/4, taken by the Executive Body in December 2019, established the scope and content of the review of the Amended Gothenburg Protocol (AGP). The Group for the Review of the Gothenburg Protocol (GPG) developed the document "Preparations for the review of the Protocol to Abate Acidification, Eutrophication, and Ground-level ozone, as amended in 2012 (2020/3)", adopted in December 2020. In the Annex I of this document, a list of questions concerning all the aspects to be considered during the review process, is reported. In particular the questions in section 1.6 are related to the Technical Annexes (TAs) to the AGP. In order to answer the questions in section 1.6, in 2021, TFTEI carried out an extensive review of the Tas: IV - Limit values for emissions of sulphur from stationary sources, V - Limit values for emissions of nitrogen oxides from stationary sources; VI - Limit values for emissions of volatile organic compounds from stationary sources; X - Limit values for emissions of particulate matter from stationary sources and XI - Limit values for volatile organic compounds content of products and its associated Guidance Documents (GDs). The main conclusions of such review work were included in the GPG "Draft report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012" (ECE/EB.AIR/WG.5/2022/3) and, also, in the TFTEI co-chairs Report of the Task Force on Techno-economic Issues (ECE/EB.AIR/WG.5/2022/1), both official documents for WGSR, at its 60th session in April 2022.

In the following sections, an extended and detailed report of the results regarding the review of the technical annex VIII, "Limit values for fuels and new mobile sources" to the Amended Gothenburg Protocol, and its associated GD, carried out by TFTEI, is provided. In particular, the emission limit values (ELVs) in the existing TA VIII are compared to the emission levels achievable with state-of-the art abatement technologies. The current report is aimed at providing, a more comprehensive document with background information regarding reduction techniques and related ELVs for mobile sources. A first report covering stationary sources (Annexes IV, V, VI, X and XI) was made available, as informal document for WGSR, at its 60th session (11 - 14 April 2022).

This second report aims at completing the review of limit values for mobile sources covered in the TA VIII, as in the following:

Activities and respective ELVs listed in the annex VIII (fuels and mobile sources):

VIII: Limit values for fuels and new mobile sources

1. Limit values for passenger cars and light-duty vehicles
2. Limit values for heavy-duty vehicles steady-state cycle load-response tests
3. Limit values for heavy-duty vehicles – transient cycle tests
4. Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (stage IIIB)
5. Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (stage IV)
6. Limit values for spark-ignition engines for non-road mobile machines
7. Limit values for engines used for propulsion of locomotives
8. Limit values for engines used for propulsion of railcars
9. Limit values for engines for propulsion of inland waterways vessels
10. Limit values for engines in recreational crafts
11. Limit values for motorcycles (> 50 cm^3 ; > 45 km/h)
12. Limit values for mopeds (< 50 cm^3 ; < 45 km/h)

13. Environmental specifications for marketed fuels to be used for vehicles equipped with positive-ignition engines
14. Environmental specifications for marketed fuels to be used for vehicles equipped with compression-ignition engines

1. Introduction

The rationale behind the proposals of potential updating of the limit values from Annex VIII (limit values for emissions from mobile sources) are provided in the following chapters. All the types of vehicles have been examined and information is provided for potential updatable limit values (ELVs). An "Update Index" (1-3) has been defined to express the level of update which can be potentially introduced in the technical annexes, according to the results of the research carried out by the TFTEI Techno Scientific Secretariat, on the available technologies (1 is high level of update, 3 means no update available/possible). ELVs and the related information on evolution of international regulations and reduction techniques, are provided in this technical document.

This document aims at completing the first report "TFTEI background informal technical document for the review of the Gothenburg Protocol for Industrial processes (Annexes IV, V, VI, X and XI) made available for WGSR, at its 60th session in April 2022.

Many new developments occurred in Europe since the amendments to the Gothenburg Protocol adopted in 2012. These evolutions concern the introduction of more realistic certification cycles, real-driving emission measurements and more ambitious limit values. Techniques also evolved.

2. Annex VIII: Limit values for fuels and new mobile sources

2.1. Passenger cars and light-duty vehicles

2.1.1. Current limit values of the 2012 AGP

Limit values for power-driven vehicles with at least four wheels and used for the carriage of passengers (category M) and goods (category N) are given Table 1 of annex VIII of the Amended Gothenburg Protocol (AGP) (Table 1).

Table 1: Table 1, annex VIII, current limit values for passenger cars and light-duty vehicles

			Limit values[a]													
			Carbon monoxide L1 (g/km)		*Total Hydrocarbons (HC) L2 (g/km)*		*Non-methane volatile organic compound (NMVOC) L3 (g/km)*		*Nitrogen oxides L4 (g/km)*		*Hydrocarbons and nitrogen oxides combined L2 + L4 (g/km)*		*Particulate matter L5 (g/km)*		*Number of particles[a] (P) L6(#/km)*	
Category	*Class, application date**	*Reference mass (RW) (kg)*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*	*Petrol*	*Diesel*
Euro 5																
M[b]	1.1. 2014	All	1.0	0.50	0.10	–	0.068	–	0.06	0.18	–	0.23	0.0050	0.0050	–	6.0x1011
N_1[c]	I, 1.1.2014	RW 1305	1.0	0.50	0.10	–	0.068	–	0.06	0.18	–	0.23	0.0050	0.0050	–	6.0x1011
	II, 1.1.2014	1305 < RW≤ 1760	1.81	0.63	0.13	–	0.090	–	0.075	0.235	–	0.295	0.0050	0.0050	–	6.0x1011
	III, 1.1.2014	1760 < RW	2.27	0.74	0.16	–	0.108	–	0.082	0.28	–	0.35	0.0050	0.0050	–	6.0x1011
N_2	1.1.2014		2.27	0.74	0.16	–	0.108	–	0.082	0.28	–	0.35	0.0050	0.0050	–	6.0x1011
Euro 6																
M[b]	1.9.2015	All	1.0	0.50	0.10		0.068	–	0.06	0.08	–	0.17	0.0045	0.0045	6.0x1011	6.0x1011
N_1[c]	I, 1.9.2015	RW ≤1305	1.0	0.50	0.10	–	0.068	–	0.06	0.08	–	0.17	0.0045	0.0045	6.0x1011	6.0x1011
	II, 1.9.2016	1305 < RW≤ 1760	1.81	0.63	0.13	–	0.090	–	0.075	0.105	–	0.195	0.0045	0.0045	6.0x1011	6.0x1011
	III, 1.9.2016	1760 < RW	2.27	0.74	0.16	–	0.108	–	0.082	0.125	–	0.215	0.0045	0.0045	6.0x1011	6.0x1011
N_2	1.9.2016		2.27	0.74	0.16	–	0.108	–	0.082	0.125	–	0.215	0.0045	0.0045	6.0x1011	6.0x1011

* The registration, sale and entry into service of new vehicles that fail to comply with the respective limit values shall be refused as from the dates given in the column.

[a] Test cycle specified by NEDC

[b] Except vehicles whose maximum mass exceeds 2,500 kg.

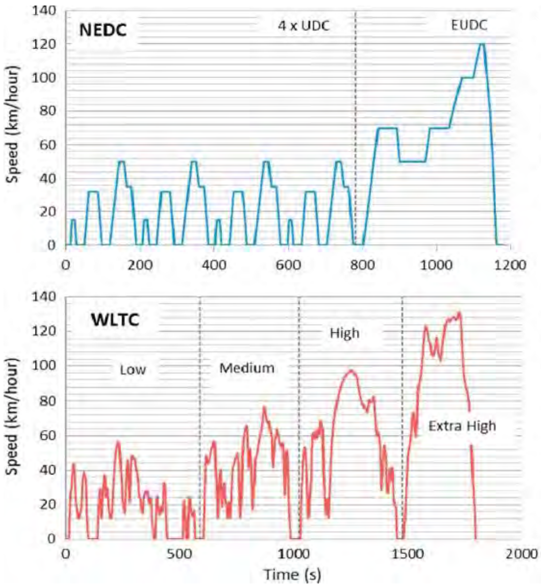
[c] And those category M vehicles specified in note *b*.

Annex VIII of the AGP contains emission limit values for passenger cars and light-duty vehicles up to Euro 6, in line with the Annex 1 of European Commission regulation (EU) N°459/2012 May 2012 [1].

2.1.2. Rationale for potential updates of limit values

The limit values reported in Table 1 above, were established using New European Driving Cycle (NEDC) test cycle specified in UNECE R101 [2]. Since then, a new cycle for light vehicles testing has been set-up, the Worldwide harmonized Light vehicles Test Cycle (WLTC) in the framework of the Worldwide harmonized Light vehicles Test Procedure (WLTP). This cycle is supposed to be more representative of the real-world emissions and has been set-up to answer to numerous studies showing that real on-road emissions and fuel consumption could be substantially higher than those reported during NEDC test.

The WLTP, developed under the aegis of the UNECE (United Nations Economic Commission for Europe) was adopted as a global technical regulation (GTR No. 15 [3]) on March 12, 2014, by the World Forum for Harmonization of Vehicle Regulations (WP.29, a technical group within the UNECE) [4]. The WLTP procedure, which measures specific emissions from light vehicles, includes a new harmonized laboratory test cycle that better reflects real-world driving conditions than the NEDC laboratory test cycle (Figure 1). It is based on real-world driving data (from urban traffic to freeways) collected from all over the world and therefore provides a more accurate, representative and reliable basis for measuring fuel consumption, as well as specific emissions of CO_2 and pollutants. The WTLC requires the vehicle manufacturer to comply with emission regulations over a wider engine operating range that is more representative of the actual engine operating range.



Parameters	NEDC	WLTC
Duration (s)	1180	1800
Distance (km)	11.03	23.27
Average speed (km/h)	33.6	46.5
Maximum speed (km/h)	120.0	131.3
Stop duration (%)	23.7	12.6
Constant driving (%)	40.3	3.7
Acceleration (%)	20.9	43.8
Deceleration (%)	15.1	39.9
Average positive acceleration (m/s^2)	0.59	0.41
Maximum positive acceleration (m/s^2)	1.04	1.67
Average positive "speed*acceleration" (m^2/s^3)	1.04	1.99
Maximum positive "speed*acceleration" (m^2/s^3)	9.22	21.01
Average deceleration (m/s^2)	-0.82	-0.45
Minimum deceleration (m/s^2)	-1.39	-1.50

Figure 1: Speed profile and key parameters of the driving cycles NEDC and WLTC (Marotta et al. 2015 [5])

A comparison between emissions of air pollutants and CO_2 made by Marotta et al. (2015) [5] showing that moving from NEDC to WLTC could have a strong impact on NOx emissions from Diesel vehicles, with a potential remaining exceedance of the limit value for several vehicles.

For this reason, in addition to the WLTC test procedure, Real-Driving Emissions (RDE) tests have also been implemented. In fact, before being introduced on the European market, light vehicles must be approved according to the WLTC procedure, with tests in the laboratory as well as on roads.

Since the amendments to the Gothenburg Protocol adopted in 2012, the Euro 6 (equivalent to Euro 6a/b) standard has been revised several times: Euro 6c, Euro 6d-Temp, Euro 6d-Full [6] which extend the required test conditions and lower the emission thresholds for NOx, CO, fine particles and unburned hydrocarbons. It also introduces the Not-To-Exceed (NTE) values within RDE tests.

Since January 1st, 2021, the Euro 6.d-Full Norm [6] strengthens the air pollutant emission thresholds not to be exceeded. CO, HC, and NOx are particularly targeted. All engines are therefore concerned: Diesel and gasoline cars, as well as those with a hybrid or LPG engine.

The certification method also evolved with the revision of the Euro 6 Norm, from NEDC cycle, to WLTC, starting from Euro 6c. Since September 2017, new vehicles have to pass two tests before they can be sold on European market, one WLTC laboratory test and one Real-Driving Emissions test, for Euro 6d-Temp and Euro 6d-Full. The RDE tests allow to compare air pollutants emissions measured in the laboratory during the homologation cycle and the real-world emissions on different type of roads.

Real-driving emissions of NOx and Particles Number (PN) are measured using a Portable Emissions Measurement System (PEMS) (Figure 2). To consider the measurement uncertainties which is higher with a PEMS than with laboratory instruments, a Conformity Factor (CF) is applied that allows a discrepancy between the regulatory limit value and the real-driving measurements. Thus, the conformity factor allows for higher emissions under real driving conditions to consider a margin of error.

The following figure illustrates a vehicle equipped a Portable Emissions Monitoring System (PEMS) which measures the real driving emissions during vehicle operation.

Figure 2: Portable emission monitoring system (PEMS) Photo – source: AVL M.O.V.E. [7]

Since 2017, the gap between pollutant emissions measured in the laboratory and on the road under real-world conditions has significantly decreased. The JRC (Joint Research Centre) tested different types of vehicles and demonstrated that the latest generation of Diesel passenger cars emits between 20 and 60 mg of NOx per km under the RDE conditions (Figure 3) [8].

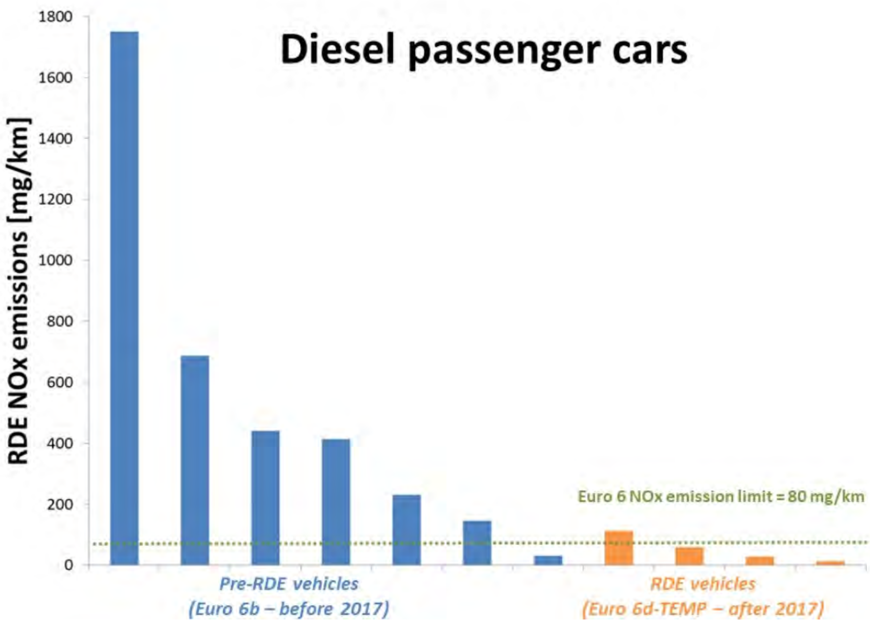


Figure 3: Data produced by the European Commission's Joint ResearchCenter (JRC). Every bar indicates the emissions performance of a type of vehicle [8]

The European Parliament proposed the conformity factor to be annually lowered, based on the assessment by the JRC. After a decrease from 1.5 to 1.43, under the 4th RDE Act [8], the conformity factor has been lowered to 1.32 in 2020. The European Parliament proposed that the conformity factor cease to apply by 30 September 2022 [9]. By this date, the real-driving emissions measurements data would be used to determine compliance with EU emission limits.

2.1.3. Proposals of potential updated limit values in table 1

Since 2014, Euro 6 norm has been updated. Since the Dieselgate, independent real conditions testing is required. Euro 6c is the limit value for WLTP method. Euro 6d-Temp and Euro 6d-Full are the standard for RDE measurements (Table 2). The conformity factor allowed a deviation from the limit value for NOx until September 2022. Thus, this factor is not included in this proposal.

Update Index 1.

Table 2: Table 1, annex VIII, proposal for potential update of limit values for passenger cars and light-duty vehicles

				Limit value													
				Carbon monoxide L1 (g/km)		**Total hydrocarbons (HC) L2 (g/km)**		**Non-Methane Volatile Organic Compounds (NMVOC) L3 (g/km)**		**Nitrogen oxides L4 (g/km)**		**Hydrocarbons and nitrogen oxide combined L2+L4 (g/km)**		**Particulate matter L5 (g/km)**		**Number of particles (P) L6 (#/km)**	
Category	Cycle	Class application date	Ref mass RW (kg)	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
EURO 5																	
M		1.1.2014	All	1.0	0.50	0.10	-	0.068	-	0.06	0.18	-	0.23	0.0050	0.0050	-	6.0x10^{11}
N1		1.1.2014	RW 1305	1.0	0.50	0.10	-	0.068	-	0.06	0.18	-	0.23	0.0050	0.0050	-	6.0x10^{11}
	NEDC 2000	1.1.2014	1305 < RW ≤ 1760	1.81	0.63	0.13	-	0.090	-	0.075	0.235	-	0.295	0.0050	0.0050	-	6.0x10^{11}
		1.1.2014	1760 < RW	2.27	0.74	0.16	-	0.108	-	0.082	0.28	-	0.35	0.0050	0.0050	-	6.0x10^{11}
N2		1.1.2014		2.27	0.74	0.16	-	0.108	-	0.082	0.28	-	0.35	0.0050	0.0050	-	6.0x10^{11}
EURO 6																	
M		1.9.2015	All	1.0	0.50	0.10	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N1		I. 1.9.2015	RW 1305	1.0	0.50	0.10	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
	NEDC 2000	II. 1.9.2016	1305 < RW ≤ 1760	1.81	0.63	0.13	-	0.090	-	0.075	0.105	-	0.195	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
		III. 1.9.2016	1760 < RW	2.27	0.74	0.16	-	0.108	-	0.082	0.125	-	0.215	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N2		1.9.2016		2.27	0.74	0.16	-	0.108	-	0.082	0.125	-	0.215	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
EURO 6c																	
M		1.9.2018	All	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N1		I. 1.8.2018	RW 1305	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
	WLTP	II. 1.9.2019	1305 < RW ≤ 1760	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
		III. 1.9.2019	1760 < RW	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N2				1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
EURO 6d																	
M		1.9.2019	All	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N1		I. 1.8.2018	RW 1305	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
	WLTP+RDE	II. 1.9.2019	1305 < RW ≤ 1760	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
		III. 1.9.2020	1760 < RW	1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}
N2				1.0	0.5	0.1	-	0.068	-	0.06	0.08	-	0.17	0.0045	0.0045	6.0x10^{11}	6.0x10^{11}

2.2. Heavy-duty vehicles

2.2.1. Current limit values of the 2012 AGP

Limit values for Heavy-Duty Vehicles (HDV) are given in tables 2 and 3 of annex VIII of the AGP. They are based on the applicable test procedures:

Table 2: limit values for heavy-duty vehicles: steady-state cycle load-response tests,

Table 3: limit values for heavy-duty vehicles: transient cycle tests.

They are reproduced hereafter.

Table 3: Table 2, annex VIII, current limit values for heavy-duty vehicles steady-state cycle load-response tests

	Application date	*Carbon monoxide (g/kWh)*	*Hydro-carbons (g/kWh)*	*Total hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*	*Smoke (m^{-1})*
B2 ("EURO V")[a]	1.10.2009	1.5	0.46	–	2.0	0.02	0.5
"EURO VI"[b]	31.12.2013	1.5	–	0.13	0.40	0.010	–

[a] Test cycle specified by the European steady-state cycle (ESC) and the European load-response (ELR) tests.
[b] Test cycle specified by the world heavy duty steady state cycle (WHSC).

Table 4: Table 3, annex VIII, current limit values for heavy-duty vehicles transient cycle tests

	*Application date**	*Carbon monoxide (g/kWh)*	*Total hydro-carbons (g/kWh)*	*Non-methane hydrocarbons (g/kWh)*	*Methane[a] (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulates (g/kWh)[b]*
B2 "EURO V"[c]	1.10.2009	4.0	–	0.55	1.1	2.0	0.030
"EURO VI" (CI)[d]	31.12.2013	4.0	0.160	–	–	0.46	0.010
"EURO VI" (PI)[d]	31.12.2013	4.0	–	0.160	0.50	0.46	0.010

Note: PI = Positive ignition, CI = Compression ignition.
* The registration, sale and entry into service of new vehicles that fail to comply with the respective limit values shall be refused as from the dates given in the column.
[a] For natural gas engines only.
[b] Not applicable to gas-fuelled engines at stage B2.
[c] Test cycle specified by the European transient cycle (ETC) test.
[d] Test cycle specified by the world heavy duty transient cycle (WHTC).

Table 2 and 3 of annex VIII of the AGP contain emission limit values up to EURO VI for heavy-duty vehicles under the test cycle specified by the World Heavy Duty Steady State Cycle (WHSC) and the World Heavy Duty Transient Cycle (WHTC). These limit values are based on the European Commission regulation 595/2009/EC of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (EURO VI) [10] and amending Regulation 715/2007/EC and Directive 2007/46/EC and repealing Directives 80/1269/EC, 2005/55/EC and 2005/78/EC.

2.2.2. Proposal of potential updated limit values in tables 2 and 3 of annex VIII

To be in line with the Annex II of the European Commission's regulation 133/2014/EC of 31 January 2014 [11], amending, for the purposes of adapting to technical progress as regards of emission limits, Directive 2007/46/EC of the European Parliament and of the Council, Regulation (EU) 595/2009 of the European Parliament and of the Council and Commission Regulation (EU) 582/2011, limit values regarding the Particles Number (PN) should be added to Table 2 and Table 3.

Thus, the following limit values for Particles Number (PN) are proposed to be added:

8.0×10^{11} (steady-state cycle load-response tests)

6.0×10^{11} (transient cycle tests)

Update Index 1.

Table 5: Table 2, annex VIII, proposal for potential update of limit values for heavy-duty vehicles steady-state cycle load-response tests

	Application date	*Carbon monoxide (g/kWh)*	*Hydro-carbons (g/kWh)*	*Total hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*	*Smoke (m^{-1})*	*Particles Number PN (#/kWh)*
B2 ("EURO V")[a]	1.10.2009	1.5	0.46	–	2.0	0.02	0.5	
"EURO VI"[b]	31.12.2013	1.5	–	0.13	0.40	0.010	–	8×10^{11}

[a] Test cycle specified by the European steady-state cycle (ESC) and the European load-response (ELR) tests.
[b] Test cycle specified by the world heavy duty steady state cycle (WHSC).

Table 6: Table 3, annex VIII, proposal for update of limit values for heavy-duty vehicles transient cycle tests

	*Application date**	*Carbon monoxide (g/kWh)*	*Total hydro-carbons (g/kWh)*	*Non-methane hydrocarbons (g/kWh)*	*Methane[a] (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulates (g/kWh)[b]*	*Particles Number PN (#/kWh*
B2 "EURO V"[c]	1.10.2009	4.0	–	0.55	1.1	2.0	0.030	
"EURO VI" (CI)[d]	31.12.2013	4.0	0.160	–	–	0.46	0.010	8×10^{11}
"EURO VI" (PI)[d]	31.12.2013	4.0	–	0.160	0.50	0.46	0.010	8×10^{11}

Note: PI = Positive ignition, CI = Compression ignition.
* The registration, sale and entry into service of new vehicles that fail to comply with the respective limit values shall be refused as from the dates given in the column.
[a] For natural gas engines only.
[b] Not applicable to gas-fuelled engines at stage B2.
[c] Test cycle specified by the European transient cycle (ETC) test.
[d] Test cycle specified by the world heavy duty transient cycle (WHTC).

2.3. Euro 7/VII emission limit scenarios

While the end of internal combustion engines is scheduled by 2035 in Europe [11], a new standard is scheduled to be introduced at the EU level to tighten the pollutant emission limits of new vehicles. The future Euro 7/VII standard, which should come into effect in 2025, will be even more stringent, requiring the anticipation of its requirement during the design and validation phases of future vehicles. It should be characterized by:

- a harmonization between gasoline and diesel engines in terms of gaseous pollutant emissions,
- a reduction in emissions compared to last Euro 6 standards,
- a reduction in the size of the particles taken into account (from 23 nm to 10 nm) for the calculation of the number of particles emitted,
- a wider range of driving condition profiles (driving profile, road profile, temperature, altitude, etc.),
- broader testing in real driving conditions.

The Euro 7/VII standards, currently being drafted, divides countries and parliamentarians. As these standards have not yet come into force, they are not taken into account for potential update of the annex VIII of the Gothenburg Protocol. Nevertheless, we will present here the planned limit values, and the argumentation and scientific studies pro and cons of this new standard.

2.3.1. CLOVE – Consortium for Ultra-Low Vehicles Emissions

The Consortium for Ultra-Low Vehicle Emissions (CLOVE) was created to support the European Commission regarding mobile sources emissions analysis and reduction pathway [12]. This consortium is composed of European academic, research and business experts: LAT/Auth, Emisia, FEV, Ricardo, TNO, TUGraz and VTT.

- LAT/Auth is the Laboratory of Applied Thermodynamics of the University of Thessaloniki with extensive experience in conducting emission testing.
- Emisia is working closely with LAT/Auth, it is a spin-off company expert in transport emissions.
- FEV is a large independent engineering service suppliers in the automotive industry with headquarters in Germany.
- Ricardo is a global strategic engineering and environmental consultancy specialised in the transport, energy and scarce resources sectors.
- TNO is an independent research organization from the Netherlands which has been testing vehicles for air quality, technology and policy assessments for many decades.
- The Institute of Internal Combustion Engines and Thermodynamics of the Technical University TUGraz (Austria) is expert in mobile source emissions.
- VTT is the Technical Research Centre of Finland, with a research team in the field of engine and vehicle emissions.

In 2021, the CLOVE consortium (Samaras et al., 2020 [13]) presented proposals to the Advisory Group on Vehicle Emission Standards[1] (AGVES) to reform vehicle emission standards (Euro 7/VII). New Euro 7/VII proposals by CLOVE are limit values lower than current limits, compatible with existing available techniques (Best Available Techniques).

Lower emission limits are presented as two potential emission limit scenarios 1 and 2. Scenario 2 is the most ambitious proposal requiring the largest decrease in tailpipe emissions of key pollutants. These emission limit values are technology- and fuel-neutral limits. It is the first standard in Europe with the same limit values for diesel and gasoline vehicles (Figure 4).

[1] A stake holder group chaired by DG GROW (Directorate General for the Internal Market, Industry, Entrepreneurship and SMEs) of the European Commission

CLOVE aims at limiting all pollutants – especially NOx, but also CO, PM and PN, NH_3, CH_4, N_2O and NO_2. The new emission limit values should be applicable in all driving scenarios, including driving immediately after a cold start, in stop-start traffic, hard acceleration, driving uphill and when towing a trailer.

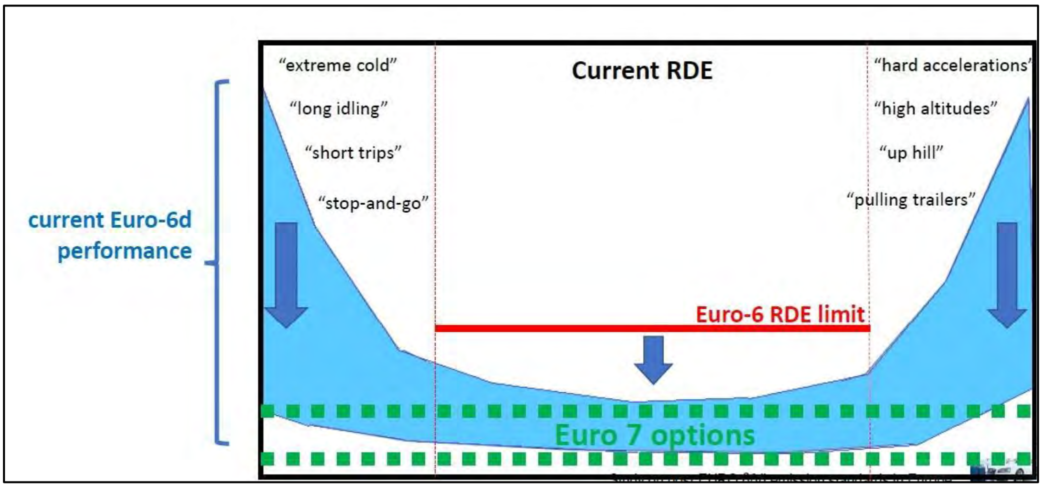


Figure 4: CLOVE proposal for emission limit setting [13]

Euro 7 vehicles must remain compliant with the stricter emissions standards for 240,000 km (or 15 years), then, higher emission limits will be applied until end of life. In addition, the temperature range for the vehicles testing would be extended from [-7°C; +35°C] to [-10°C; +40°C].

CLOVE's proposed emission limit values for light vehicles

The CLOVE's Petrol Passenger Cars Euro 7 limit values proposed in the two scenarios represent a large decrease of air pollutant emissions. CLOVE's Euro 7 emission limit scenarios for Light-duty vehicles in mg/km, #/km are presented in Table 7.

The Euro 6 norm sets NOx standards at 60 mg/km for gasoline vehicles and 80 mg/km for diesel vehicles. With the Euro 7 standard, the NOx emission standards should be set between 10 mg/km (Scenario 2) and 30 mg/km (Scenario 1).

CLOVE's proposed standards concerned only M and N1 class I vehicles. No proposal is given for heavier N1 vehicles (class II & III).

Table 7: CLOVE's Euro 7 emission limit scenarios for LDV in mg/km, #/km [15][13]

	Norm	NOx	PM	CO	CH_4	N_2O	NH_3	SPN_{10}
		mg/km						#/km
REF	EURO 6	60/80 (PI/CI)		1000/500 (PI/CI)	-	-	-	$6x10^{11}$ (SPN_{23})
CLOVE Euro 7	Scenario 1 M & N1 class 1	30	2	400	10	10	10	$1x10^{11}$
	Scenario 2 M & N1 class 1	20	2	400	10	10	10	$1x10^{11}$
	Scenario 1 N2	45	2	600	10	10	10	$1x10^{11}$
	Scenario 2 N2	30	2	600	10	10	10	$1x10^{11}$

The size of particles taken into account in the calculation of the number of particles is reduced from 23 nm to 10 nm. In addition, the standard for particle number is strengthened from $6x10^{11}$ with the Euro 6 norm, to $1x10^{11}$ with Euro 7-Scenario 1 and $6x10^{10}$ with Euro 7-scenario 2.

CLOVE also proposed to introduce emission limits for unregulated pollutants: ammonia (NH_3), N_2O, CH_4 and formaldehyde.

To reach these very low emission limit values, especially for NOx, technologies to tackle emissions are given by CLOVE. As an example, heating systems with pre-heating functionality and secondary air injection can be used to reduce cold start and short trips emissions. Regarding particles number, CLOVE recommends high Diesel particles filter filtration efficiency during and immediately after regeneration, in conjunction with regeneration frequency control.

CLOVE's proposed emission limit values for heavy-duty vehicles

CLOVE's EURO VII emission limit values with the scenarios 1 and 2 for heavy-duty vehicles are given in Table 8 in mg/kWh and #/kWh.

Table 8: CLOVE's Euro VII emission limit values with scenarios 1 and 2 for HDV in mg/kWh, #//kWh [16][15][13]

[# or mg/kWh]	Scenario for different technologies	NOx	SPN_{10}	PM	CO	NH3	N_2O	CH_4
CLOVE EURO VII	HD2 (opt. + ccSCR diesel)[1]	150	$2x10^{11}$	10	1250	65	140	30
	HD3 (as HD2 + pre-heat)[2]	100	$2x10^{11}$	10	600	65	140	30
	HL2 (LNG as HD2)[3]	150	$2x10^{11}$	10	2700	25	200	500
	HC2 (opt. CNG SI)[4]	150	$2x10^{11}$	10	2300	70	260	180

(1) HD2: optimised diesel with cc SCR (2) HD3: optimised diesel with cc SCR and pre-heating with diesel burner (3) HL2: Optimised LNG HPDI (High-Pressure Direct Injection) engine (4) HC2: Optimised SI CNG engine.

The emission standards are also significantly reduced with the EURO VII norm for HDV. NOx standards are lowered from 460 mg/kWh with EURO VI to 100 - 150 mg/kWh with EURO VII-Scenario. The number of particles is calculated for particles with a diameter above 10 nm instead of 23 nm. CLOVE also proposes to introduce emission limits for unregulated pollutants: NH_3, N_2O and CH_4.

2.3.2. Ongoing debate regarding Euro 7/VII ELVs

ACEA's proposal

The European Automobile Manufacturers' Association, or ACEA, unites 16 major Europe-based car, truck, van and bus makers. ACEA acts as one with common industry positions of its members.

In its position paper (ACEA, 2020 - [17]), ACEA considered that "The proposals presented by the CLOVE consortium in AGVES are, to the greatest extent, technically infeasible for vehicles with combustion engines". In 2021 paper (ACEA, 2021 - [18]), ACEA proposes an alternative to the CLOVE standards.

New dates of application are proposed (but they stay close to the 2025 CLOVE proposal):

- 1 September 2025 for new types, and
- 1 September 2026 for all new registrations.
- The dates for N1 class II and class III light-commercial vehicles (vans) will apply one year later, retaining the same formulation of Euro 6.

ACEA's Euro 7 standards for cars and light duty vehicles are given in the .

Table 9 and are compared with Euro 6 standards and with Euro 7 CLOVE's standards.

Table 9: Comparison between CLOVE and ACEA Euro 7 emission limits scenarios for LDV in mg/km, #/km

	Norm	NOx	SPN_{10}	CO	CH_4	N_2O	NH_3
REF	Euro 6	60/80 (PI/CI)	$6x10^{11}$ (SPN_{23})	1000/500 (PI/CI)	-	-	-
CLOVE	Scenario 1 M & N1 class I	30	$1x10^{11}$	300	10	10	10
	Scenario 2 M & N1 class I	10	$6x10^{10}$	100	5	5	10
ACEA	M & N1 class I	35	$6x10^{11}$	500	-	-	40
	N1 class II	46	$6x10^{11}$	630	-	-	53
	N1 class III	55	$6x10^{11}$	740	-	-	61

The ACEA proposal is between the current Euro 6 standard and the CLOVE Euro 7 standard for NOx, with a standard of 35 mg/km for both diesel and gasoline vehicles. The particle number standard remains the same as the Euro 6 standard but takes into account particles with a diameter higher than 10 nm instead of 23 nm.

ICCT position on CLOVE's standards

The International Council of Clean Transportation (ICCT) is an independent non-profit organization found in 2001. The ICCT's goal is to improve the environmental performance and energy efficiency of road, marine, and air transportation, in order to benefit public health and mitigate climate change. It provides independent research, technical and scientific analysis to environmental regulators.

ICCT's position is opposed to that of ACEA, since, according to ICCT, the standards proposed by CLOVE could be even more stringent. In its comments submitted to the European Commission on the proposal for Euro 7/VII pollutant emission standards (ICCT, 2021 - [19]), ICCT supports the ambition and gives arguments on the feasibility and benefits of stringent pollutant emission standards.

Light-duty vehicles: Real-driving emissions tests

Regarding the technological feasibility of stricter limits than those proposed by CLOVE, the ICCT mentioned that "even the most stringent CLOVE-scenario-2 (NOx limit of 20 mg/km) would lead to a higher limit than in the US for NOx and Non-Methanic Organic Gases[2] (NMOG) combined (18.6 mg/km)" (Figure 5).

[2] Equivalent to NMVOC

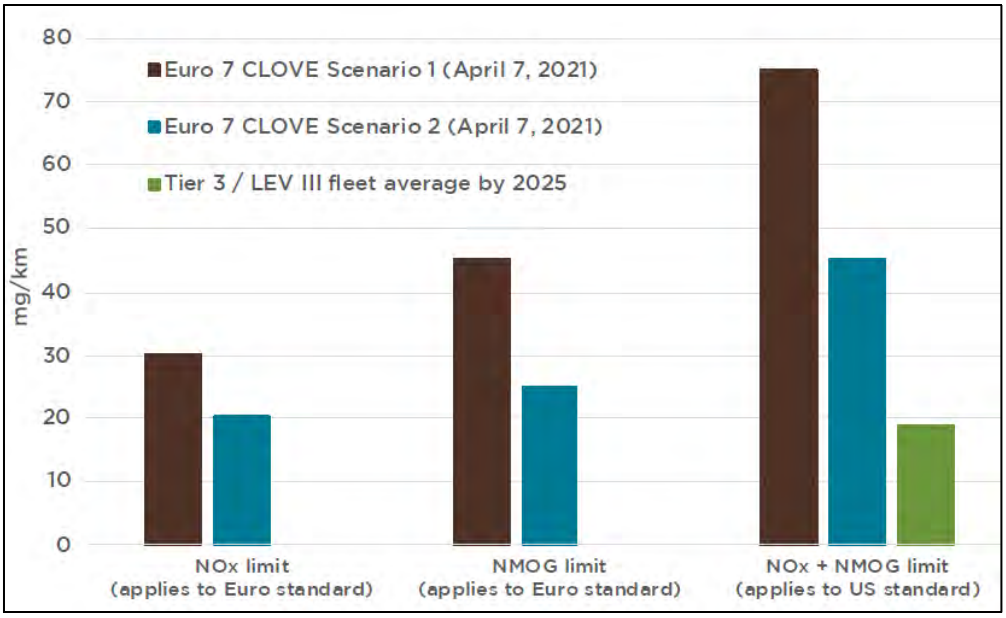


Figure 5: Comparison between CLOVE emission standards and US emission standards Source ICCT, 2021 [19]

Real Driving Emission tests were performed by ICCT for three Euro 6d light vehicles, a gasoline mild-hybrid, a gasoline plug-in hybrid, and a diesel vehicle. An AVL M.O.V.E. PEMS [20][19] was used to perform the tests on two different routes. Normal and more dynamic driving styles were applied.

Figure 6 illustrates the emission of CO, NOx and number of particles for the three types of vehicles, two of which are gasoline vehicles and the last one, a diesel vehicle. Modern diesel and gasoline engines are almost fit to meet the CLOVE-scenario-1 limits for CO and NOx and therefore a more ambitious target seems reasonable to ICCT. Emissions with the two CLOVE scenarios and with the ICCT proposal are compared with Euro 6d emissions for different types of driving style, payload and coolant temperatures.

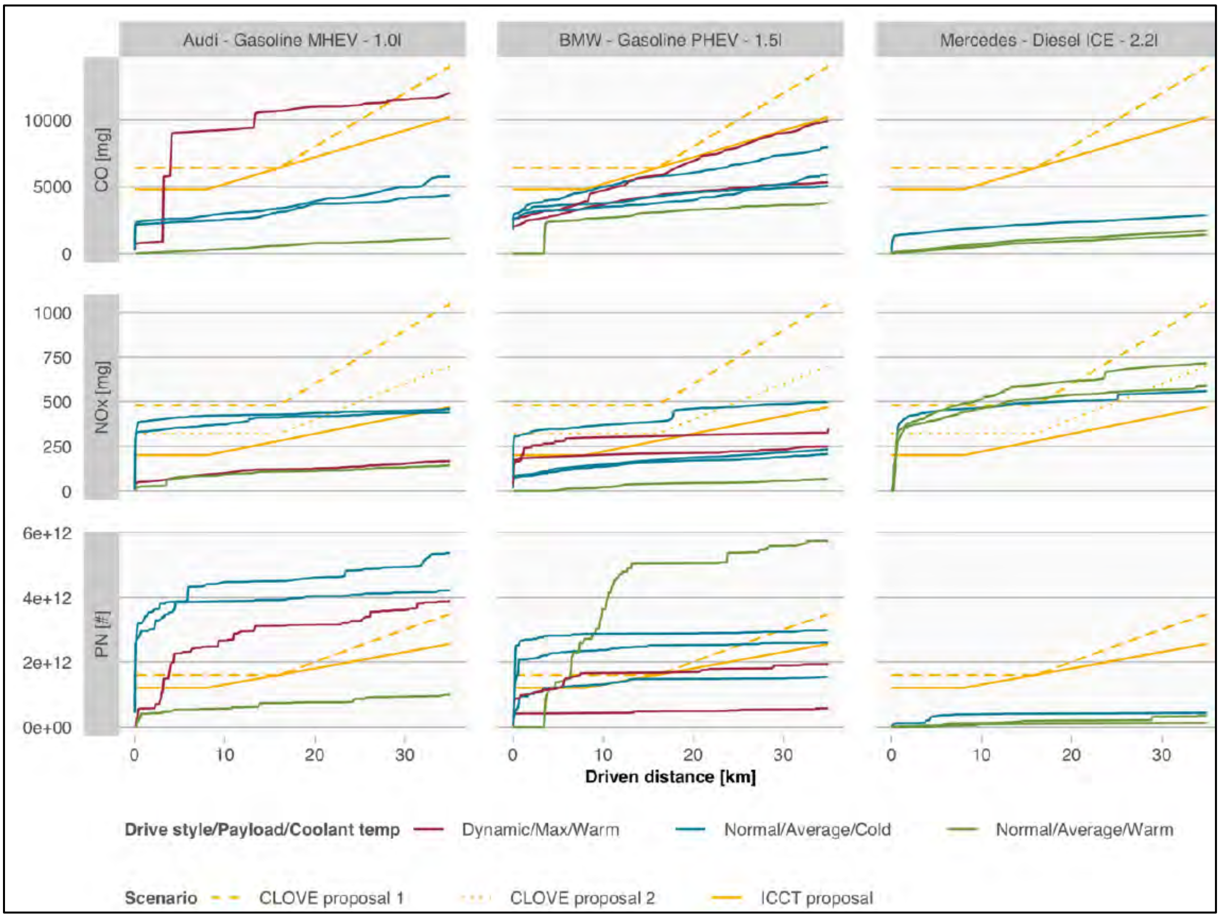


Figure 6: Cumulative emissions measured with PEMS during on-road tests on two different routes for 3 different Euro 6d-ISC- FCM vehicles (The yellow lines present three different emission limit scenarios with an emission budget for the first cycle phase. The graphs show a zoom in for 0 - 35 km driven distance). Source ICCT, 2021 [19]

The majority of the emissions is generated over the first few kilometers and therefore a shorter range for the emission budget than 16 km seems justified.

ICCT highlights the need to focus on urban emissions to achieve the European *Zero pollution ambition*. Thus, efforts could be done to reduce cold-start emissions. In fact, cold-start conditions are an important factor affecting vehicle emissions. During cold start, emissions are significantly higher than after the engine and especially the exhaust aftertreatment system have warmed up to its normal operating temperature. Most of the emissions is generated over the first few kilometers and therefore a shorter range for the emission budget than 16 km seems justified.

ICCT suggests reducing the trip distance from 16 km to 8 km: "The current CLOVE proposal suggests an emission budget based on 16 km, when typical urban trips in European cities can be significantly shorter. To ensure Euro 7 delivers low emission in conditions typical of European cities, ICCT suggests shortening the emission budget to a maximum distance of 8 km, adjusting the budget limit accordingly, and recognizing the disproportionate impact of cold-start emissions in such operations".

Light-duty vehicles: Lab tests

Similarly to the on-road observations, three Euro 6d light vehicles were tested in a laboratory on a chassis dyno. The vehicles were tested on several driving cycles: WLTC, at -5, 23 and

35°C and three other cycles, a Common Artemis 150 (CADC150)[3], 3 consecutive US06 and 3 consecutive New York City Cycles NYCC[4]. The Audi performed in addition a CADC150 and 3x NYCC at -15 °C.

The results for all chassis dyno tests performed with Euro 6d vehicles are very close to the CLOVE-scenario-1 limits for CO and NOx (Figure 7). Therefore, ICCT considers that "more ambitious limits are justifiable to pull new emission control technologies to the market that goes beyond the current technology adoption".

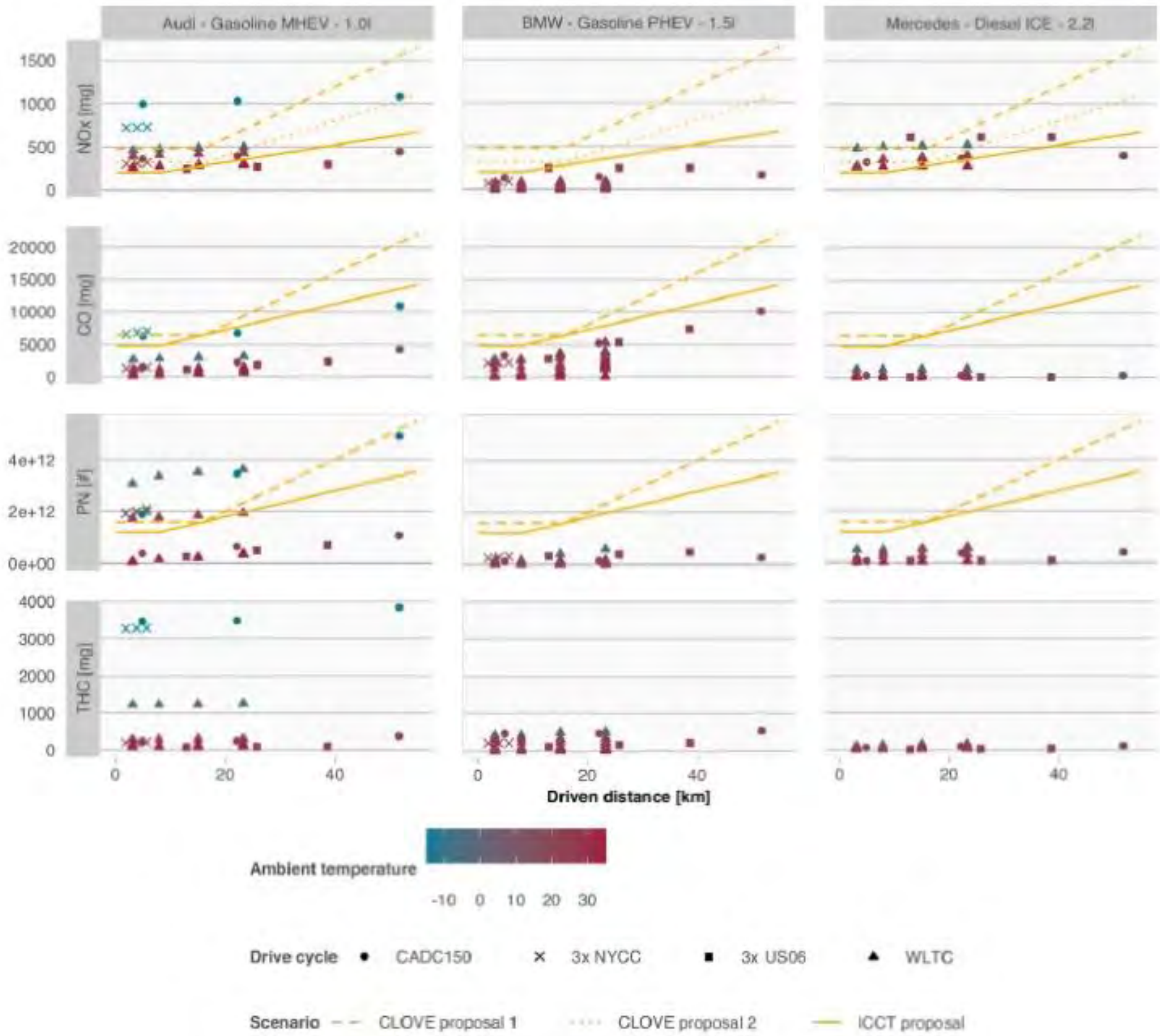


Figure 7: Emission test results of three Euro-6d-ISC-FCM vehicles on chassis dyno. Source ICCT, 2021 [19]

Unregulated pollutants such as CH_4, NH_3 and N_2O were also measured during the chassis dyno tests and compared with the Euro 7 standards (Figure 8). For ICCT, "the scenario 1 proposed

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[3] The Common Artemis Driving Cycles (CADC) are chassis dynamometer procedures developed within the European Artemis (Assessment and Reliability of Transport Emission Models and Inventory Systems) project, based on statistical analysis of a large database of European real world driving patterns [2321]. The cycles include three driving schedules: Urban, Rural road and Motorway. The Motorway cycle has two variants with maximum speeds of 130 and 150 km/h.

[4] The US EPA NYCC test has been developed for chassis dynamometer testing of light-duty vehicles. The test simulates low speed urban driving with frequent stops.

by the CLOVE consortium is not necessarily an ambitious scenario for Euro 7 on unregulated pollutants" [19].

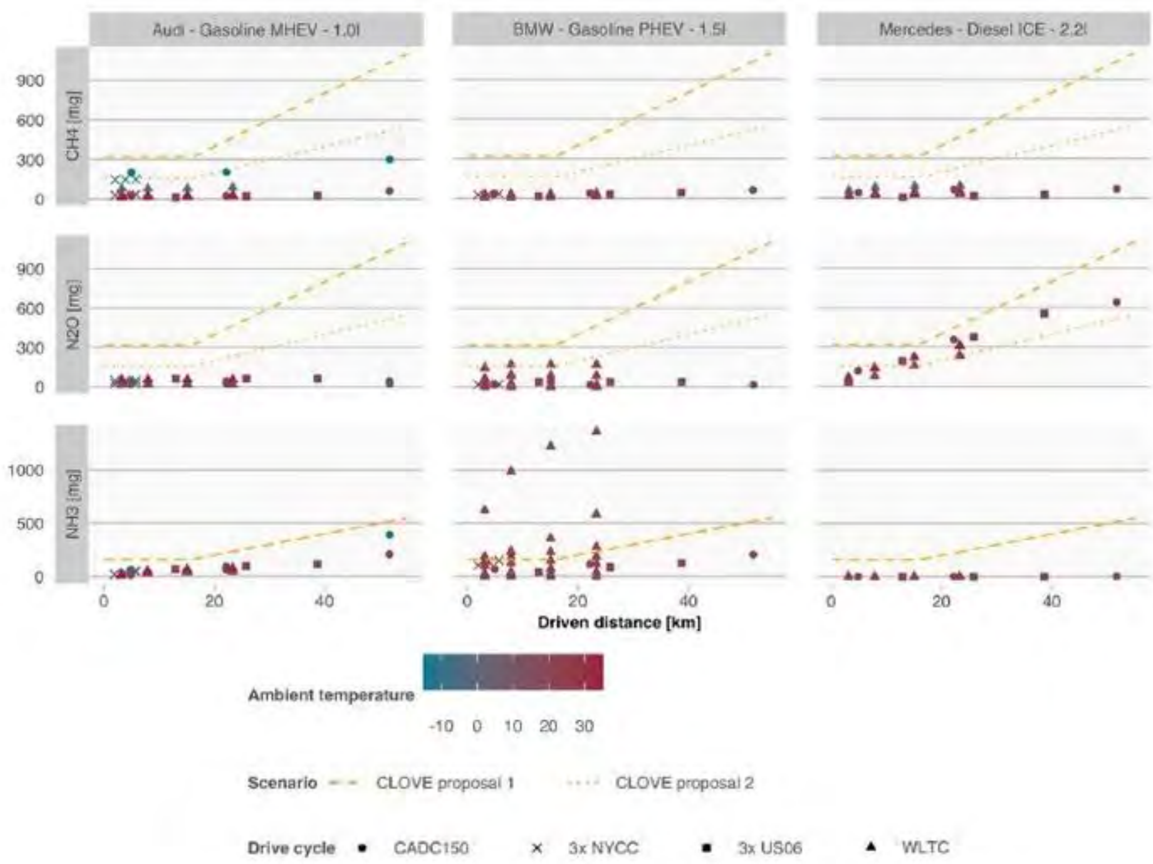

Figure 8: Emission test result for not or only indirectly regulated polluants under Euro 6 standards. Source ICCT, 2021 [19]

Heavy Duty Vehicles

Regarding High Duty Vehicles, the limits in hot operations set by CLOVE for unregulated pollutants, NH_3 and N_2O, are considered as too high by ICCT which consider they should be further reduced. Thus, ICCT urges the Commission to set more stringent limits for these two pollutants. In fact, ICCT considered that future technology should allow to settle stringent limits for emissions from HDV.

ICCT relies on a recent demonstration project by AECC [21] that shows "that the integration of close-coupled catalysts combined with the advanced controller have achieved high NO_x conversion efficiencies with a minimum NH_3 slip and results show good control of the N_2O under the conditions tested" to encourage CLOVE proposal since measured values are below.

European Commission's proposal

On November 10th, 2022, the European Commission published a regulatory proposal [58] for discussion. This regulation concerns all M1, M2, M3, N1, N2 and N3 vehicles. It proposes emission limit values for tailpipe exhaust emissions and evaporation from petrol vehicles, as well as for brake abrasion from light vehicles and tyre abrasion rate limits.

If adopted, this proposal will become a new regulation applicable from July, 1rst 2025 for light vehicles (M1 and N1) and from July, 1rst 2027 for heavy vehicles (M2, M3, N2 and N3).

Table 10 provides the emission limit values per pollutant for light vehicles. These limit values are the same whatever the fuel. They correspond to the minimum Euro 6 limit values for each petrol or diesel fuel. Limit values for NMVOCs and NH3 have been added, compared to Euro 6.

Table 10: Euro 7 exhaust emission limits for M1 and N1 vehicles with internal combustion engine

Pollutant emissions	**M_1, N_1 vehicles**	**Only for N_1 vehicles with power to mass ratio[1] less than 35 kW/t**	**Emission budget for all trips less than 10 km for M_1, N_1 vehicles**	**Emission budget for all trips less than 10 km only for N_1 vehicles with power to mass ratio less than 35 kW/t**
	per km	*per km*	*per trip*	*per trip*
NO_x in mg	60	75	600	750
PM in mg	4.5	4.5	45	45
PN_{10} in #	6×10^{11}	6×10^{11}	6×10^{12}	6×10^{12}
CO in mg	500	630	5000	6300
THC in mg	100	130	1000	1300
NMHC in mg	68	90	680	900
NH_3 in mg	20	20	200	200

[1] Measured in accordance with paragraph 5.3.2. of UN/ECE Regulation No 85 in the case of ICEVs and PEVs, or, in all other cases, measured in accordance with one of the test procedures laid down in paragraph 6 of UN Global Technical Regulation 21

Table 11 provides the emission limit values per pollutant for heavy vehicles. The limit values for the stationary cycle (WHSC) have been replaced by limit values for cold starts for the transient cycle (WHTC). Limit values for N_2O, CH_4 and HCHO have been added, compared with EURO VI.

Table 11: EURO VII exhaust emission limits for M2, M3, N2 and N3 vehicles with internal combustion engine and internal combustion engine used in those vehicles

Pollutant emissions	**Cold emissions[2]**	**Hot emissions[3]**	**Emission budget for all trips less than 3*WHTC long**	**Optional idle emission limits[4]**
	per kWh	*per kWh*	*per kWh*	*per hour*
NO_x in mg	350	90	150	5000
PM in mg	12	8	10	
PN_{10} in #	$5x10^{11}$	$2x10^{11}$	$3x10^{11}$	
CO in mg	3500	200	2700	
NMOG in mg	200	50	75	
NH_3 in mg	65	65	70	
CH_4 in mg	500	350	500	
N_2O in mg	160	100	140	
HCHO in mg	30	30		

[2] Cold emissions refers to the 100th percentile of moving windows (MW) of 1 WHTC for vehicles, or $WHTC_{cold}$ for engines
[3] Hot emission refers to the 90th percentile of moving windows (MW) of 1 WHTC for vehicles or $WHTC_{hot}$ for engines
[4] Applicable only if a system is not present that automatically shuts down the engine after 300 seconds of continuous idling operation (once the vehicle is stopped and brakes applied)

Table 12 provides limit values for NMVOC emissions by evaporation from light petrol vehicles.

Table 12: Euro 7 evaporative emission limits for M1 and N1 gasoline vehicles up to 2650 kg

Pollutant emissions	M1, N1 with maximum mass up to 2650 kg	N1 with maximum mass equal or more than 2650 kg
Evaporative emissions (in hot soak + 2 day diurnal test)	0.50 g at worst day + hot soak	0.70 g at worst day + hot soak
Refuelling emissions	0.05 g/L of fuel	0.05 g/L of fuel

Proposed Euro 7 standard introduces the possibility of assigning emission limit values for brake and tyre abrasion on light and heavy vehicles. In the proposal, only PM_{10} emissions from brake abrasion on light vehicles are quantified. For brakes, 2 dates are proposed with different PM_{10} limit values.

Table 13: Euro 7 brake PM_{10} emission limits for M1, M2, M3, N1, N2 and N3 vehicles until 31/12/2034

Emission limits in mg/km per vehicle	M_1, N_1 vehicles	M_2, M_3 vehicles	N_2, N_3 vehicles
Brake particle emissions (PM_{10})	7		
Brake particle emissions (PN)			

Table 14: Euro 7 brake PM_{10} emission limits for M1, M2, M3, N1, N2 and N3 vehicles from 01/01/2035

Emission limits in mg/km per vehicle	M_1, N_1 vehicles	M_2, M_3 vehicles	N_2, N_3 vehicles
Brake particle emissions (PM_{10})	3		
Brake particle emissions (PN)			

Table 15: Euro 7 tyre PM_{10} abrasion rate limits

Tyre mass lost in g/1000 km	C1 tyres	C2 tyres	C3 tyres
Normal tyres			
Snow tyres			
Special use tyres			

Remark: Euro 7 limit values which could be finally adopted at the EU level, could potentially be considered in an updated version of Annex VIII.

2.4. Compression-ignition (CI) and spark-ignition (SI) non-road vehicles and machines

2.4.1. Current limit values for agricultural and forestry tractors and other non-road vehicle/ machine engines listed in tables 4 to 6 of annex VIII

The AGP annex VIII considers both Stage IIIB and Stage IV for diesel engines for non-road mobile machines (NRMM), agricultural and forestry tractors. These standards are based on the Directive 97/68/EC that has been updated to Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery [22]. This last version is amending Regulations (EU) 1024/2012 and (EU) 167/2013, and amending and repealing Directive 97/68/EC.

Thus, current tables 4 to 6 of annex VIII are proposed to be updated according to the regulation (EU) 2016/1628 [22]:

- Table 4: Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (Stage IIIB)

- Table 5: Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (Stage IV)
- Table 6: Limit values for spark-ignition engines for non-road mobile machines

Tables 16 to 18 provide the current limit values for these vehicle categories.

Table 16: Table 4, annex VIII, curent limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (Stage IIIB)

Net power (P) (kW)	*Application date[*]*	*Carbon monoxide (g/kWh)*	*Hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*
130 ≤ P ≤ 560	31.12.2010	3.5	0.19	2.0	0.025
75 ≤ P < 130	31.12.2011	5.0	0.19	3.3	0.025
56 ≤ P < 75	31.12.2011	5.0	0.19	3.3	0.025
37 ≤ P < 56	31.12.2012	5.0	4.7[a]	4.7[a]	0.025

[*] With effect from the given date and with the exception of machinery and engines intended for export to countries that are not parties to the present Protocol, Parties shall permit the registration, where applicable and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.

[a] *Editor's note*: This figure represents the sum of hydrocarbons and nitrogen oxides and was reflected in the final approved text by a single figure in a merged cell in the table. As this text does not include tables with dividing lines, the figure is repeated in each column for clarity.

Table 17: Table 5, annex VIII, current limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (Stage IV)

Net power (P) (kW)	*Application date**	*Carbon monoxide (g/kWh)*	*Hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*
130 ≤ P ≤ 560	31.12.2013	3.5	0.19	0.4	0.025
56 ≤ P < 130	31.12.2014	5.0	0.19	0.4	0.025

[*] With effect from the given date and with the exception of machinery and engines intended for export to countries that are not parties to the present Protocol, Parties shall permit the registration, where applicable and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.

Table 18: Table 6, annex VIII, limit values for spark-ignition engines for non-road mobile machines

	Hand-held engines	
Displacement (cm^3)	*Carbon monoxide (g/kWh)*	*Sum of hydrocarbons and oxides of nitrogen (g/kWh)[a]*
Disp < 20	805	50
20 ≤ disp. < 50	805	50
Disp ≥ 50	603	72
	Non-hand-held engines	
Displacement(cm^3)	*Carbon monoxide (g/kWh)*	*Sum of hydrocarbons and oxides of nitrogen (g/kWh)*
Disp < 66	610	50
66 ≤ disp. < 100	610	40
100 ≤ disp. < 225	610	16.1
Disp ≥ 225	610	12.1

- *Note:* With the exception of machinery and engines intended for export to countries that are not parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.
- [a] The NO_X emissions for all engine classes must not exceed 10 g/kWh.

2.4.2. Principles of regulation (EU) 2016/1628 and rationale for updating current limit values

Regulation (EU) 2016/1628 [22] on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery provides limit values up to Stage V. In addition, this regulation addresses health-damaging evidence of ultrafine particles by setting a standard for the number of particles (PN#/kWh).

Given that Stage IIIB is already an obsolete standard, and since the Commission Regulation 2016/1628 does not include any updates emission limit values for Stage IIIB, it is therefore proposed to delete the current Table 4 [Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors - Stage IIIB] and to replace it by Table 19 and Table 20 with Stage V standards.

With respect to the current Table 5 of AGP [Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors - Stage IV], it is proposed to update it to comply with the most recent standard, i.e. Stage V, instead of Stage IV. Such a change calls for the following updates to be in line with Annex II of the Commission Regulation 2016/1628:

- Net power (P) (kW) categories $P \leq 560$
  - Introduction of a standard regarding particles number « PN#/kWh ».
  - Stringent limit values for particles.
- Addition of $P > 560$ Net power (P) (kW) category and corresponding limit values.

2.4.3. Proposals of potential updates of limit values for tables 4 to 6 of annex VIII

The updated emission limit values, from Regulation (EU) 2016/1628, are presented in the following tables. The emission limits are applicable for all the new Non-Road Mobiles Machines as indicated in the timetable for the application of the Regulation (EU) 2016/1628 in respect of EU type-approvals and placing on the market in Table III, Annex III.

Update index 1.

Table 19: Table 4, annex VIII, proposal of potential updates: Stage V emission limits for engine category NRMM having a reference power of less than 560 kW

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NO_x	PM mass	PN	A
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	NRE-v-1 NRE-c-1	0 < P < 8	CI	8,00	($HC + NO_x \leq 7{,}50$)		0,40 (1)	—	1,10
Stage V	NRE-v-2 NRE-c-2	8 ≤ P < 19	CI	6,60	($HC + NO_x \leq 7{,}50$)		0,40	—	1,10
Stage V	NRE-v-3 NRE-c-3	19 ≤ P < 37	CI	5,00	($HC + NO_x \leq 4{,}70$)		0,015	1×10^{12}	1,10
Stage V	NRE-v-4 NRE-c-4	37 ≤ P < 56	CI	5,00	($HC + NO_x \leq 4{,}70$)		0,015	1×10^{12}	1,10
Stage V	NRE-v-5 NRE-c-5	56 ≤ P < 130	all	5,00	0,19	0,40	0,015	1×10^{12}	1,10
Stage V	NRE-v-6 NRE-c-6	130 ≤ P ≤ 560	all	3,50	0,19	0,40	0,015	1×10^{12}	1,10
Stage V	NRE-v-7 NRE-c-7	P > 560	all	3,50	0,19	3,50	0,045	—	6,00

(1) 0,60 for hand-startable, air-cooled direct injection engines.

Table 20: Table 5, annex VIII, proposal of potential updates: Stage V emission limits for engine category NRMM having a reference power of more than 560 kW

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NO_x	PM mass	PN	A
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	NRG-v-1 NRG-c-1	P > 560	all	3,50	0,19	0,67	0,035	—	6,00

Furthermore, Table 6 [Limit values for spark-ignition engines for non-road mobile machines] is proposed to be replaced by tables indicated in Table 21 and Table 22 to comply with European Regulation (EU) 2016/1628.

Table 21: Table 6, annex VIII, proposal of potential update: Stage V emission limits for hand-held Spark Ignition engines having a reference power of less than 19 kW

Emission stage	Engine sub-category	Power range	Ignition type	CO	$HC + NO_x$
		kW		g/kWh	g/kWh
Stage V	NRSh-v-1a	0 < P < 19	SI	805	50
Stage V	NRSh-v-1b			603	72

Table 22: Table 6, annex VIII, proposal of potential update: Stage V emission limits for non-hand-held Spark Ignition engines having a reference power of less than 56 kW

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC + NO_x
		kW		g/kWh	g/kWh
Stage V	NRS-vr-1a NRS-vi-1a	0 < P < 19	SI	610	10
Stage V	NRS-vr-1b NRS-vi-1b			610	8
Stage V	NRS-v-2a	19 ≤ P ≤ 30		610	8
Stage V	NRS-v-2b NRS-v-3	19 ≤ P < 56		4,40 (*)	2,70 (*)

(*) Optionally, as an alternative, any combination of values satisfying the equation $(HC + NO_x) \times CO^{0.784} \leq 8{,}57$ as well as the following conditions: $CO \leq 20{,}6$ g/kWh and $(HC + NO_x) \leq 2{,}7$ g/kWh

2.5. Locomotives and railcars

2.5.1. Current limit values for locomotive and railcars listed in tables 7 and 8 of annex VIII

Limit values for locomotive and railways are provided in the Table 7 and 8 of annex VIII. An error has been detected in the annex VIII, tables corresponding to Railcars (RLR) and Locomotives (RLL) were inverted.

Table 23: Table 7, annex VIII, current limit values for engines used for propulsion of locomotives

Net power (P) (kW)	*Carbon monoxide (g/kWh)*	*Hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*
130 < P	3.5	0.19	2.0	0.025

Note: With the exception of machinery and engines intended for export to countries that are not Parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.

Table 24: Table 8, annex VIII, current limit values for engines used for propulsion of railcars

Net power (P) (kW)	*Carbon monoxide (g/kWh)*	*Sum of hydrocarbons and oxides of nitrogen (g/kWh)*	*Particulate matter (g/kWh)*
130 < P	3.5	4.0	0.025

2.5.2. Proposal of potential update of limit values in tables 7 and 8

The limit values are proposed to be updated according to Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) 1024/2012 and (EU) 167/2013, and amending and repealing Directive 97/68/EC [22].

In the Regulation (EU) 2016/1628, there is no change in the limit values for locomotives compared to the limit values in table 7. However, for railcars, updates are proposed: the limit value for particulate matter is lowered from 0.025 to 0.015 and a limit value for particles in number is added.

Proposal of update of limit values for locomotives (RLL) and Railcars (RLR) are presented in Table 25 and Table 26.

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Table 25: Table 7, annex VIII, proposal of potential update: Stage V emission limits for engine category RLL (Locomotives)

Net power (P) (kW)	*Emission Stage*	*Carbon monoxide (g/kWh)*	*Sum of hydrocarbons and oxides of nitrogen (g/kWh)*	*Particulate matter (g/kWh)*
P>0	Stage V	3.5	4.0	0.025

Table 26: Table 8, annex VIII, proposal of potential update : Stage V emission limits for engine category RLR (Railcars)

Net power (P) (kW)	*Emission Stage*	*Carbon monoxide (g/kWh)*	*Hydrocarbons (g/kWh)*	*Nitrogen oxides (g/kWh)*	*Particulate matter (g/kWh)*	*Particles Number PN #/kWh*
P > 0	Stage V	3.50	0.19	2.00	0.015	1×10^{12}

2.6. Inland waterway vessels

2.6.1. Current limit values for inland waterway vessels listed in table 9, annex VIII

Table 9, annex VIII includes only limit values up to Stage III A, which is an obsolete EU regulation. Also, only emission limit values for engines for propulsion of inland waterways vessels are displayed, namely IWA (auxiliary engines) table is missing.

Limit values for inland waterway vessels provided in Table 9, annex VIII, are as in the following:

Table 27: Table 9, annex VIII, current limit values for propulsion of inland waterways vessels

Displacement (litres per cylinder/kW)	*Carbon monoxide (g/kWh)*	*Sum of hydrocarbons and oxides of nitrogen (g/kWh)*	*Particulate matter (g/kWh)*
Disp. < 0.9 Power ≥ 37 kW	5.0	7.5	0.4
0.9 ≤ disp. < 1.2	5.0	7.2	0.3
1.2 ≤ disp. < 2.5	5.0	7.2	0.2
2.5 ≤ disp. < 5.0	5.0	7.2	0.2
5.0 ≤ disp. < 15	5.0	7.8	0.27
15 ≤ disp. < 20 Power < 3300 kW	5.0	8.7	0.5
15 ≤ disp. < 20 Power > 3300 kW	5.0	9.8	0.5
20 ≤ disp. < 25	5.0	9.8	0.5
25 ≤ disp. < 30	5.0	11.0	0.5

Note: With the exception of machinery and engines intended for export to countries that are not Parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.

2.6.2. Proposal of potential update of limit values

The limit values are proposed to be updated according to Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) 1024/2012 and (EU) 167/2013, and amending and repealing Directive 97/68/EC by including IWA (auxiliary engines) and include up to Stage V [22].The regulations define ten categories of engines according to their power and use, identified by codes. For inland waterway vessels, the following categories of engines are used:

- IWP: engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19 kW;
- IWA: auxiliary engines exclusively for use in inland waterway vessels and having a reference power that is greater than or equal to 19 kW;
- NRE: engines having a reference power of less than 560 kW used in the place of Stage V engines of categories IWP and IWA.

In 2019, all new engines for inland waterway vessels need to comply with the Stage V emission requirements set by the European Union for Non-Road Mobile Machinery (NRMM). The Stage V requirement limits the emission of CO, HC, NOx, PM and Particle Number (PN).

To be in line with Tables II-5 and II-6 from Annex II of the Commission Regulation 2016/1628, the new title should be "Limit values for propulsion and auxiliary engines of inland waterways vessels (Stage V)".

The new table 9 could be divided in two parts or a new numbering of tables could be adopted.

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Table 28: Table 9, annex VIII, proposal of potential update: Stage V emission limits for engine use in inland waterway vessels category IWP/IWP*

Emission stage	**Engine sub-category**	**Power range**	**Ignition type**	**CO**	**HC**	**NOx**	**PM**	**PN**	**A**
	IWP/IWA	kw		g/kWh				#/kWh	
Stage V	v/c-1	19≤P<75	All	5,00	HC+NOx≤4,70		0,30		6,00
Stage V	v/c-2	75≤P<130	All	5,00	HC+NOx≤5,40		0,14		6,00
Stage V	v/c-3	130≤P<300	All	3,50	1,00	2,10	0,10		6,00
Stage V	v/c-4	P≥300	All	3,50	0.,19	1,80	0,015	1x10^{12}	6,00

Table 29: Table 9, annex VIII, proposal of potential update: emission limits for NRE category engines suitable for inland navigation subject to test cycles C1 (constant speed engines) or D2 (variable speed engines)

Emission stage	**Engine sub-category**	**Power range**	**Ignition type**	**CO**	**HC**	**NOx**	**PM**	**PN**	**A**
	NRE	kw		g/kWh				#/kWh	
Stage V	v/c-1	0<P<8	CI	8,00	HC+NOx≤7,50		0,40*	-	1,10
Stage V	v/c-2	8≤P<19	CI	6,60	HC+NOx≤7,50		0,40	-	1,10
Stage V	v/c-3	19≤P<37	CI	5,00	HC+NOx≤4,70		0,015	1x10^{12}	1,10
Stage V	v/c-4	37≤P<56	CI	5,00	HC+NOx≤4,70		0,015	1x10^{12}	1,10
Stage V	v/c-5	56≤P<130	All	5,00	0,19	0,40	0,015	1x10^{12}	1,10
Stage V	v/c-6	130≤P<560	All	3,50	0.,19	0,40	0,015	1x10^{12}	1,10
Stage V	v/c-7	P≥560	All	3,50	0,19	3,50	0,045	-	6,00

*0,60 for hand-startable, air-cooled direct injection engines

2.7. Recreational crafts

2.7.1. Current limit values for recreational crafts listed in table 10, annex VIII

Table 10 of annex VIII considers only limit values per engine type (2-stroke, 4-stroke and CI).

Table 30: Table 10, annex VIII, current limit values for engines in recreational crafts

Engine type	CO (g/kWh) $CO = A + B/P^n_N$			Hydrocarbons (HC) (g/kWh) $HC = A + B/P^n_N$ [a]			NO_x g/kWh	PM g/kWh
	A	B	n	A	B	n		
2-stroke	150	600	1	30	100	0.75	10	Not Appl.
4-stroke	150	600	1	6	50	0.75	15	Not Appl.
CI	5	0	0	1.5	2	0.5	9.8	1

Abbreviations: Not Appl. = Not Applicable.

Note: With the exception of machinery and engines intended for export to countries that are not Parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market of new engines, whether or not installed in machinery, only if they meet the respective limit values set out in the table.

[a] Where A, B and n are constants and P_N is the rate engine power in kW and the emissions are measured in accordance with the harmonized standards.

2.7.2. Proposal of potential update of limit values

Based on the specific Directive 2013/53/EC of the European Parliament and of the Council of 20 November 2013 on recreational craft and personal watercraft and repealing Directive 94/25/EC [23], a proposal of update is made for Table 10 and display in more disaggregated emission limit values (in terms of Rated Engine Power) for:

- Exhaust emission limits for compression ignition (CI) engines (Table 31).
- Exhaust emission limits for spark ignition (SI) engines (Table 32).

These limit values are now applicable for all new vehicles as the limit values were applicable from 18 January 2016 according to the directive 2013/53/EC.

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Table 31: Table 10, annex VIII, proposal of potential update: exhaust emission limits for compression ignition (CI) engines (**)

Swept Volume SV (L/cyl)	Rated Engine Power P_N (kW)	Particulates PT (g/kWh)	Hydrocarbons + Nitrogen Oxides $HC + NO_x$ (g/kWh)
$SV < 0,9$	$P_N < 37$	The values referred to in table 1	
	$37 \leq P_N < 75$ (*)	0,30	4,7
	$75 \leq P_N < 3\ 700$	0,15	5,8
$0,9 \leq SV < 1,2$	$P_N < 3\ 700$	0,14	5,8
$1,2 \leq SV < 2,5$		0,12	5,8
$2,5 \leq SV < 3,5$		0,12	5,8
$3,5 \leq SV < 7,0$		0,11	5,8

(*) Alternatively, compression-ignition engines with rated engine power at or above 37 kW and below 75 kW and with a swept volume below 0,9 L/cyl shall not exceed a PT emission limit of 0,20 g/kWh and a combined $HC + NO_x$ emission limit of 5,8 g/kWh.
(**) Any compression-ignition engine shall not exceed a Carbon monoxide (CO) emission limit of 5,0 g/kWh.

Table 32: Table 10, annex VIII proposal of potential update: Exhaust emission limits for spark ignition (SI) engines

Type of engine	Rated Engine Power P_N (kW)	Carbon monoxide CO (g/kWh)	Hydrocarbons + Nitrogen Oxides $HC + NO_x$ (g/kWh)
Stern-drive and inboard engines	$P_N \leq 373$	75	5
	$373 < P_N \leq 485$	350	16
	$P_N > 485$	350	22
Outboard engines and PWC engines	$P_N \leq 4,3$	$500 - (5,0 \times P_N)$	30
	$4,3 < P_N \leq 40$	$500 - (5,0 \times P_N)$	$15,7 + \left(\frac{50}{P_N^{0,9}}\right)$
	$P_N > 40$	300	$15,7 + \left(\frac{50}{P_N^{0,9}}\right)$

2.8. Motorcycles and mopeds (L-category)

2.8.1. Current limit values for motorcycles and moped listed in table 11 and table 12 of annex VIII

Limit values for motorcycles and moped currently in the 2012 Gothenburg Protocol Amendment are obsolete. The tables 11 and 12 include only 2 categories (> 50 cm^3; > 45 km/h) and (<50 cm^3; < 45 km/h).

Table 33: Table 11, annex VIII, current limit values for motorcycles (> 50 cm^3; > 45 km/h)

Engine size	*Limit values*
Motorcycle < 150 cc	Hydrocarbons (HC) = 0.8 g/km NO_x = 0.15 g/km
Motorcycle > 150 cc	HC = 0.3 g/km NO_x = 0.15 g/km

Note: With the exception of vehicles intended for export to countries that are not Parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market only if they meet the respective limit values set out in the table.

Table 34: Table 12, annex VIII, current limit values for mopeds (<50 cm^3; < 45 km/h)

CO (g/km)	*Hydrocarbons (HC) + NO_x (g/km)*
1.0[a]	1.2

Note: With the exception of vehicles intended for export to countries that are not Parties to the present Protocol, Parties shall permit the registration, where applicable, and the placing on the market only if they meet the respective limit values set out in the table.

[a] For 3- and 4-wheelers, 3.5 g/km.

2.8.2. Proposal of potential update of limit values

The tables 11 and 12 of annex VIII are proposed to be updated according to the Regulation (EU) 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles [24].

The Annex VI of the Regulation (EU) 168/2013 provides limit values disaggregated into the categories available in the regulation (Table 35): Two- or three-wheel vehicles, quadricycles, enduro and trial motorcycles as well as heavy all terrain quads. The Euro 5 limit values are mandatory for all new vehicles as of 01/01/2021. Some vehicles, enduro and trial motorcycles, three-wheeled mopeds designed for utility purposes and light quadri-mobiles, have extra time and must comply with the new Euro 5 standards by 01/01/2024. A comparison of emission standards from Euro 1 to Euro 5 is given Figure 9.

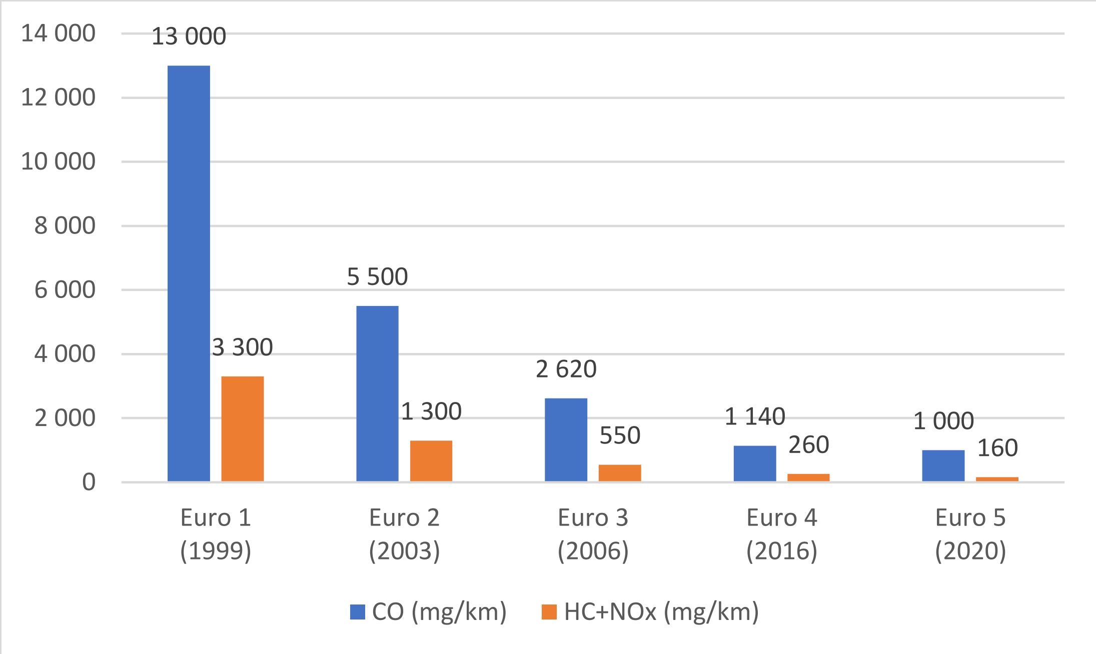

Figure 9: Emission reduction process for motorcycles: from Euro 1 to Euro 5 [24]

The Regulation (EU) 168/2013 also introduces the second-stage on-board diagnostic (OBD) which aims the early detection and identification of malfunction in the emission control system. In addition, Euro 5 adds a limit value on the amount of non-methane hydrocarbons (NMHC) in the exhaust, which was not the case for the previous Euro norms.

Table 35: Categories of two- or three-wheel vehicles and quadricycles in the Regulation (EU) 168/2013 for Euro 5 vehicles [24]

Vehicle Class (12)	Vehicle category name	Propulsion Class
L1e-A	Powered cycle	PI (11)
L1e-B	Two-wheel moped	
L2e	Three-wheel moped	
L3e L4e (7)	Two-wheel motorcycle with and without side-car	
L5e-A	Tricycle	
L5e-B	Commercial tricycle	
L6e-A	Light on-road quad	
L6e-B	Light quadri-mobile	
L7e-A	Heavy on-road quad	
L7e-B	All terrain quad	
L7e-C	Heavy quadri-mobile	

Based on the Regulation (EU) 2013/168, it is proposed to update Tables 11 and 12 of annex VIII with the limit values given in Table 36.

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Table 36: Table 11 and table 12, annex VIII, proposal of potentail update: limit values for two- or three-wheel vehicles, quadricycles, enduro and trial motorcycles as well as heavy all terrain quads

(A1) Tailpipe emission limits after cold start (Euro 4):

Vehicle category	Vehicle category name	Propulsion class	Euro level	Mass of carbon monoxide (CO)	Mass of total hydrocarbons (THC)	Mass of oxides of nitrogen (NO_x)	Mass of particulate matter (PM)	Test cycle
				L_1 (mg/km)	L_2 (mg/km)	L_3 (mg/km)	L_4 (mg/km)	
L1e-A	Powered cycle	PI/CI/Hybrid	Euro 4	560	100	70		ECE R47
L1e-B	Two-wheel moped	PI/CI/Hybrid	Euro 4	1 000	630	170	—	ECE R47
L2e	Three-wheel moped	PI/CI/Hybrid	Euro 4	1 900	730	170	—	ECE R47
L3e L4e (7) L5e-A L7e-A	— Two-wheel motorcycles with and without side-car — Tricycle — Heavy on-road quad	PI/PI Hybrid, v_{max} < 130 km/h	Euro 4	1 140	380	70	—	WMTC, stage 2
		PI/PI Hybrid, v_{max} ≥ 130 km/h	Euro 4	1 140	170	90	—	WMTC, stage 2
		CI/CI Hybrid	Euro 4	1 000	100	300	80 (8)	WMTC, stage 2
L5e-B	Commercial tricycle	PI/PI Hybrid	Euro 4	2 000	550	250	—	ECE R40
		CI/CI Hybrid	Euro 4	1 000	100	550	80 (8)	ECE R40
L6e-A L6e-B	Light on-road quad Light quadrimobile	PI/PI Hybrid	Euro 4	1 900	730	170		ECE R47
		CI/CI Hybrid	Euro 4	1 000	100	550	80 (8)	ECE R47
L7e-B L7e-C	Heavy all terrain quad Heavy quadrimobile	PI/PI Hybrid	Euro 4	2 000	550	250	—	ECE R40
		CI/CI Hybrid	Euro 4	1 000	100	550	80 (8)	ECE R40

(A2) Tailpipe emission limits after cold start (Euro 5):

Vehicle category	Vehicle category name	Propulsion class	Euro Level (4)	Mass of carbon monoxide (CO)	Mass of total hydro-carbons (THC)	Mass of Non-methane hydrocarbons (NMHC)	Mass of oxides of nitrogen (NO_x)	Mass of particulate matter (PM)	Test cycle
				L_1 (mg/km)	L_{2A} (mg/km)	L_{2B} (mg/km)	L_3 (mg/km)	L_4 (mg/km)	
L1e-A	Powered cycle	PI/CI/Hybrid	Euro 5	500	100	68	60	4,5 (9)	Revised WMTC (10)
L1e-B-L7e	All other L-category vehicles	PI/ PI Hybrid	Euro 5	1 000	100	68	60	4,5 (9)	Revised WMTC
		CI/CI Hybrid		500	100	68	90	4,5	Revised WMTC

(B1) On-board diagnostics emission thresholds (Euro 4, OBD Stage I*)

Vehicle category	Vehicle category name	Propulsion class	Euro level	Mass of carbon monoxide (CO)	Mass of total hydro-carbons (THC)	Mass of oxides of nitrogen (NO_x)	Test cycle
				OT_1 (mg/km)	OT_2 (mg/km)	OT_3 (mg/km)	
L6e-A	— On-road light quad	PI, CI or Hybrid	Euro 4	3 610	2 690	850	ECE R47
L3e (5) L4e (7) L5e-A L7e-A	— Two-wheel motorcycle with and without side-car — Tricycle — Heavy on-road quad	PI/PI Hybrid v_{max} < 130 km/h	Euro 4	2 170	1 400	350	WMTC, stage 2
		PI/PI Hybrid v_{max} ≥ 130 km/h		2 170	630	450	WMTC, stage 2
		CI/CI Hybrid		2 170	630	900	WMTC, stage 2

* Vehicles shall be equipped with an OBD Stage I system which monitors for any electric circuit and electronics failure of the emission control system and reports those failures which result in the emission thresholds as laid down in Annex VI (B1) (above Table) of the Regulation (EU) 168/2013 being exceeded

(B2) On-board diagnostics emission thresholds (Euro 5, OBD Stage II*)

Vehicle category	Vehicle category name	Propulsion class	Euro level	Mass of carbon monoxide (CO)	Mass of Non-methane hydro-carbons (NMHC)	Mass of oxides of nitrogen (NO_x)	Mass of particulate matter (PM)	Test cycle
				OT_1 (mg/km)	OT_2 (mg/km)	OT_3 (mg/km)	OT_4 (mg/km)	
L3e-L7e (6)	All L category vehicles except category L1e and L2e	PI/PI Hybrid	Euro 5	1 900	250	300	50	Revised WMTC
		CI/CI Hybrid	Euro 5	1 900	320	540	50	Revised WMTC

* Vehicles shall be equipped with an OBD Stage I system which monitors for any electric circuit and electronics failure of the emission control system and reports those failures which result in the emission thresholds as laid down in Annex VI (B2) (above Table) of the Regulation (EU) 168/2013 being exceeded

2.9. Fuel quality

2.9.1. Current environmental specifications for marketed fuels to be used for vehicles equipped with positive-ignition engines (Petrol) and for vehicles equipped with compression-ignition engines (Diesel) listed in table 13 and table 14 of annex VIII

The specifications for marketed fuels to be used in Diesel and Gasoline as currently provided in table 13 and 14 of annex VIII, are provided in Table 37 and Table 38. These specifications are extracted from Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC [26].

The tables 13 and 14 of annex VIII, are not sufficiently disaggregated with respect to the types of fuels currently available in the market.

Table 37: Table 13, annex VIII, current environmental specifications for marketed fuels to be used for vehicles equipped with positive-ignition engines (Petrol)

		Limits	
Parameter	*Unit*	*Minimum*	*Maximum*
Research octane number	–	95	–
Motor octane number	–	85	–
Reid vapour pressure, summer period[a]	kPa	–	60
Distillation:			
Evaporated at 100°C	% v/v	46	–
Evaporated at 150°C	% v/v	75	–
Hydrocarbon analysis:			
Olefins	% v/v	–	18.0[b]
Aromatics	–	–	35
Benzene	–	–	1
Oxygen content	% m/m	–	3.7
Oxygenates:			
Methanol, stabilizing agents must be added	% v/v	–	3
Ethanol, stabilizing agents may be necessary	% v/v	–	10
Parameter:			
Iso-propyl alcohol	% v/v	–	12
Tert-butyl alcohol	% v/v	–	15
Iso-butyl alcohol	% v/v	–	15
Ethers containing 5 or more carbon atoms per molecule	% v/v	–	22
Other oxygenates[c]	% v/v	–	15
Sulphur content	mg/kg	–	10

[a] The summer period shall begin no later than 1 May and shall not end before 30 September. For Parties with arctic conditions the summer period shall begin no later than 1 June and not end before 31 August and the Reid Vapour Pressure (RVP) is limited to 70 kPa.

[b] Except for regular unleaded petrol (minimum motor octane number (MON) of 81 and minimum research octane number (RON) of 91), for which the maximum olefin content shall be 21% v/v. These limits shall not preclude the introduction on the market of a Party of another unleaded petrol with lower octane numbers than set out here.

[c] Other mono-alcohols with a final distillation point no higher than the final distillation point laid down in national specifications or, where these do not exist, in industrial specifications for motor fuels.

Table 38: Table 14, annex VIII, current Environmental specifications for marketed fuels to be used for vehicles equipped with compression-ignition engines (Diesel)

Parameter	*Unit*	*Limits*	
		Minimum	*Maximum*
Cetane number	–	51	–
Density at 15°C	kg/m3	–	845
Distillation point: 95%	°C	–	360
Polycyclic aromatic hydrocarbons	% m/m	–	8
Sulphur content	mg/kg	–	10

2.9.2. Proposals of potential updates of limit values

Regarding the table 13 (Petrol), in order to be in line with the latest fuel specifications, it is advisable to update (Professional Petroleum Committee, Specifications and quality of fuels, 2021 - [27]). The latest specifications are more disaggregated (Table 39) and consider a larger number of fuels.

Update index 1.

Table 39: Table 13, annex VIII, proposal of potential update of specifications for marketed premium unleaded 95, 98 and 95-E10 fuels to be used for vehicles equipped with positive-ignition engines (Petrol) (specifications n° 1-2-10 de la CSR)

Parameter	*Unit*	*Limits* Premium unleaded 95 and 98		*Limits* Premium unleaded 95-E10 - S95-E10	
		Min.	*Max.*	*Min.*	*Max.*
Research octane number	–	95	–	95	
Motor octane number	–	85	–	85	
Reid vapour pressure, summer period[a]	kPa	45	60	45	60
Distillation:					
Evaporated at 100°C	**% v/v**	46	**71**	46	**72**
Evaporated at 150°C	% v/v	75	–	75	
Hydrocarbon analysis:					
Olefins	% v/v	–	18.0b		18
Aromatics	% v/v	–	35		35
Benzene	% v/v	–	1		1
Oxygen content	% m/m	–	2.7		3.7
Oxygenates:					
Methanol, stabilizing agents must be added	% v/v	–	3		3
Ethanol, stabilizing agents may be necessary	% v/v	–	5		10
Parameter:					
Iso-propyl alcohol	% v/v	–	12		12
Tert-butyl alcohol	% v/v	–	15		15
Iso-butyl alcohol	% v/v	–	15		15

		Limits		Limits	
		Premium unleaded 95 and 98		Premium unleaded 95-E10 - S95-E10	
Parameter	*Unit*	*Min.*	*Max.*	*Min.*	*Max.*
Ethers containing 5 or more carbon atoms per molecule	% v/v	–	22		22
Other oxygenates[c]	% v/v	–	15		15
Sulphur content	mg/kg	–	10		10
Manganese	mg/l		2		2
Lead content	mg/l		5		5

[a] The summer period shall begin no later than 1 May and shall not end before 30 September. For Parties with arctic conditions the summer period shall begin no later than 1 June and not end before 31 August and the Reid Vapour Pressure (RVP) is limited to 70 kPa.

[b] Except for regular unleaded petrol (minimum motor octane number (MON) of 81 and minimum research octane number (RON) of 91), for which the maximum olefin content shall be 21% v/v. These limits shall not preclude the introduction on the market of a Party of another unleaded petrol with lower octane numbers than set out here.

[c] Other mono-alcohols with a final distillation point no higher than the final distillation point laid down in national specifications or, where these do not exist, in industrial specifications for motor fuels.

With respect to table 14 (Diesel), the recommended values for the update are provided in Table 40. The data are provided by (Professional Petroleum Committee, Specifications and quality of fuels, 2021 - [27]).

Update index 1.

Table 40: Table 14, annex VIII, proposal of potential upadte of specifications for marketed fuels to be used for vehicles equipped with compression-ignition engines (Diesel)

		Limits	
Parameter	*Unit*	*Minimum*	*Maximum*
Cetane number	–	51	–
Fatty acid methyl esters (FAME)	% v/v		7
Density at 15°C	kg/m3	820	845
Distillation point: 95%	°C	–	360
Polycyclic aromatic hydrocarbons	% m/m	–	8
Sulphur content	mg/kg	–	10
Manganese content	mg/l		2

3. Upgraded and new technologies for mobile sources

This chapter aims at providing first pieces of information for updating the 2015 technical report on "Best Available Techniques for Mobile Sources in support of a Guidance Document to the Gothenburg Protocol of the Long-range Transboundary Air Pollution (LRTAP) Convention" (Papadimitriou et al., 2015) [28].

Most vehicles across all transport modes are powered by Industrial Combustion Engines, with gasoline and Diesel being the main fuel for passenger cars, LDV, HDV, 2- and 3- wheelers, vessels and trains (other than the electric ones) and kerosene being the fuel for aircraft engines. Nevertheless, alternative fuels, like biofuels, hydrogen, natural gas are emerging and the development of electric vehicles that strongly reduce air pollutant emissions is quite rapid.

In the following chapters, alternative fuels, alternative motorization and upgraded/new technologies are examined for each type of vehicles.

3.1. Passenger cars, light-duty and heavy-duty vehicles

3.1.1. Alternative fuels

Hydrogen

The use of hydrogen as a replacement for fossil fuels is considered as an effective way to decarbonize the transport sector and to reach almost zero air pollutant emissions. There are two types of techniques associated with hydrogen. The fuel cell technology allows to reduce significantly NOx emissions, which is not systematically the case for hydrogen used as a fuel as explained in the following paragraphs:

- <u>Combustion in thermal engines:</u> hydrogen can be injected as a gas into an Internal Combustion Engine (ICE). It can be used alone or mixed with other gases such as Renewable Natural Gas (RNG). Although CO_2 emissions are reduced proportionally to the hydrogen content of the fuel, NOx emissions are higher, all other things being equal. On the other hand, since hydrogen is not a hydrocarbon fuel, THC and CO level drop when RNG is blend with H_2 [29].A few studies were recently published on the relevance of a pure hydrogen powered engine and show that several ways exist to reduce NOx emissions at the source, namely: Exhaust Gas Recirculation (EGR) and water injection that could reduce NOx emissions levels by respectively 57 and 97%, injection and ignition control strategy [30], mixture formation and equivalence ratio [31]. Almost zero NO_x level can be reached in lean mixture with an optimized injection system even at high engine power output by using a boost air system to compensate the loss of energy content of the mixture due to the decrease in equivalence ratio [32]. In addition, for these internal combustion engines, exhaust gas after-treatment techniques to reduce NOx emissions like the Three-Way Catalytic convertor (TWC), Selective Catalytic Reduction (SCR) and Lean NOx Traps (LNT) (Lewis, 2021 – [33]) already exist. On the other hand, special attention must be paid to unburned hydrogen emissions which according to very recent studies could have an indirect effect on the greenhouse effect [34]. It is also important to note that each of the studies above show relatively high engine efficiencies of up to 40%, which are globally higher than the actual Spark Ignition (SI) gasoline engines and in the same order of magnitude than a Compression Ignition (CI) one.

Therefore, if ICE fuelled with pure hydrogen can operate in a near zero-emission mode, it could become very interesting since the engine technology is already available. This means that current vehicles could be adapted to hydrogen by only changing the injection and storage system on board.

- <u>Fuel cell vehicles (FCV):</u> the chemical energy contained in the hydrogen is converted into electrical energy in the form of direct current. FCEVs use a propulsion system similar to that of electric vehicles, where energy stored as hydrogen is converted to electricity by the fuel cell. Unlike conventional internal combustion engine vehicles, these vehicles produce no harmful tailpipe emissions. The only waste product is the heat of water.

The most common type of fuel cell for vehicle applications is the polymer electrolyte membrane (PEM) fuel cell. In a PEM fuel cell, an electrolyte membrane is sandwiched between a positive electrode (cathode) and a negative electrode (anode). Hydrogen is introduced to the anode, and oxygen (from air) is introduced to the cathode. The hydrogen molecules break apart into protons and electrons due to an electrochemical reaction in the fuel cell catalyst. Protons then travel through the membrane to the cathode.

Different types of fuel cells exist, the most mature, affordable, and efficient being the Proton-exchange membrane fuel cells (PEMFC) type, already applied to transport. This technology allows for a rapid refuels and offer a driving range similar to today's gasoline/diesel LDVs, but with a high-cost increment [36].

Hydrogen faces several challenges, particularly in terms of deployment and financing. Nevertheless, hydrogen offers concrete benefits in terms of air quality improvement and decarbonization of the transport sector. Several projects have already been carried out. The sector is facing challenges of large-scale application being supply and storage as well as financing.

In fact, there are various issues related to the deployment of the hydrogen technology in transport:

- In terms of investments, the additional costs compared to thermal propulsion can be significant, even without integrating the investments related to hydrogen production and distribution infrastructures.

- The price at the pump, which can be important in the first years, but which can then drop rapidly with a consequent deployment.

- The maintenance costs. It seems that the costs are much lower than those of thermal engines.

- The type of storage for the supply chain: integrated, modular, solid or liquid, each with advantages and disadvantages in handling, distribution, operation, etc.

Ammonia

More marginal, ammonia being a hydrogen carrier can also represent an interesting innovation track. Both storage and transport infrastructures are already existing since it represents one of the most produced chemical products. Although ammonia is a toxic gas, it does not have a high potential for self-ignition and a leak is easily detected, which can make it a safer element, in certain circumstances, than hydrogen. Therefore, Ammonia can not only serve as a hydrogen carrier, but a lot of work is being done to use it either directly in a dedicated fuel cell using solid oxide fuel cell (SOFC) and Membrane-electrode Assembly (MEA) technologies [35] or in an internal combustion engine since its combustion does not emit CO2. However, burning ammonia leads to NO_x, NH_3 and N_2O emissions that would need a dedicated aftertreatment system for them to be treated. Furthermore, since ammonia combustion is very slow, it is possible so far to use ammonia in engines that run slowly and stationarily (marine or power generation) while its direct use in automotive engines type still remains more challenging and restrictive.

3.1.2. Electric hybridization

There are currently five types of Electric Vehicles (EVs) that can be classified depending on their technologies (Sanguesa et al., 2021 – [37]):

- Battery Electric Vehicles (BEV): 100% electric with no internal combustion. BEVs used large packs of batteries that ensure the vehicle autonomy.
- Plug-In Hybrid Electric Vehicles (PHEVs): Plug-in hybrids combine an all-electric engine, which can be recharged at home or via a charging station through a pluggable external electric source, and another engine such as gasoline. PHEVs can store electricity to significantly reduce fuel consumption in normal driving conditions.
- Hybrid Electric Vehicles (HEVs): A hybrid electric vehicle consists of combining a combustion engine with one, or several, electric motors. Unlike PHEVs vehicles, HEVs cannot be plugged to the grid. HEVs uses the combustion engine and regenerative braking to recharge the battery with electricity.
- FCEVs (cf 3.1.1. Alternative fuel: hydrogen).
- Extended-range EVs (ER-EVs): ER-EV is effectively an all-electric vehicle, with all the motive power provided by an electric motor, but with a small Internal Combustion Engine (ICE) present to generate additional electric power if needed. ICE is only used for charging, so that it is not connected to the wheels of the vehicle.

In 2020, the main constructors are offering electric vehicles with an average autonomy of 290 km, with a minimum of 150 km and up to 600 km in the WLTP. The full charging of the battery pack can take 4 to 8 hours and fast charging to 80% capacity can take 30 minutes. Despite the higher price of EVs compared to thermal vehicles, the EVs are experiencing a significant growth in the last years (Sanguesa et al., 2021 – [37]).

BEVs have no tailpipe emissions. However, special attention should be paid to the source of electricity in the country where they are deployed. Moreover, if BEVs emit no NOx, they still emit PM through non-exhaust sources. As they tend to be heavier than the conventional vehicles, the Non-Exhaust Emissions (NEE) of particles could be greater than those from conventional vehicles. This is due to higher emissions at tyres level despite a decrease at brake one through regenerative braking. It is therefore very important to consider the NEE emissions not only from conventional combustion vehicles, but also of electric vehicles (Timmers and Achten, 2018 – [38]).

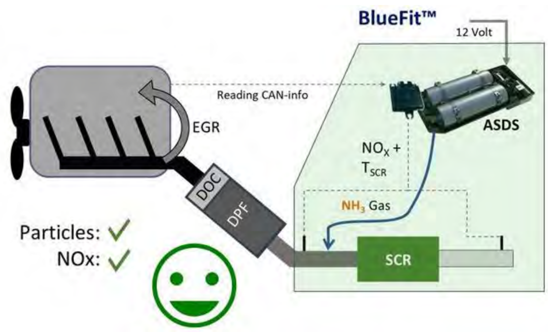
3.1.3. Retrofit solutions

Retrofit solutions from Amminex company [39] enable high NOx reduction on Euro 5/V and VI/6 light and heavy-duty in use vehicles. A consortium consisting of Amminex Emissions Technology, supported by the Technical University of Graz, Jonhson Matthey and ICCT Europe was awarded in 2018 by the European Commission for the Horizon Prize "Engine Retrofit for Clean Air" and mentioned by CLOVE as potential technologies to meet ultra-low NOx emissions.

A key point to reduce NOx emissions is to optimize the cold-start behaviour and to ensure an optimized high temperature conversion. This is achieved by increasing the SCR volume and by optimizing the SCR control [13]. To lower cold-start emissions, the EHC (Electrically Heated Catalyst) could be employed to improve light-off performance during warm-up (Gao et al., 2019 - [39]). In [13], the 48-volt hybrid system is also mentioned as an opportunity to significantly reduce the cold-start emissions.

The retrofit system BlueFitTM system, developed by Amminex and installed on a Euro 5 or on a Euro 6b diesel passenger car, is described in Table 41.

Table 41: Retrofit system BlueFitTM system, developed by Amminex installed on a Euro 5 and on a Euro 6b diesel passenger car

General Description	
Name of technique	The Retrofit system BlueFit™ system, developed by Amminex - Faurecia, supported by TU Graz, Johnson Matthey PLC and International Council on Clean Transportation Europe. It is currently available for commercialization.
Pollutants addressed	NOx
Engine/vehicle/vessel types considered	Euro 5 and 6 petrol and diesel light vehicles
Short description of technique	The Commission's 2018 Horizon Prize on Engine Retrofit for Clean Air demonstrated the effectiveness and relatively low costs of retrofitting. It spurred the development of new technologies that can be applied to recent Euro 5 and Euro 6 diesel engines. The BlueFit™ system, developed by Amminex, consists of two key elements: A scaled-down version of the Amminex ASDS ammonia storage (two or three cartridges) and delivery system that is already used on commercial vehicles and a SCR catalyst (Figure 10). It was the champion of the EU Horizon retrofit prize, whose IP rights have been recovered by the European Commission and are available for any interested company.  Figure 10: BluFit™ System. Source: https://retrofit4emissions.eu/existing-systems/ - Testing Retrofit Technologies
Environmental benefit and costs	
Specific claims (% reduction range of pollutants addressed)	**Euro 5 Diesel personal car:** NOx emissions from a 2014 mid-sized Euro 5 diesel car retrofitted with the BlueFit system could be reduced from 800-1300 to 40 mg/km, or 50% below the Euro 6 NOx limit, according to Amminex. The testing was performed in real conditions by the University of Graz under real driving conditions, using PEMS analyzers (Johannessen, 2018 - [41]). In Giechaskiel et al., 2018 [42], **the average NOx average emissions is reduced from 865 mg/km to 150 mg/km with BlueFit system** (Figure 11). After 3 km of urban driving, the Euro 5 vehicle reach the appropriate catalyst temperature for a considerable NOx reduction.

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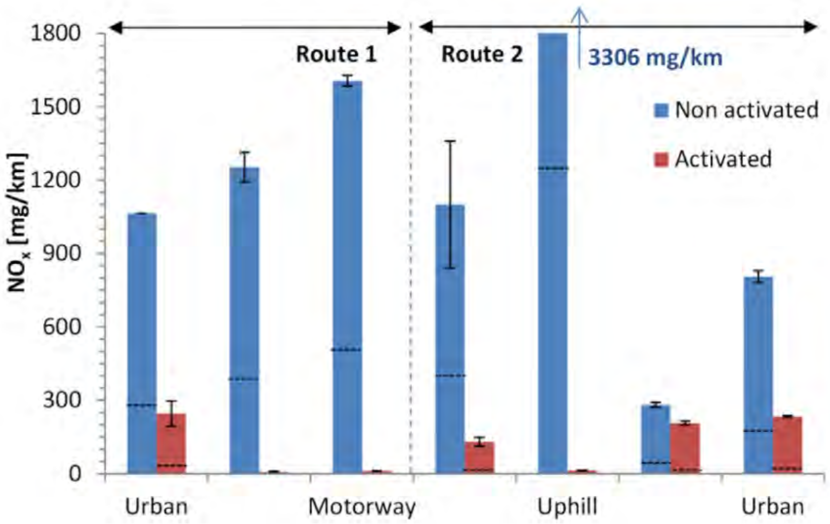

Figure 11: NOx emissions during the real driving emissions testing. The first Urban part is with engine cold start. Error bars show the maximum and minimum value of the 2 repetitions. Dashed lines show the NO_2 emissions (lower part of bars). Note that the y axis is cut at 1800 mg/km and the “Uphill” emissions exceeded 3300 mg/km (Giechaskiel et al., 2018 - [42])

<u>Euro 6 personal car:</u>

NOx emissions from a Euro 6b diesel passenger car retrofitted with the BlueFit system could be reduced from 25% (50 mg/km) to 82% (725 mg/km) both in the laboratory and on the road. The minimum reduction occurred in cold start conditions and the maximum at hot start cycles (Figure 12). The mean NOx emissions for all cycles were 571 mg/km and were reduced to 198 mg/km when the retrofit was activated (Giechaskiel et al., 2019 - [43]).

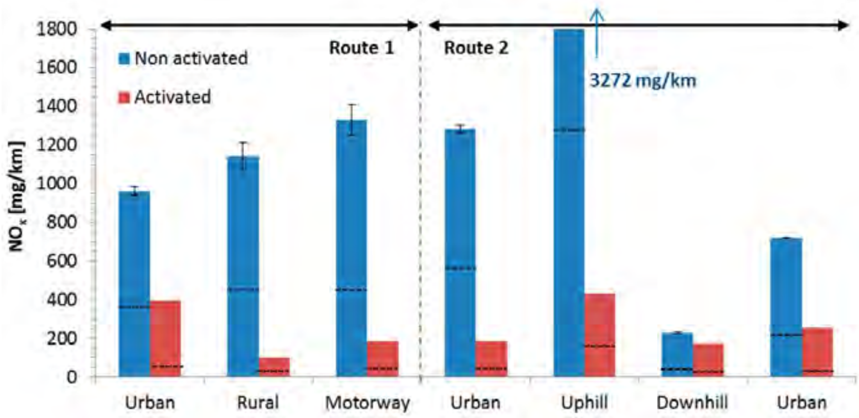

Figure 12: NOx emissions during the real driving emissions testing. Error bars show the maximum and minimum value of the 2 repetitions when available. Dashed lines show the NO_2 emissions. Note that the y axis is cut at 1800 mg/km and the “Uphill” emissions exceeded 3250 mg/km.
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<td>Costs for implementation and operation (order-of magnitude estimations per unit or any other metric)</td>
<td>

- Acquisition and <u>installation costs < 2 K Euros</u>
- <u>Running costs ~ 200 Euros</u> for 100,000 km
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Environmental Side Effects	
Impact on fuel consumption (positive/negative impact and typical % effect)	Fuel penalty of only < 2% and engine upgrade with minimal impact on CO_2 (~1% CO_2 from SCR brick & ASDS)
Non-regulated pollutants and trade-offs (e.g., NH_3 or N_2O emissions, NO2 formation, PM/NOx trade-offs, etc.)	In some high-speed conditions significant increase of ammonia (NH_3) and nitrous oxide (N_2O) were measured for Euro 5 and only an increase of N_2O for Euro 6b vehicles.
Limitations and Implementation Issues	
Limitations in its applicability (e.g. environmental conditions, fuel specifications, technological barriers, behavioural changes, etc.)	-
Ease of implementation (technology or expertise required, infrastructural needs, etc.)	The system fits easily in spare-wheel compartment. Stand-alone integration: − Not engine recalibration or modification on the certified DOC/DPF or hot-end exhaust in engine compartment. − Use existing vehicle power/battery system.
Maintenance and operation (additional maintenance requirements, monitoring requirements, …)	The driving range will be around 15,000 km before it is time for a two-minute cartridge exchange at a workshop and can be extended to 20,000 km for car model with three adBlue Cartridges.
Durability/lifetime of emission control equipment	Customer-friendly solution with up to ~15,000 km range.
Impacts on safety (users, citizens, …)	The retrofit seems not to pose any significant safety hazard.
References and Other Points	
Comments or remarks not addressed above	If combined with some level of cooperation with a manufacturer, better cold start performance of the retrofitted vehicles could be achieved.
Successful examples of implementation	-

References for further details	https://retrofit4emissions.eu/ https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-results-platform/21764;resultId=21764;needList=13 https://theicct.org/icct-part-of-a-research-group-awarded-the-european-commissions-horizon-prize/ https://www.vert-dpf.eu/j3/images/pdf/VERT_FORUM_2018/day1/13_Johanessen-VERT-Forum-2018.pdf

Table 42: Retrofit system, developed by Amminex installed on EURO V and VI Diesel heavy-duty vehicles

General Description	
Name of technique	ASDS™ Technology by Amminex
Pollutants addressed	NOx
Engine/vehicle/vessel types considered	Euro V and VI diesel heavy duty vehicles
Short description of technique	ASDS™ Technology is used with complementary system to achieve trucks and buses emissions upgrade: - AdAmmine™ is the core material in all products ➢ Solid, safe ammonia storage ("ammonia in salt") ➢ 2x volumetric capacity compared to lia. urea) ➢ Cartridge not pressurized at room temperature - ASDS™ provides ammonia dosing on-demand ➢ Plug & play system replacing an AdBlue system ➢ Controlled release: Pure NH_3 on-demand into exhaust line - Direct ammonia dosing: "Always-on SCR" ➢ Enables the full conversion of the SCR catalyst, also at temperatures below 200°C where DEF dosing is critical.
Environmental benefit and costs	
Specific claims (% reduction range of pollutants addressed)	Performances given in Johannessen (2018) [41] for commercial vehicle segment (including retrofit): - EURO VI proven on WHTC and low load/speed cycles. - Real Driving Emissions below EURO VI NOx: - Europe: In-service conformity (with PEMS) proven at <20% engine load - US perspective: ASDS has proven high DeNOx performance well below current 250°C Not-To-Exceed temperature threshold.
Costs for implementation and operation (order-of magnitude	-

estimations per unit or any other metric)	
Environmental Side Effects	
Impact on fuel consumption (positive/negative impact and typical % effect)	-
Non-regulated pollutants and trade-offs (e.g. NH_3 or N_2O emissions, NO_2 formation, PM/NOx trade-offs, etc.)	N_2O (CO_2-eq) less than 1%
Limitations and Implementation Issues	
Limitations in its applicability (e.g. environmental conditions, fuel specifications, technological barriers, behavioural changes, etc.)	-
Ease of implementation (technology or expertise required, infrastructural needs, etc.)	-
Maintenance and operation (additional maintenance requirements, monitoring requirements, …)	-
Durability/lifetime of emission control equipment	-
Impacts on safety (users, citizens, …)	-
References and Other Points	
Comments or remarks not addressed above	
Successful examples of implementation	ASDS upgrade of the London Diesel Buses fleet: - London City bus: ADL Enviro 200 - 4.5L EURO V Cummins engine, non-EGR, fitted with ASDS and DOC/DPF/SCR/ASC exhaust by Eminox - Emissions on London Buses: ➢ From 17 g/km to 76 mg/km engine out emissions ➢ 99% NOx reduction
References for further details	Johanessen (2018) [41] - Presentation title (vert-dpf.eu)

3.2. Locomotives and railcars

Locomotive and railways are a significant source of non-exhaust particles emitted during braking and abrasion of the catenary. In fact, particles are present between the disc and the pad and allow the adaptation of the speed between a fixed part (the pad) and a moving part (the disc). Without these particles, braking would not be effective. After a few revolutions, the particles come out and are emitted in the air.

The Tamic® concept, by Tallano [44], was created to capture particles at the source by suction, with the aspiration being carried out by a mini turbine. The Tamic® system was designed to be adapted, after adjustment, to different types of rail transport ranging from a subway train to a tramway. Tamic® develops a capture power of over 90%. Most of the particles emitted during braking are captured.

In March 2022, the Seoul Metropolitan Government selected Tallano Technology as the winner of its major international Research & Development competition to identify and select the world's most innovative solutions for improving the air quality of the Seoul metro. The first tests will be conducted in Korea very soon. Tallano is also cooperating with the Ile-de-France region (France), the Tamic® system has been adapted to the regional train (RER C). In China, the Tamic® system was adapted to a subway train in Shanghai [44].

(cf. 3.6. Non-exhaust emissions (NEE).

3.3. Inland waterway vessels

Post-treatment technologies: catalytic converters and diesel particulate filters

NOx reduction techniques such as Exhaust Gas Recirculation (EGR), and Selective Catalytic Reduction (SCR) can be used. The SCR reduces NOx emissions via a chemical reaction over a catalyst. In the case of marine fuel oil, the catalytic reaction enables to reduce drastically the NOx emissions with efficiency varying between 70% and 95% depending on the operating conditions. Diesel Particulate Filter (DPF) technology is used to reduce particulate matter (PM) emissions. The most effective type of DPF is the wall DPF, which is made of a ceramic honeycomb matrix with microscopic parallel channels that are alternately connected to each other.

The report [45] provides a brief analysis of the best available greening technologies on a European scale, as part of the Prominent project.

Alternatives fuels

Alternative fuels are also a simple and cost-effective alternative, requiring few engine modifications. Among the most frequently cited fuels are Gas to Liquid (GTL) and natural gas. The report [45] describes these alternative fuels.

GTL is a chemical process in which natural gas is converted to gasoline or diesel fuel. The conversion results in synthetic super clean liquid fuels. The final product is easier to transport and targets wider markets of petroleum products. This increases the energy efficiency per cubic meter.

According to CEMEX (personal communication), which is a supplier of building materials, the use of GTL allows a reduction of at least 20% of fine particle emissions and 15% of NOx compared to conventional diesel fuel. No modifications are required to conventional engines; however, its price would be 10% higher than standard fuels [45].

LNG is a natural gas that has been converted into a liquid through a natural gas cooling process and kept at atmospheric pressure. It occupies one six-hundredth of the volume of natural gas at atmospheric pressure. There are different possible configurations to equip a ship with LNG propulsion:

- 80% LNG and 20% diesel dual fuel engine: diesel engine converted for LNG use.

- Dual fuel engine 99% LNG and 1% diesel: engine fully optimized for LNG use. Can still run on 100% diesel. Widely used in coastal and ocean freight transport.

- LNG spark ignition engine: purely LNG engine and cannot use diesel fuel.

- Gas-electric engine: the latest development in river freight transport, it uses one or more LNG engines that drive electricity generators (gensets). The electric energy then feeds an electric motor that drives the boat.

In comparison to diesel, using LNG allow to achieve a reduction of 70% and 95% of NO_x and particulate matter emissions, respectively. Although CO_2 emissions can be lowered by 20 to 25%, 0% of GHG is saved due to relatively high CH_4 slip.

HVO (Hydrotreated Vegetable Oil) is a blend of paraffins with a composition similar to GTL and Biomass To Liquid (BTL) fuels. HVO is not to be confused with Biodiesel. The raw material of HVO consists of renewable sources, which can be plant or animal residues from the food industry or residues from the production of vegetable oils. Furthermore, HVO is considered climate neutral. According to [46], HVO would be an effective solution for reducing emissions of CO_2, PM and NOx from inland waterway transport (Table 43).

Electric hybridization

Electric hybridization has advantages depending on the type of configuration, hybridization and 100% electric configuration (cf. 3.1.2. Electric hybridization). Electrification allows to reduce the mechanical propulsion to the strict necessary and to reach a higher engine efficiency (because the efficiency of the electric motor is higher). Moreover, the integration of an electric motor implies less fossil fuel used and therefore, less pollutant emissions.

The costs compared to the purchase of a new thermal propulsion are higher (about 20% more expensive for all types of boats) but the advantages in terms of component size (electric motor takes up significantly less space than the main engine with an internal combustion engine) and energy efficiency are much higher. The efficiency of converting electrical power into movement is about 85 % compared to diesel engines with an efficiency of about 40 %. In manoeuvring, the gains in consumption are constant whatever the type of boat (about 20%). These figures are indicative but show the advantages of this solution despite the financial barrier [46].

In addition, hybridization has a high level of maturity having already multiple applications in other types of transport on the sea or near ports (waiting and harbour lay, cargo handling, manoeuvring, transit). Given the technical requirements and composition to the European fleet families, it is estimated that hybridization could be applied to 10 to 50% of the fleet [45].

Hydrogen: fuel and fuel cell

Hydrogen is an effective way to replace fossil fuels and thus to decarbonize the transport sector by reaching almost zero pollutants emissions. As mentioned in paragraph 3.6. on “Hydrogen for on-road vehicles”, the hydrogen sector is facing numerous challenges. Nevertheless, several European projects are currently focusing on fuel cell-based propulsion systems onboard inland waterway vessels to demonstrate the benefits of hydrogen in inland waterway vessels:

- H2SHIPS (2019-2022) is a North-West INTERREG project which aims to demonstrate the technical and economic feasibility of hydrogen bunkering and propulsion for shipping. In the framework of this project, a new hydrogen powered port vessel will be built in Amsterdam and in Belgium. After the end of the project, a plan for the implementation of a hydrogen pilot on the river Seine in Paris will be done [47].

- As part of the European Flagships Program, the French "Compagnie Fluviale de Transport" is designing a hydrogen fuel cell boat which will transport goods on the Seine (Paris region). Starting at the end of 2021, an operational demonstrator running on compressed hydrogen fuel cells will run for eighteen months. The aim of the project is to measure the ecological, technological, and economic relevance of the renewable hydrogen fuel cell [48]. As mentioned by the "Compagnie Fluviale de Transport", the green hydrogen will be produced by electrolysis of water with an electric current coming from at least 50% of renewable energies. This green energy is still expensive compared to Diesel (as shown on Figure 13) but should drop as the market grows.
- The Implementation of Ship Hybridization (ISHY) is an INTERREG project (2019-2022) aiming at the development, testing and validation of technical tools and socio-economic models for the implementation of hybrid and hydrogen fuel cell technologies in vessels and ports. In part of this project, the following pilots will be realized: a Crew Transfer Vessel (CTV) with hydrogen propulsion system, the retrofitting of an inland barge with a hydrogen-based propulsion system and the construction of a new passenger vessel with a full hydrogen propulsion system [49].

Emission reduction and cost of alternative fuels

LNG, GTL, HVO and PTL (Power to Liquid) are assumed to be used with a Stage V engine and compared to the fleet in 2015 (Table 43).

Table 43: Emission reduction potential of alternative fuels with ideal upstream chains [46]

Fuel	CO_2	NO_X	PM
Battery	-100 %	-100 %	-100 %
Hydrogen in fuel cells	-100 %	-100 %	-100 %
Bio-Methanol in fuel cells	-100 %	-100 %	-100 %
LNG	-13 %	-84 %	-97 %
Hydrogen in ICE	-100 %	-84 %	-100 %
GTL	-0 %	-84 %	-97 %
HVO	-100 %	-84 %	-97 %
PTL	-100 %	-84 %	-97 %

The "Battery" line corresponds to the case of 100% electrification of the propulsion. Other technologies are being studied such as "hydrogen in fuel cells", "bio-methanol in fuel cells" and "hydrogen in ICE". "PTL" is another type of synthetic fuel produced entirely from renewable resources. Despite growing interest in these technologies, they are still less mature than LNG, GTL and HVO (there are very few PTL refineries, for example, but with growing interest in these innovative fuels, their production capacity could increase).

According to [46], the operational prices for each type of fuel, projected to 2050 under different assumptions, are as follows:

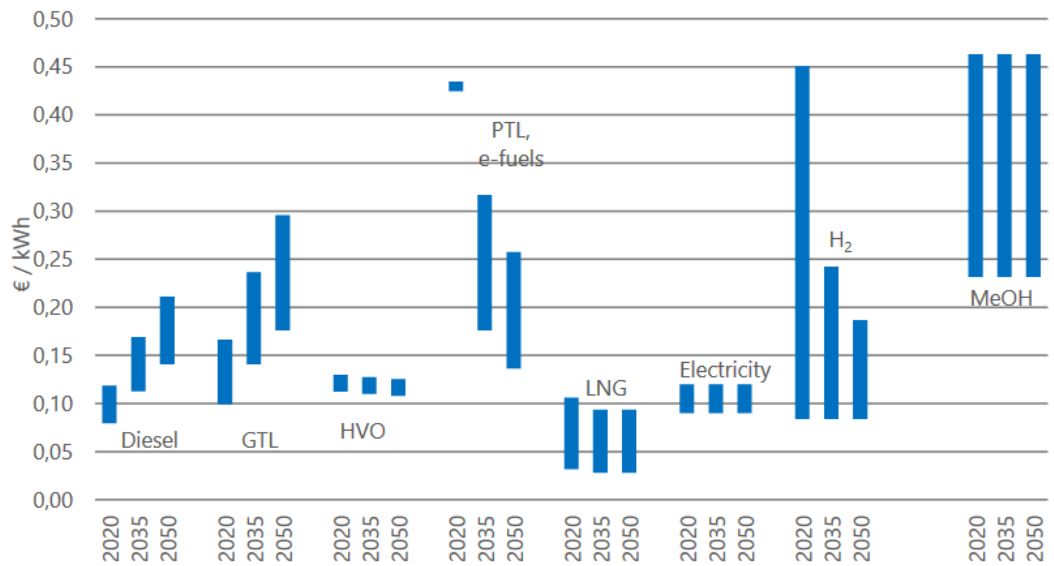

Figure 13: Operational costs per kWh for different energy carriers in inland transport [46]

The prices per kWh are more affordable for HVO, electricity and LNG fuels. However, they must be put into perspective in relation to the energy supplied. Indeed, as an example hydrogen is very unaffordable per kWh in the first years, but then become closer to the other fuels.

Engine replacement: Retrofitting

The retrofit operation consists in making modifications to the boat, after it has been ordered or after a period of use. To reduce emissions of NRE engines, the retrofit action may consist in replacing the engine by a newer one, through a marinization operation, as example, by installing a EURO VI road vehicle engine, in order to align with the new directives of the European regulation EU 2016/1628 [22]. A factsheet on Euro VI truck and NRE engines has been published by Interreg Danube Transnational Programme [50].

Thus, several solutions are available for retrofitting:

- Stage V and EURO VI engines,
- Diesel or LNG hybrid electric propulsion systems,
- Hydrogen combustion engines,
- Battery-powered electric motor,
- Fuel cell system.

Each of these types of propulsion requires varying degrees of investment and technological and operational barriers to be overcome. For a retrofit consisting of marinizing a conventional engine from the road that complies with recent standards, gains in fuel consumption and pollutant emissions are already significant and make it possible to align with the Stage V standard.

3.4. Motorcycles and mopeds (L-Category)

To comply with the new Euro 5 standard, several technologies are available like the 3-ways catalysts with oxygen sensor controls, electric engine management systems, advanced fuel injection and variable valve timing and lift technologies (ACEM [25]).

At this point, there is only little interest in hybrid technology for Motorcycles and moped firms as the Euro 5 limits can be achieved without resorting to hybrid technology [51].

Electric vehicles are developing but concern mainly small vehicles for urban purpose.

3.5. Non-exhaust emissions (NEE)

Emission reduction technologies have led to a reduction of exhaust emissions over time. However, these technologies focused on exhaust emissions (i.e. particle filters can capture a significant share of particles from the tailpipe, SCR reduced NOx emissions…). This is why, NEE particles emitted from abrasion of brake, road and tyres have been taking greater importance compared to total emissions (Figure 14).

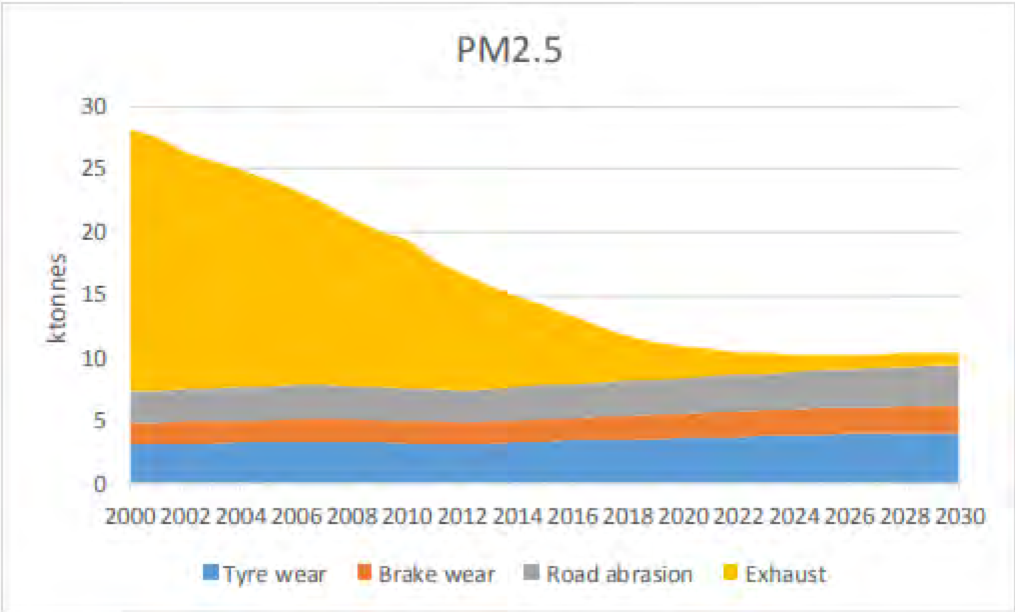

Figure 14: Projected $PM_{2.5}$ emissions from road transport for UK [52]

To reduce the impact of NEE, several technical options are available (EEA, 2021 – [52]):

- Reducing formation of particles,
- Trapping particles at the source after formation,
- Removing particles from the environment.

The first strategy to reduce NEE is to reduce the volume of traffic, lower the speed where traffic is free-flowing and promote eco-friendly driving [53].

All on-road vehicles, regardless of their engines, emit non-exhaust particles. Thus, despite having no tailpipe emissions, BEVs still produce particulate matter (PM). In fact, tyre wear accounts for up to 50% of PM NEE from road transport. As electric vehicles are approximately 24% heavier than conventional combustion engine vehicles, their PM emissions from tyres and road abrasion could be greater than those from ICE (internal combustion engine) vehicles. It is therefore very important to consider the NEE not only from ICE vehicles, but also from electric vehicles.

Technologies to trap NEE particles are presented in the next chapters. These technologies that capture/absorb NEE emissions at the source are recent and there are very few on the market.

Technology to reduce NEE from tyre: "The Tyre Collective"

The Tyre Collective, a consortium of students from the Imperial College of London, aims to reduce NEE of particles by capturing the tyre particles at the source. The device is fitted to the wheel and uses electrostatics to collect particles as they are emitted from the tyres, by taking advantage of various air flows around a spinning wheel (Figure 15). The prototype can collect 60% of all airborne particles from tyres, under a controlled environment on their test rig [54].

Figure 15: the tyre collective system. Photo: [54]

After collection, the particles are separated depending on their sizes. Particles with a diameter lower than 50 µm could be reused in new tyre walls.

There is still a lack of data available on this promising technology.

Technology to reduce NEE from brake: Tallano technology

Tallano technology

TAMIC® system by Tallano was designed to trap at least 80% of brake particles directly at the pad-disc interface without altering braking efficiency. It is composed of a brake calliper? especially designed for the integration of grooved pads and of an aspiration system where brake particles are trapped. The aspiration system relies on pipes connected to a turbine equipped with a high efficiency filter. The whole system is driven by an embedded electric brushless motor (Hascoët and Adamczak, 2020 – [55]).

All means of transport are concerned by the release of fine particles into the air during braking, including electric vehicles. The particles capture solution developed by Tallano Technology is scalable and adaptable to all type of vehicles such as small city cars, saloon cars, trucks, bus and railways.

The vacuum system is supposed to be lightweight and self-contained and does not affect vehicle performance. Tamic® reduces particle emissions during braking by more than 90% without impacting the vehicle performance. Most of the particles are retained by the Tamic® system, whose filters must be changed every two years (or every 30,000 km) and then recycled [56].

Brake composition

In the report [57], the contribution of brake formulation to the amount of particulate matter emitted is emphasized. Thus, Non-Asbestos Organic (NAO) brake pad formulation, which is more common in Japan and the U.S. induced a 45-48% lower particles mass emission than Low Metal (LM) content brake formulations commonly used in Europe. The cost of NAO brake pads is mentioned as a barrier to their implementation [57].

4. Summary table

This summary table was provided to the GPG in 2021.

Pag.	Reference and priority	Potential update	Description	Potential Applicability (%)	Potential ELVs
19	Table 1: Limit values for passenger cars and light-duty vehicles	**Update Index 1** Inclusion of: • Euro 6b and 6c [1] 6d-TEMP and 6d [6].	To be in line with the Commission Regulation (EU) No 459/2012 [1] and with Commission Regulation (EU) 2017/1347 [6]. Euro 6c (WLTP measurements), Euro 6d-TEMP and Euro 6d (RDE measurements)	100% for new vehicles. Implementation dates for new vehicles in ANNEX III [6].	Refer to [1] for Euro 6b and 6c and to [6] for 6d-TEMP and 6d. Inclusion of Conformity factors for Euro 6c & Euro 6d-Temp. Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.
20	Table 2: Limit values for heavy-duty vehicles steady-state cycle load-response tests	**Update Index 1** Inclusion of PM number	To be in line with the Regulation (EC) No 595/2009 [10].	100% for new vehicles (from 31 December 2012)	Worldwide harmonised steady state driving cycle /Compression Ignition WHSC (CI): 8.0×10^{11} #/kWh
21	Table 3: Limit values for heavy-duty vehicles — transient cycle tests	**Update Index 1** Inclusion of PM number	To be in line with the Regulation (EC) No 595/2009 [10].	100% for new vehicles (from 31 December 2012)	Worldwide harmonised transient driving cycle (WHTC) for PI (Positive Ignition) & CI (Compression Ignition): 6.0×10^{11} #/kWh
30	Table 4: Limit values for diesel engines for non-road mobile machines (NRMM), agricultural and forestry tractors (Stage IIIB)	**Update Index 1** Delete table (old regulation Stage IIIB).	No updated EF for Stage IIIB. Now in Commission Regulation 2016/1628 [22].	No updated EF for Stage IIIB in Commission Regulation 2016/1628 [22]. Proposition to delete table (old regulation Stage IIIB).	Proposition to delete table (old regulation Stage IIIB).
30	Table 5: Limit values for diesel engines for non-road mobile machines, agricultural and forestry tractors (Stage IV)	**Update Index 1** Replace (Stage IV) by (Stage V) in the table title	To be in line with Annex II the Commission Regulation 2016/1628 [22]. Consider the following updates: • for Net power (P) (kW) categories P ≤ 560 o Add « PN #/kWh » limit values o Stringent PM ELV • Add P > 560 Net power (P) (kW) category and corresponding EFs.	100% for new NRMM Timetable for the application of this Regulation in respect of EU type-approvals and placing on the market in Table III, ANNEX III of the regulation.	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.
31	Table 6: Limit values for spark-ignition engines for non-road mobile machines	**Update Index 1** Update the formatting and the way the table is displayed	To be in line with Annex II the Commission Regulation 2016/1628 [22]	100% for new NRMM	Refer to informal report developed by TFTEI, on the review of

Pag.	Reference and priority	Potential update	Description	Potential Applicability (%)	Potential ELVs
					technical annexe VIII for complete tables of values.
33	Table 7 Limit values for engines used for propulsion of locomotives	**Update Index 1** ERROR detected: tables Railcars (RLR) and Locomotives (RLL) are inverted. Delete “locomotives” and add “railcars” to the table title. Include (Stage V) in the table title and make the following updates to the table: Stringent PM ELV Add PN #/kWh	To be in line with Table II-8/Annex II of the Commission Regulation 2016/1628 [22].	100% Mandatory date of application of this Regulation for Placing on the market of engines = 01/01/2021	Update Particulate matter EF = 0.015 g/kWh (instead of 0.025) Add PN = 1×10^{12} #/kWh
34	Table 8 Limit values for engines used for propulsion of railcars	**Update Index 1** ERROR detected: tables Railcars (RLR) and Locomotives (RLL) are inverted. Delete “railcars” and add “locomotives” to the table title. Include (Stage V) in the table title.	Table II-7/ Annex II of the Commission Regulation 2016/1628 [22].	100% Mandatory date of application of this Regulation for Placing on the market of engines = 01/01/2021	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.
35	Table 9 Limit values for engines for propulsion of inland waterways vessels	**Update Index 1** Replace current table (Stage III A values) for Stage V by including: • IWA (auxiliary engines) • Update to Stage V	To be in line with Tables II-5 and II-6 from Annex II of the Commission Regulation 2016/1628 [22]. Proposed new title: “Limit values for propulsion and auxiliary engines of inland waterways vessels (Stage V)” The Stage V requirement limits the emission of Carbon Monoxide (CO), Hydrocarbons (HC), Nitrogen Oxides (NOx), Particulate Matter (PM and Particle Number (PN).	100% In 2019, all new engines for inland waterway vessels need to comply with the Stage V emission requirements set by the EU for NRMM.	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.
37	Table 10 Limit values for engines in recreational crafts	**Update Index 1** Display more disaggregated ELV (in terms of Rated Engine Power) [22]. * Exhaust emission limits for compression ignition (CI) engines * Exhaust emission limits for spark ignition (SI) engines	Update according to values from Table 2 and Table 3; ANNEX I of the Directive 2013/53/EU [23].	100% Values applying from 18 January 2016	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.
39	Table 11 Limit values for motorcycles (> 50 cm^3; > 45 km/h) Table 12 Limit values for mopeds (<50 cm^3; < 45 km/h)	**Update Index 1** Inclusion of Euro 4 and 5 [23]	Update according to Annex VI of the Regulation (EU) No 168/2013 [23], disaggregating into the categories available in the regulation: Two- or three-wheel vehicles, quadricycles, enduro and trial motorcycles as well as heavy all terrain quads.	100%Timetable for the application of this Regulation in Annex IV of Regulation (EU) No 168/2013 [24]	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.

Pag.	Reference and priority	Potential update	Description	Potential Applicability (%)	Potential ELVs
42	Table 13 Environmental specifications for marketed fuels to be used for vehicles equipped with positive-ignition engines Type: Petrol	**Update Index 1** To be in line with [27], update and display more disaggregated tables for: • premium unleaded 95 (specifications n° 1-2-10 of the CSR); • premium unleaded 98 (specifications n° 1-3-09 of the CSR); premium unleaded 95-E10 (specifications n° 1-4-11 of the CSR);	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.	100%	Refer to informal report developed by TFTEI, on the review of technical annexe VIII for complete tables of values.

5. Conclusions

The review work of the Technical Annexes (TA) to the Amended Gothenburg Protocol carried out by TFTEI, in 2021 and the beginning of 2022, specifically concerned:

1. Annex IV: limit values for emissions of sulphur from stationary sources
2. Annex V: limit values for emissions of nitrogen oxides from stationary sources
3. Annex VI: limit values for emissions of volatile organic compounds from stationary sources
4. Annex VIII: limit values for fuels and new mobile sources
5. Annex X: limit values for emissions of particulate matter from stationary sources
6. Annex XI: limit values for emissions of volatile organic compounds of products

Key message:

From a technological point of view, potential new ELVs have been identified as technically feasible/consistent with the new/upgraded technologies now available, which would allow significant emission reductions, in many of the sector/fuel/technology combinations.

For what concerns fuels and new mobile sources:

In Annex VIII, the abatement techniques are rather the same compared to the techniques considered during the previous review of the GP, in 2008-2010, but, in many cases, their performances have evolved, and the innovations introduced significantly improved the abatement efficiency of the technologies and/or expanded their domain of application.

Updated limit values technically achievable have been identified for:

- Passenger cars and light-duty vehicles. Moreover, since the Dieselgate, independent real conditions testing is required before introduction to the European market.
- Heavy-Duty vehicles; with more stringent LV and the introduction of a limit value for particles number.
- Railcars with the introduction of a limit value for particles number.
- Inland waterway vessels, with more stringent LV and the introduction of a limit value for particles number.
- Recreational crafts.
- Motorcycles and moped (L-Category).

In the meantime, new technologies are developing as alternatives to diesel and gasoline for mobile sources: electricity, hydrogen, biomethanol, LNG, GTL, HVO and PTL…

Techniques to reduce non-exhaust emissions are also blooming. As technologies to reduce particles from exhaust emissions become increasingly efficient, particles from abrasion of brake, road and tyres have been taking greater importance compared to total emissions from mobile sources.

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