Non-exhaust emissions: Evaporation & Brake wear control

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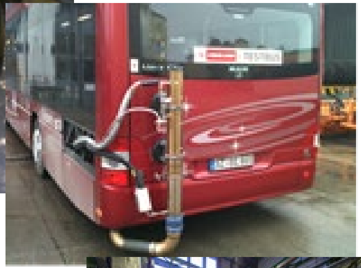
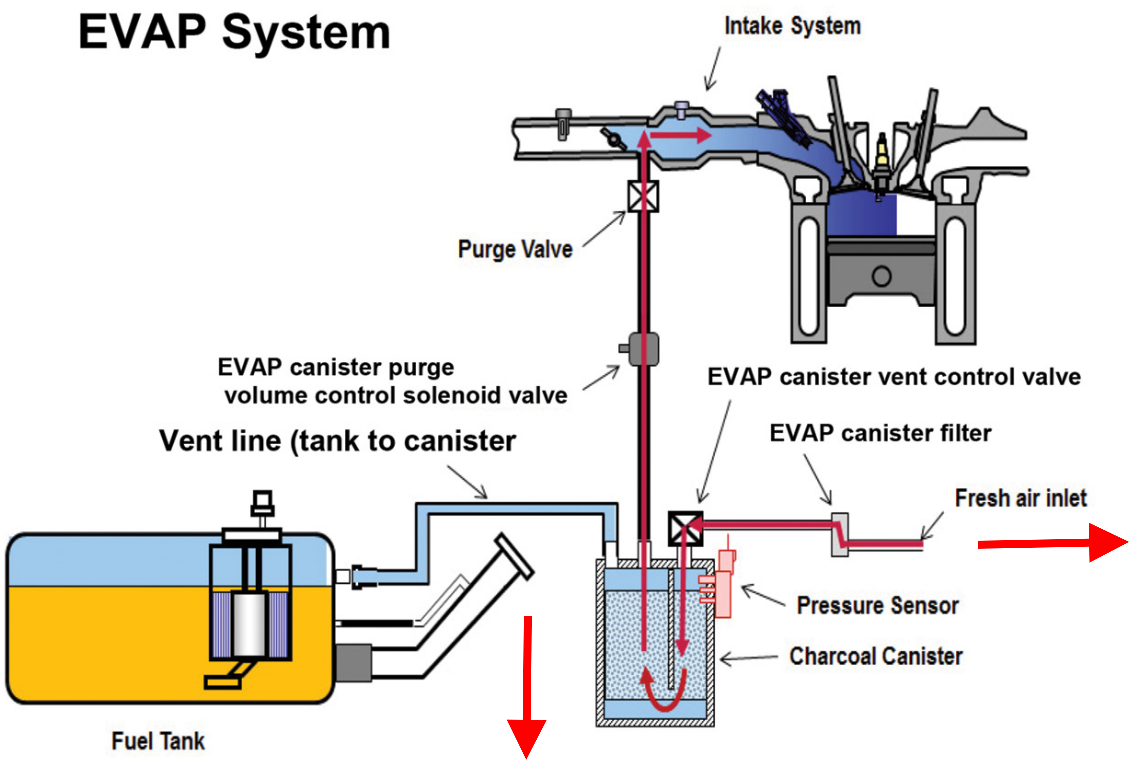



FUEL EVAPORATION

Open issues for evaporative emissions



Diurnal emissions

Emissions under extreme conditions not sufficiently controlled, e.g.:
- very short trips (purging might not be sufficient)
- very high ambient temperatures (heat waves, prolonged parking duration)

Running losses

- Currently not regulated in the EU
- Can be significant due to high temperature build-up in the fuel tank
- DT (from ambient temperature) ranging 2-8 °C for 1-hour trip (JRC tests) and increasing with driving time

Leakages

- Leaks not detected in the EU
- US data show that ~3% of vehicles have leaks greater than 1mm
- Emissions can be significant (several grams per day) depending on leak size

Refuelling emissions

- Most gas stations (over 500 m^3 annually) are Stage II compliant
- Certification efficiency is 85% but may be lower in practice (depends heavily on facility maintenance)

Euro 7 evap limits and technologies

	Emission limits	Technology
Diurnal emissions limit	0.50 g/day (48 h test, worst of 2 days)	• Increased canister capacity • High flow purge valve
	0.30 g/day (48 h test, worst of 2 days)	• Increased canister capacity • High flow purge valve • Low permeation fuel tanks
Refuelling emissions (ORVR)	0.05 g/L	• Increased canister capacity • High flow purge valve • Fuel system design (fill pipe, vent line, etc.)
Leak threshold	0.5 mm (~0.02 inch) diameter	• Pump system (active leak detection) • Passive leak detection (less accurate)

Testing conditions

	Testing conditions	Comments
Preconditioning	• Reduce drive time • Soak and drive temperature between 25 and 38°C	• Enforce more frequent purging • Exact temperature not defined to prevent tuning of purging strategy
SHED test	• 48-h diurnal test (+hot soak) remains as is	• Emission limit applies to worst of two days (+hot soak)
Running losses	• No test and hence no limit during certification	• Running losses effectively controlled by the technology used to achieve lower diurnal emissions
ISC and MaS	• Diurnal emissions (and indirectly also running losses) checked during ISC and MaS	
OBD leak detection	• Checked during PTI, ISC, MaS	

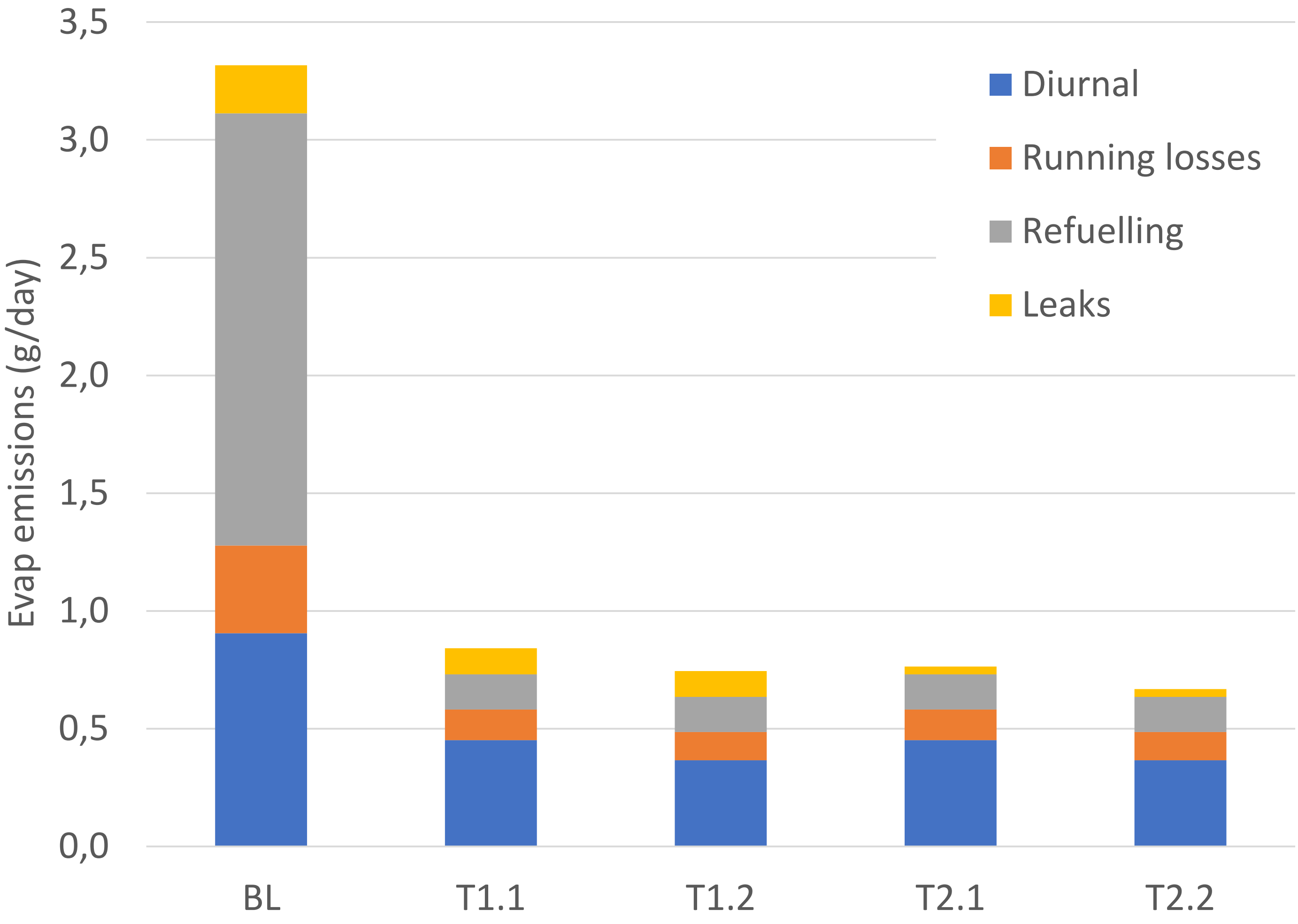
Euro 7 evap technology packages

Evap emissions source	Emission limit	Technology package 1		Technology package 2	
		1.1	1.2	2.1	2.2
Diurnal emissions	0.50 g/day (48 h test, worst of 2 days)	√		√	
	0.30 g/day (48 h test, worst of 2 days)		√		√
Refuelling emissions (ORVR)	0.05 g/L	√	√	√	√
Leak threshold	0.5 mm (~0.02 inch) diameter			√	√

Technology packages to meet evap requirements

Components	Technology package 1		Technology package 2	
	1.1	1.2	2.1	2.2
ORVR carbon canister	√	√	√	√
Anti spitback/vapour seal valve	√	√	√	√
Purge valve	√	√	√	√
Tank vent hose	√	√	√	√
Larger canister for 0.3g/test		√		√
Low permeability tank and hoses		√		√
Pump system for OBD leak check			√	√

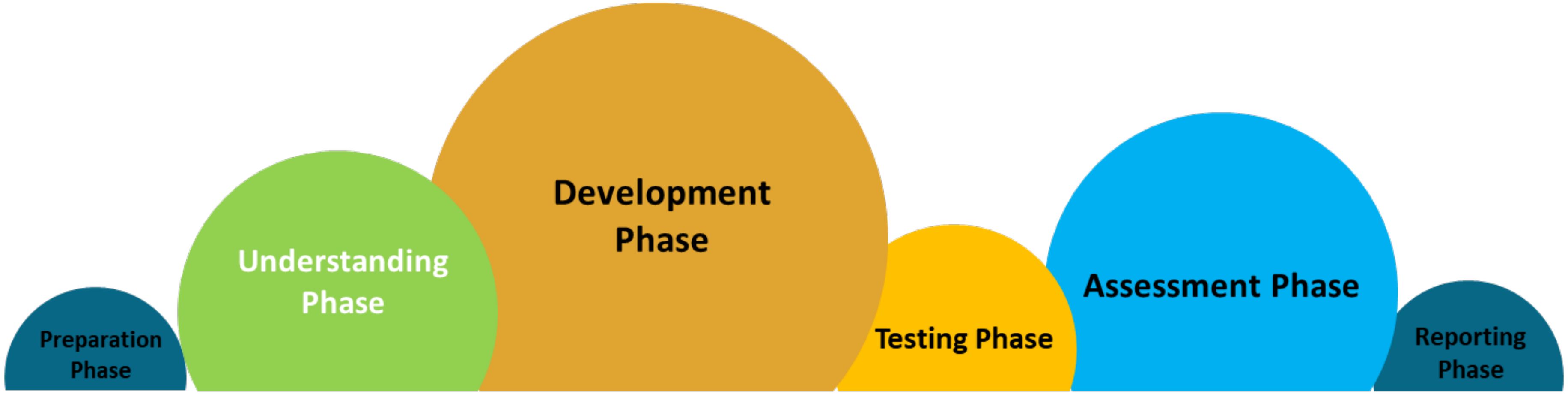
Emissions reduction potential



* Simulation results shown for a Euro 6d medium car, year 2030
Emissions reflect average EU conditions

BRAKE WEAR EMISSIONS

The GRPE – PMP procedure at a glance



Understanding Phase

Study of existing brake dyno configurations for brake PM & PN sampling and measurement

COMPLETED

Testing Phase

Application of the reuirements in an Interlaboratory study. Decisions on technical specifications

DEADLINE – DEC 2021

Reporting Phase

Publication of the PMP-Brake Protocol

DEADLINE – JUN 2022

Preparation Phase

Literature review & decision on test method approach

COMPLETED

Development Phase

Definition of minimum requirements for sampling and measurement of brake PM and PN emisssions

ON-GOING DEADLINE – JUN 2021

Assessment Phase

Assessment of the RR results. Refinements and finalization of the method specifications

DEADLINE – FEB 2022

Procedure and timeline presented by at the PMP Webconference on 24.03.2021

Emission levels from the AEI Guidebook

Table 3-5 TSP emission factors for source category 1.A.3.b.vi, road vehicle brake wear

Vehicle category (j)	TSP emission factor (g/km)	Range (g/km)	Quality code
Two-wheel vehicles	0.0037	0.0022 – 0.0050	D
Passenger cars	0.0075	0.0044 – 0.0100	B
Light-duty trucks	0.0117	0.0088 – 0.0145	B
Heavy-duty vehicles	Equation 6	0.0235 – 0.0420	B–C

Speed profile affects emissions

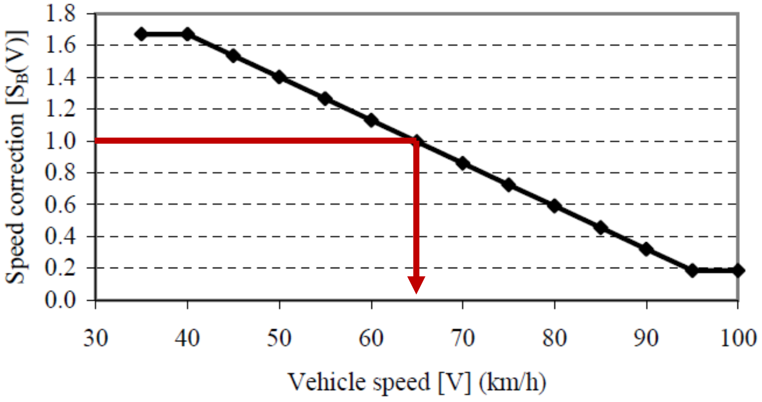


Table 3-6 Size distribution of brake wear particles

Particle size class (*i*)	Mass fraction ($f_{B,i}$) of TSP
TSP	1.000
PM_{10}	0.980
$PM_{2.5}$	0.390
PM_1	0.100
$PM_{0.1}$	0.080

Approx. 40% resides in the $PM_{2.5}$ range → health implications

Recent measurements on PM_{10} emission levels from brake wear

- ✓ AVL (Atmosphere – Mamakos et al. 2019) reported a PM_{10} EF of 4.5 mg/km per brake (LS Pad / Cast Iron Disc) over the WLTP-Brake cycle. This corresponds to approximately ***13 mg/km*** per vehicle
- ✓ Ford (Environmental Science and Technology – Zum Hagen et al. 2019) reported a PM_{10} EF of 4.6 mg/km per brake (LS Pad / Cast Iron Disc) over the short LACT cycle. This corresponds to ***13-14 mg/km*** at a vehicle level
- ✓ JARI (50th PMP – Hagino et al. 2019) presented a PM_{10} EF of ***11-12 mg/km*** per vehicle – depending on the dyno settings – (LS Pad / Cast Iron Disc) over the WLTP-Brake cycle
- ✓ CARB (SAE 2020-01-1637 – Agudelo et al. 2020) found PM_{10} EFs of ***9-13 mg/km*** per vehicle (LS Pad / Cast Iron Disc) over the CBDC cycle for two typical US fleet vehicles (F-150 and Toyota Camry)
- ✓ AVL-BMW (Atmosphere – Mamakos et al. 2021) found a PM_{10} EF of 5.6 mg/km per brake (Cu-free LS Pad / Cast Iron Disc) over the WLTP-Brake cycle. This corresponds to ~***17 mg/km per vehicle***
- ✓ TUI-Porsche-Audi (Atmosphere – Hesse et al. 2021) calculated a PM_{10} EF of 4.7 mg/km per brake (LS Pad / Iron Cast Disc) over the WLTP-Brake cycle. This corresponds to ***~14 mg/km per vehicle***. Lower PM_{10} EFs were found for other types of discs (i.e. Coated disc)

Summary conducted by Theo Grigoratos, JRC, PMP, 2021

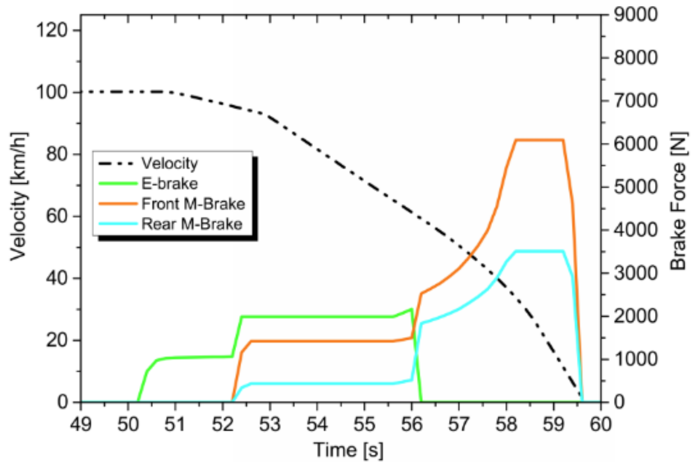
Confirming emission levels

- Based on recent evidence, average brake-wear PM_{10} emission level for conventional vehicles confirmed at ~**12 mg/km** (depending on national conditions) for the average passenger car in urban conditions
  - Scaled for heavier LCVs according to AEIG functions
  - Actual present emission levels are lower due to the presence of regenerative braking in current fleet vehicles (BEV, PHEV, HEV but also some conventional ones)
  - This corresponds to 30-50× exhaust emission levels from Euro 6d cars

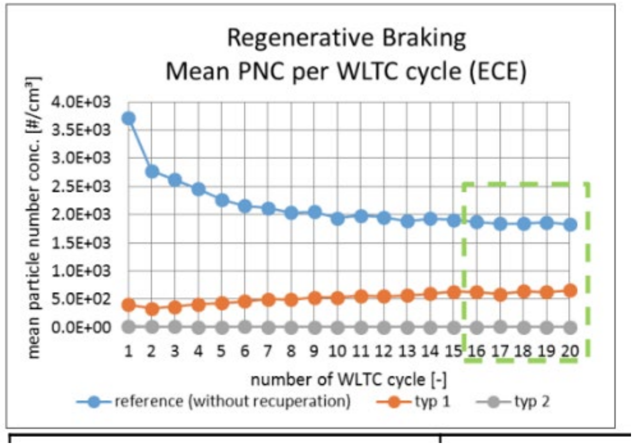
- Estimated EU27 contribution of brake wear to total road transport $PM_{2.5}$:
  - LDVs: 23% (2020) → 45% (2050)
  - HDVs: 13% (2020) → 27% (2050)

Future development of baseline emission factors

- Vehicle weight development (BEVs vs ICEs) may affect brake component size and wear rates
- Regenerative braking (RB) systems penetration
  - Could not find solid information on impact of regenerative braking on $PM_{2.5}$ (lower but how much lower? 30%?, 50%?, 80%?)
  - Not just one RB implementation in the market

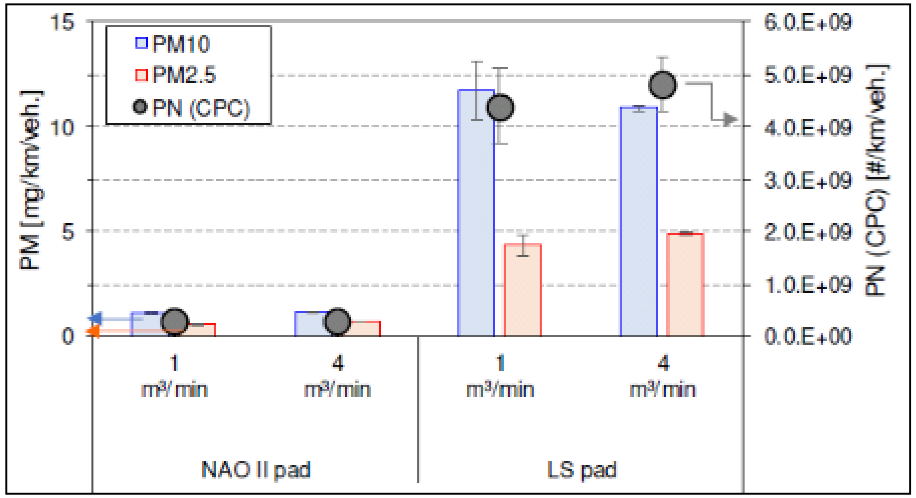


Xiao et al., 2017. Energies 2017, 10, 1875; doi:10.3390/en10111875



Augsburg et al., 2018, 48th PMP Meeting

- Non-asbestos organic (NAO) pads have shown to result in much less wear particles
  - SAE 2020-01-1637 (Agudelo et el. 2020): The front brakes of three vehicles typical of the US fleet were tested over the CBCD cycle on the dyno. PM and PN data for different configurations are given in the paper
  - ✓ PM_{10} EF (mg/km) of LS pads ~1.3 to 5 times higher compared to NAO. $PM_{2.5}$ EF (mg/km) of LS pads ~1 to 4 times higher compared to NAO.



- JARI (Hagino H.) reported measurements on LS and NAO pads (50th PMP, 2019)
  - ✓ PM_{10} EFs of LS pads ~10 times higher compared to NAO (14 mg/km vs. 1.2 mg/km)
  - ✓ $PM_{2.5}$ EFs of LS pads found to be ~5 times higher compared to NAO

Technologies to control emissions: Coated discs

- ✓ The H2020 LOWBRASYS Project reported ~10-15% lower PM_{10} EFs from brake couples featuring coated discs compared to similar brakes with conventional (Gray Cast Iron) discs. Similar emission performance has been observed for $PM_{2.5}$. This was attributed to reduced disc wear
- ✓ TUI-Porsche-Audi (Atmosphere – Hesse et al. 2021) reported more than 50% reduced PM_{10} EFs over the WLTP-Brake cycle with the application of a Coated Disc against a conventional Cast Iron Disc. This corresponds to ***~6 mg/km per vehicle*** vs. ***14 mg/km per vehicle***

Coated discs not widely spread in the market;

- there are already some applications available and continuous research
- great emission reduction potential expected
- cost of the solution is still unknown, especially for smaller vehicles

Technologies to control emissions: Particle collection

- Two different technologies at various stages of development
  - Method 1: Vacuum aspiration of particles
  - Method 2: Particle collection on filters
- Collection efficiencies according to suppliers:
  - Method 1: Up to 85%
  - Method 2: 20%(today) – 50%(future)
- Any of these systems may already find commercial application to retain clean rims (especially in luxury cars)

Possible technology packages and limits for Euro 7

- Implementation on cars and vans (no consideration yet for HDVs):
  - Option 1: NAO Pads mandatory to all vehicles
  - Option 2: NAO Pads + PM Collection devices to all vehicles
  - Expectation that all future heavier PCs/LCVs will have some sort of RB to address CO_2 emissions
- Achievable limits based on measured levels
  - Option 1 could be linked to a reduction of 40%
  - Option 2 could lead to a reduction of 60%

Over current levels per category

Case	PM_{10} (mg/km)	Technology
Current (2020) Reference	11	LS + 15% RB
Limit Option 1	7	NAO (+ X% RB)
Limit Option 2	5	NAO + PM Collection (+ X% RB)

Limits over WLTP-Brake for PCs, adjusted per weight for heavier LCVs

Tyre emissions contribution

Table 3-4 TSP emission factors for source category 1.A.3.b.vi, road vehicle tyre wear

Vehicle class (j)	TSP emission factor (g/km)	Uncertainty range (g/km)	Quality code
Two-wheel vehicles	0.0046	0.0042–0.0053	B
Passenger cars	0.0107	0.0067–0.0162	B
Light-duty trucks	0.0169	0.0088–0.0217	B
Heavy-duty vehicles	Equation 3	0.0227–0.0898	B–C

Table 3-5 Size distribution of tyre wear particles

Particle size class (*i*)	Mass fraction ($f_{T,i}$) of TSP
TSP	1.000
PM_{10}	0.600
$PM_{2.5}$	0.420
PM_{1}	0.060
$PM_{0.1}$	0.048

Similar order of magnitude to brake wear but different size distribution (larger particles)

Estimated EU27 contribution of tyre wear to total road transport $PM_{2.5}$:

LDVs: 27% (2020) → 52% (2050)

HDVs: 20% (2020) → 34% (2050)

Tyre/Road wear emissions - developments

No standardized – or commonly accepted – method for sampling and measuring tyre/road wear airborne PM and PN emissions. There are no known developments for such a method anywhere in the world.

H2020 Project – LEON-T Consortium

- ✓ The LC-MG-1-14-2020 call aims in addressing the issue of **particle emissions** and noise from tyres. Starting date is 01.06.2021 and LEON-T will work among others on the following topics.
  - Assessment and characterization of tyre wear particles emitted under different driving conditions both in the lab and on-road
  - Development of reliable and repeatable methodologies for the assessment of tyre emissions in the laboratory and on-road and for measuring tyre abrasion rate
  - Particles tracing and quantification in different environmental compartments with focus on microplastics emissions

Abrasion Rate

- ✓ DG-GROW is assessing proposals regarding the development of a tyre abrasion methodology. The winning consortium will be announced and the project is expected to start soon
- ✓ PMP's target remains to explore the possible correlation of tyre abrasion rate with PM_{10} and $PM_{2.5}$ emissions as soon as the method becomes available

Thank you!

(Advance apologies for possible spelling errors in the reports…)

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