Study on the Development and Filtration Performance of Gasoline Particulate Filters as a Promising Solution for PN23 and PN10 Control in Indian Two-Wheelers and Their Extension to Future Regulations

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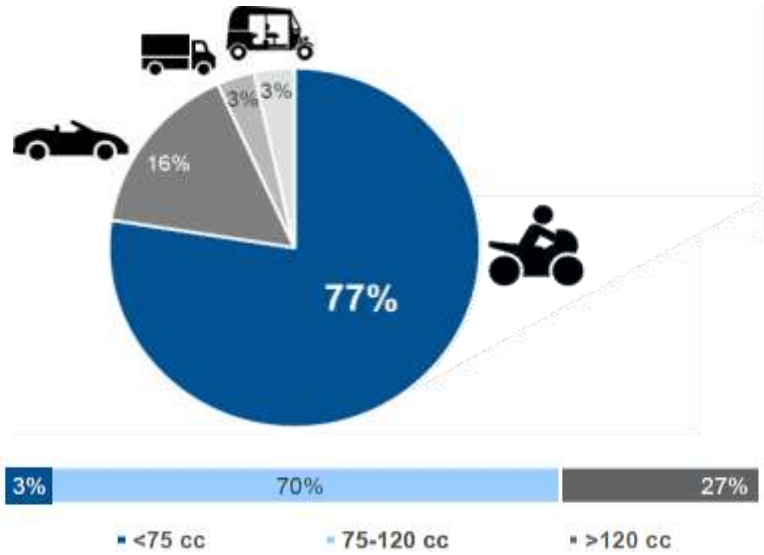
Outline

- Background
- Two-wheelers BS6.2 models for study
- Design Matrix / ATS system
- WMTC / Surrogate RDE cycle at various low temperatures
- GPF performance
- Conclusions

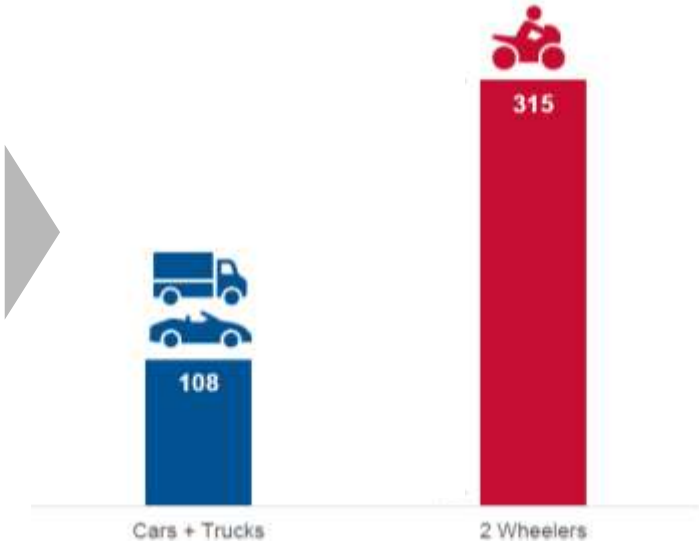
General - Corning (L4)

Two-wheelers: Opportunity for future particle emissions; address the other ¾ of vehicles emitting particles (so we can breathe easier)

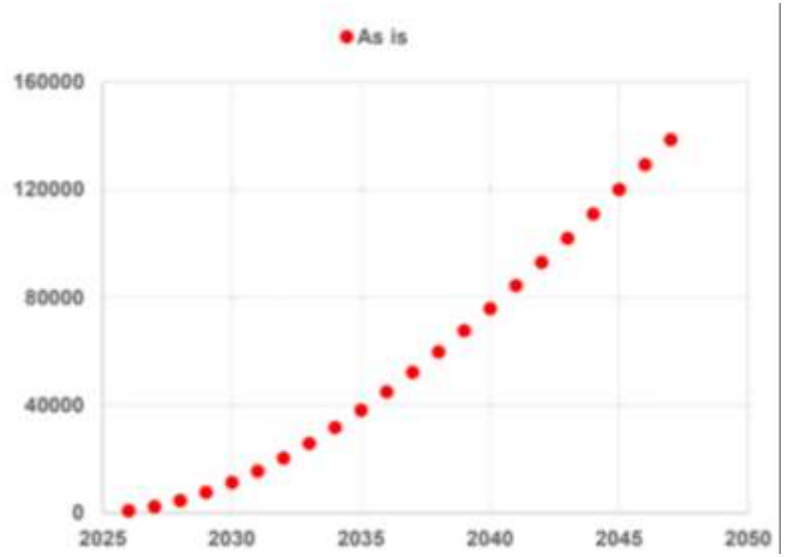
77% of vehicles sold annually in India are 2-wheelers



3x Annual distance travelled by 2-wheelers vs cars and trucks combined



~140 kt Projected cumulative particulate mass emissions from 2-wheeler fleet through 2047



Source: EMCA Research paper published by Corning

We tested five India two-wheelers (motorcycles and scooters) covering Class 1 and Class 2.1 (BS6.2/OBD II)

1 Class-1 [100cc]

2 Class-1 [125cc] Scooter

3 Class-1 [125cc]

4 Class-2.1 [160cc]

5 Class-2.1 [350cc]

India BS6 regulates PM mass for GDI two-wheelers – but not Particle Number (PN)

The Emission Standards for Bharat Stage-VI (BS VI)

for 2 wheeler vehicle models manufactured on 1st April 2020 as per GSR 889(E) dt.16th Sept 2016

Limit Values for 2 wheelers fitted with PI & CI engines: BSVI

	Vehicle Class	BS VI Emission Norms							
		CO mg/km	HC mg/km	NOx mg/km	NMHC mg/km	PM mg/km	EVAP mg/test	OBD	Durability mileage (km) Type V
PI Vehicles	1 & 2-1	1000	100	60	68	4.5*	1500	STAGE I & STAGE II***	20000
	2-2	1000	100	60	68	4.5*			
	3-1 & 3-2	1000	100	60	68	4.5*			35000
CI Vehicles	All	500	100	90	68	4.5*	-		35000
	DF (for all classes)	1.3	1.3 (SI) 1.1 (CI)	1.3 (SI) 1.1 (CI)	1.3 (SI) 1.1 (CI)	1.0 (CI)	300**	-	-

* Applicable to gasoline direct injection (DI) engines only.

**Fixed DF of 300 mg/test shall be added to SHED test results. Alternative to fixed DF, manufacture may opt for ageing of evaporative emission control devices as per procedure specified in AIS 137 and as amended time to time.

*** OBD STAGE II will be applicable from 1st April 2023

PI= Positive Ignition CI= Compression Ignition

Mass Emission Standards (Bharat Stage VI) for 2 wheelers with Spark Ignition engines (Vehicles with cc ≤ 50 and Vmax ≤ 50 km/hr)

Pollutant	TA=COP norms mg/km	Deterioration Factor (D.F.)	Test Cycle (Cold Start at T=0 sec)
CO	500	1.2	IDC as per AIS137
HC	350	1.2	
NOx	150	1.2	

Source: ARAI

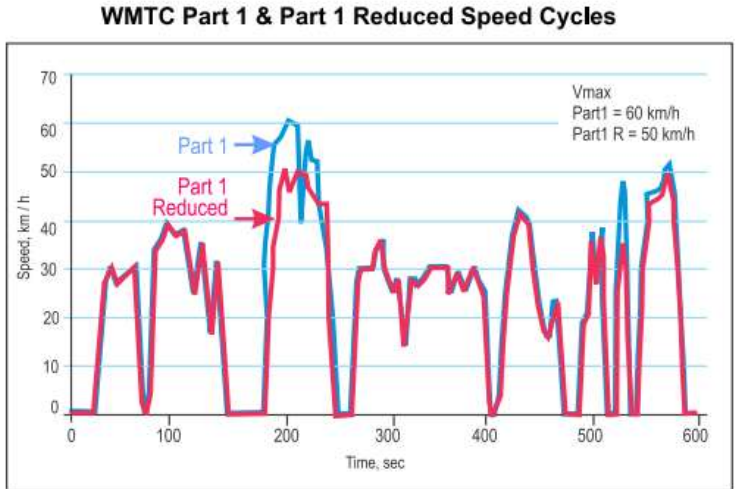
India two-wheeler WMTC requirements: Class 1: 50 km/h max.speed | Sub-Class 2-1: 82.5 km/h max.speed

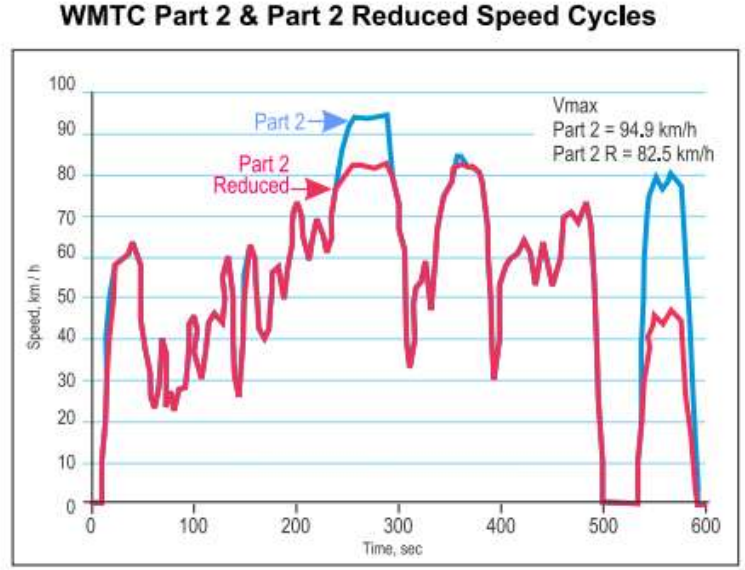
Classification of Vehicles and Weighting Factor

	Definition of class	WMTC Cycles	Weighting Factors
Class 1	Vehicles that fulfill the following specifications belong to class 1 : 50 cm³ < engine capacity < 150 cm³ and Vmax ≤ 50 km/h or engine capacity < 150 cm³ and 50 km/h <Vmax< 100 km/h	Part 1 Reduced Speed Cold followed by	W1:30%
		Part 1 Reduced Speed Hot	W2:70%
Sub Class 2-1	Vehicles that fulfill the following specifications belong to sub class 2-1: Engine capacity < 150 cm³ and 100 km/h ≤Vmax< 115 km/h or Engine capacity ≥150 cm³ and Vmax< 115 km/h	Part 1 Reduced Speed Cold followed by	W1:30%
		Part 2 Reduced Speed Hot	W2:70%
Sub Class 2.2	Vehicles that fulfil the following specifications belong to sub class 2 - 2 : 115 km/h ≤ Vmax< 130 km/h	Part 1 Cold followed by	W1:30%
		Part 2 Hot	W2:70%
Sub Class 3-1	Vehicles that fulfill the following specifications belong to sub class 3 - 1 : 130 km/h ≤ Vmax< 140 km/h	Part 1 Cold followed by	W1: 25 %
		Part 2 Hot followed by	W2: 50%
		Part 3 Reduced Speed	W3: 25%
Sub Class 3-2	Vehicles that fulfill the following specifications belong to sub class 3 - 2 : Vmax ≥ 140 km/h	Part 1 Cold followed by	W1: 25 %
		Part 2 Hot followed by	W2: 50%
		Part 3	W3: 25%

Source: ARAI

WMTC Test Cycles





Objectives and Experimental Approach of our Study

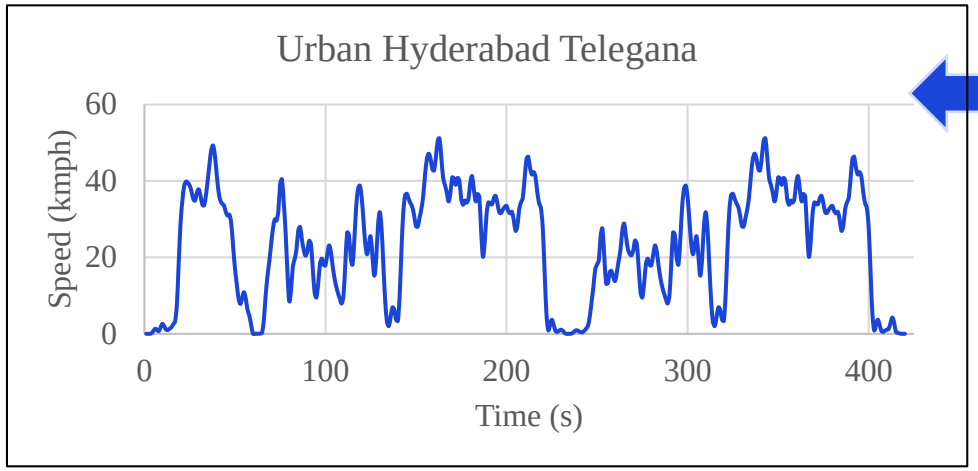
Objective

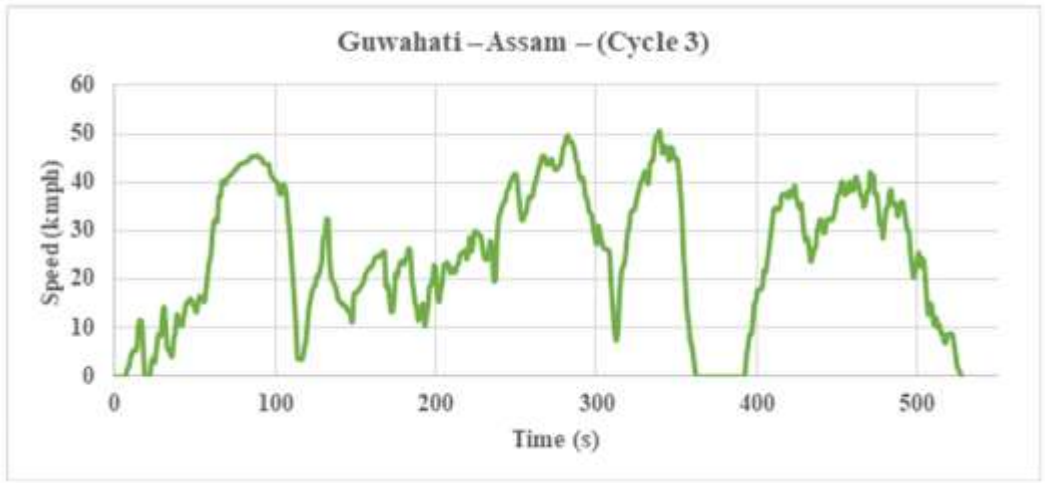
Evaluate particulate (PN23/PN10) emissions of two-wheelers under WMTC and real-world driving conditions, and how far gasoline particulate filters (GPF) help to reduce them

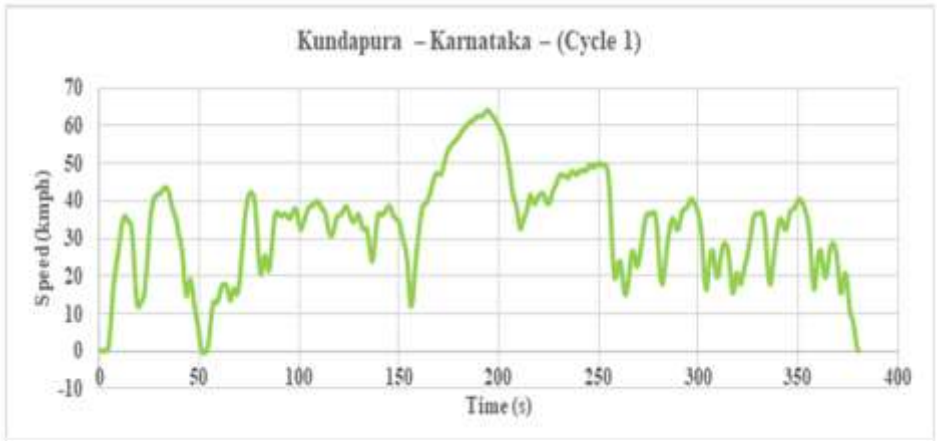
Experimental Approach

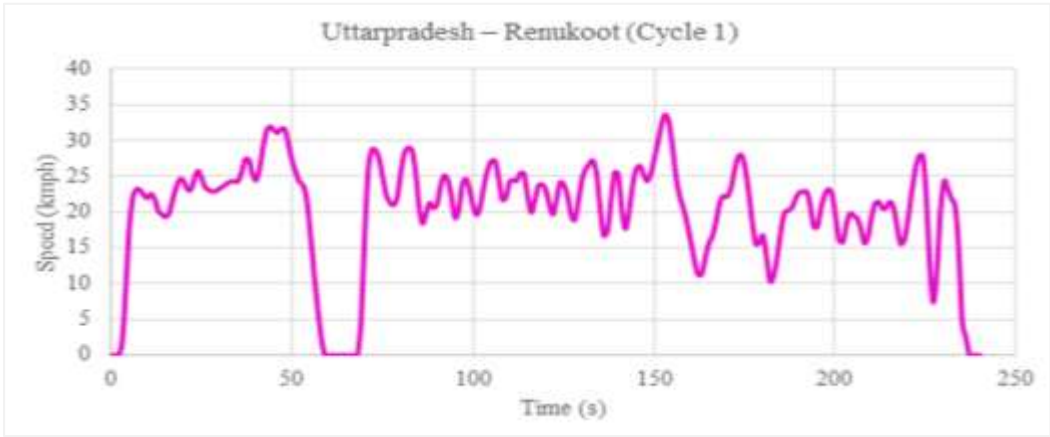
- Program included **5 purchased BS6.2 OBD II (MY 12/2025) motorcycles** representing different classes of 2-wheelers
  - Class 1: 100cc and 125cc motorcycles, and 125cc Scooter;
  - Class 2.1: 160cc and 350cc motorcycles
- Testing included **2 types of exhaust systems**:
  - OEM production exhaust system with **TWC only**
  - OEM exhaust system with TWC and retrofitted uncatalyzed **GPF**
  - No changes to OBD or vehicle sensors
- Different test cycles and conditions
  - **WMTC** and a **surrogate RDE** cycle
  - Various temperatures **23°C** as well as potential RDE conditions **5°C / 0°C**
  - One test with **added load** (60kg) representing the real-world condition of a passenger
- Emission measurements included PM (MSS), PN23/PN10, gaseous emissions

Also selected a surrogate RDE test cycle: Urban cycle programmed on Chassis Dynamometer (CD)







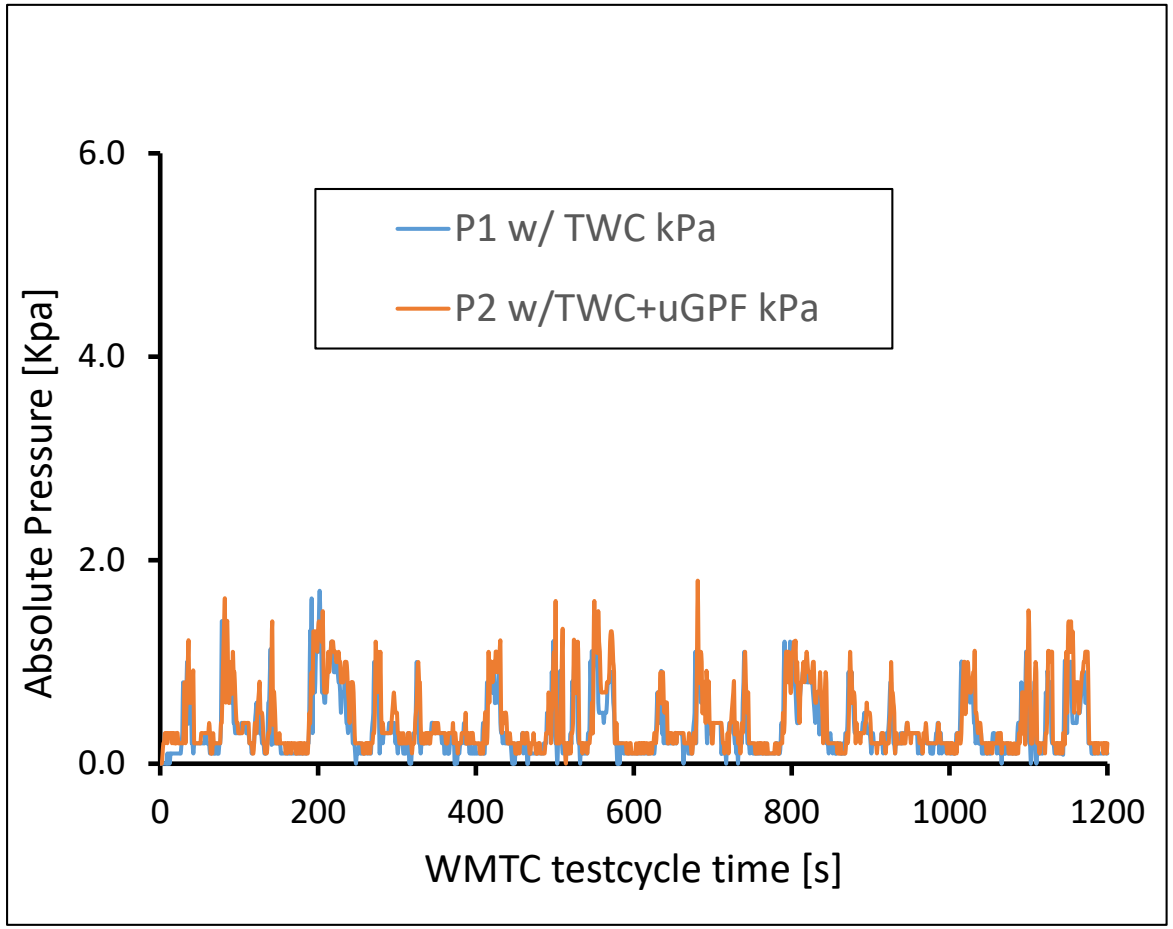


Source: Technical Report “Electric 2-wheeler drive cycle-based drivetrain sizing: A comprehensive analysis” 26 March 2022

Successful prototype integration of an uncoated GPF downstream of the existing OEM metallic TWC

uGPF- Uncatalysed/ Uncoated Gasoline Particulate Filter [Ceramic]
TWC-Three Way Catalyst [Metal]

Two-wheeler system backpressure remains comparable after GPF integration

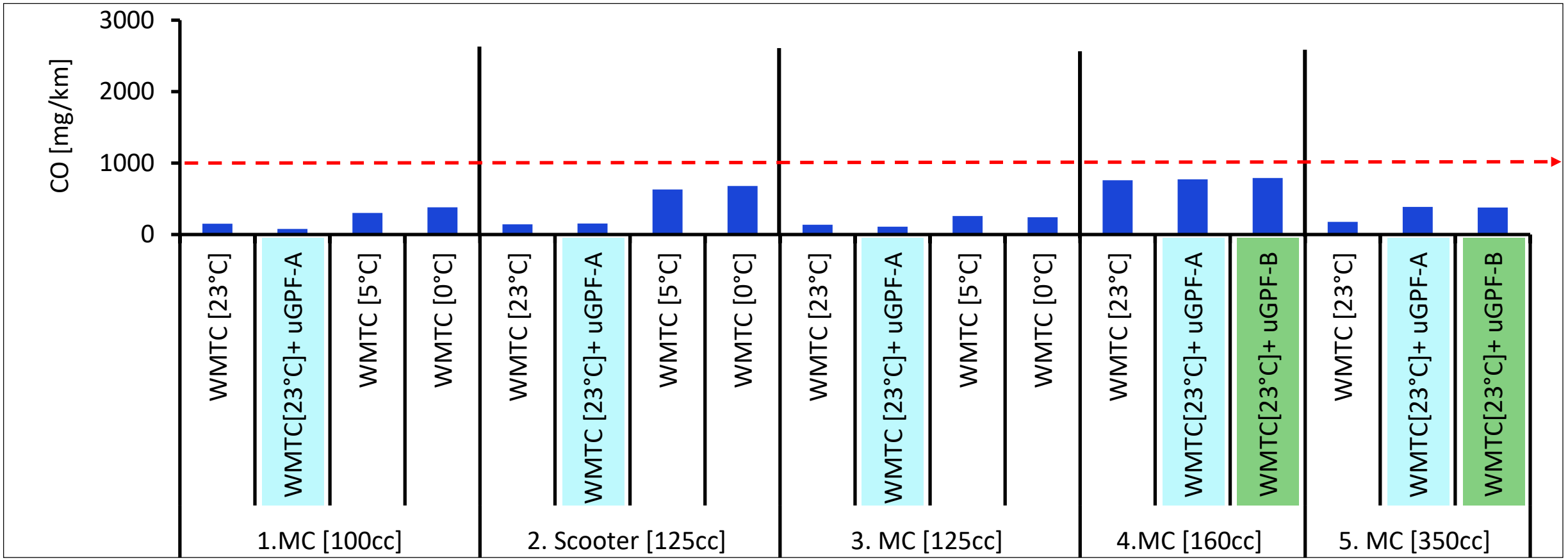


P1 Absolute Pressure sensor

P2 [w/GPF] Absolute Pressure sensor

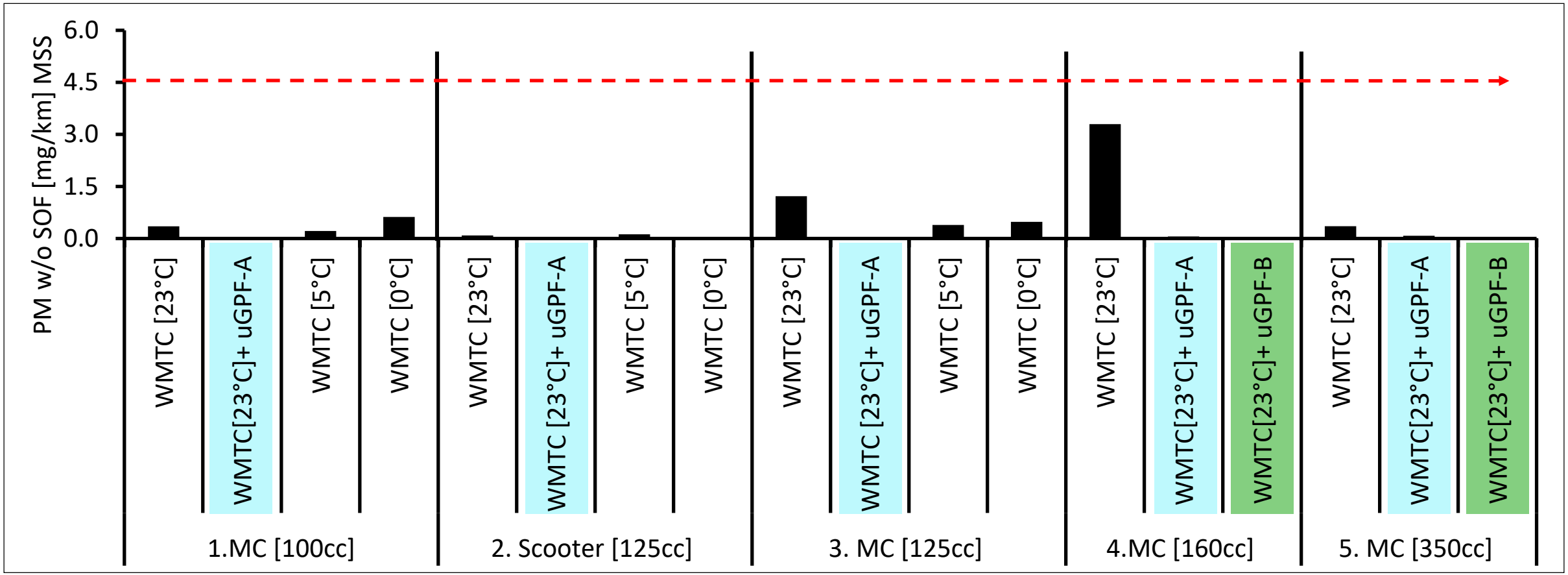
uGPF- Uncatalysed/ Uncoated Gasoline Particulate Filter [Ceramic]
TWC-Three Way Catalyst [Metal]

Emission test results of all gaseous emissions [CO/THC/NOx/NMHC] with existing OEM Metallic TWC and add-on uncoated GPF (uGPF)



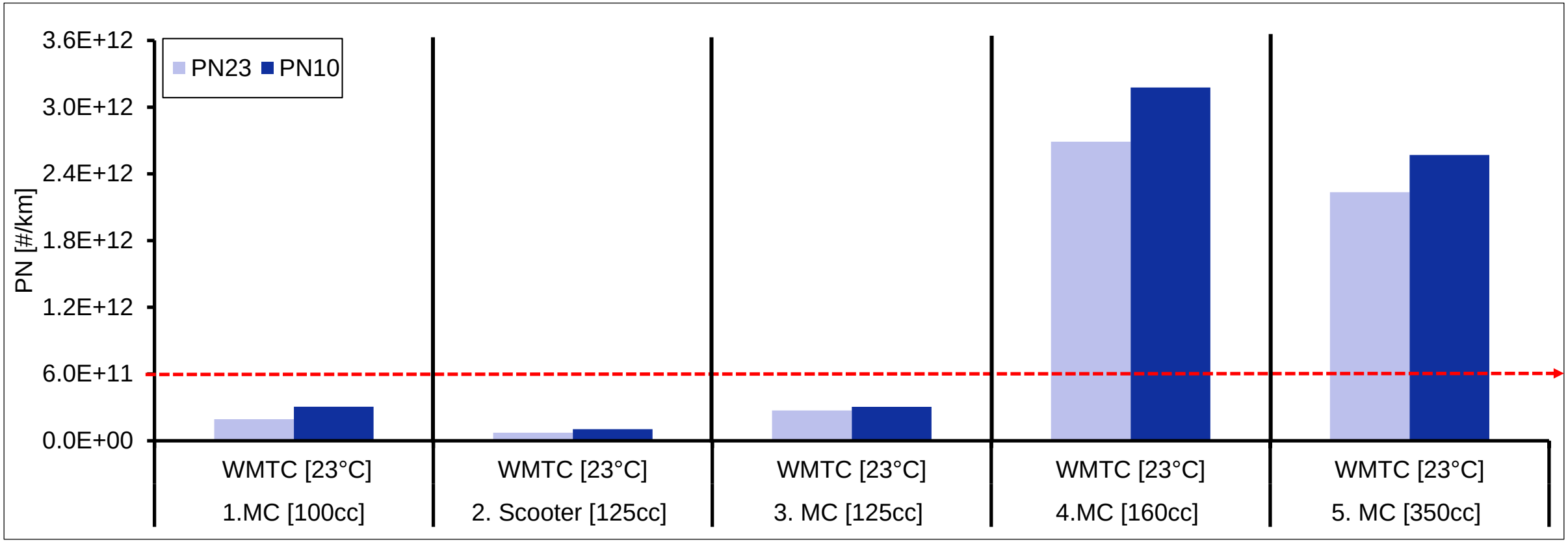
Conclusion: As uGPF was used, no change/ negligible change in all gaseous emissions observed between the existing OEM metallic TWC and the system with the uGPF across all tested worst-case conditions, including RDE

PM with existing OEM Metallic TWC was within <4.5mg/km and uGPF increased filtration



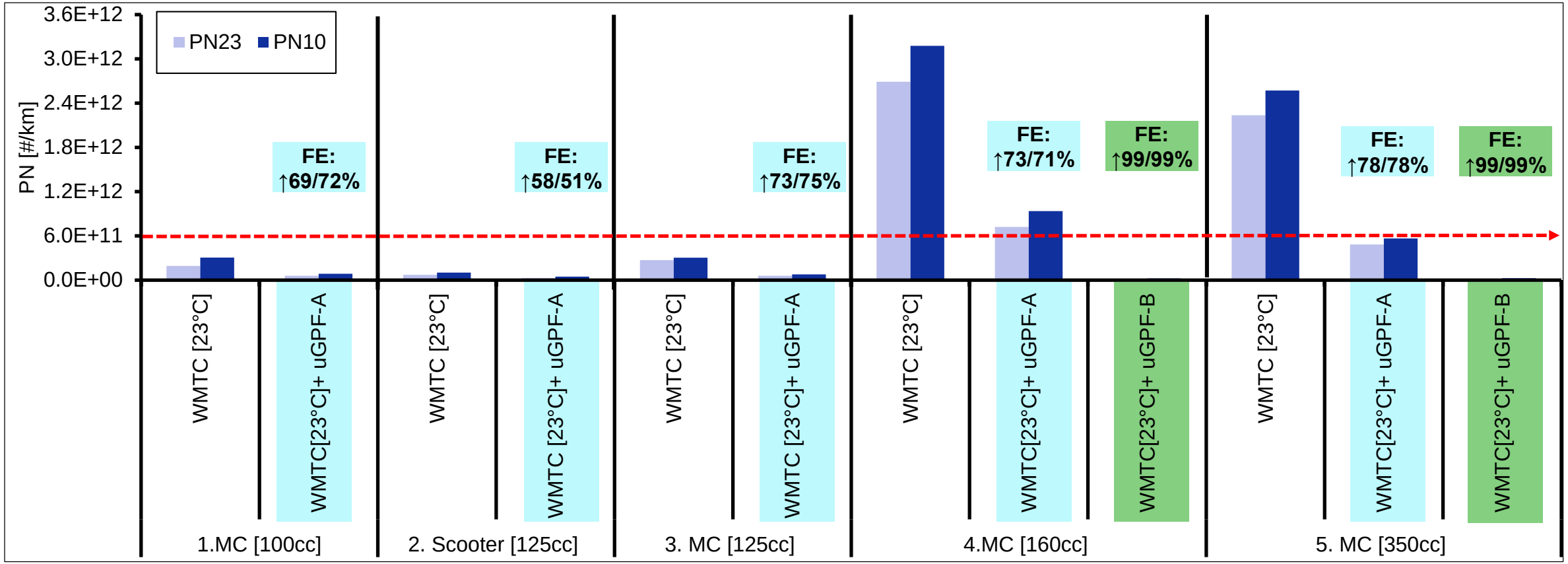
Conclusion: Soot emission remained below 4.5mg/km under all tested conditions, including RDE. The bare GPF provided effective PM filtration across all vehicles.

I. Baseline testing: PN23 & PN10 Emissions WMTC 23°C existing OEM Metallic TWC [without GPF] – all vehicles



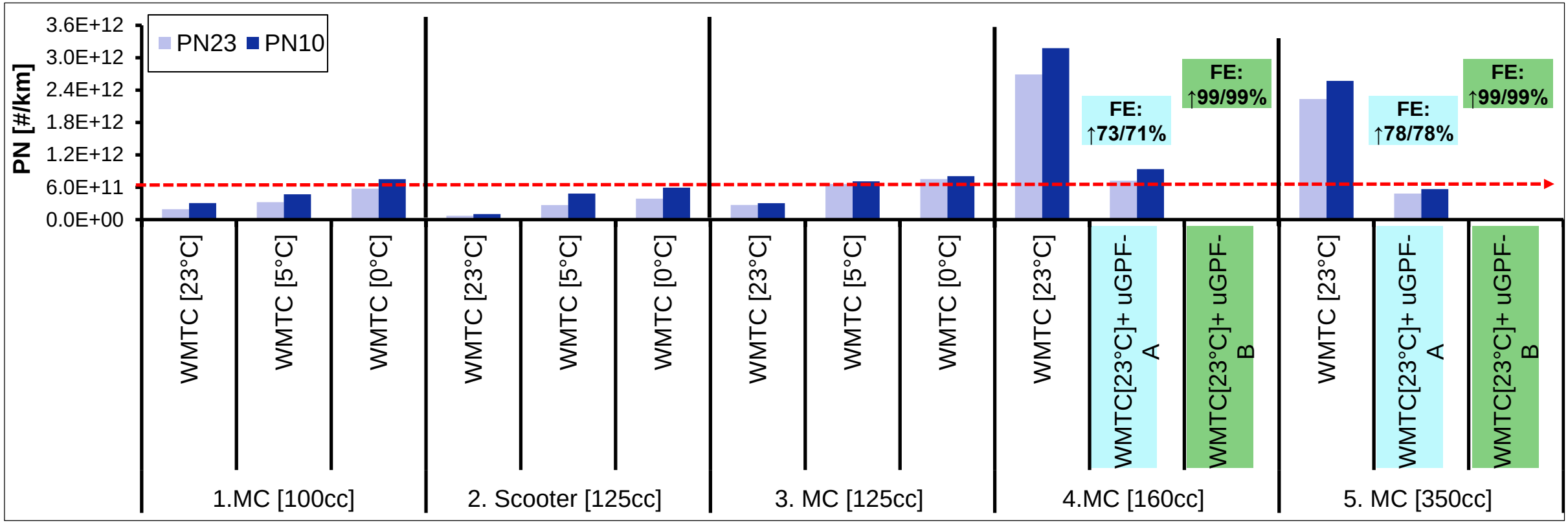
Conclusion: PN emission from 2-wheelers are of the same order of magnitude as those from 4-wheelers. For some tested 2-wheelers, PN23/PN10 emissions are very high (>6e11#/km) during WMTC at 23°C.

II. Baseline testing: PN23 & PN10 Emissions WMTC 23°C with OEM Metallic TWC without and with GPF – all vehicles



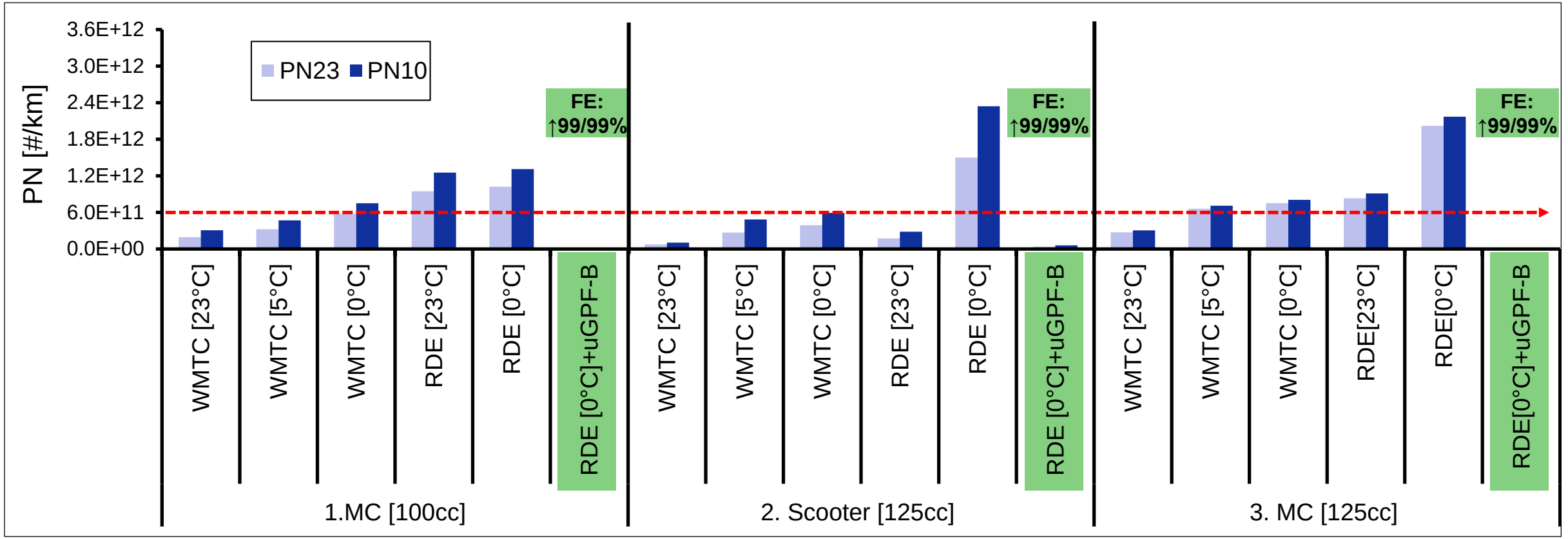
Conclusion: For all vehicles PN23/PN10 emissions with uGPF allows for a robust reduction in particulate emissions of PN23/10 FE 99% with uGPF-B

III. Impact of ambient air temperature: PN23 & PN10 Emissions WMTC at other temperatures (include all 23°C / 5°C / 0°C)



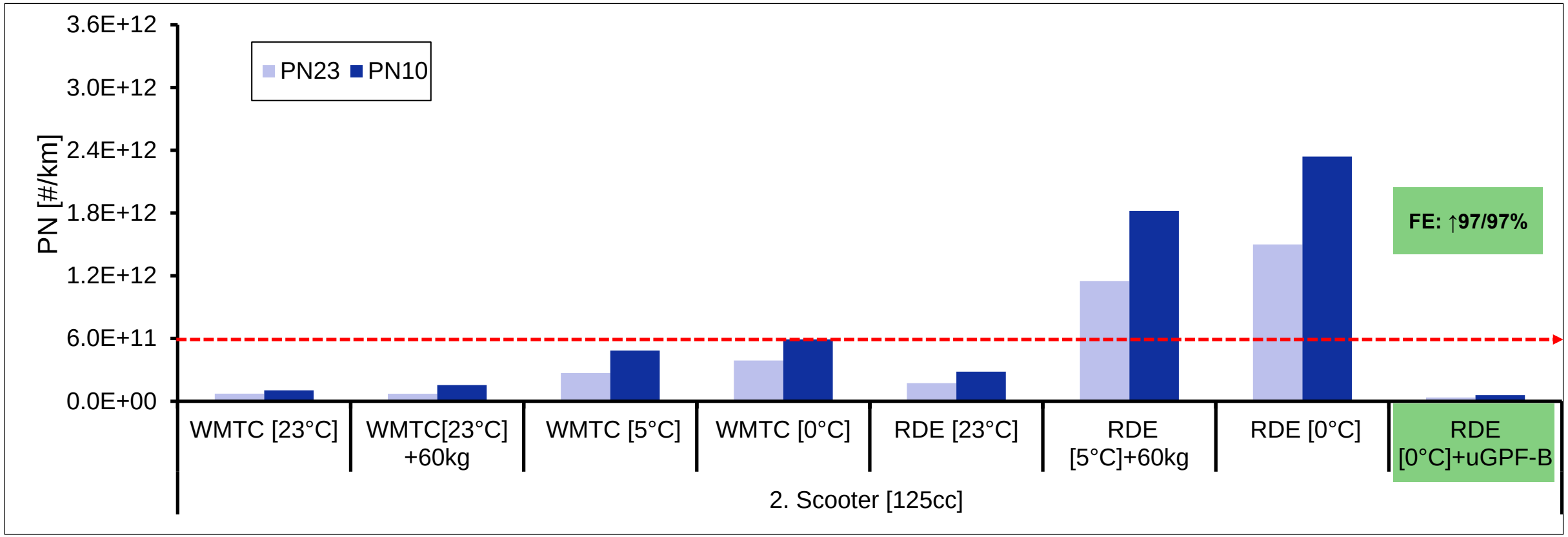
Conclusion: Low-temperatures conditions are a realistic operating scenario and can significantly increase particulate number emissions. A GPF offers a robust and practical solution for particle-number reduction.

IV. Impact of Drive Cycle and temperature: PN23 & PN10 Emissions WMTC and Hyderabad RDE Cycle at the different temperatures



Conclusion: Low temperatures and real-world driving conditions can significantly increase particulate number emissions. A GPF offers a robust and practical solution to support improved air quality.

V. For Scooter: Impact of load vs PN23 & PN10 emissions Another realistic real world driving condition



Conclusion: Higher load, as expected, increases PN emissions. A GPF therefore provides an effective solution for PN control.

Conclusions

- Despite their smaller size, the five two-wheelers (Class 1 and 2.1, BS6.2/OBD II, model year 2025) appear to emit **particle numbers of the same magnitude** as four-wheeled vehicles.
  - Higher particle number emissions are observed during real-world driving and at cooler temperatures.
  - Assuming four-wheeler PN limit of $6x10^{11}$/km:
    2/5 exceeded this limit in WMTC at 23°C, **5/5** exceeded it in RDE at 0° C.
- As with four-wheeled vehicles, PN control is possible through the addition of a bare GPF.
  - PN10 control is achievable with a relatively simple solution.
  - Pressure drop appears manageable with a 2x GPF size to engine displacement.

Next steps

- Demonstrate catalyst integration on the GPF to support gaseous emissions across several two-wheelers while maintaining excellent PN control.
- Demonstrate appropriate form, fit, and function on several motorcycles through full on-road testing.
- Prepare to scale-up GPF technology for two-wheelers, assuming this technology is useful.

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