

18<sup>th</sup> ETH Conference  
on Combustion  
Generated  
Nanoparticles

# 18<sup>th</sup> ETH Conference on Combustion Generated Nanoparticles

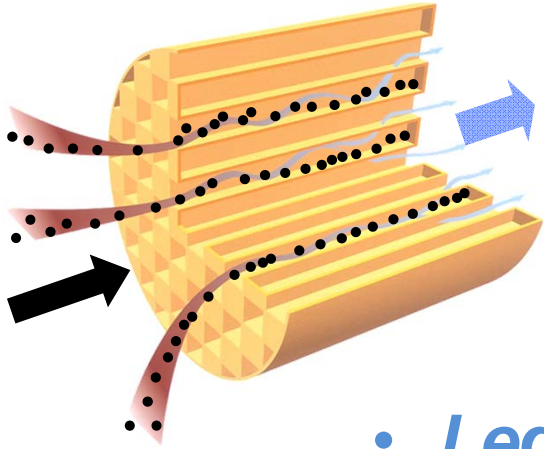


## *Advanced Catalyzed Gasoline Particulate Filter to Fulfill Future Emission Targets*

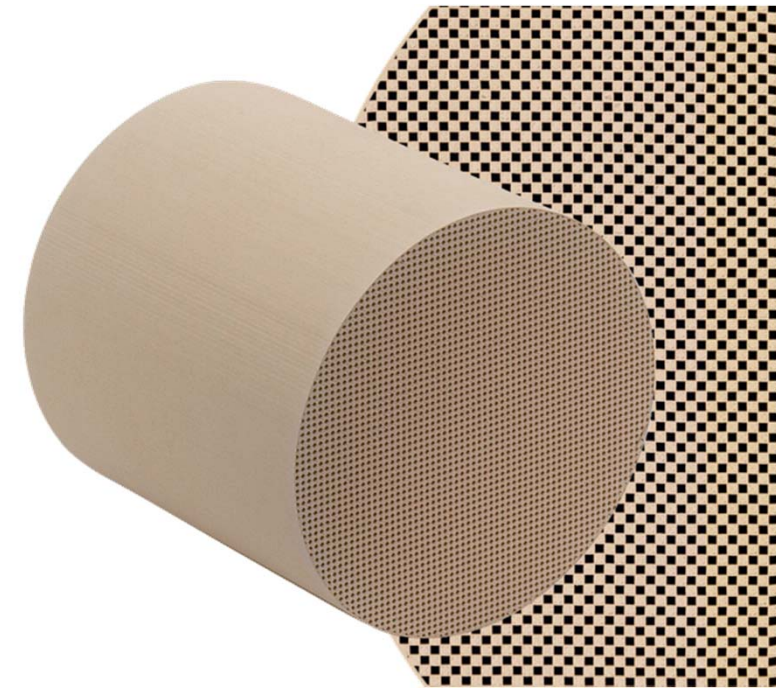
*K. Kato*

D.Thier, P. Kattouah, E. Ohara, C. D. Vogt  
NGK EUROPE GmbH

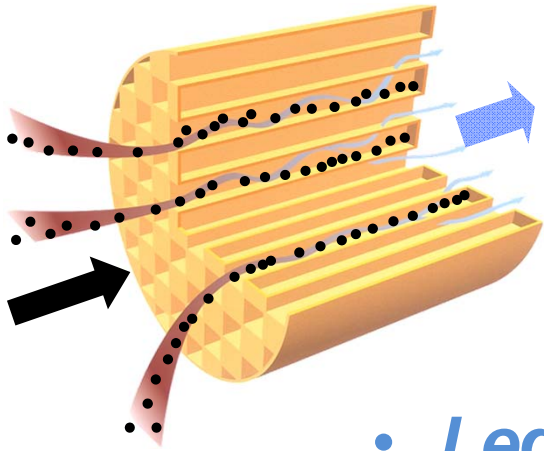
Y. Ito, T. Aoki, T. Shimoda,  
K. Yuuki, H. Sakamoto  
NGK INSULATORS, Ltd.



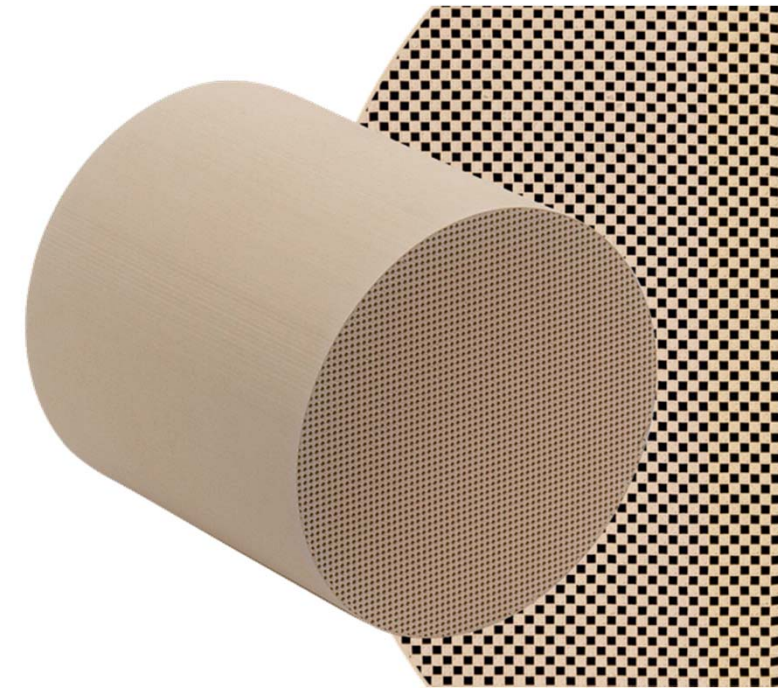
- *Legislation and Market Trend*
- *GPF to fulfill PN Legislation with Gasoline Engines*
- *Robust Catalyzed type GPF*



Gasoline Particulate Filter : GPF



- *Legislation and Market Trend*
- *GPF to fulfill PN Legislation with Gasoline Engines*
- *Robust Catalyzed GPF*

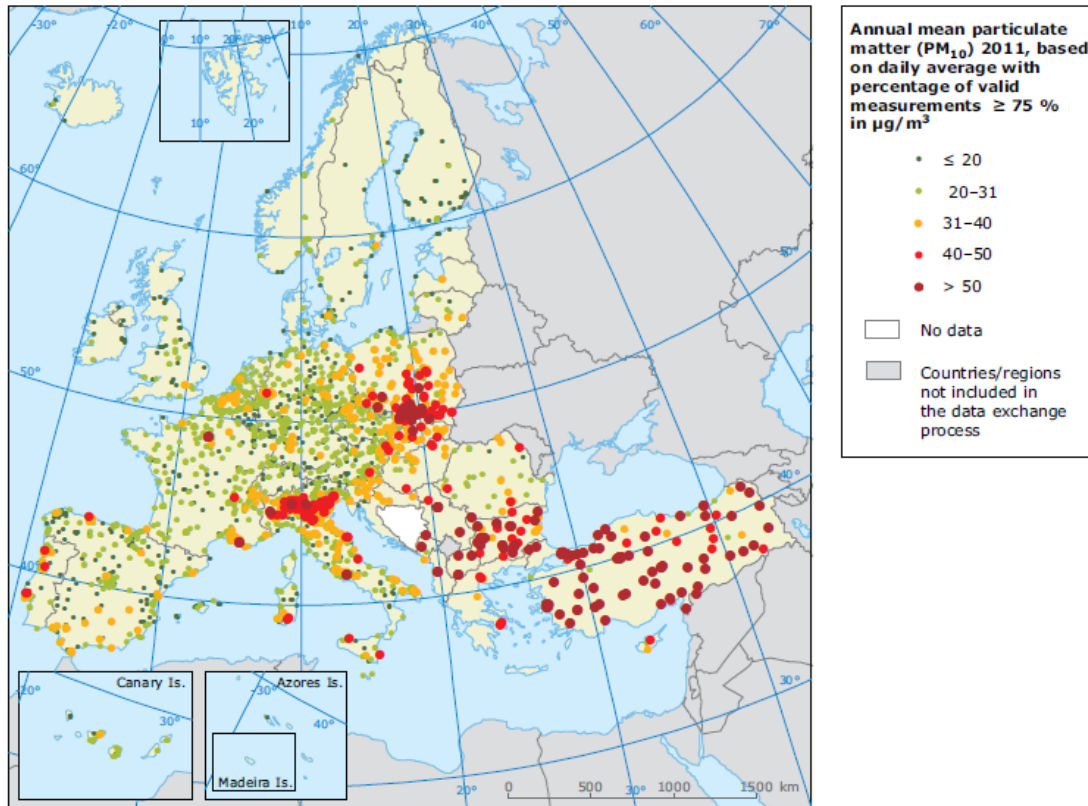


Gasoline Particulate Filter : GPF



# Current PM Situation in Europe

PM<sub>10</sub> Concentration > 50 µg/m<sup>3</sup>



Source: European Environmental Agency (EEA) 2012

Paris, March 2014



Paris March 2014, Source: AFP



London, February 2013



London February 2013, Source: airqualitynews.com

In some European cities PM limits were still temporarily exceeded!

# Trend of Particulate Matter Legislation (LDV)

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2025
	<b>Euro5</b> NEDC Diesel: PM 5.0 mg/km Gasoline (DI): PM 5.0 mg/km		<b>Euro6b</b> NEDC Diesel: PM 4.5 mg/km PN 6 x 10 <sup>11</sup> #/km Gasoline (DI): PM 4.5 mg/km <b>PN6 x 10<sup>12</sup> #/km</b>			<b>Euro6c</b> NEDC + <b>WLTC + RDE</b> Diesel/Gasoline (DI): PM 4.5 mg/km <b>PN6 x 10<sup>11</sup> #/km</b> All: <b>CO<sub>2</sub> 120 g/km</b>			<b>Euro7?</b> WLTC + RDE Low Temp? PN / PM? All: <b>CO<sub>2</sub> 95 g/km</b>	
	<b>LEV2</b> FTP Diesel/Gasoline(DI): PM 10 mg/mile		<b>LEV3</b> FTP Diesel/Gasoline (DI): <b>PM 6 mg/mile</b>		<b>LEV3</b> FTP Diesel/Gasoline (DI) Phase-in: <b>PM 3 mg/mile</b>			<b>LEV3</b> FTP All: PM <b>3 mg/mile</b>		<b>LEV3</b> FTP All: PM <b>1 mg/mile</b>

“...it was decided to primarily develop on-road testing with PEMS as the main real-driving test procedure.”

Sources: [http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt\\_code=NWS&obj\\_id=16180&ori=RSS](http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt_code=NWS&obj_id=16180&ori=RSS)

Future PM emission limits will be tightened and new test procedures will come into focus.

# European CO<sub>2</sub> Legislation for Passenger Cars – The GDI engine as candidate to meet CO<sub>2</sub> targets

CO<sub>2</sub> Legislation for Diesel and Gasoline Passenger Cars (Category M1)  
approved by the European Parliament (as of 23/06/2009)

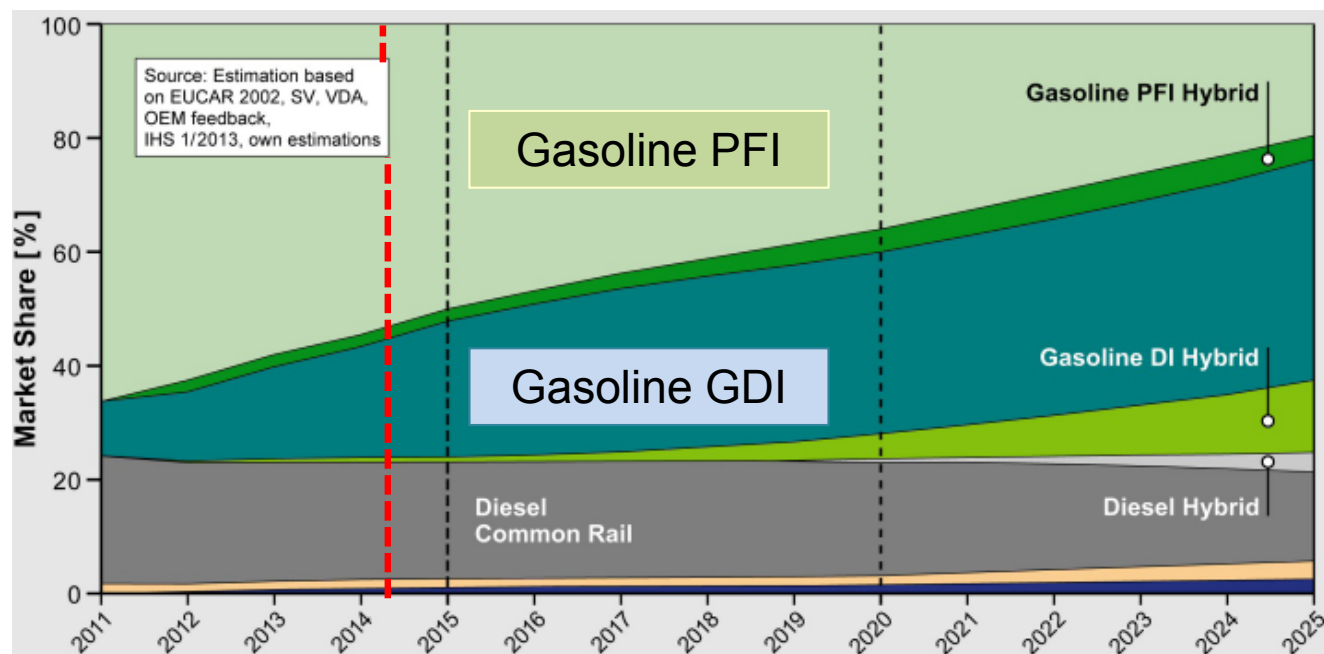
YEAR	PC CO <sub>2</sub> [g/km]	FLEET SHARE*2
2014	130	80%
2015	130	100%
2020	95	95%
2021	95	100%

\*2 Based on new car registrations within the EU.

\*3 So called excess emissions premium.

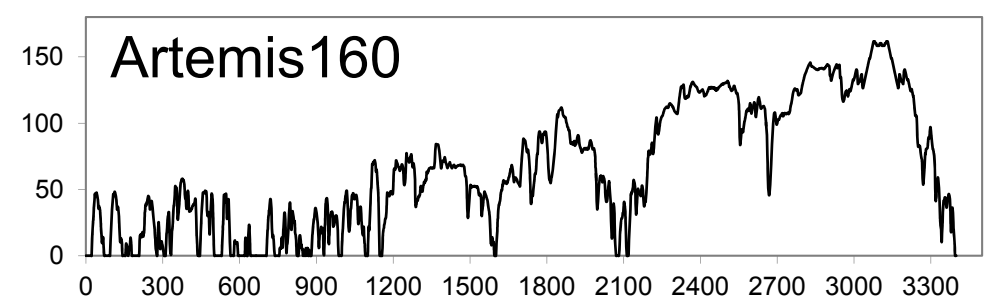
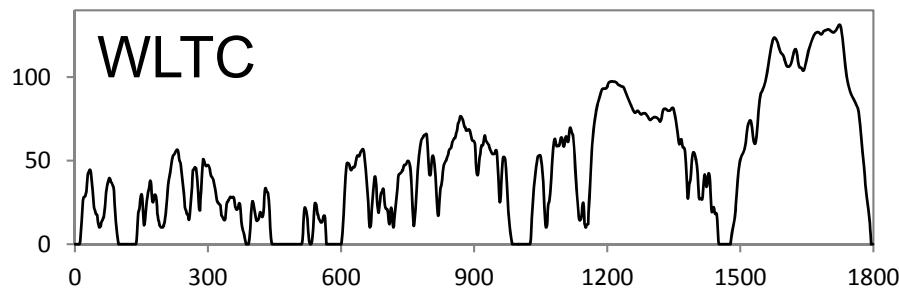
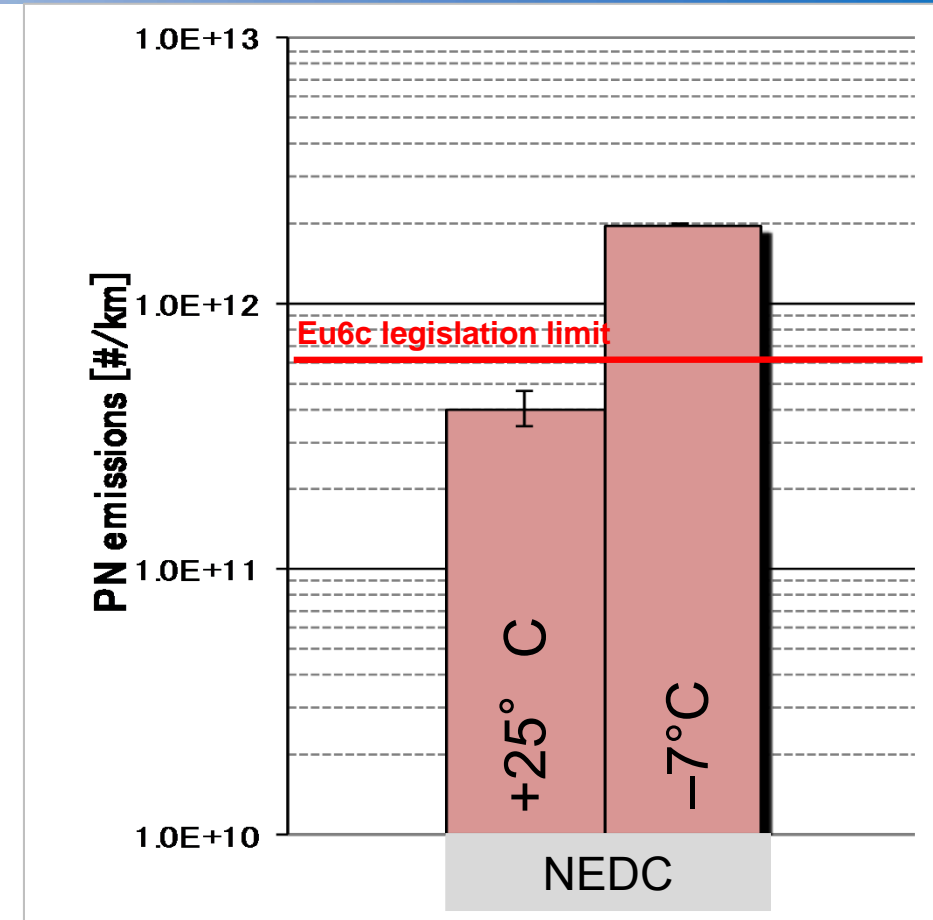
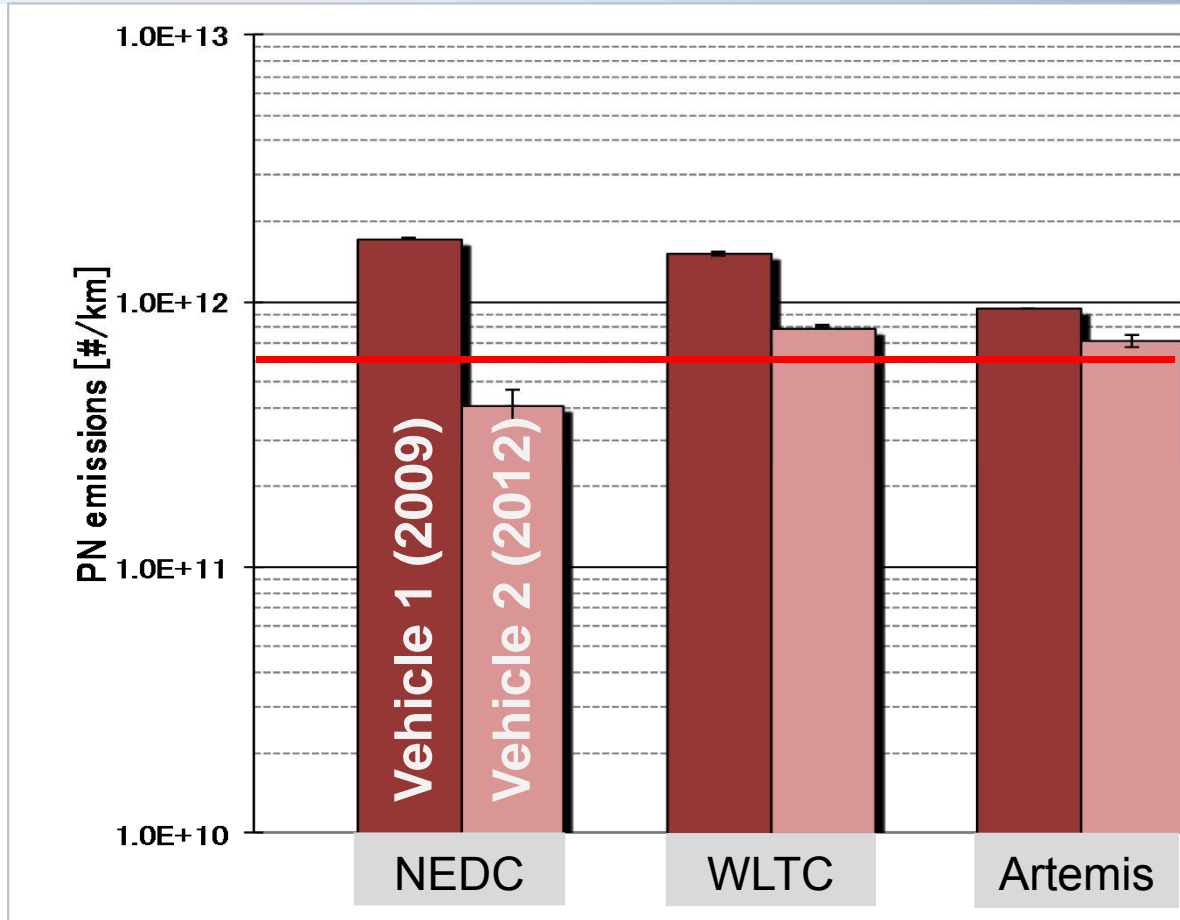
PENALTY*3 [€(gCO <sub>2</sub> /km)]
From 2012 until 2018:
• 5€ for the first gram
• 15€ for the second gram
• 25€ for the third gram
• 95€ from the fourth gram onwards
From 2019:
• 95€ for each gram above the limit

Source: Continental,  
International Vienna Motor  
Symposium 2013,  
Next Generation Engine  
Management Systems for  
Gasoline Direct Injection

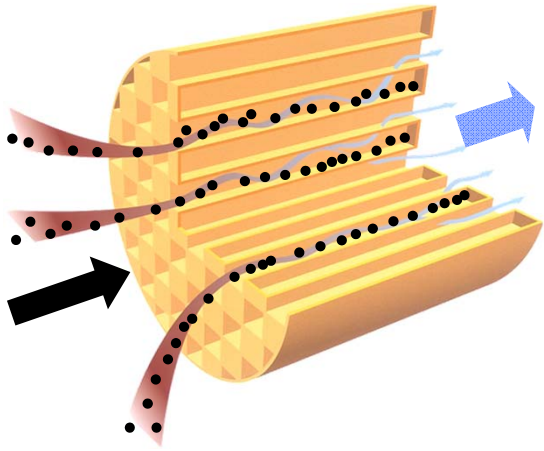


CO<sub>2</sub> legislation limits become more stringent from now and in future.  
Due to CO<sub>2</sub> saving potential GDI engine market share increases.

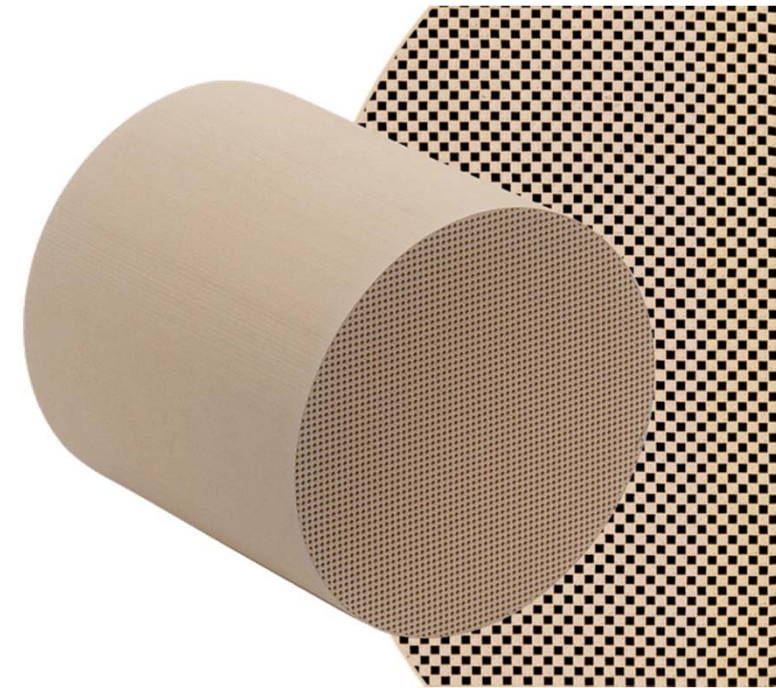
# Current status: Particle Number Emissions of GDI Vehicles



Some current GDI vehicles show PN emissions above EU6c legislation limit.



- *Legislation and Market Trend*
- *GPF to fulfill PN Legislation with Gasoline Engines*
- *Robust Catalyzed GPF*

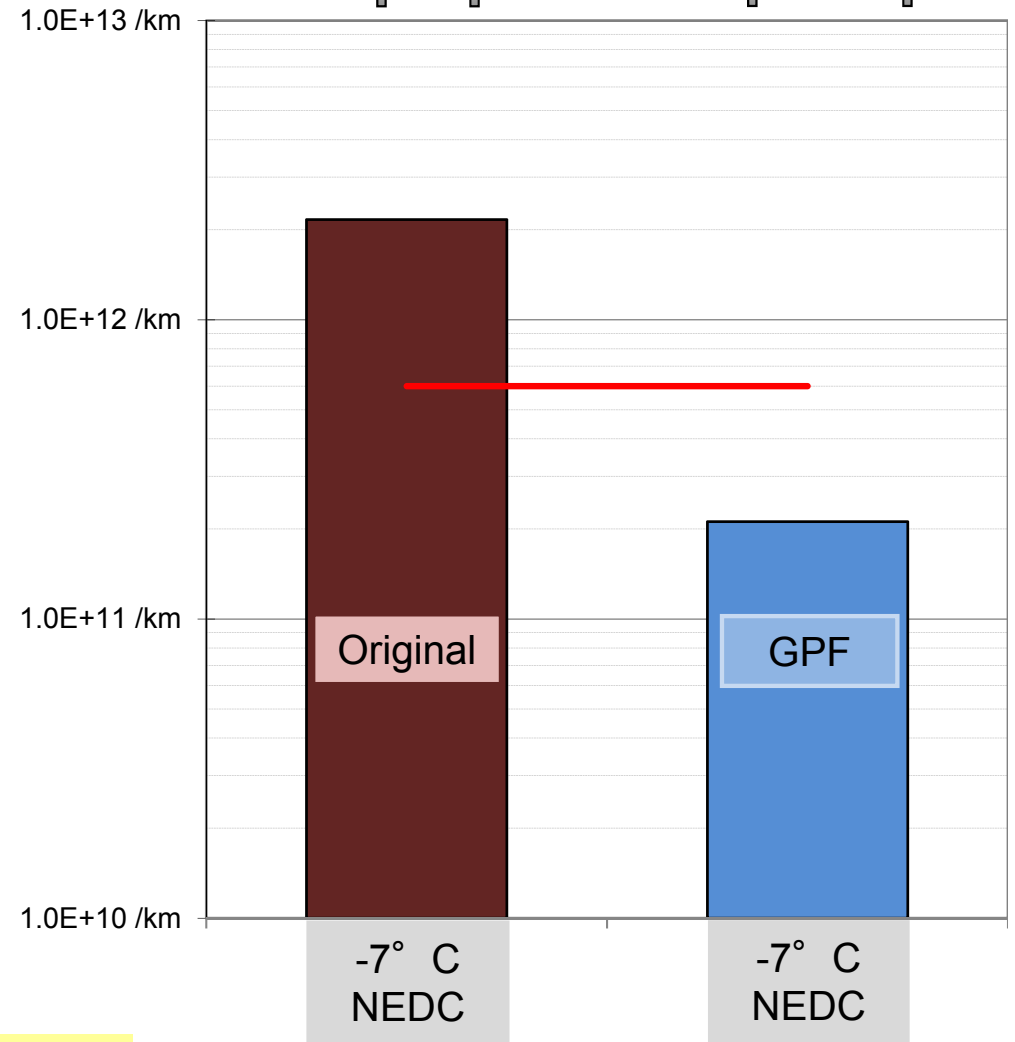
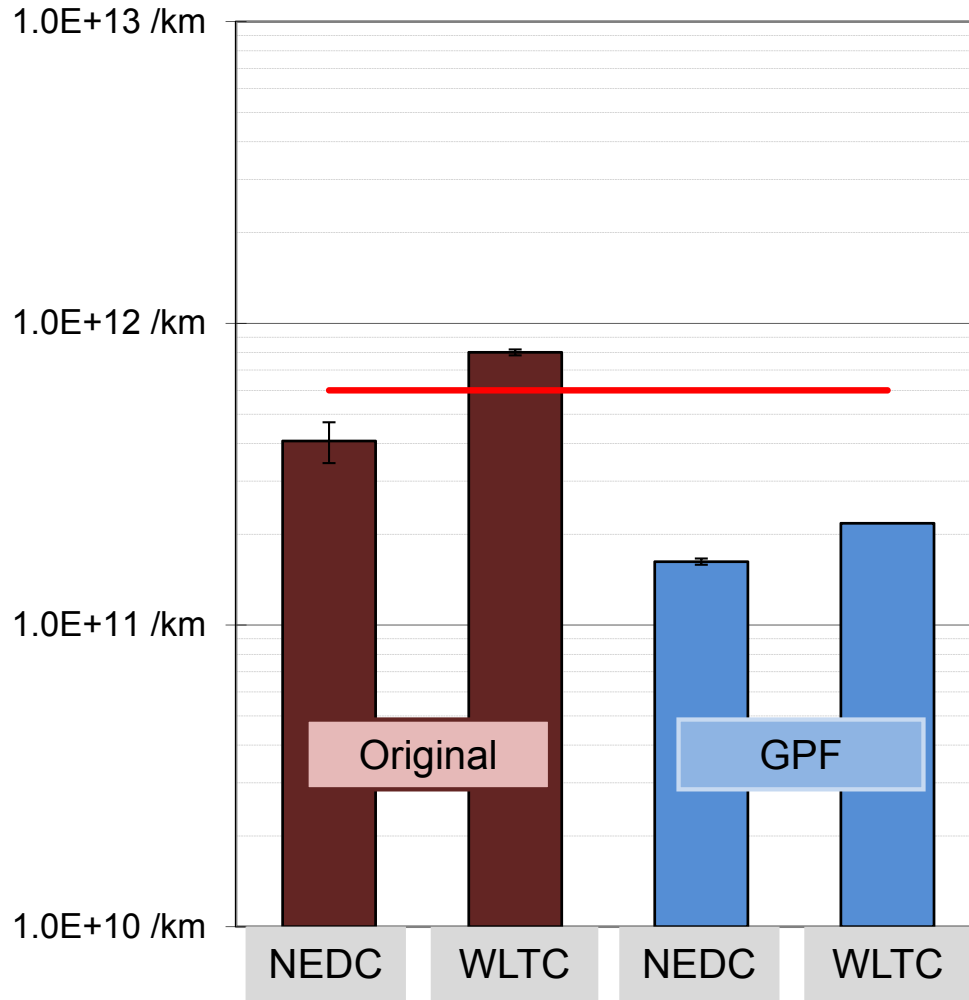
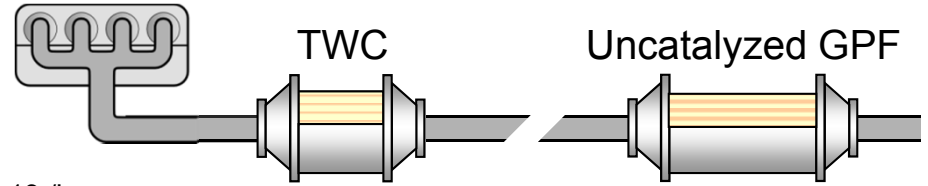


Gasoline Particulate Filter : GPF



# Particle Number Reduction by uncatalyzed GPF

**Vehicle:** 1.4L and 1.8L DI Gasoline  $\lambda=1$   
**GPF:**  $\phi$  118.4 x 127 mm L, uncatalyzed  
**Position:** Underfloor

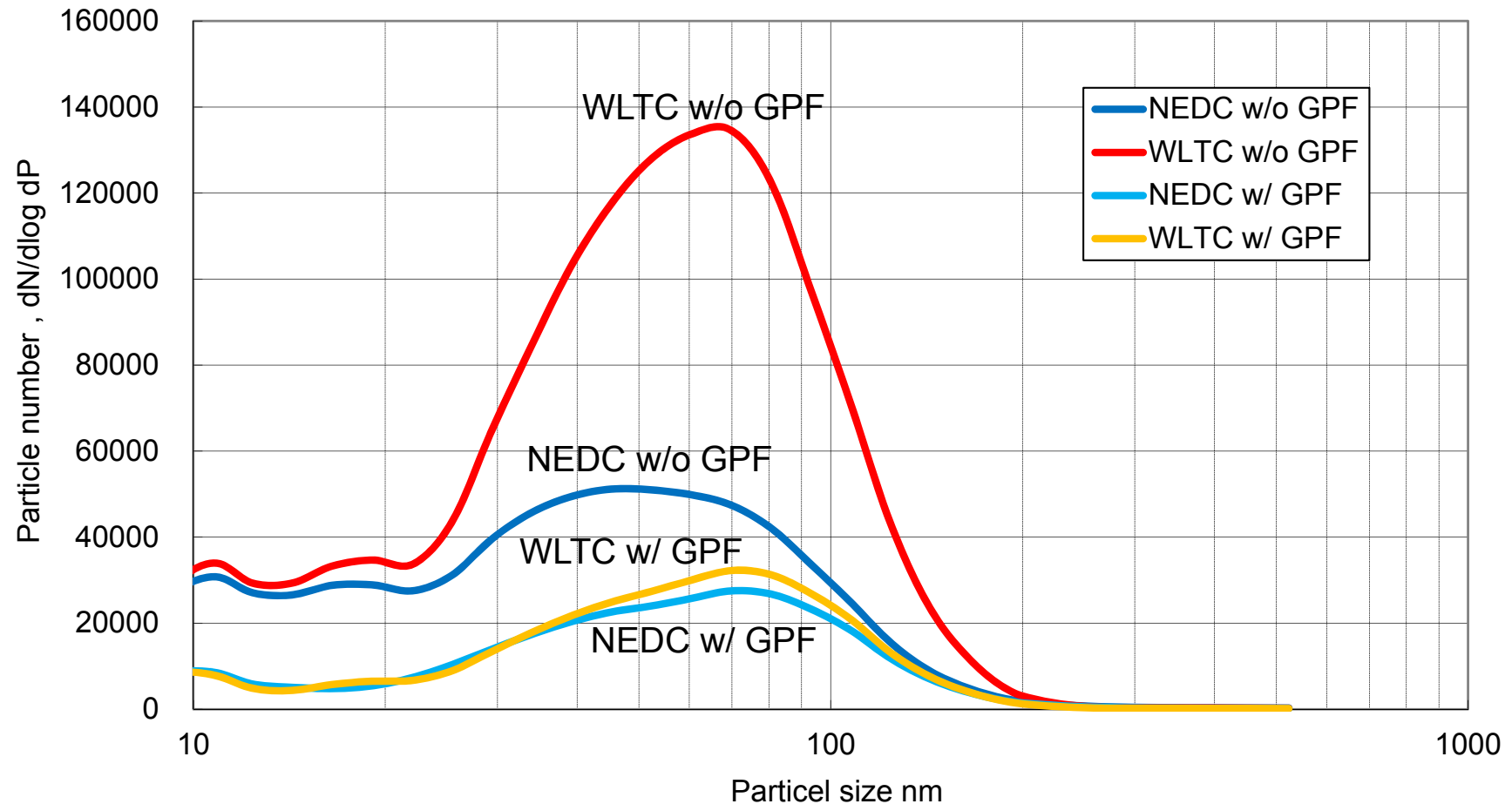


GPF reduce PN emissions significantly in all test cycles.

— Eu6c legislation limit

# Particle size distribution with GPF

**Vehicle:** 1.8L DI Gasoline  $\lambda=1$   
**GPF:**  $\phi$  118.4 x 127 mm L, uncatalyzed  
**Position:** Underfloor

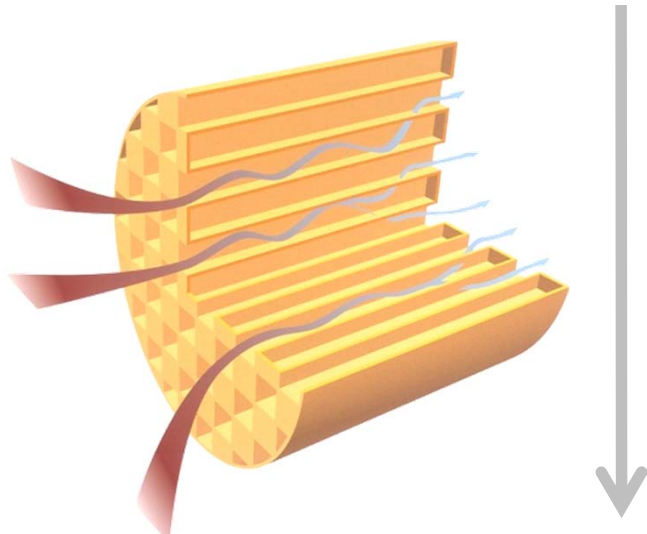


Particle numbers were well reduced by GPF over whole range of particle size

# GPF to meet PN legislation limits



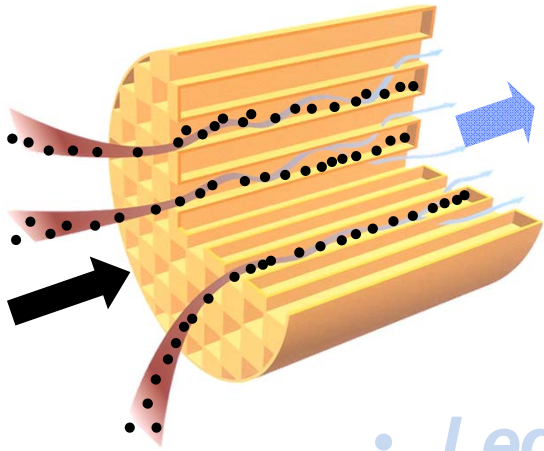
*DI gasoline engines  
to reduce CO<sub>2</sub> emissions*



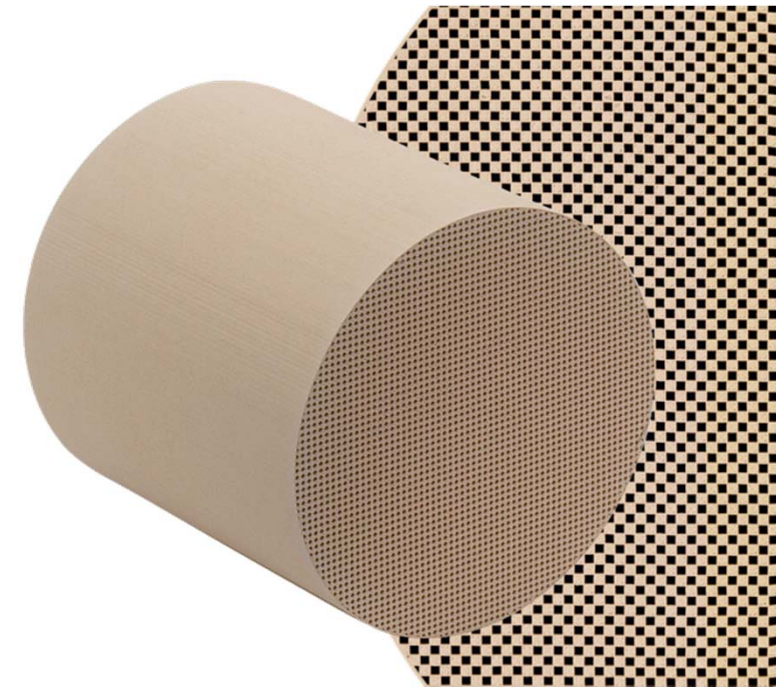
**GPF to meet PN  
legislation limits**

<b>Material</b>	<b>Cordierite Gasoline Particulate Filter</b>
<b>Porosity</b>	<b>40-50 %</b>
<b>System Layout</b>	
<b>Micro Structure [ SEM ]</b>	
<b>Application</b>	<b>UnCatalyzed GPF</b>

GPFs reduce PN by aftertreatment to stay below PN legislation limits.

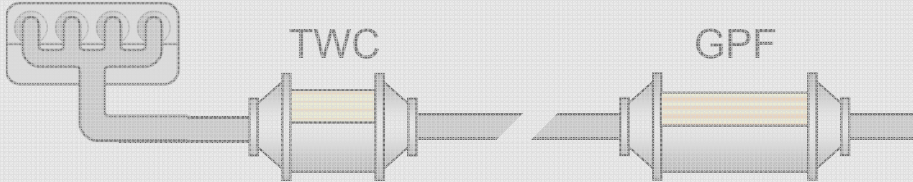
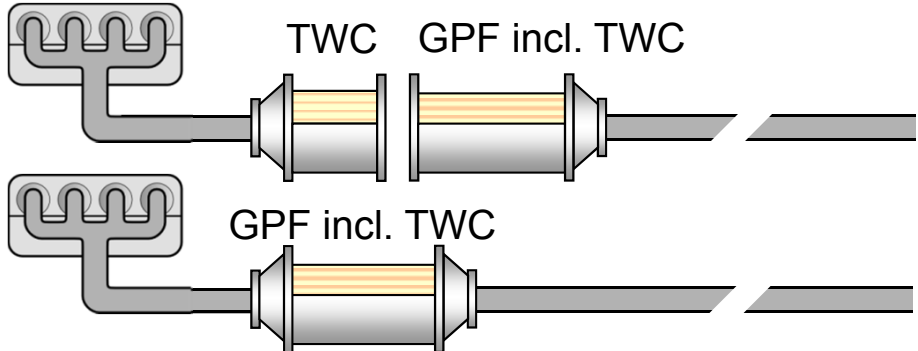
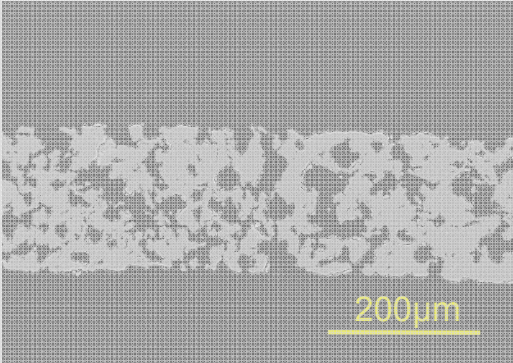
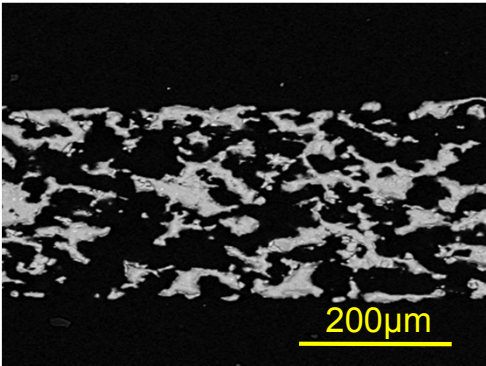


- *Legislation and Market Trend*
- *GPF to fulfill PN Legislation with Gasoline Engines*
- *Robust Catalyzed GPF*



Gasoline Particulate Filter : GPF



Material	Cordierite Gasoline Particulate Filter	
Porosity	40-50 %	60-65 %
System Layout		
Micro Structure [ SEM ]		
Application	UnCatalyzed GPF	Catalyzed GPF

Higher porous material is preferred for Catalyzed GPF.

# Vehicle Durability Test on catalyzed GPF 160,000 km

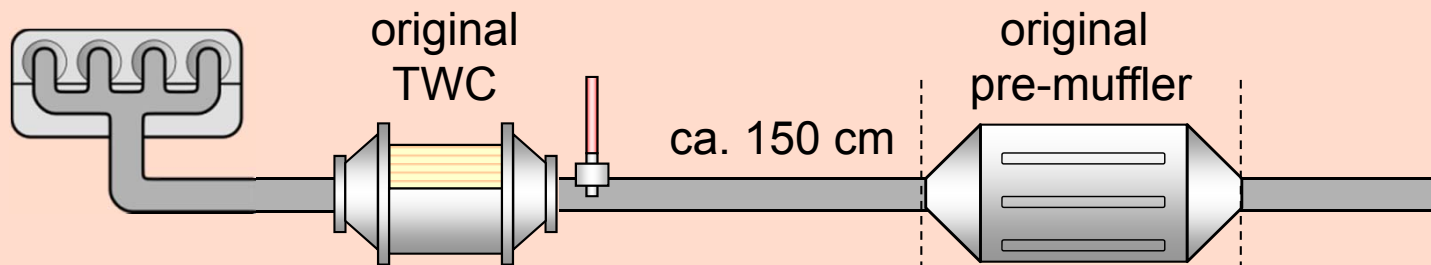
## Vehicle Spec:

- Engine: 1.8 liter turbo GDI, Euro 5
- Average Speed: 80 km/h
- Fuel: 8.46 l/100 km (Gasoline RON 95 E5)
- Oil: 0.305 l/10,000 km (Super Tronic Longlife III 5W-30)

## GPF Spec:

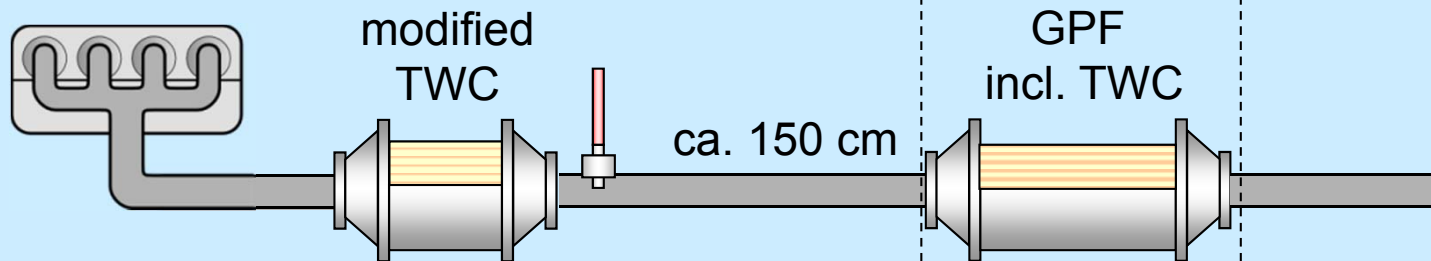
- High Porosity Material, 1.3 liter GPF volume with integrated TWC

### Original System



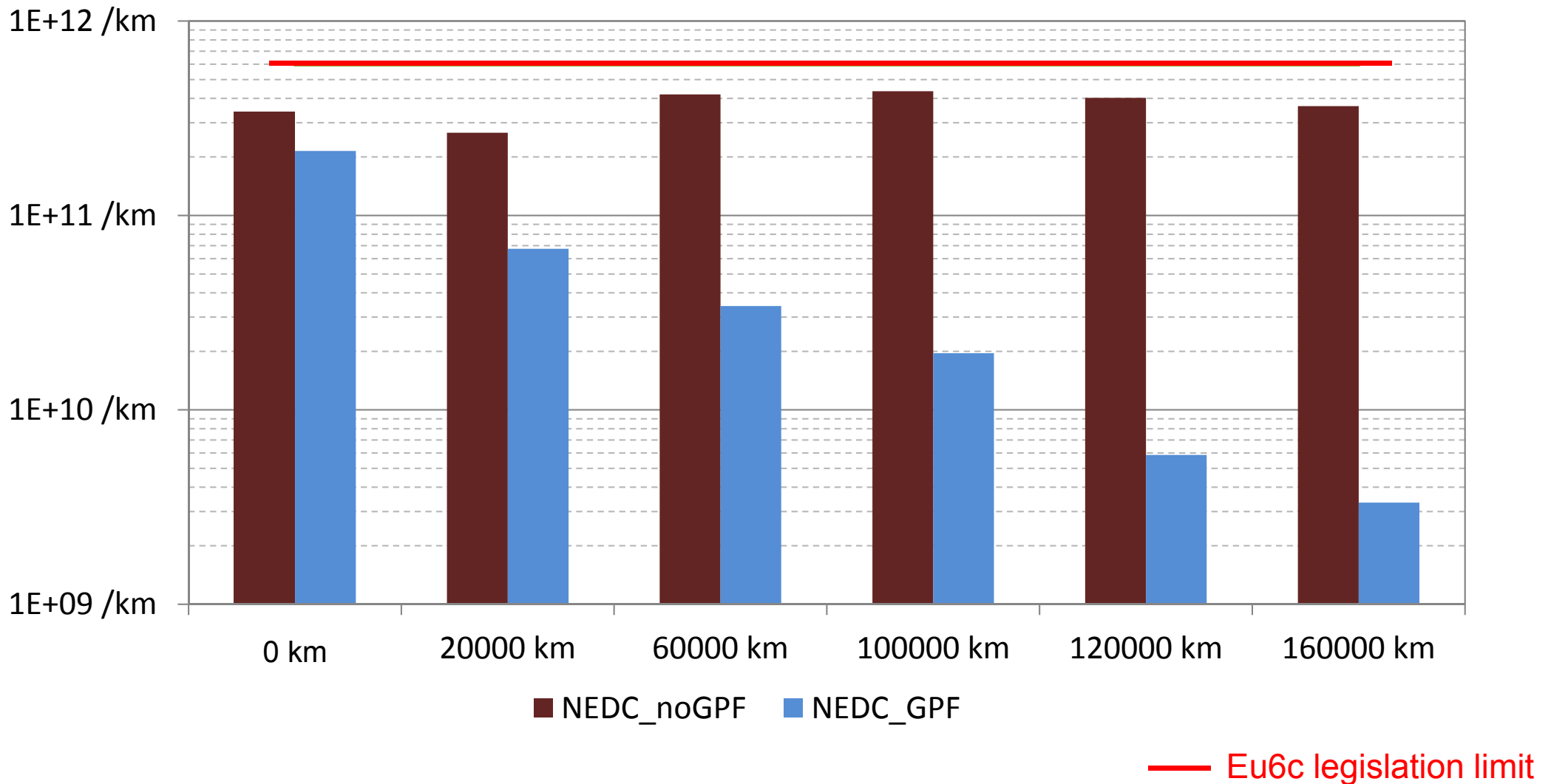
(Same total PGM system amount)

### Modified System



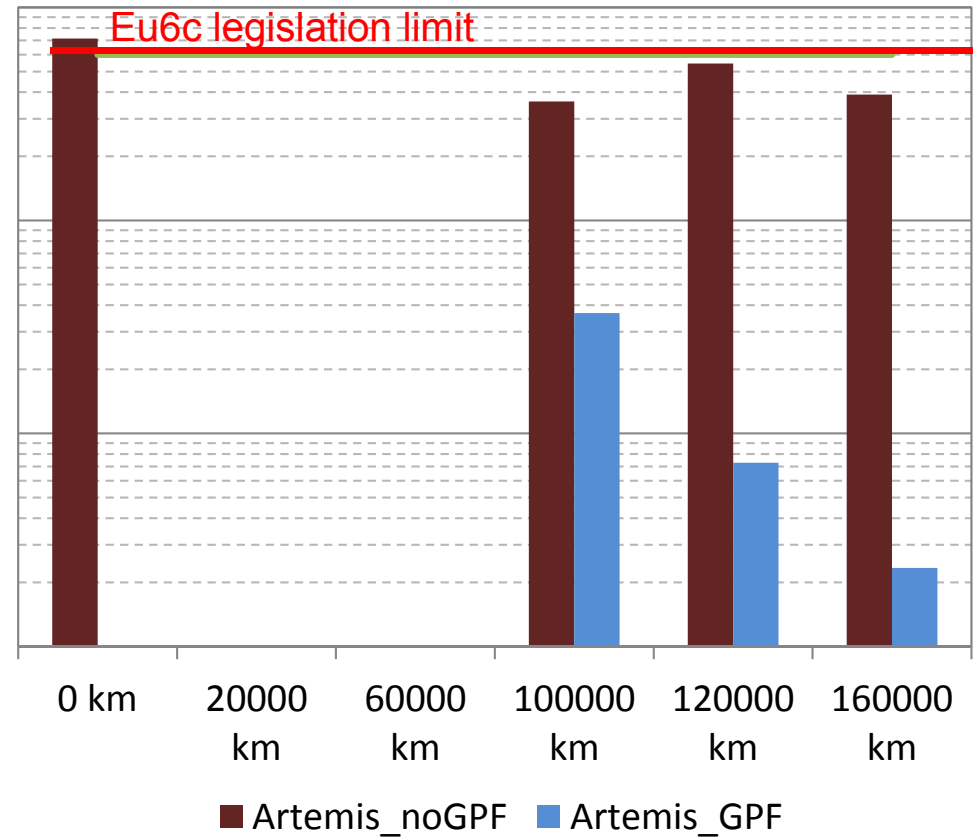
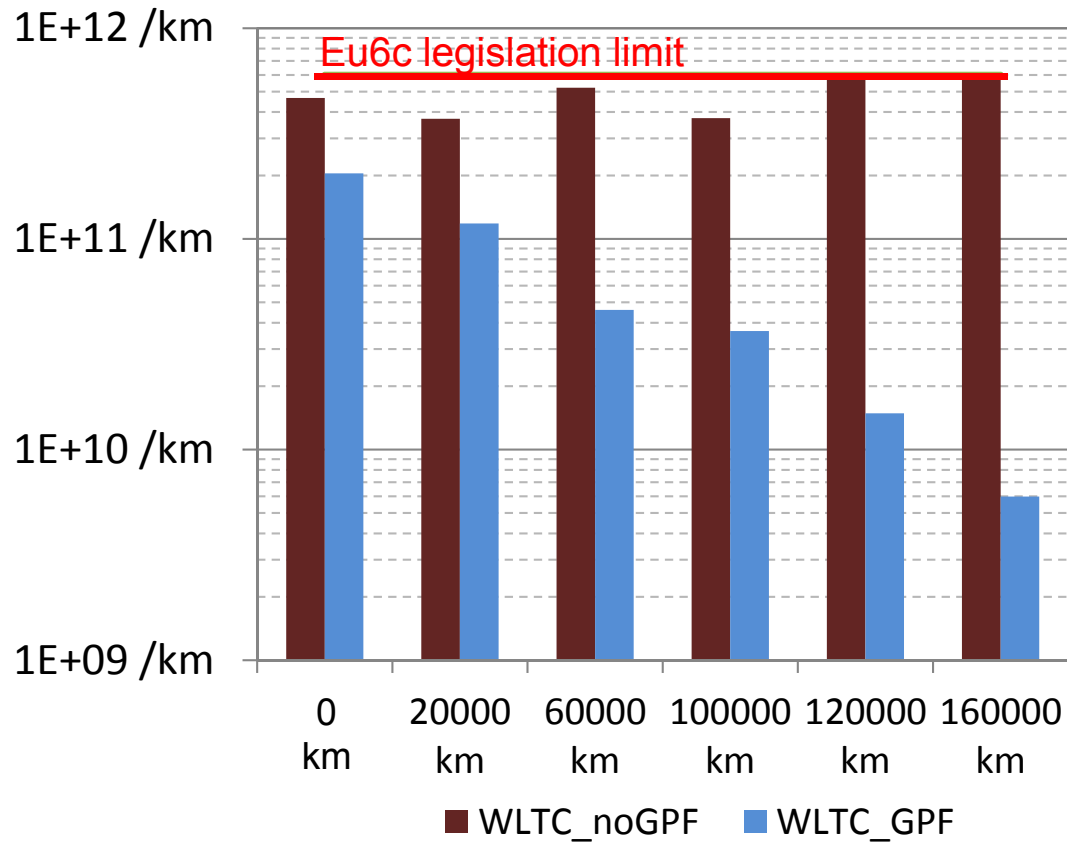
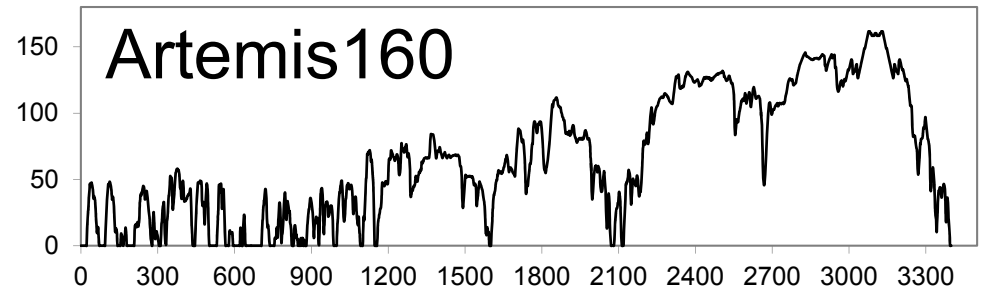
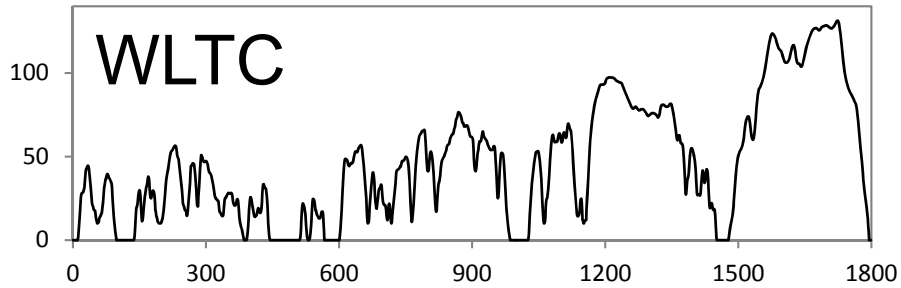
Driving Mode	
City	6% ( $\leq 50$ km/h)
Country	11% ( $\leq 100$ km/h)
Motorway	81% ( $\leq 220$ km/h)
Transit	2%
Emission Test Intervals (km)	
0	100,000
20,000	130,000
60,000	160,000

# Particle Number Emissions during NEDC



GPF effectively and reliably reduces PN emissions at least up to 160,000 km.

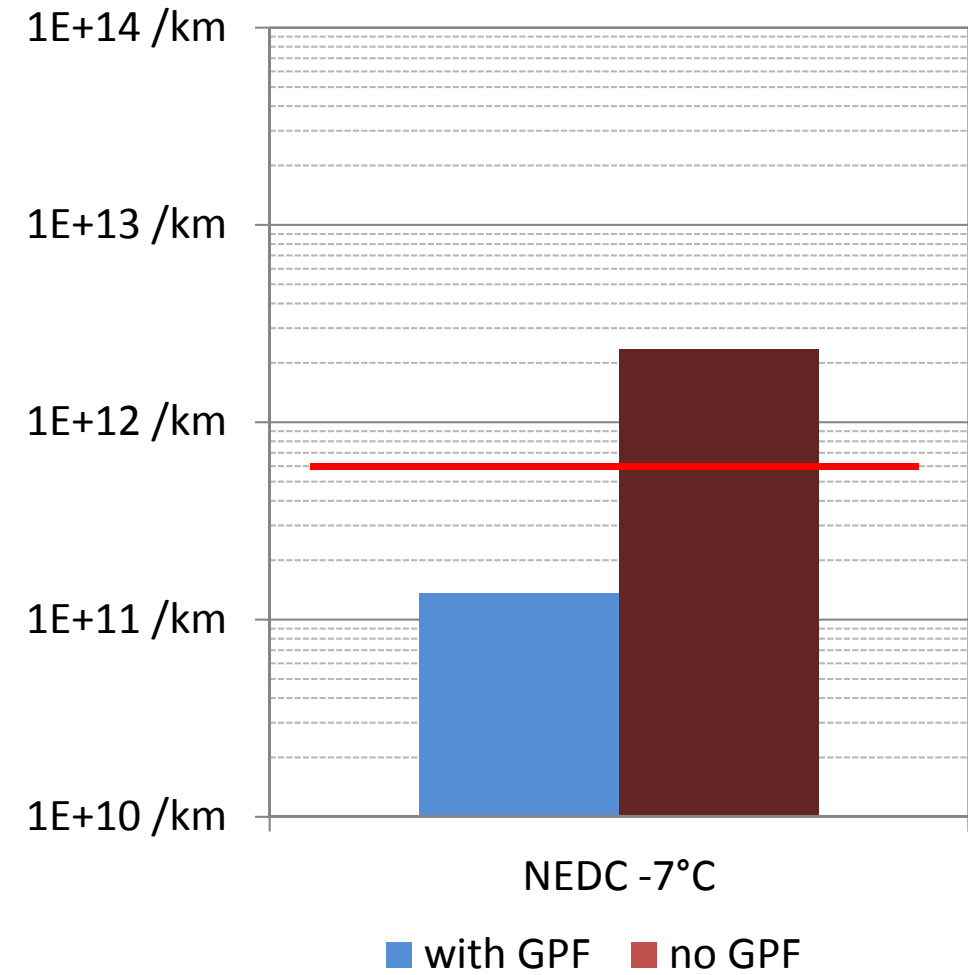
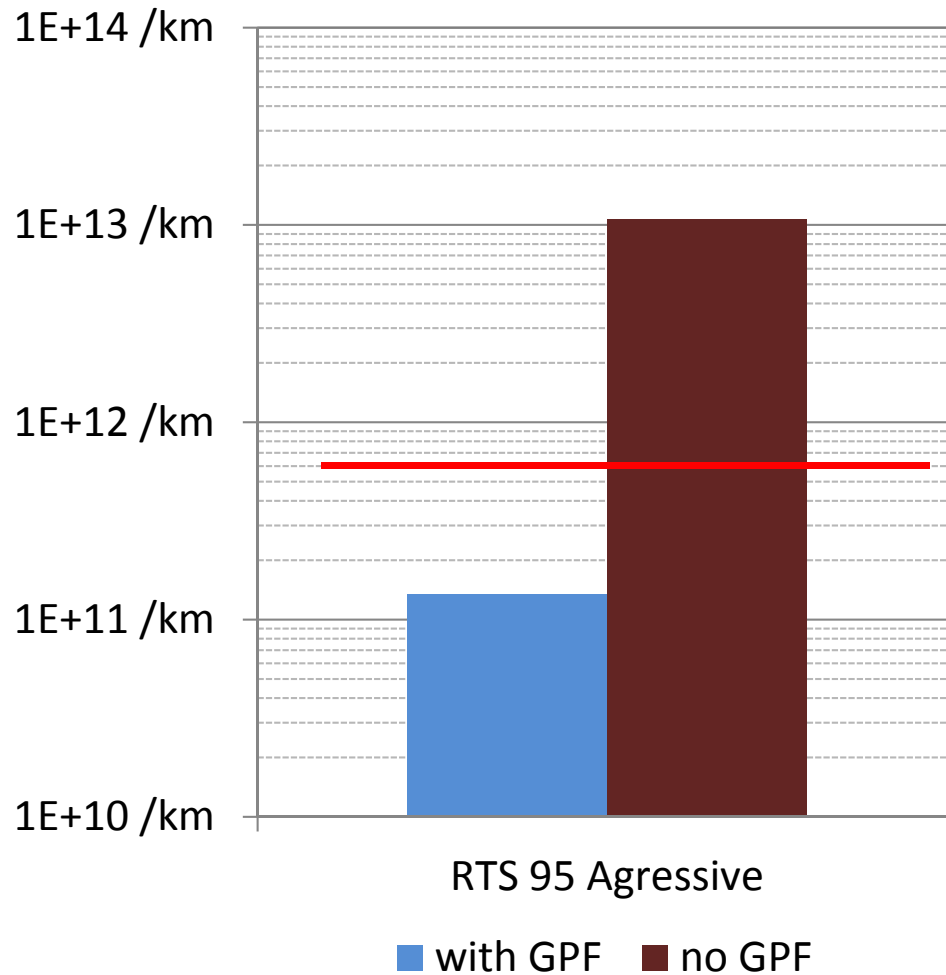
# Particle Number during WLTC and Artemis160



GPF effectively reduces PN emissions at least up to 160,000 km even during dynamic cycles.

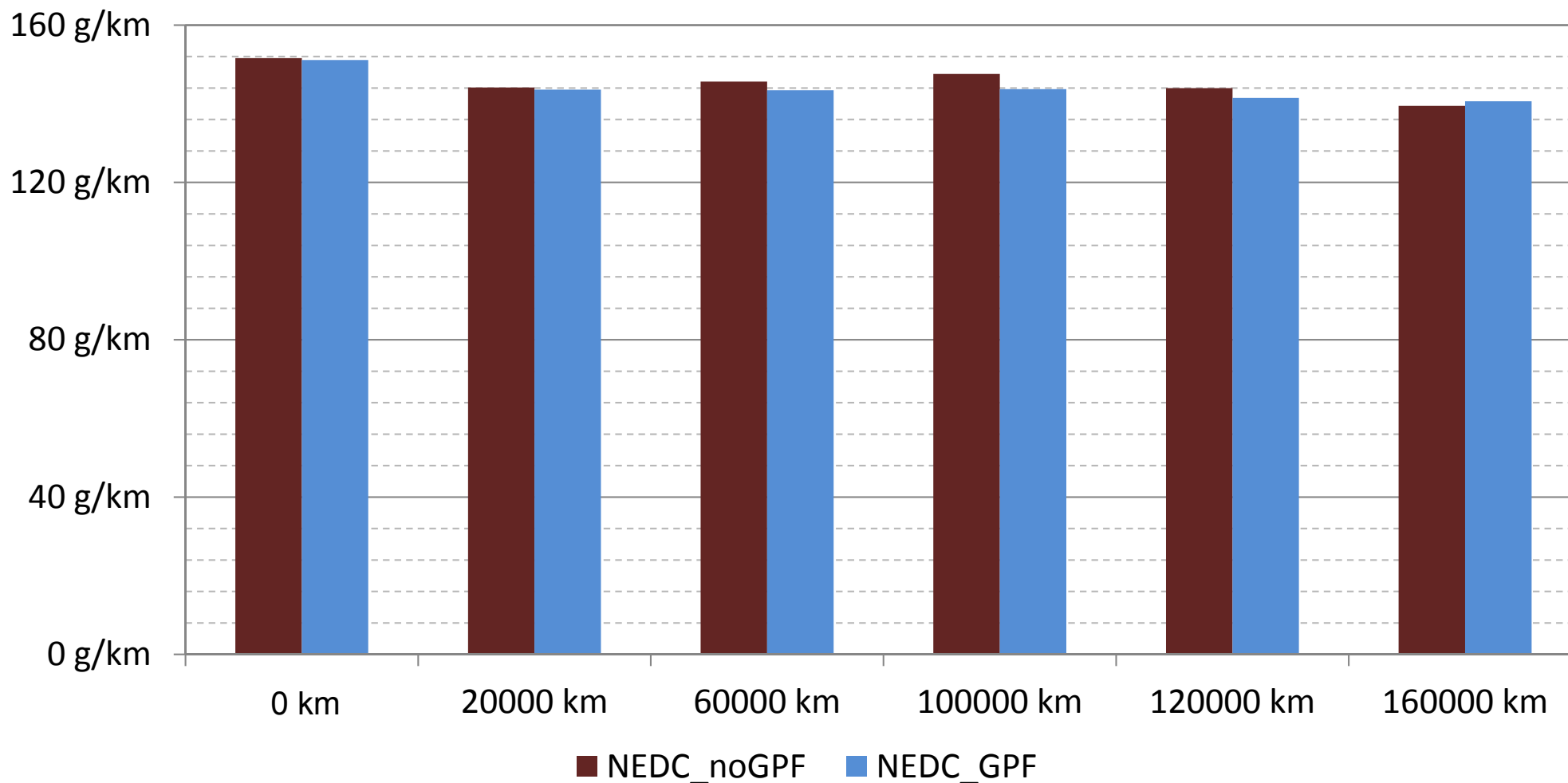


# Particle Number RTS 95 Aggressive and NEDC -7°C



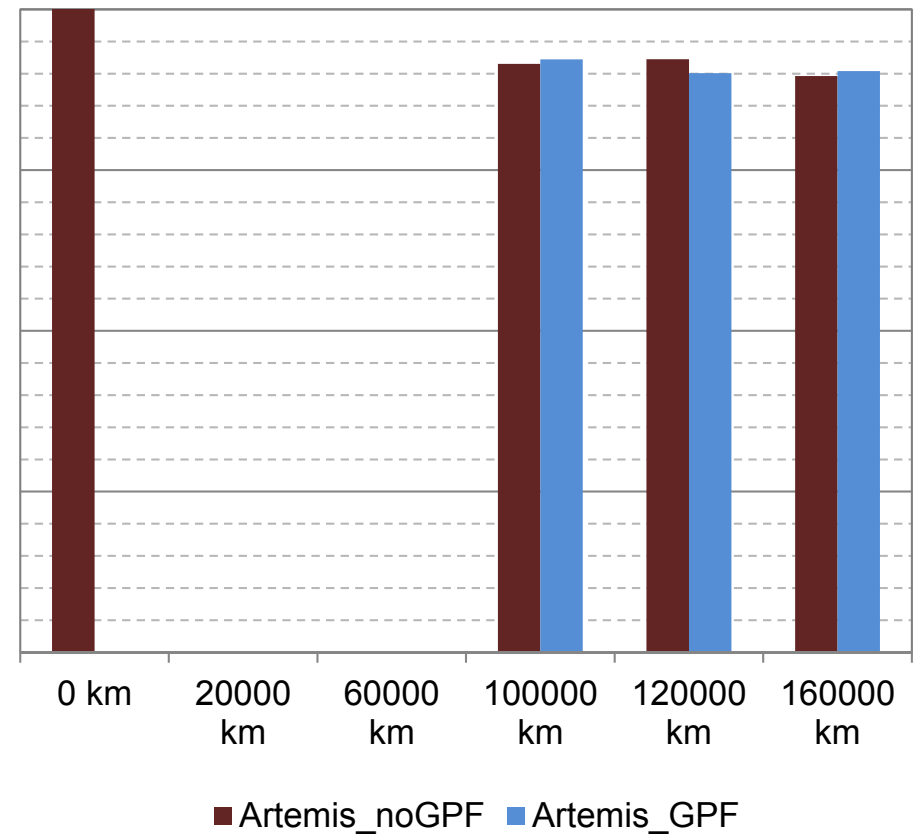
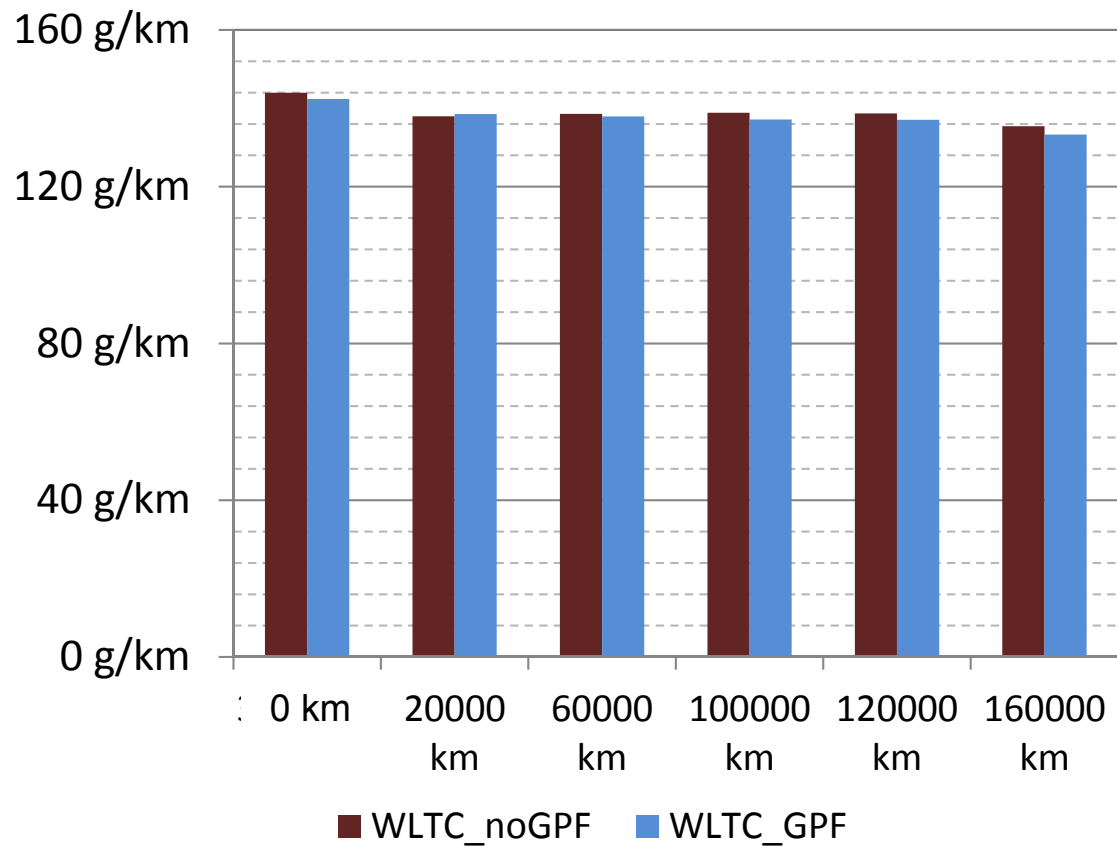
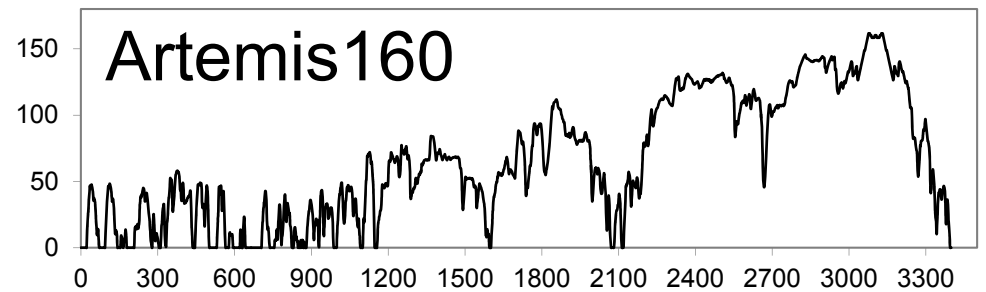
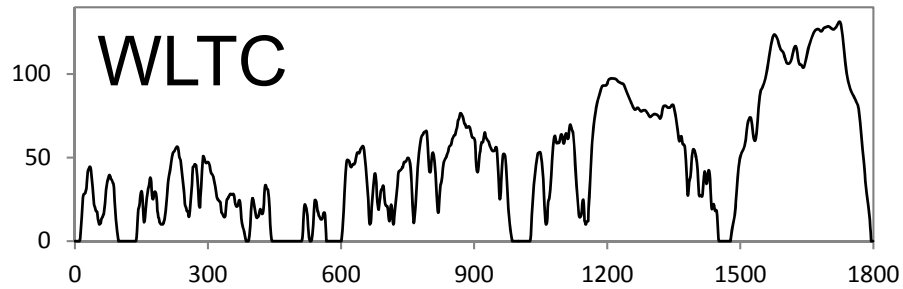
— Eu6c PN legislation limit

Catalyzed GPF can reduce PN significantly during RTS 95 Aggressive and NEDC -7°C.



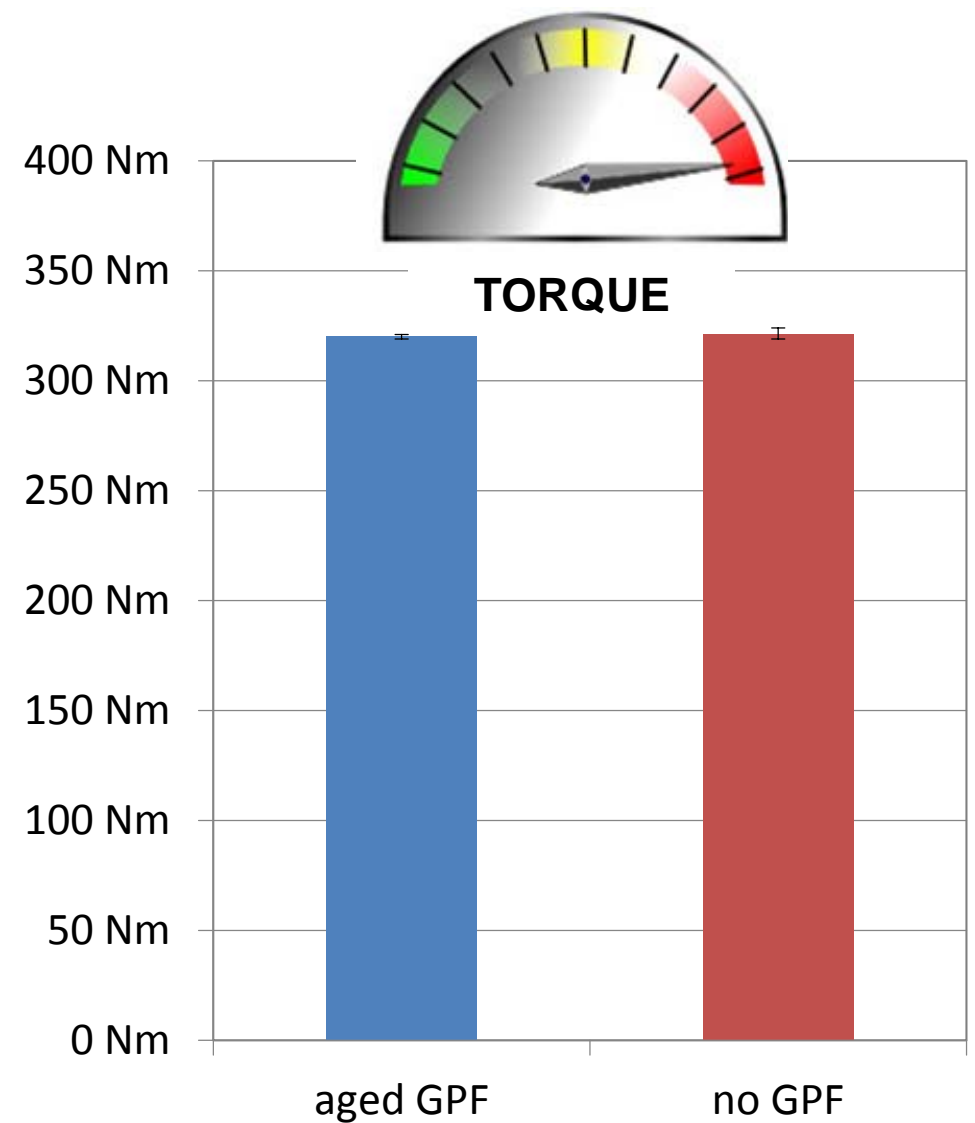
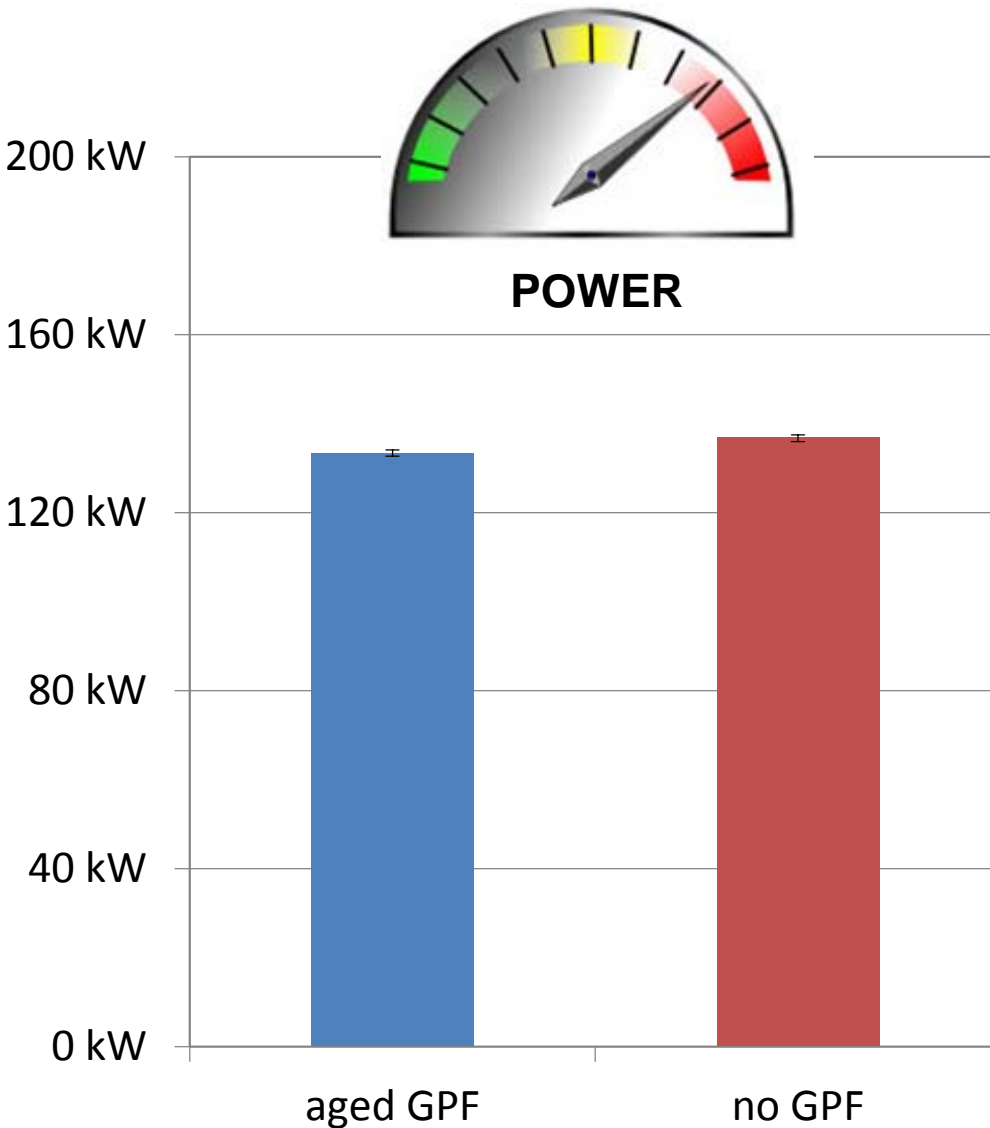
Impact on CO<sub>2</sub> emission from a catalyzed GPF is negligible during the NEDC drive cycle.

# CO<sub>2</sub> Emissions during WLTC and Artemis160



Impact on CO<sub>2</sub> emission from a catalyzed GPF is negligible during other dynamic drive cycles.

# Wide Open Throttle Power Measurement



Only 2.5% power loss with aged GPF after 160,000 km during wide open throttle acceleration.

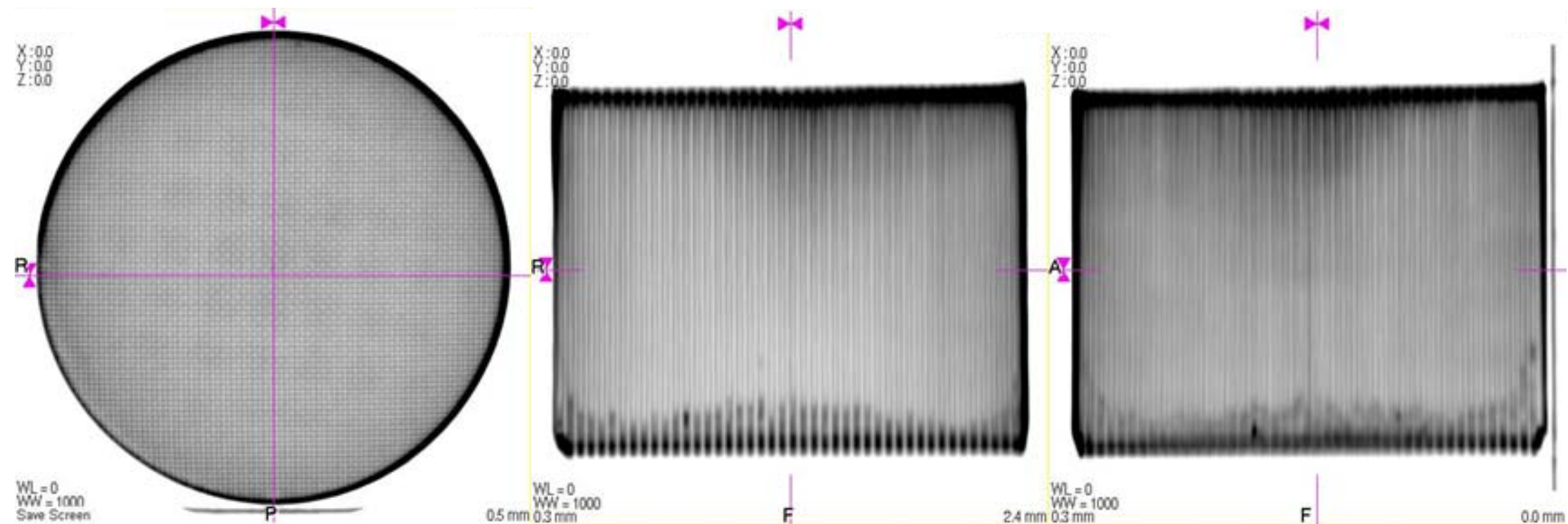


# CT Scan of GPF after 160,000 km

Oil:  
Aral Super Tronic Longlife III  
5W-30 DIN 51511  
(consumption: 0.305 l/10,000 km)

Fuel:  
Gasoline RON 95 E5 DIN EN 228  
(consumption: 8.46 l/100 km)

Engine: 1.8 liter turbo GDI, Euro 5  
Average Speed: 80 km/h



→ Weight of accumulated deposition (ash) in the filter after 160,000km durability run: 22g

Ash is accumulating in the rear of the GPF channels.  
No damage or crack could be observed.

- ***Today Air Quality Targets for PM cannot be met in all areas of EU.***
- ***Combustion engines remain major share of powertrains even beyond 2020.***

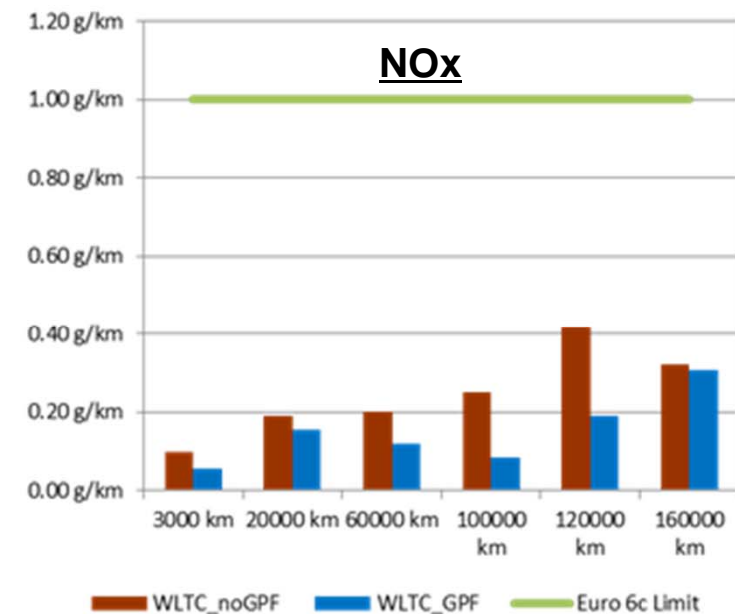
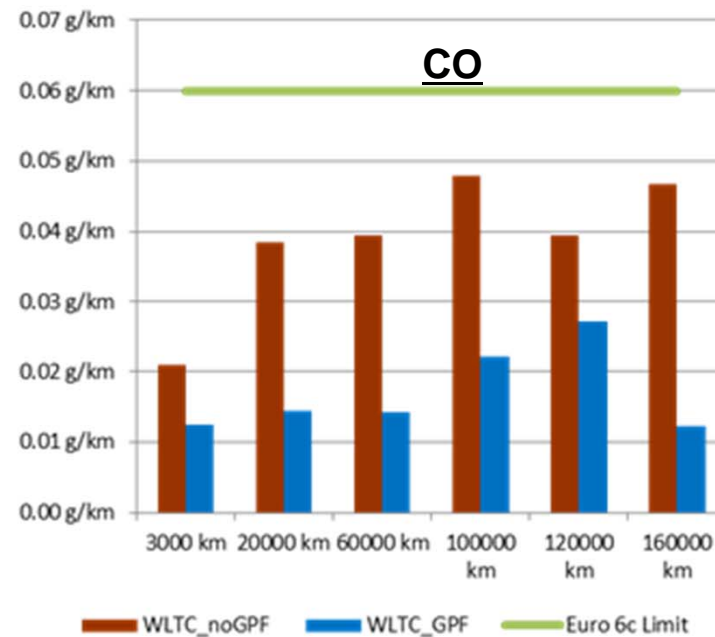
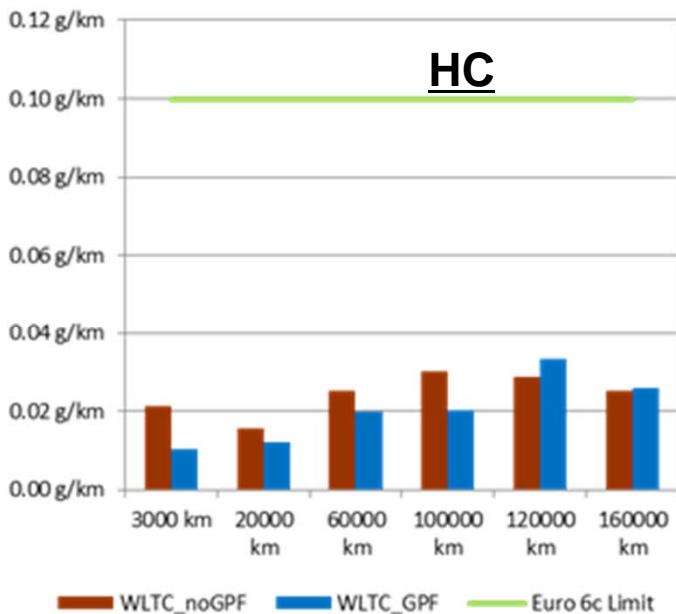
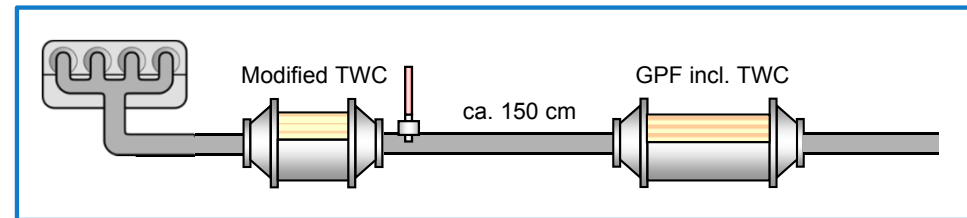
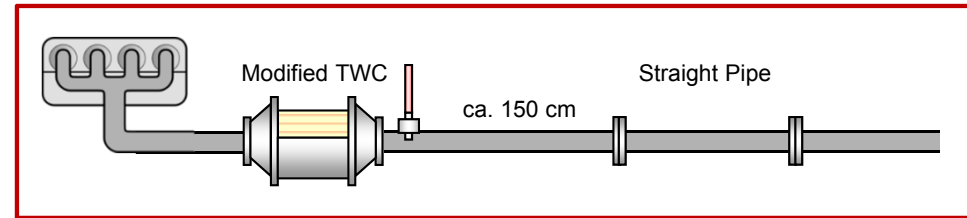
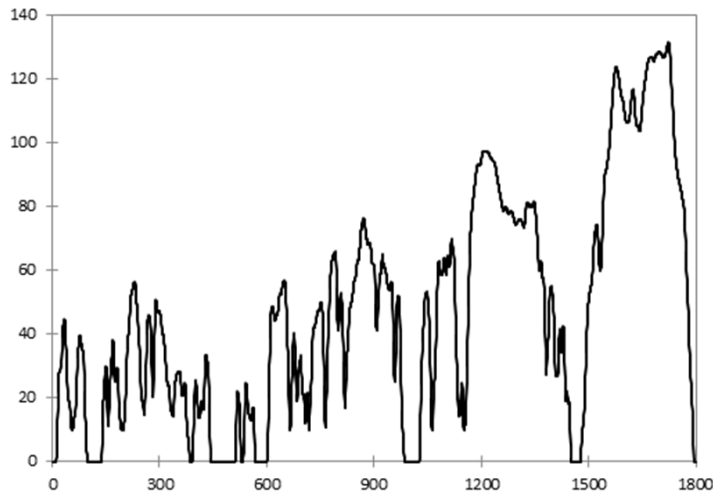
***Key focus of long term powertrain development is low CO<sub>2</sub> and thus GDI market share will increase.***
- ***New GPF concepts for GDI applications have been developed:***
  - ***Effective PN reduction in different test cycles and under real driving conditions.***
  - ***GPF concepts show no significant impact on CO<sub>2</sub> emission during NEDC and other more dynamic drive cycles.***
  - ***GPF with integrated TWC activity for additional gas conversion works for extensive travel distance at least up to 160,000 km.***



**NGK**

**Thank you!**

# Euro 6c Criteria Pollutants during WLTC



Catalytic conversion sustains at least up to 160,000 km even for dynamic drive cycles.



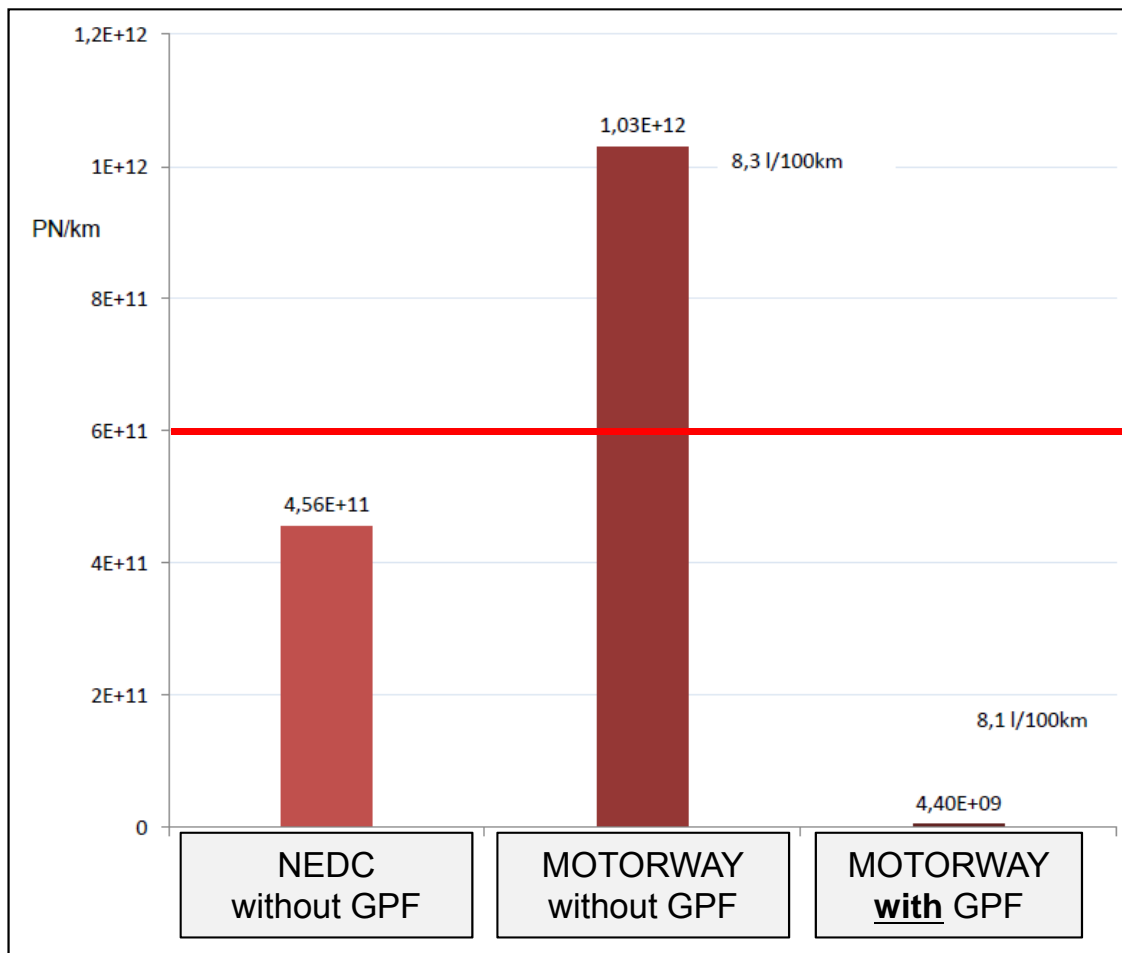
	Cordierite	SiC
Filtration Efficiency	<b>Reference</b>	=
Pressure Drop		-
Thermal Shock		-
Thermal Stability (Decomposition)		=
Passive Regeneration		-

- Inferior to ref  
= Equal to ref

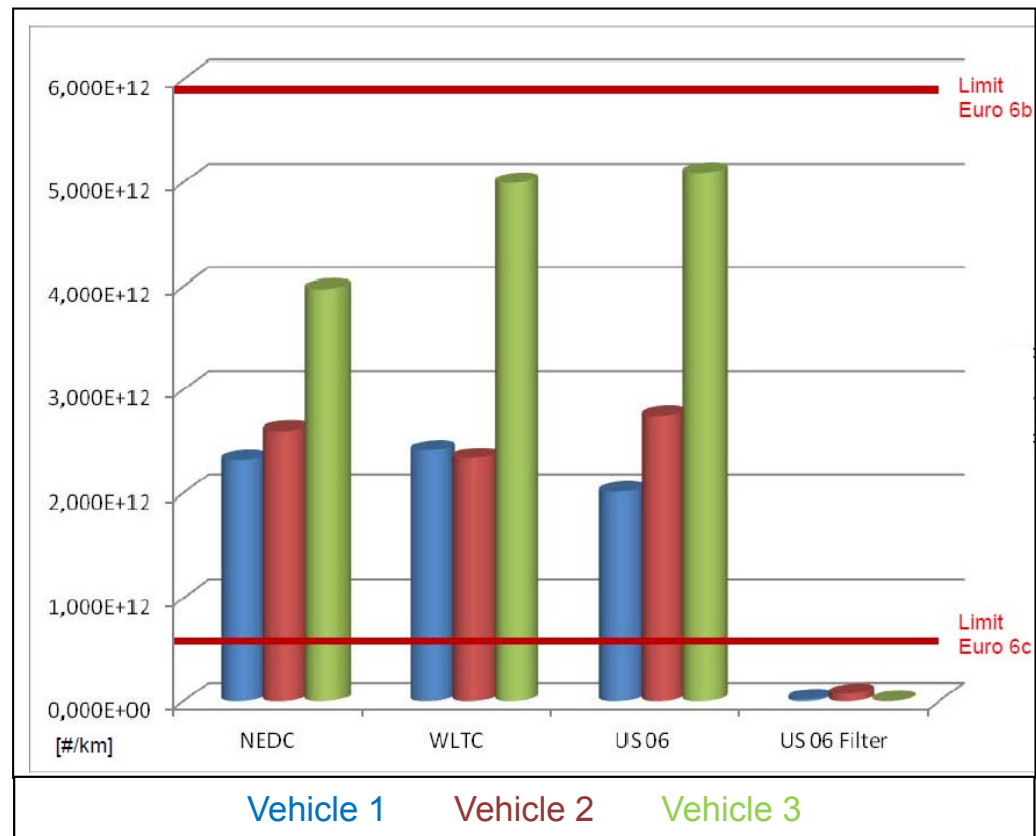
Cordierite is balanced material for required performance of GPF.



# Current status: Particle Number Emissions of GDI Vehicles



Source: DUH, 29.10.2013



Source: TÜV, 26.09.2013

— Eu6c legislation limit

Some GDI vehicles show PN emissions above EU6c legislation limit.



From 2021  
CO<sub>2</sub> limit for  
100% of fleet: 95g/km



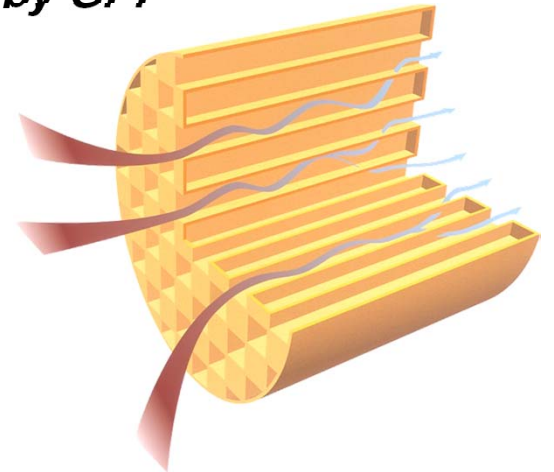
Higher engine load  
driving cycles / RDE  
for PN emission  
certification!?

**PN/PM aftertreatment  
by GPF**



Dl gasoline engines  
to reduce CO<sub>2</sub> emissions  
→ Further market share  
increase in future  
is forecasted

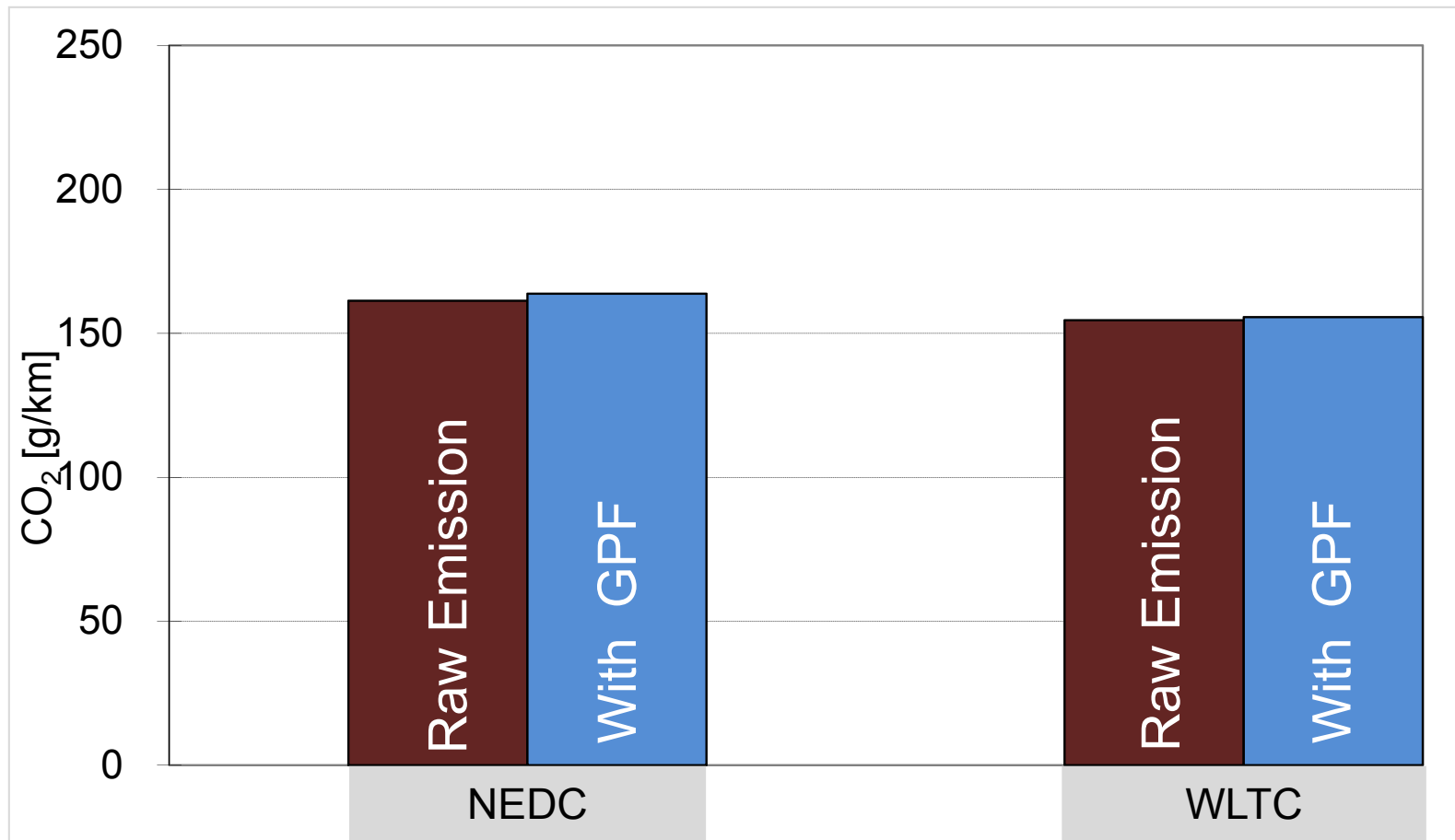
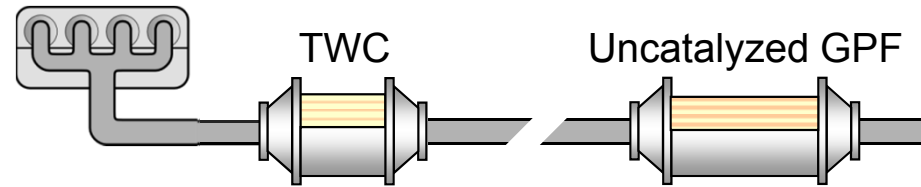
PN limit for gasoline  
DI engines:  
6E11/km from 2017



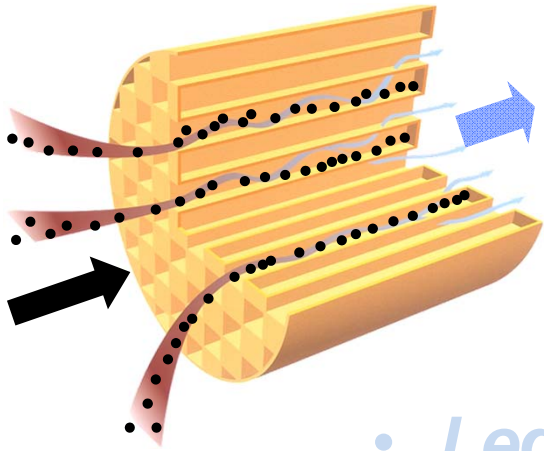
Gasoline Particulate Filter (GPF) helps to reduce Particle Number of gasoline engines!

# Vehicle test results for CO<sub>2</sub> emission

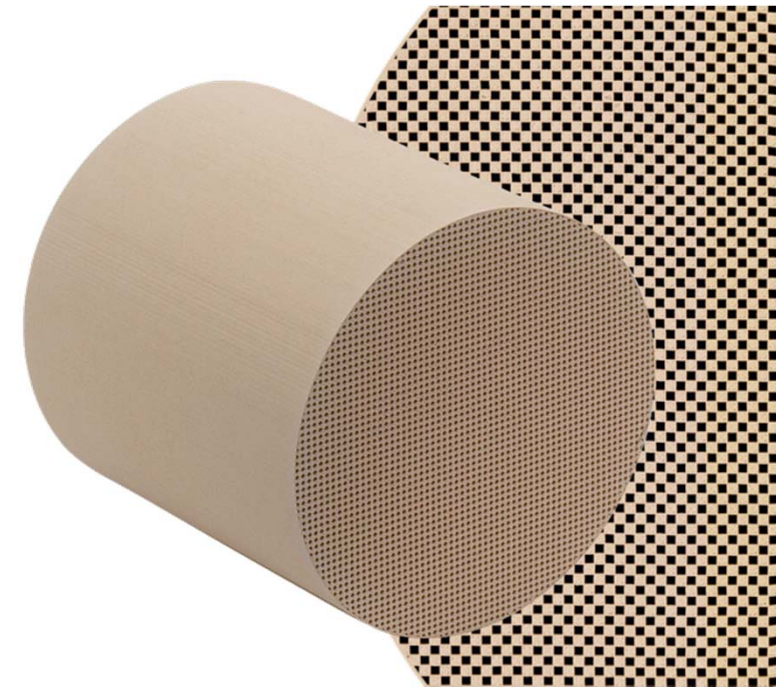
**Vehicle:** 1.4L DI Gasoline  $\lambda=1$   
**GPF:** ~48% porosity,  $\phi$  118.4 x 127 mm L,  
uncatalyzed  
**Position:** Underfloor



NEDC and WLTC test show no measurable impact by GPF on CO<sub>2</sub> emissions.

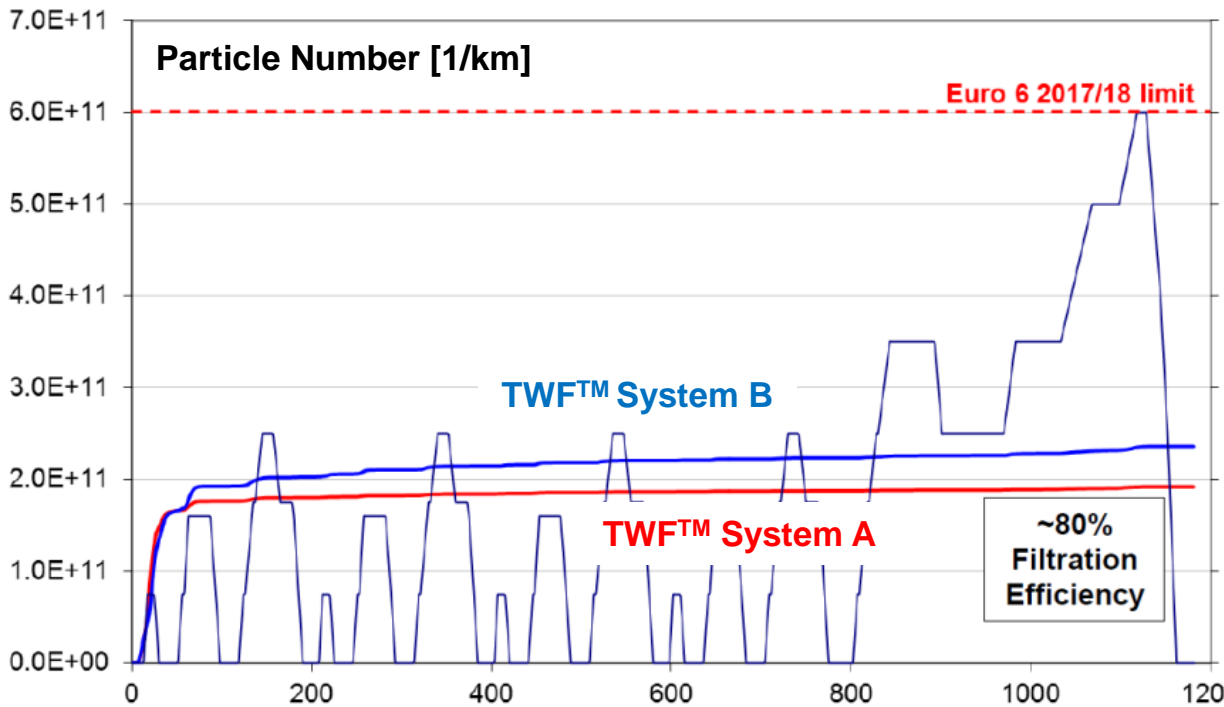


- *Legislation and Market Trend*
- *GPF to fulfill PN Legislation with Gasoline Engines*
- *Extended Functions on GPF*
- *Robust Catalyzed GPF*

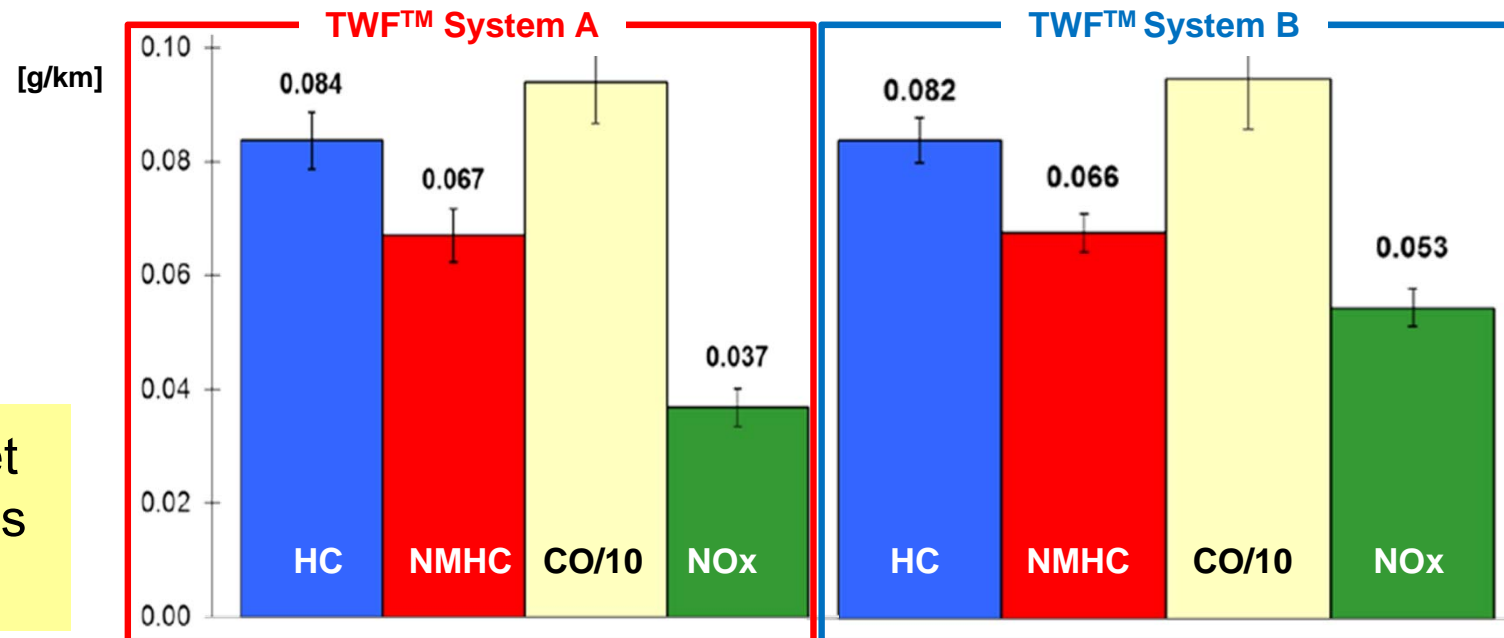


Gasoline Particulate Filter : GPF

# Performance of Three-Way-Filter (TWFT<sup>TM</sup>)



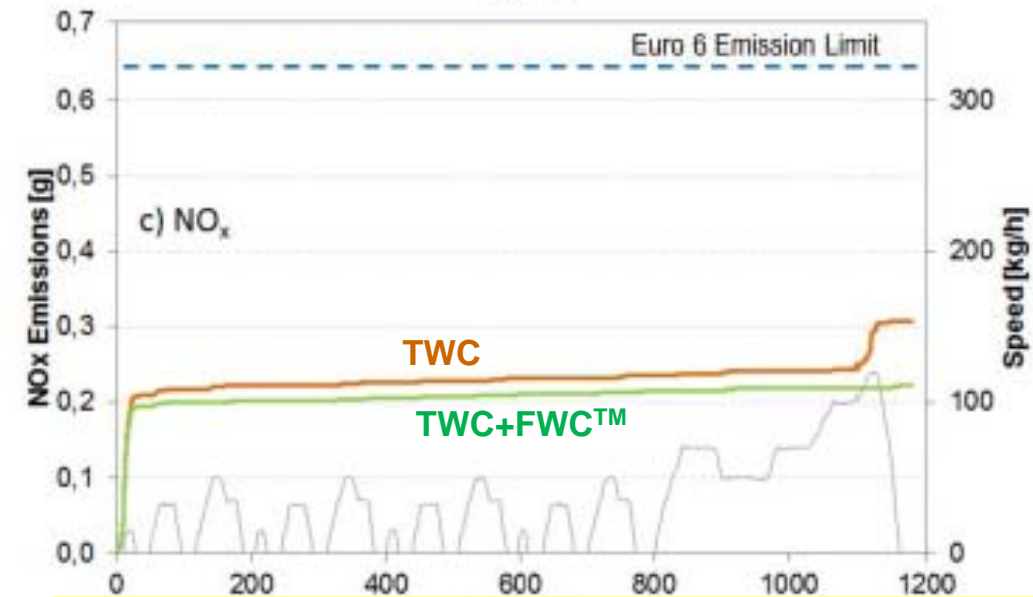
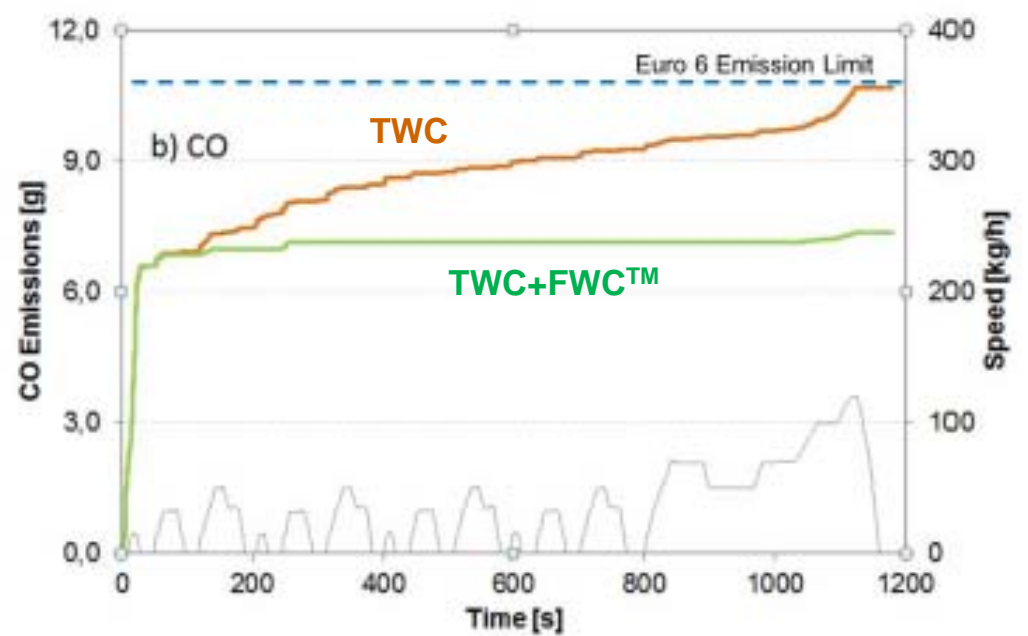
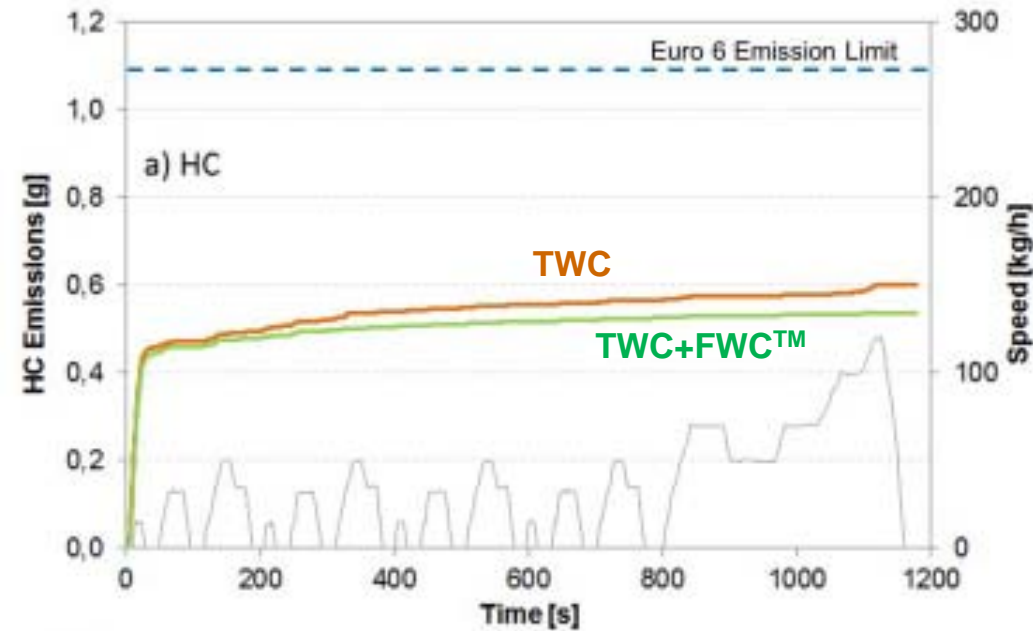
Source: Dr. David Greenwell, 2<sup>nd</sup> International Conference - Advanced Emission Control Concepts for Gasoline Engines, 13.-14.05.2013, Bonn



Catalyzed GPF can meet Euro 6c limits for gaseous and particle emissions.



# Performance of Four-Way-Catalyst (FWC™)



Close-coupled TWC only

Close-coupled TWC + underfloor FWC™

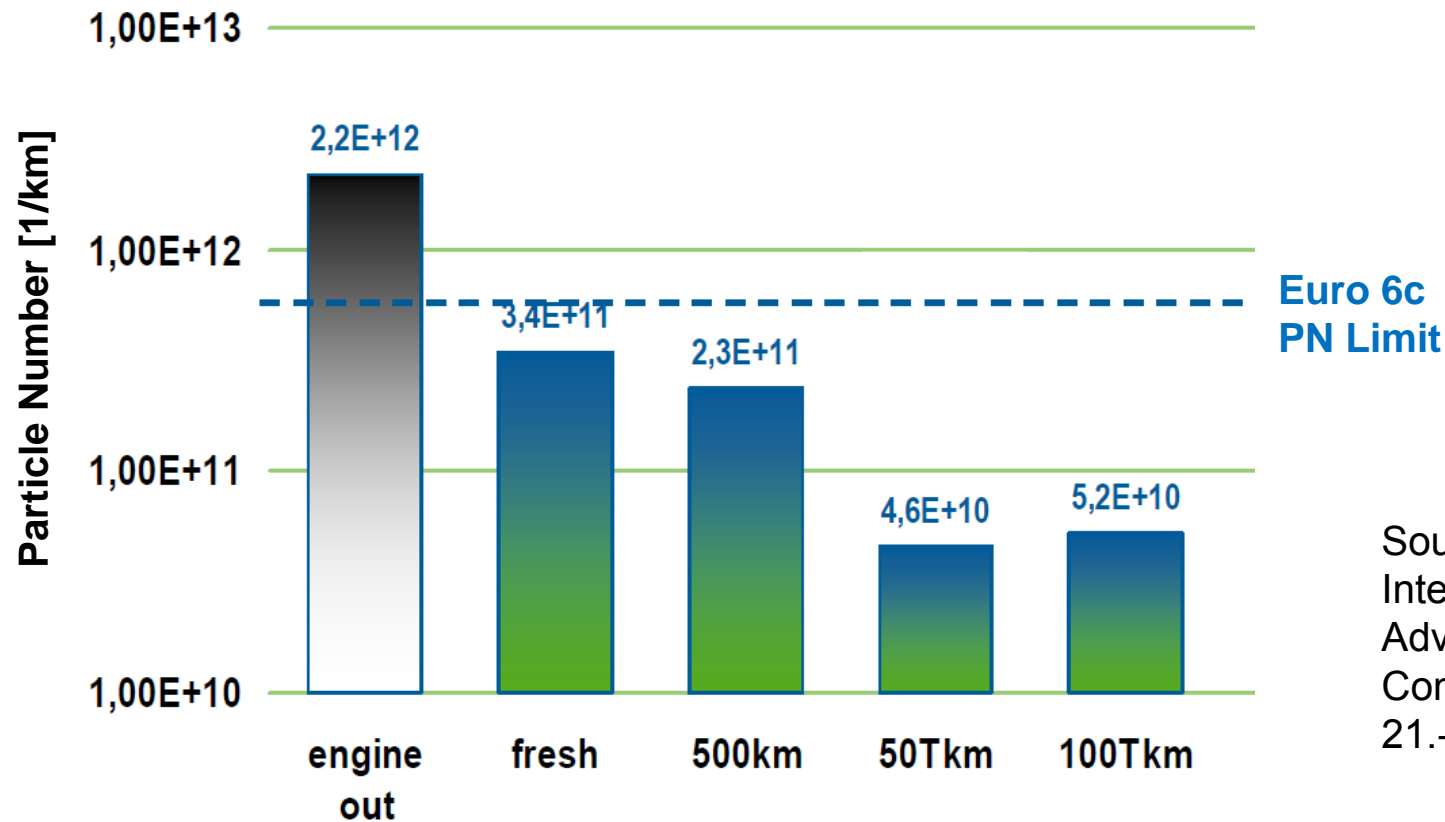


Source: BASF, International Vienna Motor Symposium 2013, Catalyzed Gasoline Particulate Filters: Integrated Solutions for Stringent Emission Control

Catalyzed GPF can improve catalytic conversion efficiency.

## Real world road durability validation

TWC + add on GPF downstream, PN over distance

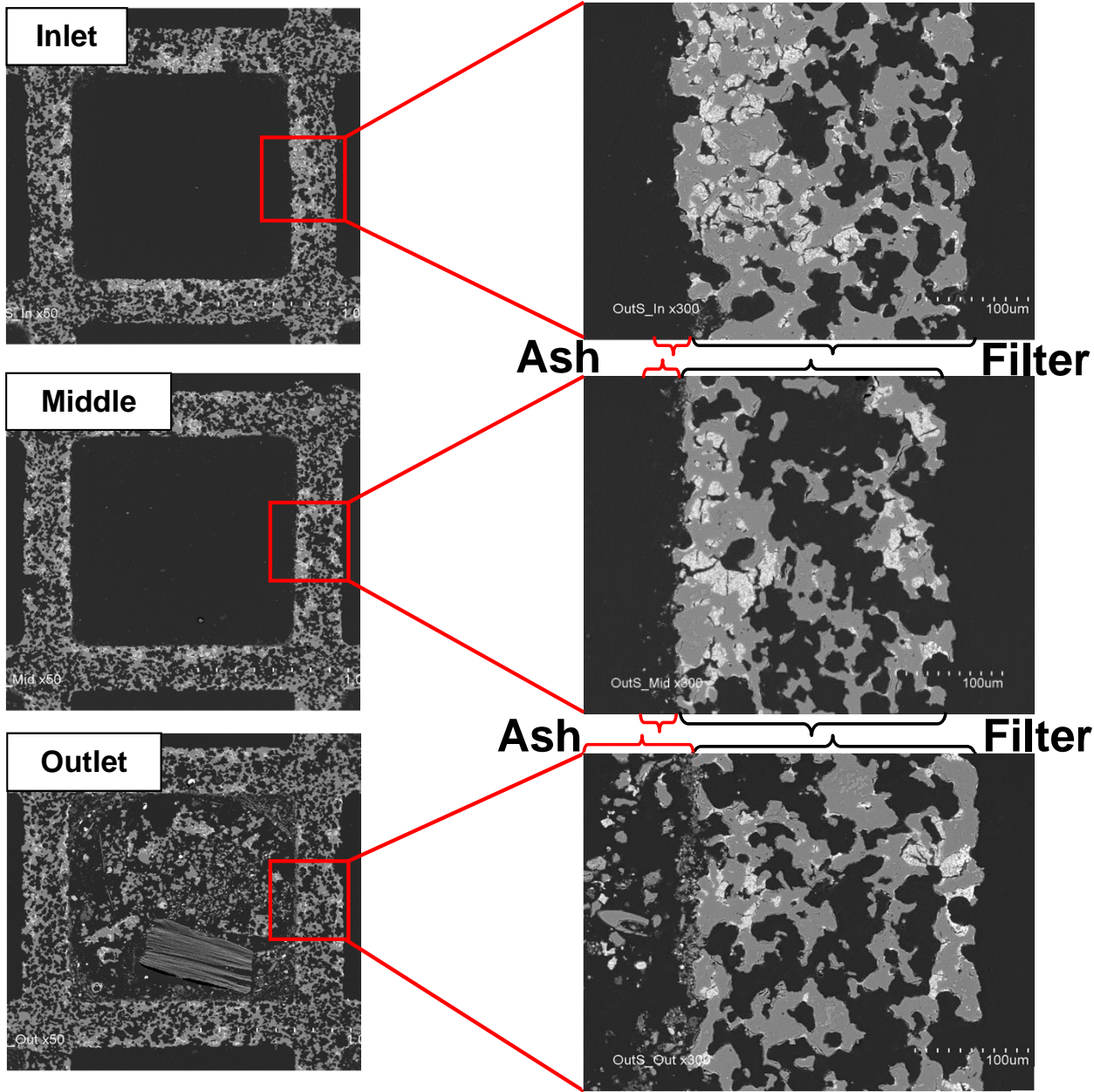
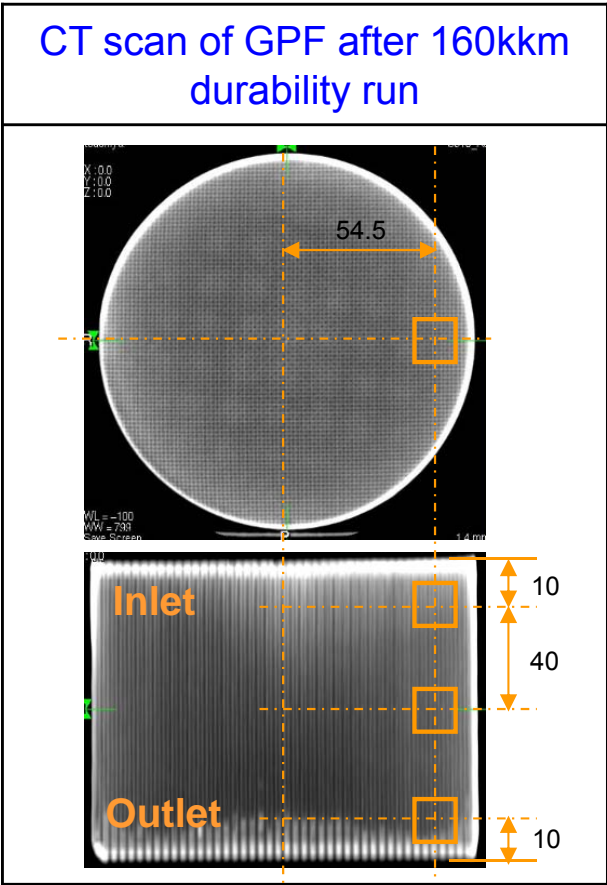


Source: Bernhard Kern,  
International Congress -  
Advanced Emission Control  
Concepts Gasoline Engines,  
21.-23.05.2012, Stuttgart

Catalyzed GPF can meet PN limit fresh and sustain high filtration efficiency over extended distance (up to 100,000 km).

# Ash observation of peripheral portion (cross section)

Test Engine : 1.8L turbo GDI (EU5)  
 Material : C810  
 Cell structure : 10mil/300cps  
 GPF size/volume: (DxL)129 ×100mm / 1.3L  
**Coated GPF**



<<peripheral portion>> The channels was blocked by ash on outlet portion

Catalyst: umicore Automotive Catalysts