From DPF to GPF: the success story of particulate filters

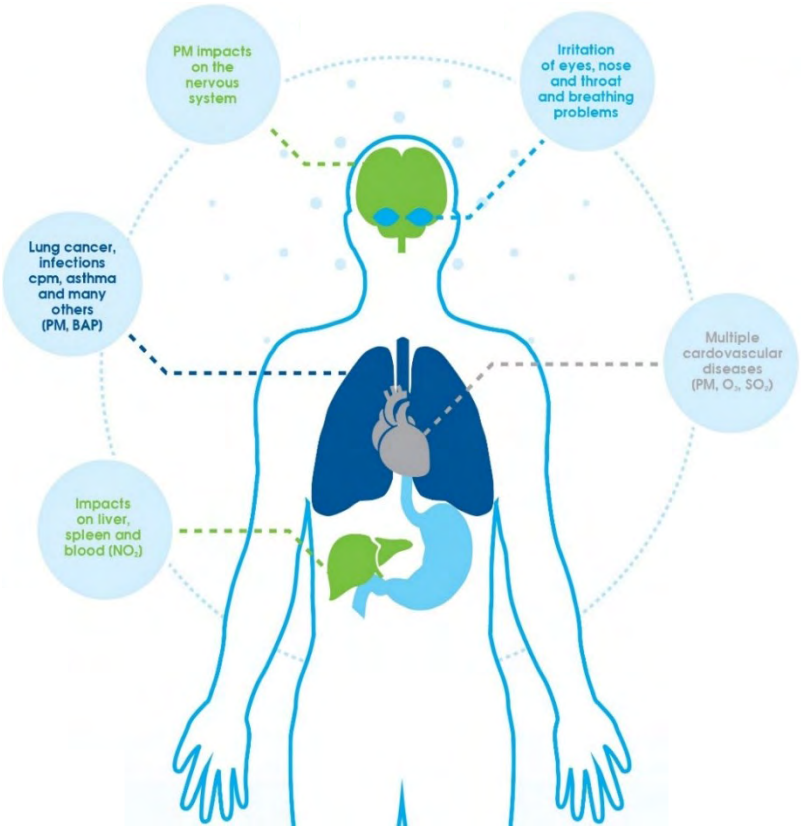
AECC Technical Seminar on RDE PN

4 July 2016

Association for Emissions Control by Catalyst AISBL

Air pollution health effects

- Globally, WHO estimates that 3.7 million people died from air pollution in 2012.
- 480 000 people died prematurely from air pollution in the EU in 2012.
- PM pollution: 8.6 months of life lost for every EU citizen.
- Health impacts external cost in the EU: €330-940 billion (3-9% of EU GDP).

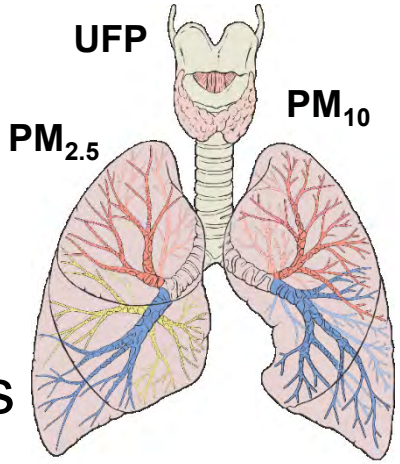


- Direct economic damage in the EU: lost workdays €15 bn, healthcare costs €4 bn, crop yield loss €3 bn, damage to buildings €1 bn.
- OECD report (May 2014): health impact of road transport air pollution in OECD countries was €0.6 trillion in 2010.

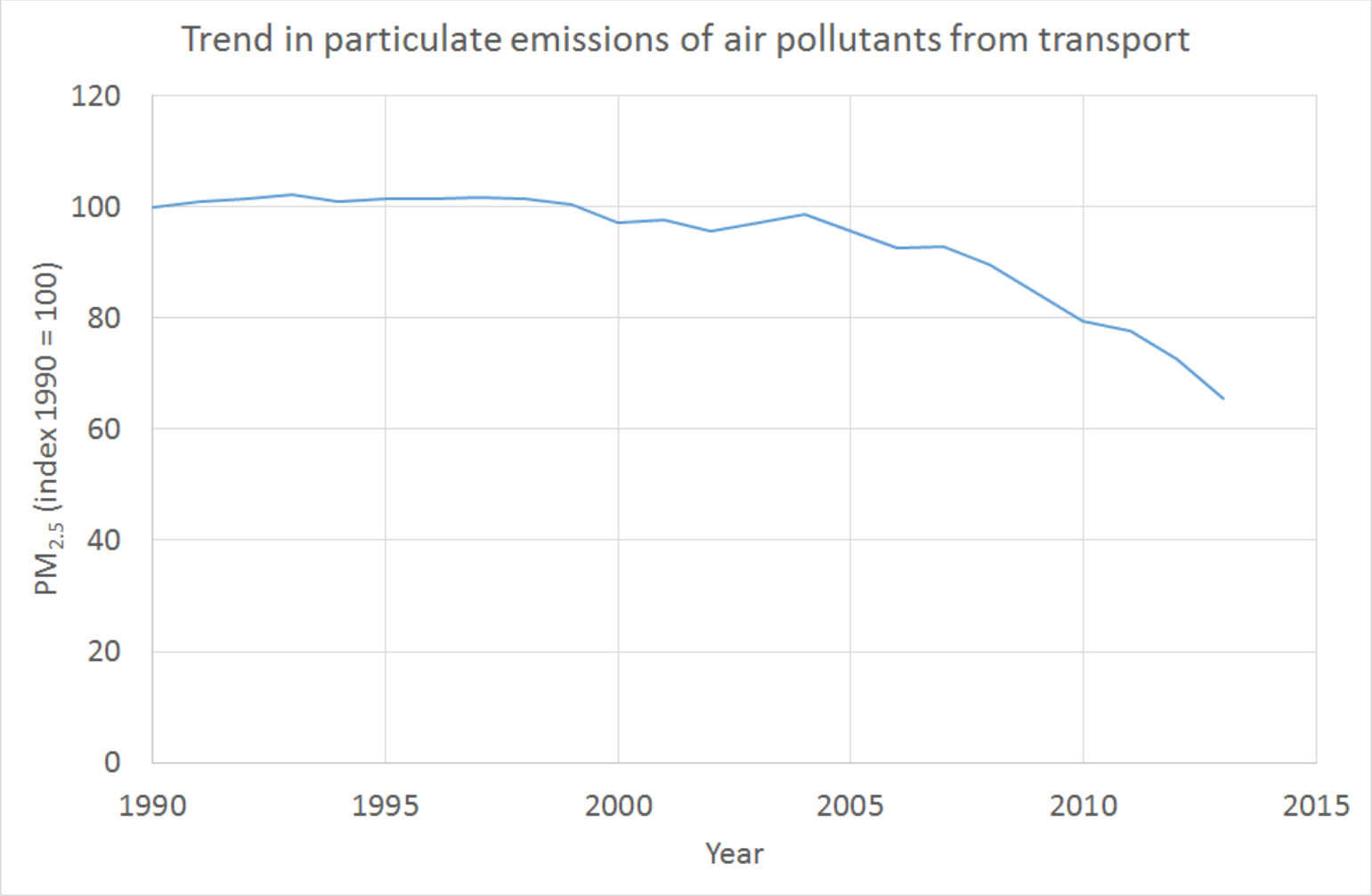
Health impact of ultrafine particles

- Concerns reported because of the surface area of UFP and its translocation capability into the human body
- Conclusions of 2013 WHO Review of Evidence on Health Aspects of Air Pollution (REVIHAAP)
  - Indications for toxic effects of UFP
  - Not enough epidemiological evidence for UFP air quality guideline in addition to $PM_{2.5}$ and PM_{10}
  - Precautionary principle:
    WHO supports regulatory efforts to reduce the number of UFP (PN) in engine emissions

World Health Organization
REGIONAL OFFICE FOR Europe



$PM_{2.5}$ emissions from transport have declined in the EU over the past 10 years…



Source: National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention) provided by European Environment Agency (EEA)

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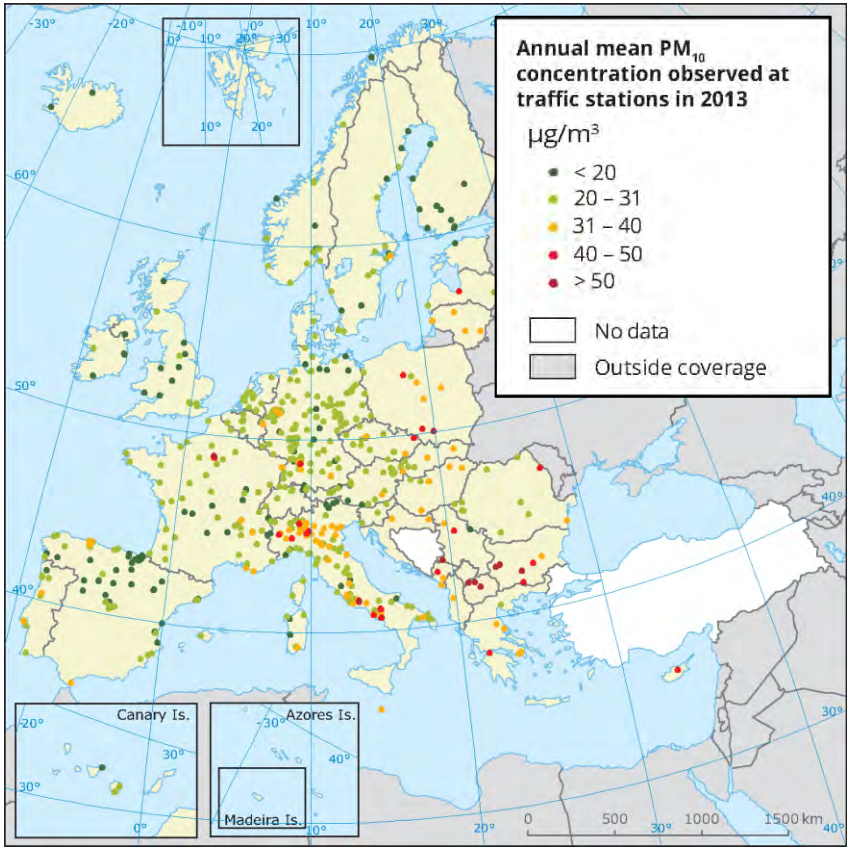
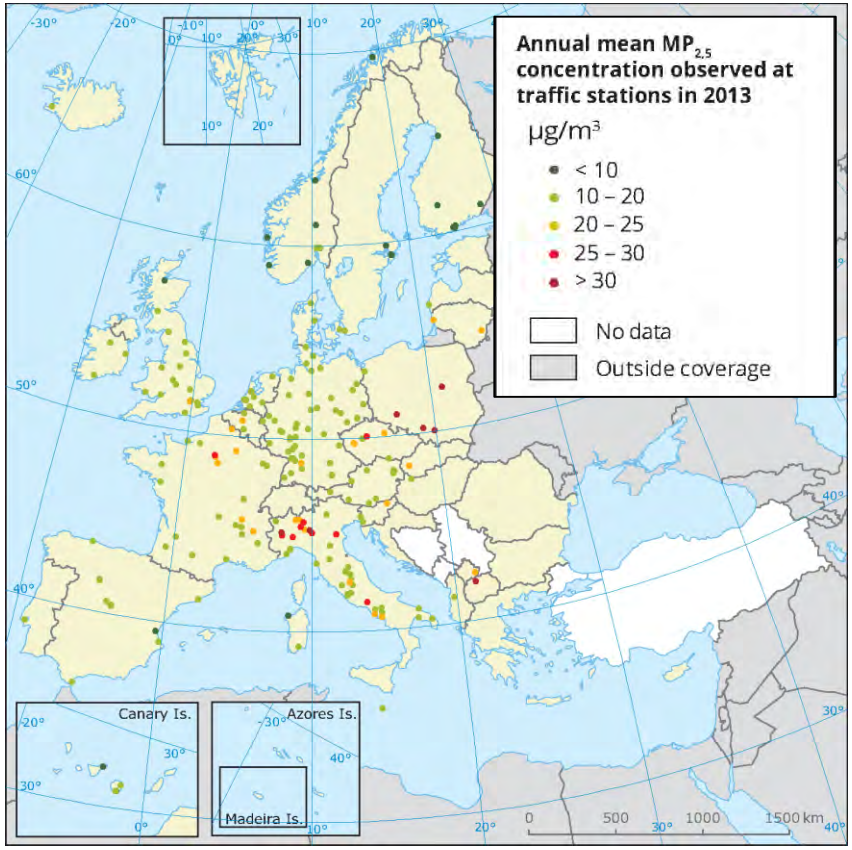
…however PM_{10} and $PM_{2.5}$ concentrations are still in exceedance in a number of major cities





Source: European Environment Agency (EEA), 2016

European Commission

Why a particle number limit?

- A proven causal relationship exists between exposures to PM2.5 and adverse effects on human health and mortality
- It remains a challenge to determine relationships between specific constituents or sources of PM2.5 and the various health effects observed
- 'Precautionary principle' invoked – elimination of carbon particles via the use of DPFs was considered necessary
- European Governments felt that previous PM limit values had intended, but failed, to mandate the use of DPFs
- It was considered that forcing the use DPFs couldn't be achieved without a new measurement method
- UN-ECE Particle Measurement Programme (PMP) was conceived, chaired by the UK with strong political backing from France, Germany, Holland and Sweden

Joint Research Centre

Source: Martini (JRC), "Engine exhaust particles: status of play and future developments", 12th Integer Conference on Emissions, Brussels, June 2016

Wall-flow particulate filter

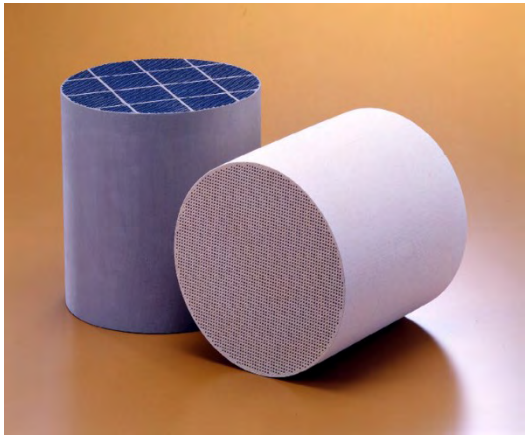
Porous Ceramic Wall

Soot Particles

Tailpipe Emissions

Engine Out Emissions

Alternately Open / Plugged Channels



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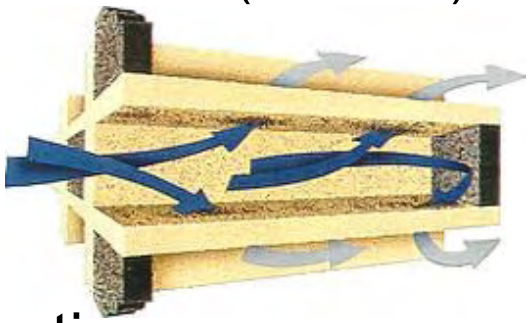
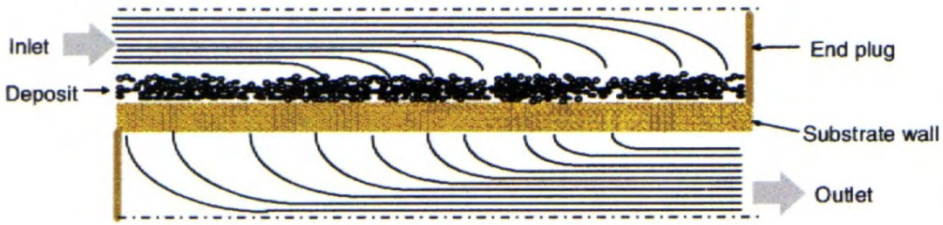
Wall-flow particulate filter

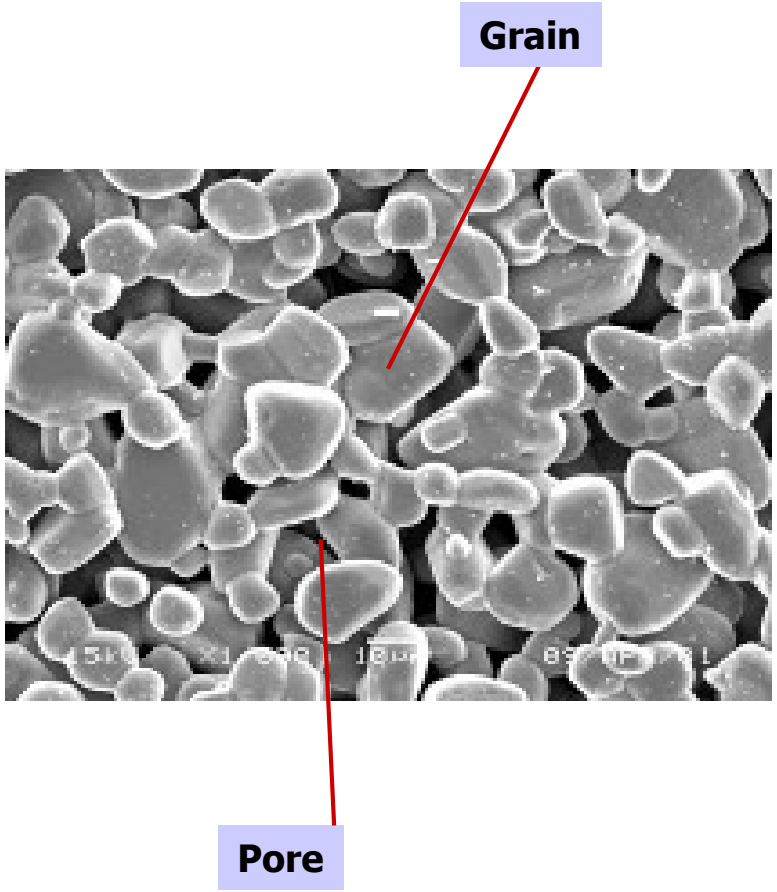
- Description
  - Ceramic honeycomb with porous walls.
  - Channels (~1-2mm) alternately plugged at the ends.

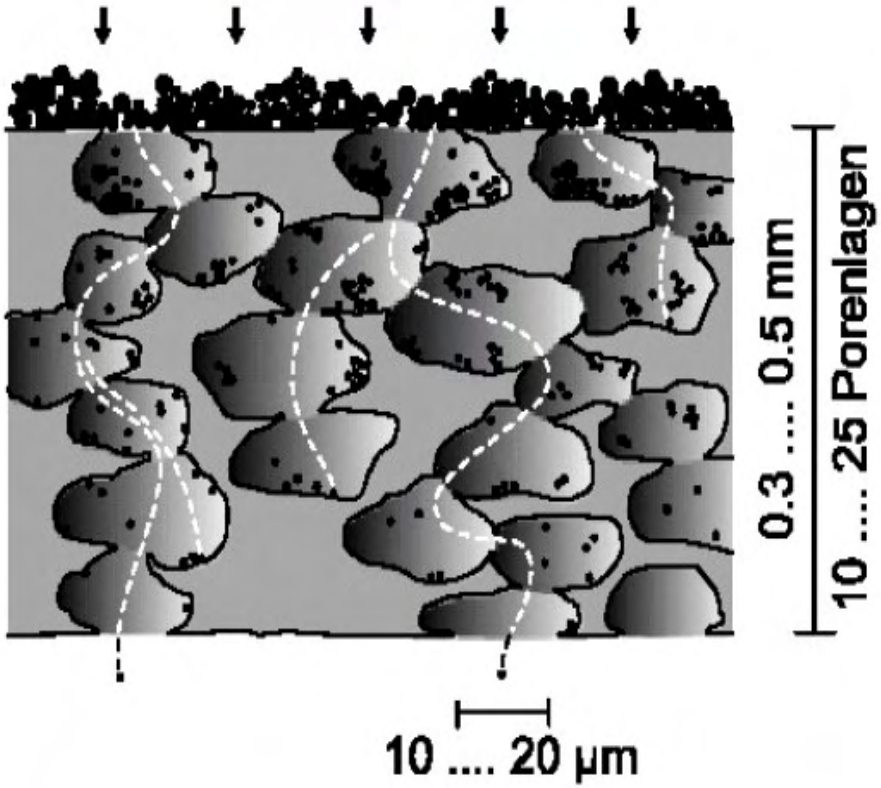




- Functions
  - Trap and store the particulates over the whole size range.
  - Support the catalytic coating.
  - Enable soot burning (regeneration). High temperature and thermal gradient resistance.
- Requirements
  - Minimum back pressure.
  - Maximum ash storage.

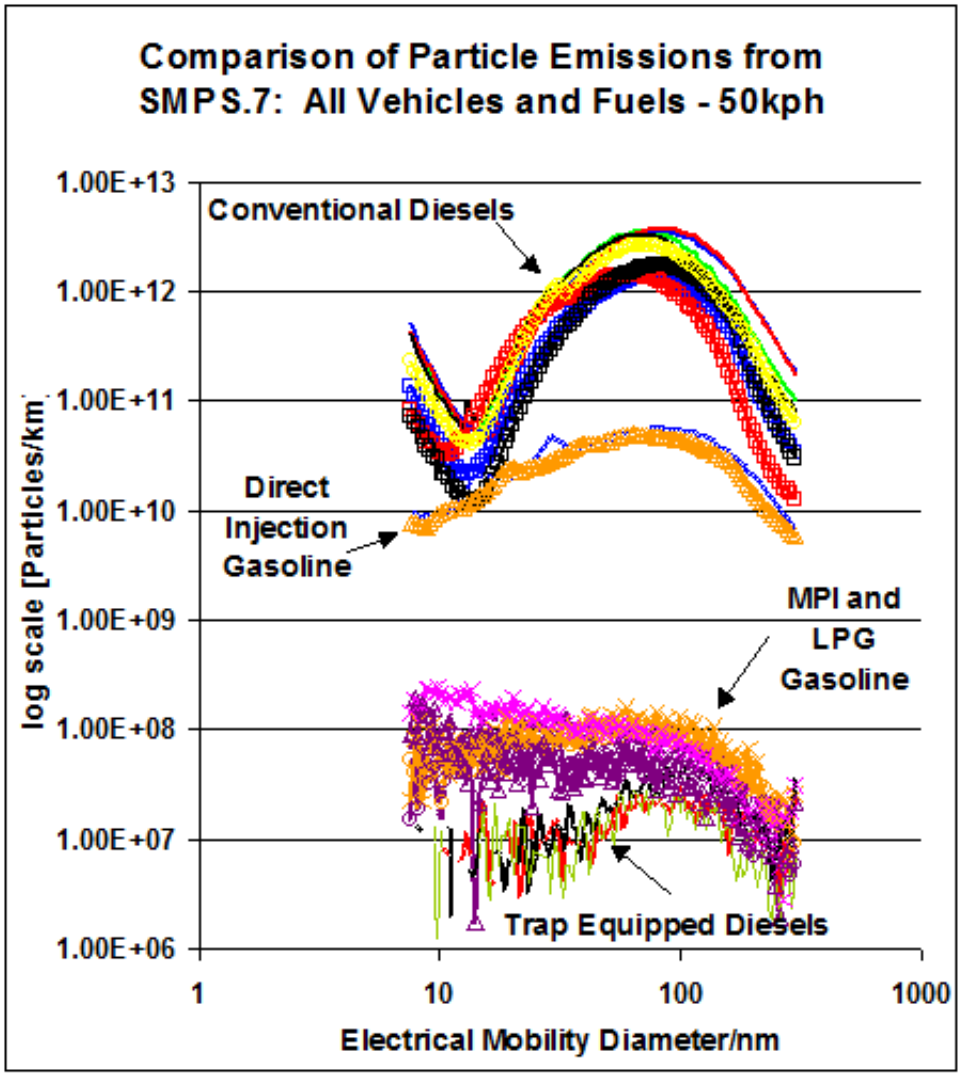
Wall-flow particulate filter: porous walls





Source : Anforderungen an Partikelfiltersysteme für Dieselmotoren, A.Mayer, TTM

DPF reduces particles by several orders of magnitude



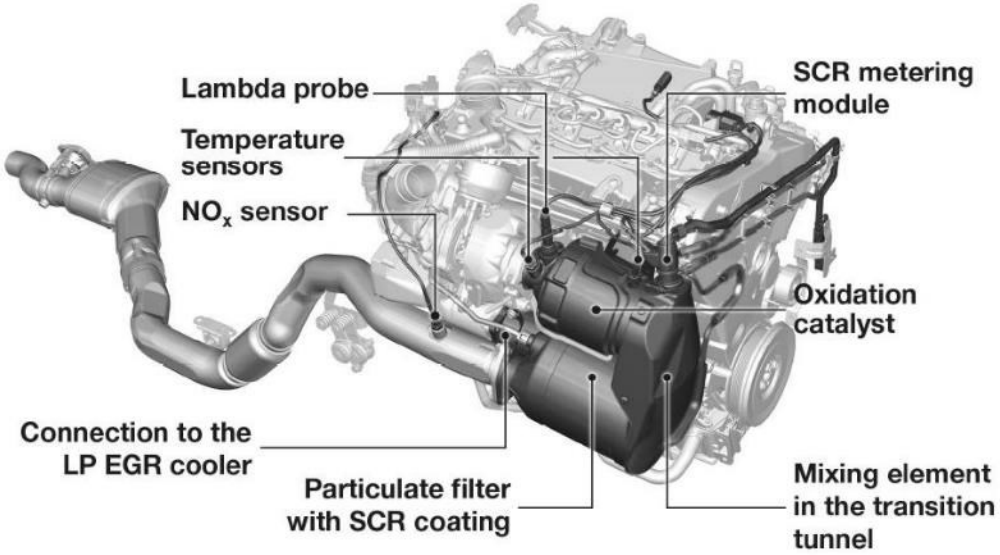
Source: Ricardo (2001)

Euro 6 Diesel vehicle tested by AECC

- 2.0l Euro 6b Diesel car, 120 kW
- Emission Control System: Close Coupled DOC + SCR on DPF, High and Low Pressure EGR
- Vehicle and exhaust ageing ~5800 km
- Pump grade EN590 Diesel fuel (~9 ppm S, 2.6% FAME)

	Emissions
CO_2	111 g/km
CO	203.4 mg/km
NOx	56.4 mg/km
THC+NOx	82.4 mg/km
PM	0.15 mg/km
PN	2 x 10^9/km

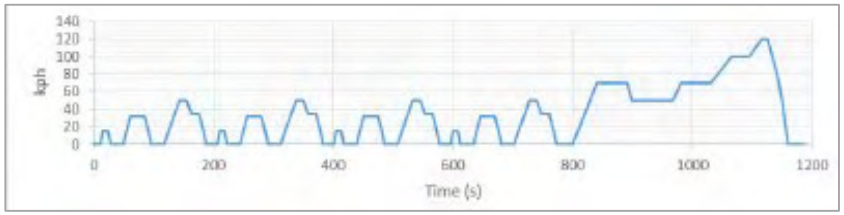
Source: CoC



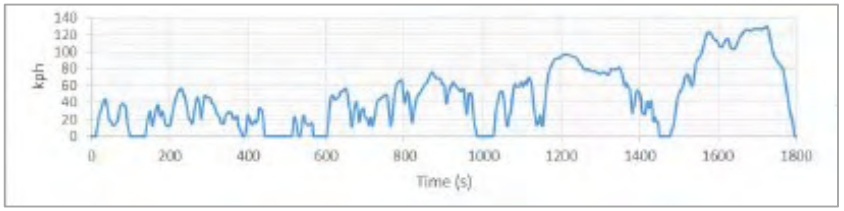
Source: Lörch, Aachen Colloquium 2013

Emissions test regime

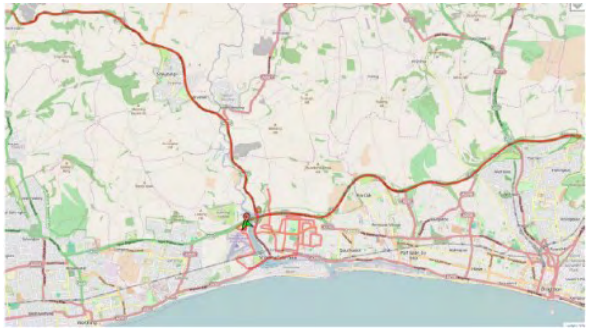
- NEDC



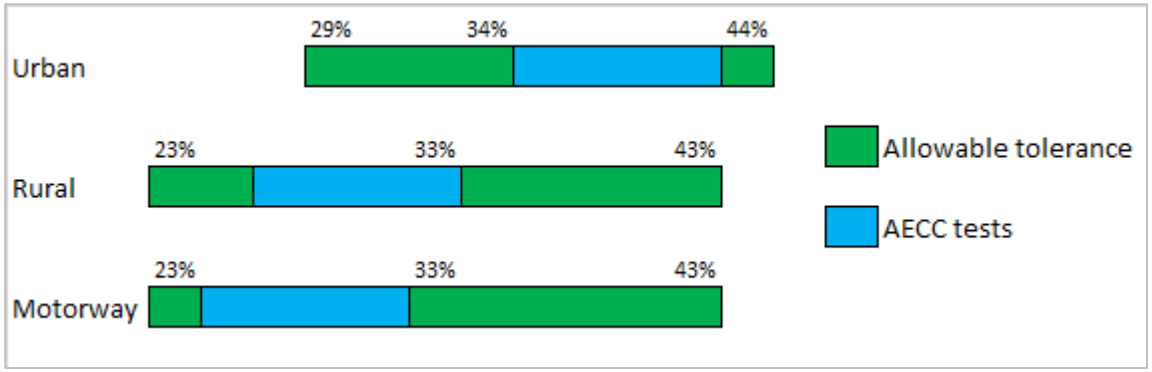
- WLTC



- Real-Driving Emissions (RDE) route driven with PEMS-PN on-board



Duration	103 to 112 min
Ambient temperature	8 to 29°C
Altitude	-8 to 130 m
Max. speed	121 to 130 km/h



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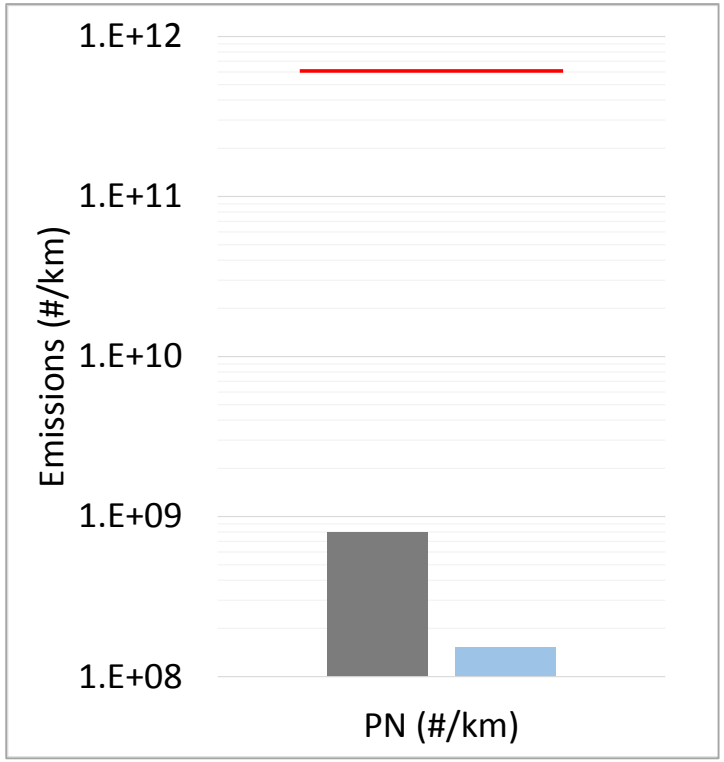
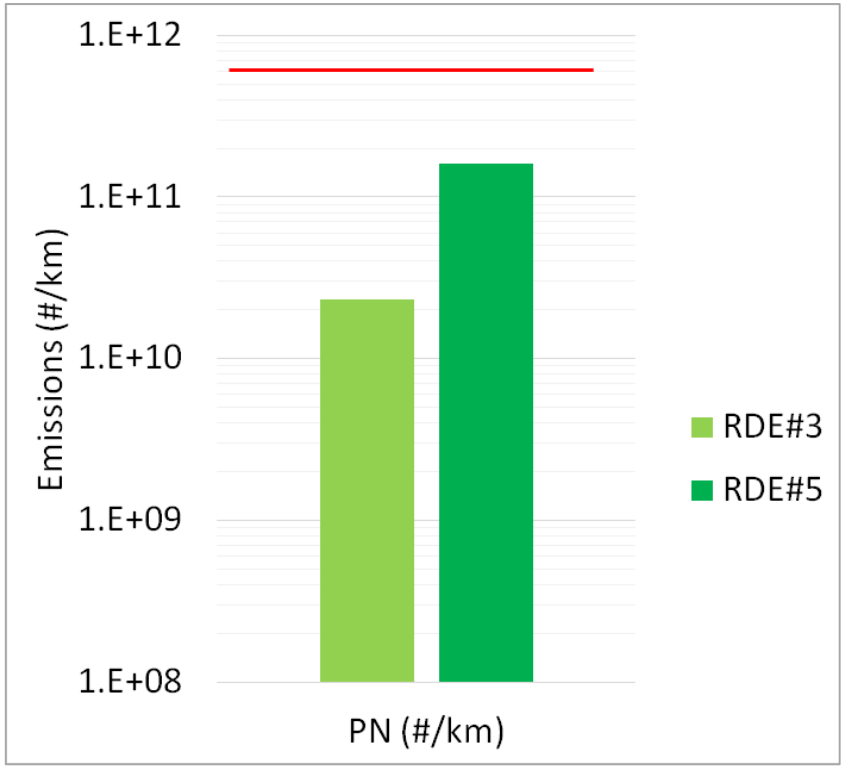
With a DPF, Particle Number emissions are controlled under all driving conditions





NEDC WLTC Euro 6 limit

Vehicle inertia: NEDC: 1590 kg, WLTC: 1680 kg.

A DPF regeneration occurred before RDE#5 which can explain the higher PN emissions.

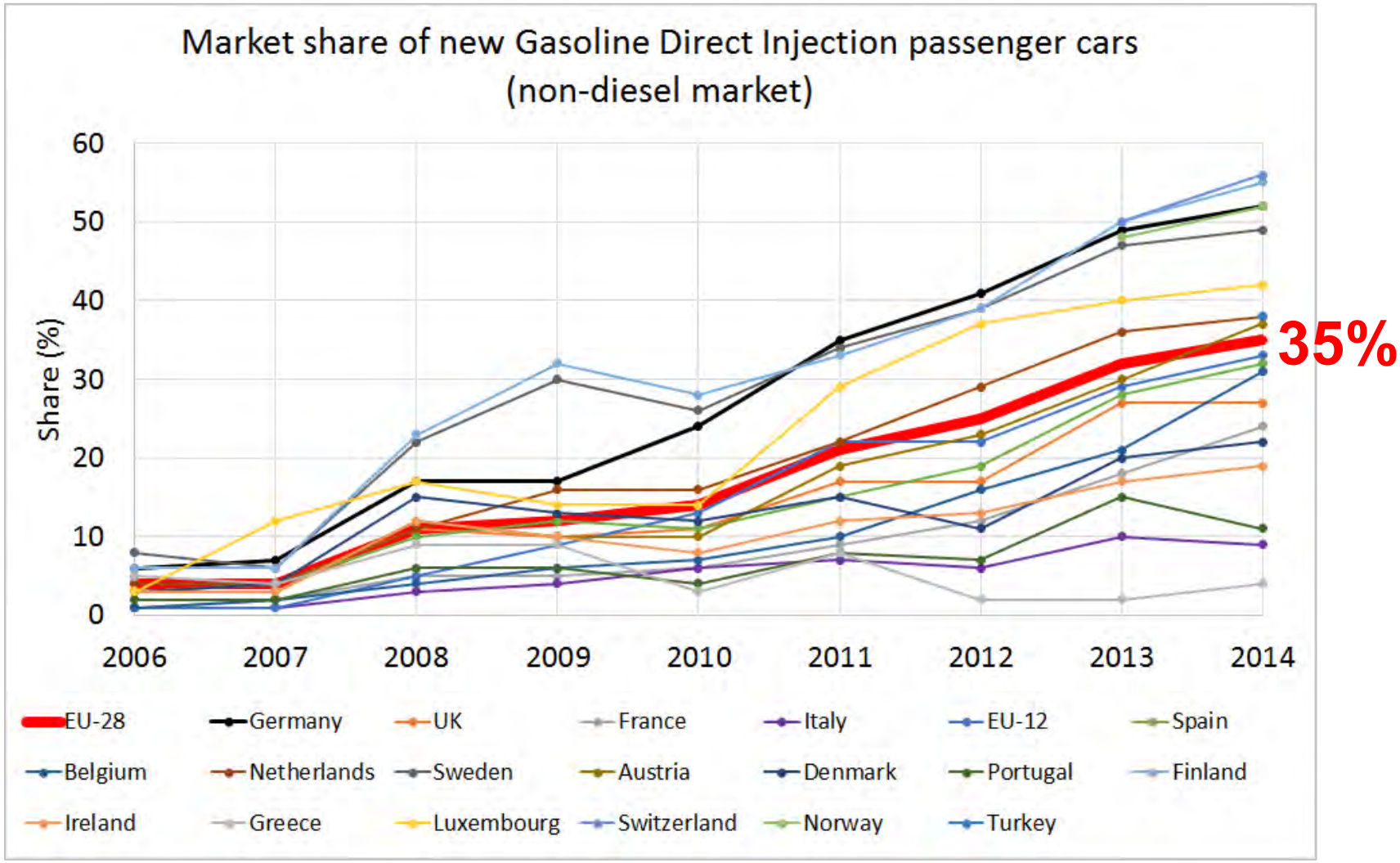
Gasoline Direct Injection

- Gasoline Direct Injection (GDI) is one of the most promising technical solutions for CO_2 reduction.

Vehicle system	Technology	Approximate GHG per mile reduction
Engine	Variable valve timing	2-8%
	Cylinder deactivation	3-6%
	Turbocharging	2-5%
	Gasoline direct injection (stoich. and lean)	10-15%
	Compression ignition diesel	15-40%
	Digital valve activation	5-10%
	Homogeneous charge compression ignition	15-20%
Transmission	6+ speed	3-5%
	Continuously variable	4-6%
	Automated manual, dual clutch	4-8%
Overall vehicle	Light weighting	10-20%
	Aerodynamics	5-8%
	Tire rolling resistance	2-8%
	Stop-start mild hybrid	5-7%
	Hybrid electric system	20-50%

Source: Technologies and Trends for Reducing Automobile Greenhouse Gas Emissions in the 2025 Timeframe, California ARB, March 2010

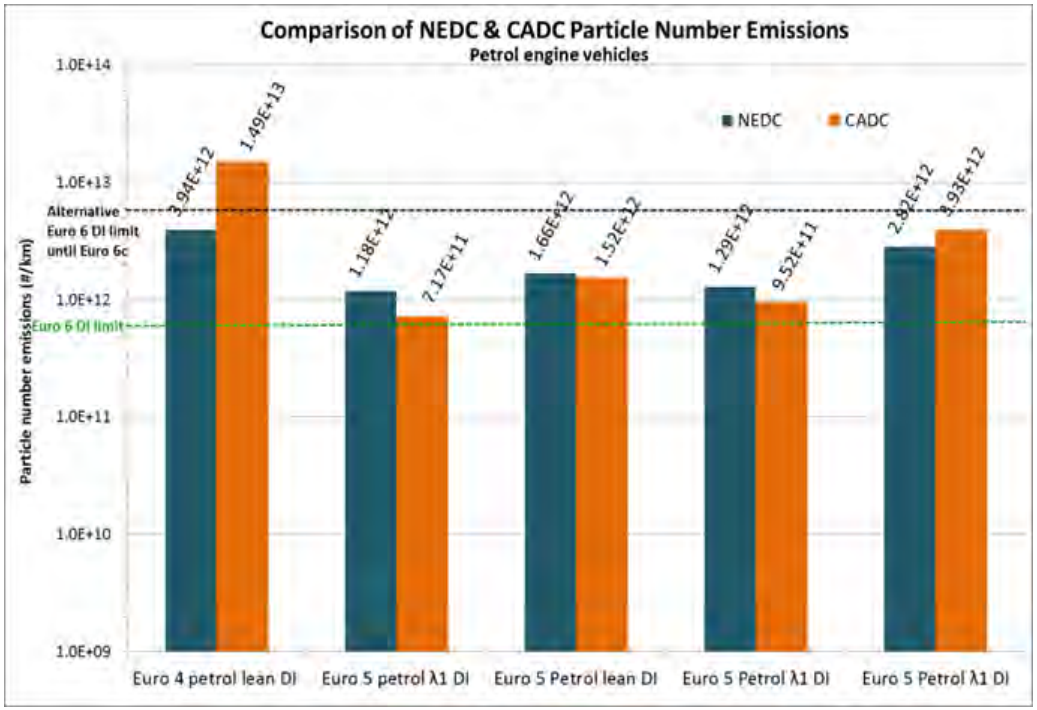
GDI market has grown in the EU



Source: European vehicle market statistics, ICCT pocketbook 2015/16

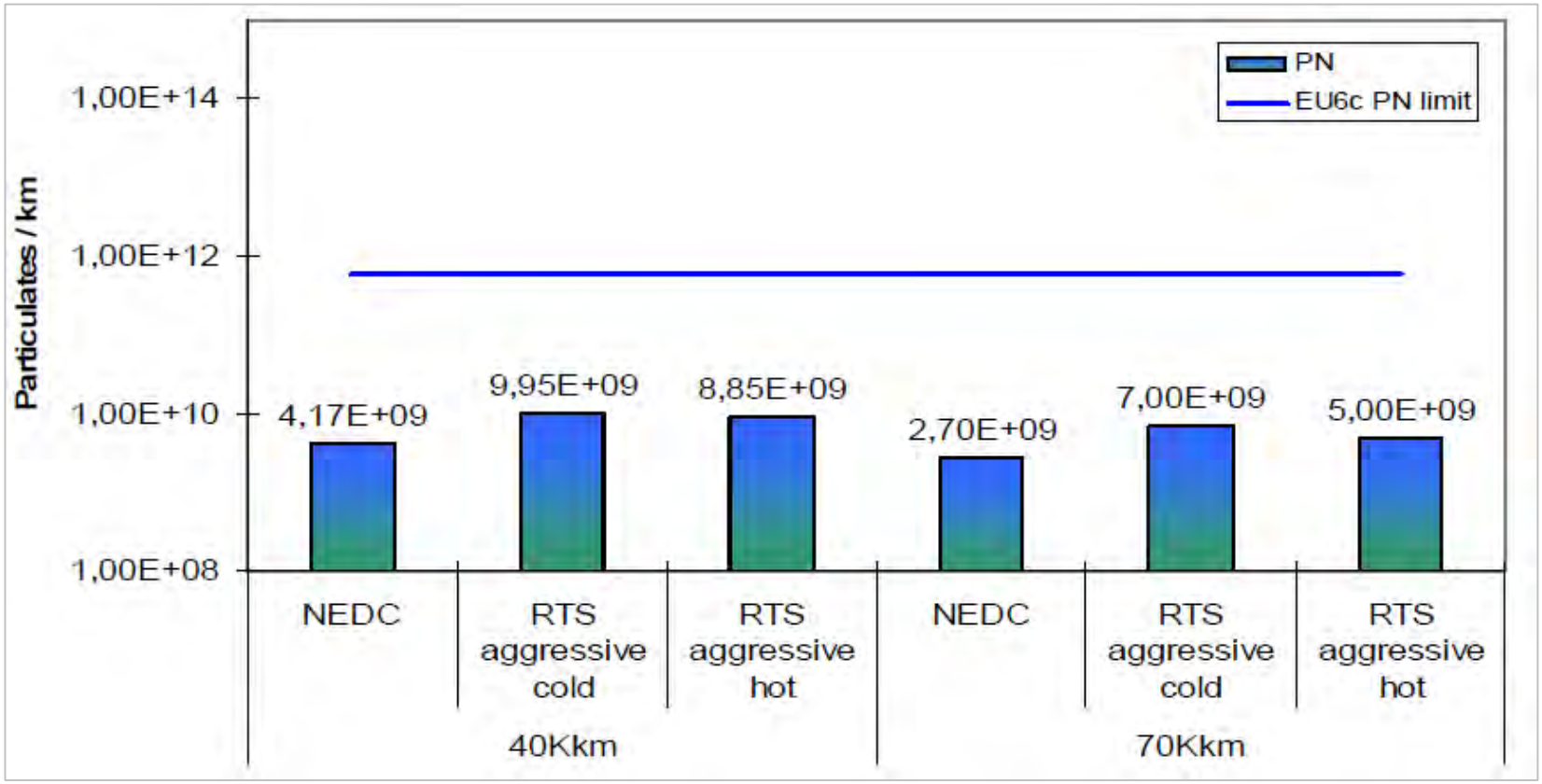
The GDI Particles issue

- CO_2 legislation promotes fuel-efficient Gasoline Direct Injection (GDI) in the EU.
- The number of particles emitted by DI gasoline vehicles has been higher than the PN levels allowed for diesel cars.
- Euro 6b introduced a PN limit for GDI in 2014, 10 times higher than the Diesel limit.
- Euro 6c PN limit will align with Diesel in 2017 ($6x10^{11}$/km).

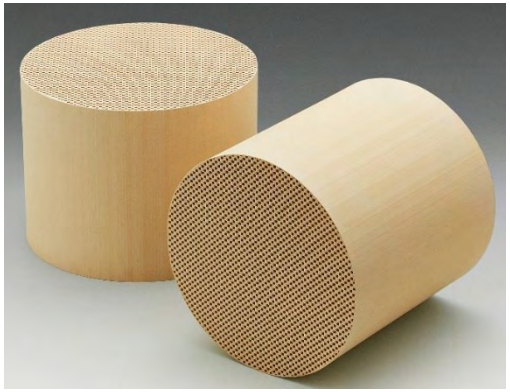


Source: AECC light-duty test programmes

GPF is a durable technology



Source: Comprehensive gasoline exhaust gas after-treatment, an effective measure to minimize the contribution of modern direct injection engines to fine dust and soot emissions, Kern et al., Umicore, SAE 2014-01-1513, 2014.



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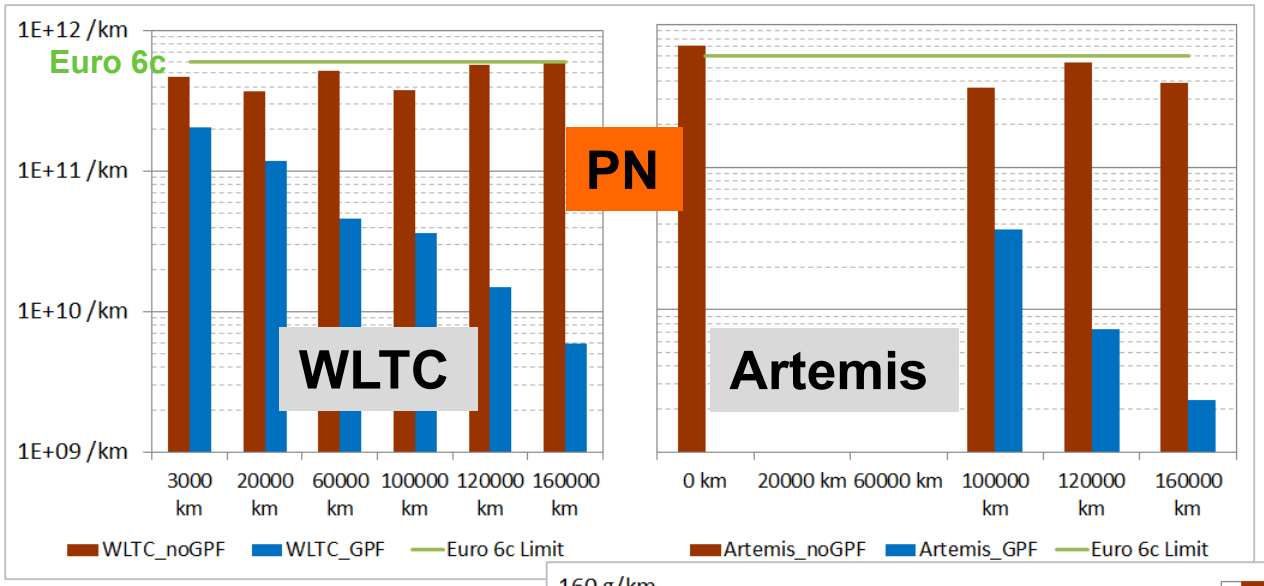
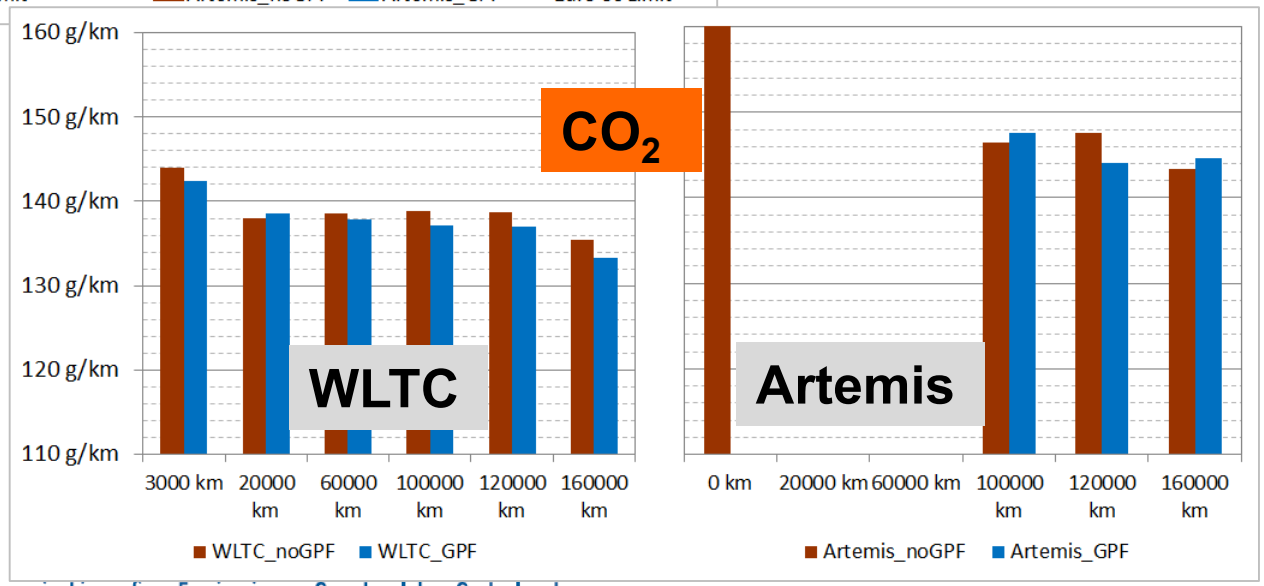
GPF ensures PN control without measurable CO_2 penalty throughout its lifetime



Source: Potential of an advance GPF concept for low pressure drop and low CO_2 emission, Kattouah, NGK, ATZ international engine congress 2014

No GPF

GPF



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Daimler and VW have announced large scale introduction of GPF

DAIMLER

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Innovative solution for diesel and gasoline
invests approximately €3 billion in ne

Gasoline engines with particulate filters in the future

Thanks to a large number of development advances, diesel engine
been continually reduced in recent years. Also many of the moder
lower levels of particulate matter than the limits to be introduced i
modifications within the engines as well as through the applicatior

For the further improvement of environmental compatibility, Mercedes-Benz plans the large-scale use of particulate filters also for gasoline engines – the first manufacturer to do so. After more than two years of positive field tests with the Mercedes-Benz S 500, additional versions of the S-Class with gasoline engines are to be equipped with this new technology with the next model upgrade. That will be followed by gradual implementation in further new models, model upgrades and new engine generations. After that, particulate filters will also be applied in the current model ranges.

Help

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Press Release
News

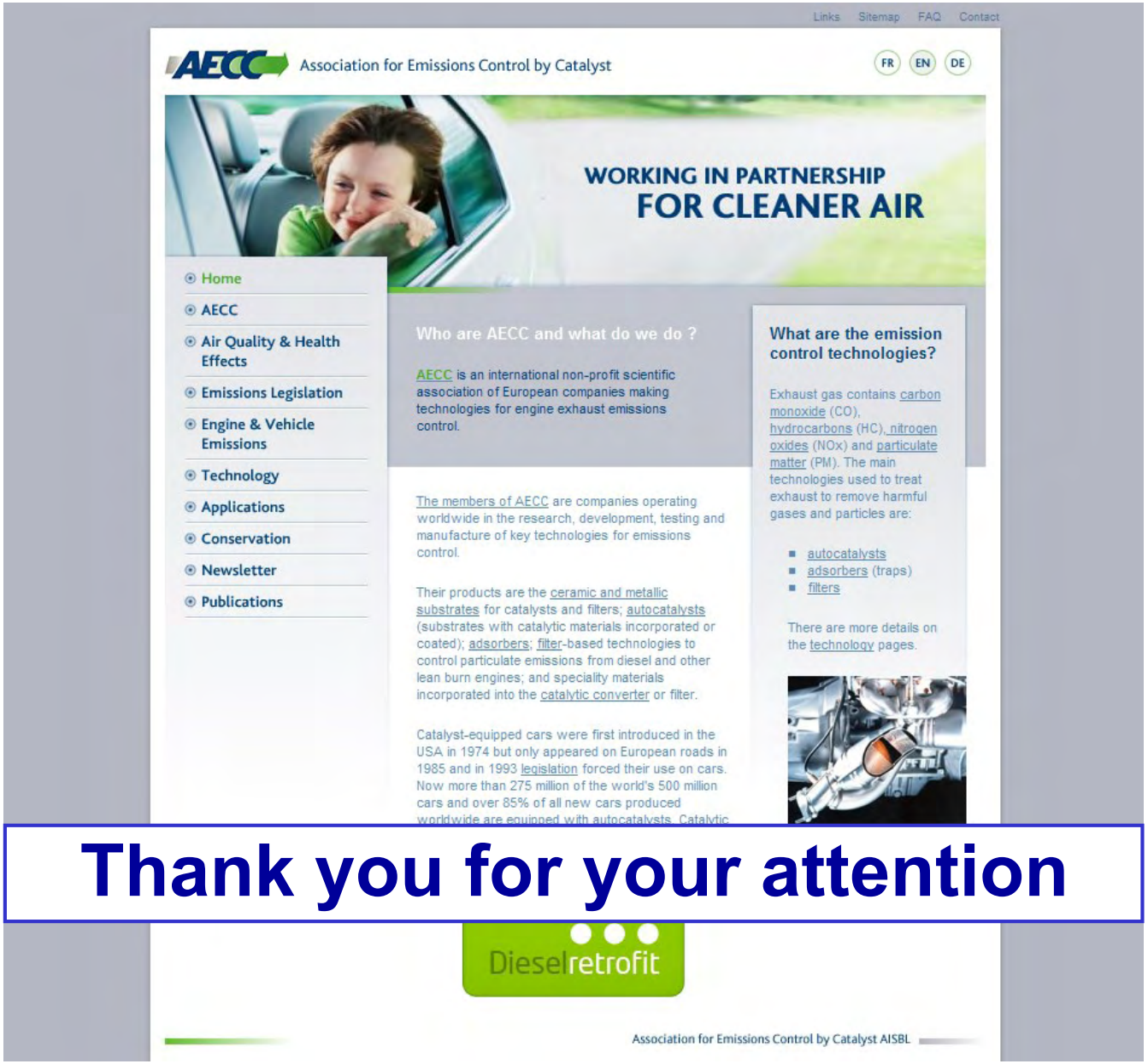
Hanover/Wolfsburg, 22 June 2016

Matthias Müller: We have launched the biggest change process in Volkswagen's history

- "TOGETHER - Strategy 2025", the Company's vision for the next decade, presented to shareholders for the first time at the 56th Annual General Meeting
- Speaking to around 3,000 shareholders in Hanover, Müller reaffirms multi-billion euro investment in an "electrification initiative second to none in the industry"
- Autonomous driving, digitalization and new business fields such as mobility services are also focal areas
- Volkswagen Group will successively equip new TSI and TFSI engines with gasoline particulate filters from June 2017
- Recall gathers speed with approval from the Federal Transport Authority for more than 3.7 million vehicles
- The Group is to become a model for a modern, transparent and successfully company in terms of "Integrity & Legal Affairs"

Conclusions

- Ultrafine particles are harmful.
- With a DPF, Particle Number emissions from Diesel vehicles are efficiently controlled under real-world driving conditions.
- GPF technology has been derived from successful experience with DPF and is available.
- GPF ensures control of ultrafine particles from Gasoline Direct Injection engines under real-world driving conditions.
- Results of AECC test programme on real-world performance of GPF with various fuels and under different driving styles to follow.



Thank you for your attention

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