Technologies for Controlling Particulate Emissions from Transportation

Dr. Rasto Brezny

Manufacturers of Emission Controls Association
rbrezny@meca.org

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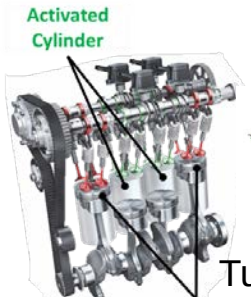
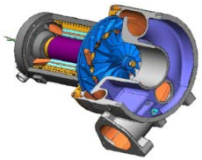
1st Latin American Conference on Ultrafine Particulate Emissions from Transportation

Mexico City, DF

MECA Represents Suppliers of Emission Control, Efficiency and Electric Technology for all Mobile Sources

Engine Efficiency

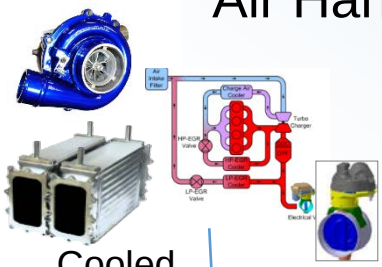




Turbo compounding

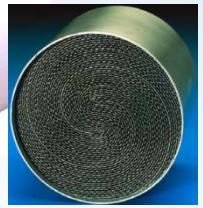
Cylinder Deactivation

Air Handling

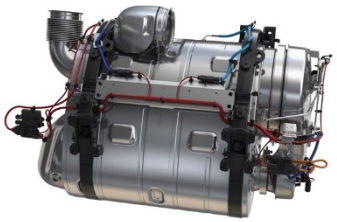


Cooled EGR

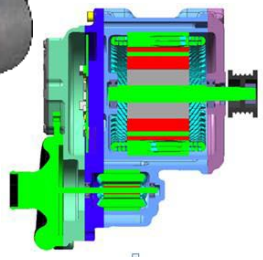
Filters & Substrates



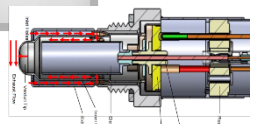
Exhaust System Integration



Powertrain Electrification



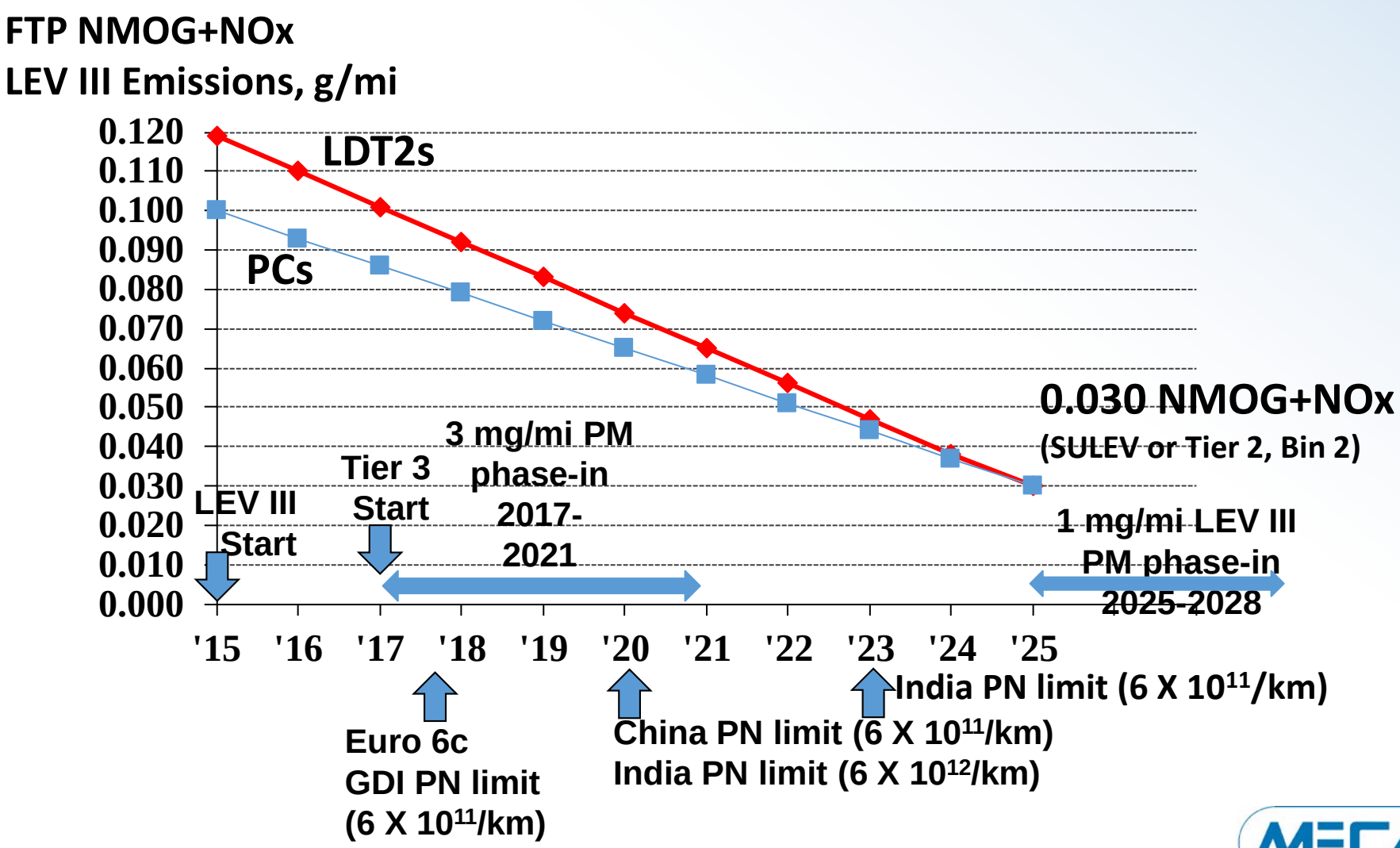
Evaporative Controls



OBD Sensors

LEV III/Tier 3 Regulations Being Phased-In U.S. and Canada

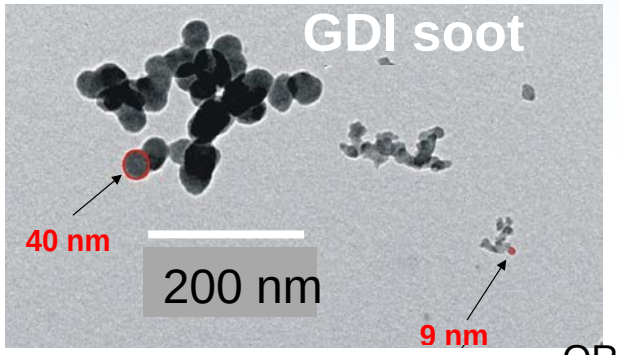
PN limits Being Implemented around the World

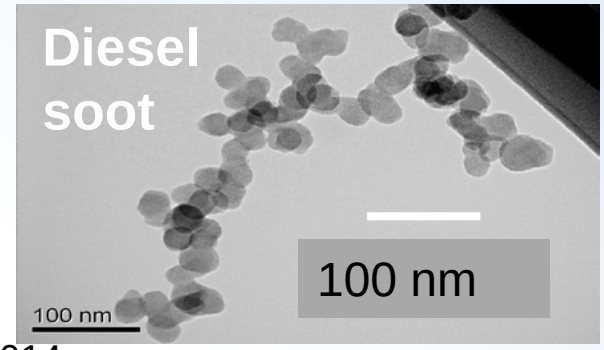


Understanding GDI PM Emissions

- GDI fleet is growing; expected to exceed 50% of new vehicles by 2020
- Decade of MECA sponsored research on GDI engines and GPF performance.
  - PM/PN emissions are highest during cold start, transient and sub-ambient temps (Environment and Climate Change Canada (ECCC))
  - Fuel chemistry (aromatics, olefins) can affect GDI PM (ECCC)
  - Lean GDI combustion emits range of solid and volatile PM (Oak Ridge National Lab)
  - Secondary organic aerosol UFPs are reduced by GPFs (UC-Riverside)
- Advanced fuel injection systems are reducing PM levels below 1 mg/mile and PN below the regulatory limit.
- GPFs reduce PM and PN to lowest possible levels.

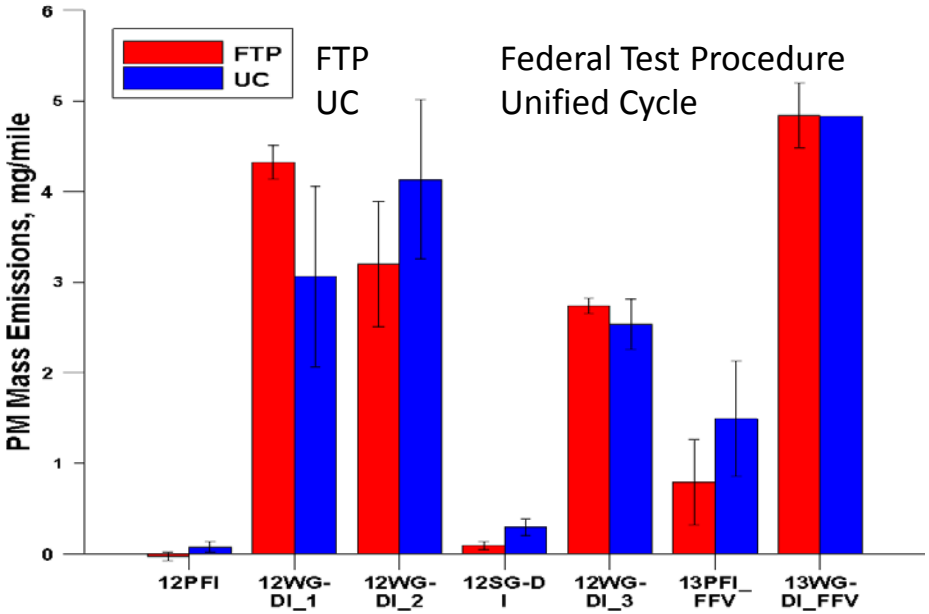
GDI PM Resembles Diesel PM





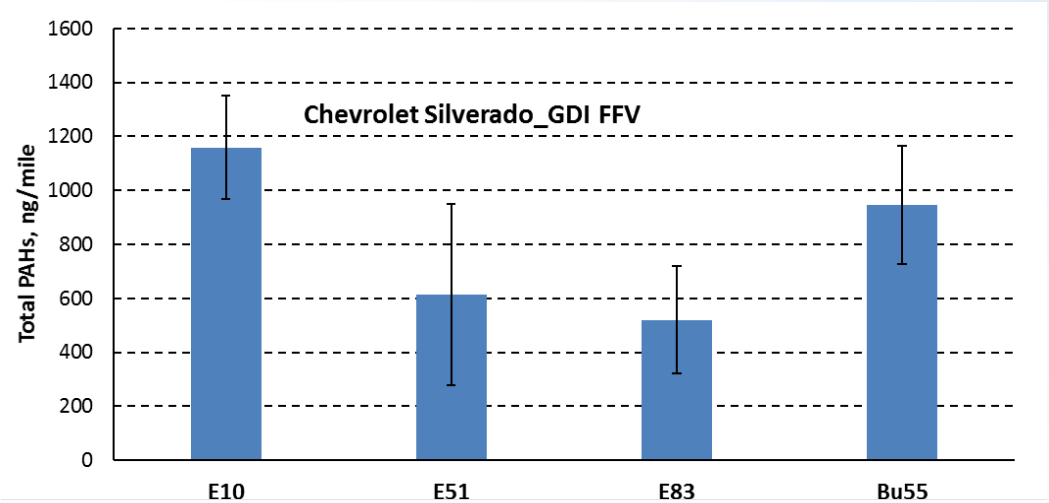
ORNL, 2014

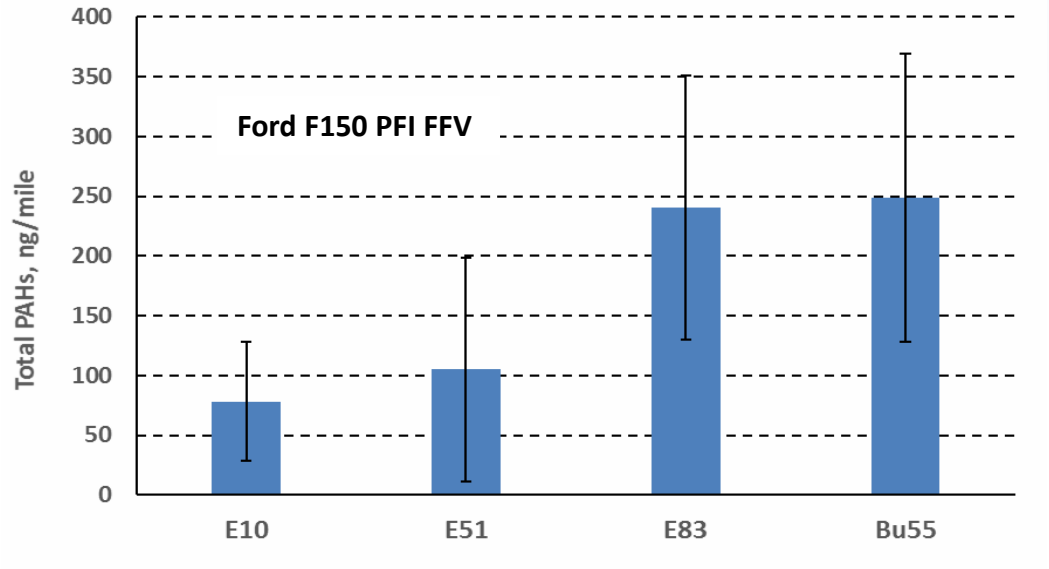
WG-DI	Wall guided direct injection
SG-DI	Spay guided direct injection
PFI	Port fuel injected
FFV	Flex fuel vehicle
FTP	Federal Test Procedure
UC	Unified Cycle



CE-CERT, Karavalakis et al., ES&T, 2014

GDIs Emit 2-5X more PAHs than PFI: GPFs remove them



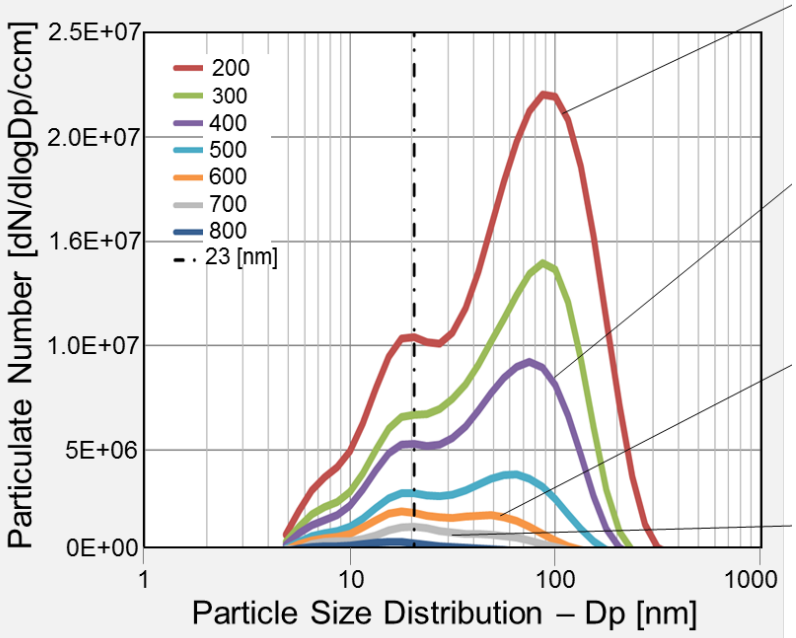


Karavalakis, CE-CERT SAE 2016 PFL-0362

Engine and Fuel Injection Technology Improving to Reduce PM/PN Emissions and Improve Fuel Economy

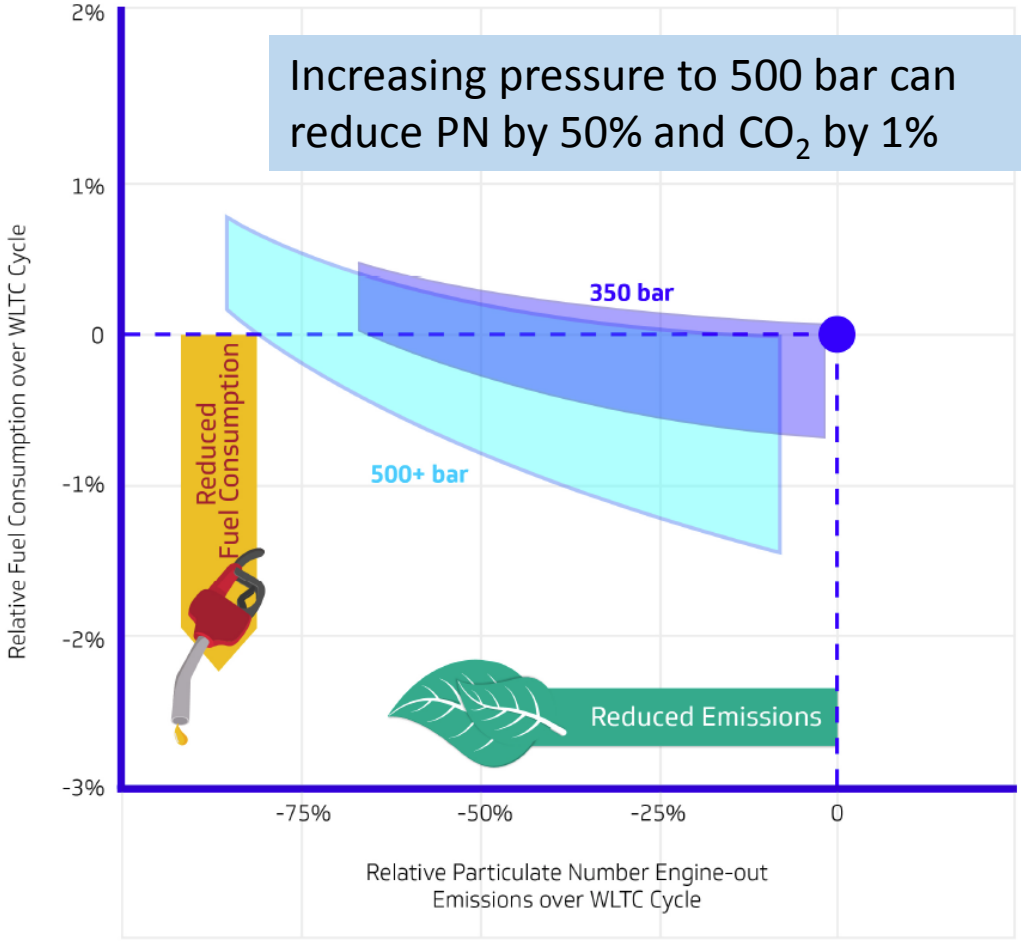
Fuel pressure and particulate number

Improved injector tip cleaning

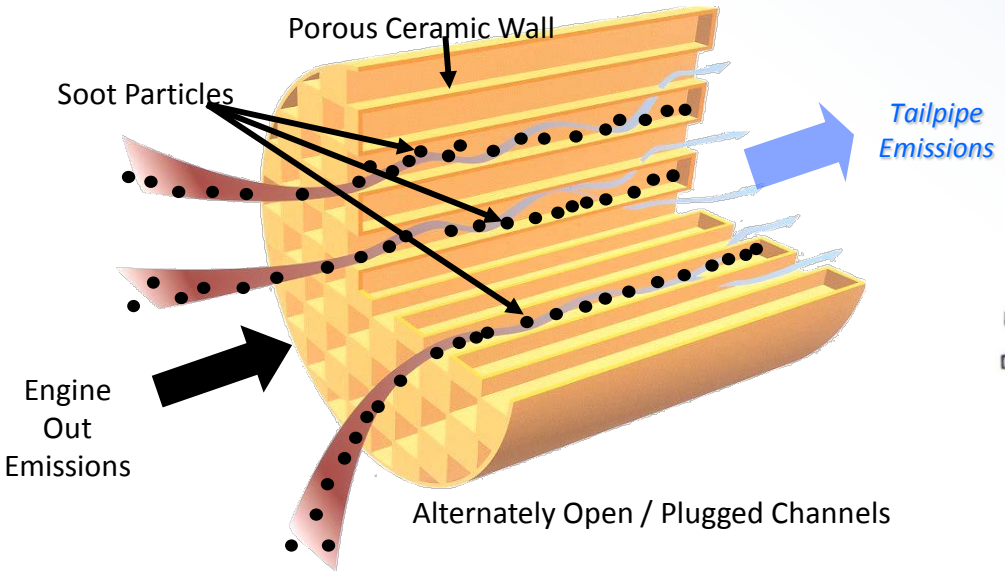


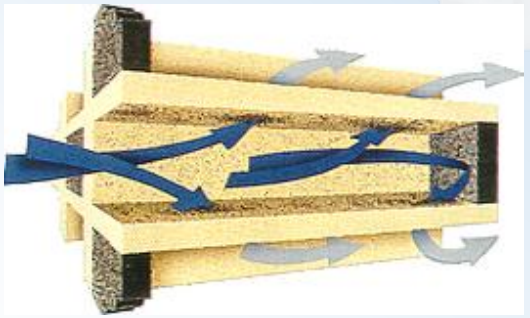
Current state of the art technology is about 600 bar pressure

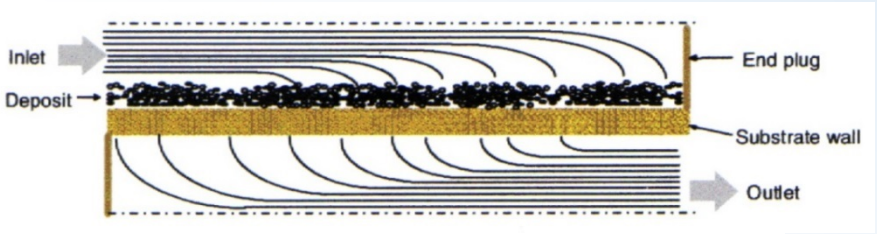
Increasing pressure to 500 bar can reduce PN by 50% and CO_2 by 1%

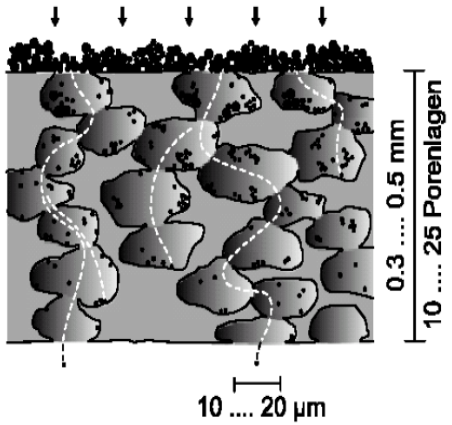


Wall-flow Particulate Filter Provides Best Control of UFPs









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

- Effectively reduce: >95% PM, >99% UFP
- Catalyzed filters capture and incinerate soot and associated toxics including PAHs and metal oxide particles
- Installed on 100% of GDI and many PFI engines in Europe.

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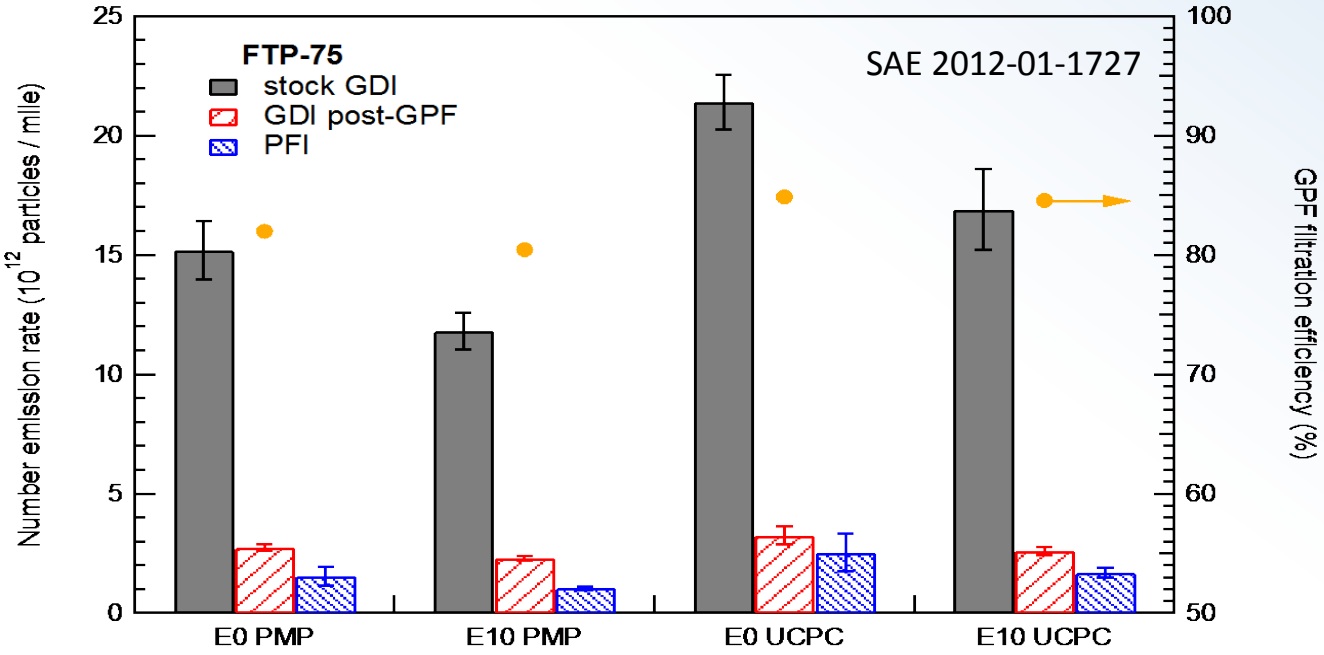
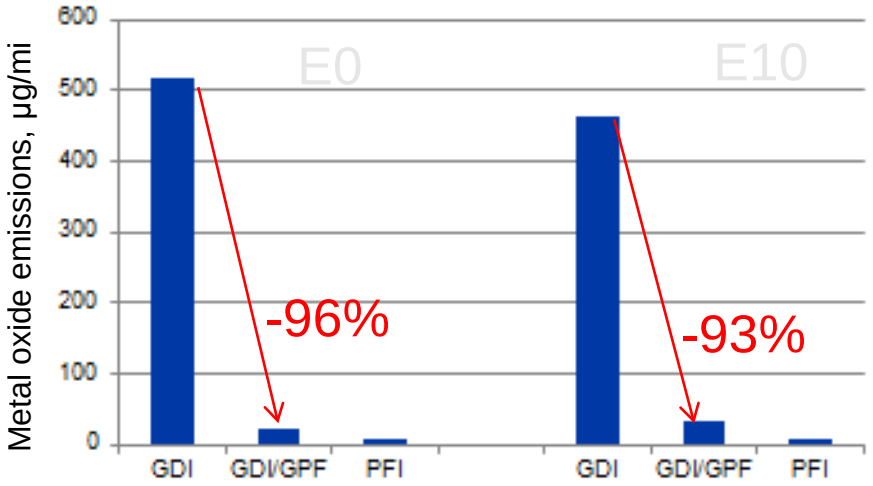
GPF Effectively Reduces GDI Particle Emissions – MECA/Environment Canada Test Program



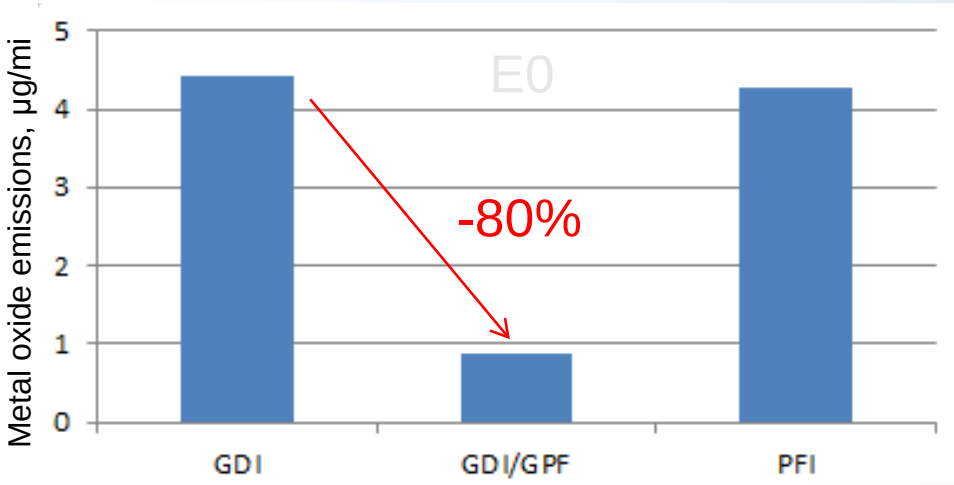
- GDI shows higher particle number emissions than PFI
- Highest PM emissions during cold-start and acceleration
- E10 vs. E0 – relatively small effects at normal ambient temps.
- Both PFI and GDI emit ultrafine particles below 23 nm

GPF Effectively Reduces Ultrafine Metal Oxide Ash Particulates

US06



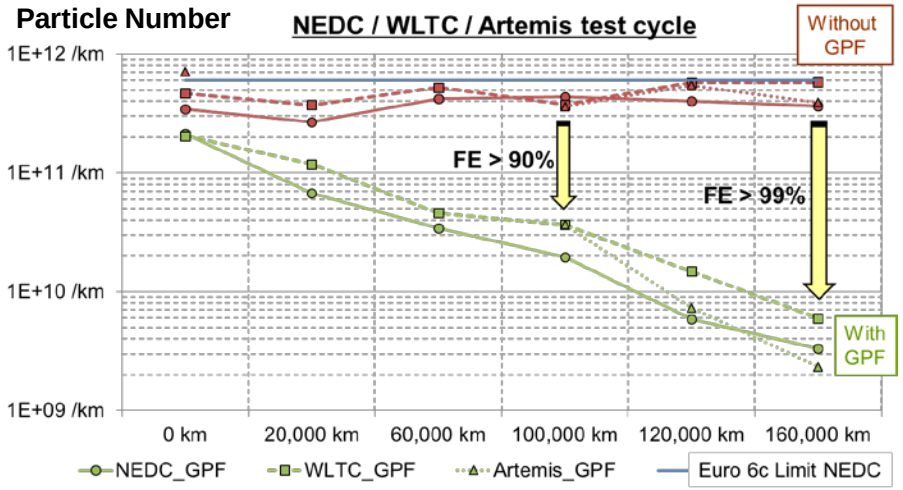
FTP-75

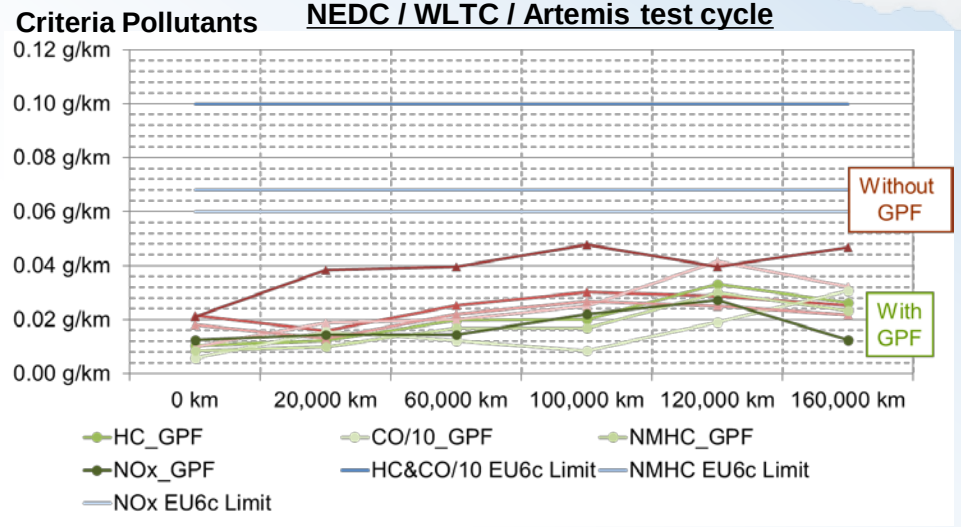


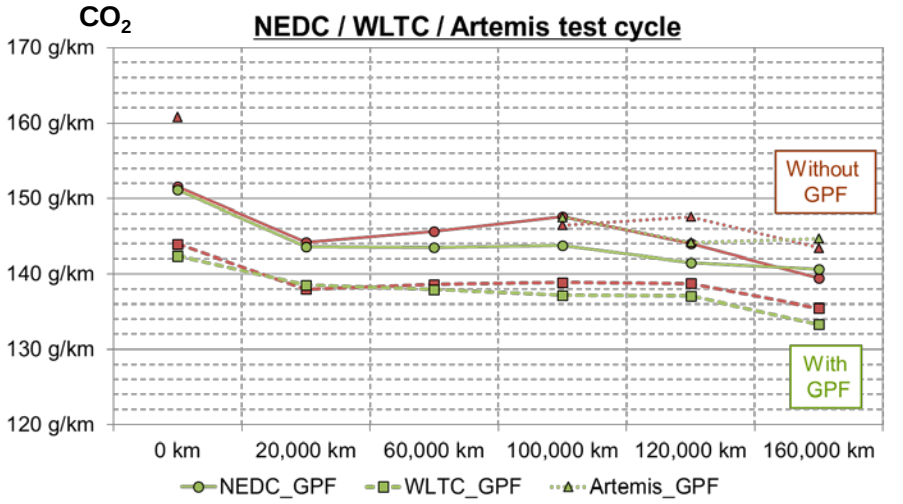
- Metal oxide ash particles have been shown to exhibited high oxidative stress response
- These ultrafine particles are less than 10 nm
- High concentrations observed under high-load (US06)
- GPF demonstrated high removal efficiency.

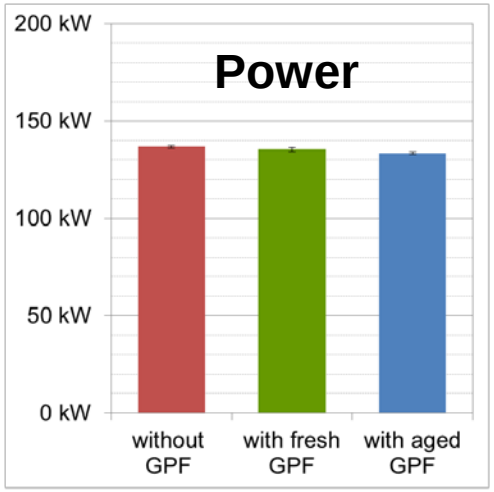
Source: Environment Canada, 2012

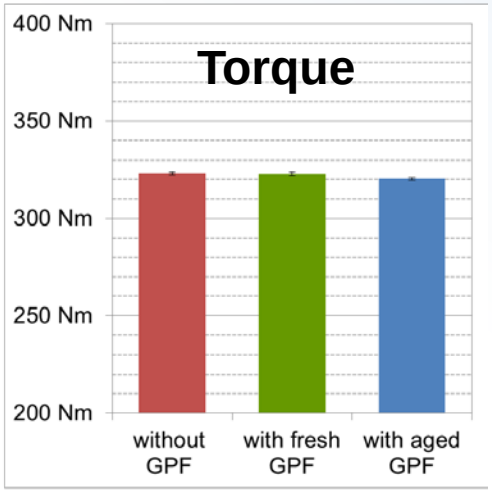
GPF Durability Demonstrated in Europe





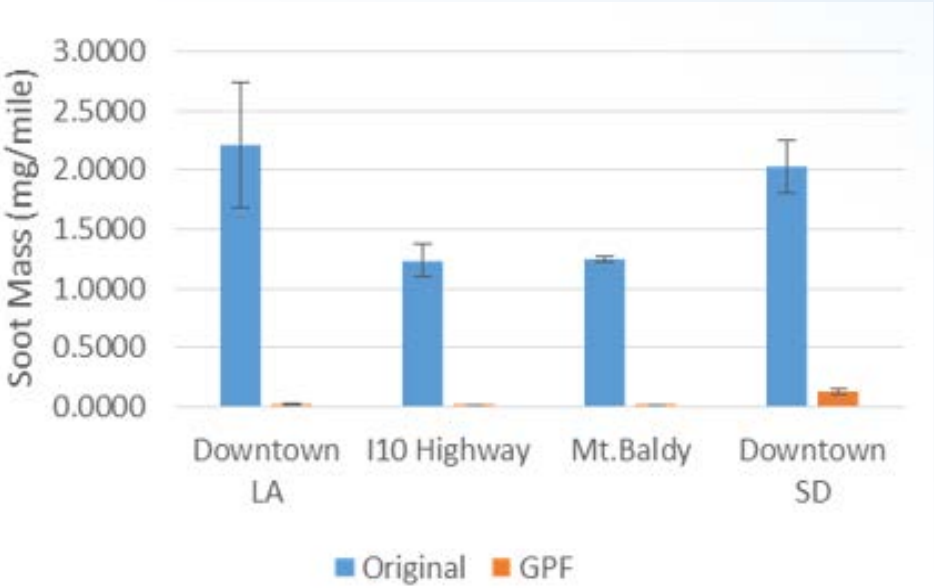






SAE 2015-01-1073

Particle Mass Emissions vary by Driving Conditions GPF Reduces PM by 99%

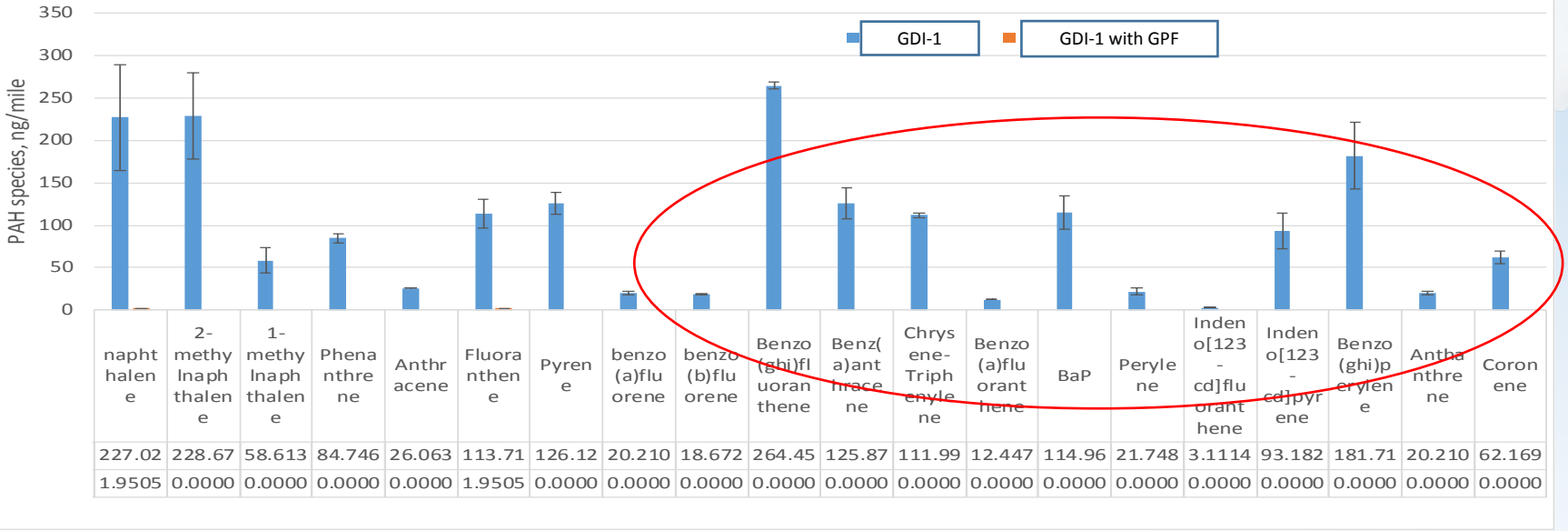


MSS PM Soot (mg/mi)	Down-town LA	I-10 Highway	Mt. Baldy	Down-town SD
% Diff	-99%	-99%	-99%	-94%

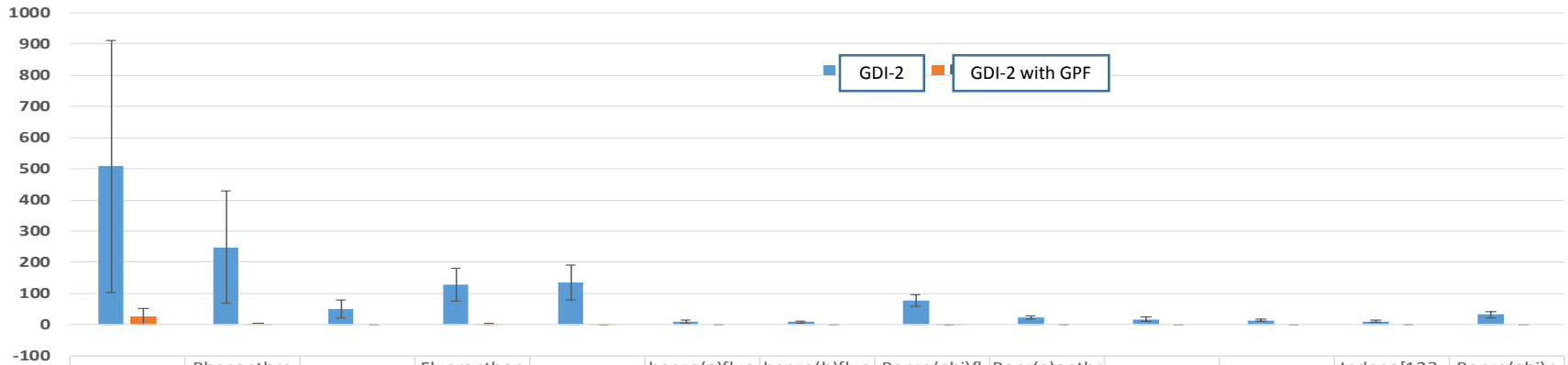
Karavalakis, UC-Riverside, 2018

- Solid particle results show high GPF filtration efficiency
- Vehicle is meeting LEV3/Tier3 PM limits over all driving cycles

GPFs Capture and Destroy >95% of Solid PAHs Associated with Particles



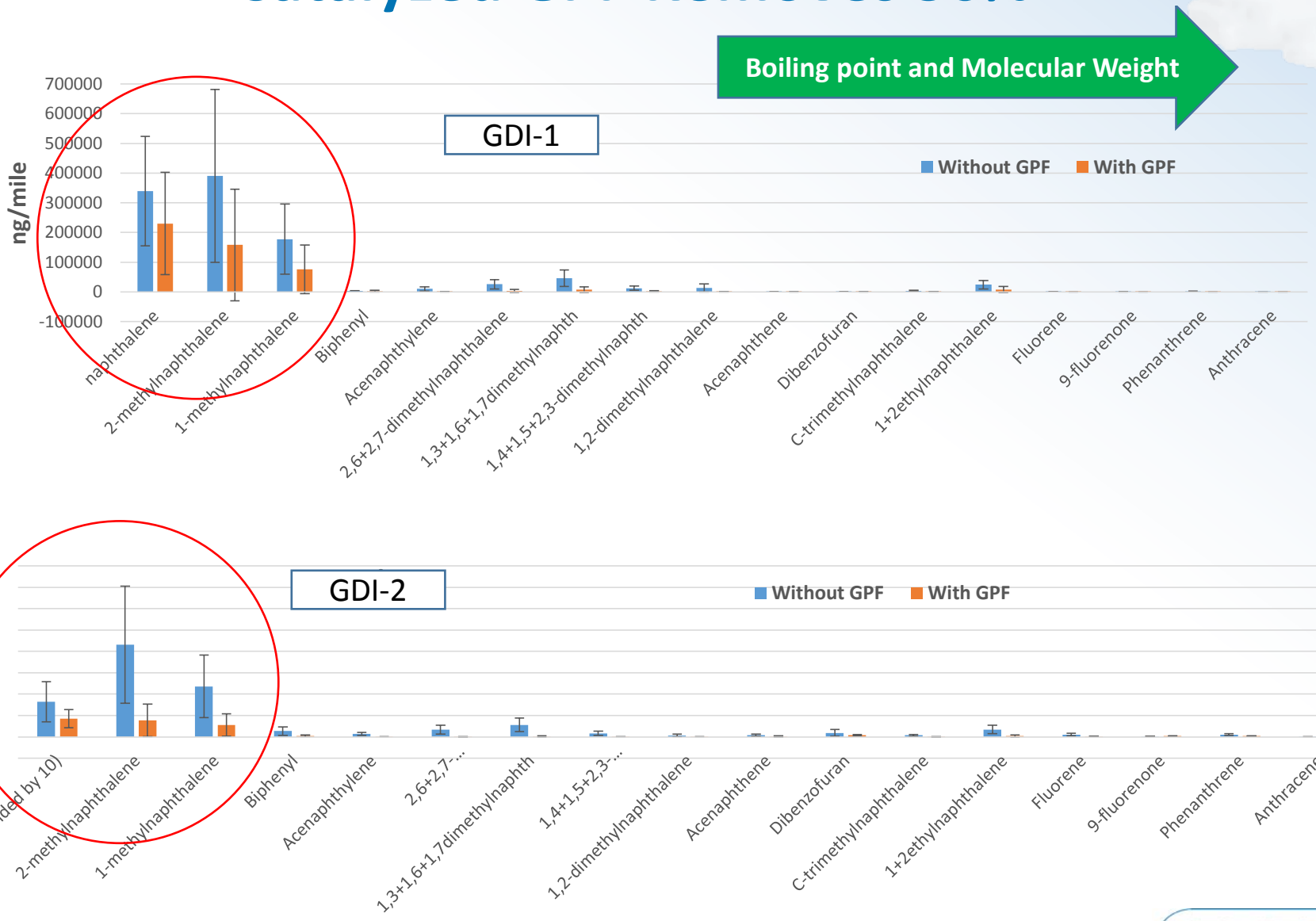
	naphthalene	2-methylnaphthalene	1-methylnaphthalene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	benzo(a)fluorene	benzo(b)fluorene	Benzo(ghi)fluoranthene	Benz(a)anthracene	Chrysene-Triphenylene	Benzo(a)fluoranthene	BaP	Perylene	Indeno[123-cd]fluoranthene	Indeno[123-cd]pyrene	Benzo(ghi)perylene	Anthanthrene	Coronene
GDI-1	227.02	228.67	58.613	84.746	26.063	113.71	126.12	20.210	18.672	264.45	125.87	111.99	12.447	114.96	21.748	3.1114	93.182	181.71	20.210	62.169
GDI-1 with GPF	1.9505	0.0000	0.0000	0.0000	0.0000	1.9505	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000



	naphthalene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	benzo(a)fluorene	benzo(b)fluorene	Benzo(ghi)fluoranthene	Benz(a)anthracene	Chrysene	BaP	Indeno[123-cd]pyrene	Benzo(ghi)perylene
GDI-2	507.4095	248.7337	50.8181	129.5111	135.9069	9.5934	7.9948	76.7477	22.3838	17.5882	14.3910	11.1924	31.9782
GDI-2 with GPF	26.8564	4.3805	0.0000	3.1243	2.0681	0.0000	0.0000	1.0562	0.0000	0.0000	0.0000	0.0000	0.0000

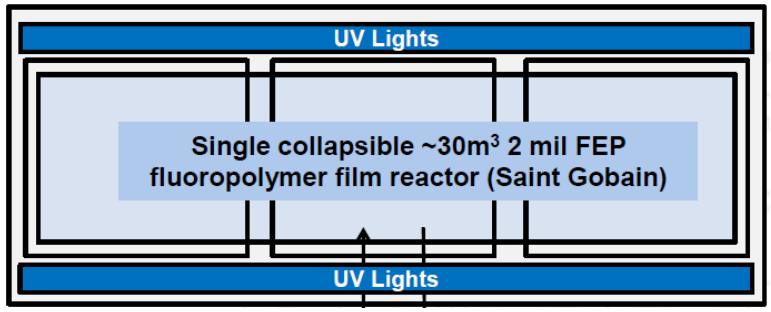
Karavalakis, UC-Riverside ES&T 2018

Vapor Phase PAHs can be up to 1 mg/mile
Catalyzed GPF Removes 50%

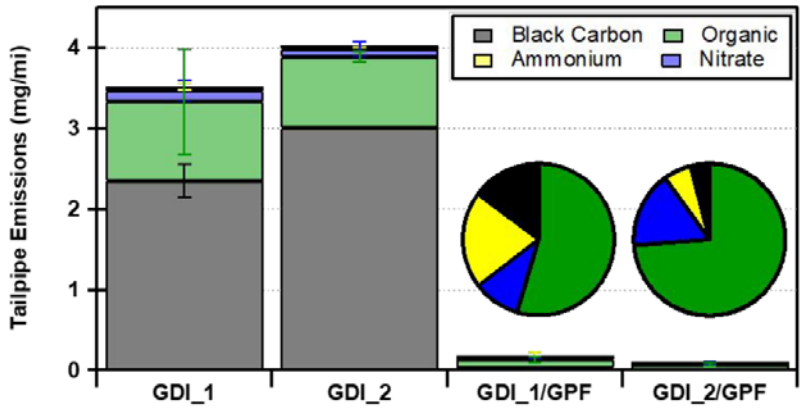


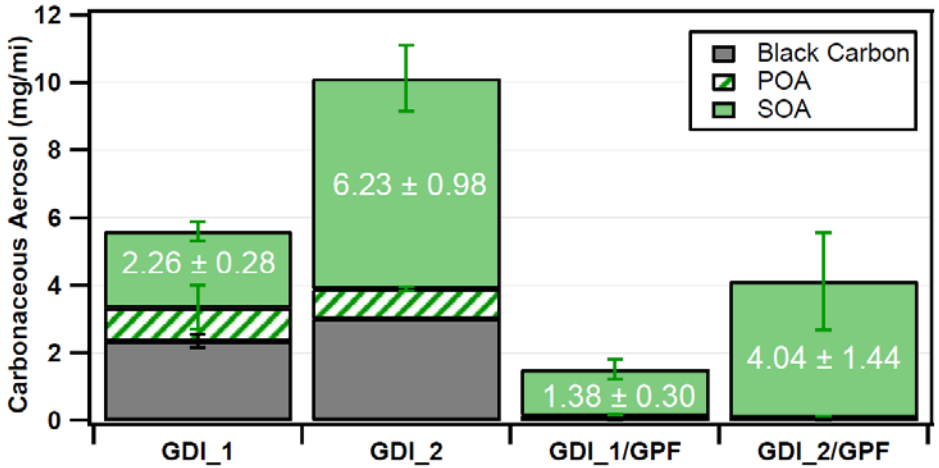
Karavalakis, UC-Riverside ES&T 2018

GPFs can Reduce Organic Precursors to SOA formation



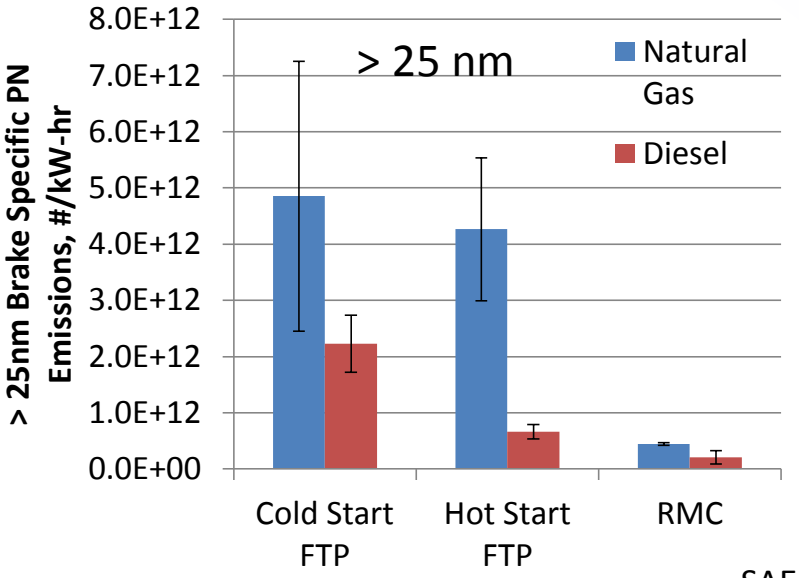
Source: ES&T, Karavalakis, 2019

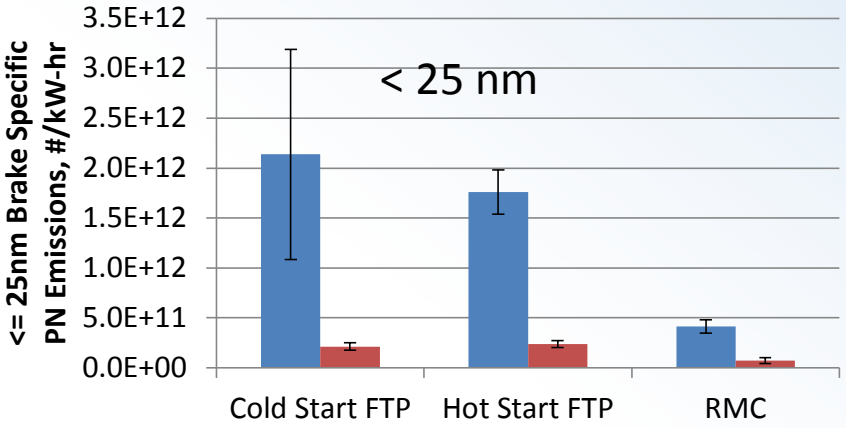




- MECA program at UC-Riverside to characterize primary and secondary PM/PN from GDI vehicles
- Catalyzed GPF removed nearly all of the black carbon and carbonaceous POA and some of the organic precursors to SOA.
- C-GPFs reduced SOAs by over 75% and solid particles by over 95%

Natural Gas Engines Emit many more Particles than Diesel with a DPF

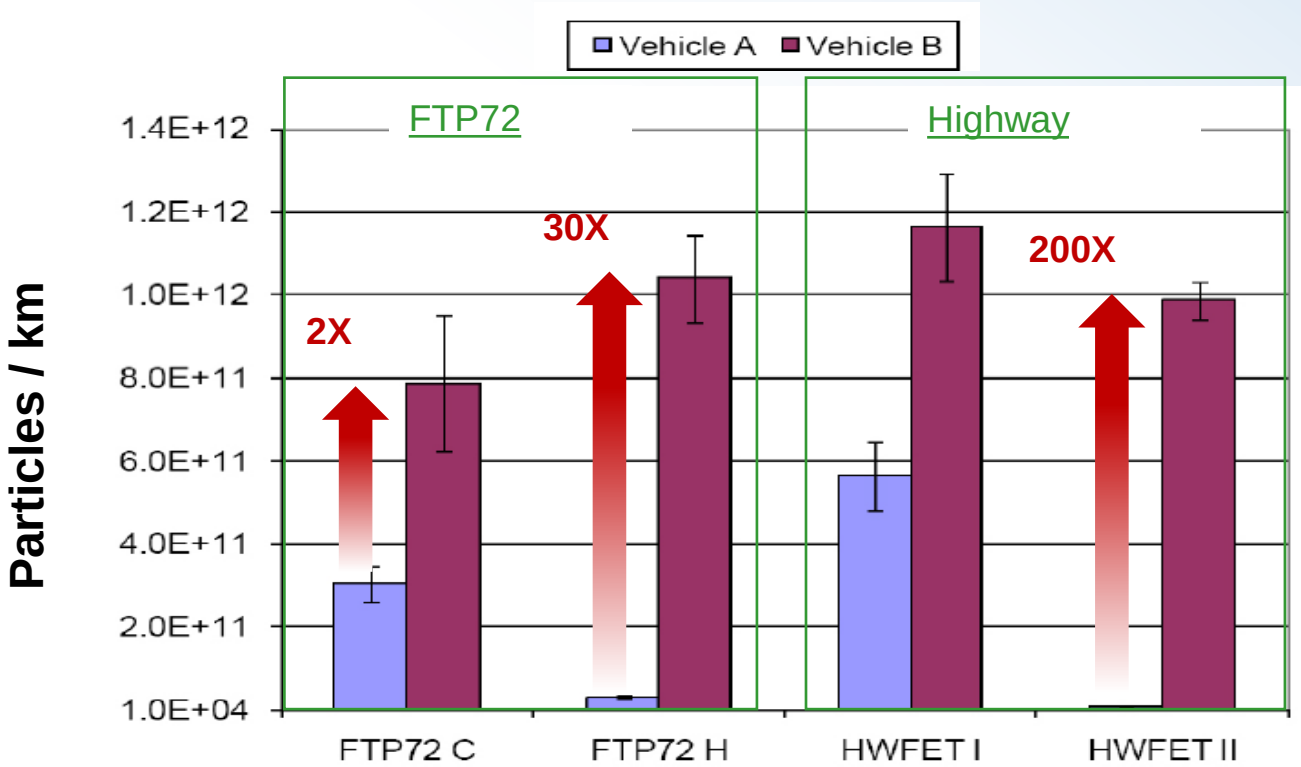




SAE Paper: 2018-01-0362

- Natural gas engines emit low PM but high PN because they are not required to install filters
- A diesel with a DPF emits lower number of particles (<6X10^{-11}/km)
- Particles from CNG engines come from lube oil

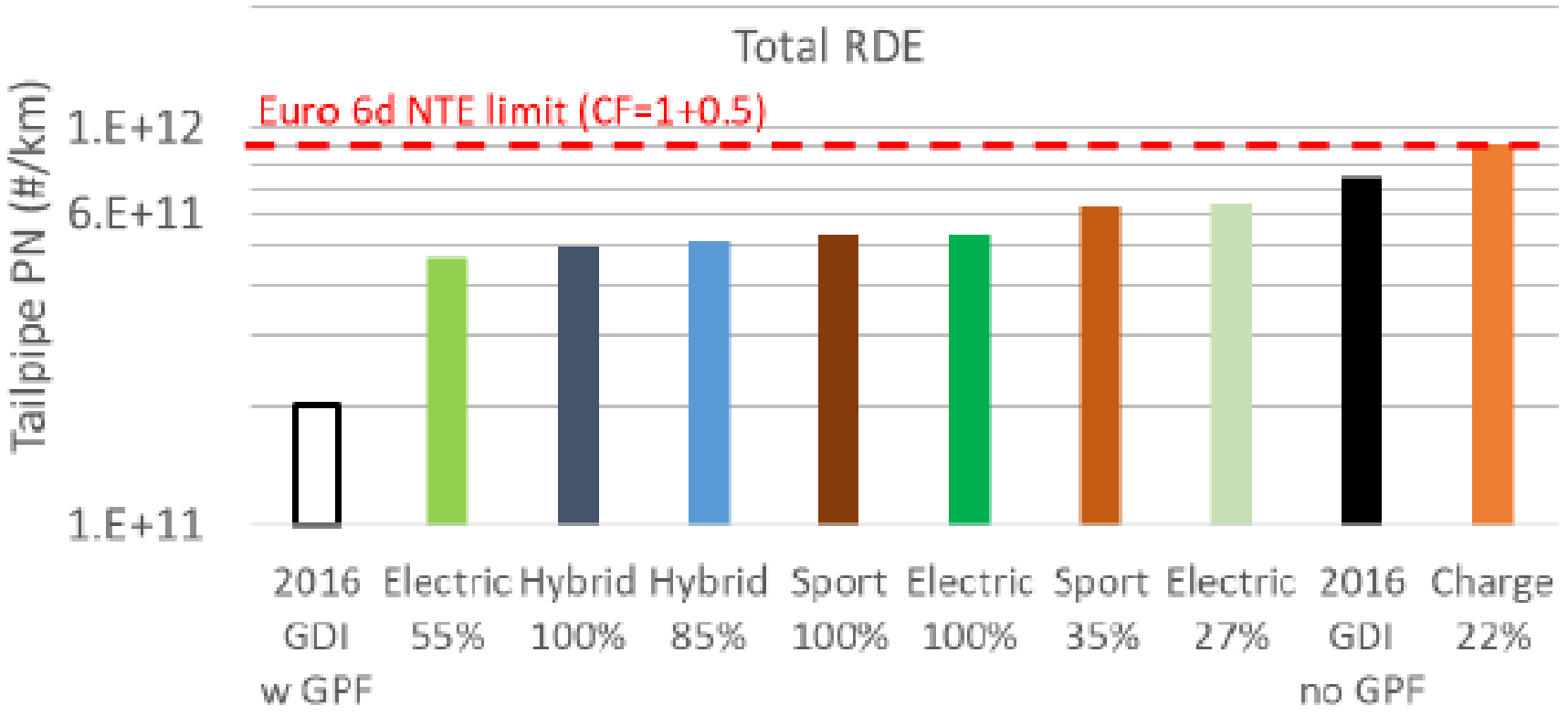
Electrified Vehicles can Create Emission Challenges



SAE Paper: 2011-01-0625

- PHEV exhaust temperatures lower than non-hybrids (up to 200°C)
- PHEVs emit particles during engine restarts and hard accelerations even when battery is charged. (Vehicle A: ICE, Vehicle B: PHEV)
- GPFs and advanced fuel injectors can provide particle control during real world driving conditions.

All total RDE PN Emissions from PHEV Higher than GDI with GPF



- Electric mode – full battery: ICE operates for 2/3 of trip, but PN emissions as high as other modes
- Charge mode – empty battery: high power demand on ICE → highest PN emissions

Summary and Conclusions

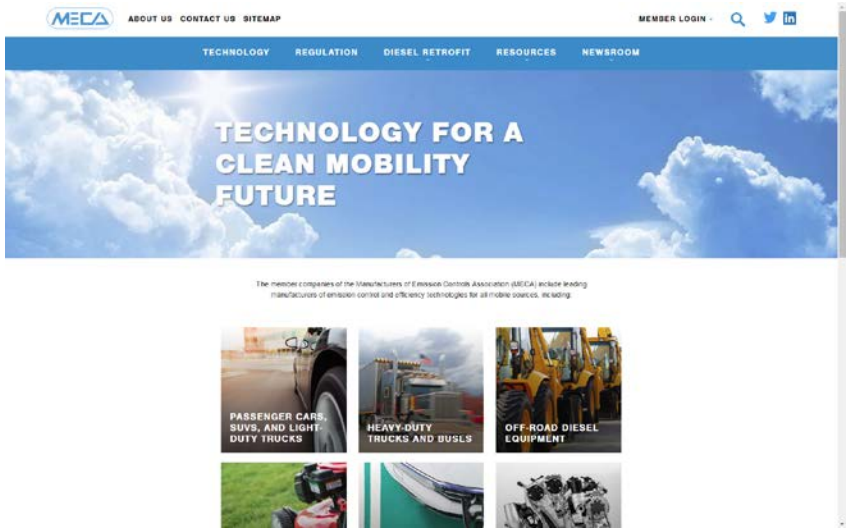
- GDI and Diesel PM are similar, should toxicity of GDI PM be reclassified?
- Fuel Injection and filter technologies can meet EU PN standard and LEV III 1 mg/mile standard, RDE requires GPF.
- GPFs have demonstrated high PM and PN reduction efficiency with no measurable fuel economy impacts.
- Particle number regulations in Europe, India and China will demand best available technologies in 2017-2023 timeframe.
- As electrified propulsion drives vehicles to lower GHG emissions we need to insure that engines remain as clean as possible.
  - Focus on real world emissions is creating opportunities to address off-cycle emissions from PHEVs

How Can Voluntary Policy Benefit Environment in the absence of a PN Standard in North America

- GHG technology costs about $50-100 per % CO_2
- Black carbon particles have high GWP of about 2000.
- GPFs can significantly reduce black carbon.
- A voluntary CO_2 credit of 2 g/mi CO_2 (equal to 1 mg/mile BC or 1.25% CO_2) for GPF
  - Would cover the incremental cost of technology for the OEM
  - Achieve early SLCP and localized warming reductions which is a direct climate benefit
  - Deliver bonus health benefits of reduced toxics and ultrafine particles

MECA on the Internet:
Your emission control and efficiency technologies resource

www.meca.org



- Technology white papers and fact sheets
- Testimony and press releases
- Regulatory information

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