

Technologies for Controlling Particulate Emissions

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September 18, 2019

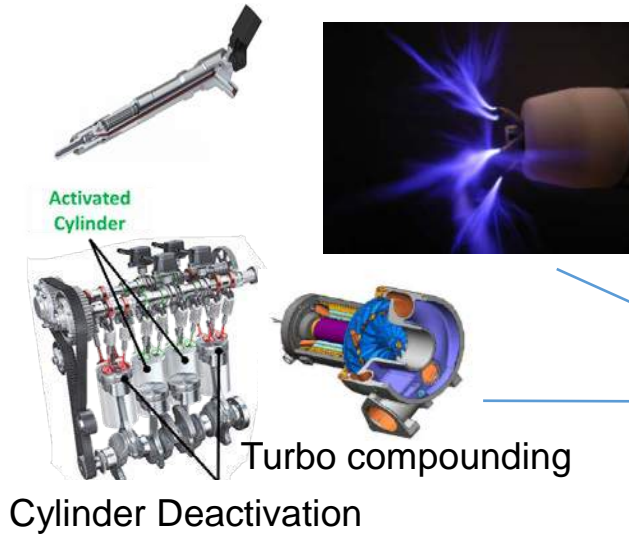
Workshop on Ultrafine Particulate Emissions from Transportation

University of Toronto

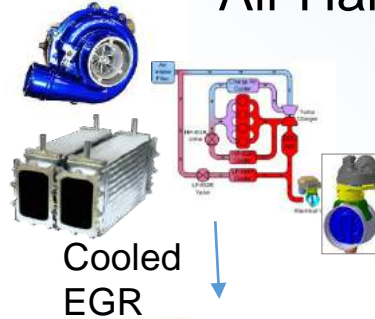


MECA Represents Suppliers of Emission Control, Efficiency and Electric Mobility Technology for all Mobile Sources

Engine Efficiency



Air Handling



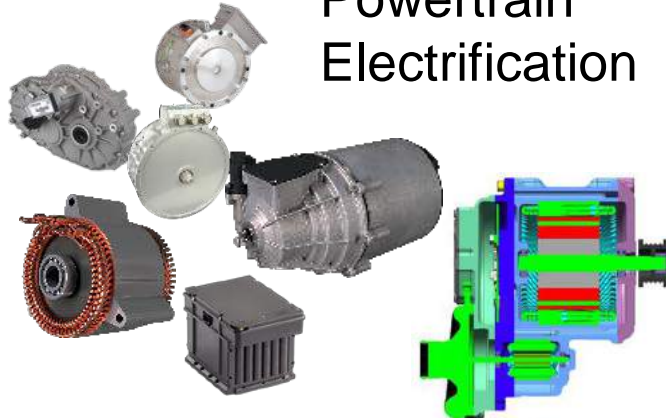
Filters & Substrates



Exhaust System Integration



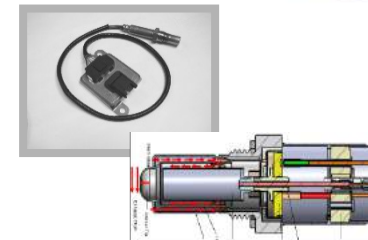
Powertrain Electrification



Evaporative Controls



OBD Sensors

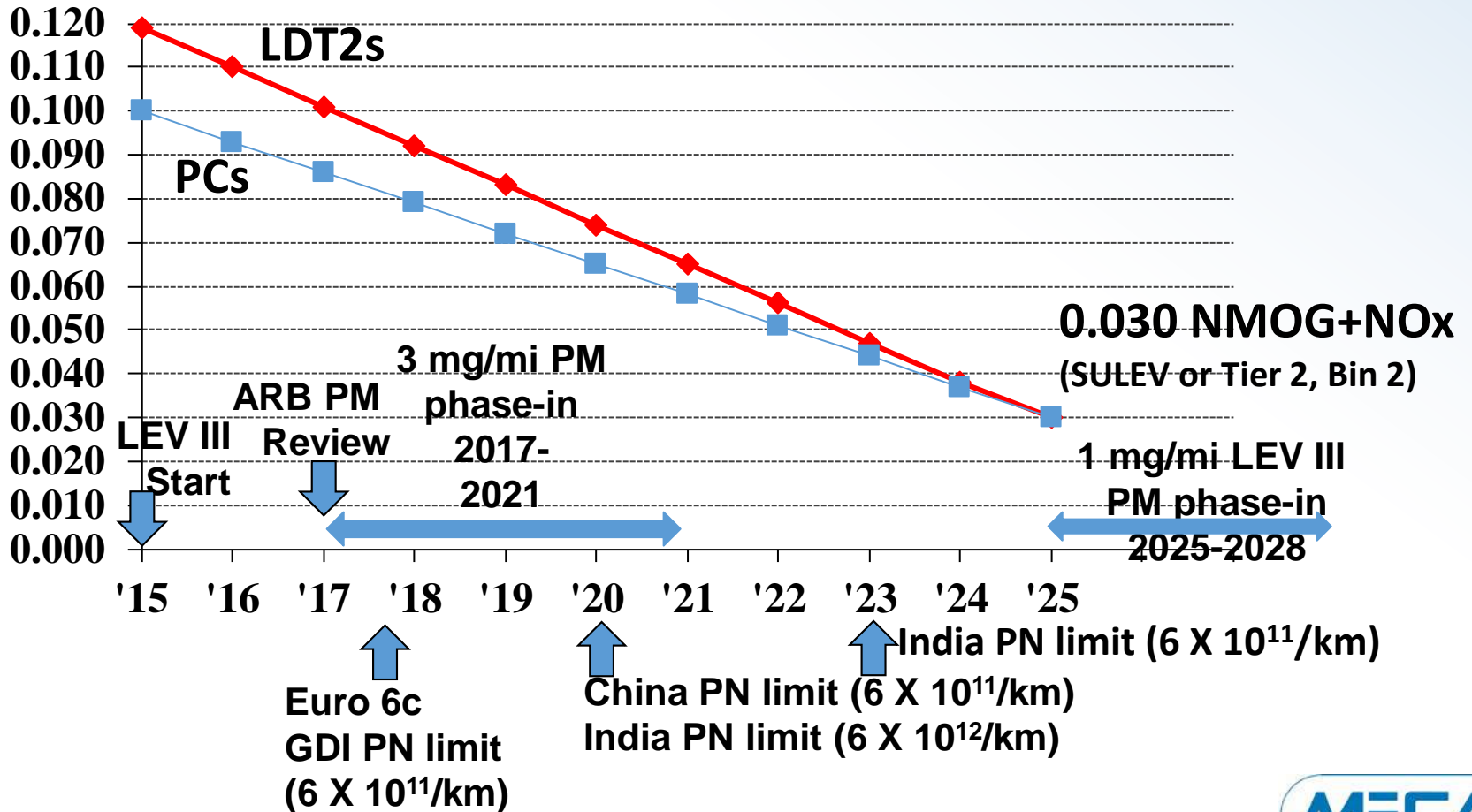


LEV III/Tier 3 Regulations Being Phased-In North America

PN limits Being Implemented around the World

FTP NMOG+NOx

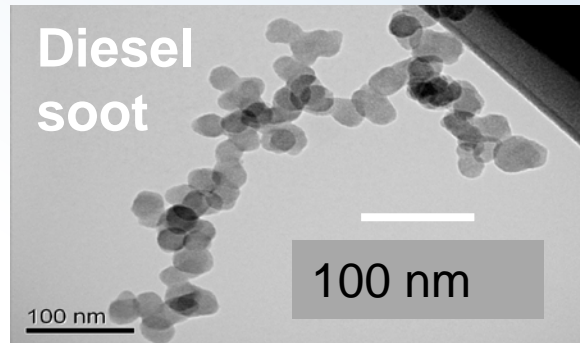
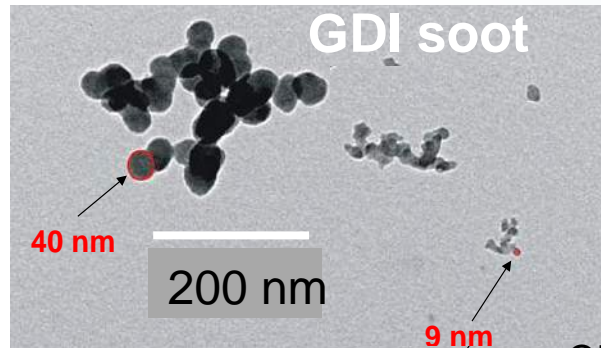
LEV III Emissions, g/mi



Understanding GDI PM Emissions

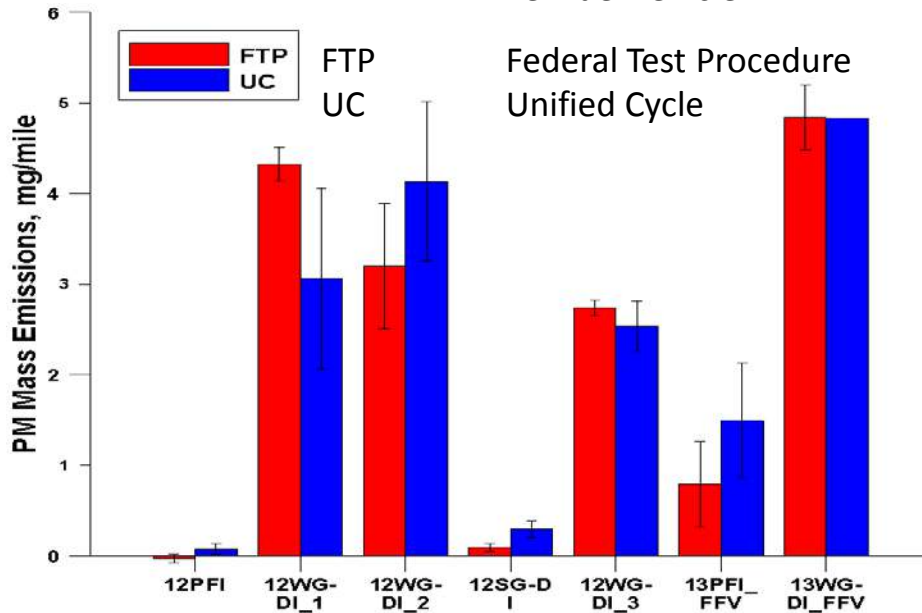
- GDI fleet is growing; expected to reach 40% by 2020 in U.S.
- MECA sponsored research on GDI engines and GPF performance including a number of studies with ECCC.
 - PM/PN emissions are highest during cold start, transient and sub-ambient temps
 - Fuel chemistry (aromatics, olefins) can affect GDI PM
 - Lean GDI combustion exhibits range of solid and volatile PM chemistry
 - Secondary organic aerosol emissions may be important
- Advanced fuel injection systems are reducing PM levels well below 1 mg/mile and PN below the regulatory number 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



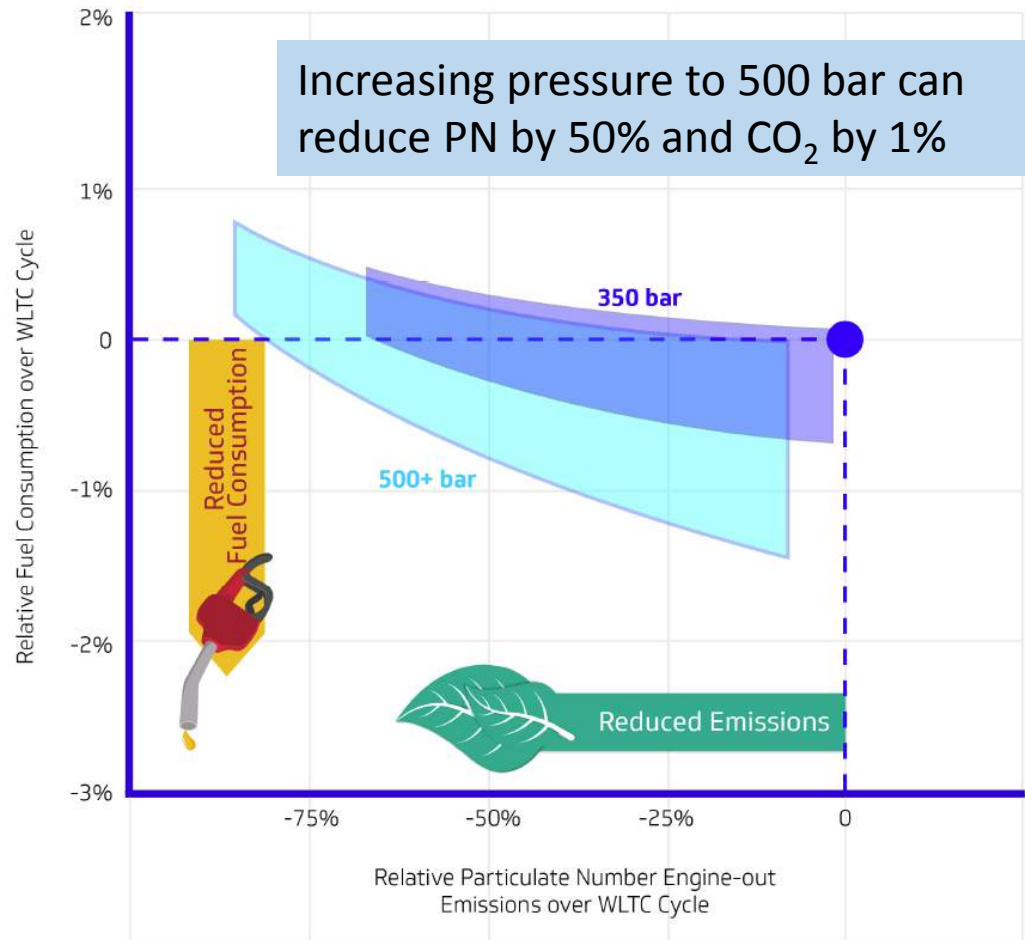
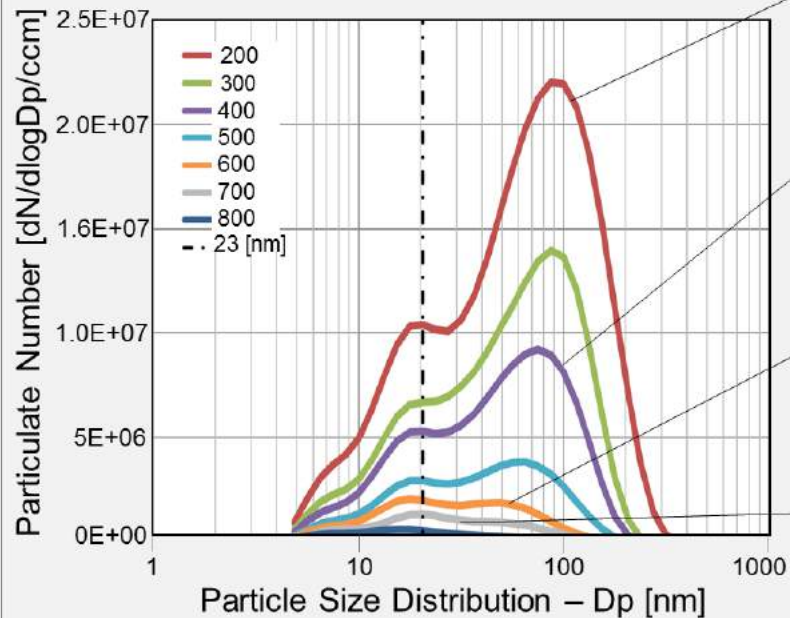
CE-CERT, Karavalakis et al., ES&T, 2014



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

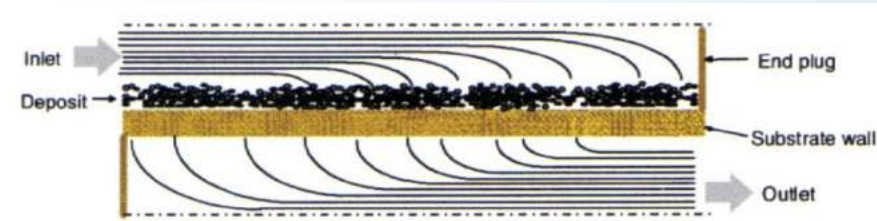
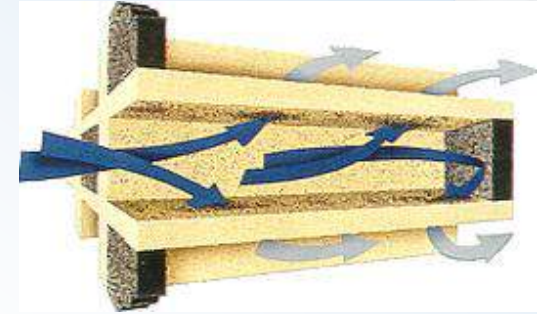
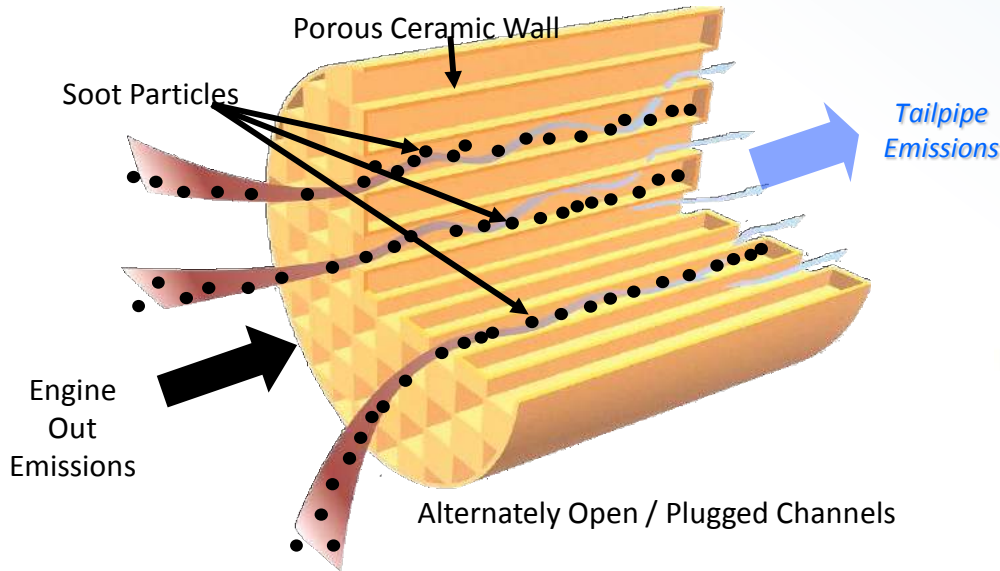
Fuel pressure and particulate number

Improved injector tip cleaning

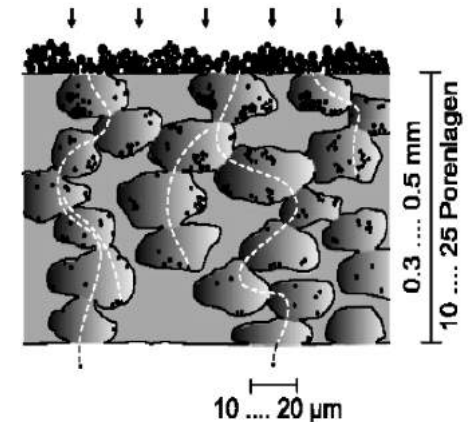


Current state of the art technology is about 600 bar pressure

Anatomy of a Wall-flow Particulate Filter

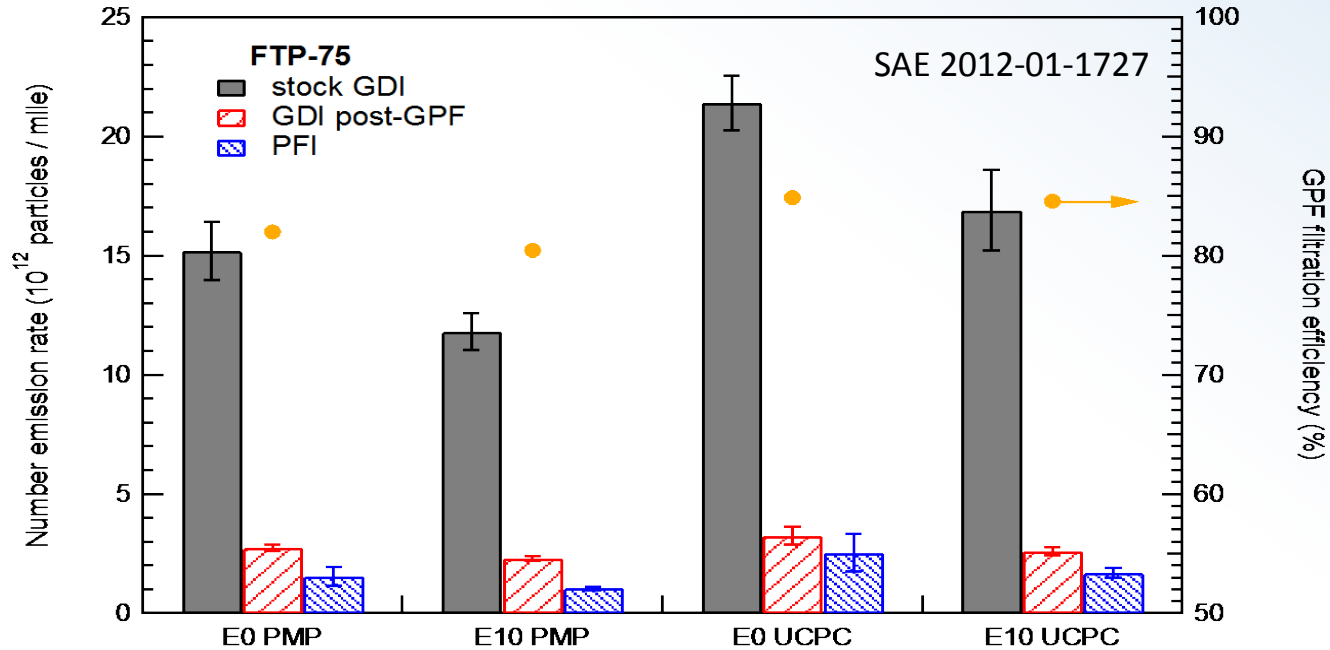


- Effectively reduce: >95% PM, >99% UFP
- Catalyzed filters capture and incinerate soot and associated toxics including PAHs and metal oxide particles
- Installed on 100% of GDI and many PFI engines in Europe.



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

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

Particle Mass Emissions vary by Driving Conditions

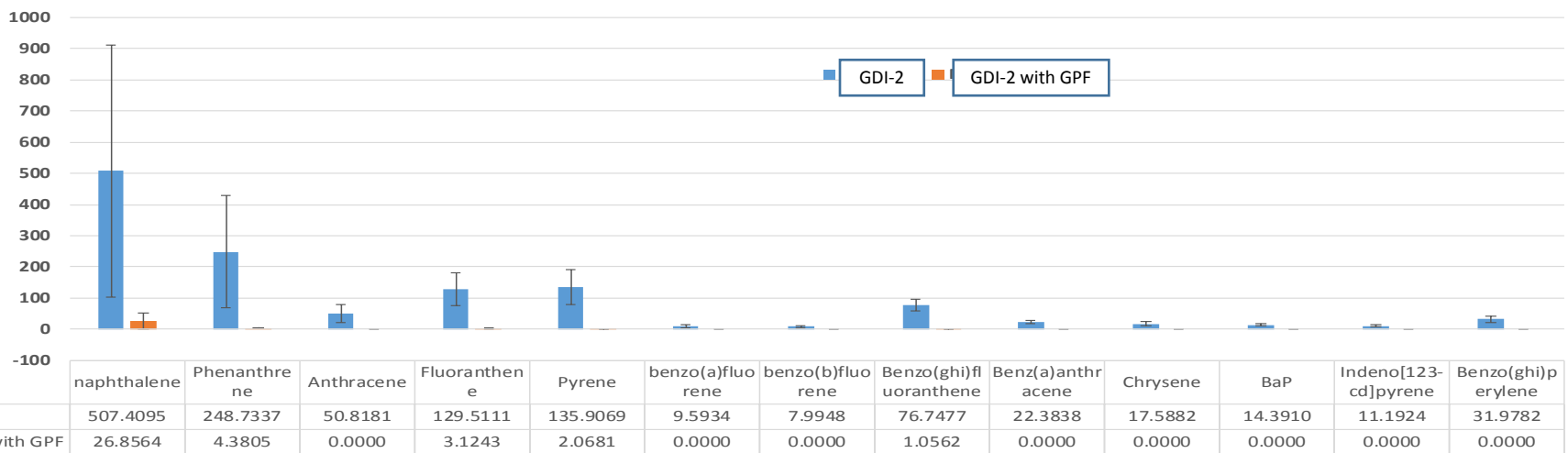
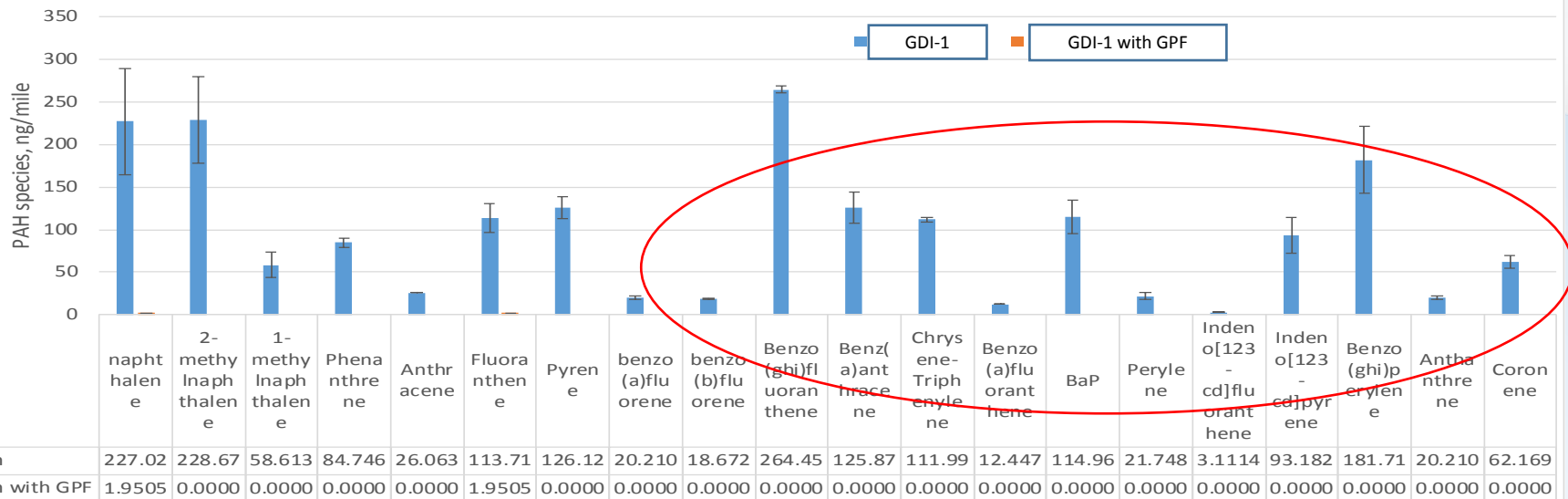
GPF Reduces PM by 99%



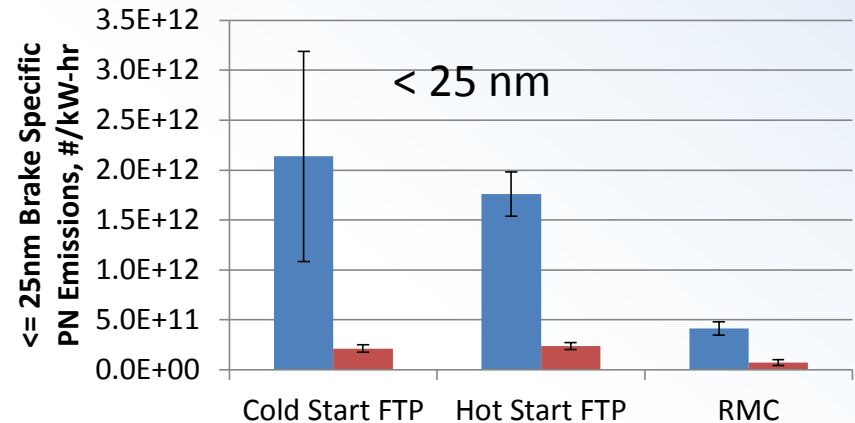
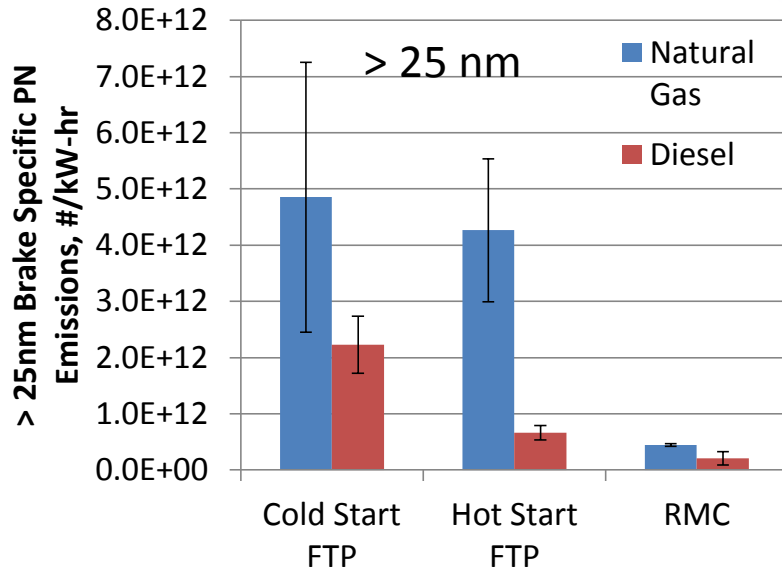
MSS PM Soot (mg/mi)	Down-town LA	I-10 Highway	Mt. Baldy	Down-town SD
% Diff	-99%	-99%	-99%	-94%

- 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



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

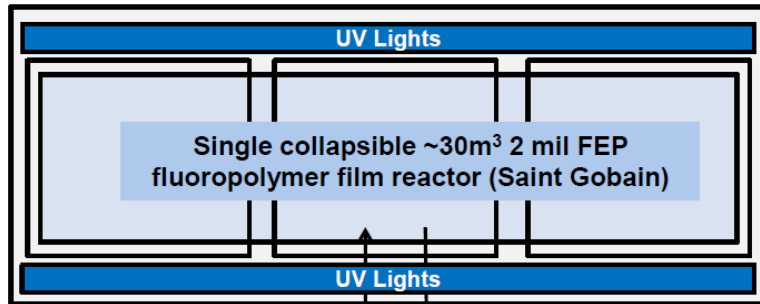
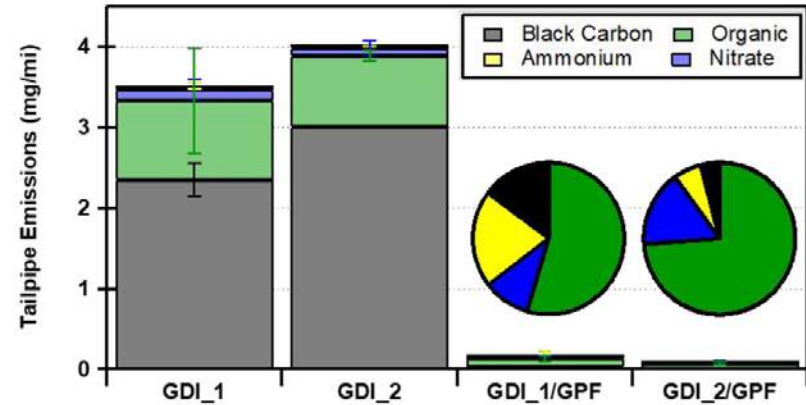


SAE Paper: 2018-01-0362

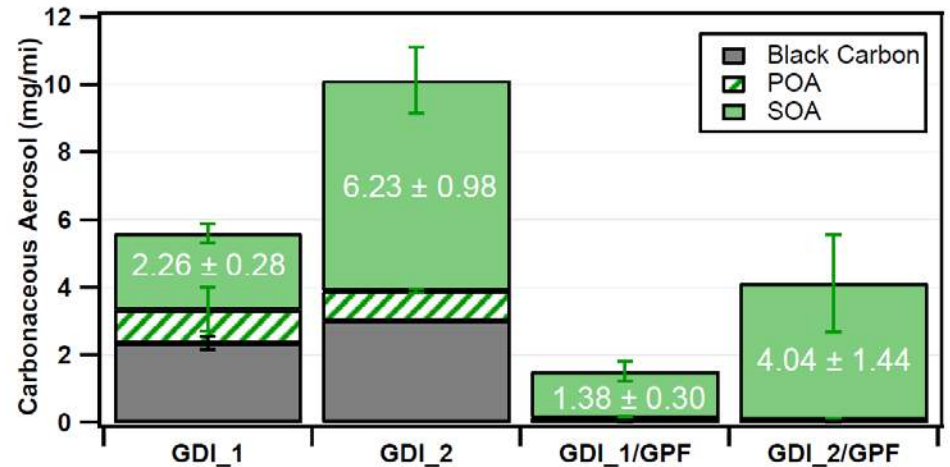
- Natural gas engines emit low PM but high PN because they are not required to install filters
- A diesel with a DPF emits lower number of particles ($<6 \times 10^{-11}/\text{km}$)
- Particles from CNG engines come from lube oil



GPFs can Reduce Organic Precursors to SOA formation



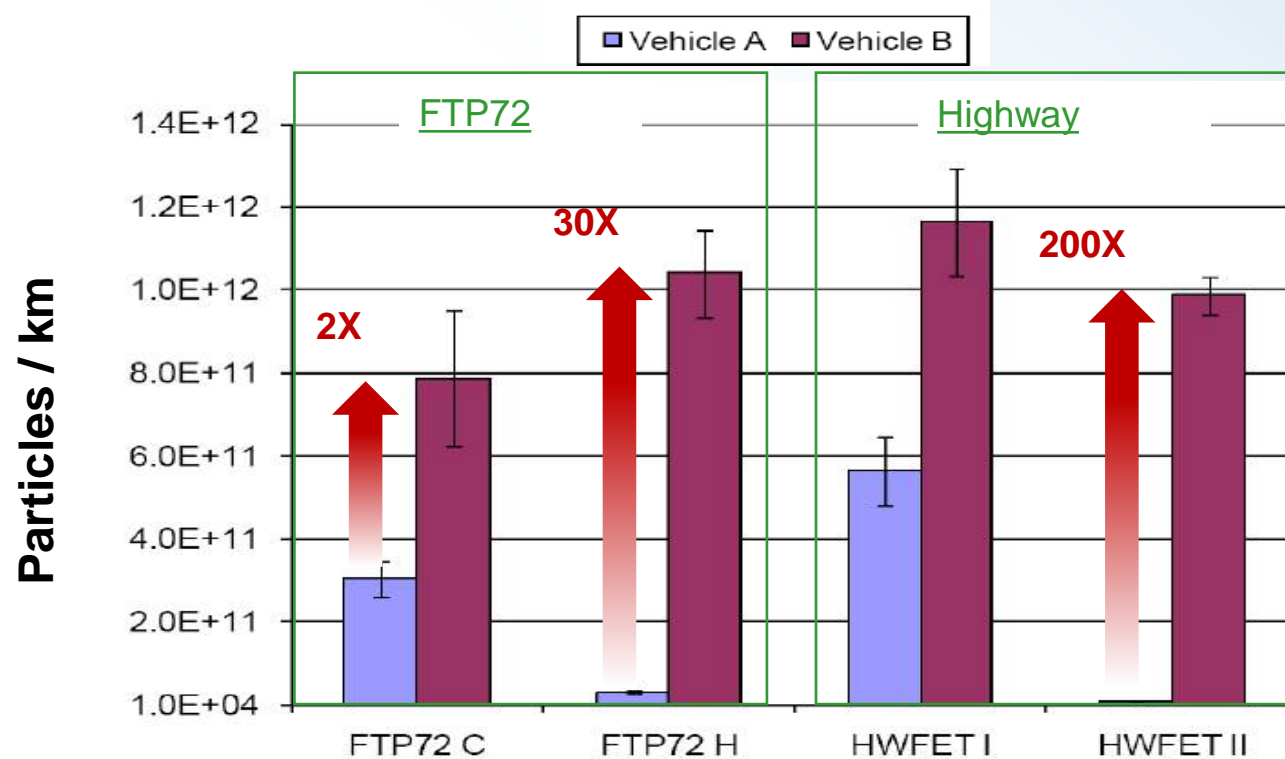
Source: ES&T, Karavalakis, 2019



- 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%



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: HEV)
- GPFs and advanced fuel injectors can provide particle control during real world driving conditions.

Summary and Conclusions

- GDI and Diesel PM are similar, should toxicity of GDI PM be reclassified?
- Fuel Injection and filter technologies demonstrated ability to meet EU PN standard and LEV III 1 mg/mile standard
- 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
 - Multiple technologies offer solutions.

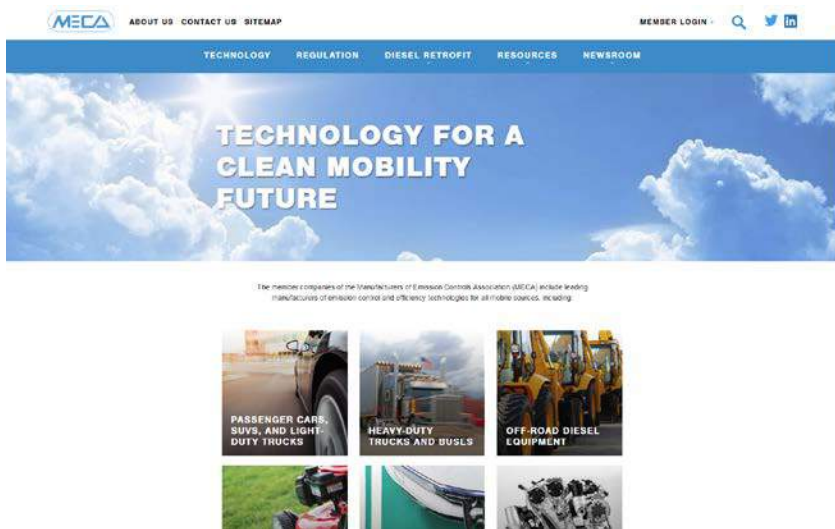
How Can Voluntary Policy Benefit Environment in the absence of a PN Standard in North America

- GHG technology costs about \$50-100 per % CO₂
- GPFs or advanced fuel injectors can significantly reduce black carbon which has GWP of about 2000.
- A voluntary CO₂ credit of 2 g/mi CO₂ (equal to 1 mg/mile BC or 1.25% CO₂) for installing advanced injectors or 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

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