CORNING

Advanced high-porosity filter technologies to meet BS VI regulations

Dr. Ameya Joshi, Dr. Timothy V. Johnson
JoshiA@corning.com JohnsonTV@Corning.com

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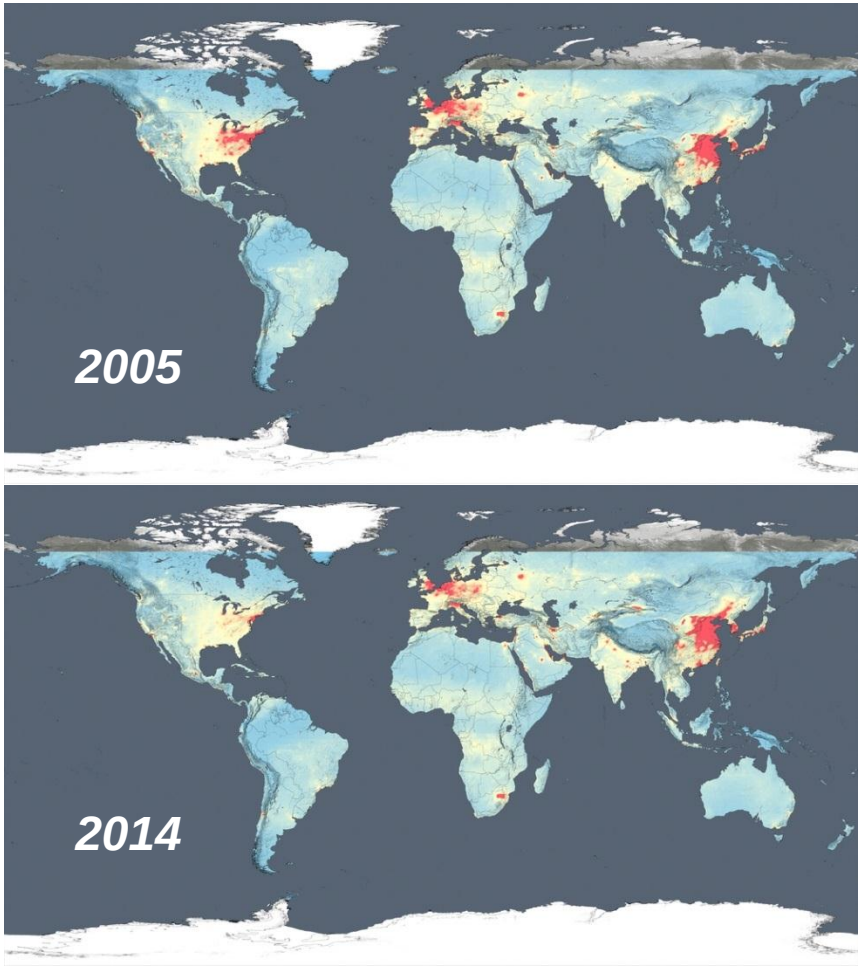
Significant advances in past decades towards cleaner air … yet challenges ahead to reduce particulates, NOx, CO_2

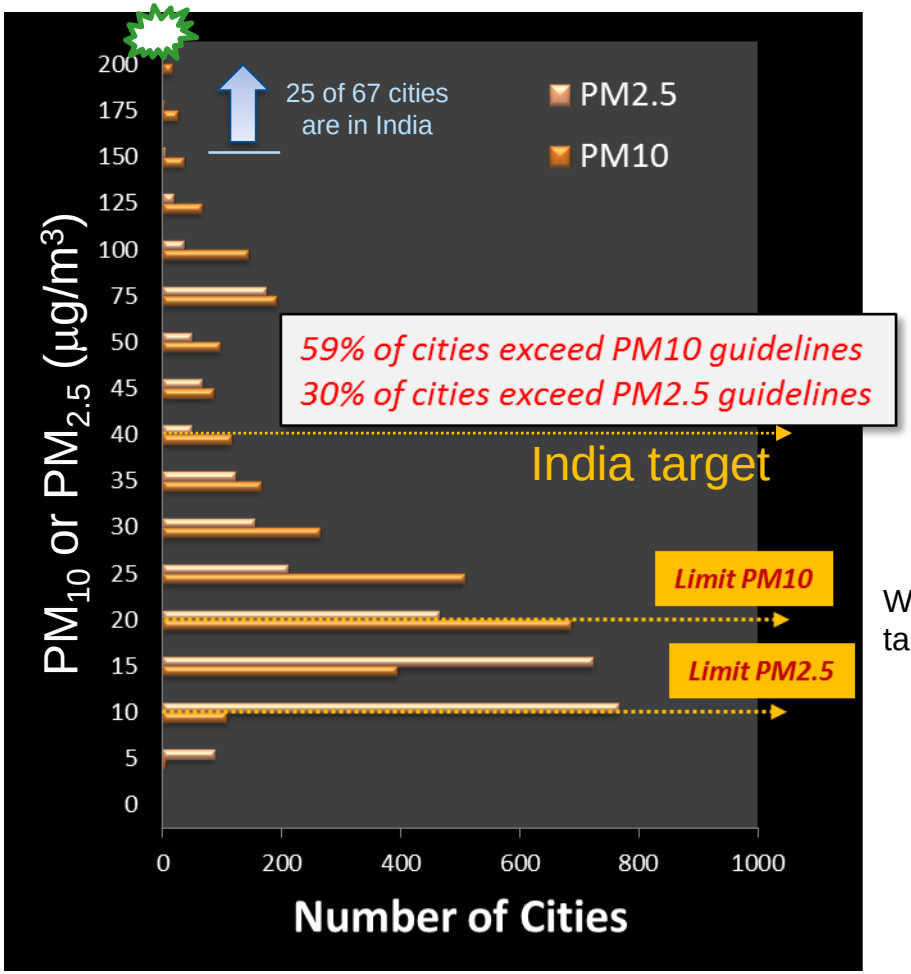
NO_2 concentrations in troposphere



Images from
NASA's Goddard Space Flight Center

WHO Global Urban Ambient Air Pollution Database
~ 3000 cities, 2012 – 2015

New Delhi PM_{10} = 229 μg/m^3



WHO targets

Particulate regulations expected to drive adoption of DPFs and GPFs globally

		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
USA	EPA	Tier 2			Tier 3 (phase in)								
	CARB	LEV III Phase in									3mg/mi > 1mg/mi		
EU		EU6b GDI PN 6e12#/km				EU6c GDI PN 6e11#/km					EU7?		
	Cycle	NEDC				WLTC							
	RDE			Monitor		CF 2.1			CF 1.5		CF 1.0		
China	Nation	China 4 (~EU4)			Diesel / Gasoline	China 5 (~EU5)		China 6 (~EU6c and tighter)					
	Beijing	Beijing 5			BJ 6 (LEV III ULEV 70) or CN6b								
India	Nation	BS III (EU3)				BS IV		BS VI (~ EU6b)			BS VI-2 GDI PN 6e11 #/km		
	12 Cities	BS IV (~EU4)											

Expected needs for particulate filters

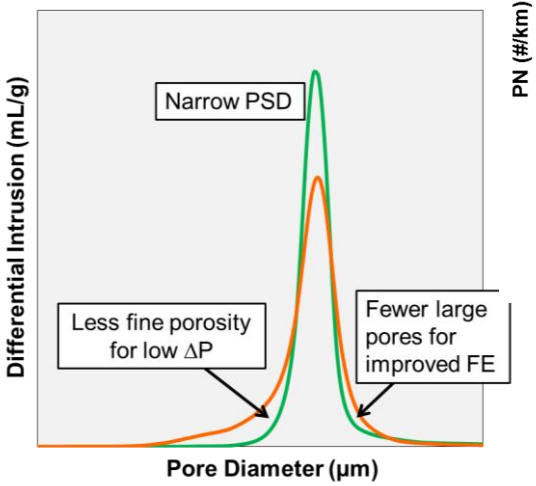
Particulate filters have been designed to meet stringent performance needs

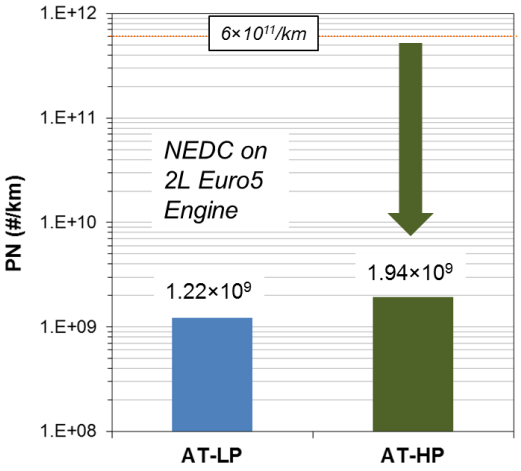
Need	Implication
High filtration efficiency	Engineered pore size & Optimized cell design
Low pressure drop - Coated, soot/ash loaded	
Maintain catalytic performance	Adequate porosity for catalyst
Soot management	Wide operating window
Durability & strength	High strength, low CTE, chemical resistance, etc.

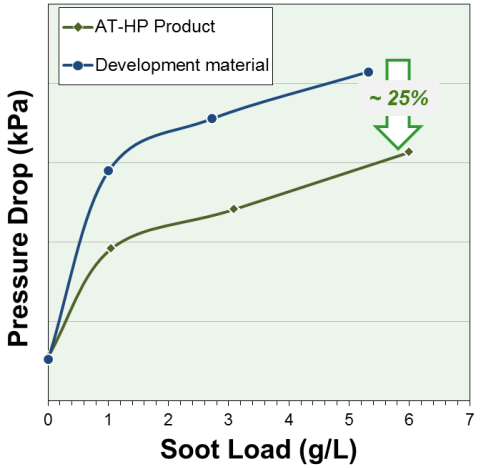
***Results using Corning's AT filter technology**
AT-LP = Low porosity for high SML application
AT-HP – High porosity for SCR integration

Example*

Engineered pore size to meet conflicting requirements of high FE & low ΔP



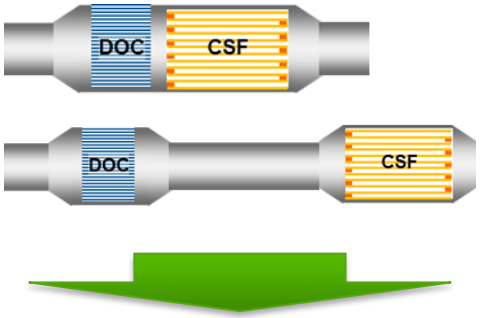




Diesel and gasoline emissions after-treatment systems are evolving to meet Euro6-level regulations

Light-Duty Diesel

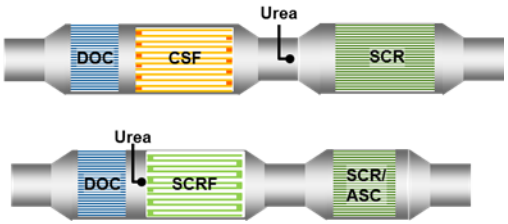
EU5



EU6c / BSVI

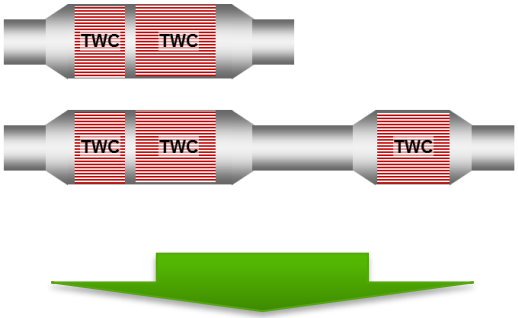
LNT / passive SCR

Active SCR



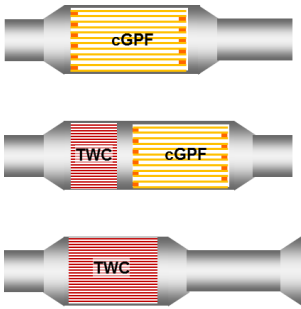
Gasoline

EU5/6b

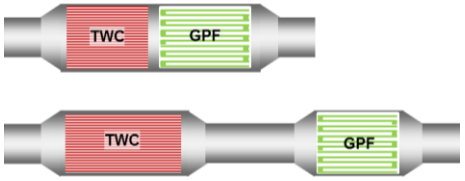


EU6c / BS VI

Filtration + TWC

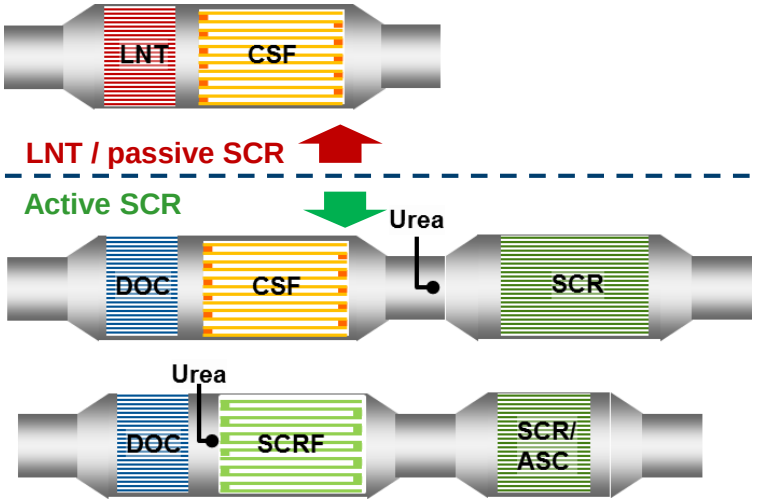


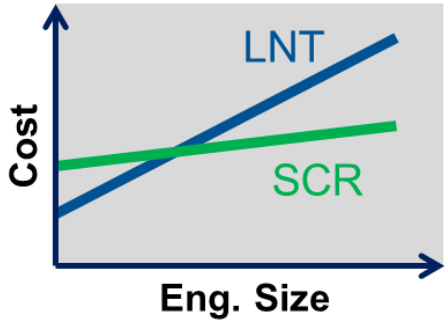
Filtration only



LD Diesel
Likely BS VI after-treatment solutions

Potential BS VI architectures



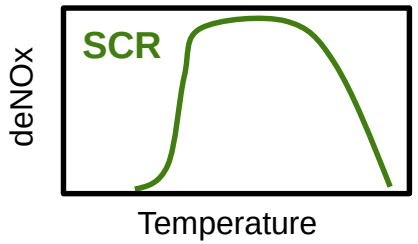


Choice of LNT vs. SCR dictated by engine size & system cost

Considerations for integrated SCR on filters

Aspect	Explanation
Better space utilization	Combines 2 components
Less passive regeneration	NO_2 competition
Lower deNOx @ equal SCR cat. and/or NH_3	Limited urea decomposition & low NO_2
System pressure drop	Could be higher at high WCL
Faster heat-up (cold start)	Better deNOx
Cost, system complexity	PGM (LNT), Urea infrastructure, controls

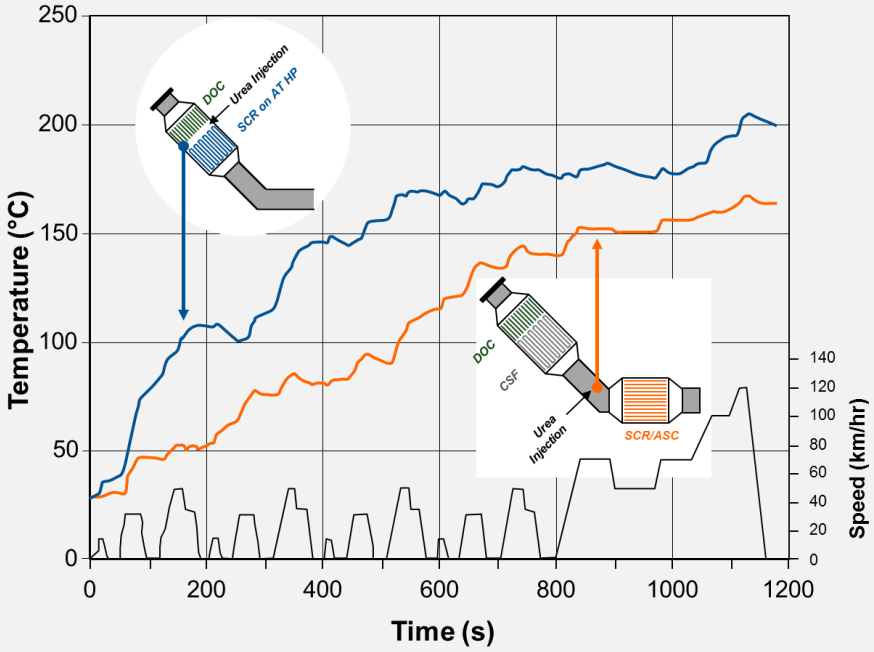
Integration of SCR on DPF for enhanced deNOx performance

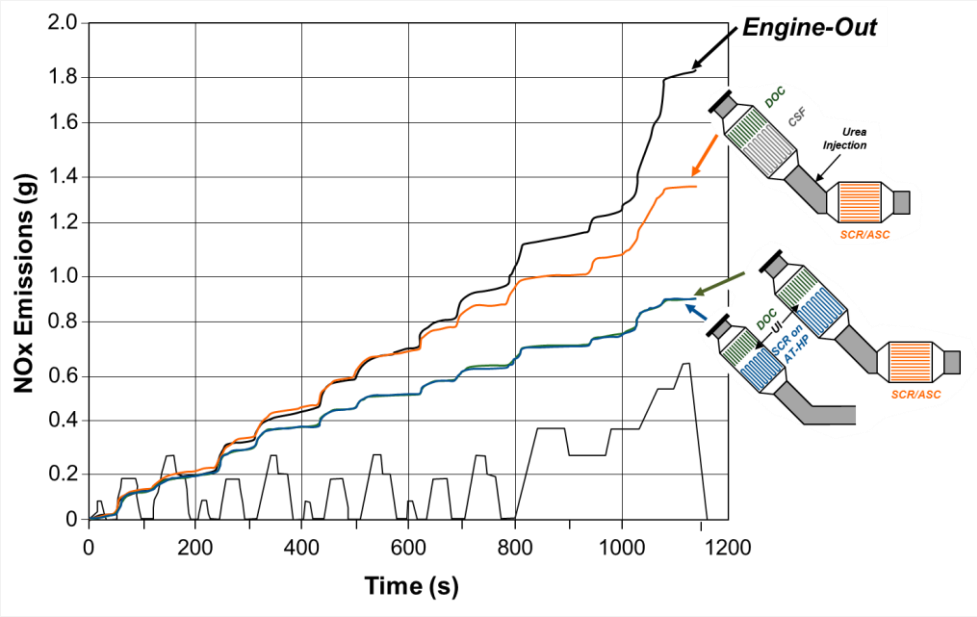


- Challenge with zeolite SCR technology is still improving deNOx at low temperatures (cold start)
- Close-coupled application enables early catalyst light-off and urea injection

Close-coupled implementation
= *Faster Thermal Response*

Translates to earlier Urea Injection & Lower Emissions





Results using Corning's AT-HP filter

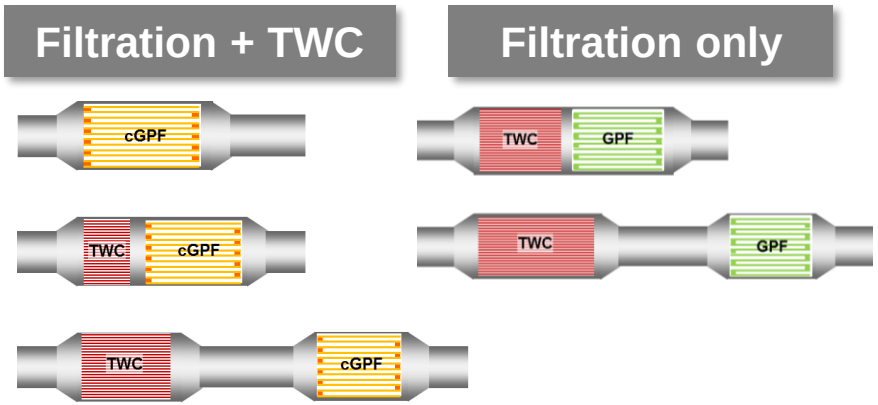
LD Gasoline
Advanced substrates and particulate filters to meet BSVI regs.

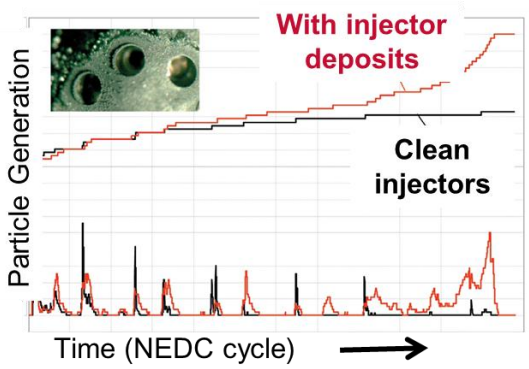
In-cylinder methods are insufficient for maintaining low PN over <u>real world</u> conditions

- Variation in speed/load
- Ambient temperature
- Deposits – Injectors, combustion chamber, valves
- Production tolerances
- Wear, aging
- Variation of fuel, lube oil quality
- Variability across fleet
- Measurement challenges

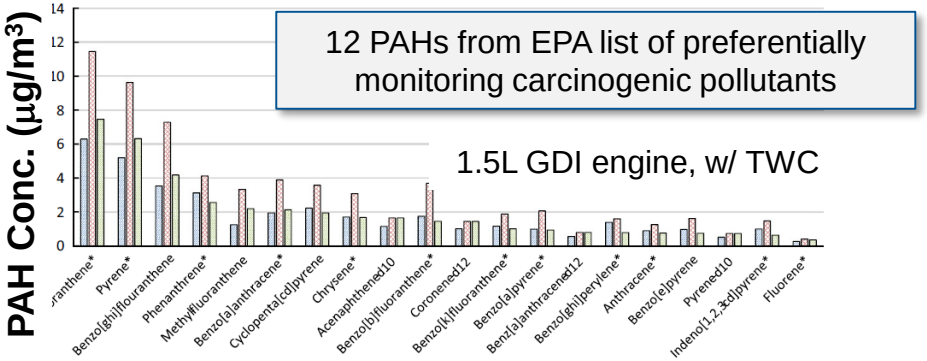
Gasoline Particulate Filters offer a robust solution to minimize tailpipe PN and capture PAHs

Potential BS VI Architectures





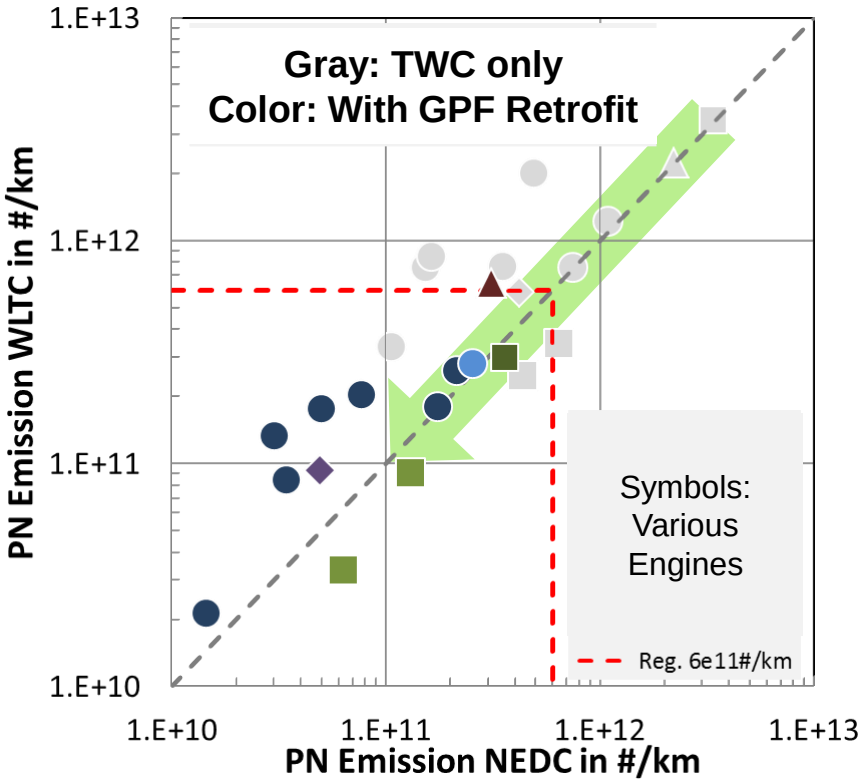
Fraidl et al. (AVL, 2012)



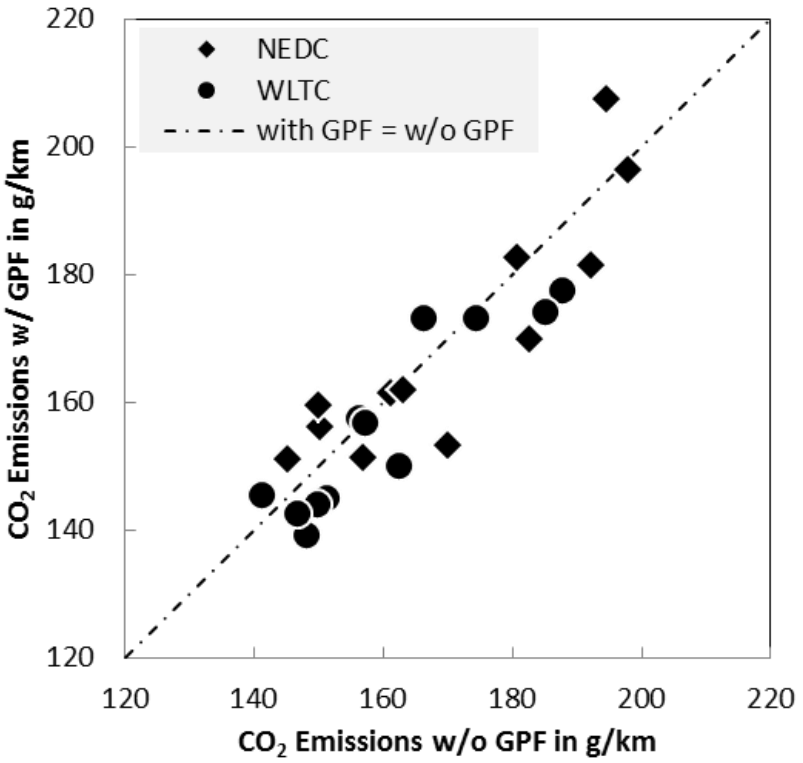
Tsinghua & Peking Univ., Fuel, 2016

Extensive vehicle fleet experiments confirm robust filtration performance of GPF with minimal Δp penalty

- PN Filtration studied using large Vehicle Fleet with GPF retrofits
  - 12 GDI vehicles (EU5/6b), Engines 1.4 – 3.0L, various segments (C,D,E, SUVs)
  - GPFs uncoated and some TWC coated

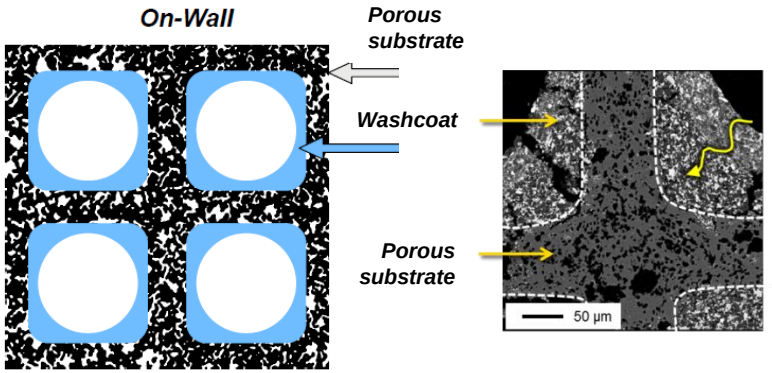


No clear trend for impact of GPF on CO_2 emissions observed

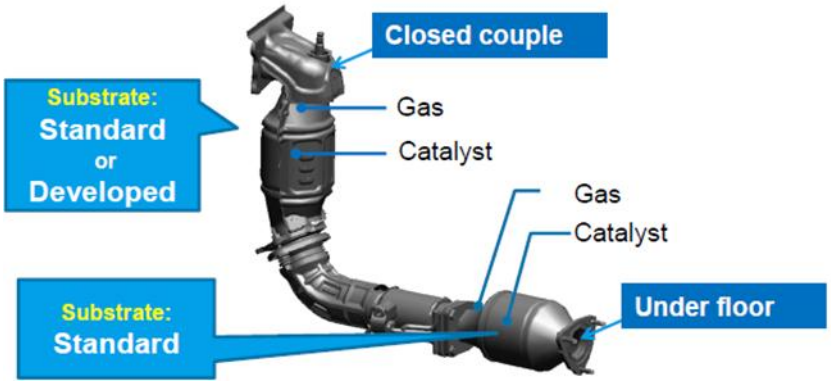


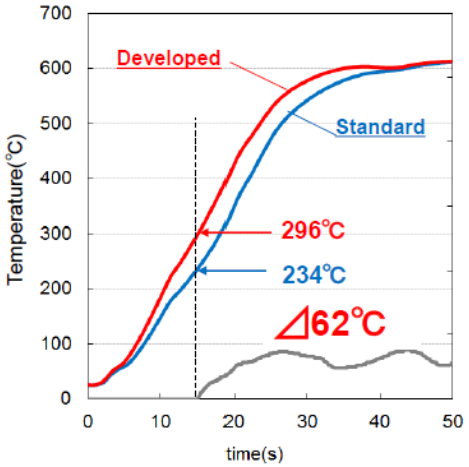
LD Gasoline
Advanced substrates enable early light-off

Low thermal mass FLORA® substrates

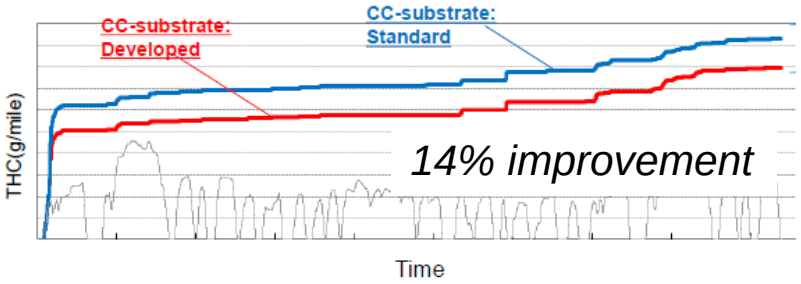


Corning SAE 2015-01-1009, Honda SAE 2015,01-1001

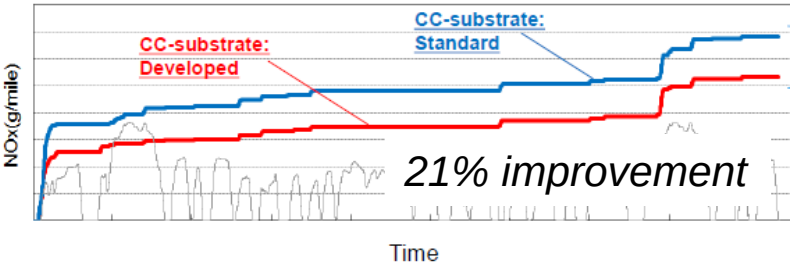




THC



NOx



Summary

- Implementation of BSVI regulations is an important step towards cleaner air
  - Emissions are typically higher under “real-world” driving conditions, development of RDE and monitoring of in-use compliance is important
- After-treatment solutions exist and have been developed to meet the stringent requirements of reduced gas and particulate tailpipe emissions
- Choice of diesel after-treatment solution (SCR vs. LNT) will depend on engine size, urea infrastructure, control strategy etc.
  - In either case, filters and substrates are capable of meeting the requirements
- BSVI regulations or gasoline implies use of advanced substrates, catalysts and particulate filters for GDI engine (for $6x10^{11}$ #/km limit)
  - Extensive testing has shown robustness of GPF technology to meet regulations without significant impact on fuel economy