Light-Duty Vehicle Emission Control Technologies

Mexico City Workshop
April 8-9, 2015

Dr. Rasto Brezny
Manufacturers of Emission Controls Association
www.meca.org

Light-duty Vehicle Emission Control Technologies
Outline

- Gasoline Vehicle Technologies for Tier 2/Tier 3 & LEV II/LEV III
- Light-duty Diesel Emission Control Technologies

MECA - Industry Technology Voice with North American Regulatory Agencies and Stakeholders; 38 Member Companies Cover Major OEM & Aftermarket Emission Control Suppliers

OEM

OEM

Sourcing Decisions Made by the OEM

SUBSTRATES & MATS → **CATALYSTS** → **EXHAUST SYSTEMS** **(sensors, canning, air pumps, urea delivery)** →

EVAP. SYSTEMS **(carbon canisters; purge valves; low permeation materials)**

Manufacturing Flow

Emission Control Industry supports > 65,000 jobs in the U.S.; manufacturing facilities also in Mexico

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Mobile Source Emissions Regulations Drive Technology Innovation

- Light-duty: U.S. Tier 2/LEV II moving to Tier 3/LEV III
  - <u>Near Zero</u> gasoline exhaust emissions: advanced TWCs, HC adsorber cats, high cell density substrates, direct ozone reduction catalysts
  - <u>Near Zero</u> gasoline evap. emissions: advanced carbon canisters, low permeation materials, air intake adsorbents
  - <u>Near Zero</u> diesel exhaust emissions: EGR, DPFs, LNT, SCR

- U.S. 2007-2010 Heavy-Duty Highway Diesel
  - DOC, DPFs, SCR, EGR
- U.S. Tier 4 Off-Road Diesel
  - DOC, DPFs, SCR, EGR

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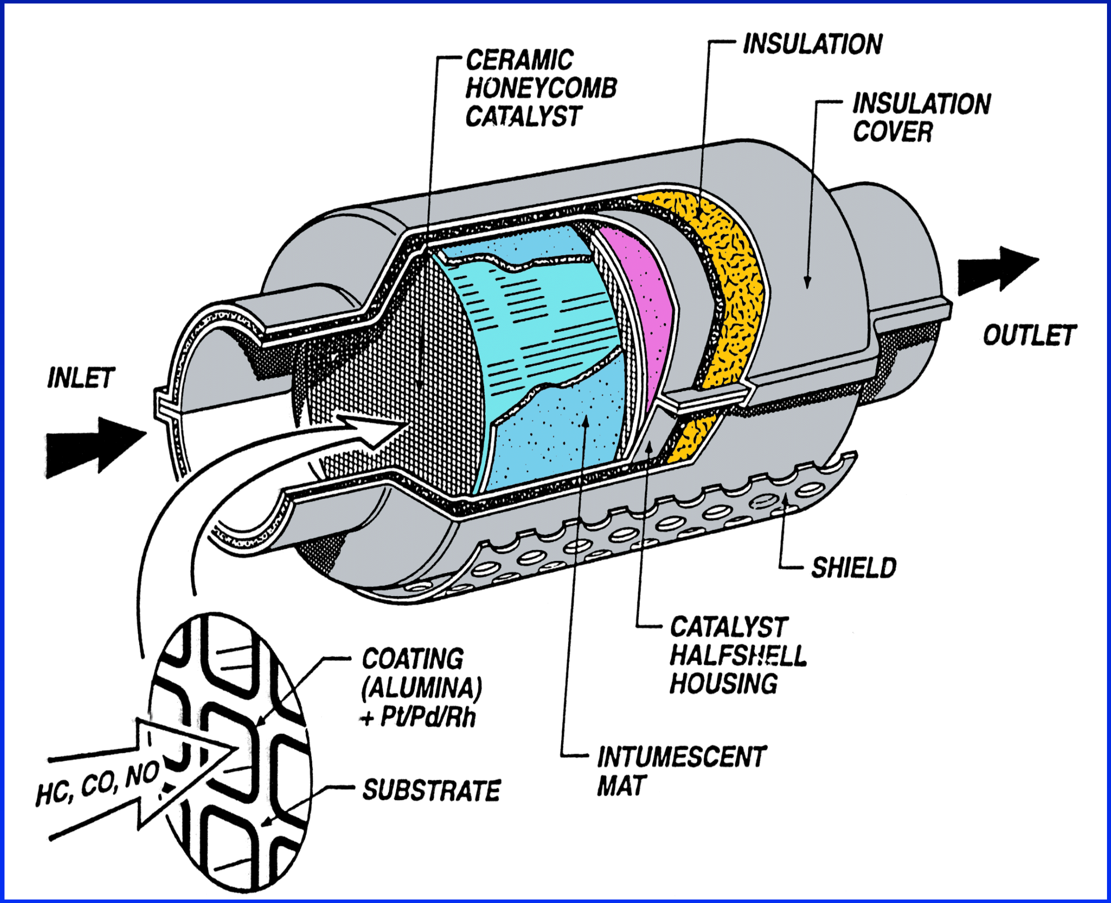
The Three-way Catalytic Converter: A Familiar Technology Re-Engineered for High Performance



- Provides high efficiency "three-way (HC, CO, NOx)" performance
- High cell density ceramic or metallic substrates
- Advanced materials with high thermal stability
- Layered catalytic architectures to maximize noble metal (Pt, Pd, Rh) effectiveness

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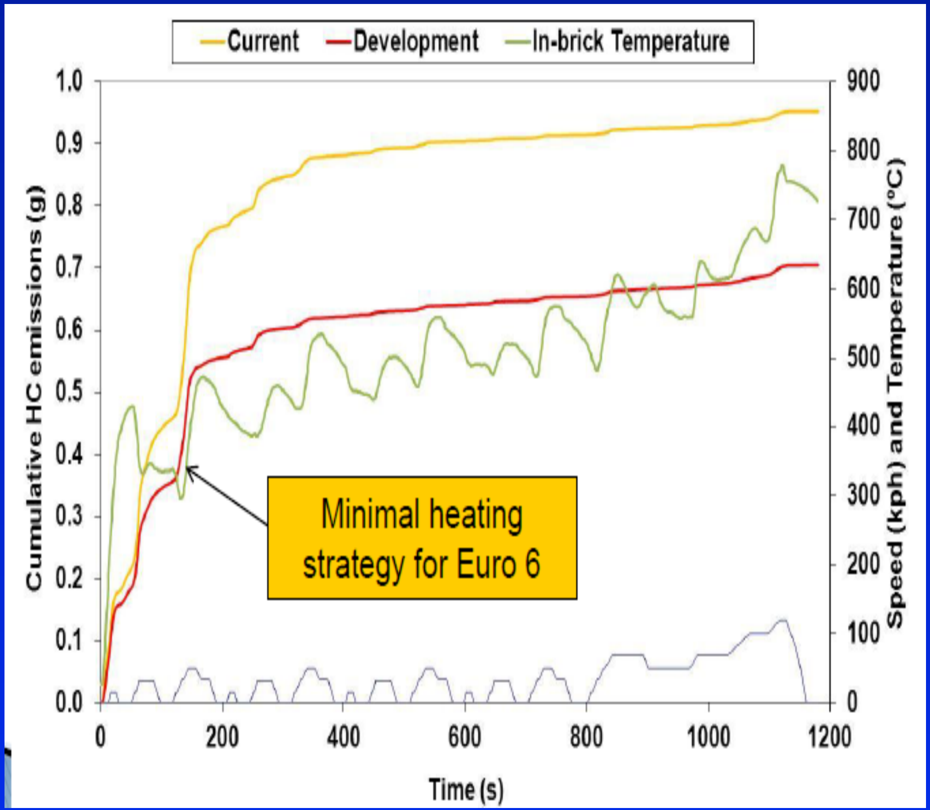
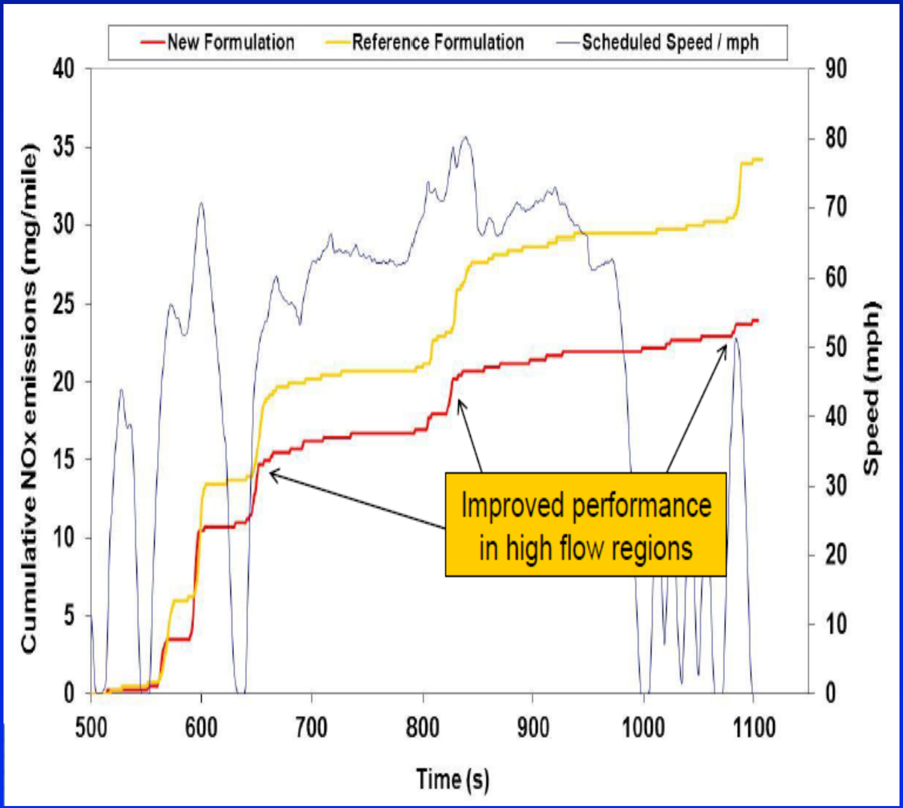
LEV III/Tier 3 Applications Continue to Emphasize Cold-Start & High Speed NOx Performance





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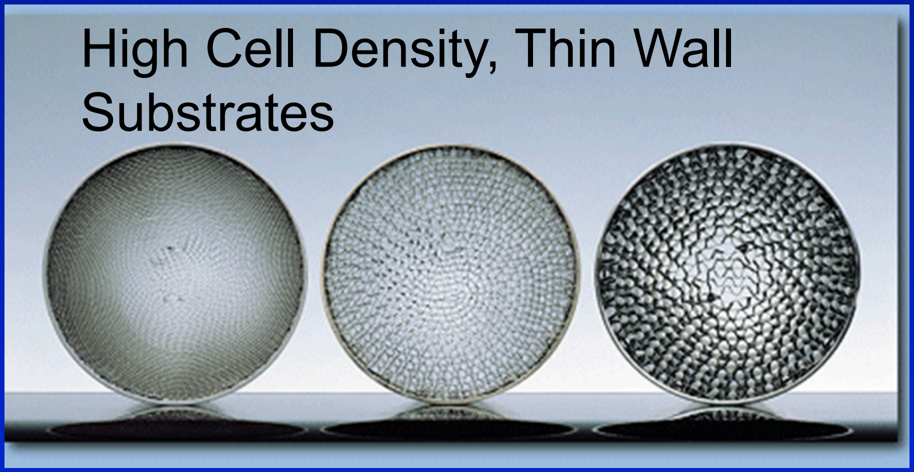
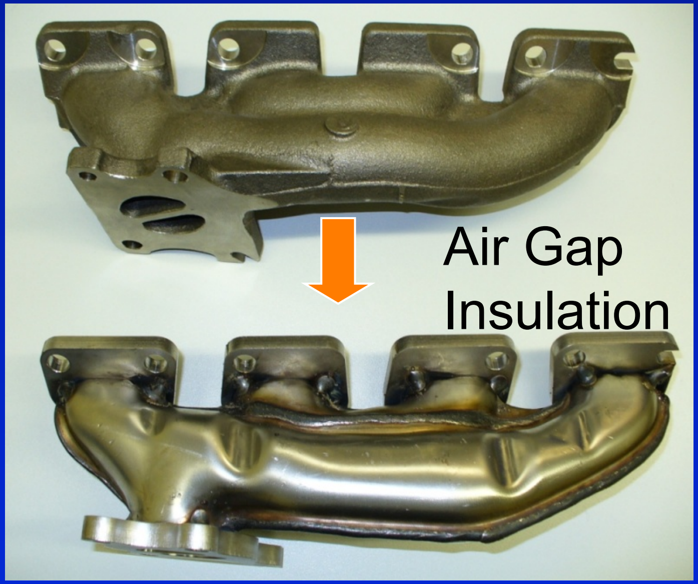
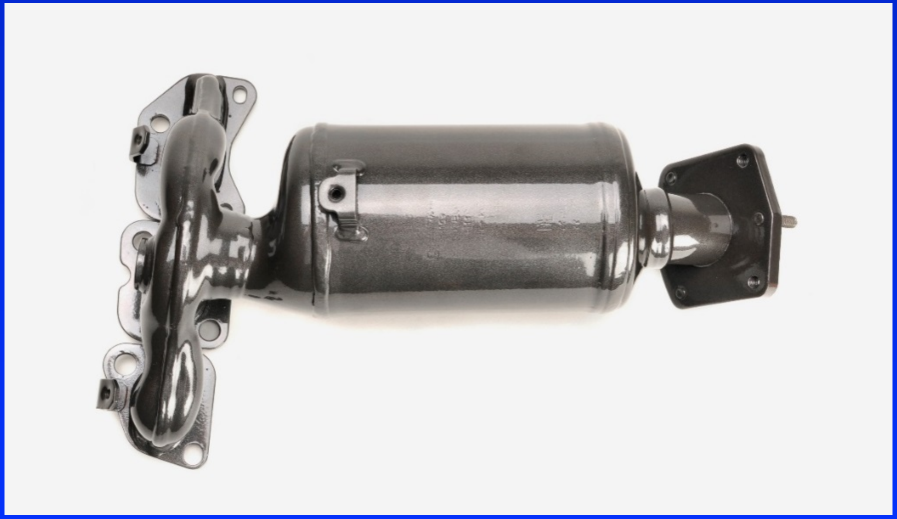
Thermal Management Focused on Cold-Start Emission Reductions







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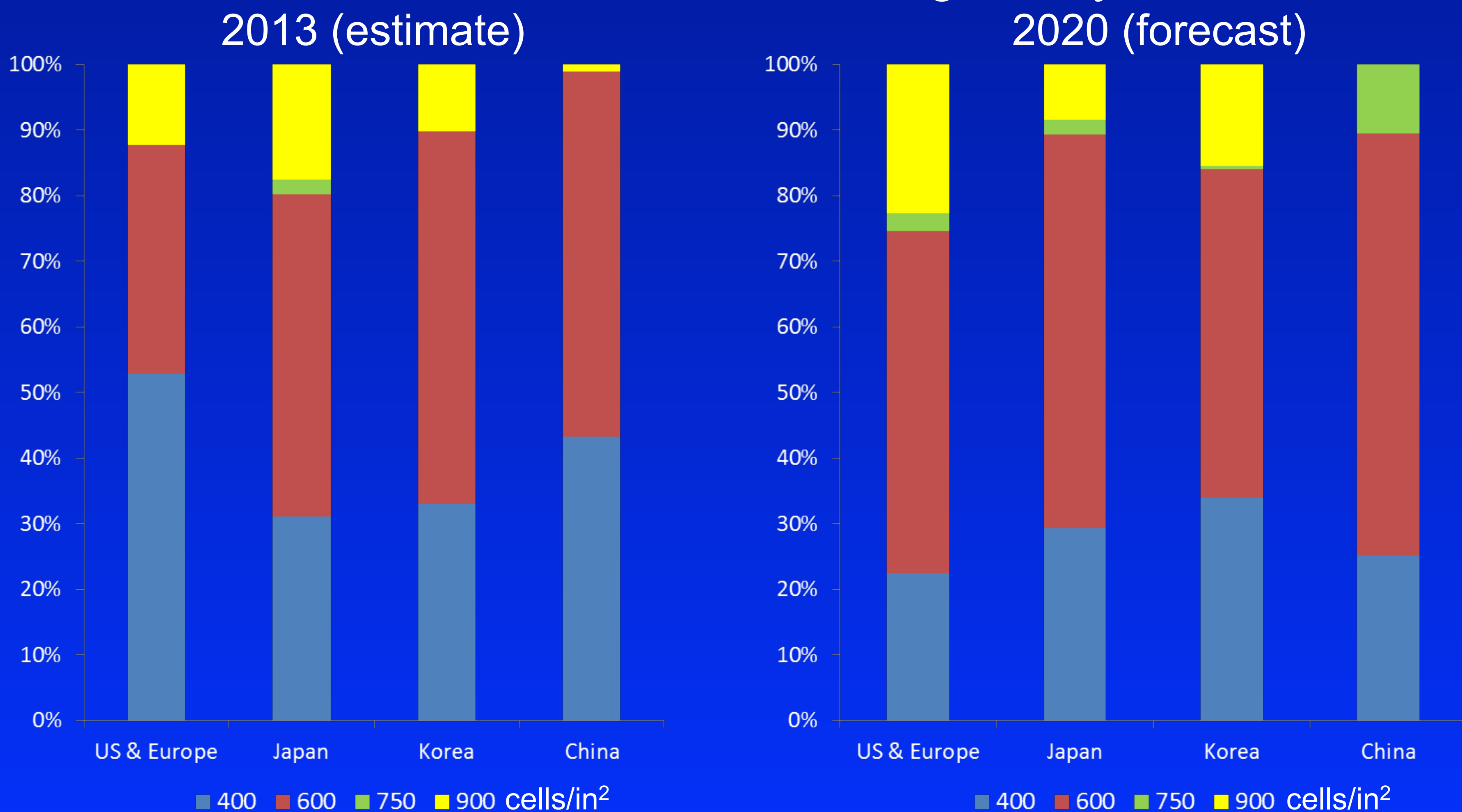
Tightening Regulations Require Higher Substrate Cell Density/ Geometric Surface Area; Emerging Markets Moving from Standard Wall to Thin Wall and Ultra-thin Wall Substrates

Substrates Used on Gasoline Light-duty Vehicles



By 2020 400 cpsi substrates primarily used only in underfloor converters that utilize high cell density (≥ 600 cpsi) close-coupled converters

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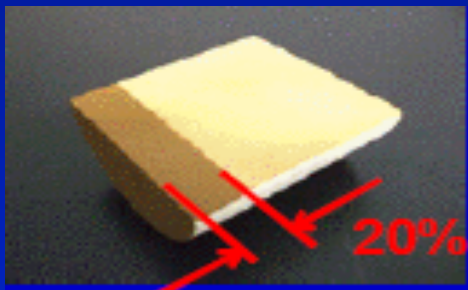
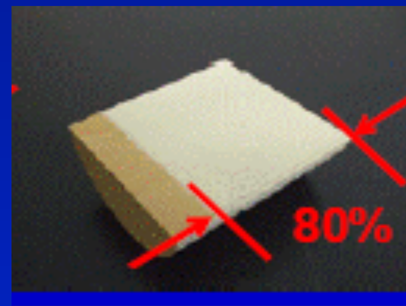
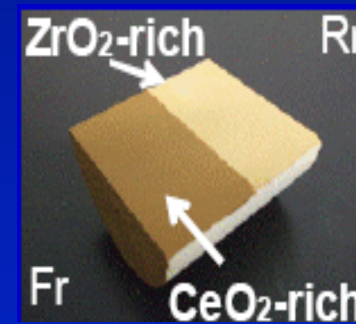
Gasoline Three-way Catalysts Utilize Advanced Design Architectures to Maximize Performance



Pd is zoned in the front to give fast HC light-off



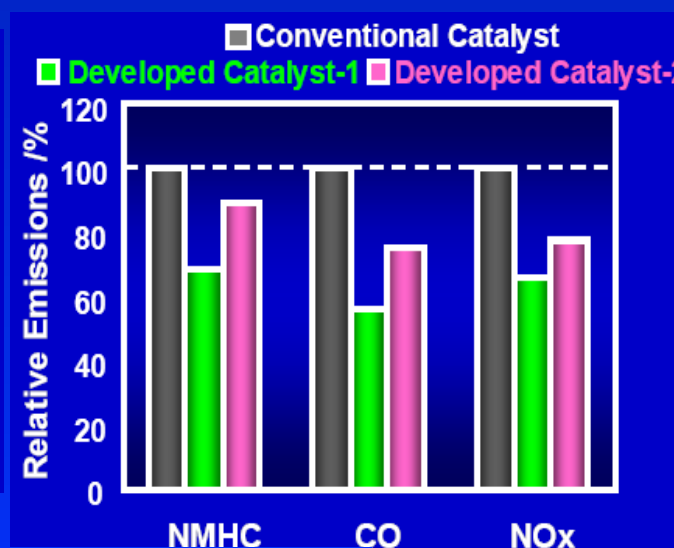
Rh is zoned in the back to protect against catalyst poisons



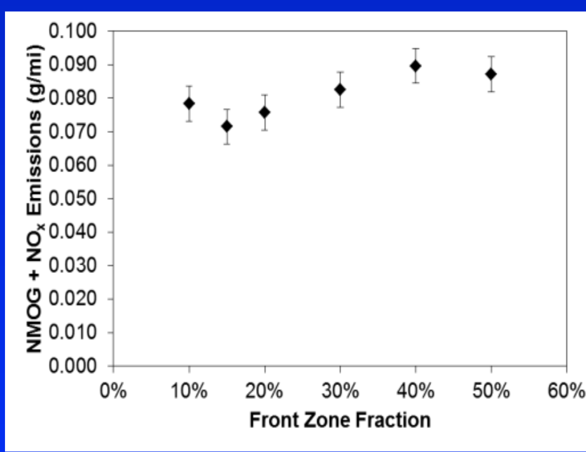
Zoned OSC to give optimum performance

	Conven tional	Developed Catalyst	
		1	2
Coat	Double Layer	Zone-Coat	
Noble Metal	Pd/Rh	Pd/Rh	Rh45% reduced

Substrate Volume: 0.9[L]
Aging: Equivalent of 120K miles
Vehicle: '05MY ULEV/CAMRY

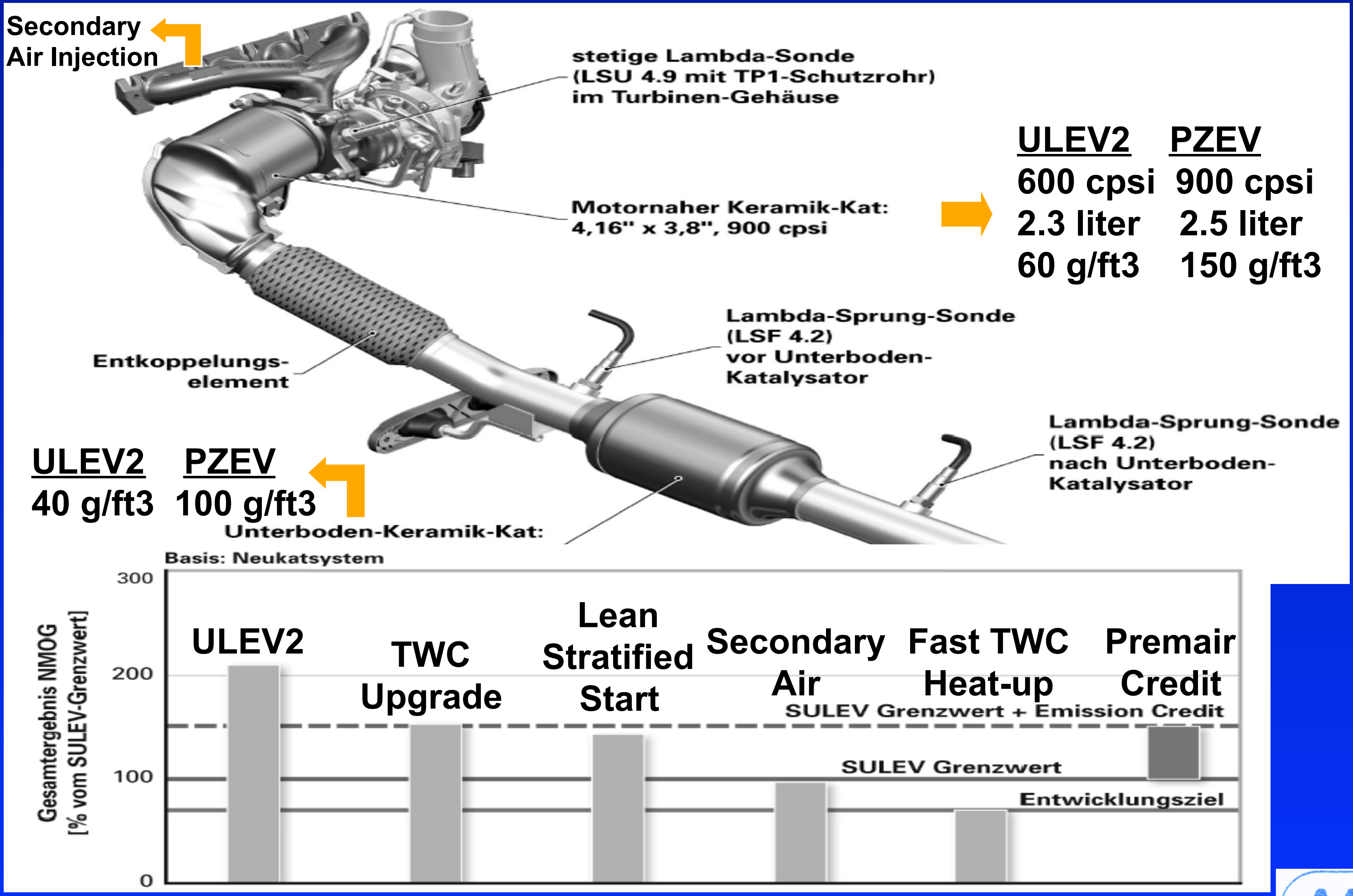


Toyota, SAE 2011-01-0296



SAE 2014-01-1508

PZEV Experience with Turbo-GDI Applications



Source: 2007 Aachen Colloquium

Variety of PZEV Strategies in the U.S. Market

Vehicle	A	B	C	D	E
Engine Displacement	2.0	2.4	2.0	2.4	2.4
PFI or DI	DI	PFI	PFI	DI	PFI
NA or Turbo	Turbo	NA	NA	NA	NA
AIR or non-AIR	AIR	AIR	non-AIR	non-AIR	AIR
Average Ignition Setting (^{o}btc)	-20	0	-7	-12	-5
Engine Speed (rpm)	1150	1200	1500-1700	1200-1500	900-1200
Lambda	1.05 (AIR)	>>1 (AIR)	.95-1	.95-1	>>1 (AIR)
Max Cat Temp (^{o}C)	670	1000	500	700	950

Vehicle	Positives	Negatives
A	PZEV turbo, low startup engine speed, more accurate fuel control	High system cost/complexity
B	Extremely fast catalyst light-off, low startup engine speed, less calibration time	Cost of AIR, excess fuel used in start-up
C	Lowest system cost	High engine speed in first idle
D	Split injections enable fast lightoff w/o AIR	Additional calibration effort
E	Extremely fast catalyst light-off, low startup engine speed, less calibration time	Cost of AIR, excess fuel used in start-up

Ref. : SAE 2012-01-1245

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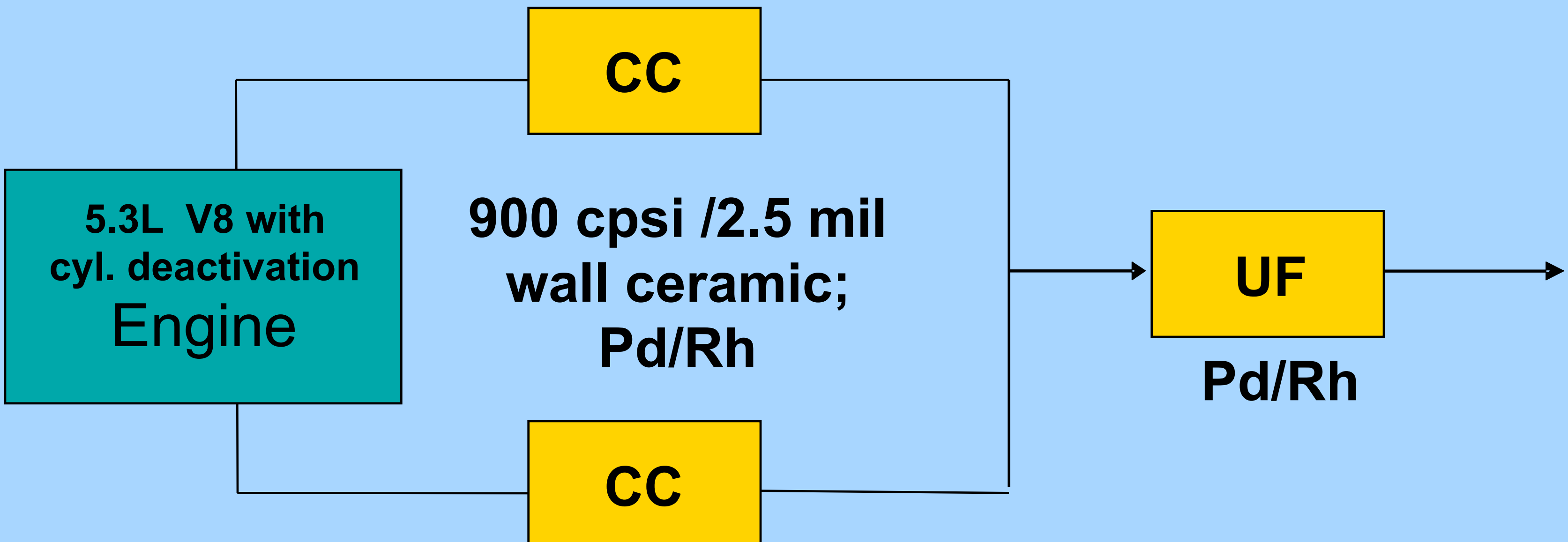
2011 5.3 L Chevy Silverado Full Size Pick-up: 150K mi Aged Advanced TWC System ⇨ Tier 3 Bin 30

FTP Emissions with *9* ppm S E10: **18 mg/mi** NMOG+NOx
with *29* ppm S E10: **29 mg/mi** NMOG+NOx

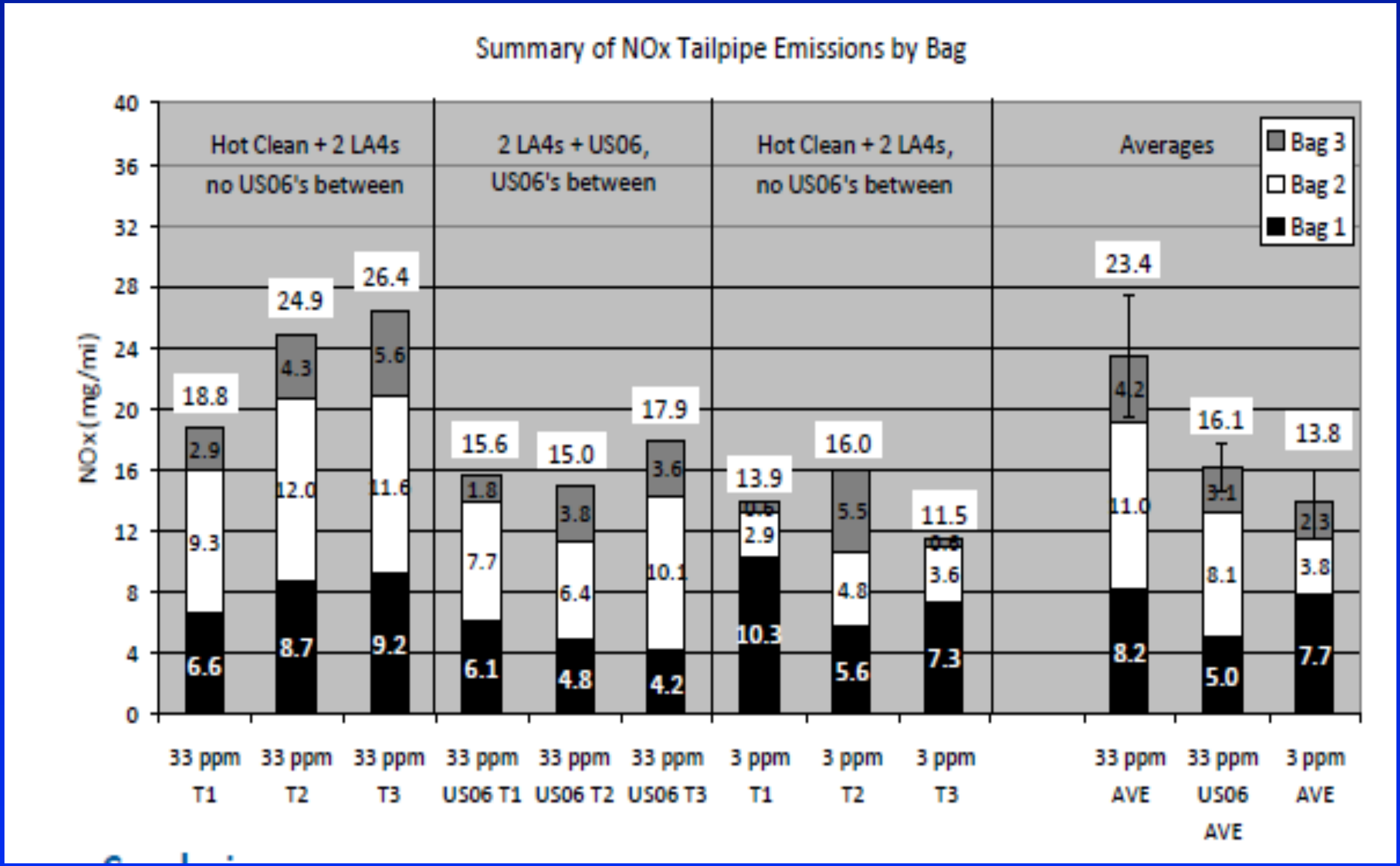


TWC System Bench Aged to 150K miles;
Total TWC Catalyst Volume: 1.90 L (0.36 SVR)
Pd/Rh = 16/1; 125 g/cu.ft. (8.4 g PGM total)

Gasoline Sulfur Degrades Catalyst Performance: Example Chevy Malibu PZEV Application

2.4 liter, 4 cyl.: CC+UF TWCs

Ref.: SAE 2011-01-0300



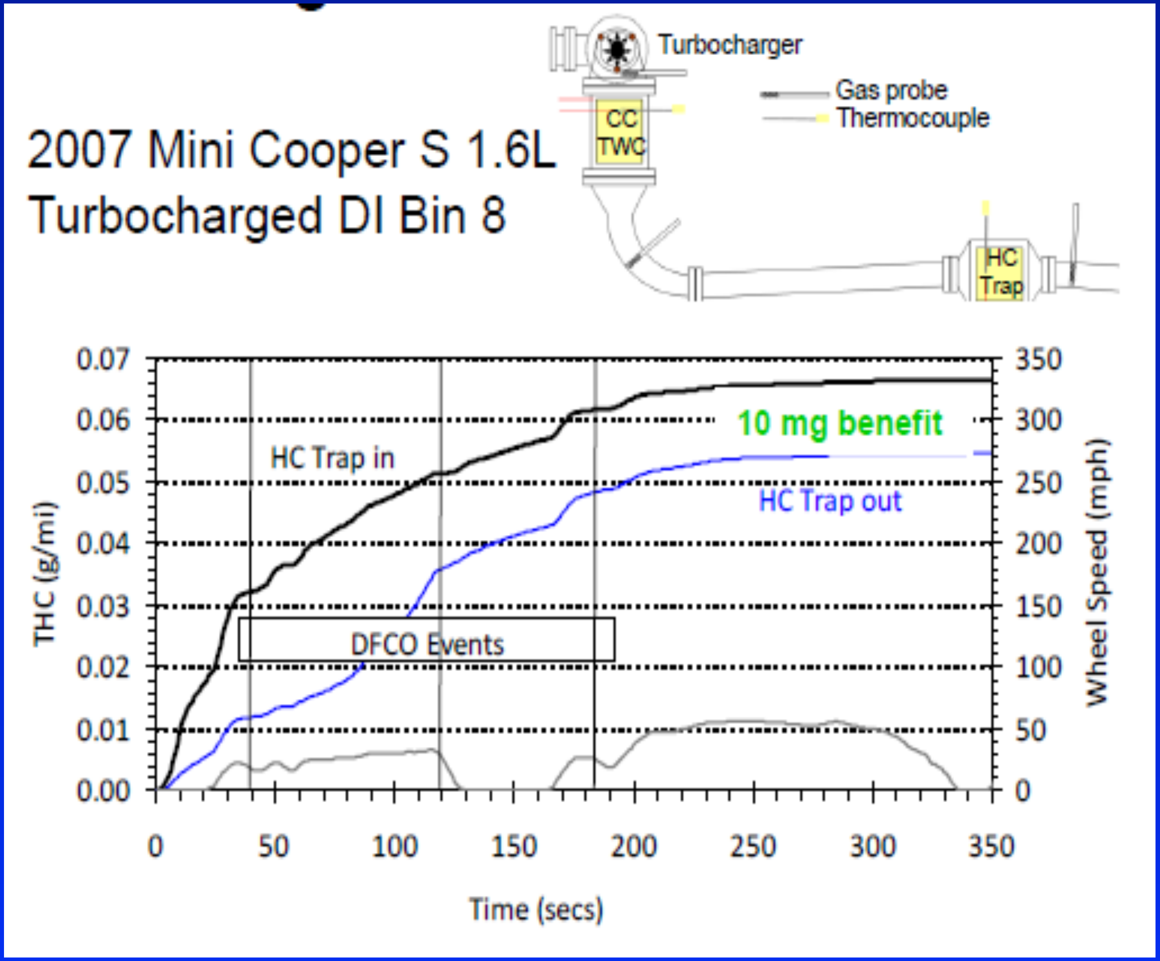
UF never above 600 C with FTP; <u>**NOx "creep"**</u>

UF at 700-750 C during US06; <u>**NO NOx "creep"**</u>

<u>**NO NOx "creep"**</u> **with 3 ppm S**

Additional Cold-Start HC Control Available From Hydrocarbon Traps

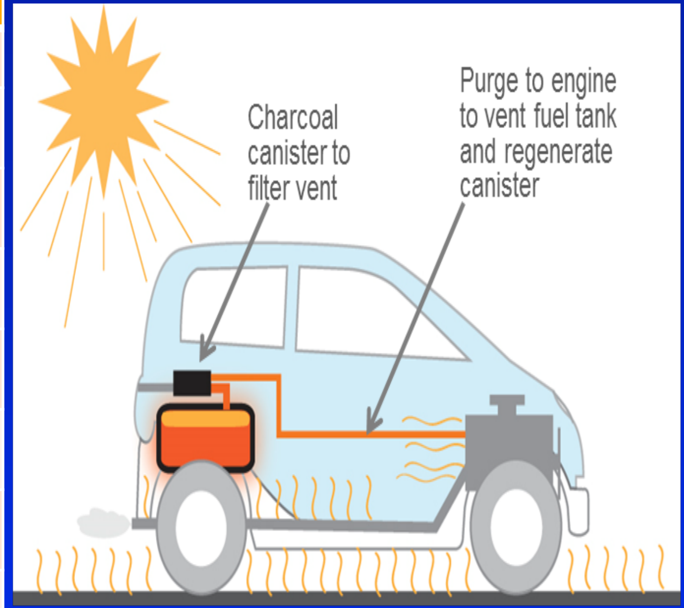
- Limited SULEV/PZEV HC trap applications to date
- Development work continuing with focus on durability/cost
- Example: HC trap PGM loading of only 26 g/ft^3



Reference: SAE 2013-01-1297

U.S. Evaporative Emission Standards Provide Comprehensive VOC Controls for Gasoline Vehicles

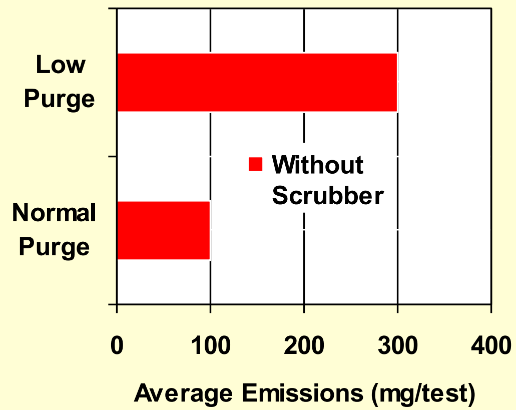
Standard	US ≤ 1995 and Euro Evap. Stds.	US ≥ 1996-2004
ORVR		✓
24-hr Diurnal	✓	
48-hr Diurnal		✓
72-hr Diurnal		✓
Evap Standard = 2 g/day	✓	
Evap Standard < 0.5-1.2 g/day		✓
Hot Soak	✓	✓
Running Loss		✓
In-use standards and monitoring		✓
OBD		✓



Since 1996, the US progressively added ORVR, extended diurnals, short drive cycles, running loss, low certification and in-use emissions standards, and OBD to improve air quality.

Carbon Technologies to Achieve PZEV/LEV III Evaporative Requirements

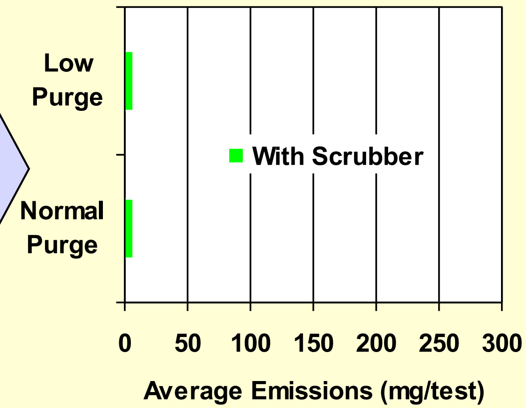
CANISTER EMISSIONS



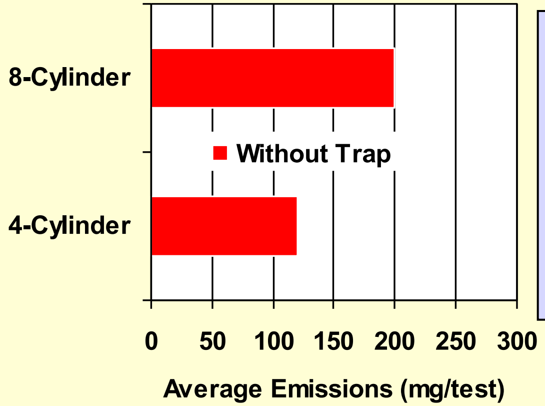
Addition of Canister Scrubbers

- Honeycombs
- Low Bleed Carbon

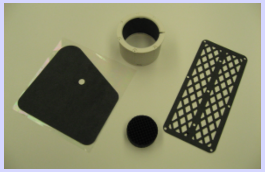
Reduction of 95-295 mg/test



AIS EMISSIONS

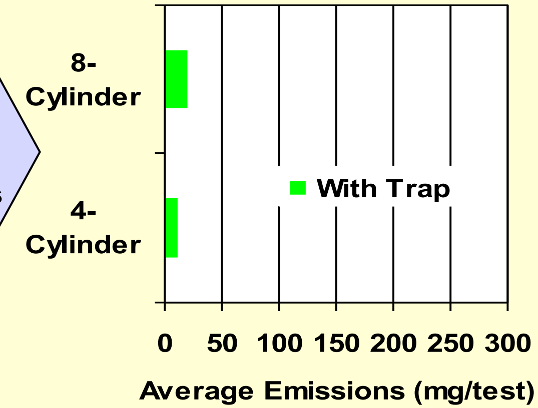


Addition of AIS Traps



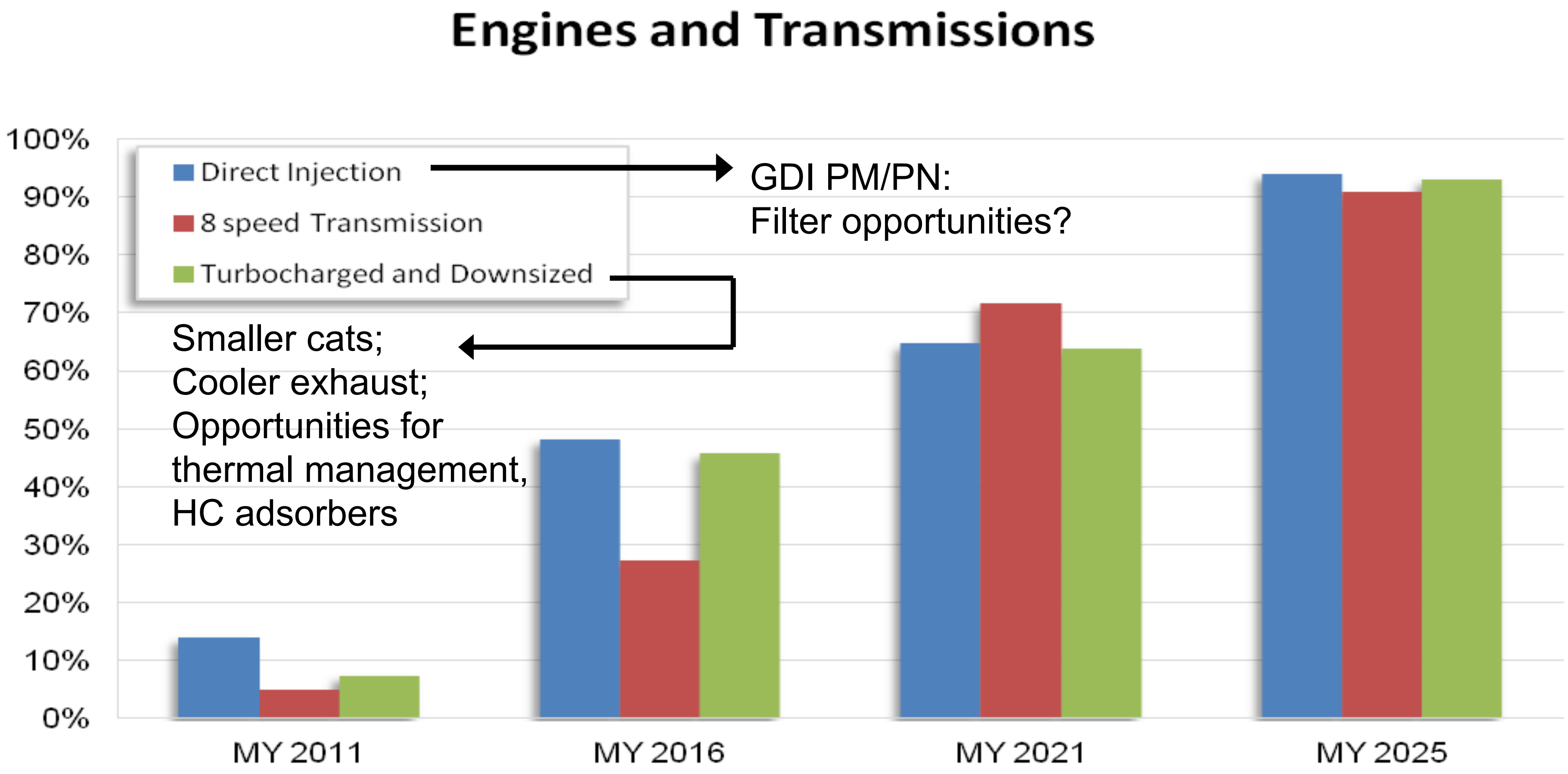
- Honeycombs
- Carbon Sheet
- Low dP Elements
- Carbon Cylinders

Reduction of 100-200 mg/test

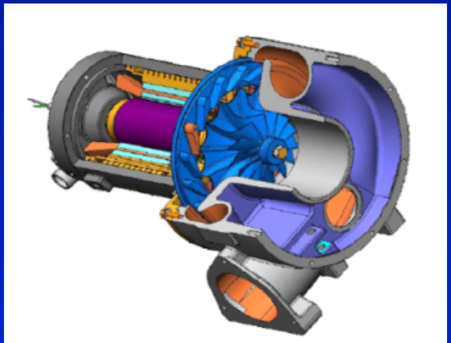


Combustion Efficiency Technologies and Gasoline Particulate Filters

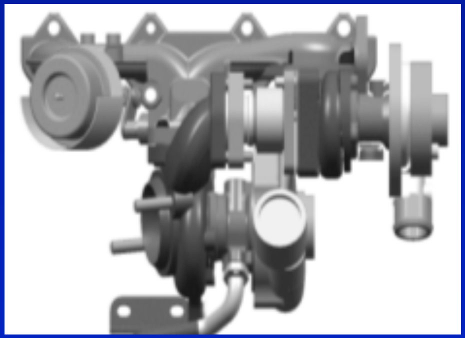
GHG Compliance Creates Emission Control Opportunities



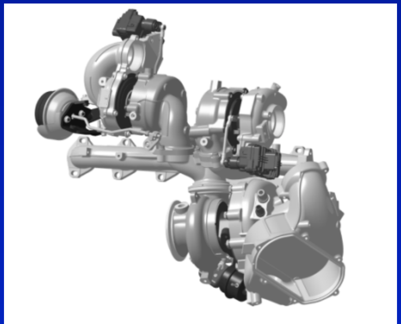
Engine Downsizing Driving Turbo Advances



Turbo compounding

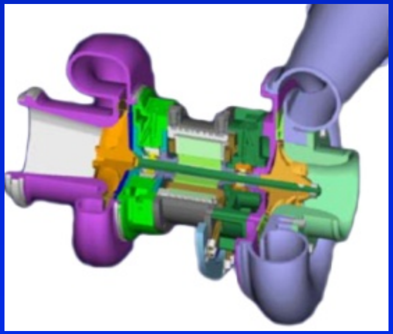


Regulated 2-Stage

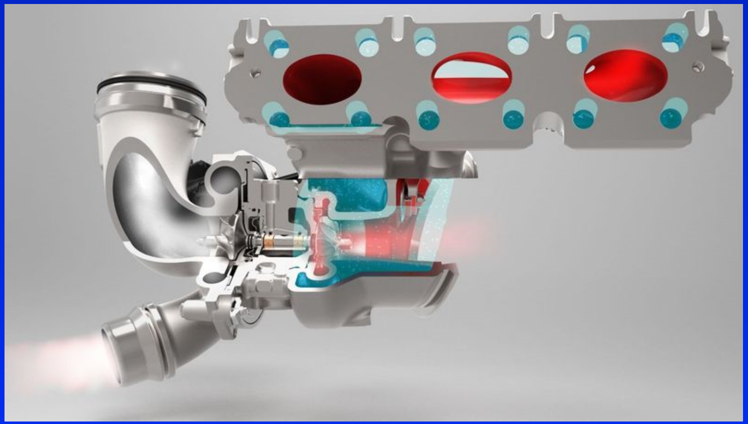


Regulated 3-Turbocharger System

Stamped turbo housing



Electric turbocharging



Water-cooled Turbocharger

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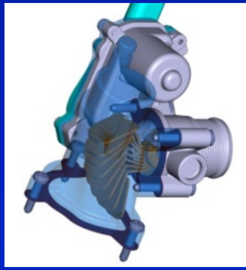
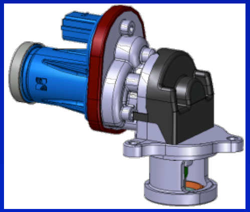
Lower Engine Out Emissions must Include GHGs

Decoupling the CO_2 – NOx Relationship

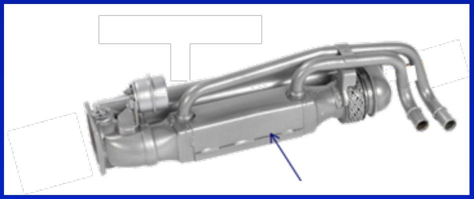
- Low and high pressure EGR



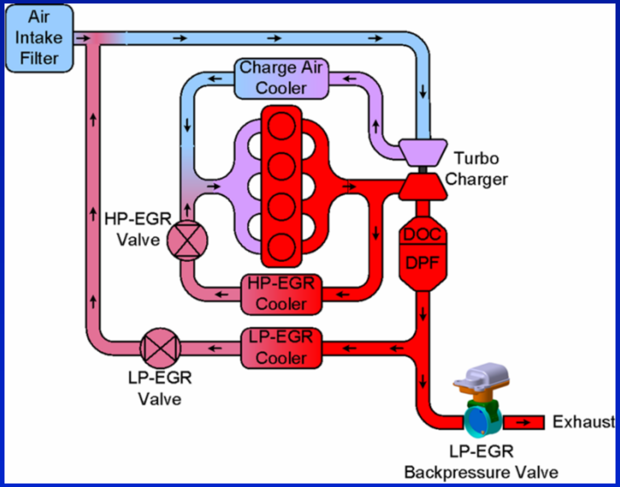
LP EGR Valve

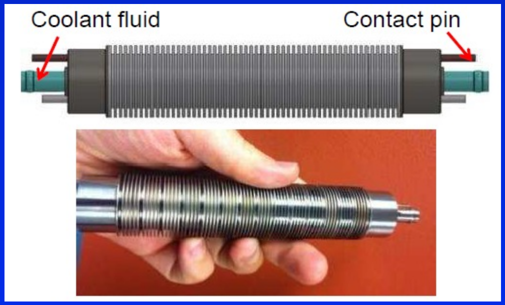


HP EGR Valve

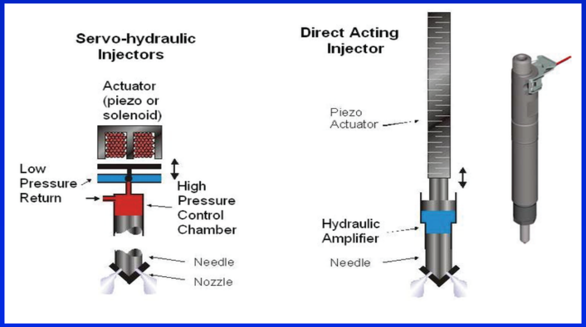


EGR Cooler

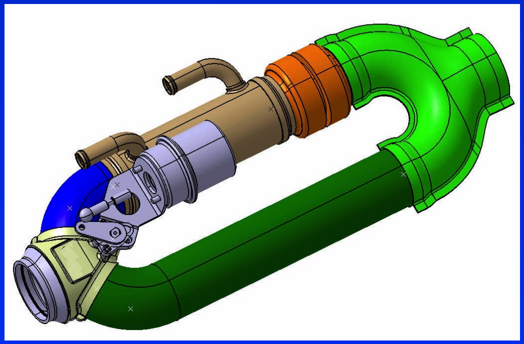




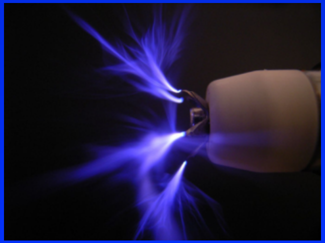
Thermoelectric Generators



Piezo Injectors



Exhaust Heat Recuperators



Corona Ignition

GPF Vehicle Durability Run Completed

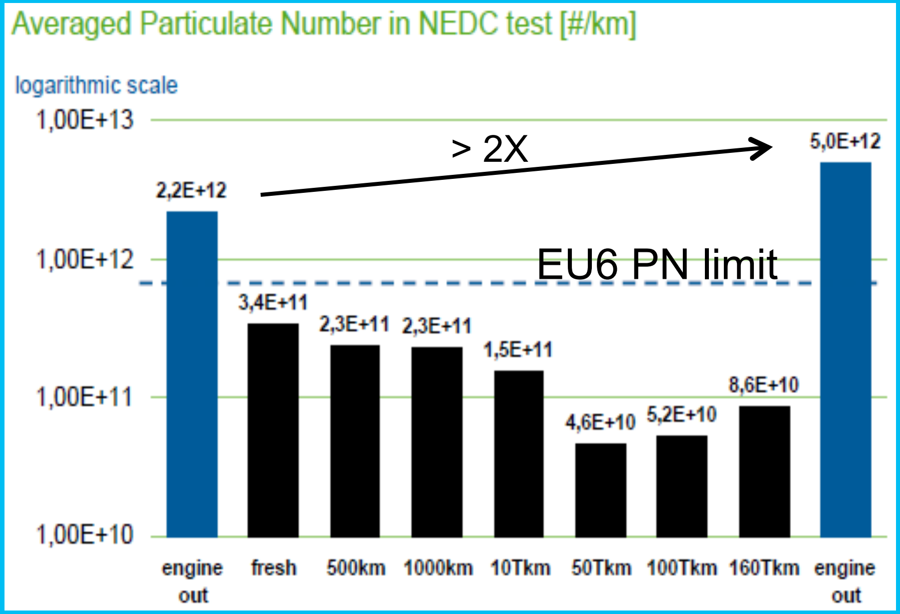
2.0 L Audi TFSI
CC TWC (stock) + UF TWC GPF

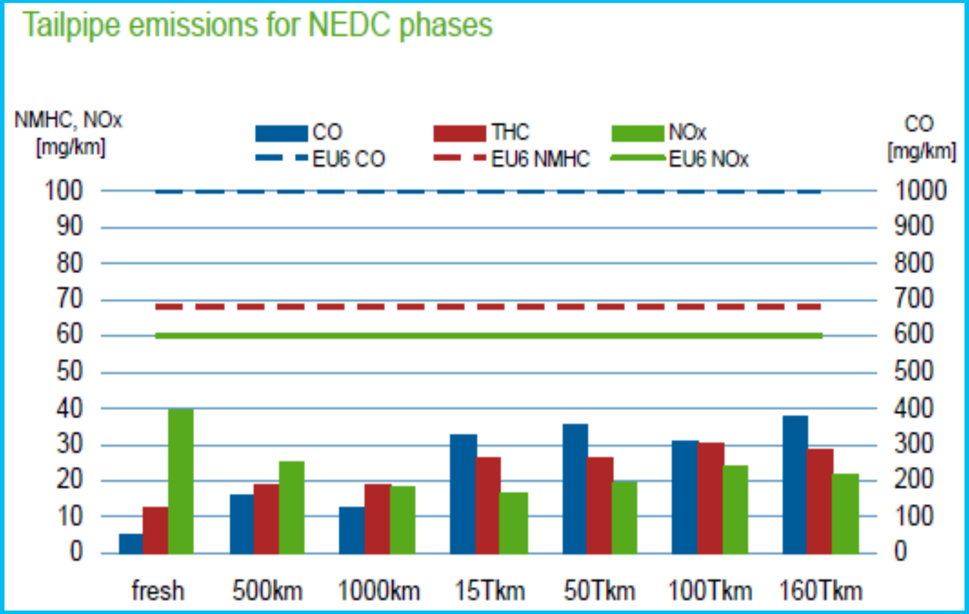
Stock Catalyst
CC: TWC 1.24L 80g/ft³

<u>Test Converter Layout</u>

CC TWC + UF converter

CC: TWC	1.24L	64g/ft³
UF: GPF	1.68L	10g/ft³

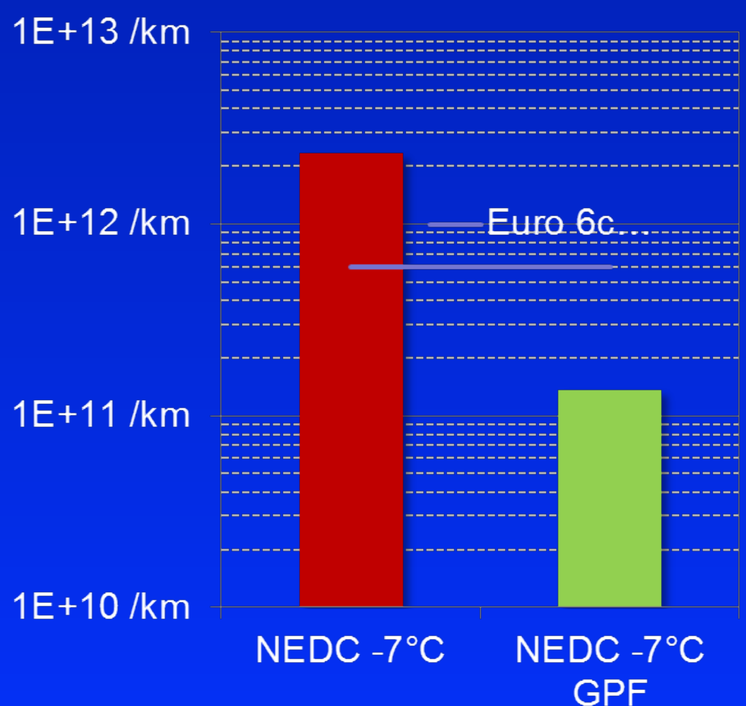


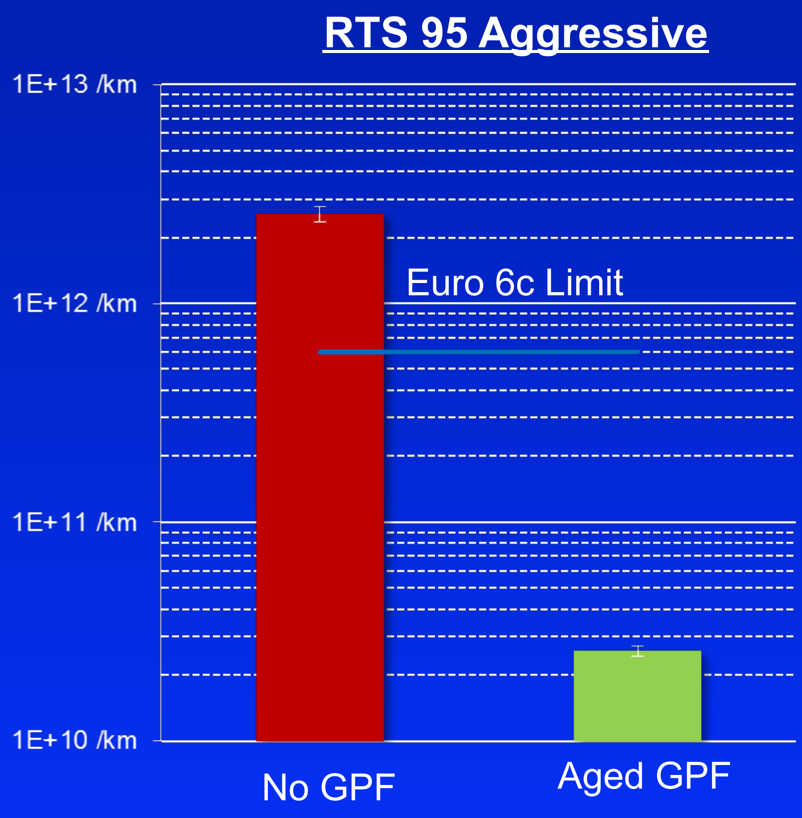


CAPoC9, August 2012

Gasoline Particulate Filters Commercialized in Europe

- Mercedes S500 is first GPF introduction
- Durability has been demonstrated
- Benefits in off-cycle driving

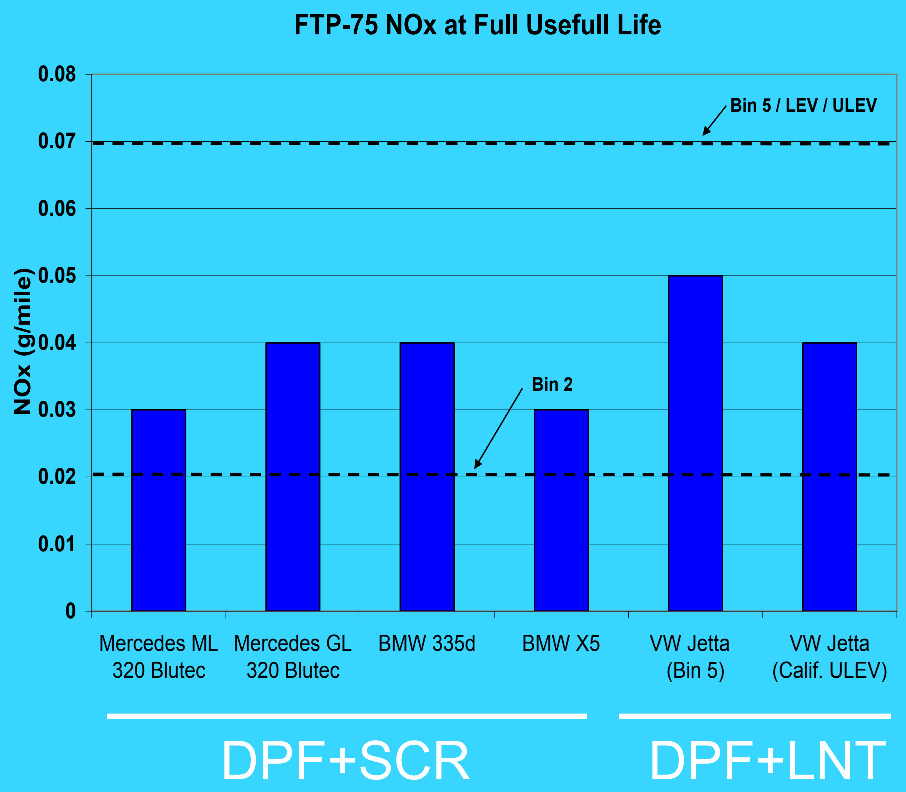


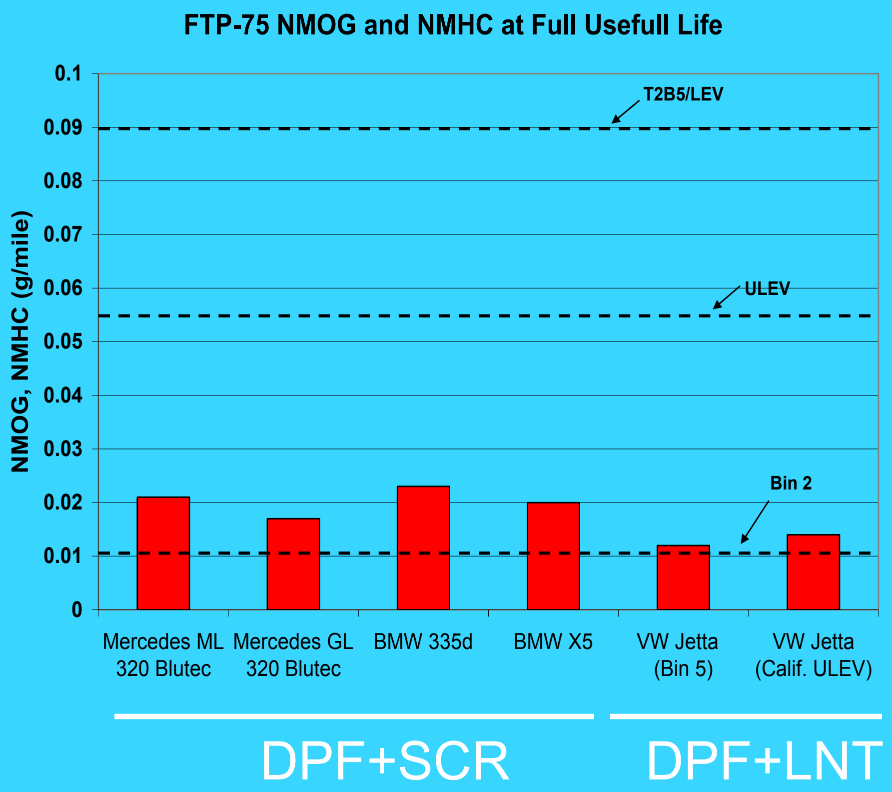


2014 Aachen Colloquium

Light-duty Diesel Emisson Control Technologies

First Wave LEV II/Tier 2 Light-Duty Clean Diesels FTP Emissions: 30 to 50 mg/mi NOx; 12 to 23 mg/mi NMHC





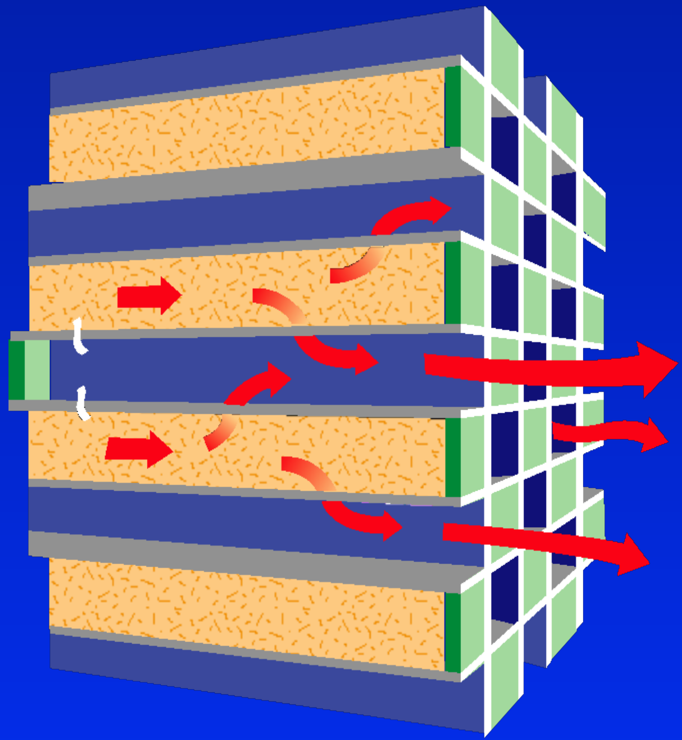
Current best in class: 50 mg/mi NMHC+NOx
(compare to 30 mg/mi NMHC+NOx for Bin 2 or SULEV)

CARB certification data

MECA

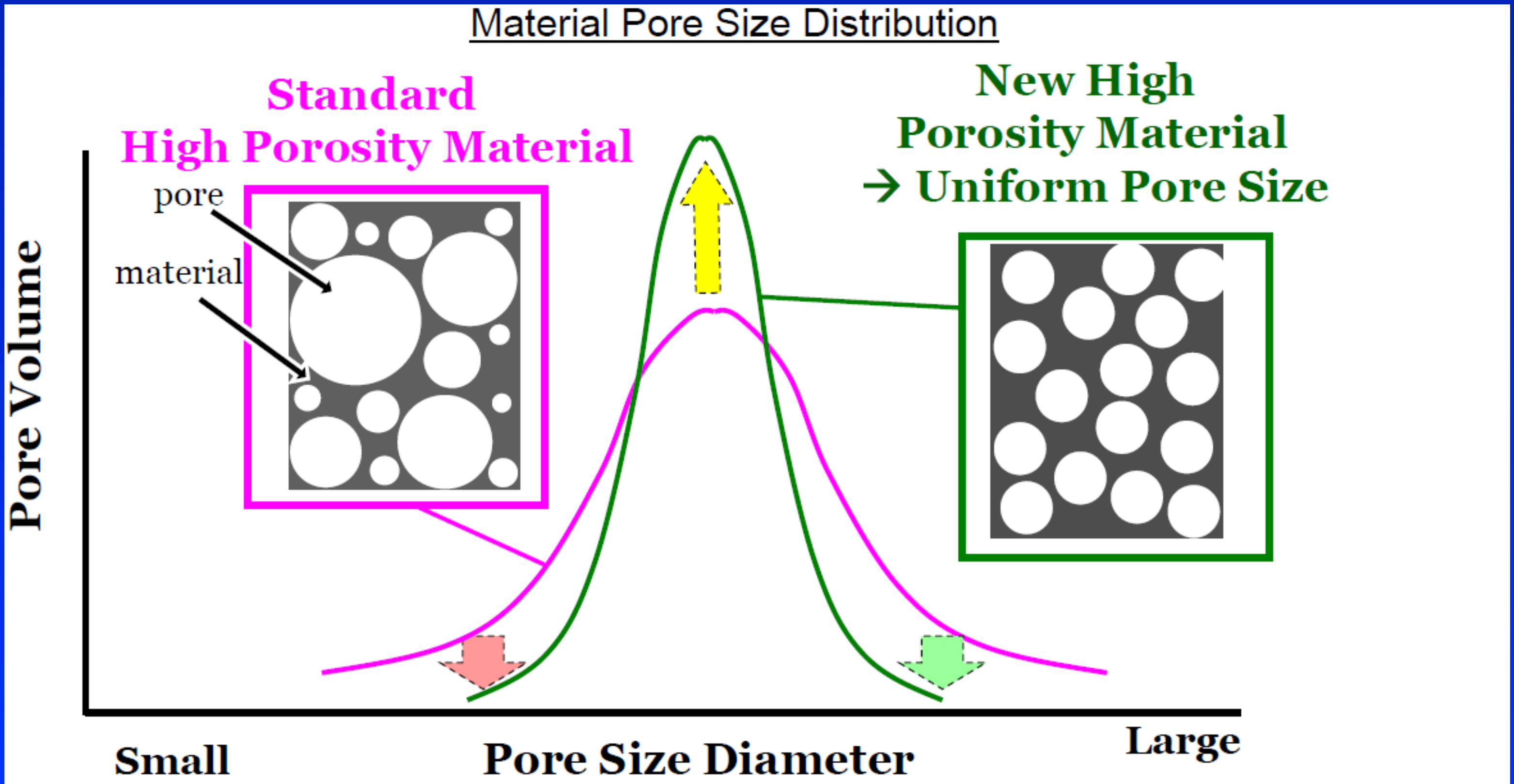
Diesel Particulate Filters (DPFs) Provide High PM/PN Removal Efficiency

- Wall flow ceramic filter element with high capture efficiency for particulates over a broad size range (cordierite or SiC filter elements)
- Captured soot needs to be burned off (regenerated) to manage backpressure on engine
- Commercialized on light-duty diesels in Europe in 2000, on US LDD starting in 2006; standard on US 2007+ trucks/buses, on 2013+ Euro VI trucks/buses – 10s of millions in-use worldwide
- Capture ultrafines and inorganic-based particles associated with engine wear, lubricant consumption: regular maintenance required (filter cleaning)



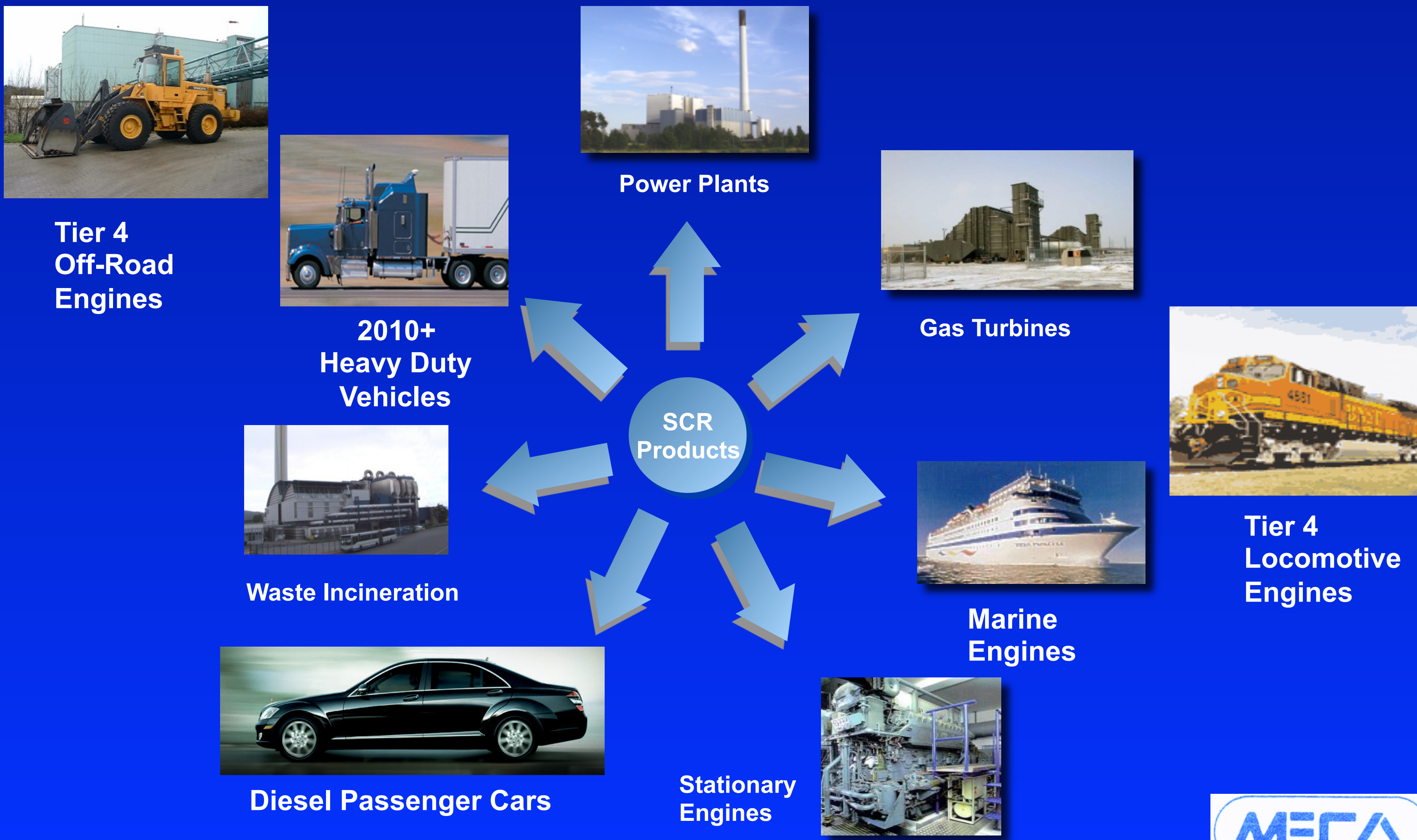
DPF Optimization Focused on Backpressure and Cold Start

- DPF designs with higher porosity, smaller, uniform sized pores
- Reduces backpressure
- Facilitates SCR catalyst coating on DPF
- Earlier ammonia injection and light-off

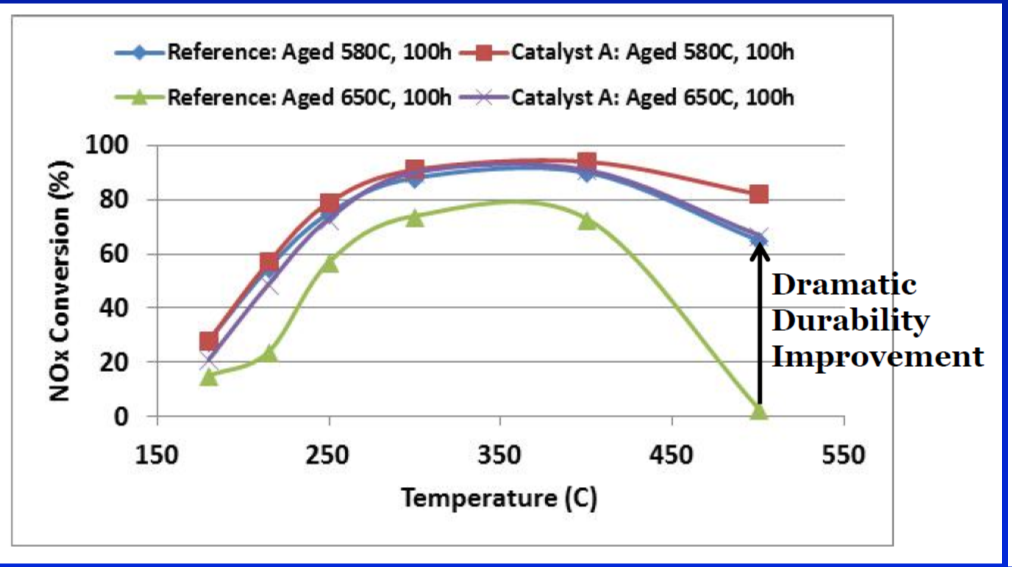


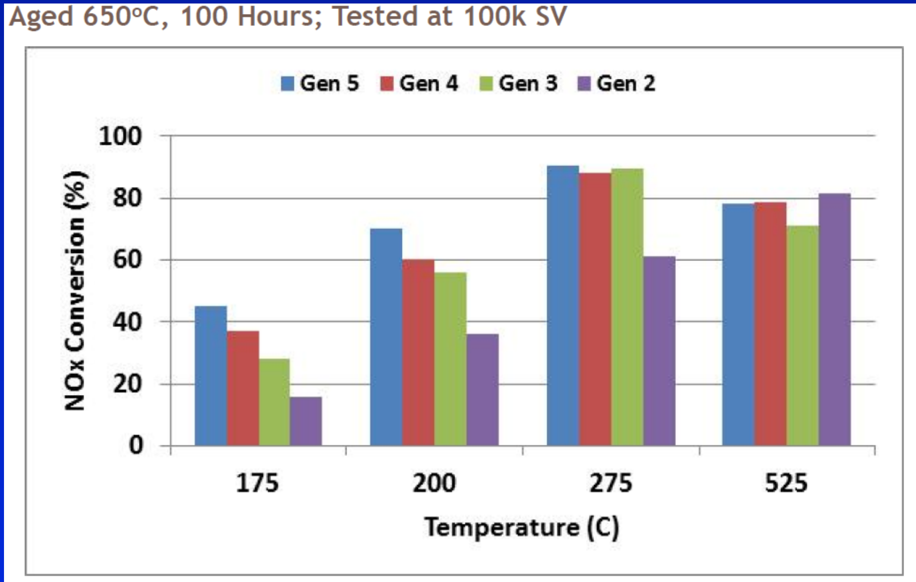
Source: SAE2012-01-0843, Kawakami, NGK

SCR Applications Moving from Stationary to Mobile Sources: Urea Infrastructure Expanding



SCR Catalysts Continue to Improve

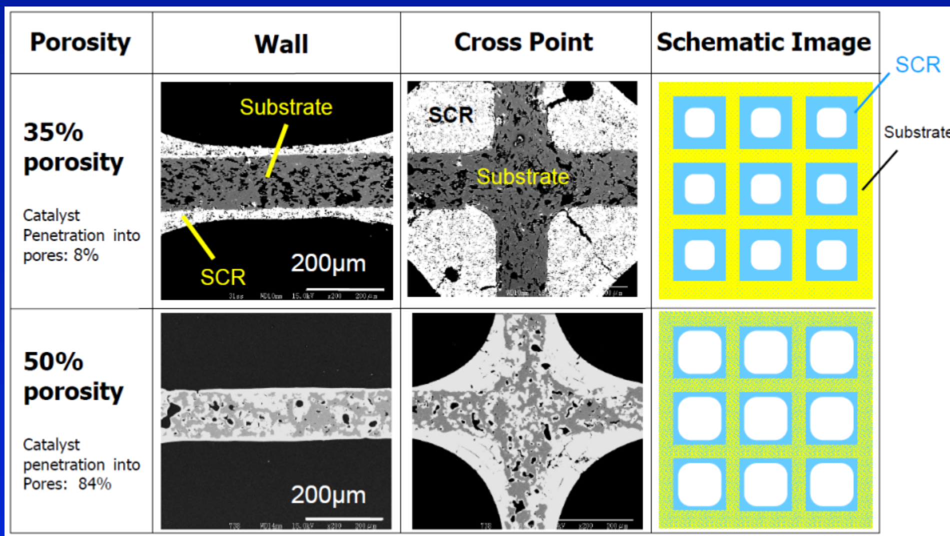




V-SCR with Excellent Durability

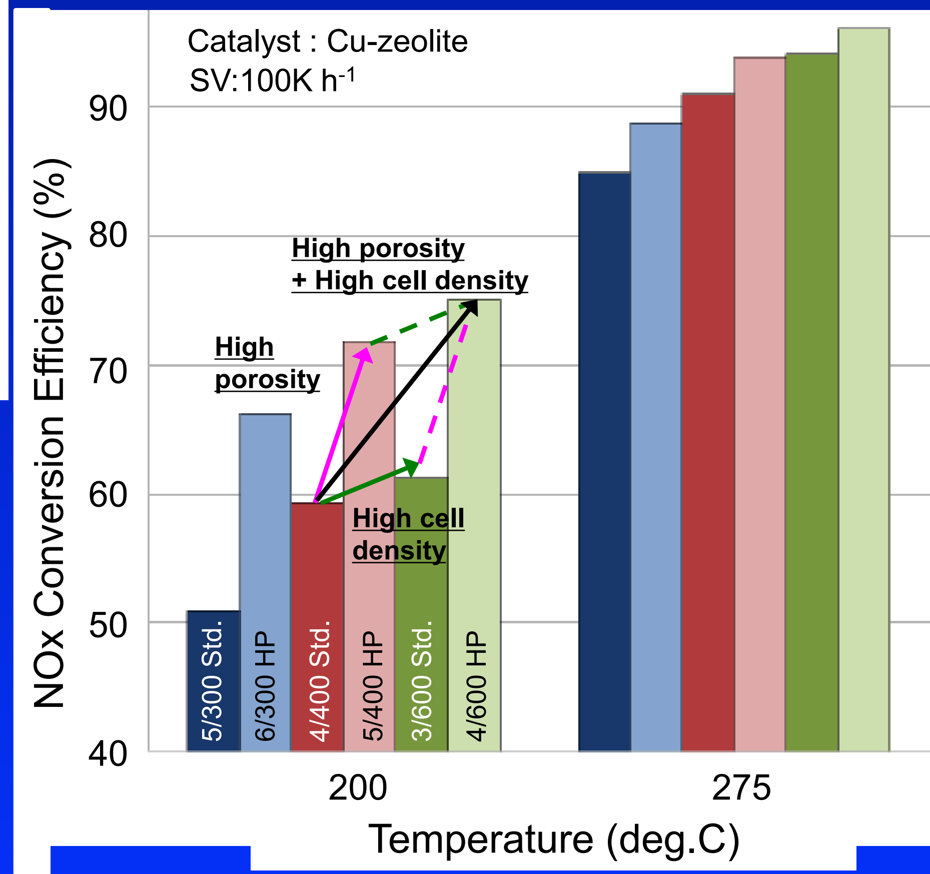
Cu-SCR Demonstrate Better Low Temperature Conversion

Substrates Optimized for Catalyst Loading, Backpressure and Thermal Mass



CTI 2012 NOx Reduction

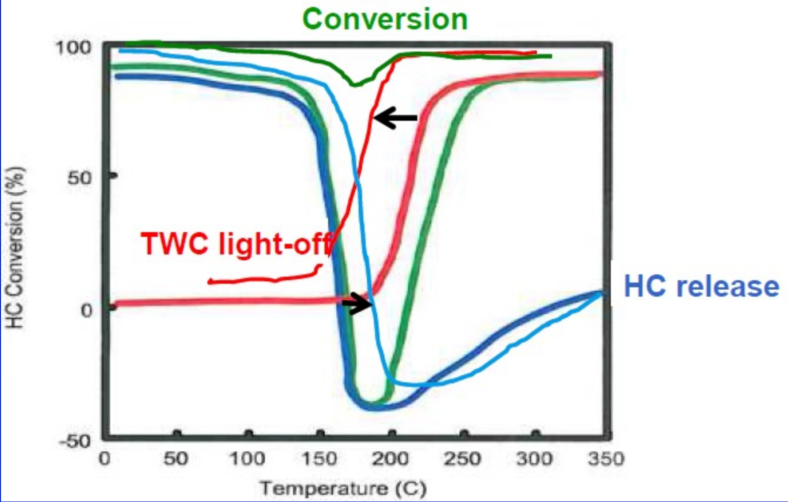
- High porosity incorporates catalyst into cell wall
- Lower backpressure for efficiency
- High cell density, thin wall designs improve conversion
- Fast heat-up and earlier urea injection
- Higher conversion or reduced catalyst volume



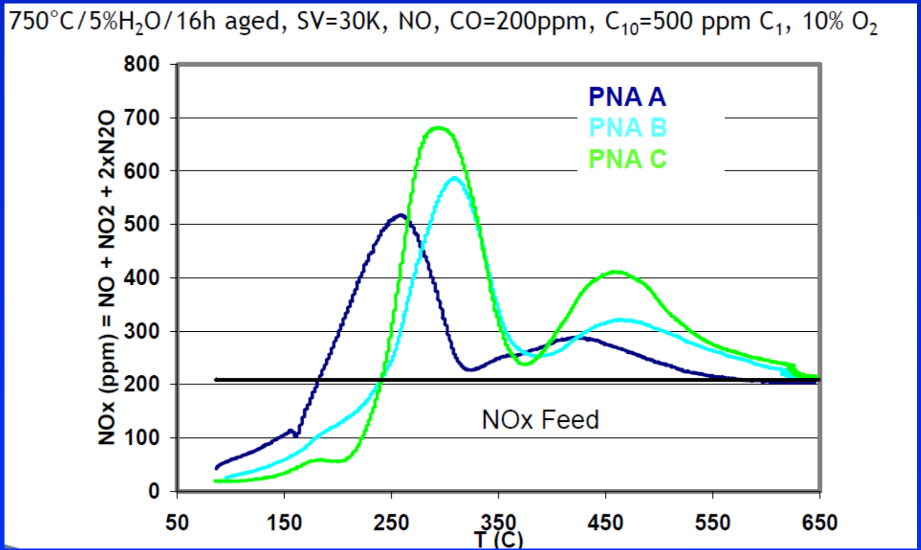
SAE 2014-01-1528

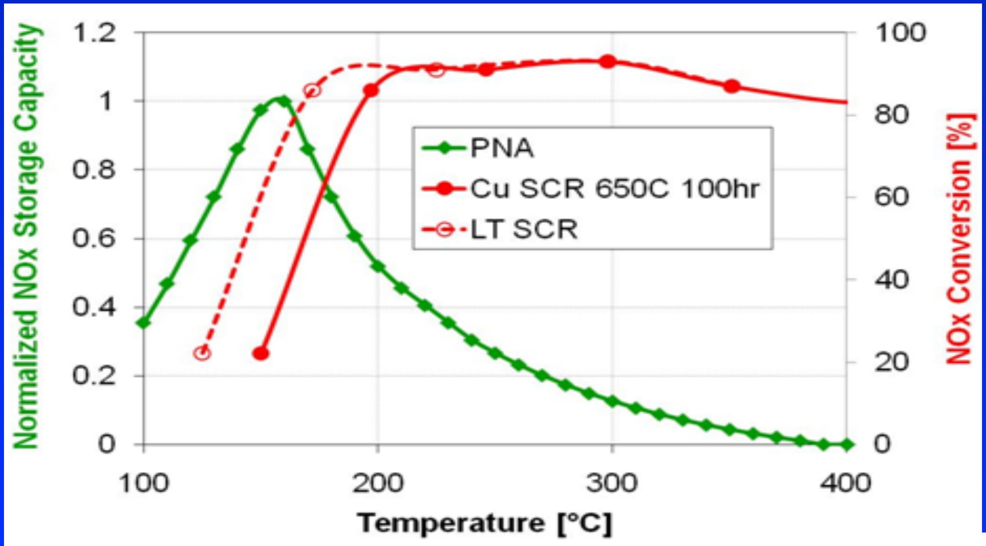
Multifunction Low Temperature Catalysts

- PNA combines trapping with low temperature conversion
- HC trap + TWC
- NOx trap + DOC
- Desorption after catalyst becomes active.



SAE 2014-01-1509

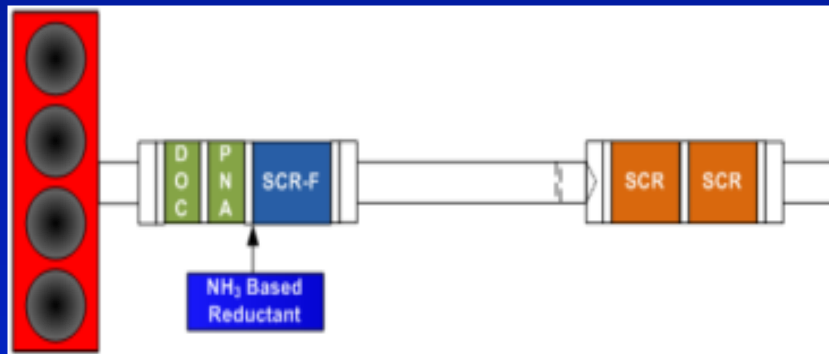




JM SAE HDD Symp. 9/12

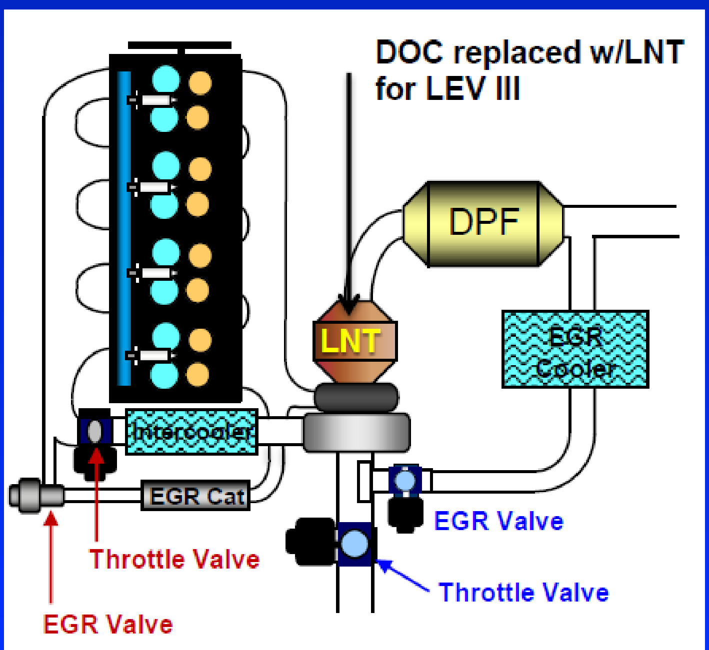
Cummins, DEER Conf. 10/11

Advanced Emission System Integration Reaching SULEV NOx Levels

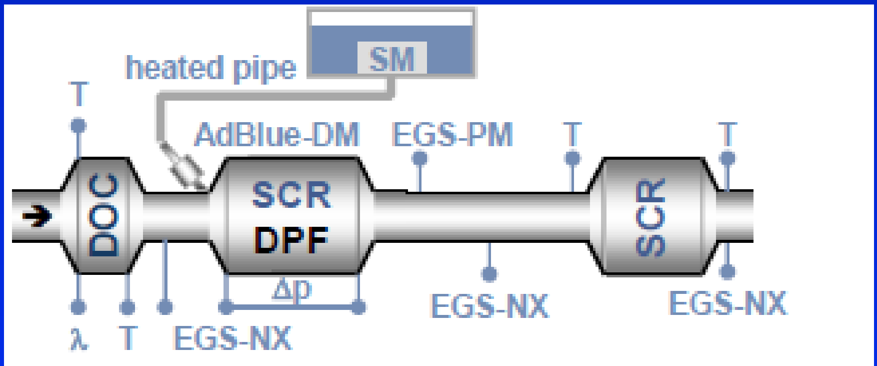


Cummins DEER 10-2012

Solid NH_3



SAE 2014-01-1552



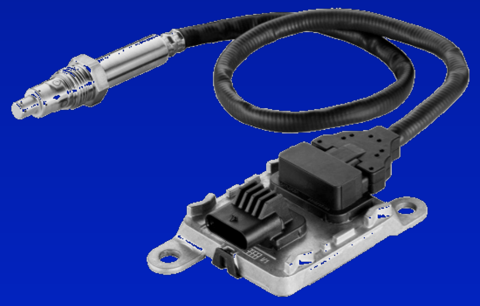
SCR-on-DPF + SCR

SCR-on-DPF → covers cold start

SCR → covers high load / temperature

Bosch SAE 2014 Congress

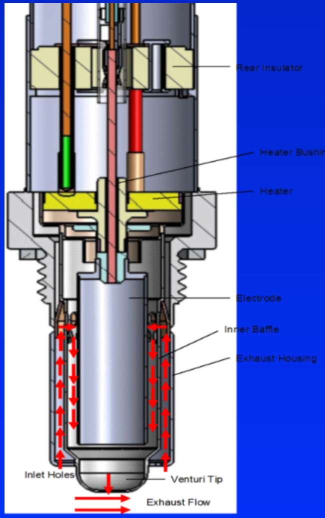
Clean Diesel Vehicles Include Sophisticated Sensors and Diagnostics



SMART NOx Sensor

Ammonia Sensor

Soot Sensors in Development



Urea Quality Sensor

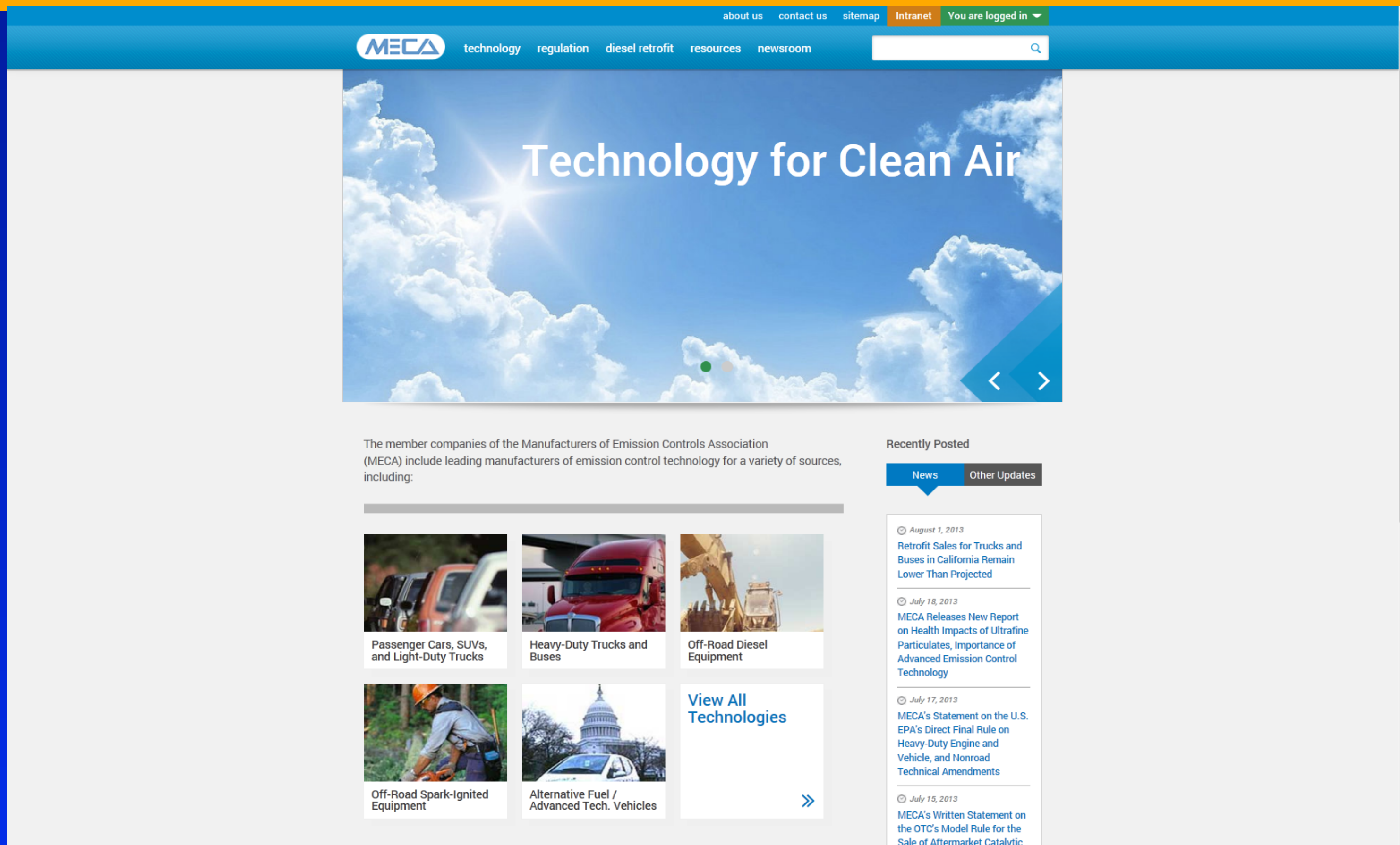
Rapid Response Temperature Sensors

MECA

Summary

- Health impacts of ozone, PM and climate change will continue to drive regulatory groups to revisit the need to achieve even more emission reductions from mobile sources
- U.S. light-duty emission standards are the world's benchmark – drive emission control technology innovation
- Developing world quickly moving to catch-up on clean vehicle technologies but introduction of clean fuels will dictate the pace of change
- Future powertrains will need to compete on both emissions and climate change performance

www.meca.org – *Newly redesigned*
Your emission control technology resources on the web

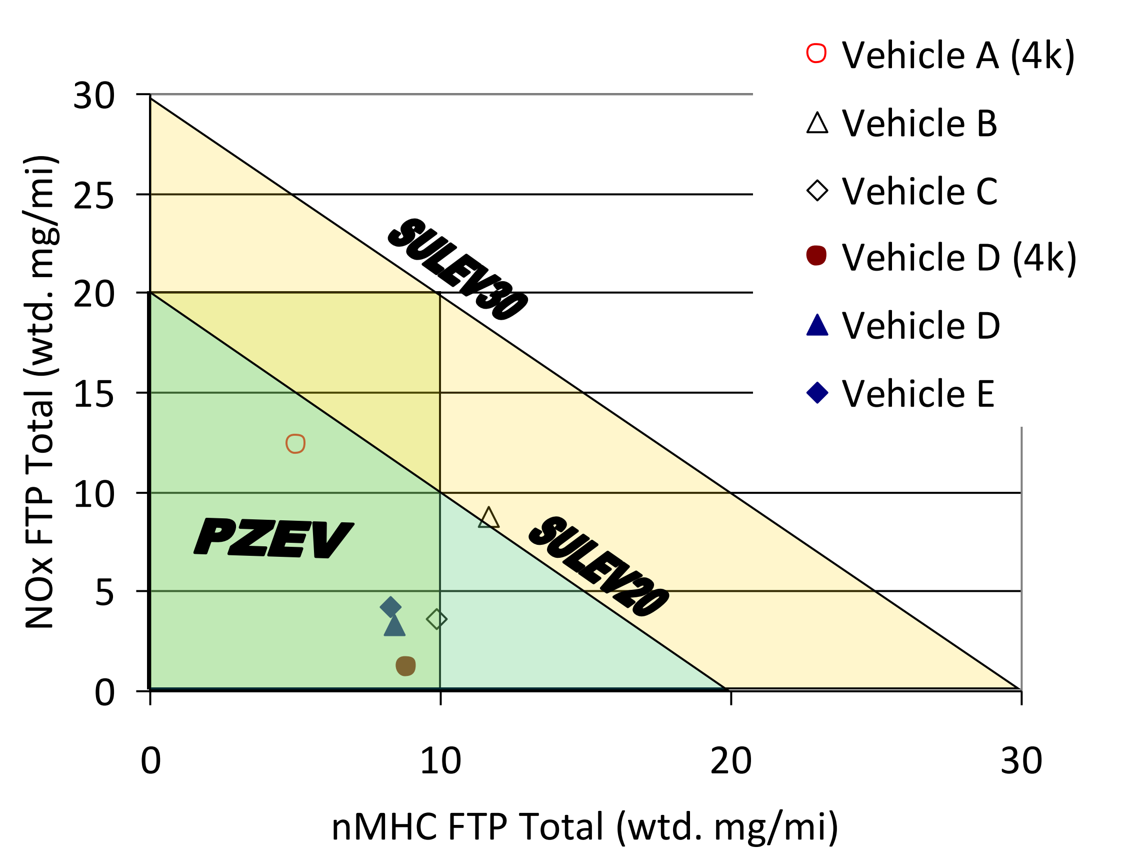


- Emission control technology white papers and fact sheets
- Public testimony
- Regulatory information
- Retrofit technology descriptions
- Contacts for retrofit suppliers
- Case study reports

Back-up Slides

Combined NMOG+NOx Standard Provides Additional Flexibility

- PZEV Vehicle Evaluations
  - 4/5 vehicles struggle with the 10 mg NMOG standard
  - Vehicle A(4K) is most comfortable
- SULEV20
  - 3 of the 5 vehicles get relief from the 10 mg NMOG standard
- SULEV30
  - No problem with current 4 cylinder PZEV vehicles
  - Opportunities to thrift catalysts



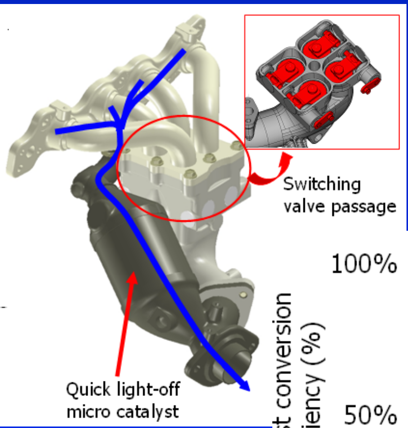
Ref. : SAE 2012-01-1245

1/10 SULEV Achieved on Gasoline Vehicle with Advanced Engine and Emission Controls

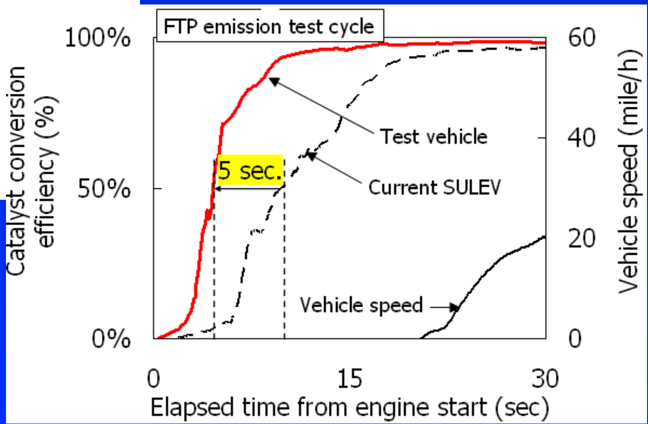
	Outline of the Measures
(1) Reduction of Engine-out Emissions	· Keep lean A/F at engine startup · Promote in-cylinder oxidation
(2) High Exhaust Gas Temperature	· Retarded ignition combustion at engine startup
(3) Quick Light-off Close-coupled Catalyst	· Minimize the heat loss of exhaust gas · Suppression of thermal degradation
(4) High Conversion Efficiency Underfloor Catalyst	· Control the temperature of underfloor catalysts

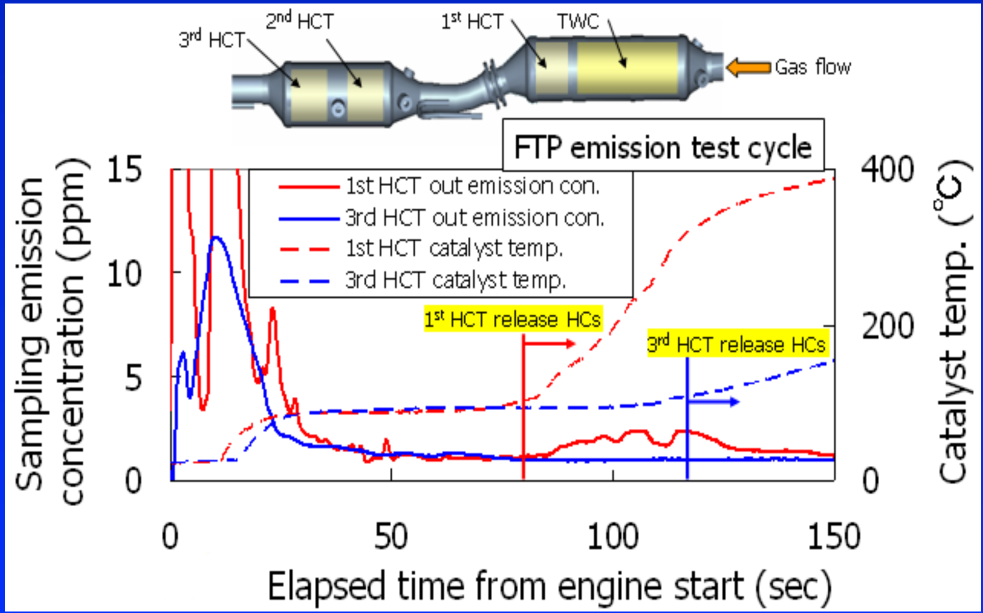
(With aged catalysts)

	NMOG (g / mile)	CO (g / mile)	NOx (g / mile)
SULEV standard	0.010	1.0	0.02
Attained value	0.00038	0.00727	0.00152



Exhaust manifold by-pass quick catalyst lights-off 5 sec sooner

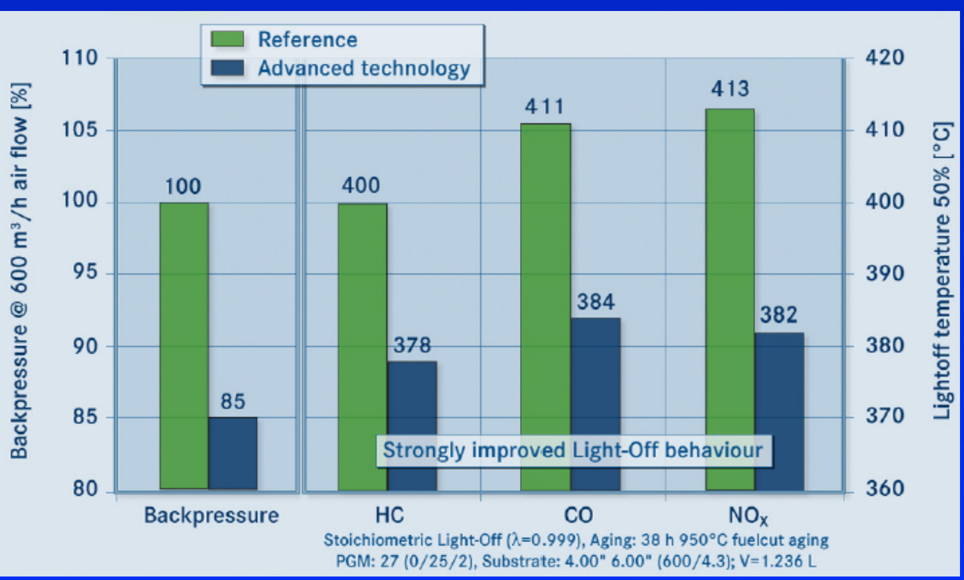


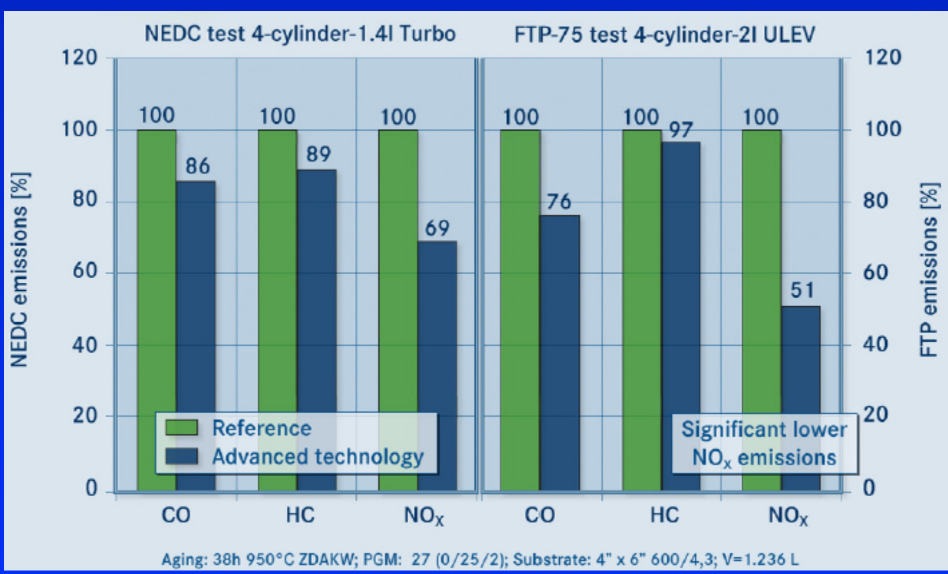


Source: SAE 2009-01-1076

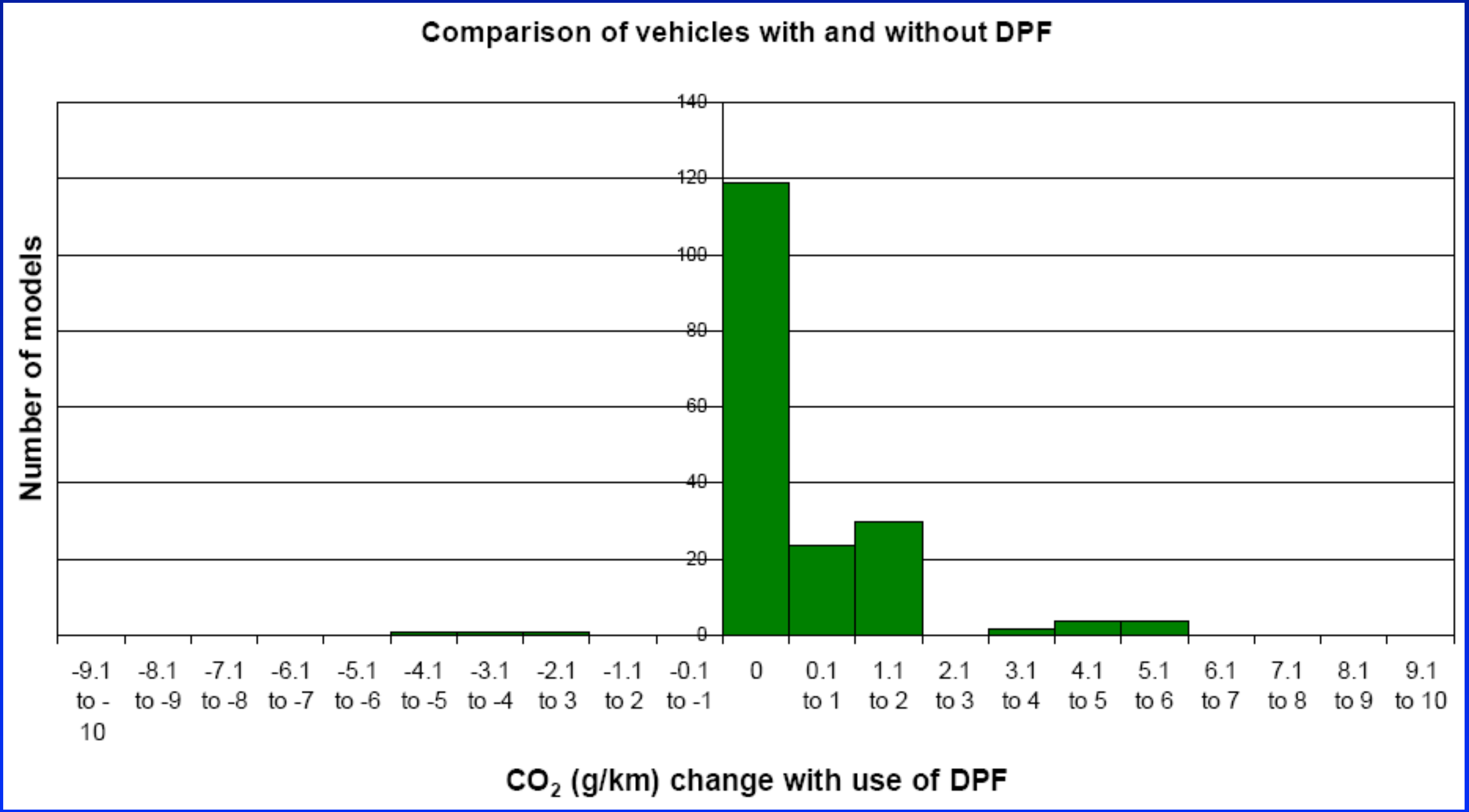
HEV and PHEV Vehicles Require Unique Catalyst Systems

- Emission peaks during engine restart
- Cool-down of exhaust system during pure electric drive
- Battery SOC (45-60%) impacts engine operation and temperature
- Catalysts must demonstrate rapid, low temperature light-off and low back-pressure.



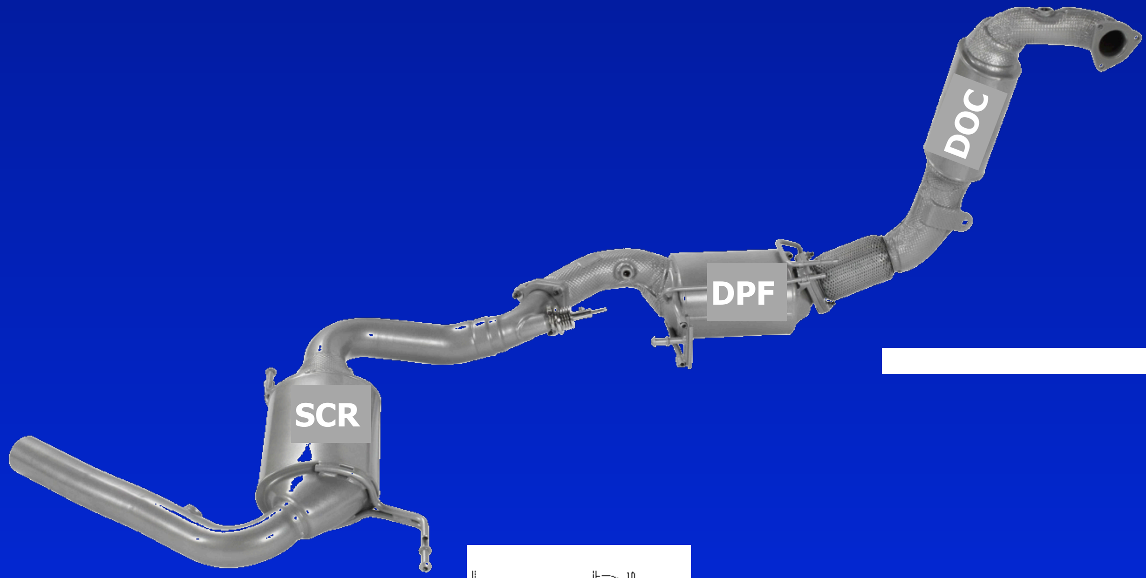


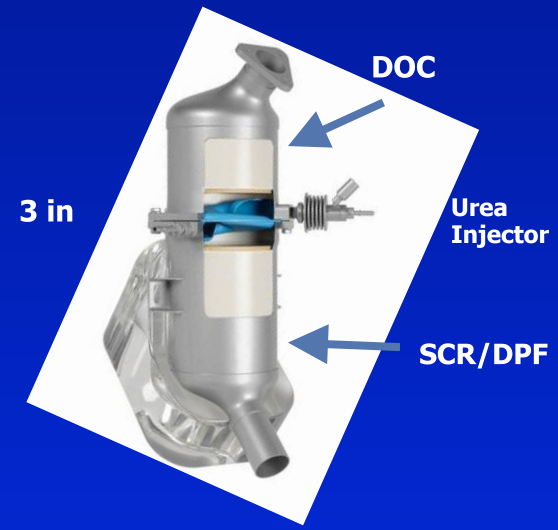
DPFs Generally Have Small Impact on Fuel Consumption (0.6% ave. increase in CO_2 for 184 recent Euro models available with or without DPF)

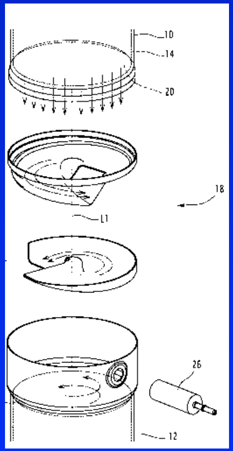


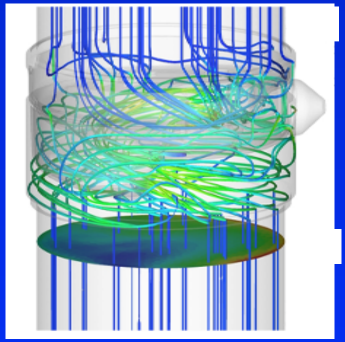
Reference: AECC analysis of 2007 model European vehicles

Advanced Diesel Systems Packaging Reduce Cold-Start Emissions





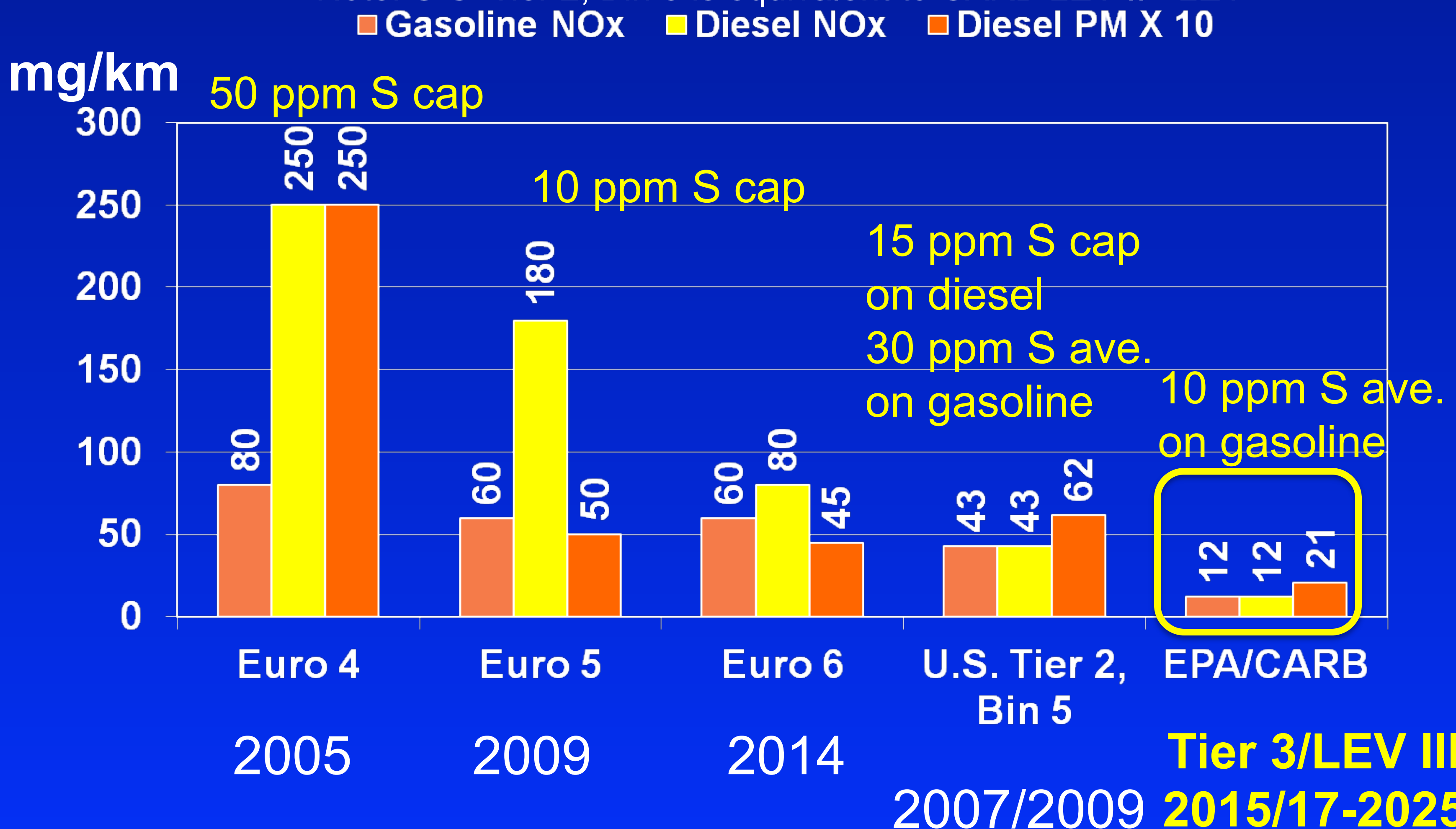




SAE Paper No. 2011-01-1318

U.S. vs. Euro Light-Duty Vehicle Emission Standards

Note: U.S. Tier 2, Bin 5 is equivalent to CARB LEV II - LEV



Euro 5+ (2011) and 6 include 6 X 10^{11}/km diesel particle number limit; Euro 6c includes PN limit for GDI