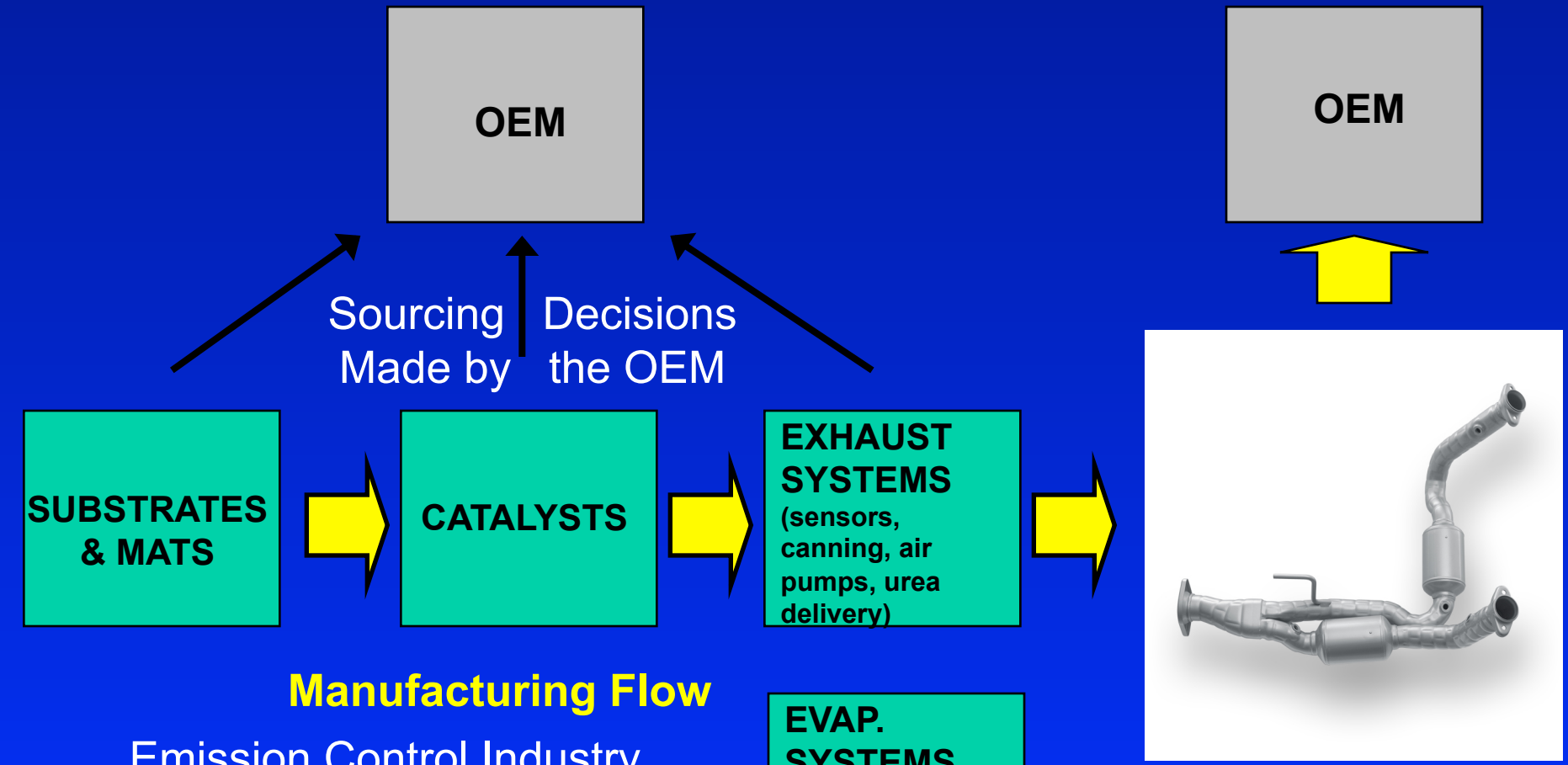
Light-Duty Vehicle Emission Control Technologies

Mexico City Workshop
July 2014

Dr. Joe Kubsh
Manufacturers of Emission Controls Association
www.meca.org

MECA - Industry Technology Voice with ARB, EPA, Environment Canada other Stakeholders; 41 Member Companies Cover Major OEM & Aftermarket Emission Control Manufacturers



Manufacturing Flow

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

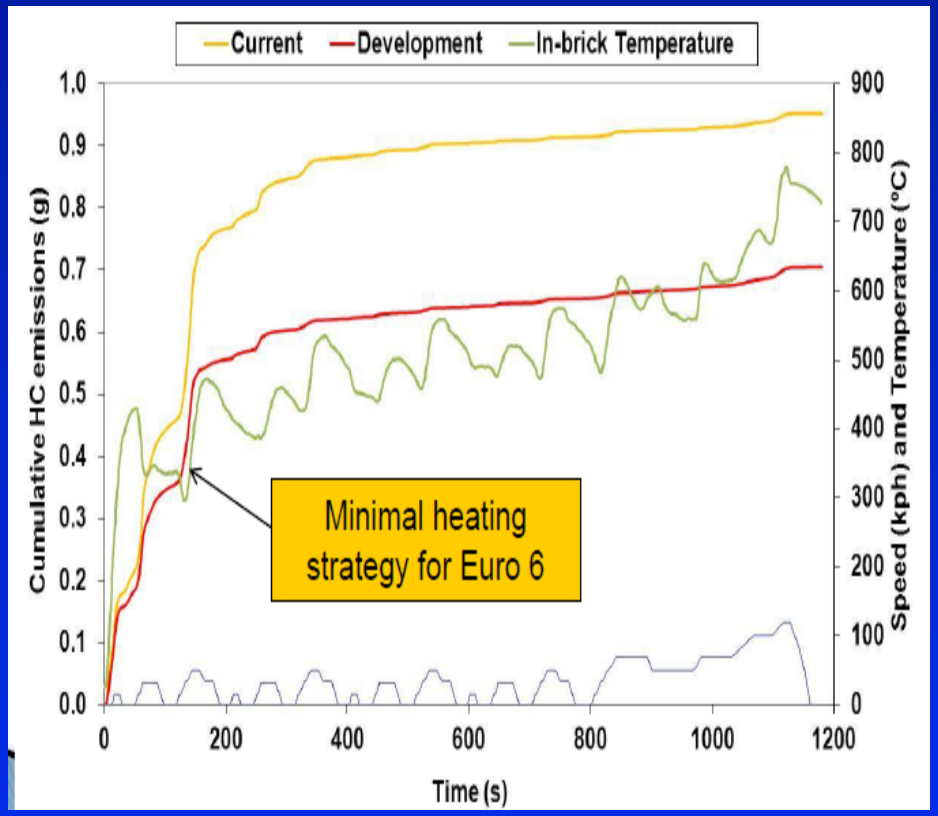
Light-duty Vehicle Emission Control Technologies

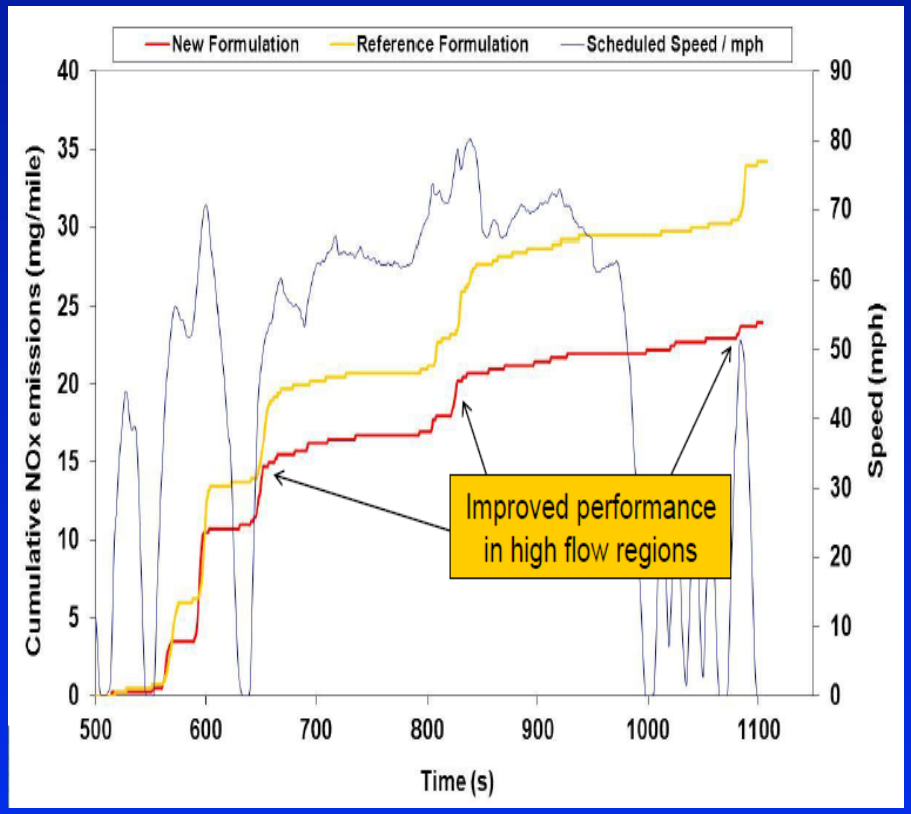
- Gasoline Vehicle Technologies for Tier 2/Tier 3 & LEV II/LEV III
- Light-duty Diesel Emission Control Technologies

Mobile Source Emissions Regulations Drive Technology Innovation

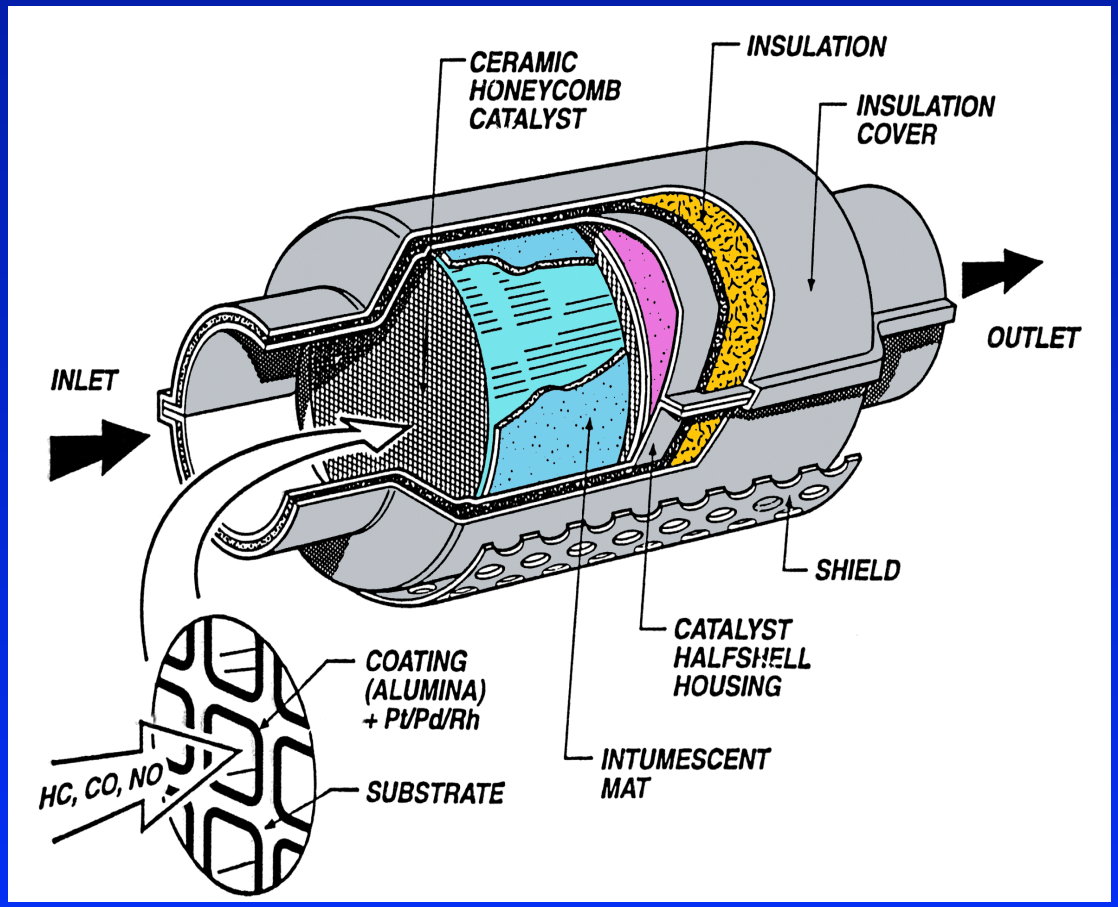
- Light-duty: U.S. Tier 2/LEV II moving to Tier 3/LEV III
  - Near Zero gasoline exhaust emissions: advanced TWCs, HC adsorber cats, high cell density substrates, direct ozone reduction catalysts
  - Near Zero gasoline evap. emissions: advanced carbon canisters, low permeation materials, air intake adsorbents
  - Near Zero diesel exhaust emissions: EGR, DPFs, lean NOx catalysts, SCR
- U.S. 2007-2010 Heavy-Duty Highway Diesel
  - DPFs, SCR, EGR
- U.S. Tier 4 Off-Road Diesel
  - DPFs, SCR, EGR

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



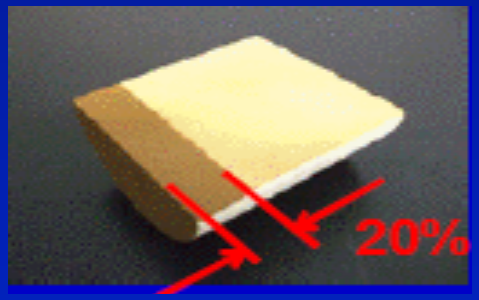


The Three-way Catalytic Converter: A Familiar Technology Re-Engineered for High Performance

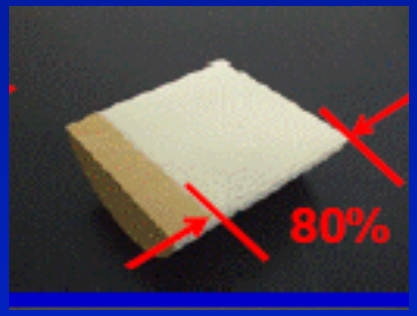


- Provides high efficiency “three-way (HC, CO, NOx)” performance
- Layered catalytic architectures to maximize noble metal (Pt, Pd, Rh) effectiveness
- Advanced materials with high thermal stability
- High cell density ceramic or metallic substrates

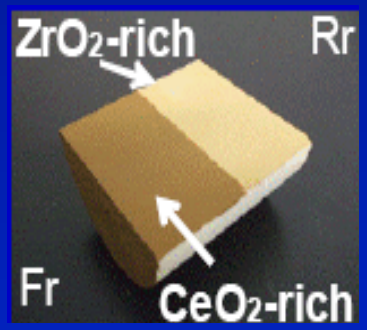
Gasoline Three-way Catalysts Utilize Advanced Design Strategies to Maximize Performance



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



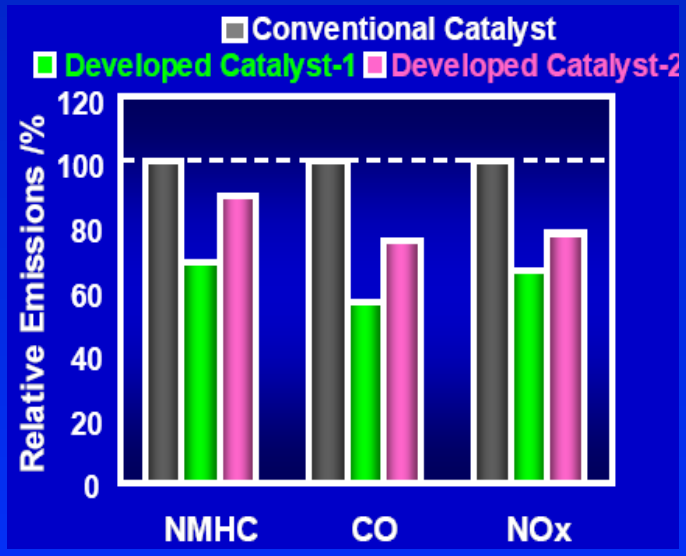
Rh is zoned in the back to protect against catalyst poisons



Zoned OSC to give optimum performance

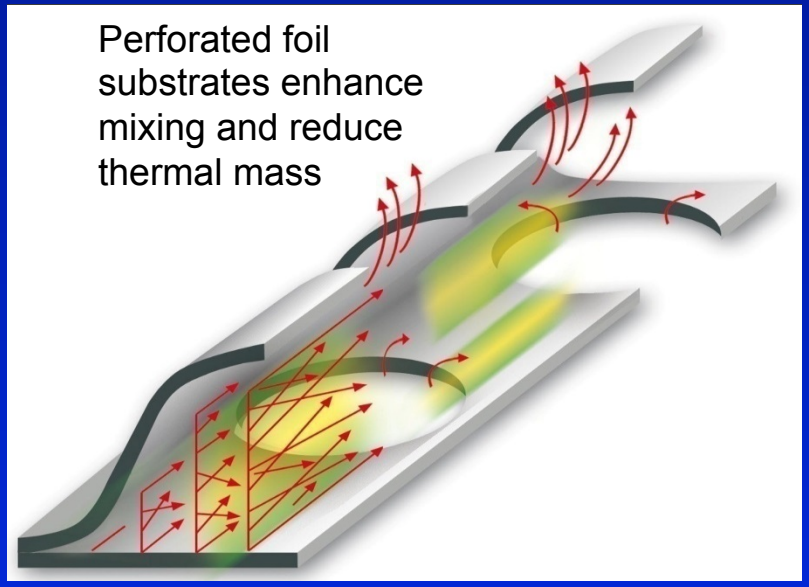
	Conventional	Developed Catalyst	
		1	2
Coat	Double Layer	Zone-Coat	
Noble Metal	Pd/Rh	Pd/Rh	Rh45% reduced

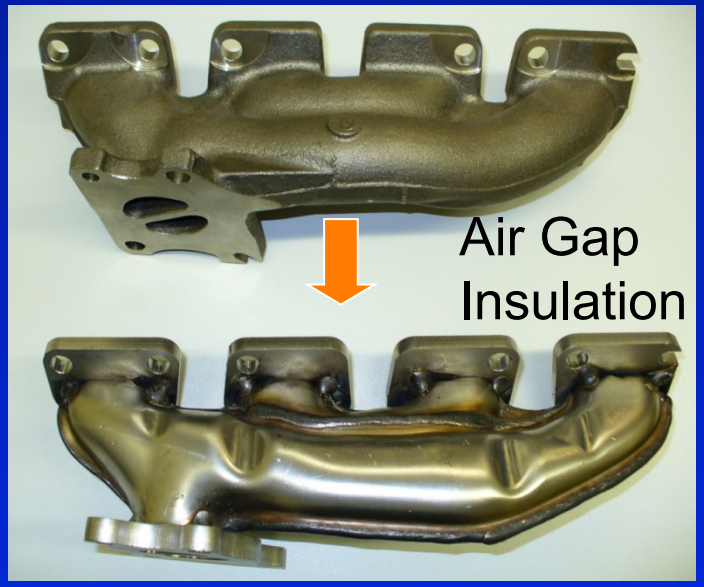
Substrate Volume: 0.9[L]
Aging: Equivalent of 120K miles
Vehicle: '05MY ULEV/CAMRY

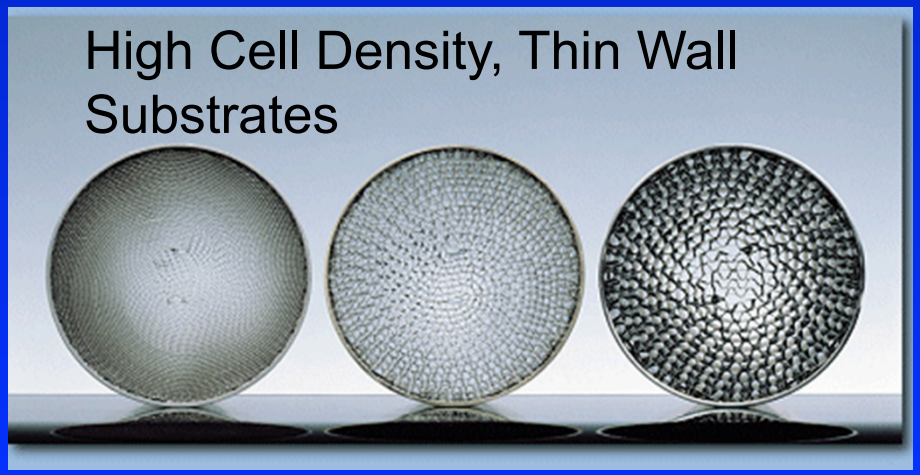


Toyota, SAE 2011-01-0296

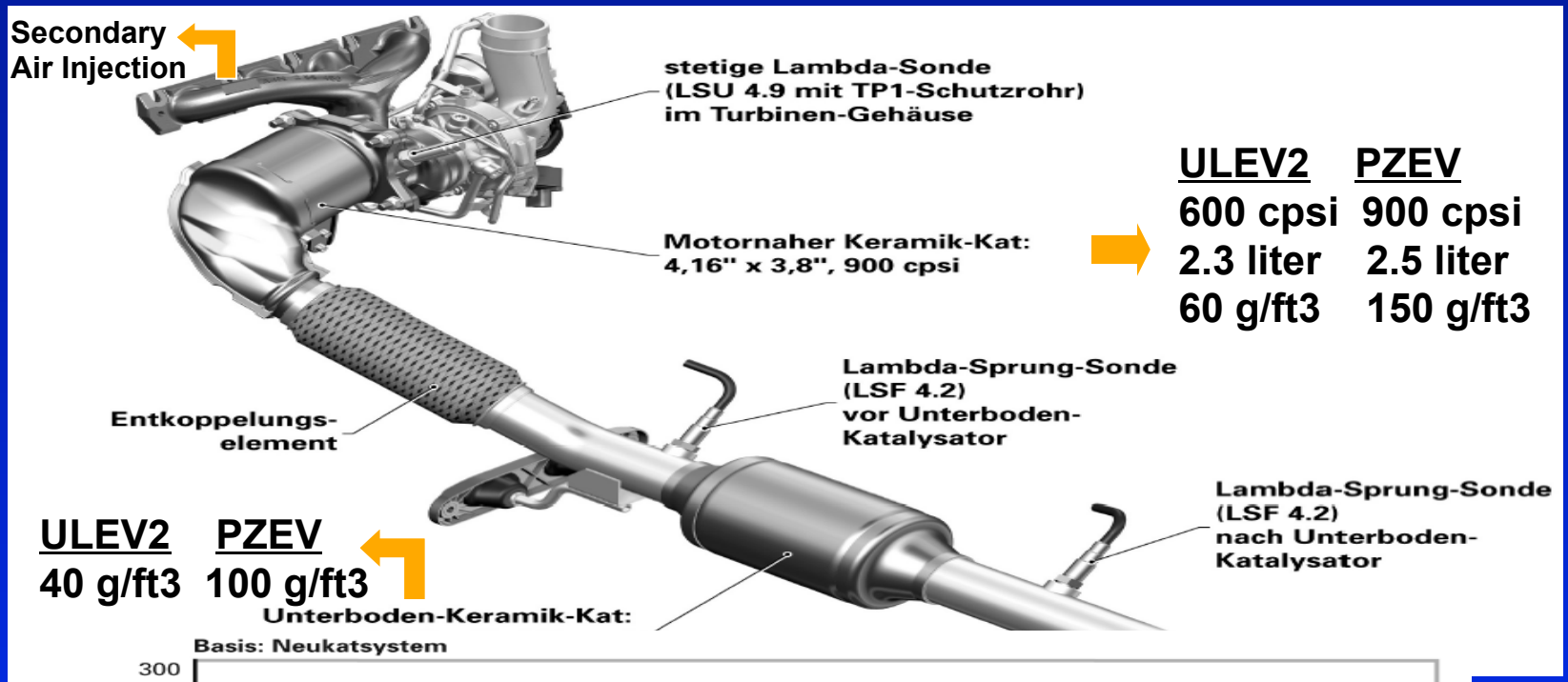
Thermal Management Focused on Cold-Start Emission Reductions





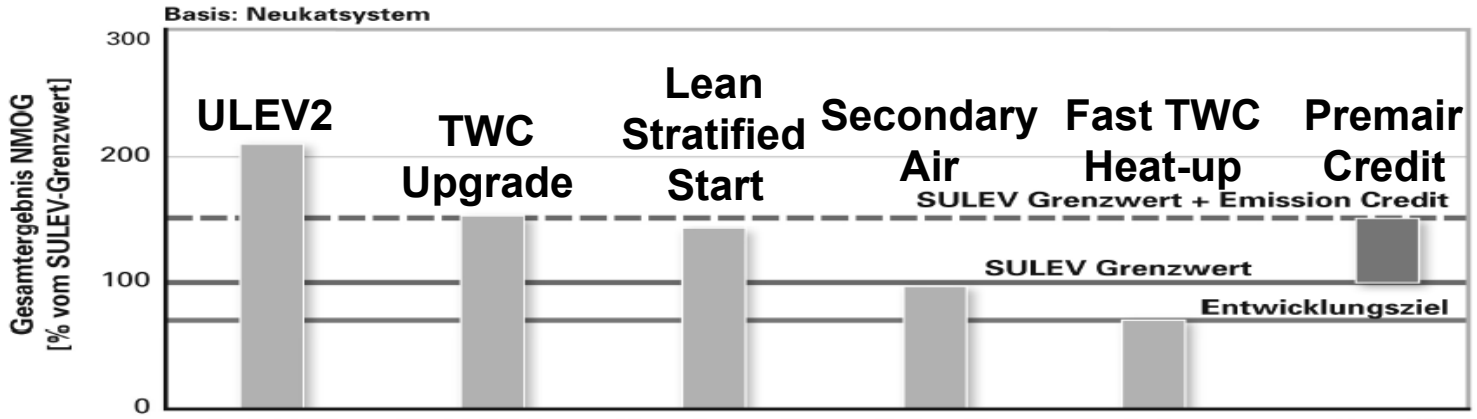


PZEV Experience With Turbo-GDI Application



ULEV2	PZEV
600 cpsi	900 cpsi
2.3 liter	2.5 liter
60 g/ft3	150 g/ft3

ULEV2	PZEV
40 g/ft3	100 g/ft3



Source: 2007 Aachen Colloquium

Variety of PZEV Strategies in the U.S. Market

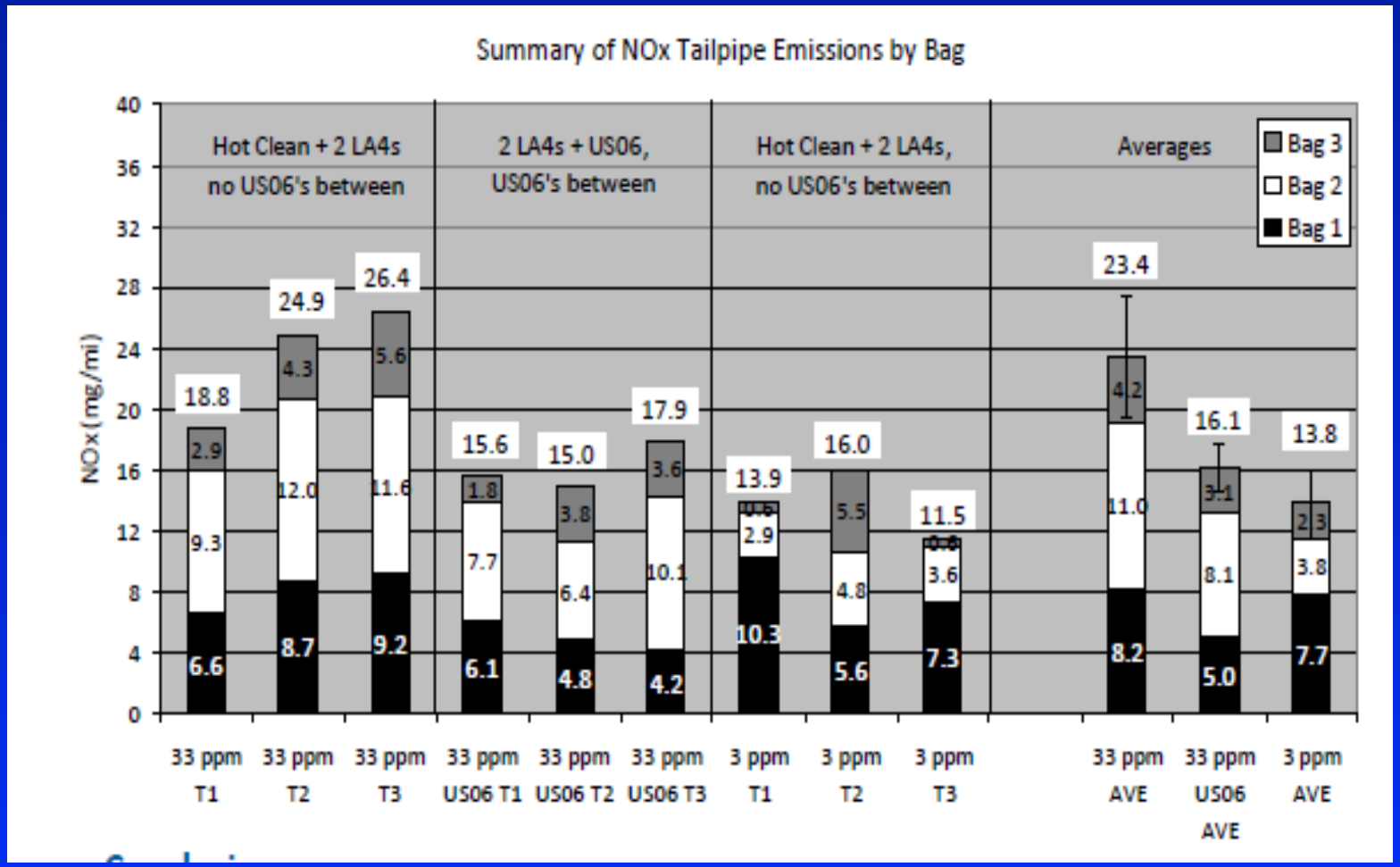
Vehicle	A	B	C	D	E
Engine Displacement	2.0	2.4	2.0	2.4	2.4
PFI or DI	DI	PFI	PFI	DI	PFI
NA or Turbo	Turbo	NA	NA	NA	NA
AIR or non-AIR	AIR	AIR	non-AIR	non-AIR	AIR
Average Ignition Setting (^{o}btc)	-20	0	-7	-12	-5
Engine Speed (rpm)	1150	1200	1500-1700	1200-1500	900-1200
Lambda	1.05 (AIR)	>>1 (AIR)	.95-1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

Gasoline Sulfur Degrades Catalyst Performance: Example Chevy Malibu PZEV Application

2.4 liter, 4 cyl.: CC+UF TWCs
Ref.: SAE 2011-01-0300



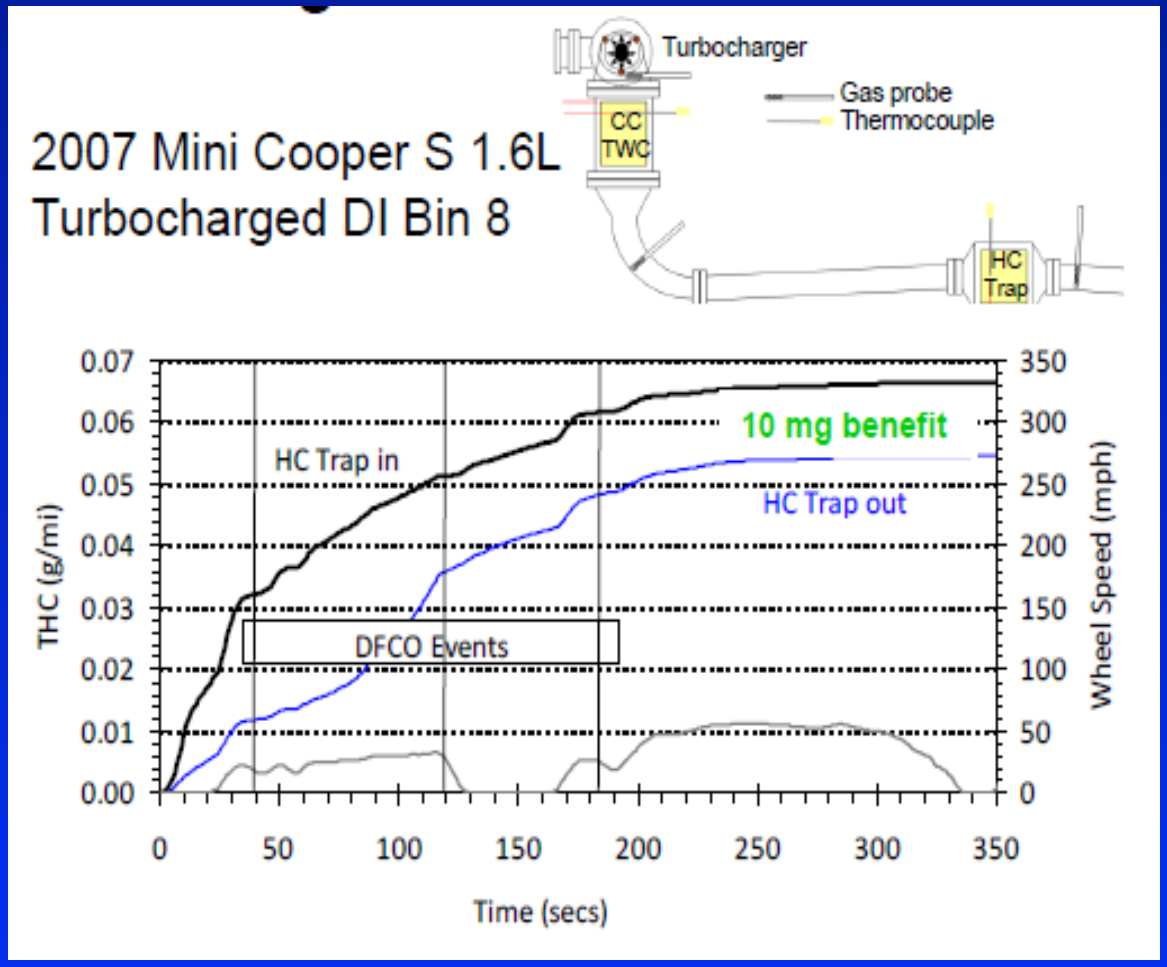
UF never above 600 C with FTP; <u>NOx "creep"</u>

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

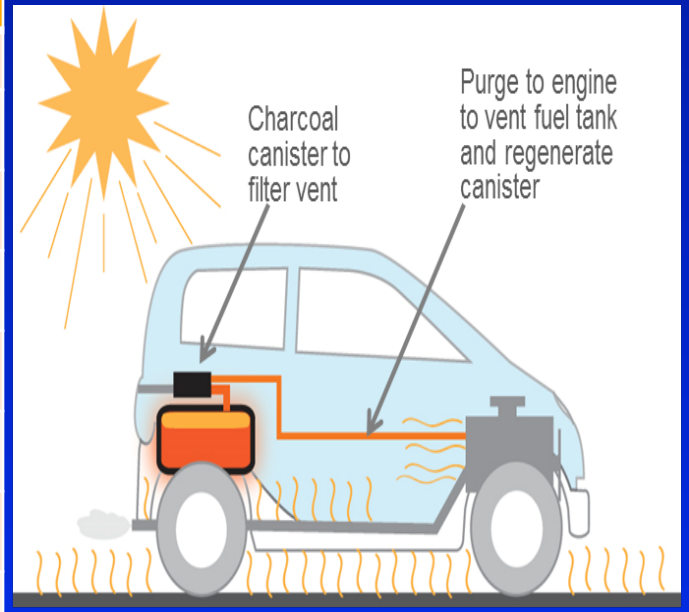
- Limited SULEV/PZEV HC trap applications to date
- Development work continuing with focus on durability/cost
- Example: HC trap PGM loading of only 26 g/ft^3
- Calibration support needed for O_2 during HC desorption – decel. fuel cut-off



Reference: SAE 2013-01-1297

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

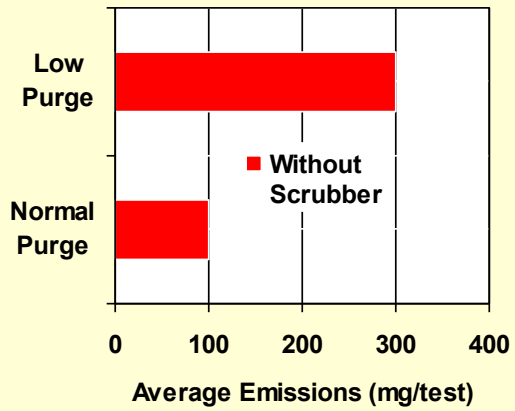
Standard	US ≤ 1995 and Euro Evap. Stds.	US ≥ 1996-2004
ORVR		✓
24-hr Diurnal	✓	
48-hr Diurnal		✓
72-hr Diurnal		✓
Evap Standard = 2 g/day	✓	
Evap Standard < 0.5-1.2 g/day		✓
Hot Soak	✓	✓
Running Loss		✓
In-use standards and monitoring		✓
OBD		✓



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

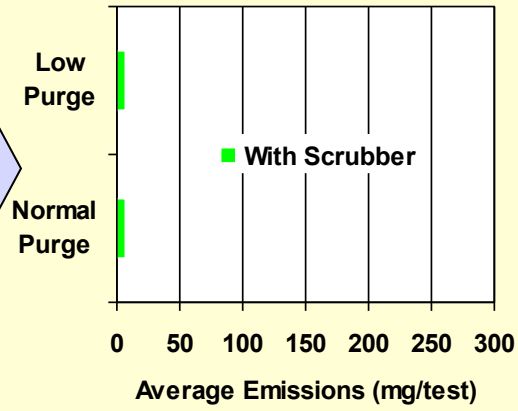
CANISTER EMISSIONS



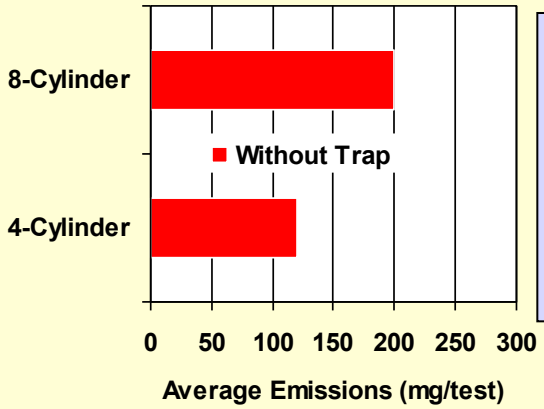
Addition of Canister Scrubbers

- Honeycombs
- Low Bleed Carbon

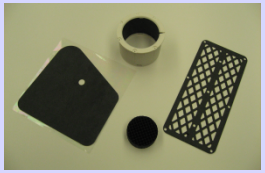
Reduction of 95-295 mg/test



AIS EMISSIONS

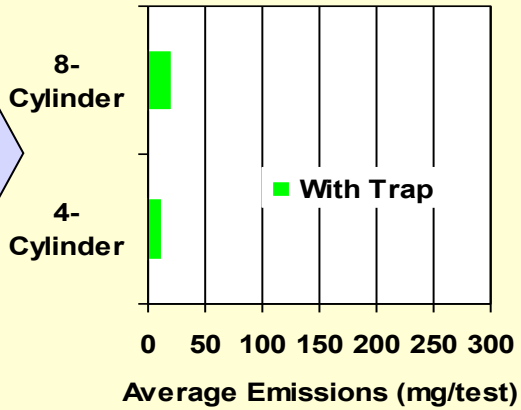


Addition of AIS Traps



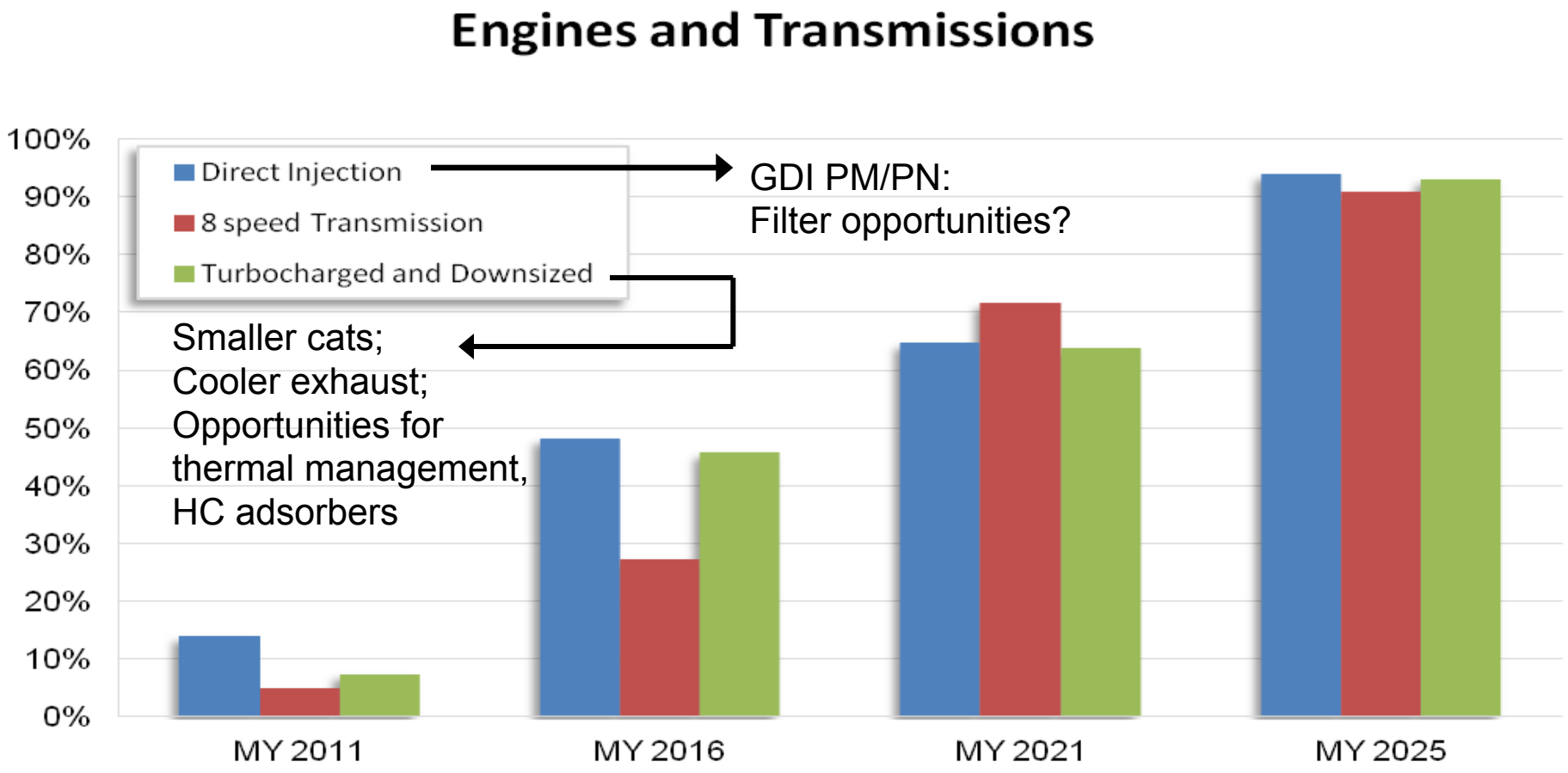
- Honeycombs
- Carbon Sheet
- Low dP Elements
- Carbon Cylinders

Reduction of 100-200 mg/test



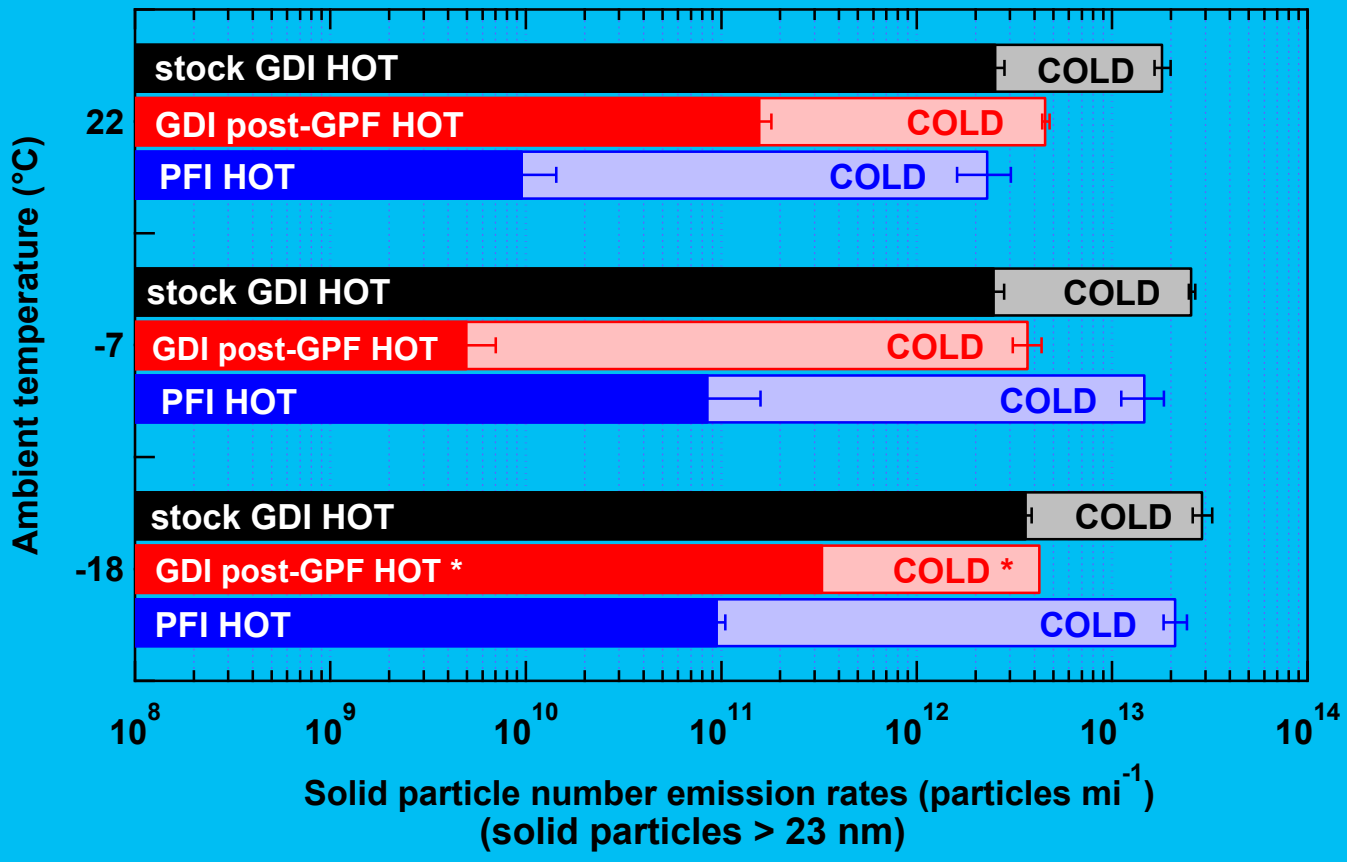
Gasoline Particulate Filters

GHG Compliance Creates Emission Control Opportunities



GPF Effective at Reducing Particle Emissions even at Cold Ambient Temperatures

FTP Particle Emissions
in Bag 1 (Cold-start) and Bag 3 (Hot-start)



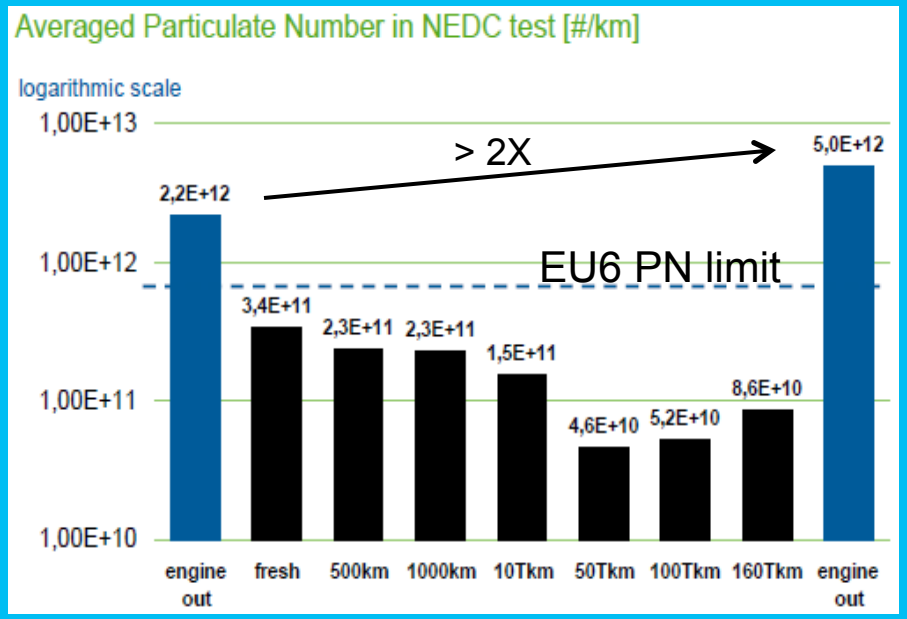
SAE Paper No. 2013-01-0527

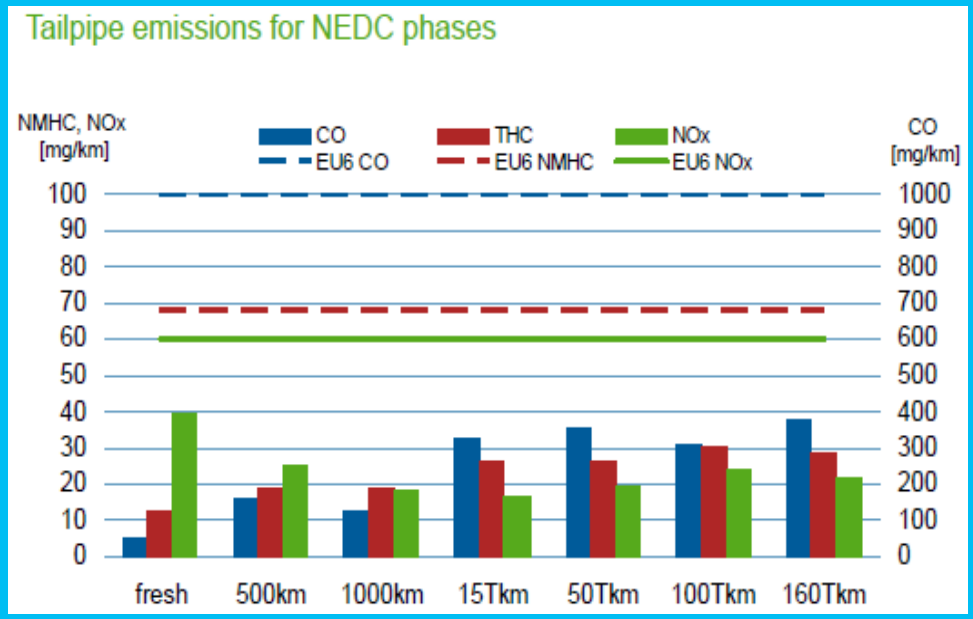
GPF Vehicle Durability Run Completed

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

Stock Catalyst
CC: TWC 1.24L 80g/ft³

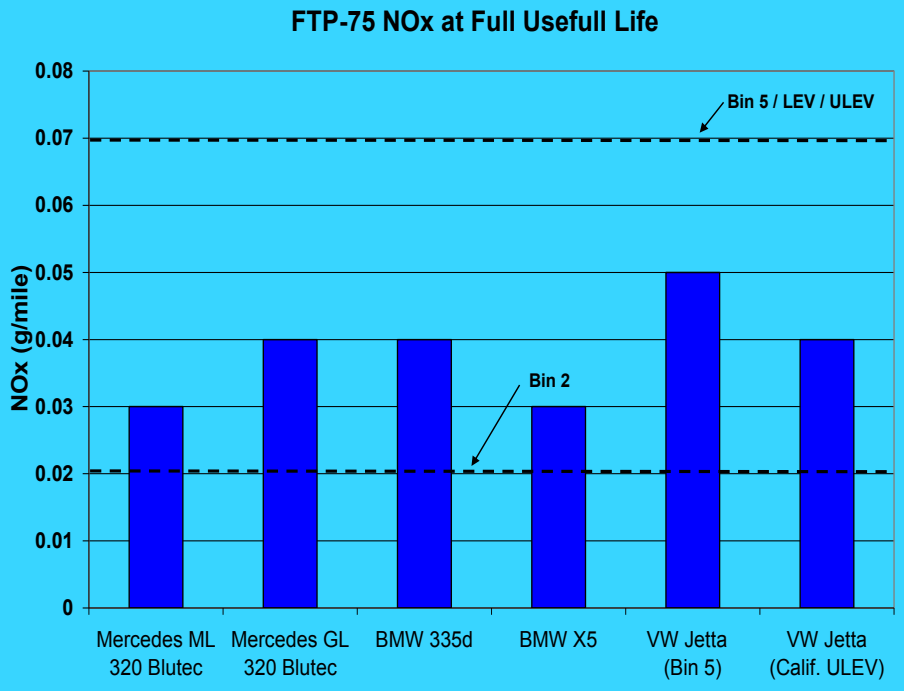
Test Converter Layout
CC TWC + UF converter
CC: TWC 1.24L 64g/ft³
UF: GPF 1.68L 10g/ft³

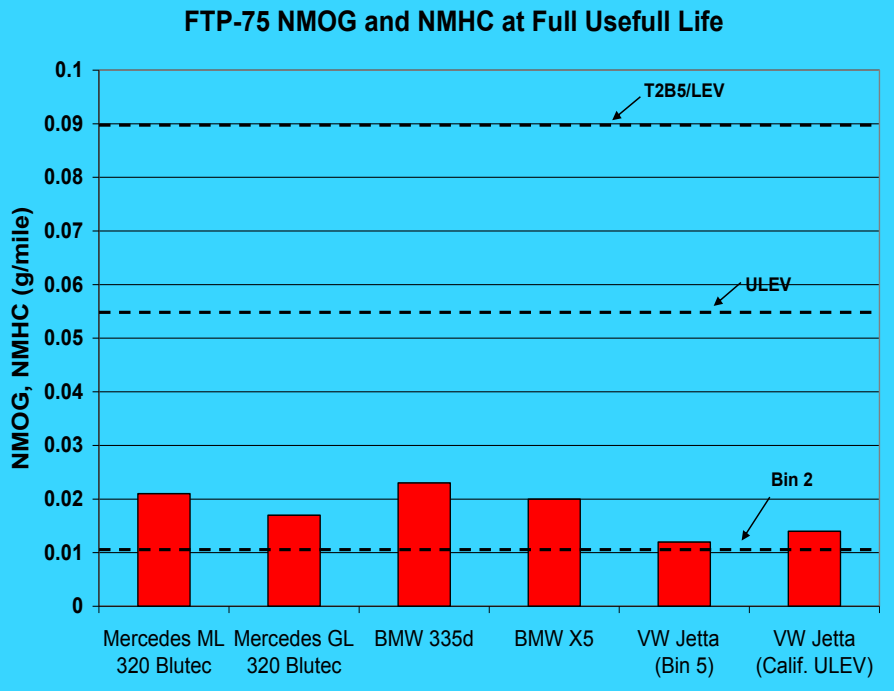




Light-duty Diesel Emisson Control Technologies

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



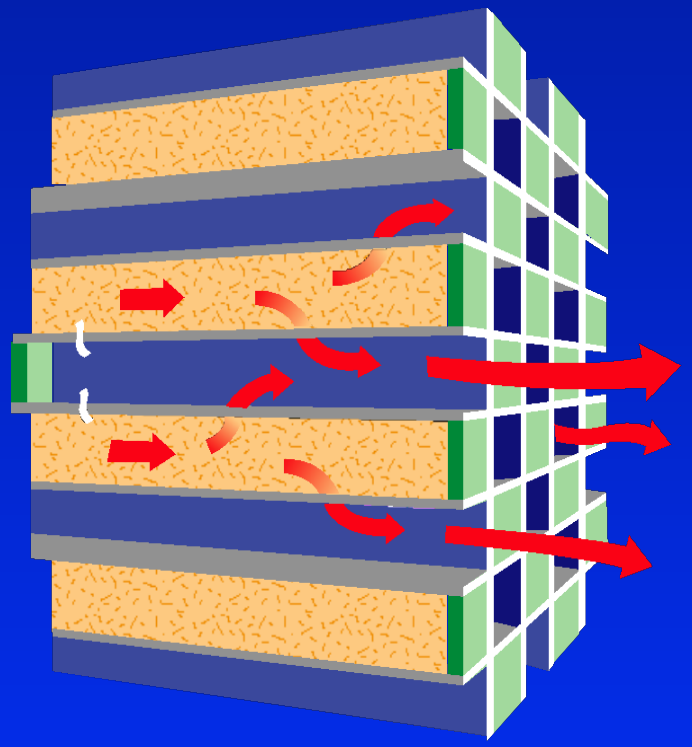


Current best in class: 50 mg/mi NMHC+NOx
(compare to 30 mg/mi NMHC+NOx for Bin 2 or SULEV)

CARB certification data

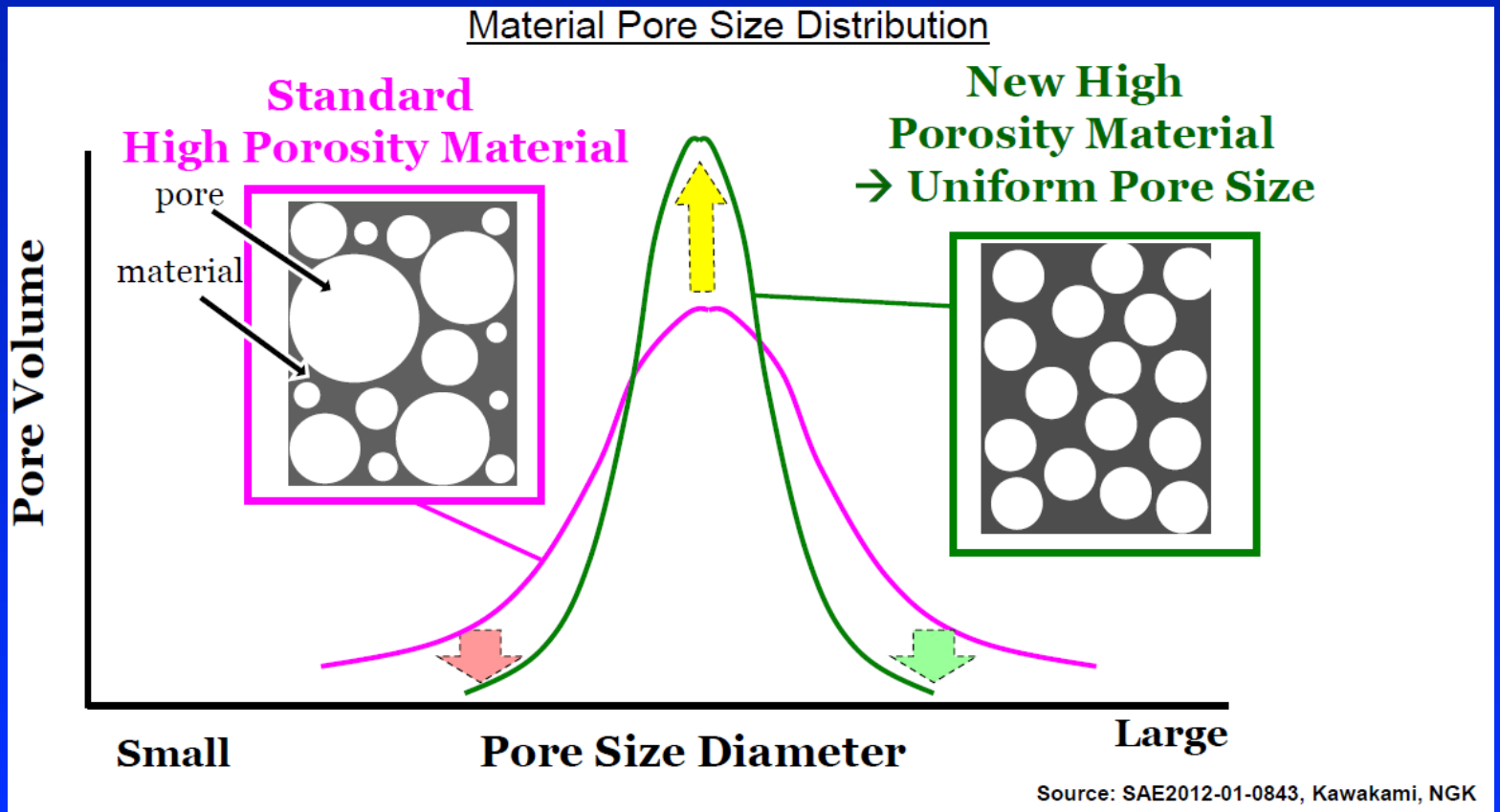
Diesel Particulate Filters (DPFs) Provide High PM/PN Removal Efficiency

- 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) at regular intervals 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 soot and inorganic-based particles associated with engine wear, lubricant consumption: regular maintenance required (filter cleaning)



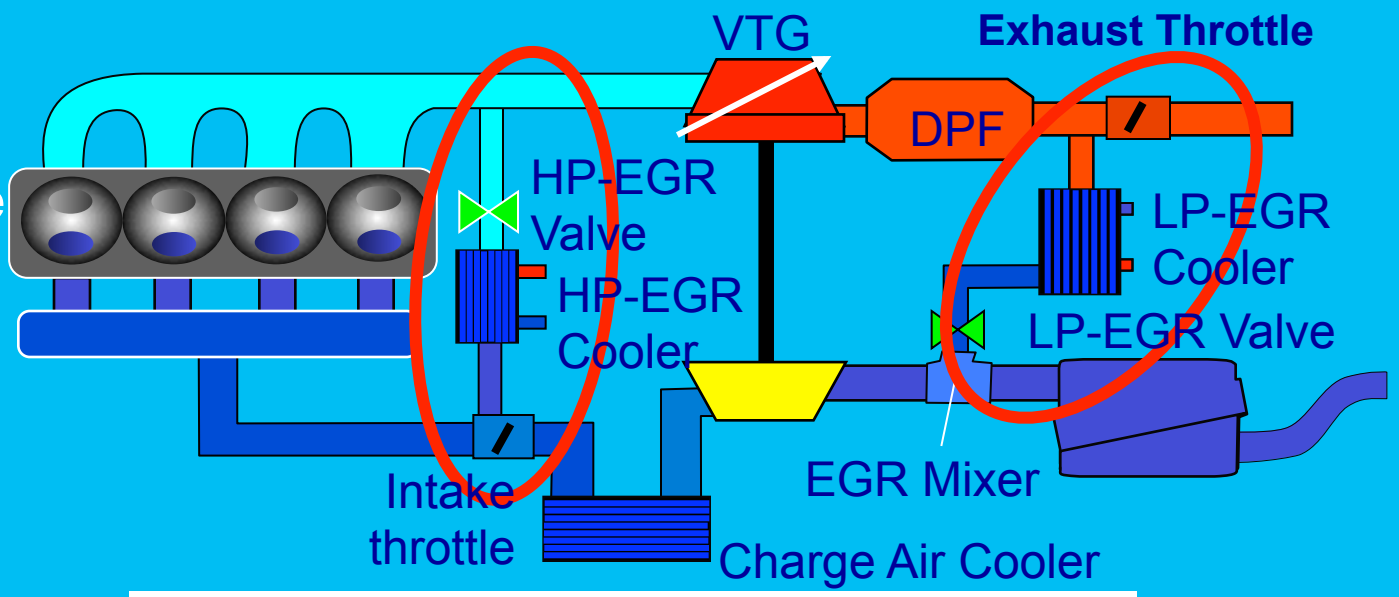
DPF Optimization Focused on Backpressure and Cold Start

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

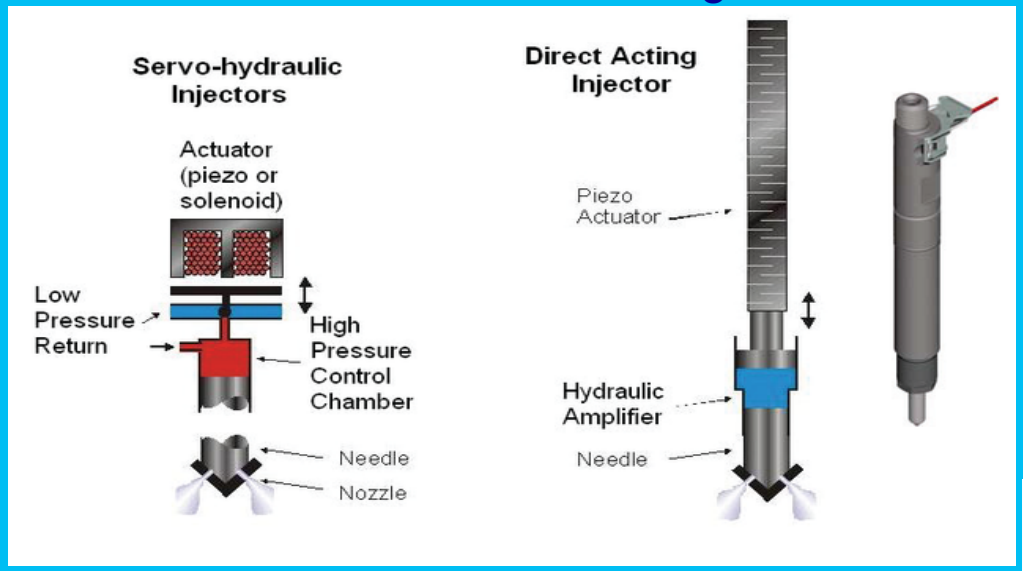


Diesel Engines Continue to Evolve Systems that Contribute to Lower Engine-out Emissions and Improved Efficiency

"Hybrid" EGR Systems Combine High Pressure & Low Pressure EGR Loops



Advanced Fuel Injection Systems Provide Enhanced Combustion Control and Lower Emissions



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

Tier 4
Off-Road
Engines

2010+
Heavy Duty
Vehicles

Power Plants

Gas Turbines

Tier 4
Locomotive
Engines

Waste Incineration

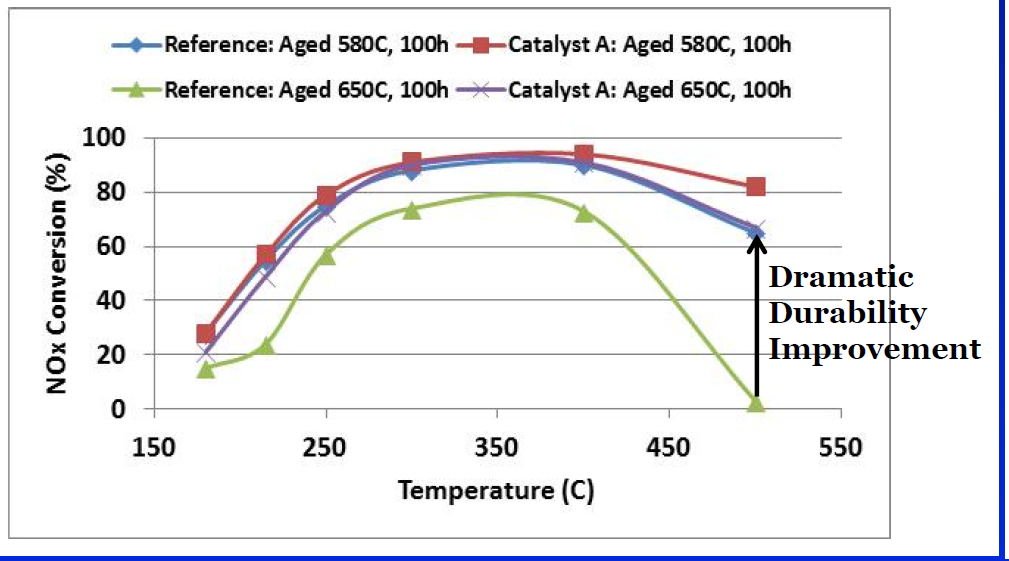
SCR
Products

Marine
Engines

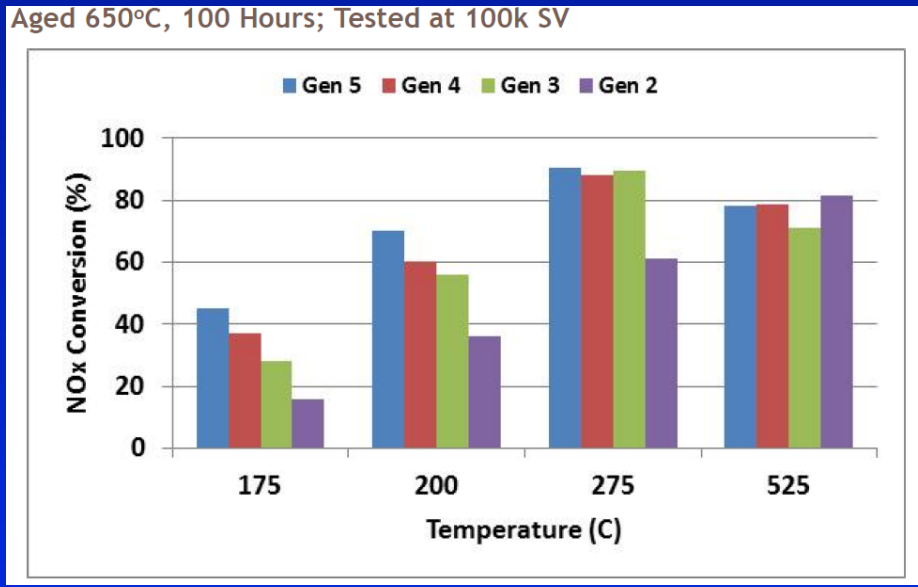
Diesel Passenger Cars

Stationary
Engines

SCR Catalysts Continue to Improve

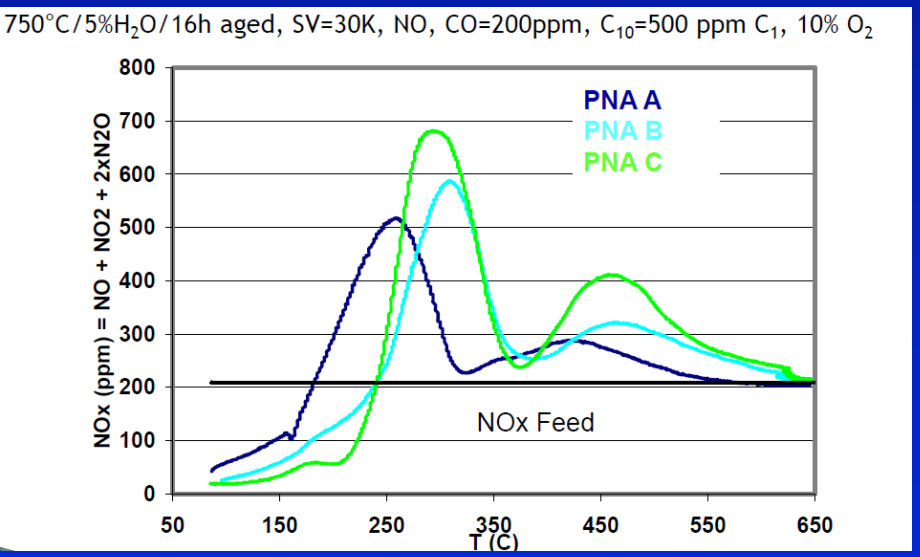


V-SCR with Excellent Durability

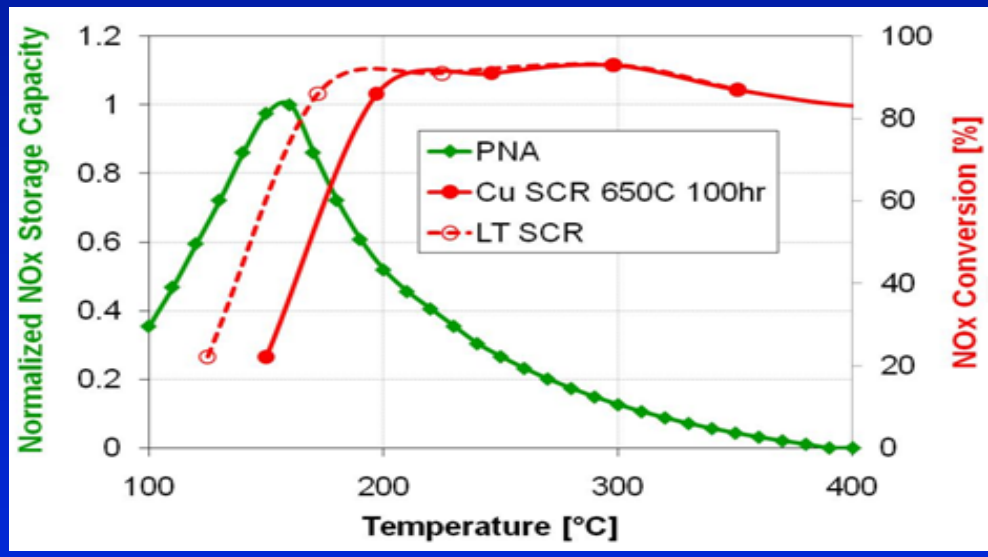


Cu-SCR Demonstrate Better Low Temperature Conversion

Combined NOx Adsorber/SCR for Low Temperature NOx



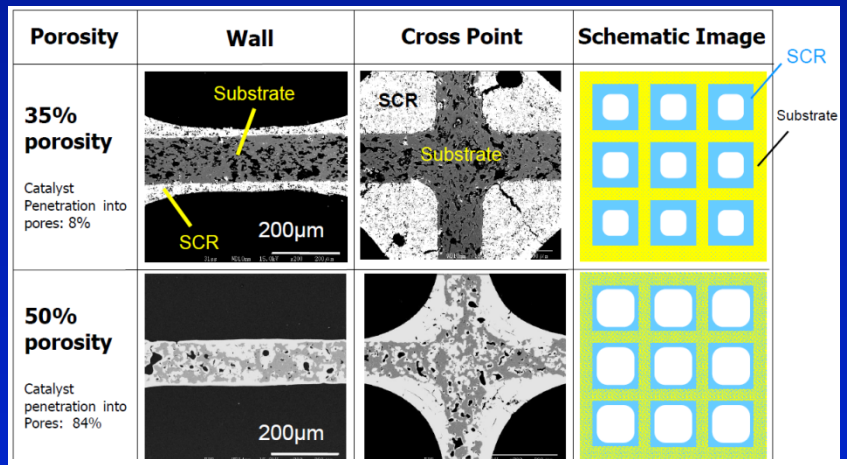
JM SAE HDD Symp. 9/12



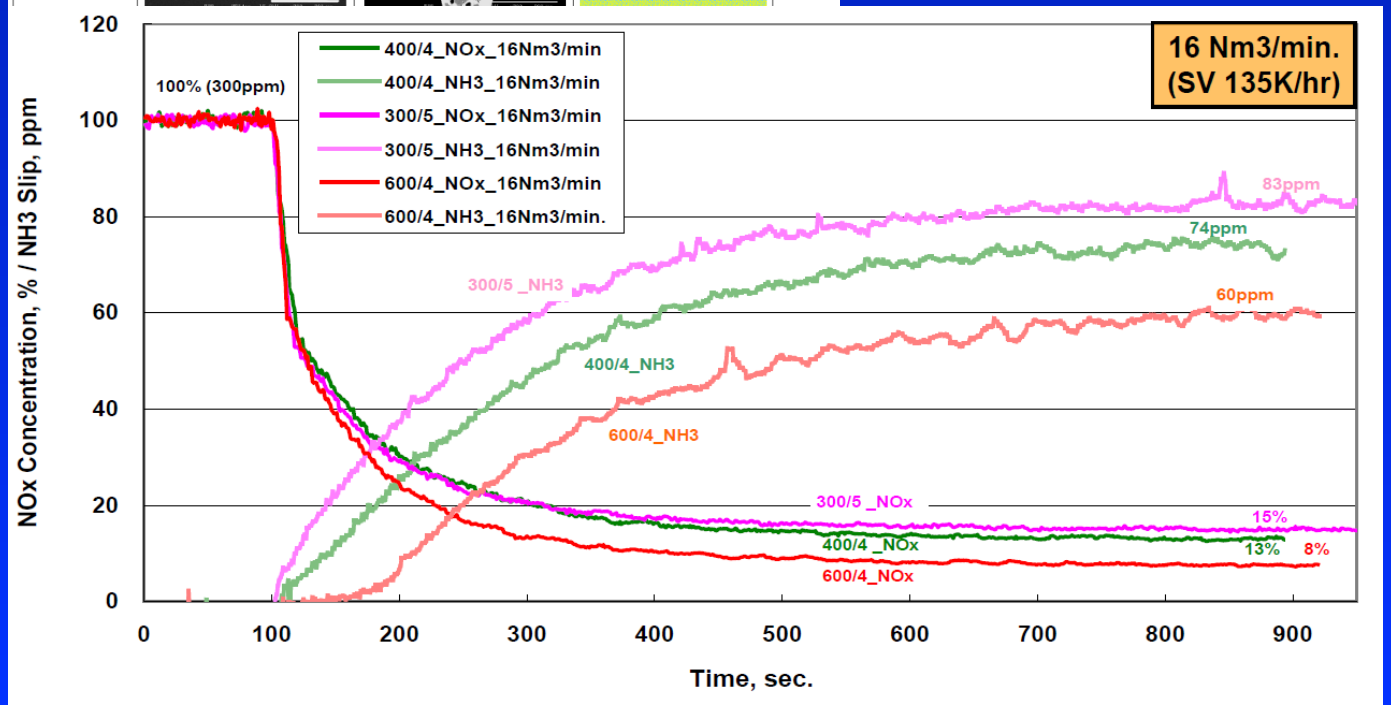
Cummins, DEER Conf. 10/11

- Passive NOx adsorber (PNA) begins to capture NOx below 150°C
- NOx release can be matched to SCR NOx conversion profile

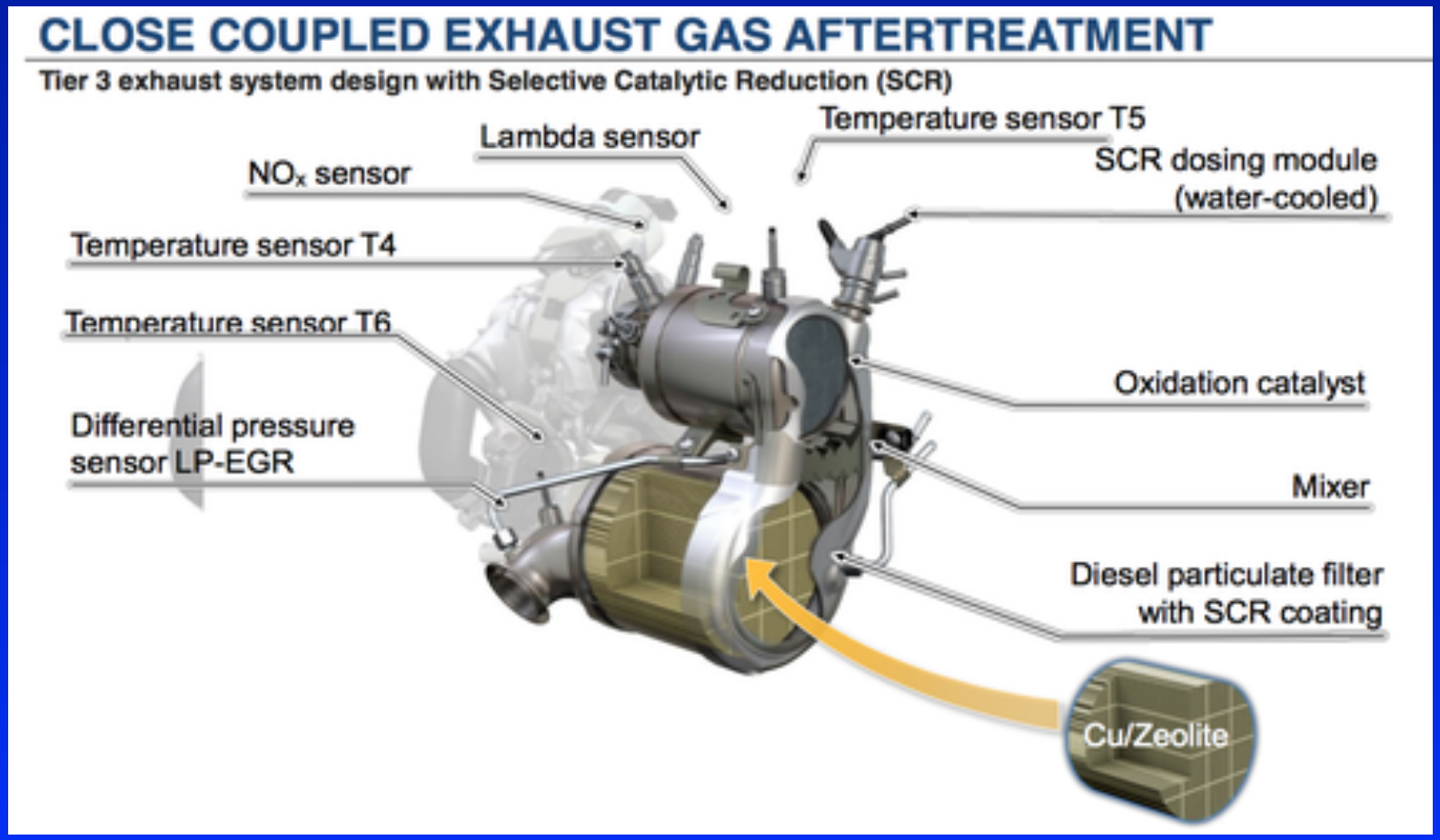
Substrates Optimized for SCR



- High porosity incorporates catalyst
- High cell density, thin wall designs improve conversion
- Fast heat-up and earlier urea injection



SCR Catalysts Are Being Integrated with DPFs to Improve Cold-start NOx Performance: VW New 2.0 liter TDI



Clean Diesel Vehicles Include Sophisticated Sensors and Diagnostics

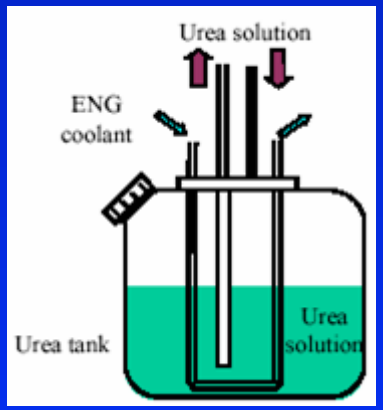
Combined O_2/NOx Sensor

Ammonia Sensor

Soot Sensor

Urea Quality Sensor

Diagnostic Systems

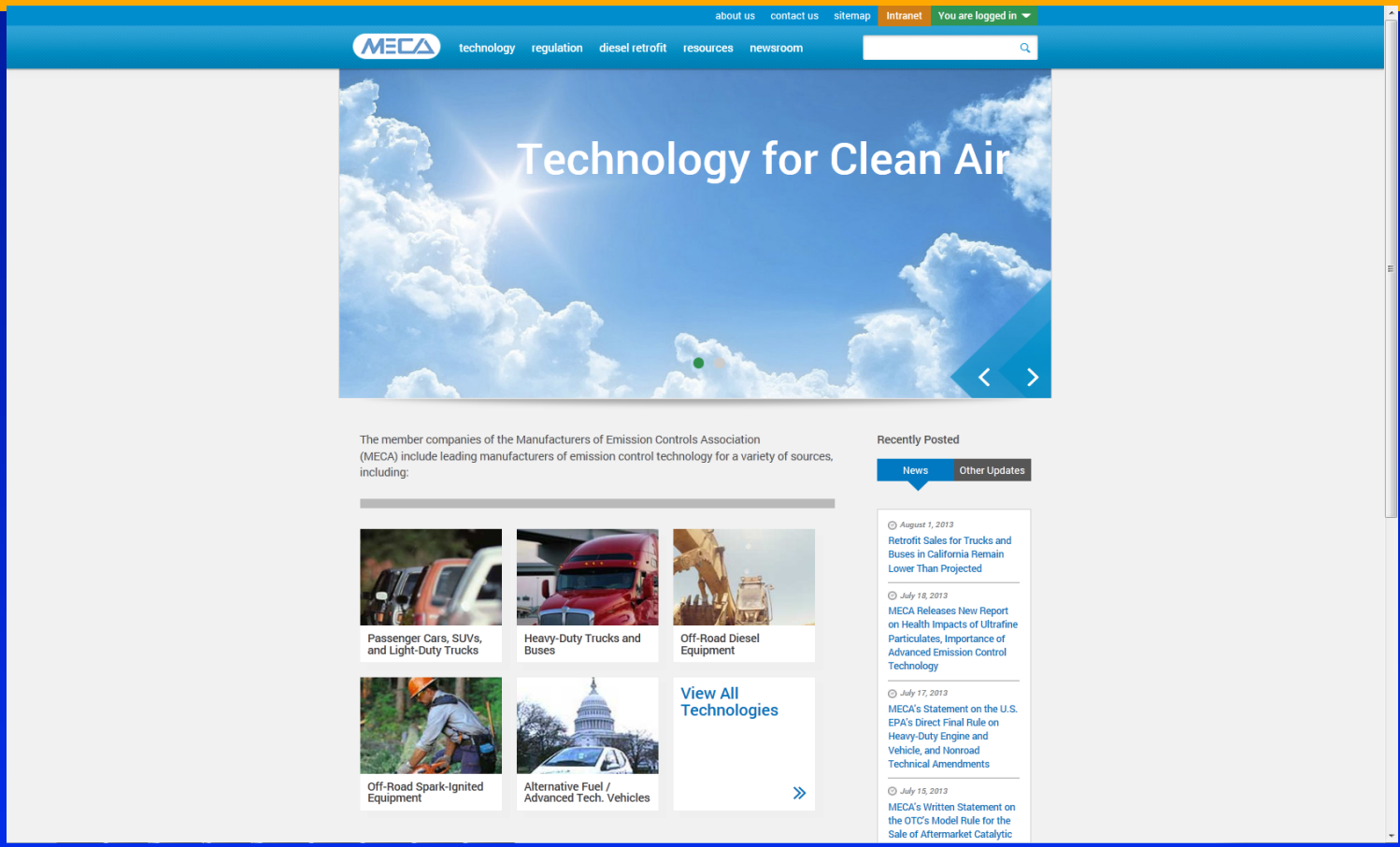


Heated Urea Tanks

Summary

- 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
- Health Impacts of Ozone, PM, Climate Change Will Continue to Drive Regulatory Groups to Revisit the Need to Achieve Even More Emission Reductions from Mobile Sources

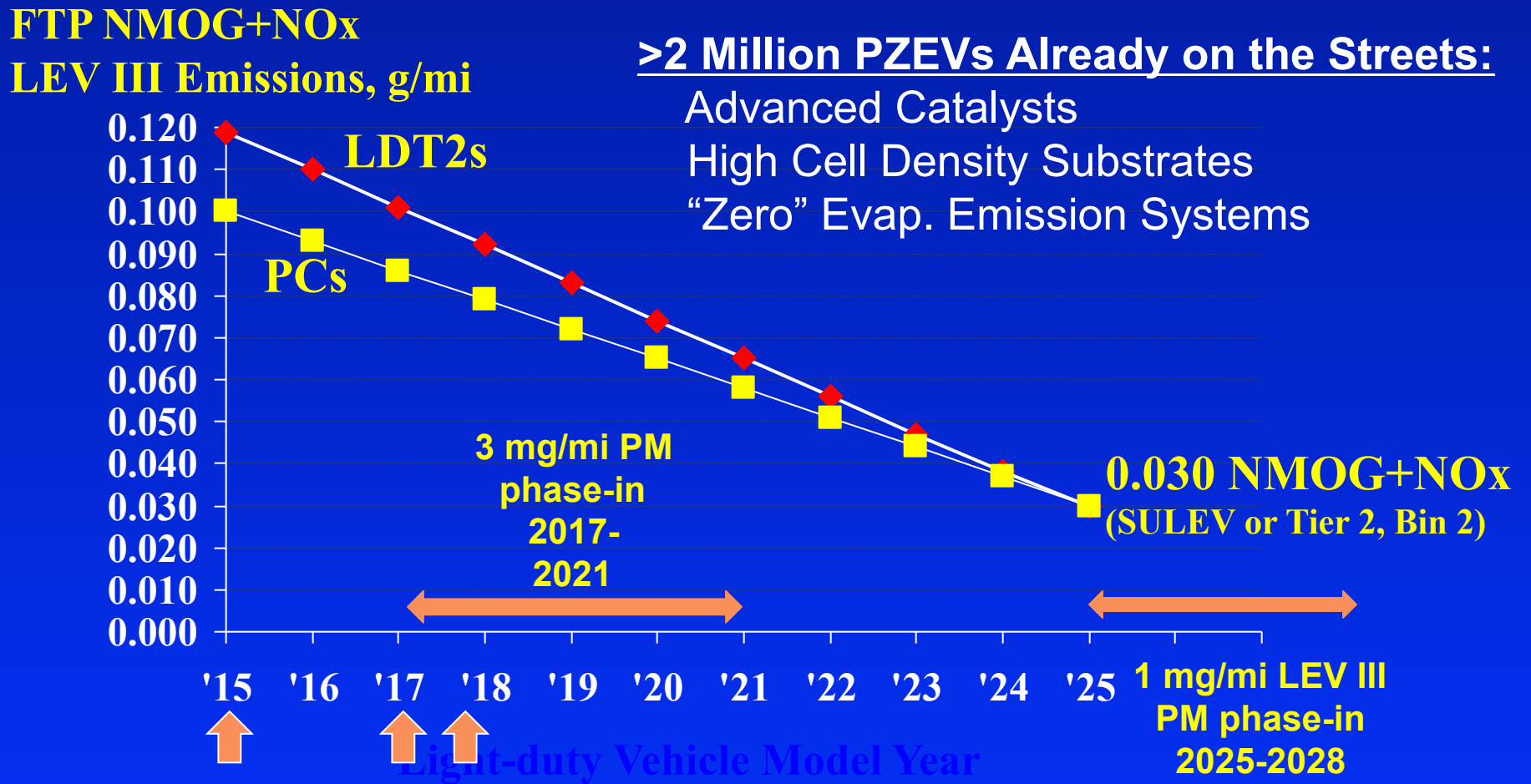
www.meca.org – *Newly redesigned*
Your emission control technology resources on the web



- 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

LEV III/Tier 3 Resets the Emissions Performance Bar for Light-duty Vehicles – Drives Innovation



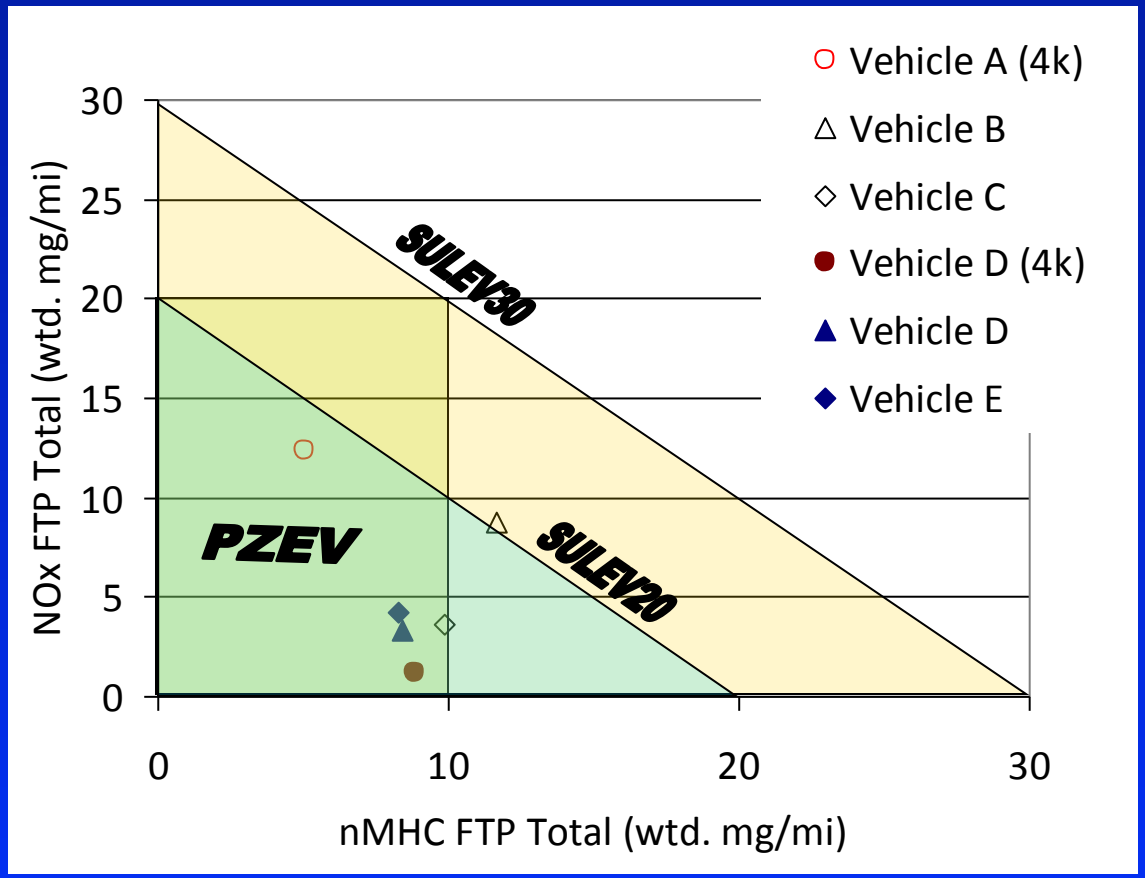
>2 Million PZEVs Already on the Streets:

Advanced Catalysts
High Cell Density Substrates
"Zero" Evap. Emission Systems

Note: California has a gasoline sulfur cap of 20 ppm; Tier 3 includes 10 ppm gasoline sulfur average

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



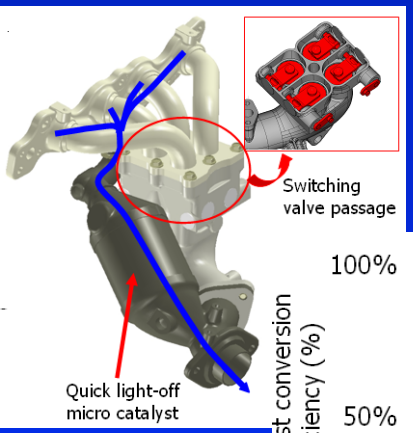
Ref. : SAE 2012-01-1245

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

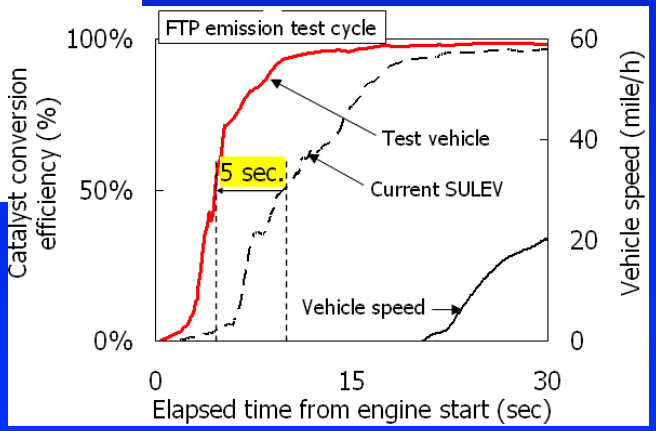
	Outline of the Measures
(1) Reduction of Engine-out Emissions	· Keep lean A/F at engine startup · Promote in-cylinder oxidation
(2) High Exhaust Gas Temperature	· Retarded ignition combustion at engine startup
(3) Quick Light-off Close-coupled Catalyst	· Minimize the heat loss of exhaust gas · Suppression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

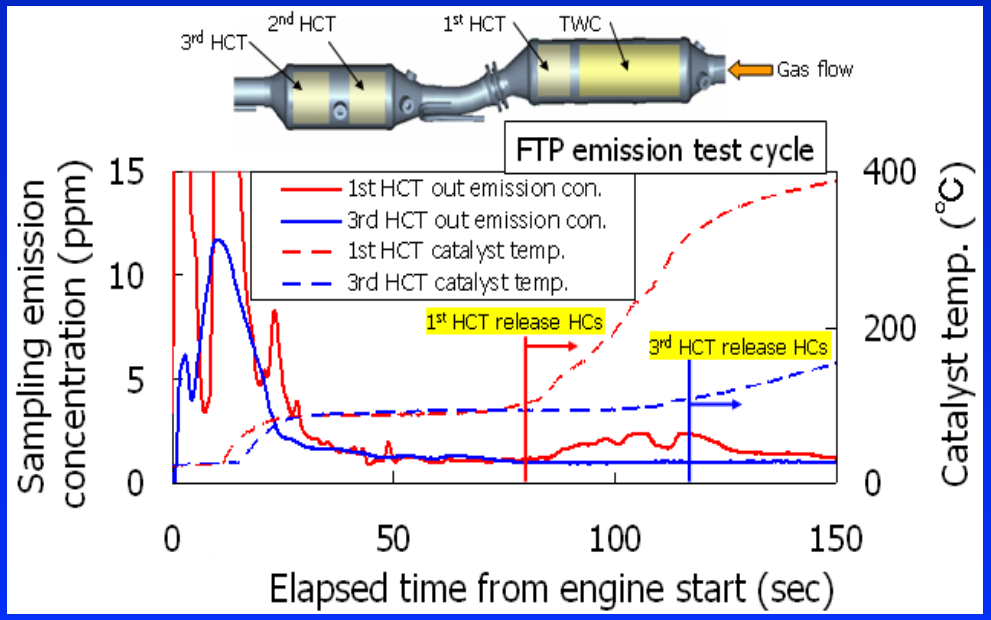
(With aged catalysts)

	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

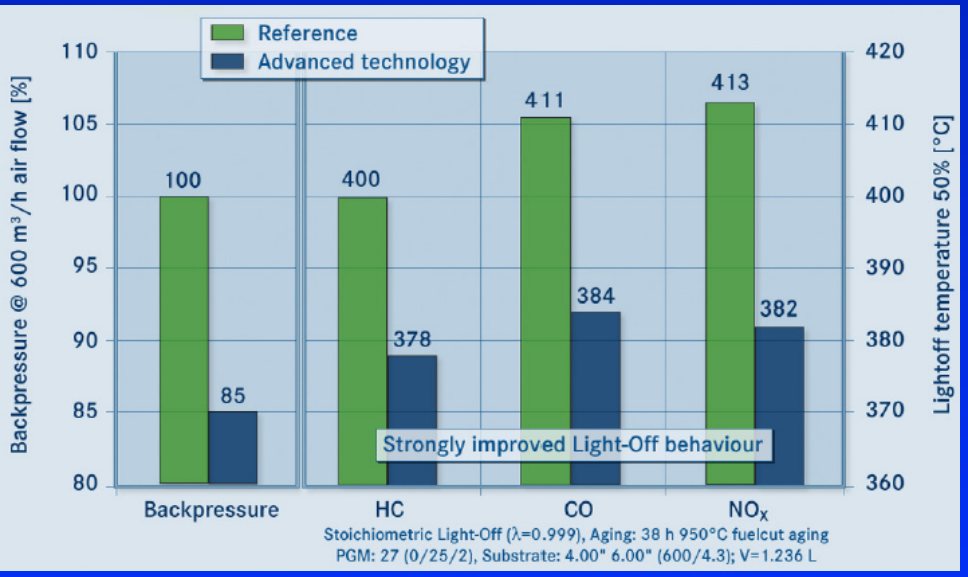


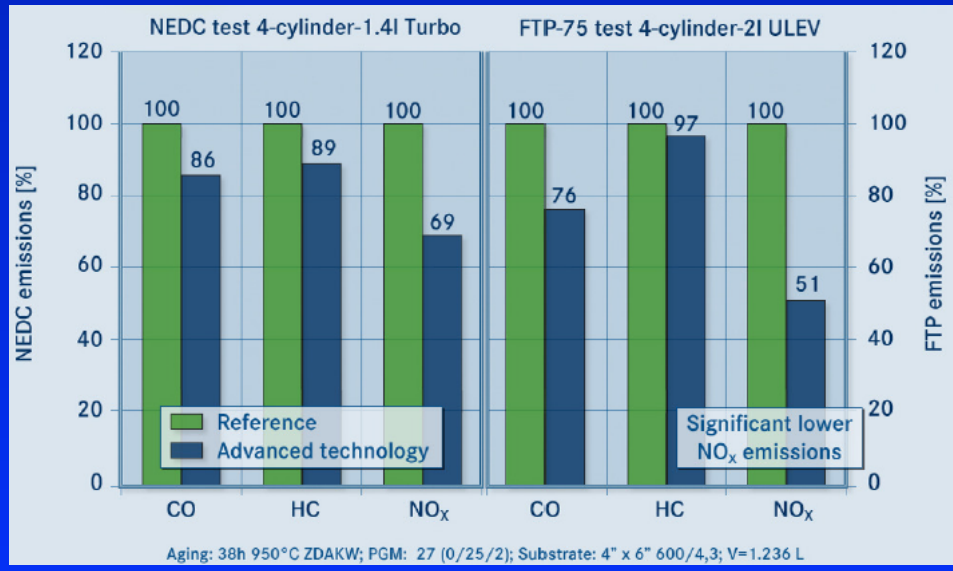


Source: SAE 2009-01-1076

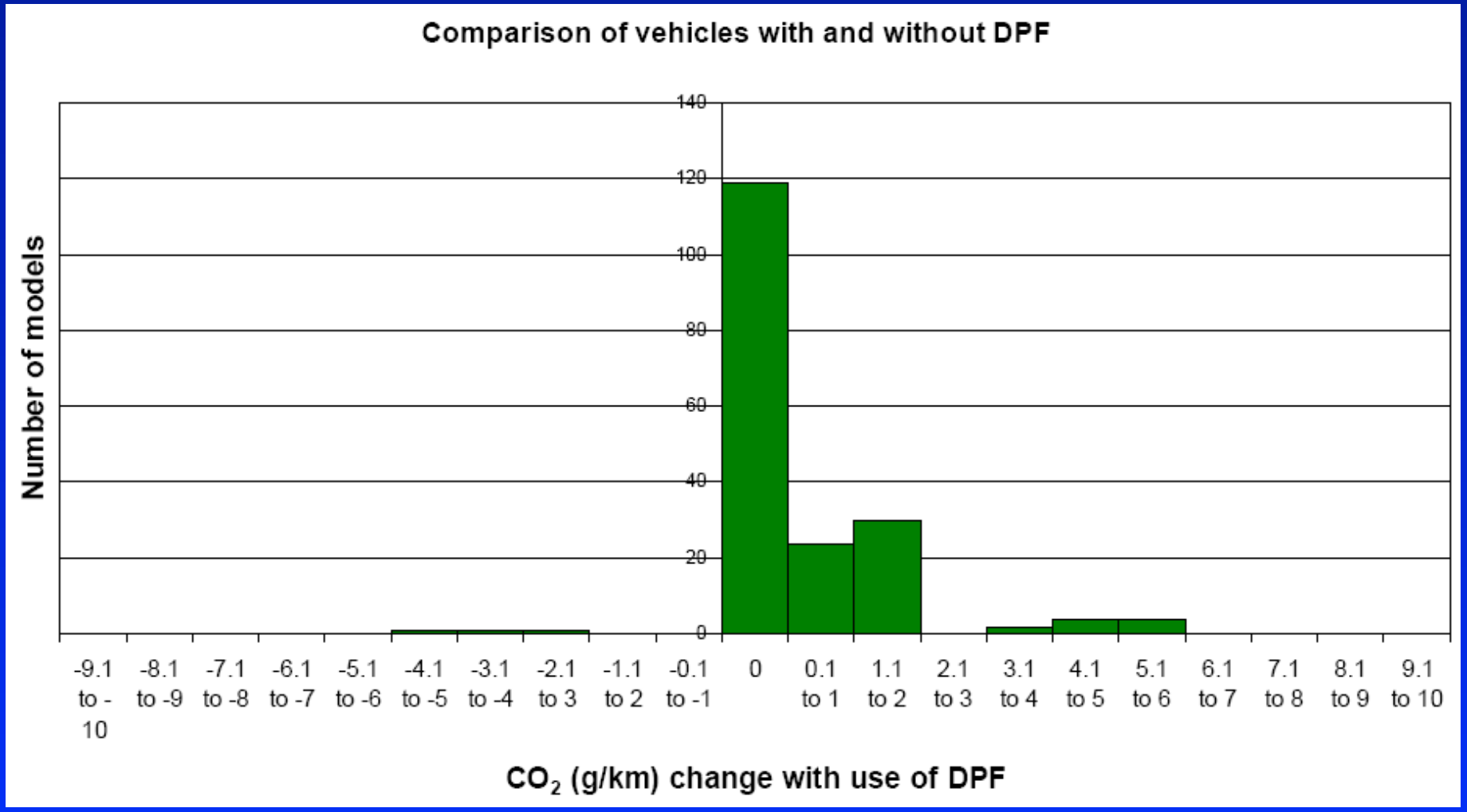
HEV and PHEV Vehicles Require Unique Catalyst Systems

- 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.



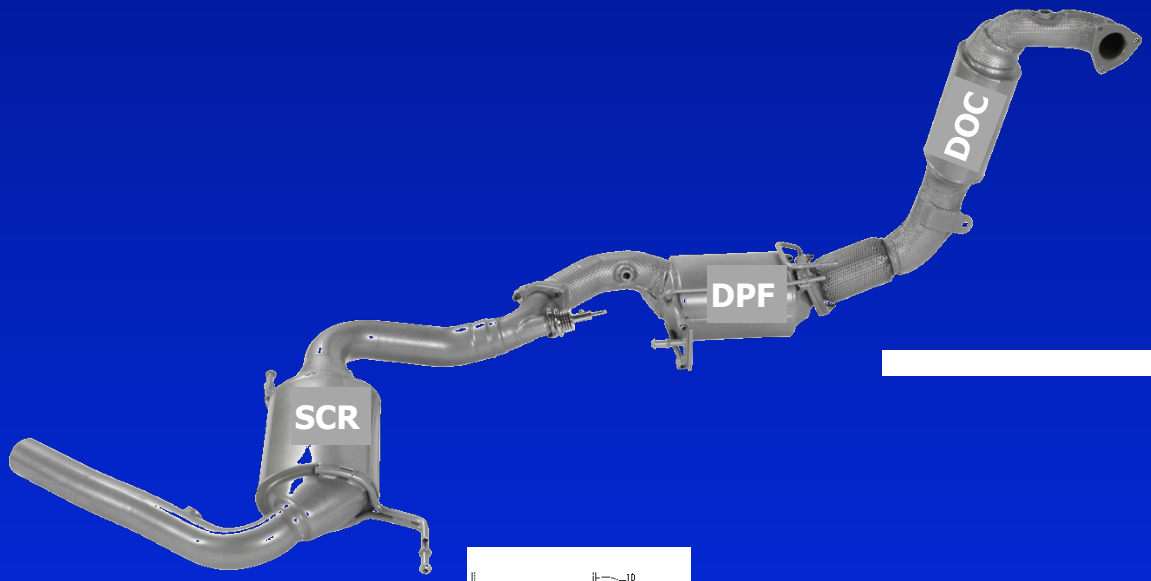


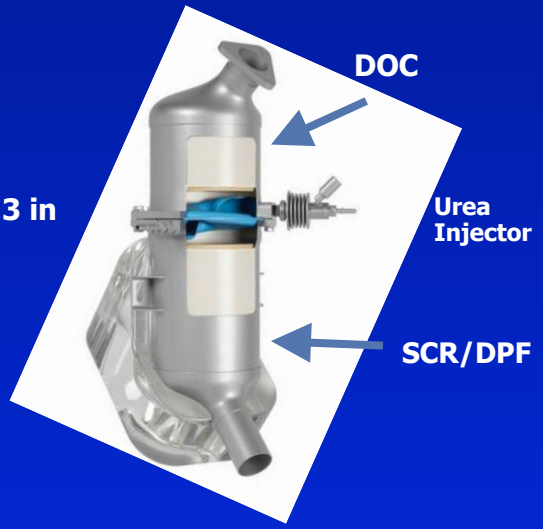
DPFs Generally Have Small Impact on Fuel Consumption (0.6% ave. increase in CO_2 for 184 recent Euro models available with or without DPF)

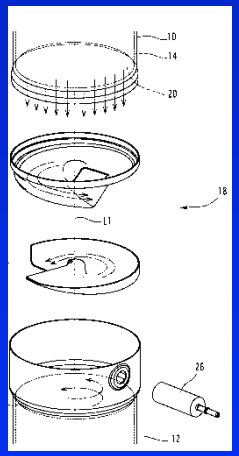


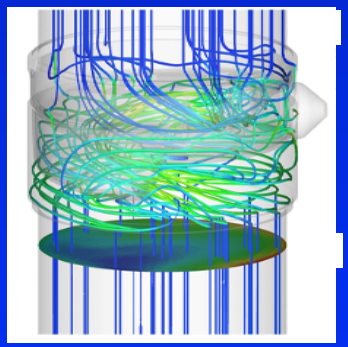
Reference: AECC analysis of 2007 model European vehicles

Advanced Diesel Systems Packaging Reduce Cold-Start Emissions



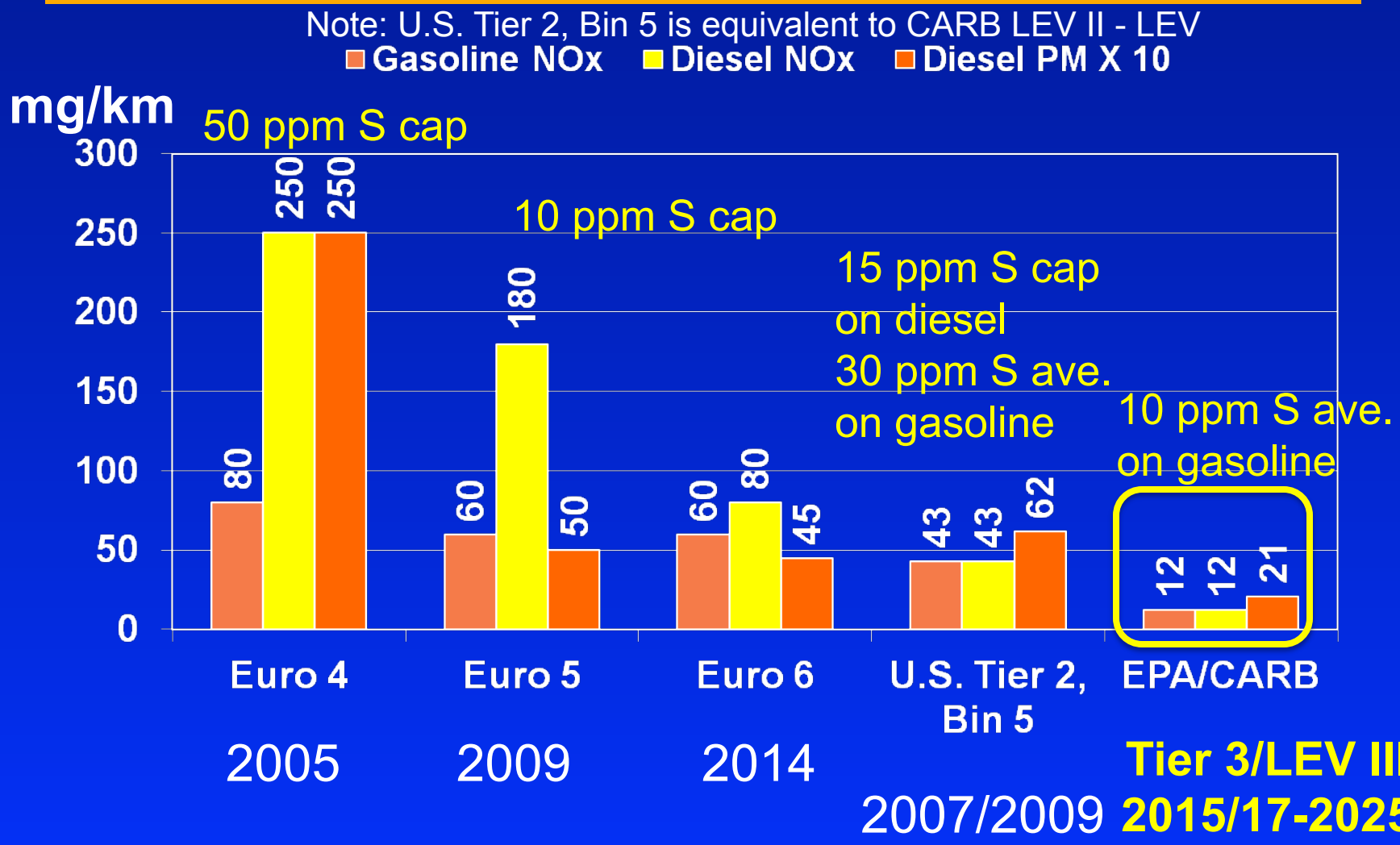






SAE Paper No. 2011-01-1318

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



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