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Vehicle Emissions Review - 2012

Tim Johnson
October 16, 2012

Summary

- Regulations
  - LEVIII finalized, Tier 3? RDE in Europe developing and very important
  - CARB looking at 0.05 g/bhp-hr NOx (-75%)
  - US (2025) and EU (2020) LD CO_2 regs finalized. 3 yr consumer payback period indicated
- Engines
  - LD gasoline diesel advancing quickly. Mild HEV, downsizing. High specific power. GDI PN development focus in Europe.
  - HD achieving 50% BTE with common themes. EGR analysis show advantages/disadvantages.
  - New engine designs. NG emerging
- Diesel emission control
  - 98% deNOx desired to remove EGR. SCR systems showing continuous improvement. Durability issues being addressed.
  - DPF+SCR systems advancing
  - New LD system deNOx systems coming from Japan. Stoich diesel in transients, NH3 better-controlled storage. HT NSR (LNT) system going commercial.
    - HD: LNC has strong interest in Brazil.
- Gasoline emissions control
  - GPF being defined. TWC on GPF shows advantages.

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Regulations

CARB tightened LD fleet NMOG+NOx average ~75% by 2025. EPA proposal (tbd) is similar

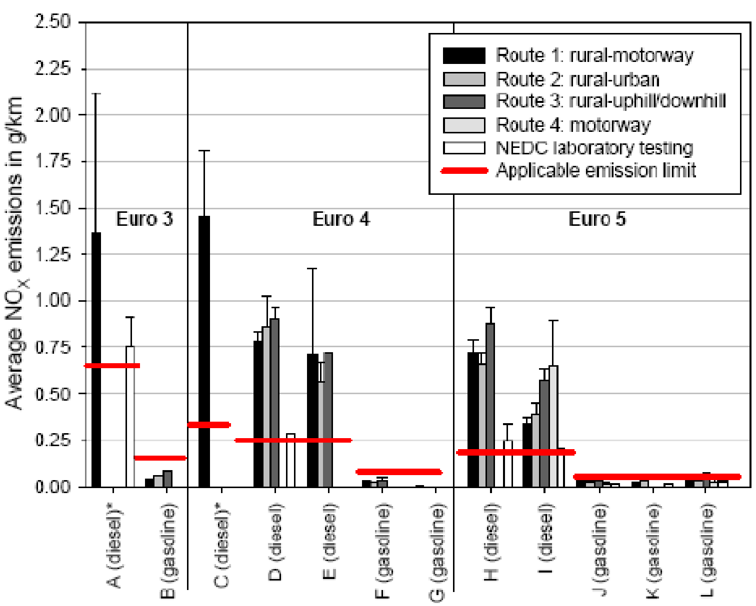
ARB LEV III	vs. EPA Tier 3
• OAL approval complete; waiver request at EPA	• Proposal in 2012 with final rule by end of 2013 (?)
• SULEV fleet ave. by *2025*; start in 2015; multiple bins	• SULEV fleet ave. by *2025*; start in 2017 (?); multiple bins
• 150K mi durability with credit	• 120K mi durability for lighter weight vehicles
• Extend "zero" evap. to all LD & MD vehicles	• Add ARB "zero" evap. + leak detection for cert. and in-use
• E10 cert. fuel (existing 20 ppm S cap for gasoline)	• E15 cert. fuel; 10 ppm S ave. for gasoline
• Full useful life SFTP	• Full useful life SFTP
• Tighter MD exhaust standards	• Tighter MD exhaust standards
• 3 mg/mi PM standards starting in 2017, 1 mg/mi in 2025, US06 PM standard, 2015 review of 1 mg/mi standard	• 3 mg/mi PM standards starting in 2017 + US06 PM standard

MECA

Euro in-use emissions regulations are being developed

"the need to bring on-road off-cycle emissions in line with those measured at type approval"

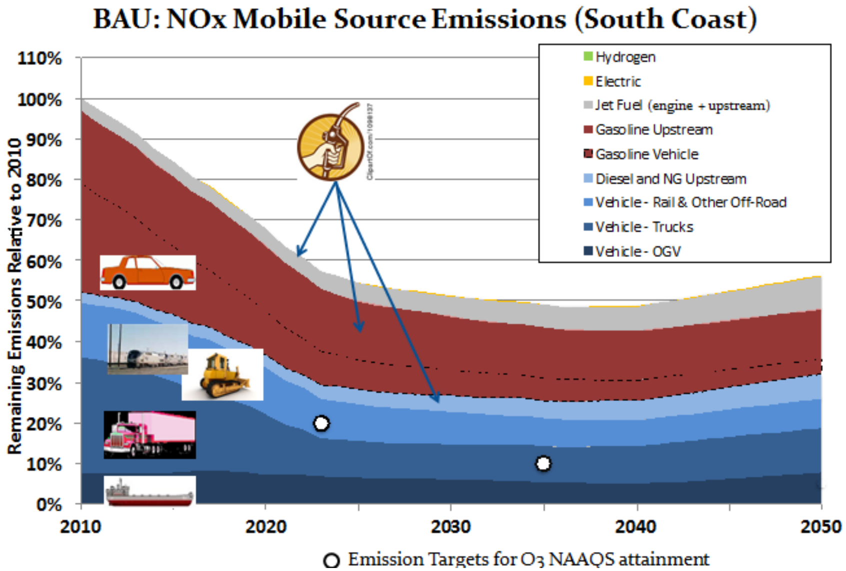
- Very significant impacts on emissions certification and design
  - LDD NOx
  - Gasoline PN
- Two options being developed: random test cycle or the use of PEMS (portable emissions measurement systems)
- Procedure development occurring in 2013
  - Boundary conditions are most critical



Real-world Euro 5 NOx emissions can be 3-4X higher than NEDC emissions

NOx emissions from Euro 5 LDD are >NEDC levels 80+% in common types of real-world driving

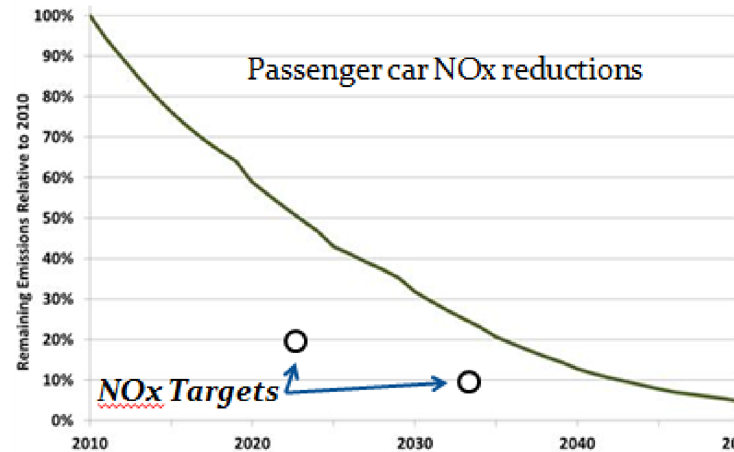
California is looking for 75% reductions in mobile NOx to meet new ozone standards. 0.05 g/bhp-hr HD NOx standard by 2020 being considered. Reduced VMT and in-use emissions in LD sector



Attainment Year	Reduction needed from BAU to achieve target in that year*	Pollutant
2023	65%	NOx
2032	80%	NOx
2050	85%	GHG statewide

SCAQMD has significant challenges to meeting the ozone ambient air standards. ~75% additional reductions are needed from all mobile sectors.

CARB, SAE OBD Symposium, 9/12



Additional to LEVIII, CARB is looking for 20% VMT reductions and cleaning up in-use vehicles to meet the targets.

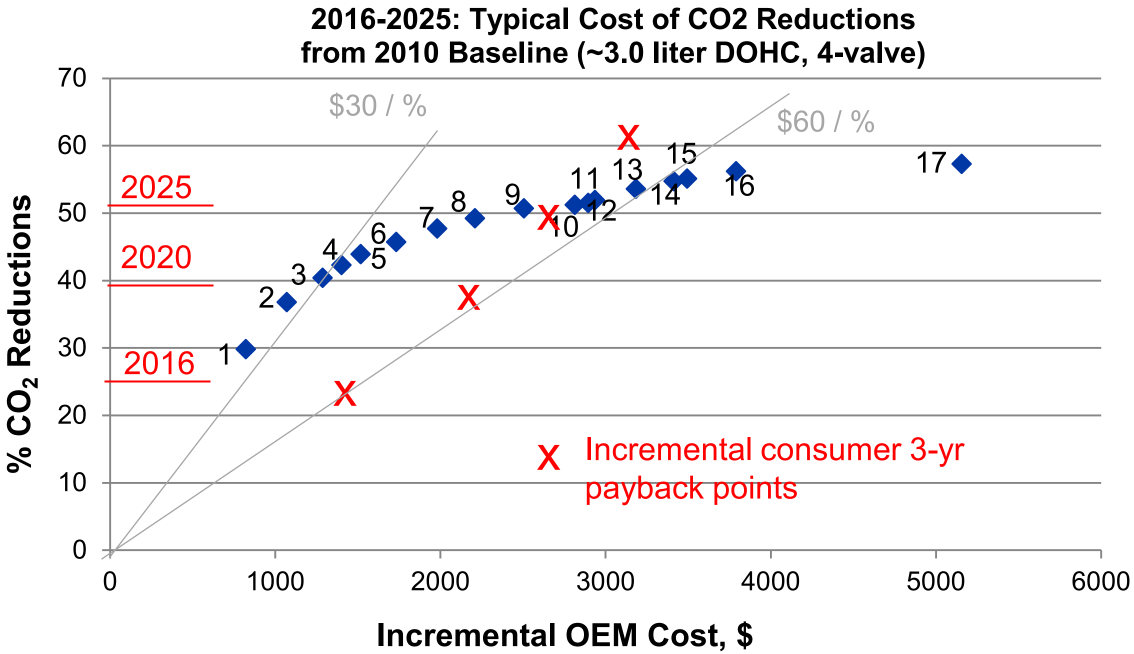
HDV Individual Measures	2050 % HDV NOx reductions in South Coast from 2010	2050 % HDV GHG reductions statewide from 2010
Target reductions from 2010 (HDV "fair share")	**95**	**85**
Business as usual (BAU)	*47*	*-78*
Fuel economy only	54	-20
New NOx standard only	72	-78
Low carbon biofuels only	60	68
Combined fuel economy, new NOx standard, biofuels	86	80

For trucks, CARB is looking at 0.05 g/bhp-hr NOx by 2020.

Regulatory developments on Non-Road

- Europe is exploring the next round of NRMM emission tightening
  - Likely approaches targeting PN, in-use monitoring, and harmonization with Euro VI.
  - Commission report due to the Parliament in 2014
- US EPA surprised with Tier 4f approaches without DPF
  - Very concerned and exploring options
- US EPA exploring CO_2 regulation for non-road
  - Reduced priority relative to LD emissions issues
- China has no plans for tightening on non-road
  - Lower priority to on-road

Analyses of EPA cost and CO_2 reduction estimates show incremental <3 yr customer payback to 2025. $4.50/gal



Incremental 3 yr payback points assume $4.50/gal and 12,000 mi/yr; $ are sticker price assuming 15% margin on hardware and dev cost

1. Aggr frict red, aggr shift, low drag brake, impr eff accessories, elect PS, aero, LRR tires, high eff gearbox, dual cam phase, 5% WR, 6-sp wet DCT
2. 1 + TC GDI 18 bar BMEP
3. 2 + more aero, accessories eff., LRR tires
4. 3 + 8-sp wet DCT
5. 4 + 10% weight reduction
6. 5 + TC GDI 24 bar BMEP
7. 6 + cEGR
8. 7 + 15% weight reduction
9. 8 + 20% weight reduction
10. 9 + start-stop
11. 10 + secondary axle disconnect (SAX)
12. 11 + MHEV, 10% wt red, -EGR, -SAX
13. 12 + cEGR
14. 13 + 15% weight reduction
15. 14 + SAX
16. 15 + 20% weight reduction
17. 16 + discreet var valve lift + ATKCS (?)

- 2010 baseline 27 mpg (8.8 l/100 km), 3 liter DOHC, 4 valve, 3554 pounds (1615 kg)
- Costs are hardware + development costs

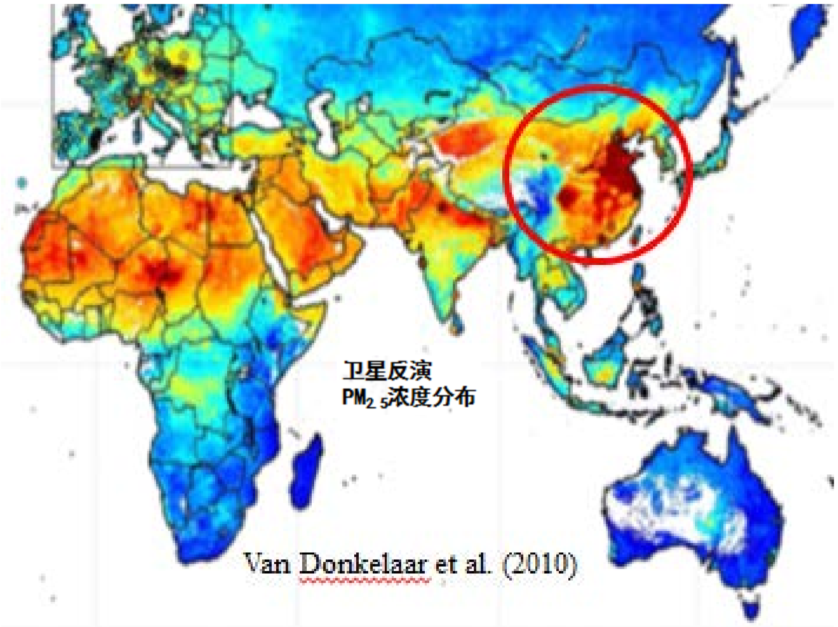
EPA420-R-12-016, 2017-25 GHG RIA; Table 1.3-8

Commission confirms 95 g/km CO2 limit for 2020 new cars

- **Same as previous indications. 147 g/km for LCV**
- Achievable, cost effective, lower costs than previous estimates, good for Europe
- **Based on vehicle mass**
  - All other bases rejected, except footprint (like US)
  - Didn't want to change as benefits minimal
  - €95/g/km penalty (vs. Euro €25-50/g/km estimated cost)
- **Test cycles: No change, for now**
  - NEDC gives different results on RDE, but the correlation is strong.
  - Still developing WLTP
- Super-credits to stimulate new technology
  - <35 g/km gets 1.3X vehicle multiplier for fleet average
  - 2020-23, but 20,000 car limit
- Now goes to Parliament and Council

China has very high levels of PM2.5 in heavily populated regions.

Much more exposure than anywhere else in the world.



Government is Responding

- November, 2010: 12th Five-Year Plan
  - 10% NOx emission reduction target
- February, 2012: New national focus on reducing PM2.5
  - February 22, 2012: Air quality discussion at the Executive Meeting of the State Council (Prime Minister and all the Ministers)
  - February 29, 2012: MEP issued new air quality standard that includes PM2.5
- Monitors established in major cities

Graphics courtesy of ICCT

Final CARB HD OBD Standards - General

PM

	13MY	14MY	15MY	16MY
Current	3x (one engine) 5x (all others)	← Same	← Same	3x all engines
Proposed	Detect a fault at 5x PM standards (all engines)	Phase-in 5x w/sensor (20% of all engines)	← Same	3x all engines
		← Same	Phase-in 3x w/sensor (50% of all engines)	

NOx

	13MY	14MY	15MY	16MY
current	Detect a fault at 2x NOx stds.	2x	2x	2x
proposed	3x stds.	Phase in 2.5x	Phase in 2.5x	2x

- Natural Gas Trucks: OBD pulled ahead from 2020 to 2018
- HD-HEV – Same engine requirements, but HEV system OBD delayed to 2014

Emerging health effects and atmospheric science understanding on nanoparticles

- Metal oxides are toxic
  - They are small (<30 nm), solid, and charged (in aqueous solutions)
  - Two Chinese cities with same PM2.5 (45 µg/m3) but with 76X difference in MeOx had very different biomarkers. (Niu, to be published)
  - Numerous studies on smelter strikes and shutdowns
  - Numerous studies on Ni and V toxicity (Lippman)
- Nucleation mode condensates exhibit non-equilibrium growth in atmosphere
  - Condensation/entrapment mechanism forms "solid". Appears not to change after this. (Perraud, 2012)
    - Hong Kong had step-change in diesel sulfur and nothing else. Mortality dropped. (Hedley, 2004)

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Engines

Analysis of EPA CO_2 cost and benefit data show some very attractive technologies. Transmission, GDI, wt. reduction, VVT, cyl. deact, friction standout as being attractive

Technology	Hardware Cost	% CO_2 Reduction	$ per %CO_2
5-speed transmission → 6-speed	($108)	0.7%	----
6-speed trans → 6 speed dual clutch	($154)	3.7%	----
V6 N.A., MPI, 3l → I4 2l, TC, GDI 18 bar BMEP	$113	12%	$9.40
Dual VVT (I4) → hydraulic VVT/L (Fiat)	$149	7%	$21
Cylinder deactivation	$176	6.5%	$27
10% weight reduction	$198	7%	$28
I4, N.A., MPI, 2.4l → I4 1.6l TC GDI 24 bar	$562	20%	$28
Level 1 friction reduction	$80	2.7%	$30
V8, 5.4l SOHC → V6, 3.5l, 2xTC, DOHC, 24 bar	$825	20%	$41
Level 1 friction → Level 2 friction	$97	2.1%	$46
DS, TC, GDI, 24 bar → DS, TC, GDI w/ cEGR	$210	3.6%	$58
MPI, I4, N.A. → LDD, T2B2	$1857	22%	$84
10% wt red pkg → 20% wt red pkg	$688	7%	$98
MPI, N.A., I4 → BEV100 (w/10% wt red)	$15, 459	100%	$155
MPI, N.A. → PHEV40 (w/o charger, 20% wt red)	$12,883	63%	$204
MPI, N.A., 3l→ 2.5 l, power split HEV, NiMH	$3589	15.4%	$233
MPI, N.A. → PHEV20 (w/o charger, 20% wt red)	$9724	40%	$243
Mid-SUV I4 → BAS mild HEV, I4	$1726	6.8%	$254

Generalized 3-yr pay back, $ per %CO_2 (sticker, 12,000 mi/yr)

$4/gal

MPG	$ per %
20	$72
25	58
30	48
40	36

$5/gal

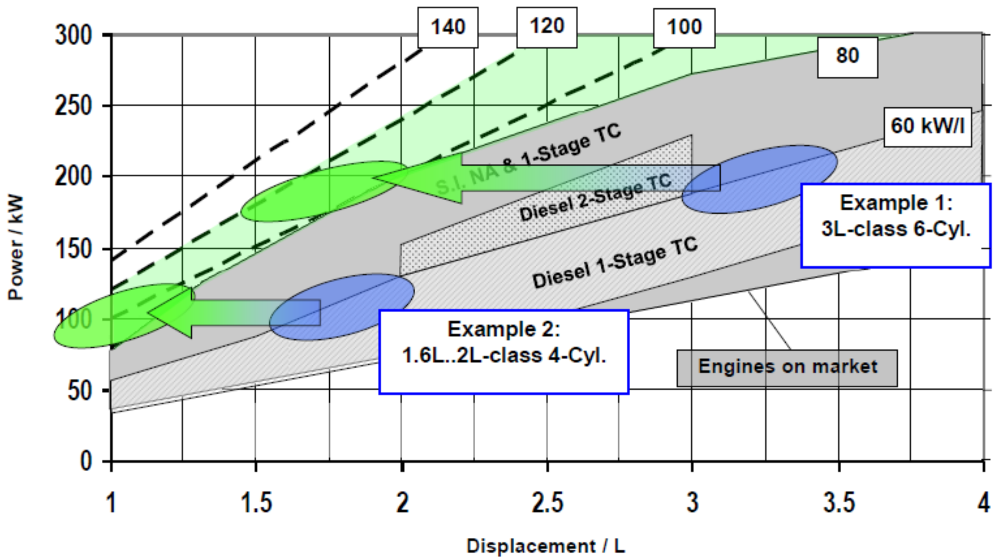
MPG	$ per %
20	$90
25	72
30	60
40	45

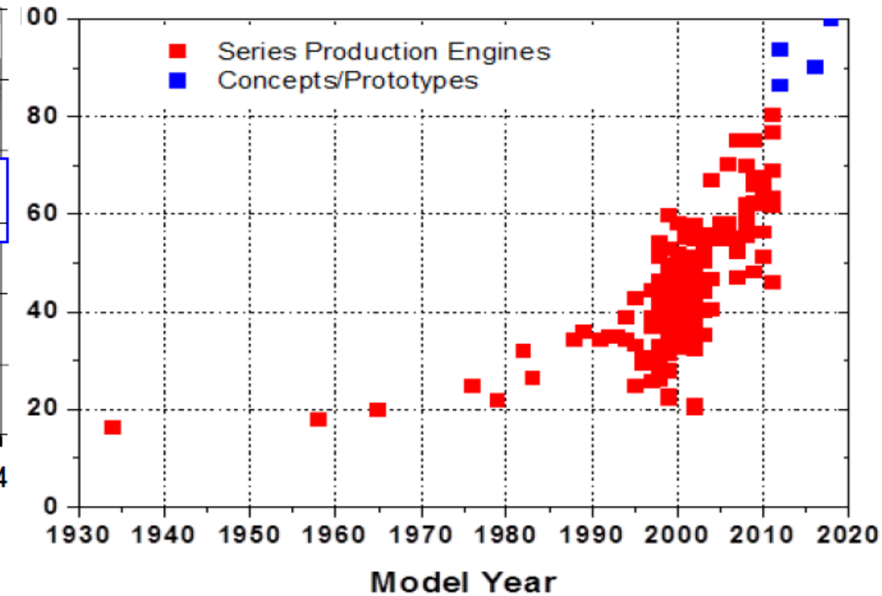
EPA, SAE 2012-01-1343

EPA420-R-12-016, 2017-25 GHG RIA

Trends in LDD engines.

Downsizing 50%, while maintaining power, 100+KW/liter, HPL and LPL EGR, 2-stage boost, advanced control. No deNOx for Euro 6 needed.





FEV HECS Specification:

- Downsized 1.6l 4-Cyl. Diesel Engine
- 80 kW/l spec. Power
- 2-stage boosting system
- High and Low Pressure EGR
- Advanced Charge Cooling Concept
- 2000 bar Piezo FIE
- DOC + DPF
- Advanced Control Strategies
- Optimized Bowl with CR 15:1

Benefits:

- 17% Fuel Consumption Reduction (vs 2.2l with 125 kW, EU4)
- EU 6 emissions w/o NOx Aftertreatment in 1700 kg Vehicle
- High Specific Torque and Power
- Robust Combustion System with Advanced Control Strategies

Gen 3 HECS:

- 2500 bar FIE
- More friction reduction – liner finish and rings
- Variable oil pump
- 7H-AMT
- 105 kW/liter
- 220 bar PCP
- SULEV compliant

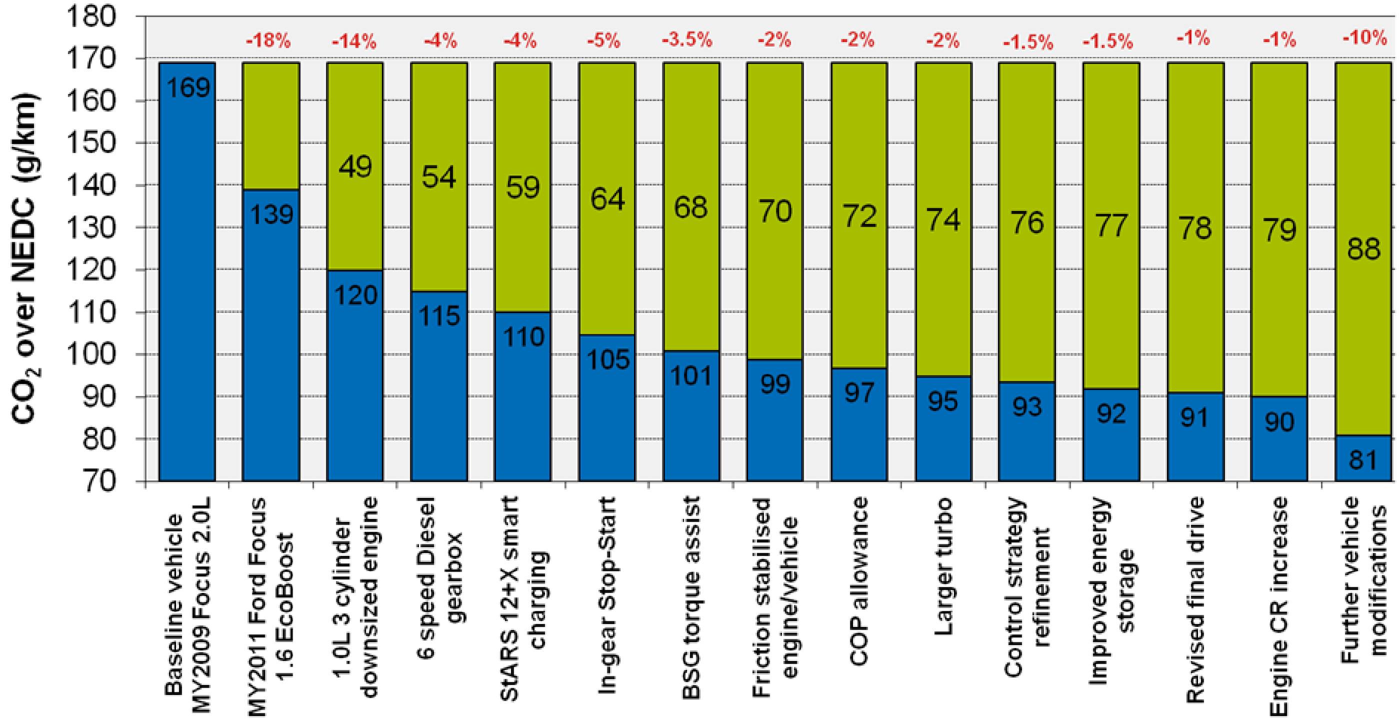
Gasoline powertrain improvements bring 1400 kg car to 90 g/km CO_2.

Micro-hybrid using ultracapacitors. Electric supercharger. -35% CO_2 vs DS 1.6 liter GDI baseline

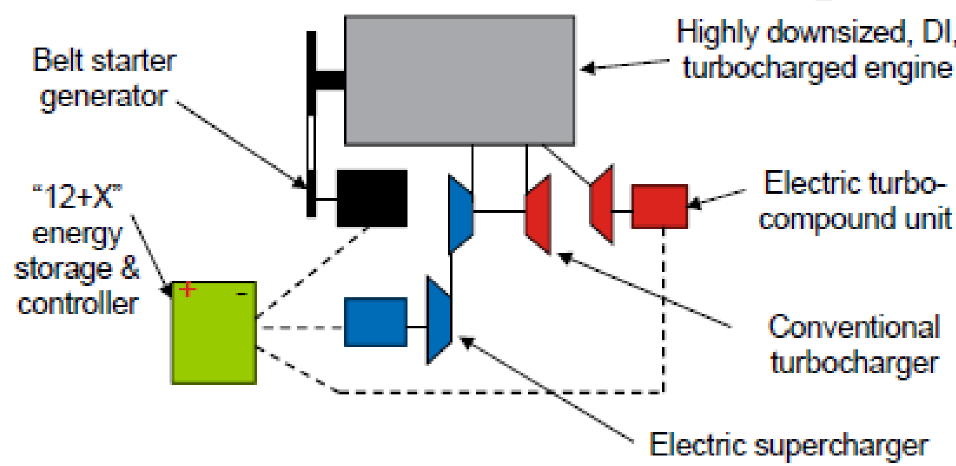
Versus E5 gasoline engine:

- -45% CO_2
- +75% cost (est. $750 from EPA data)

EPA: TC-GDI for 13% CO_2 cost at $248. Ricardo has -12% CO2 at +25% cost

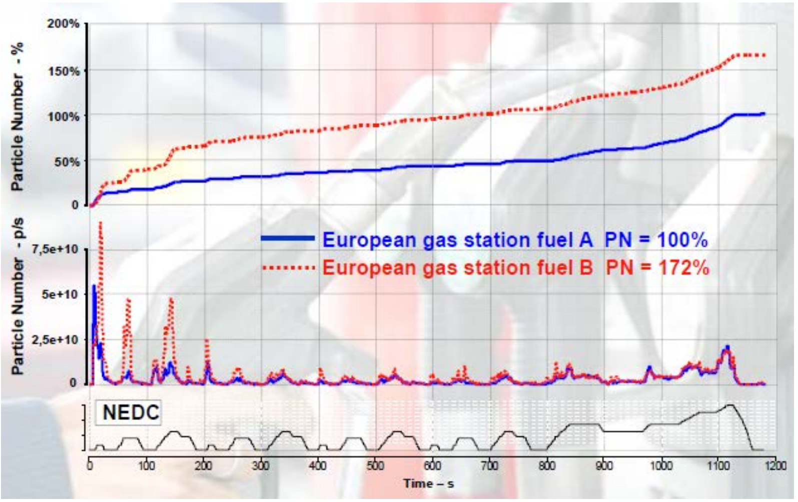


All tests are cold start (25 deg C) legislative tests
EU5 emissions compliance

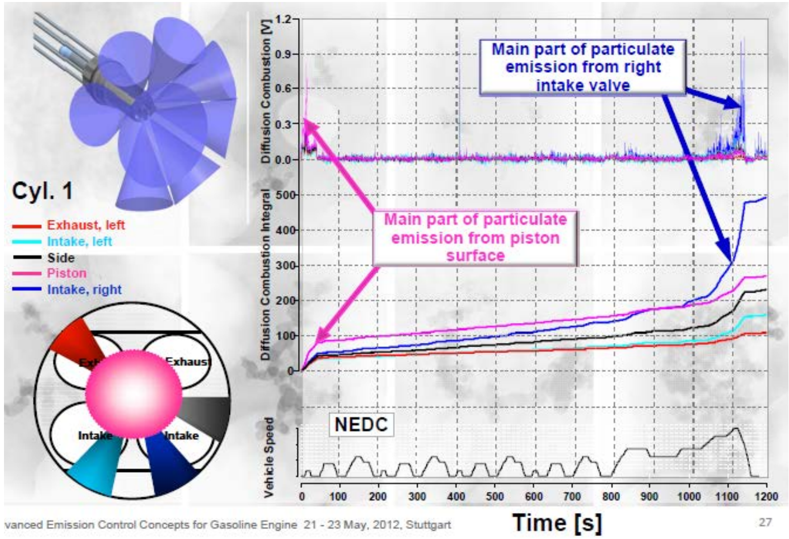


Ricardo, GAMC Emissions 2012, 6/12, SAE HEE 4/12

PN emissions are very sensitive to combustion environment and upsets. Fuel quality injector orientation and design, and deposits can all form PN.

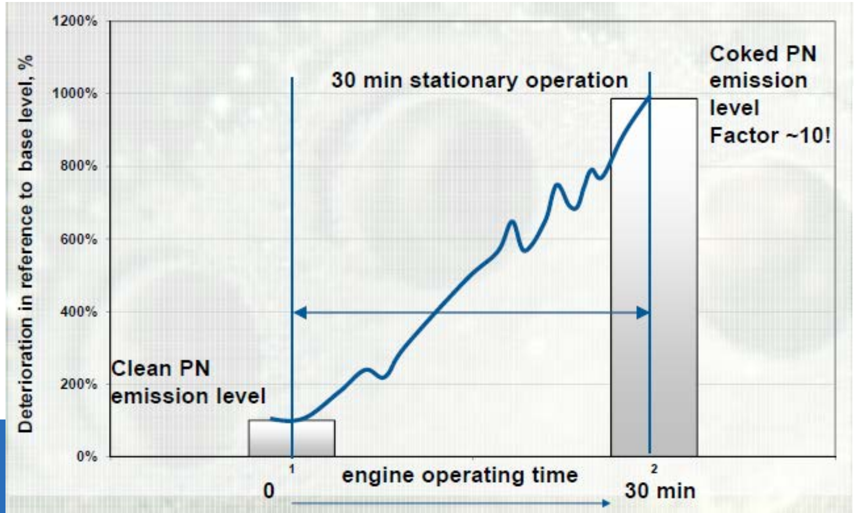


Differences in EU pump fuel can cause 1.7X increase in PN

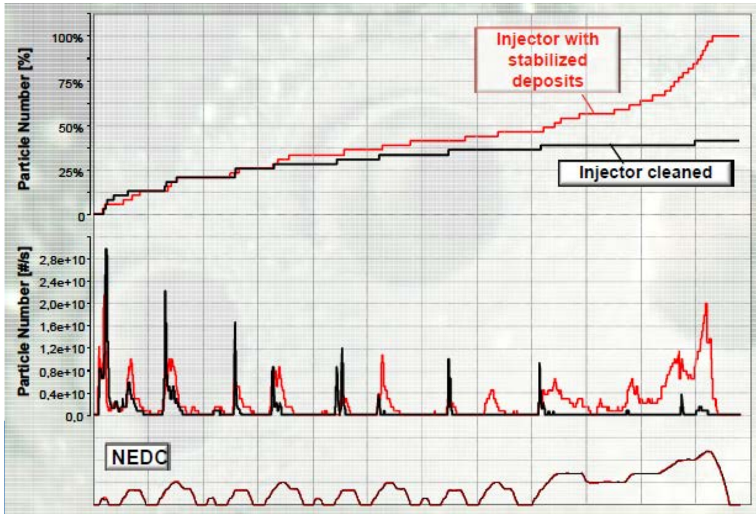


Most of the PN emission is coming from one intake valve due to improper installation of the injector.

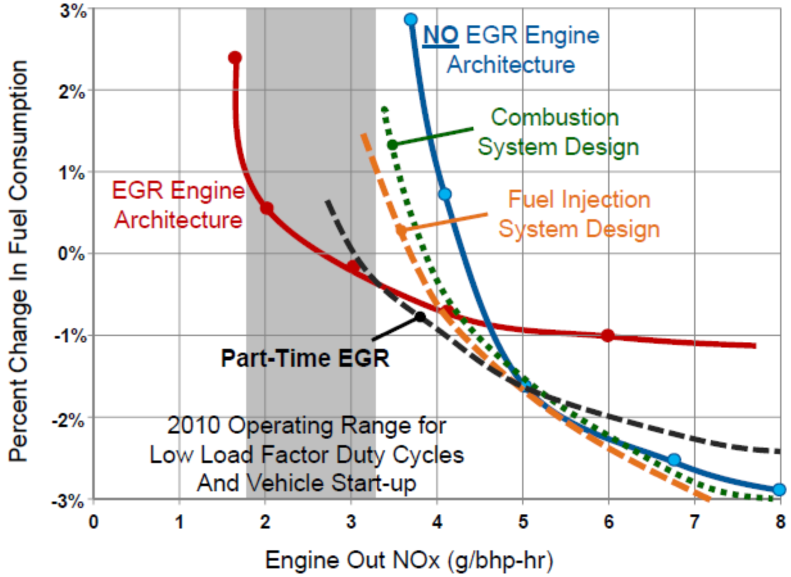
AVL, IQPC Conf, May 2012



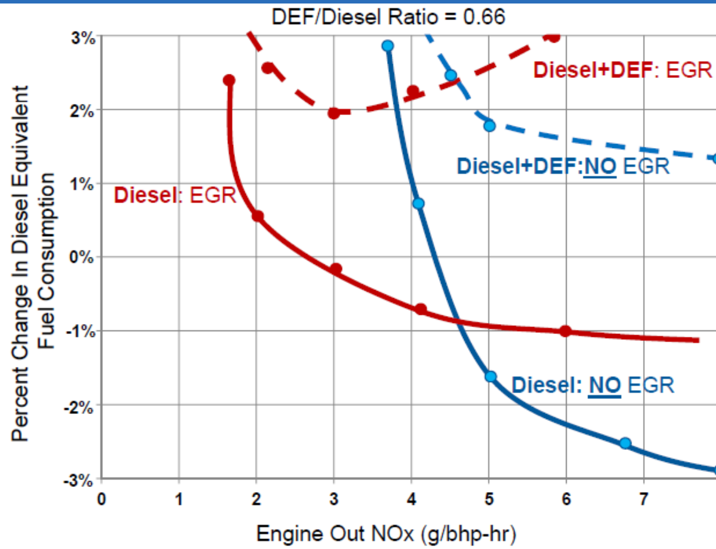
Extended idle time can increase deposits, which can increase PN



HD EGR offers advantages in fuel and DEF consumption at current levels of SCR capability (~4 g/bhp-hr NOx)



At current levels of SCR capability (~95% deNOx; 3-4 g/bhp-hr engine out), EGR offers fuel consumption advantages.



At a DEF price ~2/3 that of diesel fuel and SCR capability, EGR offer operating cost advantages.

Cummins, CTI NOx Conf 6-12

DOE SuperTruck Program participants have mostly common themes to 50% BTE

BTE Impacts

Common

- Waste heat recovery – 2-3%
- Air handling, EGR – 2-3%
- Parasitics, friction – 2-3%
- Improved SCR, other – 1-3%

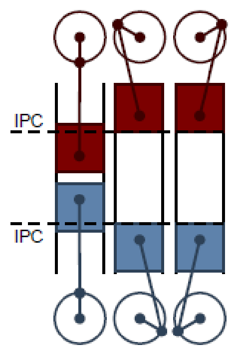
Other

- GPS integration into engine calibration
- Turbo-compounding
- Downsizing and downspeeding

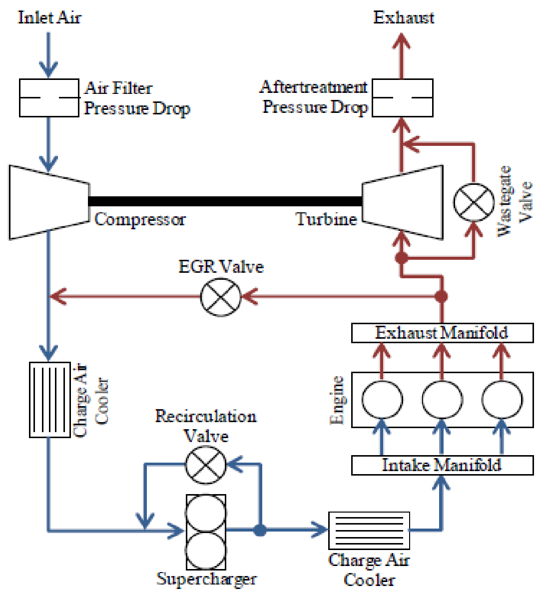
Progress is being made on the 2-stroke/opposed piston engine.

Latest 4.8 liter 3-cyl achieves 45.6% BTE with manageable emissions.

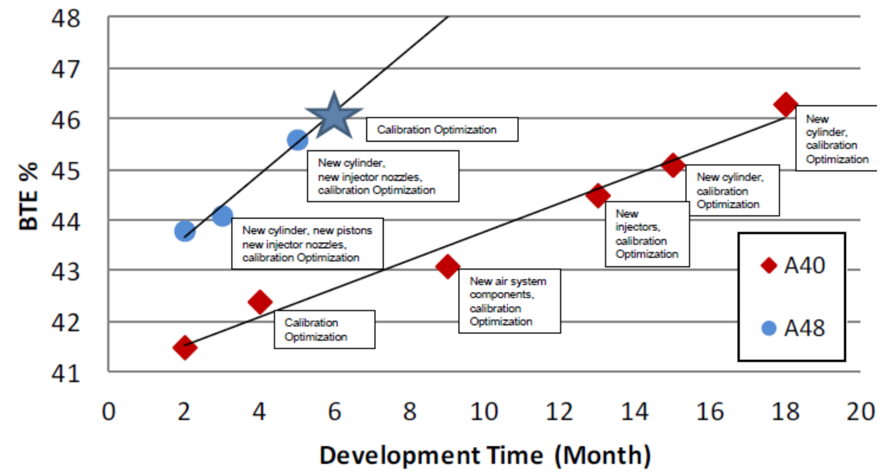
Opposed-Piston Two-Stroke (OP2S) Engine



Engine	OP2S
Cylinders	3
Trapped Volume/Cylinder	1.6 L
Bore	102.6 mm
Total Stroke	224.2 mm
Stroke per Piston	112.9 mm
Stroke/Bore Ratio	2.2
Trapped Comp. Ratio	15:1
Intake Port Closure	120 bTDC



System has supercharger, HP EGR, two CAC, turbine bypass.



Achates Power, GAMC Emissions 2012 June 2012
MTZ HD Conf November 2012

Opposed piston engine has S/B=2.2, 3-cyl, 4.8 liter

Steady state tests show peak BTE of 46% at A100 and 45.6% at A75. Max NOx of 4.5 g/kW-hr at B100. Post turbo temperatures 389C (A100) to 244C (C25).

Case Name	Speed	Torque	IMEP	BMEP	Indicated Power	Brake Power	Indicated Thermal Eff	Brake Thermal Eff	Friction Loss	Pumping Loss	Exhaust + Coolant Heat Losses	ISFC	BSFC	BSNox	BSSOOT	BSCO	BSHC
-	rpm	Nm	bar	bar	kW	kW	%	%	%	%	%	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
A25	1391	251	3.8	3.2	43.9	36.6	52.1	43.7	6.8	1.6	47.9	160.2	192.2	1.633	0.007	0.608	0.465
A75	1391	753	11.0	9.6	125.6	109.7	51.9	**45.6**	4.4	1.9	48.1	160.7	**184.1**	2.934	0.026	0.212	0.245
B50	1775	431	6.8	5.5	99.1	80.2	52.8	43.0	6.7	3.1	47.2	158.0	195.2	1.178	0.007	0.190	0.299
B75	1775	643	10.0	8.2	145.8	119.6	52.6	43.4	5.6	3.6	47.4	158.5	193.3	2.046	0.020	0.134	0.292
C25	2158	180	3.1	2.3	55.5	40.8	52.3	38.7	10.3	3.3	47.7	159.4	217.2	1.621	0.017	0.573	0.584
C75	2158	533	8.5	6.8	151.5	120.5	51.8	41.4	6.6	3.7	48.2	161.2	202.6	4.279	0.009	0.093	0.359

NG trucks are emerging.

This time driven by cost reduction, not emissions reduction.

Fuel Price Report

FUEL PRICES	Week of Oct 8
CNG Compressed Natural Gas	$2.37*
LNG Liquefied Natural Gas	$2.92*
Diesel	$4.09
Gasoline	$3.47*

**Diesel Gallon Equivalent*

Diesel and gasoline data from the U.S. Energy Information Administration. CNG and LNG data from a nationwide price survey of Clean Energy Fuels public-access stations.

Current differential price of CNG is $1.72/gal less than diesel. LNG is $1.17/gal.
CleanEnergyFuels.com

	FC vs. diesel	Emissions system	Attractive Segments	Notes
SI – stoich	+10-15%	TWC	Refuse trucks, transit buses	• CNG preferred • Payback period on cost 1.5 to 2 yrs
CI-lean, diesel pilot inj.	Similar	Same	High-mileage applications	• Generally LNG. • Line-haul interest. • Different versions include integrated or different injectors

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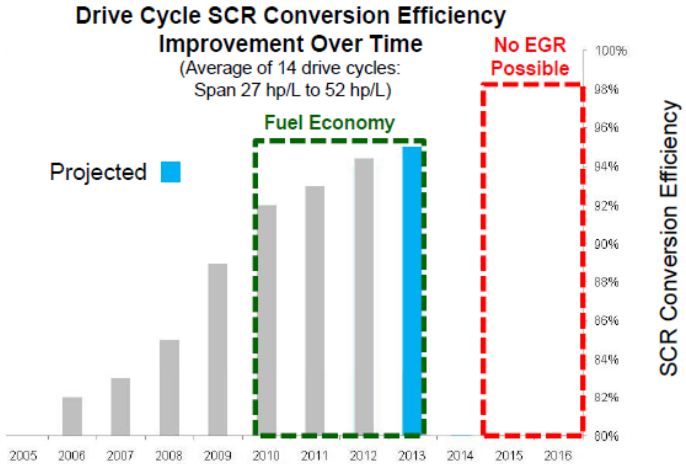
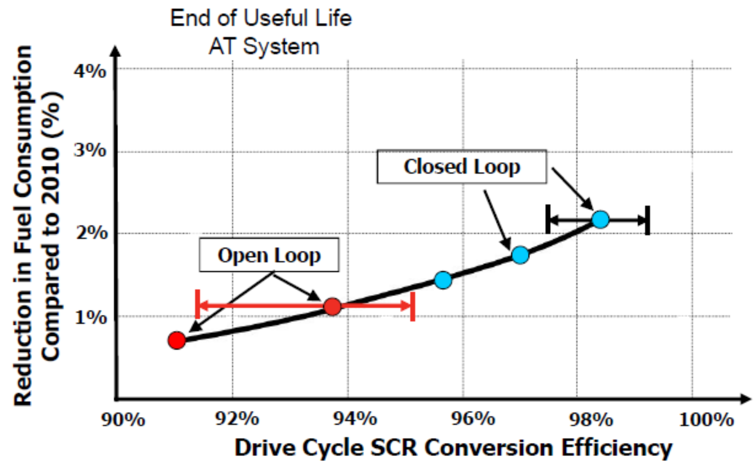
deNOx

Cummins shows that improved SCR performance can take off EGR and decrease fuel and fuel+DEF costs.



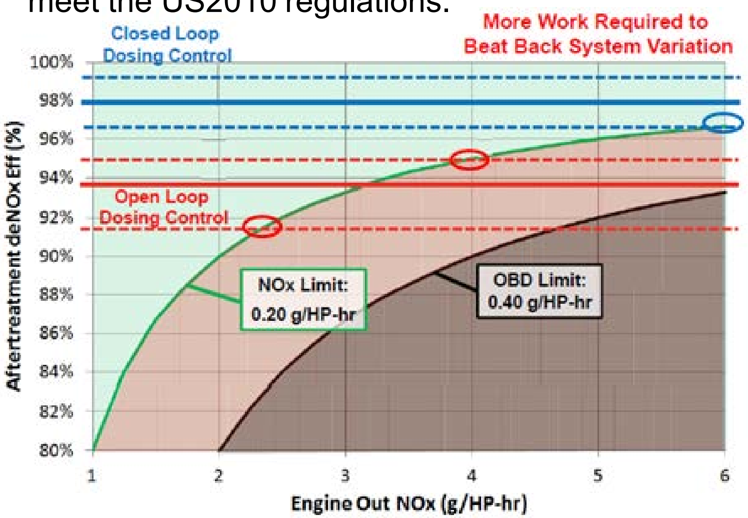
If SCR efficiency attains 98% (nominal 8-10 g/bhp-hr engine out NOx), EGR will not be needed to meet the US2010 regulations.



Closed-loop SCR control increases deNOx efficiency and decreases variability.

Other Improvements Needed for SCR

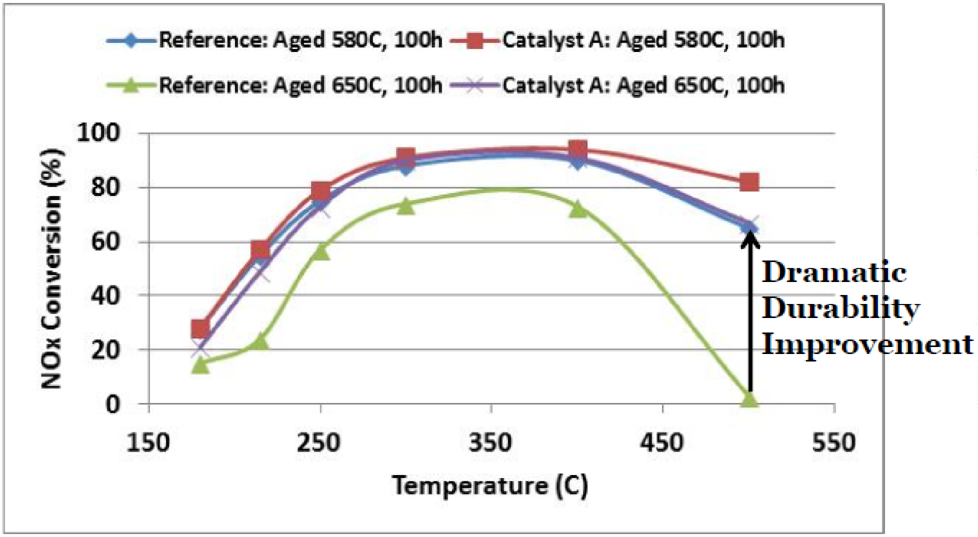
- Better understanding of SCR deactivation mechanisms for EUL robustness
  - Hydrothermal, low temp. water interaction (reasonable understanding)
  - Sulfur deactivation (less understood)
- SCR substrate
  - Reduced Catalyst Size: higher cell density and reduced wall thickness for higher power density
  - Formulation to reduce N_2O (robustness to GHG regulations at higher power density)
- Reduced SCR NOx conversion variation
  - Sensor technology
  - SCR catalyst part-to-part variation
- OBD



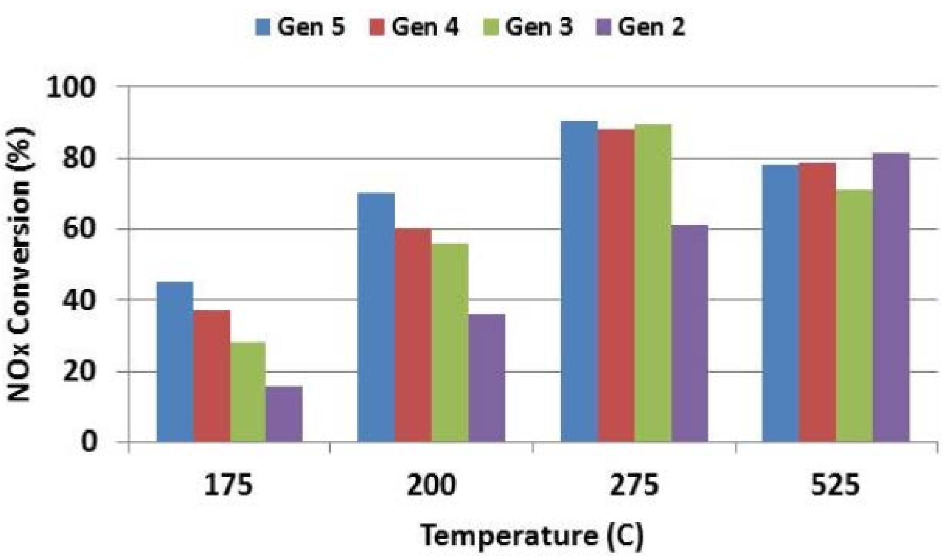
Reduced variability and higher deNOx efficiency allows significantly higher engine-out NOx.

Cummins, CTI NOx Conf 6-12

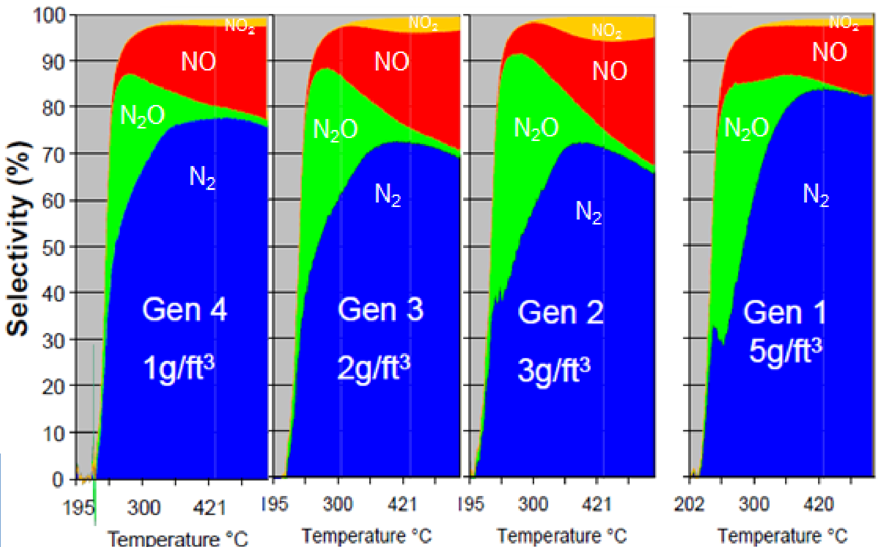
SCR catalysts are continuously improving.



New vanadia catalysts have improved HT durability. Marked improvement after 650C aging for 100 hr.



Cu zeolites aged for 100 hrs at 650C. SV=100,000/hr

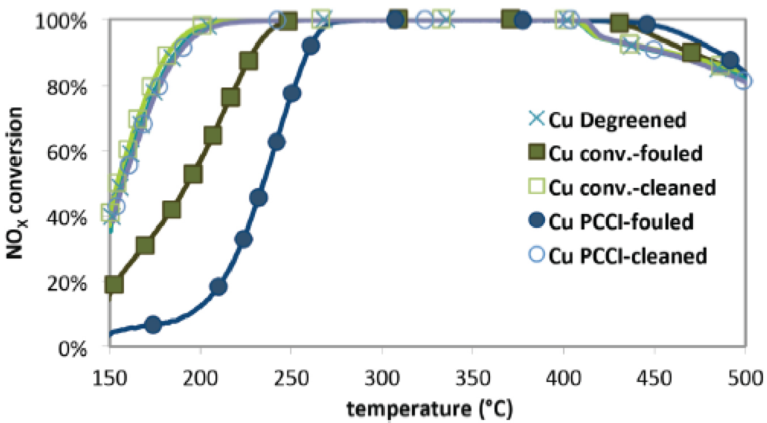


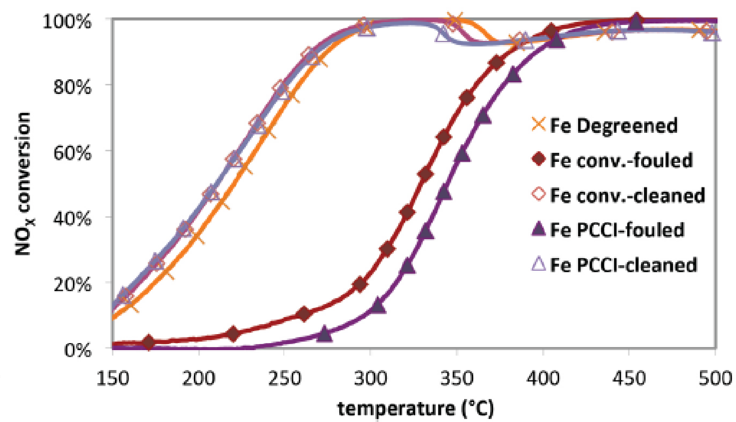
JM, SAE HDDE Symp. 9-12

PGM content of NH3 slip catalyst dropping while maintaining N_2 selectivity.

HC impact on CuZ and FeZ is explained.

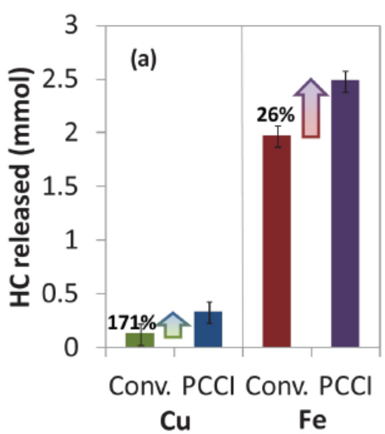
FeZ much more susceptible, but insensitive to combustion mode. CuZ (chabazite) more sensitive to PCCI (smaller HCs)

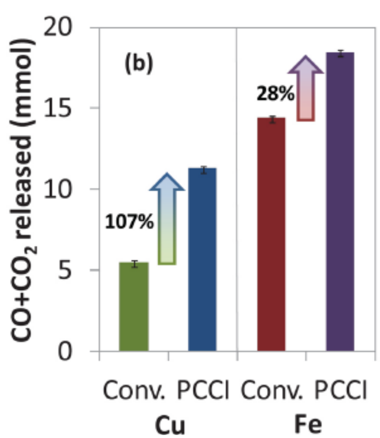




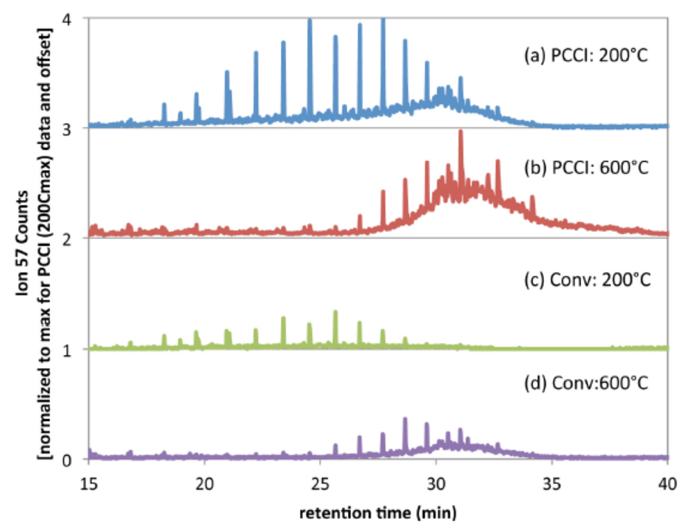
All curves come together at a temperature wherein HCs begin to oxidize rather than desorb.

CuZ (chabazite) is much less sensitive to all HC poisoning than FeZ. Both recover. PCCI HCs affect CuZ more than HCs from conventional combustion.





FeZ adsorbs much more HCs. CuZ is more sensitive to combustion source of HCs, indicating species selectivity. CuZ has strong HC oxidation potential.

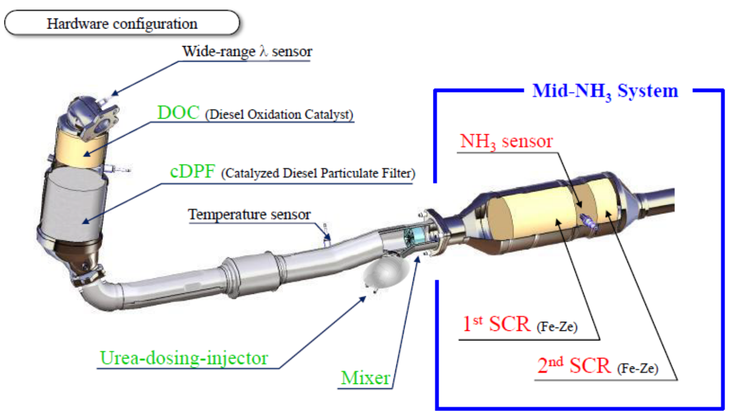


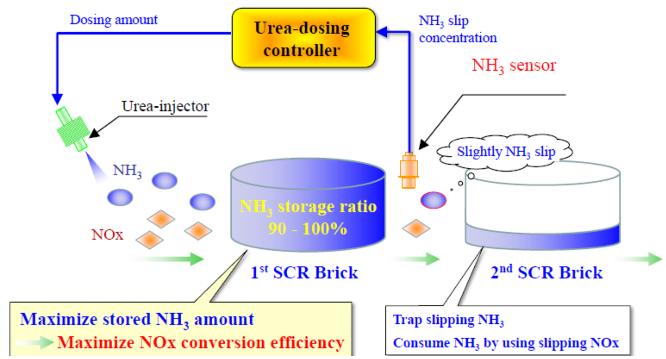
Pyrometry GC-MS shows more small HCs for PCCI coming off zeolite. Large HCs coming off at 600C likely from soot oxidation.

NH3 storage capacity is not affected by HC adsorption for either zeolite.

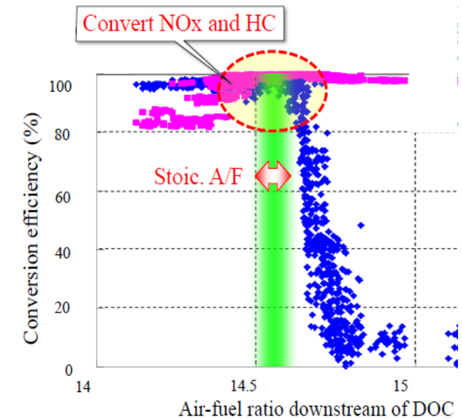
ORNL, SAE 2012-01-1080

Honda/Delphi SULEV LDD approach much EGR, uses stored NH_3 (slow SCR heat-up), and stoich DOC for deNOx



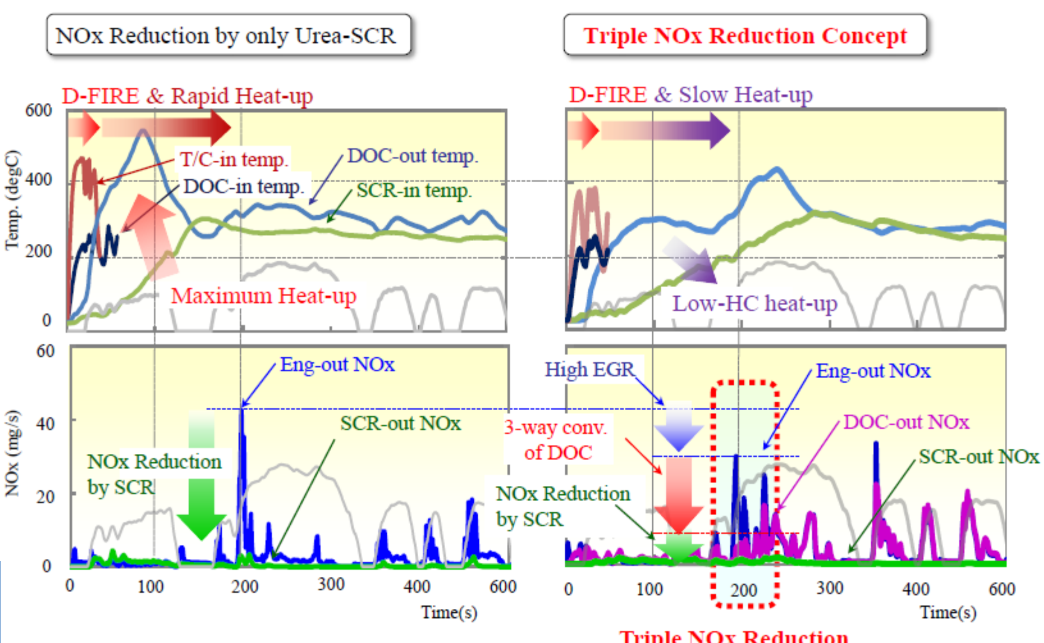


Stored NH3 strategy is important. NH3 sensor and two SCR are key.



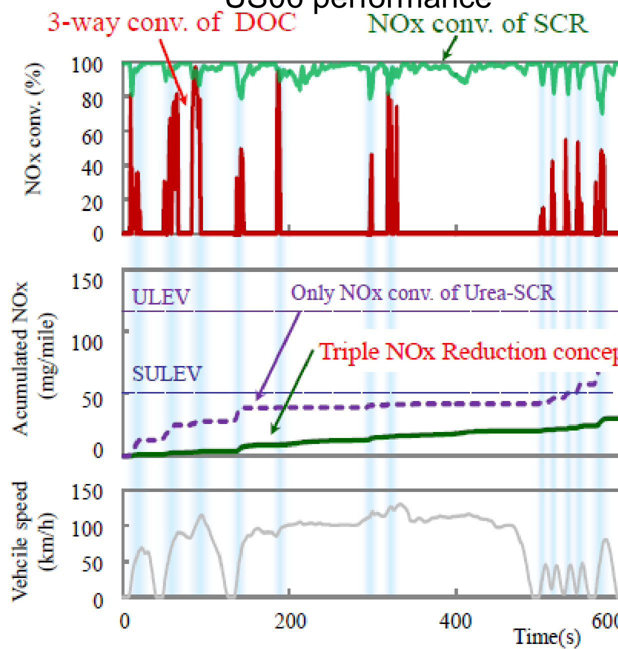
Stoich op allows DOC 5 mg/mi deNOx on FTP and 45 mg/mi on US06

FTP performance

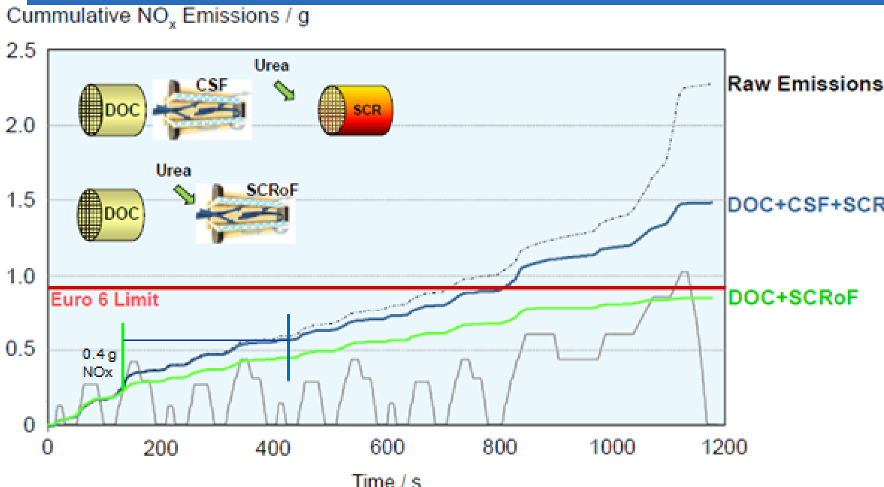


Triple NOx strategy (EGR stoich DOC, stored NH3 SCR) drops NOx more than a fast heat-up SCR-only strategy.

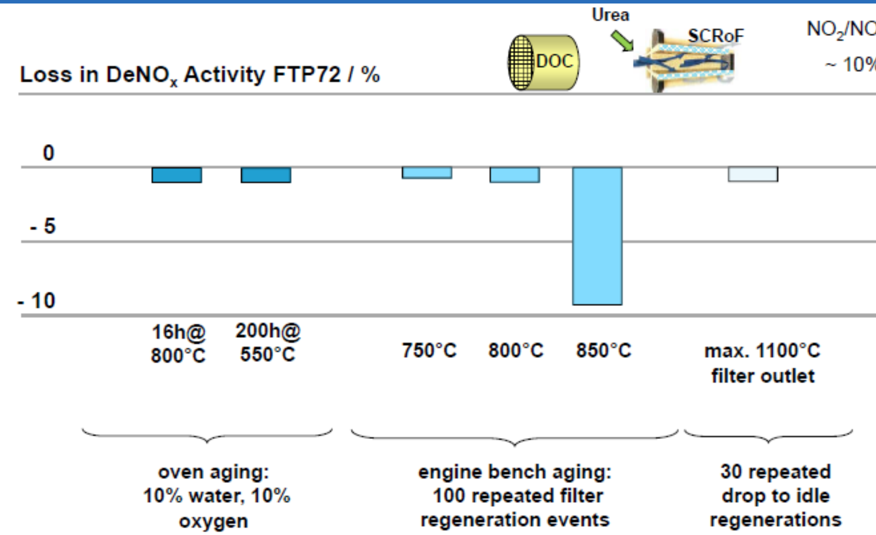
US06 performance



SCR on DPF has big light-off advantage. It can also sustain DPF regens. deNOx possible during regen.

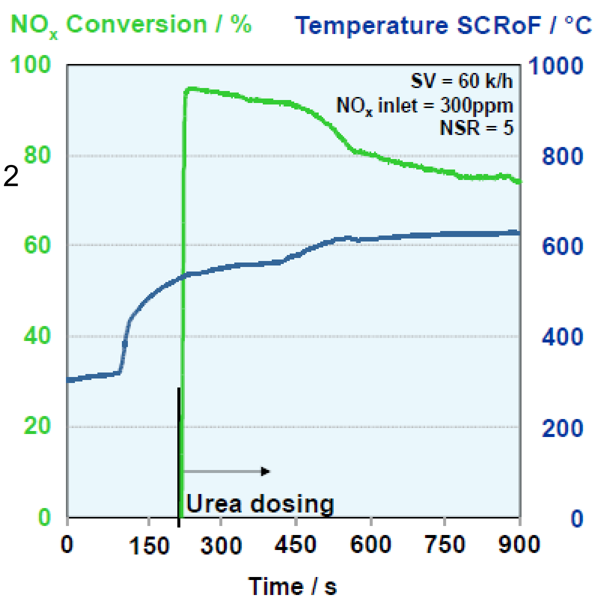


Half of the SCRoF benefit vs. SCR is realized before downstream SCR is even functioning.

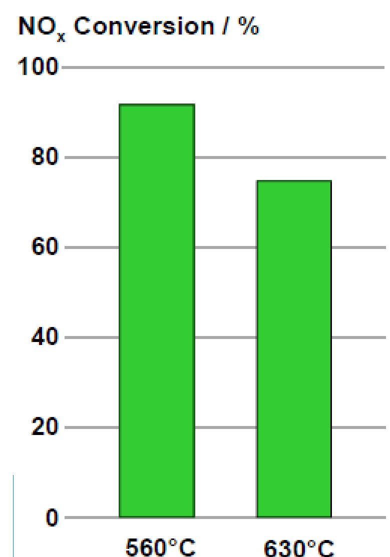


SCRoF catalyst can sustain 30 DTI regens and >100 regen exposures to 800C.

BASF, IAV MinNOx conf 6-12



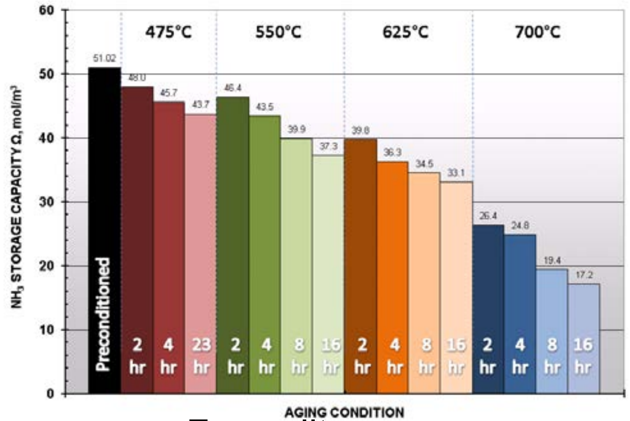
NH3 can be injected during DPF regen for 70-90% deNOx



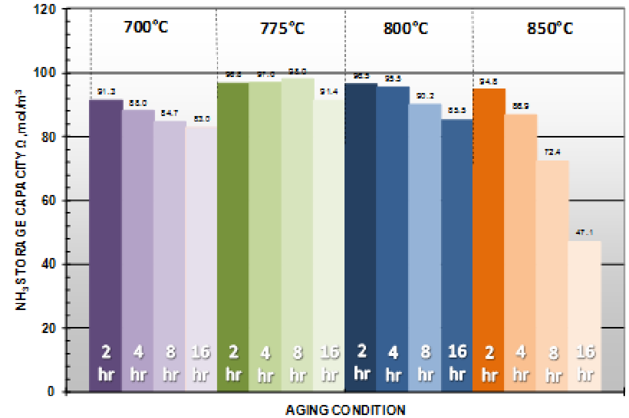
Ammonia storage capacity is characterized as a function of aging. Predictable from aging profile.

Raw Ammonia Storage Aging Data

- Groupings are aging temperature
- Bars are time at temperature



Fe zeolite



Cu zeolite

1st Principle Adsorption Equations Used to Determine Aging Parameters

Fe zeolite:

$$t_c = t_{c-1} + e^{\left[-\frac{Ed}{R}\left(\frac{1}{T2}-\frac{1}{T1}\right)\right]}$$

$$\Omega = \Omega_0 - t_c * \left[\left(A * e^{\left(\frac{Ed}{RT1}\right)}\right) * \Omega_0 + (x - yT_1)\right]$$

Cu zeolite:

$$t_c = t_{c-1} + e^{\left[-\frac{Ed}{R}\left(\frac{1}{T2}-\frac{1}{T1}\right)\right]}$$

$$\Omega = \Omega_0 - t_c * \left[\left(A * e^{\left(\frac{Ed}{RT1}\right)}\right)\right]$$

	PERCENTAGE ERRORS			
	TEMPERATURE, Kelvin			
Aging, Hrs	748.15	823.15	898.15	973.15
2	4.6	2.6	0.4	7.7
4	8.6	2.9	5.3	17.6
8		4.5	5.8	9.0
16		4.2	6.0	9.6
Average % error =		6.3		

Comparative Errors

	PERCENTAGE ERRORS			
	TEMPERATURE, Kelvin			
Aging, Hrs	973.15	1048.15	1073.15	1123.15
2	0.0		0.0	0.0
4	2.4		2.6	2.5
8	3.6		4.8	7.1
16	0.1		16.2	15.8
Average % error =		6.1		

Comparative Errors

Auto consortium formed to look at adsorbed NH3 concept. RDE, OBD, costs promising.

Consortium "Out of the Blue"

Jaguar, IAV MinNOx conf 6-12

- Founded in summer 2010
- Members are Honda, Jaguar Land Rover, Toyota and Volvo - others are welcome!
- Purpose is evaluation of ammonia dosing and delivery system
- Sharing cost but also sharing information and working towards common solutions

Work completed so far include

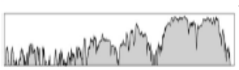
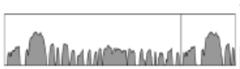
- Demonstration of Euro 6 NO_x emission level
- Demonstration of good NO_x conversion rates in off-cycle conditions
- Demonstration of robust dosing software application (minimized NH_3 slip)
- Feasibility study of OBD concept
- Study of cartridge infrastructure concept (refilling, recycling)
- Discussion on standardisation, development of key components and cost estimates

Future aspects of ASDS technology

- Standardisation, safety and legal aspects

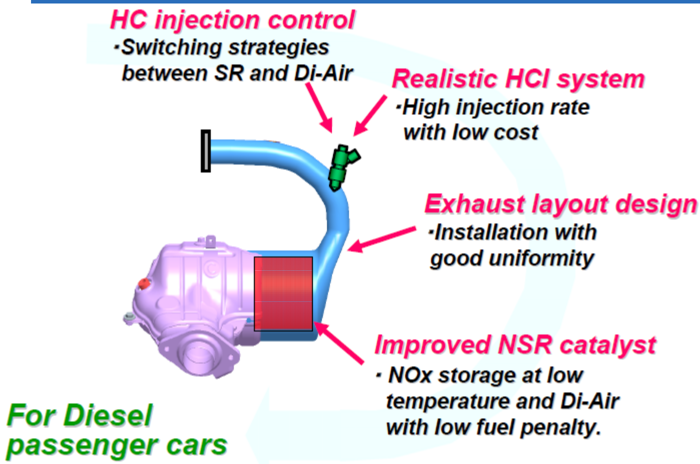
- RDE in the city shows good performance.
    - NH3 storage still important, but can refill at 100C.
    - 72-91% deNOx in variety of city driving
- OBD similar to current SCR. Concerns on fill level detection.
- LPG tank refill model; 42,000 km with two tanks
- Cost similar or lower than AdBlue to OEM and users

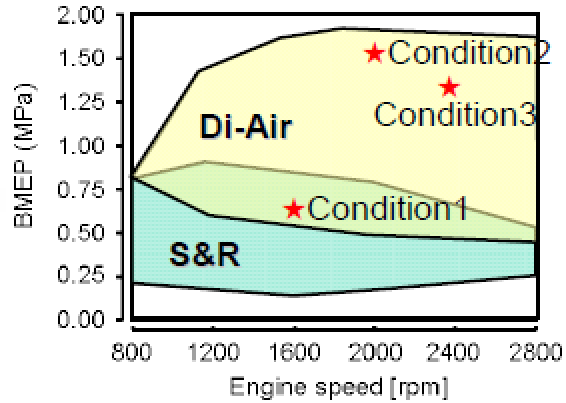
Euro 6 target NO_x: 80 mg/km

		NO_x mg/km (mg/mi)	NO_x conversion in %	CO_2 g/km (g/mi)	Fuel l/100km (mpg)
NEDC		77	48	175	6.7
Artemis 130		73	86	167	6.3
FTP75		93 (149)	75	194 (310)	7.2 (32.7)
US06		96 (153)	91	181 (289)	6.7 (35.2)

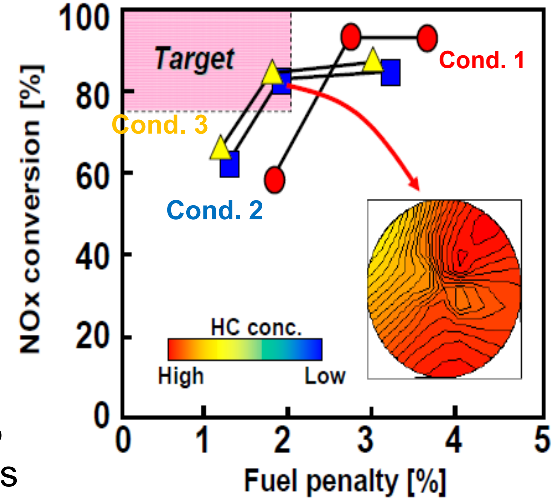
Testing conditions
- All tests with NEDC dosing calibration, aged catalysts and max 20ppm NH_3 slip
- Ammonia dosing release temperature set to 100°C upstream SCR
- All tests with pre-stored ammonia

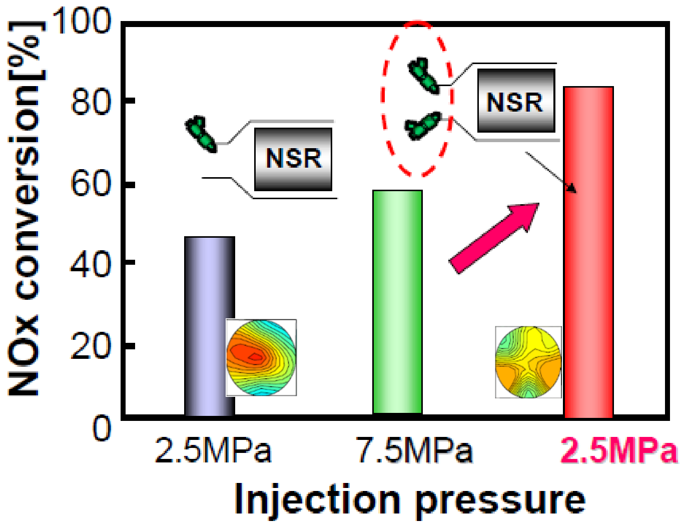
Some application fundamentals are described for the Di-Air system.



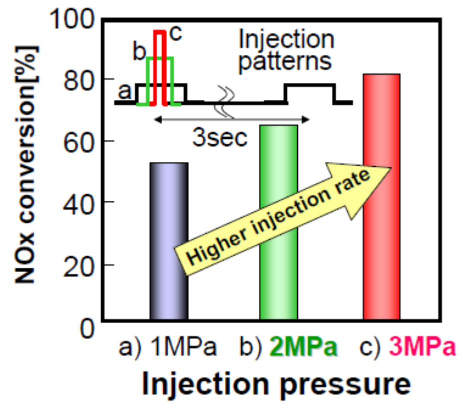


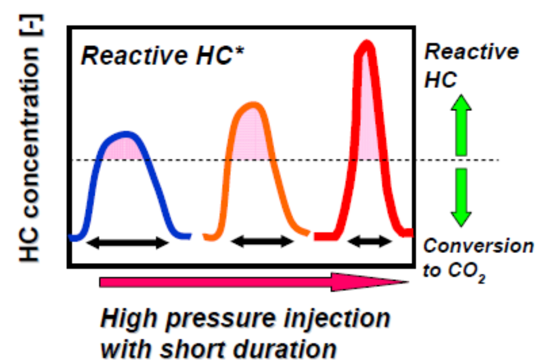
To achieve the goal of >75% deNOx with <2% FP, Di-Air is needed for conditions 2&3.





Good mixing is important.

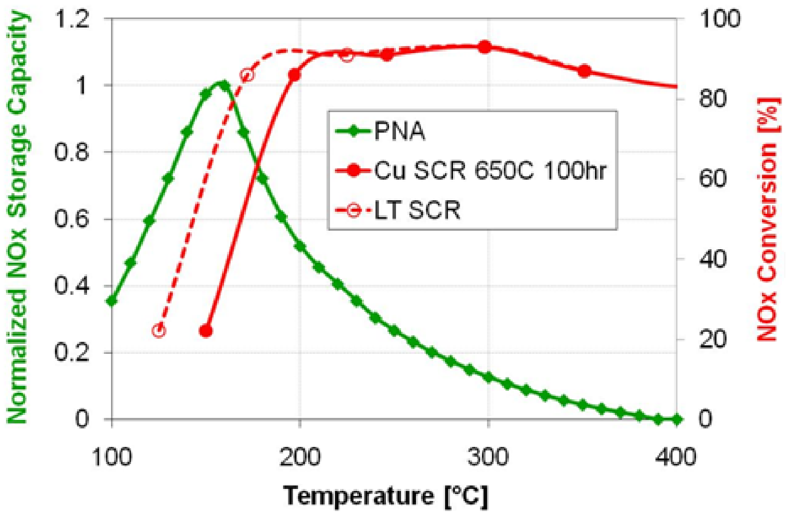


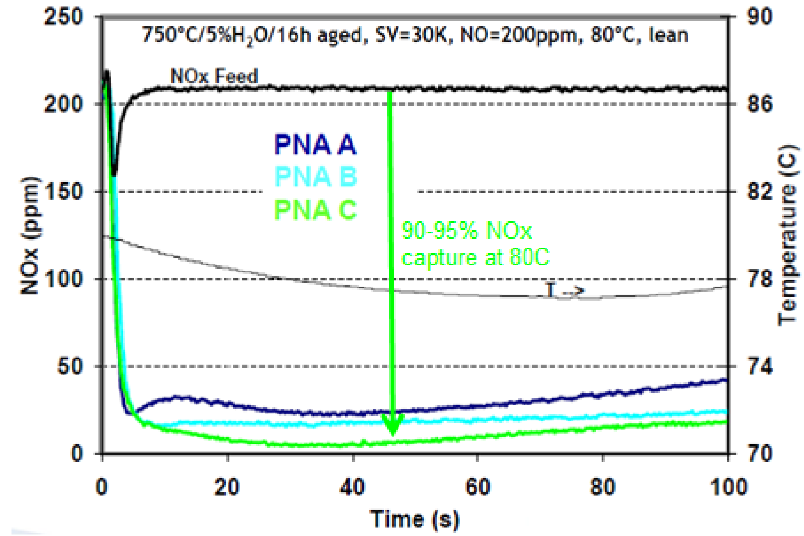


HP injection of short duration increases HC intermediaries and improves deNOx perf.

Passive NOx Adsorbers (PNAs) are being designed to work better with SCR for LT deNOx.

Adsorption at 80C, release starting at 250C.





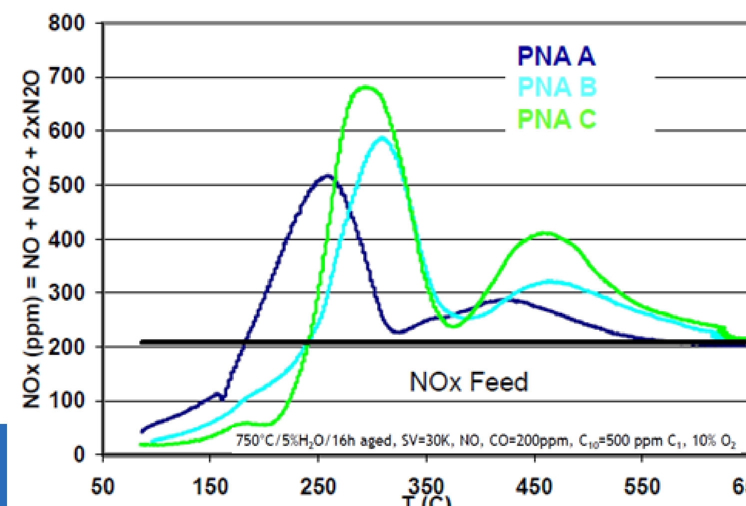
Concept is to adsorb NOx on PNA at LT, and capture it with SCR upon passive thermal release.

Cummins, DEER Conf 10-11

PNA materials are improving. Aged samples remove 90-95% of NOx at 80C. Maintain capture efficiency for ~2 minutes.

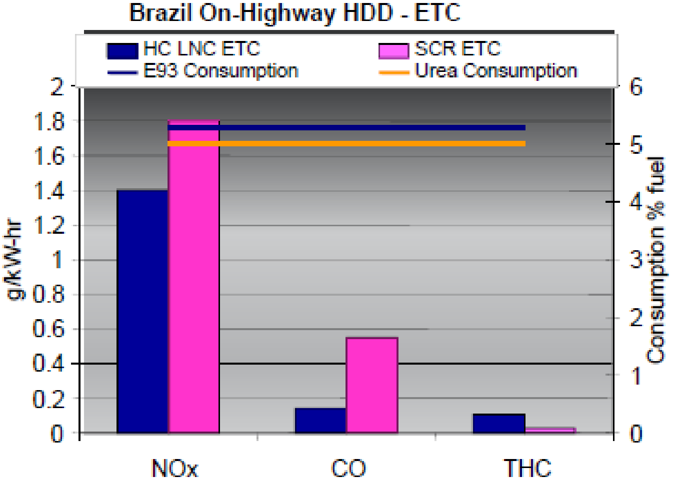
JM, SAE HDDE Symp., 9-12

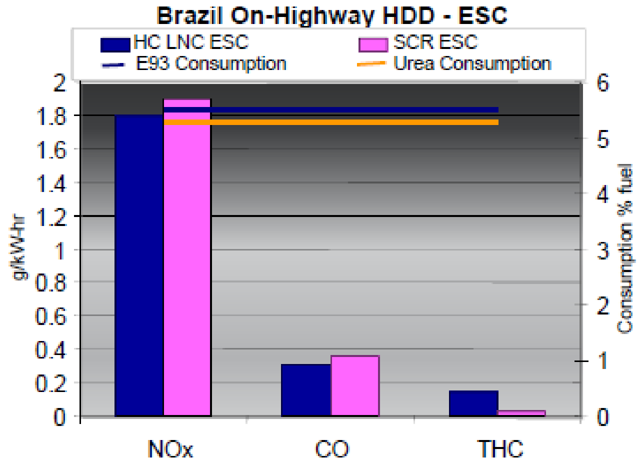
PNAs have different NOx release temperatures and properties.



The LNC system is of much interest in Brazil.

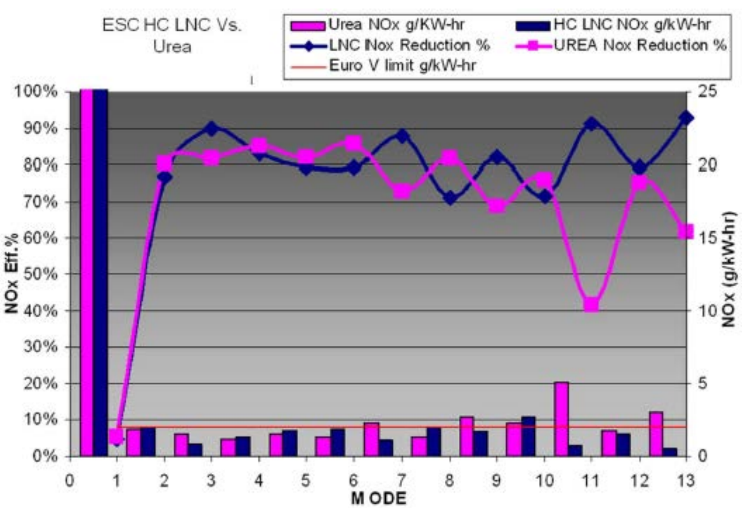
E93 reductant has advantage over urea in materials, deposits, evaporation.



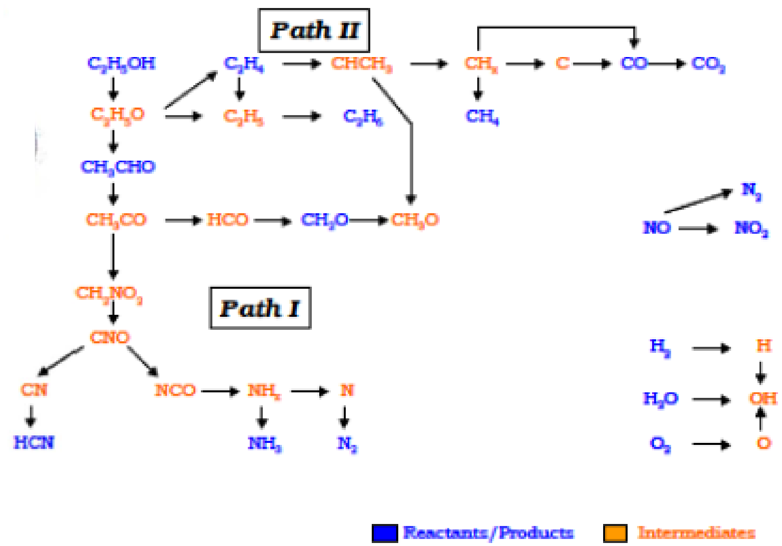


Tenneco, Integer Conf, 6/12

Steady state results are similar between urea and E93 deNOx systems.
Transient results are better for E93.



LNC E93 system performs better in mode 10 at HT.



CORNING

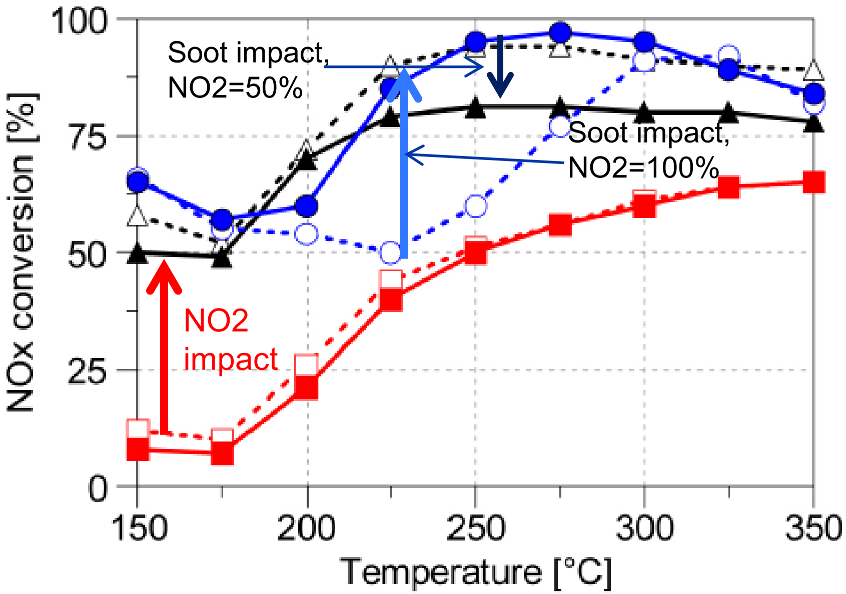
Environmental
Technologies

PM

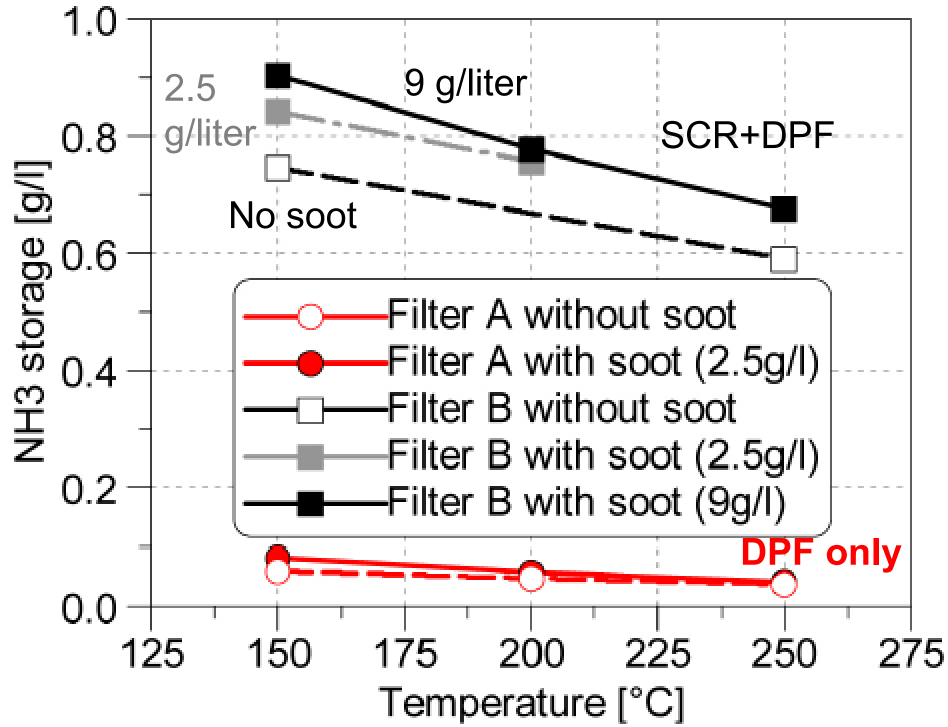
"“For comparison, an 18-wheeler diesel engine truck would have to drive 143 miles on the freeway to put out the same mass of particulates as a single charbroiled hamburger patty,” said Bill Welch, the principle engineer.

Univ Calif, Riverside Study, Sept 2012

Soot may provide synergies for NH3 storage on SCR+DPF systems.



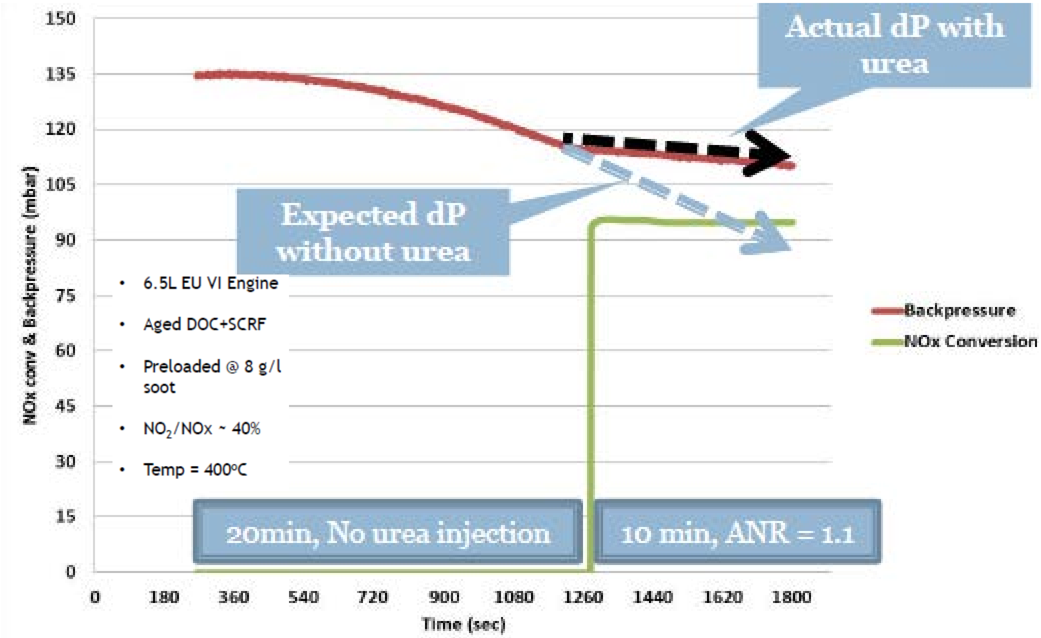
NO2 goes to the soot preferentially over the SCR catalyst. With CuZ on a DPF, 5 g/liter soot has no impact on deNOx with 0% NO2, reduces deNOx at 50% NO2, but improves deNOx at 100% NO2.



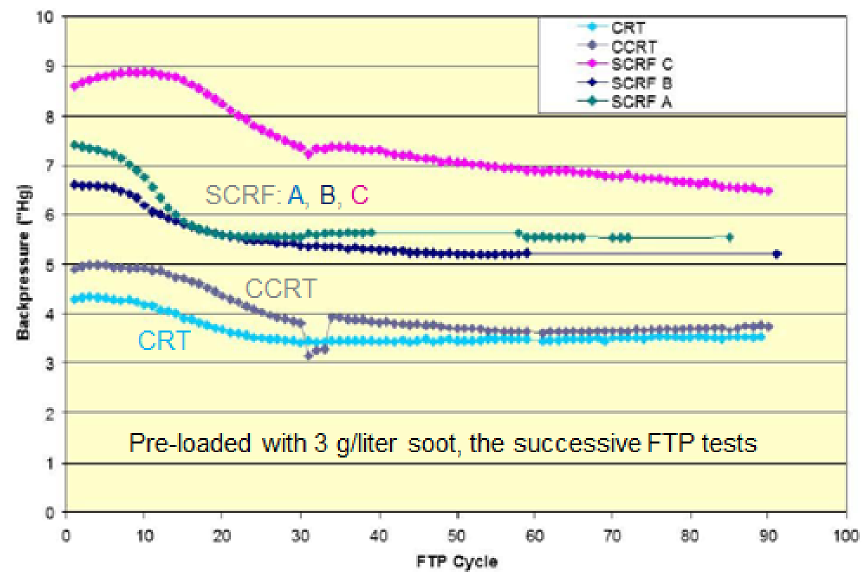
Soot on an uncoated DPF has no impact on NH3 storage. However, it favorably affects storage if Cu-zeolite is used.

IAV SAE 2012-01-1083

NH_3 can interfere with SCR+DPF regeneration. However, filter still regenerates on the HD FTP.



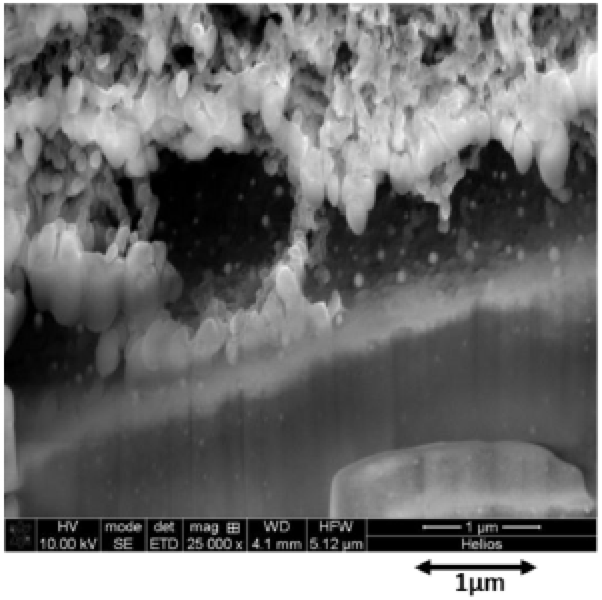
Upon urea injection, DPF regeneration decreased.



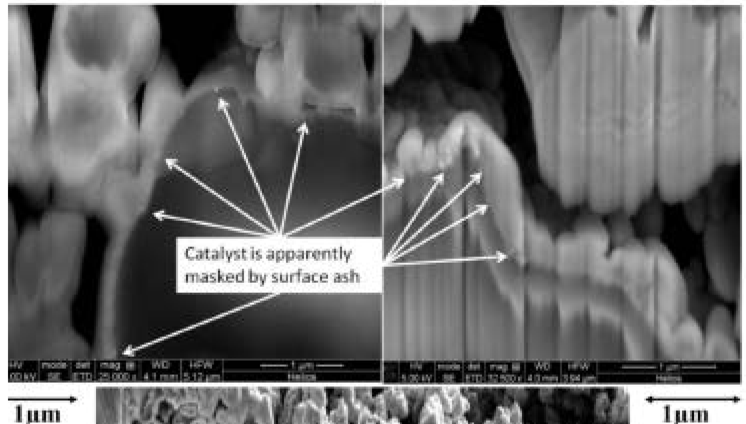
SCRF can regenerate in HD FTP testing. SCRF run for 90% deNOx

JM, SAE HDDE Symp., 9-12.

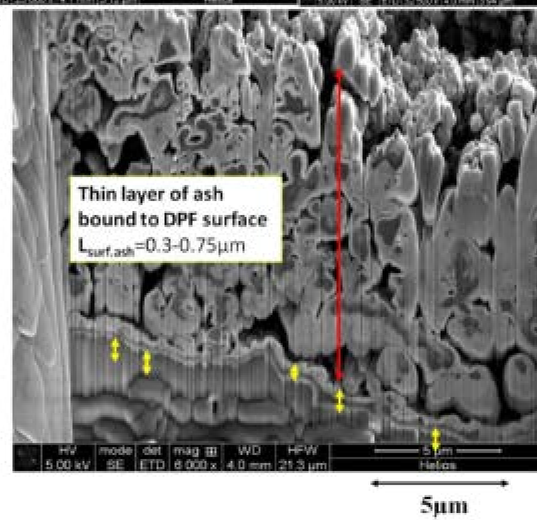
A new Focused Ion Beam (FIB) milling technique is used to analyze DPFs. Insights into ash effects on soot oxidation and ash morphology.

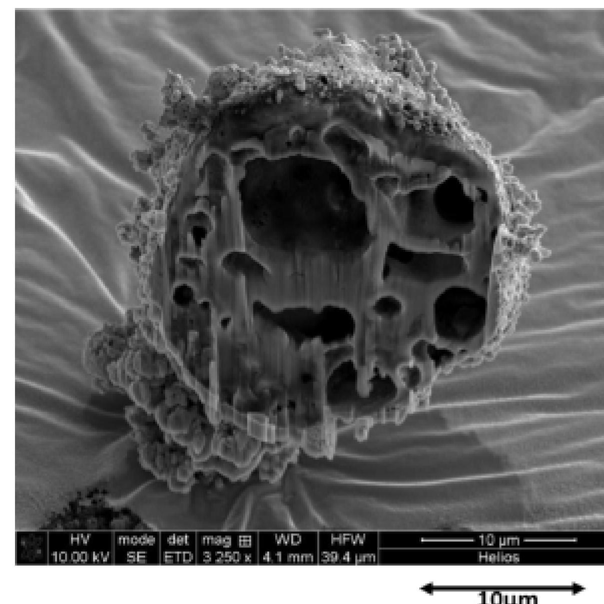


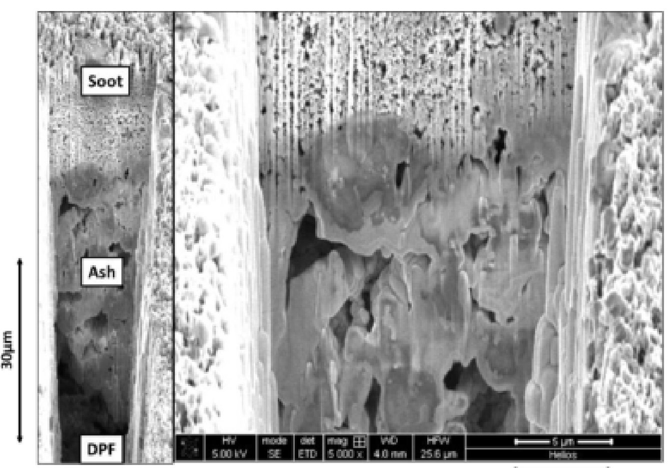
Gaps are apparent between catalyst and soot. NO_2 recycling or O spillover.



MIT, SAE 2012-01-0836







Above: Catalyst is coated with ash. If heated to >800C, it can densify. Left: No gap between soot and ash indicates loss of NO_2 recycling. No soot penetration of ash.

All analyzed ash particles were hollow.

CORNING

Environmental Technologies

DOC

New oxidation catalysts are emerging that can oxide NO and methane at substantially lower temperatures.

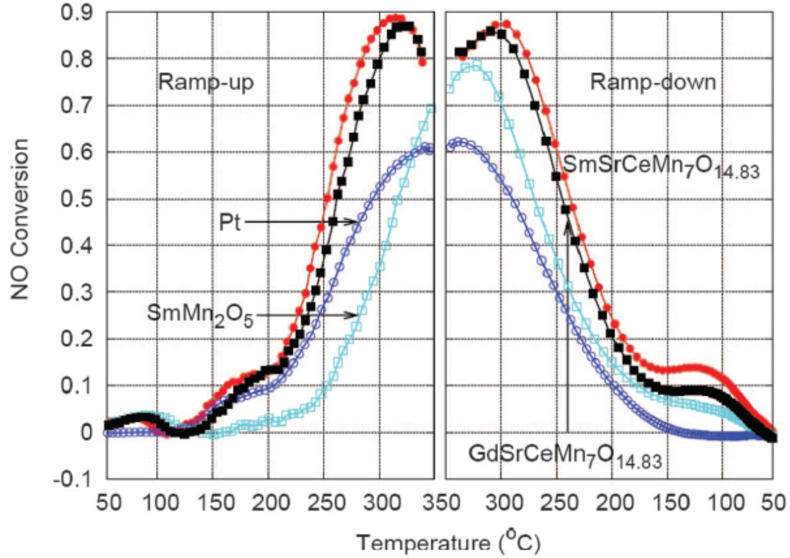
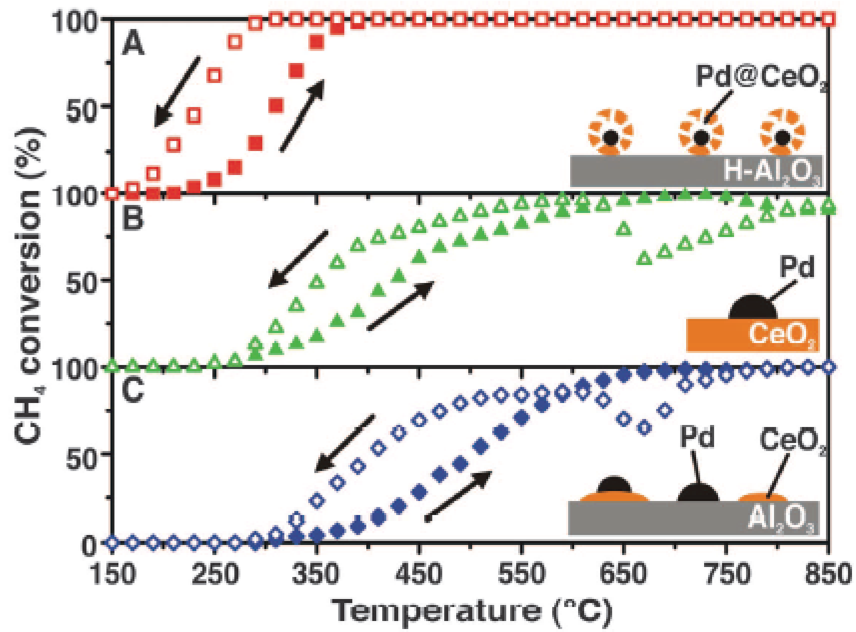


Fig. 1. NO conversion versus ramp-up and ramp-down temperatures for MnCe-7:1 (●), $SmMn_2O_5$ (□), $GdSrCeMn_7O_{14.83}$ (■), and Pt (○).

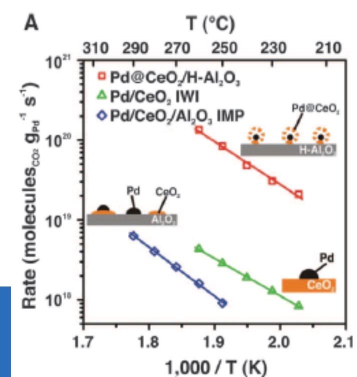
New manganese-based DOC oxidizes NO to 90% NO2, and drops optimal oxidation degree (50% NO conversion) by 50°C.

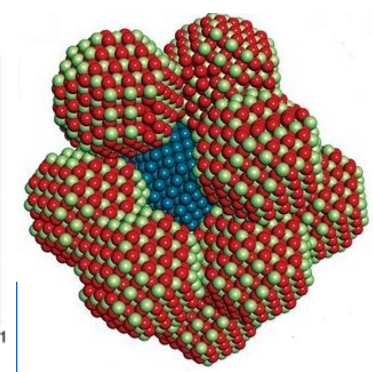
Nanostellar, Science Magazine, 8/12



New methane oxidation catalyst T50 from 400-500C down to 300C.

Univ Penn, Science Magazine, 8/12





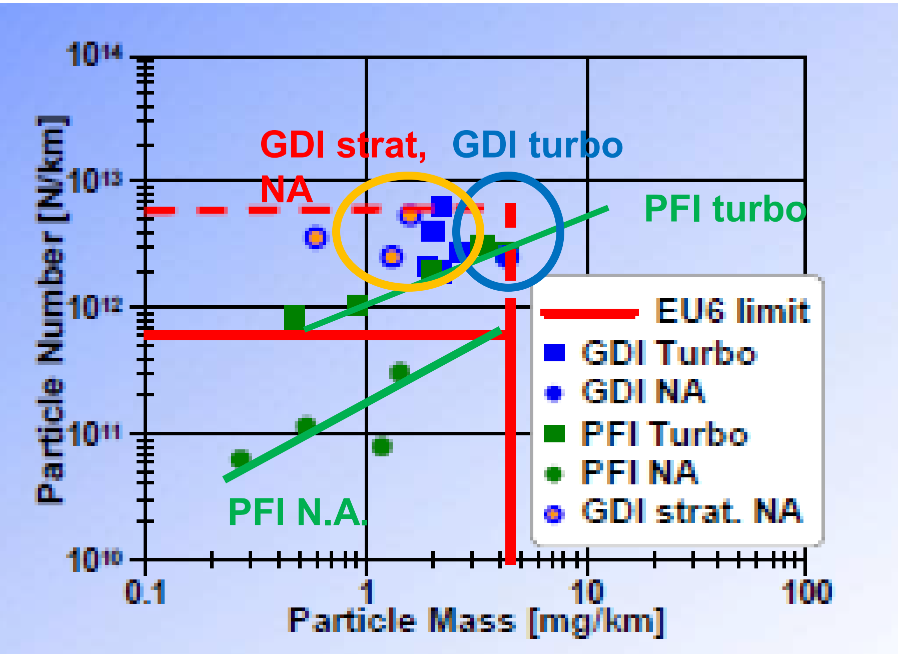
CORNING

Environmental
Technologies

Gasoline

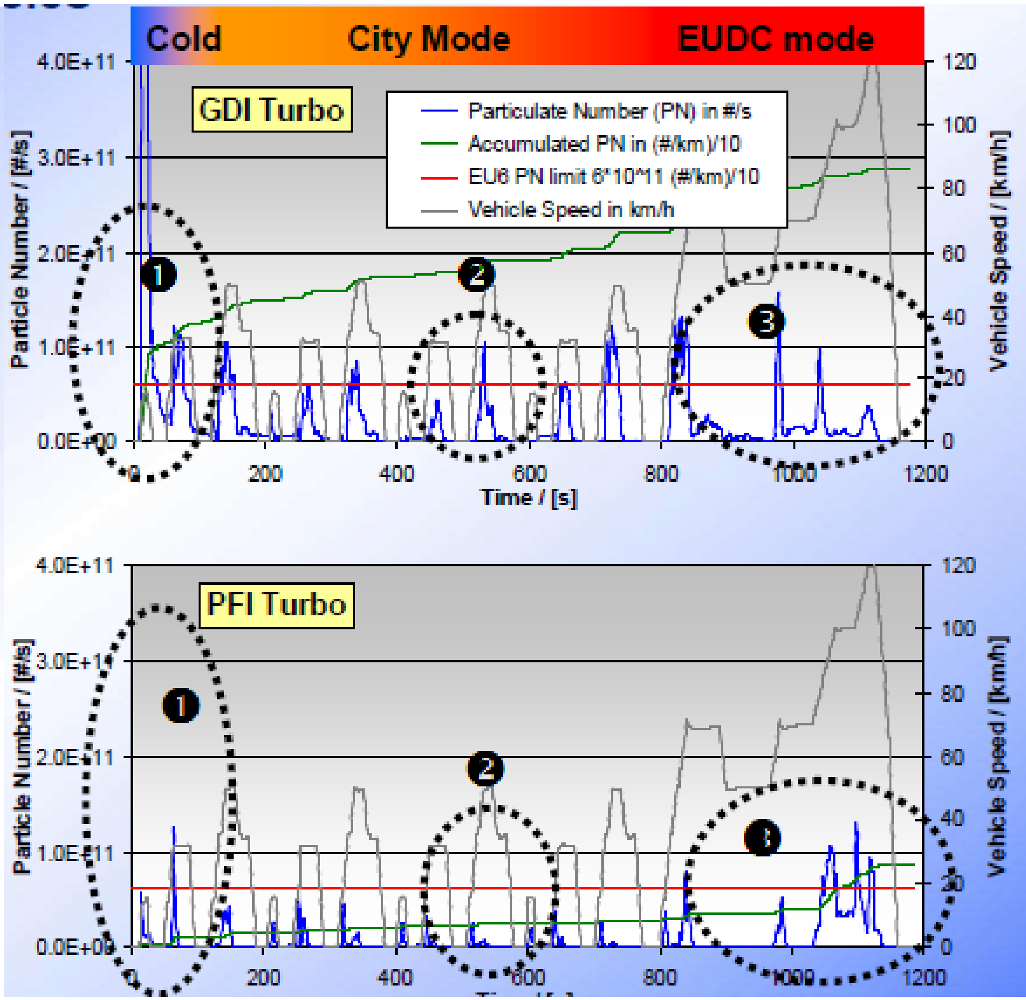
PN emissions are quantified. Status quo GDI and turbo-PFI exceed PN regulation.

Cold start issue for GDI, high speed emissions for PFI.



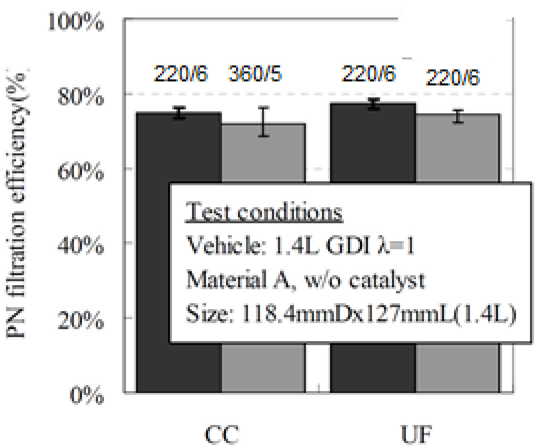
At low PM level, PN can vary up to 70X. Turbo PFI, and GDI exceed 2017 PN standard.

Hyundai, IQPC Conf 5/12



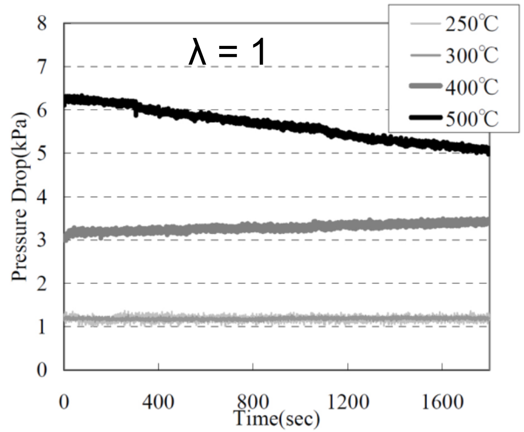
1. Warm up: PFI has lower PN; GDI fails during cold start
2. Vehicle acceleration: PFI has lower PN
3. High speed: PFI has higher PN

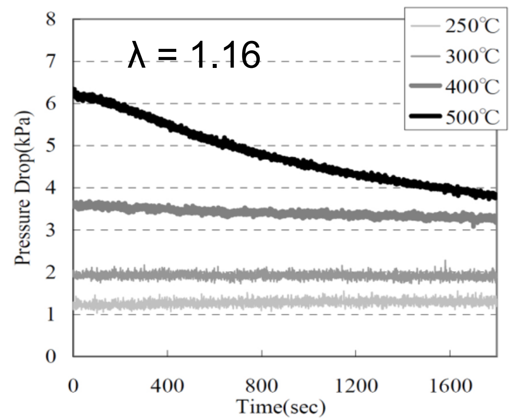
More is learned on GPF filtration efficiency with location, soot burn behavior and ash effects. Location matters little on ε. Slightly lean aids regen, but is not needed. Low ash load can help soot back pressure.



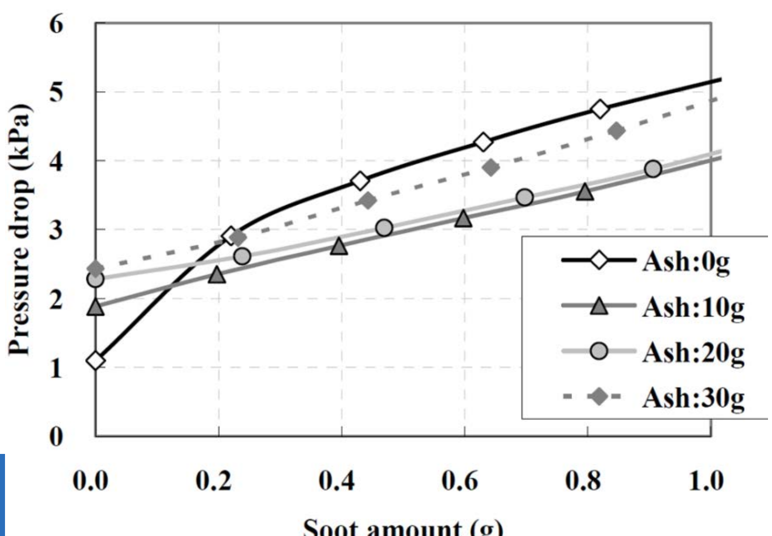
No significant difference in filtration efficiency with cell geometry nor location.

NGK, SAE 2012-01-1241



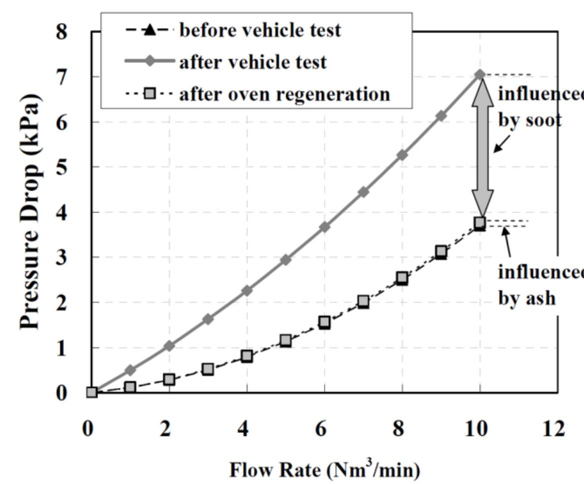


Slightly lean operation aids regeneration (left), especially at the higher temperatures. Need T>500C for stoich (1-1.6% O_2) and T>400C for lean.



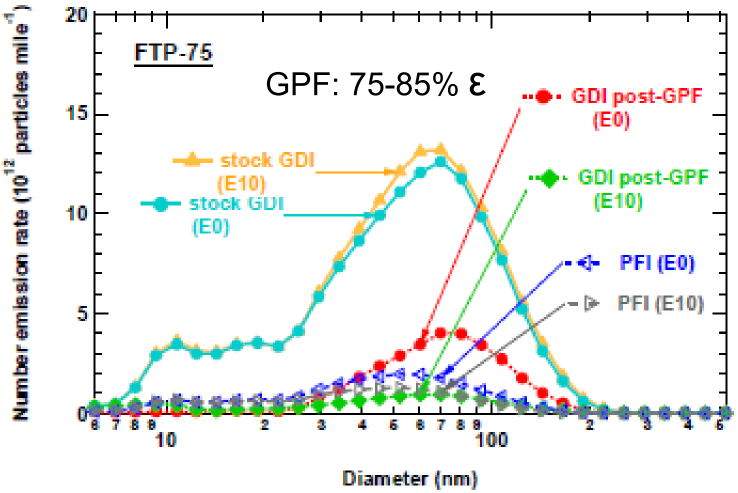
Soot-loaded Δp is initially higher with ash, but is then lower as soot is loaded. Ash keep soot from entering the wall.

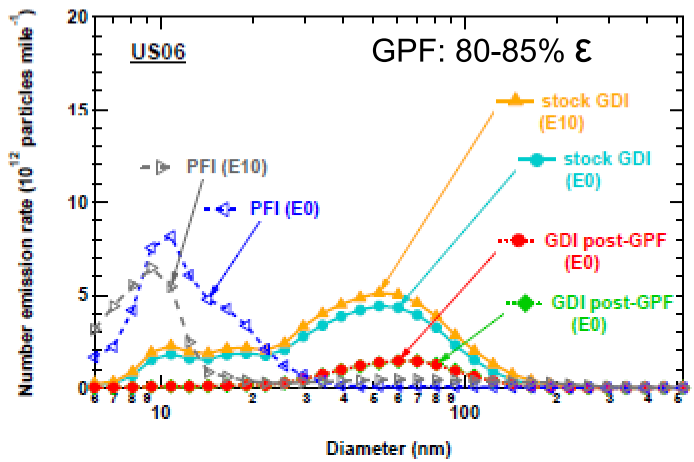
200/12, soot generator



Almost all of the loading Δp contribution is soot.

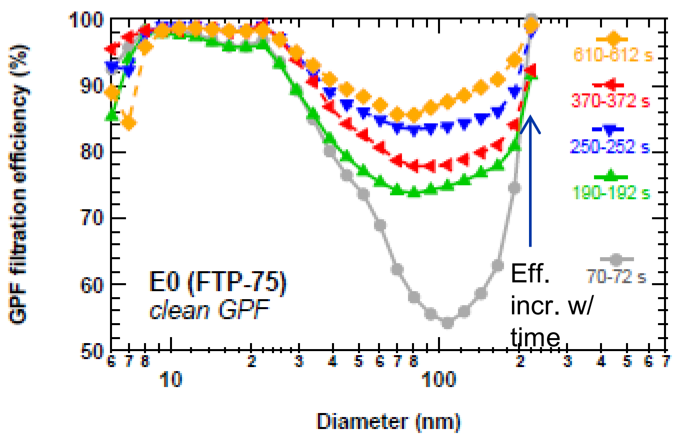
PN emissions for Tier 2 Bin 5 GDI and PFI were measured on the FTP and US06 cycles on E0 and E10. GPF removes 80%



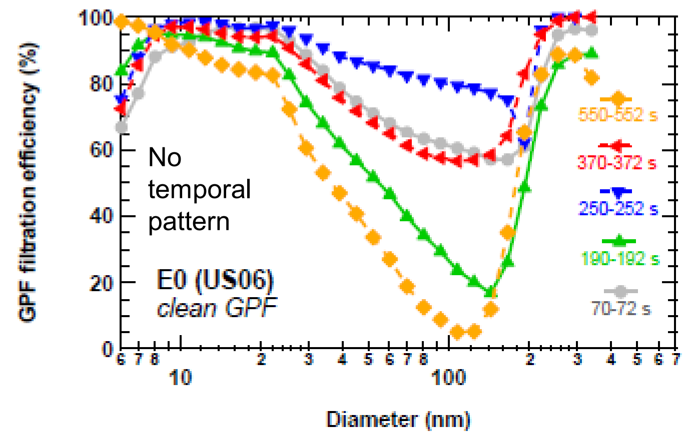


Environ Canada, SAE 2012-01-1727

GDI and PFI solid PN size distributions for E0 and E10 on the FTP-75 and US06 test cycles. FTP-75 has higher emissions (peak at 30 X 10^{12}/mile due to the cold start. High nucleation mode (10 nm) in US06 for PFI may be due to difficult A/F control and ash.

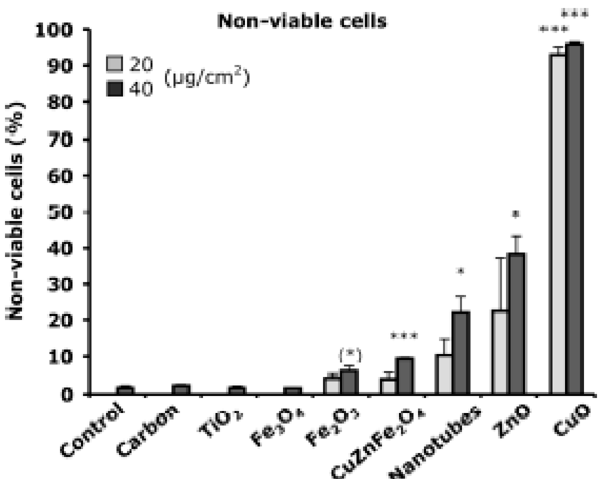


The GPF filtration eff depends on state of the filter cake. In the FTP, the cake builds with time. On the US06, there are frequent losses of the cake.

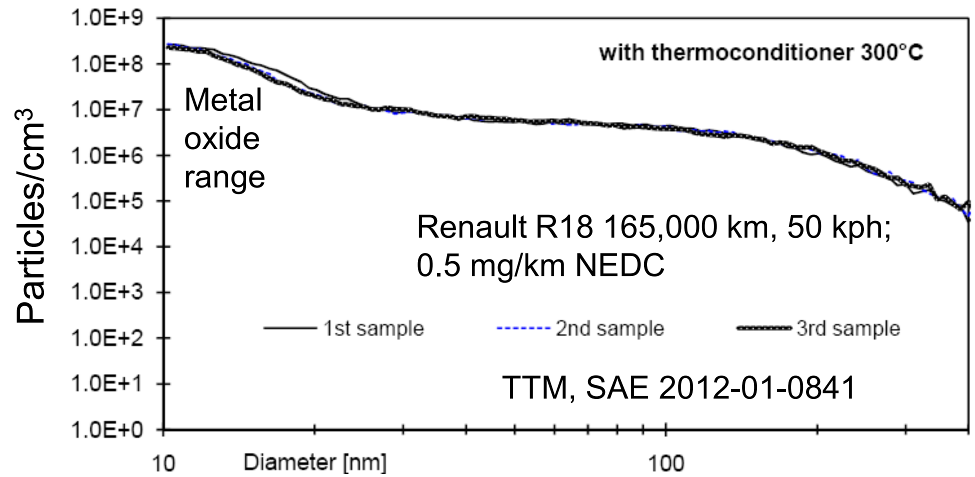


Interest in metal ash emissions is emerging. Measured for new T2B5 GDI and PFI cars, and old Euro car.

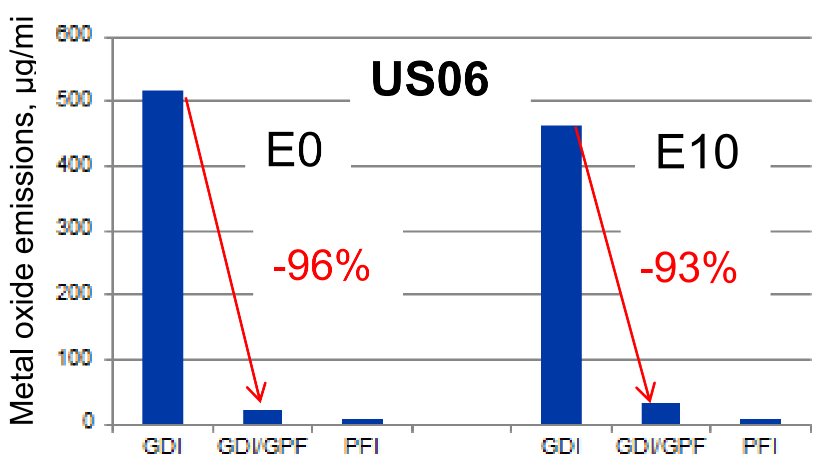
Levels low for new cars, but high for old cars. Dev GPF is effective.

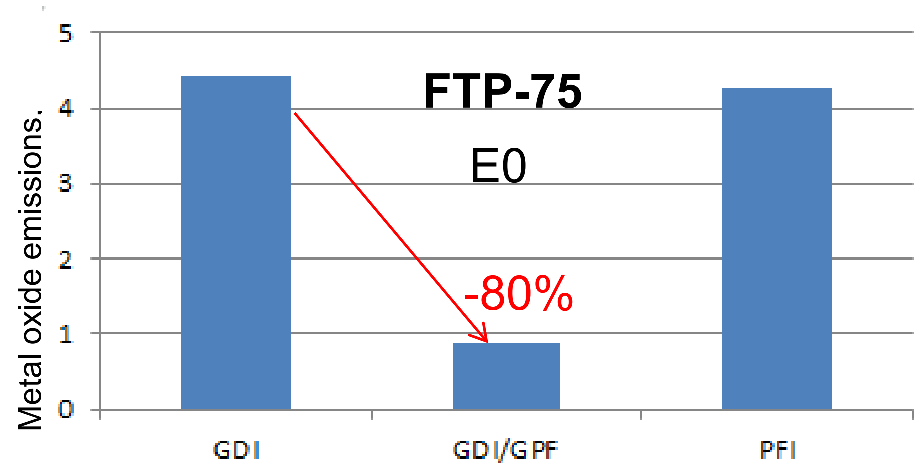


Substances in soot particles have very different toxicity. Karlsson, Chem, Res.Tox 1998



Although PM can be low, PN can be quite high, especially for ash emissions. Older car.

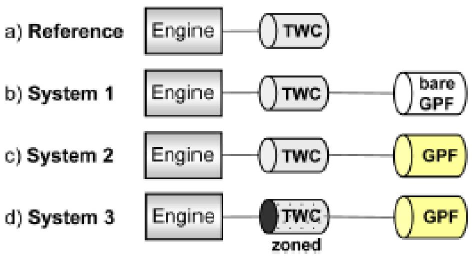




Metal oxide ash emissions are quite low from new gasoline vehicles, but can be significant under high-load or acceleration (US06). GPFs have high removal efficiency. Data from Environmental Canada

First results on coated GPFs shown. PN and NOx emissions down, even at same PGM vs. TWC system

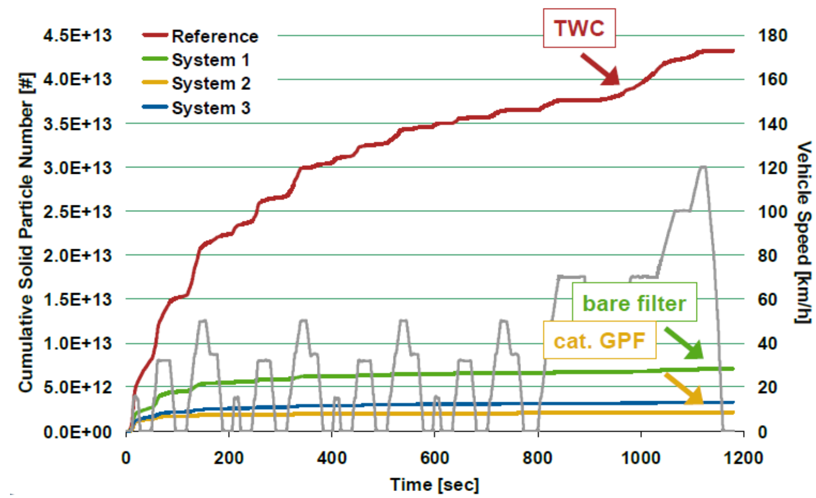
PGM is same for all designs, except syst 4 -6%



	Pd/Rh g/ft^3		PGM cost $	
	TWC	GPF	TWC	GPF
Reference	56/4		69.16	
System 1	56/4	0	69.16	
System 2	52/3	2/1	62.37	6.38
System 3	46[a]/4	2/1	58.66	6.38

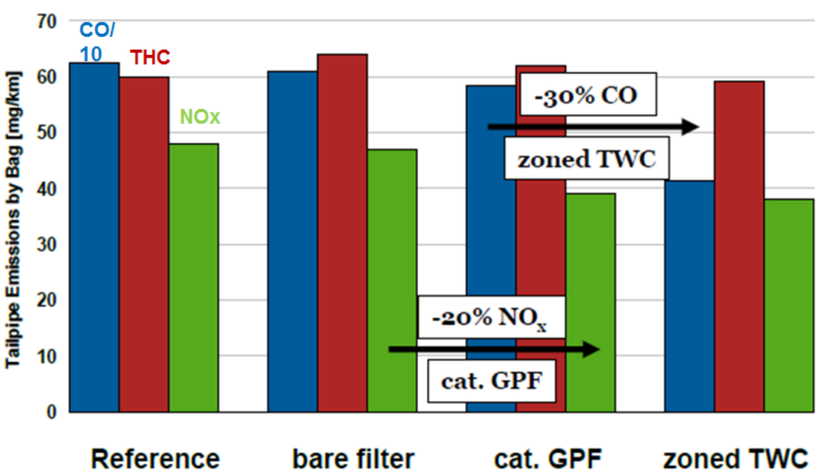
[a]Pd zoning: 3" inlet 76 g/ft^3; 3" outlet 16 g/ft^3

600 csi TWC, 300/12 cordierite GPF



Umicore, SAE 2012-01-1244

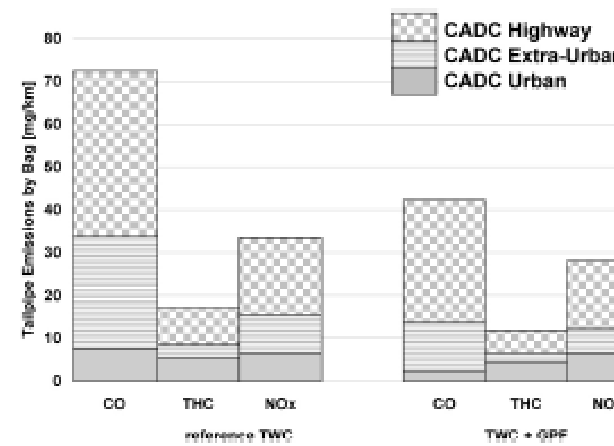
GPFs greatly reduce the cold start PN. Coated GPFs remove more (94% vs. 84% for bare GPF).



Moving TWC from flow-through to GPF drops NOx 20% on NEDC . Zone coating on TWC drops CO by 30%

Other:

- 120 kph: Δp is 23 mbar for uncoated GPF syst and 48 mbar for coated.
- No FC impact from GPH on NEDC nor CADC
- Regen needed on NEDC with GPF in back location



CO, THC, NOx all reduced when moving TWC to GPF on Artemis cycle.

Trends to watch

- Regulatory
  - RDE in Europe – will determine emissions architecture; could eventually replace dyno certifications
  - China PM regulatory developments – fuels, regs, technology, retrofits
  - Watch metal oxides and total PN emission
  - CO_2 vs. NOx trade-off
- Engines
  - High-performance gasoline
  - RCCI transition cycle developments
  - NGV
  - SuperTruck
- Emission control
  - SCR durability and variability
  - OBD
  - SCRF
  - TWC+GPF and efficiency/PGM impacts
  - LT emissions reduction