Overview of Diesel PM Emission Control Retrofit Technologies

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Outline

- Nature of Diesel PM
- Diesel Oxidation Catalysts
- Diesel Particulate Filters
- Emerging Systems
- Issues
- Summary

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Nature of Diesel PM

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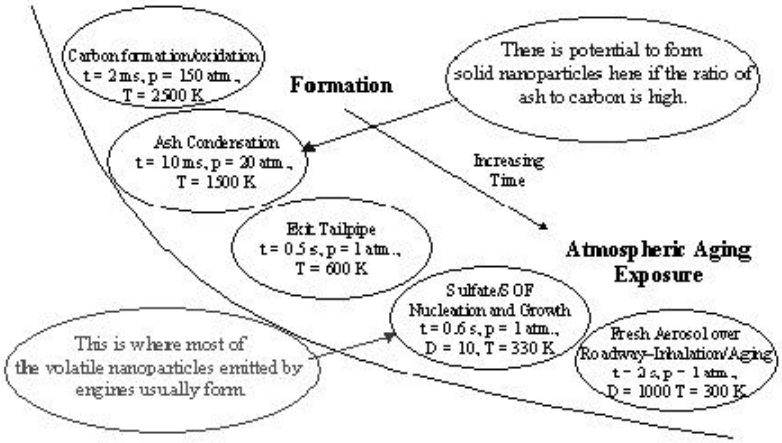
Diesel PM formation is very complex and depends on numerous factors



Univ. of MN, CRC Paris Symposium June 2000

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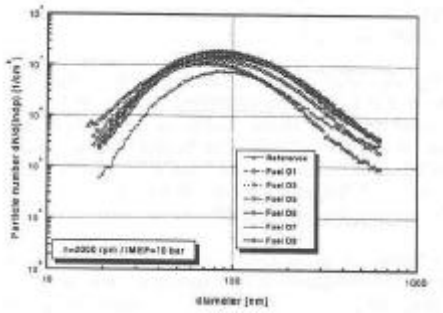
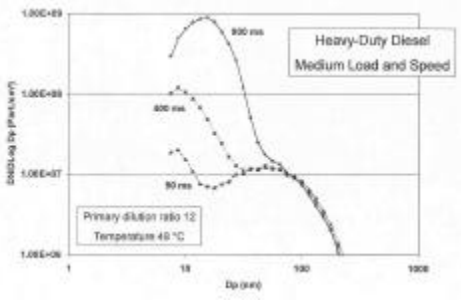
Carbon soot is formed in combustion and varies little. Nanoparticles are aerosols that vary significantly





Particle size distribution of soot in cylinder is independent of fuel.

FEV SAE 2000-01-1999

Nano-particles are aerosols of sulfuric acid and HCs. Concentrations depend on time, temperature, and dilution ratio.

Kittelson, University of MN, EPA MSTRS, July 1999

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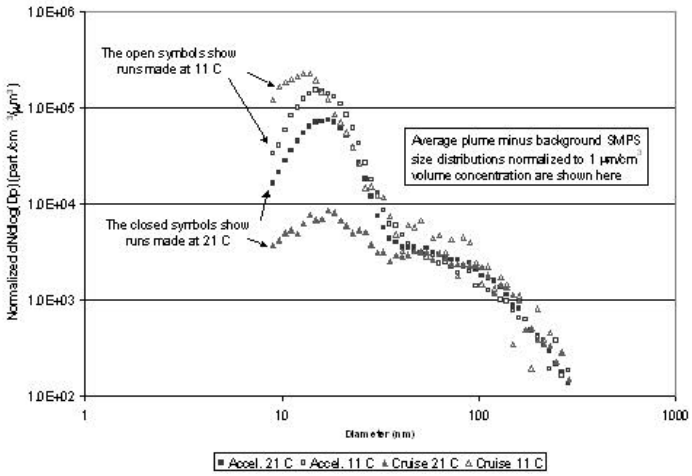
Nanoparticles can be measured in diesel exhaust plumes on the highway



From a mobile PM laboratory following a heavy-duty diesel on the highway

Univ. of MN, CRC Paris Symposium June 2000

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Diesel Oxidation Catalysts

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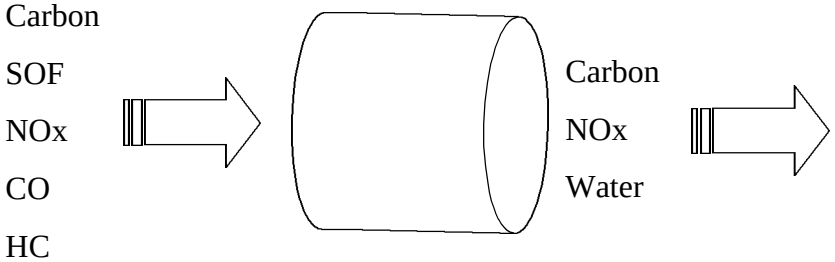
Diesel Oxidation Catalysts

$HC+O_2 = CO_2 + H_2O$
$CO + 1/2O_2 = CO_2$

Issue to balance:
$SO_2 + 1/2O_2 = SO_3$ (sulfates)



PM -- 20-50% Reduction (SOF)
CO and HC -- >90%
Toxic HCs -- >70%

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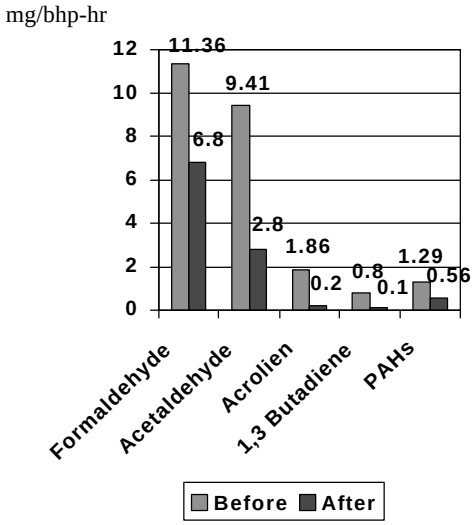
DOCs Destroy Large Fractions of Toxic Emissions



- Toxic Hydrocarbon Compounds Reduced by 68%
- PAH Emissions Reduced by 56%
- Greater Reductions Possible with Low Sulfur Fuel

Source: MECA 1999

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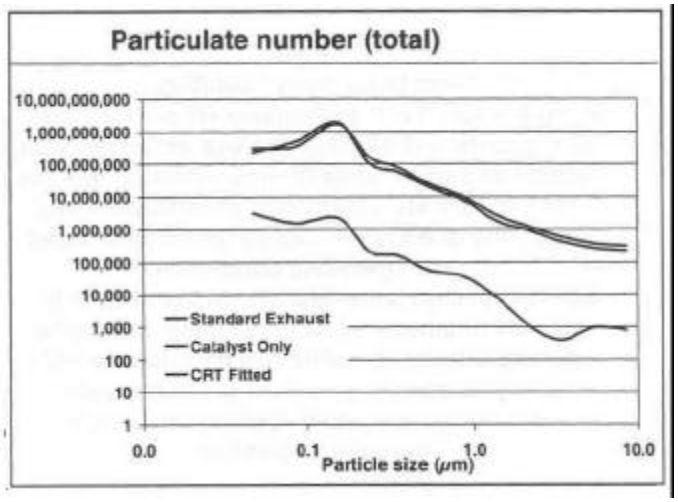
DOC's drop PM by mass but leave PM numbers the same



Millbrook Proving Grounds SAE TopTec 9/00

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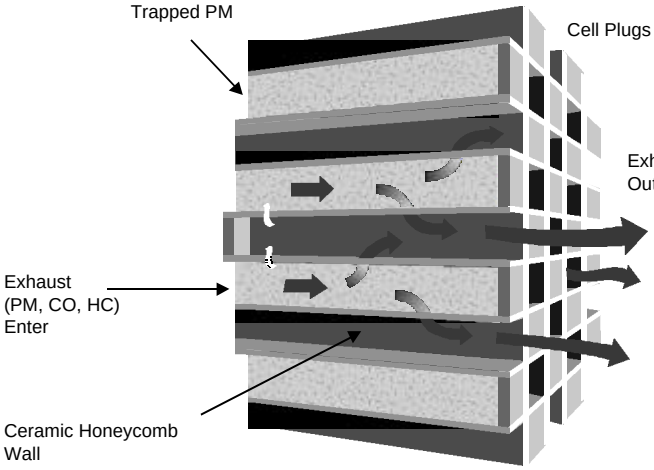
Diesel Particulate Filters



Reductions:

- **-80 to 95% PM**
- **-80-100% HC, CO**
- **-80%+ toxins**

Issues to balance:

- sulfate formation
- regeneration and back pressure

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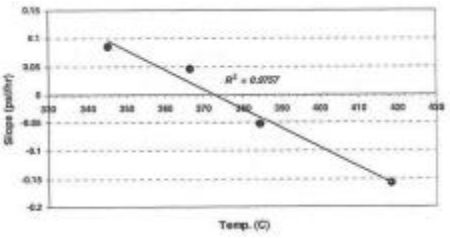
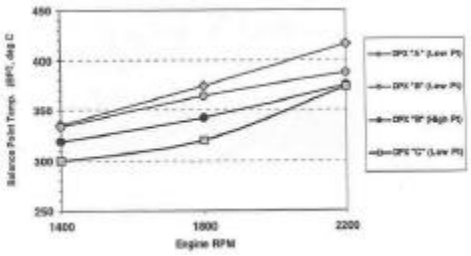
Balance point temperature is critical to ensuring filter performance



Back pressure build-up as a function of temperature is measured. Crossover point is BPT



Balance point temperature depends on catalyst formulation and system

Engine:
- MY98
- 7.2 liter, 300 HP

It is critical to make sure the actual exhaust temperatures exceed the balance point temperature at frequent intervals.

Engelhard SAE TopTec 9/00

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Filters Are Very Effective in Reducing Ultra-Fine Particles

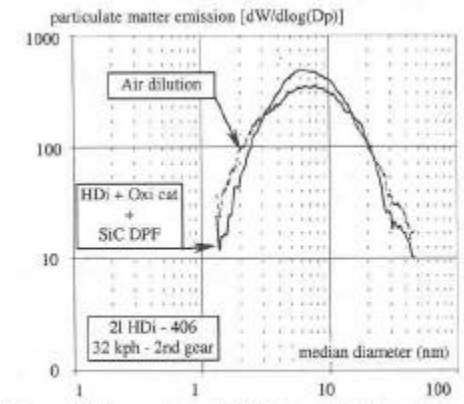

Figure 17. Comparison of SiC filter particulate matter emission with air dilution on a 406 - 2l HDI (32kph)

- Post filtered gas has the same particulate concentrations as the dilution air
- Carbon-Based Ultra-Fine Particles Reduced by more than 99.99 %

Peugeot SAE 2000-01-0473

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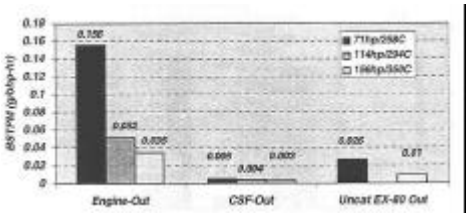
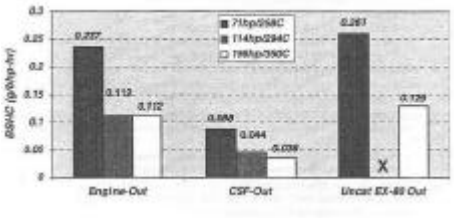
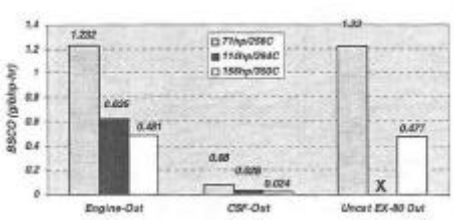
Catalyzed filters drop toxins

DPX™ Catalyzed Soot Filter Exhibits High Level Reduction of Diesel Emissions Listed by CARB as Toxic Air Contaminants

Compound	Engine-Out	DPX-Out	% Reduction
Naphtalene	295	50	83
2-Methylnapthalene	830	105	83
Acenapthalene	40	0.8	98
Acenapthene	46	6.7	85.4
Fluorene	72	29	59.7
Phenanthrene	189	33	80.5
Anthracene	10	1	90
Fluoranthene	7.7	0	100
Pyrene	14	0	100
Benzo(a)anthracene	0.22	0	100
Chrysene	0.51	0	100
Benzo(b)fluoranthene	0.28	0	100
Benzo(k)fluoranthene	0.15	0	100
Benzo(e)pyrene	0.58	0	100
Perylene	0.01	0	100
Indeno(123-cd)pyrene	0.13	0	100
Dibenzo(ah)anthracene	0.01	0	100
Benzo(ghi)perylene	0.32	0	100







7.2l 300 HP steady state

Engelhard SAE TopTec 9/00

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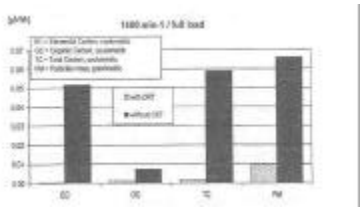
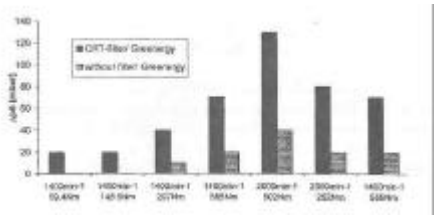
Swiss buses have been fit with CRT system



Particle mass is reduced 85%, most of what gets through is organic carbon.

Op. Point	RPM [1/min]	Torque [Nm]	with CRT Sulfur < 25 ppm γNO_2[%]	without CRT Sulfur < 25 ppm γNO_2[%]	without CRT Standard Diesel γNO_2[%]
10	1400	58.4	7.08	10.81	12.78
8	1400	148.5	13.33	6.02	11.41
6	1400	297	8.94	1.53	8.08
2	1400	585	2.80	1.38	5.70
1	2000	502	1.93	2.23	1.61
5	2000	252	12.13	2.83	5.68
Average			7.67	4.13	7.54



System back pressure is increased 20-80 mbar with filter

NO_2 is same as with standard diesel, but higher than with low sulfur fuel alone. N_2O runs 4-14 ppm, and NO_2 runs 19 to 240 ppm at maximum emissions.

TTM SAE 2000-01-1927

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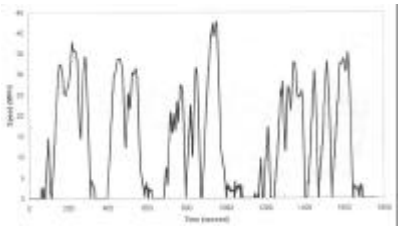
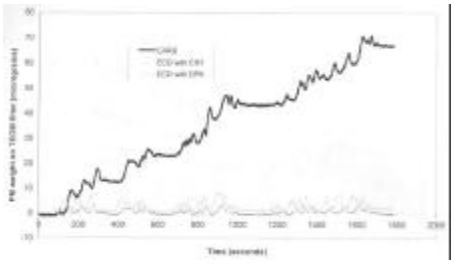
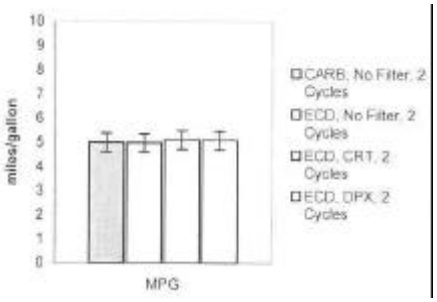
Fuel economy of Class 8 delivery trucks is unaffected by filters



Driving speed for a truck operation on the CSR delivery truck test cycle. Cycle covers range of speed and accelerations very well.



TEOM PM data from CSR. Instantaneous PM follows speed cycle.



Fuel economy unaffected. HC dropped below detection limit. PM dropped +90%

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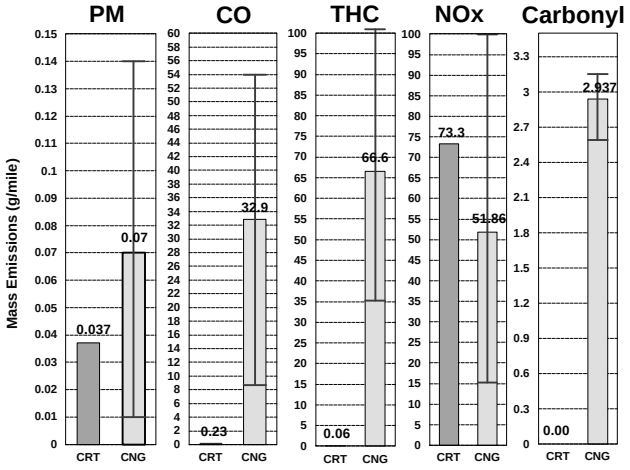
Retrofit clean diesel buses are as clean or cleaner than CNG

CRT compared to CNG on the NYC Bus Cycle



- PM is equivalent, given variability in the CNG values.
- CO is much lower on CRT; similar results on CBD cycle
- THC is much lower on CRT, but CNG has high methane emissions, which are included
- NOx is equivalent given variability. Similar results on CBD.
- Carbonyl values much lower on CRT

NYC MTA Interim Report 8/00

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The filter system durability has been verified on a range of different vehicle types.

CRT™ No.	Vehicle Application	Emission Certification Level	Accumulated Distance, km, (mi)	Accumulated in-use time, months	Engine Displacement, litres, and Power, kW	
#1	intercity train	Euro 2	600,000 (372,900)	36	14	330
#2	airport bus	Euro 0	575,267 (357,531)	57	10	210
#3	express bus	Euro 2	490,038 (304, 599)	33	10	265
#4	mail truck	Euro 0	473,800 (294,453)	83	7	170
#5	city bus	Euro 0	228,809 (142,209)	46	11	187
#6	garbage truck	Euro 0	206,503 (128,342)	57	7	168
#7	garbage truck	Euro 0	105,780 (65,743)	37	7	169

Seven vehicles from which CRT was removed for evaluation on a 12 liter US 1994 certified engine (steady state) and a 11 liter Euro 0 engine (transient).

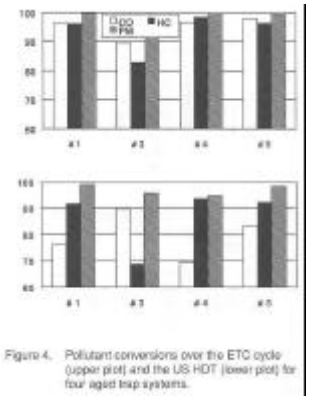
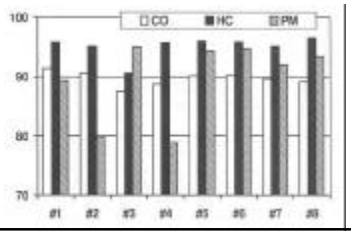


Figure 4. Pollutant conversions over the ETC cycle (upper plot) and the US HDT (lower plot) for four aged trap systems.

>70% HC efficiency and >95% PM efficiency on transient cycles.



All CRT systems had 80%or better PM efficiency and 90%or better HC efficiency on the ESC cycle.

JMI SAE 2000-01-0480

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Some Emerging Solutions

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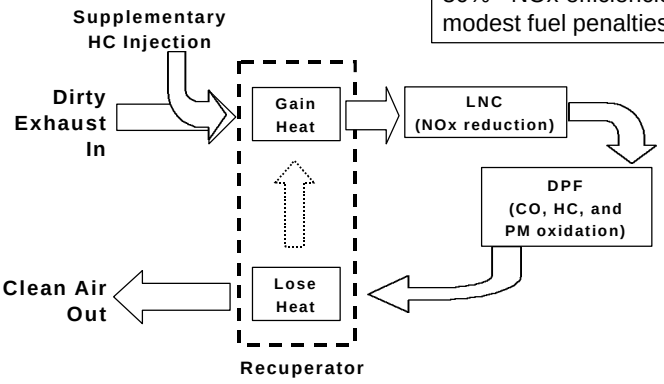
Integrated System – Lean NOx Catalysis + Filter

Integrate heat transfer and chemistry for simultaneous reduction of NOx, CO, HC, & PM

30%+ NOx efficiencies with modest fuel penalties



Ceryx

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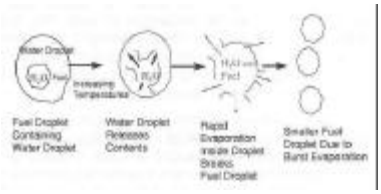
Water-blended fuel with DOC provides balanced emission reductions.



Depiction of how water emulsions improve combustion.

Using emulsion plus DOC drops HC and CO by >92%, NOx by 20%, PM by 70%.

Engine Control Systems 2000-01-0182

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Filter retrofit issues for consideration

- Exhaust temperature-time distribution
  - If ultra-low sulfur fuel is available, T>250C are needed
  - If only medium or high sulfur fuel is available (>100 ppm), T>330C are needed
- Fuel properties
  - Many more solutions are available if ULSD fuel is available
  - If only medium or high sulfur fuel is available, fuel-borne catalysts, lightly catalyzed soot filters, or active regeneration systems will be needed (electrical regeneration, etc.)
- Nature of PM
  - Loading rate dictates regeneration strategy
  - High SOF fraction aids regeneration but DOC might be needed to eliminate toxins

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A Variety of Demonstrated Technologies Are Available to Significantly Reduce Emissions from HDDEs

- Diesel oxidation catalysts are a “no-brainer” - toxins, PM, CO all decreased
- Filters applications are growing - significant PM, toxins, HC reductions
- Ultra-Low Sulfur Diesel fuel is needed for maximum flexibility

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Thank you for listening

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