Diesel Retrofit Programs to Clean-up In-Use Vehicles - U.S. Experience

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U.S. Diesel Retrofit Programs

- **> 19 million in-use diesel engines** of all types throughout the U.S. – significant source of PM and NOx; long service life
  - U.S. retrofit programs and 2007 “clean diesel” turnover have impacted < 3 million engines

- **Mandatory Efforts**
  - California – all existing diesel engines impacted
  - New Jersey, New York State, New York City, Chicago metropolitan area (public fleets or public projects)
  - Green construction contracts/requirements spreading

- **Highly Incentivized Voluntary Programs**; mostly with available local, state, or federal funding; mostly focused on PM reductions
  - Everywhere else in the U.S.

Elements of EPA/CARB Retrofit Programs

EPA

- Voluntary program, no fleet reduction regulations, emission reduction credits
- Absolute technology performance designation with durability demonstration
- Approved application scope & testing plans - designated third party test lab(s)
- Defined in-use testing requirements after 25%, 75% of warranty

CARB

- Mandatory fleet emission reduction regulations, retrofit warranty
- Technology verification performance bands (3 PM levels, 5 NOx levels) with durability demonstration
- Approved application scope, testing plans, & test lab
- Defined in-use testing requirements after 25%, 75% of warranty

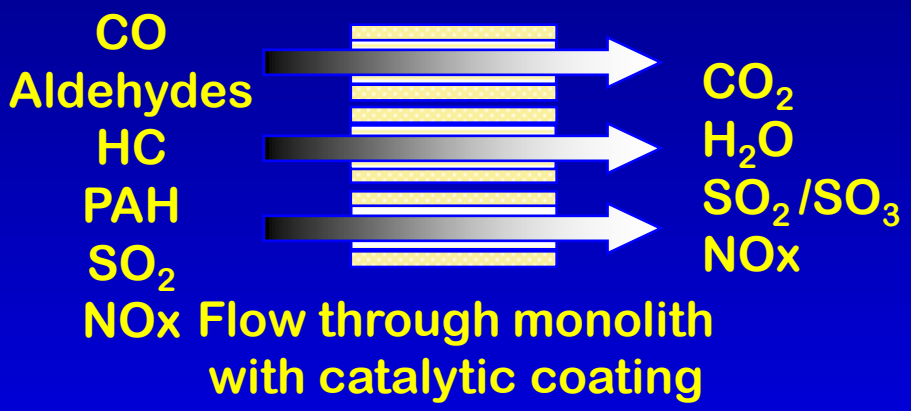
List of Available EPA - ARB-Verified Level 3 Retrofit Technologies Continues to Expand

- U.S. EPA (epa.gov/cleandiesel/verification/verif-list.htm)
  - 6 on-road passive DPFs (includes 2 DPF+SCR)
  - 2 on-road active DPFs
  - 1 off-road passive DPF
  - 1 off-road SCR (NOx control)
  - 1 locomotive SCR (NOx control)

- California ARB (www.arb.ca.gov/diesel/verdev/vt/cvt.htm)
  - 13 on-road passive DPFs (includes 1 DPF+LNC and 1 DPF+EGR)
  - 9 on-road active DPFs
  - 1 off-road passive DPF
  - 4 off-road active DPFs
  - 7 Level 3 devices for TRUs or APUs
  - 11 Level 3 devices for stationary engines

PM Reductions Offered by DOCs and Crankcase Filters

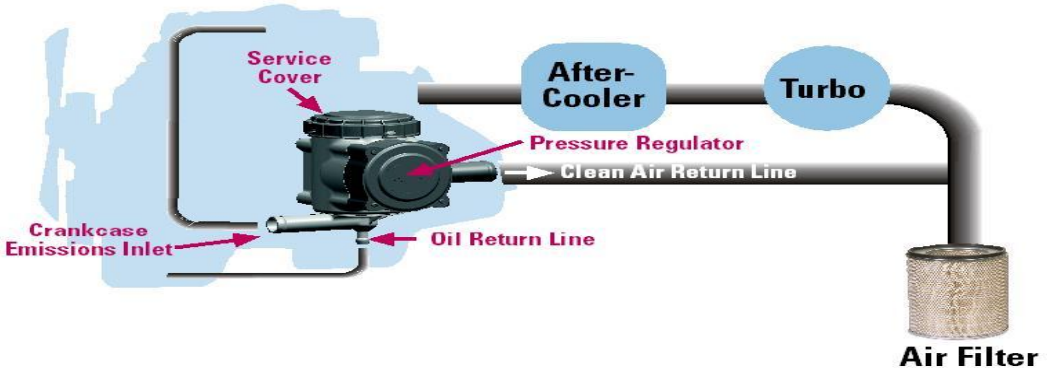
Diesel Oxidation Catalysts: 20-40% ↓ PM



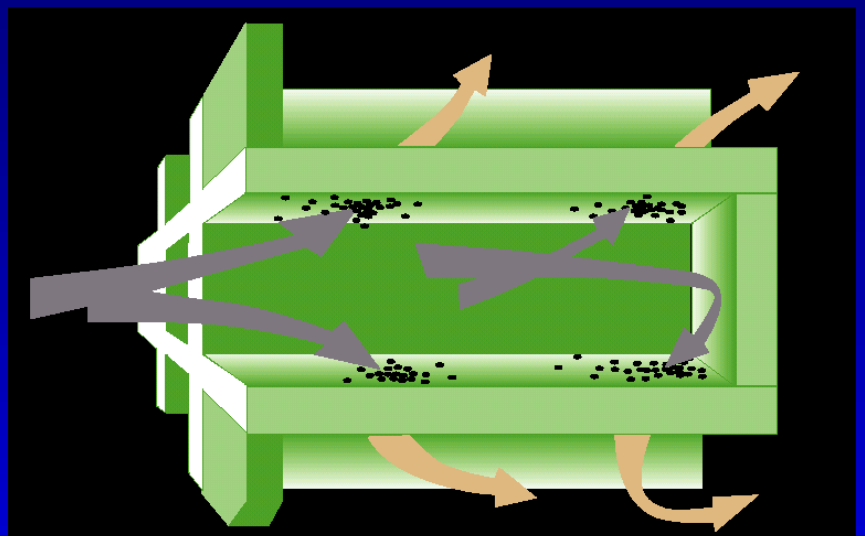
- Millions of DOC retrofits worldwide on on-road and off-road vehicles and equipment.
- Less sensitive to engine-out PM
- Fuel sulfur levels (<50 ppm)

- Eliminates about 5% of total PM from vehicle
- Effective in combination with DOCs or DPFs

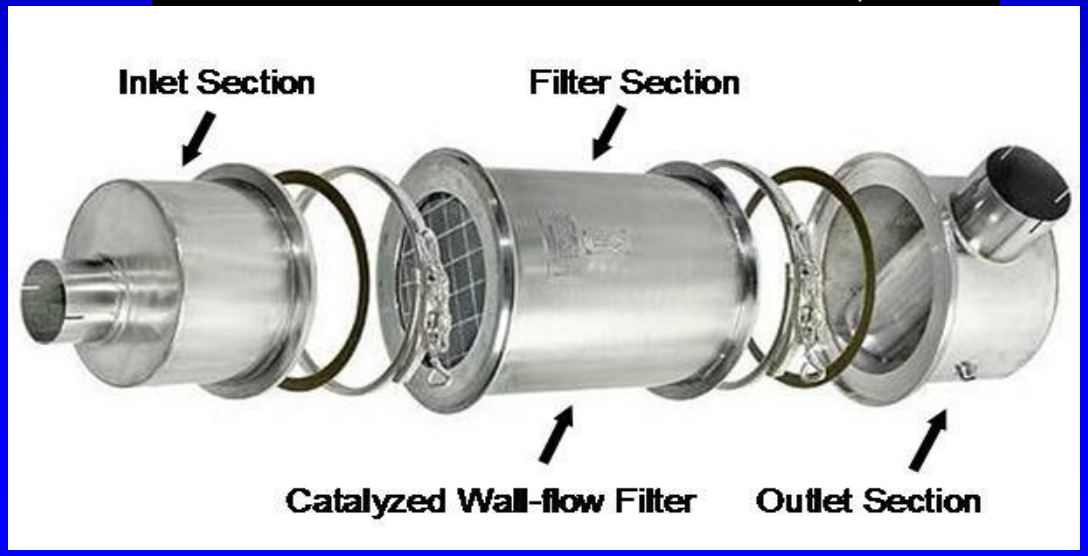
Crankcase Filters Eliminate PM & Toxic Emissions From Crankcase Breather Tubes



Wall-Flow Diesel Particulate Filters Offer the Highest PM Filtration Efficiency



- Large reduction in toxics from catalyzed DPFs
- Large reduction in black carbon (GHG)
- Same technology as on U.S. MY 2007-2009 OE trucks

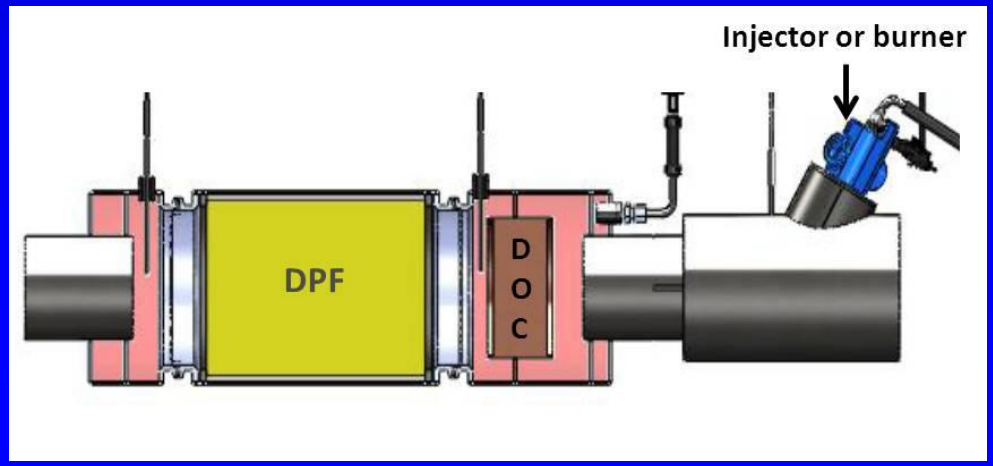


Passively regenerated DPFs employ catalysts and available exhaust heat to burn captured Soot:

1. Require specified exhaust temperature
2. 50 ppm S limit

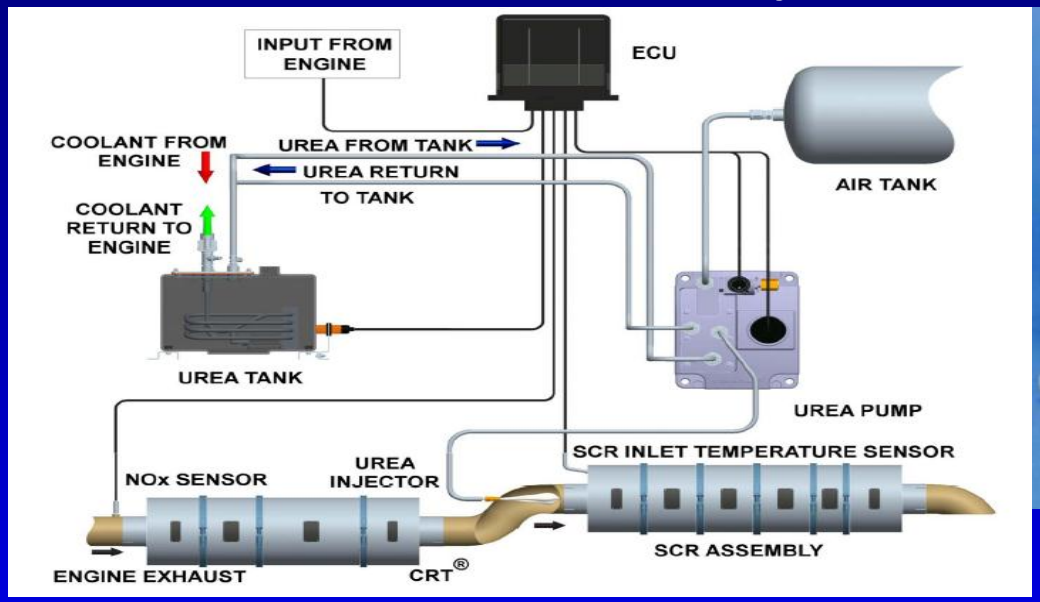
Range of Active DPFs Available for Low Exhaust Temperature Applications

- Suited for on- and off-road applications with low exhaust temperatures.
- Uncatalyzed or catalyzed wall-flow filter with electrical regeneration.
  - Catalyzed filter + electrical element combines passive and active functions
  - On or off vehicle regeneration possible
- Wall-flow filter with a fuel burner for regeneration.



Retrofit Systems that Provide PM + NOx Reductions

DPF + Urea-SCR Retrofit System



60-90% NOx Efficiency

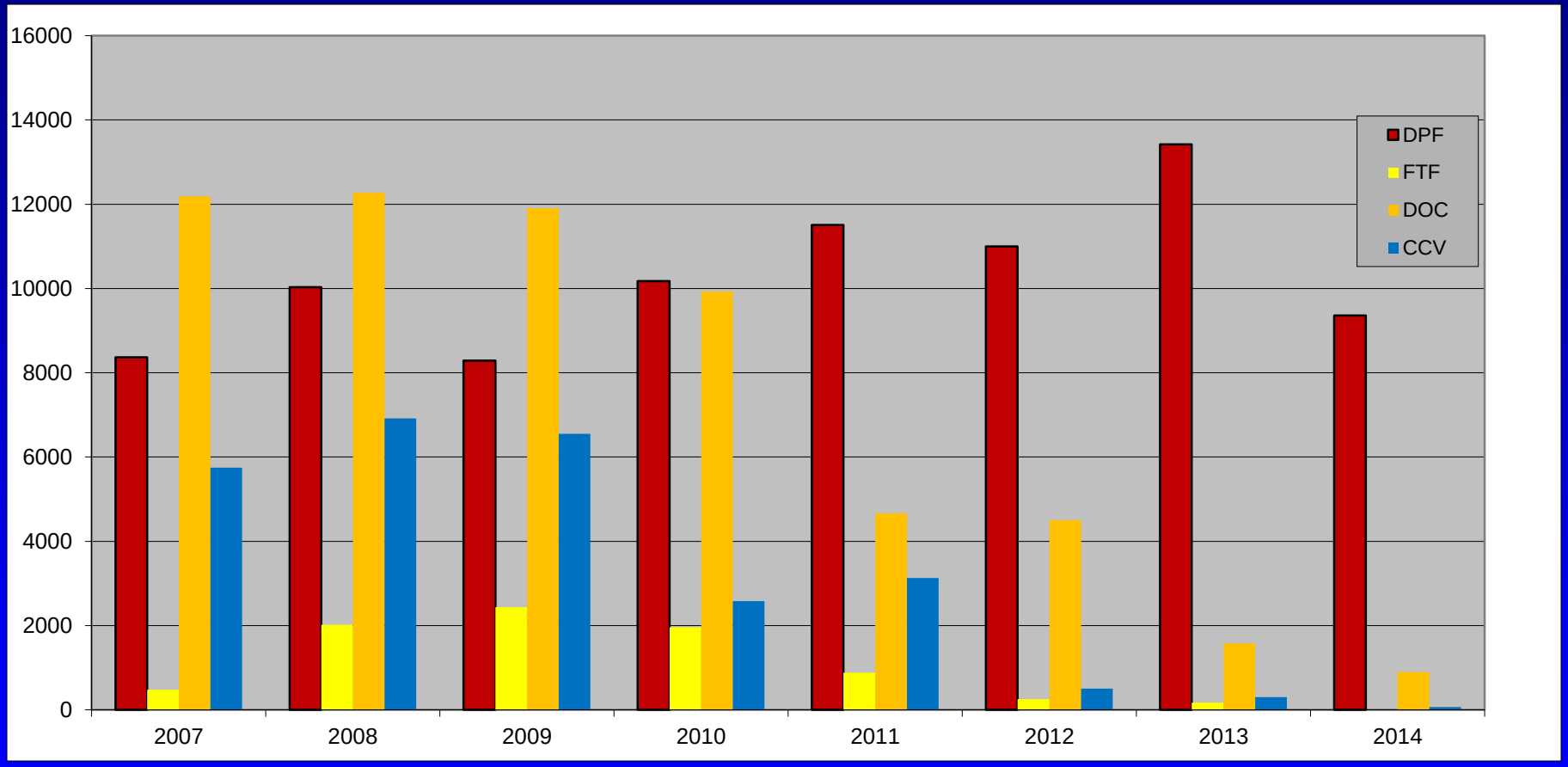
DPF + HC-SCR Retrofit System

25-40% NOx Efficiency

Significant Retrofit Experience in U.S. and Worldwide

- >100,000 on- and off-road DPF retrofits in U.S. since 2001
- >55,000 on- and off-road DPF retrofits in California since 2002
- >250,000 DPF retrofits worldwide; growing off-road experience
- >1 million DOC retrofits worldwide
- Extensive experience with retrofit technologies exists for on-road vehicles
  - School buses, transit buses, long- and short-haul trucks, refuse haulers, utility vehicles
- Retrofit experience continues to grow for many off-road applications
  - Construction equipment, port vehicles/equipment, marine engines and locomotives, stationary IC engines

MECA Diesel Retrofit Sales Survey Results (On-Road and Off-Road)



2007	2008	2009	2010	2011	2012	2013	2014
Total of 26,863	Total of 31,283	Total of 29,180	Total of 24,640	Total of 20,177	Total of 16,262	Total of 15,467	Total of 10,319

DPF Filter Experience

- California ARB conducted extensive survey of filter equipped trucks including first-fit and retrofit. Report published: http://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf

- Key Findings:
  - DPFs are effective in removing more than 98 percent of toxic diesel PM emissions
  - DPFs are operating properly, and most trucking fleets are not having problems with their engines or PM filters
  - Some fleets are experiencing problems with their DPFs, but engine durability issues and inadequate maintenance practices are the primary reasons for these problems

- Key Recommendations:
  - Educate Truck and Bus Owners and Operators about maintenance
  - Develop Stronger Inspection and Maintenance (I/M) Requirements
  - Continue to Provide Assistance to Fleets Operating Retrofits in On-Road and Off-Road Applications

Key Considerations for Successful Retrofit Projects

- Application engineering – match the right technology to the vehicle or equipment
  - Vehicle should be well maintained before considering retrofit - gross emitters are not good retrofit candidates
  - Available fuel sulfur levels dictate retrofit options – 50 ppm S required for catalyzed retrofit DOCs and DPFs
  - Vehicle duty cycles and exhaust temperature define retrofit options
  - Select retrofit technologies with proven performance/durability
- Professional installation
- Maintenance – vehicle/equipment and retrofit device require regular inspections and maintenance
- On-vehicle monitors – provide important user feedback on performance

MECA

Vehicle Pre-installation Inspection

- A pre-installation vehicle inspection is critical
- Examines the engine for potential pre-existing mechanical faults
  - Warning lights & codes
  - Air intake and exhaust system integrity
  - Visual turbocharger inspection
  - Fuel injector problems
  - Oil leak and consumption issues
- Typically includes opacity testing
- Data logging over 24 hours of typical duty-cycle
- **A healthy engine equals a successful Retrofit!**

Diesel Retrofit Summary

- A variety of retrofit technologies have been verified by both the U.S. EPA and CARB for reducing PM and NOx emissions from existing on-road and off-road diesel engines
- Significant experience with retrofit technologies exist for on-road vehicles and this retrofit experience is growing for many off-road applications
- Application engineering and pre-installation inspections are a necessary step to matching the vehicle with the correct retrofit solution
- Diesel retrofit programs provide policy makers with an important tool for cleaning-up in-use fleet and accelerating air quality improvements