# Retrofit Emission Controls for On-Road and Off-Road Diesel Engines

*September 18, 2007*

Manufacturers of Emission Controls Association (MECA)
www.meca.org
www.dieselretrofit.org

## MECA Background

- Founded in 1976 to be the technical spokesperson for the mobile source emission control industry (54 member companies)
- Member companies have over 35 years of experience and a proven track record of success in developing and manufacturing emission control technology
- Members cover diverse range of emission control technologies for both new and existing engines/vehicles:
  - Catalytic converters (all fuels)
  - Diesel particulate filters
  - Exhaust components/exhaust system integration
  - Sensors
- Emission control technology information available on two websites:
  - www.meca.org
  - www.dieselretrofit.org
  - Contact: Dr. Joe Kubsh (Executive Director) in Washington, D.C. (phone: 202-296-4797, e-mail: jkubsh@meca.org)

## Outline

- Diesel Retrofit Technology Overview
- Retrofit Application Engineering
- Installation of Retrofit Devices
- Diesel Particulate Filter Maintenance

# Diesel Retrofit Technology Overview

## Strategies to Reduce Emissions from In-Use Diesel Engines

- Retrofit – installing verified emission control devices on an existing diesel engine
- Refuel
- Repair/Rebuild
- Repower
- Replace

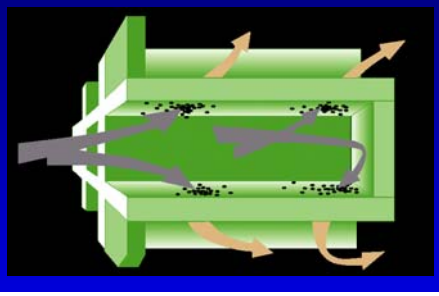
## Experience with Diesel Retrofits Spans a Variety of On-Road Vehicle Applications…

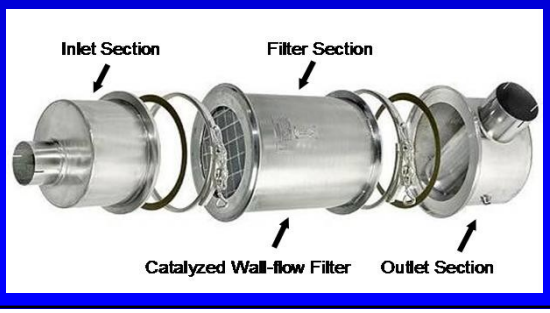
## … Construction Equipment…

## … Mining…

## … and Other Off-Road Vehicle and Stationary Engine Applications

## Wall-Flow Filters Offer the Highest PM Filtration Efficiency






- >85% PM reduction
- Catalyzed filters require operation on ULSD
- Large reduction in toxics from catalyzed filters
- ARB Level 3 filters include passive & active regen.
- >200,000 retrofits worldwide
- >4 million OE applications
- Same technology as on 2007 OE trucks

Passively regenerated filters employ catalysts and available exhaust heat to burn captured soot – specified exhaust temp. requirements

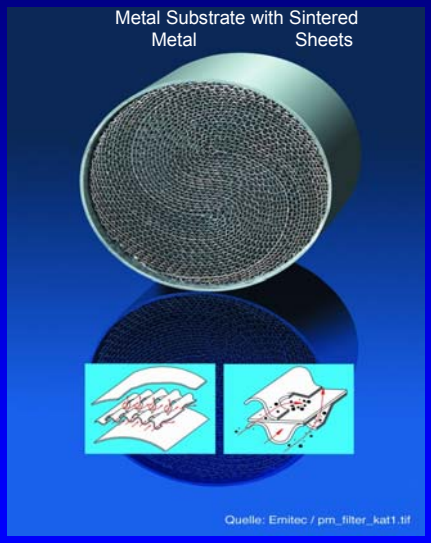
## DPFs with Active Soot Regeneration Available for Retrofits


- Suited for on- and off-road applications with low exhaust temperatures, including construction equipment, locomotives, and marine engines
- Example: Uncatalyzed wall-flow filter with electrical regeneration
- Example: Uncatalyzed wall-flow filter with a fuel burner

## Backpressure Monitors/Loggers

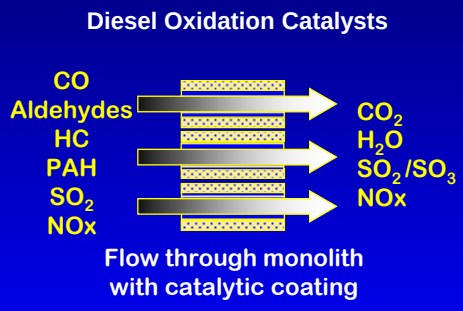
- BP monitors emerging with added features
  - Extended datalogging capability (1-2 yrs)
    - BP and temperature
  - Multi-light displays to indicate system faults, warnings, and alarm conditions
  - Real-time monitoring
- Systems come with software to allow data analysis

# Flow-Through Filter Technologies Emerging for Diesel Retrofits




- 50-75% PM reduction (ARB Level 2)
- Can be catalyzed or used with a DOC
- Has applicability on older engines
- Resistant to plugging
- Ash cleaning generally not necessary due to open structure

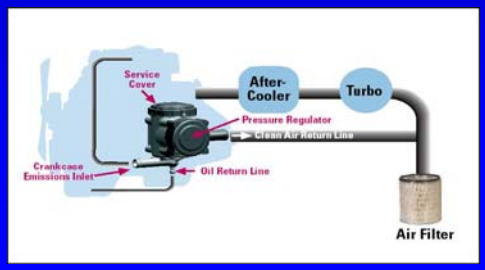
# Diesel Oxidation Catalysts




- 25-40% PM reduction ("soluble" PM species are oxidized)
- Large reduction in toxics
- DOCs have been retrofitted on on- and off-road vehicles for over 30 years
- Nearly universal application with >1 million retrofits worldwide
- Tens of millions of OE applications

## Closed Crankcase Ventilation Can Provide Additional PM Control

- Most existing diesel engines vent crankcase emissions directly to the atmosphere
- Crankcase PM emission reductions provided by CCV technologies range from 5 to 10%
- CCVs direct filtered air back to the engine air intake; lube oil returned to oil sump




## Mexico City Pilot Retrofit Project Confirmed Retrofit Performance on 20 Urban Buses

- Pilot project sponsors included U.S. EPA
- Project completed in late 2006
- 1991 buses with mechanical injection systems retrofit with DOCs and fueled with ultra-low sulfur diesel fuel (15 ppm S max.)
  - 20-30% reduction in PM, 50-70% reduction in CO
- 2001 buses with electronic injection systems retrofit with passive DPFs and fueled with ultra-low sulfur diesel fuel
  - 90% reduction in PM, 90% reduction in CO

## Integrated Solutions for Combined NOx/PM Reductions Emerging for Retrofits

- Lean NOx catalyst + DPF
- Urea Selective Catalytic Reduction (SCR) catalyst + DPF
- Low-pressure Exhaust Gas Recirculation (EGR) + DPF
- Emulsified diesel fuel + DOC (or DPF)

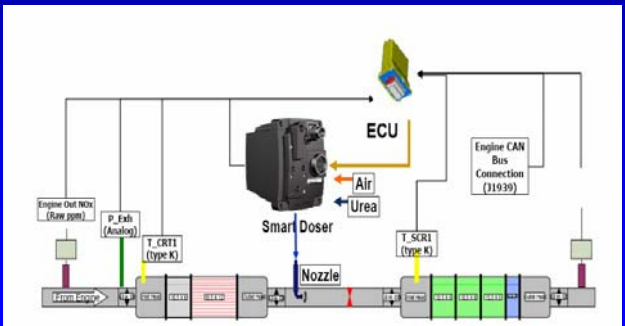
## Lean NOx Catalyst + DPF

- Diesel fuel used as a reductant with a lean NOx catalyst

Lean NOx Catalyst + DPF
(25% NOx reduction)

## Urea SCR Catalyst + DPF

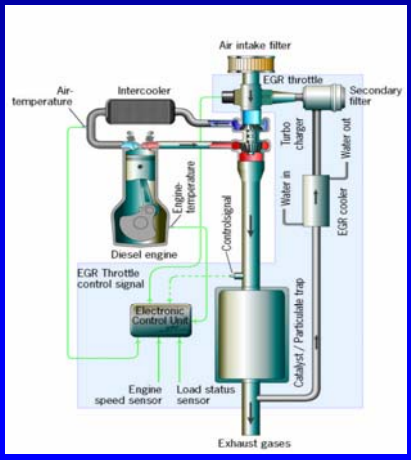
- Urea-water solution used as a reductant with an SCR catalyst
- DOC+SCR verified for limited off-road applications; additional SCR verifications expected for both on-road & off-road engines




Urea SCR Catalyst + DPF (60+% NOx reduction)

## Low-Pressure EGR + DPF

- Cleaned exhaust gas is recirculated to engine air intake to cool engine combustion temperature




Low-Pressure EGR + DPF (40-50% NOx reduction)

## Emulsified Diesel Fuel + DOC (or DPF)

- Emulsion of fuel+water lowers engine combustion temperatures and improved fuel/air mixing

Emulsified Diesel Fuel + DOC
(15-40% NOx reduction)

## Key Technical Considerations for Successful Retrofit Projects

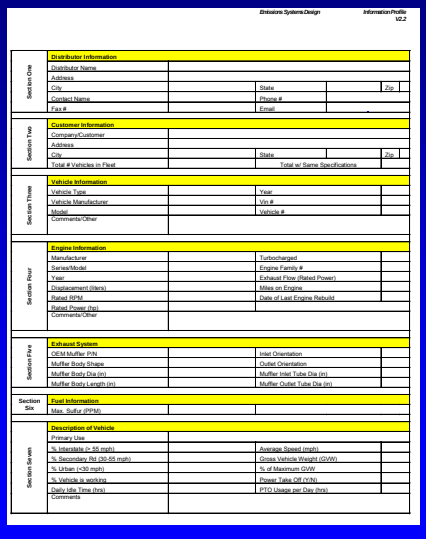
- Application engineering – matching the right technology to the vehicle or equipment
  - Vehicle should be well maintained before considering retrofit
- Proper professional installation
- Maintenance – vehicle/equipment and retrofit device may require frequent inspection and maintenance
- On-vehicle monitors – provide important user feedback on performance

➢ **Successful Retrofits Require a Cooperative Effort Between Fleet Owners, Operators, and Technology Providers**

# Retrofit Application Engineering

## Opportunity Definition

- Information Profile/Documentation
- Fleet Analysis
  - Engine/Vehicle/Make/Model/Year
  - Engine Type/Configuration
  - Exhaust System Details
  - Mounting Hardware
  - Maintenance History



Emissions Systems Design — Information Profile V2.2

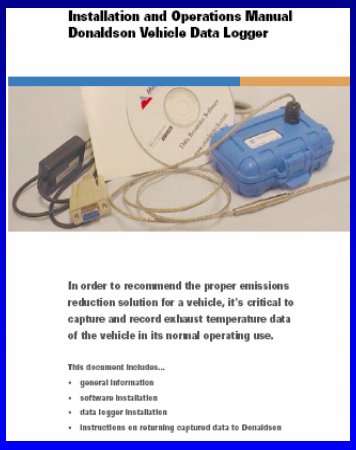
| | | | | | |
|---|---|---|---|---|---|
| Section One | **Distributor Information** | | | | |
| | Distributor Name | | | | |
| | Address | | | | |
| | City | | State | | Zip |
| | Contact Name | | Phone # | | |
| | Fax # | | Email | | |
| Section Two | **Customer Information** | | | | |
| | Company/Customer | | | | |
| | Address | | | | |
| | City | | State | | Zip |
| | Total # Vehicles in Fleet | | Total w/ Same Specifications | | |
| Section Three | **Vehicle Information** | | | | |
| | Vehicle Type | | Year | | |
| | Vehicle Manufacturer | | Vin # | | |
| | Model | | Vehicle # | | |
| | Comments/Other | | | | |
| Section Four | **Engine Information** | | | | |
| | Manufacturer | | Turbocharged | | |
| | Series/Model | | Engine Family # | | |
| | Year | | Exhaust Flow (Rated Power) | | |
| | Displacement (liters) | | Miles on Engine | | |
| | Rated RPM | | Date of Last Engine Rebuild | | |
| | Rated Power (hp) | | | | |
| | Comments/Other | | | | |
| Section Five | **Exhaust System** | | | | |
| | OEM Muffler P/N | | Inlet Orientation | | |
| | Muffler Body Shape | | Outlet Orientation | | |
| | Muffler Body Dia (in) | | Muffler Inlet Tube Dia (in) | | |
| | Muffler Body Length (in) | | Muffler Outlet Tube Dia (in) | | |
| Section Six | **Fuel Information** | | | | |
| | Max. Sulfur (PPM) | | | | |
| Section Seven | **Description of Vehicle** | | | | |
| | Primary Use | | | | |
| | % Interstate (> 55 mph) | | Average Speed (mph) | | |
| | % Secondary Rd (30-55 mph) | | Gross Vehicle Weight (GVW) | | |
| | % Urban (<30 mph) | | % of Maximum GVW | | |
| | % Vehicle is working | | Power Take Off (Y/N) | | |
| | Daily Idle Time (hrs) | | PTO Usage per Day (hrs) | | |
| | Comments | | | | |

## Control Technology Assessment

- ARB Verification Listing Review
  (www.arb.ca.gov/diesel/verdev/verdev.htm)
  - Level 1 Verified Technologies (≥ 25% PM reduction
  - Level 2 Verified Technologies (≥ 50% PM reduction)
  - Level 3 Verified Technologies (≥ 85% PM reduction)
- Best available Control Technology (BACT) Review
  - Select highest level PM reduction technology available (Level 3, 2, or 1) which is verified/approved for specific engine families and operating conditions
- Assess Exhaust Temperature/Duty Cycle Requirements
  - Match of control technology level to engine/vehicle operation
  - Determine exhaust temperature/duty cycle datalogging need

## Exhaust Temperature/Duty Cycle Assessment

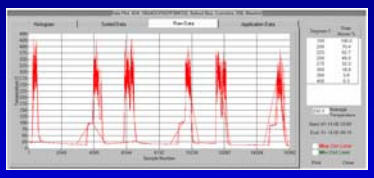
- Provide Datalogging Capability
  - Datalogger Kit
    - Hardware
    - Installation/operations manual
    - Software
    - Instructions/Data form
- Complete Datalogging
  - Temperature sampling frequencies of 2-5 seconds typical over multiple days of operation
  - Data taken and provided to control technology supplier



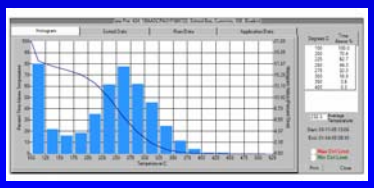
# Exhaust Temperature/Duty Cycle Assessment

- Data Analysis
  - Data imported into supplier database for analysis and storage
  - Analysis/assessment for proper temperature criteria
- Feedback Response Documented to Customer

Raw Temperature Data



Temperature Plot



# Control Technology Sales/Application

- Product Selection/Supply
  - Sales/Application Literature
- Installation/Maintenance
  - Owner's Manual
    - Installation, warranty and maintenance procedures
- Application Documentation Files
  - Specific control technology match to engine/vehicle application

## Challenges for Off-Road Retrofits

- Higher emissions than on-road heavy-duty engines (uncontrolled before 1996)
- More diverse engine/equipment applications than on-road
  - More older equipment
  - Wide horsepower range
  - Equipment stability
- More rigorous operating environment (vibrations, dust, uneven surfaces)
  - Can require extensive use of high-grade vibration isolators, especially in track-drive equipment

## Challenges for Off-Road Retrofits

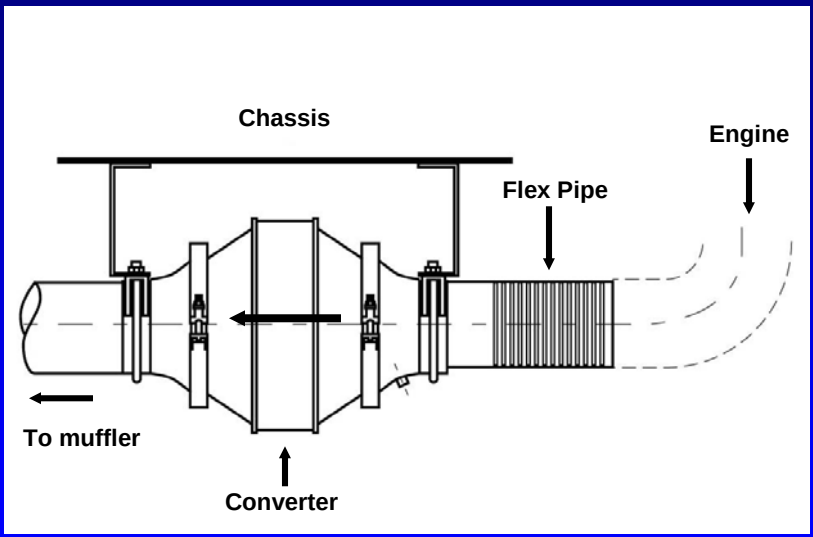
- Packaging constraints
  - Maintaining driver visibility
- Availability of clean fuel
  - ULSD allows for maximum PM control
- Need for more preventative equipment maintenance
  - Air filters, injectors, and turbochargers
  - Basic inspection and maintenance of installations
- Must be mindful of not taking short-cuts to get equipment retrofitted quickly

# Installation of Retrofit Devices

## DOCs

- Represent a new installation
  - Support of unit is critical
  - Requires adequate space to install
  - Adaptable to most engines

## Converter Installation – Underchassis

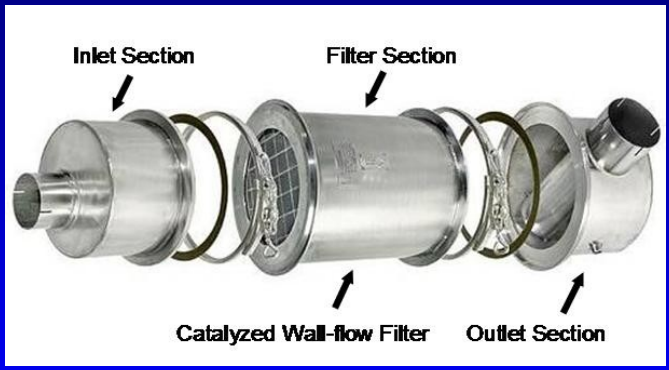



(Note that flex pipes may not be allowed in some retrofit installations)

## Converter Mufflers

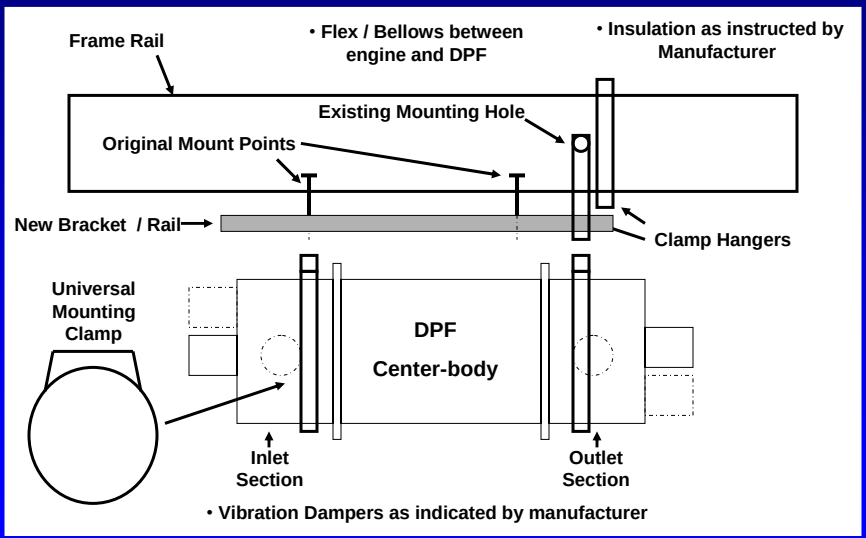
- Direct fit simply installs in place of the original muffler
  - –should have all the features of the original muffler
  - –saves labor, reduces hardware, and insures correct fit
- Generic converter mufflers may be used with a specialized pipe installation kit
  - –can be difficult to obtain replacement pipes

## Diesel Particulate Filters




- Most feature a more generic design & removable filter centerbody for maintenance
- DPF centerbody is heavy – proper support is vital
- Inlet and outlet sections rotate to facilitate fit

## DPF – Highway Underchassis



## Proper Retrofit Installation (On-Road)

## Proper Retrofit Installation (On-Road) – Vertical Installation

## Off-Road Horizontal and Vertical Filter Installations Possible


## Diesel Particulate Filter Maintenance

## Why Clean DPFs?

## DPF Maintenance

- Soot collected in the filter must be periodically combusted (like a self-cleaning oven)
  - If insufficient high-temperature events occur, PM can collect in the DPF and require physical removal
- Inorganic ash does not combust and will collect in the DPF over time
  - Ash must be cleaned out periodically to avoid substrate damage and elevated engine backpressure
  - Ash sources include lubricant additives and wear metals from the engine/exhaust

## DPF Maintenance

- Inspect the installation for problems and repair if necessary – supports, clamps, vibration dampeners, etc.
- Inspect the BP monitor function and perform any specified maintenance
- Filters are not maintenance free – every diesel particulate filter requires periodic maintenance regardless of brand or mileage or vehicle hours
- Care must be taken when handling DPFs to protect DPF from damage and protect personnel

| Vehicle Type | Engine Hours | Miles | Yearly |
|---|---|---|---|
| Urban & School Buses & Solid Waste Fleets | 1000-1500 | 20,000 to 30,000 | 1-2 |
| Service & Short Haul | 1500 | 20,000 to 50,000 | 1 |
| Delivery Fleets and Non-road | 1000-1500 | | 1 |

## DPF Cleaning Stations

- DPF cleaning station designed to safely perform regeneration or maintenance on all DPFs
- Effective way to remove ash and improve DPF durability

## DPF Cleaning Stations

- Typical DPF cleaning station
  - Three-step system of vacuum–heat–vacuum
  - Vacuum system removes soot and ash from filters
  - Does not allow contaminants to escape into the air
  - Clean cordierite & silicon carbide filters between 3 and 20 liters

## Disposal of Soot and Ash

**Captured in tail pipe . . .**

**Collected in filter bag . . .**

**Sealed in containers . . .**

**and sent to hazardous waste facility (depending on local regulations).**

## Other Diesel Retrofit Maintenance Items

- Periodic inspections should include mounting brackets & clamps; presence of soot in the tailpipe of a DPF-equipped vehicle; condensation in tubing associated with pressure sensors/monitors used with DPFs
- DOCs
  - Generally maintenance free; periodic inspections recommended
- Crankcase Filters
  - Filter change generally required at normal oil change intervals
- Low Pressure EGR
  - Regular inspections
  - Secondary filter needs replacement – 6-12 month intervals typical

## Diesel Retrofit Summary

- A variety of retrofit technologies have been verified by both the U.S. EPA and California ARB for reducing PM and NOx emissions from existing on-road and off-road diesel engines
- Significant experience with retrofit technologies exists for on-road vehicles and this retrofit experience is growing for many off-road applications
- Application engineering is a necessary step to matching the vehicle with the correct retrofit solution