
Overview of Diesel Retrofit Control Options and Key Technical Elements of a Successful Retrofit Program

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July 20, 2005
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Presentation Outline

- Diesel Emission Control Technologies – A Brief Overview
- Retrofit Technologies for Particulate Matter (PM) Control
- Retrofit Technologies for Combined PM/NO_x Control
- Key Considerations for Retrofit Programs
- Frequently Asked Questions Concerning Retrofit Programs
- Conclusions



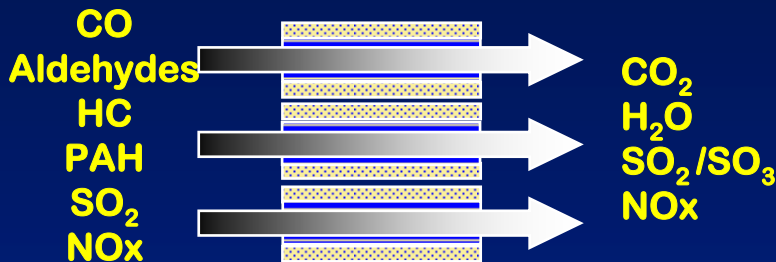
Diesel Emission Control Technology Is Making Significant Progress

- General technology approaches to hitting the regulations
 - Widespread filter usage in Japan; SCR in Japan & Europe in 2005
 - Filters provide PM control for U.S. HDE 2007
- Filter technology
 - Reliable regeneration
 - Improved properties; ash storage/management
 - Retrofit experience and options expanding
- NOx solutions
 - SCR commercial offering in Japan and Europe for HDDE
 - NOx adsorbers are on HDD engine dynos
- Integrated solutions
 - SCR/DPF are on vehicles
 - LNT/DPF in commercial sales
 - Retrofit options available for combined PM/NOx reductions



DOCs and DPFs Form the Technology Base for Reducing PM Emissions from New and In-use Diesel Engines

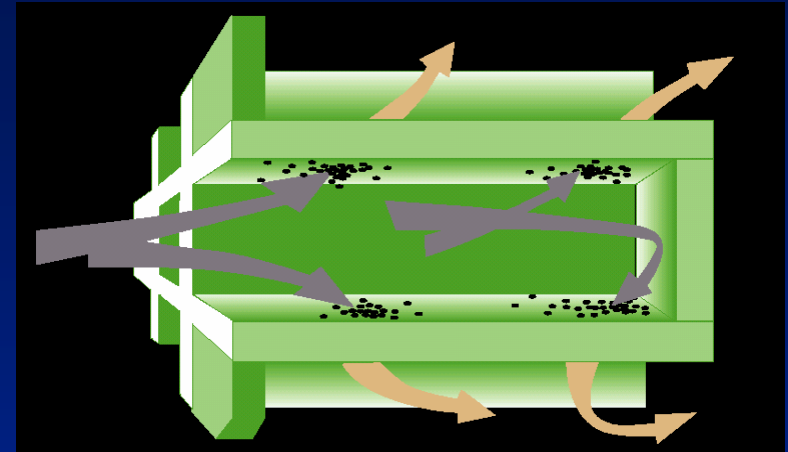
Diesel Oxidation Catalysts



Flow through monolith with catalytic coating

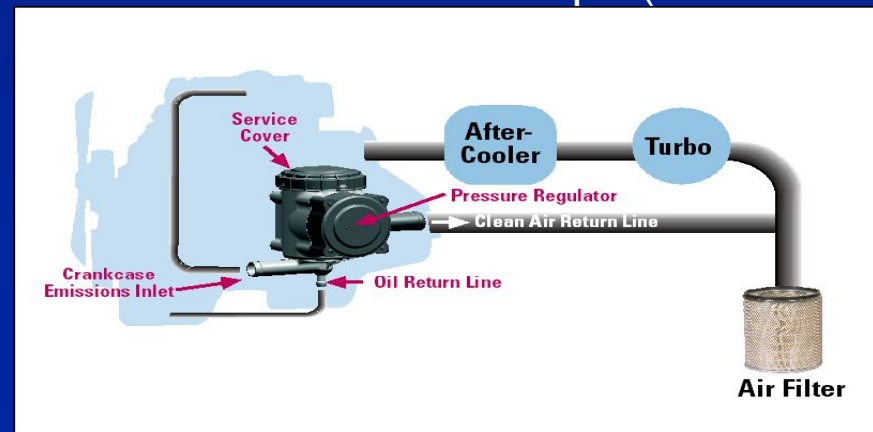
- Applicable to nearly all diesel engines; significant retrofit & OE experience base
- PM control through SOF oxidation – significant reduction of toxic HCs

Diesel Particulate Filters



- Standard on all on-road heavy-duty engines for 2007
- Significant experience base with LDD in Europe (> 1 million vehicles)

DOCs & DPFs can be combined with Crankcase Filters for additional PM control



“Flow-Thru” or “Partial” Filter Technologies Emerging for Diesel Retrofits



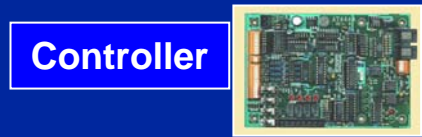
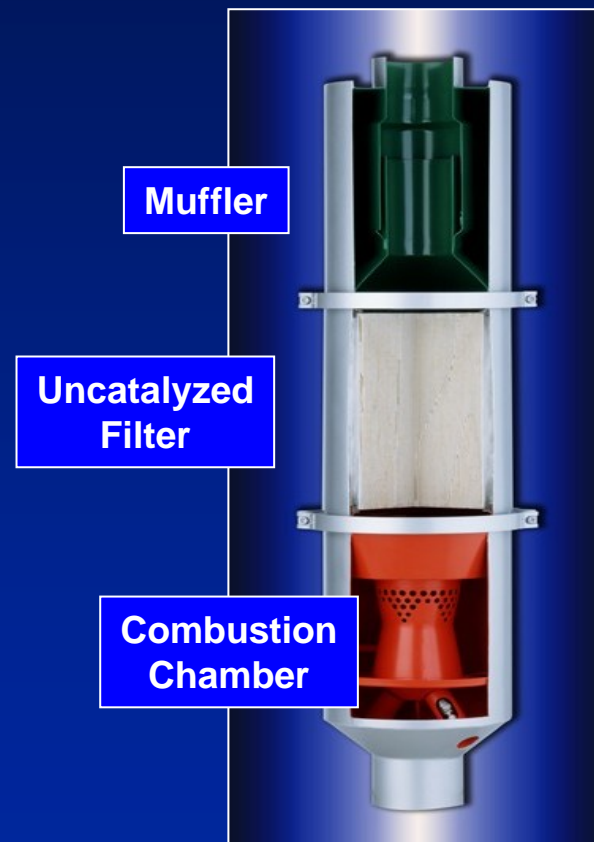
- Potential for 50-70% PM reduction (Level 2, one technology already verified)
- Can be catalyzed or used with a DOC
- May have applicability on older engines
- Filtering achieved with sintered metal sheets or wire meshes
- Resistant to plugging

Examples of Active DPF Technology Options

Catalyst-Based Filter with Electric Heater Assist

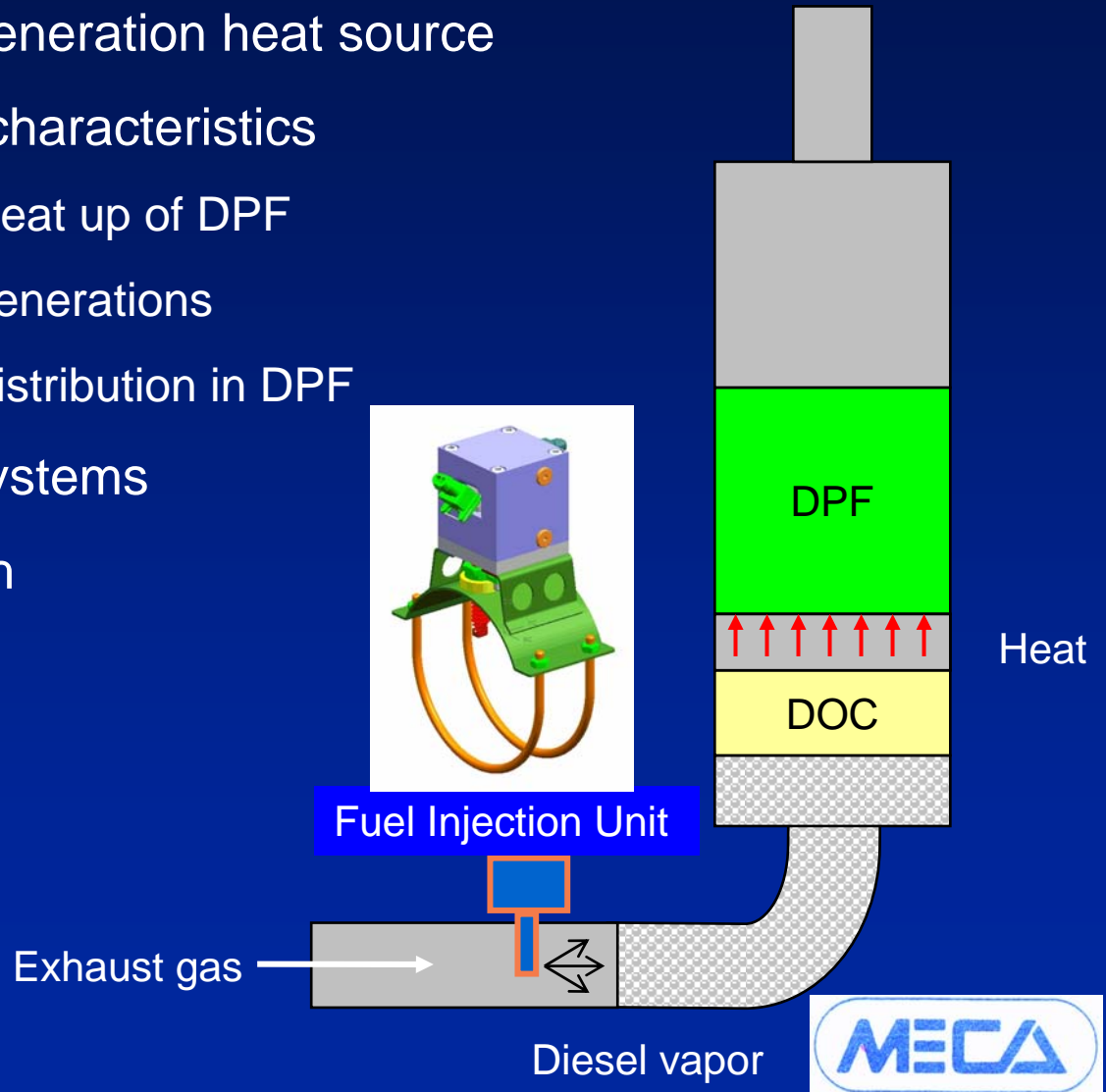
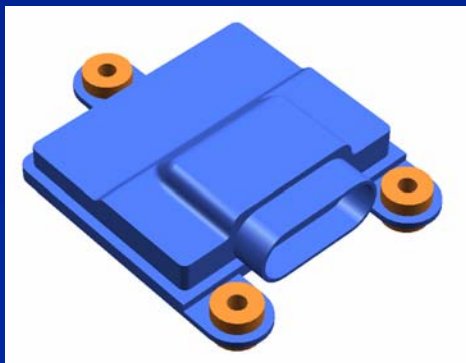


Uncatalyzed Filter with Fuel Burner



Fuel Injection Active Filter Regeneration System

- Diesel fuel provides regeneration heat source
- Preferred regeneration characteristics
 - Faster, more uniform heat up of DPF
 - Quick and efficient regenerations
 - Uniform temperature distribution in DPF
- Compatible with NOx Systems
- Dedicated controller with diagnostic functions

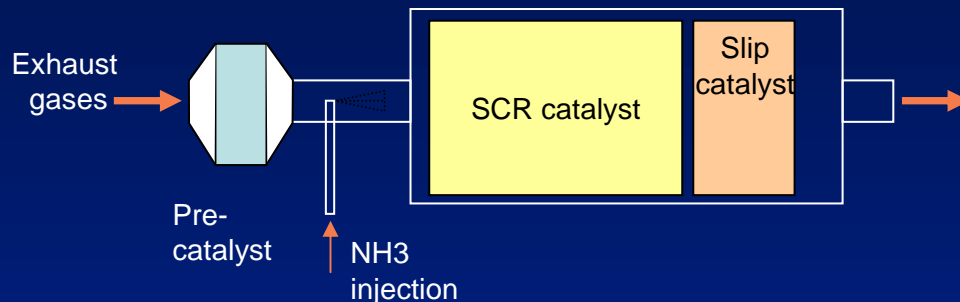


Integrated Solutions for Combined PM/NOx Reductions Available for Retrofit

Lean NOx Cat. + DPF or DOC
– 25-35% NOx reduction

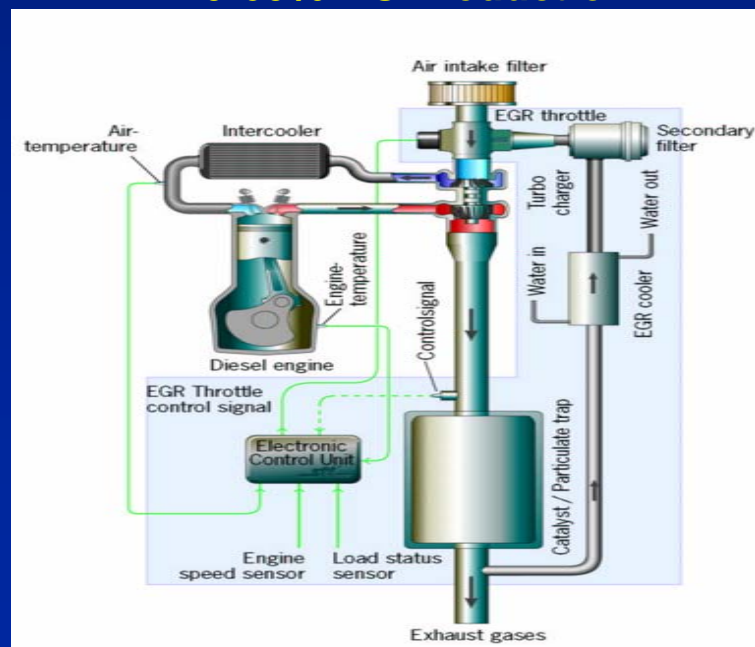


DOC + SCR
– 70-80% NOx reduction



Low Pressure EGR + DPF
– 40-60% NOx reduction

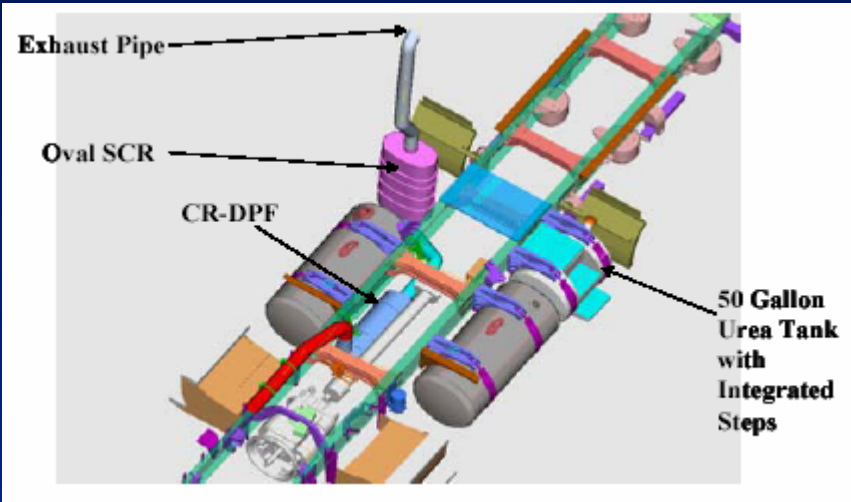
Emulsified Diesel Fuel + DOC or DPF
– 15-40% NOx reduction



DPF+SCR Systems Are On the Road

15 L Engine: 74-82% NOx Reduction
thru 75,000 mi

12 L Engine: 81-91% NOx Reduction
thru 2 years of operation



Component	Dimensions	Volume
CR-DPF DOC	12" x 6"	11.0 litres
CR-DPF Filter	12" x 15"	27.5 litres
SCR	4 off 9.5" x 6"	27.8 litres
Clean-Up Catalyst	2 off 9.5" x 4"	9.2 litres

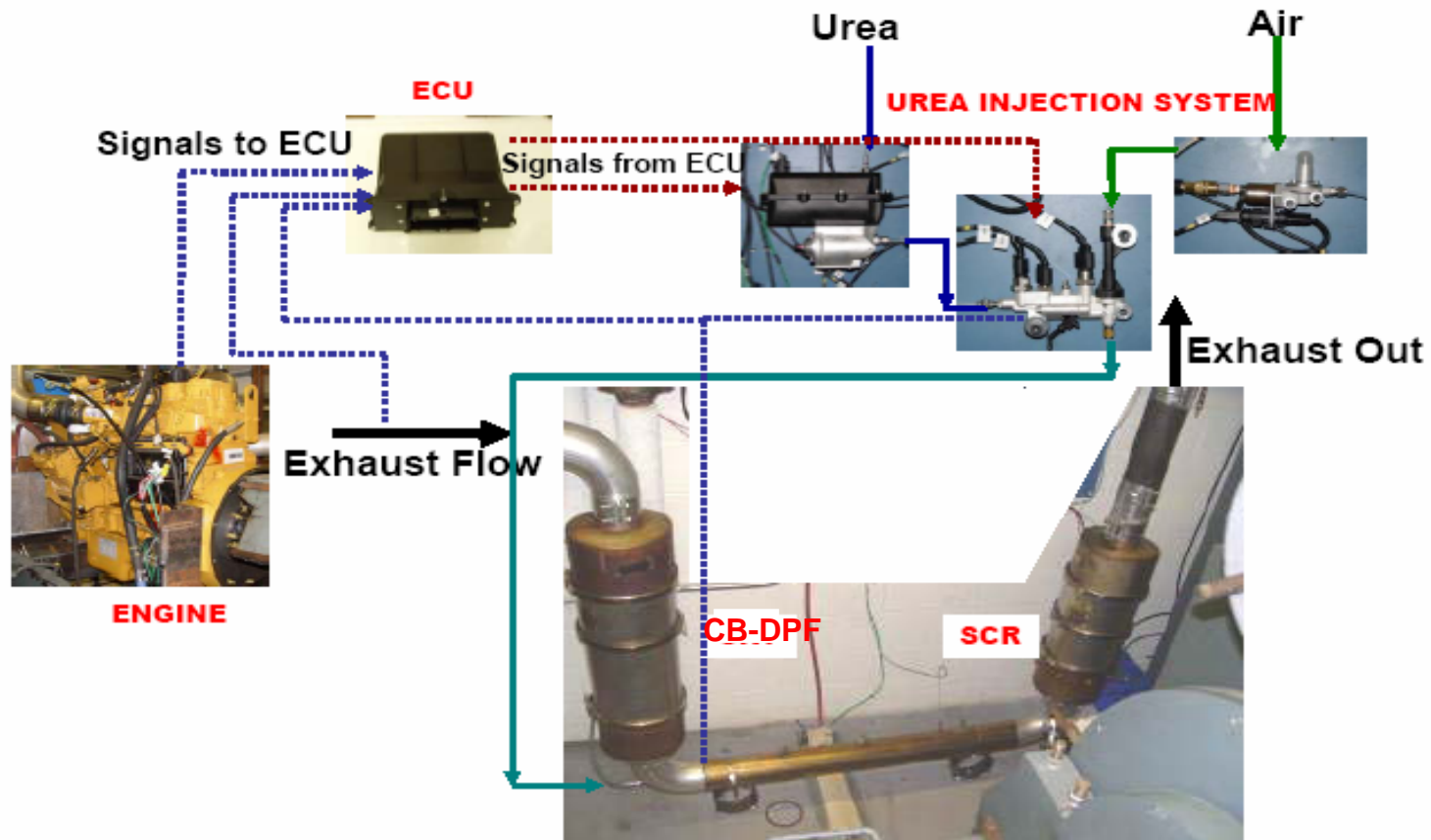
- 10 trucks operated for more than 2 million cumulative miles (2 refuse, 8 tractors; 3 emission tested)
- 45 liters of SCR cats./engine (200 cps)

Reference: SAE Paper No. 2004-01-1289



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Retrofit DPF/Urea SCR Components Include Urea Injection System, Controls, Catalysts



Reference: SAE Paper No. 2005-01-1862



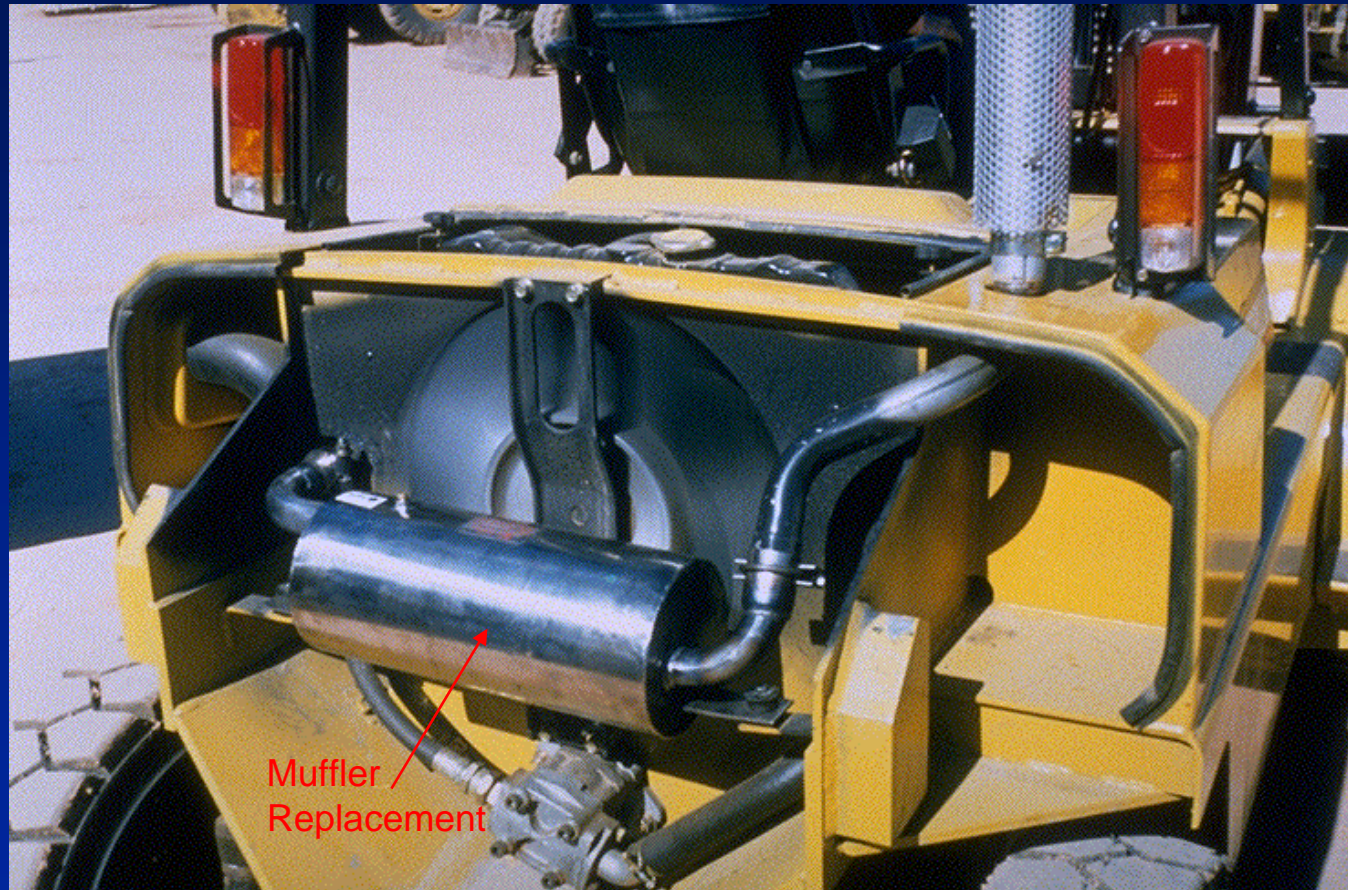
DOC/SCR Retrofit System

Verified by ARB for Off-Road Diesel Engines

- Combines DOC for PM reduction (25% minimum, Level 1), an SCR catalyst using ammonia reductant (80% NOx reduction), and an ammonia slip catalyst
- Verified for '91 thru '95 model year Cummins 5.9 L off-road engines
- Additional SCR retrofit options expected to be verified in 2005 – 2006 including DPF/SCR integrated retrofit systems



Integrated Converter Muffler



Filter System Retrofitted to a Truck



Active DPFs in Materials Handling, Construction Equipment, and Locomotives



SCR Marine Systems



SCR Retrofit



SCR Retrofit



SCR Catalyst Unit



Designing a Successful Retrofit Program



Key Considerations for Retrofit Programs

- Technology Selection
 - Target emissions
 - Engine condition and age
 - Perform maintenance
 - Suitability of control technology
 - Retrofit at the time of engine rebuild can be advantageous
 - Retire/Replace
 - Size
 - Properly sized control systems ensure low back pressure and maximum performance



Key Considerations for Retrofit Programs

- Technology Selection (cont.)
 - Vehicle Integration
 - Space, accessibility and exhaust temperature are important vehicle integration issues
 - Devices are often installed in-line or as a muffler replacement
- Maintenance
 - Proper vehicle and emission control technology maintenance is critical
- Fuel Quality
 - For PM control, <15 ppm sulfur fuel allows for maximum emission control performance and best filter regeneration characteristics
 - Fuel sulfur levels in excess of 500 ppm are not recommended



Frequently Asked Questions Concerning Retrofit Programs

● Costs

- Costs depend on many factors including:
 - Number of vehicles retrofitted (sales volume)
 - Retrofit technology used (oxidation catalyst, filter, etc.)
 - Engine size (displacement)
 - Engine out emissions
 - Fuel quality
 - Exhaust temperature and duty cycle (These factors will affect which retrofit technology will be appropriate.)
- Costs are expected to decrease as the market expands



Frequently Asked Questions Concerning Retrofit Programs (cont.)

Crankcase Filtration	\$700
Diesel Oxidation Catalysts (DOC)	\$500 to \$2000
Diesel Particulate Filters (DPF)	\$7,000 to \$10,000
Combined Lean NOx Catalyst/DPF Systems	\$15,000 to \$20,000
Combined DPF/EGR Systems	\$18,000 to \$20,000
SCR Systems	\$12,000 to \$20,000



Note: DPF costs are higher for active systems.

Frequently Asked Questions Concerning Retrofit Programs (cont.)

- Drivability
 - Properly selected retrofit technologies do not impair driving performance
- Maintenance
 - Oxidation and passive lean NOx catalysts are virtually maintenance free – periodic inspection
 - Filters require maintenance for ash removal
 - SCR maintenance and active systems -- as per manufacturer's specifications
- Effects on Engine Life
 - Properly maintained retrofit technologies do not shorten engine life



Frequently Asked Questions Concerning Retrofit Programs (cont.)

● Fuel Penalties

- Oxidation catalysts have no effect on fuel consumption
- Most filters have a negligible effect on fuel consumption (<1%)
- Urea consumption in SCR systems results in an equivalent fuel penalty of 3-5%
- Systems that rely on fuel injection as a reductant or heat are typically characterized by a 3-5% fuel penalty
- EGR results in a 1-4% fuel penalty

● Warranties

- Manufacturers provide various warranties as part of a purchase agreement



Conclusions

- A wide variety of retrofit options are available for diesel engines to reduce HC, CO, PM and toxic emissions
- NOx retrofit controls options are available
- Combined PM/NOx technology options exist
- A growing number of retrofit programs are being successfully implemented
- Technology development continues to expand the range of applications available for retrofit
- A successful retrofit program must be properly designed and implemented

