

# RETROFIT EMISSION CONTROL TECHNOLOGIES FOR HEAVY DUTY DIESEL ENGINES - THE STATE OF THE ART

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Johnson Matthey Catalysts  
**BAQ 2004**

ENVIRONMENTAL CATALYSTS AND TECHNOLOGIES

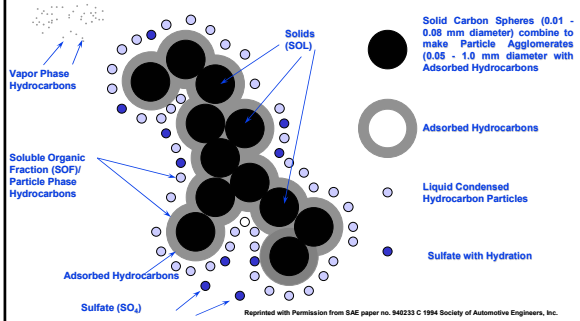
## Outline

- Diesel Engine Emissions
- PM Control Technologies
- NOx Control Technologies
- Conclusions

## Diesel Engine Emission Control

- Diesel engine emissions:
  - PM (Particle Matter)
  - NOx (Nitrogen Oxides)
  - CO (Carbon Monoxide)
  - HC (Hydrocarbons)
- New engine emissions are being significantly reduced with increasingly tighter emission standards
- However, some of the existing, high-emitting diesel engines will be in use for the next 10 to 25 years
- Using emission control technologies to produce extremely clean new engines as well as to retrofit existing engines is the way to reduce emissions

## Schematic of Diesel Particles and Vapor Phase Compounds



## Outline



- Diesel Engine Emissions
- PM Control Technologies
  - DOC technology
  - DPF technology
  - Fuel Sulfur Effect
  - Advanced DPF technology
  - Active Regeneration Filter Technology
  - Partial Filter technology
- NOx Control Technologies

## Diesel Oxidation Catalyst



## Diesel Oxidation Catalysts (DOC)



- Oxidizes CO and HC to CO<sub>2</sub> and H<sub>2</sub>O (desired)
- Oxidizes toxics such as aldehydes
- Oxidizes SO<sub>2</sub> to SO<sub>3</sub> (undesired)
- Oxidizes Soluble organic fraction (SOF, HCs) adsorbed on Particulates to reduce PM
- CO, HC reduction up to 90%.
- PM reduction up to 50% depending on SOF content of PM; Typically 25% on new engines

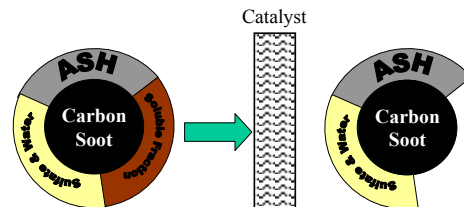


Ceramic Catalyst



DOC in a muffler

## Particulate Matter Oxidation



Note: Soluble Fraction, Sulfates and Water are in Vapor form.

## DOC - Applications



- Can work with high sulfur fuel (up to 500 ppm)
- Benefits from low S fuel (low sulfate make)
- Can activate at lower temperature for CO & HC reductions
- Proven low-cost technology
- Combined catalyst and muffler to provide sound attenuation and emission benefit
- Easy to retrofit on existing vehicles
  - 2 stroke & 4 stroke
- No required maintenance
- Variety of sizes and shapes for different applications

## DOC Performance

500 PPM S Fuel

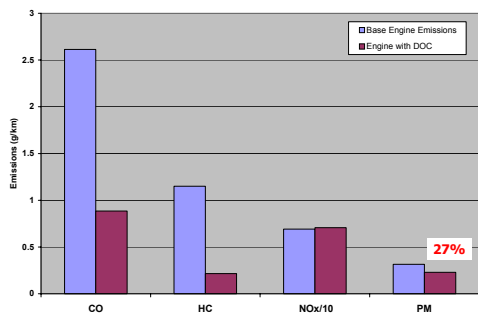


	PM (g/bhp-hr)	Reduction	CO (g/bhp-hr)	Reduction	HC (g/bhp-hr)	Reduction
<b>2-Stroke</b>						
Baseline	0.44		1.0		0.7	
W/ CEM	0.22	50%	0.6	40%	0.4	43%
<b>4-Stroke</b>						
Baseline	0.073		1.11		0.115	
W/ CEM	0.055	25%	0.35	68%	0.014	88%

Tested at Southwest Research Institute  
under  
EPA approved FTP transient test cycle

## DOC Performance on BEST EURO II Bus

500 ppm S Fuel



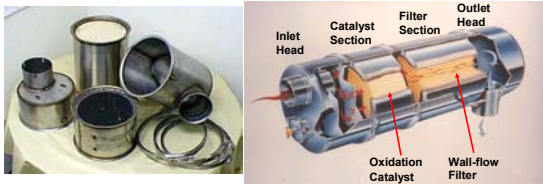
## Diesel Particulate Filter



## Diesel Particulate Filter



- Johnson Matthey Continuously Regenerating Technology (CRT®) Diesel Particulate Filter

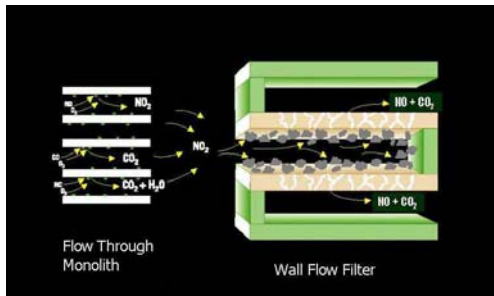


## CRT® Particulate Filter for >90% PM Removal

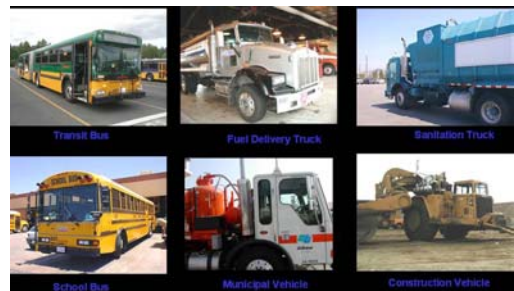


- Patented CO/HC/PM Emission Control System combining Oxidation Catalyst & Filter
- Engineered as a totally passive emission control system which requires no supplemental heat
- Uses  $\text{NO}_2$  produced by a specially formulated catalyst to burn soot collected by the filter at typical operating temperatures of diesel engine exhaust
- Requires the use of Ultra Low Sulfur fuel (< 50 ppm S) for maximum emission reduction and filter regeneration

## CRT® Particulate Filter – Operating Principle



## Examples of CRT Installations in the US

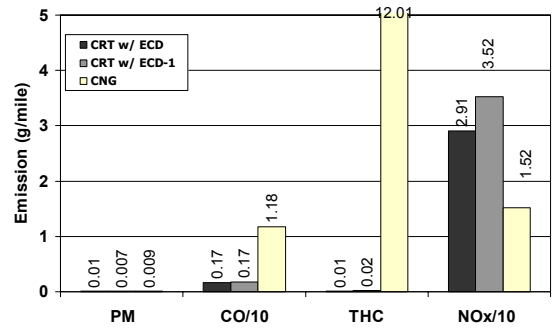


### Mumbai Transit (BEST) Hino Engine Euro II Bus with CRT

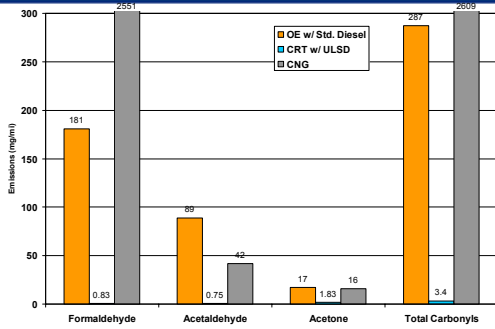


### Avg. Emissions Test Results- CRT vs. CNG

LA MTA Data – Ser 50 Engines – CBD Cycle



### Carbonyl Destruction with CRT on Ser 50 under NY Bus Cycle



### Fuel Sulfur Effect on Diesel Particulate Filter

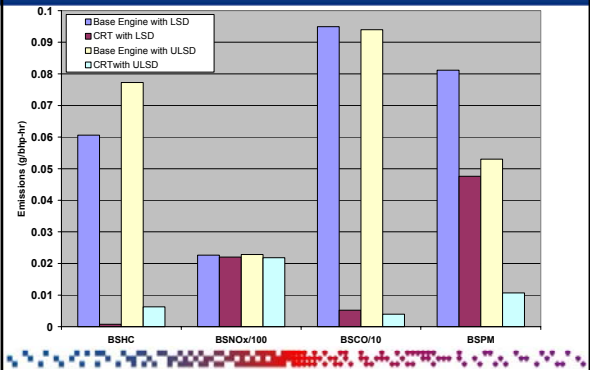
## Impact of Fuel Sulfur



- **Impact of Fuel Sulfur on CRT Regeneration**
  - Catalyst can be poisoned by high sulfur in fuel
  - Lower NO<sub>2</sub> generation; Problem in filter regeneration
- **Impact of Fuel Sulfur on CRT Particulate Emissions**
  - High SO<sub>2</sub> oxidation, so sulfate can increase measured PM
  - Low PM reduction (40 – 50%) due to high sulfate make

## Impact of Fuel S on Emissions

350 ppm vs. 15 ppm fuel with CRT under FTP



## CCRT™ - Advanced Passive Filter System

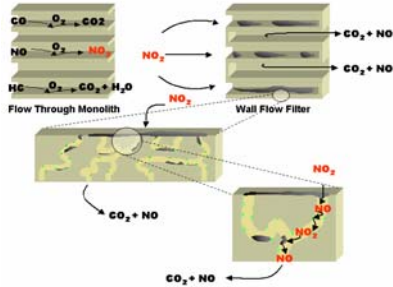


## CCRT™ – An Advanced CRT for Challenging Applications



- CCRT = DOC + Catalyzed Filter
- Advantages of CCRT:
  - Higher soot burn rate than CRT or CSF
- Install in Challenging Applications
  - Low temperature applications (200 – 250°C)
  - Low NO<sub>x</sub>/PM applications (NO<sub>x</sub>/PM > 15)
- Even at low CSF loadings, we see improved performance with the CCRT
- Successfully demonstrated in field trials in the US, Europe and Asia

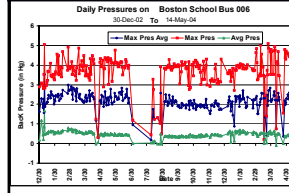
## Use of NOx Within CCRT System



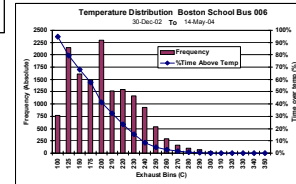
## CCRT Experience on low temperature School Bus



Boston School Bus with 175 hp 2000 MY CAT 3126 Engine



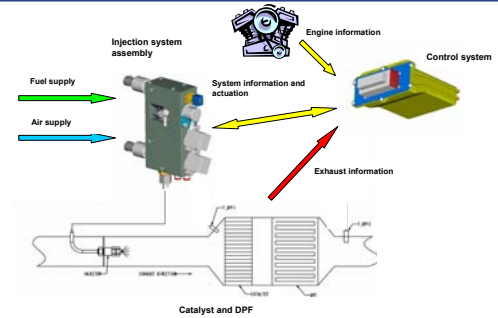
- \* Cold Exhaust Temperature Profile
- \* Only 8% of time Temp > 260 C;
- \* 40% time @ 200 C
- \* CCRT operating with stable back pressure for over 17 months



## Active Regeneration: Low NOx/PM applications

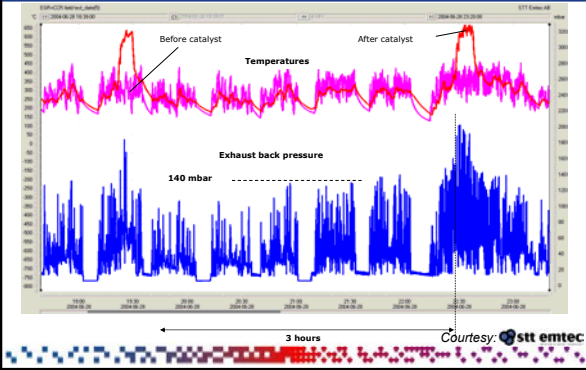


## Active Regeneration with Fuel Injection



Courtesy: stt emtec

## Active Regeneration of CRT with Fuel Injection System



## Partial Filter Systems



## Partial Filter Product Development



- Partial filtration = moderate (>50%) PM reduction, but minimize filter plugging
  - Some PM is trapped, rest goes through
- Use variety of substrates:
  - Flow through with notches
  - Wire mesh
  - Ceramic foam
- Can use in CRT or CCRT configuration for effective soot burn
- Ideally suited for old, dirty engine retrofit
  - America, Asia
- Work with ULSD proven; Tests in progress with LSD fuel

## Partial Filter Product Development



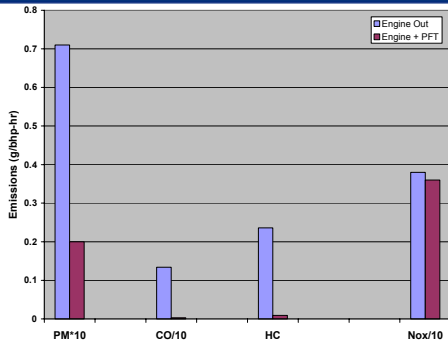
Step to filtration activity:

porous layer made of sintered metal fiber fleece

Trash Truck in CA with Partial Filter

Clean outlet head on partial filter after operation

## Emissions Results for Partial Filter System Caterpillar 3126 MY 1998, under US FTP Transient cycle



## Outline



- Diesel Engine Emissions
- PM Control Technologies
  - Fuel Sulfur Effect
- NO<sub>x</sub> Control Technologies
  - EGRT
  - SCRT
- Conclusions

## EGRT Development & Applications

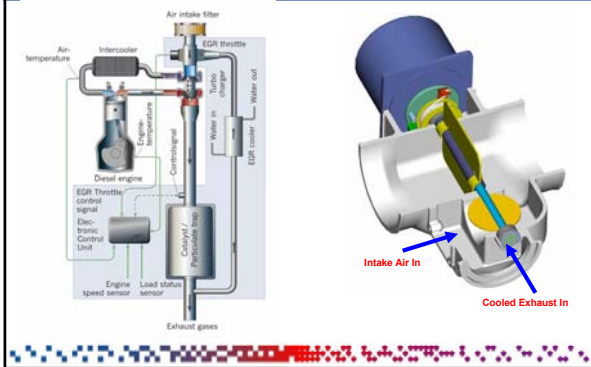


## EGRT™ System

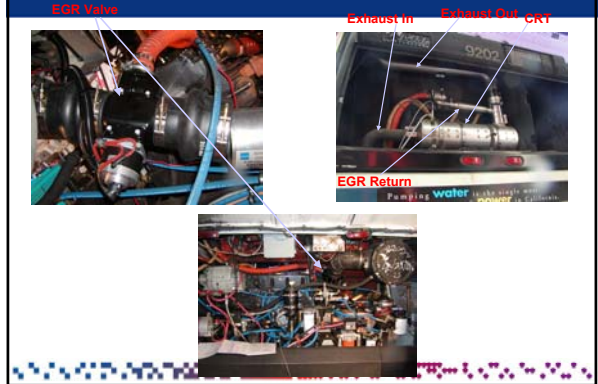


- EGRT™ = EGR + CRT®
- CRT = Continuously Regenerating Technology Diesel Particulate Filter
- EGR = Re-circulation of part of the exhaust gas to engine intake air
- Uses STT patented EGR technology in combination with the CRT particulate filter
- ULSD (< 50 ppm) fuel is required

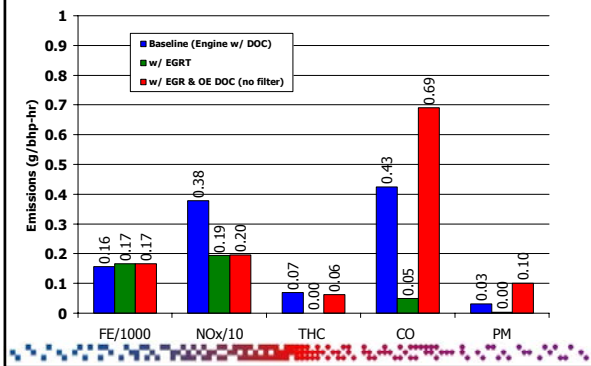
## EGRT System and Throttle Valve



## EGRT Retrofit on VTA Transit Bus

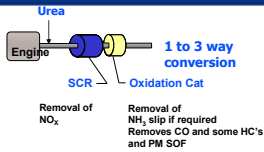


## Emissions Results for EGRT System Cummins ISL 330 Engine, FTP Cycle on Engine Dyno

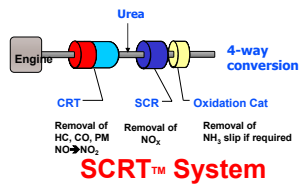


## Selective Catalytic Reduction (SCR)

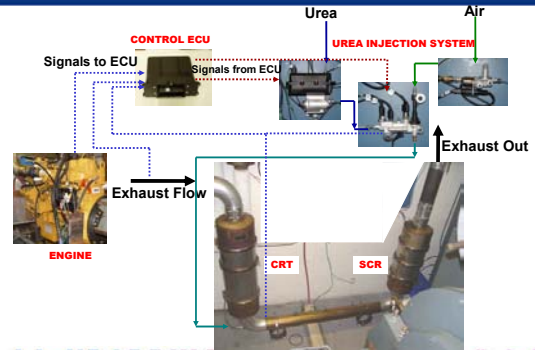
## SCR and SCRT™ System Schematics



- **SCRT = SCR + CRT**
- **System Components**
  - CRT system
  - Urea Injection system
  - SCR system



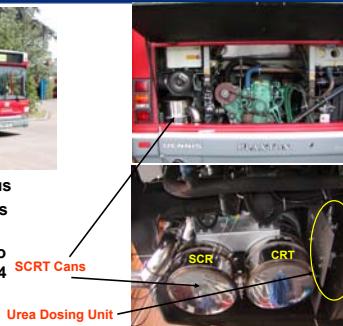
## Retrofit SCRT System



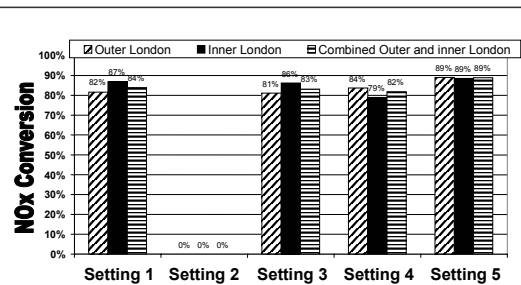
## SCRT Field Trial Bus in UK



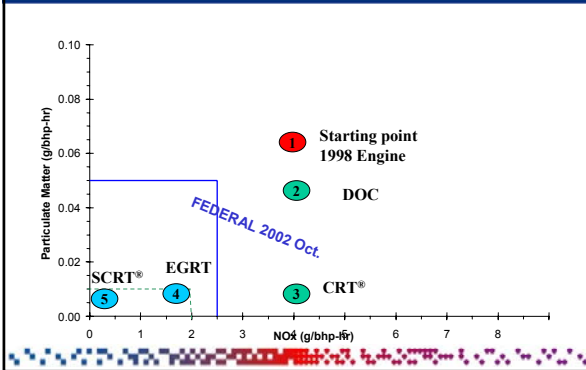
- Dennis DART Bus
- 3.9 litre Cummins Engine
- System went into service in July 04



## London Bus – Millbrook Testing



## Effect of Emission Control Retrofit on Current Engines



## Conclusions



- A multiplicity of catalytic emission control technologies now exists to aid the emissions engineer in achieving virtually zero emission levels from diesel engines
- Johnson Matthey provides a variety of PM and NOx control technologies for retrofit and OE applications
  - PM Control: DOC, CRT, CCRT, PF
  - NOx Control: EGR, SCR and LNT
- DOC is a cost effective solution for use with 500 ppm S fuel
- Improved fuel quality especially ultra low sulfur fuel (< 50 ppm) enables the most advanced control strategies (CRT)
- Some engineering challenges remain for advanced system development, and overcoming infrastructure issues

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