Johnson Matthey Catalysts

Development and Field Demonstrations of the Low NO_2 ACCRT™ System for Retrofit Applications

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Johnson Matthey

DEER 2009

EMISSION CONTROL TECHNOLOGIES

Outline

- Introduction
- System Description
- System Performance
- Field Demonstrations
- Summary

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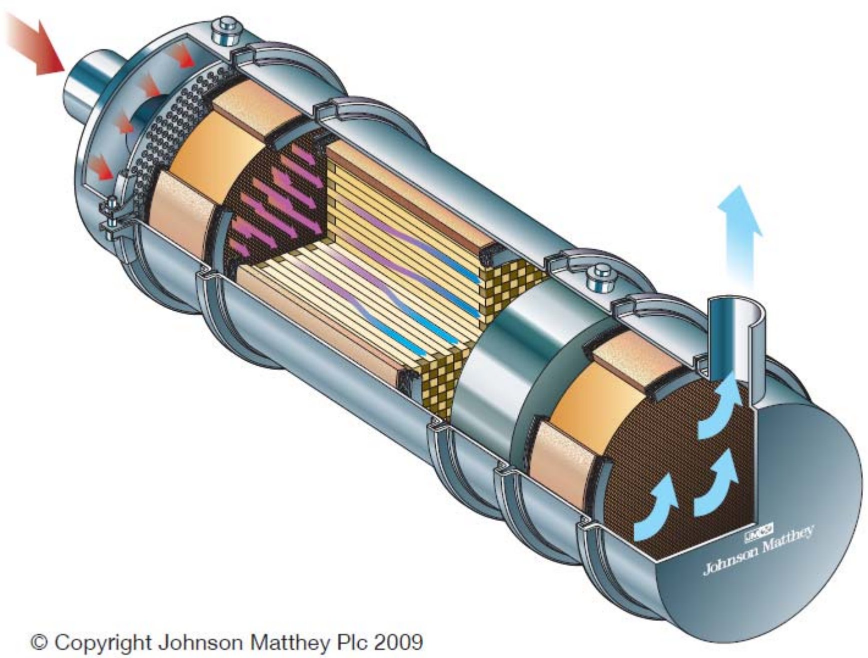
Diesel Retrofits and NO_2 Regulations

- Passive PM retrofits rely on NO_2 generation for low temperature combustion of soot
- NO_2 is classified as a criteria pollutant with both federal and state ambient air quality standards and is known to contribute to formation of ozone and particulate nitrates
    - In Jan 2009, CARB and EPA enforced a limit to the amount of allowable NO_2 increase from diesel retrofit technologies to 20% above engine baseline
    - Many retrofit technologies have been deverified due to non-compliance with the NO_2 limit

JM's solution – The ACCRT™ System

ACCRT = Advanced Catalyzed Continuously Regenerating Technology



ACCRT System Technology Highlights

- EPA and CARB Level 3 Verified Technology
  - >90% PM reduction
  - Complies with 2009 NO_2 Regulations
    - Does not increase NO_2 by over 20% of engine baseline

- For challenging applications
  - MY 2002-2006, includes both EGR and non-EGR engines
  - Fully passive regeneration
    - No high temperature regenerations
    - Minimal maintenance

Only EPA+ CARB verified passive DPF for EGR engines

ACCRT System Application Requirements

- Exhaust gas temperature must exceed 240°C for greater than 40% of operating time
- Can be applied to engine with and without EGR systems
- Engines may have a pre-existing DOC, must be removed prior to installation
- Engines manufactured between 2002-2006, certified to NOx standard of 2.5 g/bhp-hr and PM below 0.1 g/bhp-hr
- Currently available sizes allow application on engines with displacements between 5.9 liters – 15 liters, and horsepower ratings between 150 hp – 500 hp

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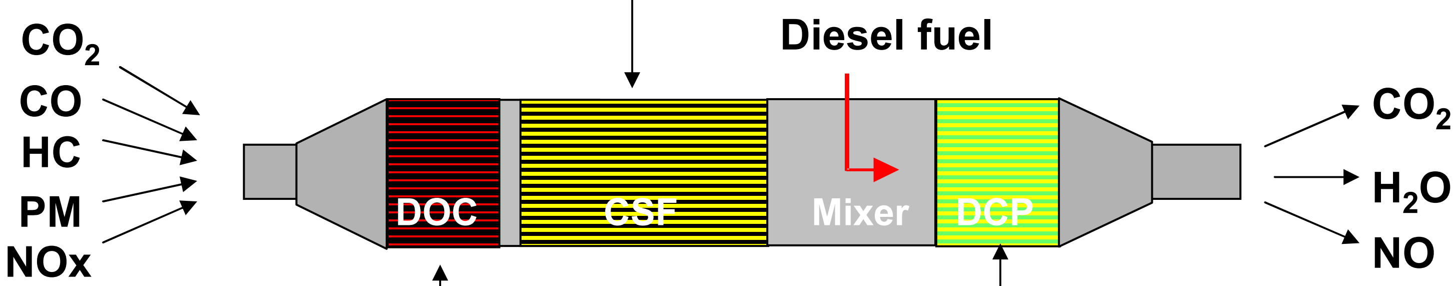
ACCRT System Principle of Operation

JM

② **CSF**

PM (C) trapped

$[C] + 2NO_2 \rightarrow CO_2 + 2NO$



① **DOC**

$CO + ½ O_2 \rightarrow CO_2$

$[HC] + O_2 \rightarrow CO_2 + H_2O$

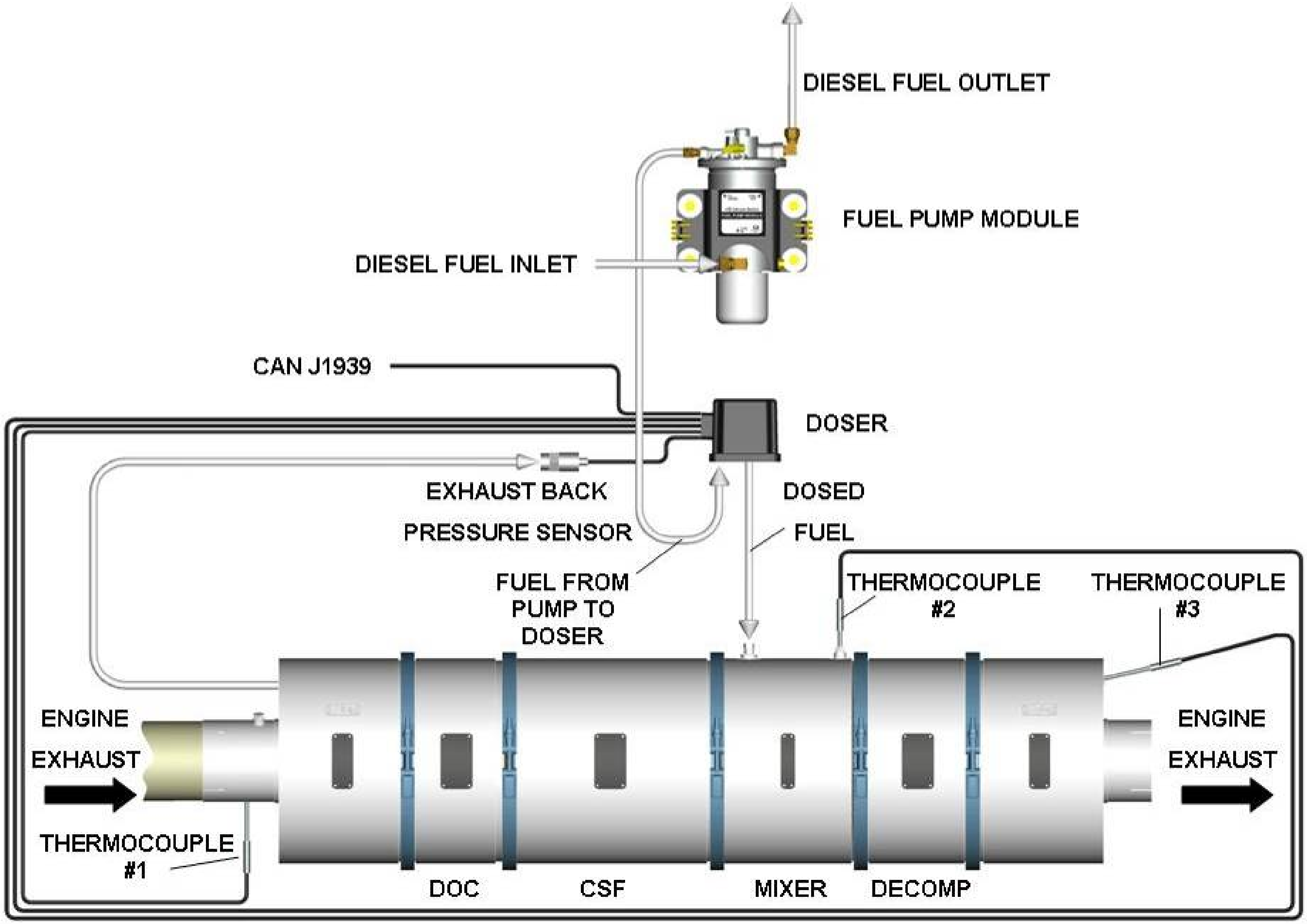
$NO + ½ O_2 \rightarrow NO_2$

③ **NO_2 Decomposition catalyst**

$[HC] + x\mathbf{NO_2} \rightarrow CO_2 + H_2O + NO$

Highly efficient DOC+CSF followed by NO_2 decomposition

ACCRT System Schematic

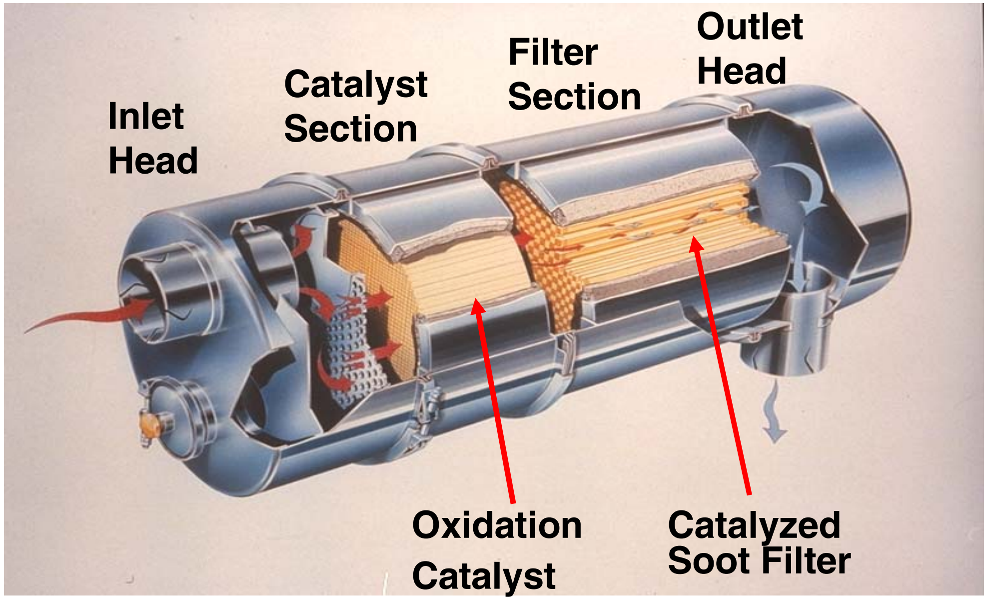


Johnson Matthey ACCRT™ System

ACCRT System Major Components

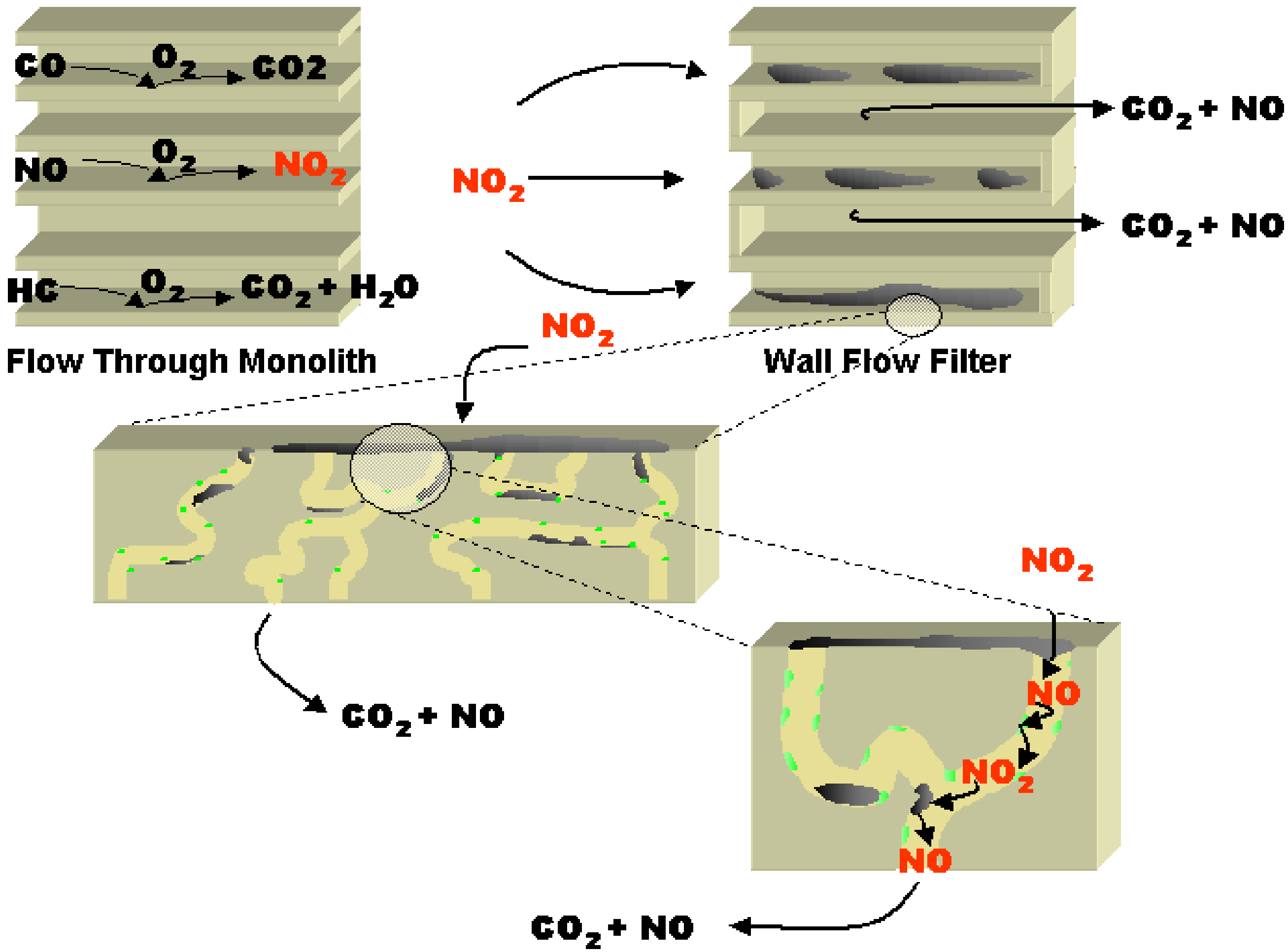
- CCRT Section
  - Diesel Oxidation Catalyst (DOC) + Catalyzed Soot Filter (CSF)
- Decomposition Catalyst
- Fuel Dosing System
  - Doser
  - Fuel Pump Module

CCRT® Section - Overview

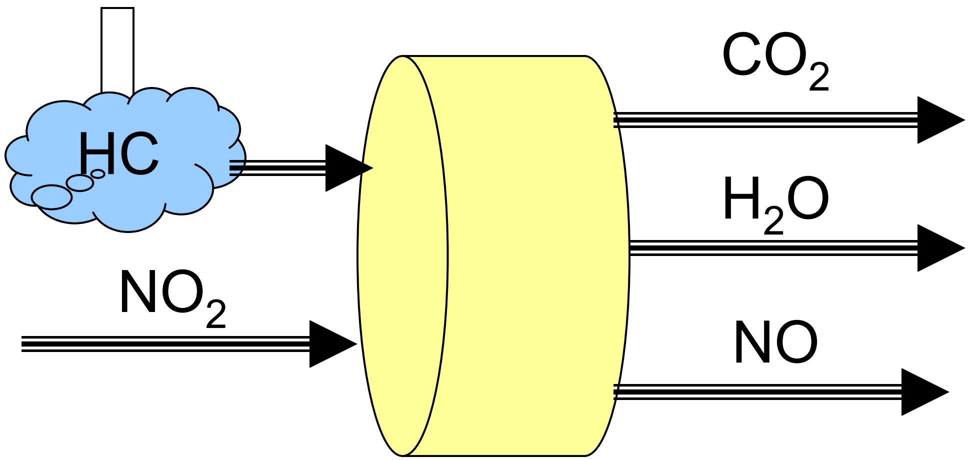


- Proven PM reduction technology for on-road, off-road and stationary applications for over 10 years
- Millions of miles of durability experience
- Previously CARB and EPA verified technology

CCRT Section – Operating Principle



Decomposition Catalyst Function

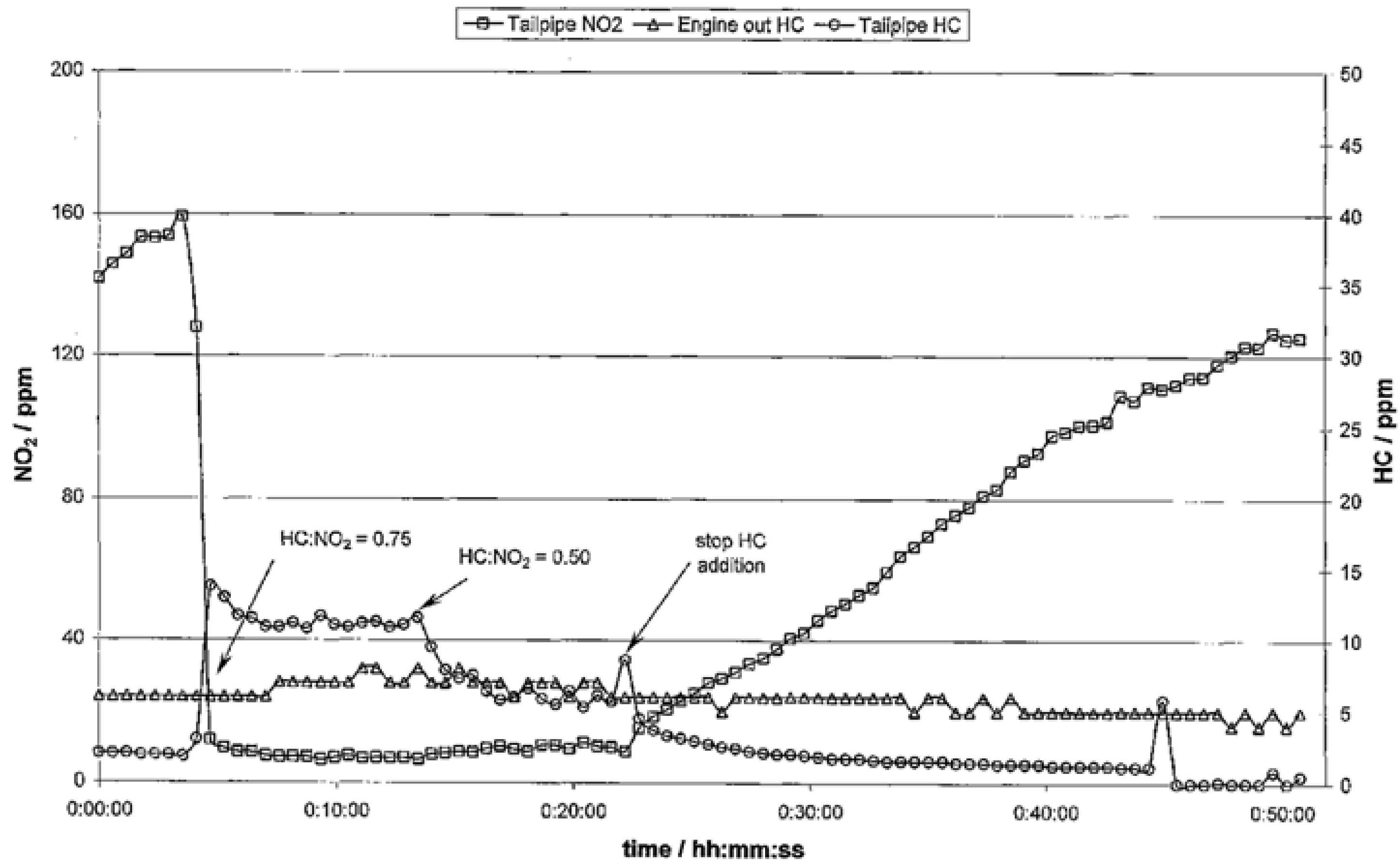


$$[HC] + xNO_2 \longrightarrow CO_2 + H_2O + NO$$

- Decomposes NO_2 to NO in a lean exhaust gas environment
- This is achieved by adjusting C1 HC:NO_2 ratio of exhaust gas and contacting the exhaust gas with a proprietary catalyst
- Amount of HC dosed is very low
- The proprietary catalyst promotes the decomposition of NO_2 to NO via reaction with HC. The catalyst is also designed to be a reservoir for the HC reductant

Decomposition Catalyst Performance

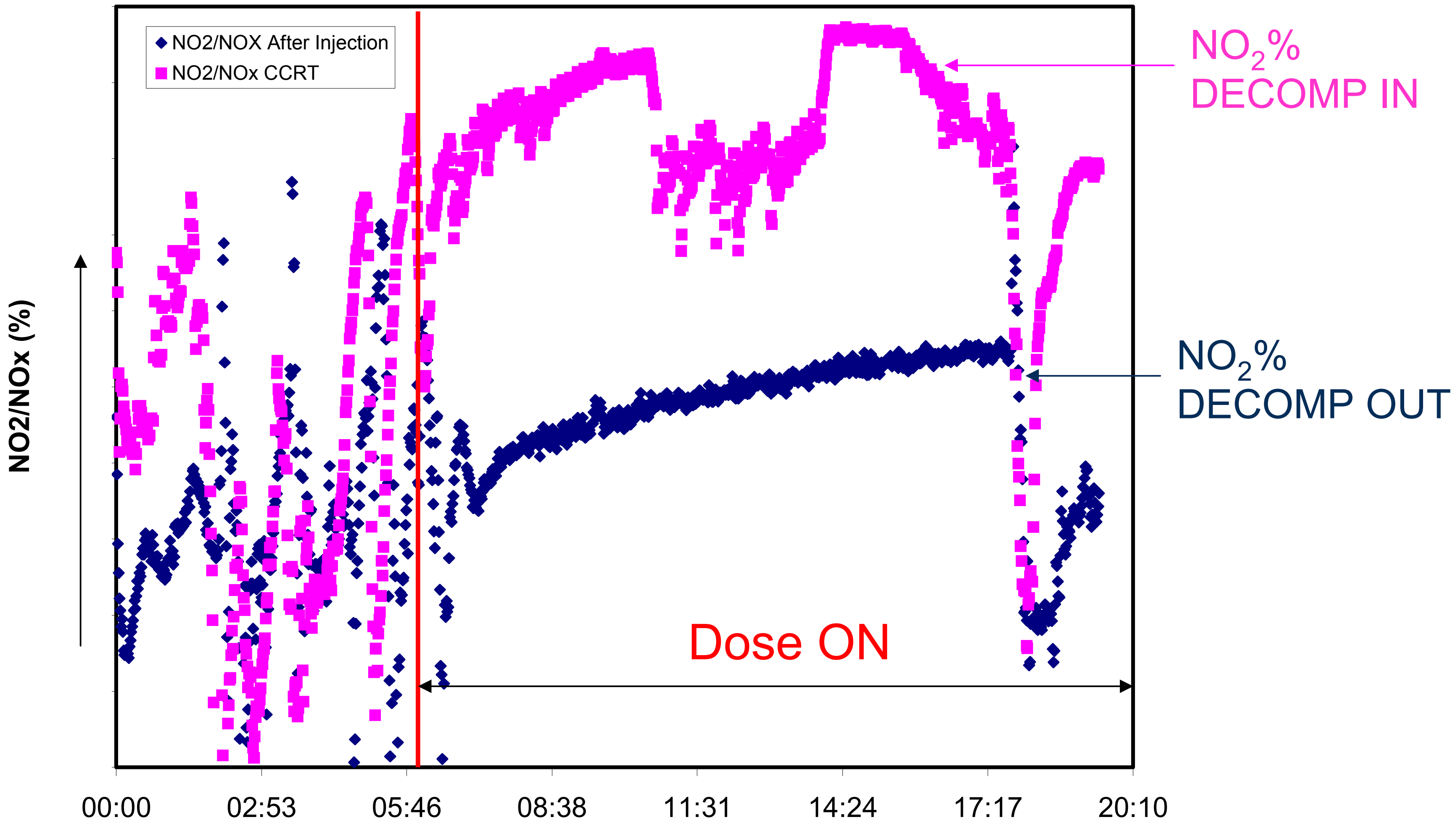
Reactor Test Data



NO$_2$ reduction achieved by controlling HC: NO$_2$ ratios

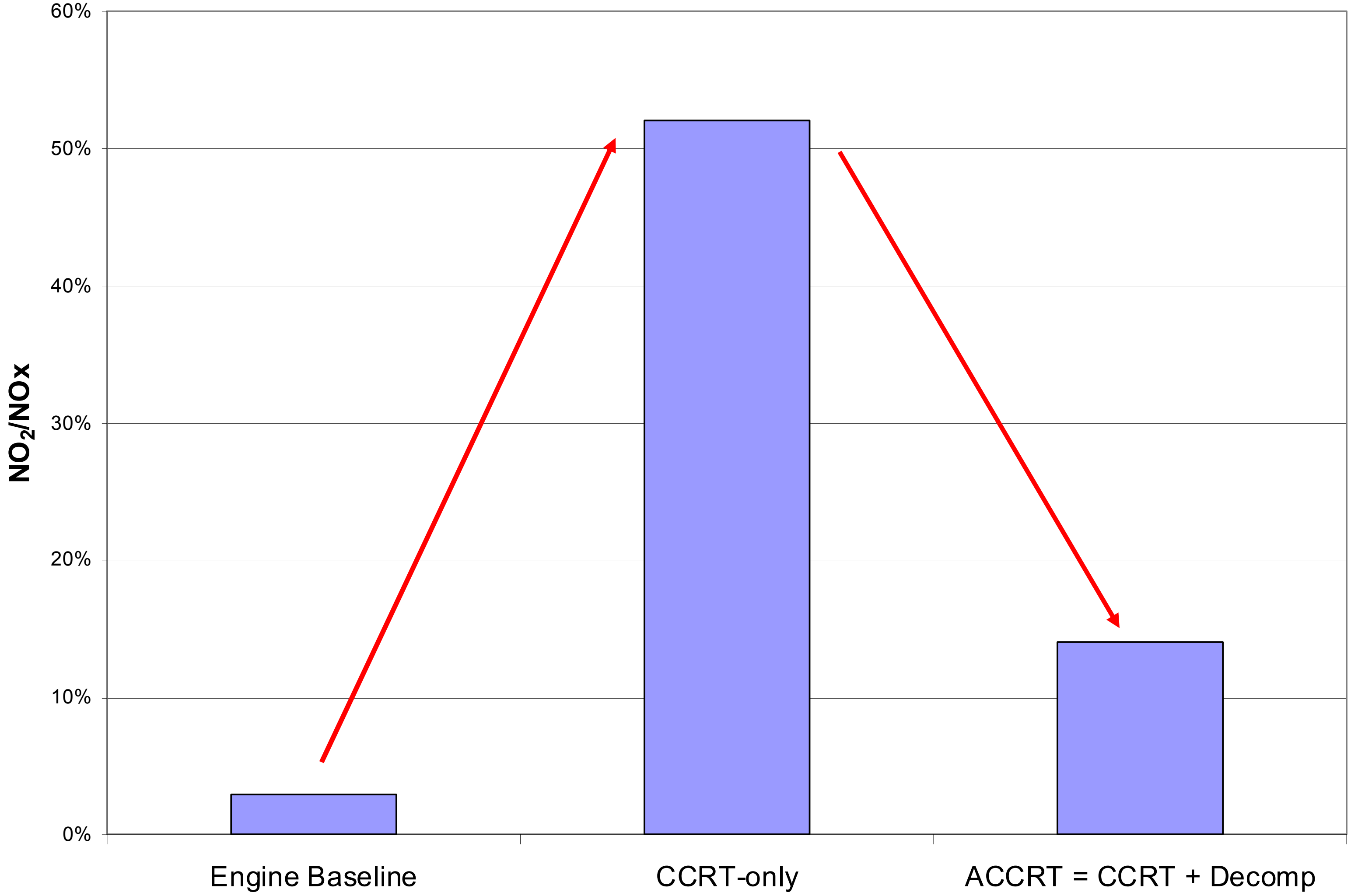
ACCRT System NO_2 Reduction

Hot Start FTP on Engine Dyno

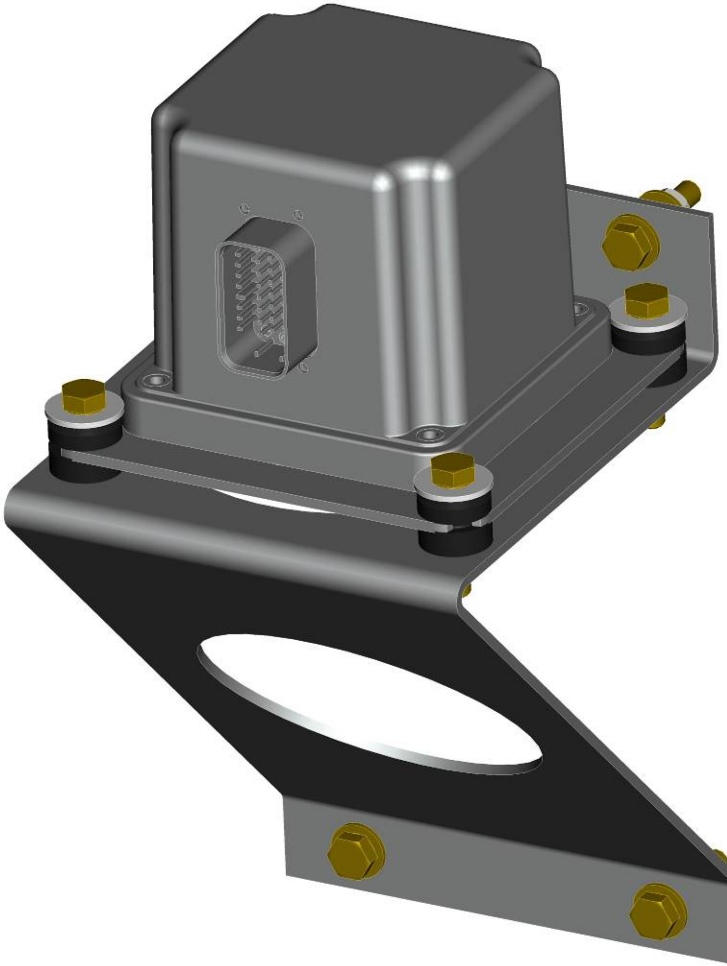


40% NO_2 reduced from CCRT out levels

NO_2 Reduction Impact of Decomposition System
Avg of 3 Hot FTPs on Cummins ISM 330 HP

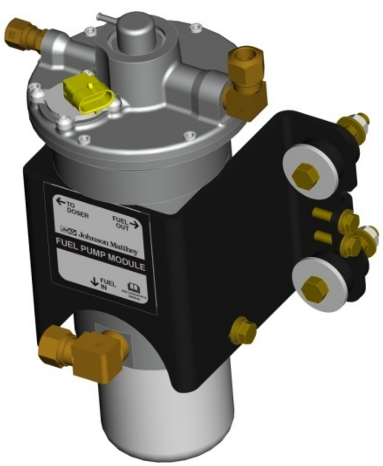


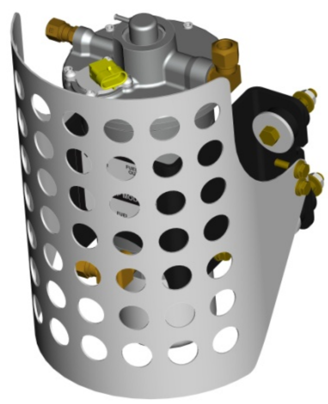
ACCRT System Doser



- Contains
  - Controller with datalogger
  - Fuel manifold
  - Fuel injector
  - Fuel pressure sensor for leak detection
- Features
  - Airless injection system
  - Over 1 year data logging
  - Rated for -20°C to 100°C

ACCRT System Fuel Pump Module

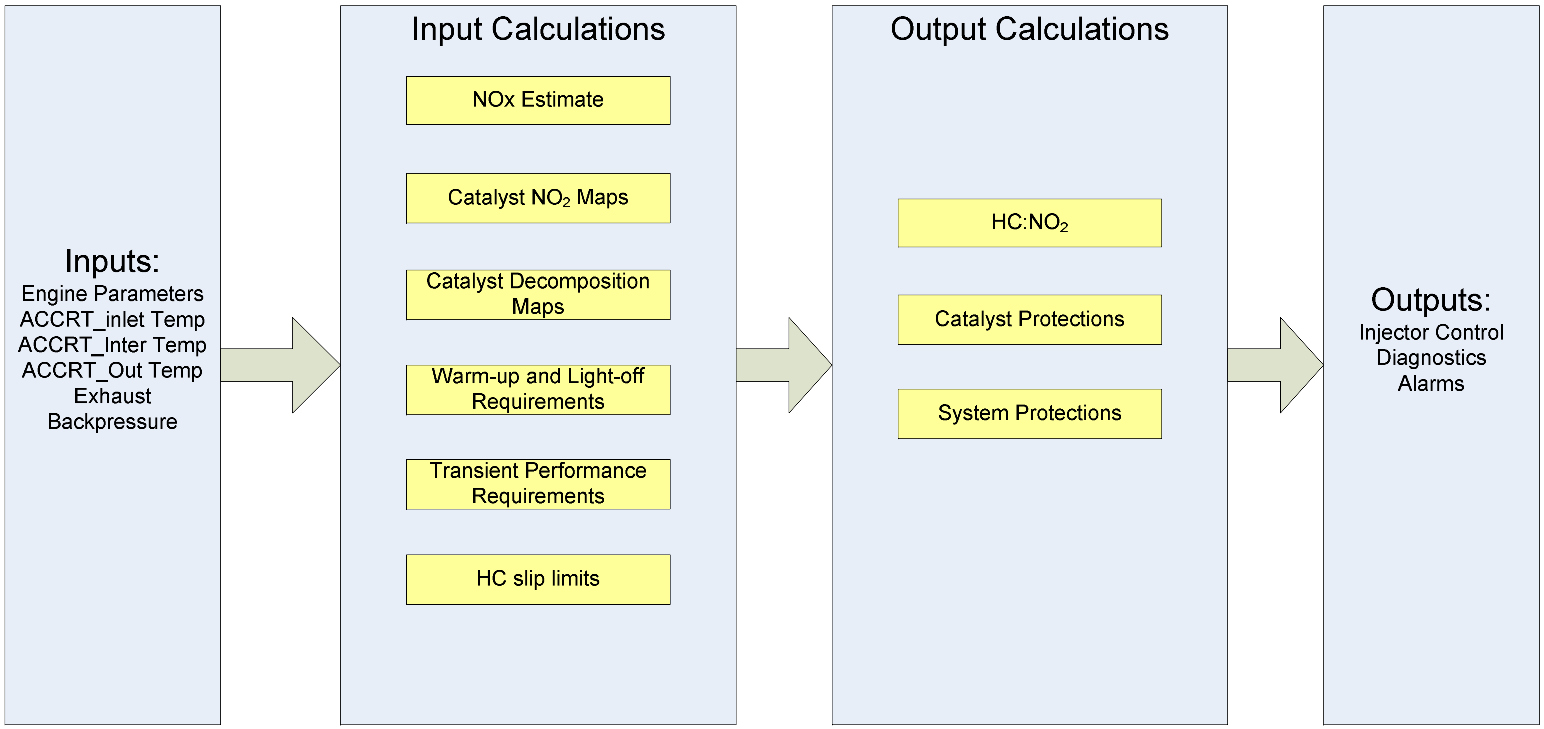




- Contains
  - Fuel Pump
  - Fuel filter
  - Pressure Regulator

- Features
  - 3 bar fuel pressure
  - 10 micron fuel filtering
  - Can be integrated into existing vehicle fuel system

Controls Overview



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Performance validated on multiple test engines

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All test engines meet applicable emissions standards

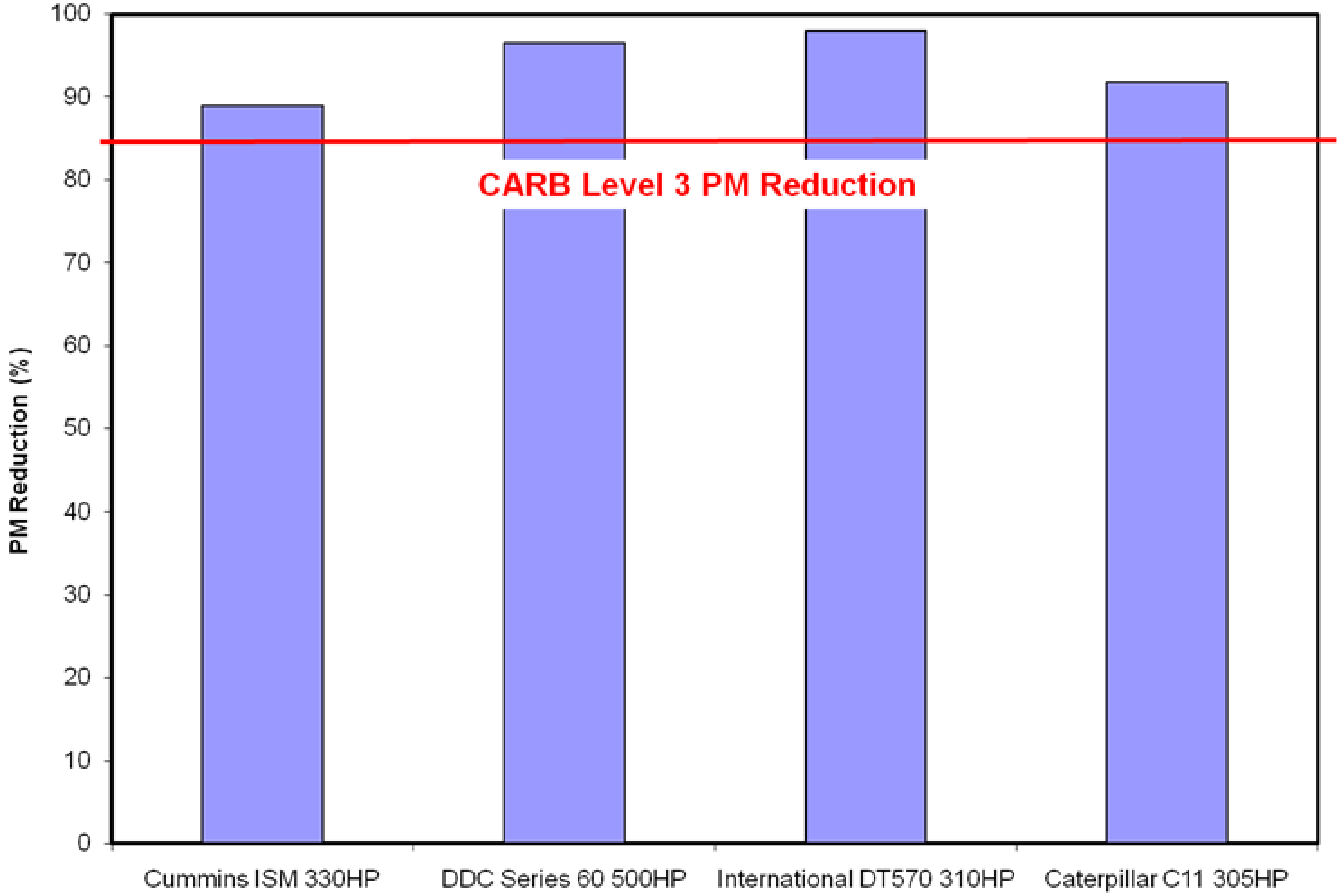
- NOx+NMHC: 2.5 g/bhp-hr
- PM: 0.1 g/bhp-hr

Test Fuel : 2007 Certification Diesel (ULSD)

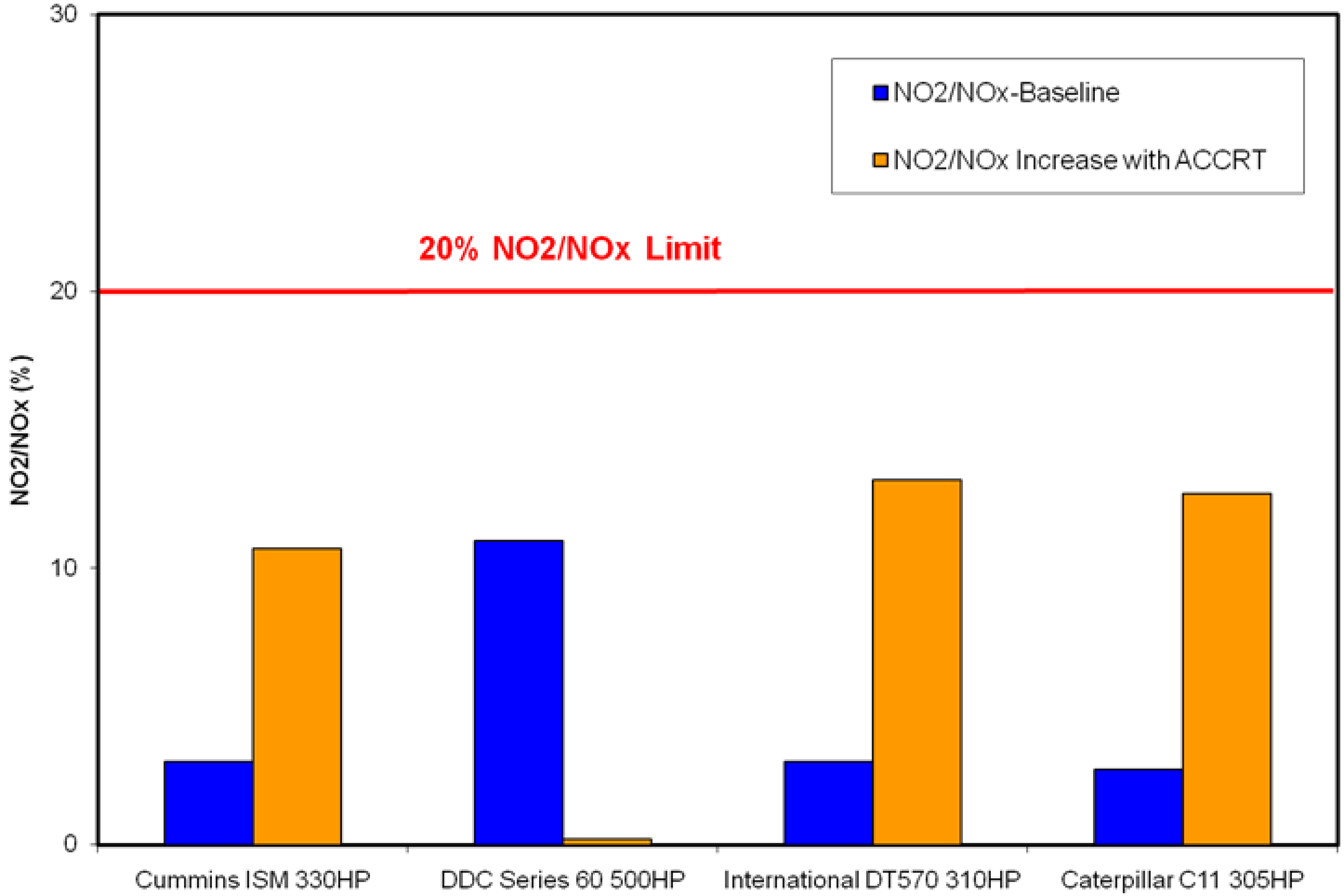
Test Cycle: FTP per 40 CFR Part 86

Emissions Measurements: HC, CO, NOx, NO, PM

PM reduction meets Level 3 Targets
Avg of 3 Hot FTP cycles



Tailpipe NO_2 maintained well below CARB 20% limit
3 Hot FTP cycles

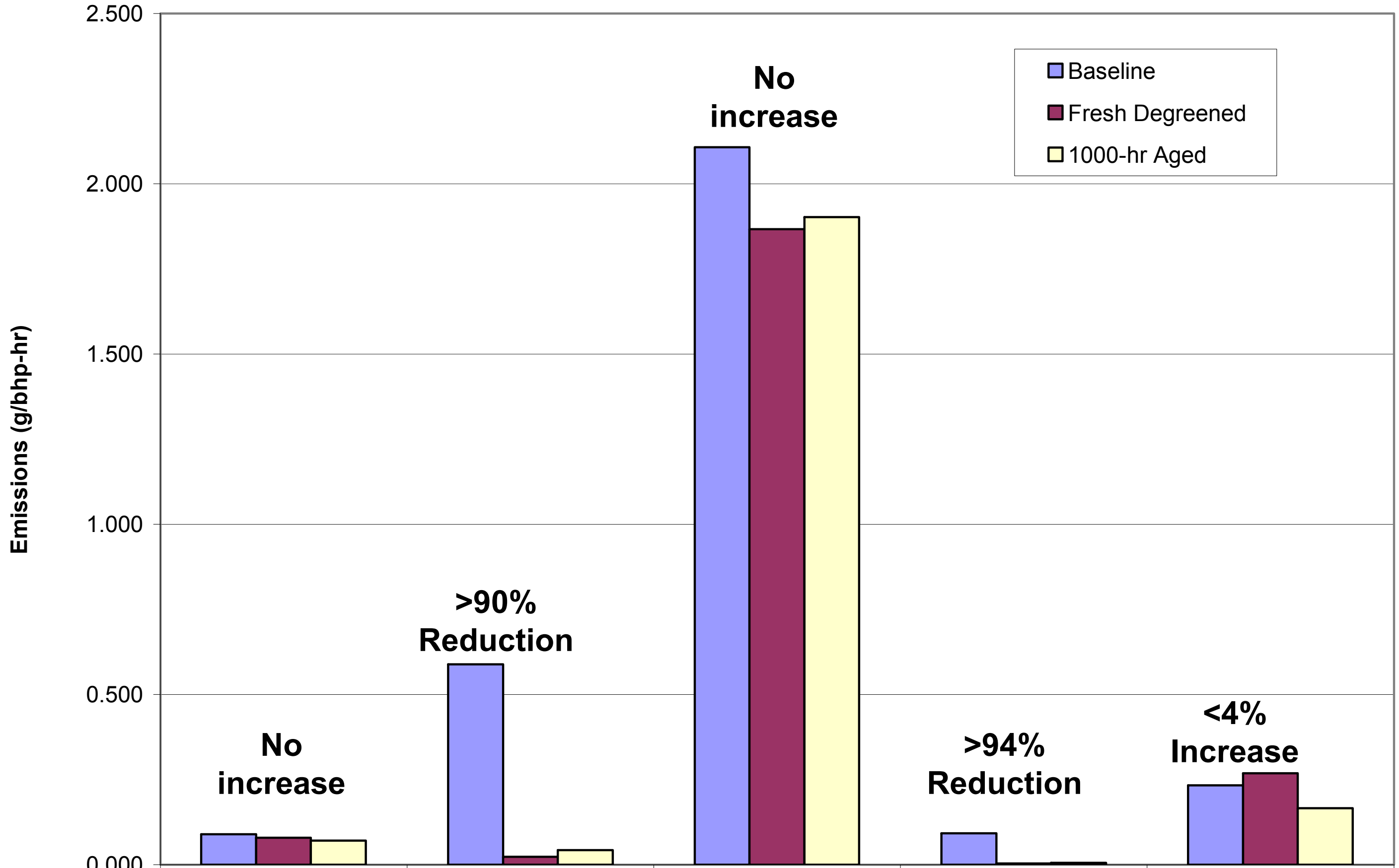


Durability demonstrated after 1000-hr aging

- Performance of 1000-hour field aged system was compared to a fresh degreened system
- 1 Cold+ 3 Hot FTP test cycles in accordance with methods described in CFR Title 40, Part 86, Subpart N
- Field - aged system from the following application:

Application	Vehicle Model	Engine	HP
Long-Haul Truck	Volvo VN Series Tractor	My 2006 Cummins ISX	400

Fresh vs. Aged System Performance Comparison
MY2003 DDC Series 60 500 HP – Composite FTP Cycle



	HC	CO	NOx	PM	NO2
Baseline	0.089	0.589	2.11	0.092	0.234
Fresh Degreened	0.080	0.023	1.87	0.003	0.268
1000-hr Aged	0.070	0.043	1.90	0.005	0.166

Field Demonstrations

- Retrofits successfully demonstrated on a variety of engines and applications types
- Applications
  - OTR trucks
  - Refuse trucks
  - Transit buses
  - School buses
  - Municipal vehicles
- NO_2 measurements are not possible on-board, PM regeneration indicated by stable backpressure

ACCRT System Installations


Transit

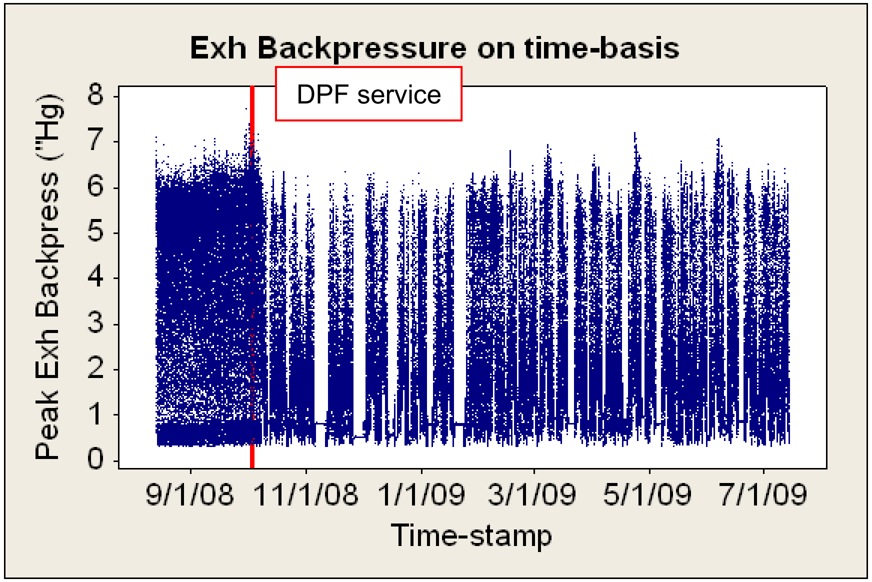

Municipal

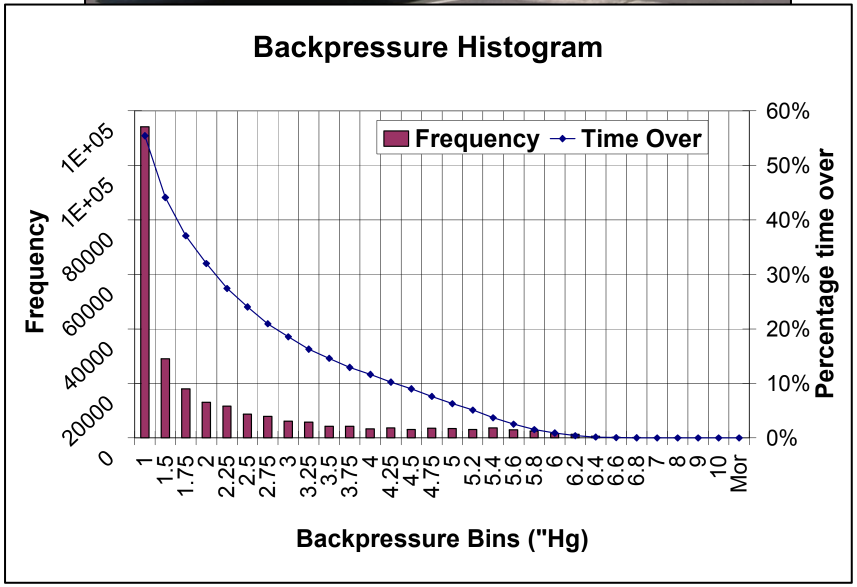
Long Haul


Refuse

Transit Bus Application
MY 2004 DDC Series 60 385 hp, 12.7 liter EGR engine

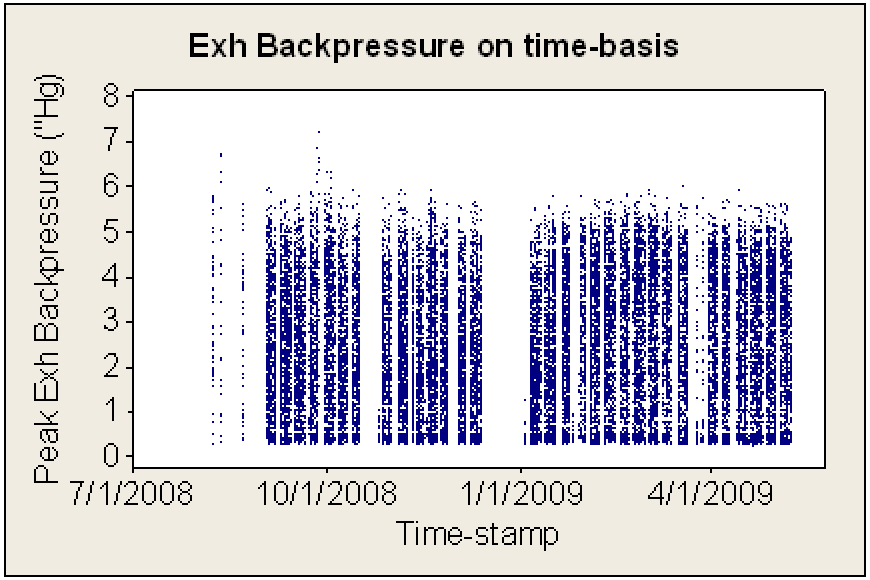
- Exhaust Temp is 290°C for over 40% of time
- Stable backpressure observed over 900 hours of operation on a single DPF

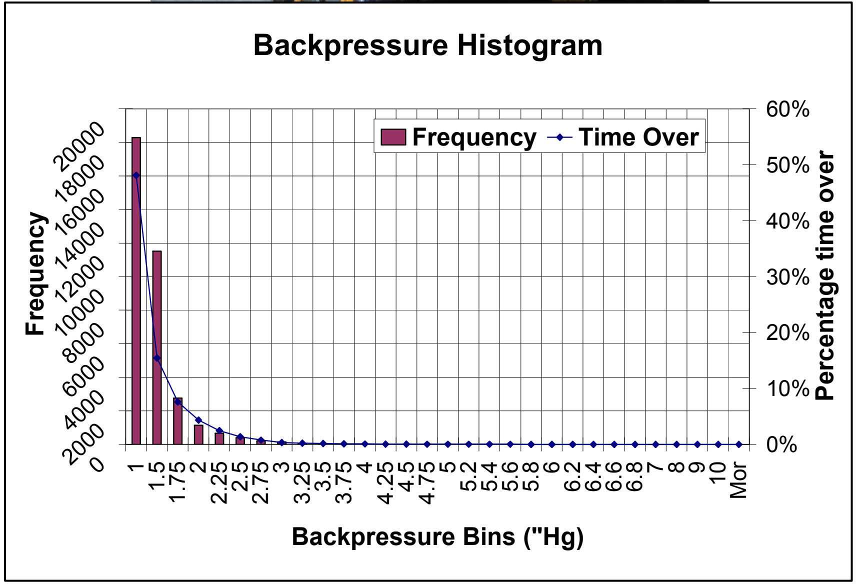




School Bus Application
MY 2006 Cummins ISB 245 hp 5.9 liter EGR

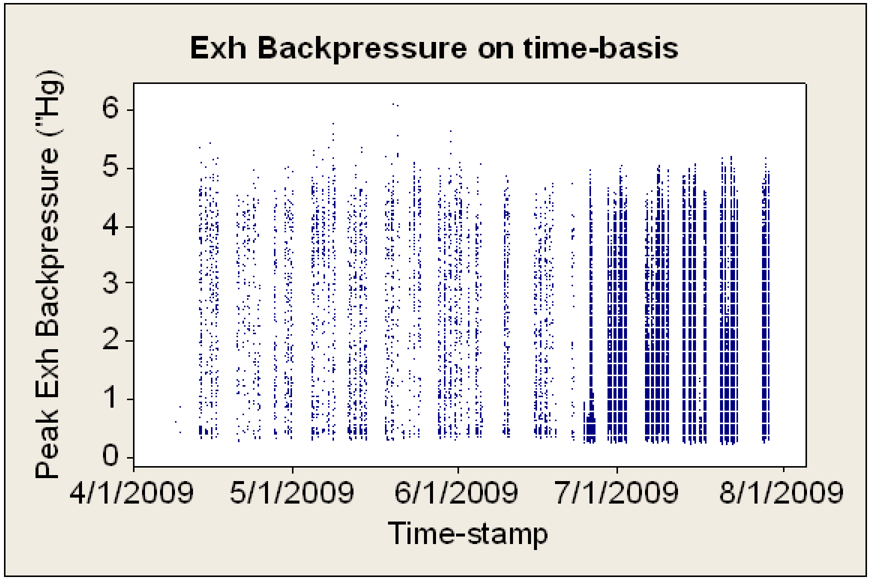
- School buses with low temperature (<220°C)
- Stable backpressure over 9 months of operation (including a winter in the North Western US)

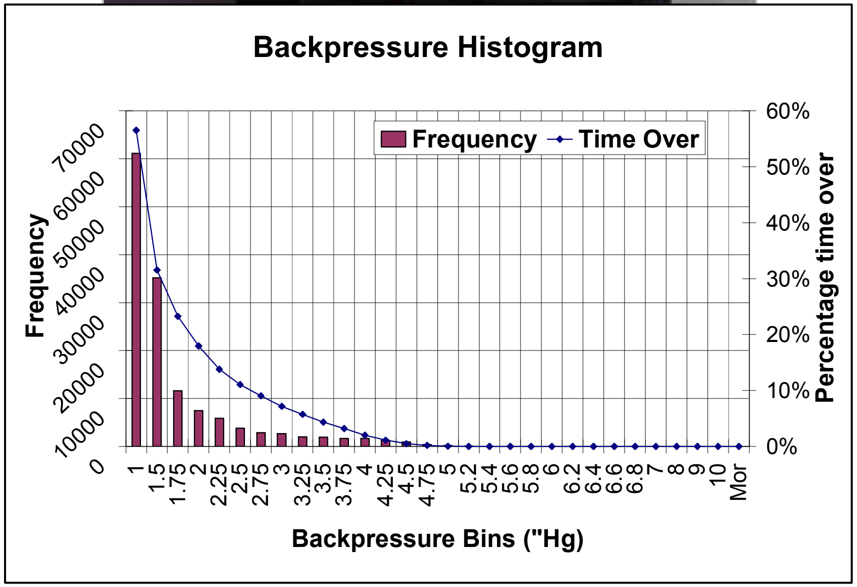




Municipal Vehicle Application
MY 2005 International DT 570 9.3 liter EGR

- High temperature application over 300°C
- Backpressure is stable for over 4 months of operation





Summary

- The CARB and EPA verified ACCRT System is the only passively regenerating Level 3 PM device for 2.5g NOx engines
- The ACCRT reduces PM emissions by over 90% while controlling increase of NO_2 below CARB and EPA regulatory limits
- The system reduces PM using a passively regenerating DPF and reduces NO_2 by dosing a small quantity of fuel over a decomposition catalyst
- Emissions performance has been proven on multiple test engines including both EGR and non-EGR engines
- Emissions durability has been demonstrated by showing that the system maintains performance after 1000 hours of field aging
- Field trials conducted on a diverse set of applications that include school buses, refuse trucks, transit buses, municipal vehicles and long haul trucks
- Commercialization of the technology is in progress