U.S. Locomotive Aftertreatment Retrofit Progress Report: SwRI Test Programs

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November 28, 2007

Topics Covered

* Field Test of Diesel Oxidation Catalyst on Line-Haul EMD SD60 locomotive
  » Also DOC application on an EMD 12-710 marine engine
* Diesel Particulate Filters on (2) EMD MP15DC switcher locomotives
* ARB Locomotive Project:
  » Selective Catalytic Reduction (SCR) efforts with EMD 710 Engine

EXHAUST EMISSIONS FROM A 3,800 hp EMD SD60M LOCOMOTIVE EQUIPPED WITH A DIESEL OXIDATION CATALYST

by

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BUILDING AMERICA℠

Acknowledgements

* SwRI performed this project in cooperation with MIRATECH Corporation, Union Pacific Railroad Company, and U.S. EPA.
* Initial Testing Funded by the U.S. EPA – Office of Transportation and Air Quality Assessment and Standards Division- National Vehicle and Fuel Emissions Laboratory- Ann Arbor, Michigan
  - » EPA Contract No. EP-C-05-018
* Subsequent Testing and Monitoring Funded by Union Pacific Railroad Company
* Catalyst design/manufacture provided by MIRATECH Corporation
* Installation, Testing and Monitoring Conducted by Southwest Research Institute

* **This Project consists of the retrofit of an experimental Diesel Oxidation Catalyst (DOC) to a Tier 0 Remanufactured Line-haul EMD SD60 locomotive.**
  - » **First such retrofit to a high HP freight locomotive in the U.S.**

Overview

* **Test Program**
* **Diesel Oxidation Catalyst (DOC) Background**
* **Test Locomotive**
* **Description of DOC housing design (within exhaust manifold)**
* **Initial Test Results**
* **Current Status**

DOC Test Program

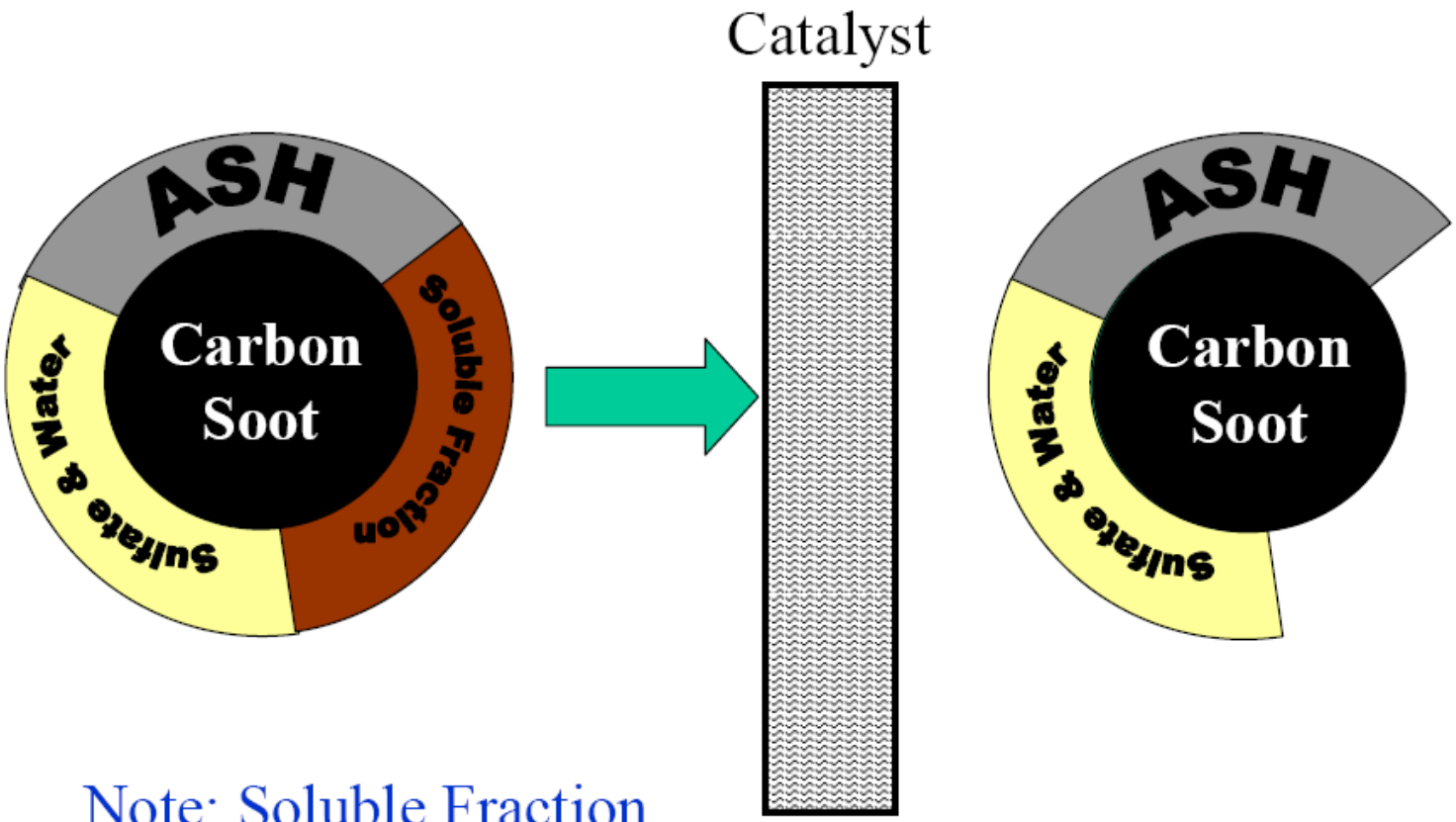
* **Design/Procure/install DOC housing (Integrated DOC/Exhaust Manifold) on SD60 Locomotive (UP 2368)**

* **Testing of Emissions and Performance at SwRI**
  - » **“As received” baseline with Current EPA Certification Fuel at 2000-4000 ppm Sulfur**
  - » **“As received” test with ULSD (<15 ppm Sulfur Fuel)**
  - » **Test with “degreened” DOC Installed and ULSD**

* **Release Locomotive Back into Service in Los Angeles**
  - » **Monitor Activity and Engine Conditions Remotely**

* **Return Locomotive to SwRI after Six and Twelve Months for Inspection and Emissions Testing**

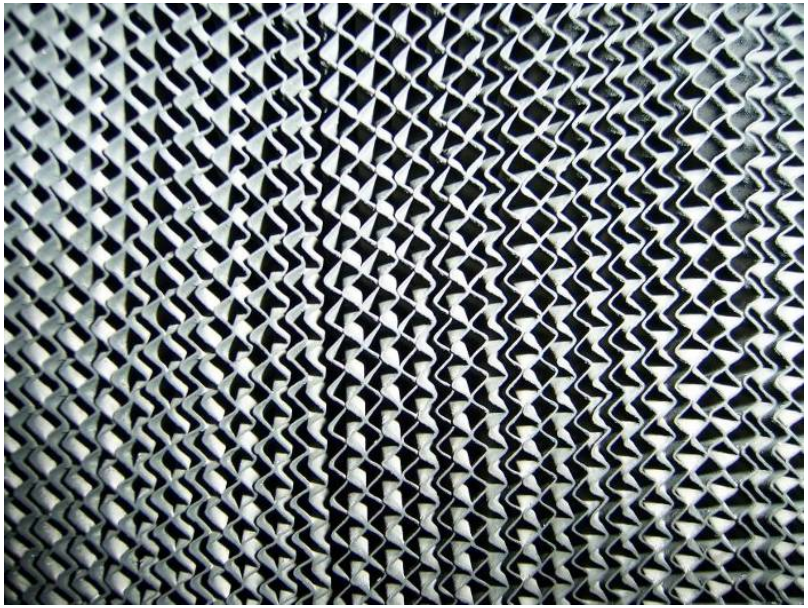
Diesel Oxidation Catalyst



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

Purpose of Diesel Oxidation Catalyst

* Soluble Organic Fraction (SOF) portion of PM
  » >80% of EMD PM emissions
* HC Emissions
  » Significant reductions are possible
* CO Emissions
  » Significant reductions possible



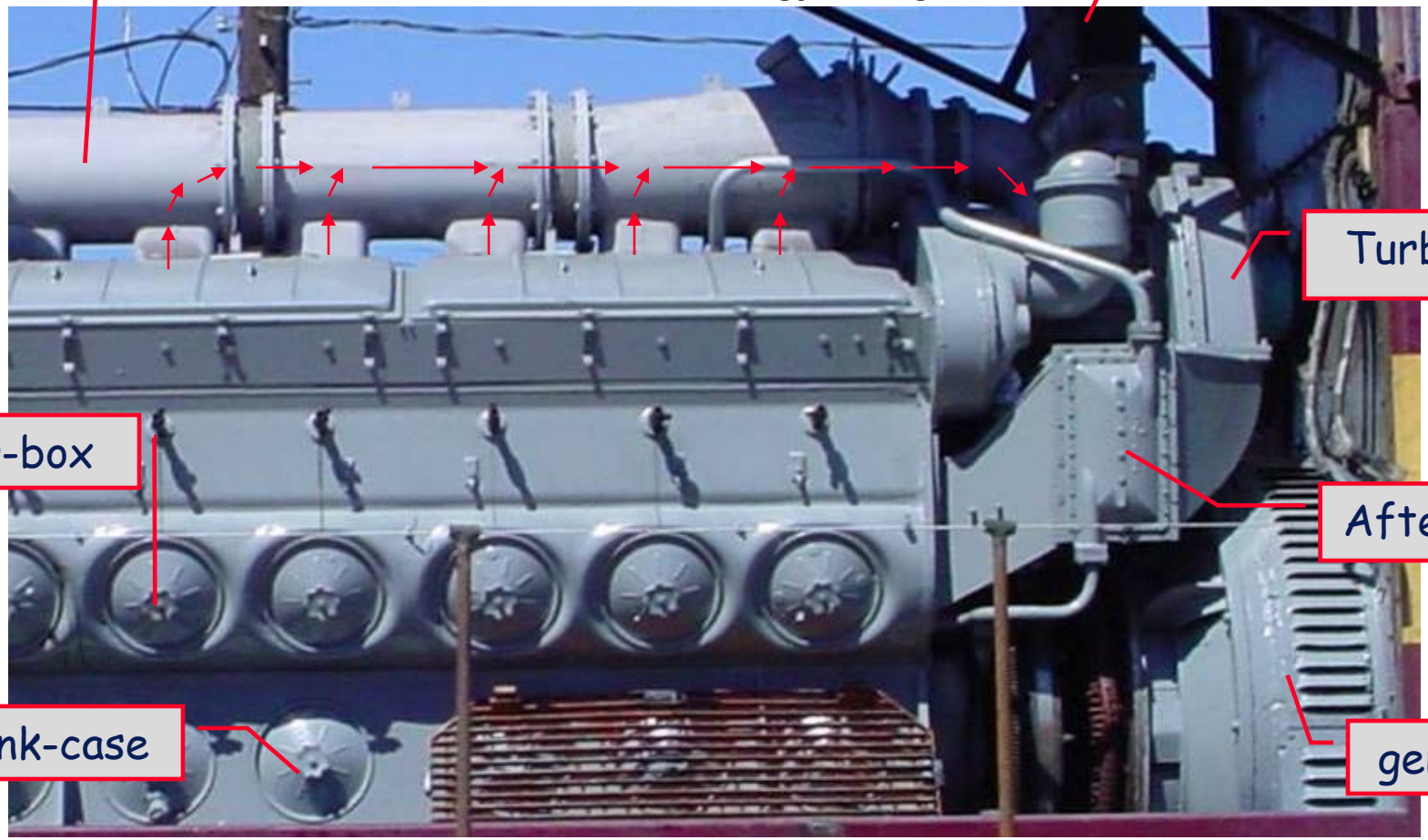
* Can increase PM if high sulfur fuel is used
  » Sulfate emissions

EMD SD60 Locomotive

Locomotive Number	UP 2368
Locomotive Model	EMD SD60M
Original Build Date	1989
Rebuilt to Tier 0	April 2006
ZTR Smart Start installed	April 2006
Engine Model	EMD 16-710-G3A
Rated Traction Power	3800 hp
Cylinder arrangement	45° V-16
Displacement/Cylinder	710 in^3
Compression ratio	16.0:1
Rated engine speed	904 rpm
Fuel Injection	Mechanical Unit Injectors
Fuel injectors	Interstate 40111736
Fuel injection static timing	TDC

EMD 16-710, Tier 0 Engine

- Two-Stroke, uniflow scavenged, DI
- Medium Speed (900 rpm)
- Turbo-Charged
  - Over-riding clutch until exhaust energy is high



DOC Retrofit Design Considerations

* **Pre-turbo or post-turbo application?**
  - » **Limited Space for Aftertreatment within Car Body**
  - » **Small Existing Silencer/muffler**
  - » **Can not block Access for Engine Maintenance**

* **Locomotives Spend a Significant Time at Idle and Low Loads**
  - » **Very Low Exhaust Temperatures-Poor DOC effectiveness**
  - » **Time Can be Reduced with a "Smart Start" or AESS (Auto Engine Start Stop) System**

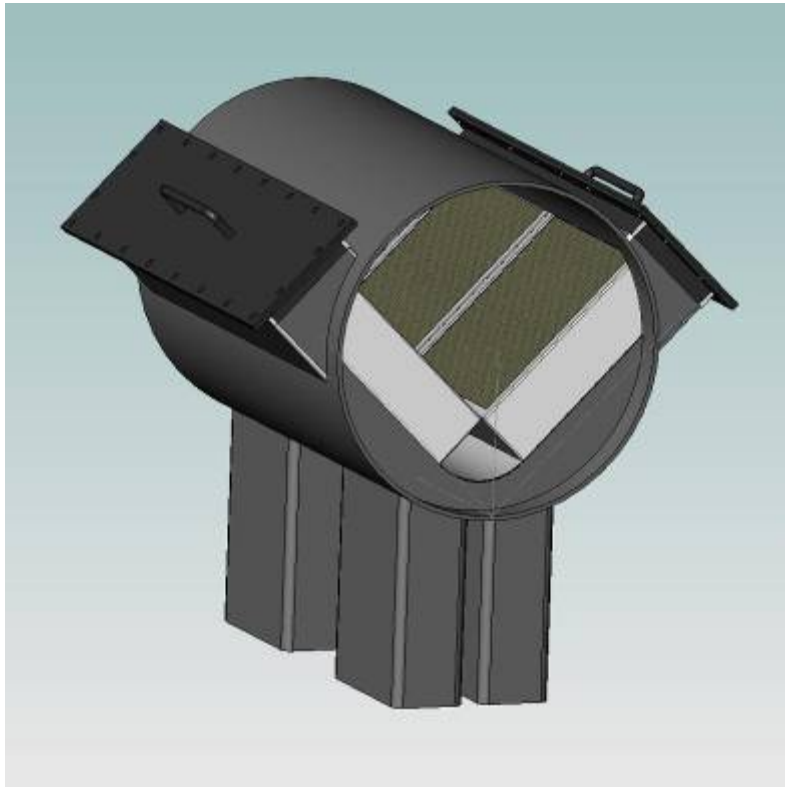
* **Engine Designed with Very Low Backpressure Limit**
  - » **"Retro-fit" did not include Turbo re-matching**

* **Relatively High Lube Oil Consumption**

* **High shock and vibration levels in engine compartment environment**

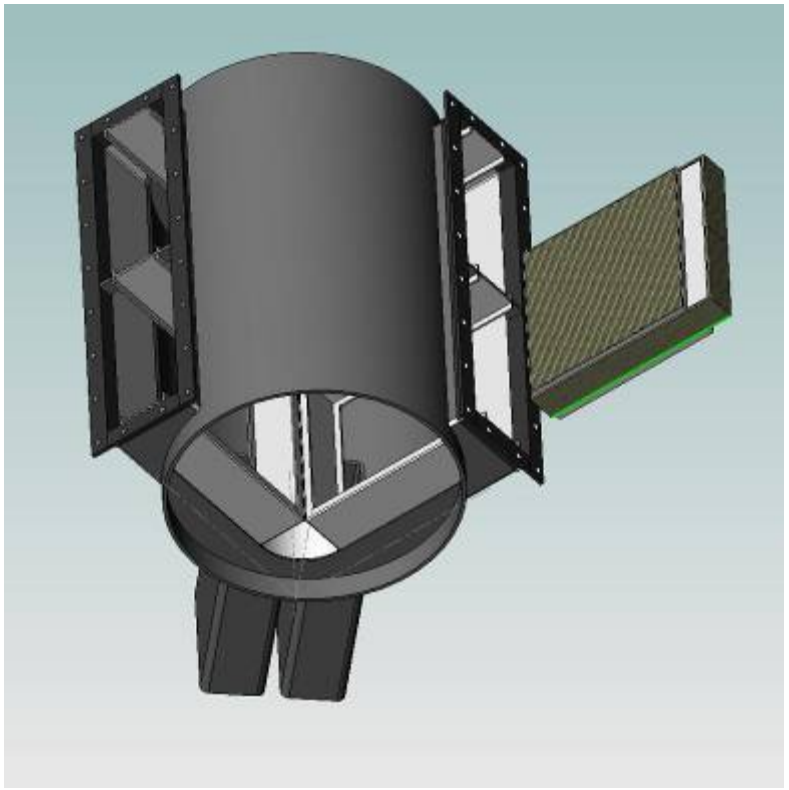
Pre-Turbo DOC Challenges

* Pre-turbo approach taken
* High Pressure (10-15 psig)
  - » Leaks are a concern
    - – Locomotives Must be shut down and repaired if exhaust leak is discovered- FRA rule
  - » Requires heavier design than standard catalyst housing for downstream catalyst applications
* Very high exhaust pressure pulsations
  - » One cylinder per catalyst element
* Crankcase Vents to atmosphere at exhaust stack
  - » Limits Maximum Achievable Reductions, but prevents fouling seen in other DOC locomotive attempts
* Catalyst Failure Could Block Turbo Screen or Send Pieces Back into Engine



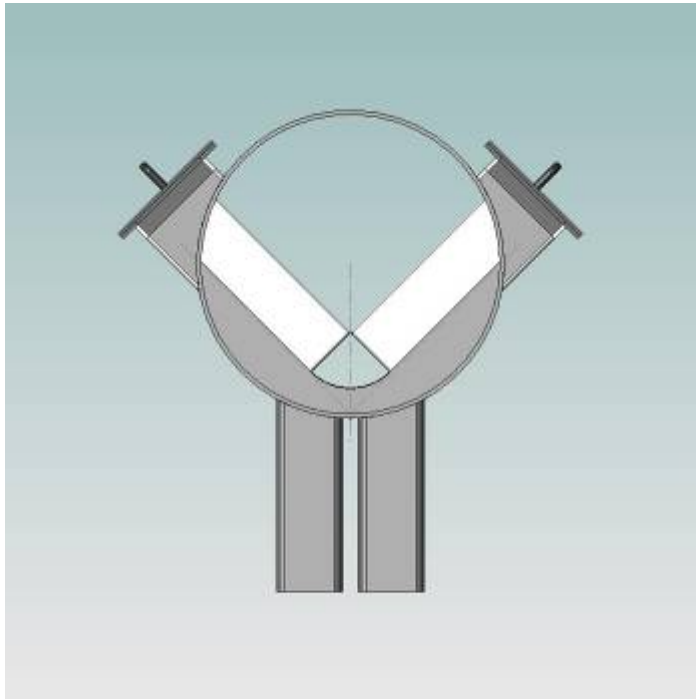
Integrated DOC/Manifold Advantages

* Replaces existing exhaust manifold within the locomotive
* Allows for sufficiently large catalyst volume
  - » Low Pressure Drop
  - » High Emissions Reductions
* Pre-Turbo Catalyst for Highest Exhaust Temperatures and to avoid fouling by crank-case ventilation
* Removable Catalyst Elements (12” x 12” x 3”)
  - » Elements will need to be Removed Periodically for Inspection/Cleaning
    - – This test used in part to determine maintenance requirements
  - » No Special Tools Required
  - » Easy Access (Removal of Manifolds Not Required)
* Durable Square Elements
  - » Corrugated, High Temperature Metal Foil Substrate
* Sulfur Tolerant Catalyst Washcoat



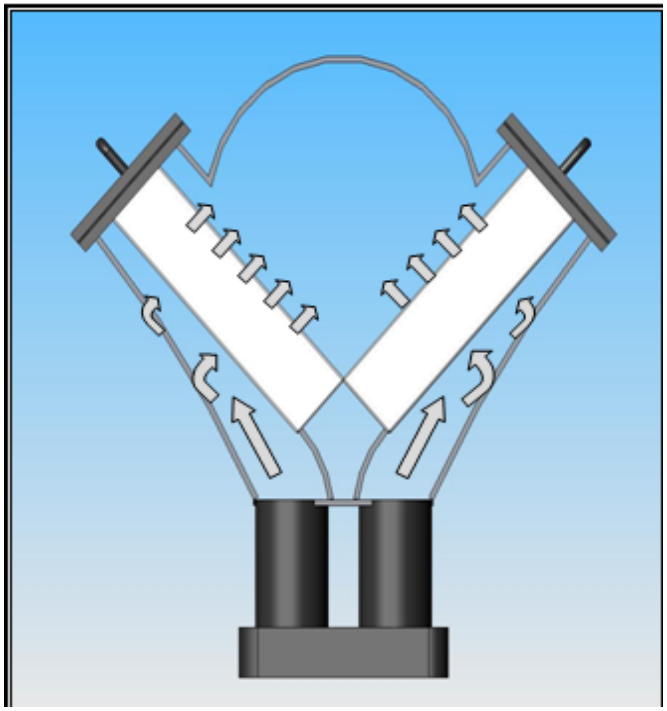
Prototype SD60 DOC Manifolds

In-Manifold DOC Design



First Attempt

“breathing” limitations



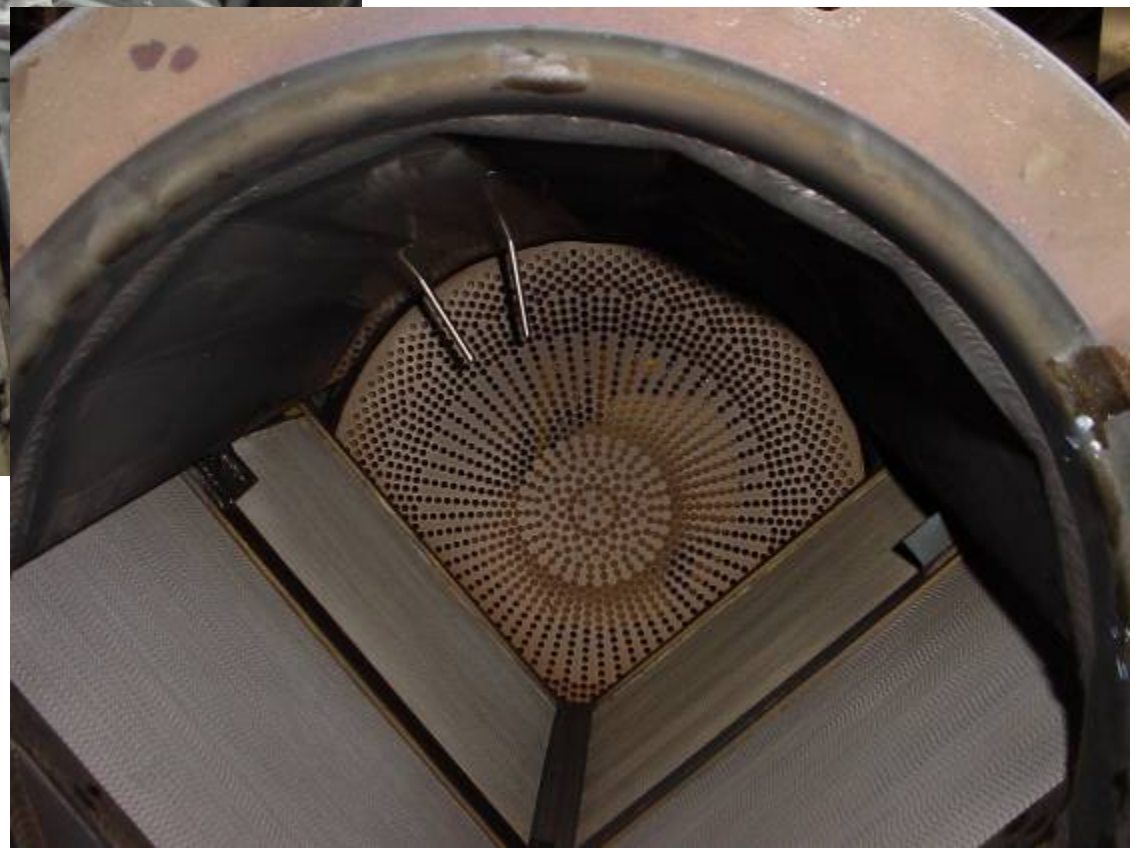
Current Design

Application of DOC on SD60 Loco

Power Assembly Service Access Remains

With Roof off of locomotive

Application of DOC (cont'd)



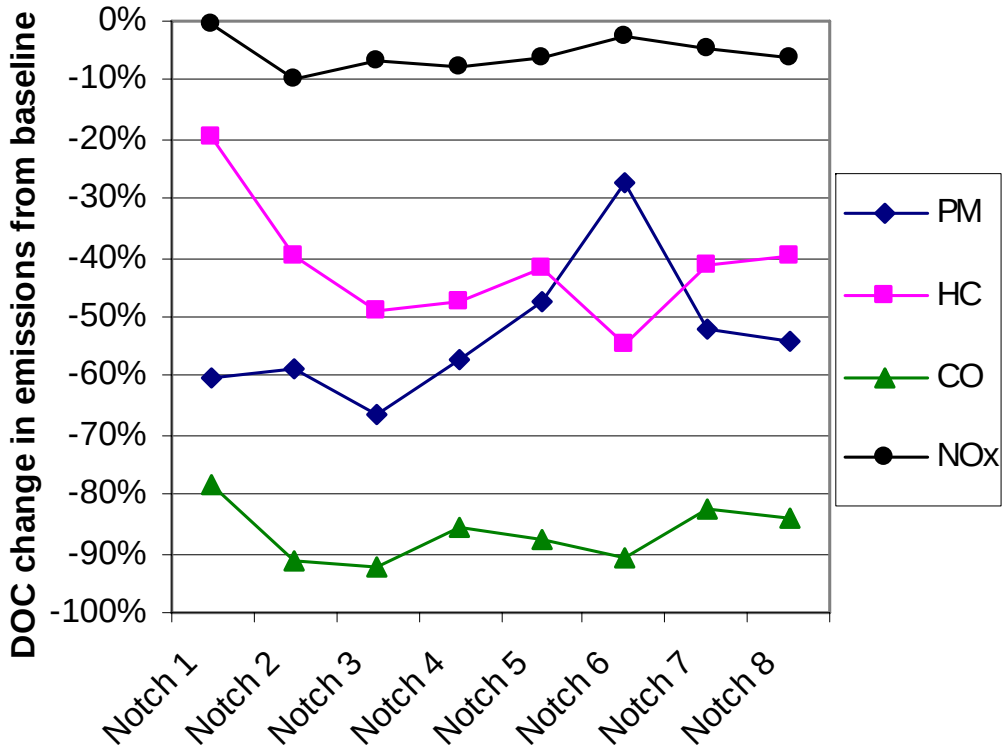
Application of DOC (cont'd)

- **Increased surface area of exhaust manifold radiates additional heat**
  - **Requires use of manifold blankets to retain heat**
  - **Energy for turbo**
  - **Keep long hood cooler**

Test Results

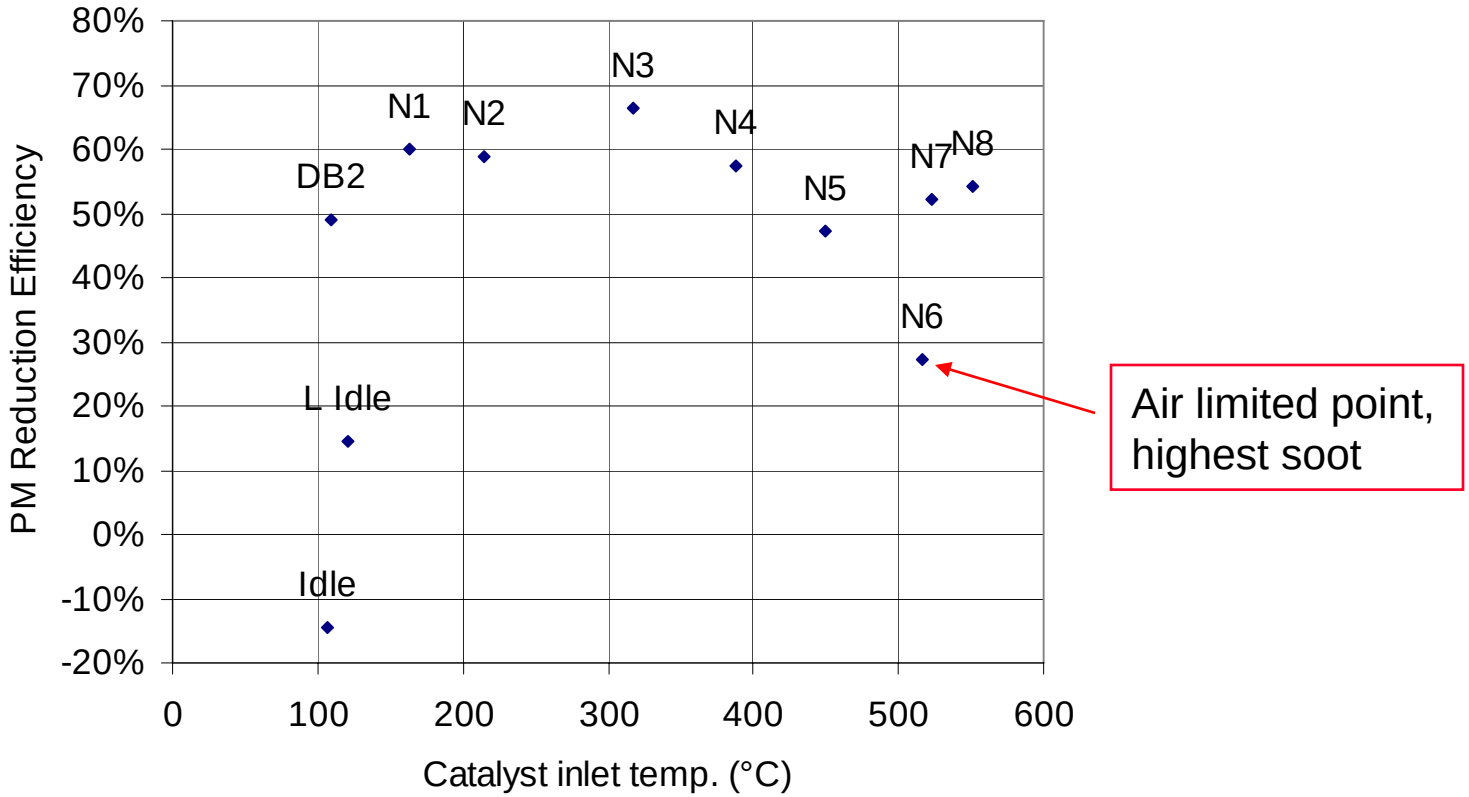
Duty Cycle	Test Configuration Change	Percent change in duty cycle composite emissions			
		HC	CO	NO_x	PM
Line-Haul Cycle	ULSD vs. Cert. Diesel	-14%	-22%	+3%	-10%
	DOC vs. ULSD	**-38%**	**-82%**	**-6%**	**-52%**
	DOC vs. Cert. Diesel	-47%	-86%	-3%	-56%
Switch Cycle	ULSD vs. Cert. Diesel	-24%	-40%	+2%	-9%
	DOC vs. ULSD	**-34%**	**-81%**	**-5%**	**-50%**
	DOC vs. Cert. Diesel	-50%	-89%	-3%	-55%

DOC Performance



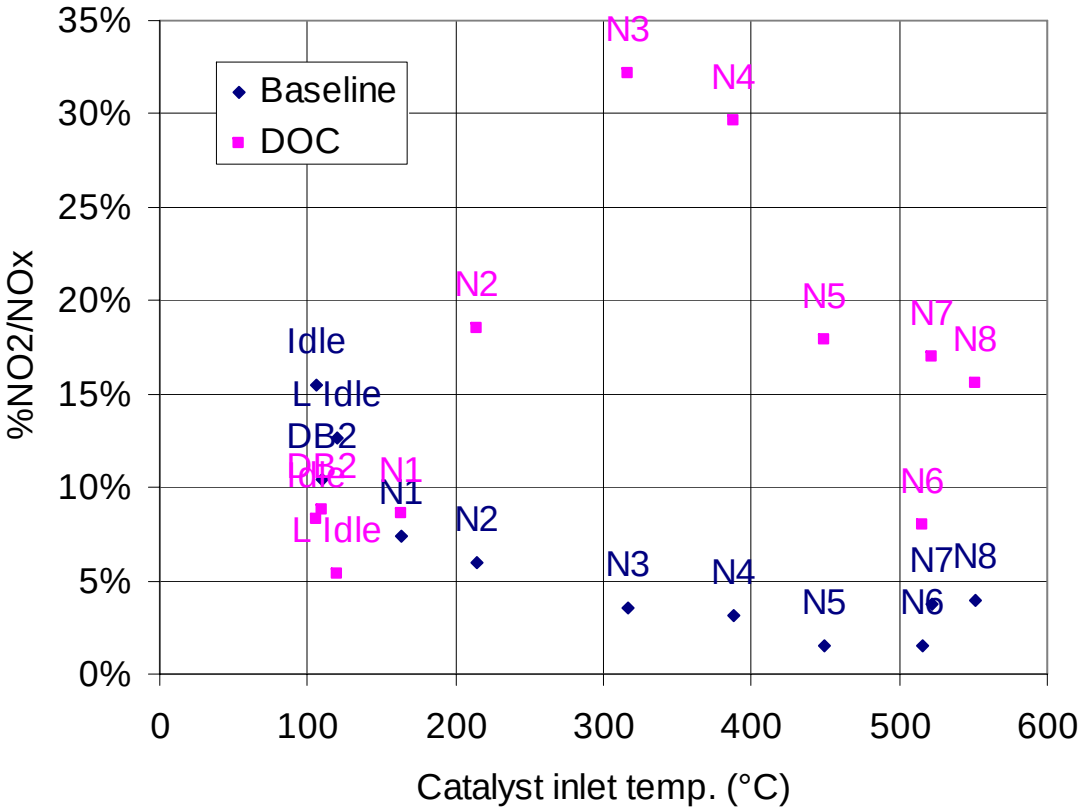
- **Good DOC performance across all Notches**

Exhaust Temperature Effects on DOC Performance



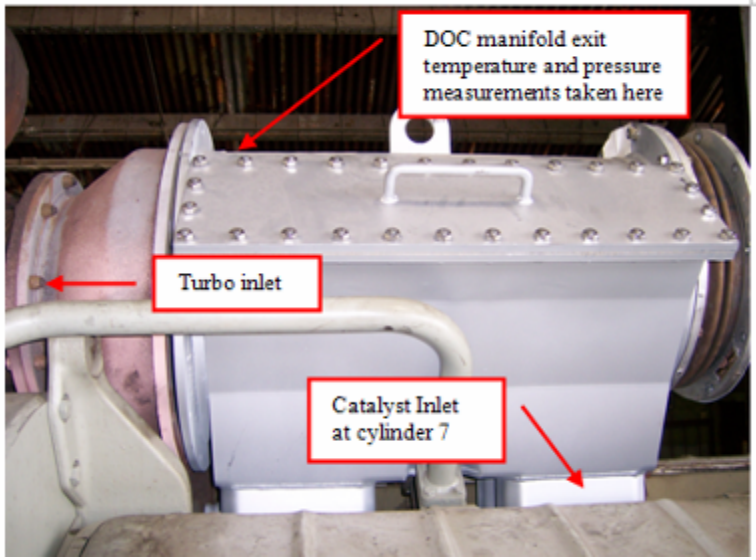
* Fast light-off occurs
* 60%PM reduction by N1 (160°C)
* After N3, space velocity likely limiting the PM reduction
* Conversion efficiency function of total inlet conditions
  - » Data points taken at different operating conditions
  - » Trends presented in data can not be solely attributed to temperature

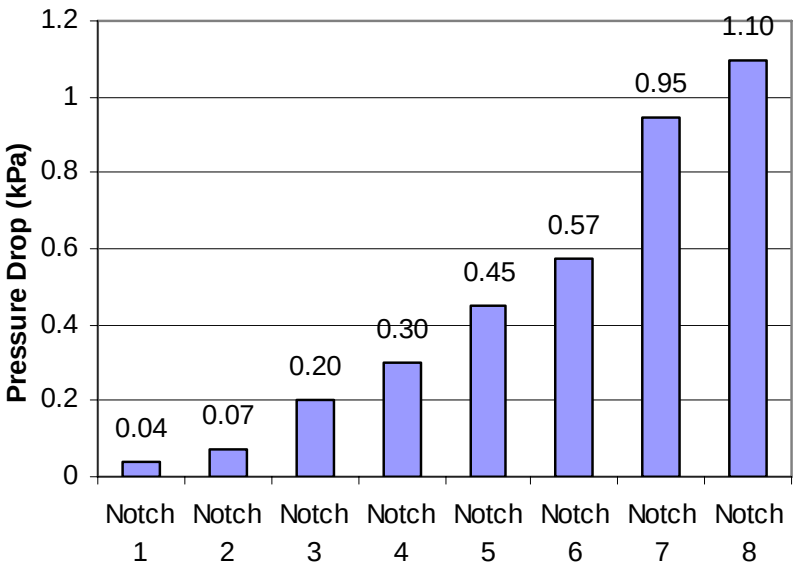
NO_2 Conversion



- **NO_2 portion of NO_x increased by DOC**
- **Maximum NO_2/NO_x of 32% at N3 (317°C)**
- **NO oxidation to NO_2 drops off after N4**

Engine Performance with DOC

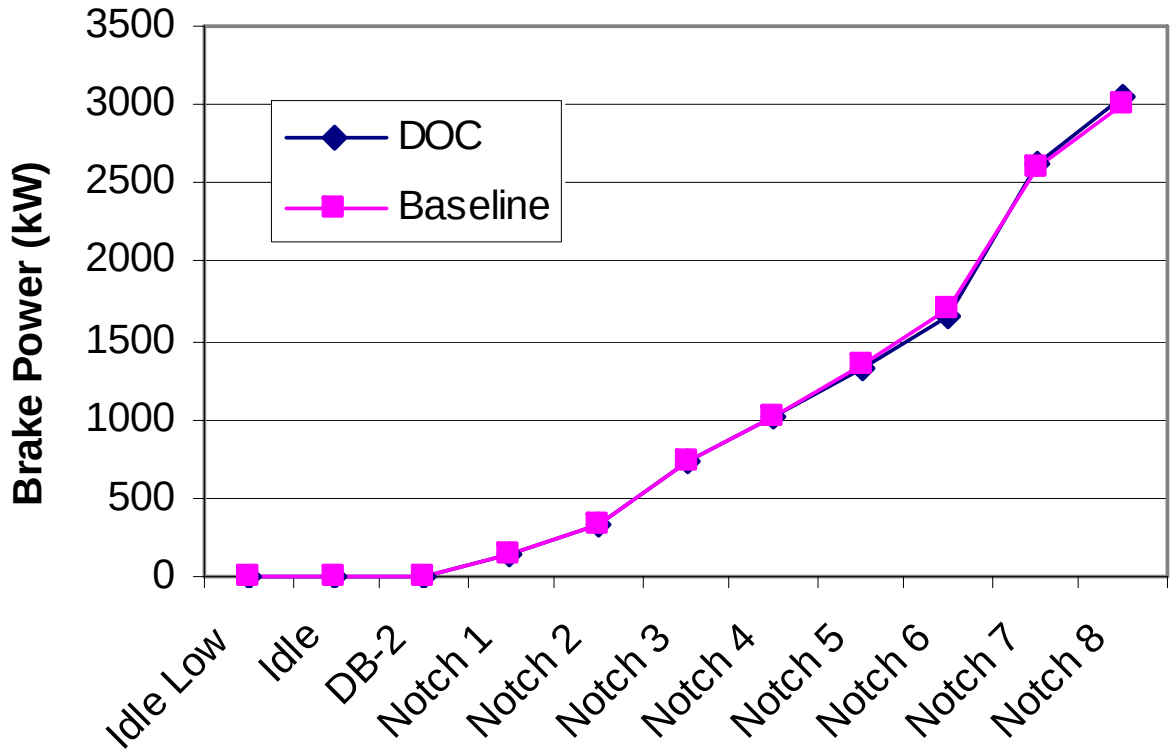




- Pressure drop associated with DOC measured with water manometer at each notch
- N8 pressure drop of 1.10 kPa (0.16 psi or 4.4 in H_2O)

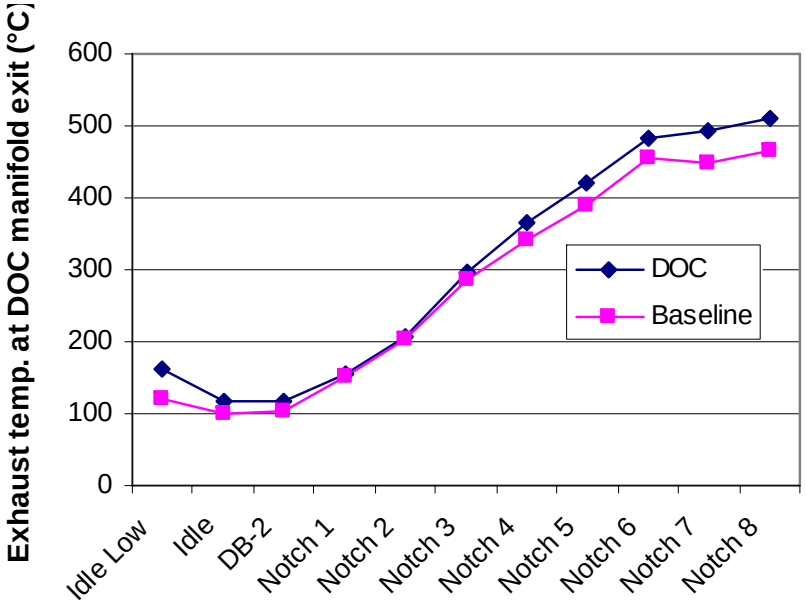
Engine Performance

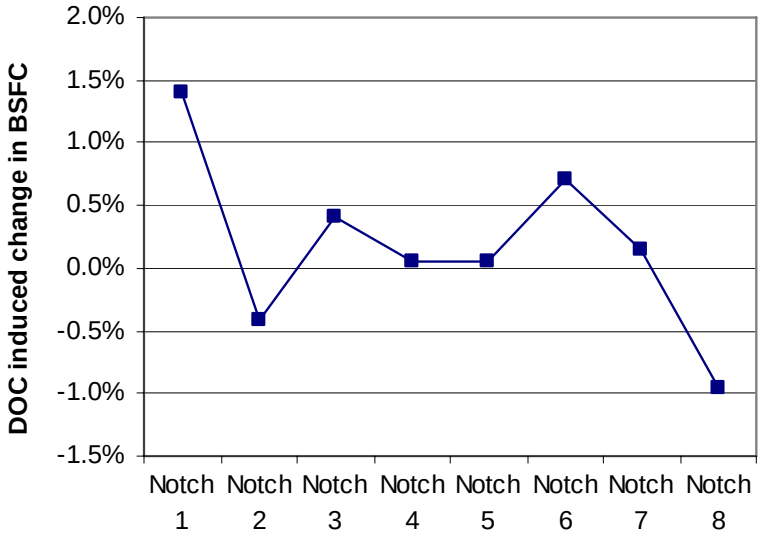
* SD60 Targets constant power at each notch
  » No problems maintaining power



Engine Performance (cont.)

- **No fuel penalty associated with the DOC**
  - **BSFC 0.6% less for line-haul cycle and 0.3% less for switch cycle**
  - **Single FTP tests**
    - **no statistical claims**
    - **However, no big hit in fuel economy**
  - **additional energy to turbo**
    - **Insulated exhaust manifold**
    - **exothermic oxidation of emissions**

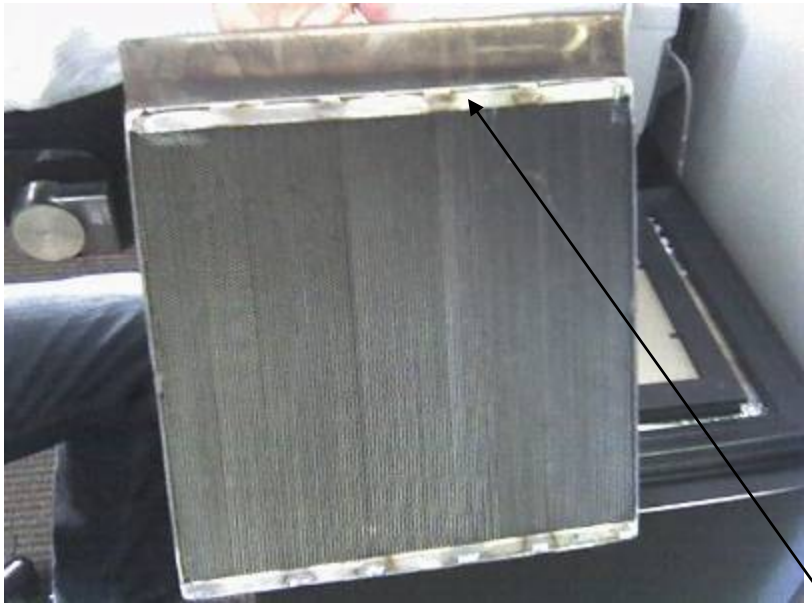


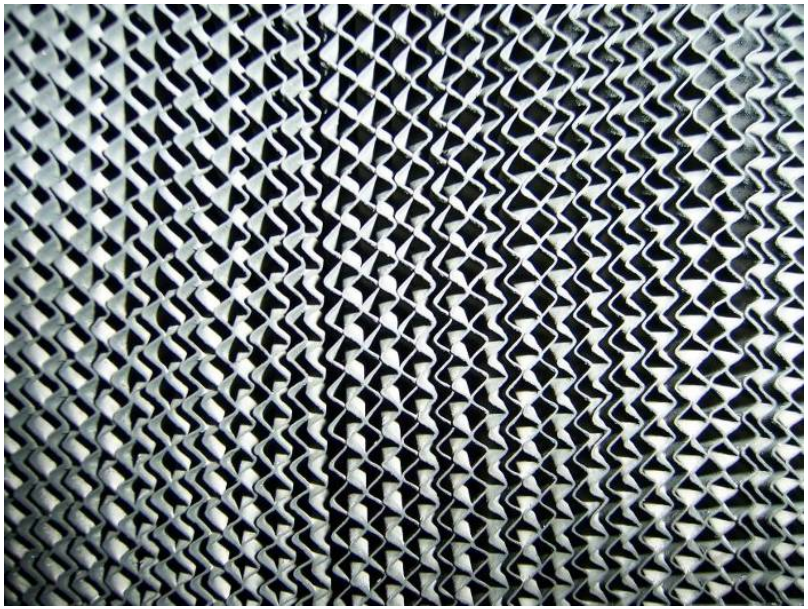


On-Board Datalogger

* UP2368 was instrumented with data logging system
* Continually monitors and records operational parameters during revenue service
  - » 12 month help hauler service inside South Coast non-attainment Area.
  - » Released for service October 2006
* Cellular phone package used to monitor and download data via internet
* GPS equipped to track movement

Field Test Status





* UP 2368 has been in Service Since October 2006 with DOC Manifolds Installed
* Three-month Inspection Revealed a minor mechanical problem with the catalyst elements that was quickly repaired
  - » Catalyst was Clean and Dry
* Locomotive Returned to San Antonio in April'07 for Second Inspection and Six-month Emissions Test
  - » Catalyst was Clean and Dry
  - » However, mechanical failures of catalyst frame
  - » Pulled all oxycat elements, returned loco to service w/o elements
  - » Miratech redesigned catalyst frame, and reinstalled at Los Angeles in June'07.

Next Steps

* Continue to monitor UP2368 In-Use performance
  - » Currently 2,762.8 hours of operation since start of field testing
  - » Replacement oxycat elements installed in LA in JUN’07
  - » 1,163.0 hours on new cats as of 07-OCT-2007

For More Information

Proceedings of JRCICE2007
2007 ASME/IEEE Joint Rail Conference & Internal Combustion Engine Spring Technical Conference
March 13-16, 2007, Pueblo, Colorado, USA

JRCICE2007-40060

EXHAUST EMISSIONS FROM A 2,850 kW EMD SD60M LOCOMOTIVE EQUIPPED WITH A DIESEL OXIDATION CATALYST

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Union Pacific Railroad Company

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MIRATECH Corporation

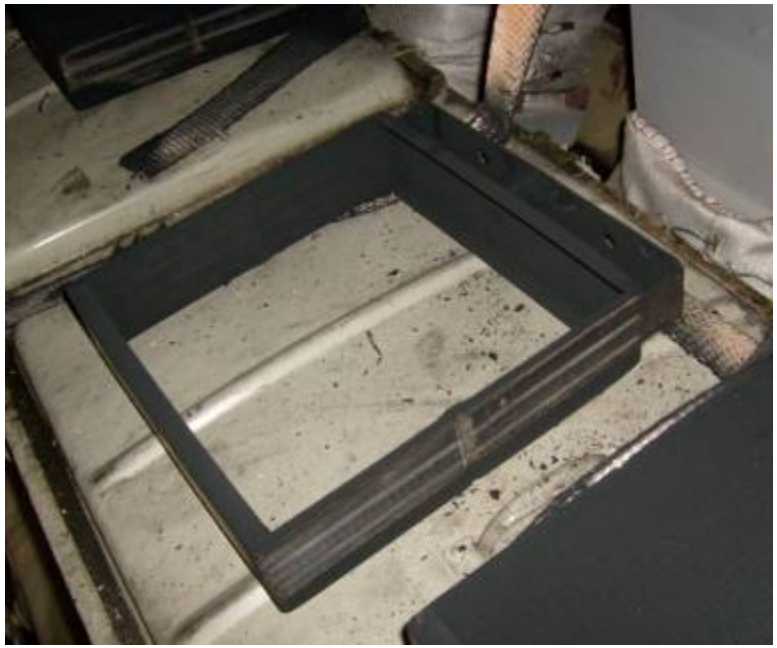
www.ASME.org

Late Breaking News

* 08-OCT-2007
  - » UP in West Colton reported low power
  - » Shop contacted Mike Iden per sticker instructions

Another Iteration on Catalyst Elements

* UPRR inspection revealed turbo screen plugged with DOC debris
* Miratech field service dispatched to inspect & remove DOC elements
* 2 of 16 catalyst elements damaged – one essentially gone!



New – Next Steps

* All 16 catalyst elements removed from UP2368 and sent to Miratech for failure analysis
* Miratech developing repair plan – estimate ready to try again in 2 months.
* UP2368 currently back in service without catalyst elements.

Questions so far?

Next,
Another Application of the Pre-Turbine Diesel Oxidation Catalyst

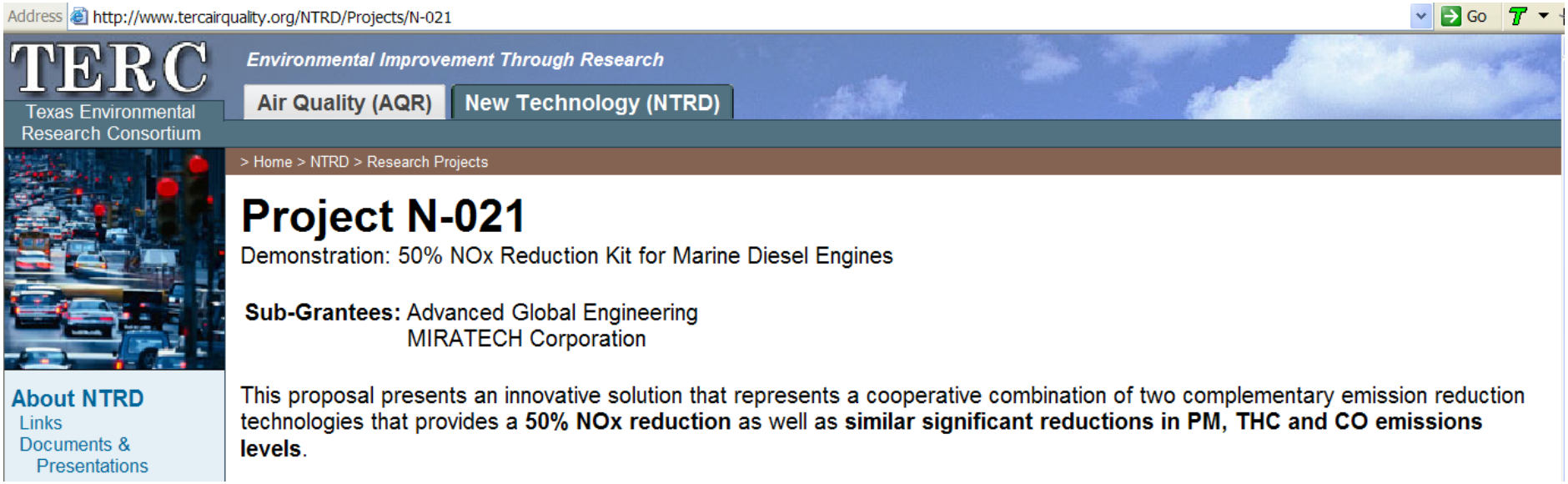
Development of a Pre-Regulation 3,000 HP EMD 12-710G7 Marine Diesel Engine to Meet EPA Tier 2 Marine Standards

Steve Fritz
Southwest Research Institute
&
Ted Stewart
Advanced Global Engineering

Nov. 28, 2007

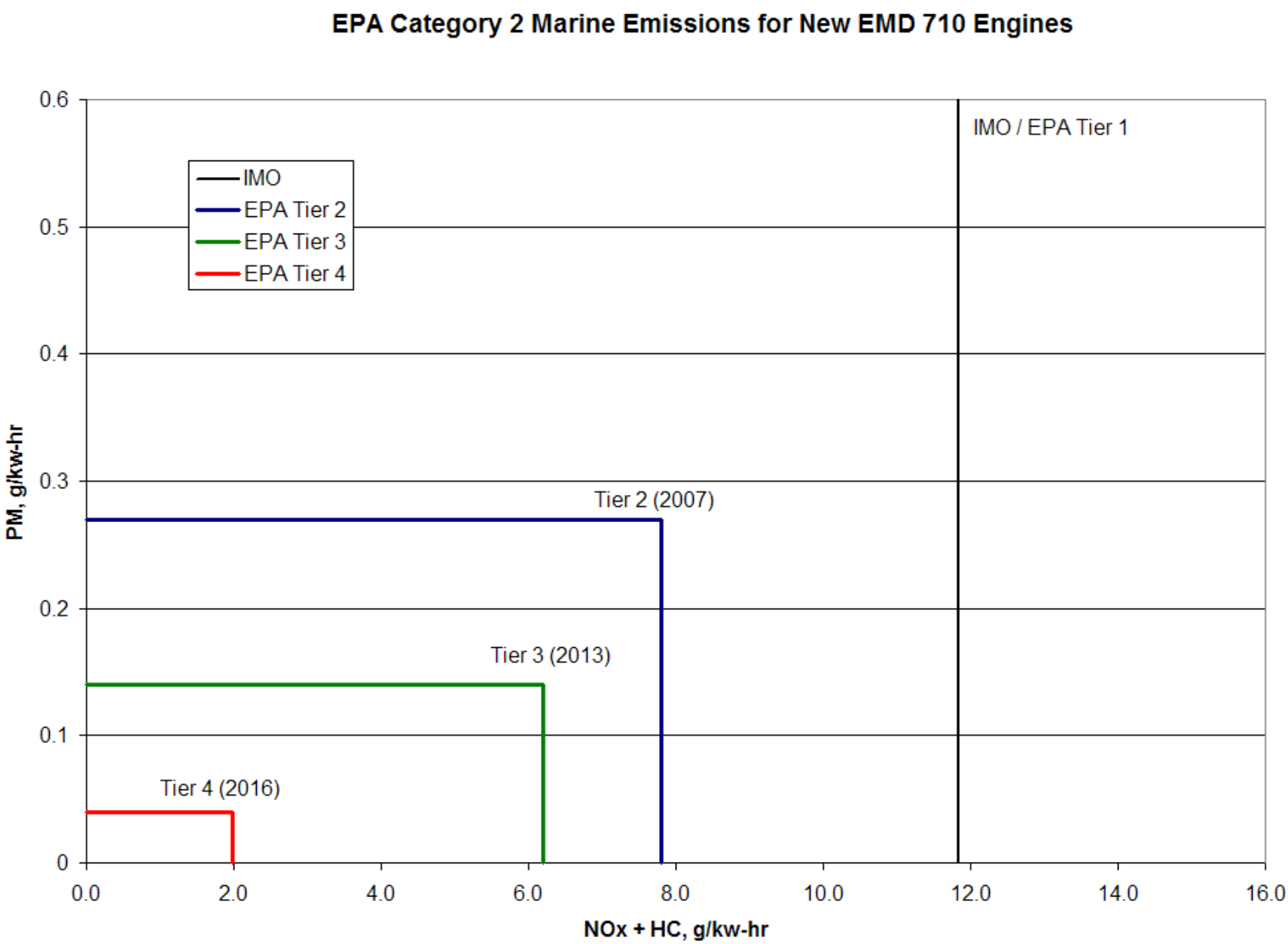
Project Funding

* Funded by
  - » Houston Advanced Research Center (HARC)
    - – Texas Environmental Research Consortium (TERC)
      - New Technologies Research & Development (NTRD)
      - Project N-021
      - Contracting Officer = Rudolf M. Smaling, Ph.D.

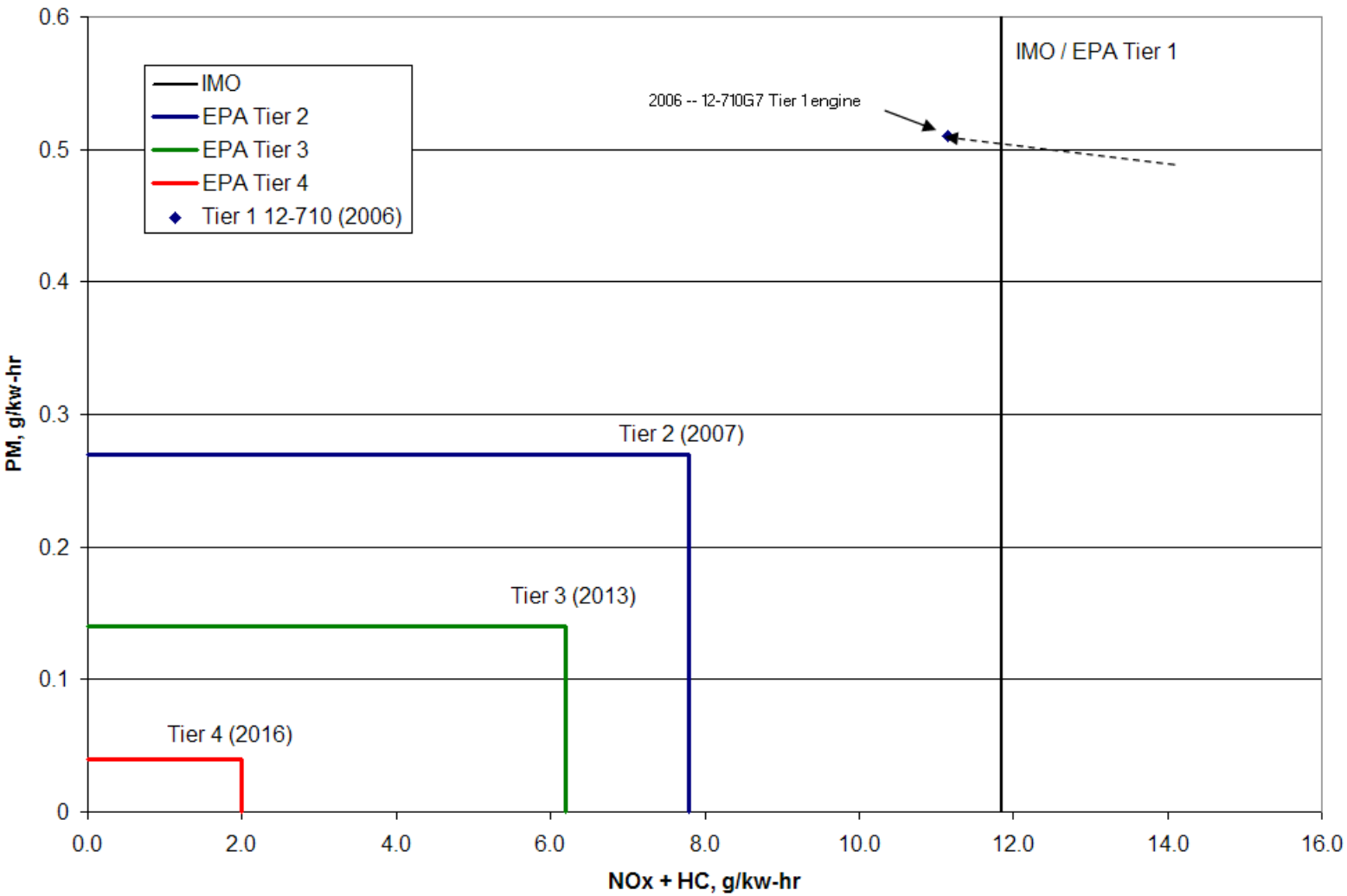


Typical Inland Marine Engine Application

3 x 3,000 HP EMD 12-710G7 Engines


EPA Category 2 Marine Emissions for New EMD 710 Engines
IMO
EPA Tier 2
EPA Tier 3
EPA Tier 4
IMO / EPA Tier 1
Tier 2 (2007)
Tier 3 (2013)
Tier 4 (2016)
PM, g/kw-hr
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
NOx + HC, g/kw-hr

2006 NTRD-funded Project
EPA Certification to IMO/EPA Tier 1



RFGA-07 N-021 Technical Approach

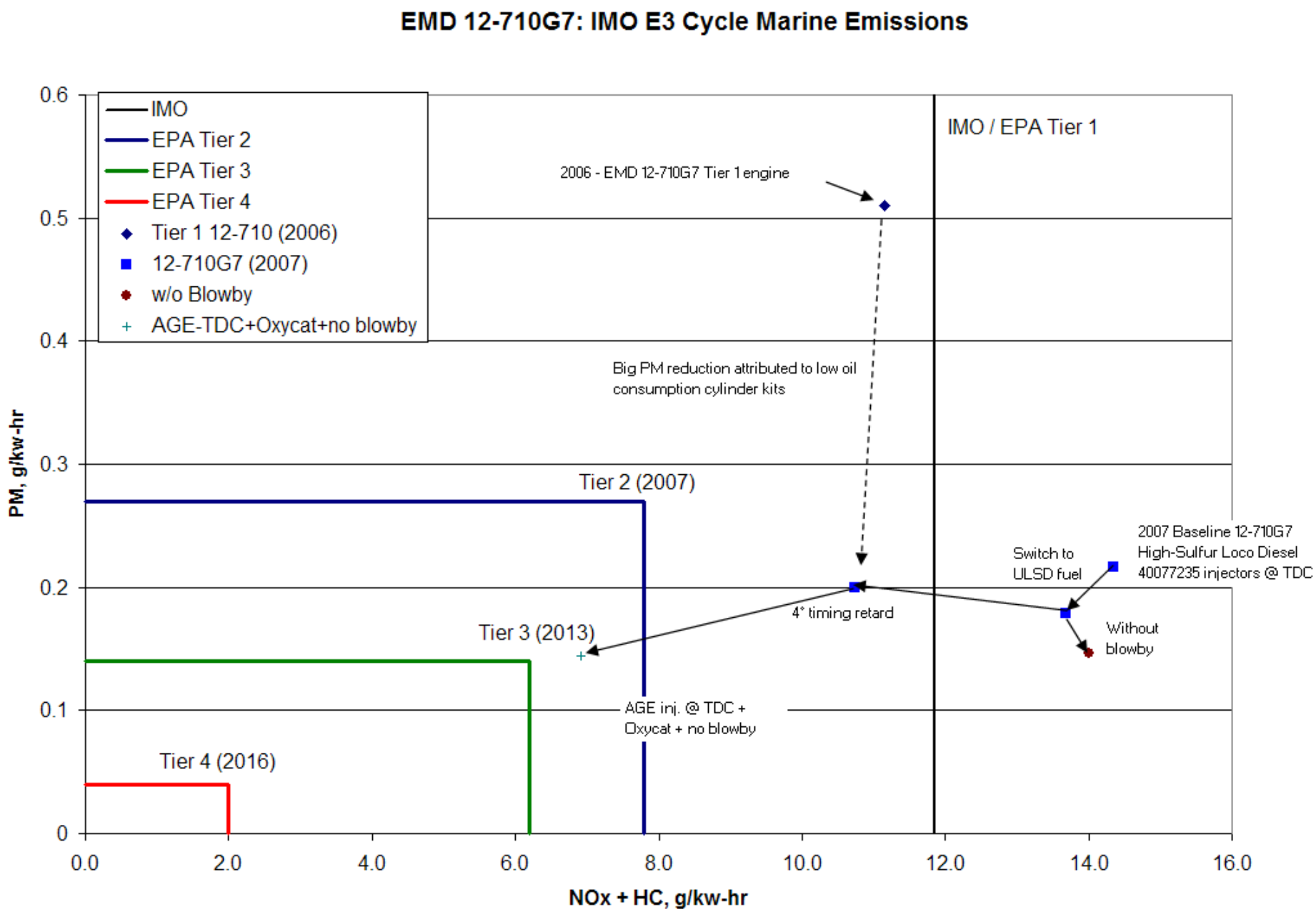
* Apply complementary technologies
  - » TxLED-ULDS – Texas Low Emission Diesel fuel
    - – Basically CARB diesel
      - < 10% aromatics
      - < 15 ppm S
  - » Low lubricating oil consumption cylinder kits
    - – Pistons, rings, cylinder liners
  - » Diesel oxidation catalyst
    - – Pre-turbine design
  - » Maintain MUI fuel injection system
    - – Optimized for best fuel consumption at a target NOx level

Some Assembly Required

1989 Model Year EMD 12-710 Engine

Install Pre-Turbine Diesel Oxidation Catalyst

Original Exhaust Manifold


EMD 12-710G7: IMO E3 Cycle Marine Emissions
IMO
EPA Tier 2
EPA Tier 3
EPA Tier 4
Tier 1 12-710 (2006)
12-710G7 (2007)
w/o Blowby
AGE-TDC+Oxycat+no blowby
IMO / EPA Tier 1
2006 - EMD 12-710G7 Tier 1 engine
Big PM reduction attributed to low oil consumption cylinder kits
Tier 2 (2007)
Tier 3 (2013)
Tier 4 (2016)
4° timing retard
AGE inj. @ TDC + Oxycat + no blowby
Switch to ULSD fuel
2007 Baseline 12-710G7 High-Sulfur Loco Diesel 40077235 injectors @ TDC
Without blowby
PM, g/kw-hr
NOx + HC, g/kw-hr
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0
0.1
0.2
0.3
0.4
0.5
0.6

Project Status

* NTRD Project N-021 Work Completed
* Project goals met
  - » In addition to the 50% NOx reduction,
  - » Demonstrated EPA Tier 2 new marine engine emission levels with a pre-regulation 1989 model year engine
* EPA Certification Testing complete
  - » EPA certification application in process

Table 1: RFGA-07 Grant 21 Proposal: 50% NOx reduction, (IMO E3 Duty Cycle)

	NOx, (gms/bhp-hr)	THC, (gms/bhp-hr)	CO, (gms/bhp-hr)	PM, (gms/bhp-hr)
***Baseline Engine Test**	10.5	0.15	1.90	0.16
Responsible Technology Applied	Modified Injector Start-of-Inj.	Diesel Oxidation Catalysts	Diesel Oxidation Catalysts	Diesel Oxidation Catalysts
***RFGA-07 Grant 21 Test Results**	5.1	0.05	0.10	0.11
% Change	**54% decrease**	**67% decrease**	**95% decrease**	**31% decrease**

*IMO E3 Duty Cycle test results, Southwest Research Institute Locomotive Technology Center
(Baseline Test = 9/24/07 TDC, RFGA-07 Test = 10/25/07 TDC)

Experimental Application of Diesel Particulate Filters to EMD Switcher Locomotives

ASME Paper ICEF2007-1626

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Introduction

* Background California Emissions Program
* Experimental Diesel Particulate Filters (DPF) Selected for Demonstration
* Application of Experimental DPF
* Emissions Test Results With Experimental DPF
* Locomotives in Demonstration Update
  - » UPY1378
  - » BNSF3703
  - » Issues
* Summary

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  - » Issues
* Summary

Background - CEP

* CEP = California Emissions Program
* Part of CARB diesel toxics reduction program
* CARB looked for a voluntary PM reduction effort from the railroad industry in lieu of greater use of CARB diesel fuel
  - » Funded by BNSF & UP railroads
    - – $5M budget
  - » Scope:
    - – PM reduction
    - – Switchers
    - – California

* CARB interest in a Diesel Particulate Filter (DPF) installed and functioning on a switcher locomotive(s) in California
* Project Managed by TTCI in Pueblo CO.

1,500 hp EMD MP15DC Switcher Locomotive

Background –CEP Approach (cont'd)

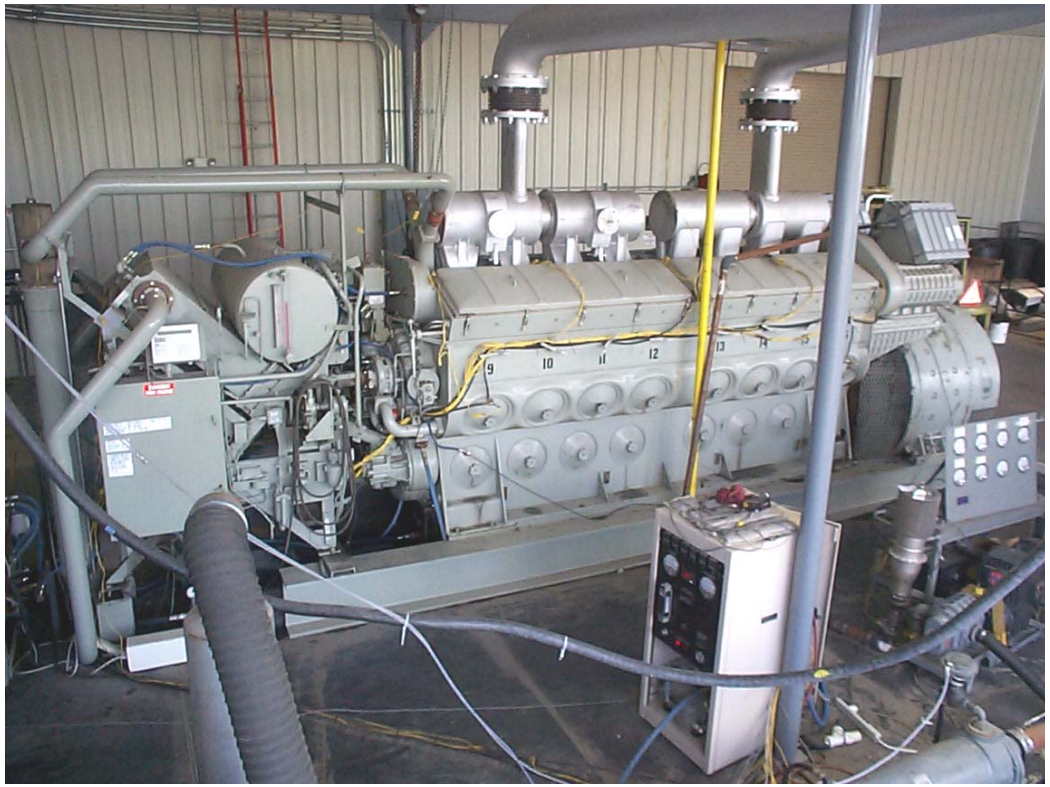
* General Technical Approach for CEP program
  - » **Phase 1** – Laboratory Screening
    - – Task 1: Install EMD 16-645E locomotive engine
    - – Task 2: Reduce lubricating oil consumption
    - – Task 3: Screen candidate DPF and Oxidation Catalyst systems on test engine
      - Evaluated 13 different DOC and DPF systems
      - Selected top 3 for 500-hour initial durability test
      - Selected best performer for Phase 2 field implementation
  - » Results of testing showed that a DPF with a diesel burner offered best trade-off for this application
  - » Additional details about Phase 1 can be found at:
    - – ASME ICE2003-549 & ICEF2003-707
    - – CIMAC 2004 – Paper #70
    - – http://www.arb.ca.gov/railyard/ryagreement/071306fritz.pdf

Background –CEP Approach

* General Technical Approach for CEP program
  - » **Phase 2** – Field Implementation of DPF on Switcher Locomotives
    - – Two EMD MP15DC locomotives retrofitted with DPF systems
      - UPY1378
        - » Operational in Oakland and Roseville California
      - BNSF3703
        - » Initial operation in San Antonio, Texas

Background - CEP Test Engine

- Electro-Motive Division (EMD) 16-645-E
- Two-stroke Diesel engine
- Roots-blown
- 1969 model
- About 3,400 of these in Class 1 railroad switcher operation



EMD 16-645-E Engine Specifications

Engine Model	EMD 16-645-E
Cylinder Arrangement	V-16
Bore	230 mm
Stroke	254 mm
Displacement/Cylinder	10.6 L
Compression Ratio	16:1
BMEP	5.9 bar @ 900 rpm
BSFC @ Rated Power	254 g/kW-hr
Air Charging	Gear Driven Roots Blower
Fuel Injection	Cam Driven Unit Injectors
Crankcase Ventilation	Crankcase Fumes Returned to Blower
Emissions Level	EPA Tier 0 - Switch Cycle

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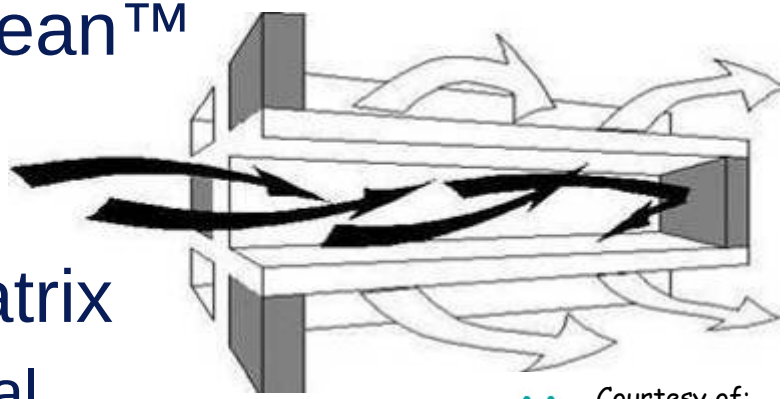
* Application of Experimental DPF
* Emissions Test Results With Experimental DPF
* Locomotives in Demonstration Update
  - » UPY1378
  - » BNSF3703
  - » Issues
* Summary

DPF Selected for Demonstration

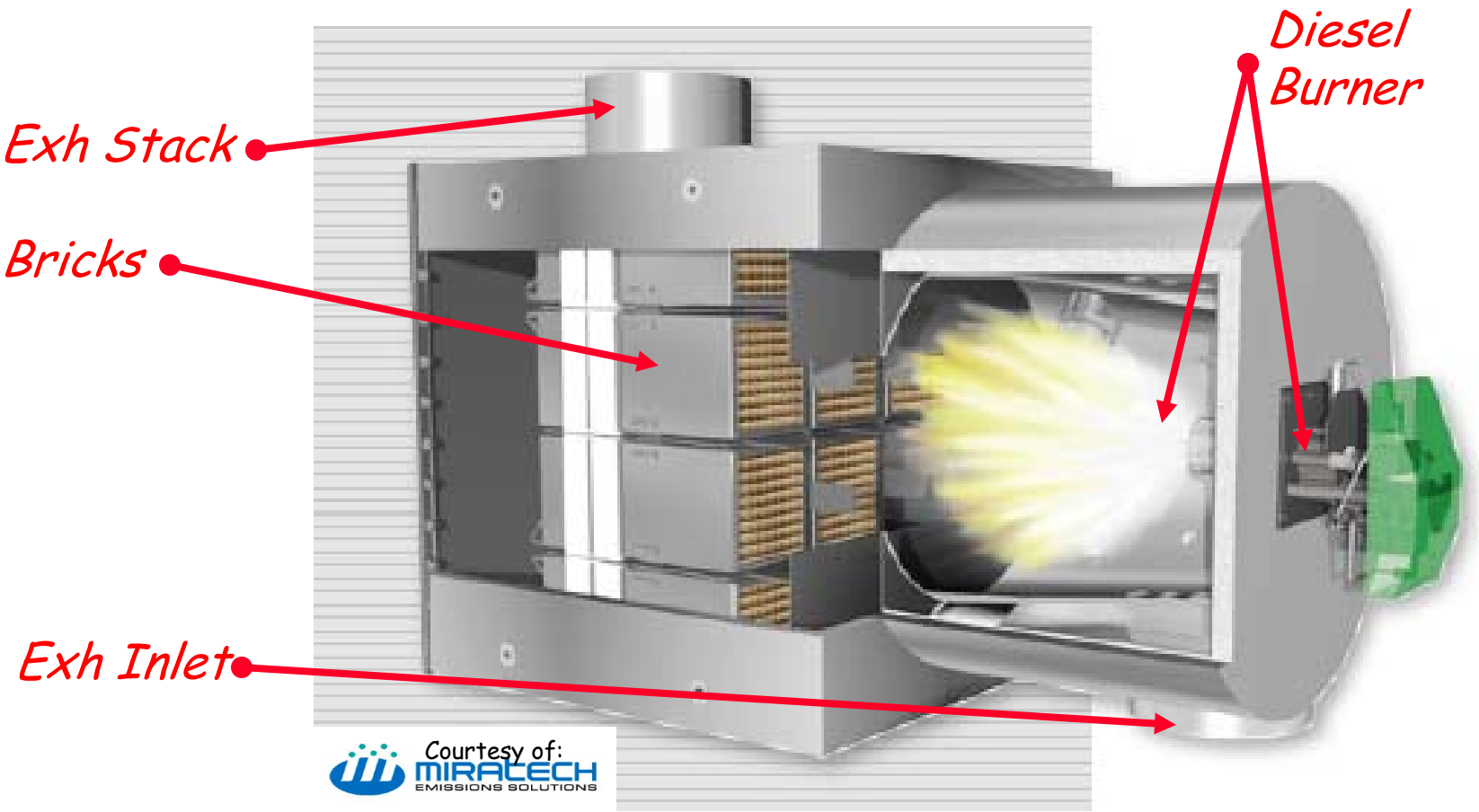
* DPF selected was a MobiClean™
  » Wall flow filter
  » High efficiency
* Each DPF has 3X4 brick matrix
  » Extended maintenance interval



Courtesy of: MIRATECH EMISSIONS SOLUTIONS

DPF Selected for Demonstration (cont'd)

* MobiClean™ DPF has diesel burner
  » Needed to provide adequate temperature for regeneration of DPF



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Application of Experimental DPF Systems

BNSF3703

- Released from overhaul on 30-JUN-06
- Equipped with idle reduction system:
  - Diesel driven heating system
  - Idle reduction system coupled to DDHS

UPY1378

- Overhauled in Fall 2005
- Routed to SwRI in Feb. 2006 for DPF mounting design concept meeting
- Equipped with idle reduction system

Application of Experimental DPF System (cont'd)

Application of Experimental DPF System (cont'd)

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Emissions Test Results

* Engines were first baseline emission tested to allow for calculation of efficiency of the DPF system
* Two different Baseline PM emissions levels
  - » UPY1378 rebuilt with standard PA's
  - » BNSF 3703 rebuilt with low oil consumption PA's and lower NOx emissions

	UPY1378 Baseline EPA Switch Cycle			
	HC	CO	NOx	PM
	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
Baseline #3	1.0	2.2	15.2	0.55
Baseline #4	1.0	1.8	14.5	0.51
Baseline #5	1.0	2.0	14.6	0.52
Average	1.0	2.0	14.8	0.53

	BNSF3703 Baseline – EPA Switch Cycle			
	HC	CO	NOx	PM
	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
Baseline #3	0.6	2.1	12.4	0.32
Baseline #4	0.6	2.2	12.4	0.33
Baseline #5	0.6	2.2	12.3	0.35
Average	0.6	2.2	12.4	0.33

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Average	1.0	2.0	14.8	0.53

	BNSF3703 Baseline – EPA Switch Cycle			
	HC	CO	NOx	PM
	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
Baseline #3	0.6	2.1	12.4	0.32
Baseline #4	0.6	2.2	12.4	0.33
Baseline #5	0.6	2.2	12.3	0.35
Average	0.6	2.2	12.4	0.33

Emissions Test Results (cont'd)

* After installation of DPF emission test were repeated
  - » NOx basically unchanged
  - » PM showed significant improvement as expected
  - » Some HC and CO reductions due to p-precious metal loading in the DPF bricks

	UPY1378 W/ DPF Installed EPA Switch Cycle			
	HC g/kW-hr	CO g/kW-hr	NOx g/kW-hr	PM g/kW-hr
Hug Test #1	0.7	2.0	15.0	0.10
Hug Test #2	0.7	2.1	14.3	0.11
Hug Test #3	0.7	2.0	15.3	0.11
Average	0.7	2.0	14.7	0.11

	BNSF3703 W/ DPF Installed EPA Switch Cycle			
	HC g/kW-hr	CO g/kW-hr	NOx g/kW-hr	PM g/kW-hr
Hug Test #1	0.5	1.6	12.3	0.08
Hug Test #2	0.4	1.7	12.2	0.07
Average	0.5	1.6	12.2	0.07

Emissions Test Results (cont'd)

* Baseline emissions levels translated directly
  - » Lower oil consumption PA's in BNSF3703 still offer lower PM with DPF installed
  - » NOx still lower with low NOx kit in BNSF3703

	UPY1378 W/ DPF Installed EPA Switch Cycle			
	HC g/kW-hr	CO g/kW-hr	NOx g/kW-hr	PM g/kW-hr
Hug Test #1	0.7	2.0	15.0	0.10
Hug Test #2	0.7	2.1	14.3	0.11
Hug Test #3	0.7	2.0	15.3	0.11
Average	0.7	2.0	14.7	0.11

	BNSF3703 W/ DPF Installed EPA Switch Cycle			
	HC g/kW-hr	CO g/kW-hr	NOx g/kW-hr	PM g/kW-hr
Hug Test #1	0.5	1.6	12.3	0.08
Hug Test #2	0.4	1.7	12.2	0.07
Average	0.5	1.6	12.2	0.07

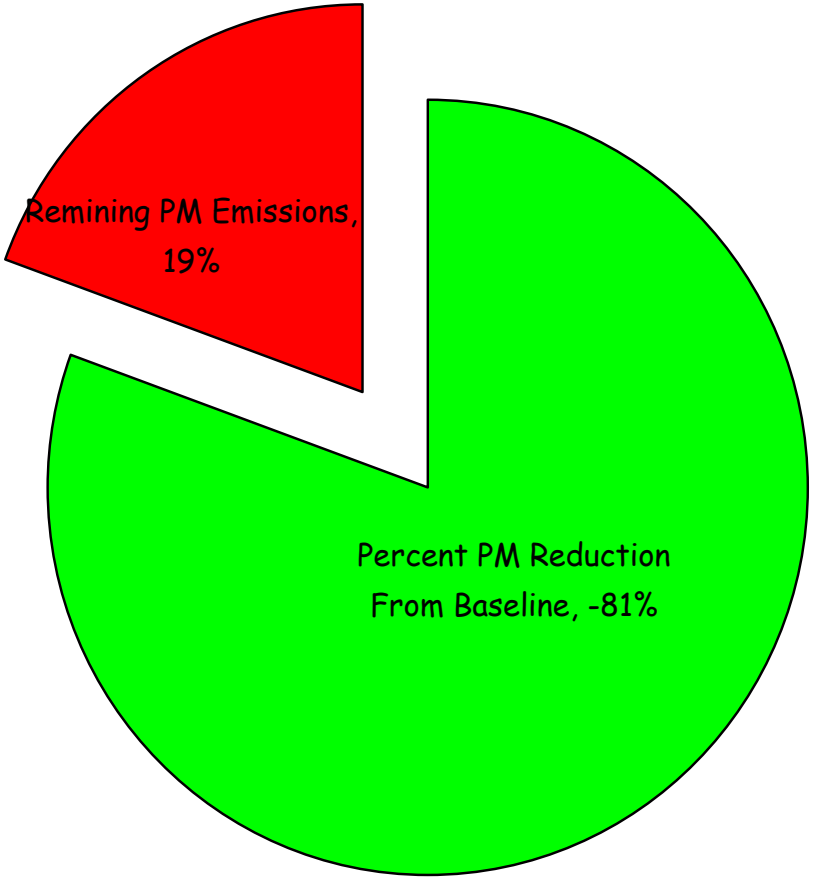
Emissions Test Results (cont'd)

* Percent change from Baseline emission tests were:

Locomotive	**HC**	**CO**	**NOx**	**PM**
UPY1378	-36%	-1%	-3%	-81%
BNSF3703	-24%	-25%	-2%	-79%

Application of Experimental DPF System (cont'd)

* Wall flow DPF should provide 90(+) % PM reduction
* Current system on UPY1378 & BNSF3708 are only ~ 80% efficient
* Ongoing work to further reduce PM emissions
  - » New DPF material selections
  - » New ways to pack DPF brick in housing
  - » Add DOC in front of DPF system to reduce VOC portion of PM emissions



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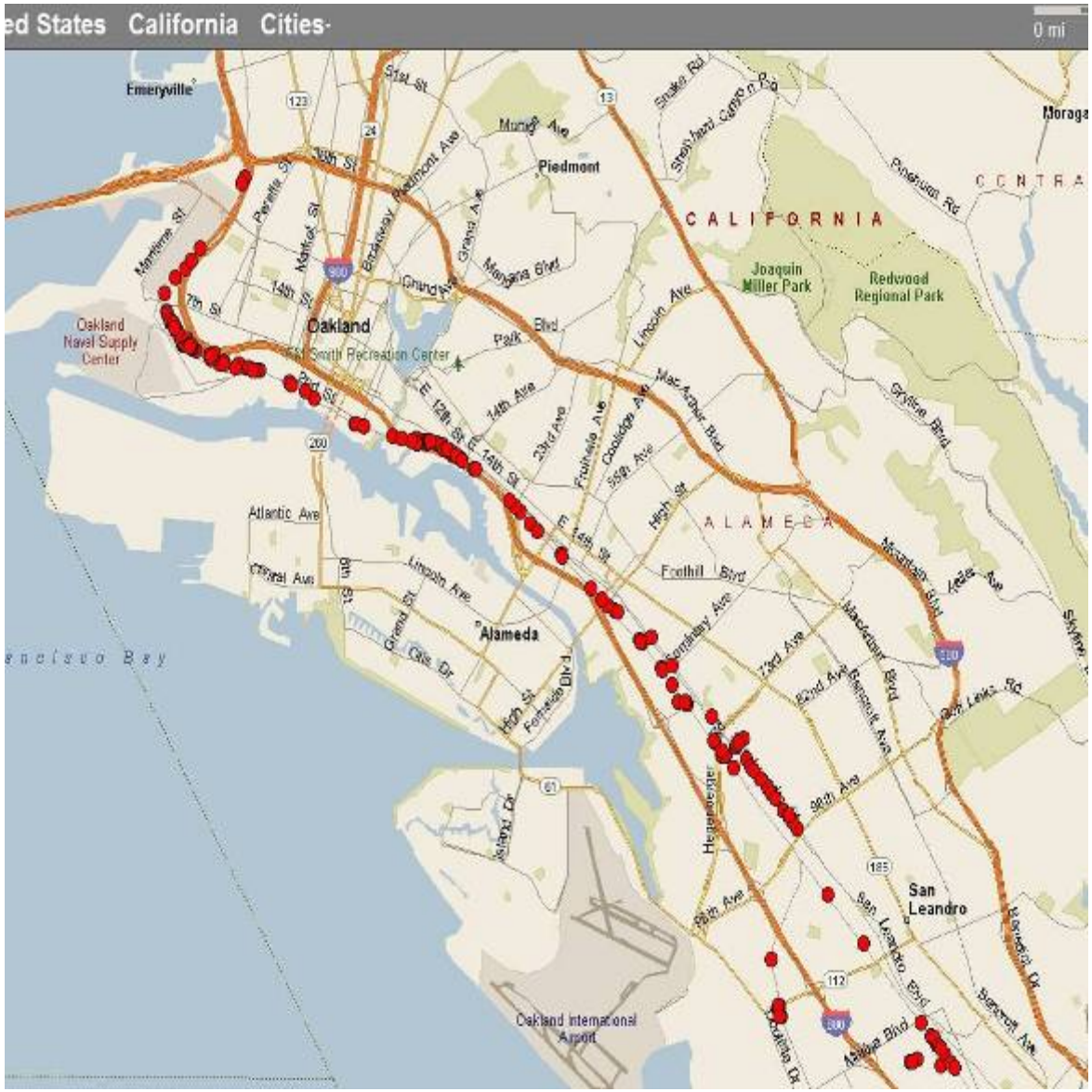
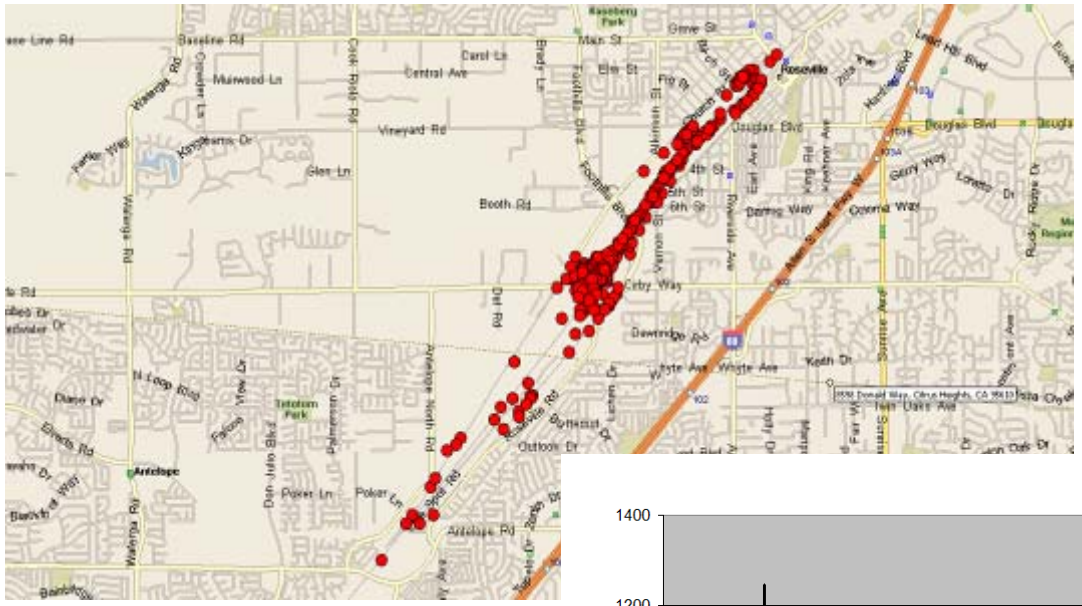
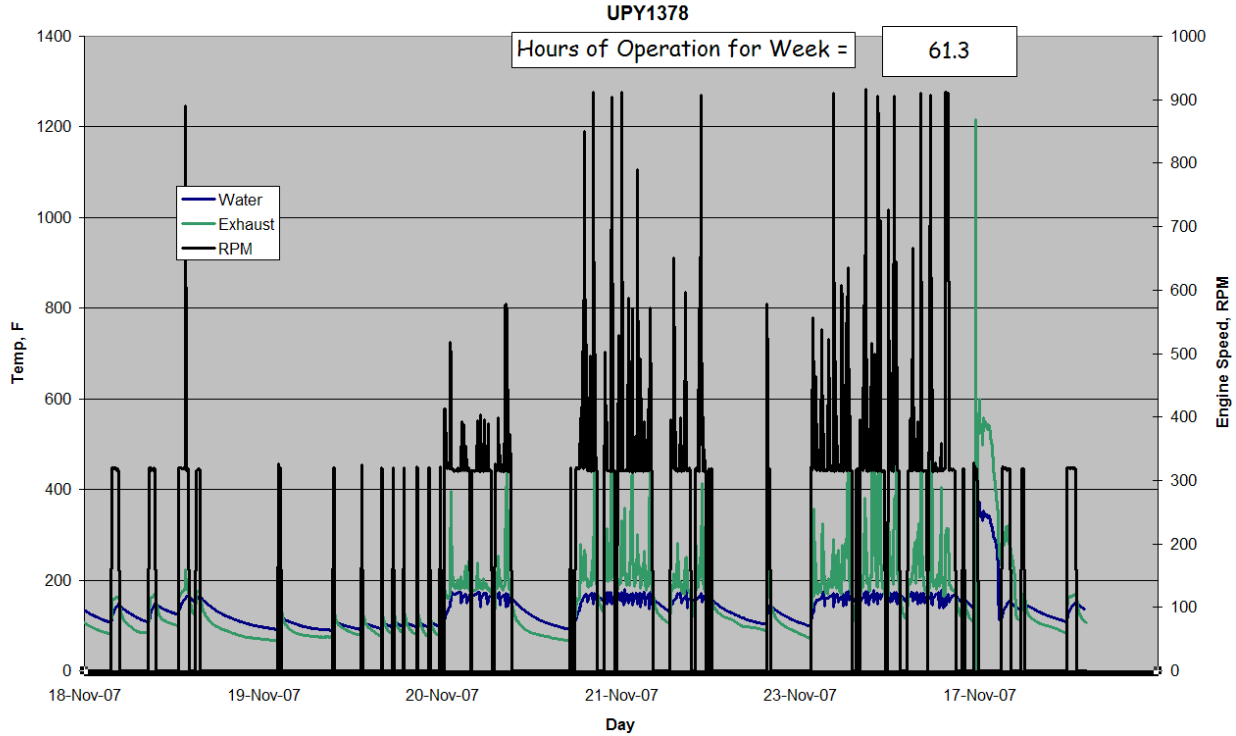
Locomotives in Demonstration - Update

* UPY1378 released to revenue service Oct 2006
  - » Had worked UP yard in Oakland California
  - » Now in Roseville Yard
  - » Will return at 12 months to SwRI for additional emissions testing



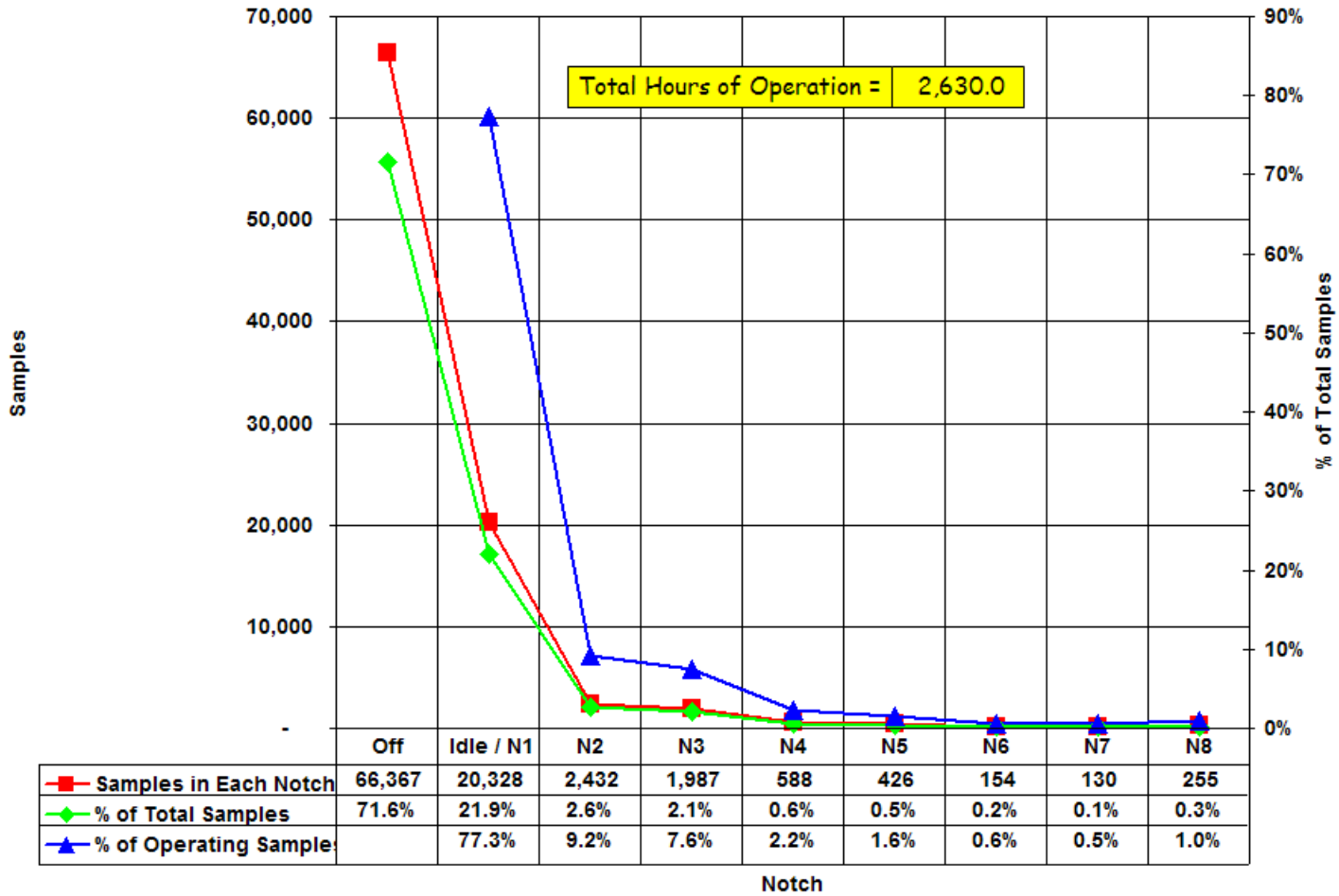
UPY1378 in Roseville, CA





Locomotives in Demonstration – Update (cont'd)

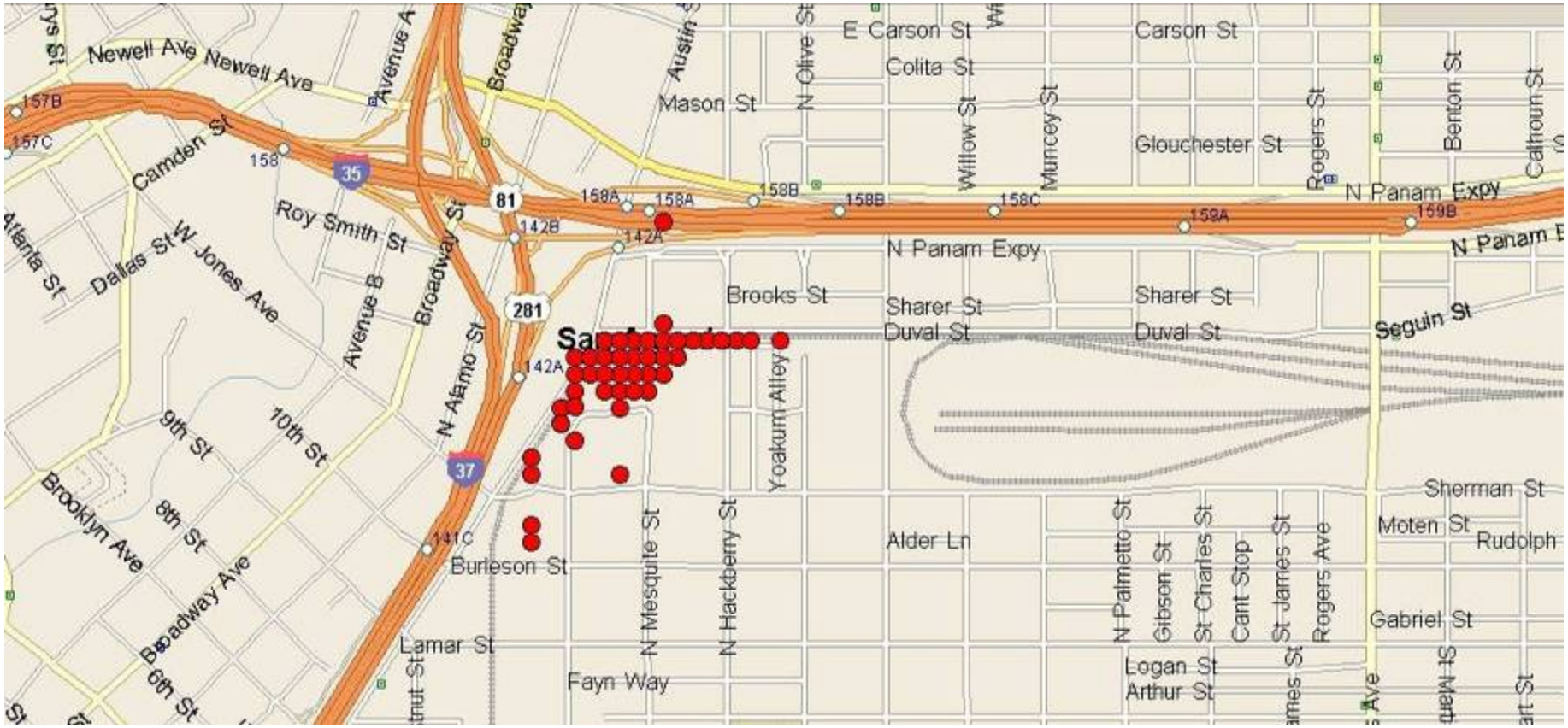
* UPY1378 operating cycle as of end of Week 47 '07



	Off	Idle / N1	N2	N3	N4	N5	N6	N7	N8
Samples in Each Notch	66,367	20,328	2,432	1,987	588	426	154	130	255
% of Total Samples	71.6%	21.9%	2.6%	2.1%	0.6%	0.5%	0.2%	0.1%	0.3%
% of Operating Sample		77.3%	9.2%	7.6%	2.2%	1.6%	0.6%	0.5%	1.0%

Locomotives in Demonstration – Update (cont'd)

* BNSF3703 has DPF system installed
  - » Working in yard in San Antonio Texas
  - » To be delivered to California Fall 2007



Locomotives in Demonstration – Update (cont'd)

* Issues encountered during demo:
  - » DPF is heavy ~ 1,100 pounds each
  - » Trapping Efficiency is below expected/desired levels
    - – Current levels are ~ 80%
    - – Targeting 90 to 95%
      - DOC in manifolds to reduce VOC
      - New filter material to reduce porosity of material
      - New housing design to reduce thermal growth / distortion
  - » White smoke @ regeneration after extended idle
    - – Caused by oil and fuel build up on "dirty" side of filter
    - – Burning off of oil & fuel causes white smoke
    - – Chance to reduce by:
      - More frequent regenerations of DPF
      - Lower oil consumption rings an liners
      - High reliability of ignition of the burner
      - High initial temperatures at the face of the DPF at start of regen cycle
  - » Burner ignition reliability
    - – Problem addressed

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Summary

* Experimental DPF aftertreatment systems are being demonstrated on switcher applications to gain North American rail experience
  - » 2 DPF's demonstrated on EMD MP15DC
  - » One year demonstration of the technology
* Emissions tests shows that:
  - » PM emissions reduced by 80%
  - » HC emissions were reduced by 30%
* Additional development and testing are being conducted to improve the efficiency of the DPF

Acknowledgements

* The Authors would like to thank:
  - » Union Pacific Railroad and BNSF Railway Company for their support and funding of this project
  - » TTCI for their management of the project
  - » The Technicians of SwRI that have worked on this project

Questions ?

Locomotive Technology Center

Southwest Research Institute®

ARB Locomotive Project:

Selective Catalytic Reduction (SCR) efforts with EMD 710 Engine

Steve Fritz

Southwest Research Institute

November 28, 2007

Project Background

* EF&EE Contracts for SCR on Metrolink F59PH passenger locomotive; funded by
  - » SCAQMD – primary funding source, plus administered additional funding from:
    - EPA - U.S. EPA Section 103 Grant funds for the 2006 Collaborative Diesel Emission Reduction Program
    - Caltrans - Caltrans High Priority Projects Special Revenue Fund (Fund 47)
  - » Metrolink (SCRRA)
  - » Texas NTRD Project N-011

Background (cont.)

* EF&EE approached CARB for SCR system verification guidance
* Synergy identified with planned EMD 12-710G3 engine testing at SwRI
  - » Same engine as in Metrolink F59PH locomotives
* Explored possibility of initial SCR system testing at SwRI on test engine
  - » Instead of first application being on a revenue service locomotive
  - » Seemed to make sense
  - » CARB agreed to fund SwRI work, SCAQMD to adjust scope and fund EF&EE at SwRI

Scope of SwRI Work

* Baseline emissions from EMD 12-710G3 engine (locomotive & marine E3 cycles)
* Backpressure effects testing
* Crankcase blowby characterization

Covered today

* SCR installation
* Emissions testing during system calibration
* FTP emissions testing (locomotive & marine E3 cycles)
  - » Including ammonia slip using FTIR

Exhaust Backpressure Testing: Objective

* Document the effect of increased exhaust backpressure on EMD 12-710 G3 engine performance.

* Why?

* Post-turbine exhaust aftertreatment systems will be required to meet future exhaust emission regulations. The pressure drop across these aftertreatment systems will increase the backpressure on the engine.

* EMD specifies a very low exhaust backpressure limit on their turbocharged engines, on the order of 5 to 8 inches of water (0.37 to 0.59 in. Hg, or 12.4 to 19.9 mBar).

* What happens if this limit is exceeded?

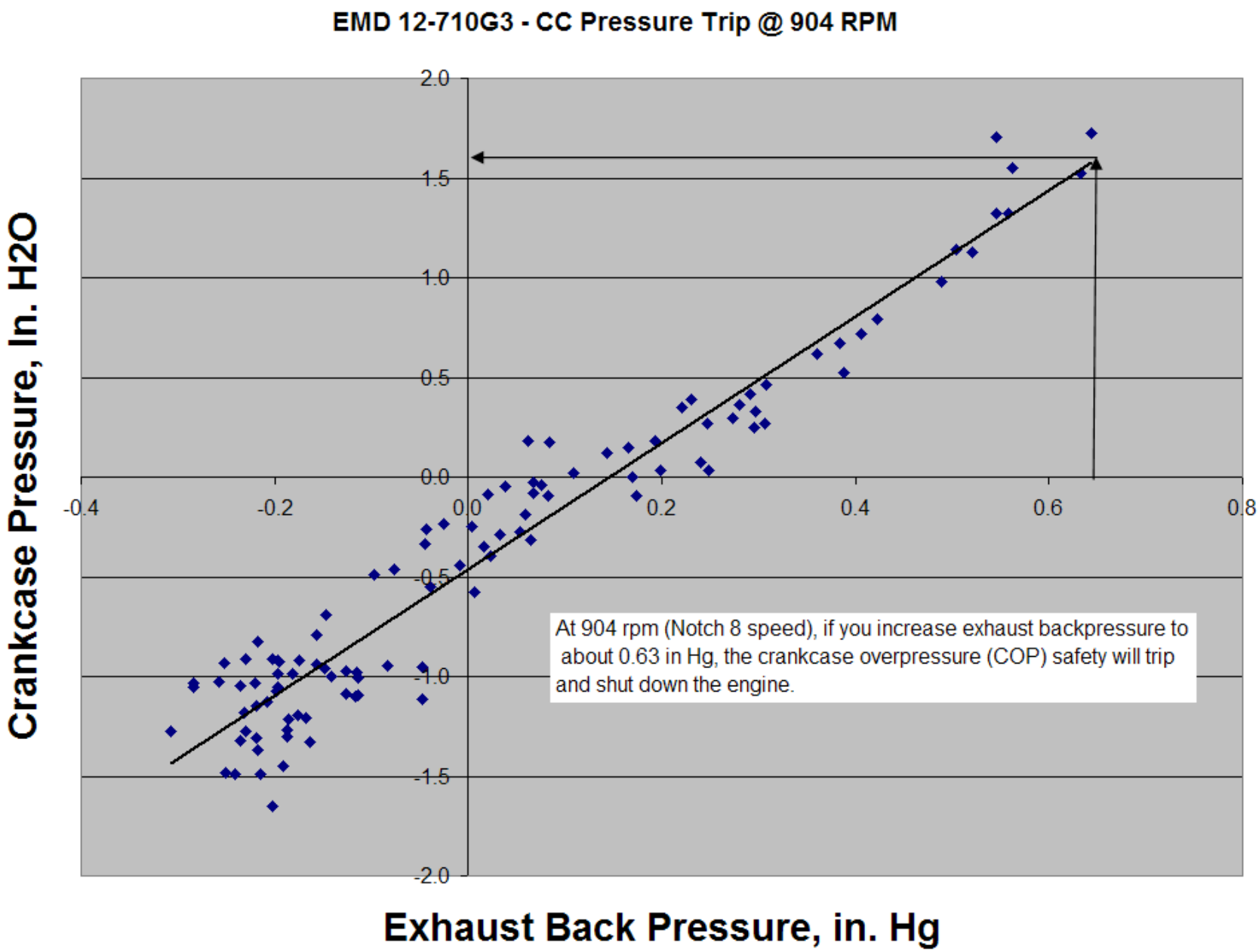
How?

* Fabricate exhaust backpressure damper for EMD 12-710G3A exhaust system
* Simulate higher exhaust backpressure of future aftertreatment systems
* Run a series of tests at several increased backpressure settings
  - » up to about 170 mBar total exhaust backpressure (5 in. Hg)
* Measure engine performance with higher exhaust backpressure

Exhaust Damper Valve

Crankcase Pressure Safety Switch

* EMD engines use a crankcase pressure safety switch that shuts down the engine when the crankcase pressure reaches a positive pressure of about 4 mBar (1.6 in. H_2O) at Notch 8.

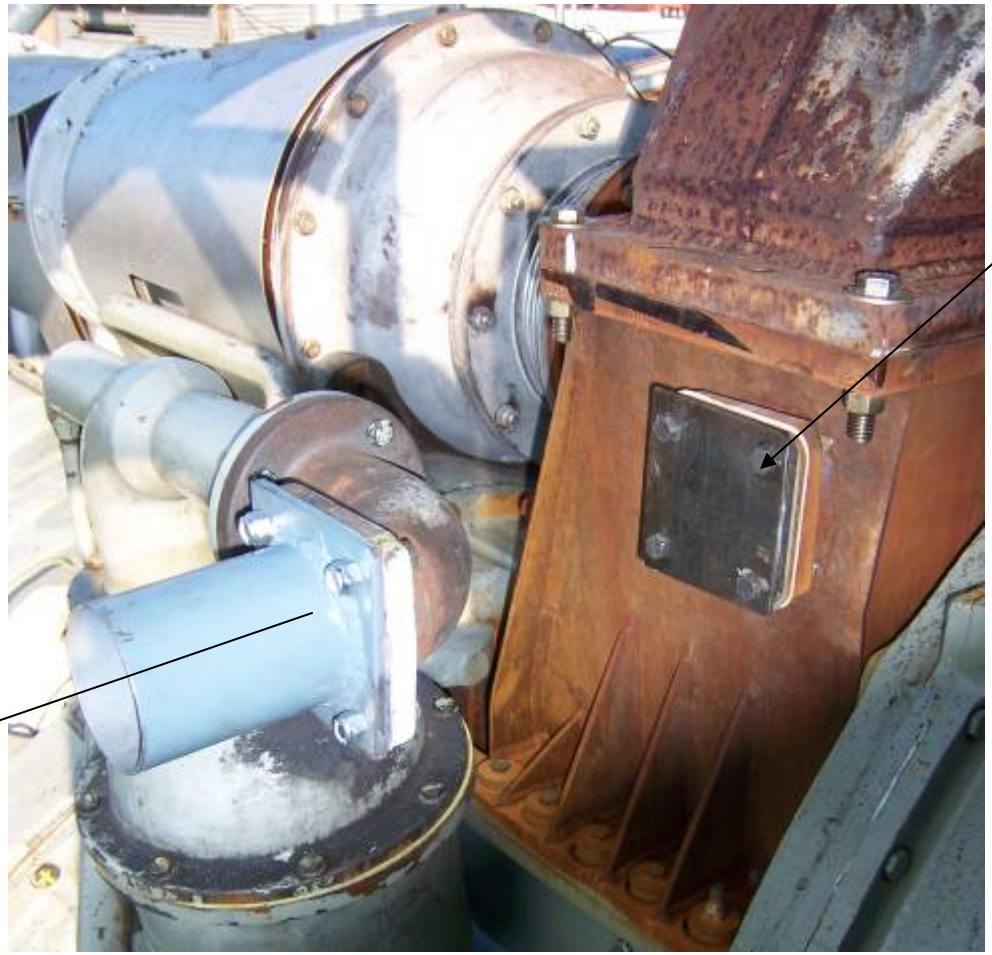

EMD 12-710G3 - CC Pressure Trip @ 904 RPM
Crankcase Pressure, In. H2O
Exhaust Back Pressure, in. Hg
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
At 904 rpm (Notch 8 speed), if you increase exhaust backpressure to about 0.63 in Hg, the crankcase overpressure (COP) safety will trip and shut down the engine.

EMD Crankcase Blowby Eductor

* The crankcase on EMD engines is typically evacuated using an eductor system that draws crankcase blowby into the exhaust system, downstream of the turbocharger outlet.

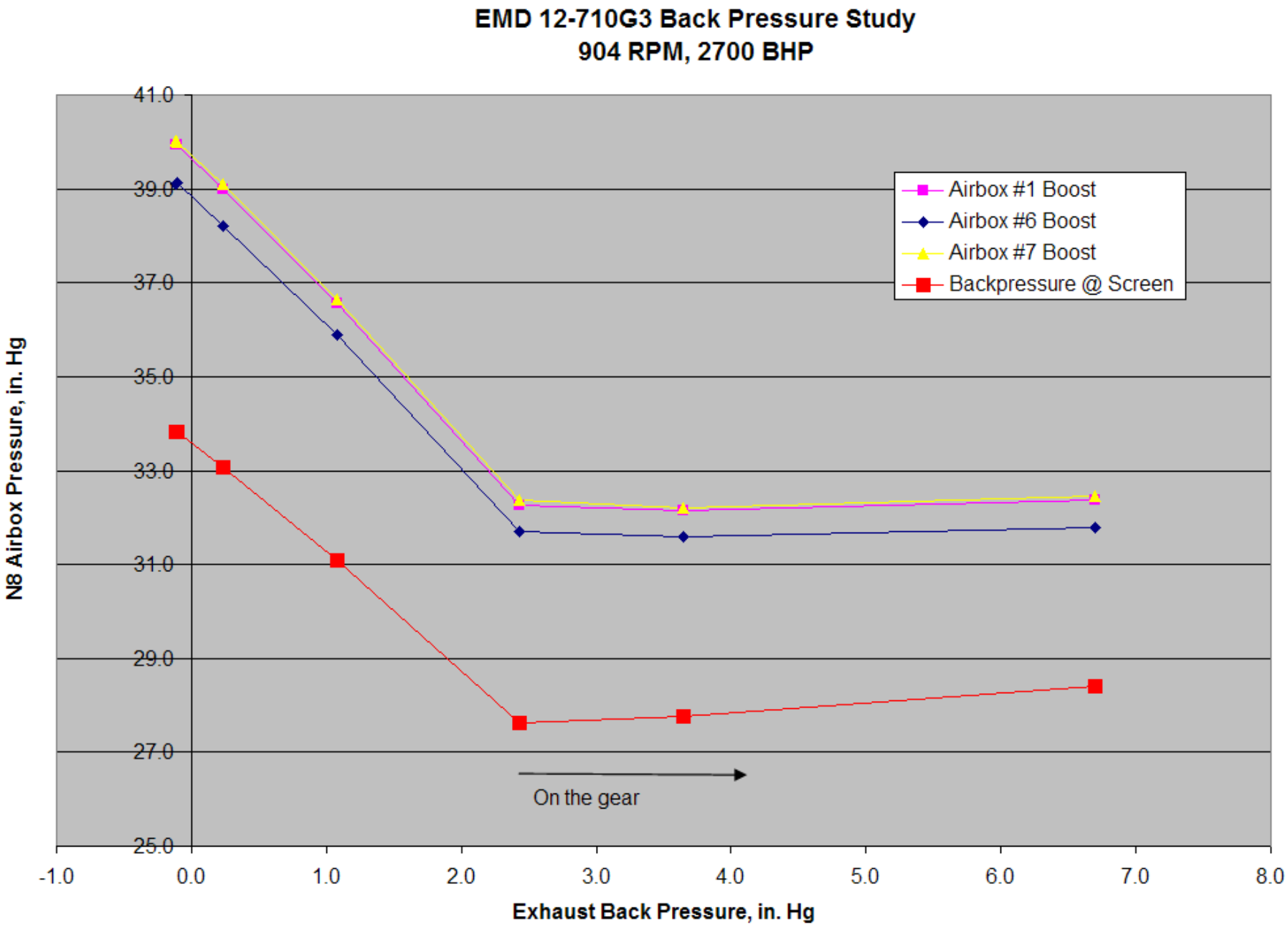
Aftertreatment systems located downstream of this location will result in increased crankcase pressure

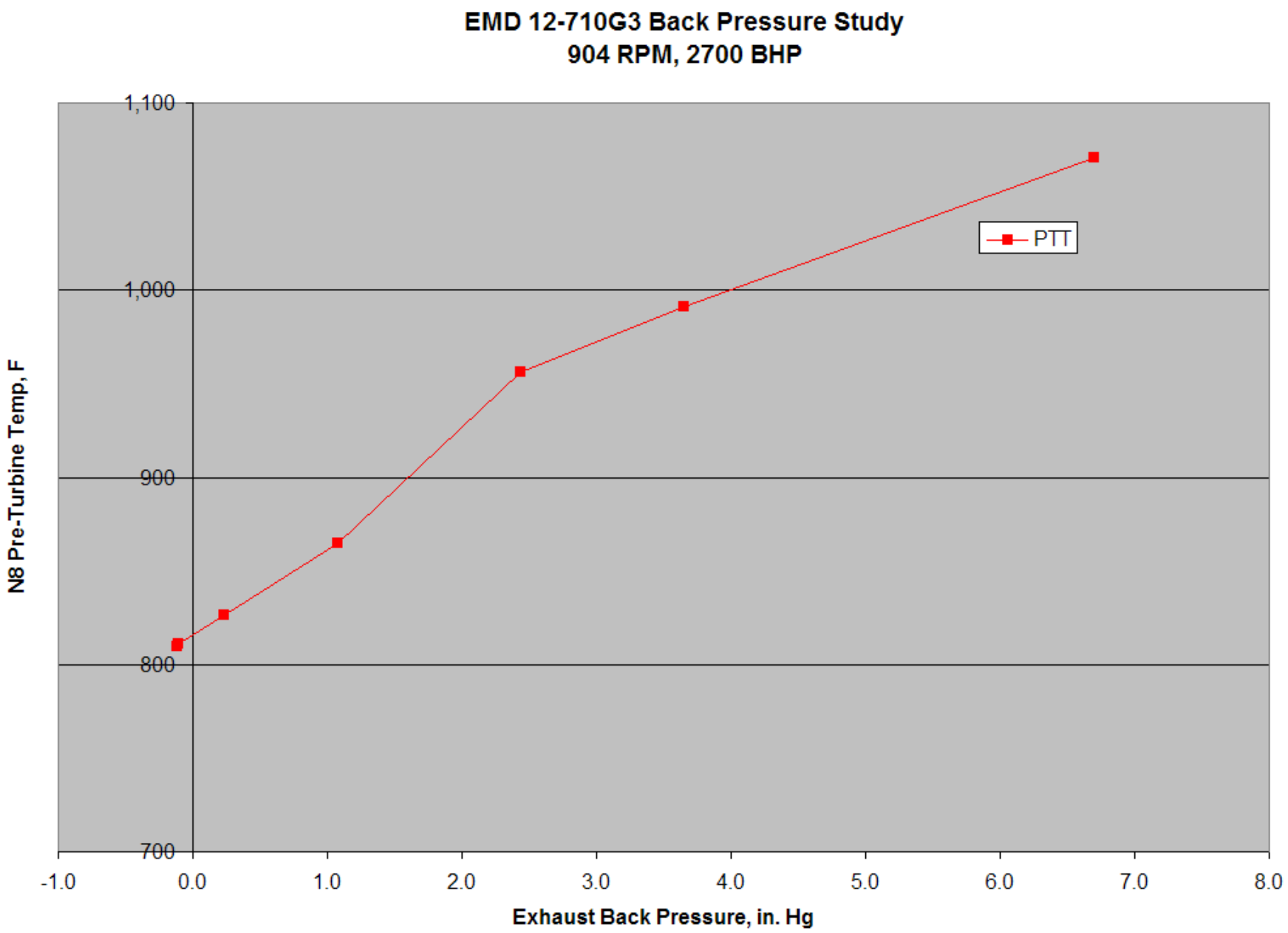
Reroute Blowby to Allow for High Backpressure Study

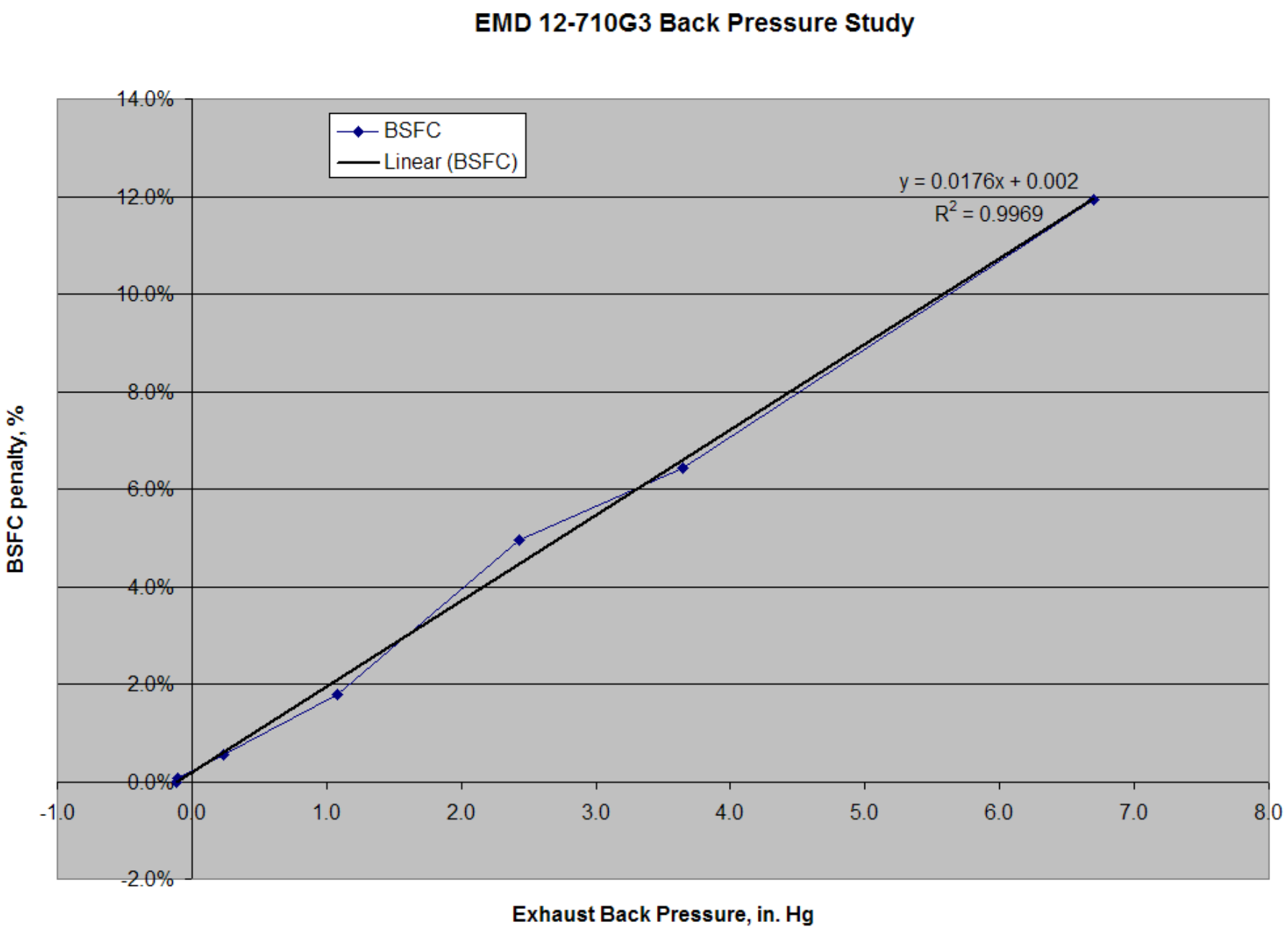


Cover Plate

Blowby vented to atmosphere


EMD 12-710G3 Back Pressure Study
904 RPM, 2700 BHP
N8 Airbox Pressure, in. Hg
41.0
39.0
37.0
35.0
33.0
31.0
29.0
27.0
25.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Exhaust Back Pressure, in. Hg
Airbox #1 Boost
Airbox #6 Boost
Airbox #7 Boost
Backpressure @ Screen
On the gear


EMD 12-710G3 Back Pressure Study
904 RPM, 2700 BHP
N8 Pre-Turbine Temp, F
1,100
1,000
900
800
700
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Exhaust Back Pressure, in. Hg
PTT


EMD 12-710G3 Back Pressure Study
BSFC
Linear (BSFC)
y = 0.0176x + 0.002
R2 = 0.9969
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
-2.0%
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
BSFC penalty, %
Exhaust Back Pressure, in. Hg

Crankcase Blowby Characterization

* Crankcase blowby is routed into exhaust system on EMD turbocharged engines
* Oil aerosols thought to be primary reason for premature fouling of several aftertreatment systems applied to EMD engines
* In support of CARB SCR project:
  - » Measure EMD 12-710G3 blowby flow rate
  - » Measure oil aerosol mass emission rate
  - » Screen candidate blowby filter systems

Blowby Flow Measurements

* Technique described in 2003 ASME paper
  » Previous blowby measurements on EMD 16-645E roots-blown engine

Proceedings of ICEF03
2003 Fall Technical Conference of the Internal Combustion Engine Division
Erie, Pennsylvania, September 7-10, 2003

ICEF2003-707

CRANKCASE BLOWBY CHARACTERIZATION FROM AN EMD 16-645-E LOCOMOTIVE DIESEL ENGINE

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Blowby Flow & Aerosol Mass Rate Measurements

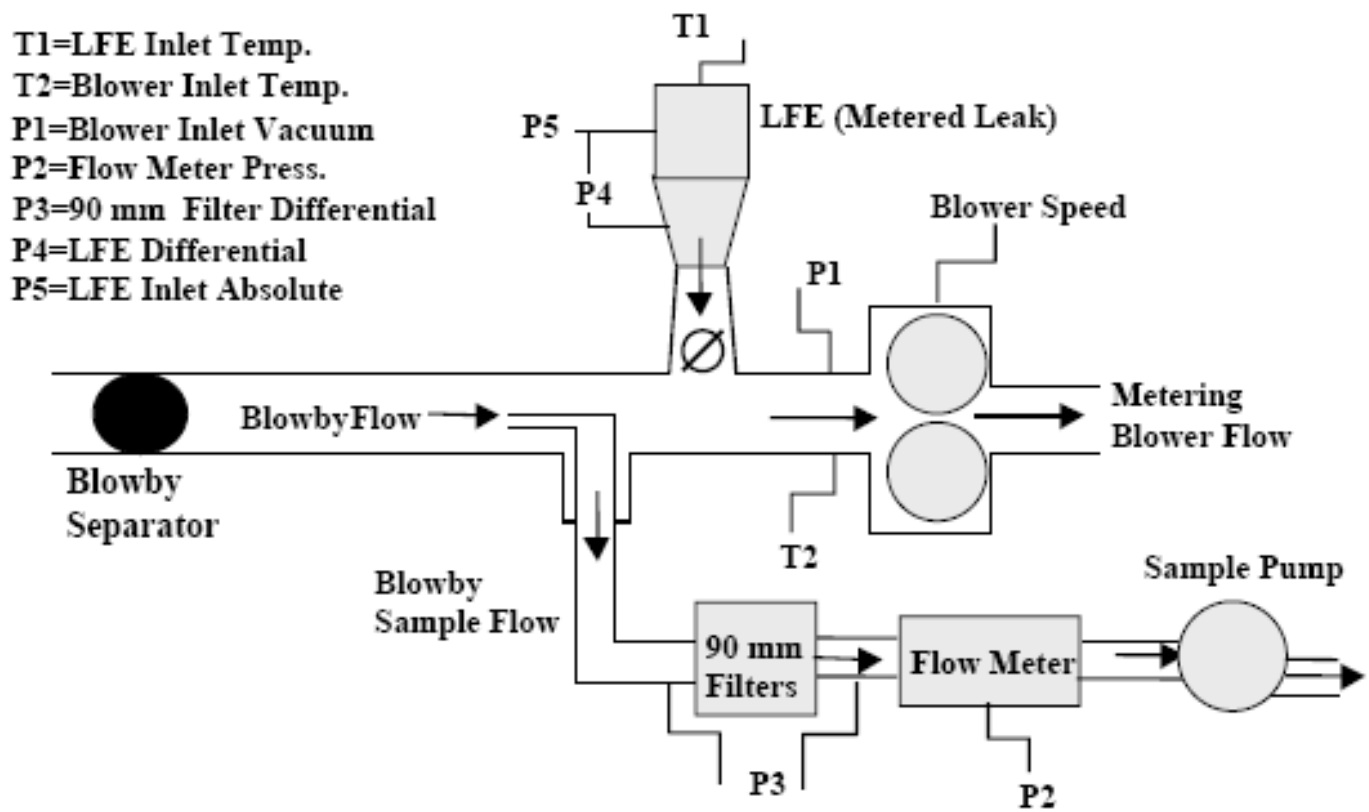
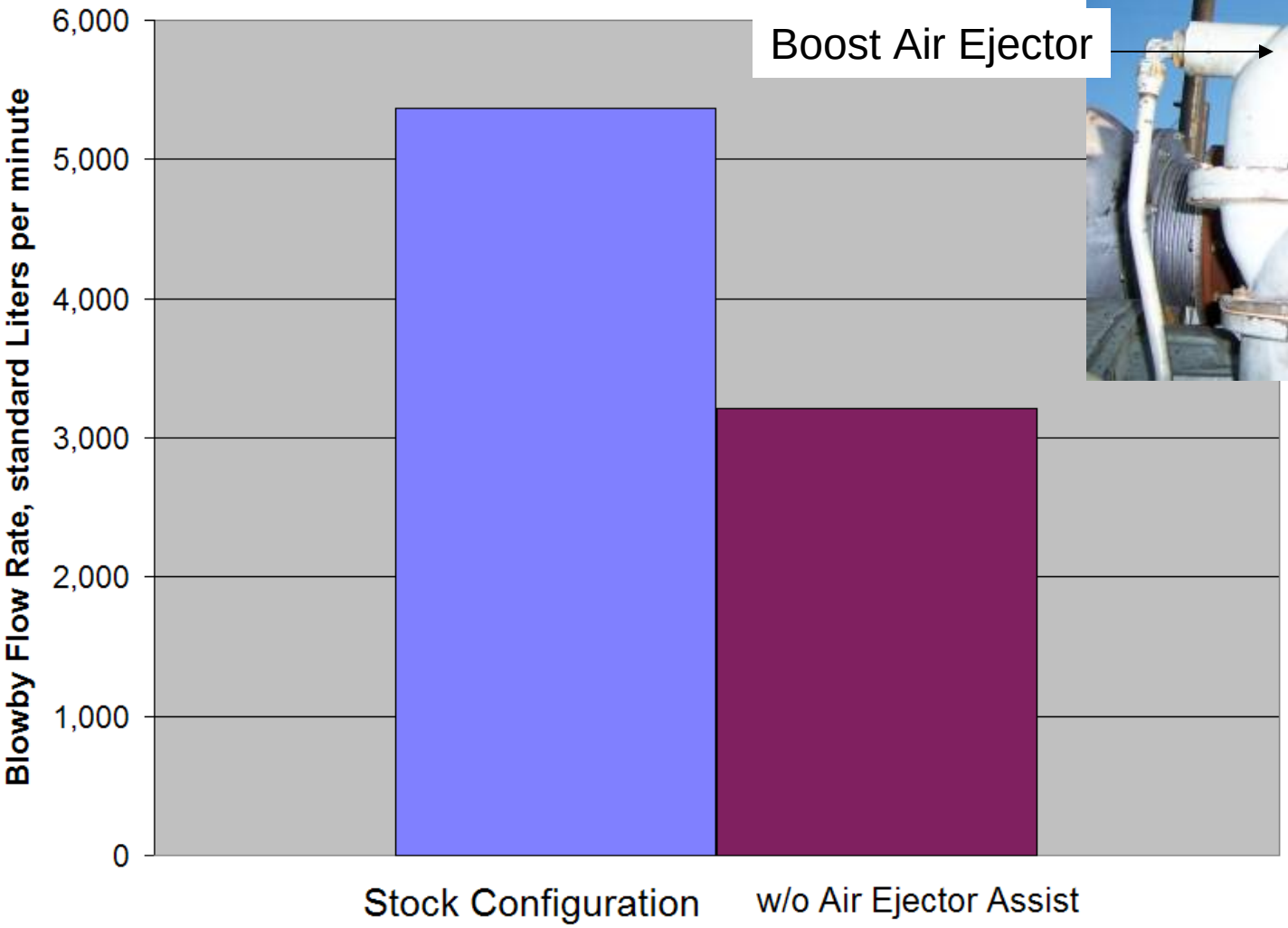
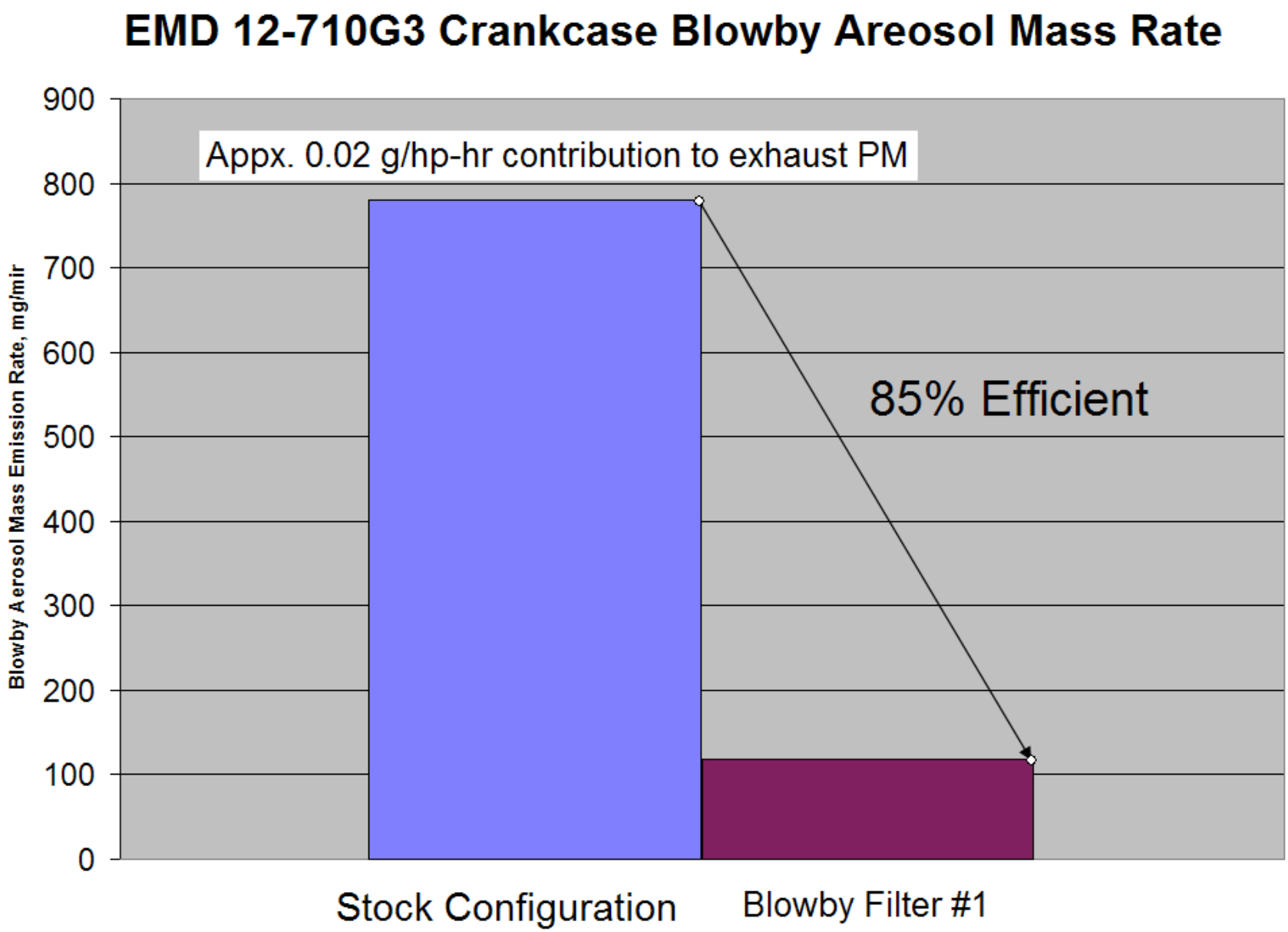


Figure 5. Blowby Measurement System Schematic

EMD 12-710G3 Blowby Flow Rate
@ 904 RPM & 3,000 hp




EMD 12-710G3 Crankcase Blowby Areosol Mass Rate
Appx. 0.02 g/hp-hr contribution to exhaust PM
85% Efficient
Blowby Aerosol Mass Emission Rate, mg/mir
900
800
700
600
500
400
300
200
100
0
Stock Configuration
Blowby Filter #1

ARB Locomotive Project Status

* Baseline testing complete
* Backpressure study complete
* Crankcase blowby flow measurements complete
  » 1 of 2 planned blowby filter evaluations complete
* Initial SCR screening tests recently performed
* Follow-up SCR testing planned 1Q08

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