

California Emissions Program: PM Reduction from EMD Switcher Locomotives

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by

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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 wants to see a Diesel Particulate Filter (DPF) installed and functioning on a switcher locomotive in California



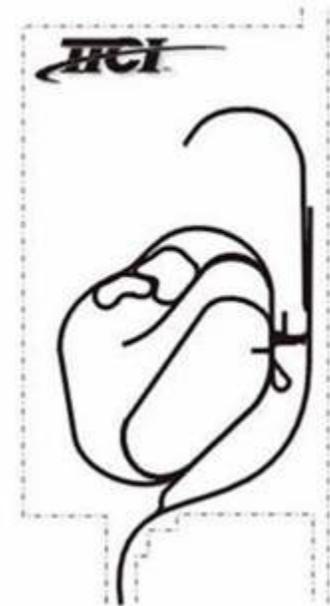
1,500 hp EMD MP15 Switcher Locomotive

CEP Administration

- * R&D work for the Association of American Railroads (AAR) is performed by the Transportation Technology Center, Inc (TTCI) in Pueblo, Colorado



- * TTCI is the CEP program manager for BNSF & UP
- * SwRI under contract with TTCI
- * Regular updates to CARB
- * AAR, CSX, and NS following project
- * These issues will ultimately affect all railroads and the OEMs.



48-miles of test track

General Technical Approach

- * Phase 1 - Laboratory Screening (complete)
 - » Task 1: Install EMD 16-645E locomotive engine
 - » Task 2: Reduce lubricating oil consumption
 - Cylinder kits (pistons, rings, cylinder liners) (ASME ICES2003-549), CIMAC 2004
 - Recirculated crankcase blowby (ASME ICEF2003-707)
 - Valve stem seals
 - Rebuilt engine with low oil consumption parts
 - » 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
- * Phase 2 - Field Implementation of DPF on Switcher Locomotives

Test Engine Installed at SwRI

- Electro-Motive Diesel (EMD) 16-645E
- 2,000 hp Two-stroke Diesel engine
- Roots-blown (i.e., non-turbocharged)
- About 3,400 of these in Class 1 railroad switcher operation
- About 300 in California
 - many to be replaced soon with genset switchers



EMD 16-645E 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

Question: What are the Baseline PM Emissions for EMD 645E Switcher Engines?

* It depends.....there are several sources of available data.

1. 1995 AAR Report R885

- » SwRI tested 5 EMD MP15AC locomotives (1,500 hp, 12-645E engines)
 - 3 of the 5 were tested at all Notches and with PM measurements
- » In-use testing for inventory and fuel injection timing effects

2. DOE/NREL Biodiesel Study

- » EPA Certification Diesel & CARB diesel in an EMD GP38-2 (2,000 hp, 16-645E)

3. CEP Baseline Emissions - As Received

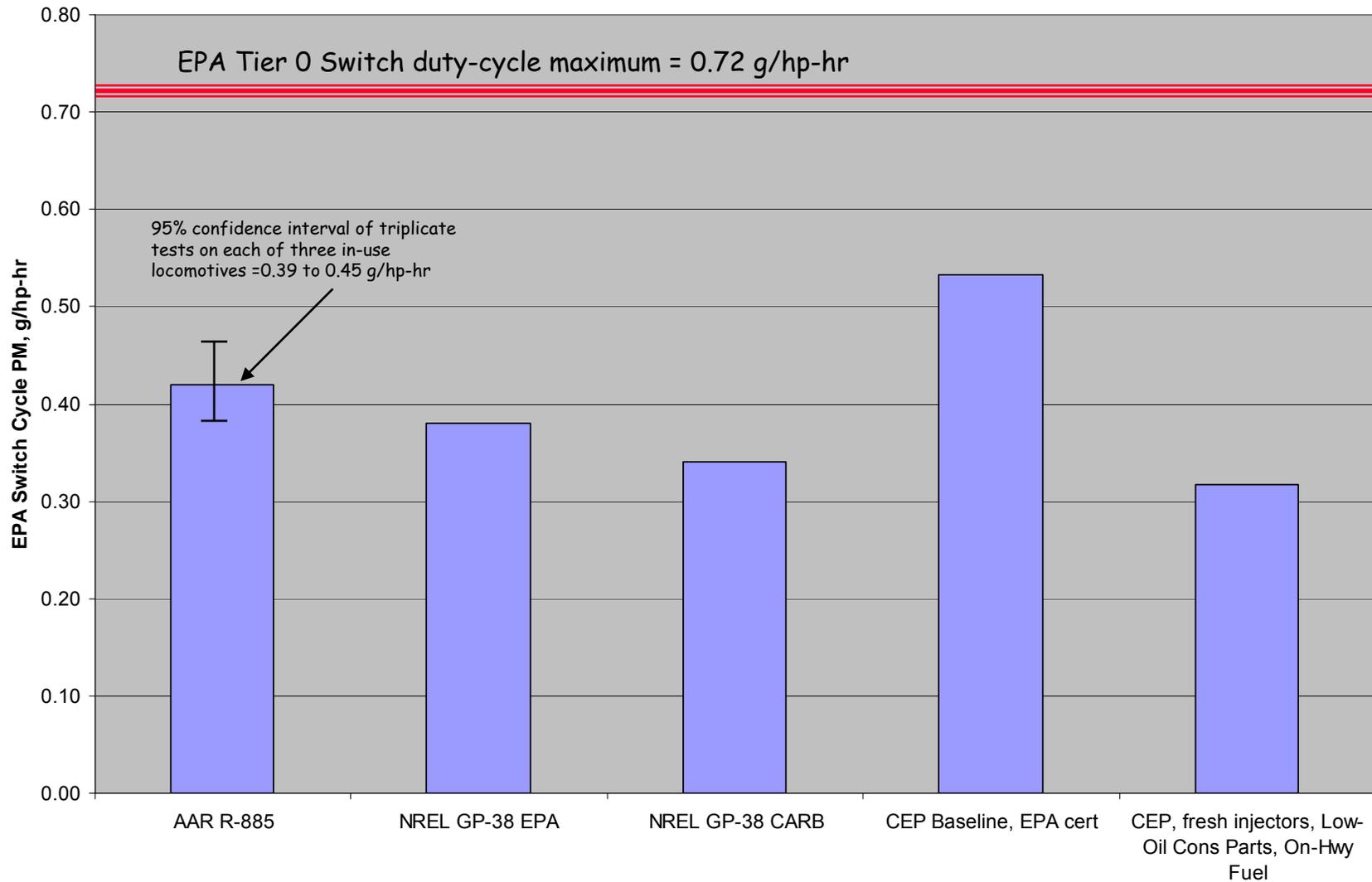
4. CEP - Current Configuration with low oil consumption parts and fresh injectors

Also;

With what fuel?

Over what test cycle?

Sources of "Baseline" EMD 645E PM Emission Rates EPA Switch Cycle



EMD 645E PM Composition

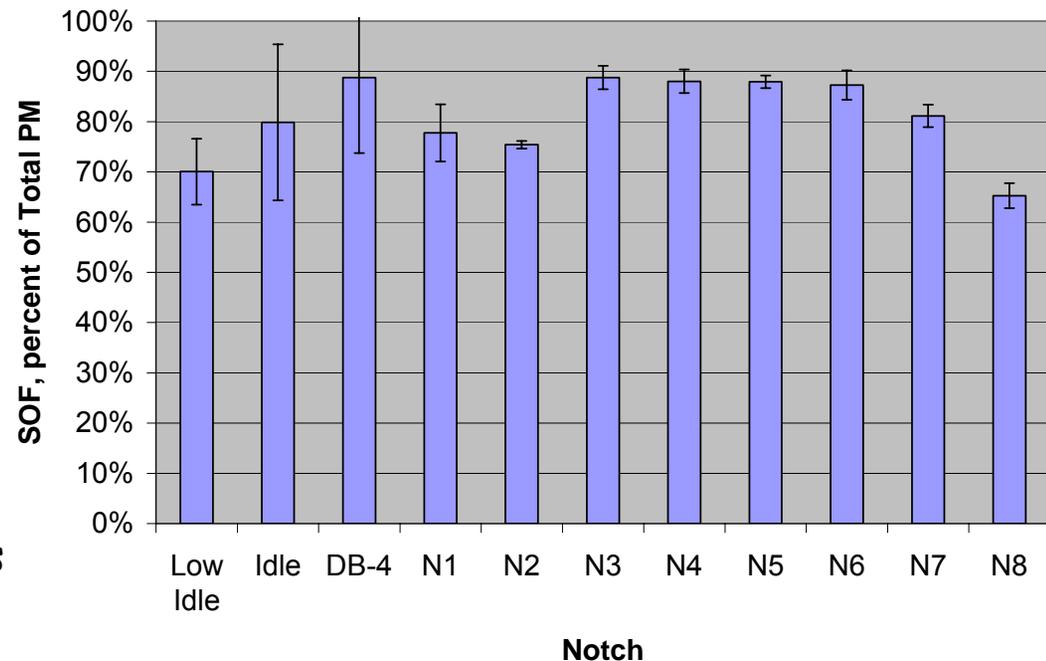
- * Soluble Organic Fraction (SOF) relatively high;
 - » 77% over EPA Switch Duty Cycle
 - » SOF is high at all Notches

- * 4-stroke engines characteristically have much lower SOF levels

- * Aftertreatment system needs to be engineered to the exhaust PM characteristics

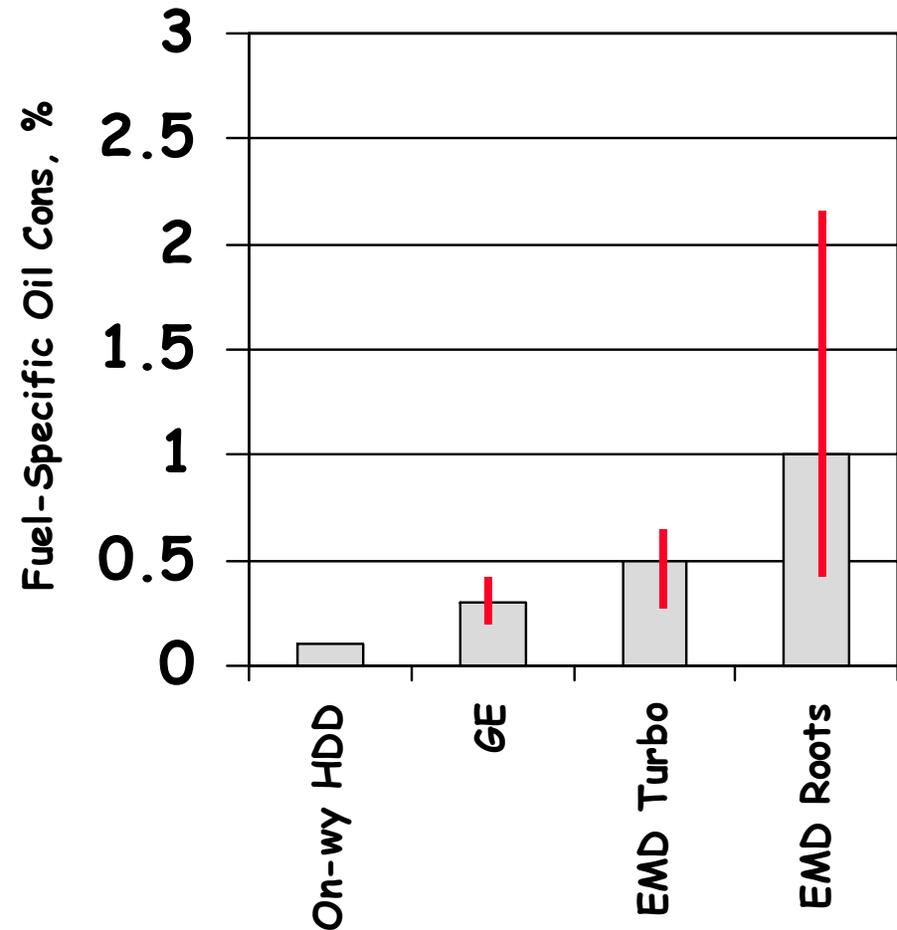
EMD 16-645-E Particulate Analysis

Triplicate FTP Baseline with Low Oil Consumption Components



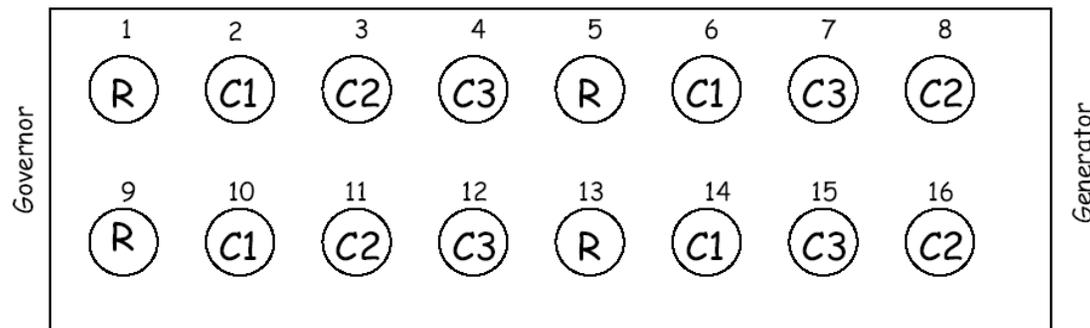
Why is SOF so high? Lube Oil Consumption

- * Oil consumption level of roots-blown EMD engines is relatively high
 - » 3 to 10 times higher than today's truck engines
- * Affects aftertreatment performance & durability:
 - » Ash loading
 - » Sulfur
 - » "Souping" - liquid oil accumulation in the exhaust manifolds during extended idling



CEP Task 2: Reduced Oil Consumption Cylinder Kits

- * Evaluated 7 cylinder kits or kit components to assess relative oil consumption
- * Used SwRI-developed RTOC-III™ technique to measure oil consumption

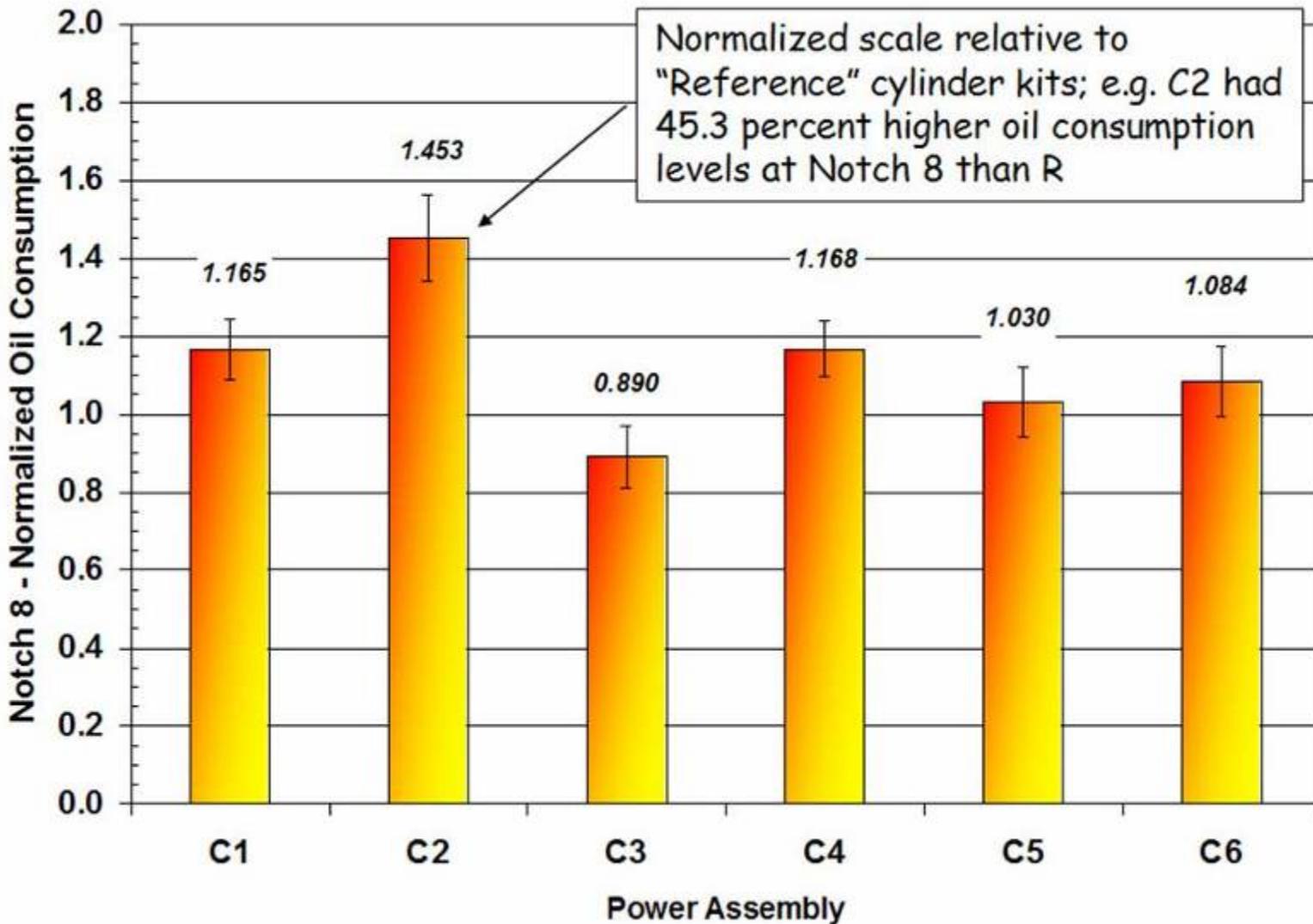


3 candidate kits (4 each of C1, C2, and C3) evaluated simultaneously, in addition to the reference "R" kits



EMD power assembly showing piston, cylinder liner, and cylinder head

Reducing Oil Consumption

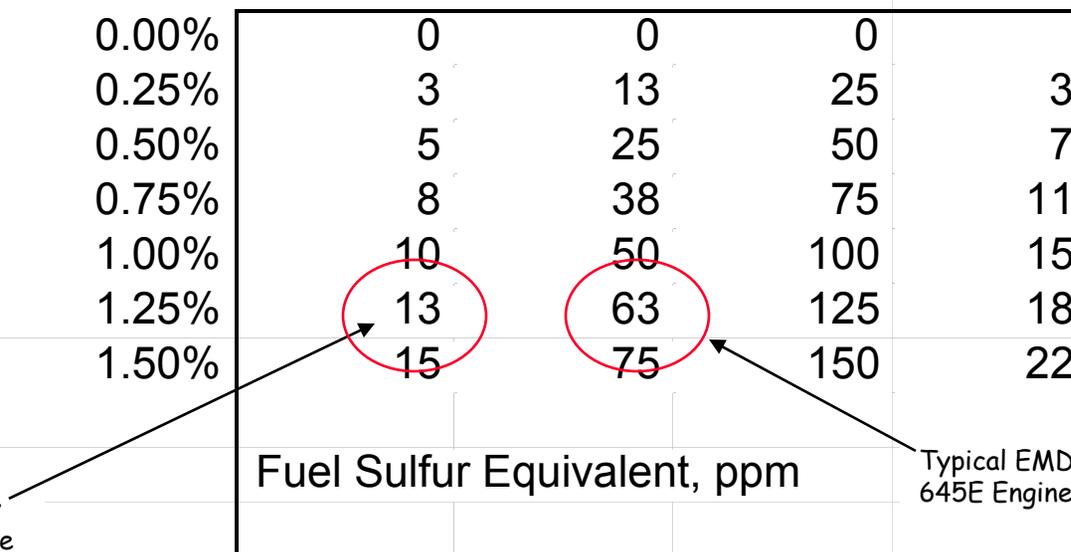


Oil Consumption & Sulfur

		Fuel-Specific Oil Consumption (gal lube / gal fuel)				
% sulfur in lube		0.1%	0.5%	1.0%	1.5%	2.0%
	0.00%	0	0	0	0	0
	0.25%	3	13	25	38	50
	0.50%	5	25	50	75	100
	0.75%	8	38	75	113	150
	1.00%	10	50	100	150	200
	1.25%	13	63	125	188	250
	1.50%	15	75	150	225	300
		Fuel Sulfur Equivalent, ppm				

On-Highway Truck Engine

Typical EMD 645E Engine



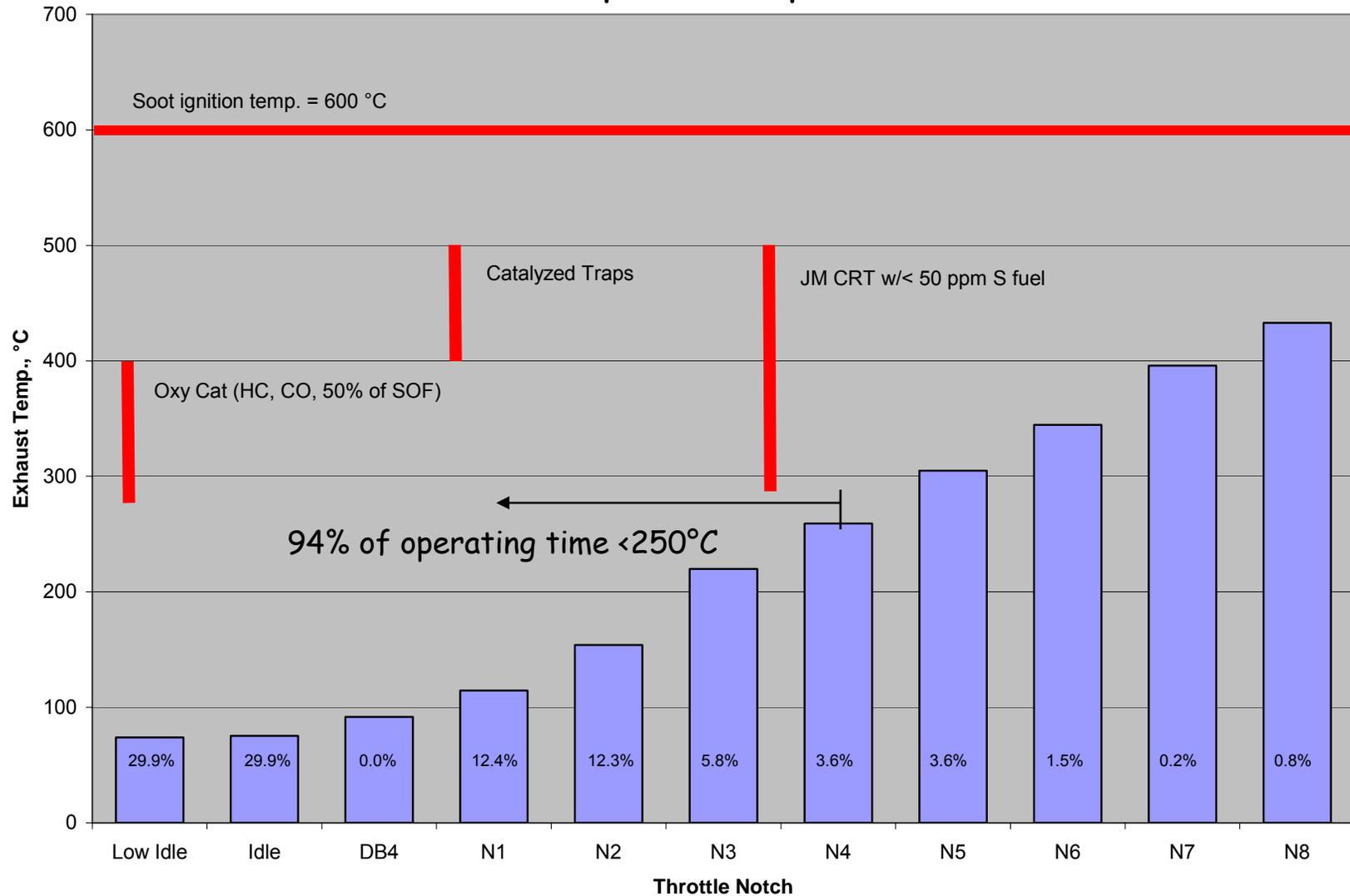
Lube-oil derived sulfur will be an issue if a catalyzed trap is used, even with ultra-low sulfur diesel fuel.

CEP Phase 1, Task 3: Aftertreatment Screening

- * Challenges in Considering DOC or DPF for this EMD 16-645E Application
 - » Exhaust temperatures are very low
 - » Compounded by switcher duty cycles
 - 60% of the time at Idle
 - Idle shutdown system will likely be needed
 - » DPF Will likely require active regeneration
 - Electrical heating possible - lots of electrical power available on the locomotive
 - Increased cost & complexity over passive systems
 - Additional fuel consumption penalty

EMD 16-645E Exhaust Temperatures

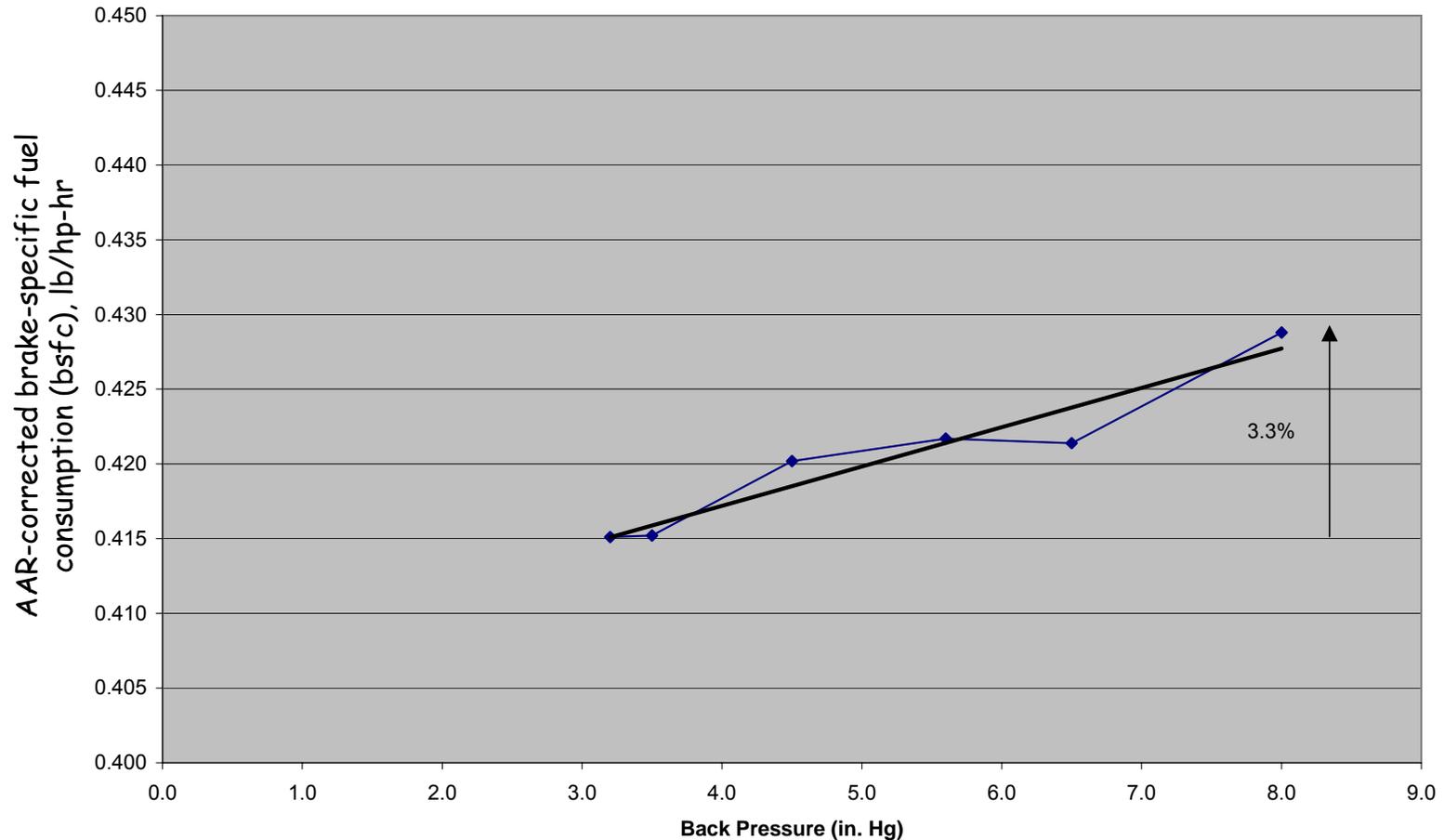
2,000 hp @ 900 rpm



Exhaust temperatures are too low for passive systems

Backpressure Sensitivity

EMD 16-645E at 2,000 hp rated power, Notch 8



As we add aftertreatment, and back pressure increases, there is a direct negative impact on fuel economy.

Candidate DPF & Oxycat Evaluations

- * Original plan was to screen "truck size" samples
 - » 135 hp/cyl = 100 kW/cyl
 - » 4 cylinders = 540 hp \approx power of large truck engine
- * Briefed MECA to invite supplier participation
 - » MECA = Manufacturers of Emissions Controls Association
 - » Jan. 2002 and again in Nov. 2003
 - » Very limited interest from MECA members
 - Challenging application (cold exhaust, low duty cycle, high SOF)
 - Potential market size too small to justify R&D cost
 - Busy with near-term, higher volume projects
- * Looked to large engine stationary source suppliers
 - » Typical market is low-volume, custom-engineered applications.

Locomotive Space Limitations

- * Need to be able to service engine without interference from exhaust manifolds or aftertreatment system

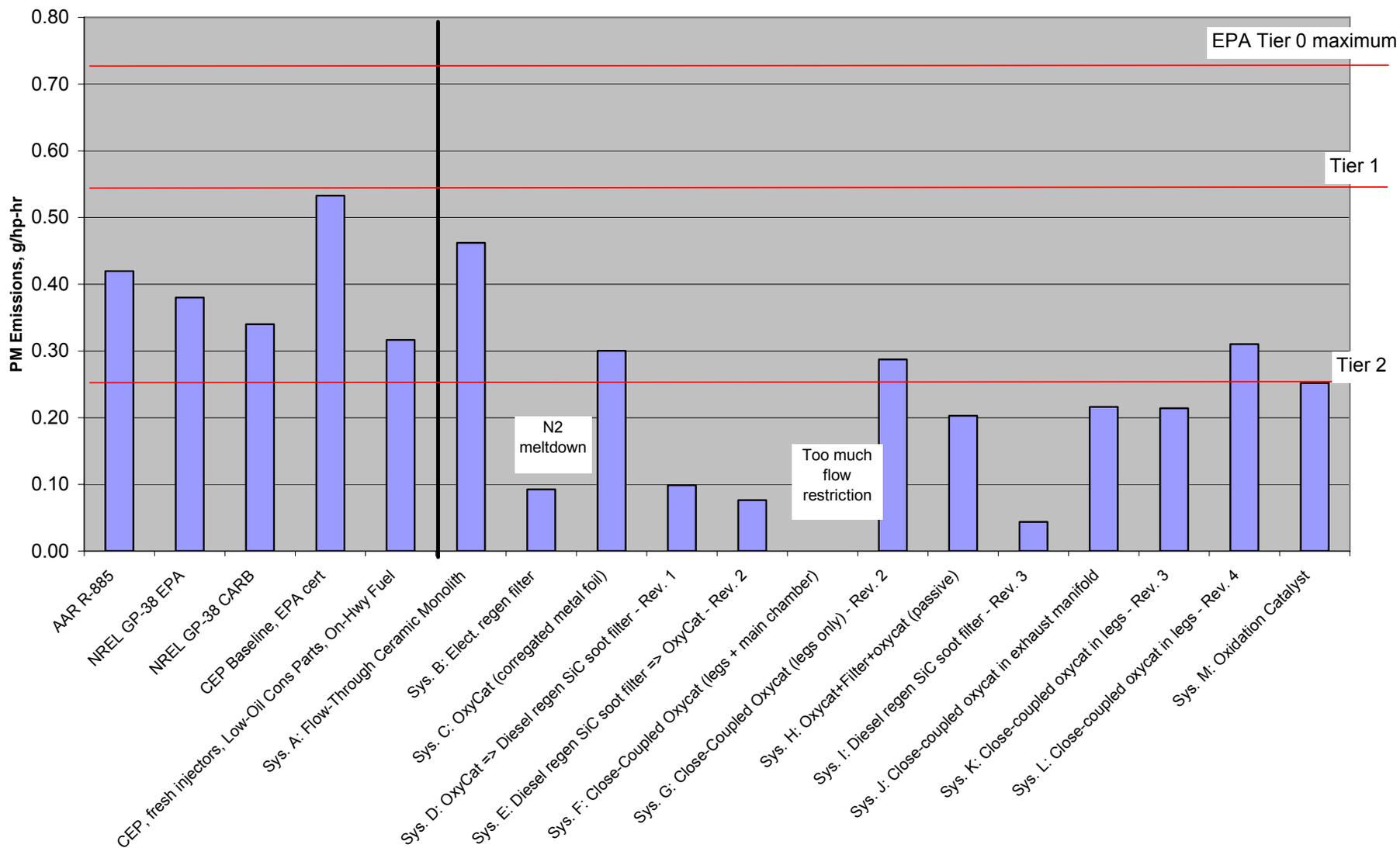


- * Valve covers open for access to power assemblies



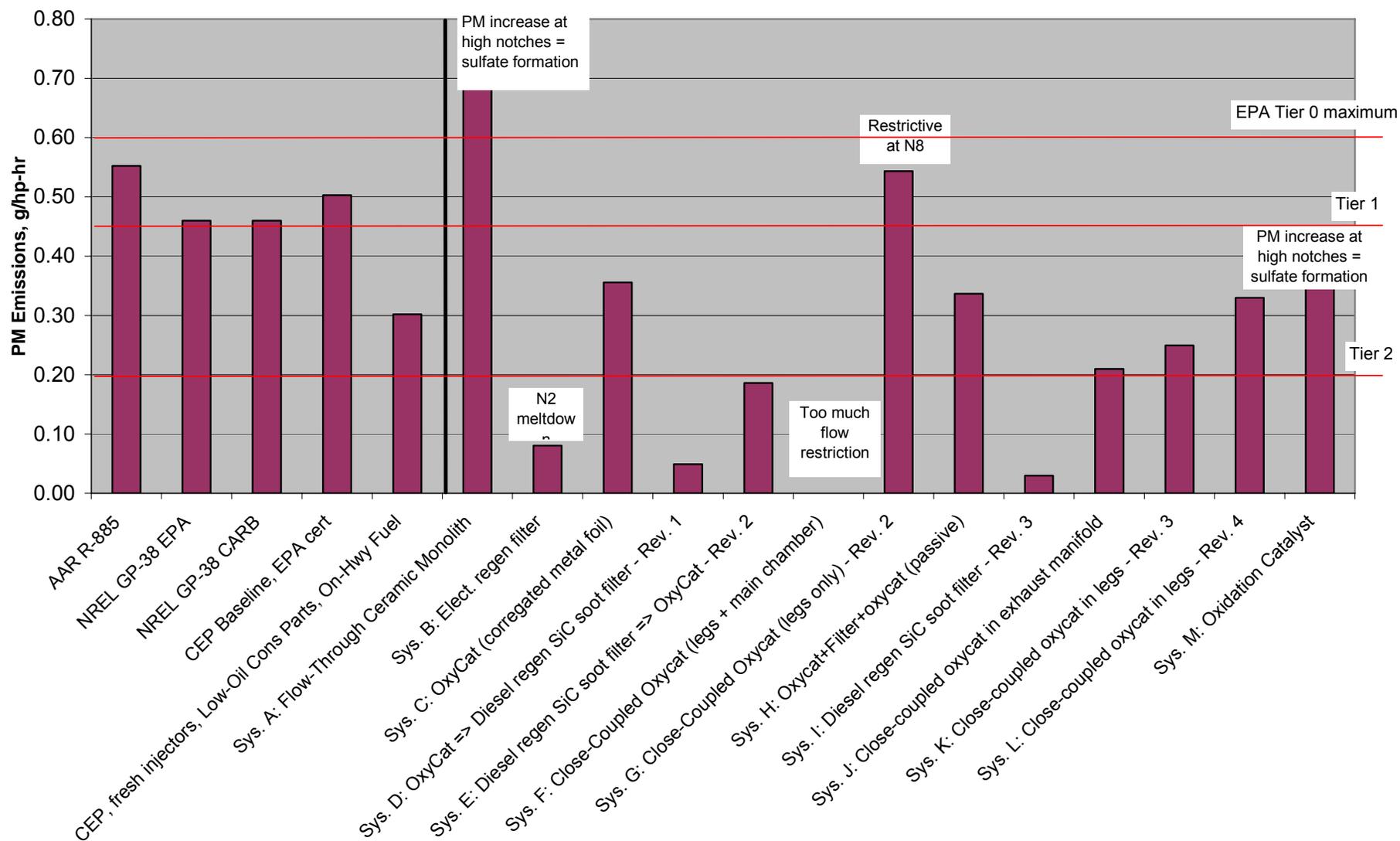
Screening Test Performance Summary

EPA Switch Cycle



Screening Test Performance Summary

EPA Line-Haul Cycle



CEP Phase 1: Summary/Conclusions

- * Low oil consumption cylinder kits a logical first step in PM reductions
 - » This is where most of the PM is coming from
 - » Reduces the burden on the aftertreatment system
- * Laboratory screening test of candidate aftertreatment systems was essential
 - » Suppliers rarely "get it right" the first time
 - » This is a challenging application
 - » Screening on 2 or 4 cylinders of exhaust has allowed for screening several candidate systems
- * If it works - will it fit?
- * Long term technology path not certain; DOC vs. DPF
 - Capital cost
 - Installation cost
 - PM Emission reduction - initial and long term
 - Durability / Reliability / Maintenance
 - Operating cost (fuel consumption penalty)

What is Next ? CEP Phase 2

- * TTCI performed engine shock and vibration characterization on revenue service switcher locomotives - completed
- * Hug Engineering DPF selected for field implementation

Initial 2 Locomotives for DPF



Photographer: CHARLES BIEL
Collection of: August 6, 2000
Location: Tulsa, OK
Subject: MP15 #3703
Previous: BN 1003
Road: SLSF 364
Numbers:
Builder Number: 74694-4
Date Built: March 1975
Date rebuilt:
Date retired:



BNSF3703 released from overhaul on 30-JUN-2006, BNSF working locomotive to SwRI now.

Equipped with Kim Hotstart DDHS (Diesel Driven Heating System) idle reduction system

UPY1378 overhauled in Fall 2006

Routed to SwRI in Feb. 2006 for Hug DPF mounting design concept meeting

Equipped with ZTR SmartStart Idle reduction system



CEP Phase 2 Program Schedule

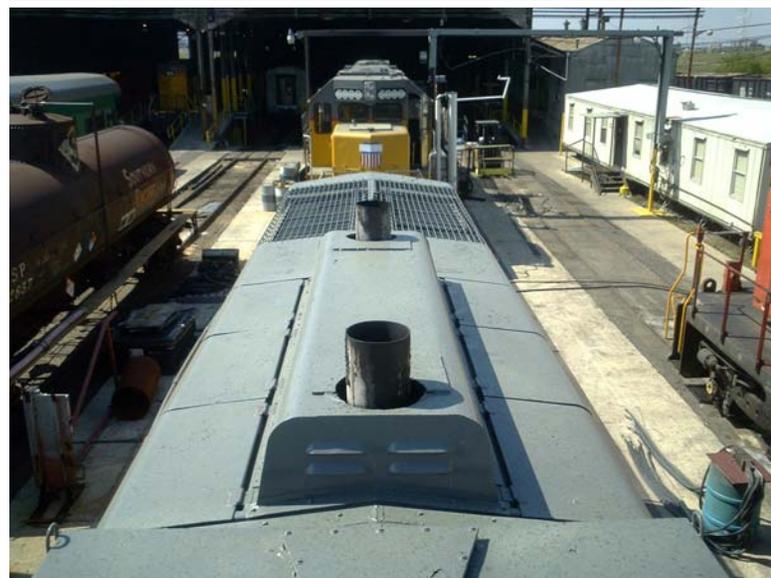
Task	Project	Q4 2005	Q1 2006	Q2 2006	Q3 2006	Q4 2006	G
		Oct	Jan	Apr	Jul	Oct	
1	CEP - Phase 2: Program Planning and Procure DPF						
1.1	Finalize CEP Phase 2 Plan & Contracting (SwRI + TTCI, TTCI + UP + BNSF)	■	■				
1.2	RRs identify demo locos - MP15DC (1 ea UP & BNSF)	■					
1.3	Identify loco structural designer for Hug filter system => Rail Sciences Inc.		■				
1.4	Lay out DPF system for demo locos		■				
1.5	Mounting design concept meeting at SwRI (UP, BNSF, Miratech, RSI, SwRI)		◆				
1.6	TTCI orders 2 complete DPF systems, with maintenance contract, and option for 2 additional units		■				
1.7	HUG manufacturers 2 DPF units => ready to ship			■	■		
1.8	Define datalogging requirements, equipment, integration with on-board systems (ARC & ZTR)			■	■		
1.9	BNSF schedule demo loco (BNSF3703) for rebuild		■				
1.10	UP rebuild demo locomotive(s) - complete (UPY1364 and UPY1378)	■					
1.11	BNSF rebuild demo locomotive (BNSF3703)		■	■	■		
1.12	HUG ships first unit via air freight				■		
1.13	HUG ships second unit via ground & sea freight				■		
1.14	Follow Oxycat and DPF market for additional locomotive applications	■	■	■	■	■	

DPF Installation & Test Plan

Task	Project	Q3 2006	Q4 2006	Q1 2007	Q2 2007	Q3 2007	Q4 2007
		Jul	Oct	Jan	Apr	Jul	Oct
2	Demo Locomotive #1 = UPY1378						
2.1	Work demo locomotive #1 to SwRI (UPY1378)	■					
2.2	Perform baseline triplicate EPA emissions tests before DPF installed	■					
2.3	Install DPF system on UPY1378 at SwRI	■					
2.4	Install data logger on UPY1378	■					
2.5	Perform triplicate EPA emissions tests on UYP1378 with DPF installed	■					
2.6	Follow UPY1378 with DPF in San Antonio revenue service (4 weeks)		■				
2.7	Inspect + Perform EPA emissions tests on UPY1378 with DPF installed @ 4-weeks		■				
2.8	Work UPY1378 from SwRI to California & monitor for 1 year		■				
2.9	Work UPY1378 from CA to SwRI for 1-year inspection + emissions test						■
2.10	Remove SwRI data logging instrumentation						■
2.11	Work UPY1378 from SwRI back to California for continued revenue service						■

DPF Installation Considerations

- * Hug DPF units are heavy (appx. 1150 lbs each)
- * Two filters required for 1,500 hp EMD 12-645E engine
- * Will be mounted above main alternator and engine blowers
- * Rail Sciences Inc. designing support frame structure
 - » needs to withstand severe shock and vibrations
 - » 5 g longitudinal design



Summary

- * First 2 locomotive DPF installations in North America will occur within the next 6 weeks
- * Generate hard data on:
 - » PM reduction efficiency
 - » Cost effectiveness
 - » Reliability / Maintenance Intervals
- * If initial 2 installations are successful;
 - » BNSF and UP have committed to 2 more locomotive installations

Questions ?

