Southwest
Research
Institute

APBF-DEC
EGR+DPF+SCR

Final Update on APBF-DEC EGR/DPF/SCR Demonstration Project at SwRI

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Objectives

- To Demonstrate The Low Emissions Performance of Advanced Diesels+Urea SCR+DPF (2 Different Systems)
- To Determine The Regulated And Unregulated Emissions W. &W/O Emission Controls
- To Examine The Emission Control System Durability over 6,000 hours
- To Sample Toxic Emissions For Analysis By Outside Lab
- To Evaluate Sensitivities of The Control System Performance To Fuel Variables

Emissions Goals: 2007 EPA HDE Standards

Participating Companies/Organizations

Automobile:
DaimlerChrysler
Ford
GM
Toyota

Government:
CARB/SCAQMD
DOE
EPA
NREL
ORNL

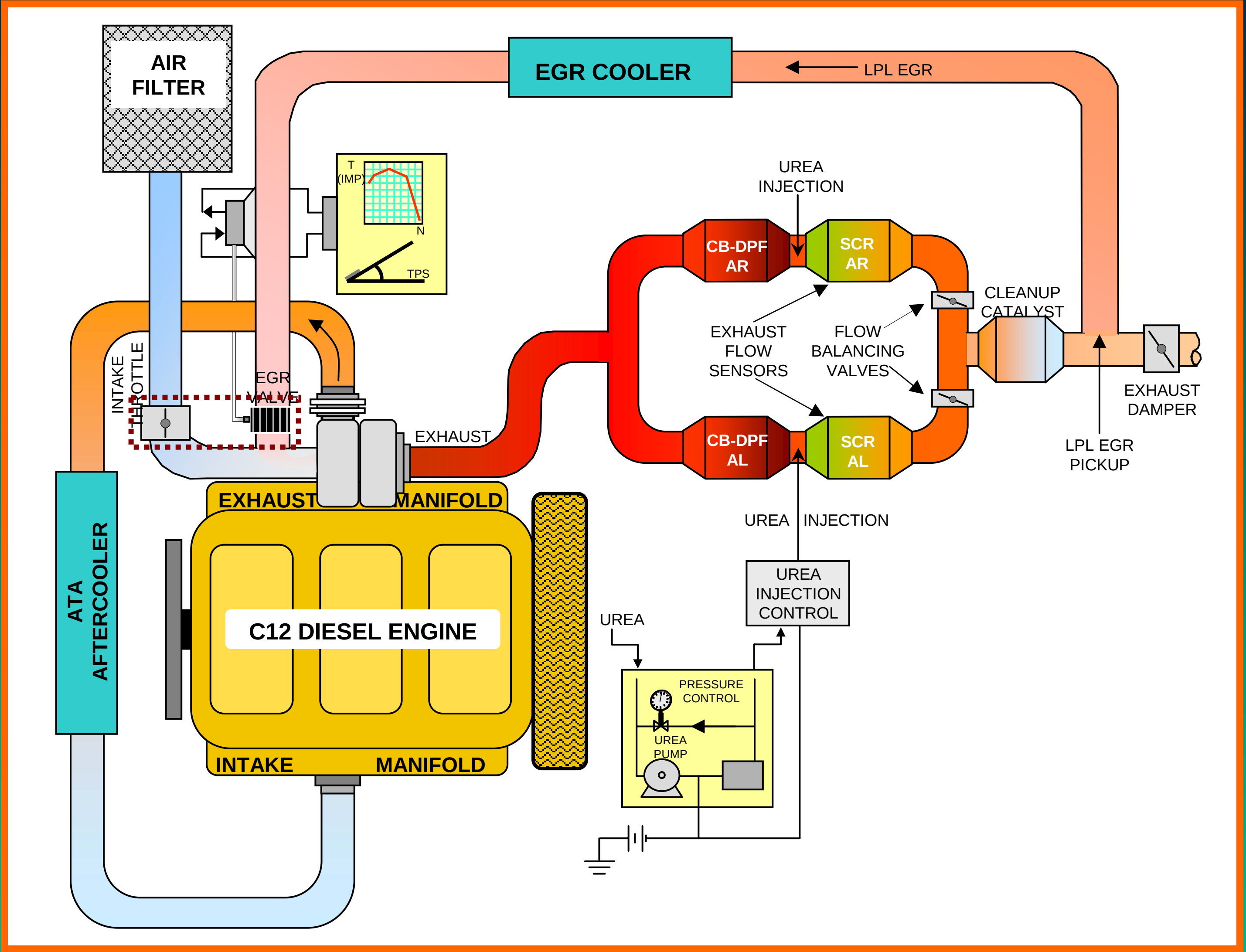
Emission Control:
Argillon
ArvinMeritor
Benteler
Clean Diesel Tech.
Corning
Delphi
Donaldson Co.
Engelhard
Johnson Matthey
MECA
NGK
Rhodia
Robert Bosch Corp.
STT Emtec AB
Tenneco Automotive
3M
Umicore

Energy/ Additives:
American Chemistry Council
API
BP
Castrol
Chevron Oronite
ChevronTexaco
Ciba
Conoco-Phillips
Crompton
Ergon
Ethyl
ExxonMobil
Infineum
Lubrizol
Marathon Ashland
Motiva
NPRA
Pennzoil-Quaker State
Shell Global Solutions
Valvoline

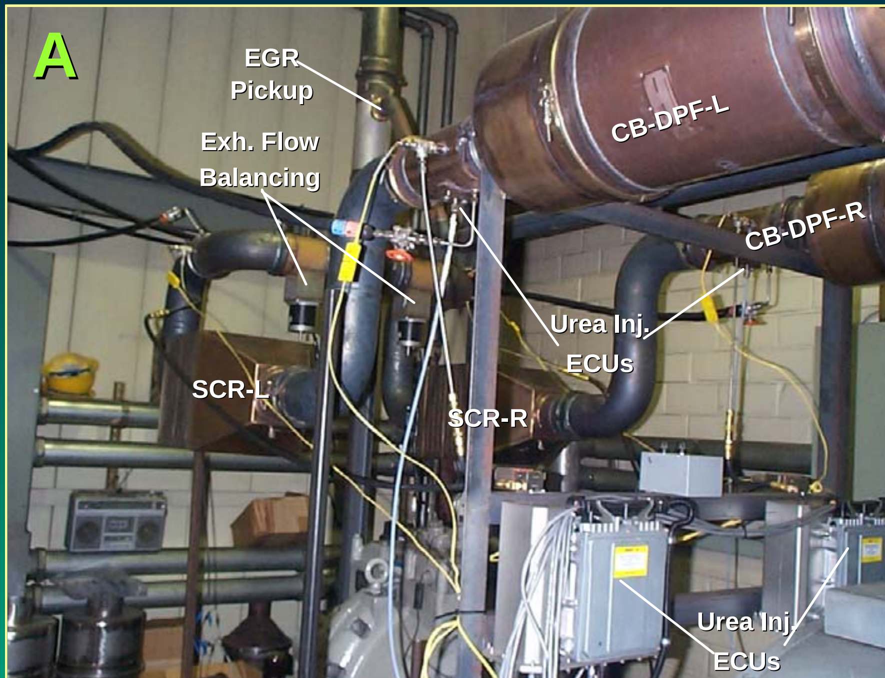
Engines:
Caterpillar
Cummins
Detroit Diesel
EMA
International Truck & Engine
John Deere
Mack Trucks

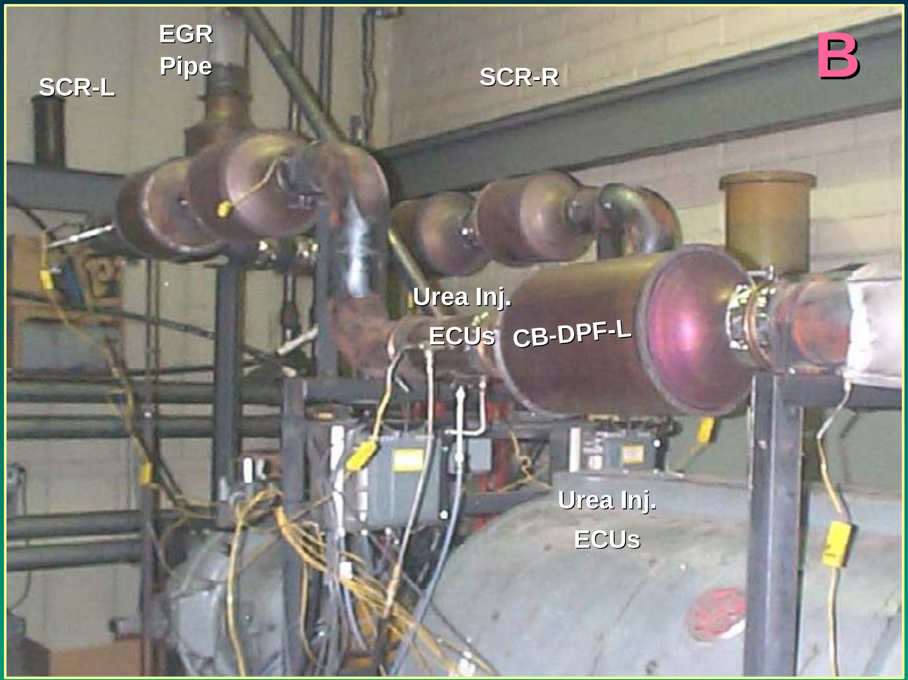
Technology:
Battelle

Test Setup - Schematic



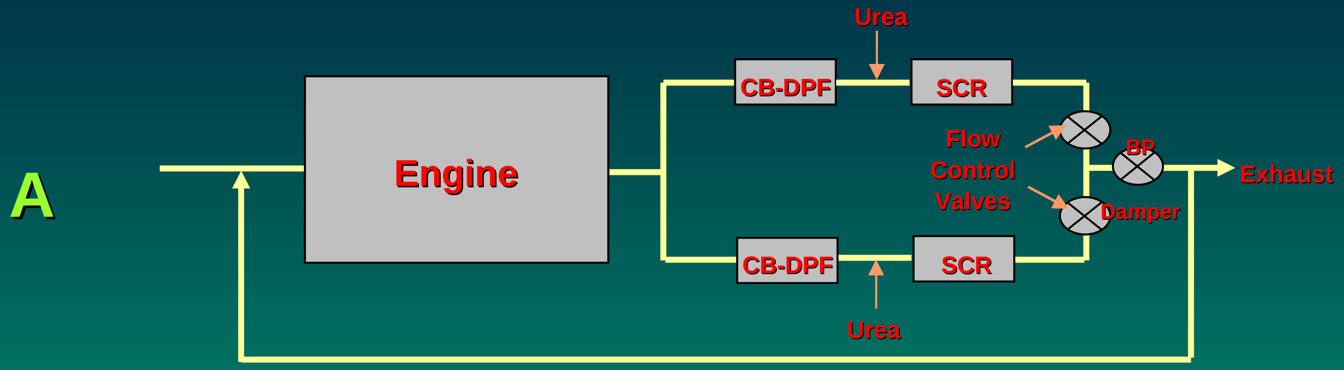
Aftertreatment Systems - *Systems A & B*

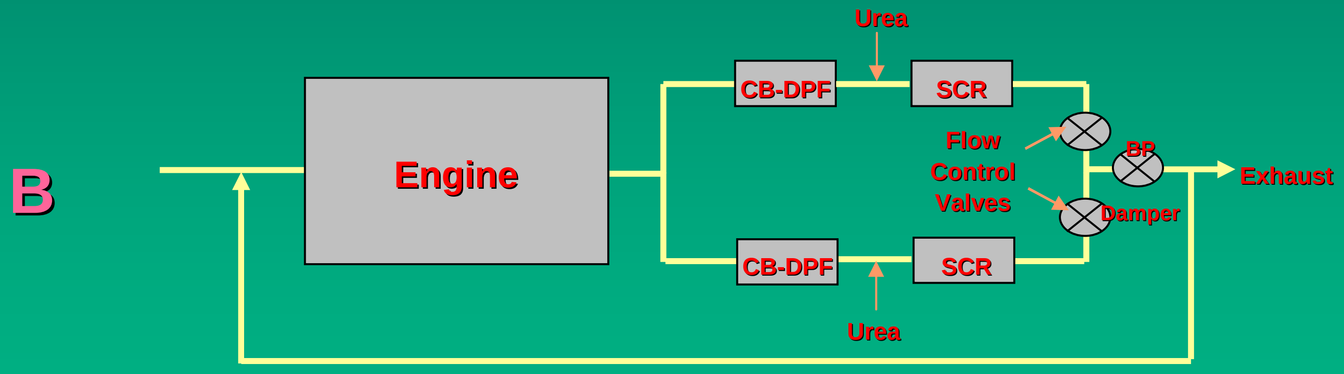




	No. of Units		Volume, L		Syst. Vol./Eng. Displ.		Remarks	
System	A	B	A	B	A	B	A	B
DPF	2	2	45.6	34.1	3.8	2.8	11.25X14”	10.5X12”
SCR	2	4	39.4	31.0	3.3	2.6	-	-
CUC	1	1	8.5	8.5	0.7	0.7	-	-
	-	-	93.5	73.5	7.8	6.1	-	-

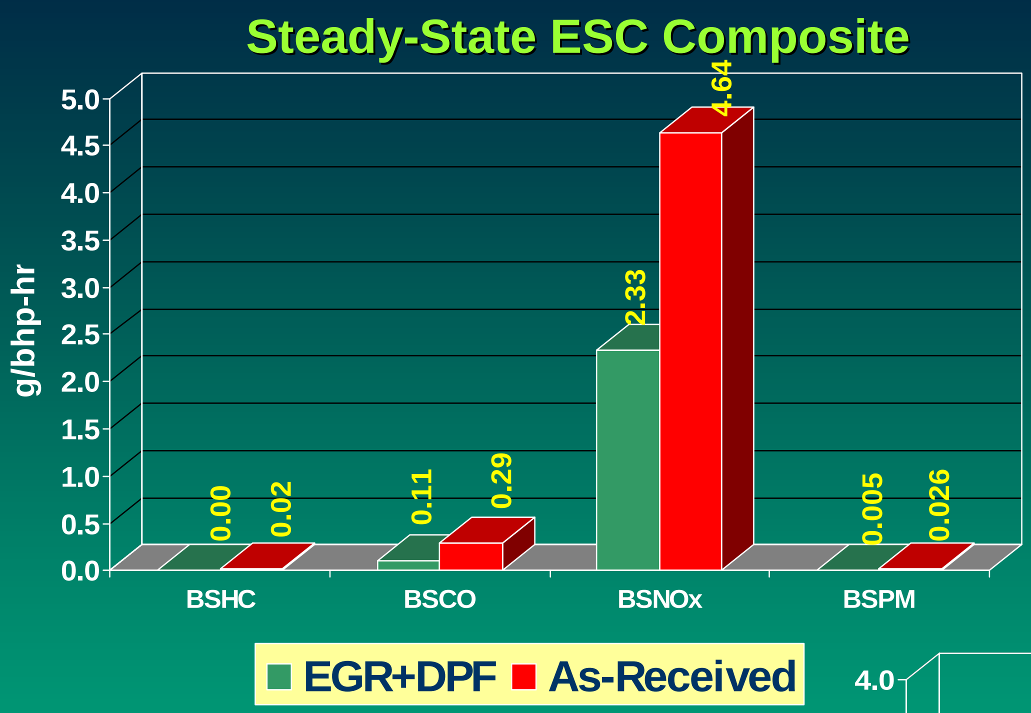
Technical Approach -- Phase 2 (6000-hour Evaluation)



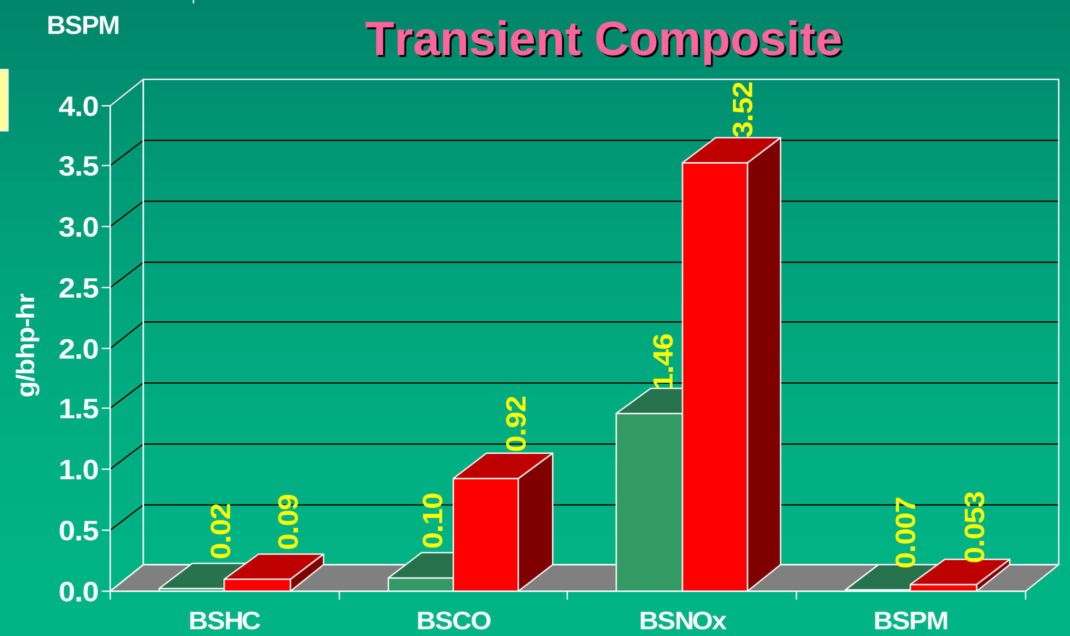


- Aging performed in parallel on durability engines
- Emission tests every 2000 hours using performance engine

Effect of LPL-EGR* and DPF - DECSE 8ppm Fuel



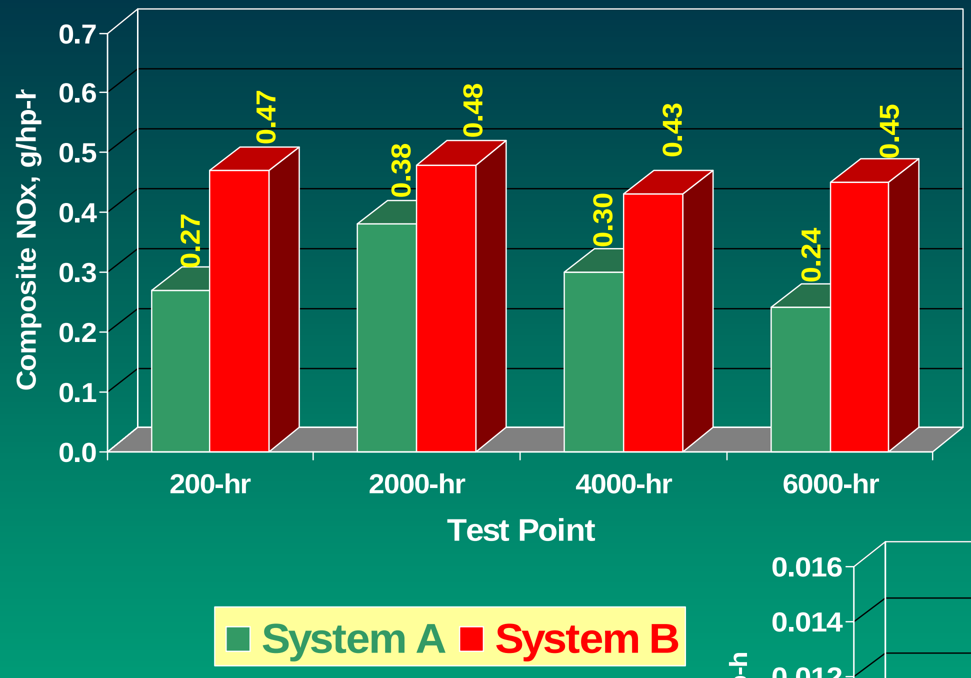
- > 50% NO_x Reduction with EGR
- HC, CO, PM nearly eliminated with catalyzed DPFs



* Low Pressure Loop EGR (includes DPF)

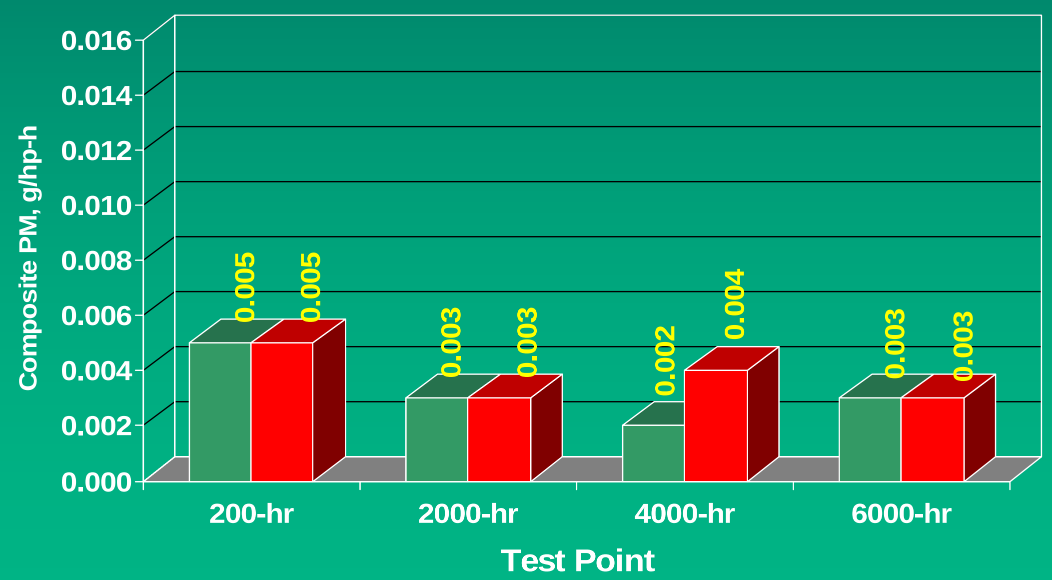
Transient Emissions--System A & B--DECSE 8 ppm Fuel - Composite

NO_x



- Transient NO_x stable for both systems
- Urea Injection problem on System A at 2000-hr point

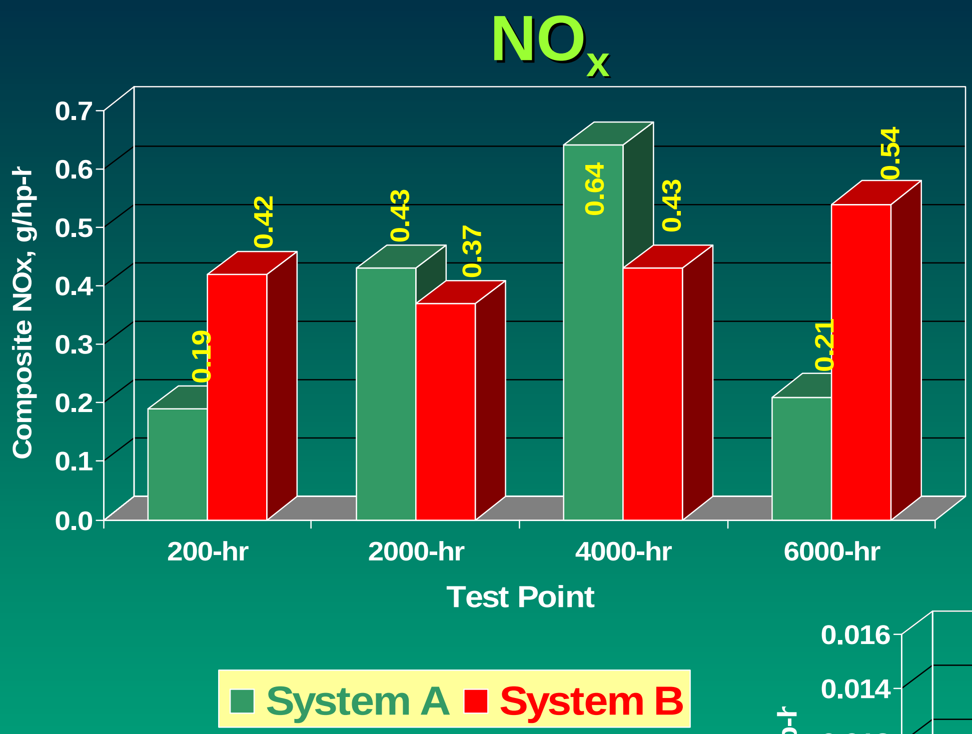
PM*



*Pre-2007 Type PM Measurement System

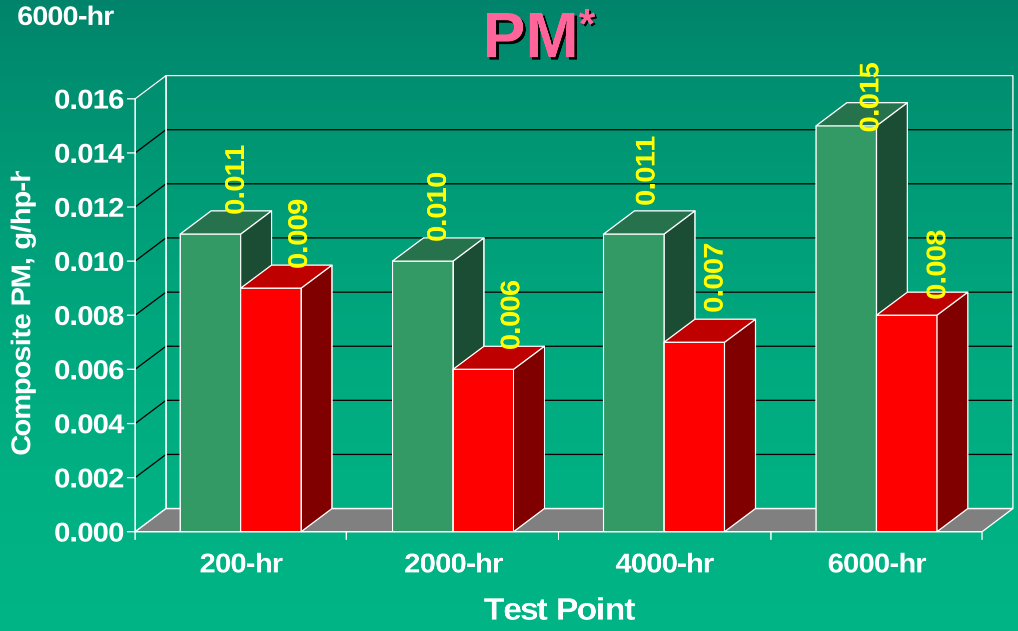
Steady-State Emissions--System A & B--DECSE 8 ppm Fuel – ESC

13-Mode Composite (Average 2 Cycles)



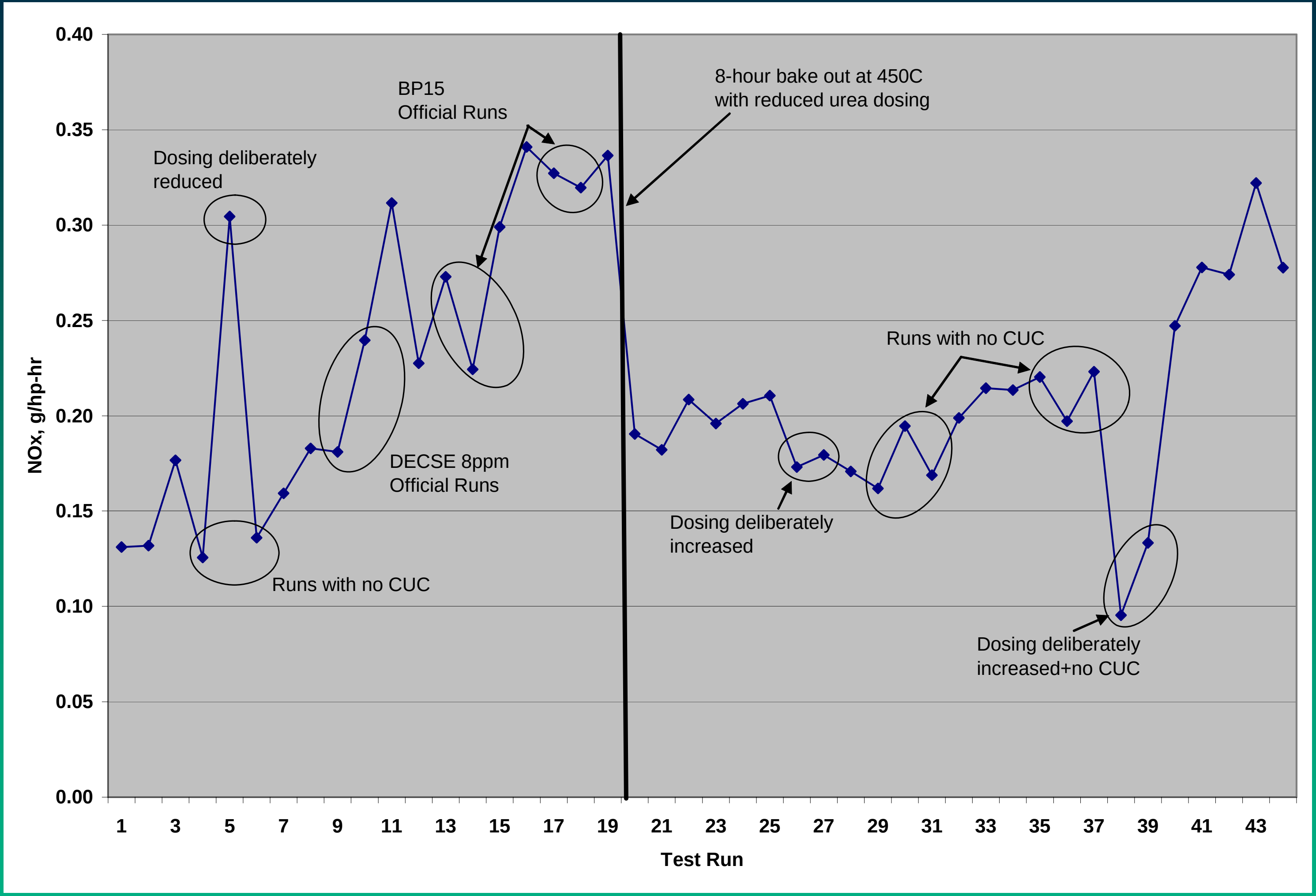
- System A NO_x apparent degradation through 4000 hours, performance restored at 6000 hours
- System B NO_x apparent degradation at 6000 hour point

Higher PM levels for ESC due to high temperatures at DPF inlet (sulfate production)



*Pre-2007 Type PM Measurement System

System A NO_x Diagnostics- ESC, 6000-Hr Point



- Gradual Loss of NO_x Conversion with each test (similar behavior seen at 2000-hr and 4000-hr test points)
- Recovery of conversion following high-NO_x burn-out

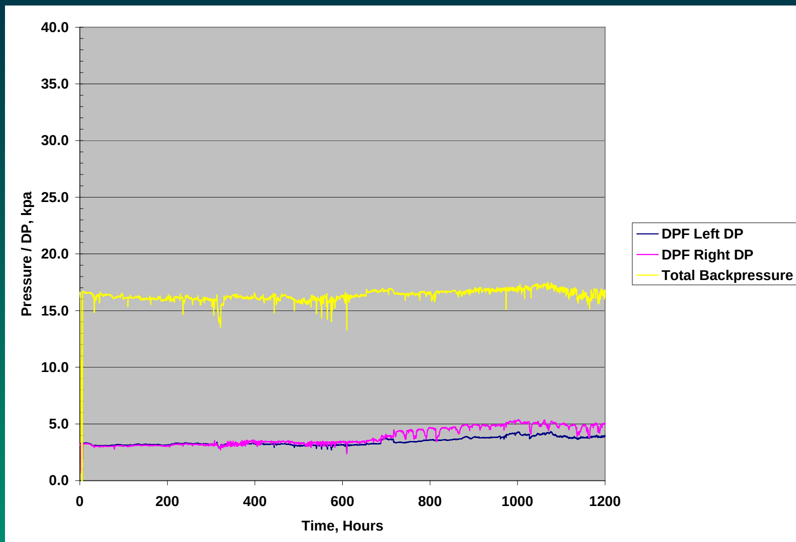
System A NO_x Diagnostics- Conclusions

- SCR Catalyst deactivation was real *(though apparently reversible)* and present on both legs equally at 2000-Hr and 4000-Hr points
- Catalyst deactivation was reversed at start of 6000-Hr point
- During test episodes, progressive loss of conversion from test to test observed following initial stable period
  - Overall NH_3-to-NO_x ratio is ~ 1.02 for ESC calibration
- Deactivation reversed at high temperature (> 400 C) with excess NO_x (NH_3:NO_x < 0.5)
  - Recovery during 4000-6000 durability during a period of high engine-out NO_x following an EGR cooler problem *(major hint)*
  - Recovery during deliberate experiment at 6000-Hr point
- <u>Temporary deactivation of SCR catalyst during periods of excess NH_3 dosing*</u>
- <u>No apparent thermal degradation of SCR catalysts after 6000 Hours</u>

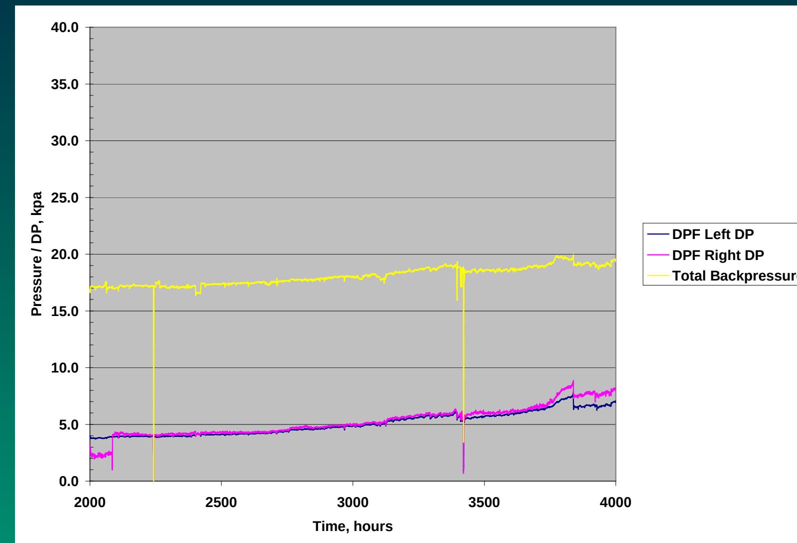
** Matches with contents of invited talk by Oliver Kroecher, Paul Scherrer Institute, CLEERS Symposium, Dearborn, MI, May 2005*

System B Backpressure - Durability Engine, ESC Mode 10

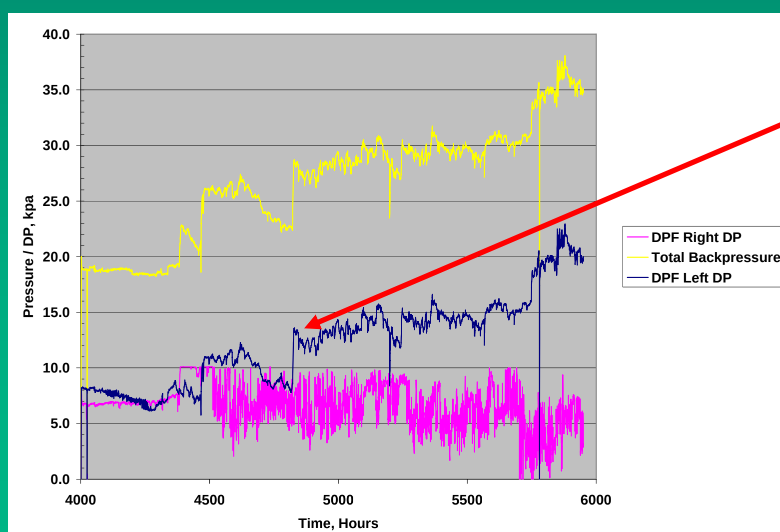
0 - 2000 Hours



2000 - 4000 Hours



4000 - 6000 Hours



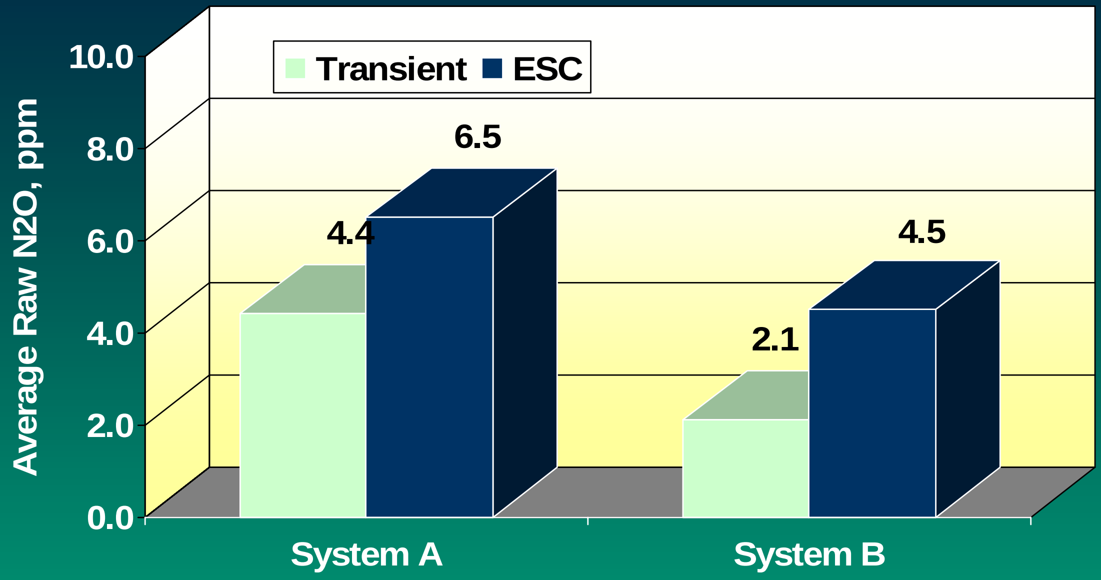
Loss of Passive Regeneration on Left-Side DPF

System B NO_x Diagnostics- Conclusions

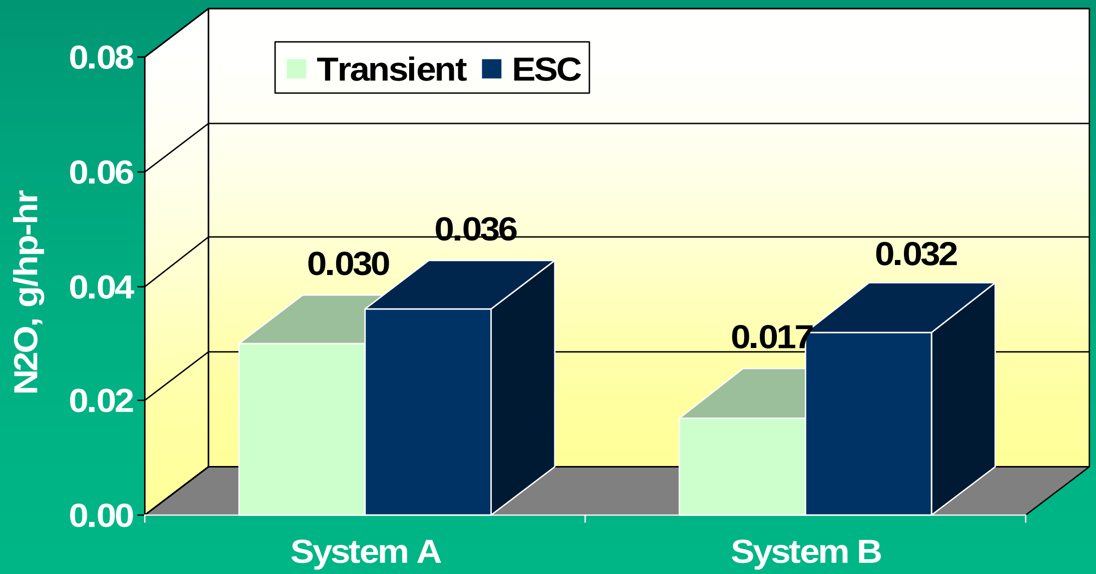
- Left-side DPF appears to have lost passive regeneration during aging
- Increased backpressure on left-side branch caused flow imbalance with more exhaust on right side
  - Right side → Not enough ammonia → lower conversion
  - Left side → Too much ammonia → Ammonia slip (to NO_x in CUC*)
  - Dual legs are a problem again
- Increased engine backpressure resulted in higher catalyst temperatures
  - SCR temperatures in Modes 3-7 up from 490 C to 520 C
  - Lower NO_x conversion due to higher temperatures (no effect on transient)
- Loss of conversion related to DPF problem
- No apparent thermal degradation of SCR catalysts after 6000 hours

* CUC = Clean-up Catalyst

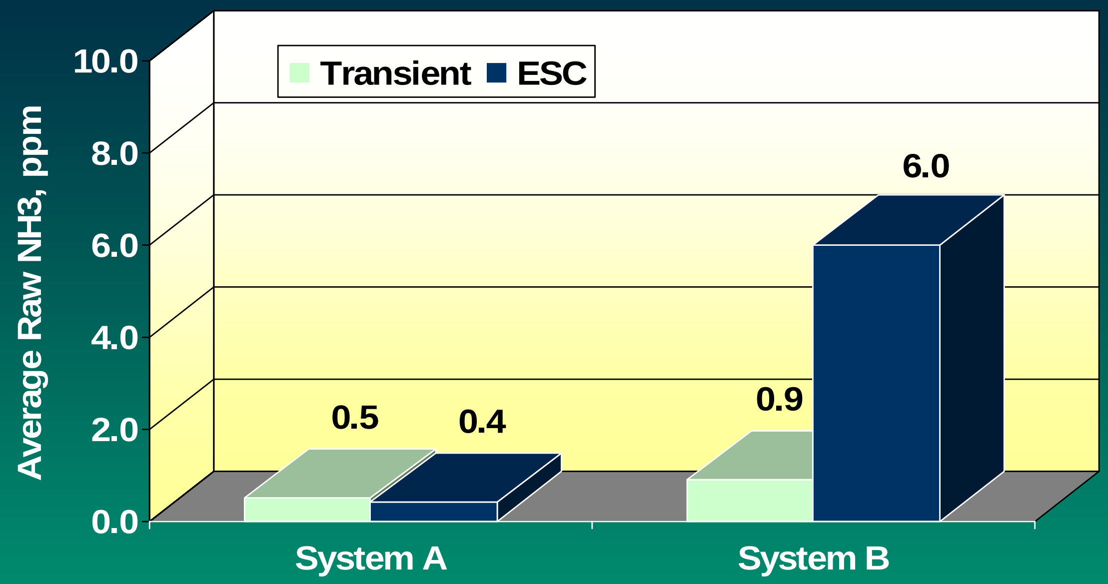
Nitrous oxide--*Steady-State & Transient --At the 6000-hour Point*



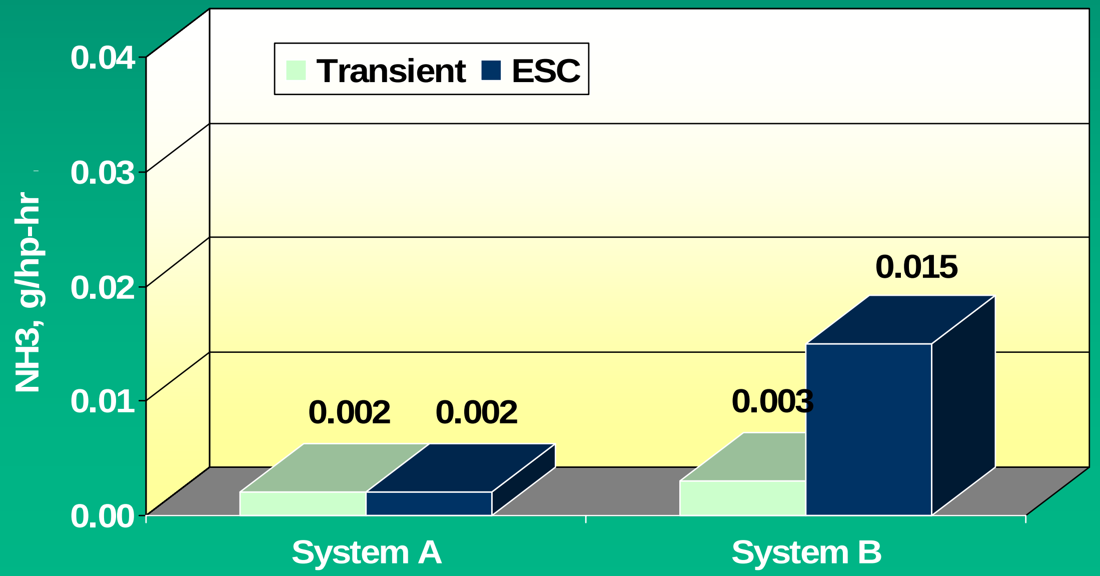
Tailpipe N_2O levels are roughly 10% of tailpipe NO_x level



Ammonia Slip--*Steady-State & Transient --At the 6000-hour Point*



NH_3 levels are roughly equivalent to DPF-out particulate levels



Fuel and Urea Consumption

- Transient BSFC increase of roughly 1-2% vs Base Engine*
- ESC BSFC increase of roughly 4-5% vs Base Engine*
  - Most, if not all of the increase is due to EGR+DPF
- Urea Consumption as percentage of fuel consumption
  - System A ~ 1.8% transient and ~ 3.8% ESC (all +/- 0.2%)
  - System B ~ 1.4% transient and ~ 3.2% ESC (all +/- 0.2%)

* Base Engine NO_x = 3.5 g/hp-hr

Summary/Conclusions

- Program is Complete
- Both Systems have completed the 6000-hour performance evaluation
- Systems A and B are showing some performance differences mostly based on their size relative to that of the engine displacement.
- After 6000 hours SCR catalyst performance appears to be holding in general.
    - Short-term, reversible deactivation of System A catalysts observed
- After 6000 hours DPF performance is still good.
    - Problem with passive regeneration on one of System B DPFs
- It appears that this combination of technologies has the potential to meet the 2010 emissions limits
- Closed Loop Controls are essential to maintain 2010 emission levels