APBF-DEC Lubricants Project

Presented by:

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APBF-DEC Participants

Government

- DOE
- NREL
- ORNL
- EPA
- CARB
- SCAQMD

Automobile

- Ford
- GM
- DaimlerChrysler
- Toyota

Technology

- Battelle

Engines

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

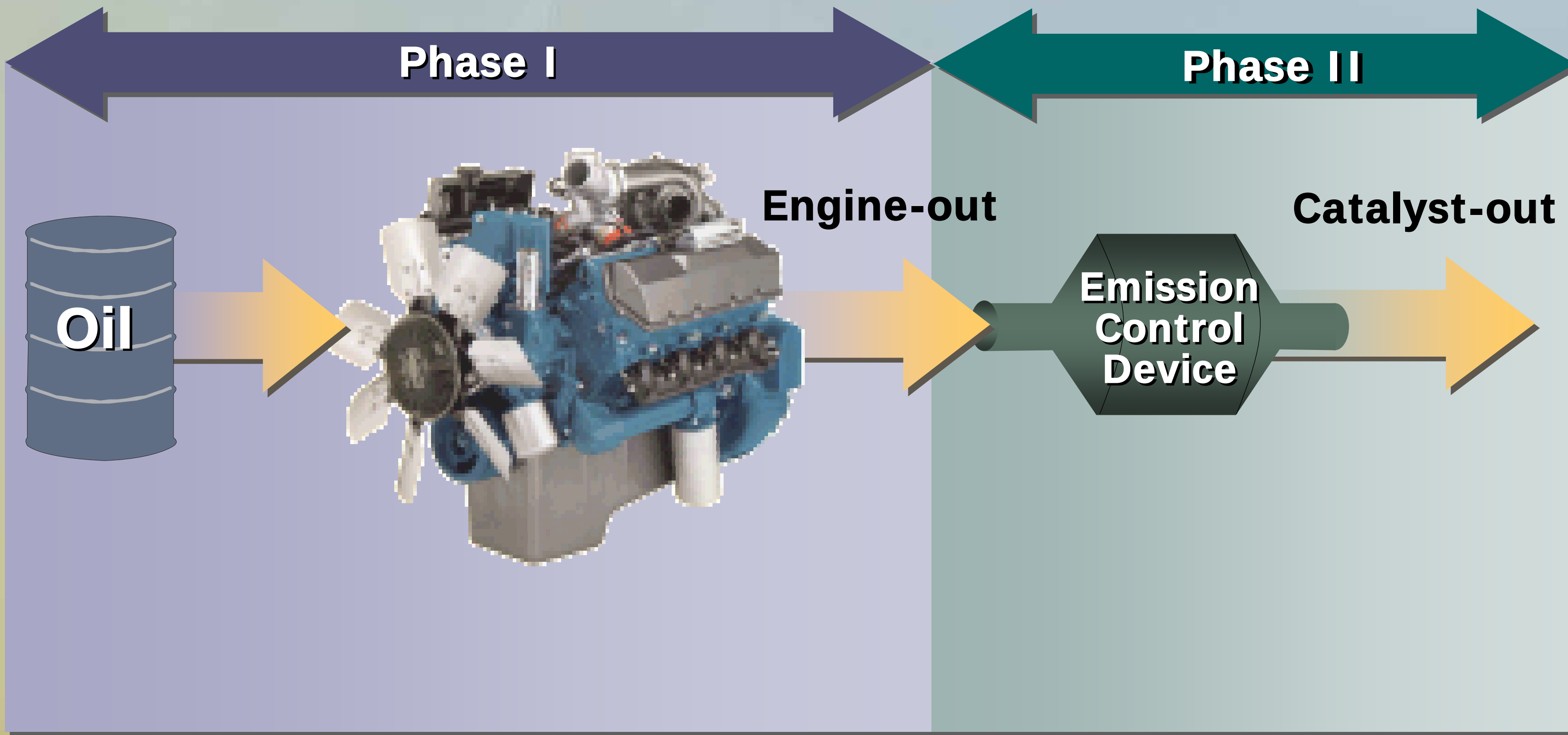
Emission Control

- MECA • Johnson Matthey
- Delphi • 3M • Engelhard
- Siemens • Benteler • ArvinMeritor
- Clean Diesel Tech. • Corning
- Donaldson Co. • OMG
- NGK • Rhodia • Argillon
- Tenneco Automotive • Robert Bosch

Energy / Additives

- API • American Chemistry Council
- BP • Castrol • ChevronOronite
- Chevron • Ciba • Ergon
- Afton • ExxonMobil • Infineum
- Lubrizol • Marathon Ashland
- Motiva • NPRA
- Pennzoil-Quaker State
- Shell Global Solutions • Valvoline
- ConocoPhillips • Crompton

Two-Phase Approach



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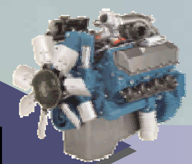
Objectives



Phase I

Determine the impact of lubricant properties and composition on engine-out/catalyst-in emissions

- Part 1: Characterize effects of lubricant properties on engine out emissions
- Part 2: Develop methods to accelerate exposures of emission control systems (ECS) to lubricant-derived emissions

Phase II

Determine if lubricant formulation impacts the performance and durability of diesel engine ECS

Desired Outcome

- Determine which (if any) lube derived emission components are detrimental to ECS performance and durability

The results will provide:

Guidelines for lubricant formulation	Design guidelines
• Basestock selection • Additive chemistry	• Engine manufacturers • ECS suppliers

Phase 1

Lubricant Selection — Phase 1Base Oils

- Group I: Valero (Paulsboro)
  - 4800-5600-ppm S, 75% saturates
- Group II: Excel (Lake Charles)
  - <20-ppm S, >99% saturates
- Group III: Motiva (Port Arthur, TX)
  - <5-ppm S, >99% saturates
- Group IV: BP
  - PAO (poly-alpha olefin, synthetic)
  - 0 sulfur
  - 5% ester for additive solubility (from Uniqema)

Lubricant Selection Additive Packages

- Five suppliers (Ciba, Chevron, Ethyl, Infineum, and Lubrizol) provided specifications on 26 candidate additive packages
- Range of constituents (in Group II base oil)

Ash	0 – 1.85%
Sulfur	0 – 6590-ppm
Calcium	0 – 4770-ppm
Zinc	0 – 1900-ppm
Phosphorus	0 – 1700-ppm
Magnesium	0 – 1700-ppm
Boron	0 – 1235-ppm

- Supplier and source of constituents not specified

Test Laboratory – Phase I

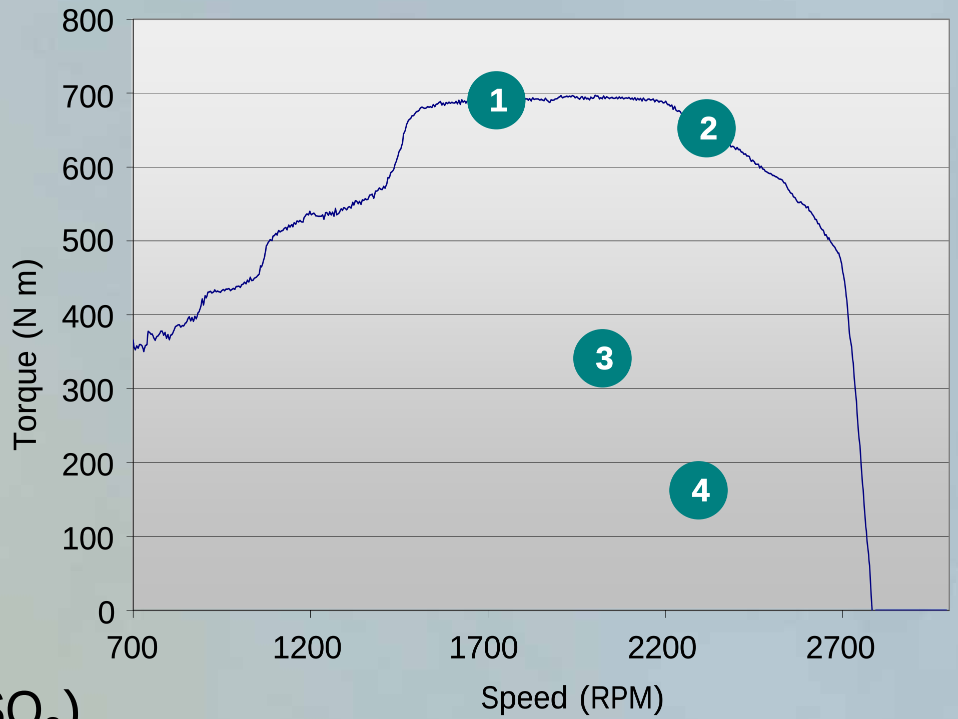
- Subcontractor: Automotive Testing Laboratories, (East Liberty, OH)

Test Engine

1999 International T444E

- 7.3L OHV V-8
- Direct injection, turbocharged w/ wastegate
- HEUI fuel system
- 215 hp at 2400 rpm
- 540 ft-lbs torque at 1500 rpm
- Exhaust gas recirculation (retrofit)
- Closed crankcase ventilation with filter
- Lube system capacity: 18 quarts

Test Modes and Emissions Measurements



Four Mode Steady-State (OICA)

- Mode 1: Rated Condition
- Mode 2: High Torque
- Mode 3: Road Load
- Mode 4: Low Torque

Emissions Measurements

- Gases (HC, CO, CO_2, NO_x, SO_2)
- PM – three sampling trains
  - TPM, SOF, SO_4
  - Metals
  - PAHs

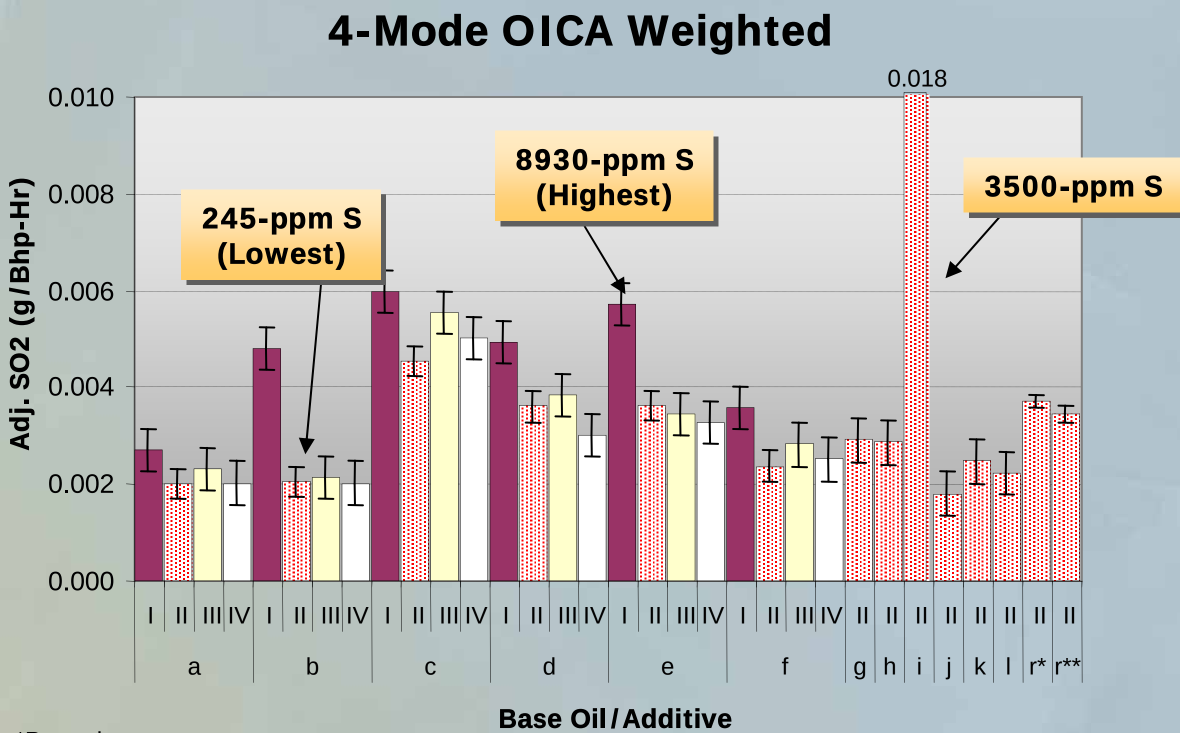
Data Analysis Questions #1 and #2

1. Are there significant differences in engine-out emissions that can be attributed to oil properties?

2. If so, how much of an impact is due to properties of the additive package? ... base oil?

SO_2 Emissions – Significant Additive and Base Oil Effects

- Additive packages c and i produced highest SO_2 emissions
- Significant base oil effect – Group 1 highest
- Magnitude of the effects do not directly correlate with sulfur content of oil

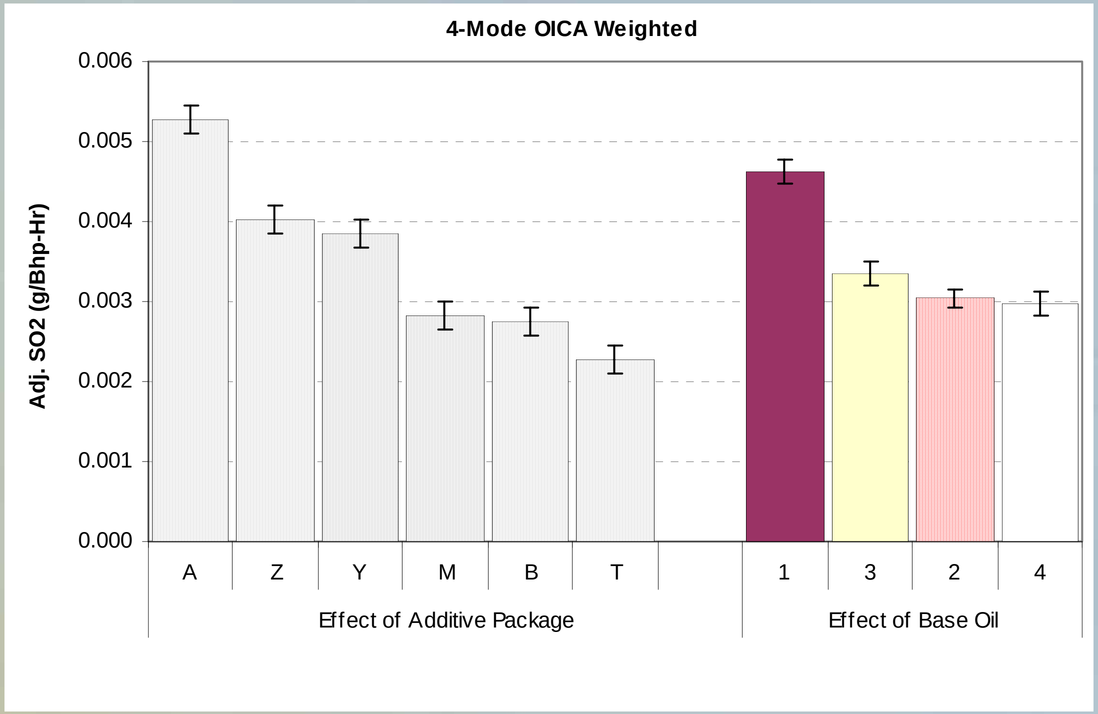


*Pre-aging.
**Post-aging.

Also… Significant Effects of Additive Packages and Base Oils on SO_2

- Many significant differences among the 6 additive packages tested in all four base oils
- Significant base oil effect – Group 1 highest
- No significant interactions between additive packages and base oils

Main Effects of Additives and Base Oils



Data Analysis Question #3

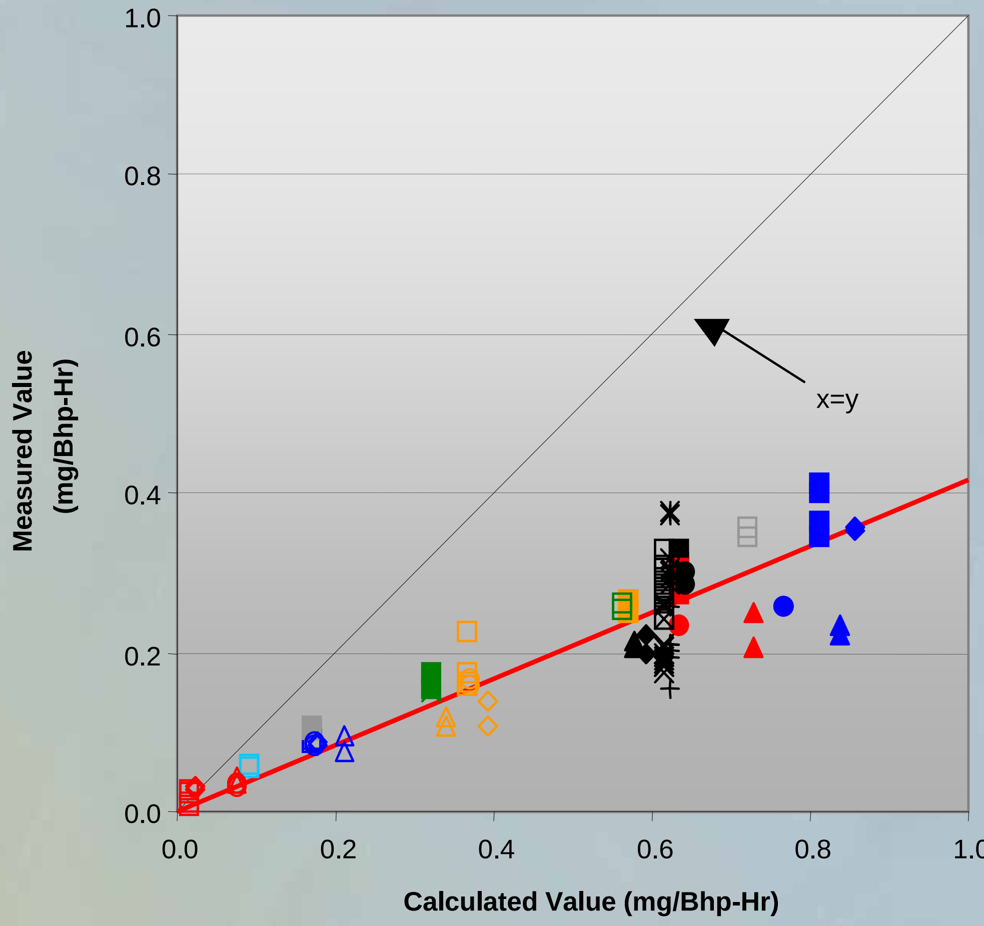
3 Which emissions species can be directly predicted from the properties of the oil and fuel?

Mass Balance

- Emissions from fuel and oil consumptions and wear metals
- Recovery rates obtained by comparing measured emissions with calculated values based on fuel and oil properties

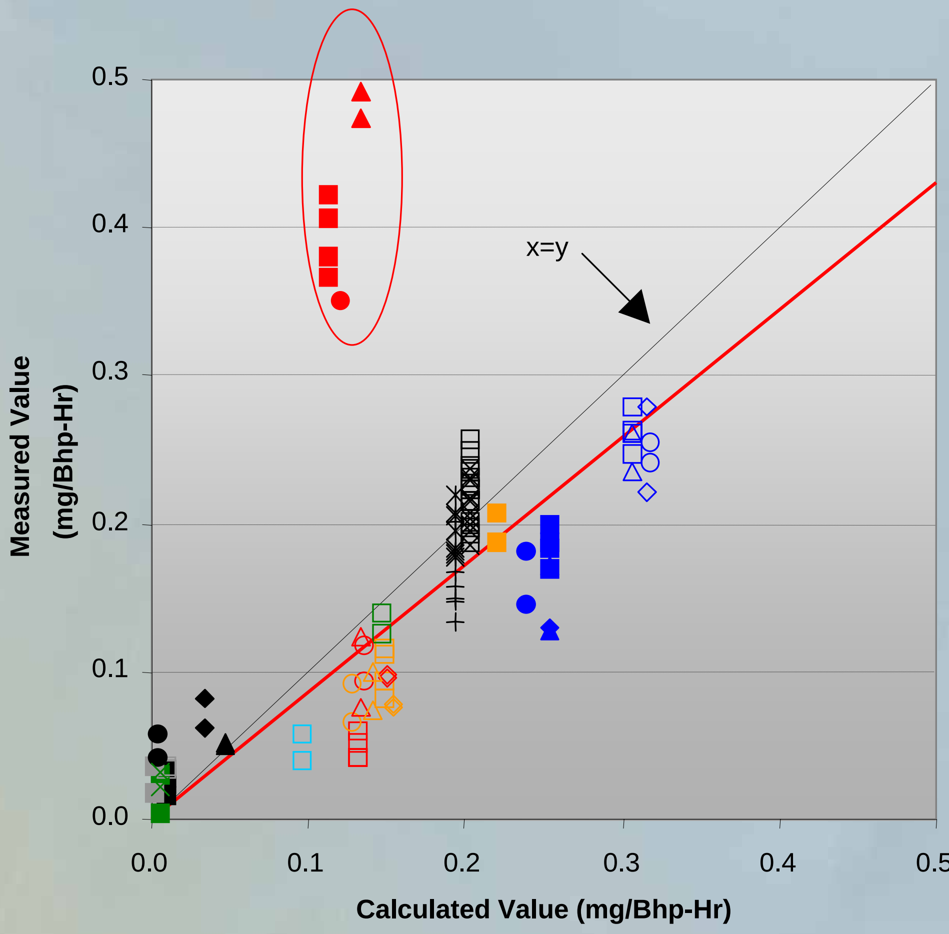
Ca Mass Balance

- Ca emissions directly correlated with concentration in oil
- No apparent composition effects
- 42% recovery rate



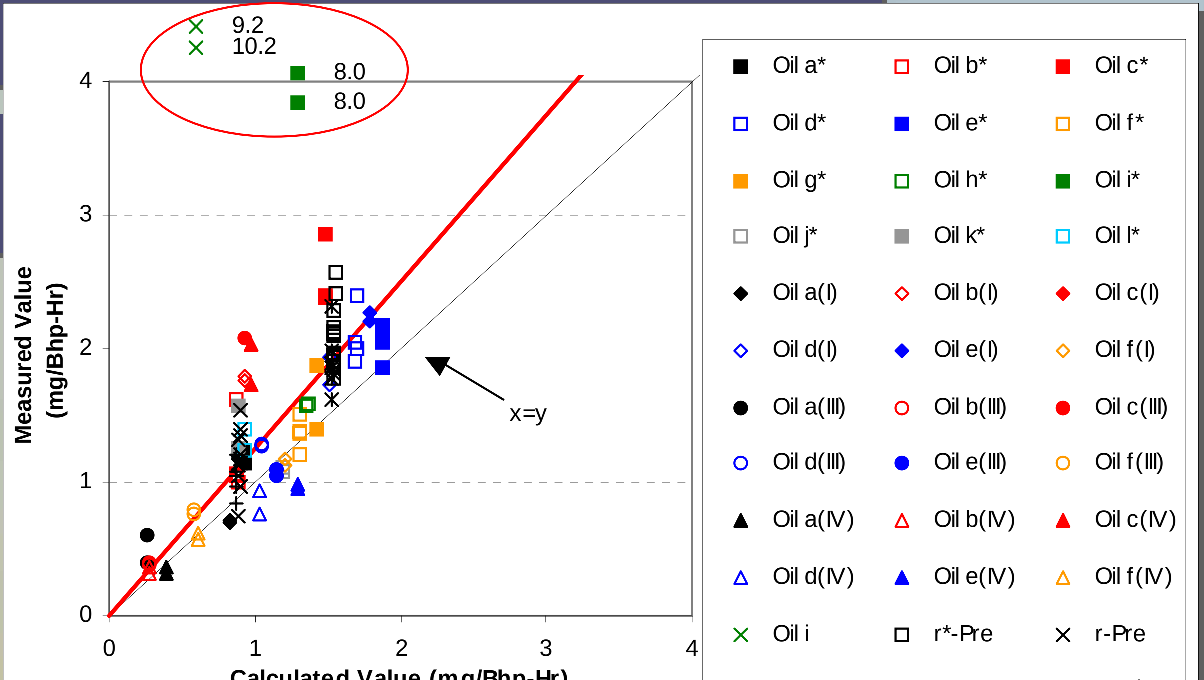
P Mass Balance

- P emissions directly correlated with concentration in oil
- Oil c2, c3 and c4 deviate significantly
- 86% recovery rate (excl. Oils c2, c3 and c4)



Sulfur Mass Balance (continued)

- S emissions directly correlated with concentration in oil
- Oil i significantly deviates
- 125% recovery rate (excl. Oils i)



*Tested using fuel with 4.54 ppm sulfur.

Note: Oil c1 excluded.

Phase I Conclusions

- Lubricant formulation has modest effects on regulated emissions
  - $\pm$10% for CO and NO_x, $\pm$20% for PM, and $\pm$30% for HC
- Sulfur content in the oil has significant effects on sulfur emissions.
- However, oil formulation (beyond oil sulfur content) can have a significant impact on SO_2 emissions (e.g. oils c and i)
- Metals (S, P, Zn, Ca) emissions correlate with concentration in oil

Phase 2

Test Laboratory – Phase 2

- Subcontractor: Analytical Engineering, Inc. (AEI) Columbus, Indiana

Test Hardware – Phase 2

- 2002 Cummins ISB – 300 hp @ 2500 rpm
- 5.9L, inline 6 cylinder
- Cooled-EGR
- Single NOx adsorber (7L)
- In-pipe regeneration fueling

Test Protocol

- 400-hour test
- Evaluations at 100-hour intervals
  - Focus on NO_x reduction efficiency
- Oil consumption measurement
- New LNT for each test
- Oil change at 200-hours
- DEC base fuel (0.6-ppm S/15-ppm S)
- Post-analysis of catalyst by XRF

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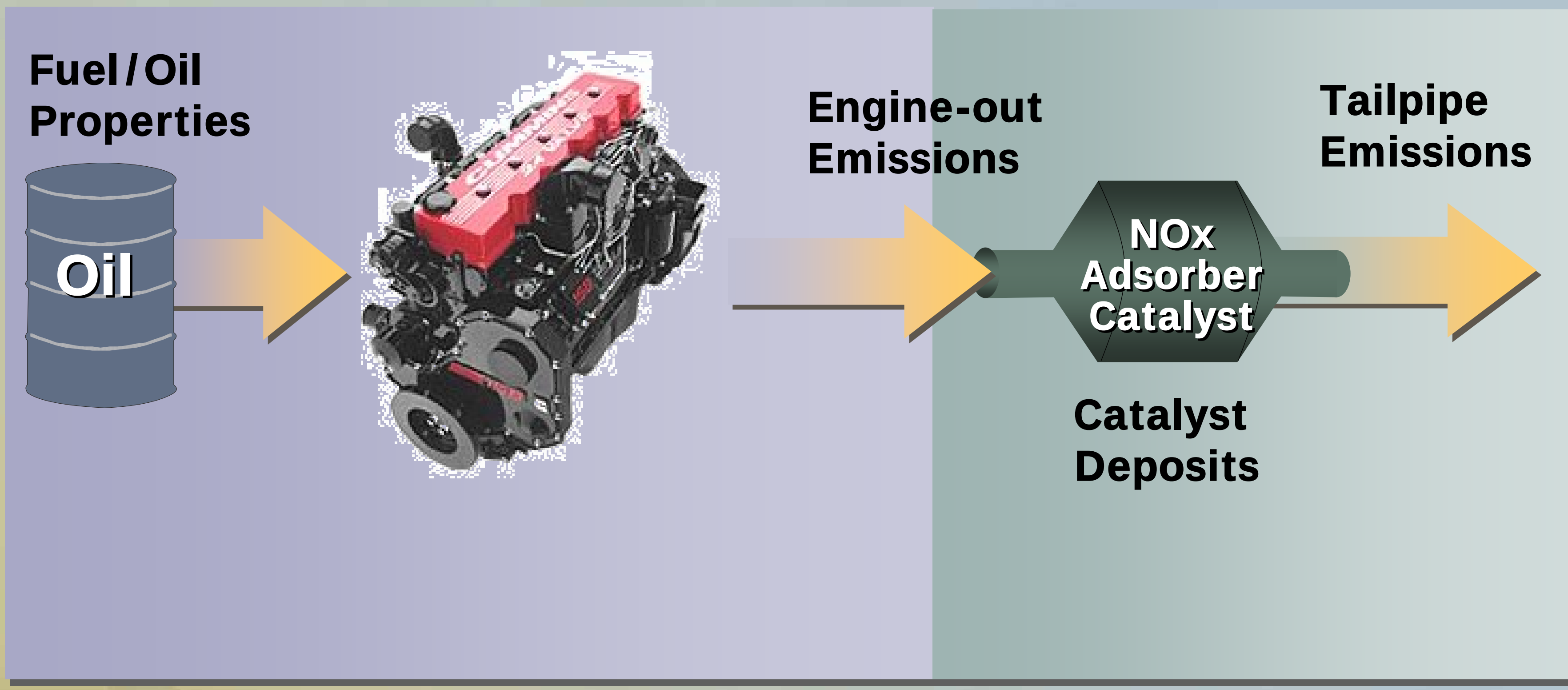
Operating Modes

Mode	Engine Speed (RPM)	Load (FT*Lbs)	Average Catalyst Mid Temp. ºF (ºC)	Space Velocity (1/hr)
1	1650	140	650 (343)	30,000
2	2100	175	650 (343)	70,000
3	1400	160	750 (399)	32,000
4	1900	225	750 (399)	63,000
5	1200	275	850 (454)	33,000
6	1700	350	850 (454)	62,000

Phase 2 Analysis Approach

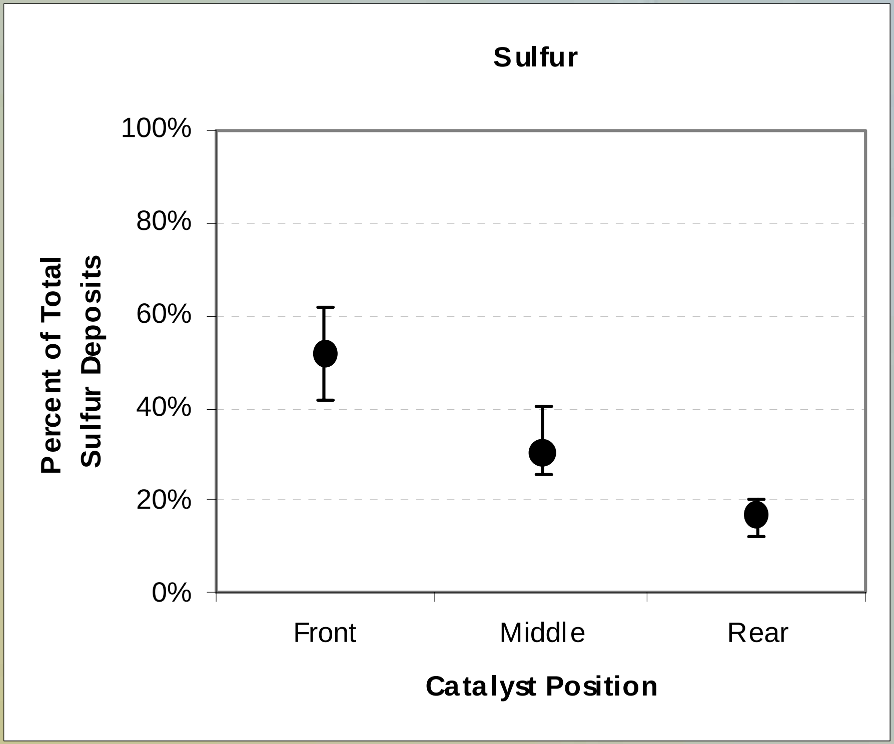


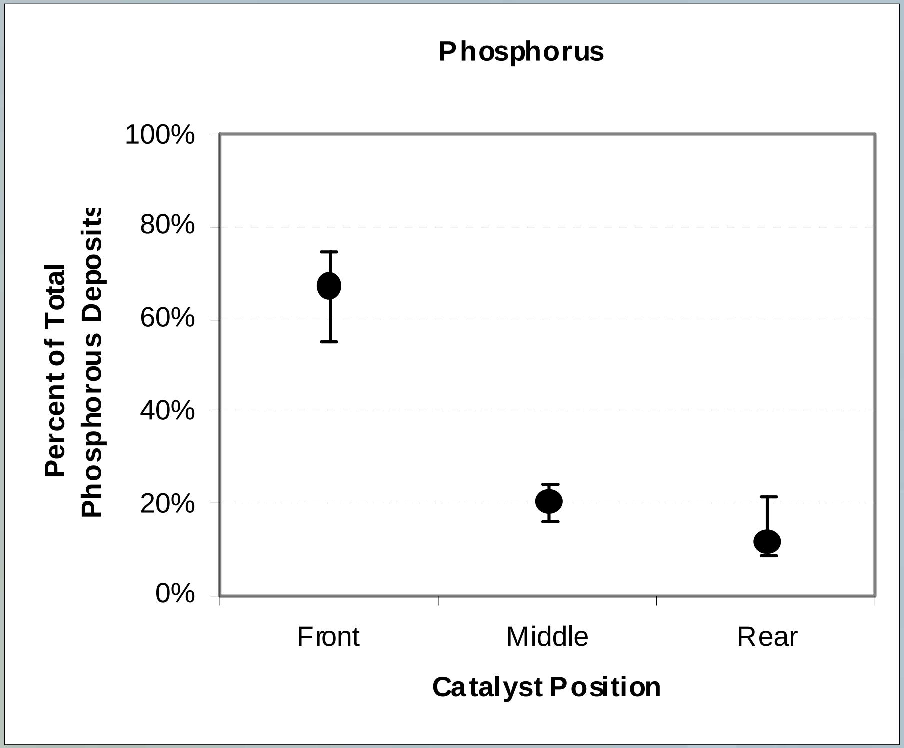
Test Matrix

Properties of Test Oils

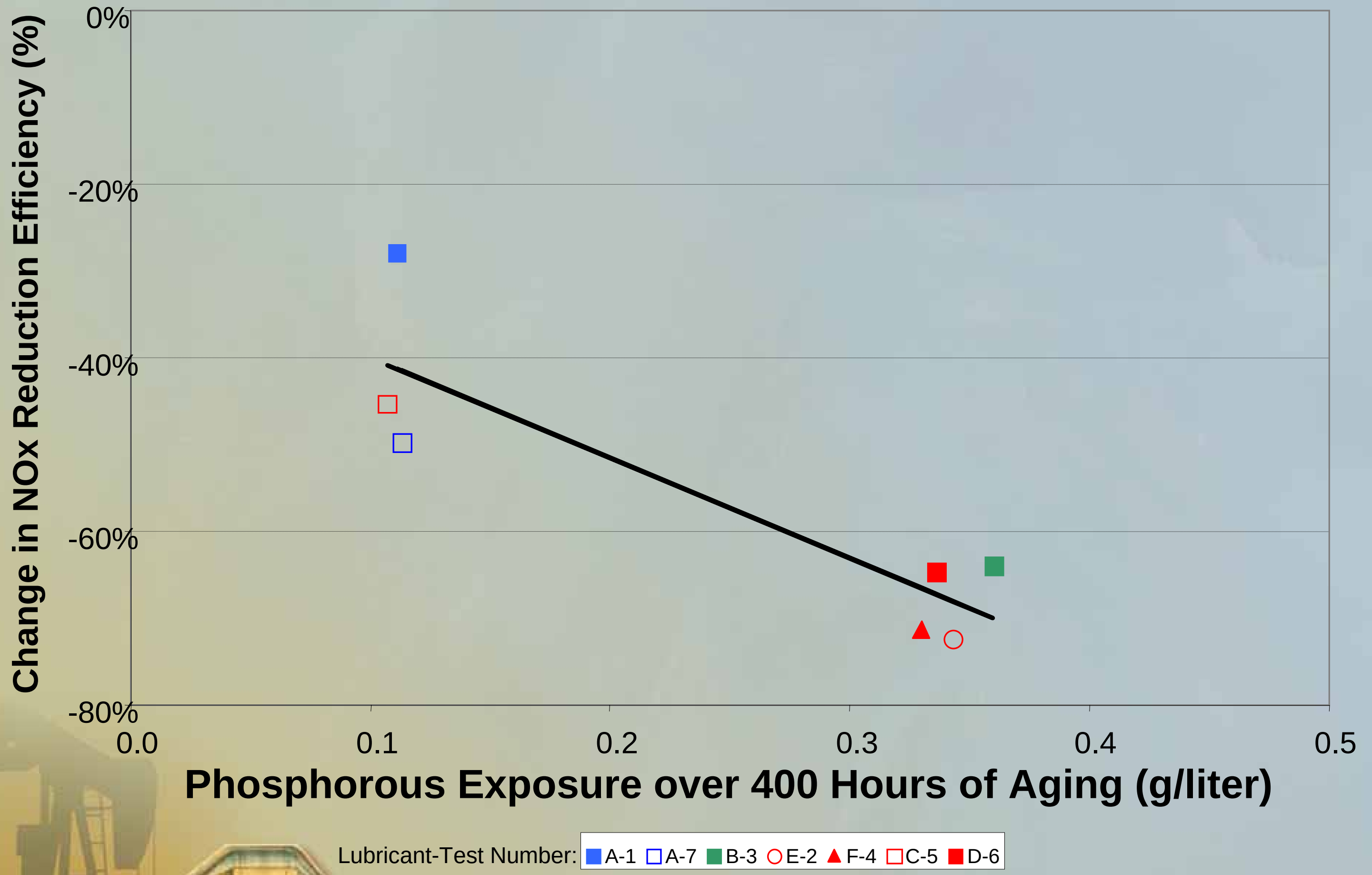
Test Number	Ash* (%)	S* (ppm)	Ca (ppm)	P (ppm)	Zn (ppm)	N* (ppm)	TBN (mg KOH/g)	Viscosity @100ºC (cSt)	Viscosity @40ºC (cSt)	Soot (%)
1	0.775	1695	1853	427	471	1128	6.99	14.9	111.3	0.07
2	1.522	2928	3258	1210	1320	1329	12.34	15.0	111.9	0.06
3	1.131	3980	2050	1430	1590	1477	7.3	15.0	111.9	0.06
4	1.316	4195	3160	1340	1520	1314	10.6	15.0	112.5	0.12
5	1.310	2228	3241	419	475	1368	9.6	14.6	107.7	0.12
6	1.497	4197	3518	1280	1480	1315	10.2	14.7	109.1	0.11
7	0.775	1695	2065	451	505	1128	6.7	14.9	110.9	0.08
8	0.775	1695	2329	483	546	1128	8.7	14.9	110.9	0.11

Catalyst Deposit Profile

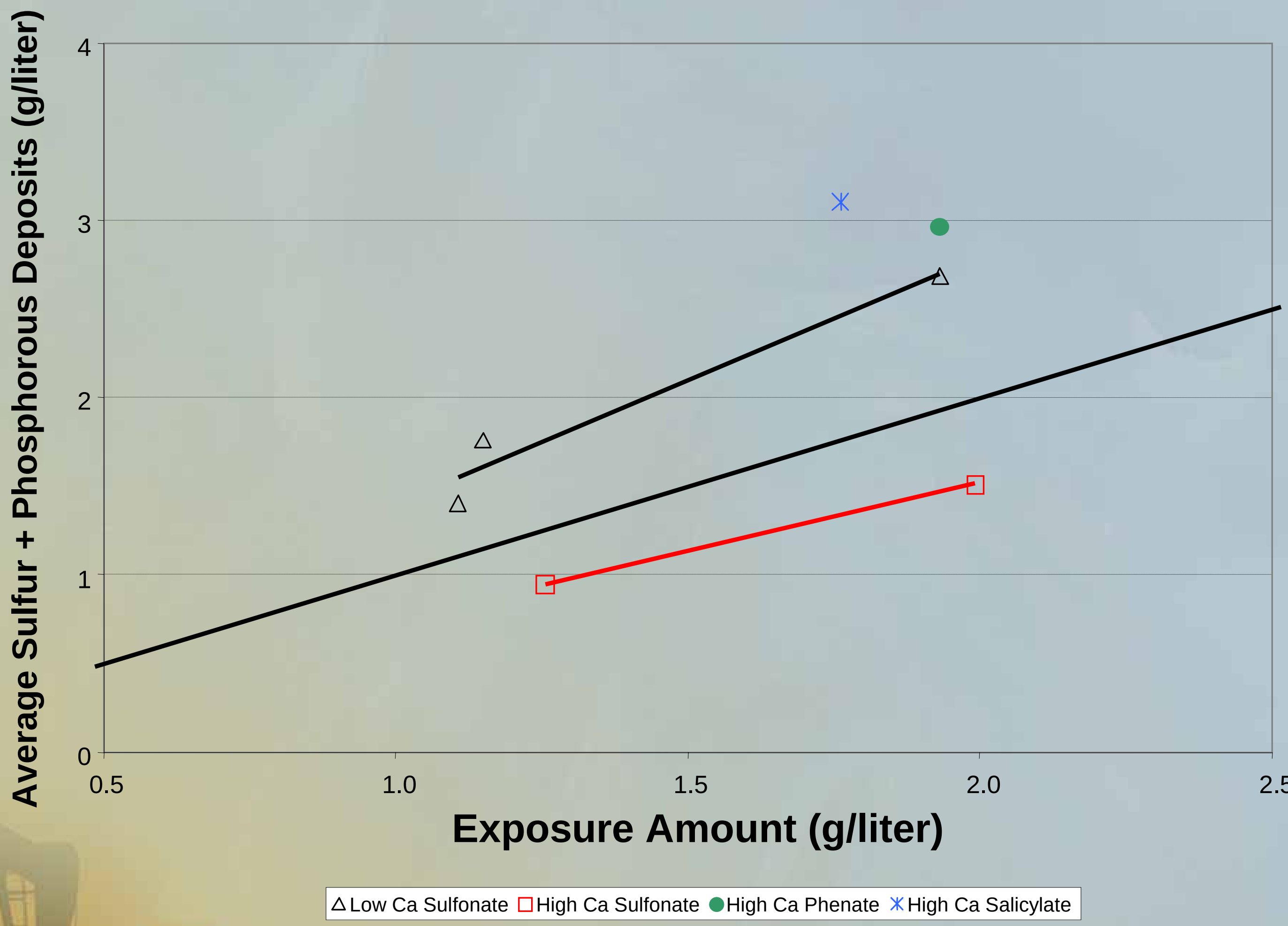




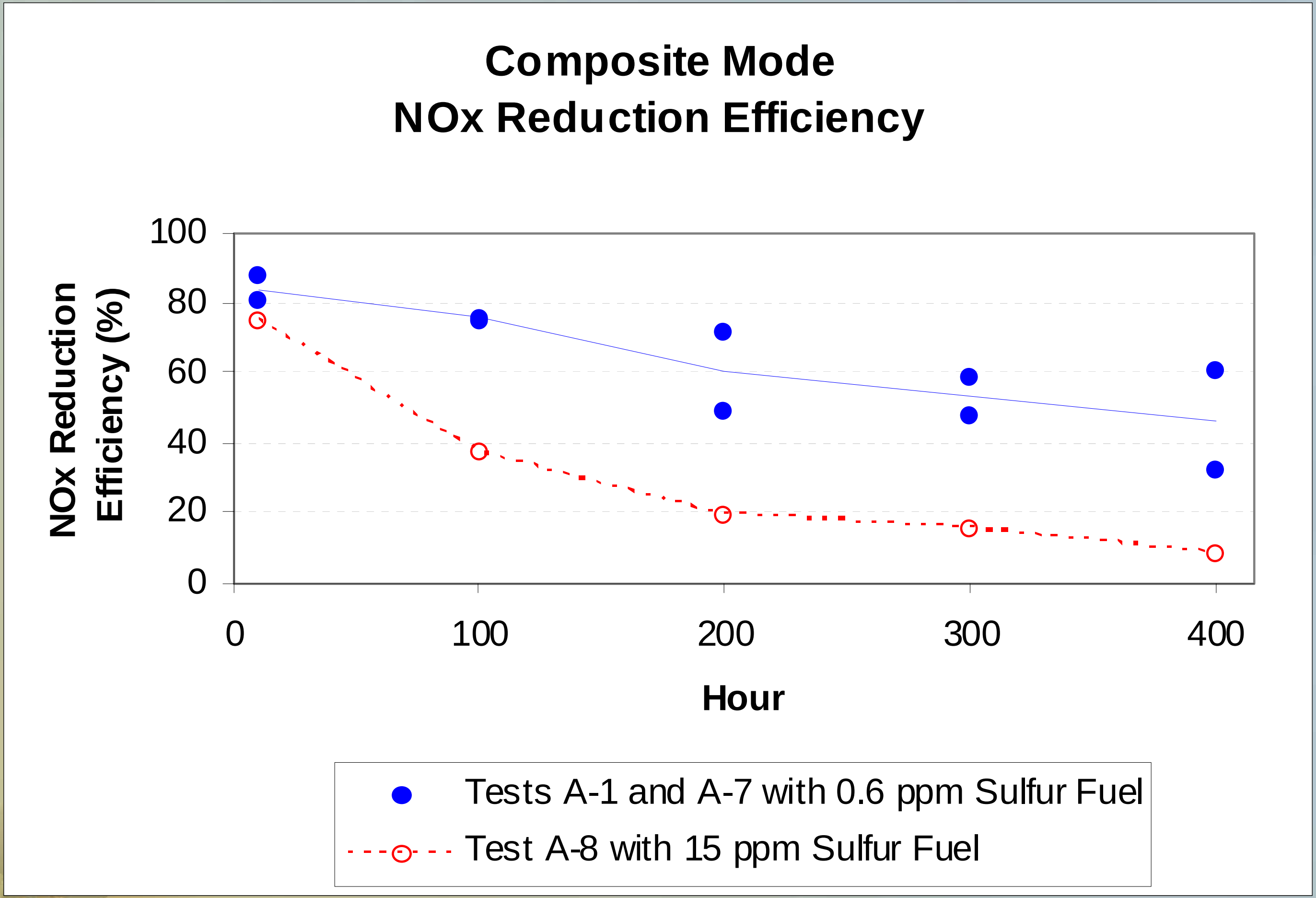
Phosphorus Impact on Performance



Impact of Detergent



Relative Impact of Fuel and Lube S



Preliminary Conclusions – Phase 2

- Final reporting still in progress
  - Will be available late 2005
- Sulfur and phosphorus in lube oil appear to impact LNT performance
- Deposits of lube oil derived species concentrated on front of catalyst
- Detergent level may temper the effect
- Fuel sulfur still appears to be dominant in terms of degradation

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THE END