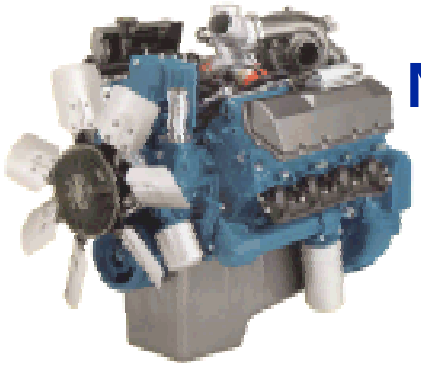
The Impact of Lubricant on Emissions from a Medium-Duty Diesel Engine

APBF-DEC Lubricants Project



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National Renewable Energy Lab

August 26, 2002
San Diego, CA

Catalyst Compatible Lubricants

- 2007 HD standards and Tier 2 LD standards are "aftertreatment forcing"
- Growing concern: lube oil sulfur and ash
  - Potential to interfere with catalyst performance
    - » NO_x adsorber catalyst poisoning
    - » Diesel particle filter plugging
- This is the first phase of a multi-year project to quantify lubricant effects on emissions and catalyst performance

- ***Objective:*** Determine which, if any, lubricant derived emission components are detrimental to ECS performance or durability.

Workgroup Participants

- BP
- CARB
- Caterpillar
- ChevronTexaco
- Chevron Oronite
- Ciba Specialty Chemicals
- Cummins
- Equilon
- Ethyl Corporation
- ExxonMobil
- Infineum
- International Truck and Engine
- John Deere
- Lubrizol
- Mack
- Marathon-Ashland Petroleum
- Motiva
- Pennzoil-Quaker State
- RohMax
- Shell Global Solutions
- Toyota
- Valvoline

APBF-DEC Funding Partners:
ACC, API, CARB, DOE, EMA, MECA, SCAQMD

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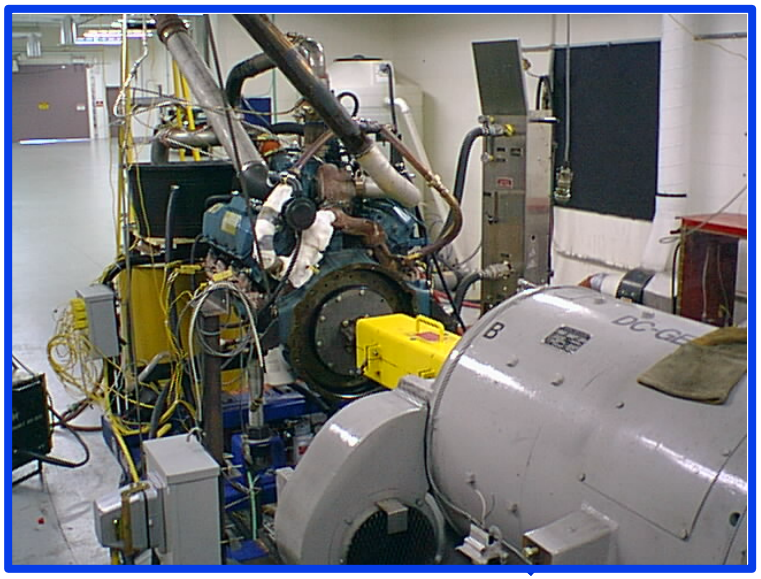
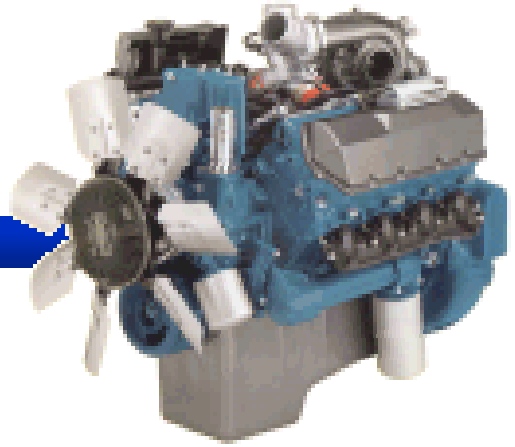
Overview

- Advanced Petroleum Based Fuels-Diesel Emission Control (APBF-DEC) Activity

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



Test Engine

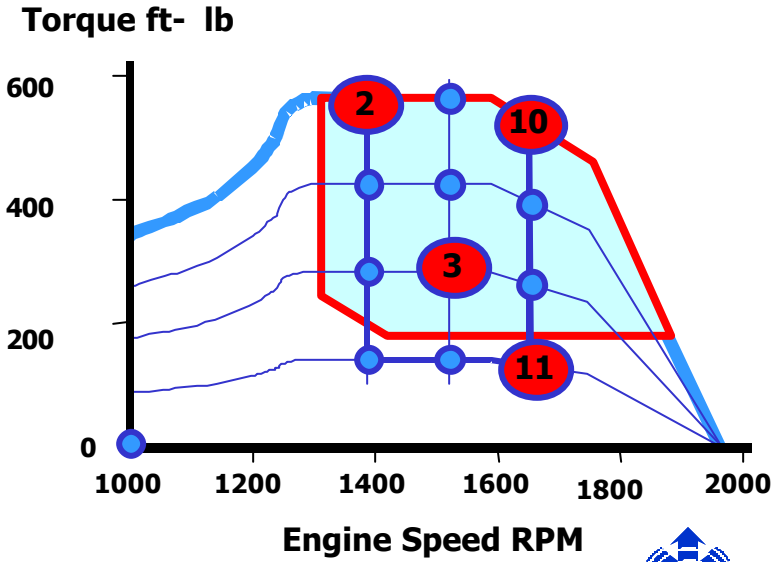


- 1999 International T444E
  - 7.3L OHV V-8
  - Direct injection, turbocharged w/ wastegate
  - HEUI fuel system
  - 215 hp at 2400 rpm
  - 540 ft-lbs torque at 1500 rpm
  - Exhaust gas recirculation (retrofit)
  - Closed crankcase ventilation with filter
  - Lube system capacity: 18 quarts

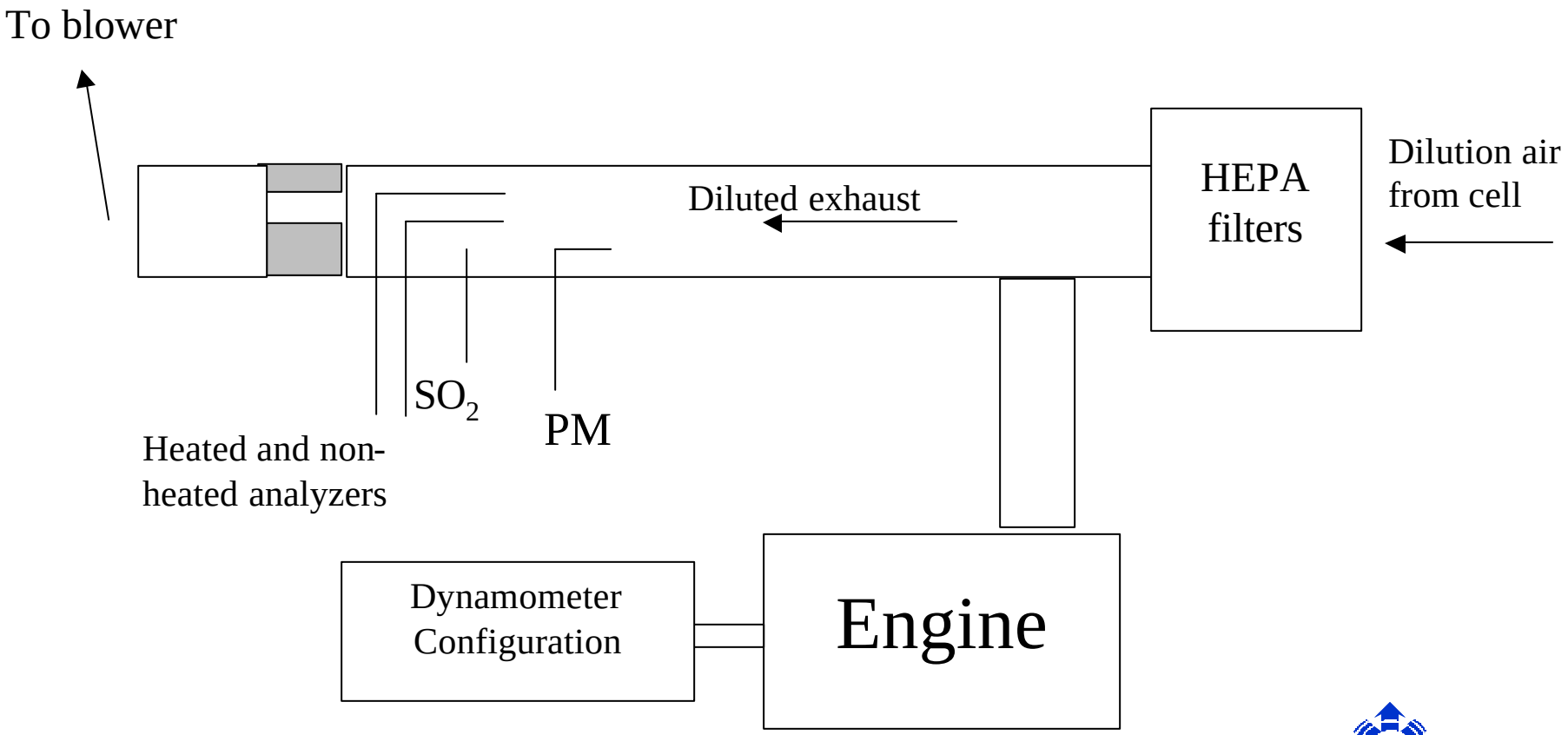
Emissions Measurements

- PM (three sample trains)
  - total weight
  - SOF and sulfate
  - metals
  - PAHs
- Four mode steady-state (OICA)

- NO_x
- SO_2
- Hydrocarbons
- CO



Test Cell Layout



Particulate Matter Sample Collection

- Train #1: PM mass (ATL/ORNL)
  - 70 mm Pallflex 'Emfab' (glass fiber w/bonded PTFE)
  - analysis for sulfate and soluble organic fraction (ORNL)

- Train #2: PM Metals
  - 47 mm Gelman 'Teflo' (PTFE w/ PMP support)
  - determined by x-ray fluorescence (DRI)

- Train #3: Poly-cyclic Aromatic Hydrocarbons (PAH)
  - 70 mm Pallflex 'Fiberfilm' (glass fiber w/bonded TFE)
  - Determined by GC-MS (SwRI)

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SO_2 Analysis - Overview

- SO_2 measured via impingement in aqueous hydrogen peroxide (wet chemistry method)
  - SO_2 converted to SO_4
- Modeled after EPA methods 6, 8, 16
- Post-test quantification of SO_4 concentration using ion chromatograph yields SO_2 emission rate (exhaust flow measured)

Additive Systems Selected

- 12 additive packages that span range of elemental composition
- Key constituents:
  - Ash: 0 – 1.85%
  - Sulfur*: 0 – 6590-ppm
  - Calcium: 0 – 4770-ppm
  - Zinc: 0 – 1900-ppm
  - Phosphorus: 0 – 1700-ppm
  - Magnesium: 0 – 1700-ppm

Additives supplied by:

*additive contribution only

Ciba, Chevron Oronite, Ethyl, Infineum, Lubrizol

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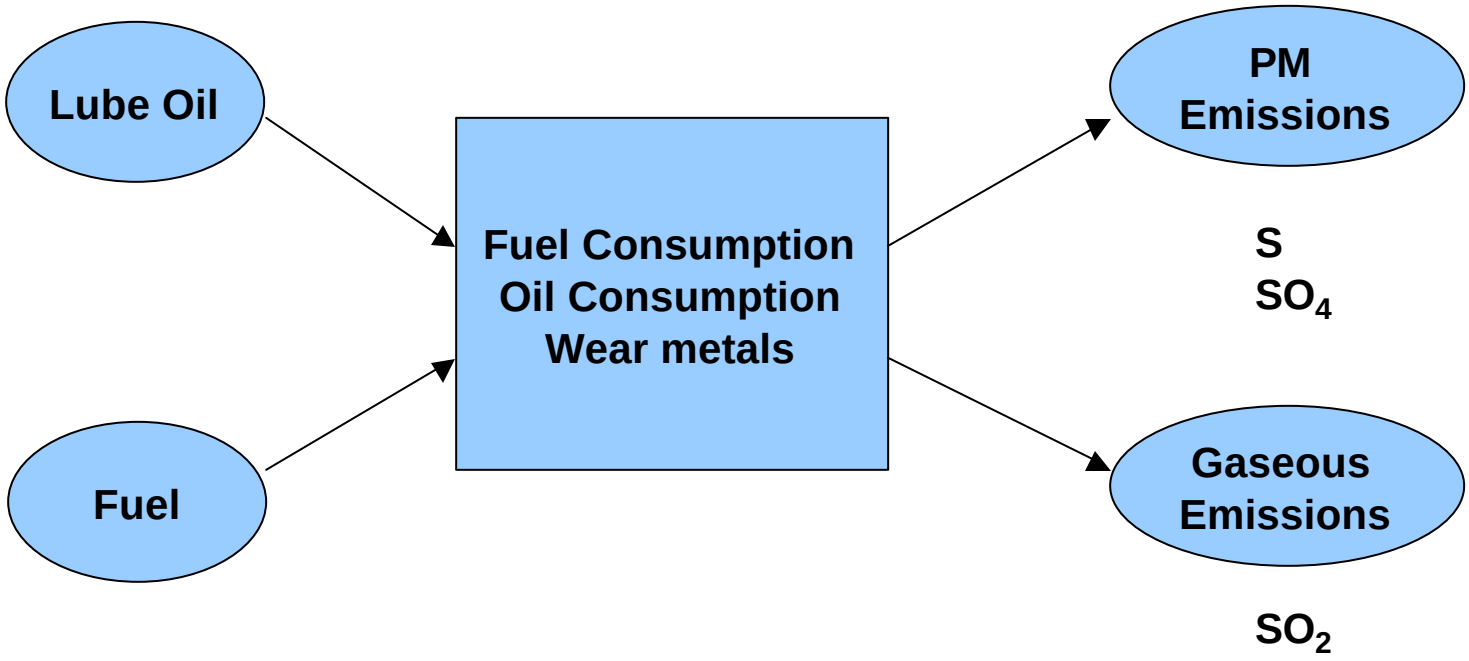
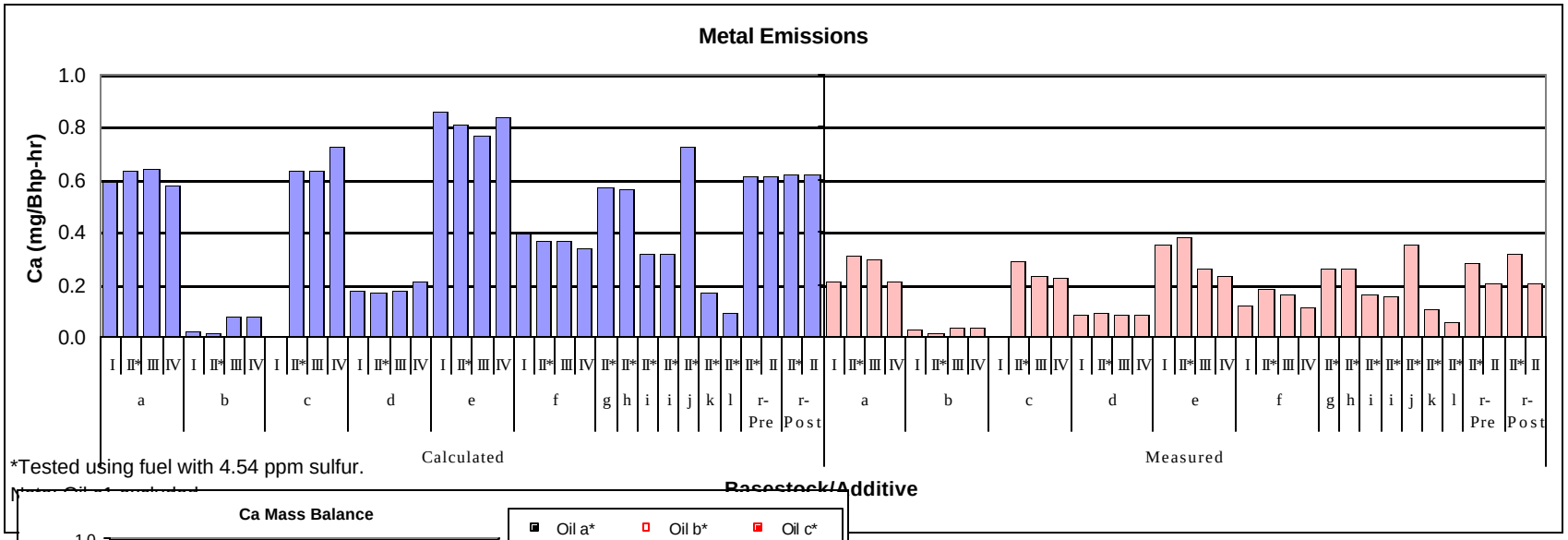
Base Oils Selected

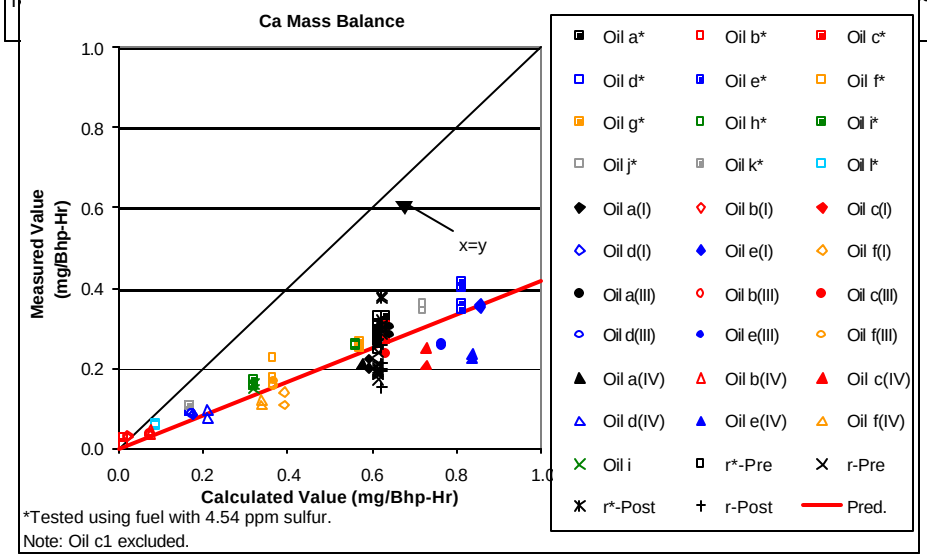
- Group I: Valero (Paulsboro, NJ)
  - 4800-5600-ppm S, 75% saturates
- Group II: Excel (Lake Charles, LA)
  - <20-ppm S, >99% saturates
- Group III: Motiva (Port Arthur, TX)
  - <5-ppm S, >99% saturates
- Group IV: BP
  - PAO (poly-alpha olefin, synthetic)
  - 0 sulfur
  - 5% ester for additive solubility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

Material Balance



Calcium in PM Emissions





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

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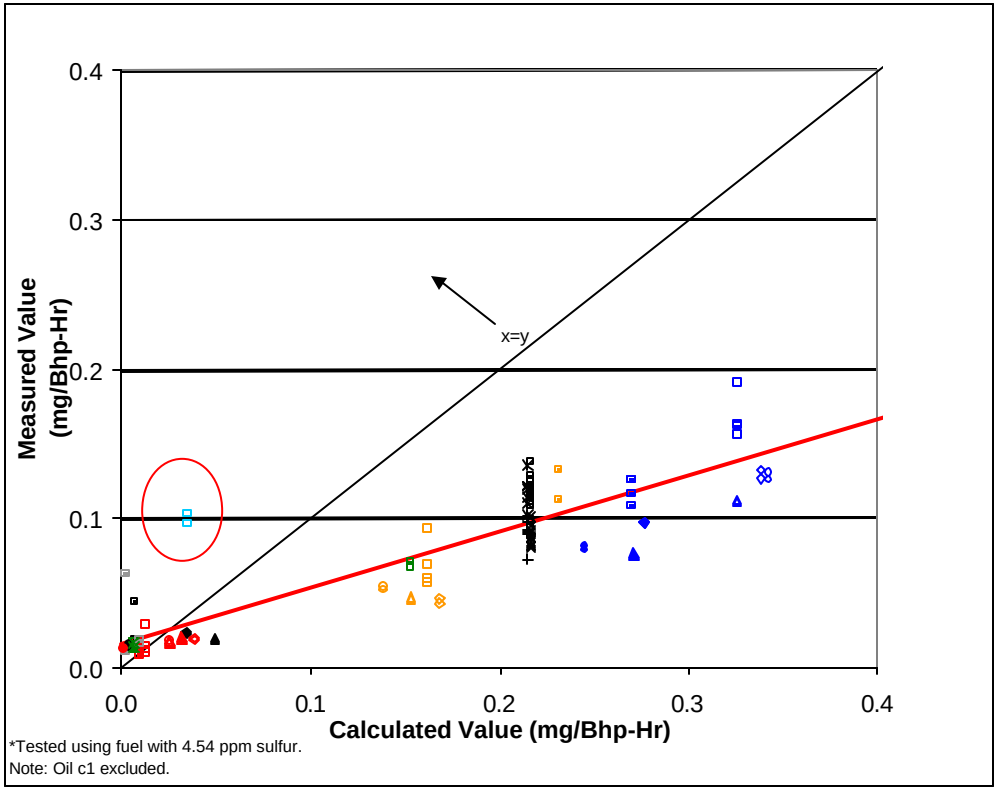
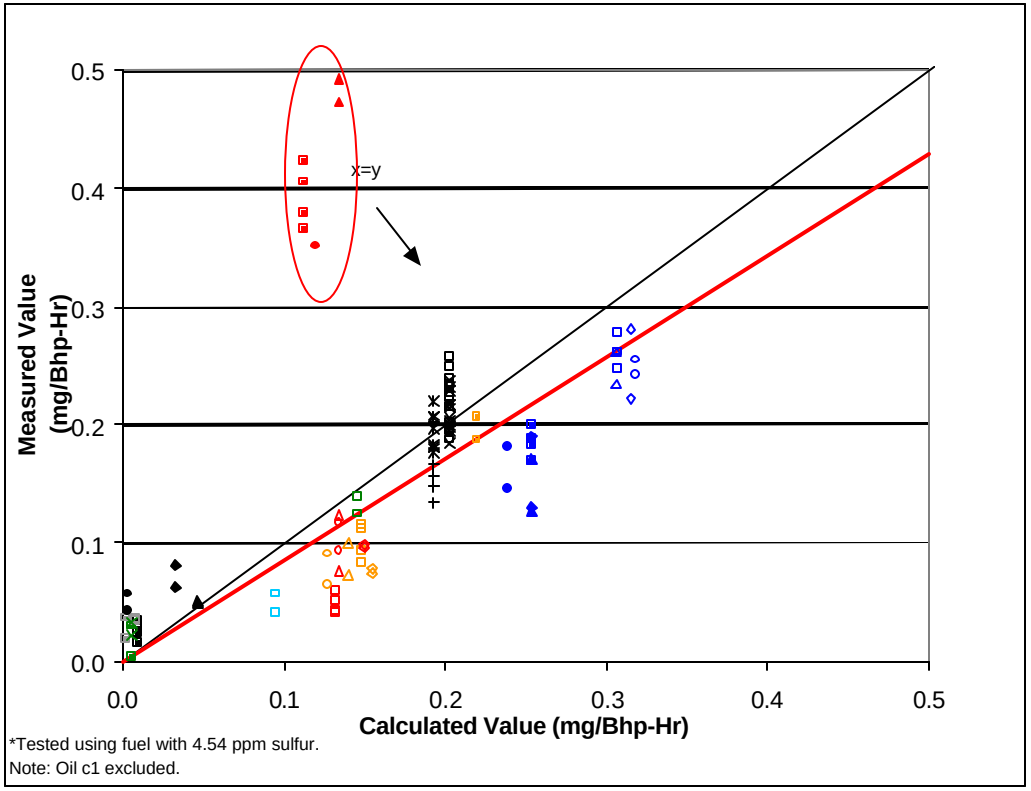
Zinc in PM Emissions



*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

- Zn emissions directly correlated with concentration in oil
- Possible composition effects
- 38% recovery rate

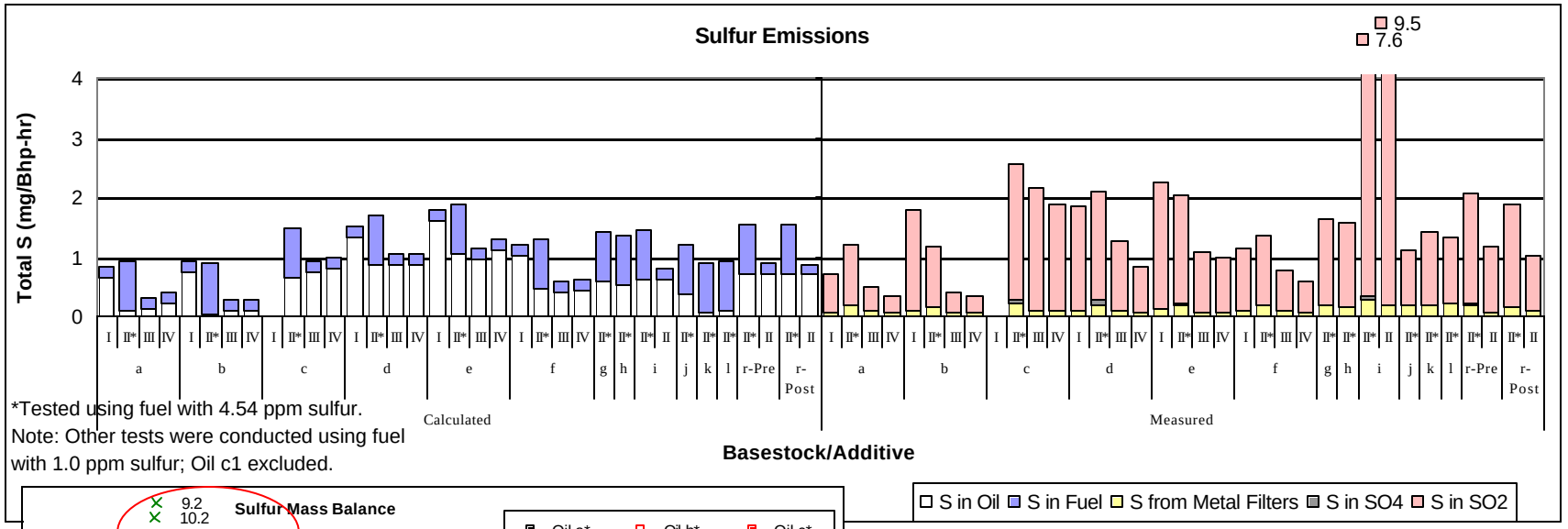
Phosphorus in PM Emissions



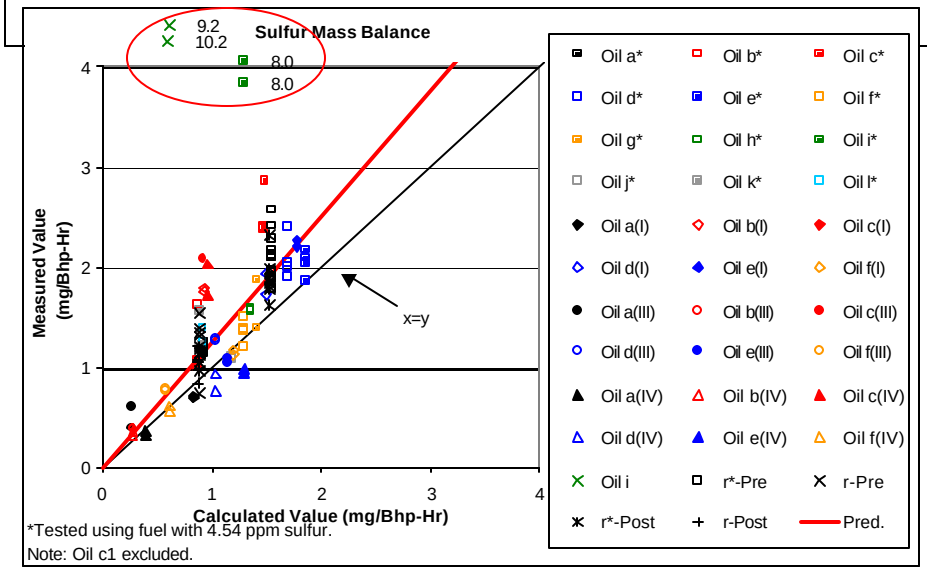
*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

- **P emissions directly correlated with concentration in oil**
- **Additive package C results significantly deviate**
- **86% recovery rate (excl. Oils C2, C3 and C4)**

Sulfur Emissions



*Tested using fuel with 4.54 ppm sulfur.
Note: Other tests were conducted using fuel with 1.0 ppm sulfur; Oil c1 excluded.



*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

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

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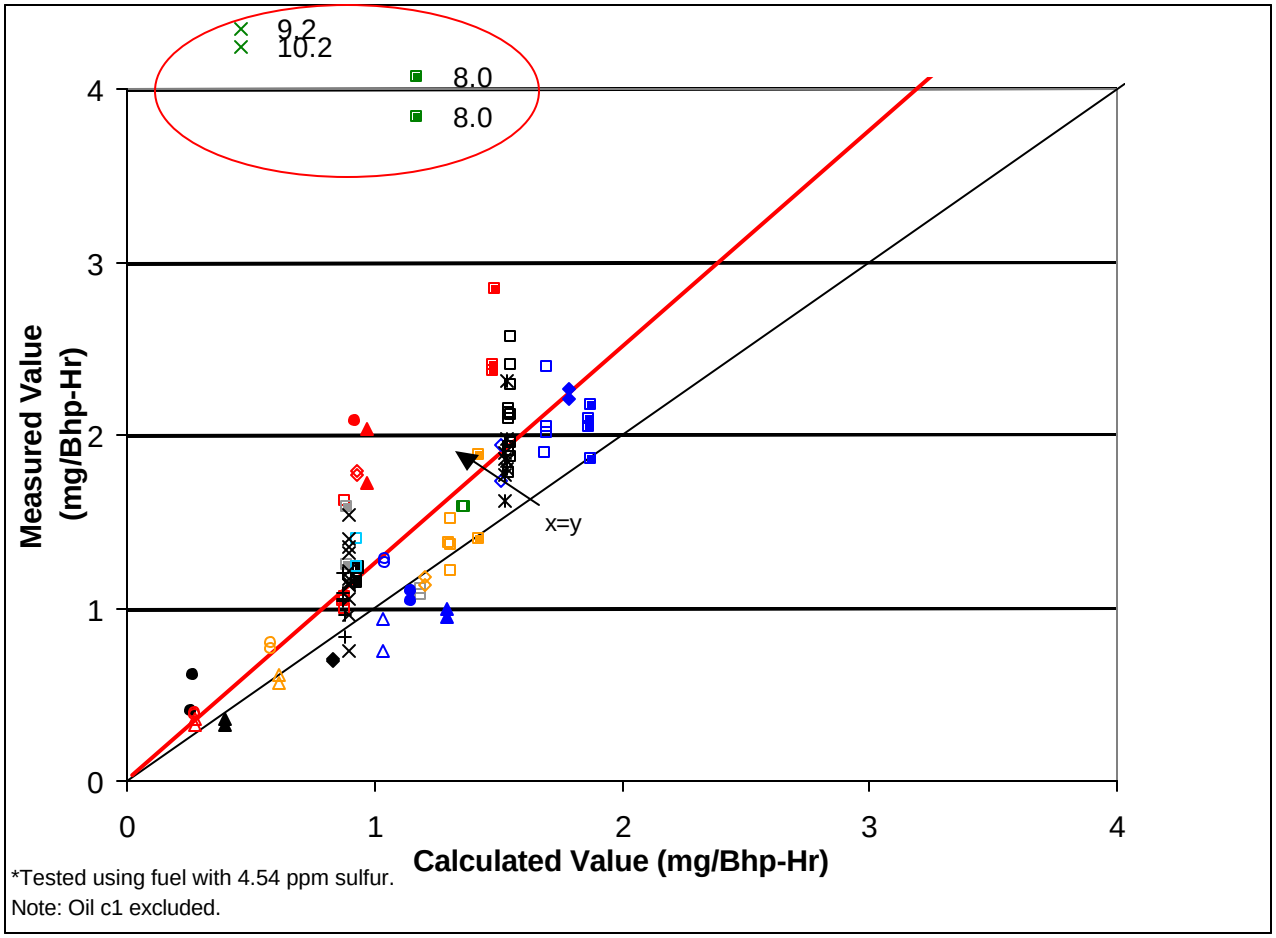
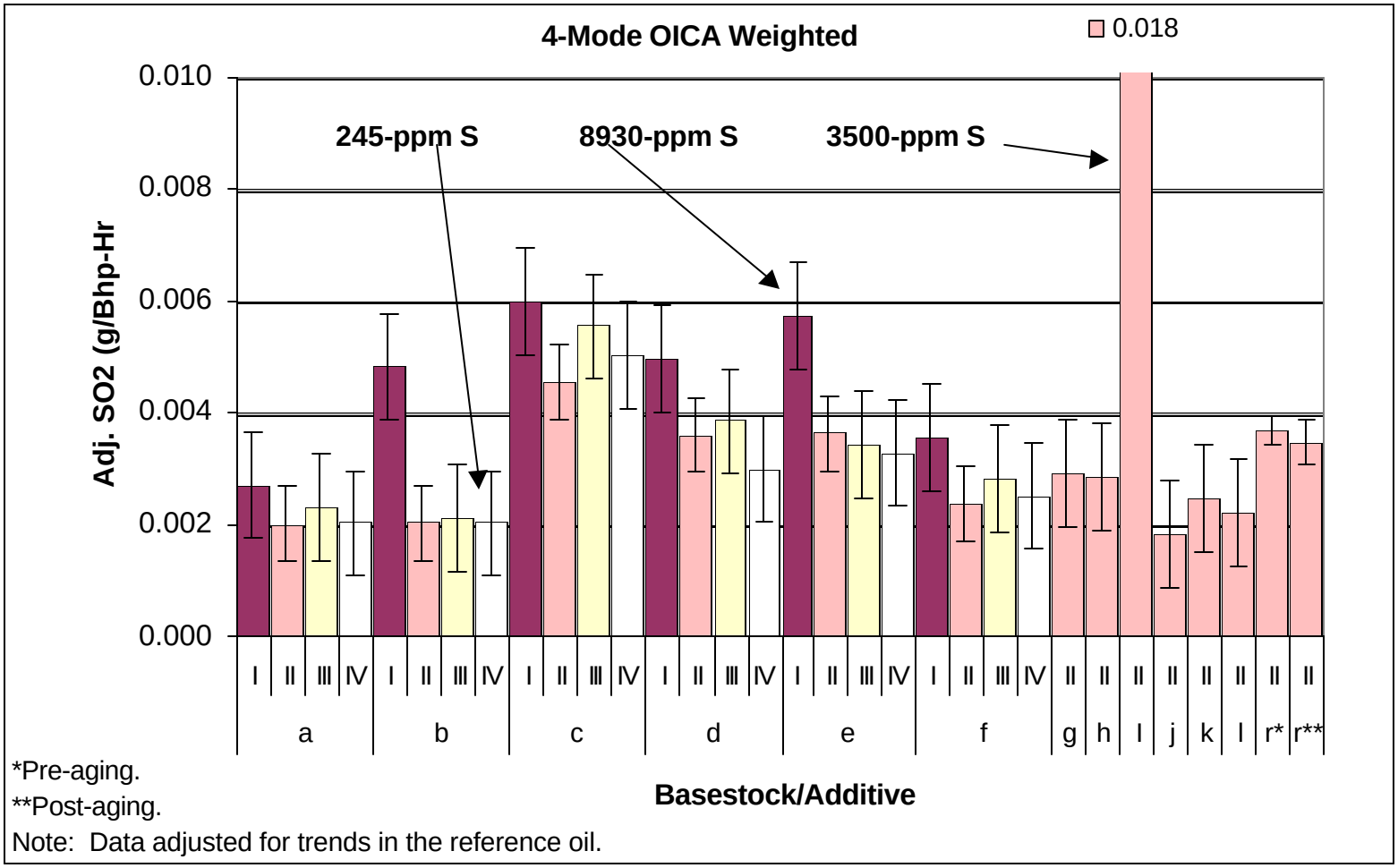
Sulfur Emissions



*Tested using fuel with 4.54 ppm sulfur.
Note: Oil c1 excluded.

Base Oil and Additive Effects on SO_2 Emissions



*Pre-aging.
**Post-aging.
Note: Data adjusted for trends in the reference oil.

Summary

- Preliminary results show the effects of oil composition on selected emissions, including metals and sulfur
- Results indicate that emissions from certain formulations deviate from those using more traditional chemistry
- Phase II will focus on development of a rapid catalyst aging protocol to determine lubricant effects on durability

Acknowledgements

- Special thanks to:
  - Oil and additive suppliers
  - International Truck and Engine Corp.
  - APBF-DEC Lubricants Project Workgroup
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  - Battelle (Hsing-Chuan Tsai and John Orban) for statistical analysis
  - **APBF-DEC Funding Partners**: ACC, API, CARB, DOE, EMA, MECA, SCAQMD

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