Desulfurization Fuel Filter

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Program

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Goal: To develop and demonstrate proof-of-concept for an "on-vehicle"desulfurization fuel filter for diesel engines.

Project Team

- **Honeywell Consumer Products Group FRAM**
- **Marathon Ashland LLC**
- **Volvo Powertrain (Mack Trucks Inc.)**
- **Johnson Matthey**
- **American Waste Industries**

Dept of Energy Contract

DOE Contract DE-FC26-02NT41219

Program began April 2002

Fuel Sulfur Removal Filter

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In-Going Rationale

- NOx adsorber technology sensitive to sulfur levels in the fuel
- Reduction in the number of desulfation events for NOx adsorbers can improve their life
- Refineries will face a challenge to achieve economical hydro-desulfurization to achieve levels low enough to not poison NOx adsorbers, 3 ppm or lower.
- Reduced fuel sulfur levels make point-of-use sulfur treatment feasible
    - volume required for an “on-board” sulfur trap is within reason
- Pipeline contamination will likely raise sulfur levels

Approach

- Develop fuel filter type device as an adsorption bed for sulfur removal.
- Integrate sulfur filter maintenance interval to other scheduled maintenance events

Sulfur Species

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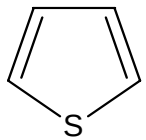
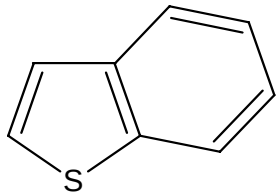
Mercaptans
Thiols
H_2S

Alkylated



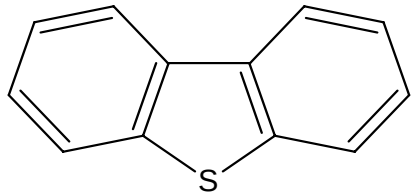
Thiophene

Alkylated



Benzothiophene

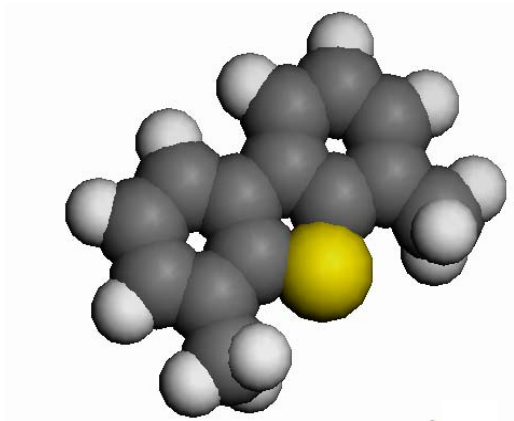
Alkylated



Dibenzothiophene

BP

4,6-dimethyldibenzothiophene
DMDBT



Challenge

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The DMDBT looks similar to and behaves like some major components in diesel fuel

Diesel Composition

- **20% 1 ring aromatics**
- **3% 2 ring aromatics (30,000ppm) very similar to DMDBT**
- **DMDBT is at 10 ppm**

3000 to 1 ratio

- **Low level polar contaminants in fuel-lubricants, oxidative degradation products and antioxidants**

Approaches

- **Remove the sulfur contaminant directly (requires high selectivity)**
- **Convert it into something more easily removed**
  - Create a “chemical hook”

Program Chronology

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- Comprehensive screening of approaches to remove sulfur
- Studied over 4000 candidate chemistries
  - Universities
  - Inventors
  - Companies
  - Papers, patents
  - Combinatorial study (UOP)
- A single candidate system identified as “go forward” approach

Sorbent Sulfur Uptake

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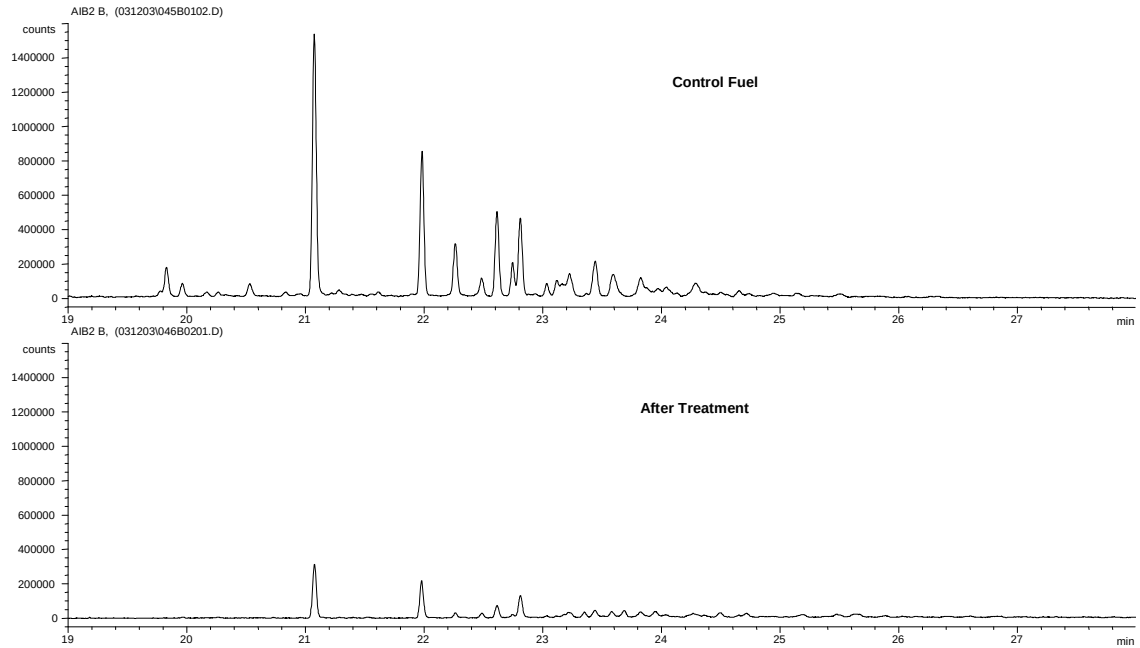
GC Trace of sulfur species removed by sorbent



Removes uniformly broad class of sulfur species also potential contamination from higher sulfur fuels

Filter Properties

- 10 gallon column
- 60 C operation
- 14-40 mesh
- Non-compressible inorganic oxide

NAC

- 8.14 L each, undersized to expedite durability test

NO_x Adsorber Catalysts (NAC)

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- **Why NOx adsorbers?**
  - HC reductant preferred (vs. on-board urea for SCR)
  - Good operating window

- **Challenges to meet with NO_x adsorbers…**
  - Regeneration steps / fuel penalty
  - Rich operation (in-cylinder OR exhaust fuel injection)
  - Impact of engine operation on PM formation rates
  - System cost and size
  - Satisfying High Temperature “NTE Zones”
  - Desulfation of NAC

Systems Impacted by Sulfur

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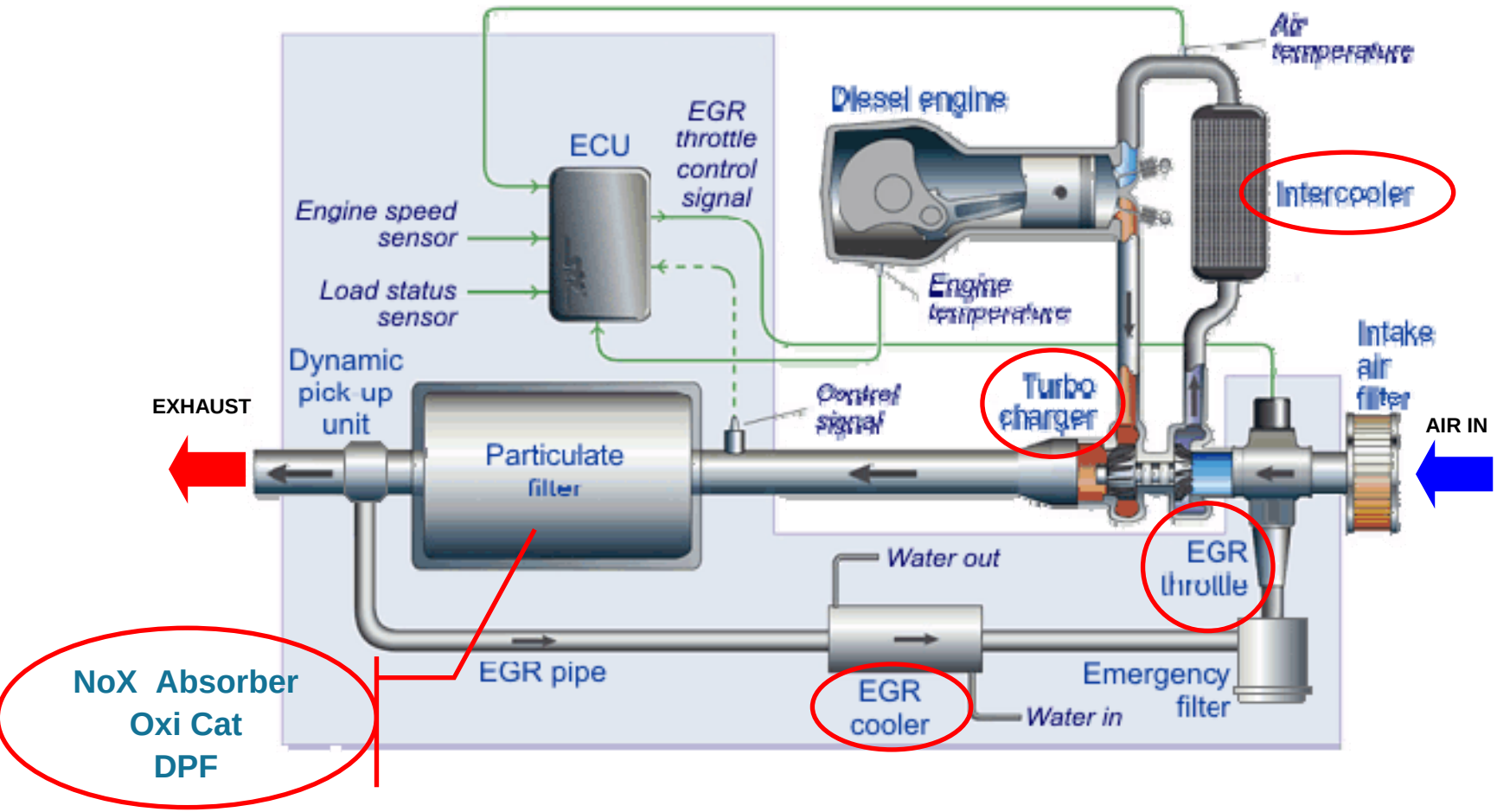

NAC Operation

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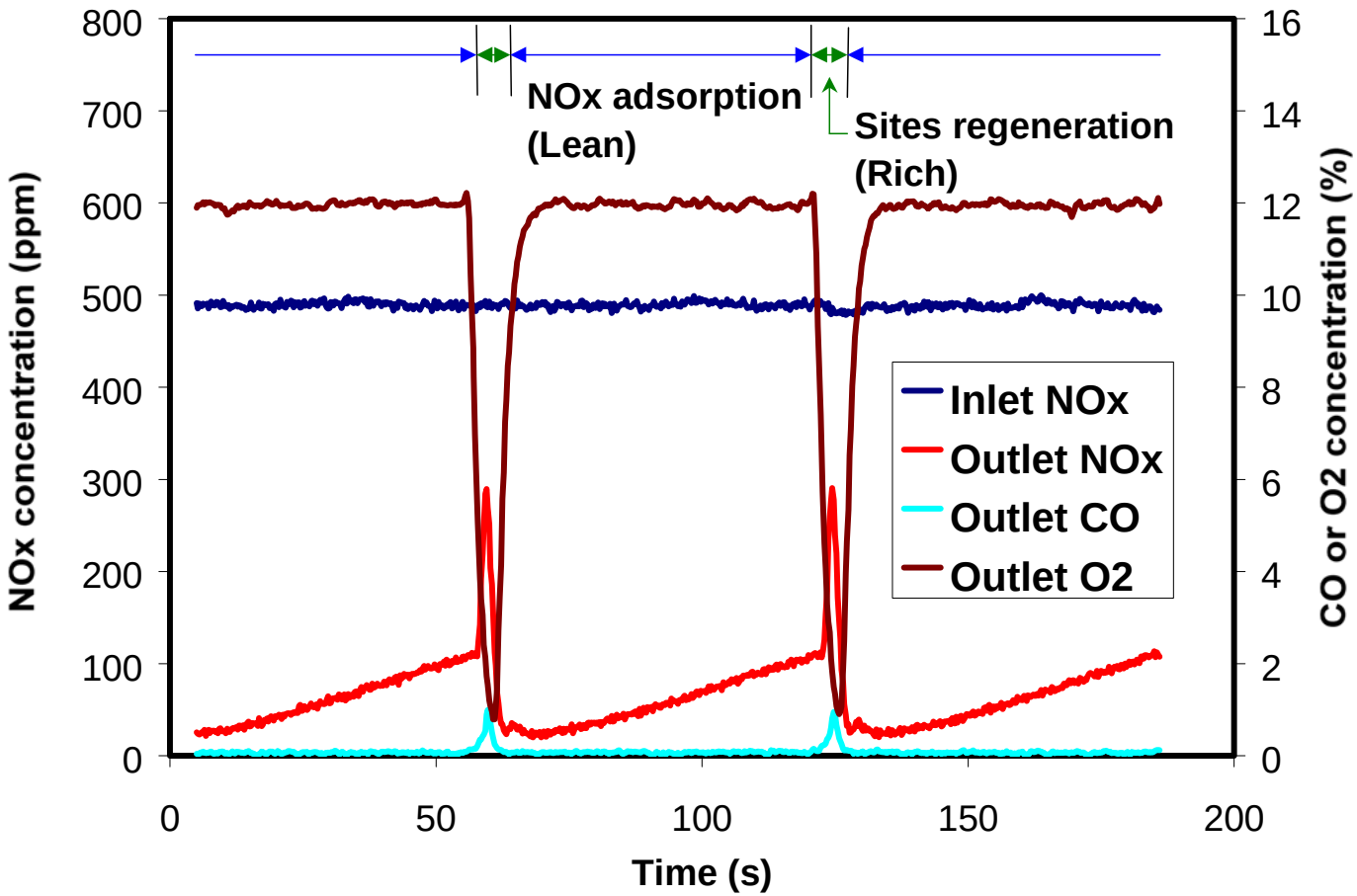
- Storage and reduction cycles are achieved by switching the exhaust between lean and rich



Sulfur Filter Benefits

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- **For current NAC operation, periodic sulfur removal is required, via desulfation cycles (DeSOx):**
  - Sulfur is driven off of catalyst by increasing temperature in exhaust
  - Thermal damage to catalysts can result from high temperature exposure
  - Significant fuel economy penalty can occur as a result of DeSOx cycles

- **Fuel sulfur filter will allow interval between DeSOx events to be extended:**
  - Less thermal damage due to less high temperature exposure
  - Higher NOx storage trapping efficiency maintained between DeSOx events
  - Improved fuel economy, compared to operation without fuel sulfur filter

HDD Test Cell Setup:

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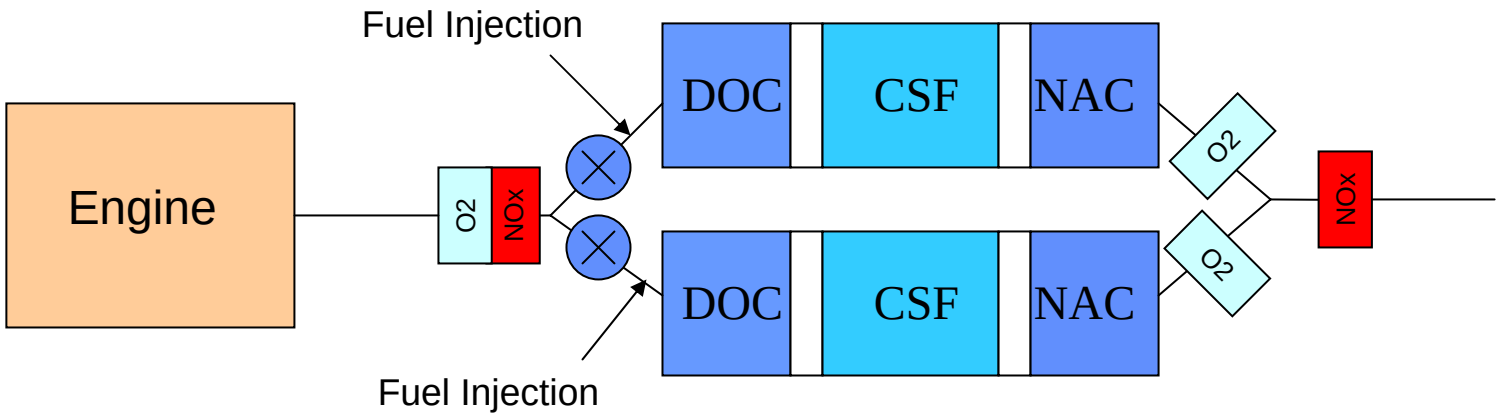

- 2002 Mack AC-427 12L Engine with cooled EGR.
- Dual leg exhaust setup, with valve switching and multiple injection upstream of DOC
- Steady-state operation at 1800 rpm, 300 ft-lbs
- Periodic soot regeneration when delta P exceeds 75 in-H_2O, (2.7 psi)
- Total system performance determined by NOx sensors before and after catalysts

After-treatment Setup & Sulfur Filter

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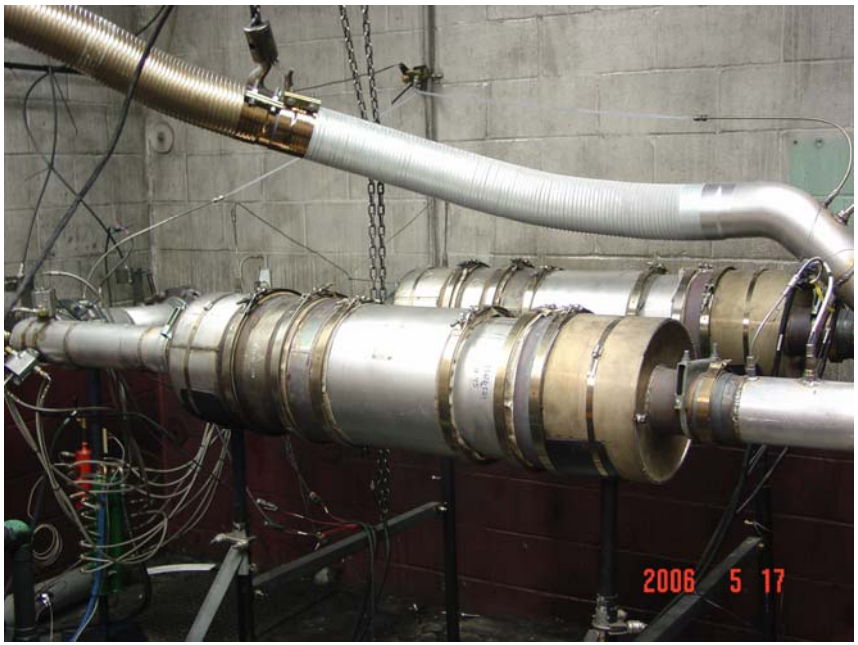

Tandem aftertreatment system DOC, CSF and NAC

Sulfur Filter-temperature controlled, fixed bed-single pass operation.

Plumbed between fuel storage tank and engine

Relative NOx Capacity 558 Hrs

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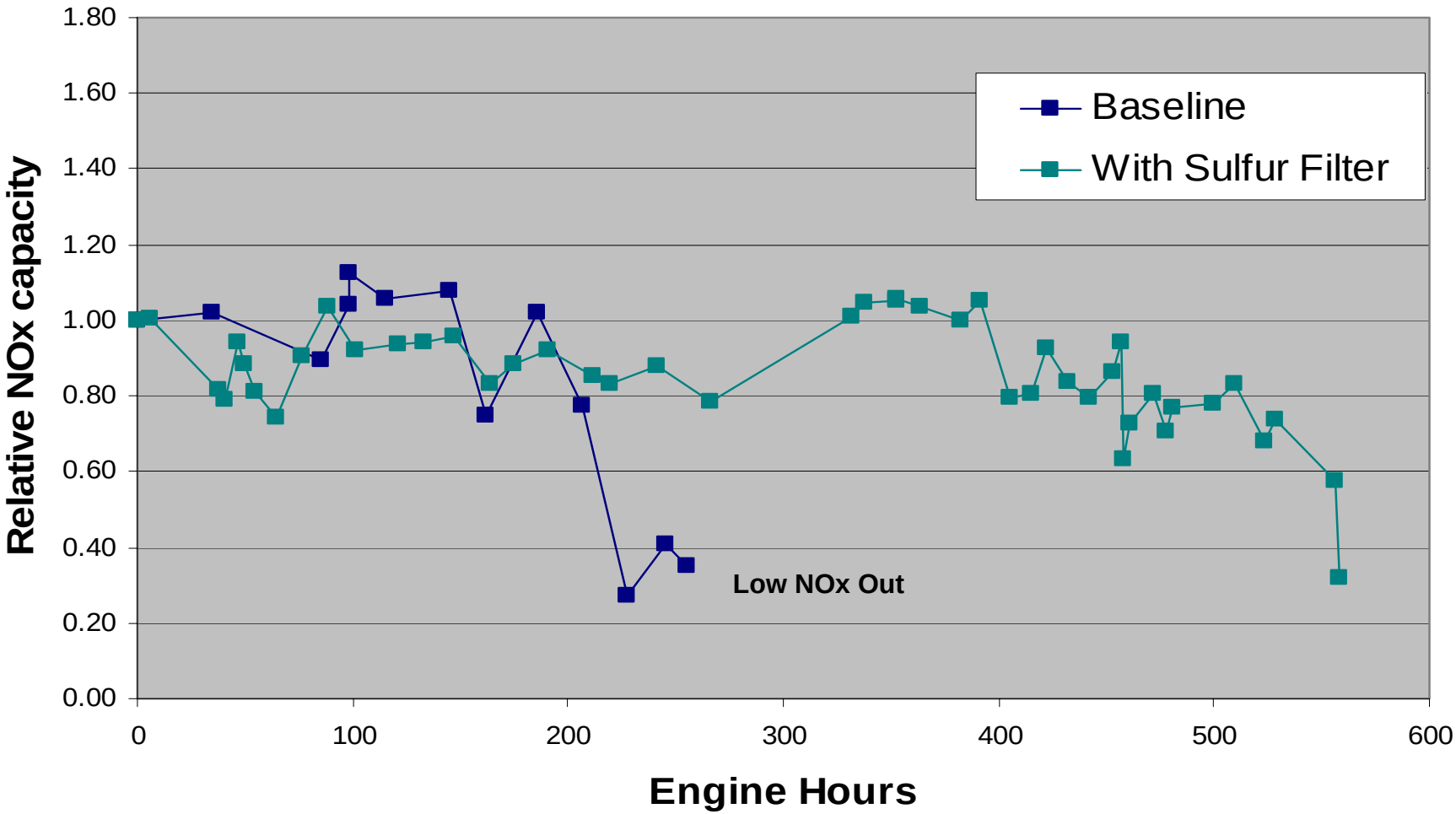

- Baseline: decay beginning at 150 hr, precipitous loss > 200 hr, 255 hr (2.53 g/l sulfur exposure)
  Sulfur exposures Baseline- 41.2 g at 255 Hr With Sulfur Filter- ~40 g at 522 Hr
- Filter Run: in progress, longer NOx conversion, after 380 hr beginning to see gradual decline,
- Post Mortem: sulfur levels on NACs to be analyzed

TEST CELL ULSD FUEL SAMPLES

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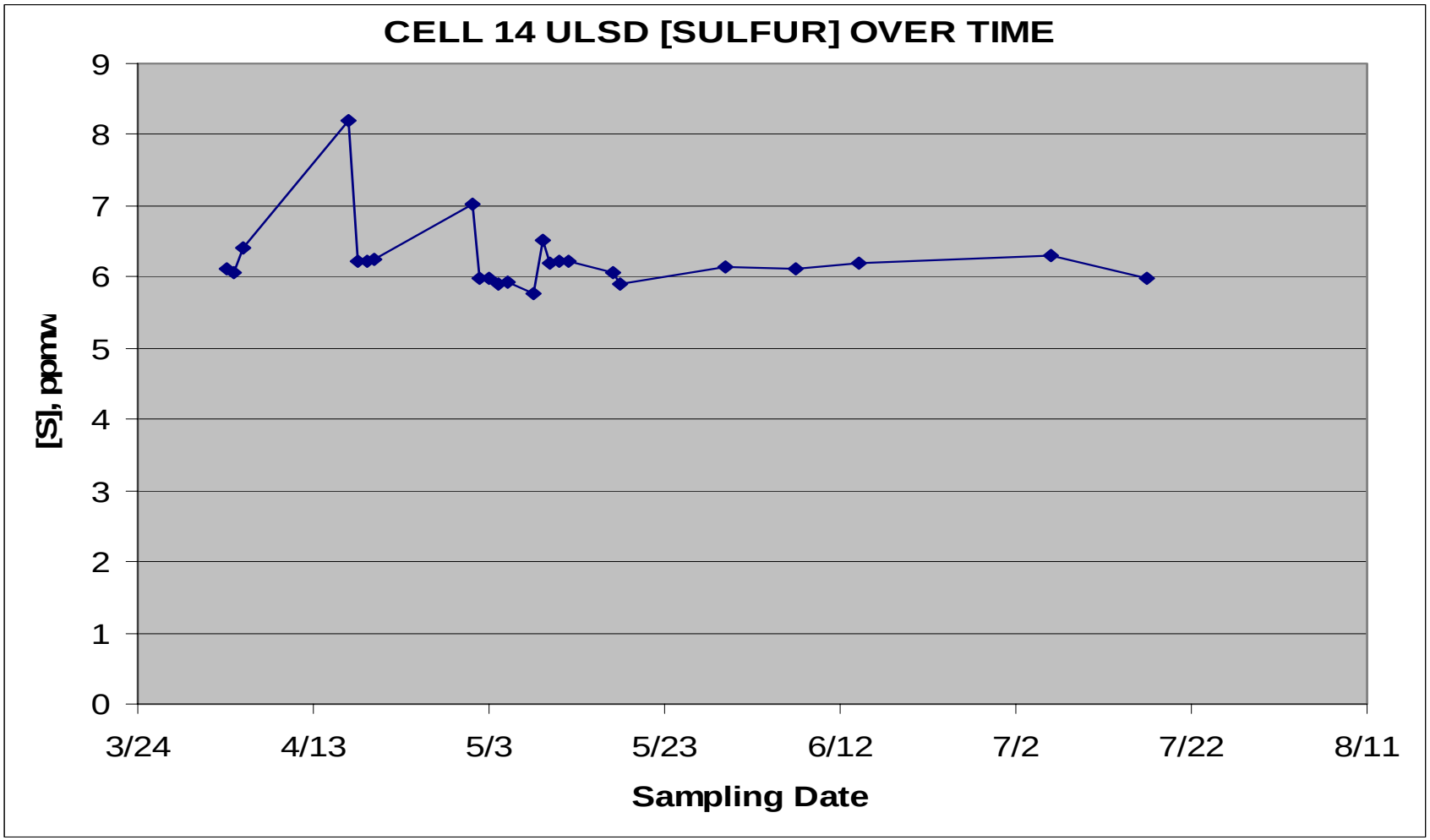

ENGINE TEST- SULFUR ELUTION PROFILE

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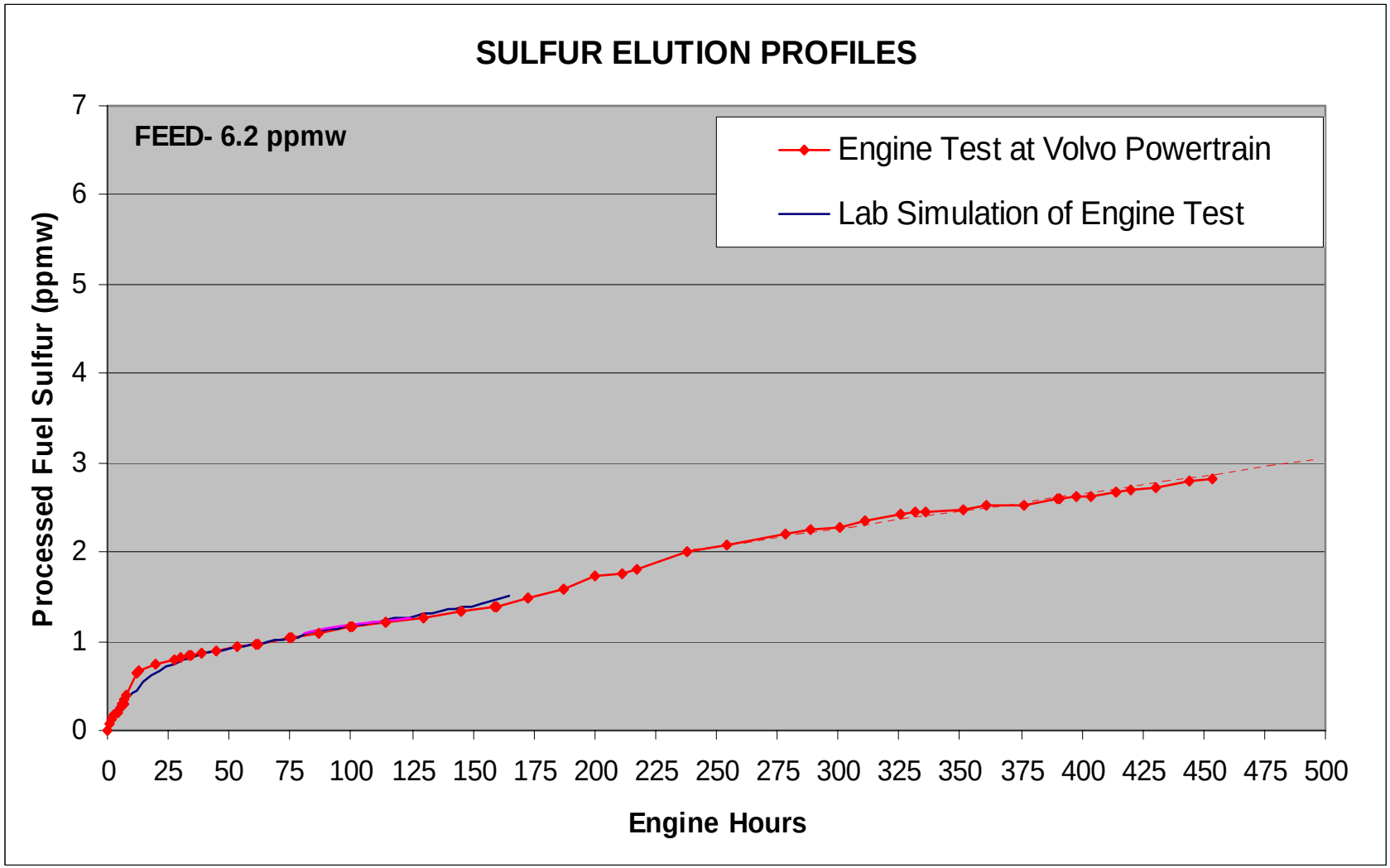

Target to meet 3 ppm target by 500 hrs or ~500 bv

FUEL PROPERTIES- CETANE No.

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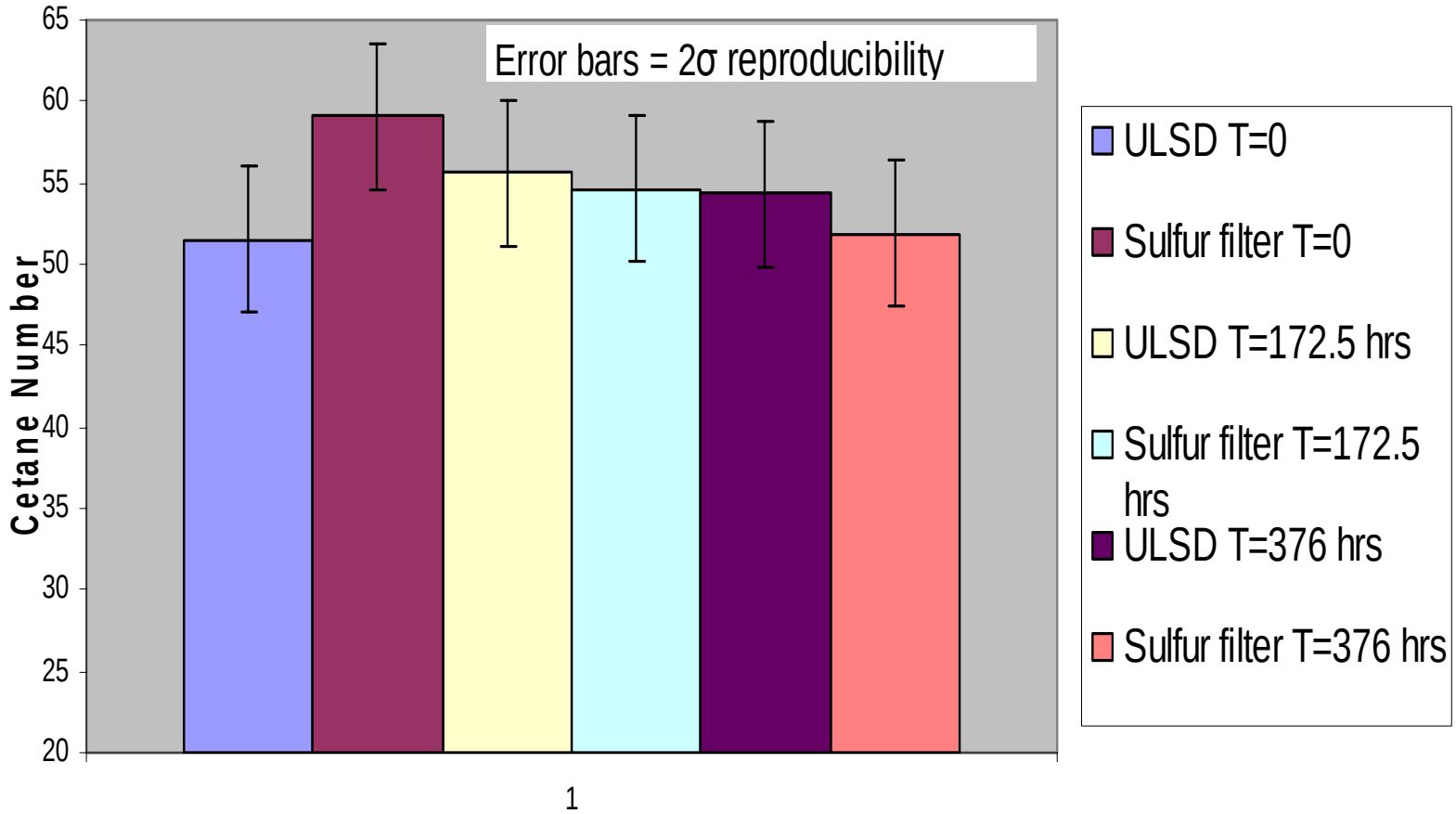

FUEL PROPERTIES- LUBRICITY

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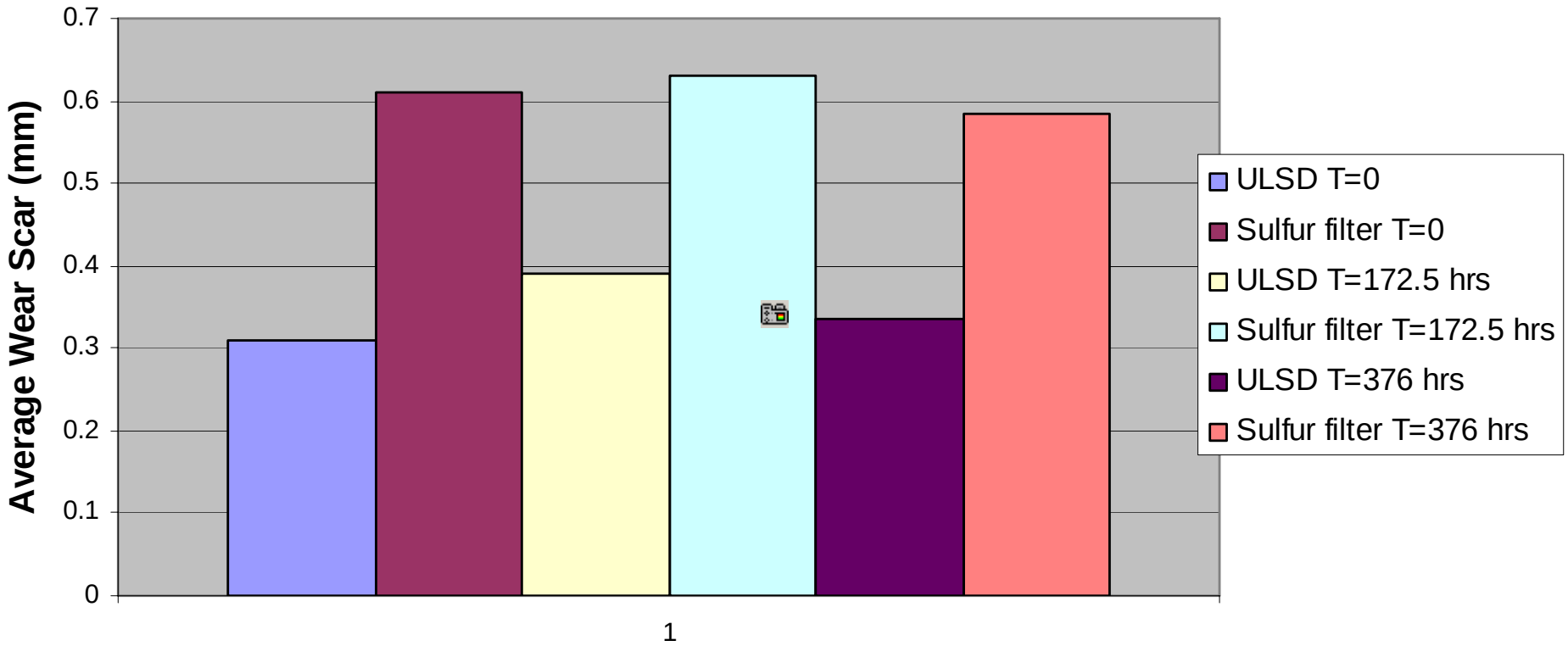

FILTER SIZE ESTIMATE

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- **Light / Medium Duty Diesel**

	OIL CHANGE INTERVAL		
MPG	5,000	7,500	10,000
15	**0.67**	**1**	**1.34**
20	**0.5**	**0.75**	**1.0**
25	**0.40**	**0.60**	**0.80**

Estimated filter size in gallons for light/intermediate duty diesel engines. Values based on current projected performance at Mack Trucks.

Next Steps

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- **Reduce size of sorbent bed**
  - Non-optimized sorbent
  - Combinatorial optimization program begun UOP, expected completion Nov 2006
- **Deal with lubricity loss issue**
  - Readditize lubricity additive within filter
- **Light duty diesel test**