Emissions from Heavy-Duty Diesel Engine with EGR using Oil Sands Derived Fuels

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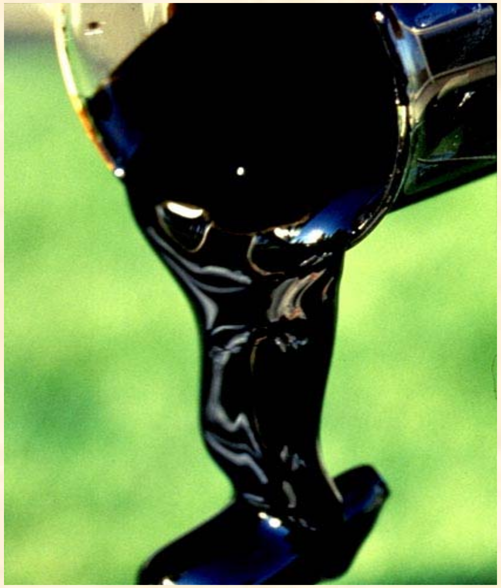
Introduction

- Canada's proven oil reserves were recently increased from 4.9 to 180 billion bbls[1] - 2nd largest oil reserves in world after Saudi Arabia
- Large reserve increase because more Canadian oil sands are now considered recoverable with existing technology and market conditions
- Oil sands are a mixture of bitumen (~10%), sand, mineral-rich clays and water
- Bitumen is a naturally-occurring viscous mixture of hydrocarbons that has been extracted from the oil sands and used to produce feedstocks for Canadian and U.S. refineries since 1967



Photograph courtesy of Syncrude Canada Ltd.

[1] Oil and Gas Journal, December 2002

Introduction - II

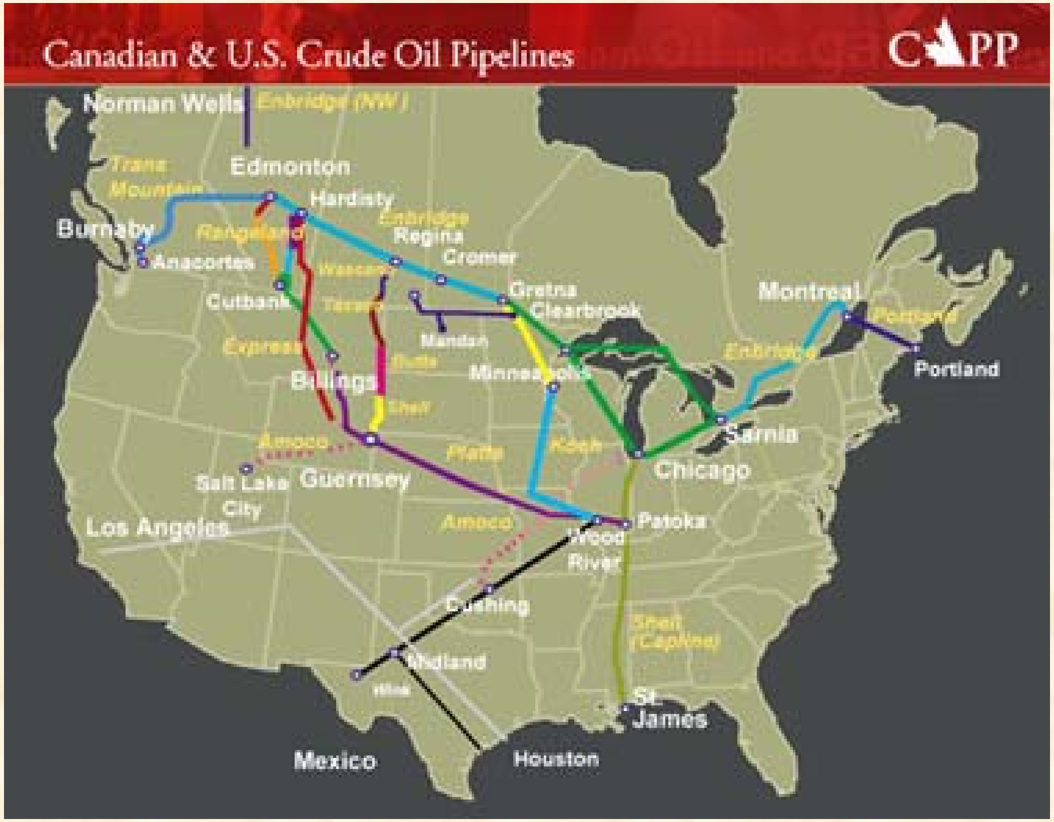
- Unique characteristics of oil sands derived crude reflect the bitumen source and the processes that the bitumen undergoes

- The resulting product can be a high-quality, light sweet crude oil, as shown to the right

Photographs courtesy of Syncrude Canada Ltd.

Introduction - III

- An extensive pipeline network exists to transport oil sands derived crude from Western Canada to refineries
- The oil sands derived diesel fuels that were used in this study have the following characteristics
  - low sulfur content
  - excellent low temperature properties
  - more cycloparaffins and mono-aromatics than conventional diesel fuels



Photograph courtesy of CAPP

Research Engine

Caterpillar 3401E

Cylinders	1
Volume (liters)	2.44
Comp. Ratio	16.25:1
Power (kW @ 1800 rpm)	74.6
Valves	4
Fuel Injection	MEUI
EGR	**Cooled**

EGR Rates

- EGR rates were selected to achieve 2.5 g/hp-hr composite NO_x emissions and reasonable soot emissions at the AVL eight-mode operating conditions using a commercial winter-grade diesel fuel

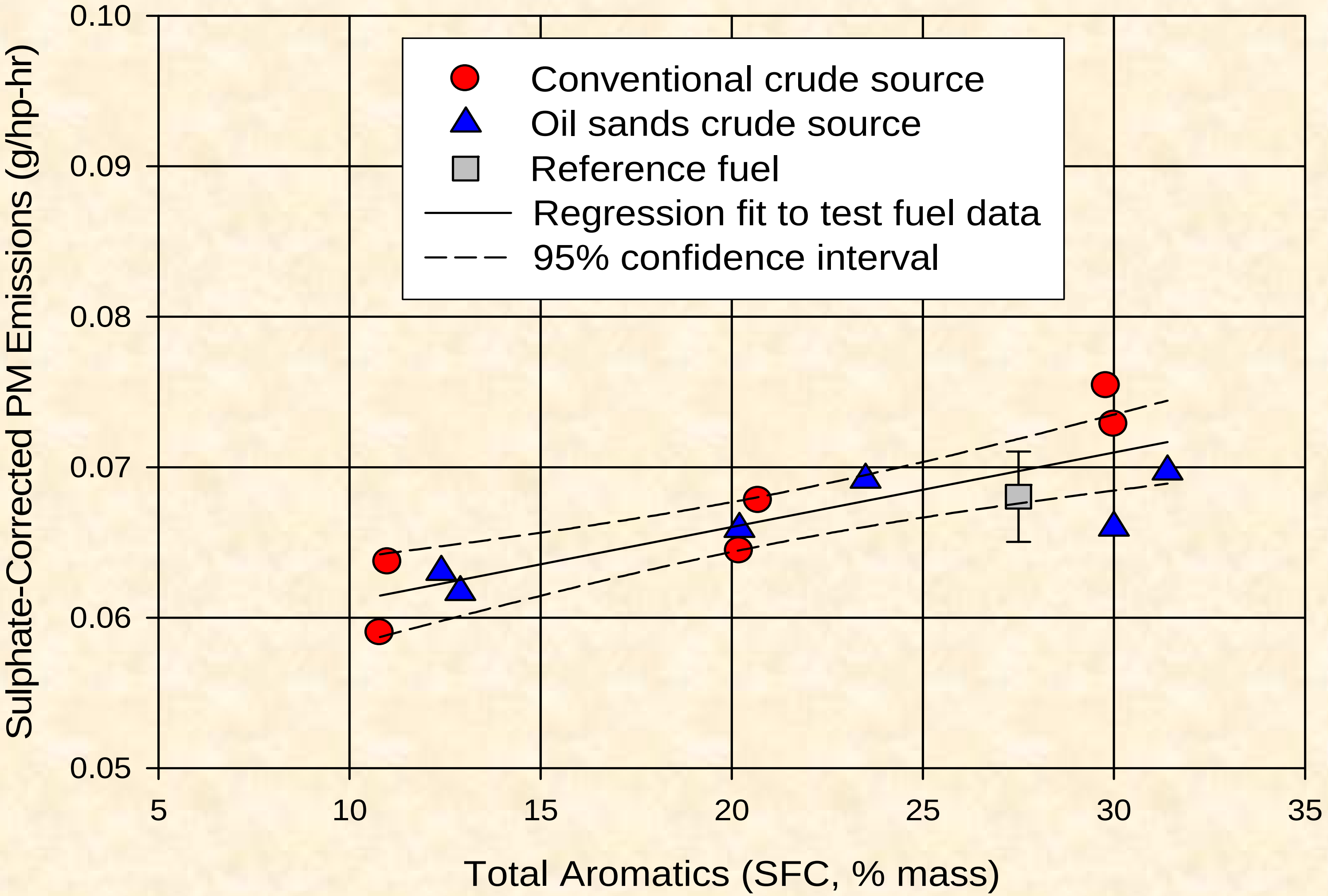
Composite Emissions (g/hp-hr)	Cat 3401E base	Cat 3401E with EGR	Δ (%)
NO_x	4.25	2.46	-42
PM	0.040	0.076	+90

Effect of Crude Oil Source

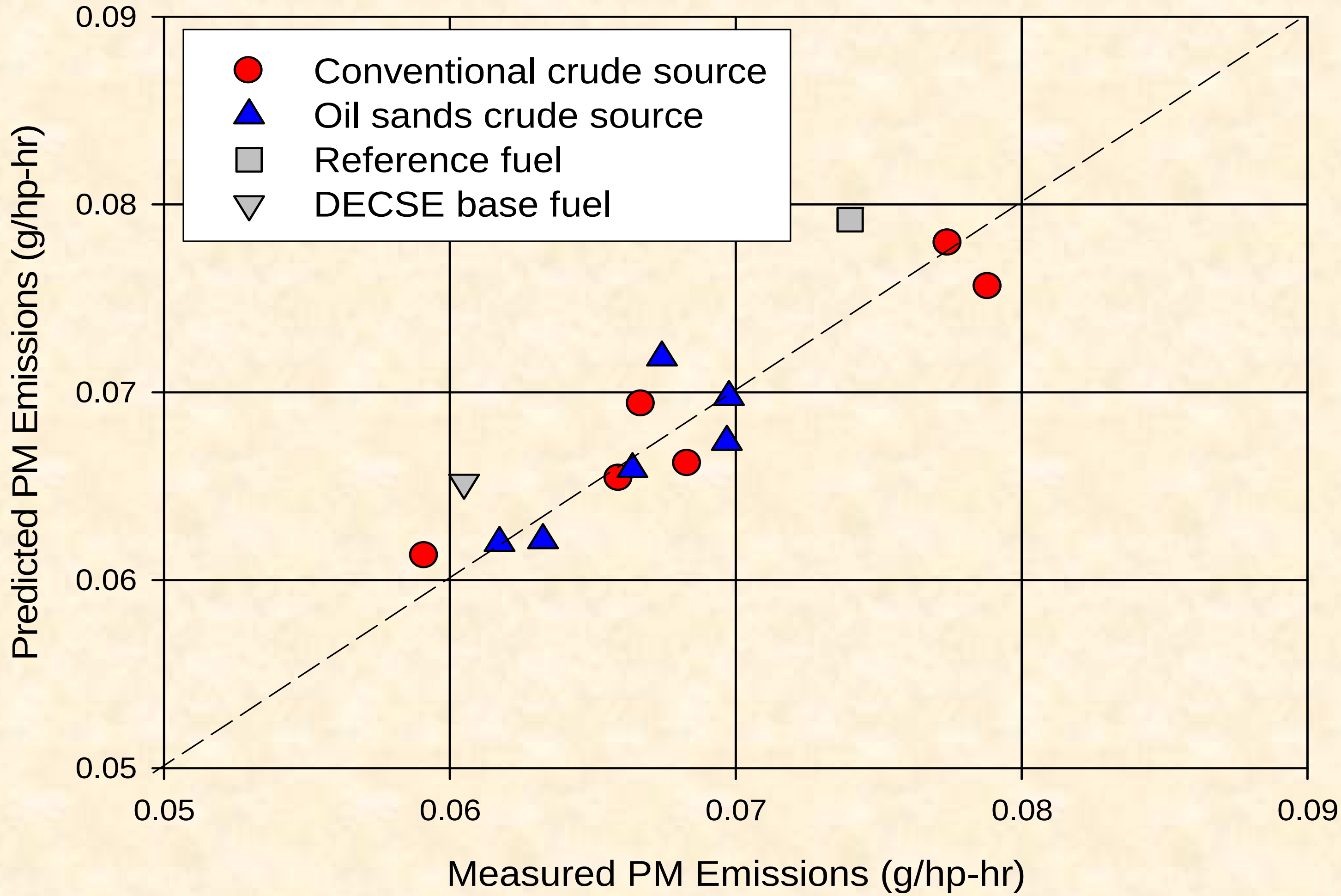
- ***Objective:*** Compare the emissions of test fuels derived from oil sands and conventional sources in a modern diesel engine equipped with EGR

- 12 fuel matrix available from a previous experiment (Ricardo Proteus engine, SAE 982487)
  - 6 test fuels each derived from oil sands & conventional sources
  - total aromatics varied from 10-30% by mass
  - cetane number was maintained at 43±3
  - EHN used to raise the CN of 3 oil sands fuels
  - sulfur content limited to 500 ppm mass
- The reference fuel was a commercial winter-grade diesel fuel obtained in the Ottawa area

PM Emissions

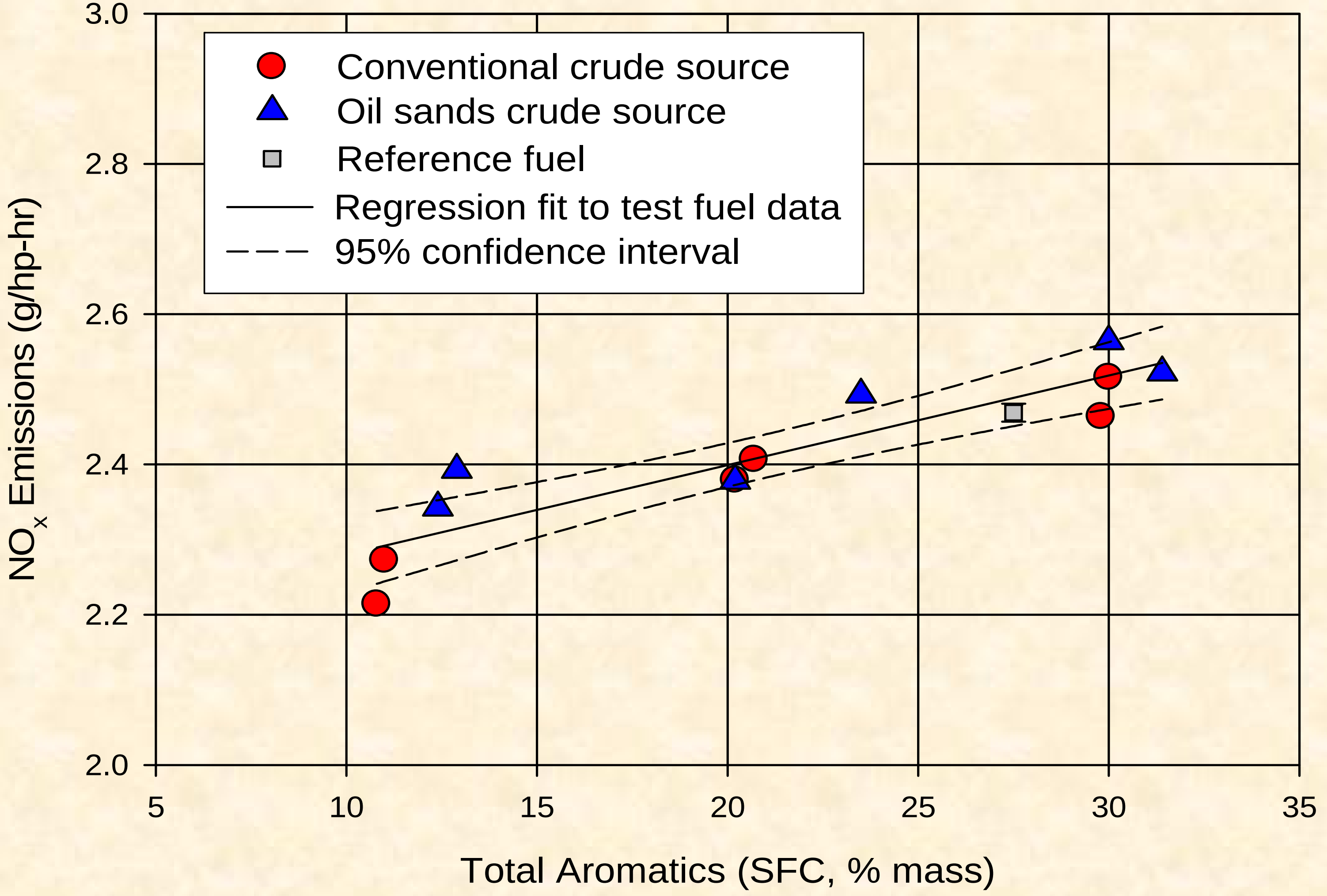


Model predicts PM emissions for fuels derived from oil sands and conventional sources



Linear Regression Model for PM Emissions (g/hp-hr) =
4.19×10^{-4} x Tot. Arom. (mass %) + 3.29×10^{-5} x Sulfur (ppm) + 0.057

NO_x Emissions



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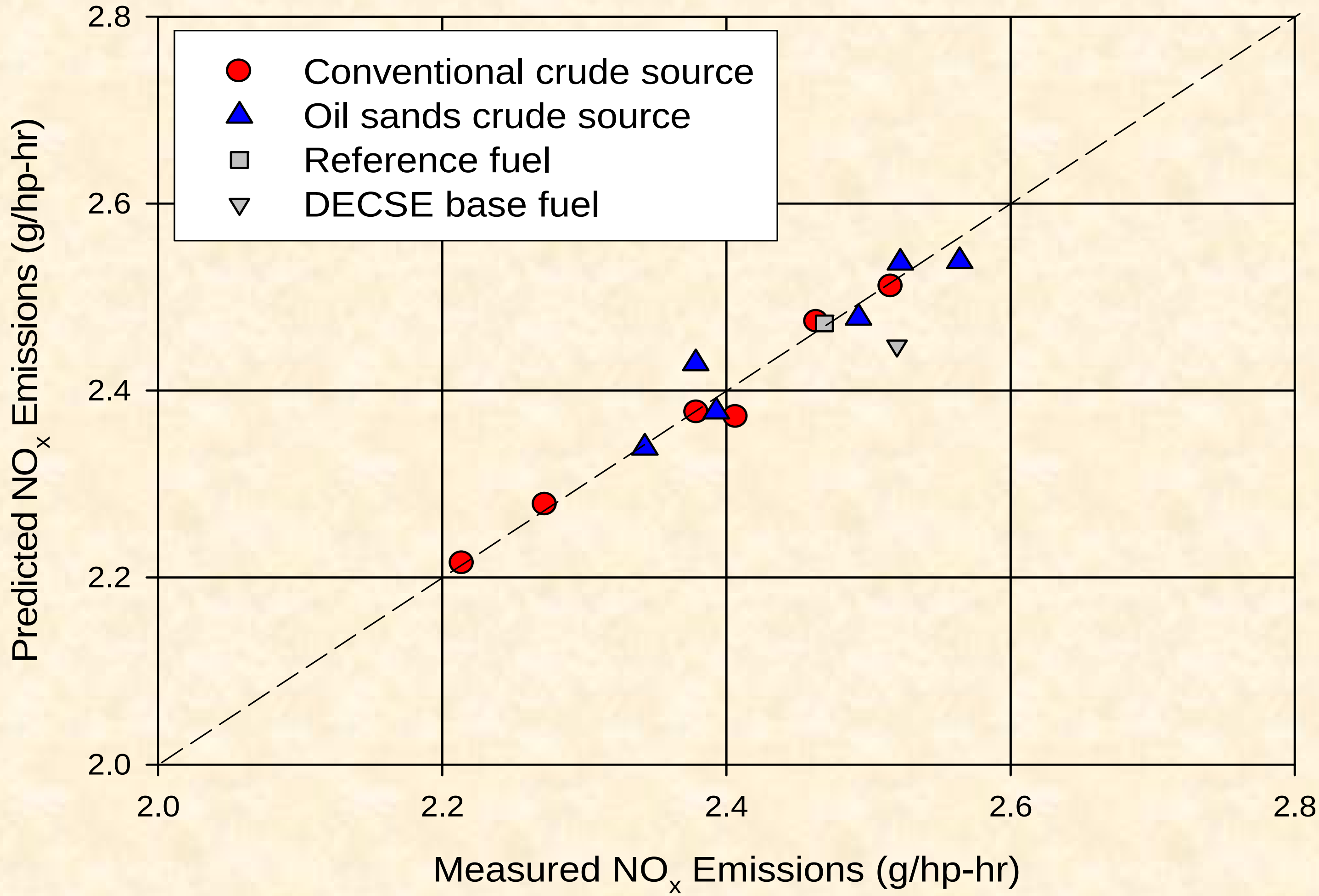
Combustion Research

Model predicts NO_x Emissions for fuels derived from oil sands and conventional sources



Linear Regression Model for NO_x Emissions (g/hp-hr) =
7.48×10^{-3} x Tot. Arom. (mass %) + 5.00×10^{-3} x Density (kg/m^3) -1.89

Research In-Progress – Evaluation of different options for improving fuel ignition quality

- Base fuel is an ultra-low sulfur diesel (ULSD) fuel derived from oil sands sources

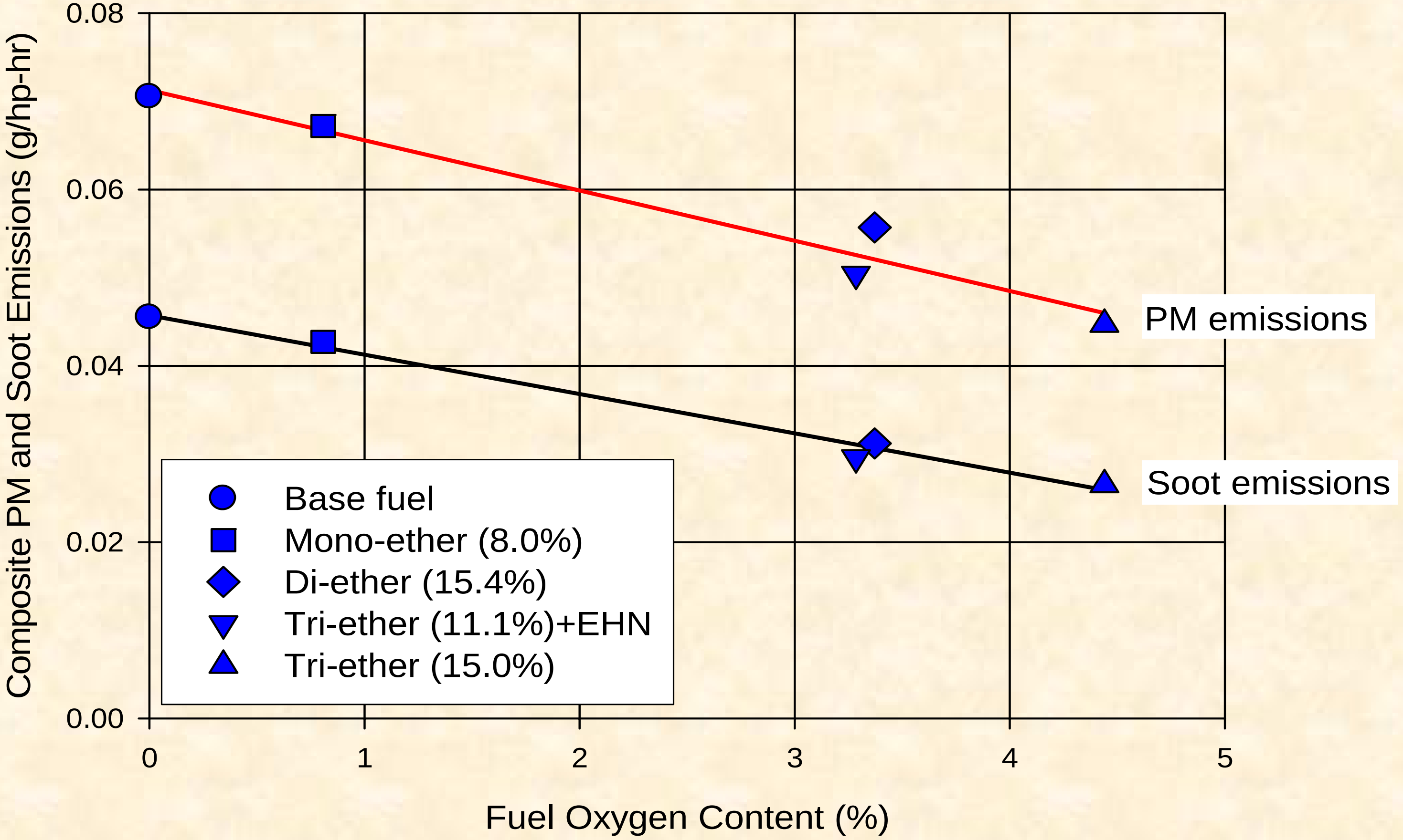
Base Fuel Properties

Density (D4052, kg/m^3)	838
Cetane number (D613)	44
Total aromatics (SFC, mass %)	15
Sulfur content (D5453, mass ppm)	10

Nine options for raising the cetane number of the base fuel by 10 are being evaluated

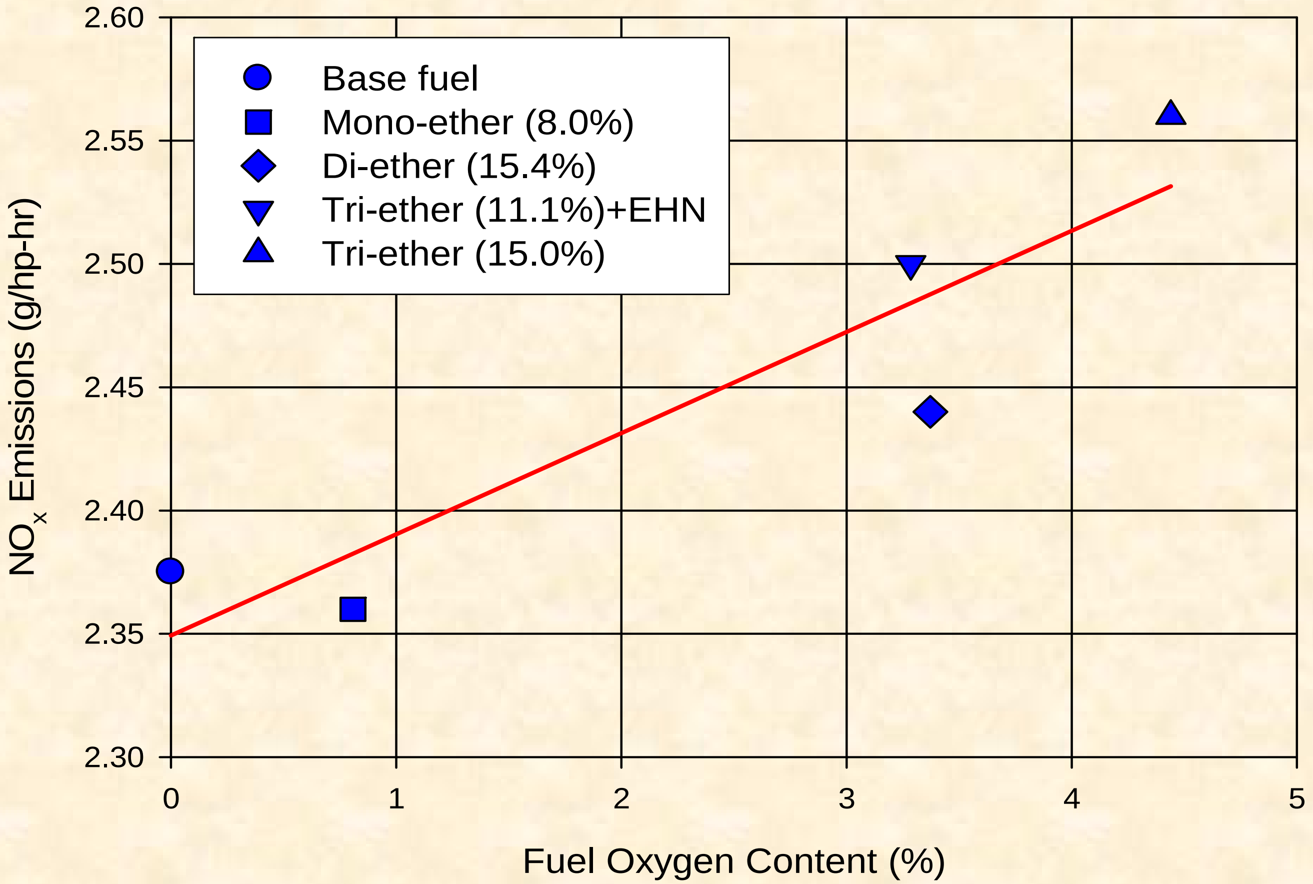
Type	Name / Molecular Structure	Status
Additives	EHN, DTBP	In Progress
Ethers	C_5H_{11}-O-C_5H_{11}	Complete
	C_2H_5-O-C_4H_8-O-C_2H_5	
	C_2H_5-O-C_2H_4-O-C_2H_4-O-C_2H_5 + EHN	
	C_2H_5-O-C_2H_4-O-C_2H_4-O-C_2H_5	
Paraffins	Fischer-Tropsch: n- + iso-C_{10-22} 'SuperCetane': n-C_{14-18}	In Progress
Methyl Ester	biodiesel: n-C_{16-18} esters + EHN	In Progress

PM and soot emissions decrease with increasing fuel oxygen content



- Composite PM emissions with reference fuel = 0.072 ± 0.002 g/hp-hr
- Soot emissions measured upstream of PM filter assembly using Laser-Induced Incandescence (LII)

NO_x emissions increase with increasing fuel oxygen content



- Composite NO_x emissions with reference fuel = 2.39 ± 0.03 g/hp-hr

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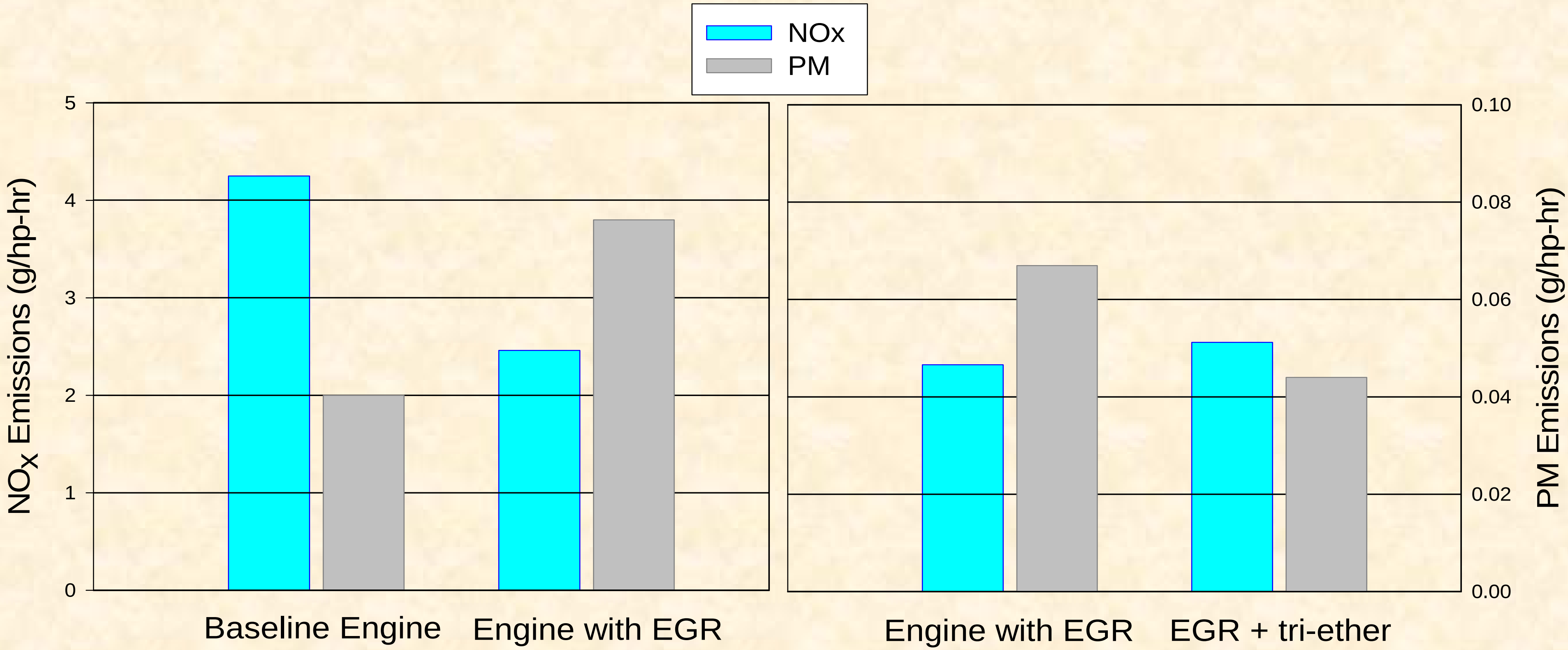
Combustion Research

ULSD base fuel & 15% mass tri-ether



Reference Fuel

(26% mass total aromatics, 356 ppm mass sulfur)

ULSD Base Fuel

(15% mass total aromatics, 10 ppm mass sulfur)

Future Research - Effect of cycloparaffin content and type on diesel emissions

- During upgrading, aromatic rings are saturated to form cycloparaffins
- The effect of cycloparaffins on diesel emissions has not been widely studied
- Challenge – the analytical methods for measuring cycloparaffins are not as well developed as those for aromatics
- Canadian refinery streams have been sampled and are currently being characterized in preparation for a planned study on the effect of cycloparaffins

Summary

Oil Sands/Conventional Fuels

- PM and NO_x emissions from a Cat 3401E engine with EGR were affected by key fuel properties, but not by the crude oil source
    - For PM emissions, the statistically significant fuel properties were total aromatics and sulfur content
    - For NO_x emissions, the statistically significant fuel properties were total aromatics and density

Ether Blends for 10 CN Increase (Preliminary)

- PM emissions decreased and NO_x emissions increased as fuel oxygen content increased
- PM emission reductions with the ether blends were primarily due to a decrease in the soot fraction
- The tri-ether blends provided the largest PM emission benefits while achieving NO_x emissions of 2.5 g/hp-hr

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