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

W. Stuart Neill

National Research Council Canada
Ottawa, Ontario, Canada

9th DEER Conference, Newport, Rhode Island
August 24-28, 2003

Content

- Introduction
- Engine setup
- Results
  - Crude oil source (oil sands/conventional)
  - Ignition quality (additives/components)
- Future Research
- Summary
- Acknowledgements

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

[1] Oil and Gas Journal, December 2002

Photograph courtesy of Syncrude Canada Ltd.

Introduction - II

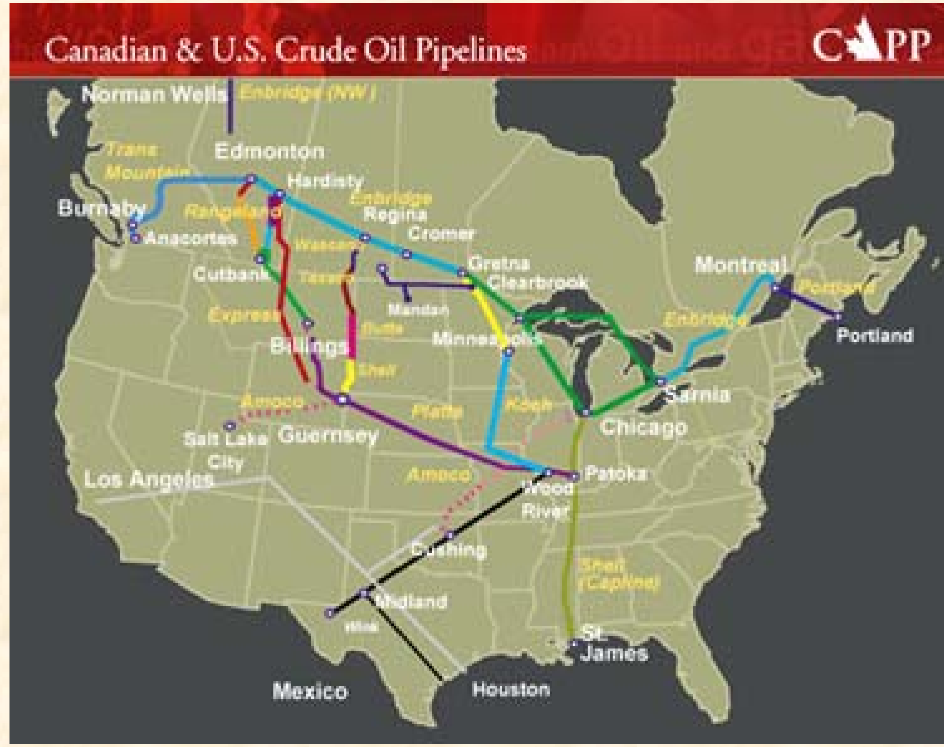
- Unique characteristics of oil sands derived crude reflect the bitumen source and the processes that the bitumen undergoes

- 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

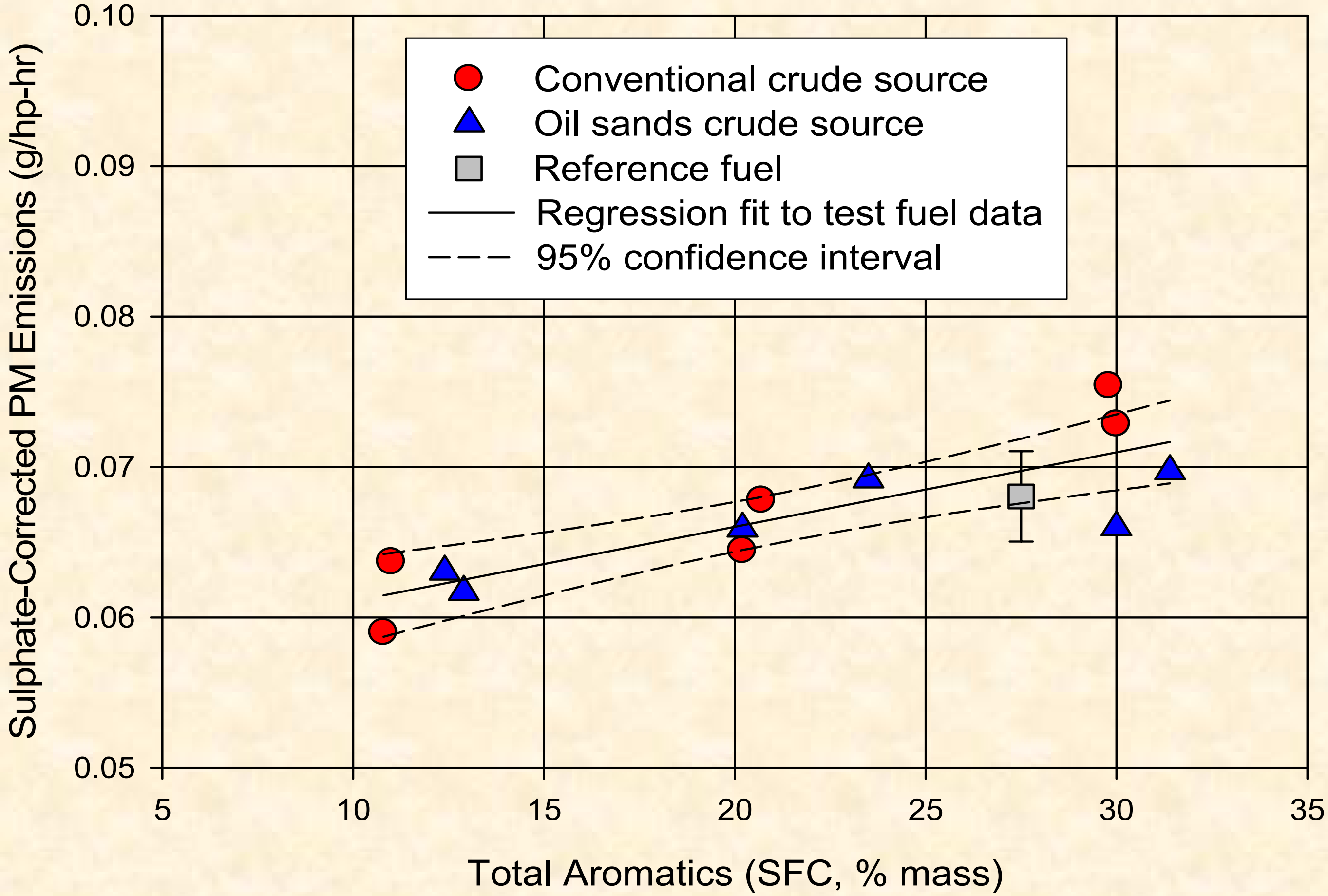
Composite Emissions (g/hp-hr)	Cat 3401E base	Cat 3401E with EGR	Δ (%)
NO_x	4.25	2.46	-42
PM	0.040	0.076	+90

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

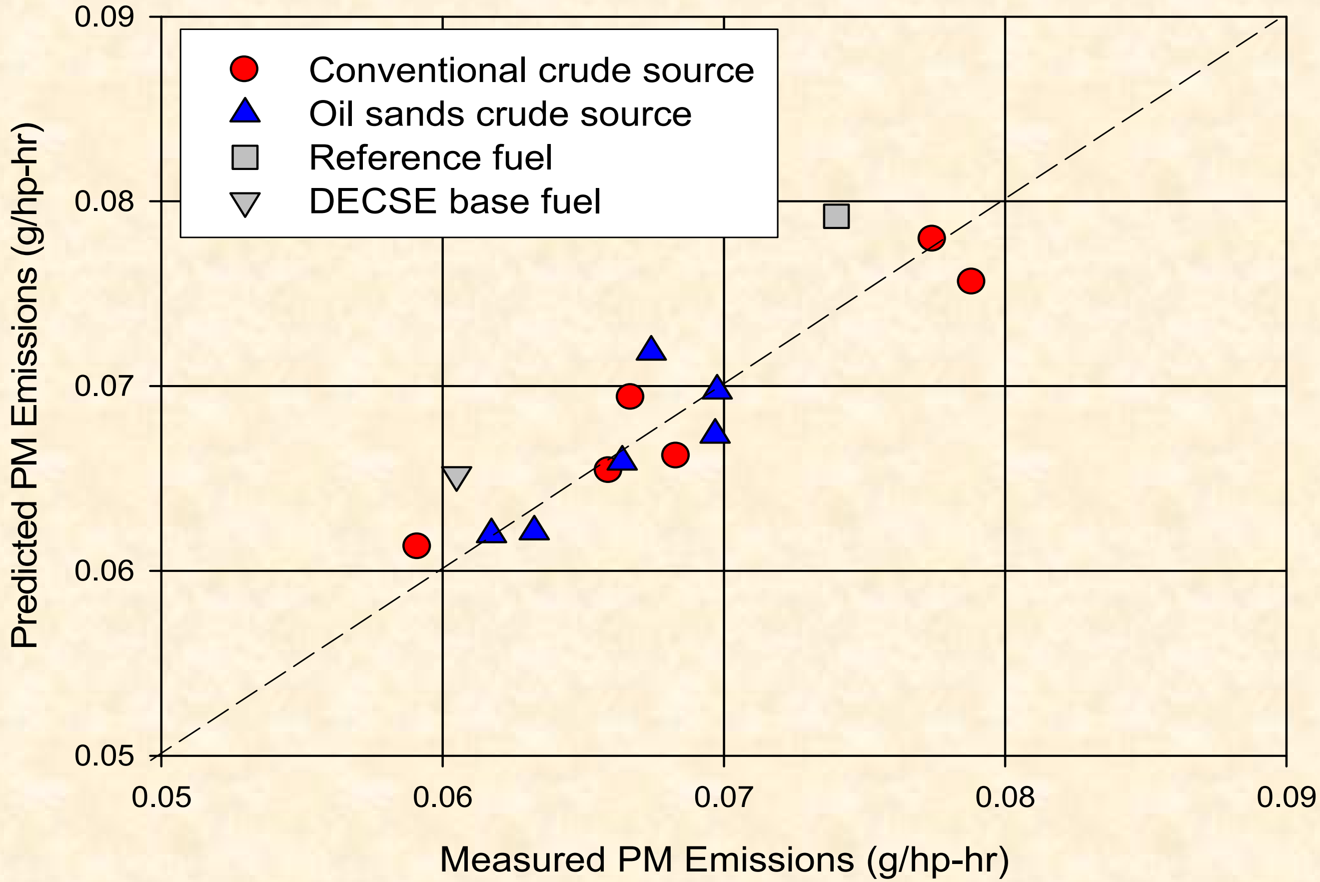
PM Emissions



NRC · CNRC

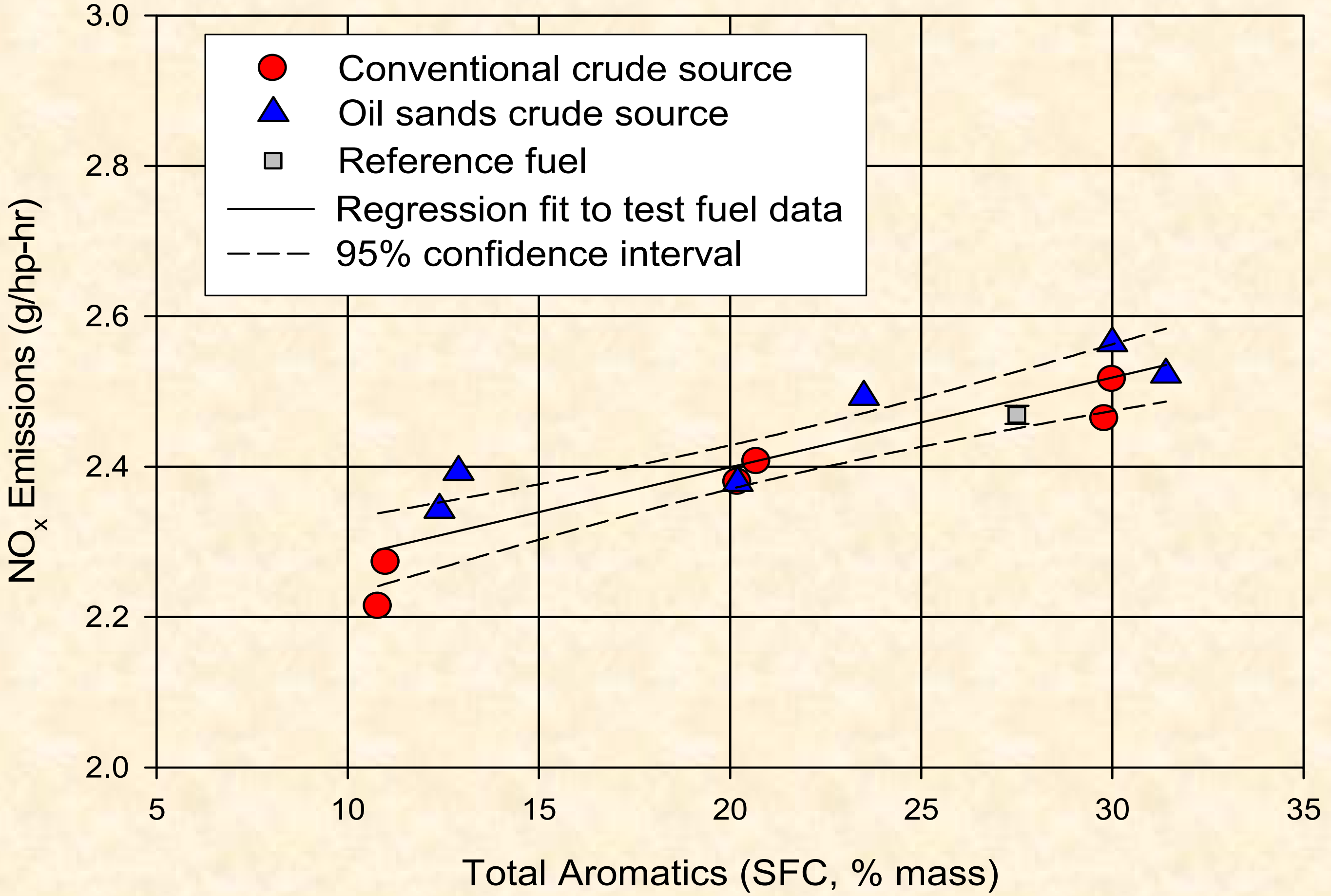
Combustion Research

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

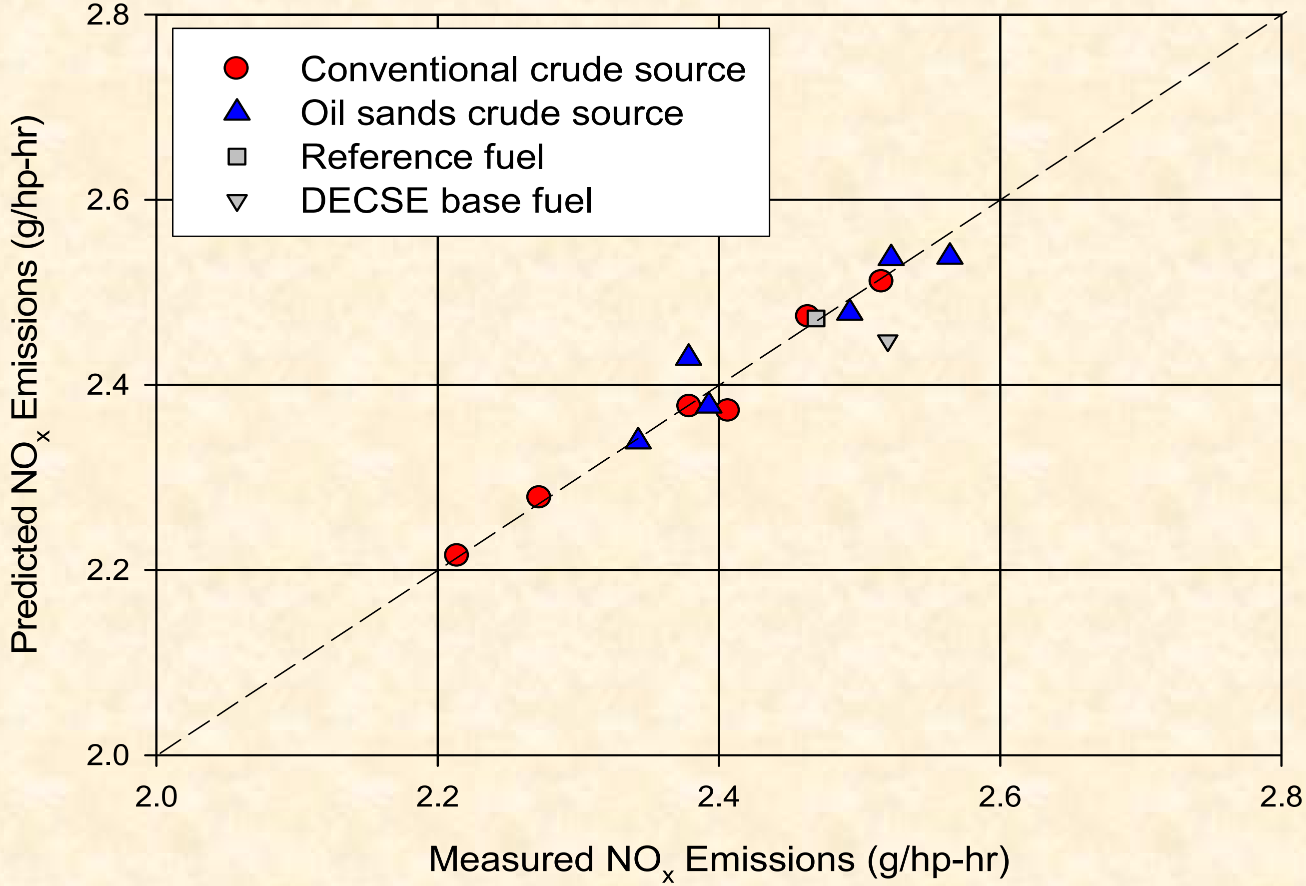


Linear Regression Model for PM Emissions (g/hp-hr) = 4.19×10^{-4} x Tot. Arom. (mass %) + 3.29×10^{-5} x Sulfur (ppm) + 0.057

NO_x Emissions



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

NRC · CNRC

Combustion Research

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

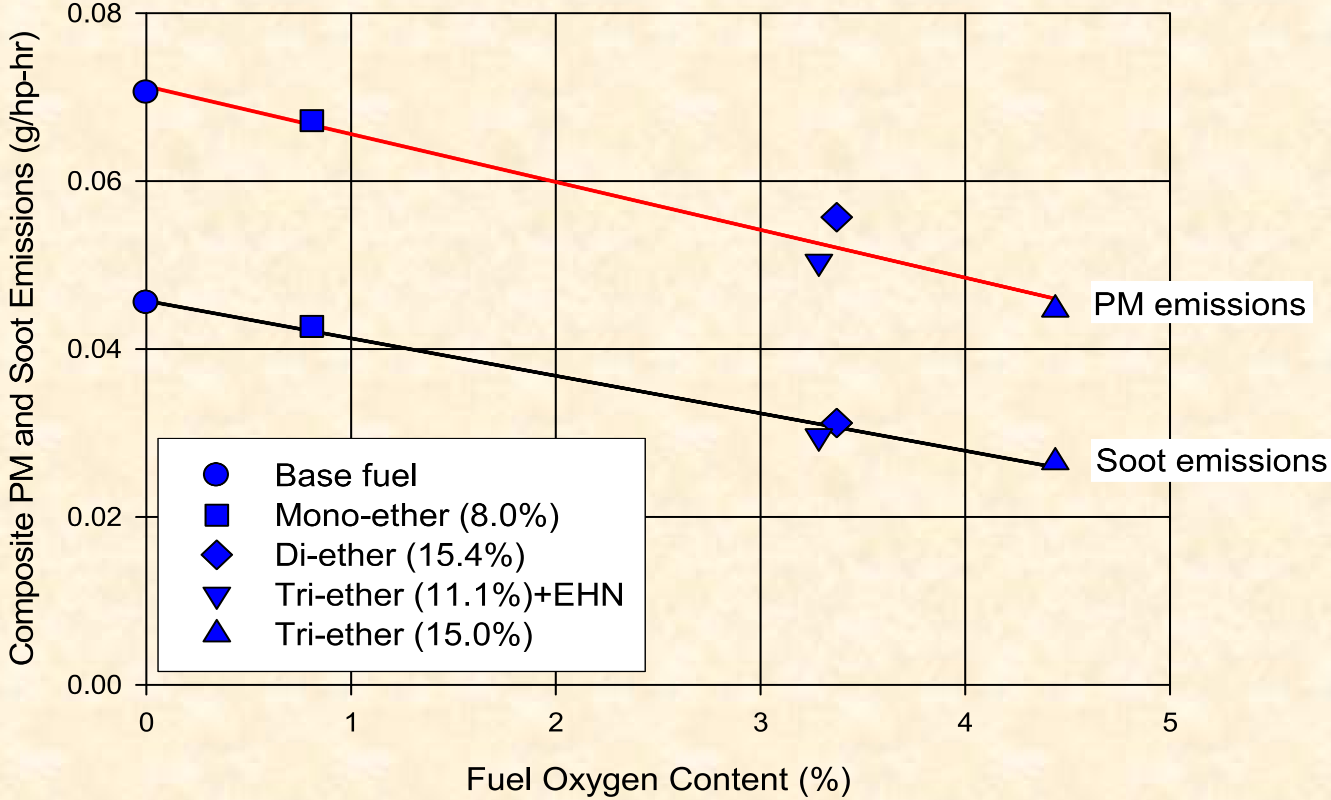
Base Fuel Properties

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

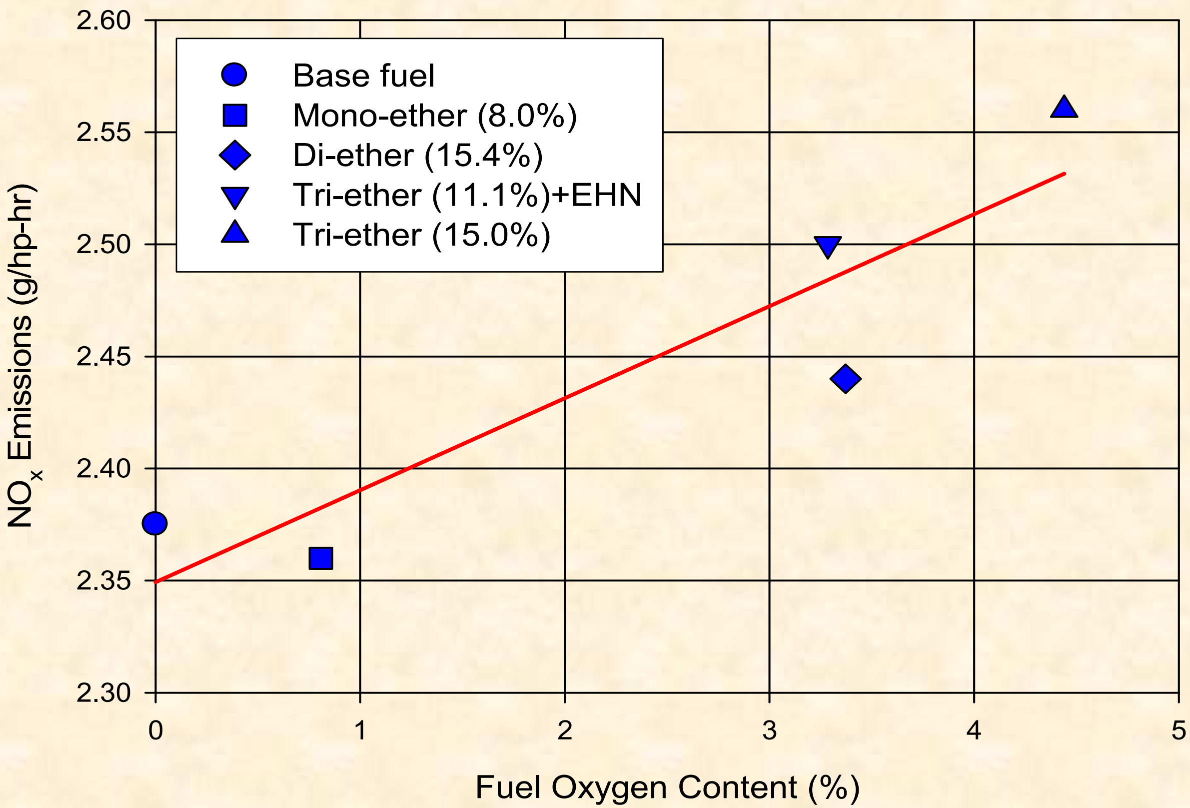
Type	Name / Molecular Structure	Status
Additives	EHN, DTBP	In Progress
Ethers	C_5H_{11}-O-C_5H_{11}	Complete
	C_2H_5-O-C_4H_8-O-C_2H_5	
	C_2H_5-O-C_2H_4-O-C_2H_4-O-C_2H_5 + EHN	
	C_2H_5-O-C_2H_4-O-C_2H_4-O-C_2H_5	
Paraffins	Fischer-Tropsch: n- + iso-C_{10-22} 'SuperCetane': n-C_{14-18}	In Progress
Methyl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

PM and soot emissions decrease with increasing fuel oxygen content



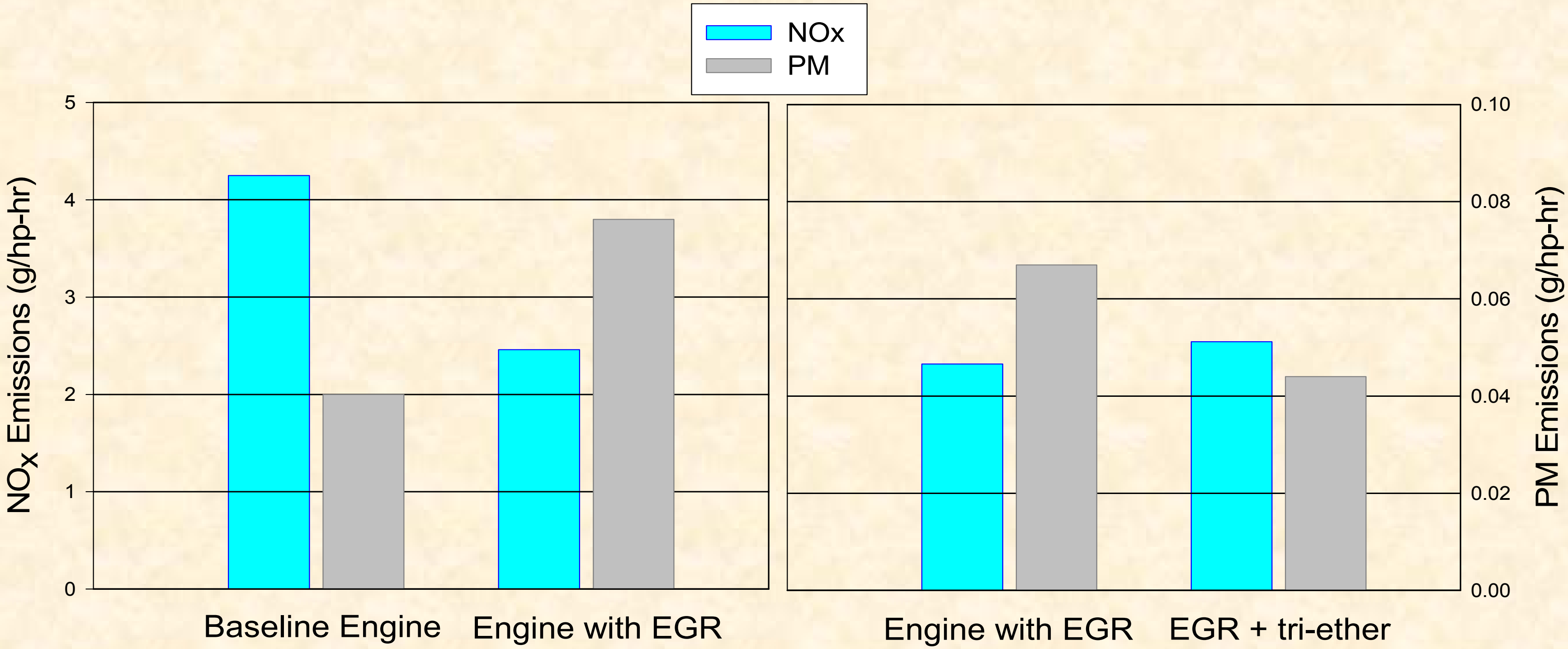
- Composite PM emissions with reference fuel = 0.072 ± 0.002 g/hp-hr
- Soot emissions measured upstream of PM filter assembly using Laser-Induced Incandescence (LII)

NO_x emissions increase with increasing fuel oxygen content



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

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

Acknowledgements

- U.S. DOE/NREL
- Syncrude Canada Ltd.
- Suncor Energy Inc.
- Canadian Petroleum Products Institute
- Shell Canada Ltd.
- Imperial Oil Ltd.
- B.C. Clean Air Research Fund
- Government of Canada - PERD/AFTER Program
- Natural Resources Canada (NRCan)
- National Centre for Upgrading Technology (NCUT)
- National Research Council Canada (NRC)