Development and Demonstration of Fischer-Tropsch Fueled Heavy-Duty Vehicles with Control Technologies for Reduced Diesel Exhaust Emissions

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Program Contributors

- South Coast Air Quality Management District RFP #P2002-18
- National Renewable Energy Laboratory
- Department of Energy
- California Energy Commission
- Other participants:
  - Cummins Engine Company – Supplied engines, modified hardware and engineering support
  - Cleaire – Supplied aftertreatment system and controllers
  - Shell – Supplied Fischer Tropsch and low aromatics baseline test fuel
  - Automotive Testing Laboratories – Supplied program management and will be responsible for vehicle installations
  - Ralph's Grocery - Will use the 2 vehicles for 6 month in service operation

Overall Program Objectives

- Develop the engine including the use of an aftertreatment system to take advantage of the fuel properties of Fischer Tropsch (F-T) fuel for emissions reduction with minimal reduction in engine efficiency.
- Demonstrate the improved emissions on vehicles fitted with modified engine and aftertreatment systems operated in the field for 6 months.

F-T Fuel Properties

	F-T	Base Fuel
Aromatics %	**<0.1**	**8.1**
Density g/cm3	**0.7836**	**0.8320**
Cetane -	**>76**	**42.1**
Heating Value Btu/lb	**20290**	**19843**
Sulfur ppmV	**<1**	**2**

Objectives of Engine Development Task

- Perform transient dynamometer tests to establish baseline hydrocarbon (HC), NOx, CO, PM, and CO_2 emissions from each unmodified engine when fueled alternately by F-T and base diesel fuels.
- Modify the engines' combustion systems to take advantage of the high cetane value of F-T fuel and improve the EGR tolerance.
- Retrofit the engines' exhaust systems with a NOx catalyst and diesel particle filters to meet the emissions goals of:

  NOx 1.2 g/hp.h

  PM 0.01 g/hp.h

  HC 1.3 g/hp.h

  CO 15.5 g/hp.h

  NO_2 0.4 g/hp.h

Overview of Approach

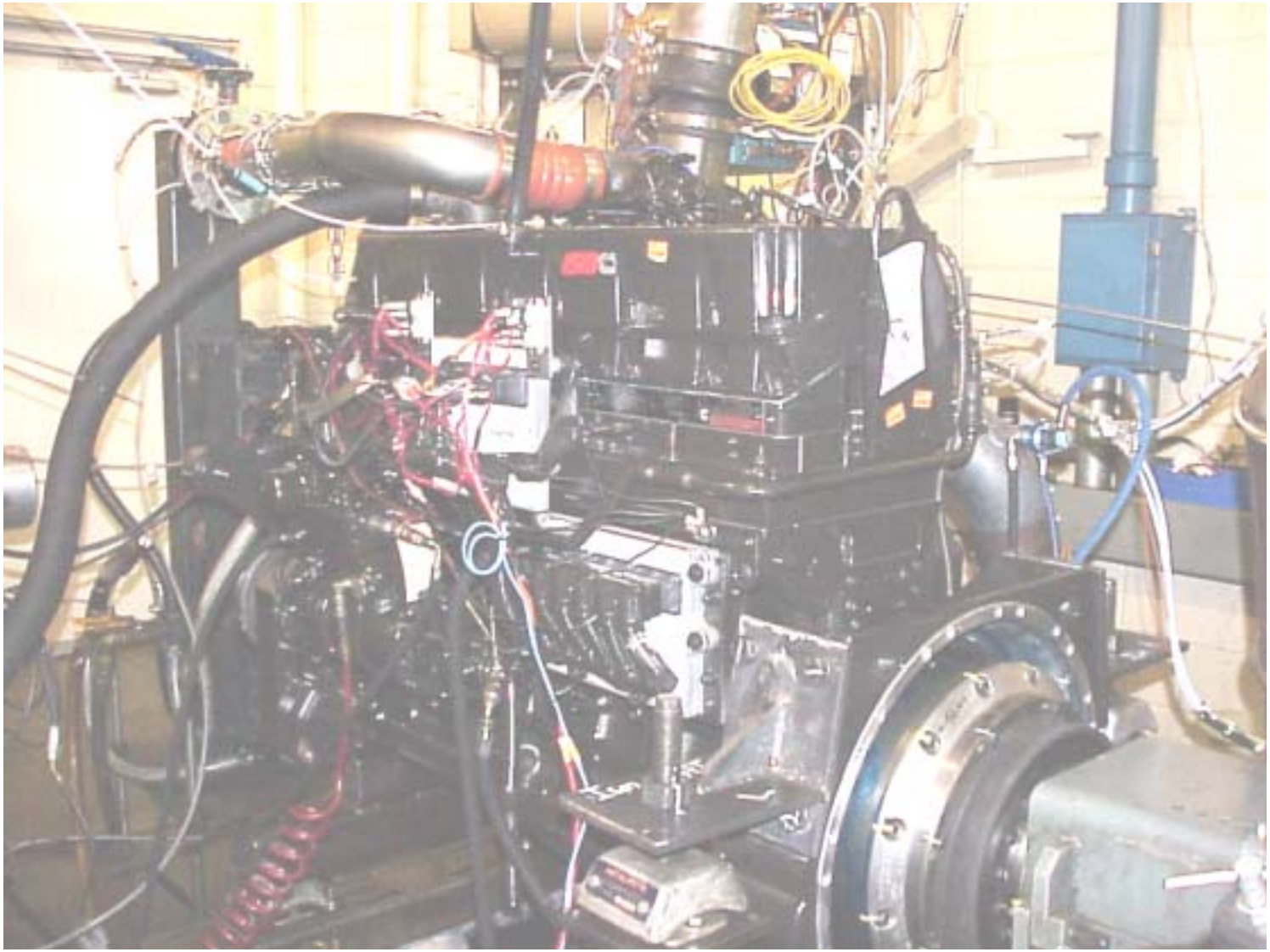
	NOx	
❑ Baseline 2002 Cummins ISM with EGR, base diesel:	2.3	g/hp.h
	↓	
❑ Using F-T diesel fuel	2.0	g/hp.h
	↓	
❑ Higher EGR rate, new combustion bowl, F-T diesel:	1.5	g/hp.h
	↓	
❑ Higher EGR rate, new combustion bowl, F-T diesel, DPF, Lean NOx catalyst:	1.2	g/hp.h

Cummins ISM Engine

- Cummins supplied two ISM 6 cylinder 10.8 liter heavy duty diesel engines, certified to October 2002 emissions limits, features include:
  - High pressure electronically controlled unit injector
  - 4 valves/cylinder
  - Two piece pistons with steel crown
  - Cooled EGR
  - Variable geometry turbocharger

- Cummins supplied 2 sets of special ECM's which allowed new calibrations to be programmed, plus software and training

Engine in Testcell at Ricardo



Summary of Baseline Results

- Composite (weighted cold and hot) FTP results on the low aromatic base fuel and F-T fuels are as follows:

Fuel	NOx	THC	PM	BSFC	Engine Build
	g/hp.h	g/hp.h	g/hp.h	g/hp.h	
Base	2.08	0.33	0.125	196.5	Base
F-T	1.96	0.22	0.102	191.8	Base
% Reduction	5.5	33.4	18.7	2.4	

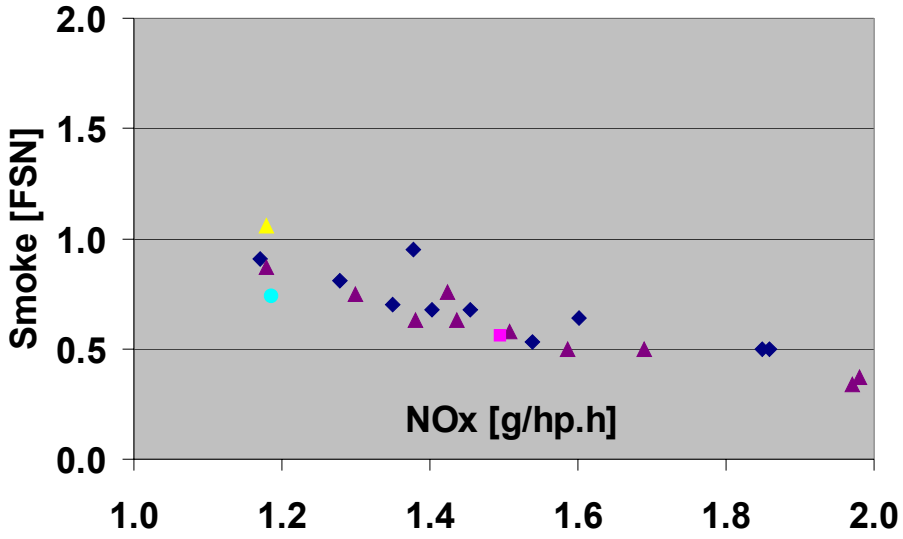
- At the same engine fuelling peak power is slightly reduced on F-T fuel due to the lower fuel density.

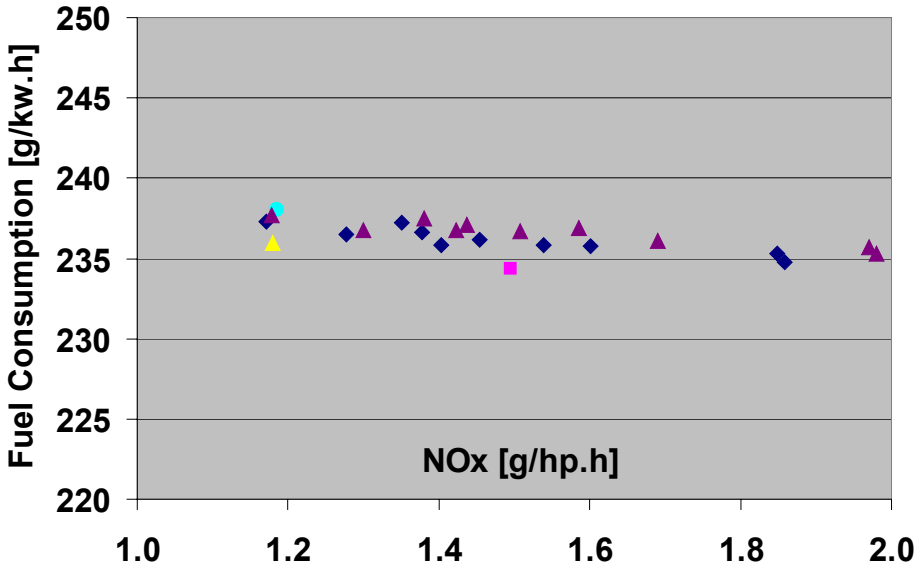
Modified Combustion Bowl

- Combustion bowl was modified to reduce compression ratio to improve air utilization and generate more air motion to compensate for higher EGR

EGR Response

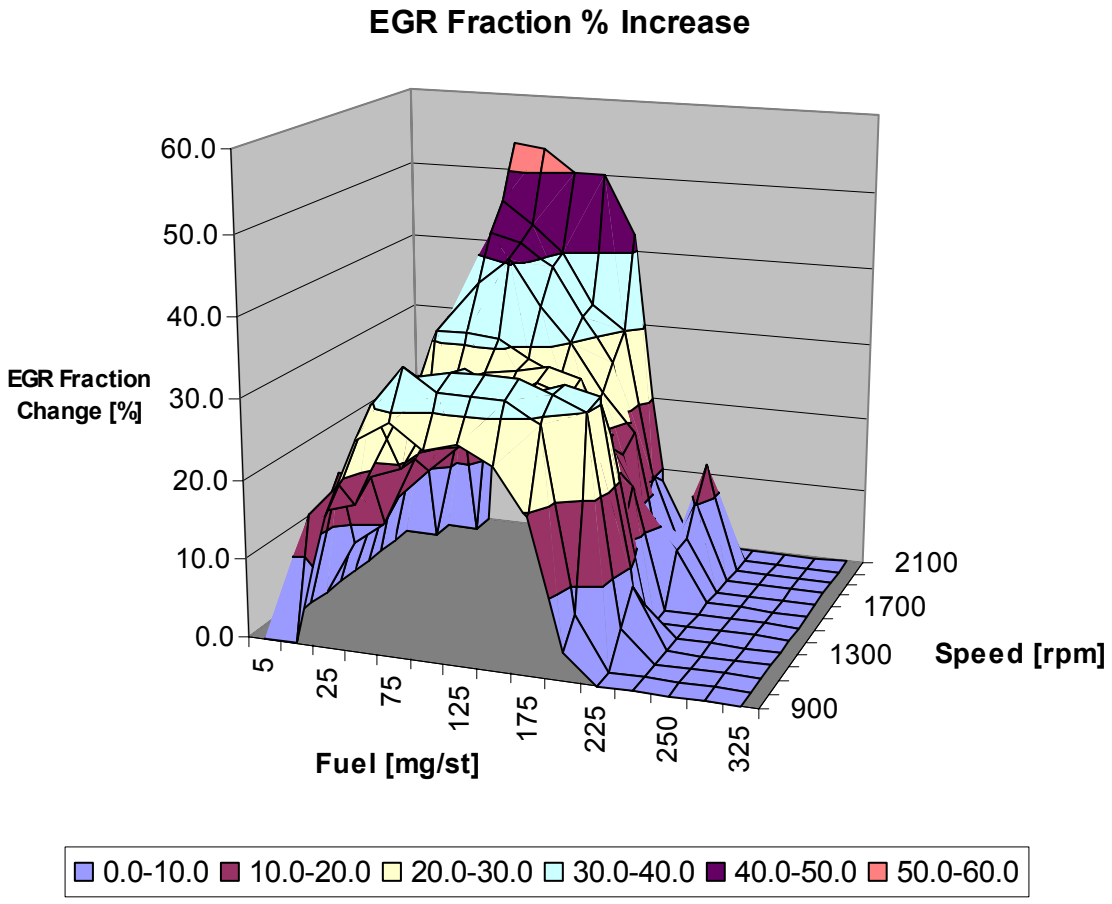
- Example of the engine response to varying EGR rate at a part load operating point, for various engine builds





Modified EGR Map

- EGR rate is substantially increased, chart shows ratio of new EGR rate to baseline EGR rate

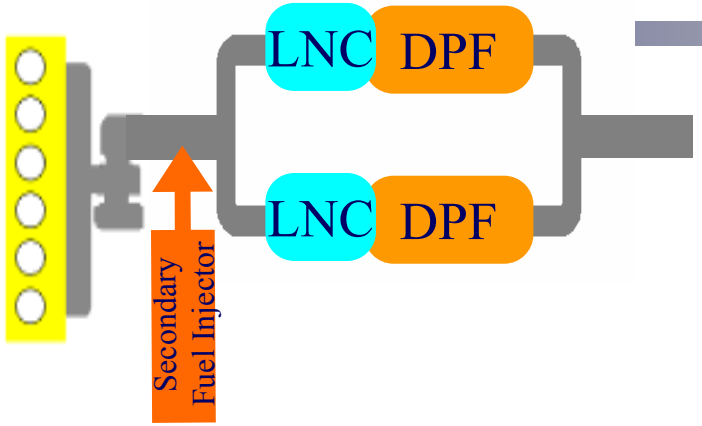


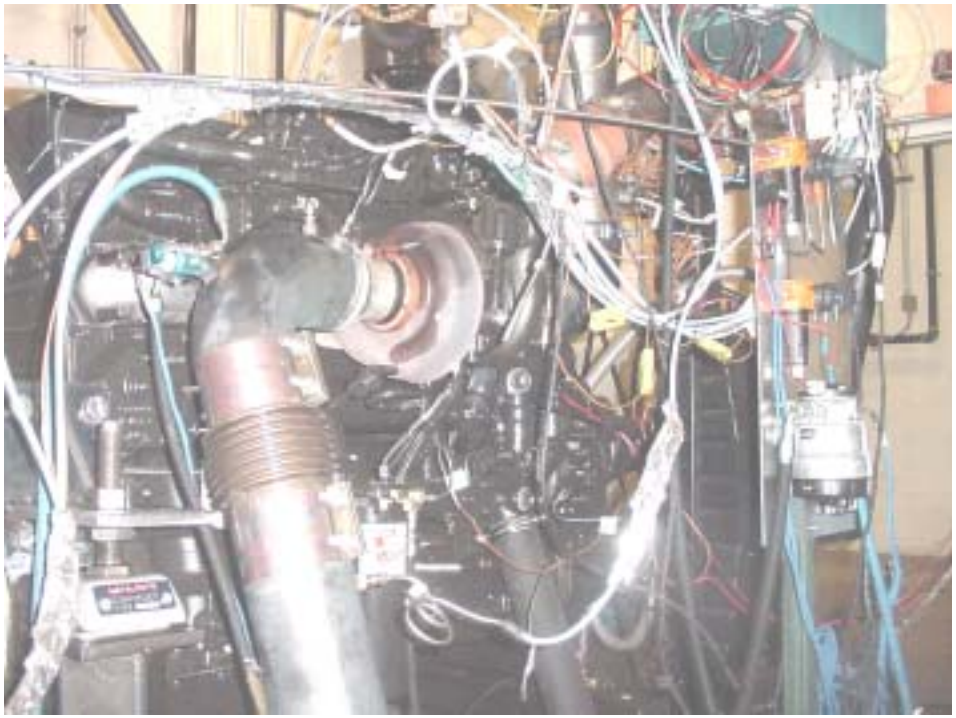
FTP Results With Modified Combustion

- Composite FTP results below show the effect of the combustion system changes and increased EGR

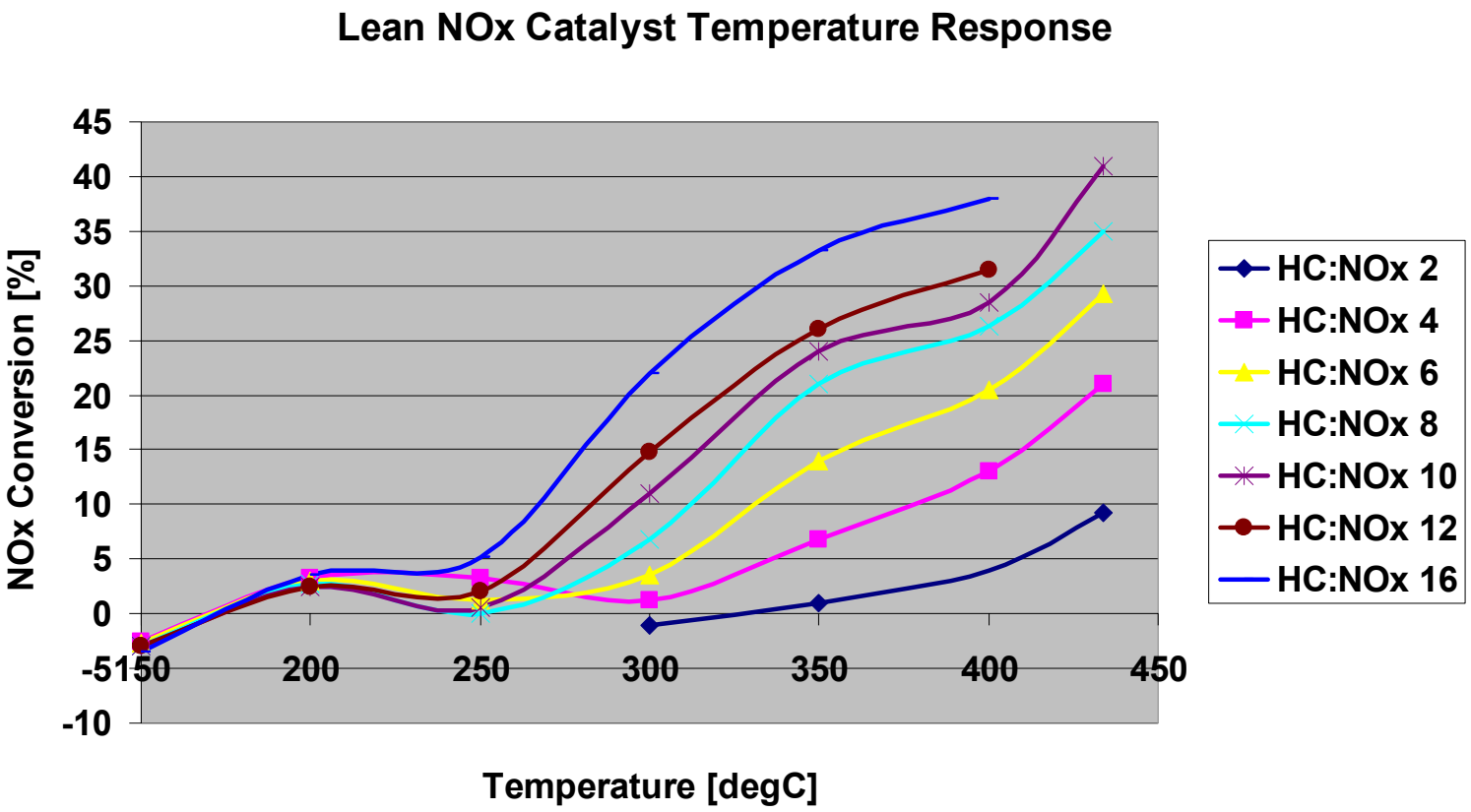
Fuel	NOx	THC	PM	BSFC	Engine Build
	g/hp.h	g/hp.h	g/hp.h	g/hp.h	
F-T	1.96	0.22	0.102	191.8	Base
F-T	1.56	0.18	0.122	197.0	Modified combustion, increased EGR
% Reduction	20.5	17.3	-20.1	-2.7	

Aftertreatment System





Catalyst DeNOx Response



- Secondary fuel rate of 12 HC:NOx ratio selected

Final Optimized Engine Results

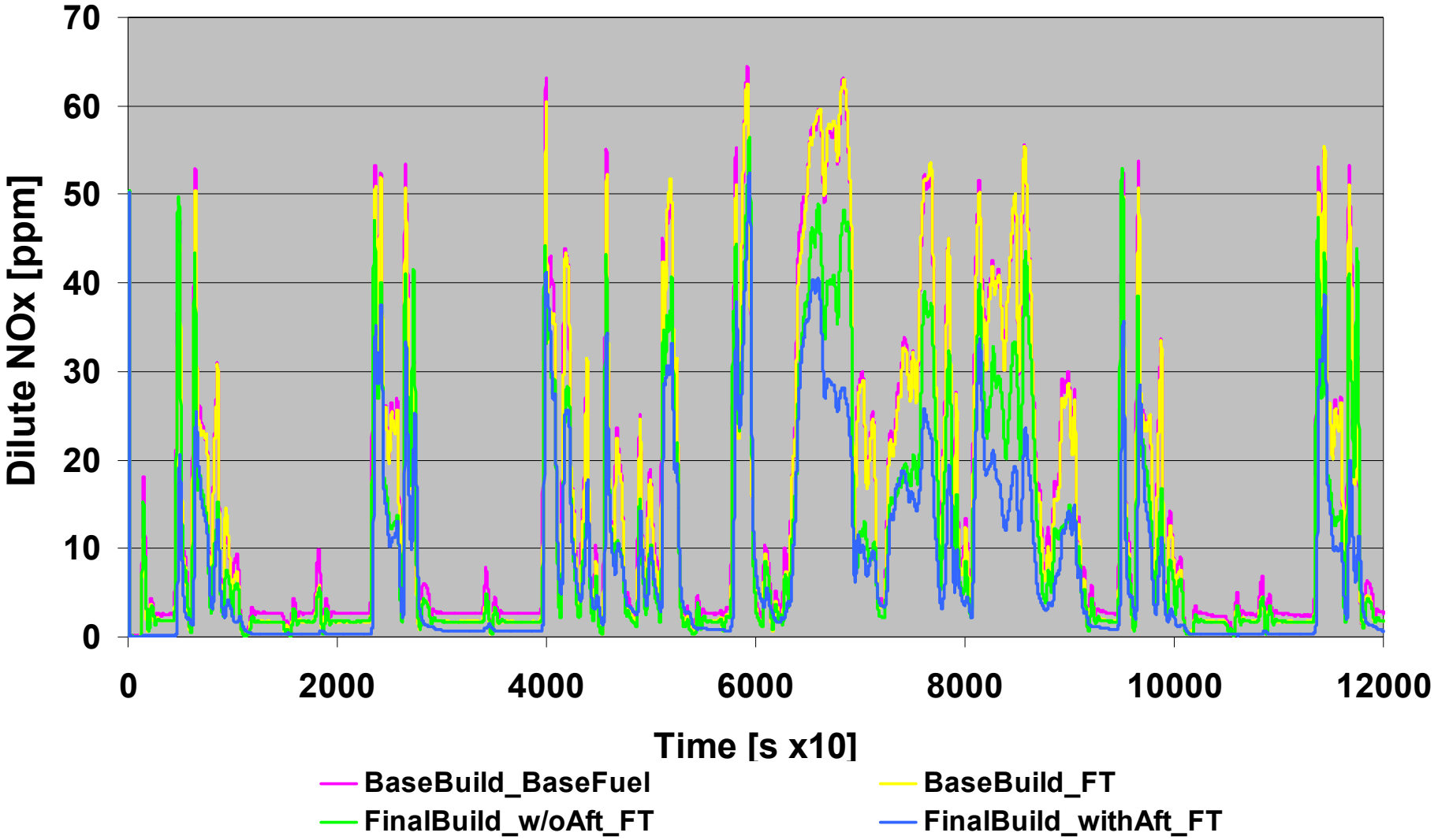
- Composite results (cold and hot FTP cycles) compared below.
- Effect of the catalyst and DPF on emissions:

Fuel	NOx	THC	PM	BSFC	Engine Build
	g/hp.h	g/hp.h	g/hp.h	g/hp.h	
F-T	1.52	0.19	0.122	196.8	Modified combustion, increased EGR
F-T	1.17	0.04	0.005	205.2	As above with exhaust aftertreatment
% Reduction	23.1	77.2	96.0	-4.3	

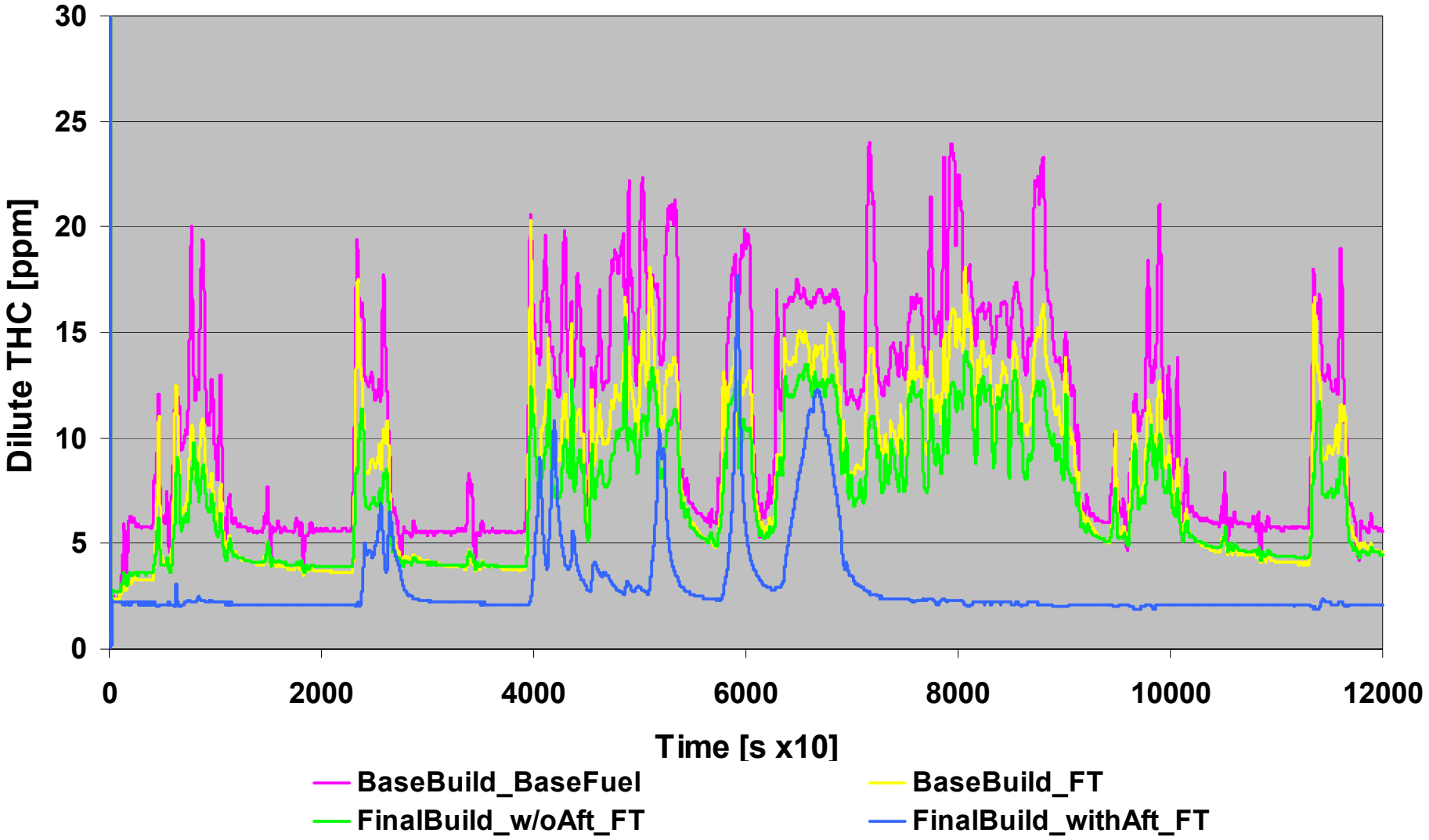
- Overall emission reduction compared to base engine on base fuel:

Fuel	NOx	THC	PM	BSFC	Engine Build
	g/hp.h	g/hp.h	g/hp.h	g/hp.h	
Base	2.08	0.33	0.125	196.5	Base
F-T	1.17	0.04	0.005	205.2	Mod. Comb, incr. EGR, Aftertreatment
% Reduction	43.9	87.3	96.1	-4.4	

Final Optimized Hot FTP Cycle NOx Trace



Final Optimized Hot FTP Cycle HC Trace



Conclusions

- Significant improvements in base engine emissions were measured with F-T fuel
- The engines have been modified to take advantage of superior properties of the F-T fuel and an aftertreatment system was installed
- Emissions targets are achieved, the testcell work is complete and the two engines are ready for installation in the vehicles:

FTP Cycle	Target g/hp.h	Achieved g/hp.h
NOx	1.2	1.17
Pm	0.01	0.005
HC	1.3	0.04
CO	15.5	0.06
NO_2	0.4	0.3

- The fuel consumption penalty over the FTP cycle was 4.4% for a 43.9% reduction in NOx emissions. The increased EGR + lean NOx catalyst + DPF approach shows potential for meeting 2007 emissions standards.