DEVELOPMENT OF ADECS TO MEET 2010 EMISSION LEVELS: OPTIMIZATION OF NO_X, NH_3 AND FUEL CONSUMPTION USING HIGH AND LOW ENGINE-OUT NOx CALIBRATIONS

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Introduction

- Temporary deactivation of an SCR system due to insufficient heat in the exhaust could result in doubling the tailpipe NOx emissions
- SCR technology allows for an engine to be programmed for optimum FC, which could lead to higher engine-out NOx emission levels (Low FC-High NOx calibration)
- Alternative engine maps that limit NOx levels (Low NOx calibration) must be available for engine control in the event of SCR malfunction or failure

Objectives

- To develop and validate a simple strategy-based technique, involving variation of four engine parameters (SOI, NOP, EGR, VGT) capable of minimizing the emissions and achieving FC improvements.

- To program the engine with multiple calibrations (Low-NOx and Low-FC maps) that optimize the exhaust gasses for aftertreatment applications.

- To evaluate the response of a given aftertreatment system under multiple calibrations.

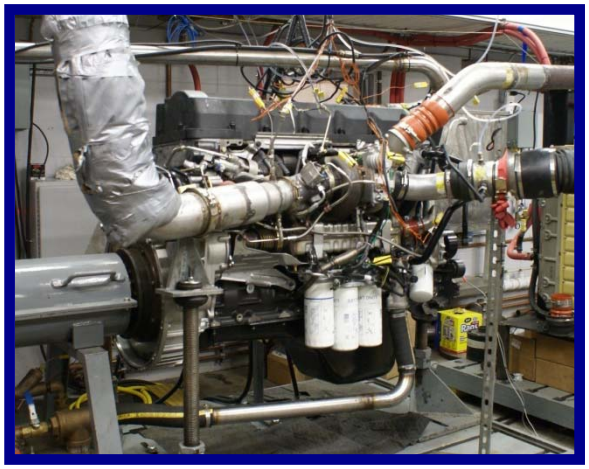
ADECS Level 1: Engine-out NOx Reduction

VOLVO MY04

Engine Output: 355 hp @ 1800 / 1360 lb-ft @ 1200 rpm

VOLVO MY07

Engine Output: 339 hp @ 1800 / 1298 lb-ft @ 1306 rpm

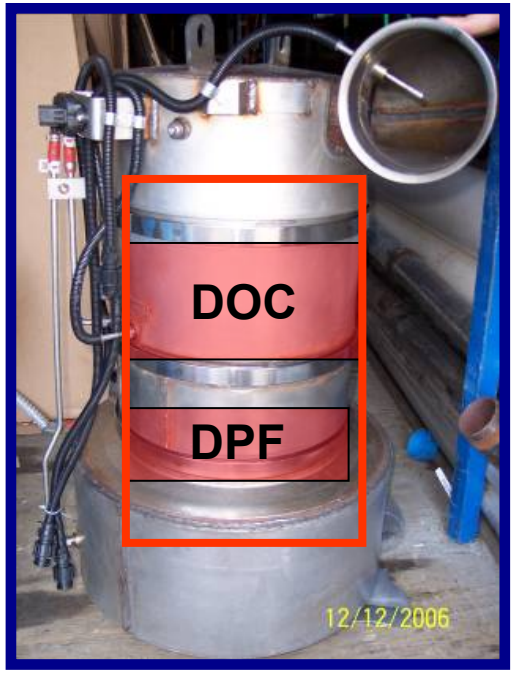


Major changes:

Enhanced cooled EGR
Enhanced injection capability
- Larger EGC
- New overhead camshaft
- Increased piping diameter
- Strengthened gear train to accommodate the 2400 bar injection pressure
- Venturi and delta P sensor to measure EGR flow
- New EGR mixer

ADECS Level 2: Aftertreatment for 2010

DPF system



- The DPF is a Fleetgard compact saver equipped with DOC, temperature and pressure sensors
- A seventh injector is available for active regeneration

SCR System

- SCR manufactured by Johnson Matthey.
- Urea pump equipped with independent custom-built controller based on urea, NO_2/NO ratio, exhaust temperature maps.

Urea injector

Catalyst Substrate

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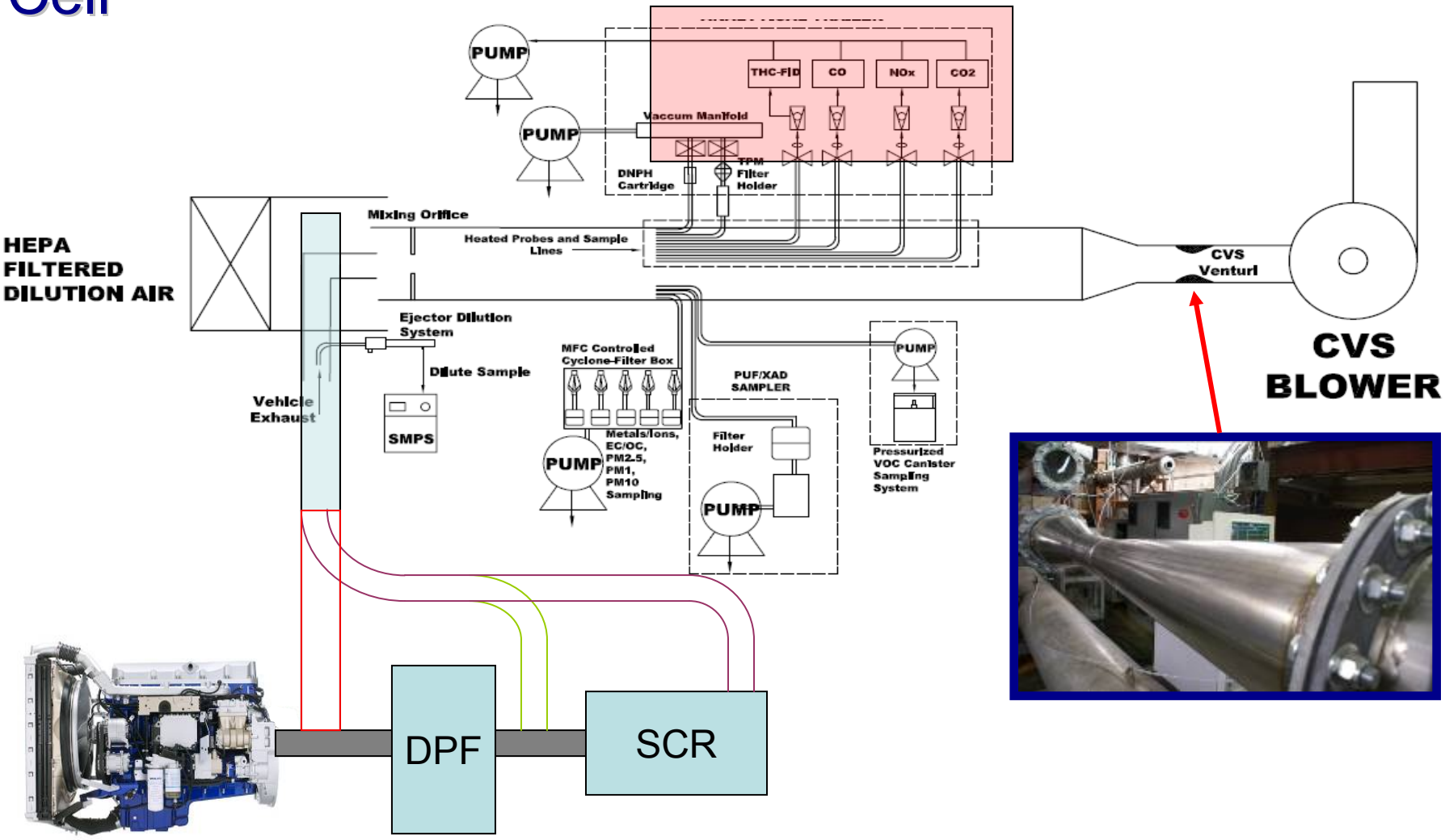
SOUTH COAST AQMD

Experimental Set up: WVU EERL HD Test Cell



Experimental Set up:
NOx and NH_3 Measurement System

Chemiluminescent analyzer

- Chemiluniscent analyzer for wet measurement of NOx and NO;
- Eco-Physics CLD822CMh

NDUV analyzer

- NDUV analyzer for simultaneous measurement of wet $NO/NO_2/NH_3$
- Limas-11 HW equipped with sample processing system

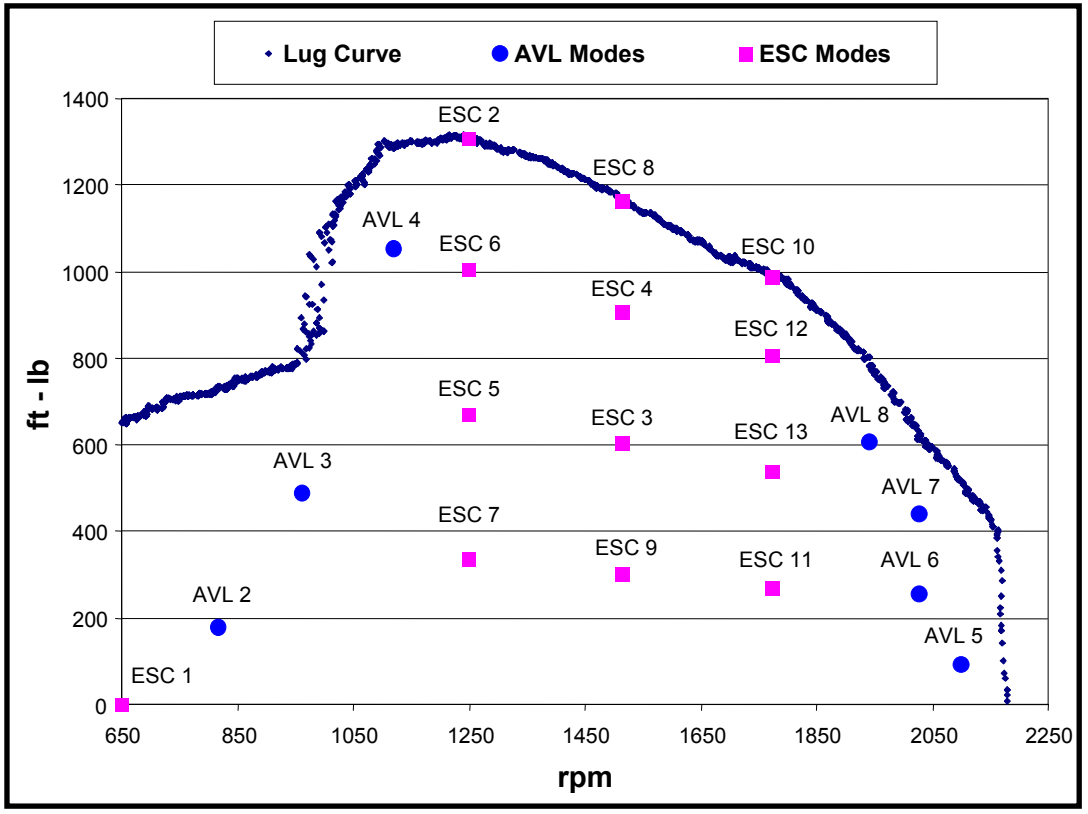
Methodology : Calibration generation

Low-NOx =>High EGR / High NOP

Engine Parameters	Level 1	Level 2	Level 3
EGR	Baseline	+	+ +
VGT	- -	-	Baseline
SOI	-	Baseline	+
NOP	Baseline	+	+ +

Orthogonal matrix

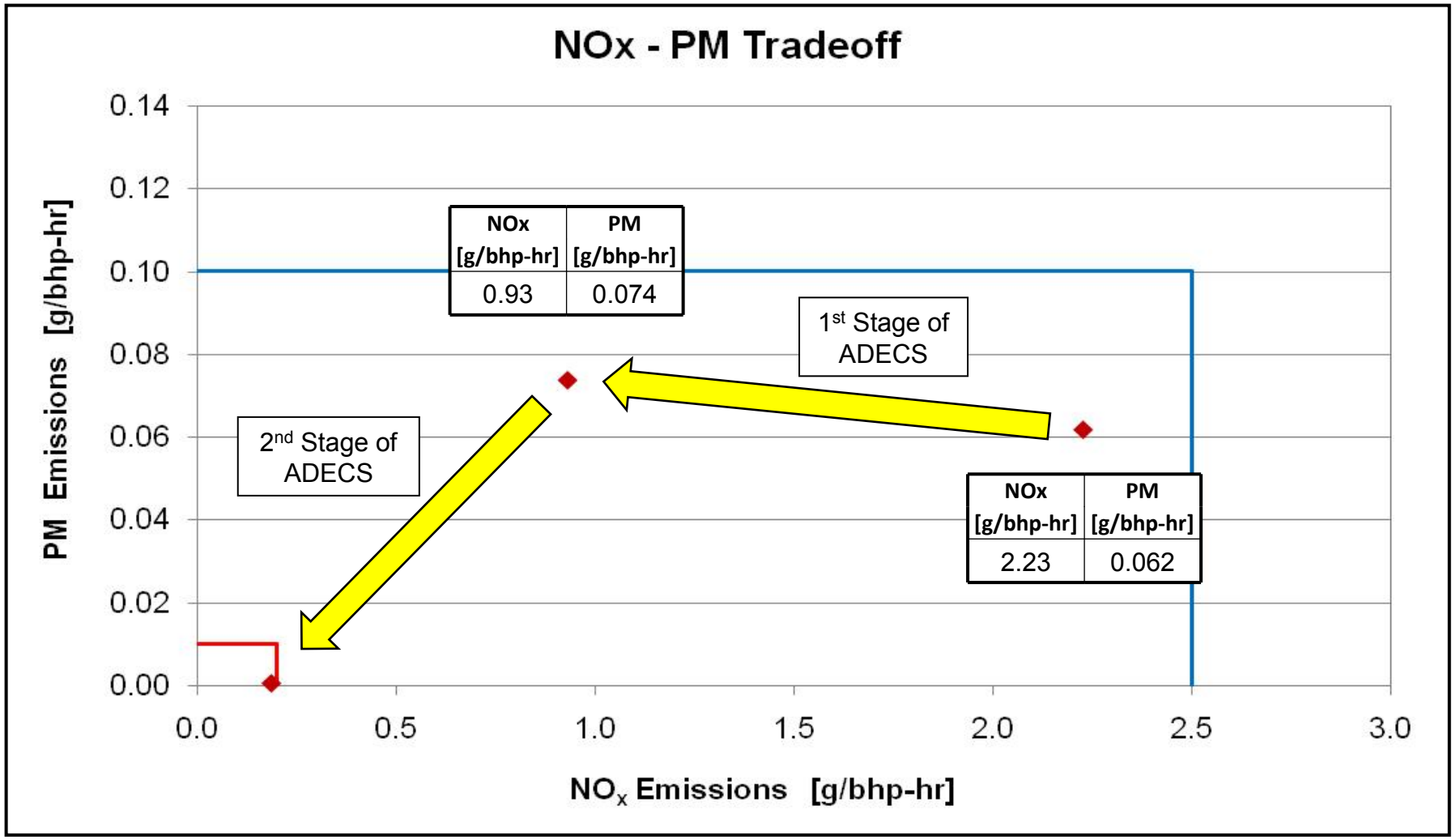
	NOP	VGT	EGR	SOI
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1



Methodology :Evaluation of the Exhaust Aftertreatment System Response

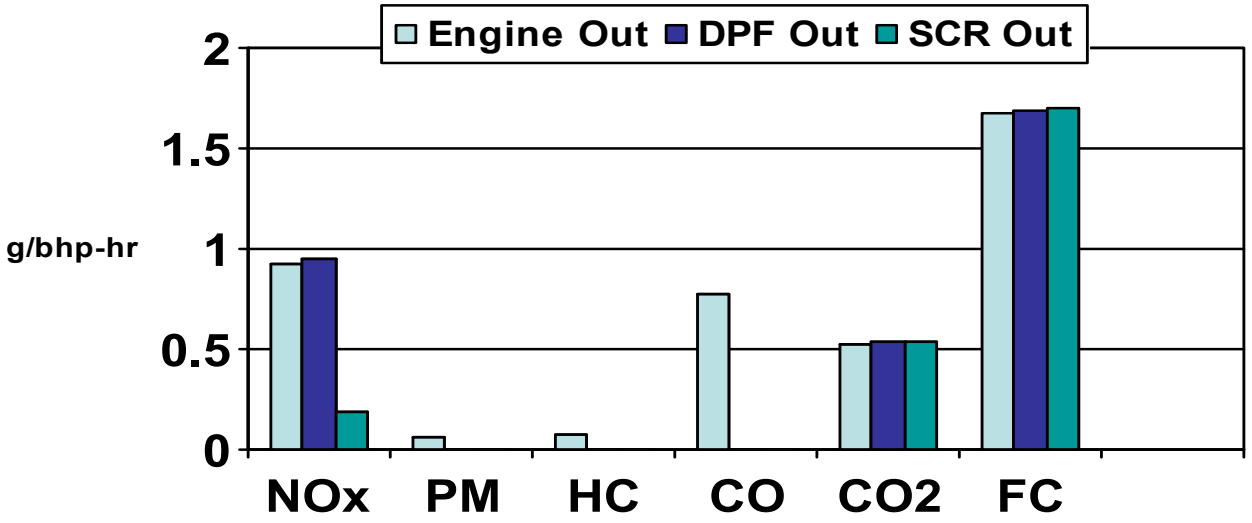
- **ADECS Requirements**:
  - NOx engine-out emissions: 1 g/bhp-hr, achieved with Low NOx calibration
  - Development of DPF-SCR exhaust aftertreament system for 2010 emissions levels
- **Generated different engine calibrations**:
  - Low-NOx / Low-PM
  - Low-NOx / High-PM
  - Low-NOx / Low-FC
  - Low-FC
- **Evaluated the DPF/SCR system over three engine calibrations**:
  - Transient (FTP) and steady state (ESC) cycles
  - Emissions measurements at three different sampling locations (Engine-out, DPF-out, SCR-out)

Results: Low NOx Calibration, ADECS Results



Results: Low NOx Calibration, Emission Levels

- **Low -NOx calibration meets ADECS requirements**

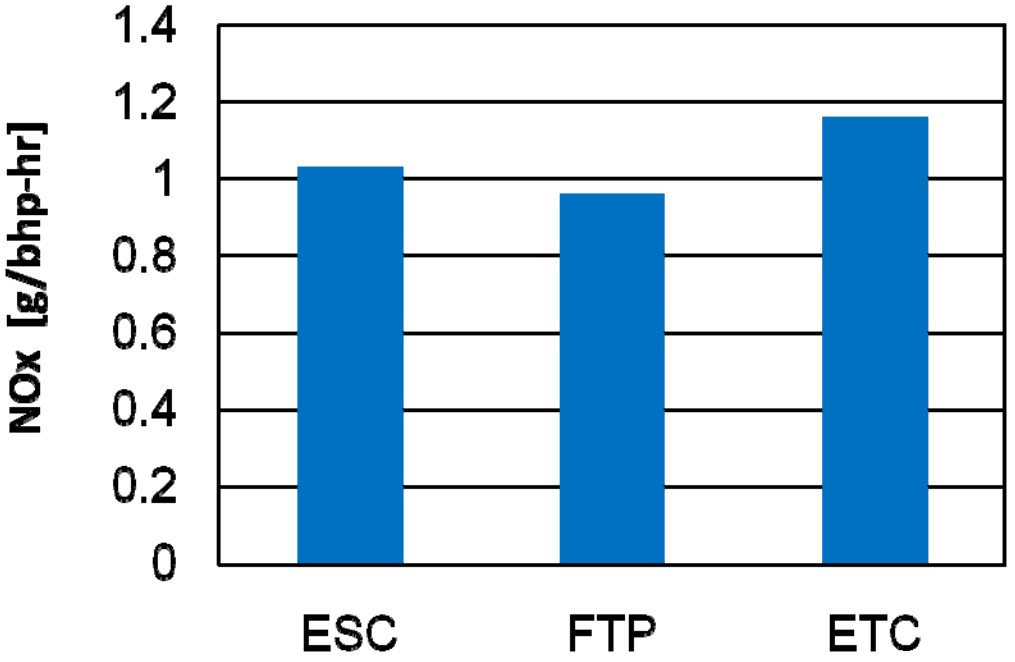


	NOx	PM	HC	CO	CO2/1000	FC/100
	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr	g/bhp-hr
Engine Out	0.93	0.074	0.08	0.78	0.531	1.67
DPF Out	0.95	0.001	0	0.01	0.535	1.68
SCR Out	0.19	0.001	0	0.01	0.538	1.69

Results: Low-NOx Calibration, Test Cycles

- Emission levels are not engine cycle dependent: Low-NOx exhibited comparable emissions over the ETC cycle, even though it was realized based on ESC and FTP test data

Test Cycle	NOx g/bhp-hr
ESC	1.03
FTP	0.93
ETC	1.16

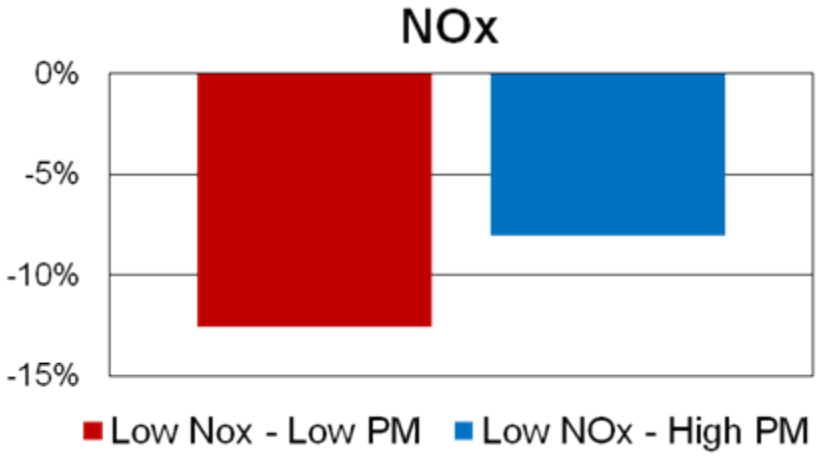


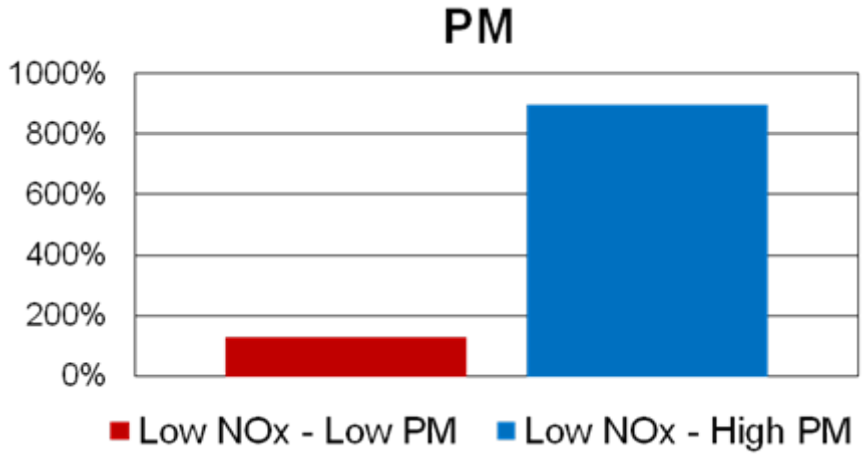
Results: Low-NOx Maps Comparison

- Two calibrations targeting NOx emissions at different PM levels (steady state)

Calibrations	NOx (g/bhp-hr)	PM (g/bhp-hr)
Baseline	1.12	0.03
Low-NOx/Low-PM	0.98	0.07
Low-NOx/High-PM	1.03	0.3

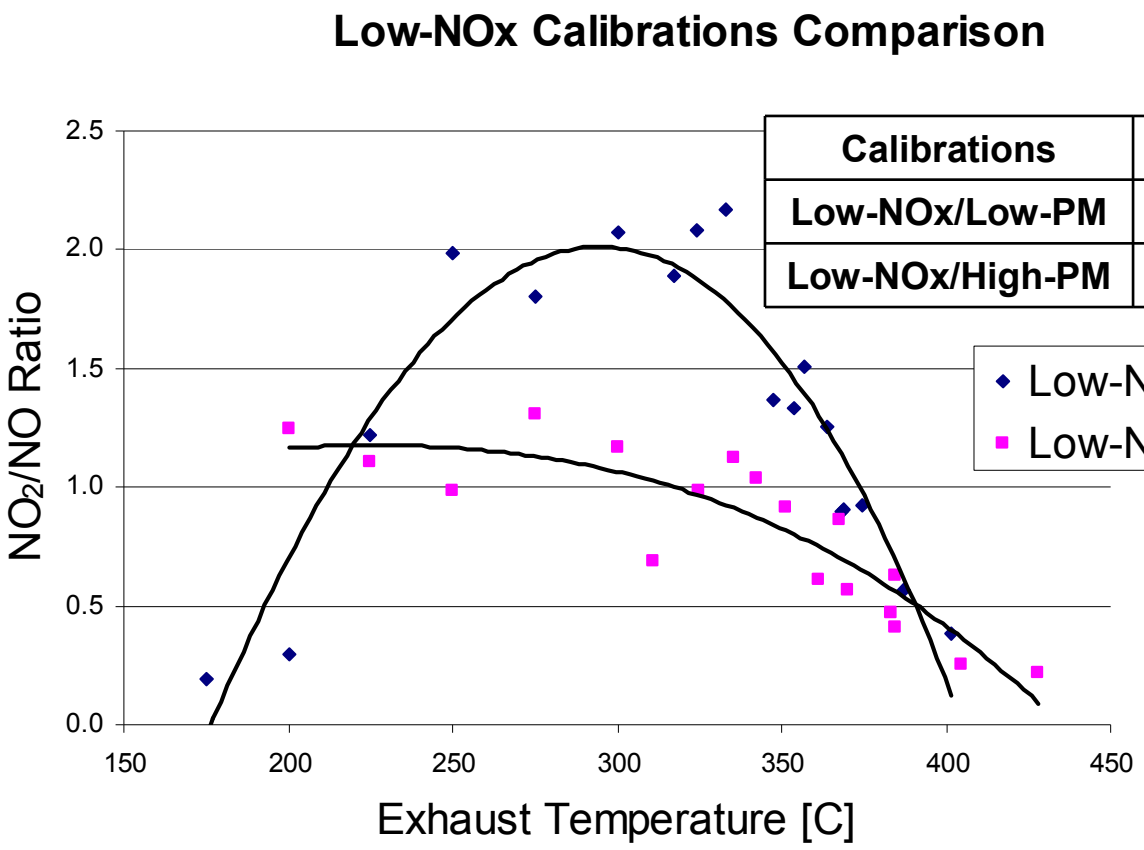
- Calibrations compared to the baseline





Results: Exhaust Aftertreatment System Response, DPF Loading

- Calibration at higher PM level lowered NO_2/NO ratio, due to DPF passive regeneration



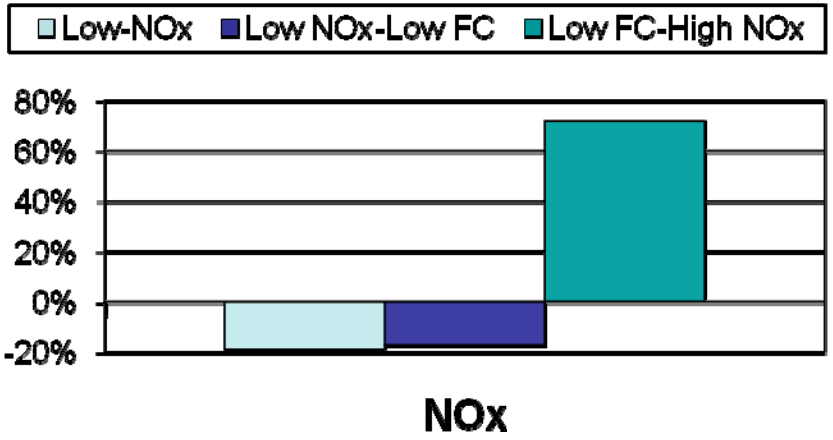
Calibrations	SCR eff. (%)	NO_2/NO Ratio
Low-NOx/Low-PM	77	1.33
Low-NOx/High-PM	68	0.81

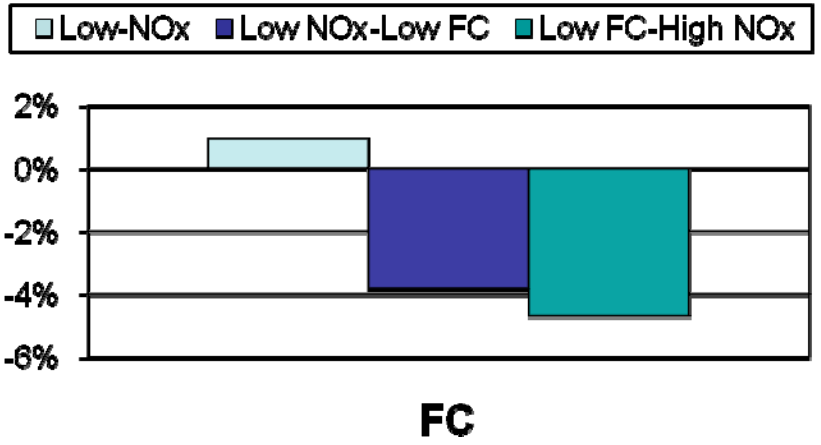
Results: Calibrations Comparison, Low-NOx / Low-FC

- Emission levels for the three different calibrations (steady state)

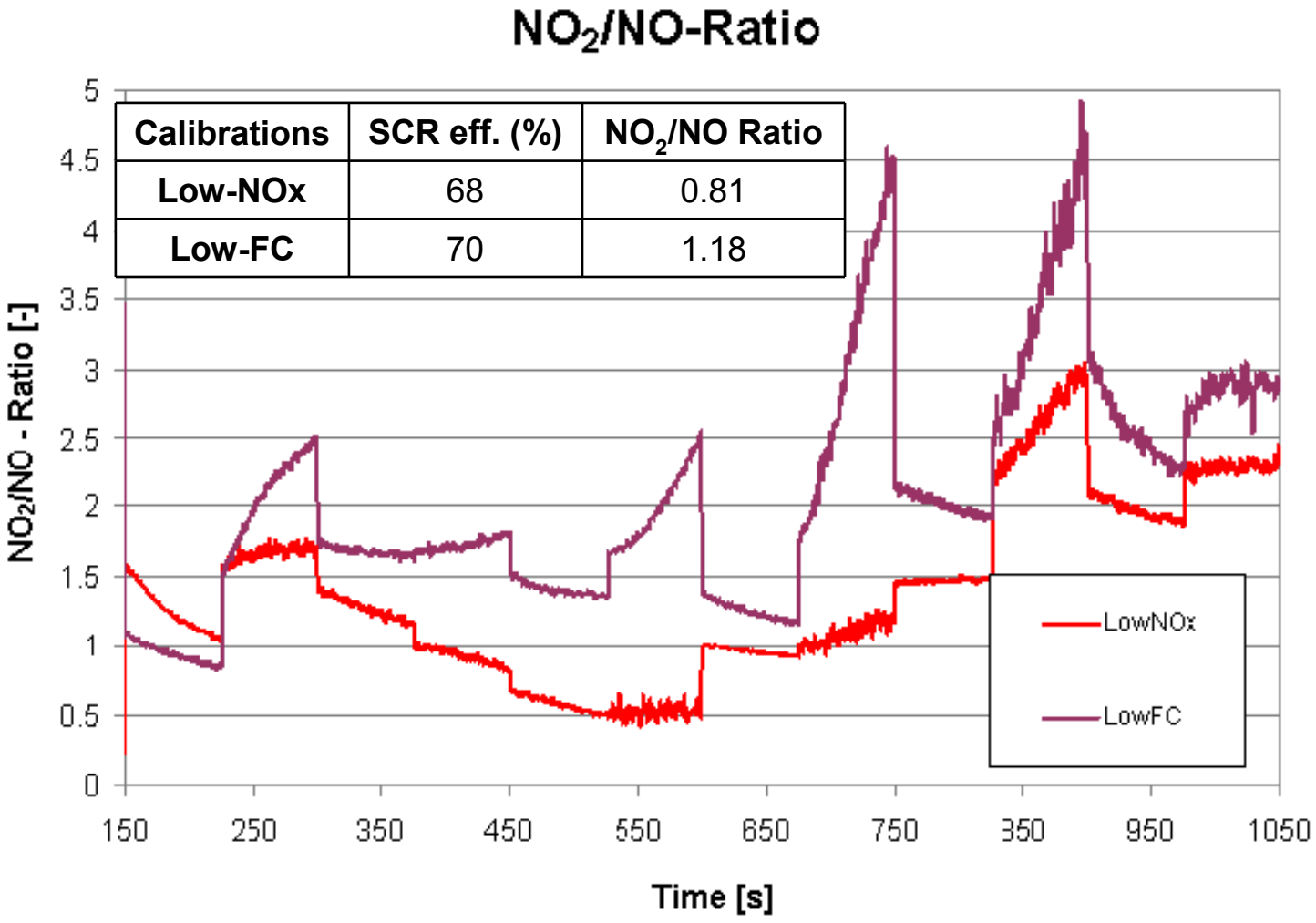
	NOx (g/bhp-hr)	FC (g/bhp-hr)
Baseline	1.12	166
Low-NOx	0.98	168
Low-NOx/Low-FC	1.00	160
Low-FC	2.08	158

- Calibrations compared to the baseline

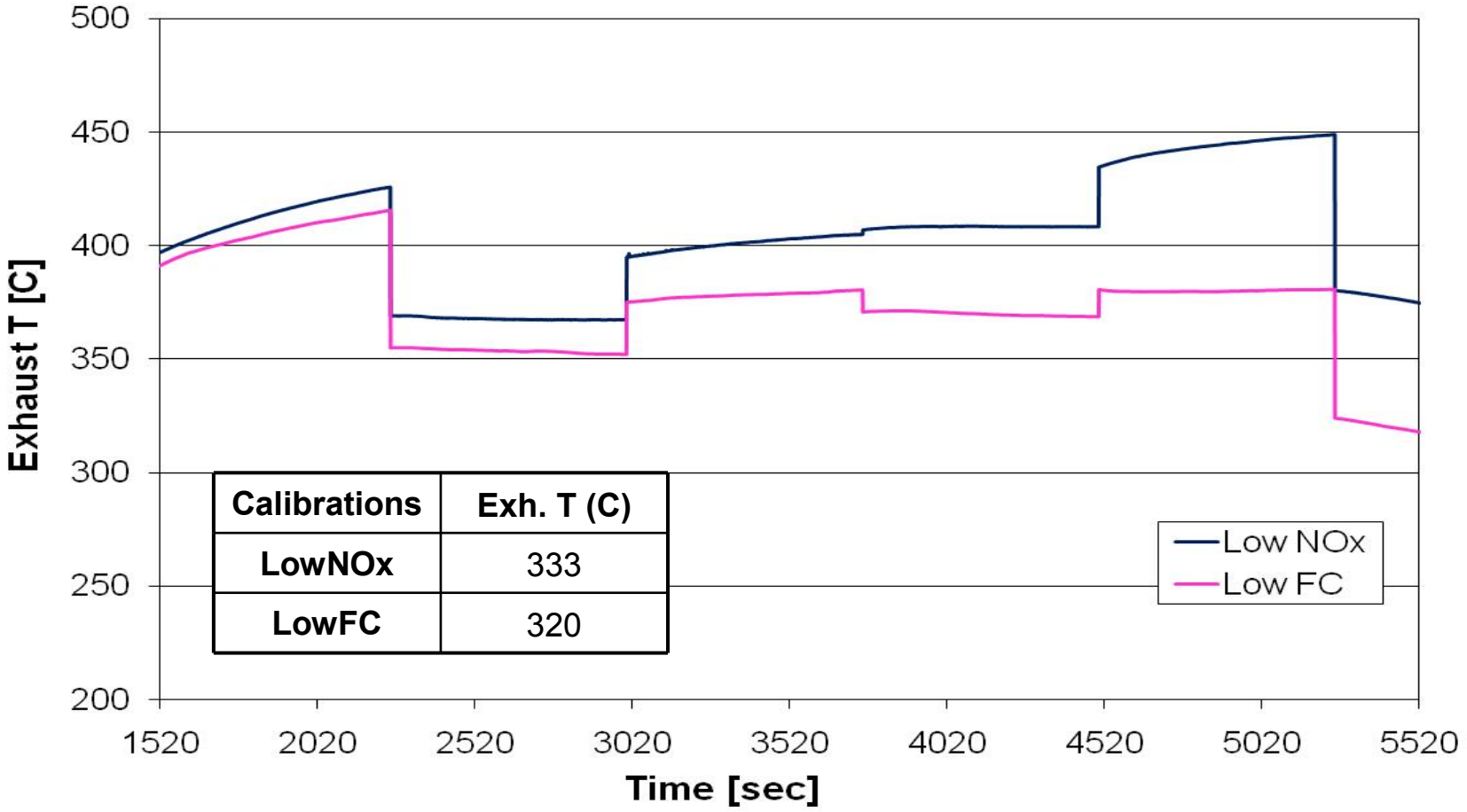




Results: Exhaust Aftertreatment System Response, NO_2/NO ratio

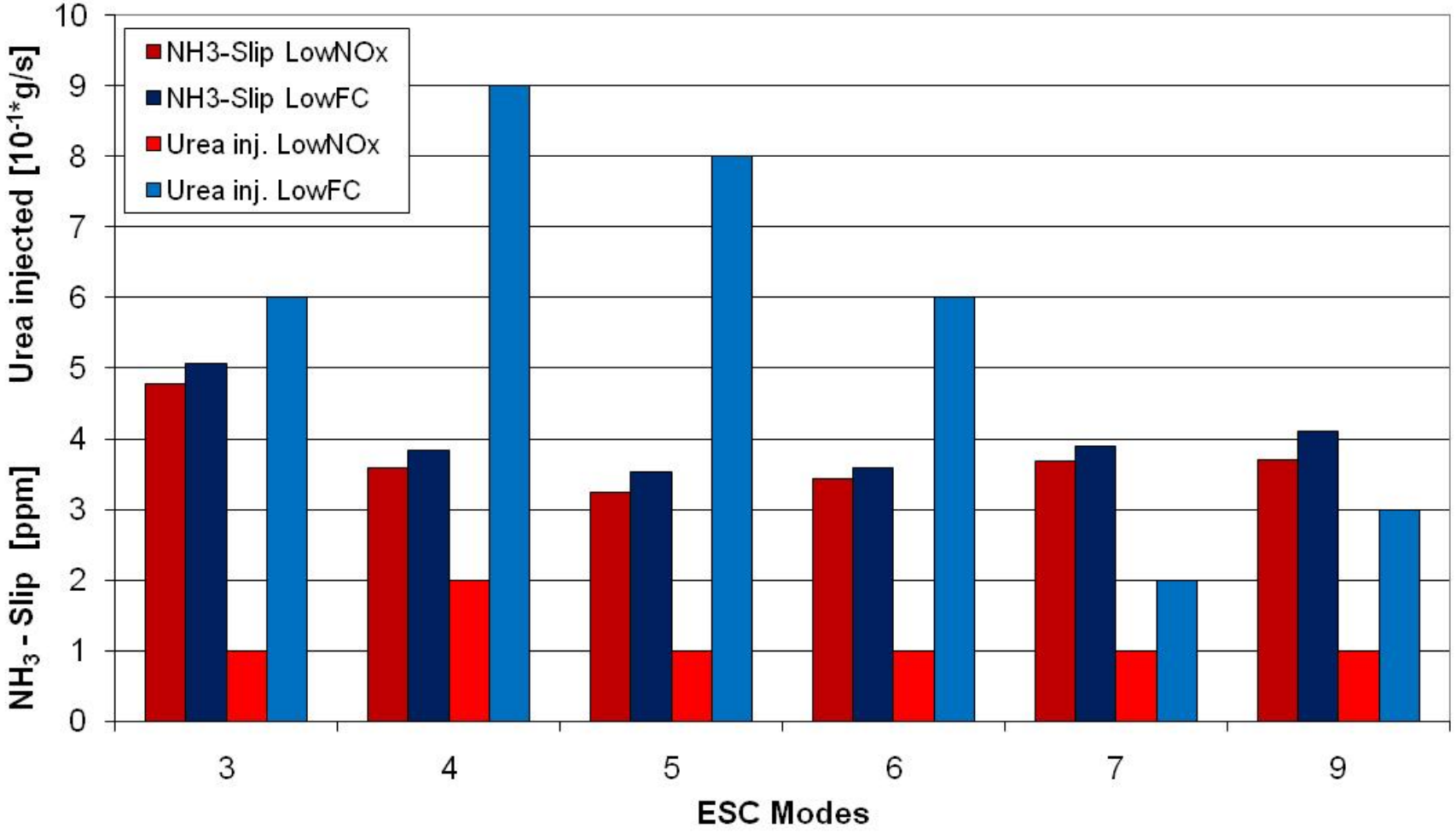


Results: Exhaust Aftertreatment System Response, Exhaust T

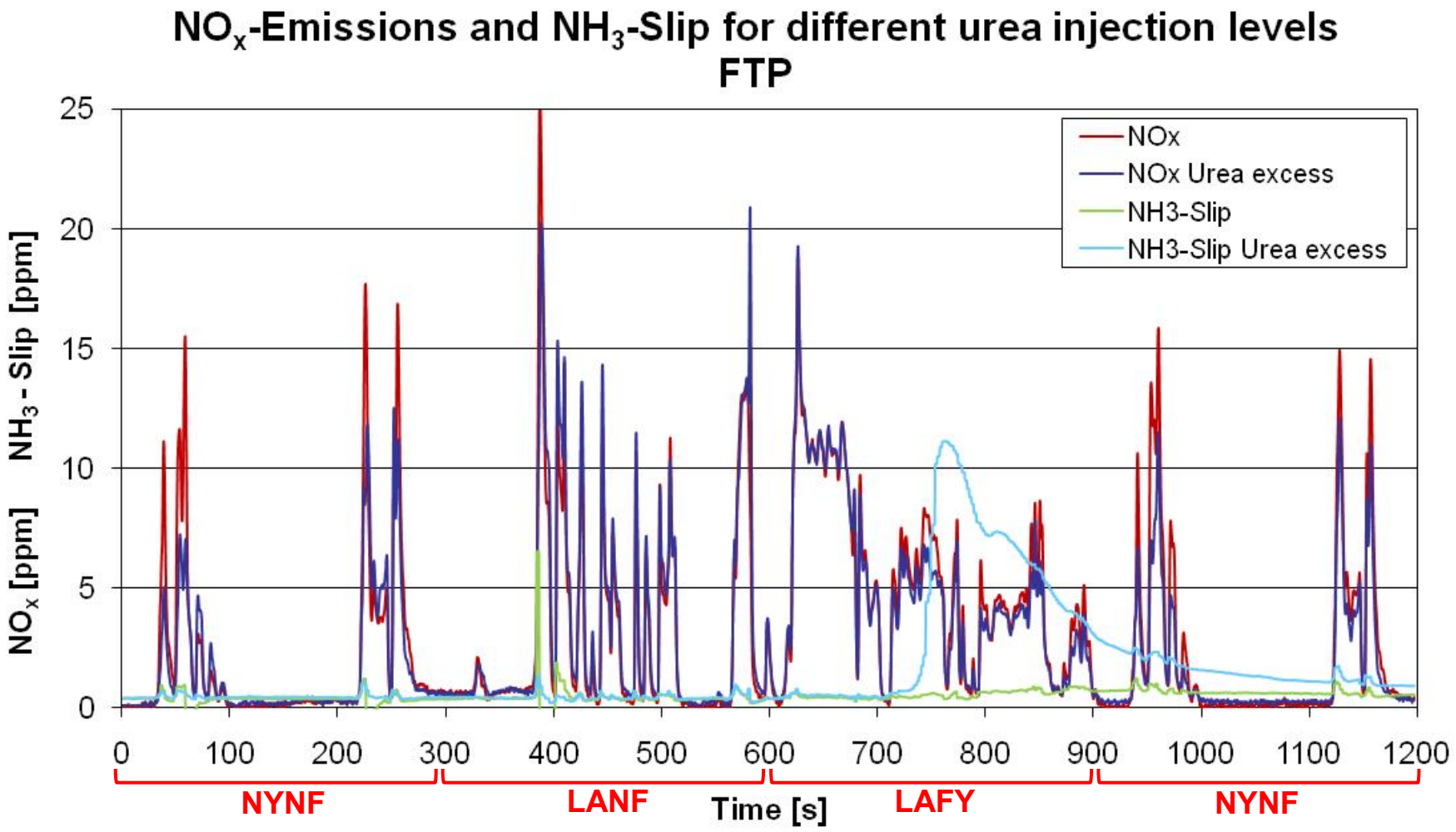


Calibrations	Exh. T (C)
LowNOx	333
LowFC	320

Results: NH_3-Slip and Urea levels



Results: NH_3-Slip Due to Catalyst Temperature Ramp



Conclusions

- The low-NOx calibration could replace the low-FC map during engine operation involving low loads for extended periods (JE05, first 600 sec of the US FTP), as it increases the SCR efficiency, lowers engine-out NOx and raises the exhaust temperature
- The technique was found to be quick, simple and efficient; significantly lower number of tests was required, and only four engine parameters were engaged
- Calibrations even more robust and insensitive to variations, that are likely to occur during in-field applications, can be obtained by implementing noise factors in the orthogonal matrix
- Multiple calibrations can be engaged as the thermodynamic conditions of the exhaust gases change during the engine operation; calibrations could target more specific parameters of exhaust aftertreatment system performance (exhaust temperature, urea level, NO_2/NO ratio, frequency of DPF regeneration)

Acknowledgements

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