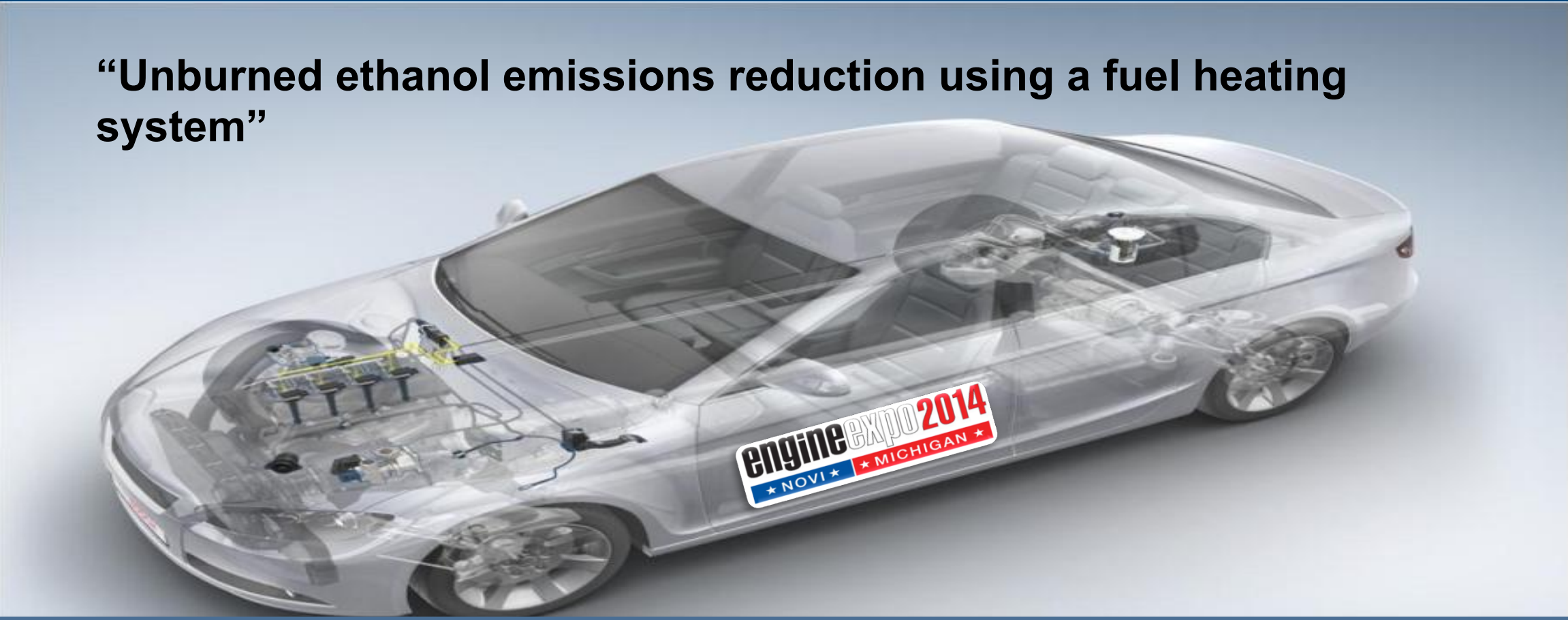
“Unburned ethanol emissions reduction using a fuel heating system”



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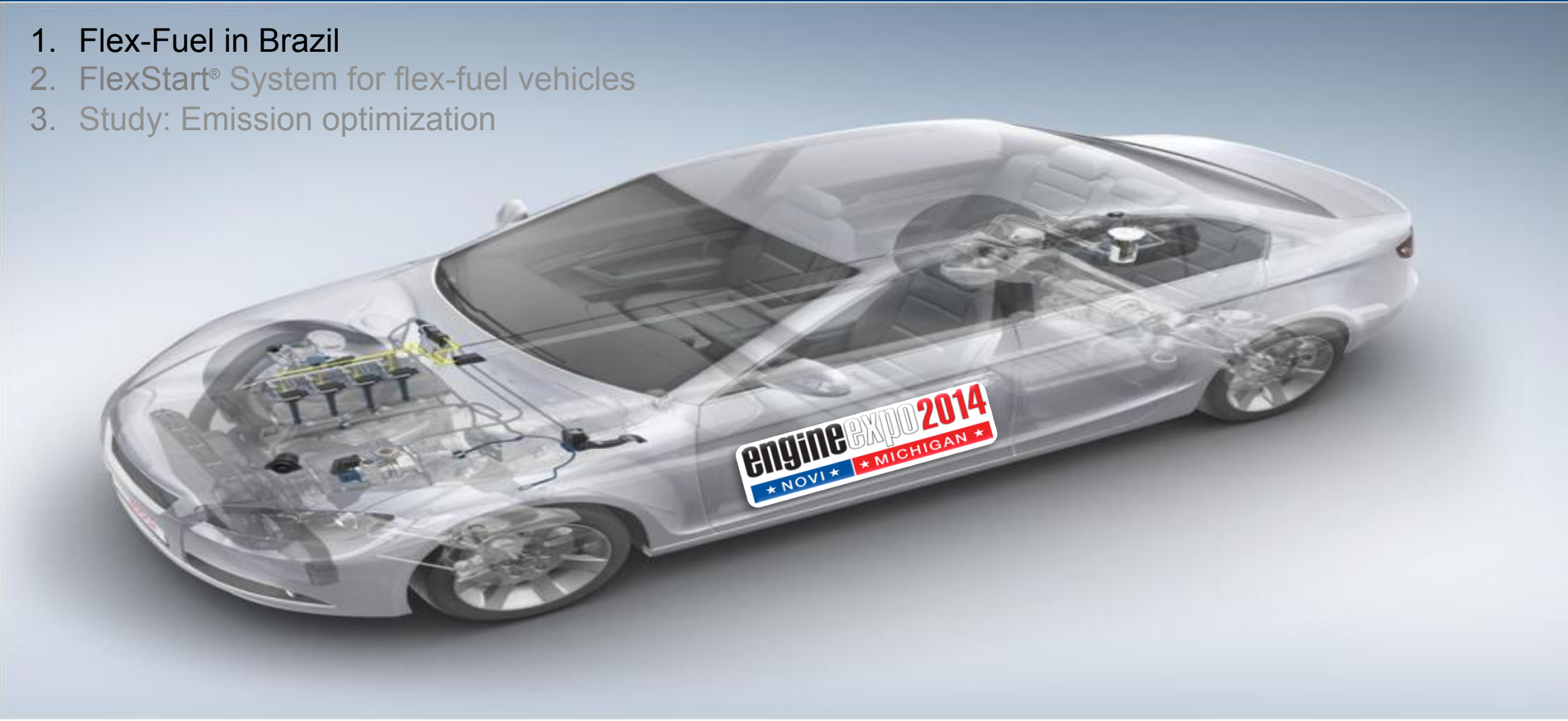
ENGINE EXPO 2014

1. Flex-Fuel in Brazil
2. FlexStart® System for flex-fuel vehicles
3. Study: Emission optimization



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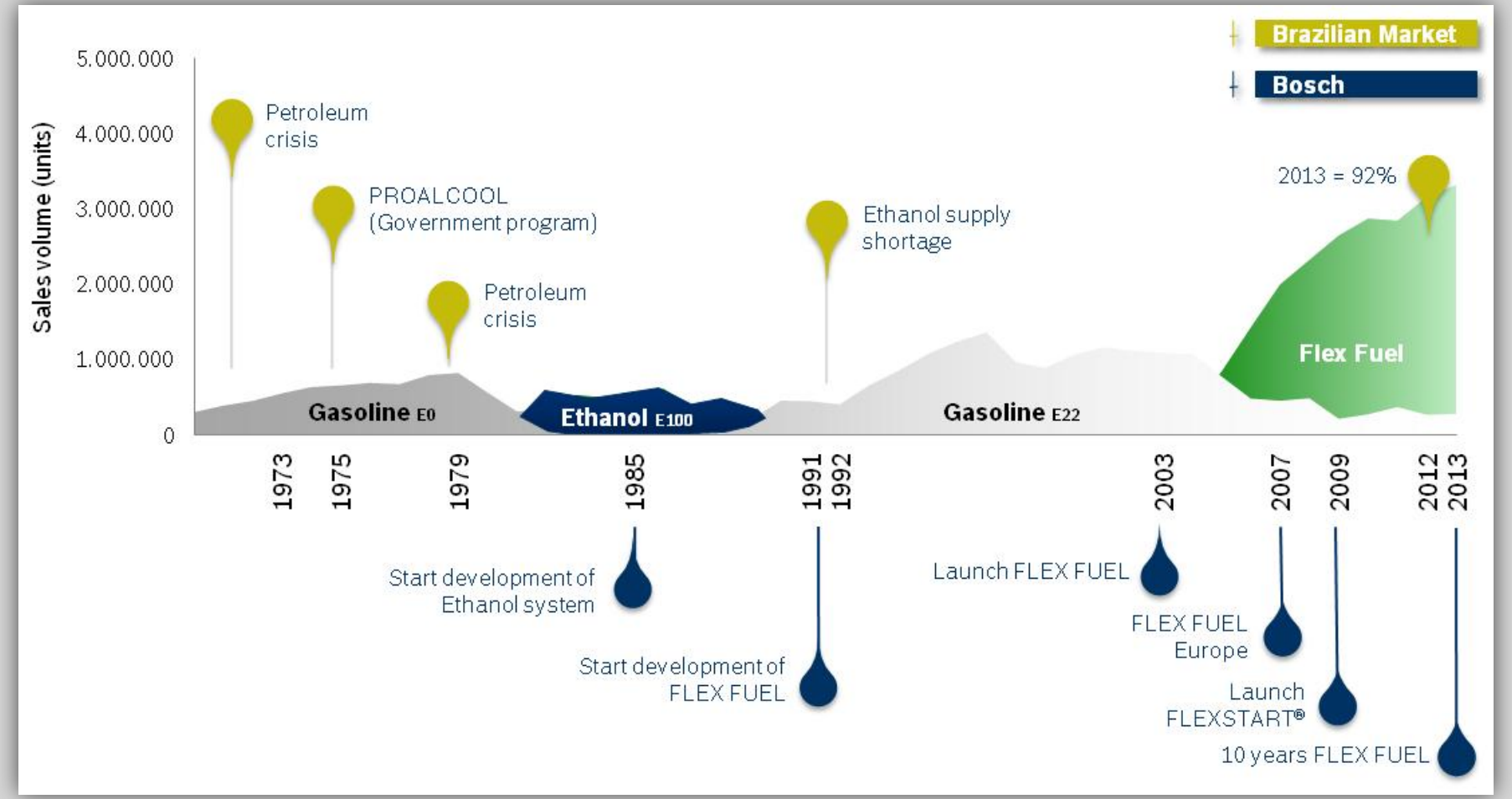
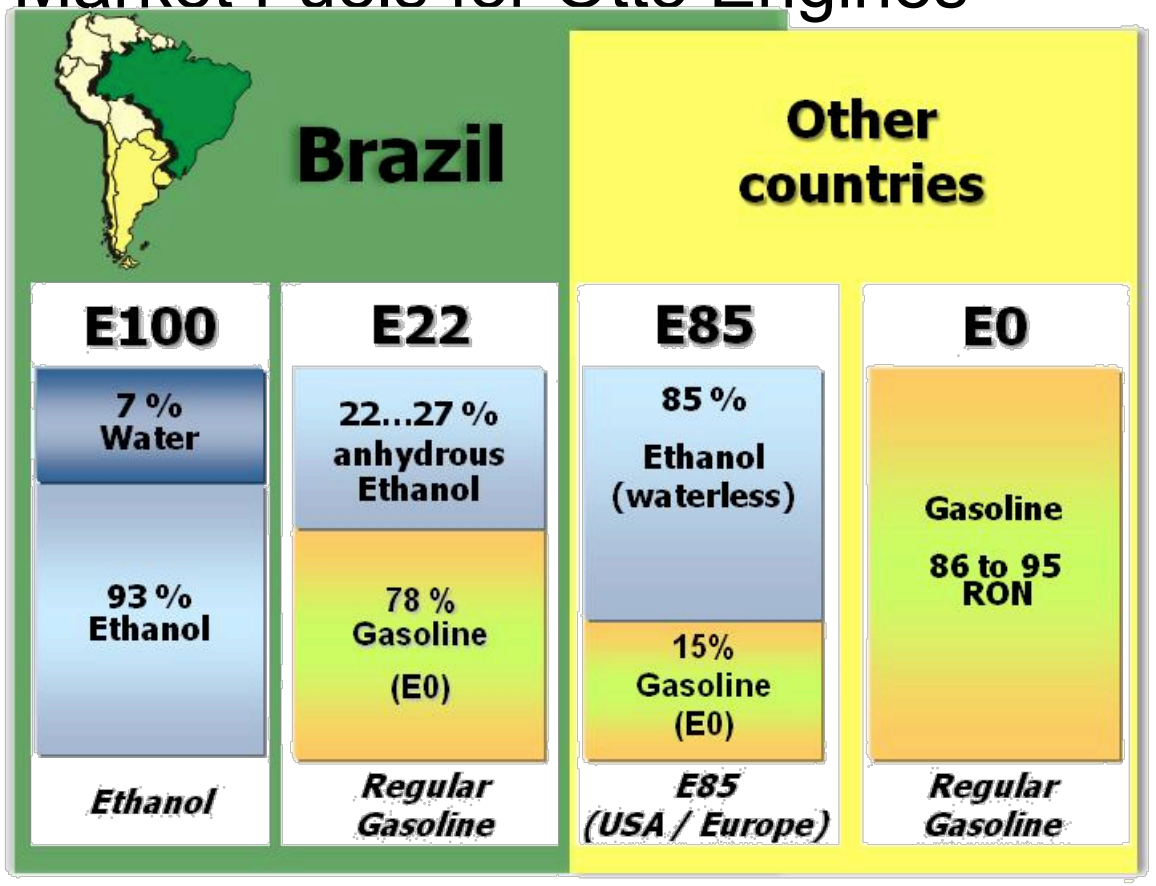


Market Fuels for Otto Engines

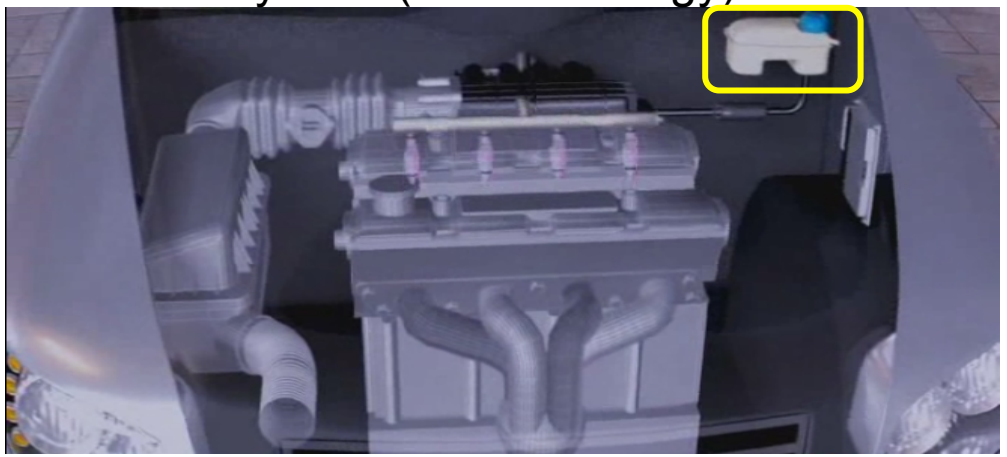


Property	Gasoline E0	E85	Ethanol E100
Air-fuel ratio	14,0	9,8	9,0
GGE (gasoline-gallon equivalent)	1,0 (100%)	1,39 (71,9%)	1,5 (66,6%)
Latent heat of vaporization [KJ/kg]	350 - 450	800	904
Evaporation curve/value [°C]	35 - 200	78	78
Octane number [RON]	>91	>=108	108

Brazil is the only country that uses hydrous ethanol

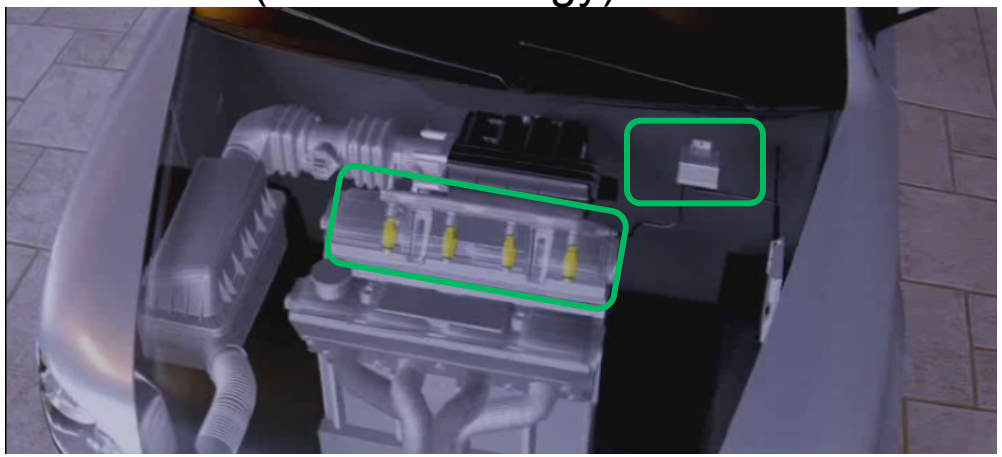
E100 cold start solutions

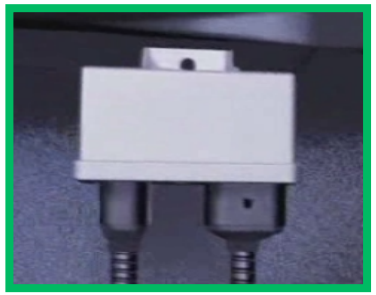
Sub-tank system (old technology)



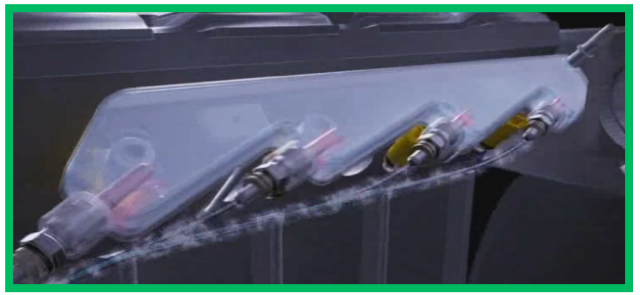
Sub-tank (gasoline reservoir)

FlexStart® (new technology)





HCU (Heating control unit)



Fuel rail with heating elements

New technology has improved cold start and post-start behavior with E100

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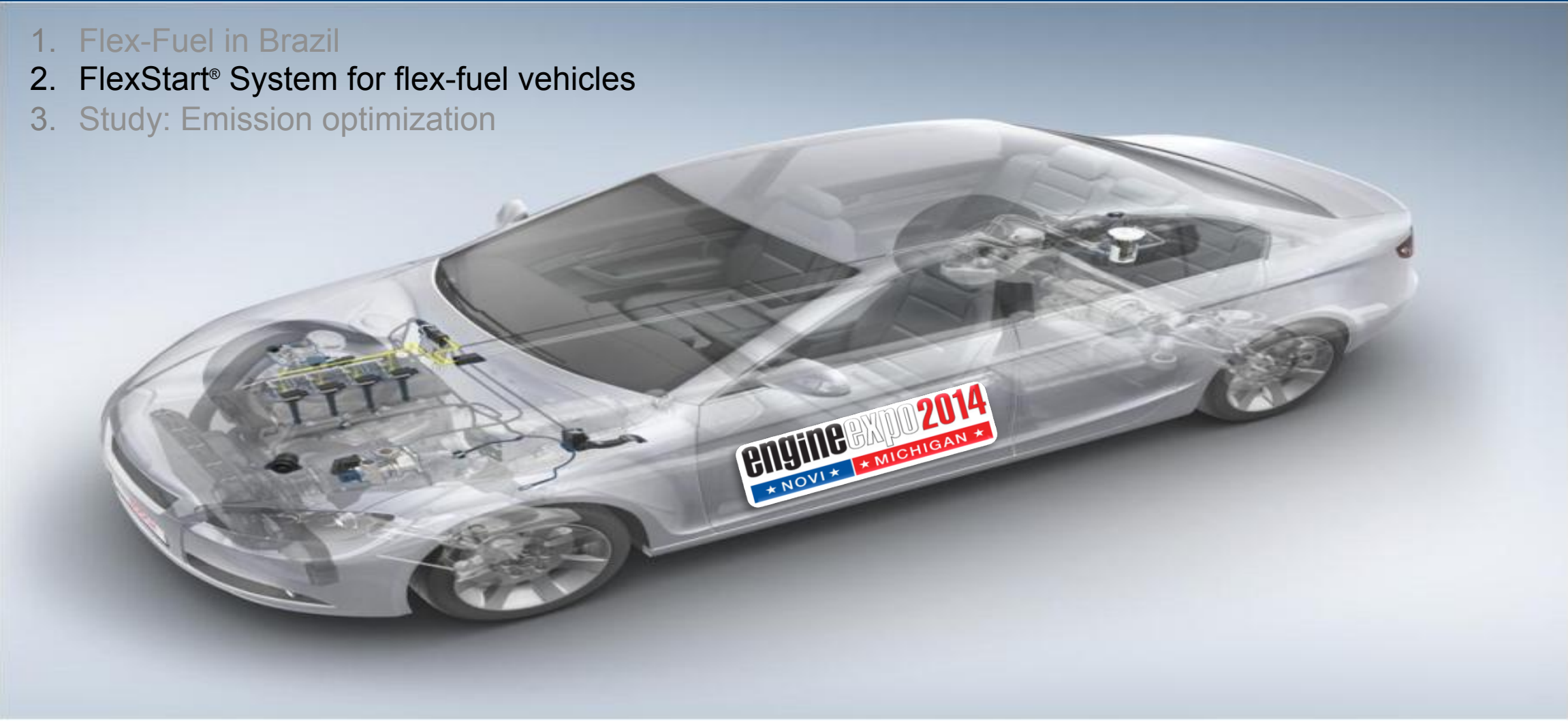

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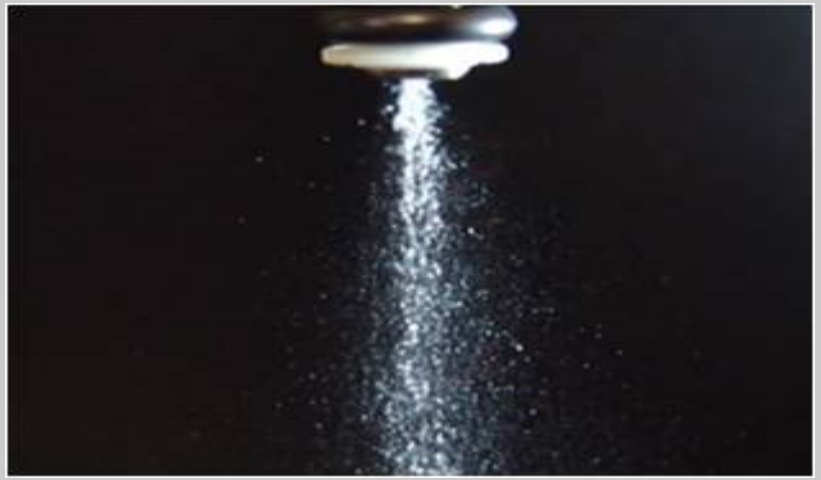
Temperature Effect on mixture formation

Due to the high latent heat and to the lower vapor pressure of ethanol, at temperatures below 12,8°C, the injected ethanol does not produce enough vapor to assure a combustion process to be initiated and sustained.



Fuel at 20°C

Fuel at 100°C

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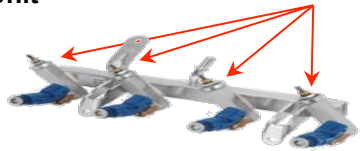
FlexStart® - heating process

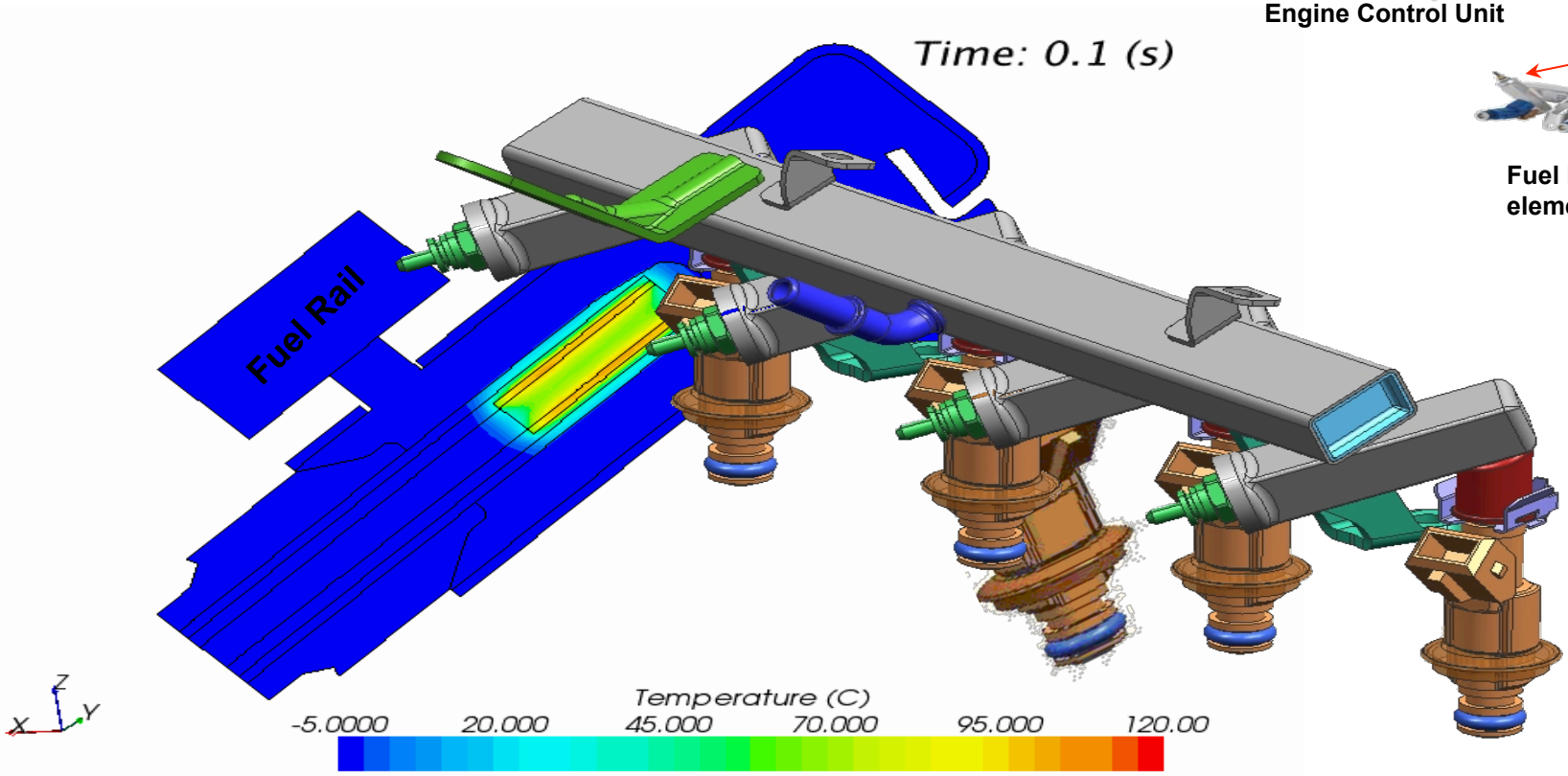
Power control, Power feedback & Diagnosis Information

Engine Control Unit

Heating Control Unit



Fuel Rail with heating elements



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FLEXSTART














3 Cyl.1,0l 12V

4 Cyl.1,6l 16V

3 Cyl.1,0l 12V

4Cyl. 2,5l 16V

4 Cyl.1,6l 16V

2009 | 2012 | 2013 | 2014 | 2015

CITROËN
PEUGEOT
PEUGEOT
HONDA
NISSAN

FlexStart® in series production since 2009 in different OEMs

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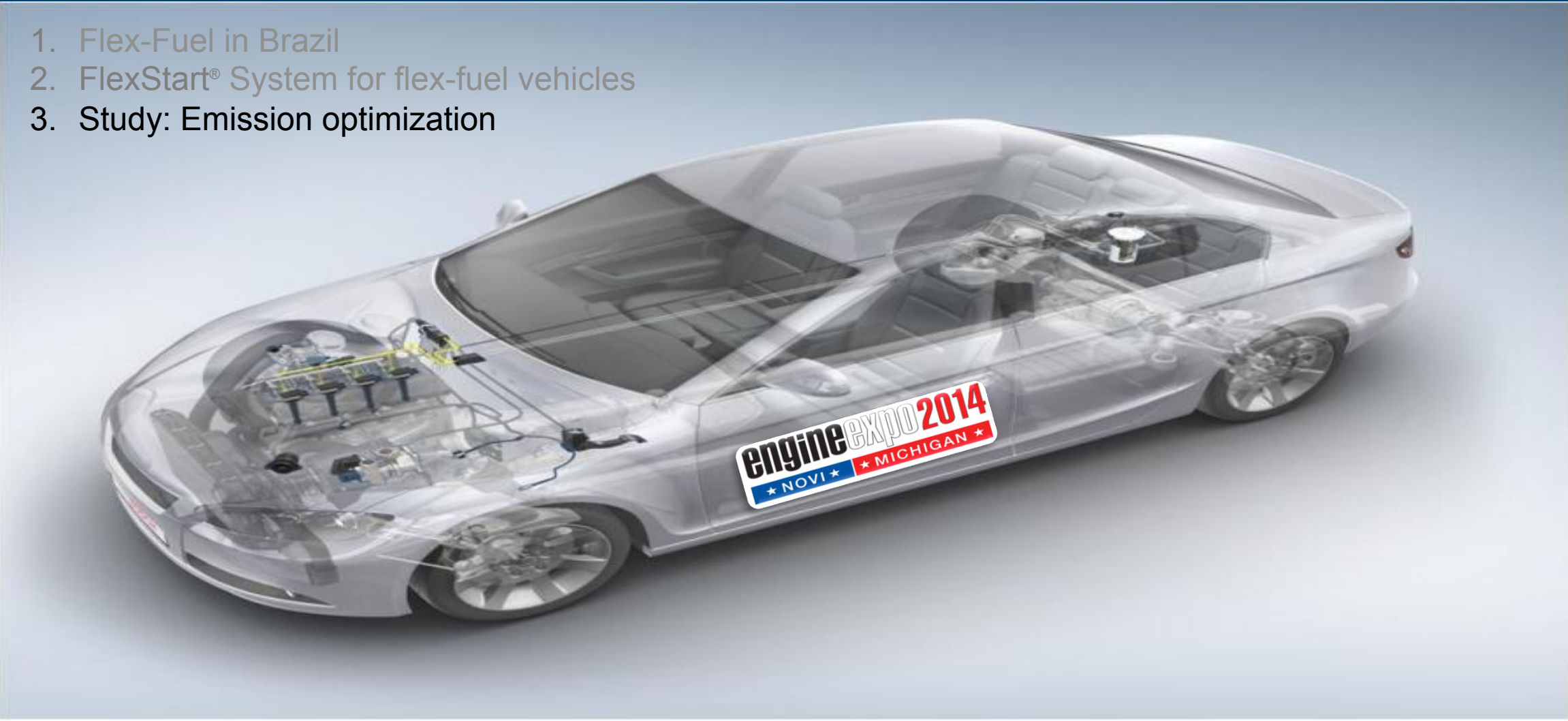
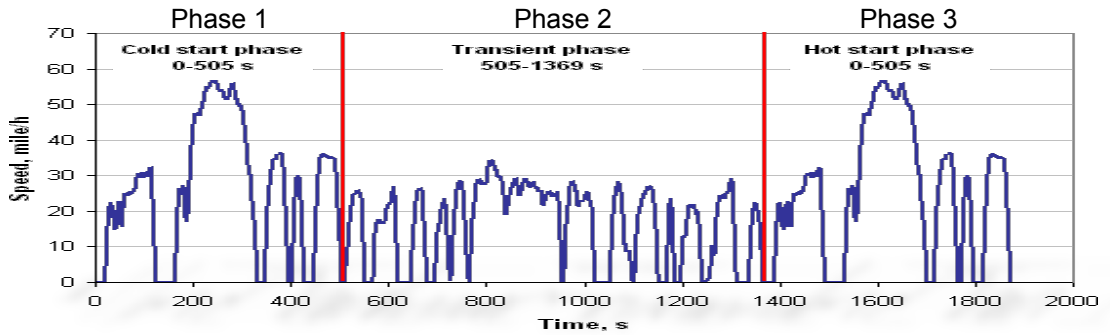


Brazilian Emission Regulation for Passenger Cars

Valid for Passenger cars and light commercial Vehicles <= 1700 kg

MY	Stage	CO	NMHC [1]	NMOG [2]	NOx
2007+	L4	2.0	0.16	n/a	0.25
2009+	L5	2.0	0.05	n/a	0.12
2014+	L6	1.3	0.05	n/a	0.08
2018+	L7	1.3	n/a	0.05	0.03



- Existing and new technologies packages need to be capable for upcoming L7 regulation
- Expected: discount of unburned ethanol no longer allowed

[1] NMHC: non-methane hydrocarbon (deduction of unburned ethanol allowed)
[2] NMOG = non-methane organic gas (NMHC + aldehyde + ethanol)

Project definition

1. Motivation:

To investigate the possibility to reduce NMHC emissions by heating up the fuel. Scope restricted to:

- Emission test – FTP75 cycle
- E100 fuel usage (Brazilian ethanol)
- Fuel heating via FlexStart®
    - Operation range extended to ambient temperature

- Engine: 1,6L 16V Flex-fuel
- Mileage: 4.800 km
- ECU type: ME7.4.9

- Test Fuel: E100
- Emission Cycle: FTP75
- Tests performed: 13

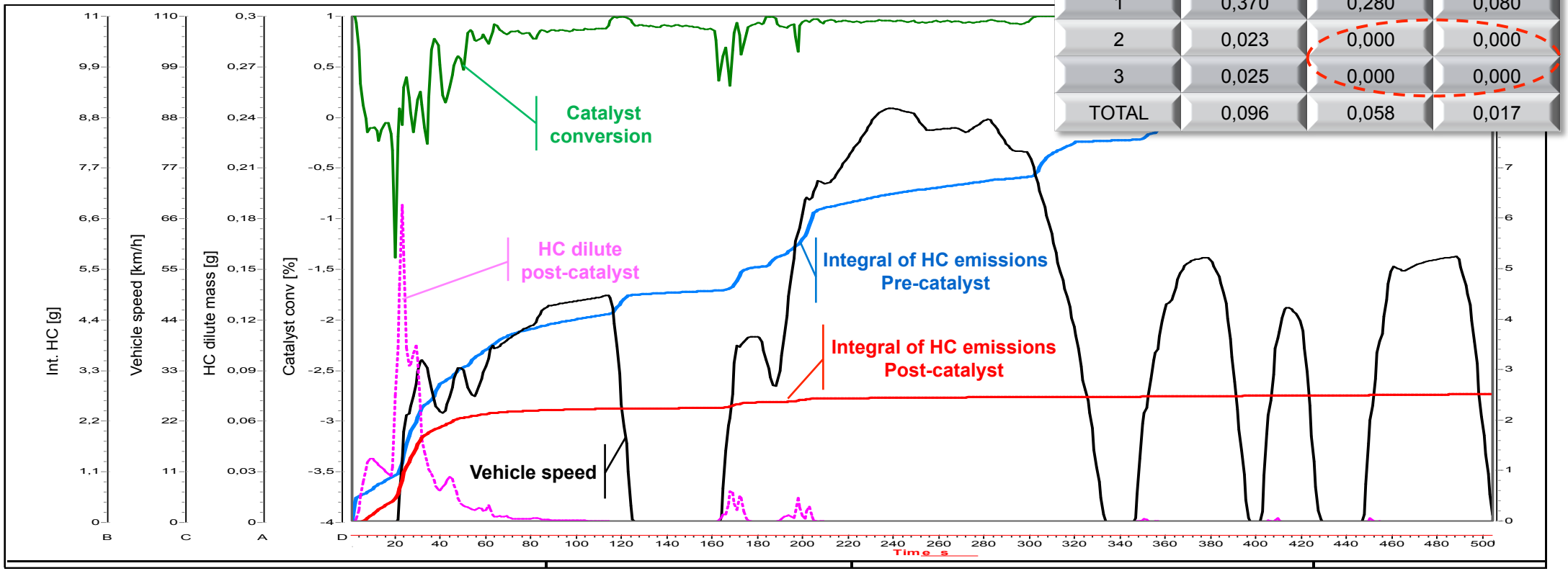
2. Target:

Achieve L6 NMHC emission limits without discounting unburned ethanol

L6 emission limits	g/km
CO	1,3
NMHC	0,05
NOx	0,08

Baseline calibration emission

Phase	HC (g/km)	NMHC (g/km)	NMHC-EtOH (g/km)
1	0,370	0,280	0,080
2	0,023	0,000	0,000
3	0,025	0,000	0,000
TOTAL	0,096	0,058	0,017



- Study focus on Phase1 of FTP75 cycle (Cold start phase - 505 sec)
- Catalyst light-off after 80 seconds dramatically reduces HC emissions

NMHC extrapolation Strategy (Phase 1 to Total NMHC emission)

From Norm NBR 6601, the gas mass emission is calculated by:

$$Mt_{city} = 0{,}43 * \frac{M_1 * D_1 + M_2 * D_2}{D_1 + D_2} + 0{,}57 * \frac{M_3 * D_3 + M_2 * D_2}{D_3 + D_2}$$

$$considering: D_1 = D_3$$

$$Mt_{city} = \frac{1}{D_1 + D_2} * (0{,}43 * (M_1 * D_1 + M_2 * D_2) + 0{,}57 * (M_3 * D_1 + M_2 * D_2))$$

$$Mt_{city} = \frac{1}{D_1 + D_2} * (0{,}43 * M_1 * D_1 + M_2 * D_2 + 0{,}57 * M_3 * D_1)$$

$$Mt_{city} = 0{,}43 * 0{,}48 * M_1 + 0{,}52 * M_2 + 0{,}57 * 0{,}48 * M_3$$

$$Mt_{city} = 0{,}21 * M_1 + 0{,}52 * M_2 + 0{,}27 * M_3$$

assumption: $M_2 = M_3 = 0$

$$Mt_{city} = 0{,}21 * M_1$$

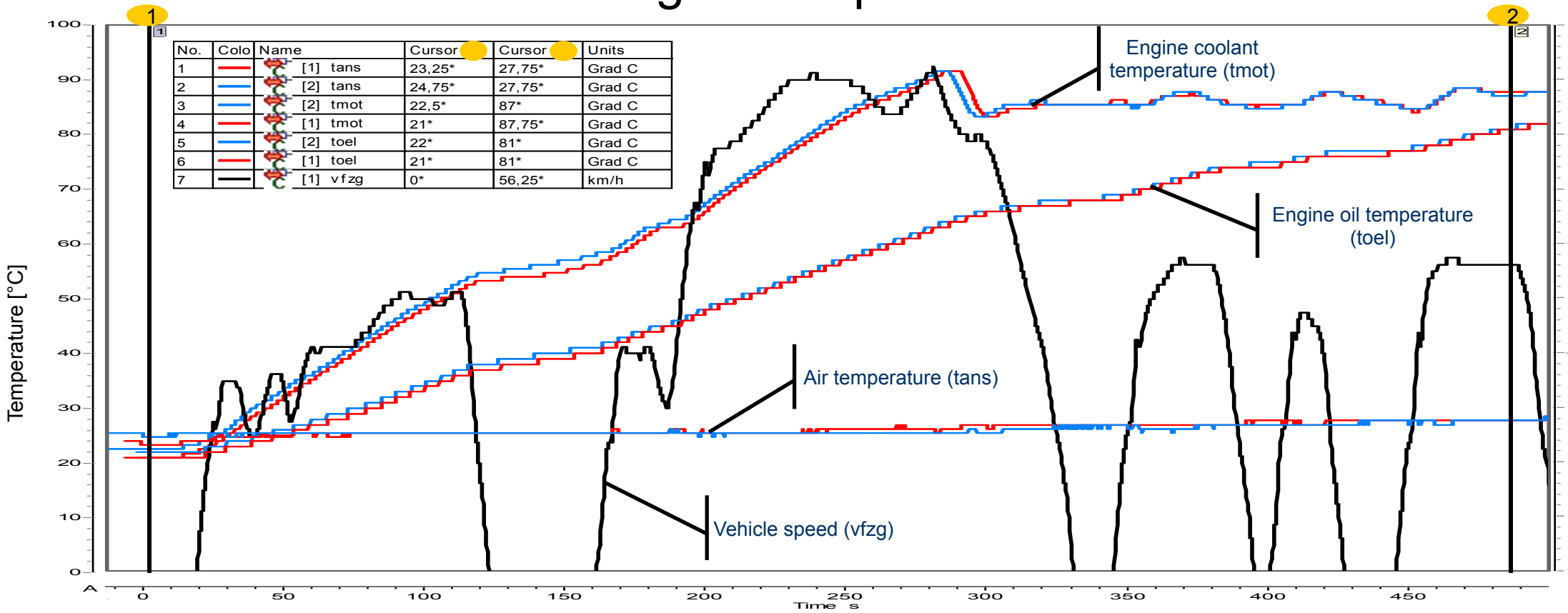
$$T\ NMHC_{E100} = 0{,}21 * NMHC_{Phase1}$$

Phase	HC (g/km)	NMHC (g/km)	NMHC-EtOH (g/km)
1	0,370	0,280	0,080
2	0,023	0,000	0,000
3	0,025	0,000	0,000
TOTAL	0,096	0,058	0,017

Note:
Mtcity: emissions in FTP75 cycle
Mx: gas emissions per cycle Phase (1, 2 or 3) [g/km]
Dx: distance per cycle Phase (D1=5,7 km; D2=6,2 km; D3=5,7 km)

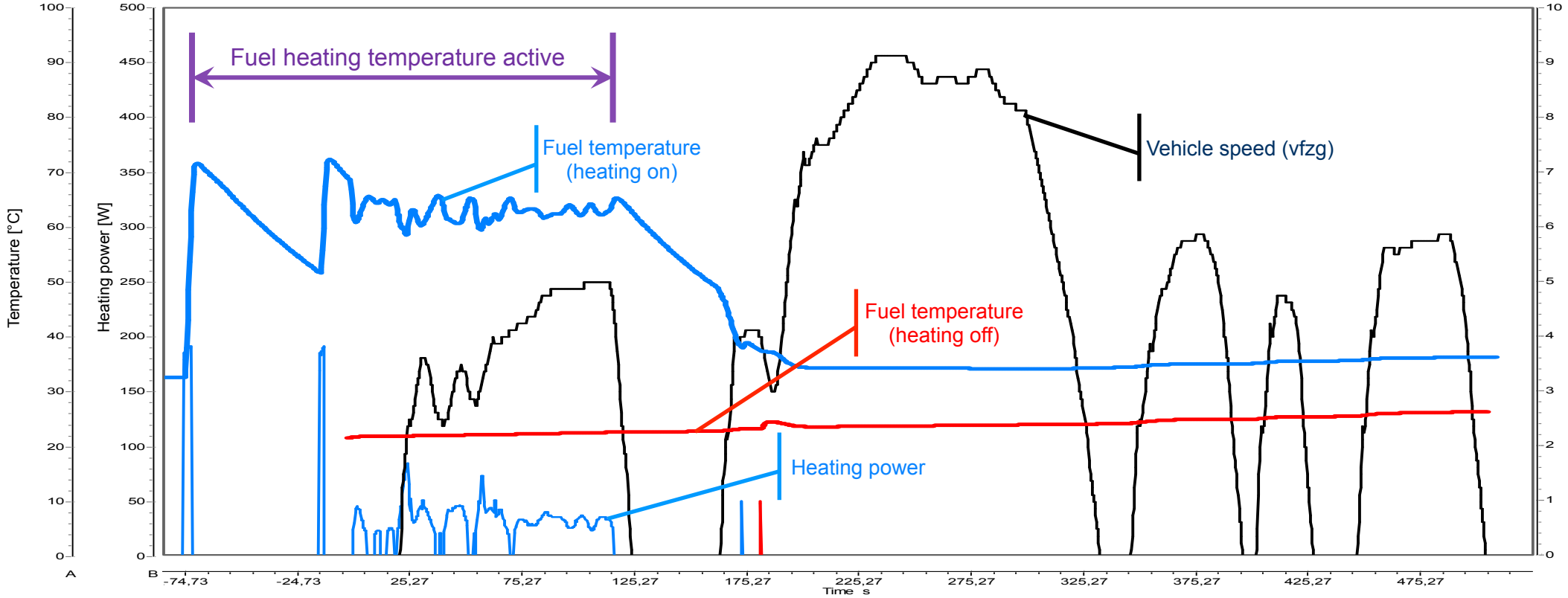
Total E100 NMHC emission corresponds to 21% of Phase 1 emission

Vehicle test condition – engine temperatures



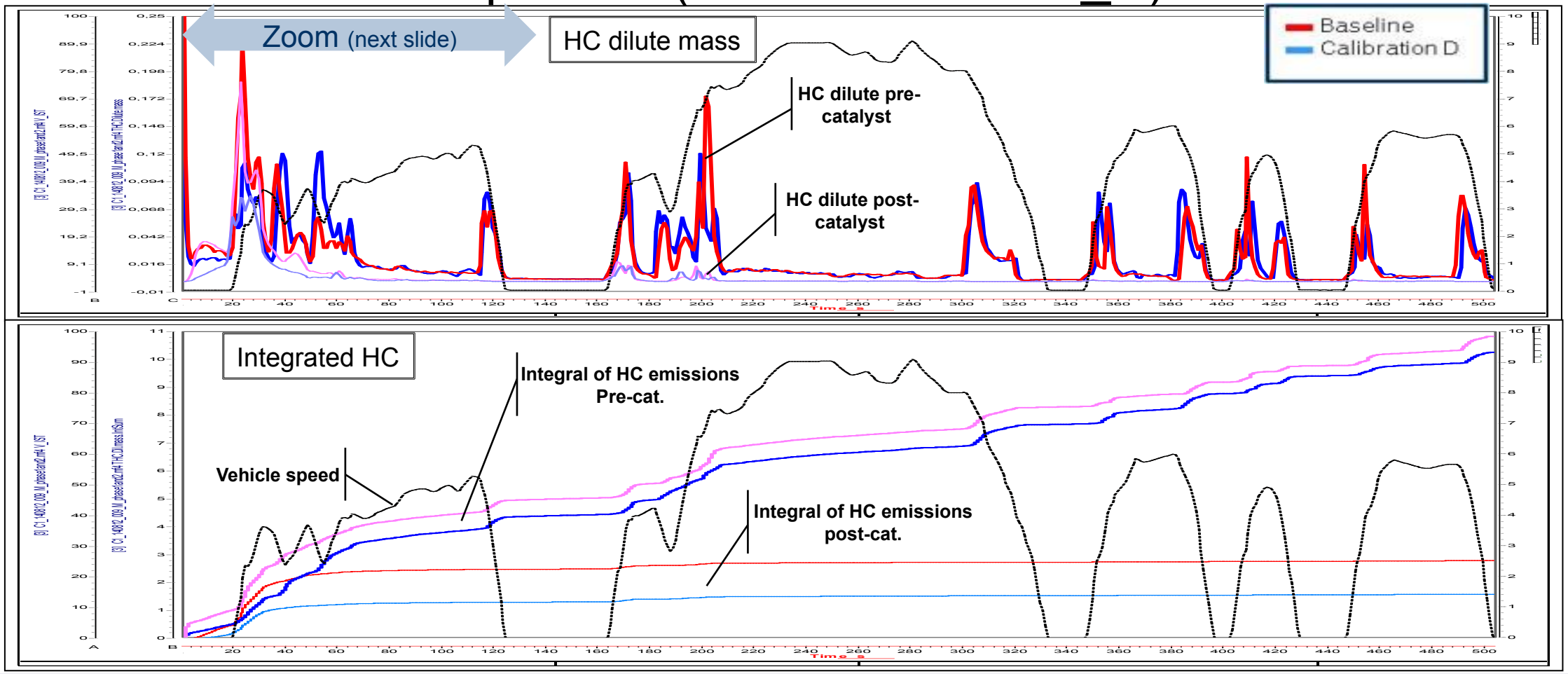
Low dispersion of engine operation conditions within the performed tests

Vehicle test condition – fuel temperature

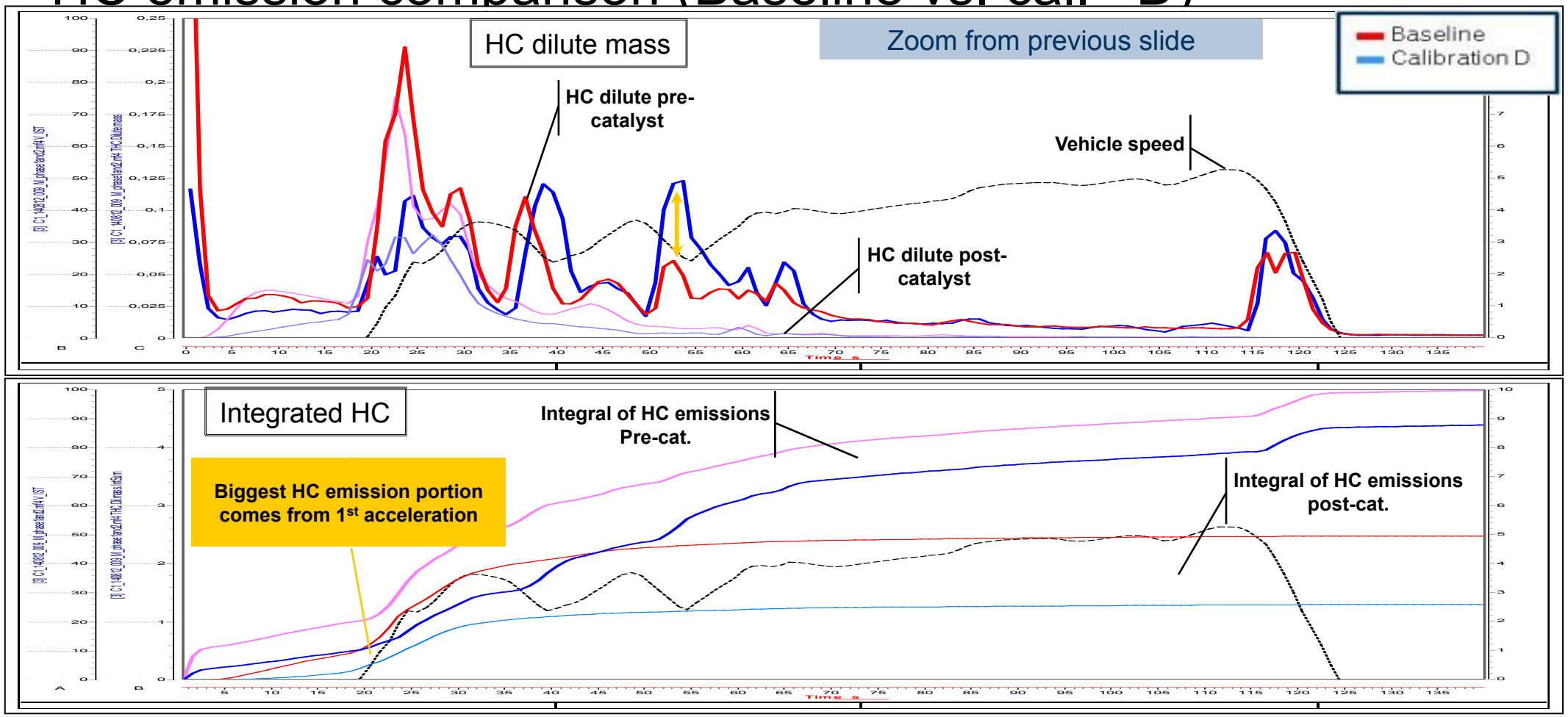


Fuel heating system active only during the first 2 minutes of test cycle

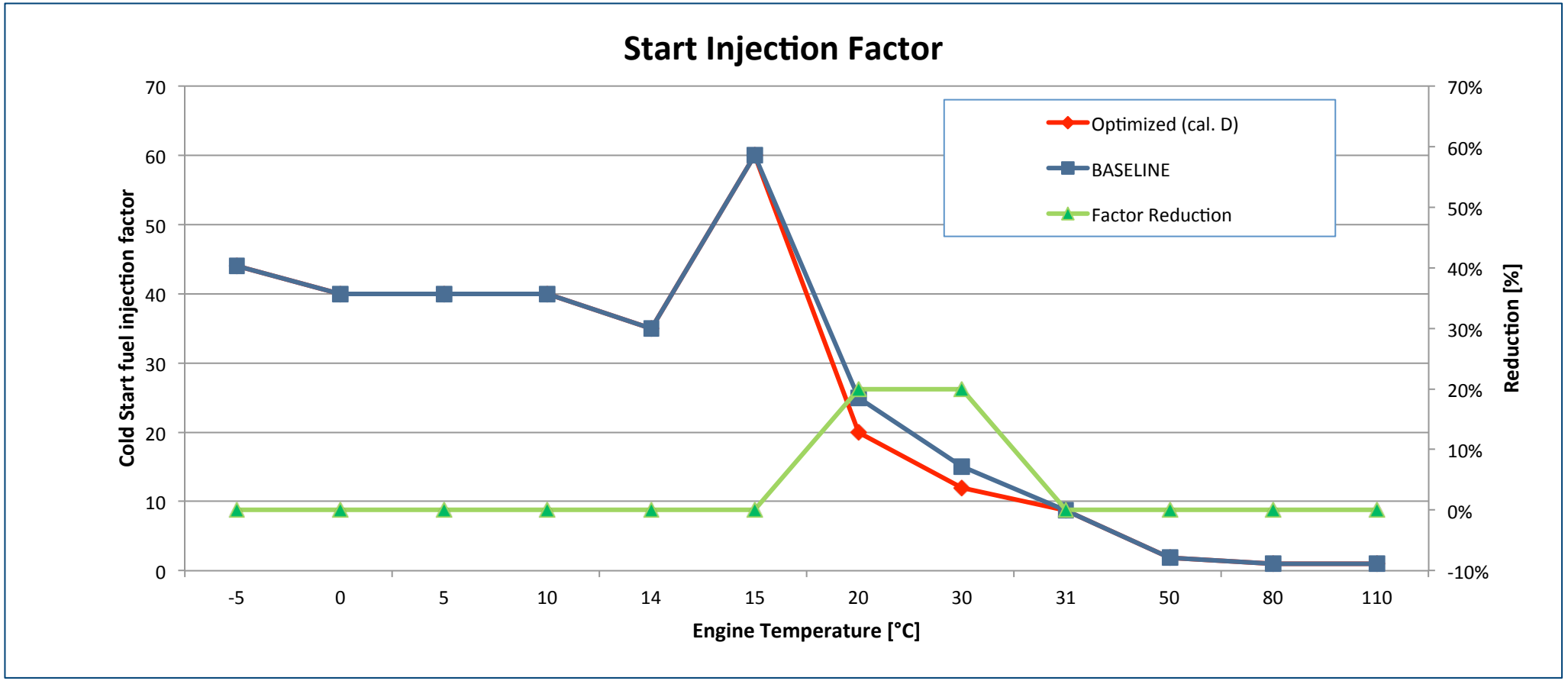
HC emission comparison (Baseline vs. cal. _D)



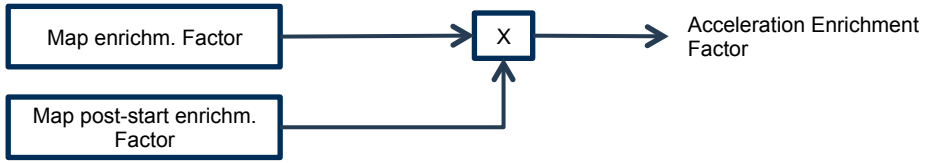
HC emission comparison (Baseline vs. cal. D)

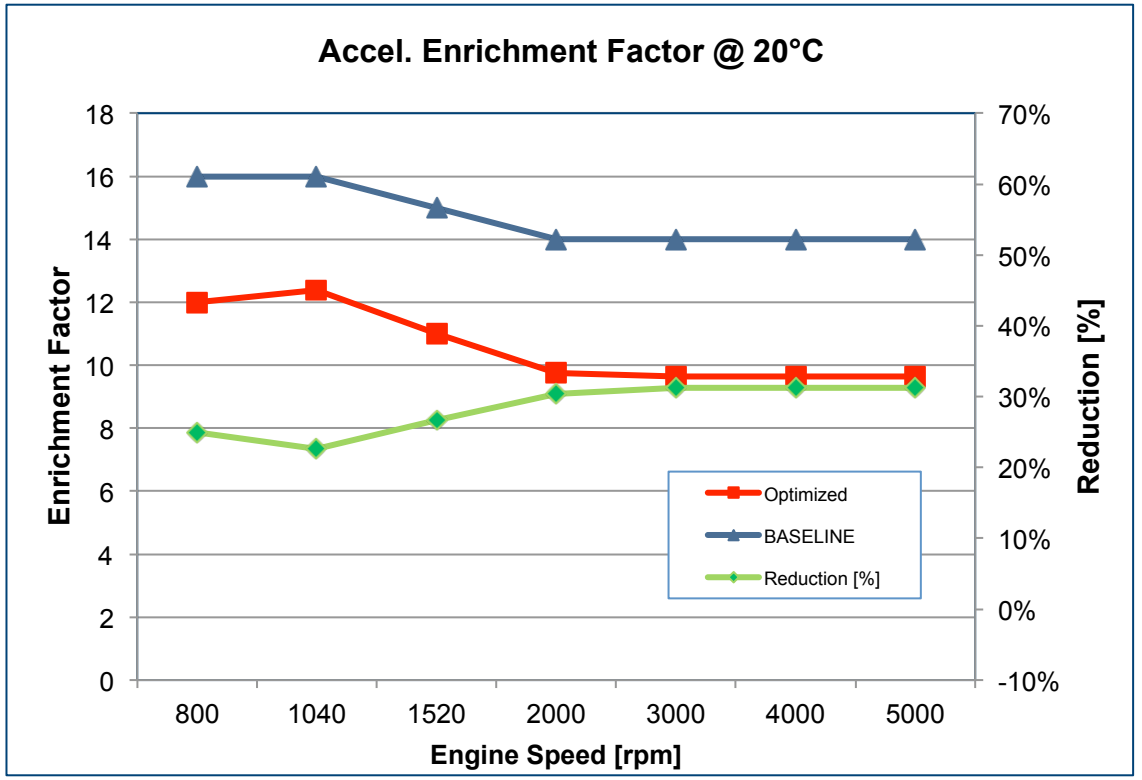


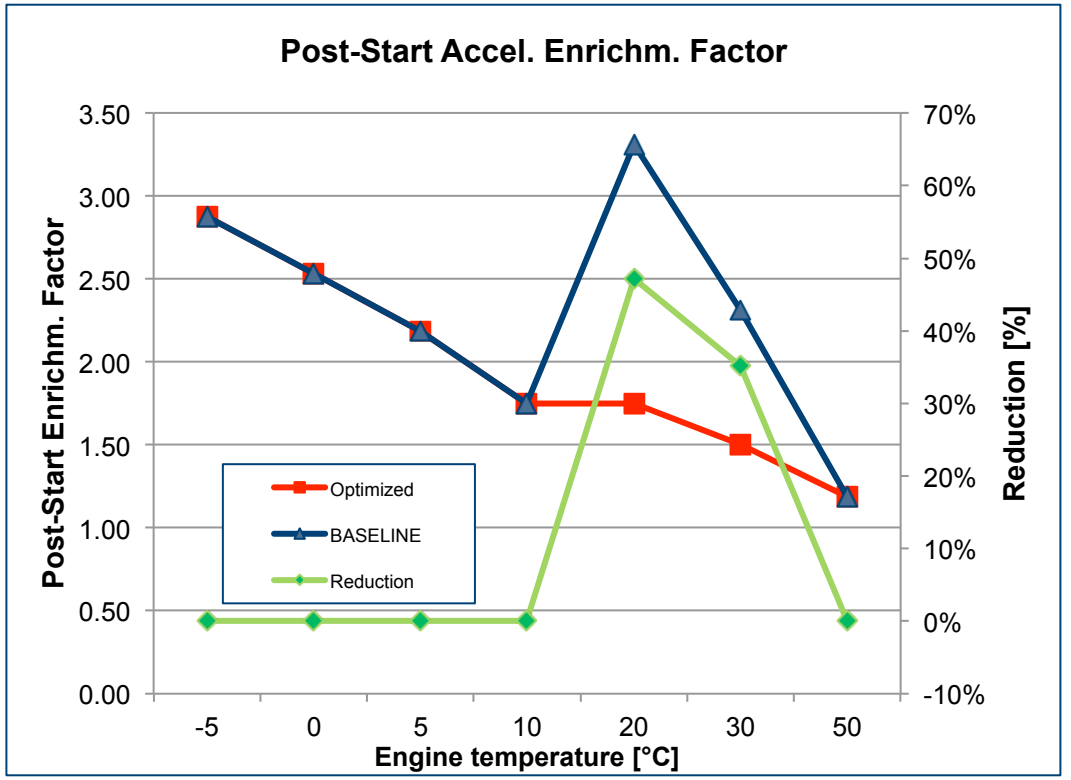
Calibration changes: Start injection Factor



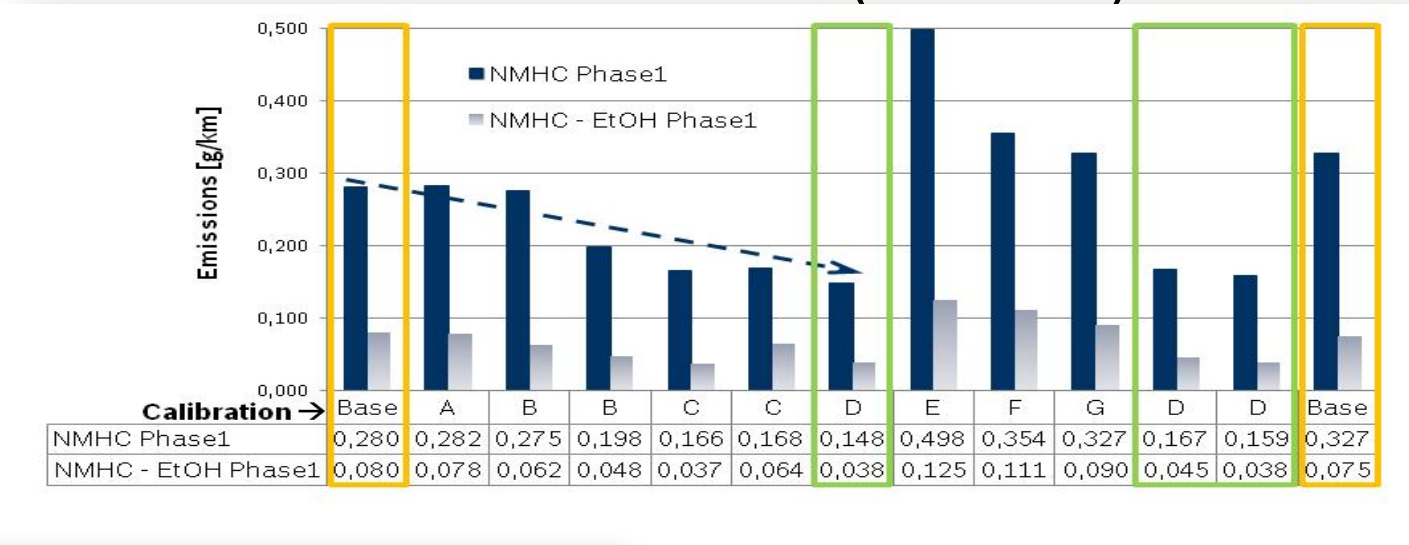
Calibration changes: Acceleration enrichment factor



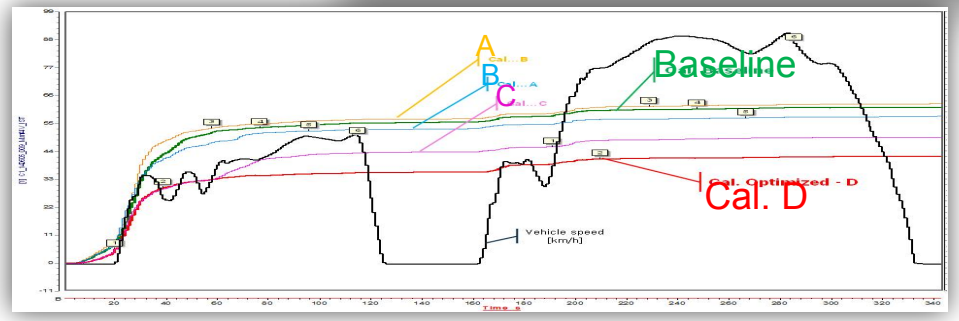




Optimization: NMHC & EtOH emission (Phase 1)



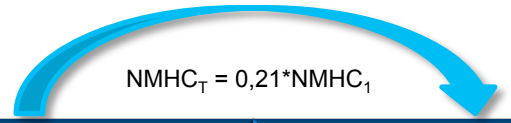
Calibration →	Base	A	B	B	C	C	D	E	F	G	D	D	Base
NMHC Phase1	0,280	0,282	0,275	0,198	0,166	0,168	0,148	0,498	0,354	0,327	0,167	0,159	0,327
NMHC - EtOH Phase1	0,080	0,078	0,062	0,048	0,037	0,064	0,038	0,125	0,111	0,090	0,045	0,038	0,075



Calibration	Average NMHC (Phase 1) [g/km]
Baseline	0,304
Calibration D	0,158
Reduction (%)	48%

13 tests performed: 3 Baselines and 7 different optimized calibrations

Conclusion



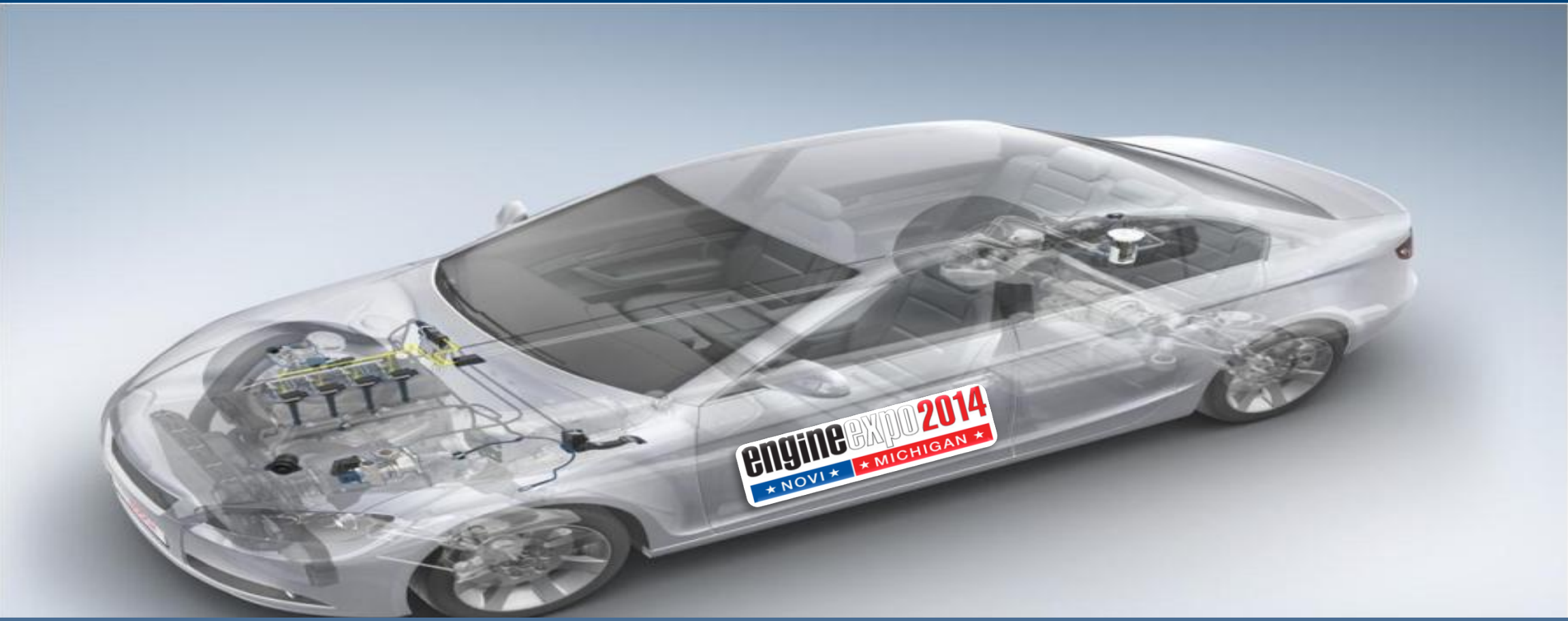
Calibration	Average NMHC (Phase 1) [g/km]	NMHC total (extrapolation) [g/km]	Difference to NMHC limit (0,05 g/km)
Baseline	0,304	**0,064**	28% over limit
Calibration D	0,158	**0,033**	**34% below limit**

48% emission reduction

Fuel heating is able to significantly reduce NMHC emissions:

- L6 NMHC emission limit (0,05 g/km) could be reached WITHOUT relying on unburned ethanol discount
- Fuel heating is particularly important prior to catalyst light-off, when HC emission have highest peak
- Extending the operation range of FlexStart represents an efficient solution to E100 emission reduction

FlexStart® is an efficient solution to reduce E100 NMHC emissions



Thank you !

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