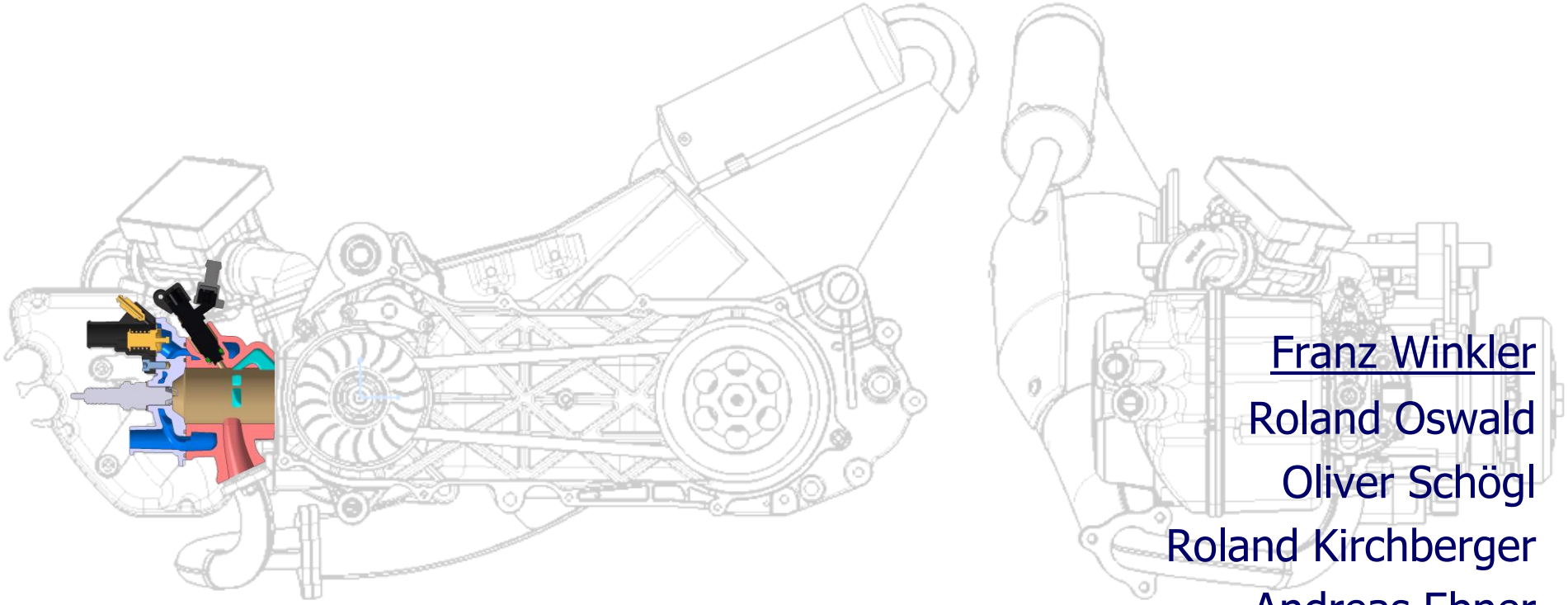
Application of Low Pressure Direct Injection and Semi-Direct Injection to a Small Capacity Two-Stroke Engine



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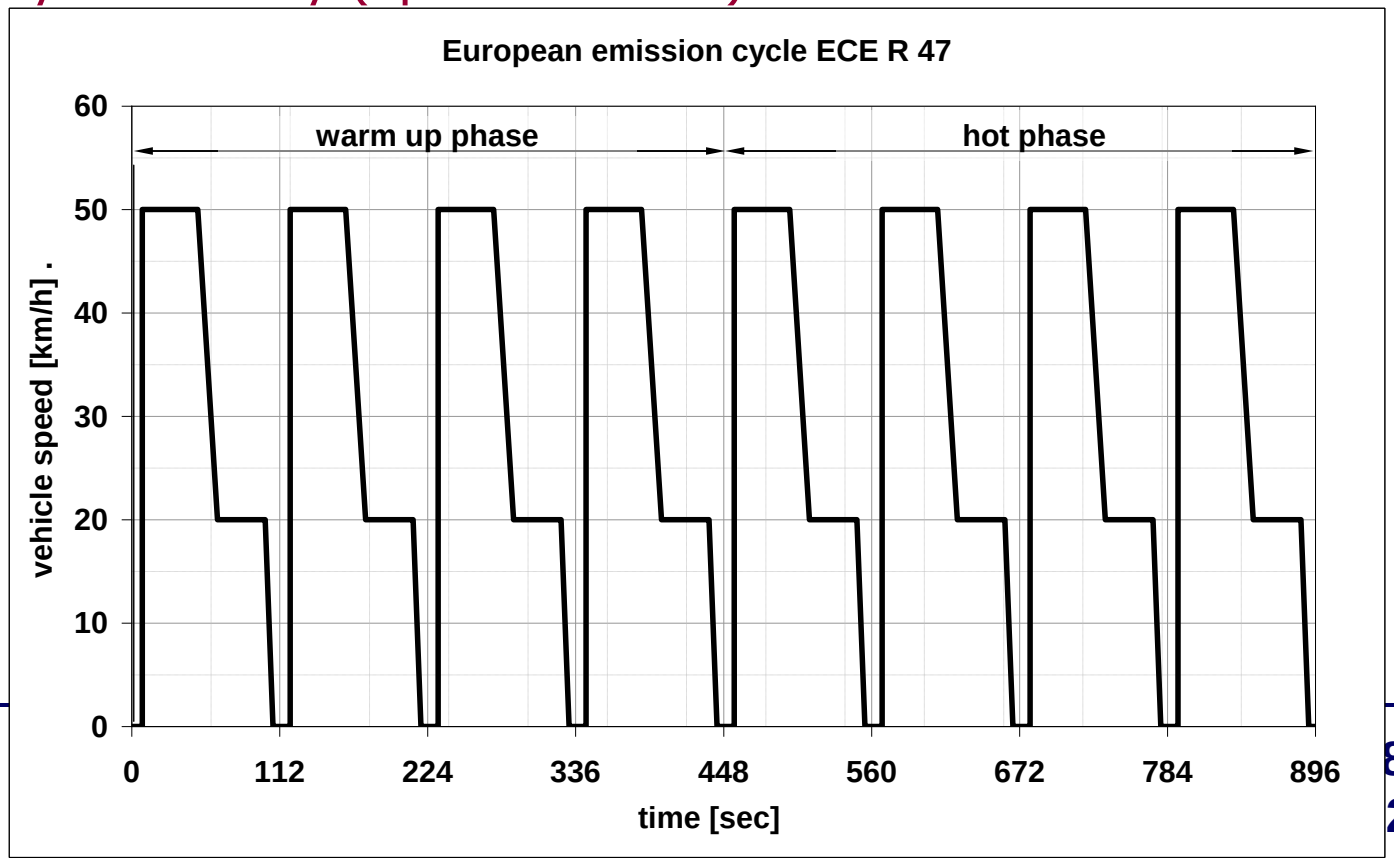
Structure

Introduction

Motivation

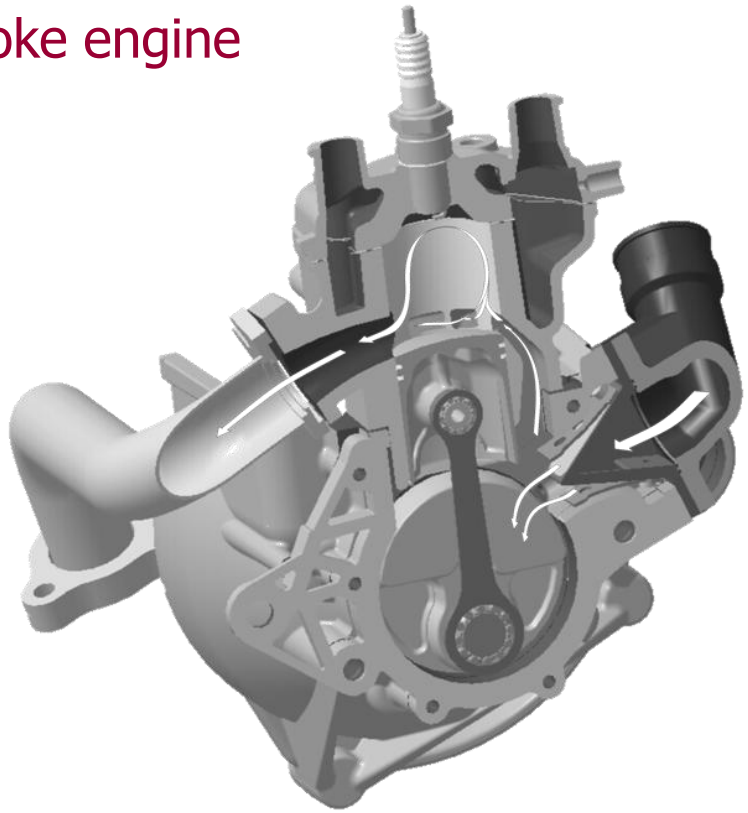
New European emission legislation EURO III < 50 cm³:

- including cold start emission (weighting factor of 30% (50%))
- catalyst durability (up to 10000km)



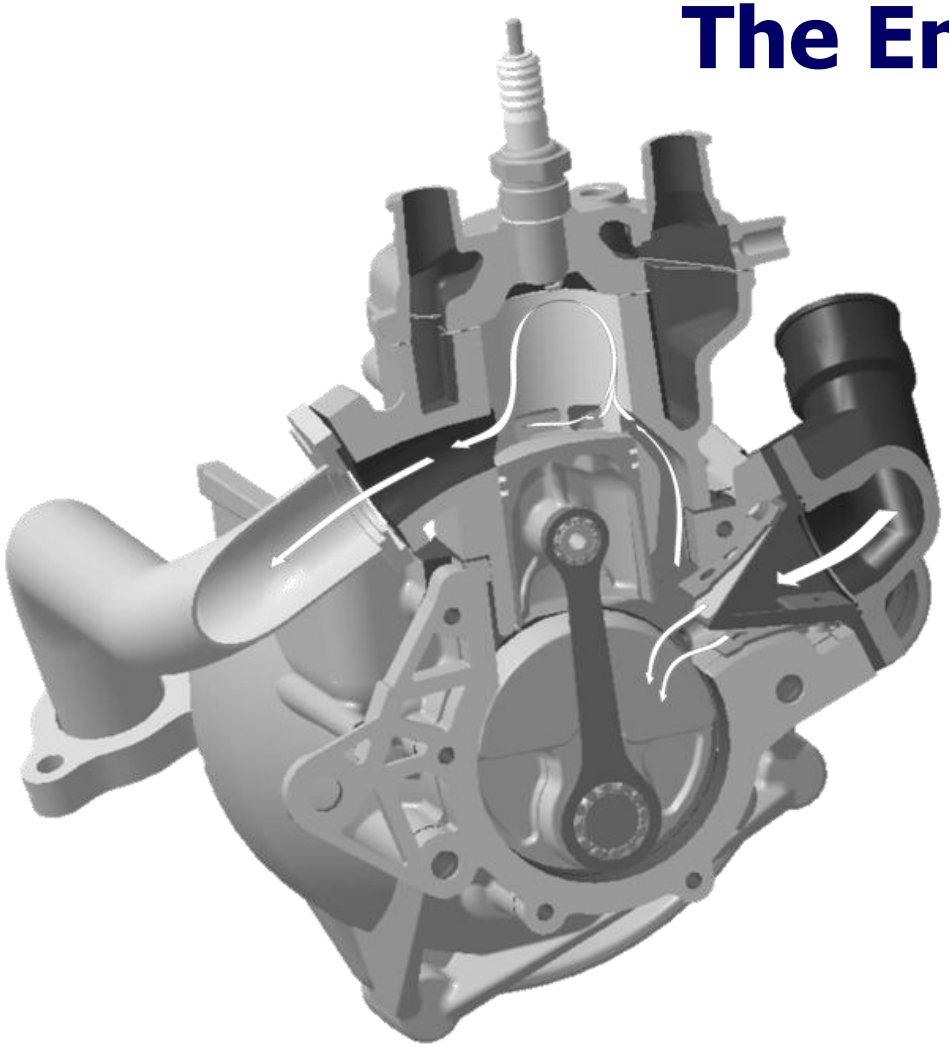
The Engine

- Basic engine data
  - Capacity: 50 cm³ 2-stroke engine
  - Bore: 40 mm
  - Stroke: 39.2 mm
  - Compression ratio: 11.68
  - Power: 3.7 kW
  - Torque: 5 Nm
  - …



The Engine

- Basic engine data
- Port configuration
  - Loop scavenged
  - 5 transfer ports
  - Reed valve



Introduction

- Direct injection mode
  - Fuel injection during scavenge process
  - Homogenization in the cylinder

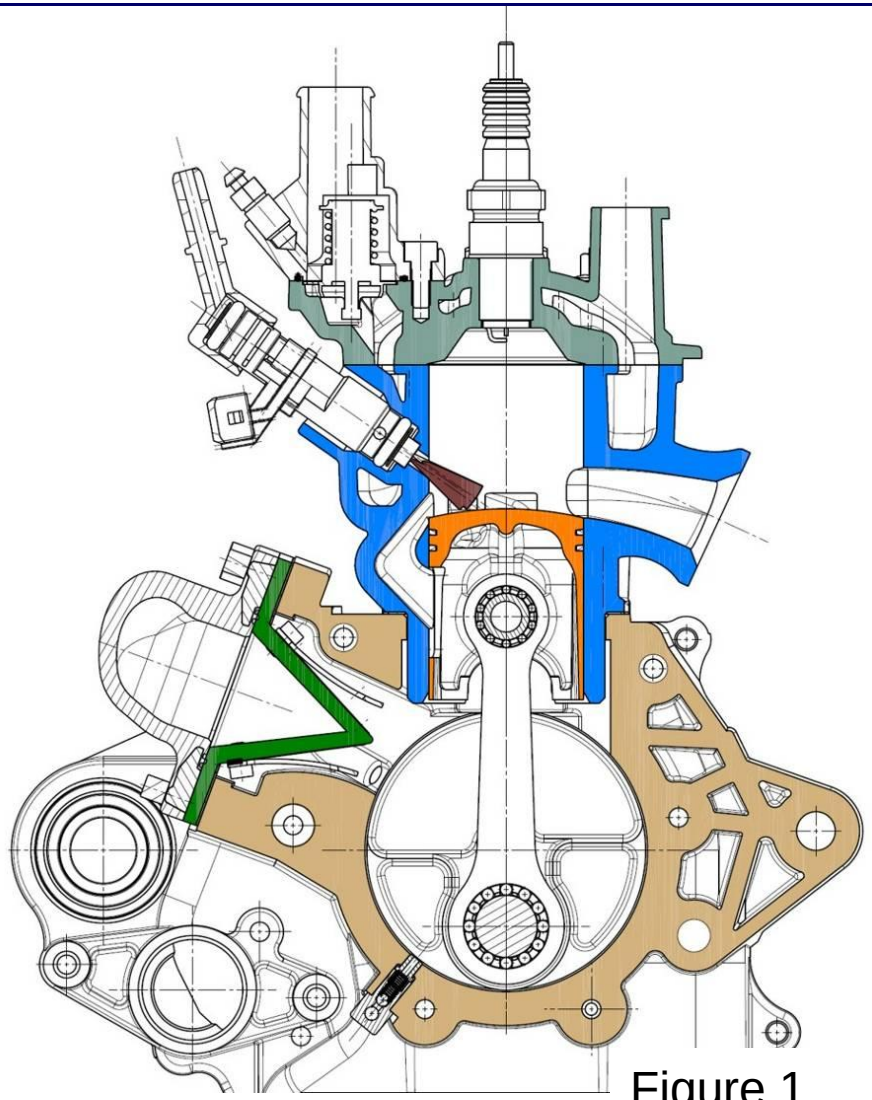


Figure 1

Introduction

- Direct injection mode
  - Fuel injection during scavenge process
  - Homogenization in the cylinder
- Stratified mode
  - Fuel injection trough the window of the piston

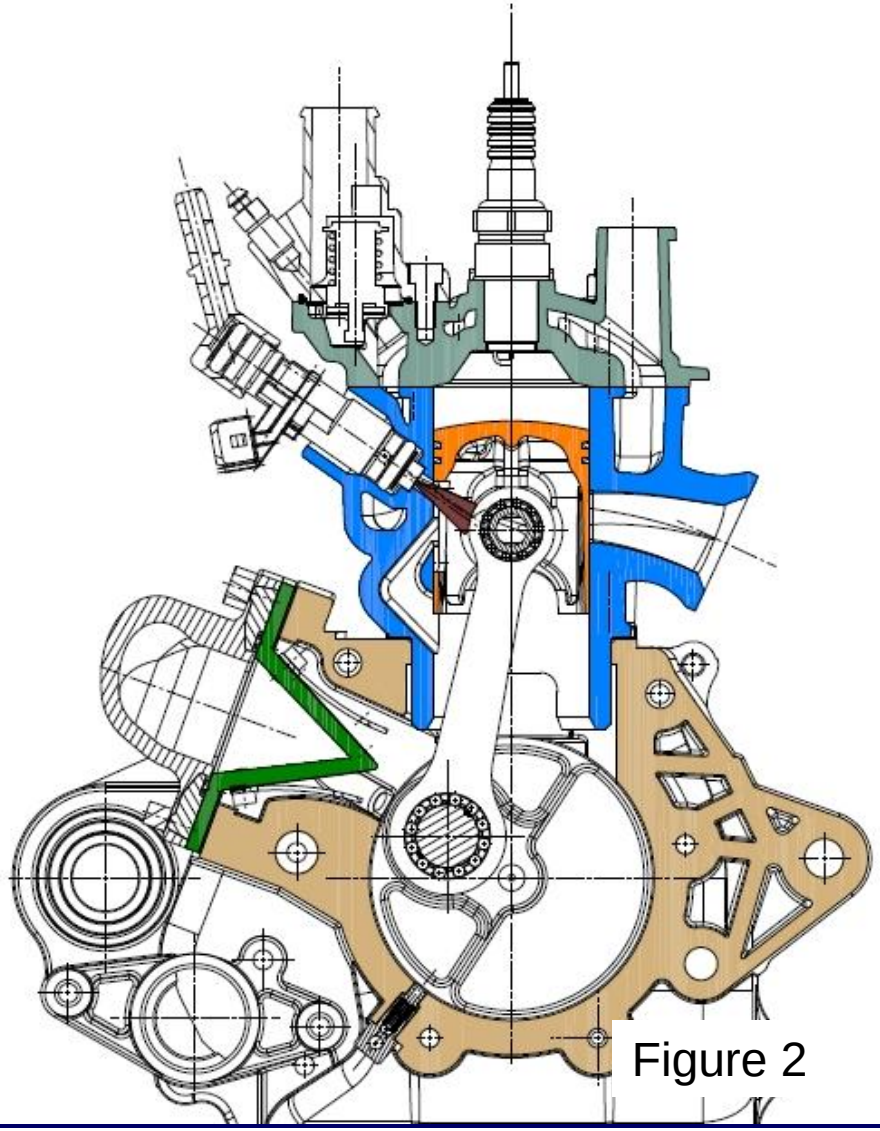
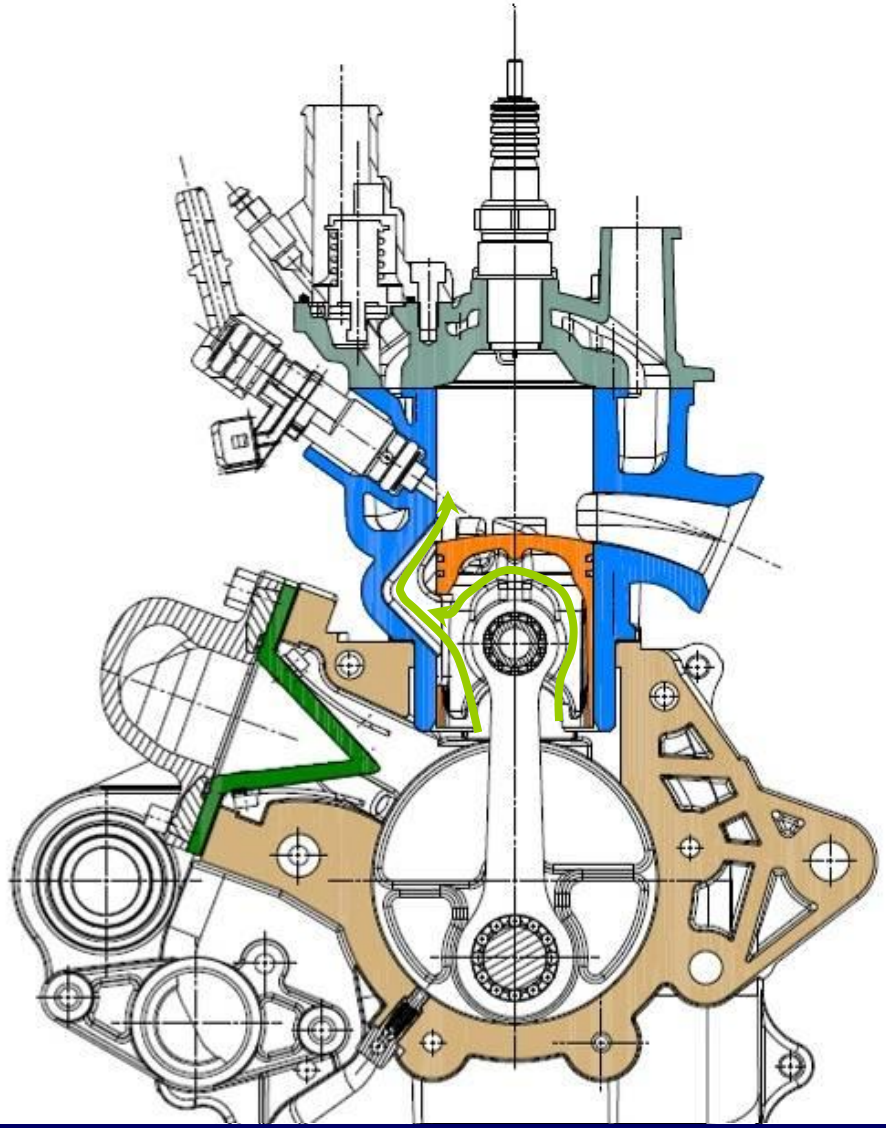


Figure 2

Introduction

- Direct injection mode
  - Fuel injection during scavenge process
  - Homogenization in the cylinder
- Stratified mode
  - Fuel injection trough the window of the piston
  - Stratified scavenging trough the boost port
  - Homogenization in the cylinder



The strategy

- Direct injection mode
  - low HCs
  - low BSFC
- Stratified mode
  - low BSFC
  - max. Power @ high rpm
  - crankcase cooling
  - stability at idle and part load
  - lower HCs than carburettor

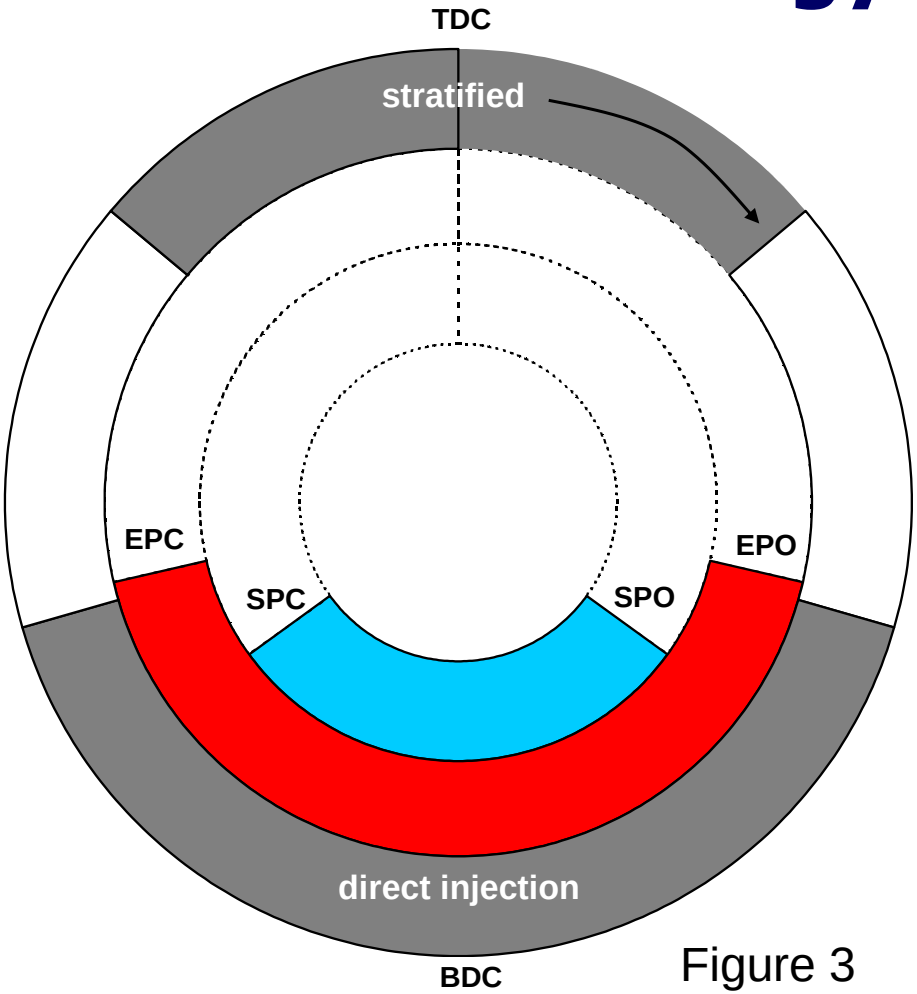


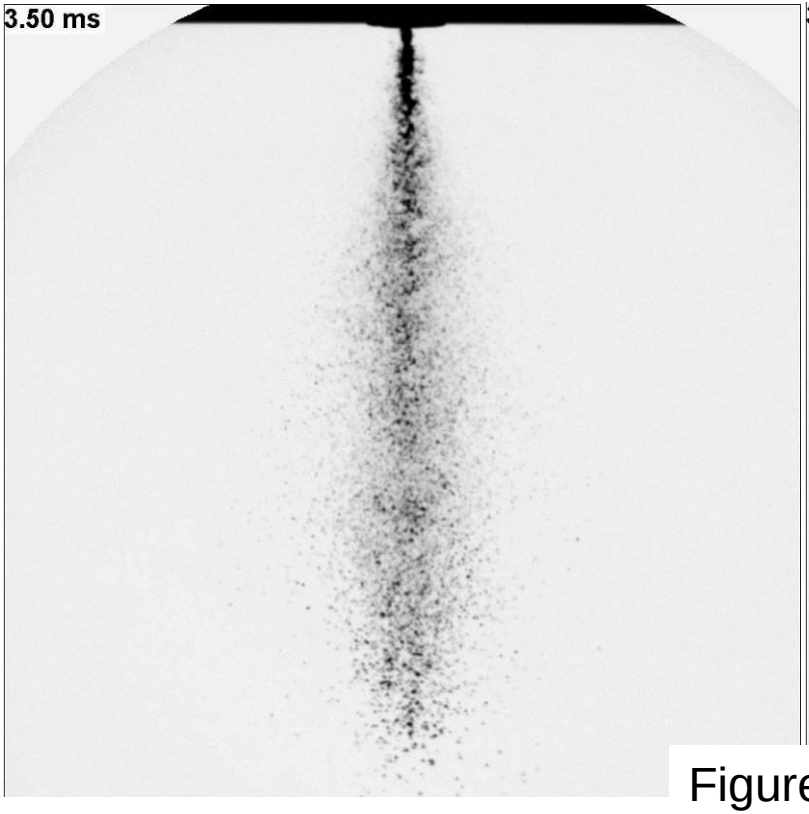
Figure 3

Combustion system development

Spray Quality and Fuel Pressure

- Two different spray types

400 kPA two holes



700 kPA three holes

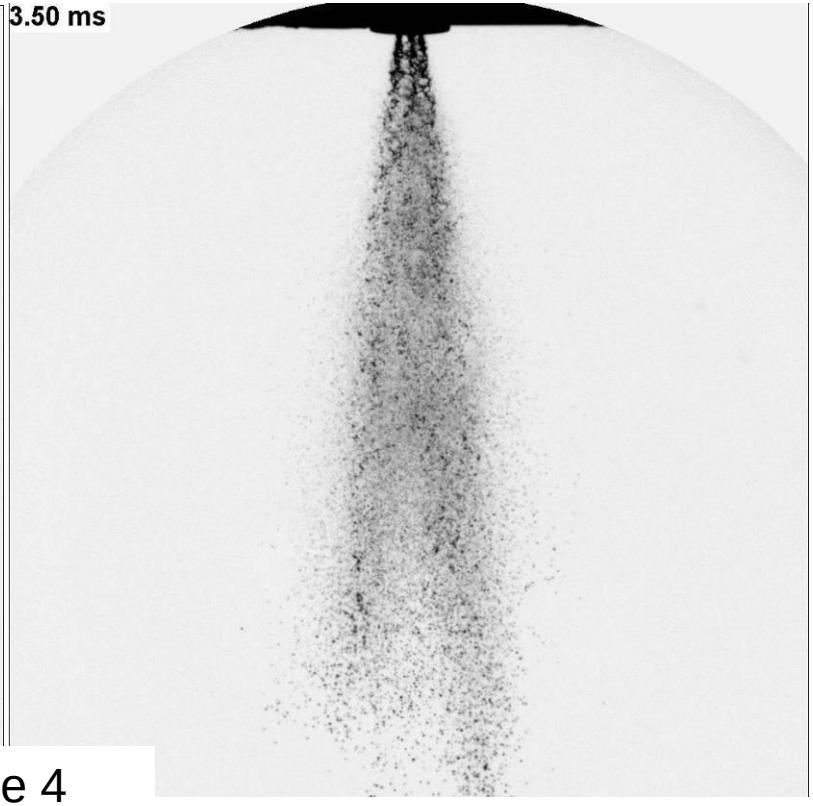


Figure 4

Spray Quality and Fuel Pressure

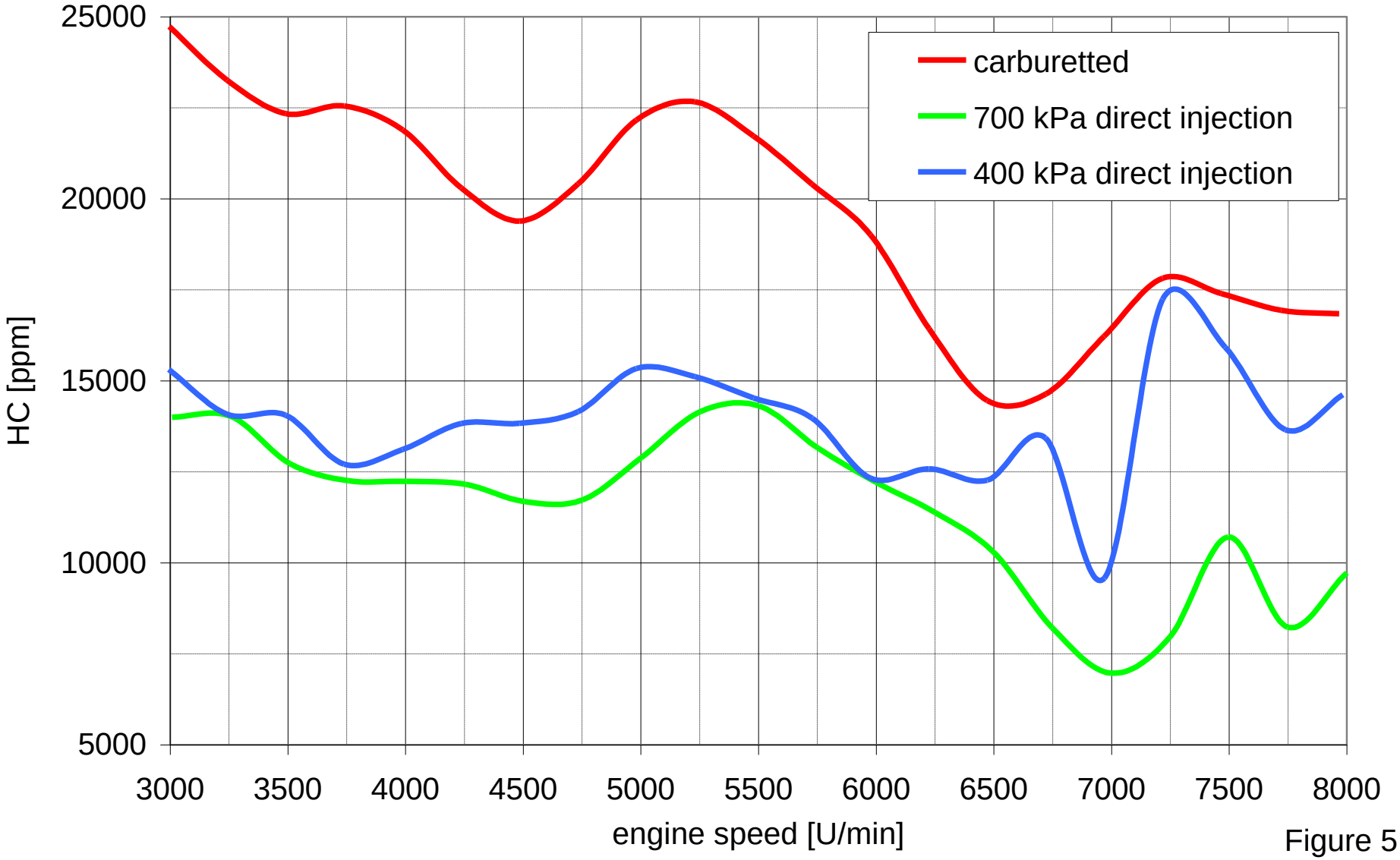


Figure 5

Spray Quality and Fuel Pressure

- 400 kPA injector

visualization 6000 rpm WOT simulation

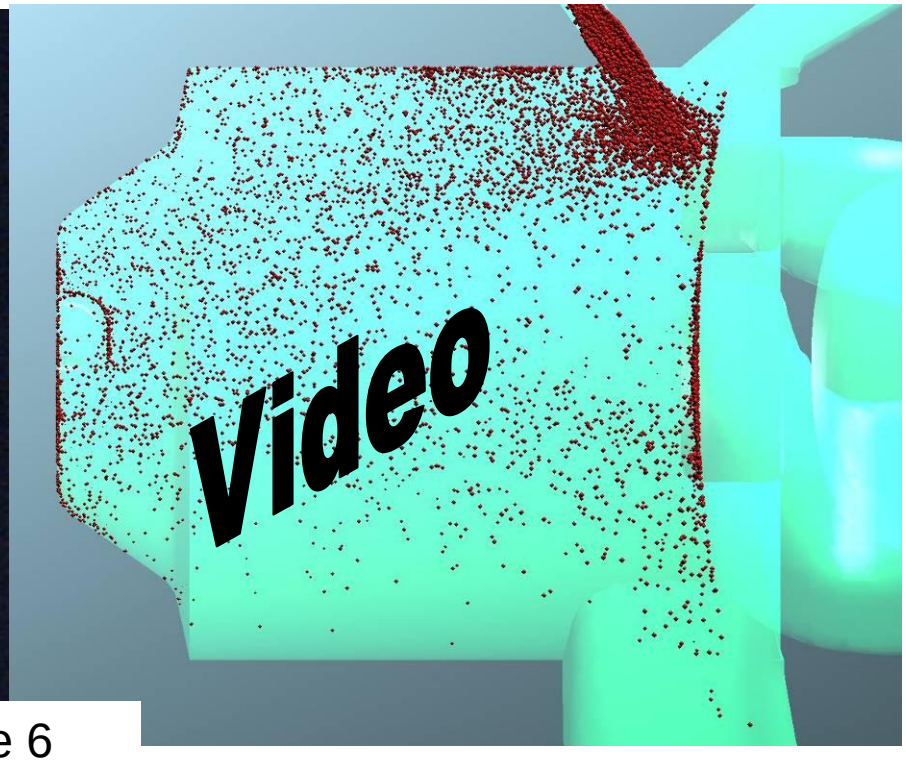


Figure 6

Spray Quality and Fuel Pressure

- 700 kPA injector

visualization 6000 rpm WOT simulation

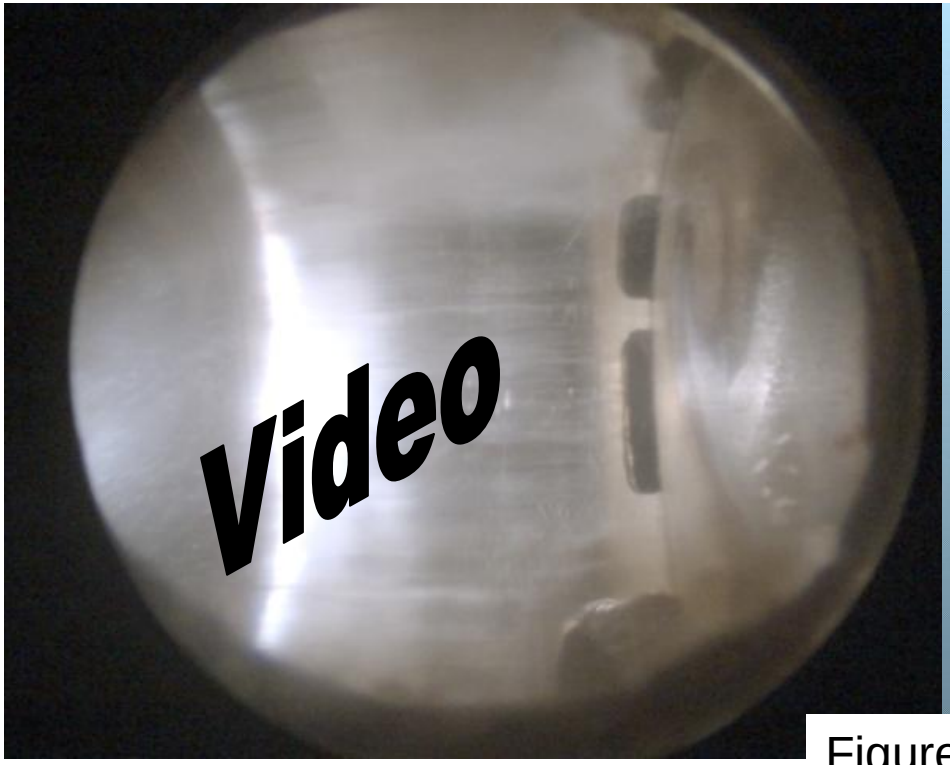
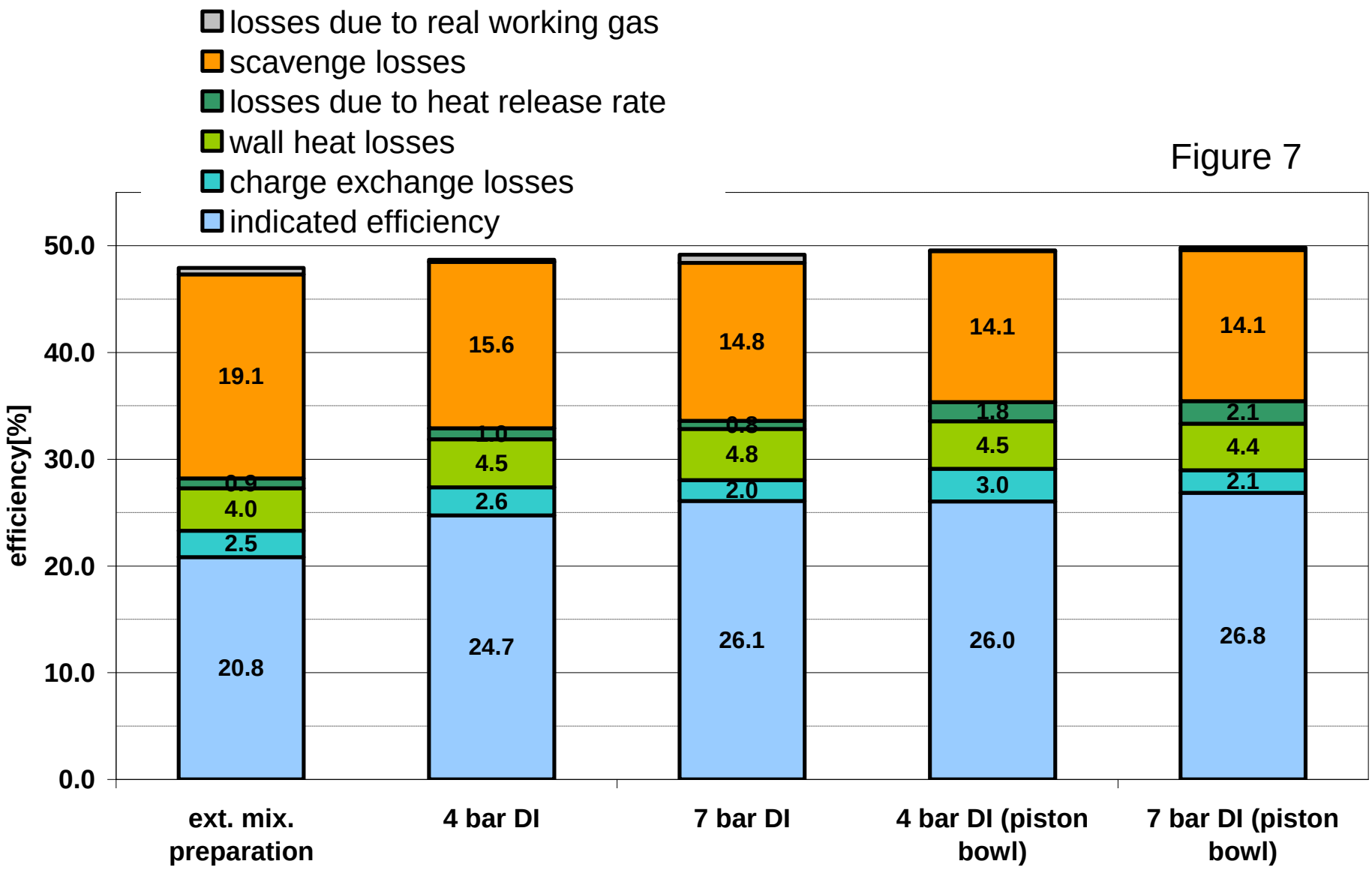


Figure 6

Thermodynamic analysis



Injection strategies

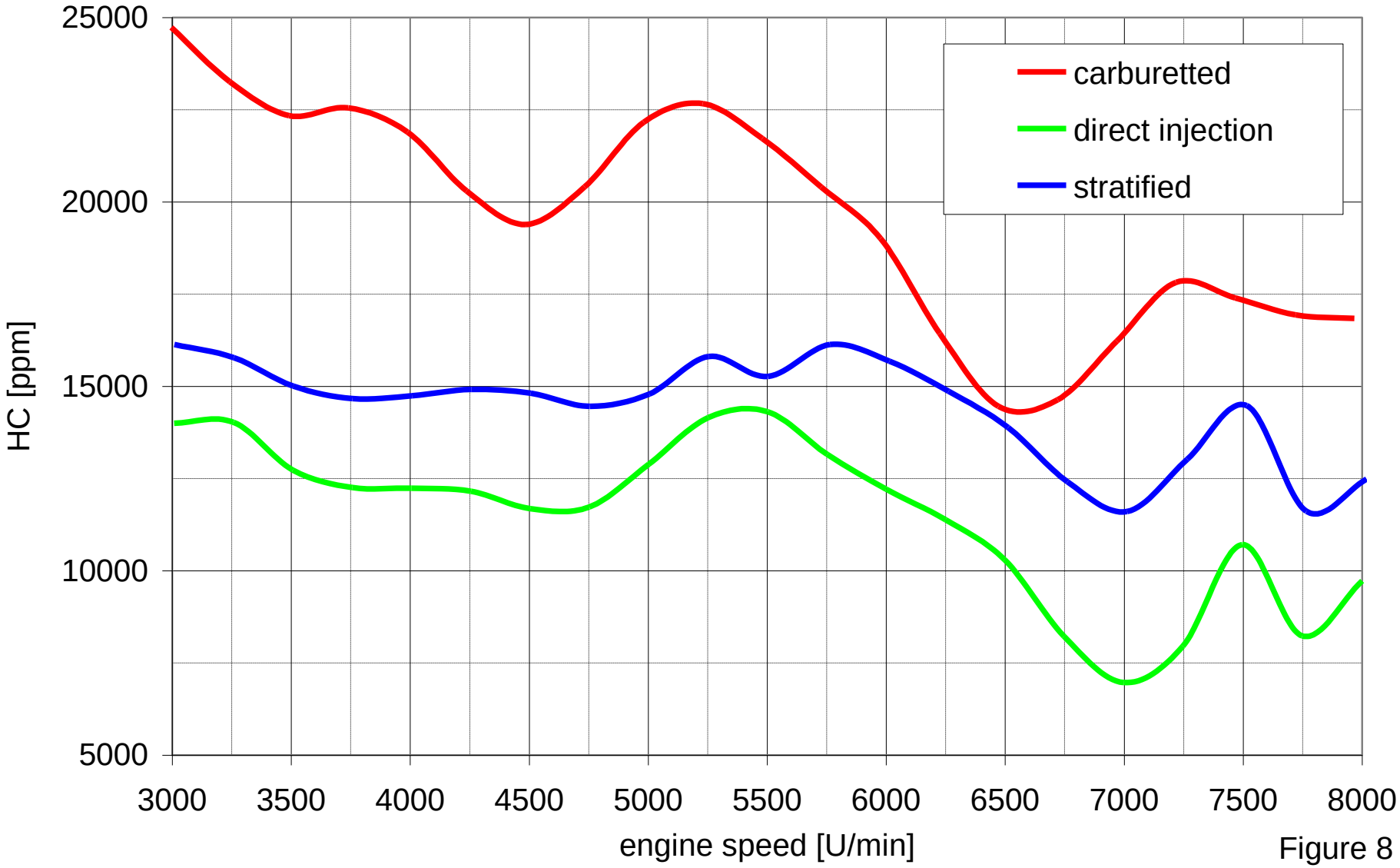
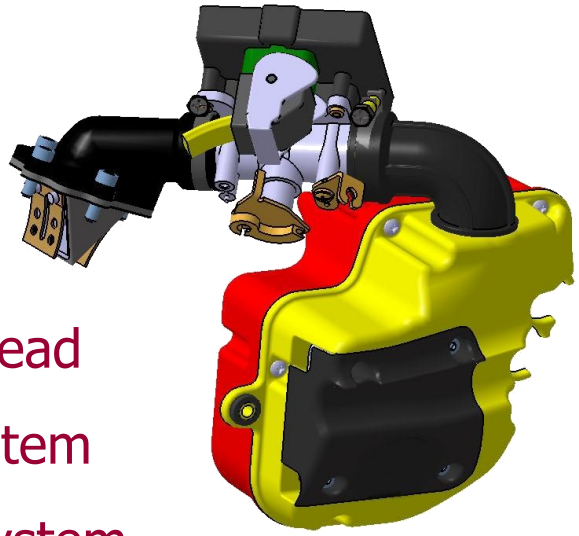


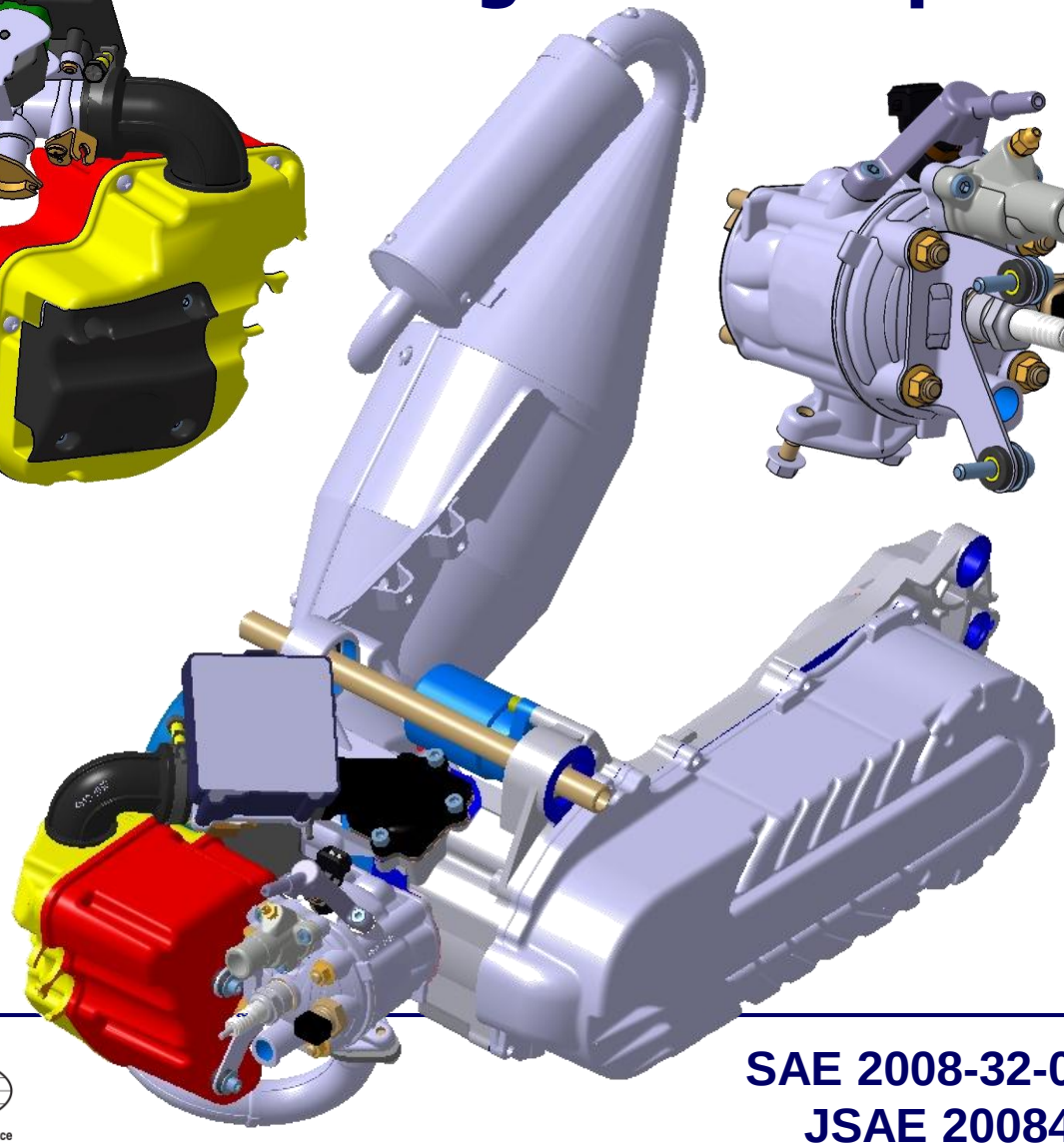
Figure 8

Engine & vehicle development

Engine development

- Design
  - Cylinder
  - Cylinder head
  - Intake system
  - Exhaust system
  - …





Engine development

- Design
- Prototyping
  - Cylinder
  - Cylinder head
  - Intake system
  - Exhaust system
  - …

Engine development

- Design
- Prototyping
- Engine test bench
  - Performance
  - Emissions
  - Durability
  - …

Test bench results – Engine test bench

Torque, Power and BSFC

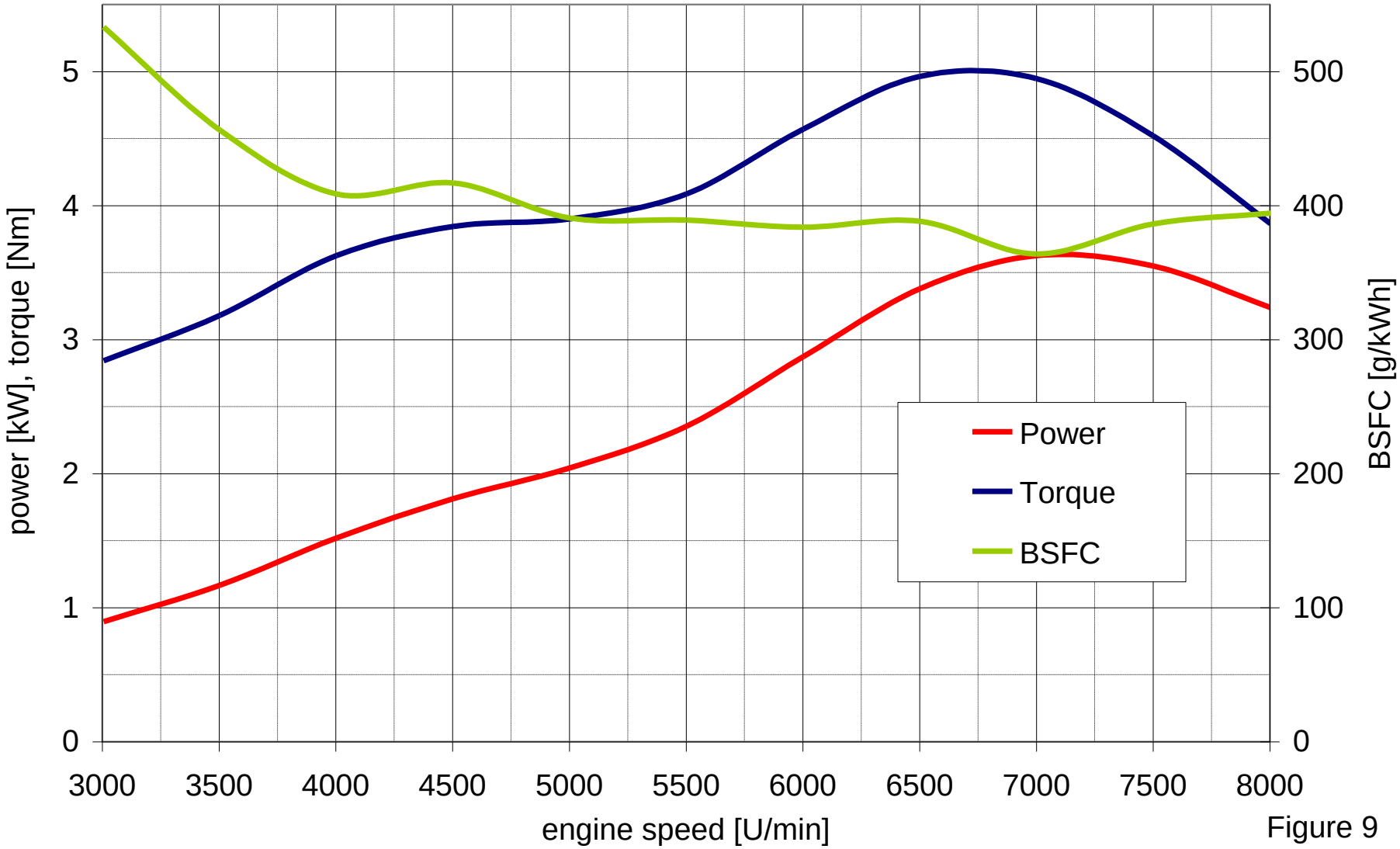


Figure 9

Untreated HC- & CO-Emissions

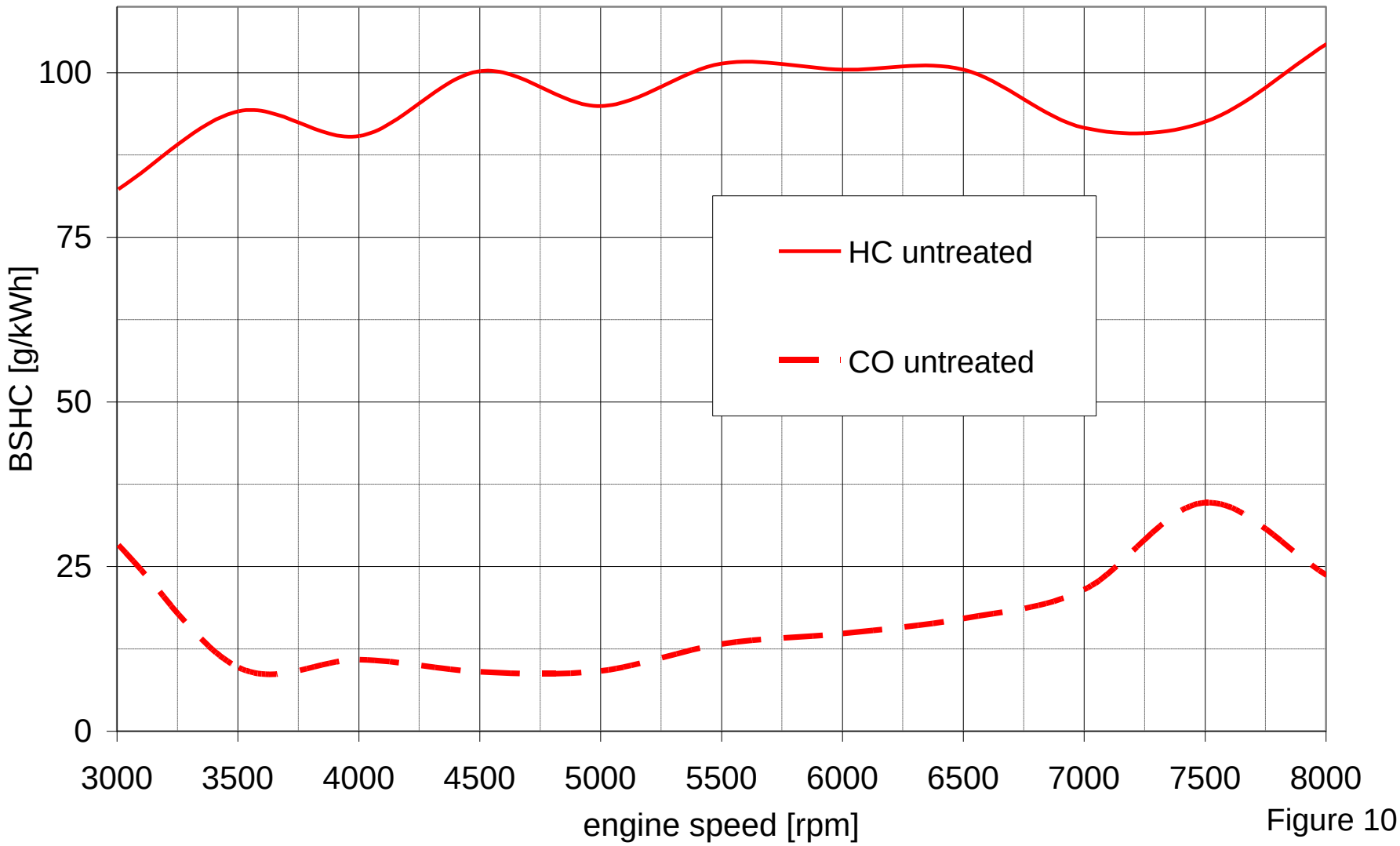
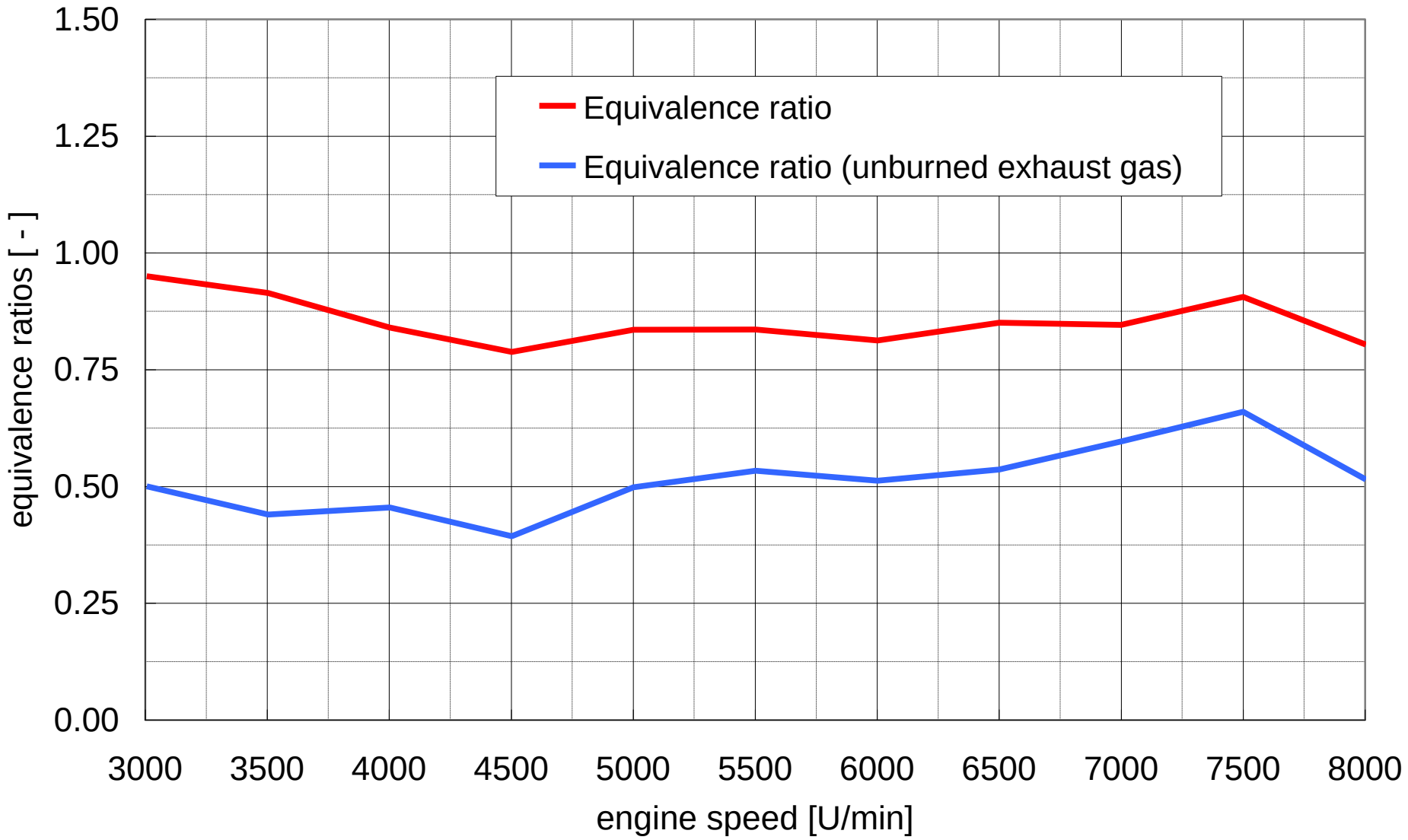


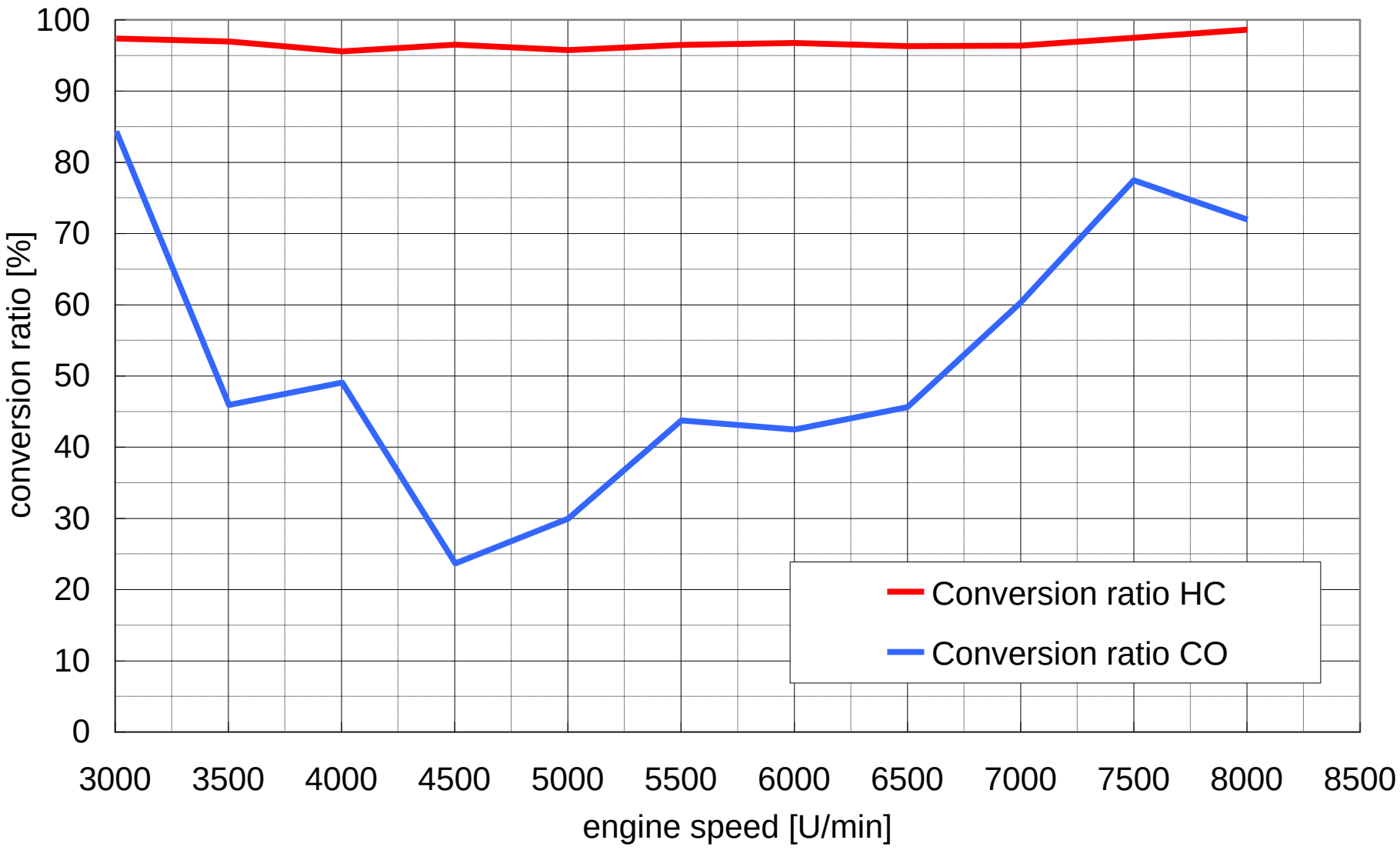
Figure 10

Test bench results – Engine test bench

Exhaust gas purification



Conversion ratio of HC and CO



HC- & CO-Emissions after catalyst

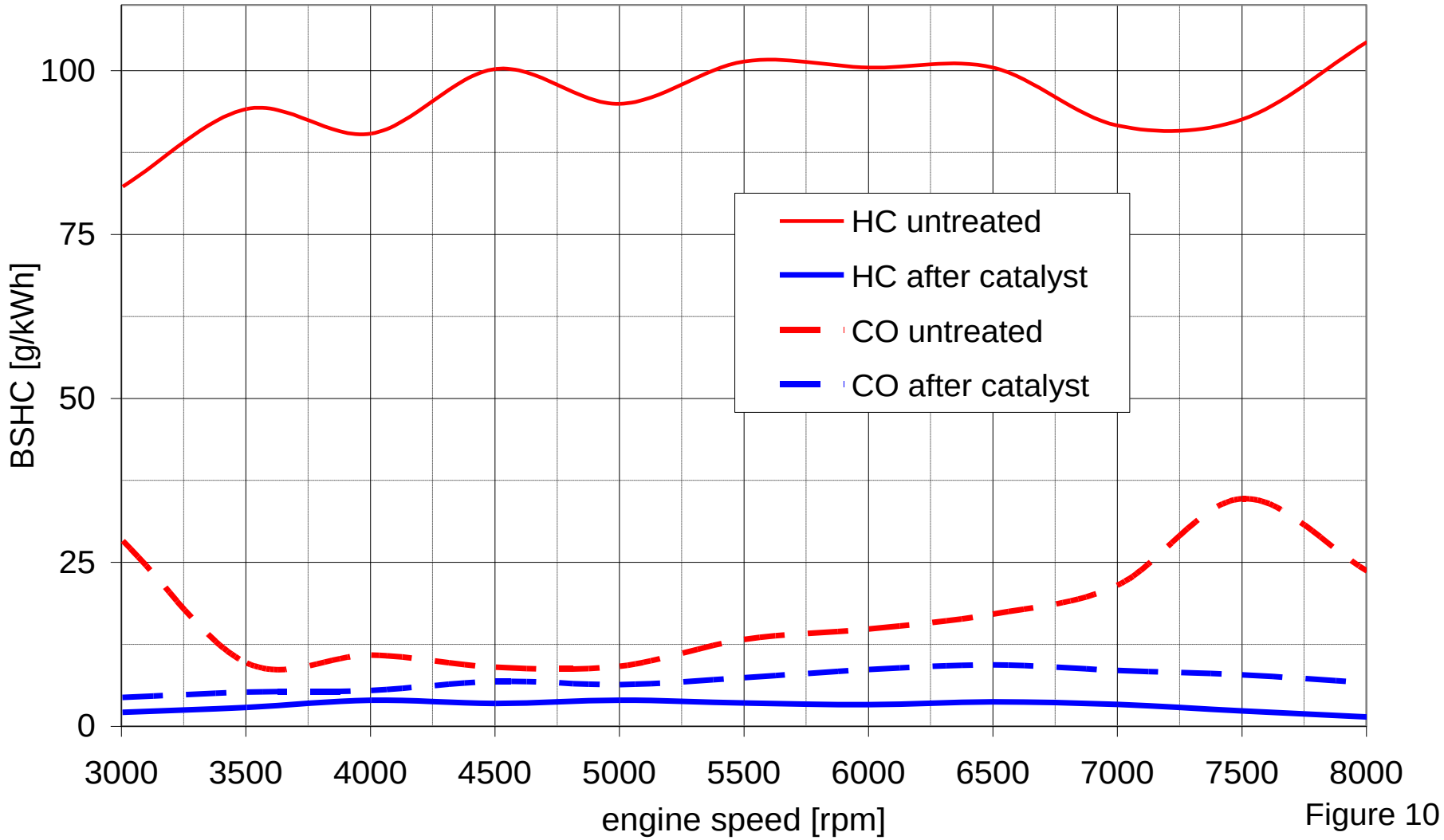
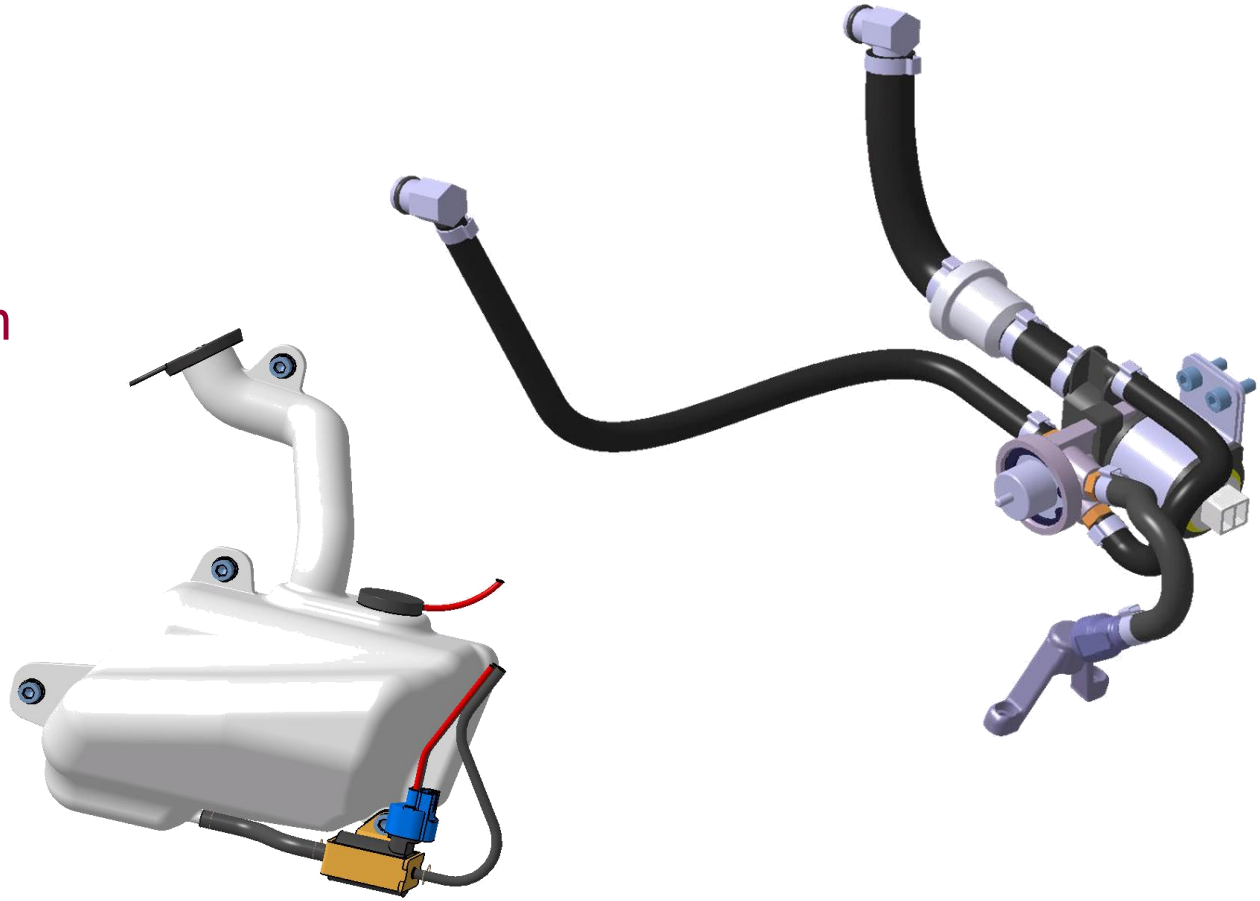


Figure 10

Vehicle development

- Design
  - Fuel system
  - Oil system
  - Cooling system
  - …



Vehicle development

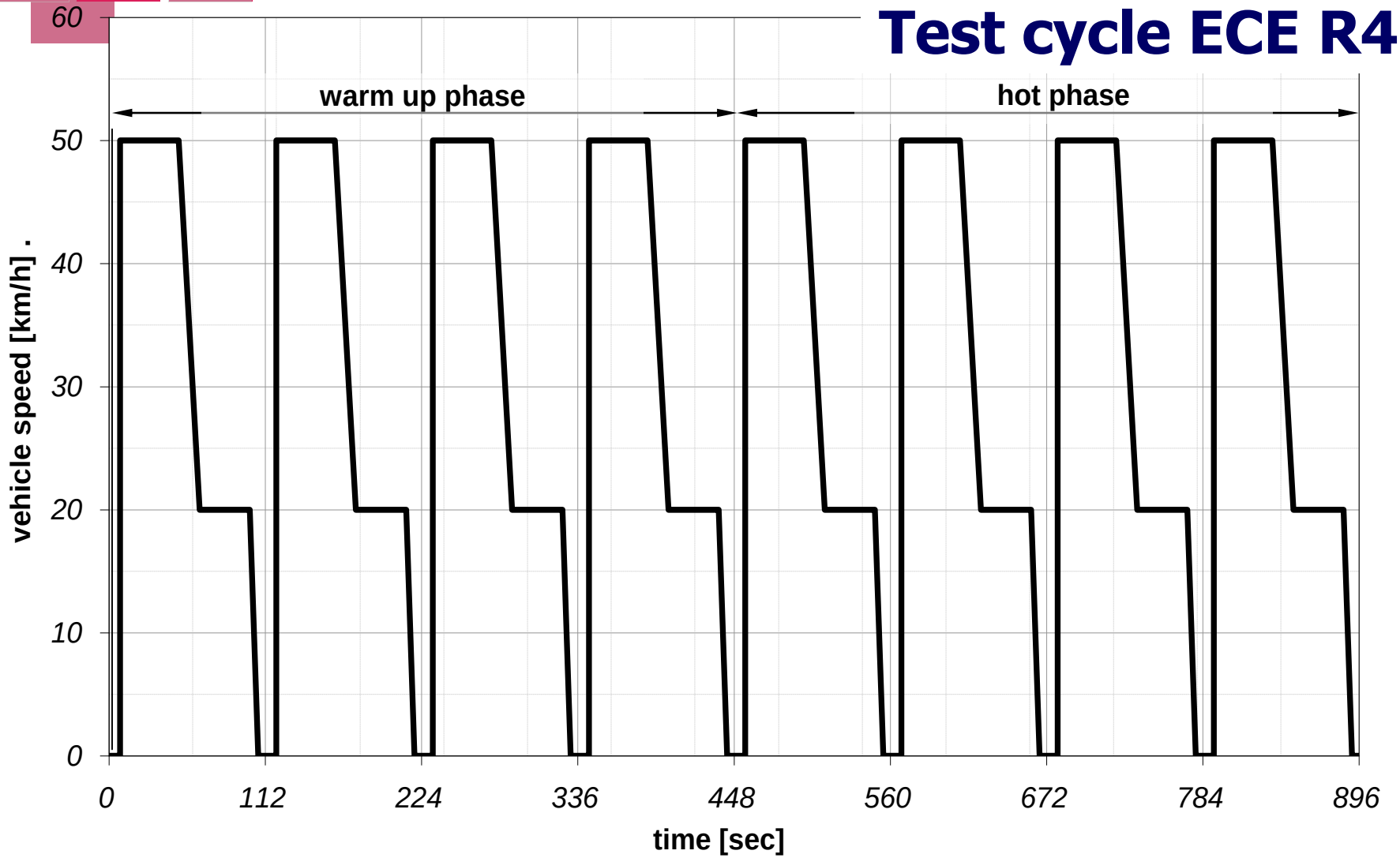
- Design
- Prototyping
  - 4 prototype vehicles
  - 2 different speed versions
  - 45 km/h ECE R47 (<50 cm³)
  - +60 km/h ECE 40 (<150 cm³)

Vehicle development

- Design
- Prototyping
- Chassis dyno & on road development
  - Performance (CVT setting)
  - Cold start
  - Warm up strategy (emissions)
  - Transient calibration
  - Cold chamber & altitude
  - …

Test bench results – Chassis test bench

Test cycle ECE R47



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Test bench results – Chassis test bench

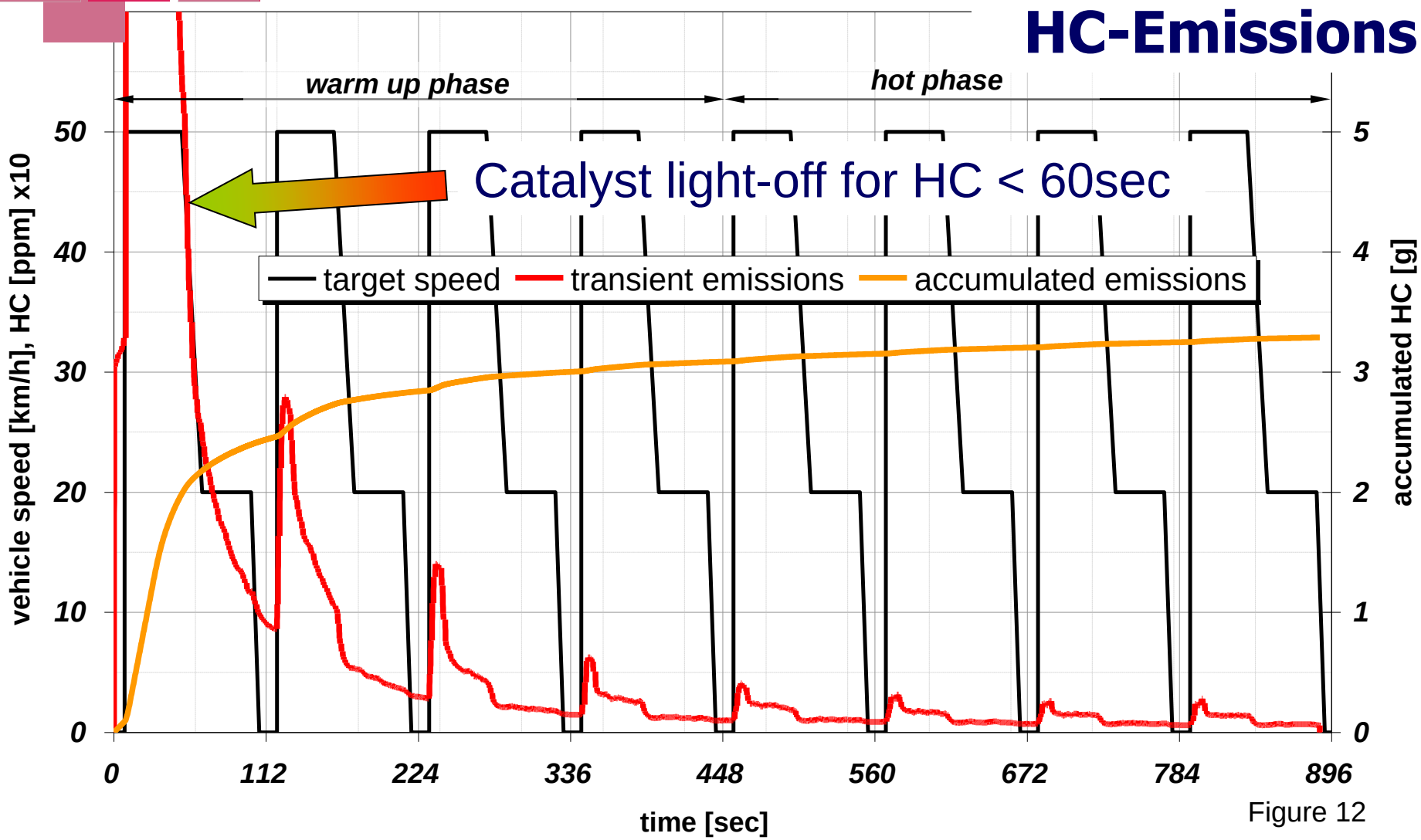

Figure 12

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Test bench results – Chassis test bench

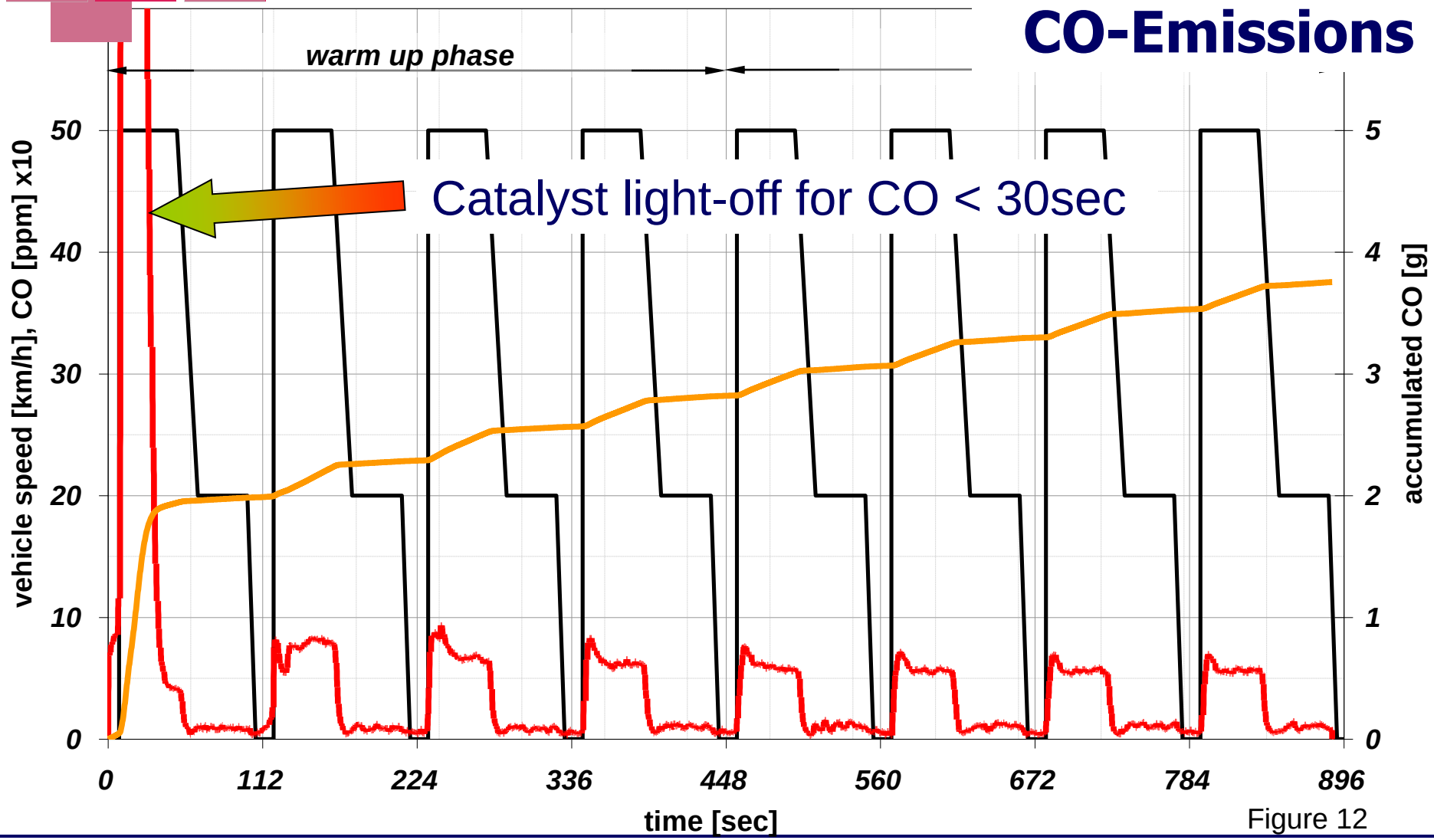

Figure 12

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Test bench results – Chassis test bench

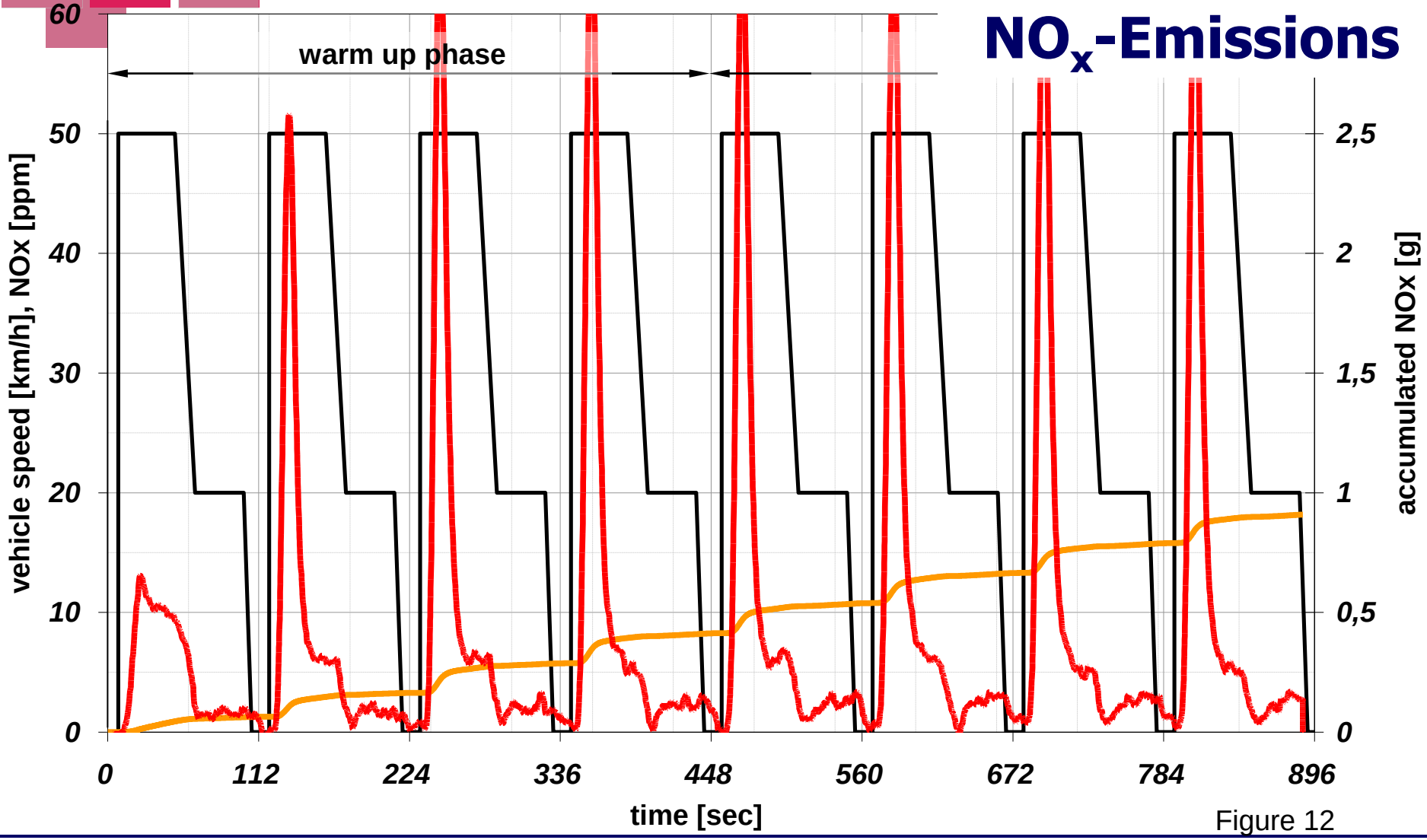

Figure 12

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ECE R 47 emission results

- Procedure
  - ECE R47 after 1000 km
- Results

< 50 %

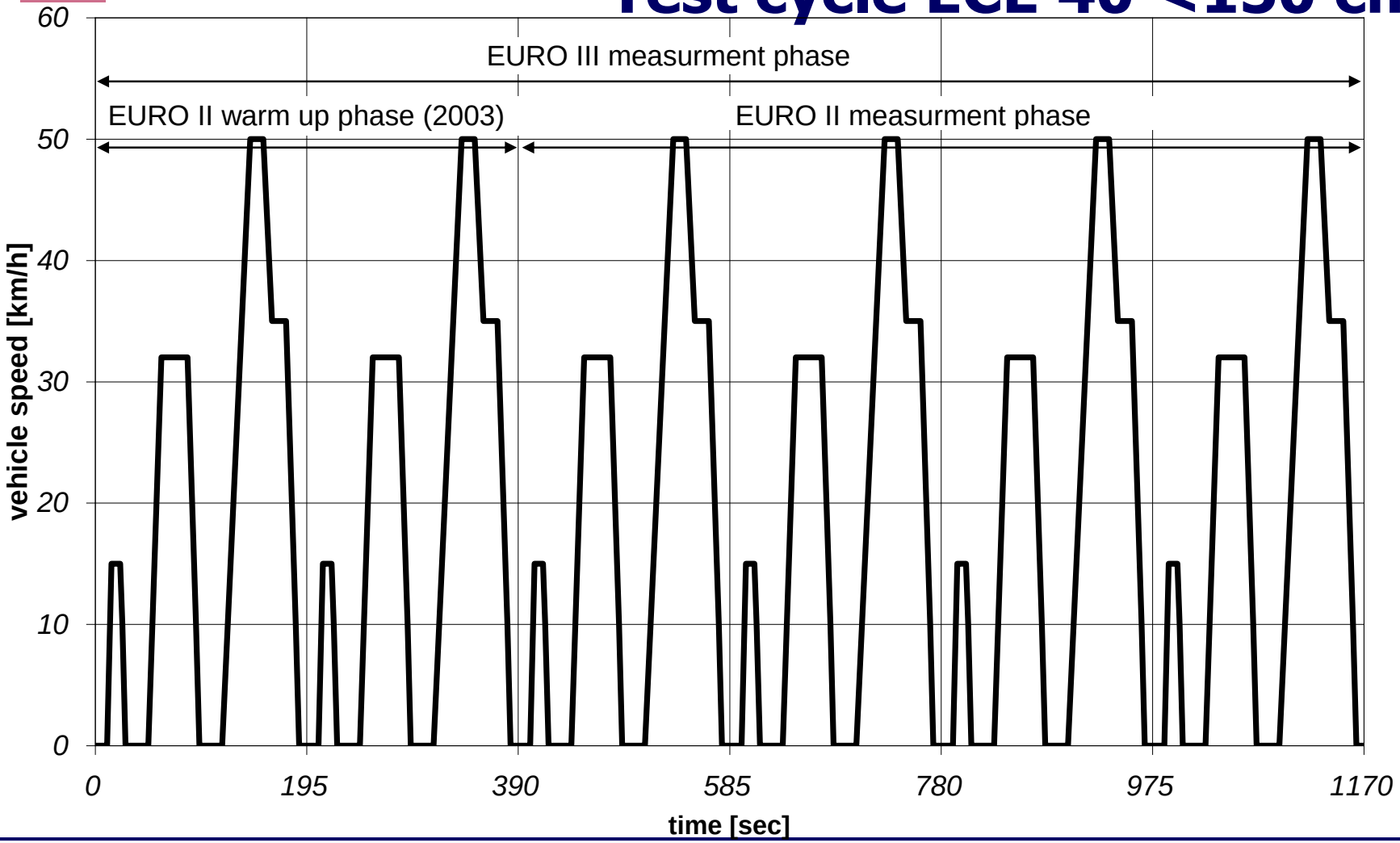
< 60 %

Emission results ECE R 47 (mileage ~1000 km)									limits:	CO [g/km]:	1
										$HC + NO_x$ [g/km]:	1.2
Emissions warm up		weighting factor					weighting factor				
CO [g/km]	0.90	x	0.3		Emissions [g/km]	% of limit	x	0.5		Emissions [g/km]	% of limit
$HC + NO_x$ [g/km]	1.14			CO	0.44	43.8			CO	0.57	57.0
Emissions hot			+	$HC + NO_x$	0.50	41.3		+	$HC + NO_x$	0.68	56.7
CO [g/km]	0.24	x	0.7				x	0.5			
HC + Nox [g/km]	0.22										

Figure 13

Test bench results – Chassis test bench

Test cycle ECE 40 <150 cm³



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Test bench results – Chassis test bench

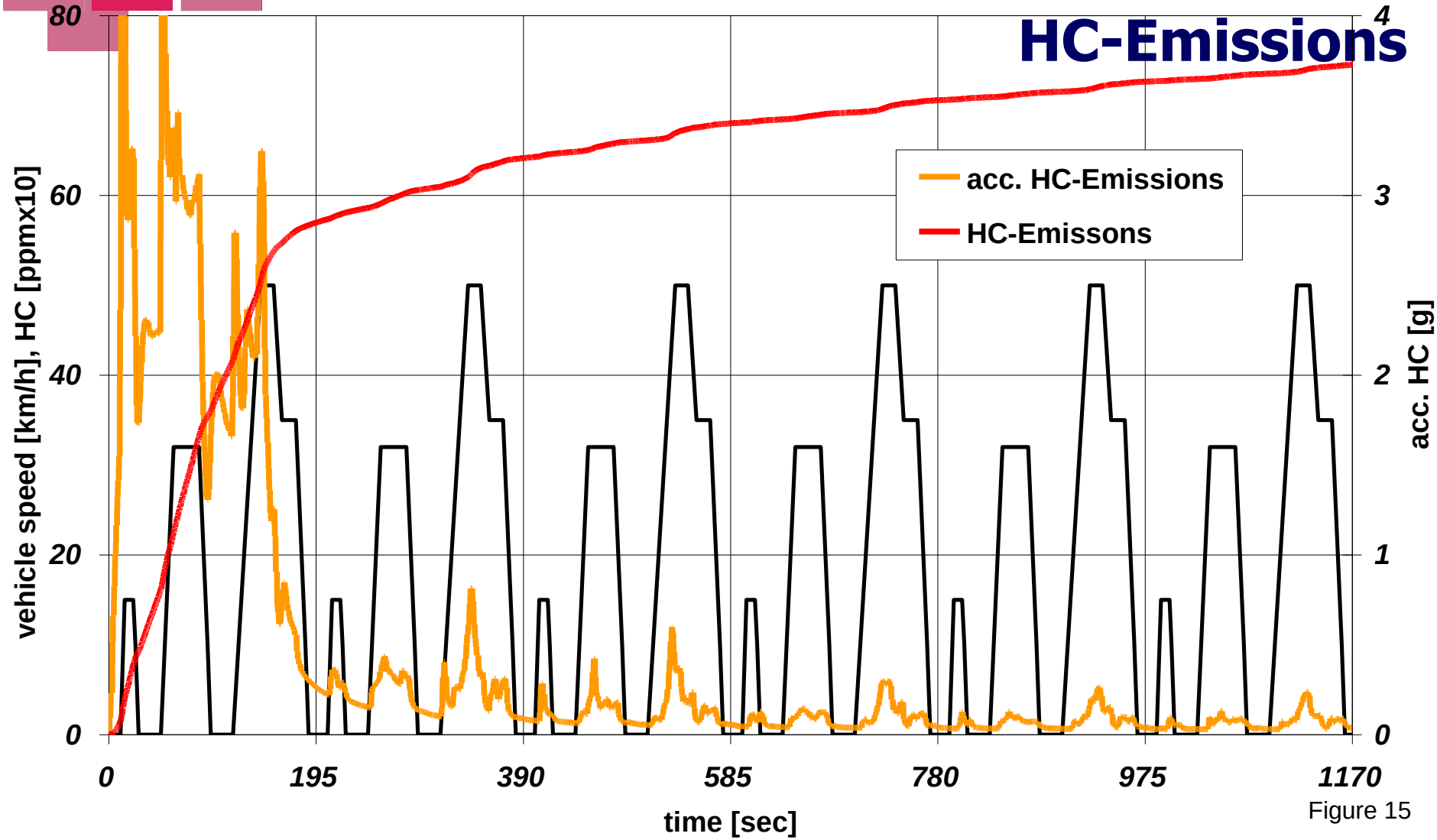

Figure 15

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Test bench results – Chassis test bench

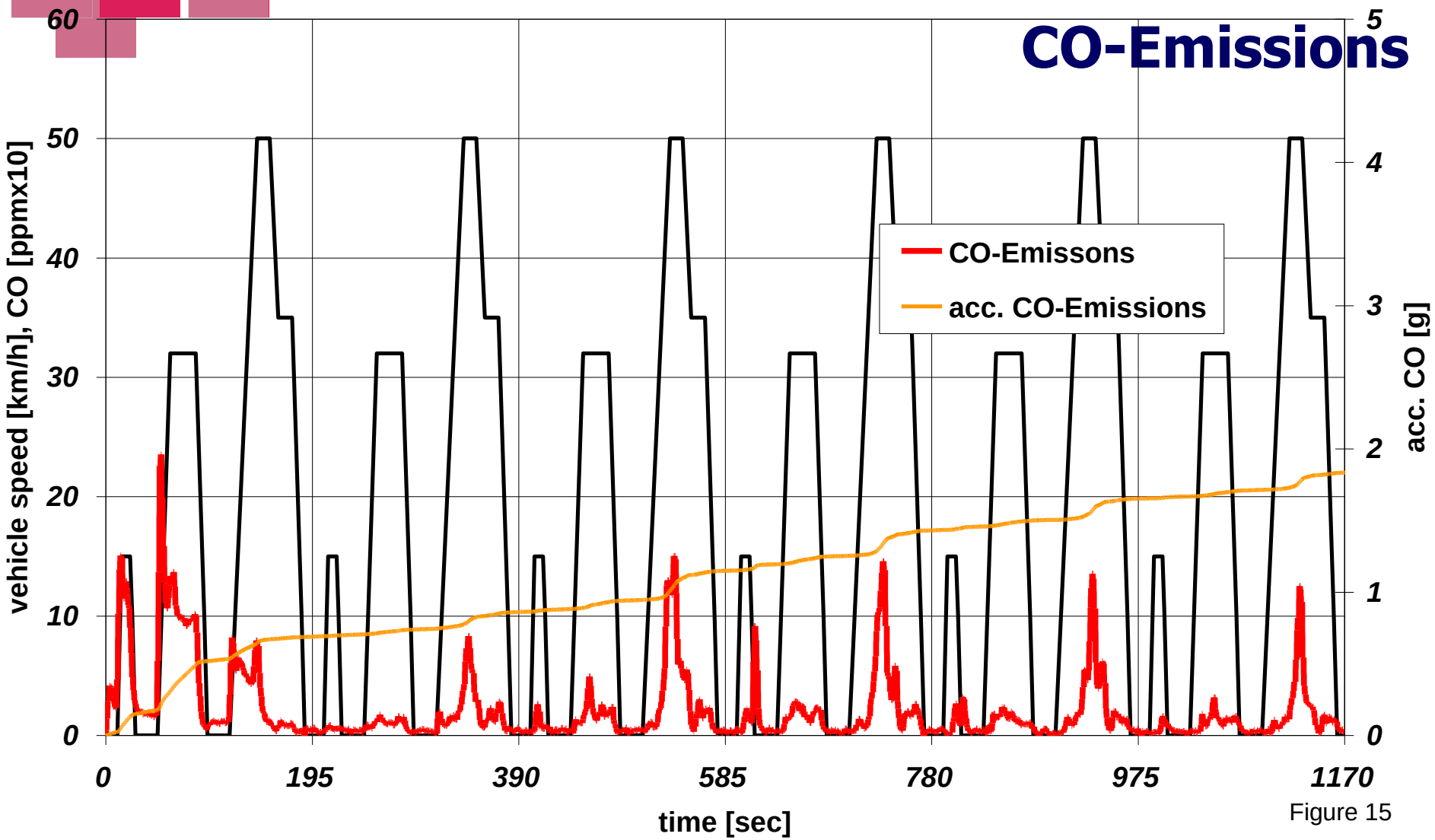

Figure 15

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Test bench results – Chassis test bench

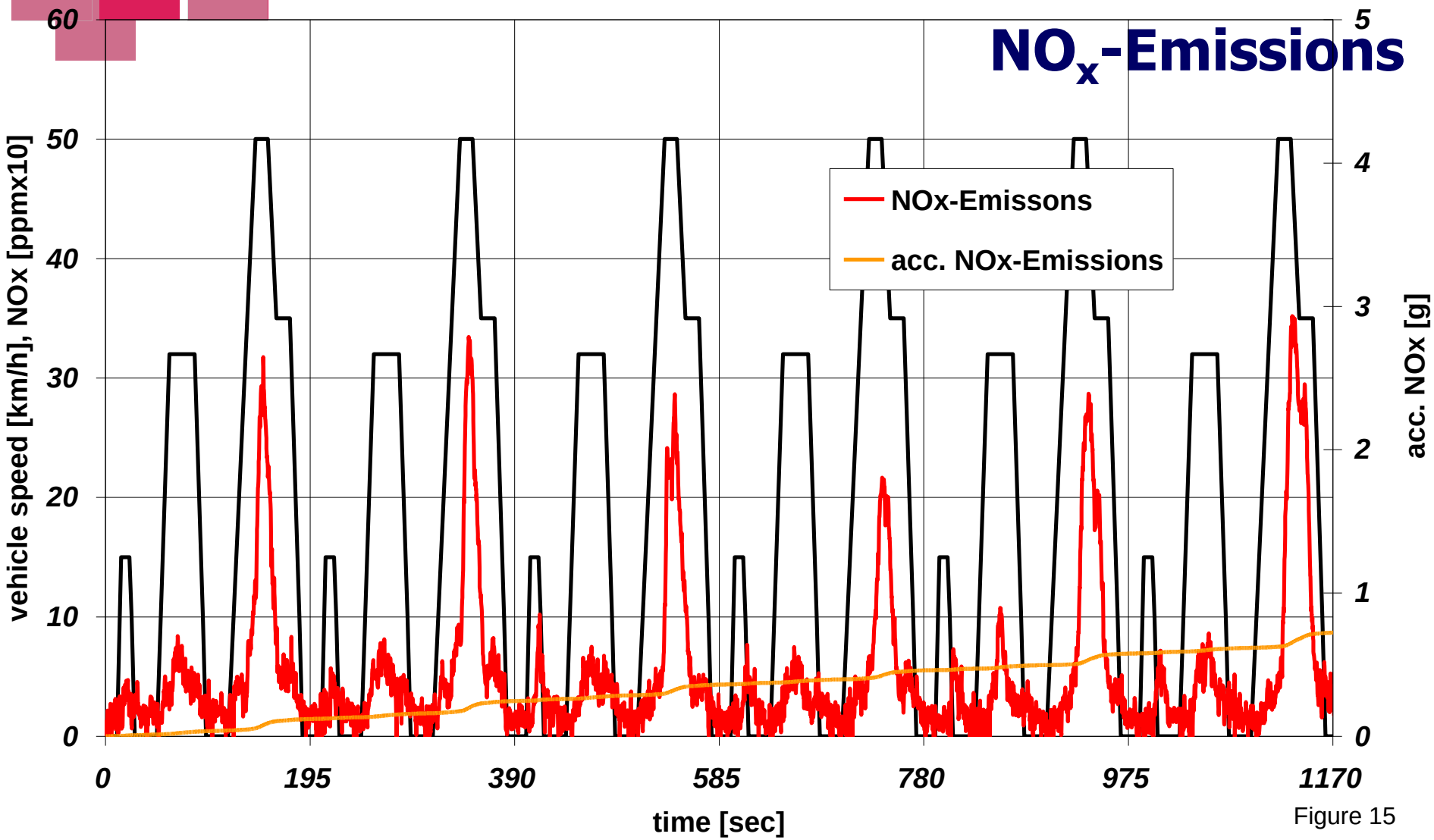

Figure 15

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ECE 40 emission results

- Procedure
  - ECE 40 after 1000 km
- Results

Emission results ECE 40 urban cycle (mileage ~ 1000 km)			
Emissions warm up + hot phase	**limits:**	**CO [g/km]:**	**2**
		HC [g/km]:	**0.8**
		NO_x [g/km]:	**0.15**

	Emissions [g/km]	% of the Limit
CO	0.31	15.46
HC	0.62	77.06
NOx	0.10	69.55

Figure 14

Benchmark

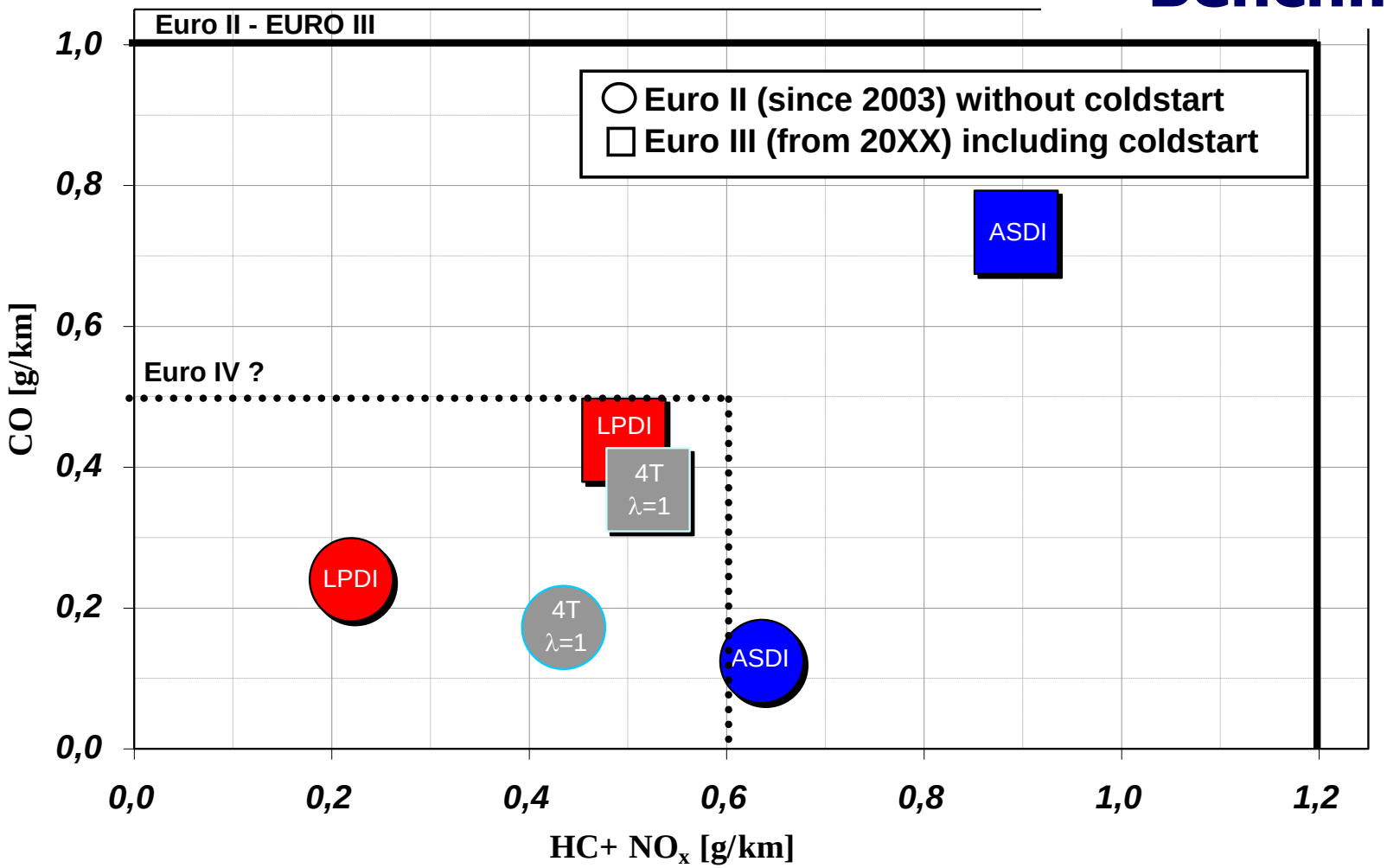
Benchmark

- Procedure
  - Comparison of 3 different low emission concepts
  - ECE R47
- Technologies
  - 50 cm³ four-stroke, efi, 3-way-catalyst
  - 50 cm³ two-stroke, air-assisted direct injection, oxidation catalyst
  - 50 cm³ two-stroke, low-pressure direct injection, oxidation catalyst

Figure 28

Benchmark

Benchmark



Conclusion

Conclusion

- It was demonstrated that with the introduced injection strategy the reduction of untreated HC emissions is ~ 40%
- The reduction of scavenge losses lead to a ~ 25% lower fuel consumption
- Very lean exhaust gas due to the stratification of the scavenge process increase the conversion ratio of HC and CO
- The increased exhaust gas temperature shortens the cat light-off time leading to reduced cold start emissions
- There is no need for specific technology development (standard two-stroke engine with standard injection components) therefore the development risk is comparatively low
- Focusing costs and market acceptance, this strategy is a valuable alternative to existing DI-systems

Thank you for your attention