9th ETH-Conference on Combustion Generated Nanoparticles
15th -17th August 2005

Paper Abstract

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Title:
Catalyzed Diesel Particulate Filter System (CPF) for EURO4 – Experiences of extended fleet test with HMC/Kia vehicles

Abstract: (min. 300 - max 500 words)
Diesel technology is an important element in the strategy to fulfil the CO_2 reduction consent made by the automobile industry (i.a. the Korean automobile association) to the European Union. Due to their driveability characteristics, vehicles with diesel engines are also increasing in popularity with customers. Over the last years, diesels have gained a market share of about 50% in most European countries.
A negative aspect of diesels is the emission of particulates. Political pressure, especially in Germany, drives the further reduction of particulate emission as a measure to reduce health risks, leading to an ongoing discussion about fine diesel particulate matter (DPM) in the public. Based on these concerns and on the political strategies, Diesel vehicles are to be equipped with diesel particulate filters (DPF), not alone to fulfil the Euro 4 legislation, but additionally to satisfy the demand of the public to get "soot-free" Diesel exhaust. For heavier vehicles, the use of DPFs is the also best feasible solution to reach the legislative limits for particulate emission. For vehicles equipped with a DPF, testing of the entire system, including the DPF and engine control interaction, is absolutely necessary, but fairly complicated due to the regeneration behaviour of the DPFs.
The paper reports on development and application work of CPF to HMC/Kia vehicles with special emphasis on an intensive fleet test with several tens of vehicles for in total more than 5 Mio. km under various driving conditions (country road, highway, city) in Korea, Spain and Sweden for:
- System durability evaluation (CPF, engine H/W, FIE system, sensors etc.)
- Regeneration functionality (initiation, duration, intervals)
- Exhaust gas emission behaviour depending on mileage
- Fuel consumption / oil consumption depending on driving profile
- Calibration refinement (emissions, regeneration, driveability, fuel consumption etc.)

Application of Catalyzed Diesel Particulate Filter System (CPF) for EURO 4: Experiences of extended fleet test with HMC/Kia vehicles

Paul ZELENKA, Wonkun KIM and John SEO

HYUNDAI · KIA MOTORS

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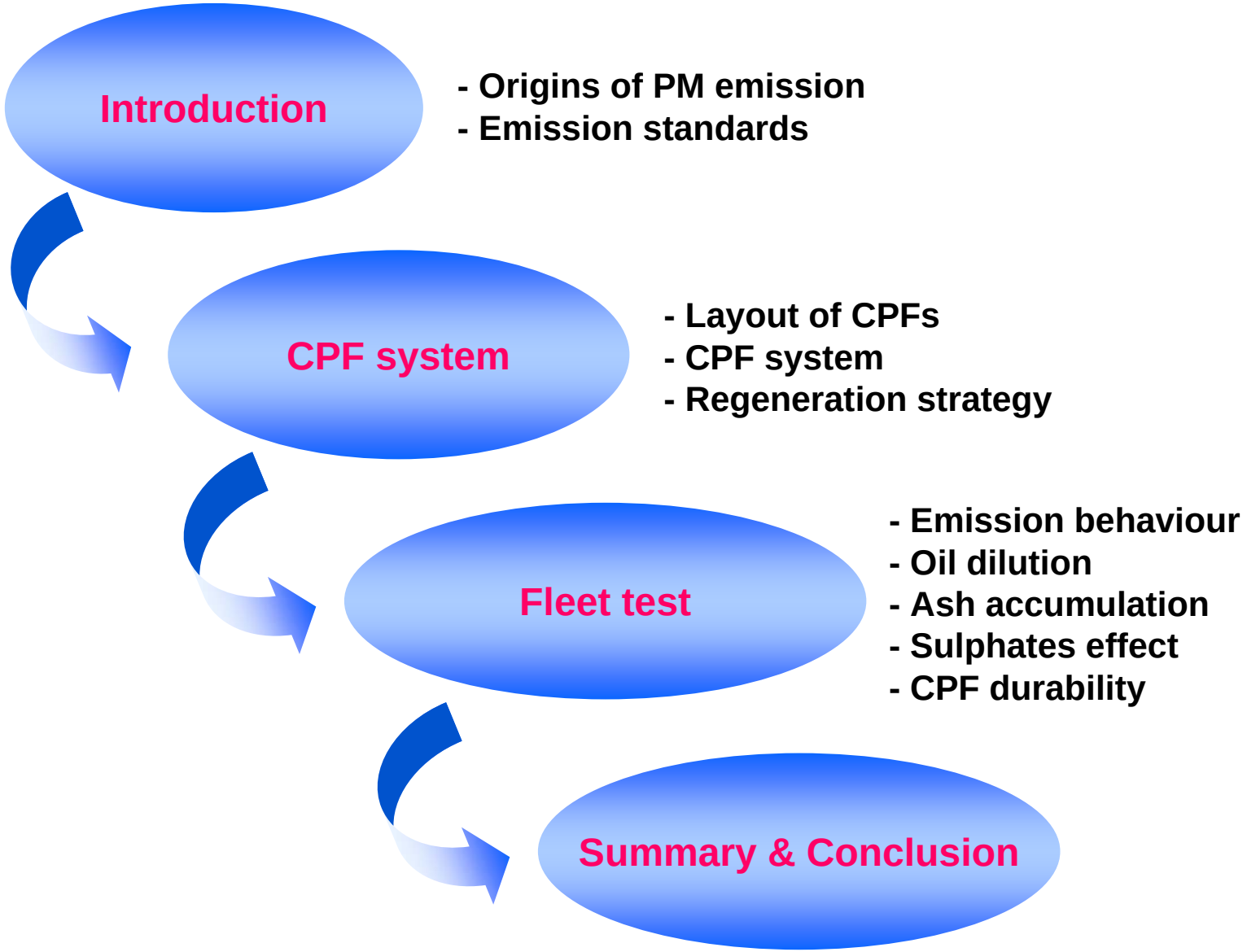
Introduction
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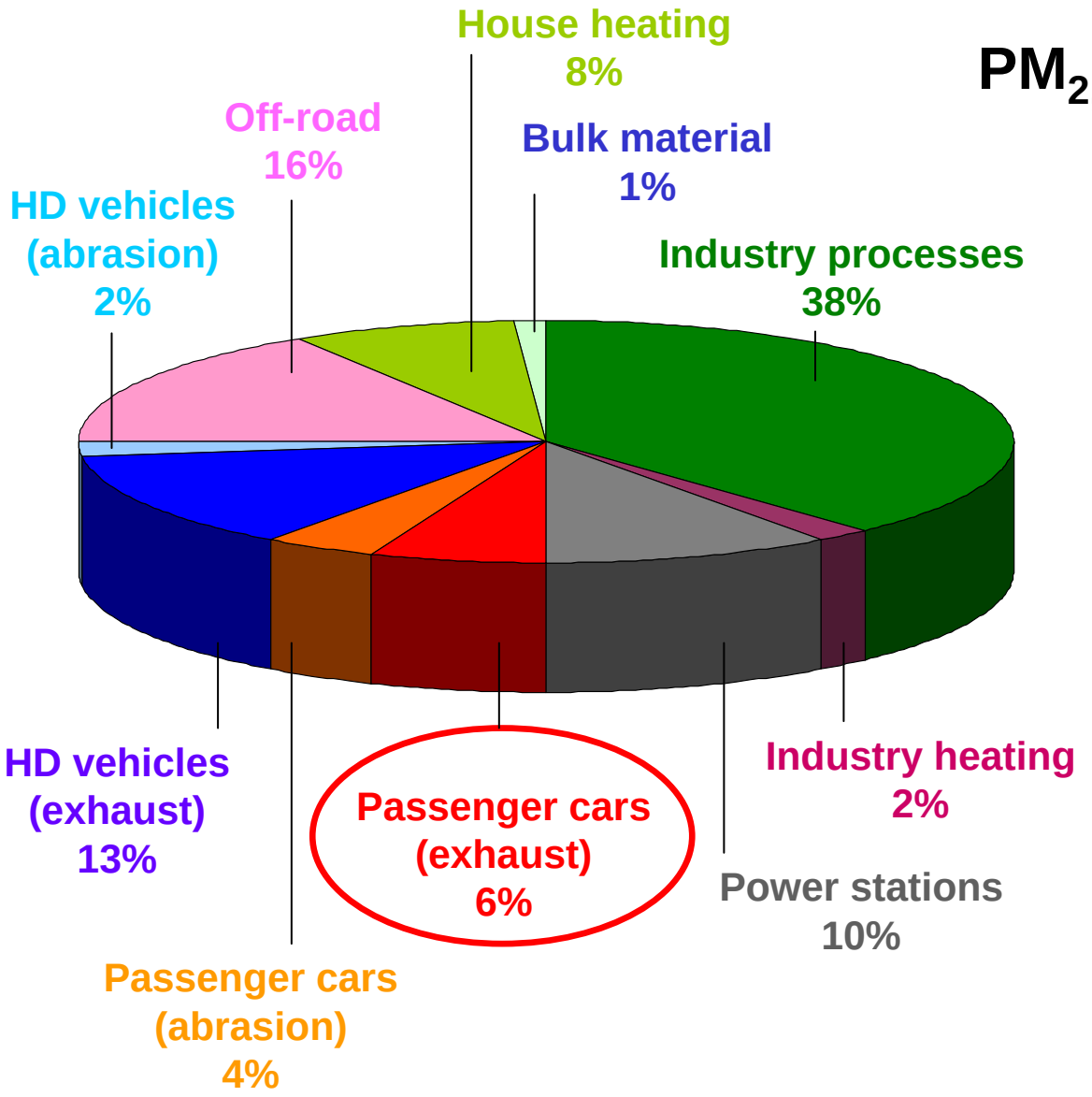
- Emission standards
CPF system
- Layout of CPFs
- CPF system
- Regeneration strategy
Fleet test
- Emission behaviour
- Oil dilution
- Ash accumulation
- Sulphates effect
- CPF durability
Summary & Conclusion

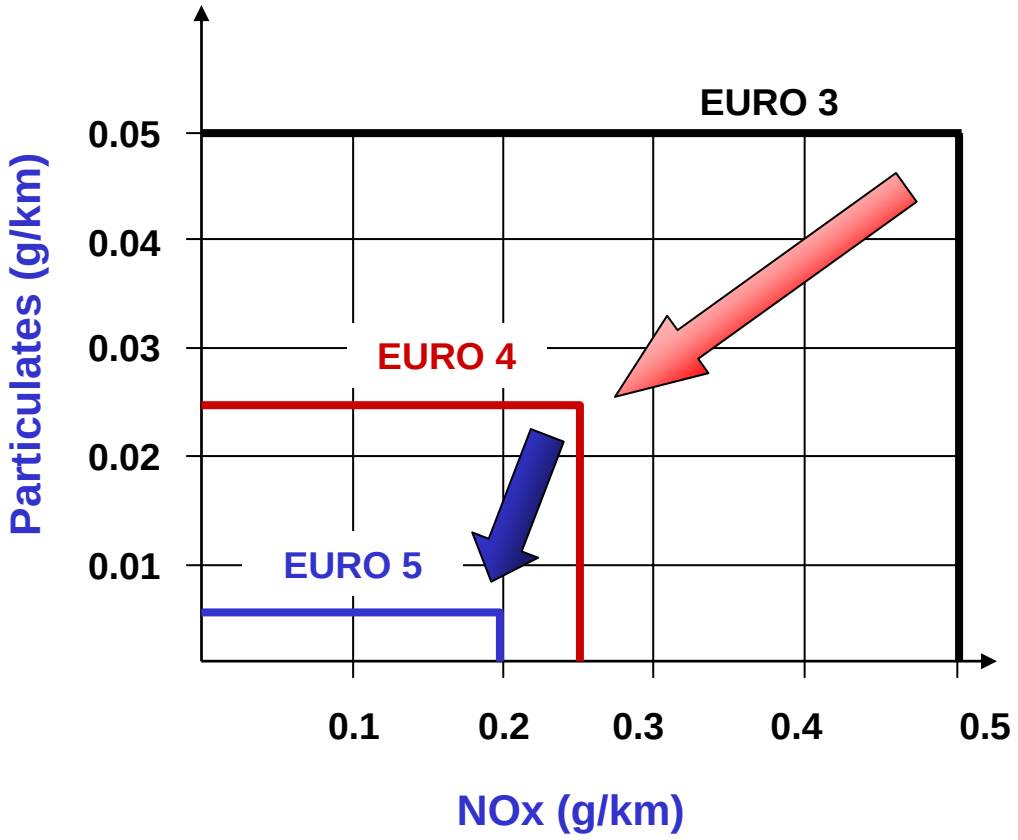


*) abrasion: tires, brakes, street

$PM_{2,5}$ emissions: 156 kt/a

Even though exhaust of passenger cars contributes only with 6% to entire $PM_{2,5}$ pollution, application of diesel particulate filters seems to be necessary to reduce potential health risks and to satisfy customers` expectation (already for EURO 4)!

Source: University of Vienna, Institute of Internal Combustion Engines, 2002



① **Reduction from EU 3 to EU4**

- PM : by 50 %
- NOx : by 50 %

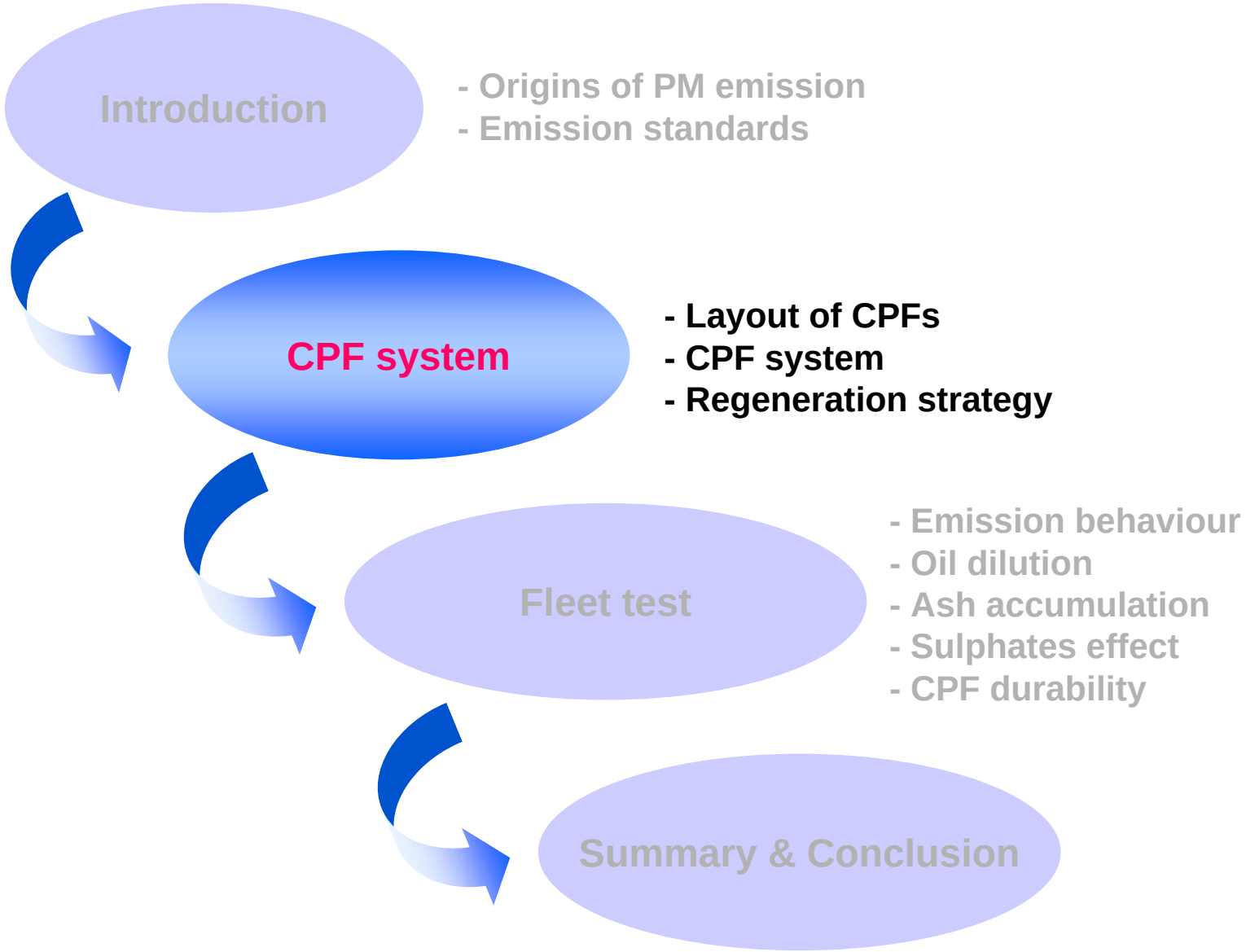
Engineering Targets

- 75 % of Standards

★ Tolerance control of FIE parts and engine production is critical.

② **EURO 5**

- first proposal from EU Commission
- PM reduction: by 80%
- NOx reduction: by 20%
- from Jan. 2009?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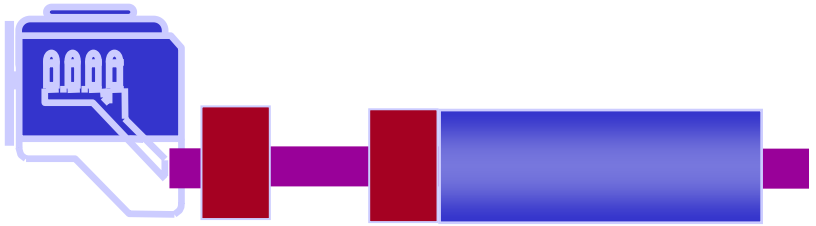
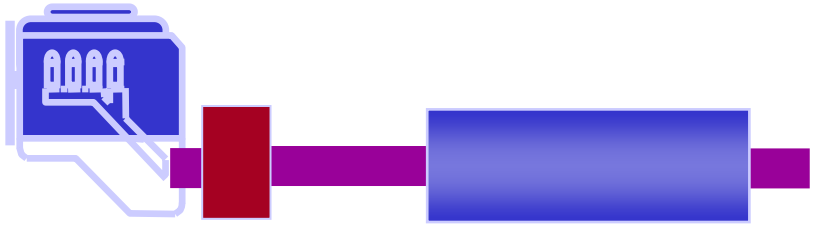
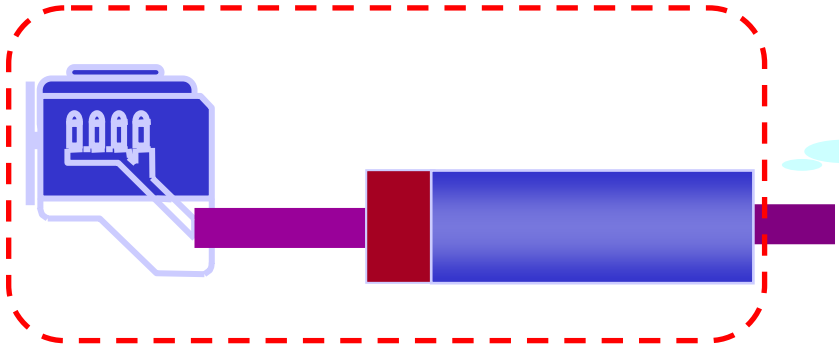


DOC_CC + DOC _UF + CPF_UF



DOC_CC + CPF_UF

DOC + CPF_CC

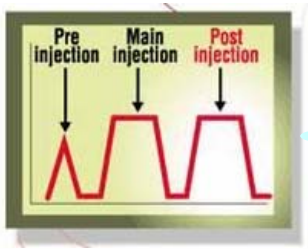


Layout of CPF depends on vehicle design and regeneration strategy.

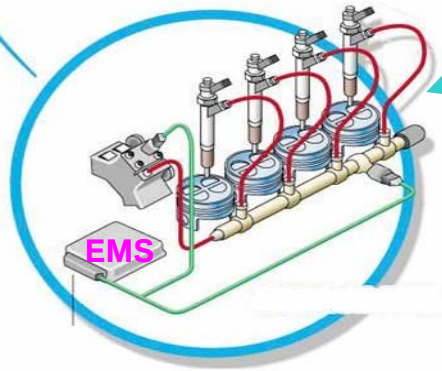
DOC + CPF_UF

➢ CC : Closed Coupled, UF: Under Floor

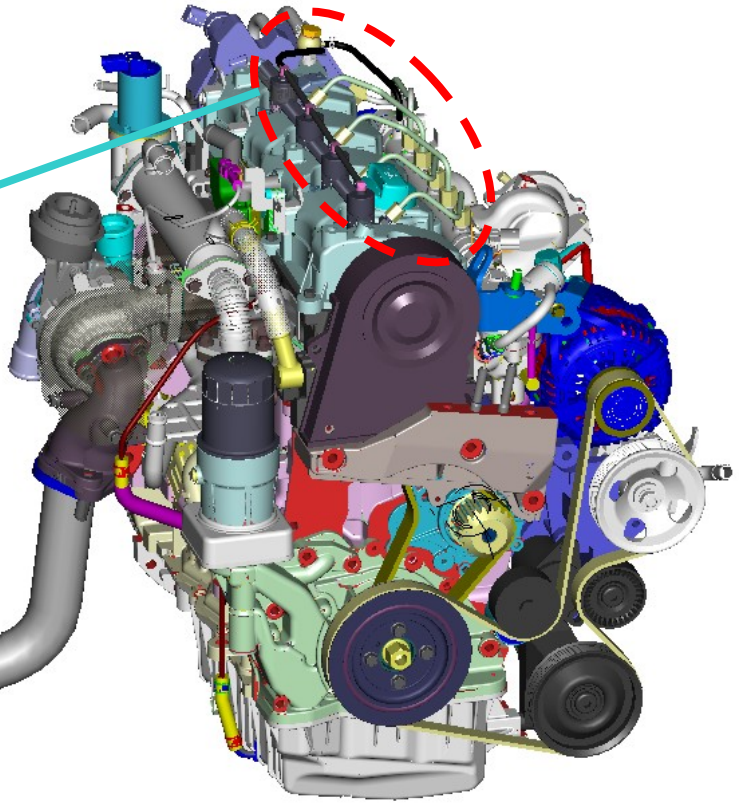
Post injection
by FIE & EMS control
is inevitable to CPF system.

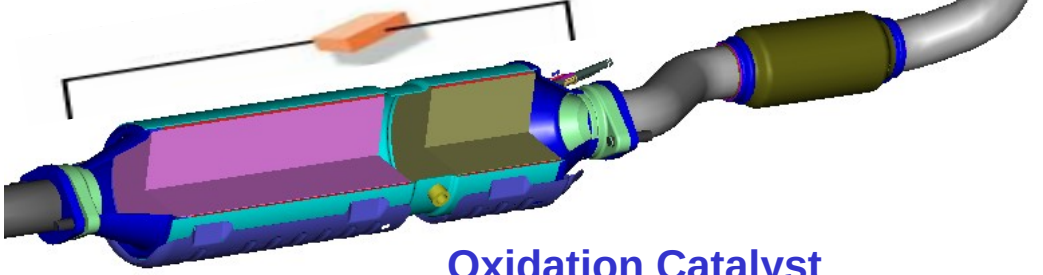


FIE & EMS control



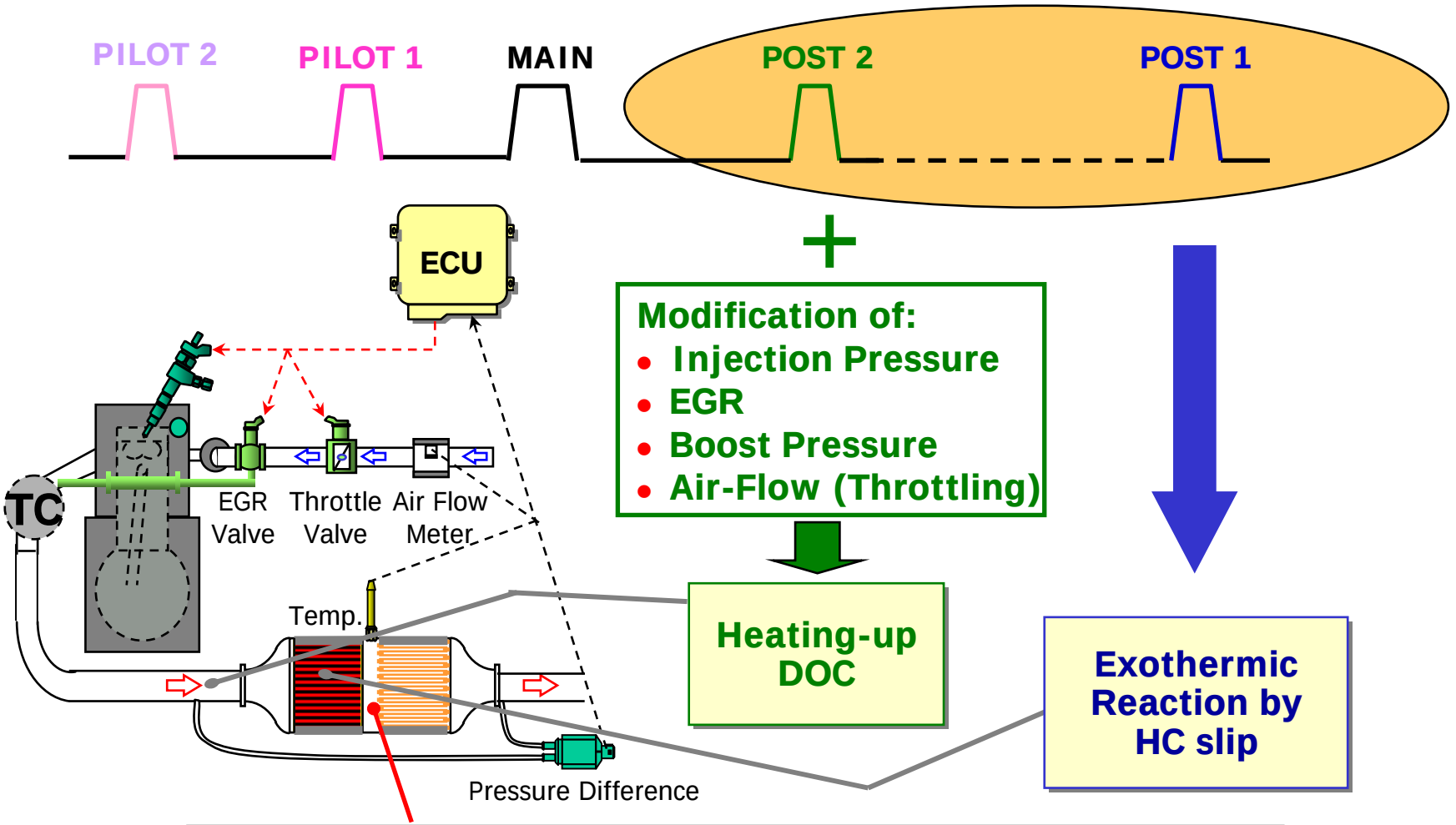
Delta P. & Temp. Sensor

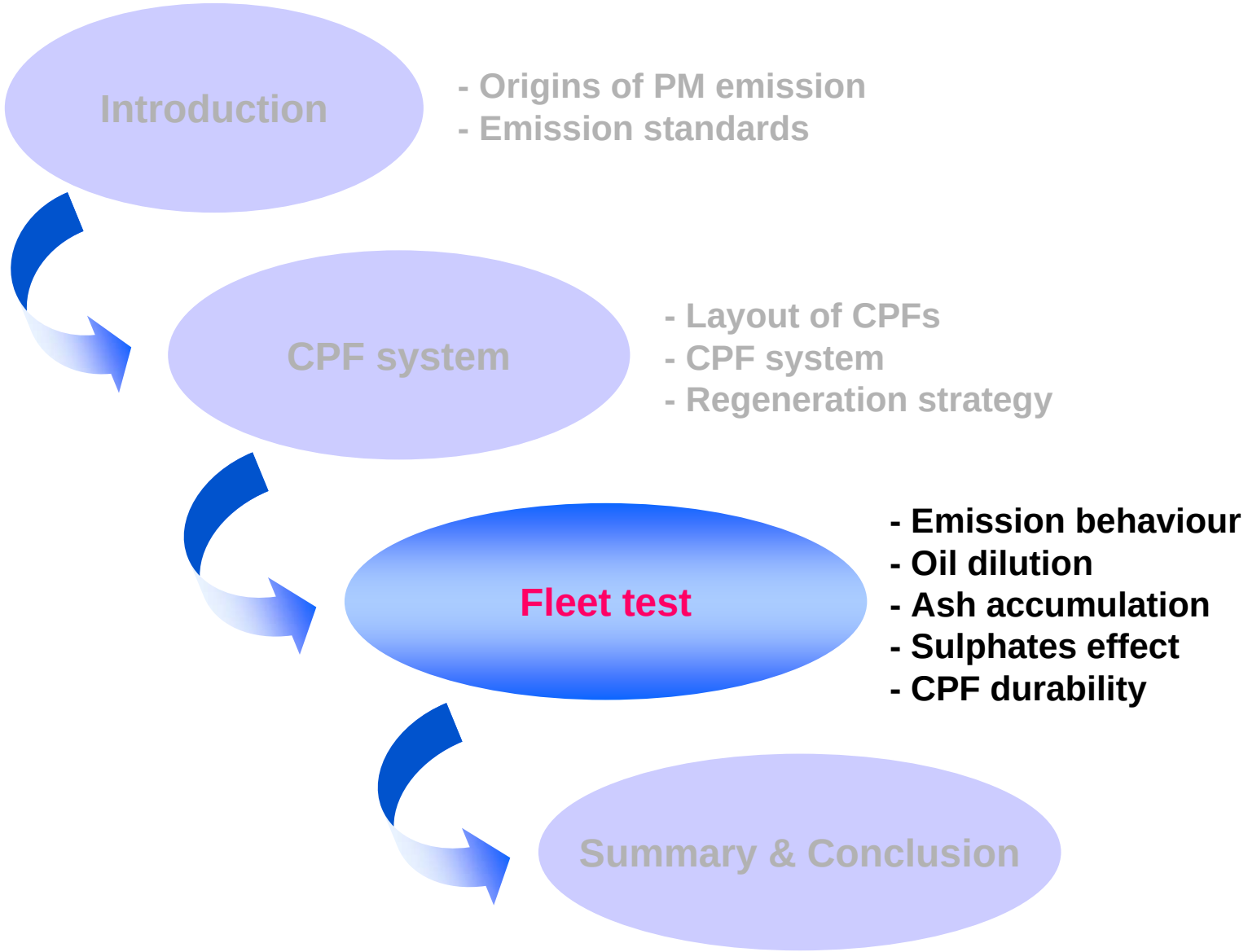




Oxidation Catalyst

SiC-CPF


PILOT 2
PILOT 1
MAIN
POST 2
POST 1
ECU
TC
EGR Valve
Throttle Valve
Air Flow Meter
Temp.
Pressure Difference
Modification of:
• Injection Pressure
• EGR
• Boost Pressure
• Air-Flow (Throttling)
Heating-up DOC
Exothermic Reaction by HC slip
Target temperature > 600 °C for regeneration of CPF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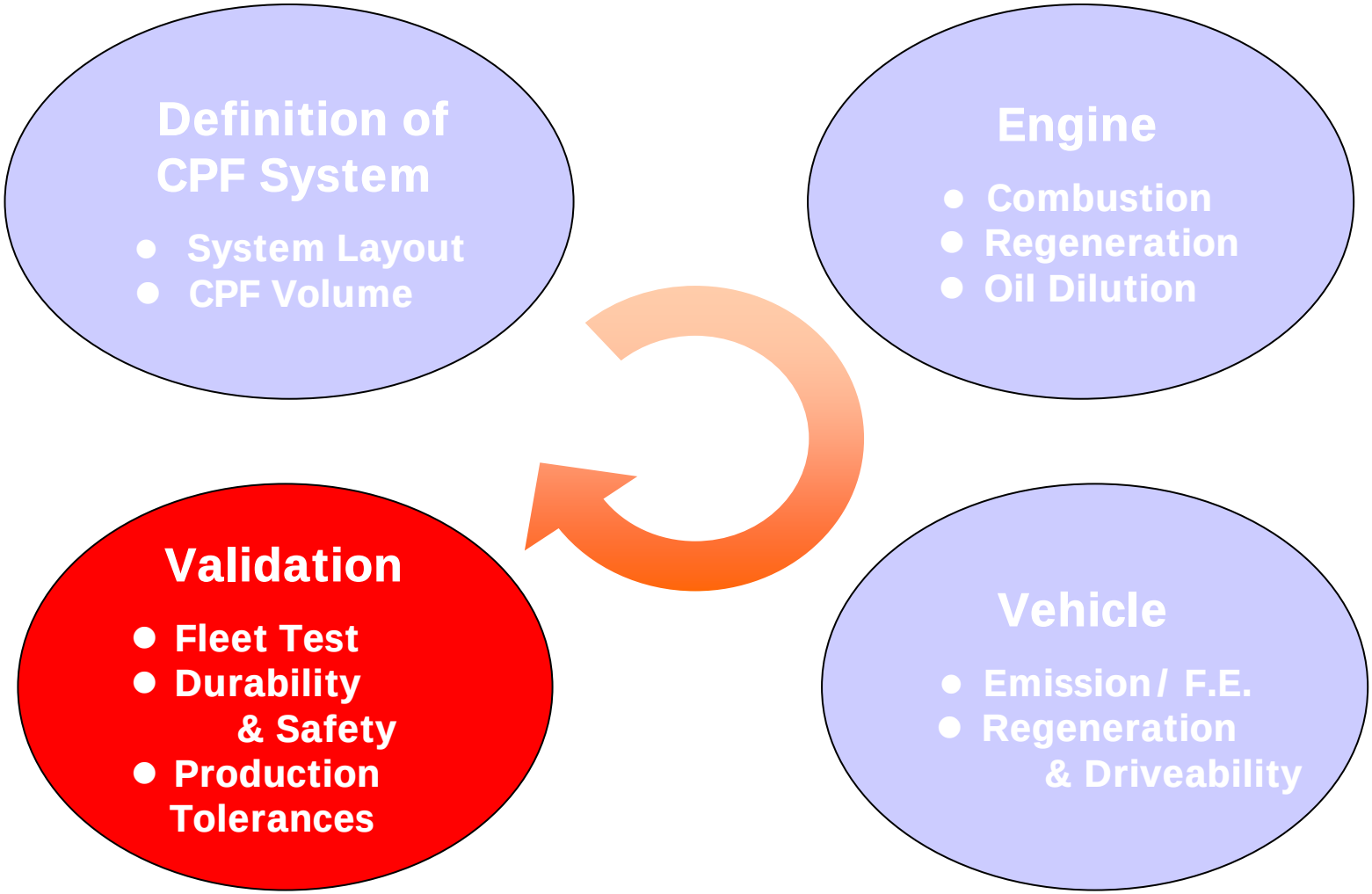
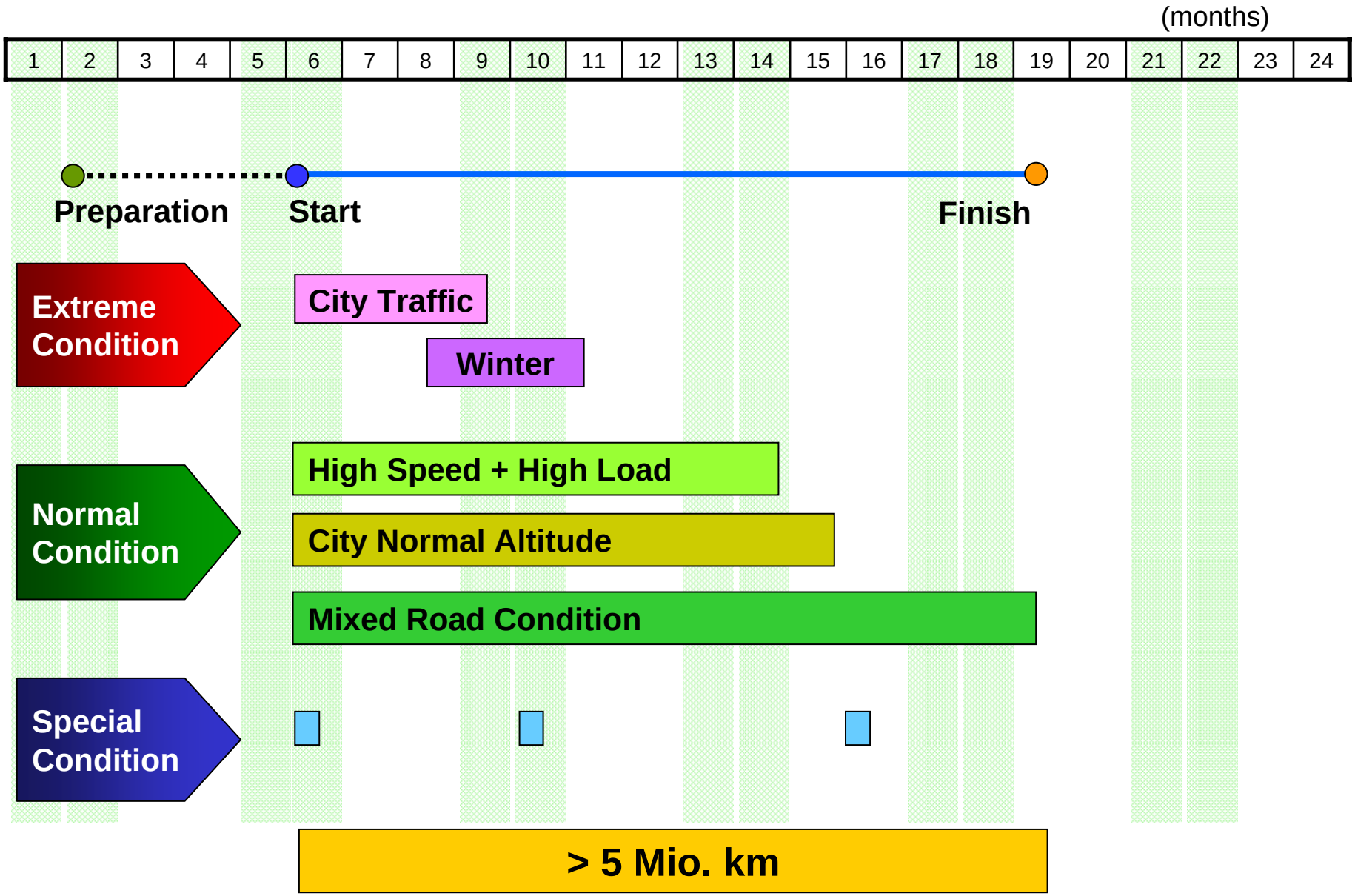
Development steps of CPF system



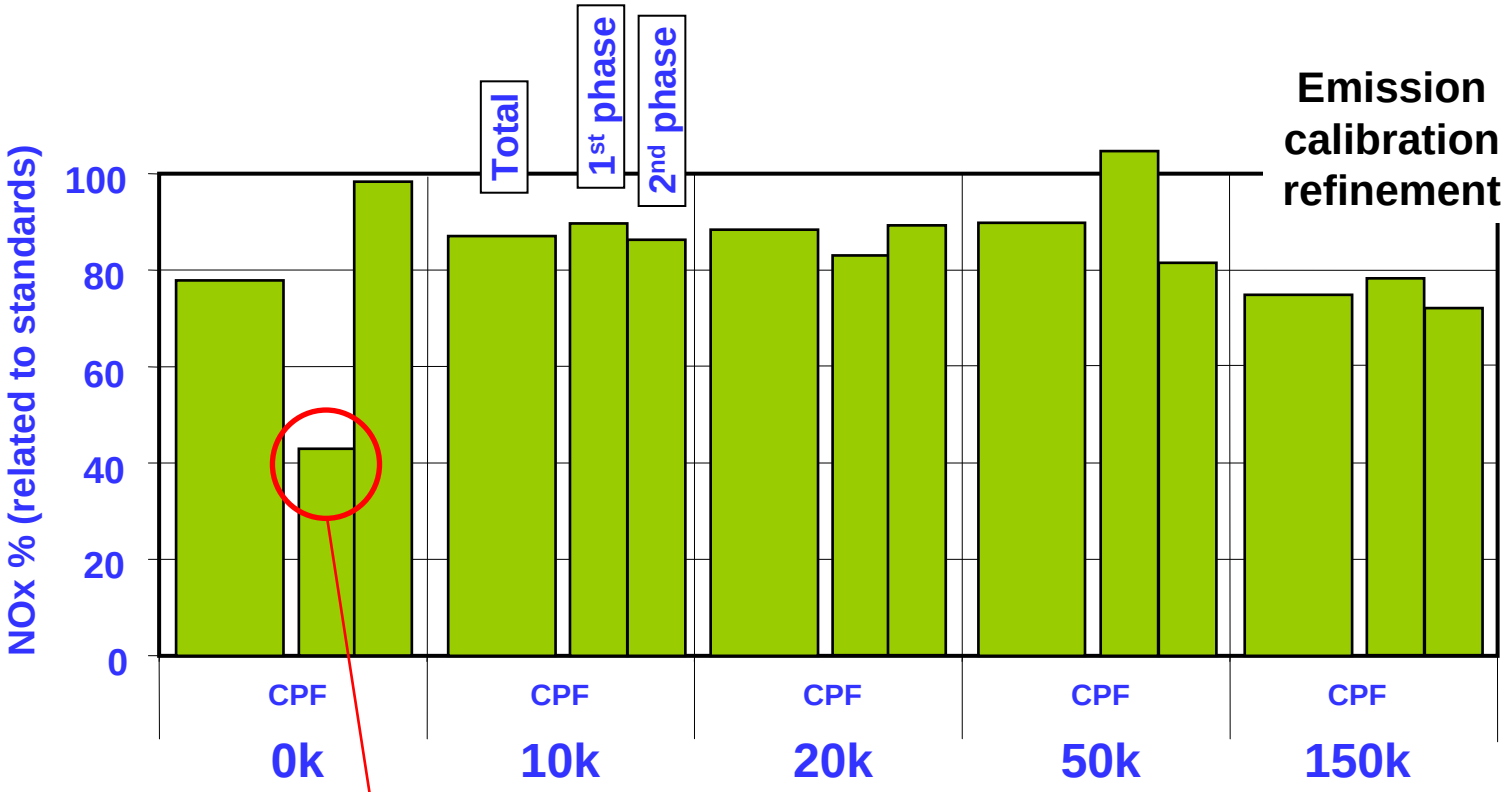
- Several tens of vehicles have been in operation for more than 5 Mio. km in total under various driving conditions (country road, highway, city) in Korea, Spain and Sweden for:
  - System durability evaluation (CPF, engine H/W, FIE system, sensors etc.)
  - Regeneration functionality (initiation, duration, intervals)
  - Exhaust gas emission behaviour depending on mileage
  - Fuel consumption / oil consumption depending on driving profile
  - Calibration refinement (emissions, regeneration, driveability, fuel consumption etc.)
  - Oil dilution investigations
  - Ash accumulation investigations for Δp model correction

Fleet test schedule



Emission behaviour over driving distance

NEDC test – passenger car #007

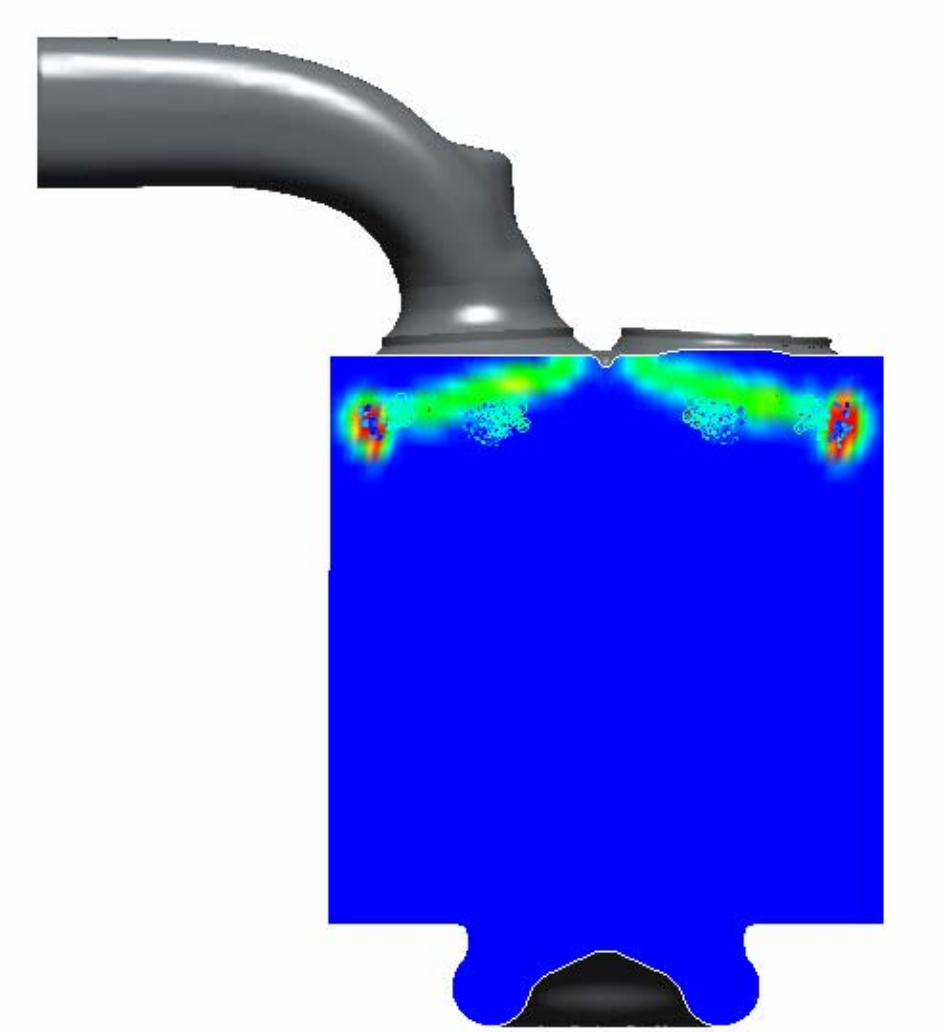


- lean NOx catalyst effect of new DOC/CPF in the 1st phase (stoichiometric reaction on DOC/CPF surface)

- PM emissions always below 0.002 g/km

Oil dilution

Oil Dilution by Late Post Injection



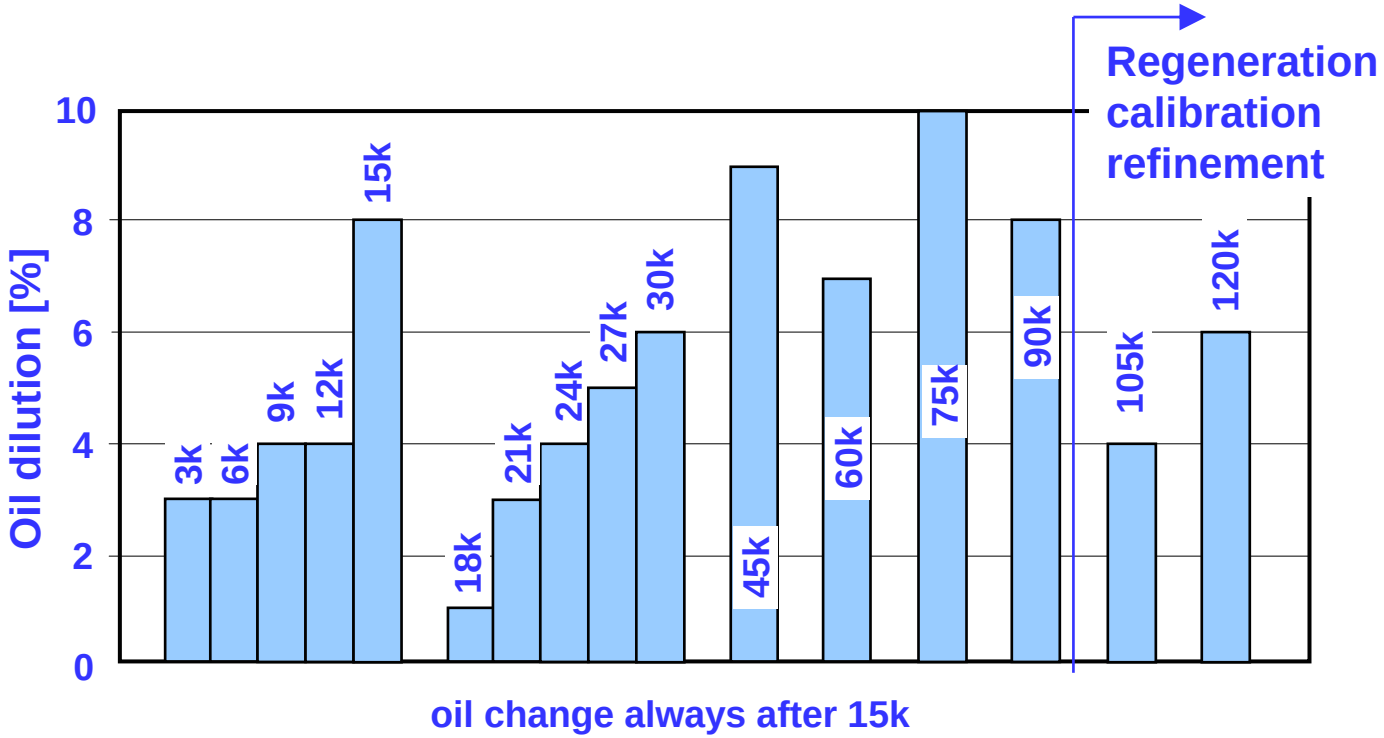
Oil dilution became a problem during DPF application work (regeneration calibration), since very late Post Injection Timing would be necessary to create unburned hydrocarbon for subsequent oxidation in DOC for additional heat (T > 600 deg. C) to burn stored soot inside DPF.

Fuel injected into the combustion chamber does not hit the combustion bowl, but directly the liner.
Due to low gas temperatures it does not burn, but evaporates only partially.

Therefore, a careful optimization of regeneration calibration parameters is a must to prevent any negative effect on engine durability (max. < 10%)

D2.0 Engine – Fleet Test Results

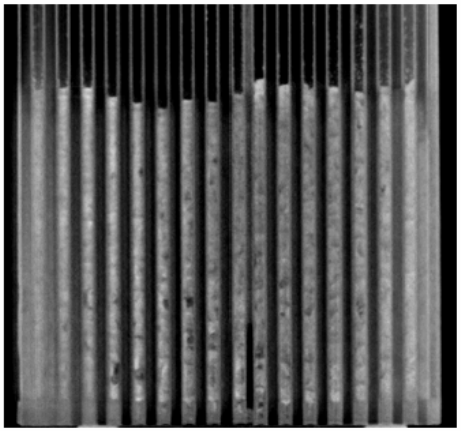
Passenger car #001 – mixed road driving profile



Oil dilution results depending on driving profile (country road, highway, city), number of regeneration events and post injection strategy.

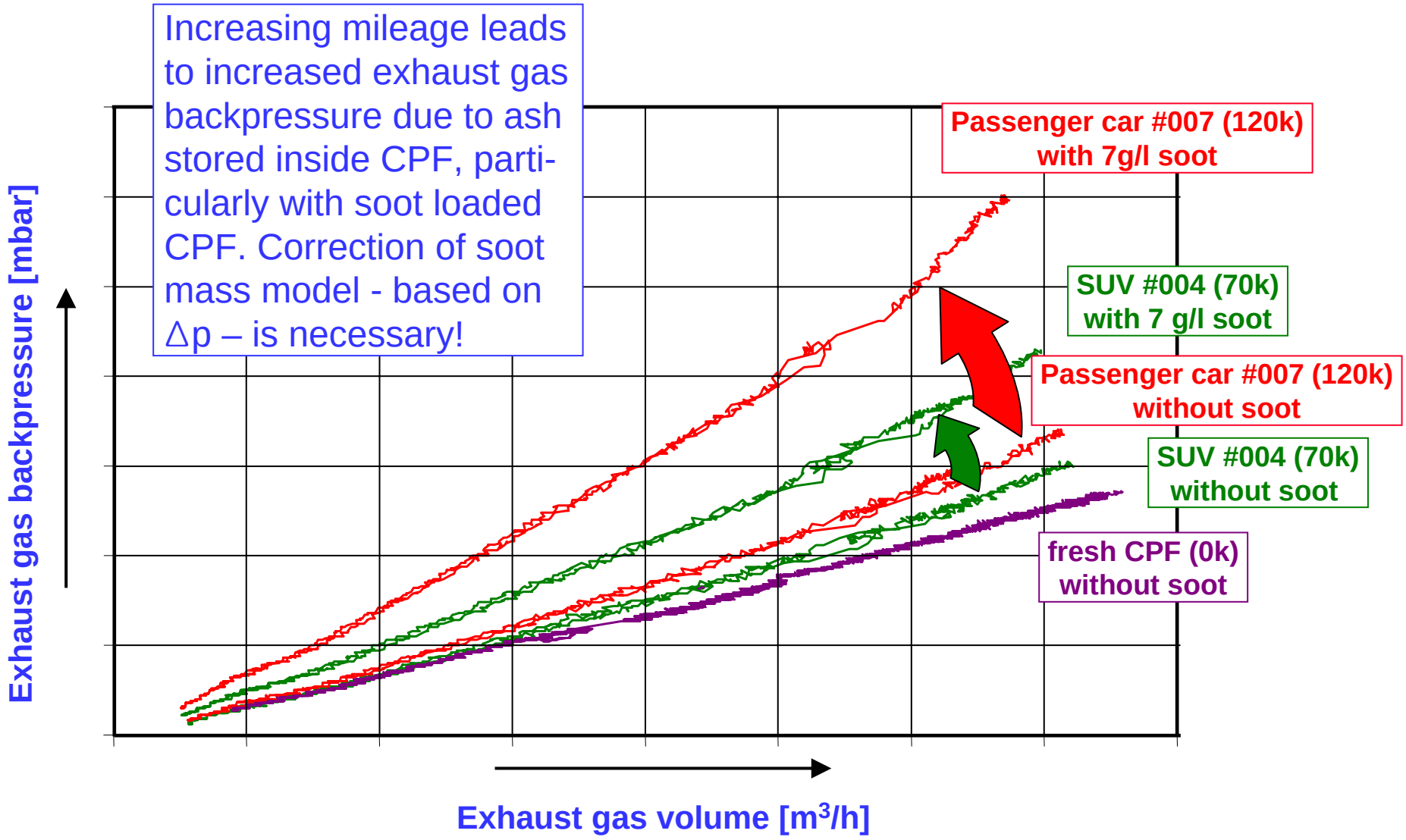
Ash accumulation

- The impact of accumulated ash on max. soot loading capacity, back pressure and regeneration behavior (exothermic reaction, rate of soot oxidation, regeneration intervals) must be clarified before SOP.
- Though real ash loading process of a DPF in vehicles consumes a lot of time and other resources, it delivers much more precise results than any “fast” ash loading runs at engine test bed.



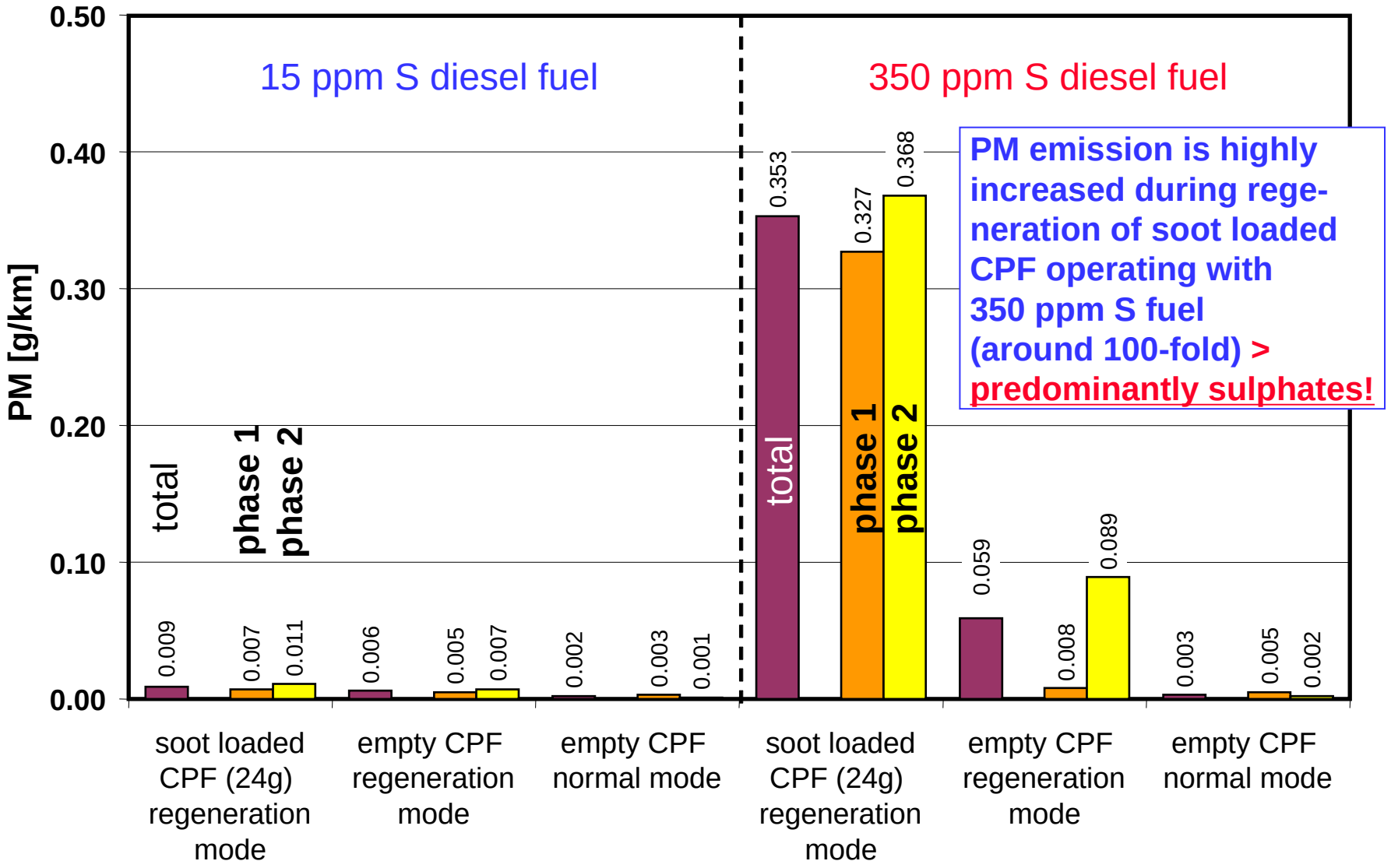
Sample with oil ash deposits (soot regeneration by O_2)

- In general, ash content inside CPF is a function mainly of oil consumption and sulphated ash content of the lube oil used (plus small amount of fuel residues – depending on fuel consumption too). Therefore, high scatterband must be expected, depending on driving conditions too.


Increasing mileage leads to increased exhaust gas backpressure due to ash stored inside CPF, parti-cularly with soot loaded CPF. Correction of soot mass model - based on Δp – is necessary!
Passenger car #007 (120k) with 7g/l soot
SUV #004 (70k) with 7 g/l soot
Passenger car #007 (120k) without soot
SUV #004 (70k) without soot
fresh CPF (0k) without soot
Exhaust gas backpressure [mbar]
Exhaust gas volume [m3/h]

Effect of diesel fuel sulphur on PM

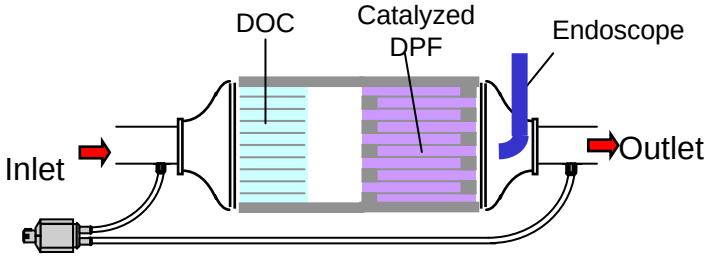
Effect of fuel sulphur on PM emission in NEDC



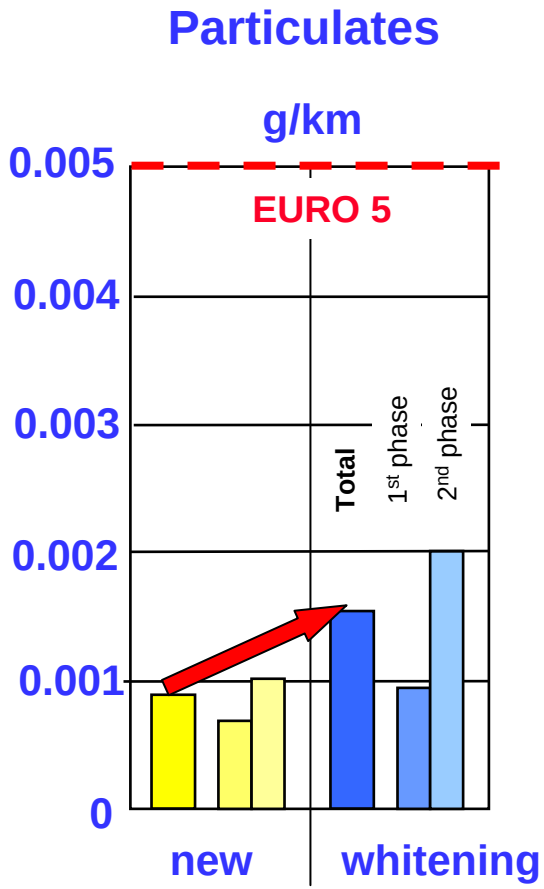
measurement by AVL Smart Sampler

Analysis of damaged CPFs

- one of the fleet test purposes was also to check CPF durability
- only very little slightly damaged CPFs could be found at the initial fleet test phase
- those CPFs were analysed with respect to damage origin and the effect on PM reduction

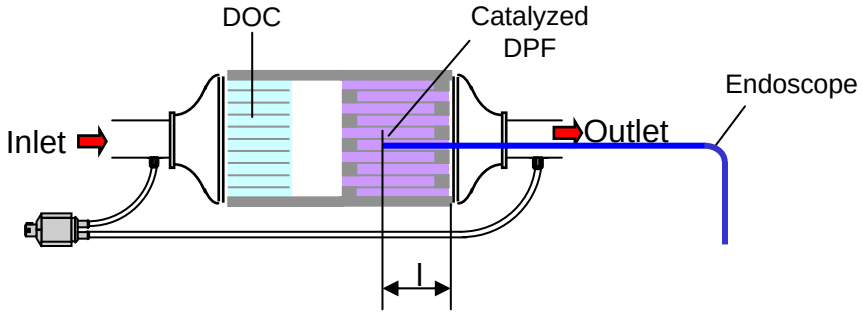


Whitening

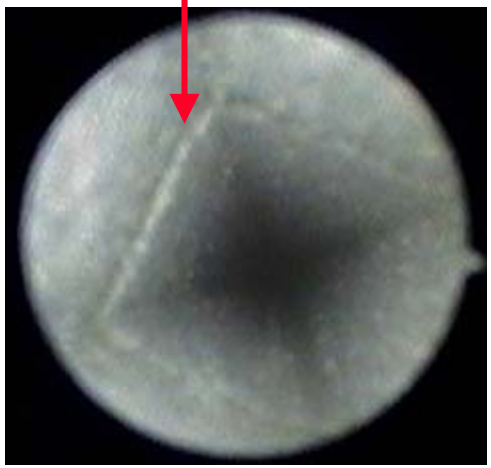


Comparison of PM measurement between new and slightly damaged CPF by whitening shows only small increase in PM emissions.
Numbers still far below EU5 limits!

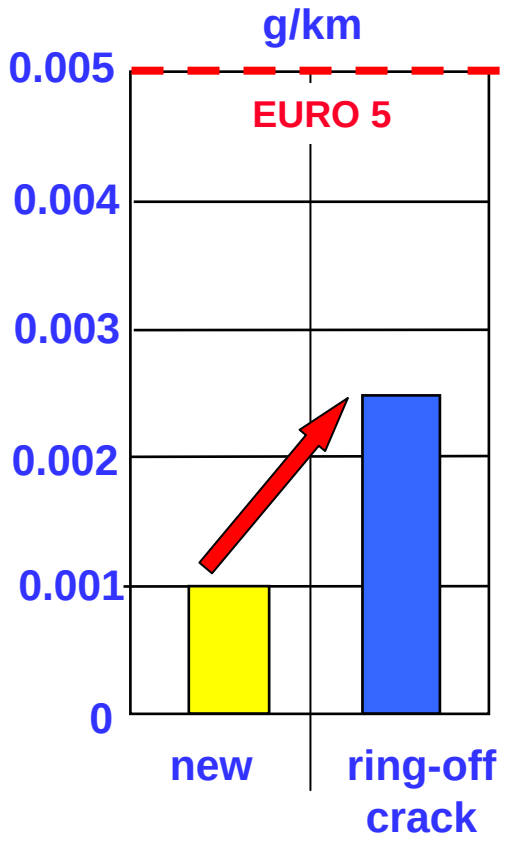
Status	1st Phase (ECE)	2nd phase (EUDC)	Total
	g/km	g/km	g/km
new	0.0007	0.0010	0.0009
whitening	0.0009	0.0020	0.0016



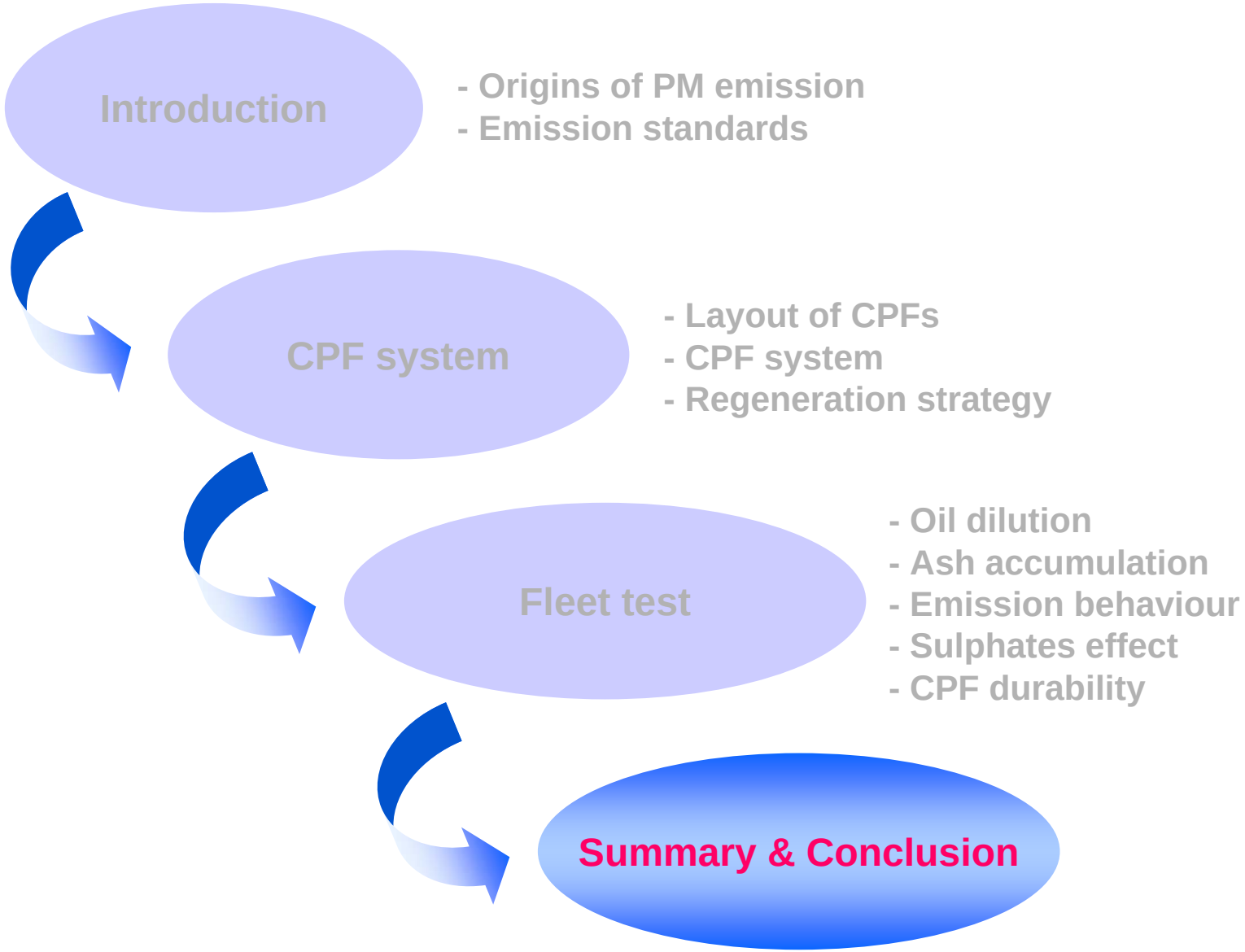
Ring-off crack (l = 135mm)



Particulates in NEDC



Ring-off cracks do not lead to total loss of CPF
Numbers are still below EU5 limits!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Summary & Conclusions (1)

- To check durability and reliability of new CPF system prior SOP, an intensive fleet test program was carried out.
- Many fleet test vehicles are still in operation to reach final mileage of more than 5 Mio. km.
- So far, no severe problems occurred with CPFs nor with the engines.
- Regular emission tests at NEDC (5k, 20k, 50k, 75k, 100k, 150k etc.) show an excellent NOx emission stability.
- There is no serious deterioration of HC and CO emissions after more than 100k, despite underfloor CPF system without close coupled catalyst.
- Particulate emissions well below proposed EU5 limits (0.005 g/km), including those which have been slightly damaged at the initial fleet test phase.

- No serious deterioration of oil properties (e.g oil dilution) have been observed yet which would lead to reduction of engine durability.
- Deterioration of fuel consumption due to regular initiation of regeneration by post injection remain very low (< 1%).
- Diesel fuel with low sulphur content seems to be necessary to improve regeneration efficiency of CPF and to eliminate undesired increase of particulate emission during regeneration by sulphates adsorbed in CPF.
- Compensation of cost increase due to diesel particulate filter application by tax incentives would help to promote sells of such vehicles.
- First cars from HMC and Kia equipped with diesel particulate filter system for the lifetime of the vehicles (240.000 km) will be available on the market in 3rd quarter of 2005.

Thank you for your attention!