Metal emissions reduction benefits without NO_2 penalty

Paul Richards Innospec Limited

Due to its fuel efficiency diesel has traditionally been the prime mover of choice for heavier land and sea based transport applications. A secondary characteristic of the diesel engine that has contributed to its popularity is its durability. However from the environmental point of view this is a penalty, as old high emitting engines remain in service for prolonged periods. Due to the environmental and health effects highlighted by successive ETH-Conferences on Combustion Generated Nanoparticles there is thus increasing pressure to retrofit existing diesel engined vehicles with devices to significantly reduce the particulate emissions. The diesel particulate filter (DPF) is now recognised as the most effective way to reduce not only the mass but also the number of emitted particles. Whilst a fuel borne catalyst (FBC) using non-precious metals is the most common form of regeneration technique for original equipment application of DPFs, the use of a precious metal catalyst coating, either on a flow through catalyst or on the DPF itself, is common for retrofit applications.

Concerns are now being raised regarding the effect of precious metal catalyst on the nitrogen dioxide (NO_2) emissions from vehicles equipped with such devices. Preliminary results presented at the 7th ETH-Conference, for a DPF system that relies on an iron based FBC for regeneration but also using a base metal catalyst coating, showed significant reductions in the regulated emissions, including an 11% reduction in NO_X. This is shown in slide 9. The second by second data for the NO_X emissions are shown in Slides 10 and 11. This testing also showed a reduction in of over 90% in the NO_2 emissions, this is shown in slides 12 and 13. Further data was presented at the 8th ETH Conference showing in excess of 90% NO_2 reduction over the more sever Millbrook London Bus Test (MLBT) cycle (slide 17). The second by second NO_2 emissions data are shown in slides 18 and 19.

This type of base metal catalysed DPF in combination with the iron based FBC has now been subjected to the VERT Secondary Emissions Test (VSET). The results showed a reduction of particle numbers across the size range (slides 24 and 25), reductions in the regulated emissions HC, CO and NO_X (slide 26), reductions in PAH and NPAH emissions (slide 27) and reductions in PCDD and PCDF emissions (slides 28 and 29). The VSET also included an assessment of the metal emissions for the metals used in the FBC as well as those used in the catalyst coating on the DPF. The FBC was tested at twice the maximum recommended treat rate. Despite the high treat rate of FBC the overall post-DPF emissions of iron were equal to the emissions of iron without use of the FBC in the absence of the DPF. This is shown in slide 31. If this data is factored to the assumption of the normally recommended treat rate of FBC then this results in a reduction in iron emissions of over 50%. This is shown in slide 37. There was also no clear evidence of metal emissions resulting from the metals used for the catalytic coating of the DPF (slides 38 to 40).

Using the data generated in the VSET regarding the filtration efficiency of the DPF in respect to the FBC metal, in conjunction with data from a previous 250,000 km field trial an estimate is made of the quantity of metal emissions reduction from the use of DPFs. This is shown in slide 46. This includes an annual reduction, per truck fitted, of 10.1 g of zinc, 22.4 mg of Lead, 123.9 mg of copper and 20.1 mg of chromium.

Metal emissions reduction benefits without NO_2 penalty

Paul Richards

Presentation outline

- Introduction
- VSET metals analysis
- Implications
- Conclusions

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Introduction

- **Additional NO_X benefits as a result of using FBC to aid DPF regeneration (7th ETH Conference)**
  P Richards, M W Vincent & W Kalischewski
- Data was presented showing the effect of a DOC, a CDPF and a DPF/FBC system with particular reference to PM and NO_2
- Preliminary results were also presented showing significant NO_2 reduction with a base metal catalyst coated DPF/FBC system

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Preliminary field application - Single deck bus

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Preliminary field application - DPF installation

DPF element

- Liqtech SiC honeycomb
- 22.9cm diameter
- 25.4 cm length
- 10.4 litre volume
- Base metal catalytic coating from Haldor Topsøe A/S

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Preliminary field application - Dennis Dart bus engine

Type	Cummins 6BTA-130
No cylinders	6 in-line
Swept Volume	5883 cm3
Bore / Stroke	102 mm / 120 mm
Compression ratio	17.6 : 1
Power	97 kW @ 2500 rev/min
Torque	470 Nm @ 1500 rev/min

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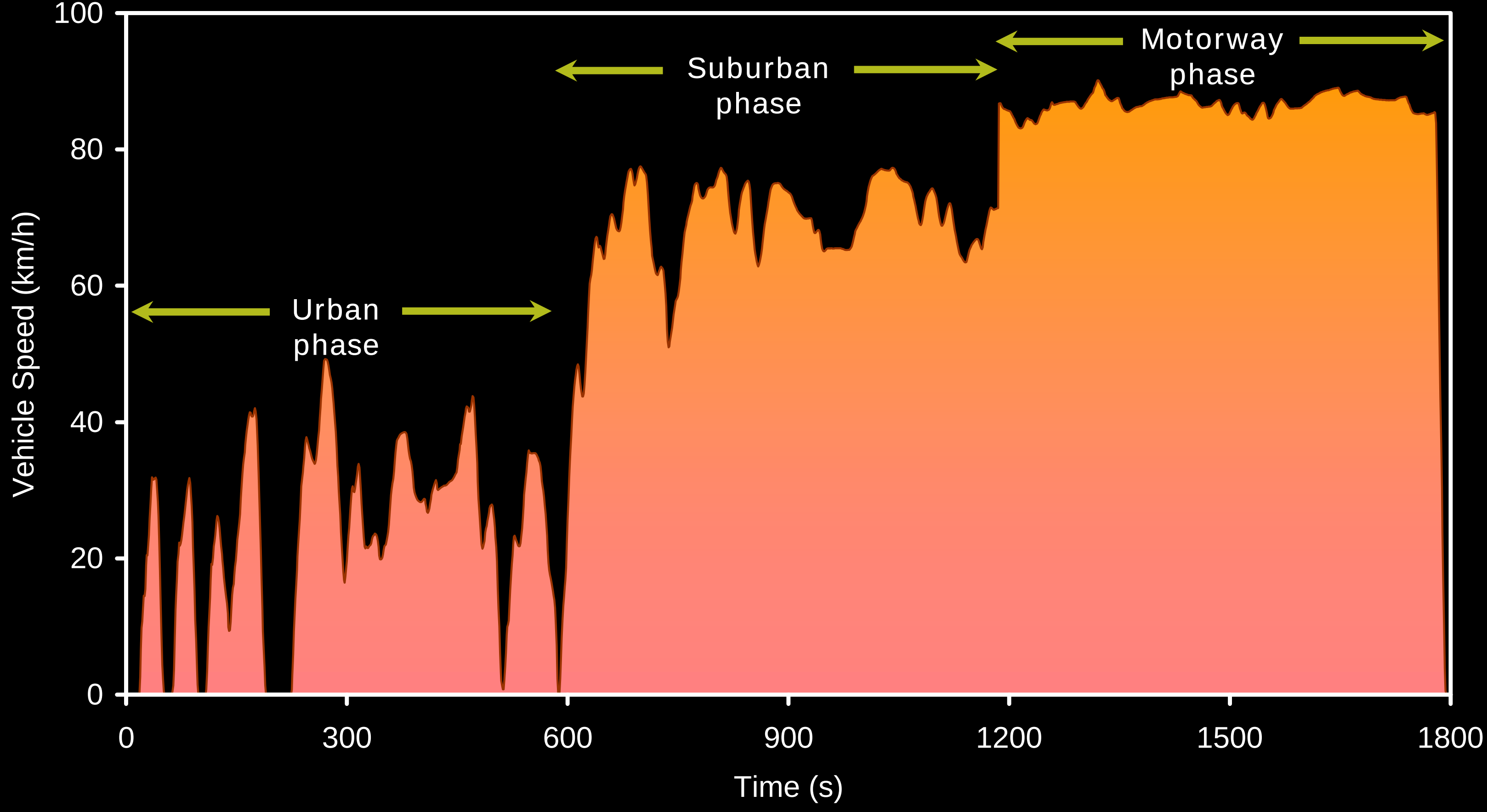
Preliminary field application - FIGE Test cycle



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Preliminary field application - Regulated emissions

Emission		Reduction
HC	……………	94 %
CO	……………	78 %
NO_X	……………	11 %
PM	……………	87 %

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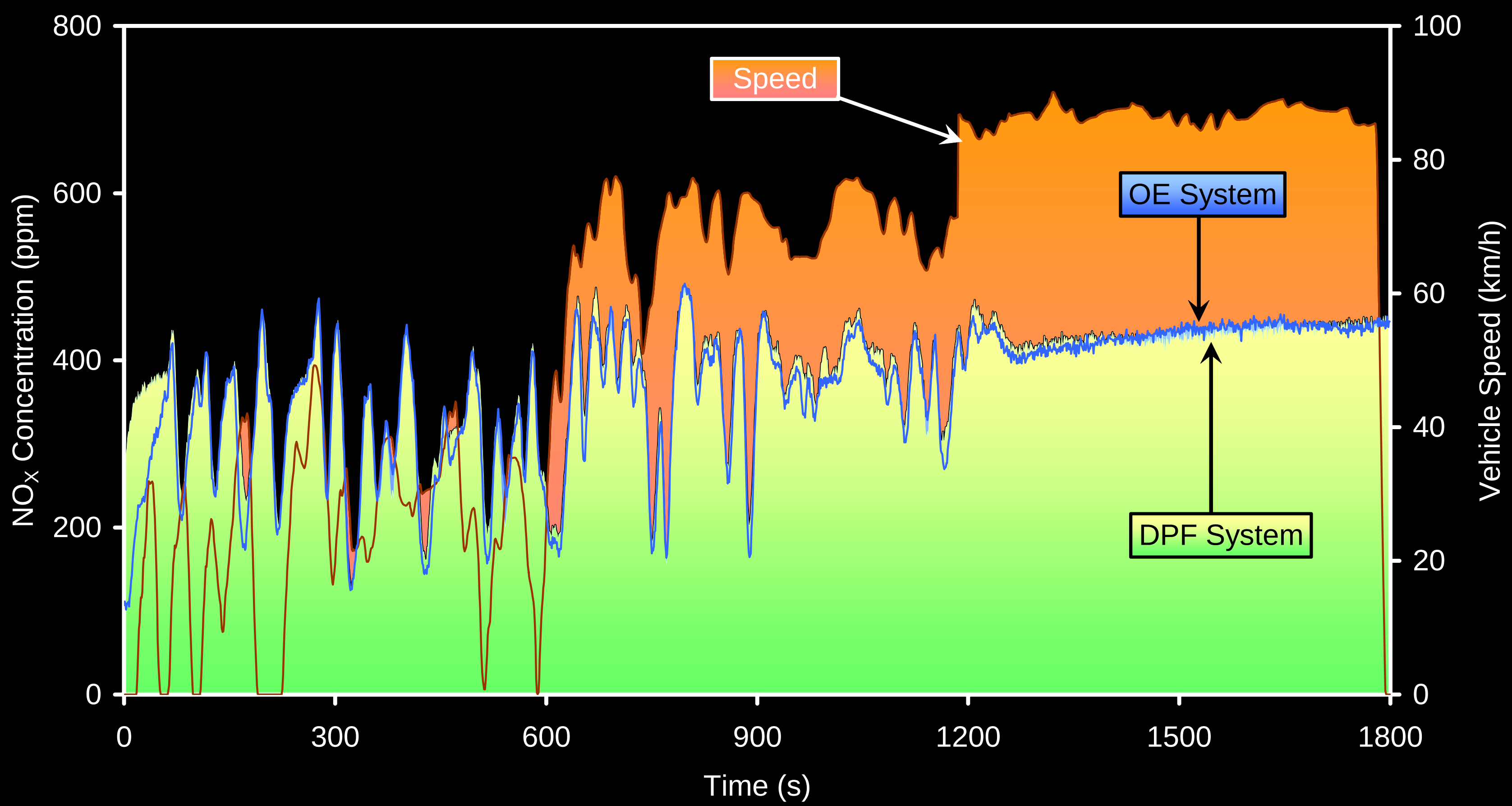
Preliminary field application - NO_X emissions



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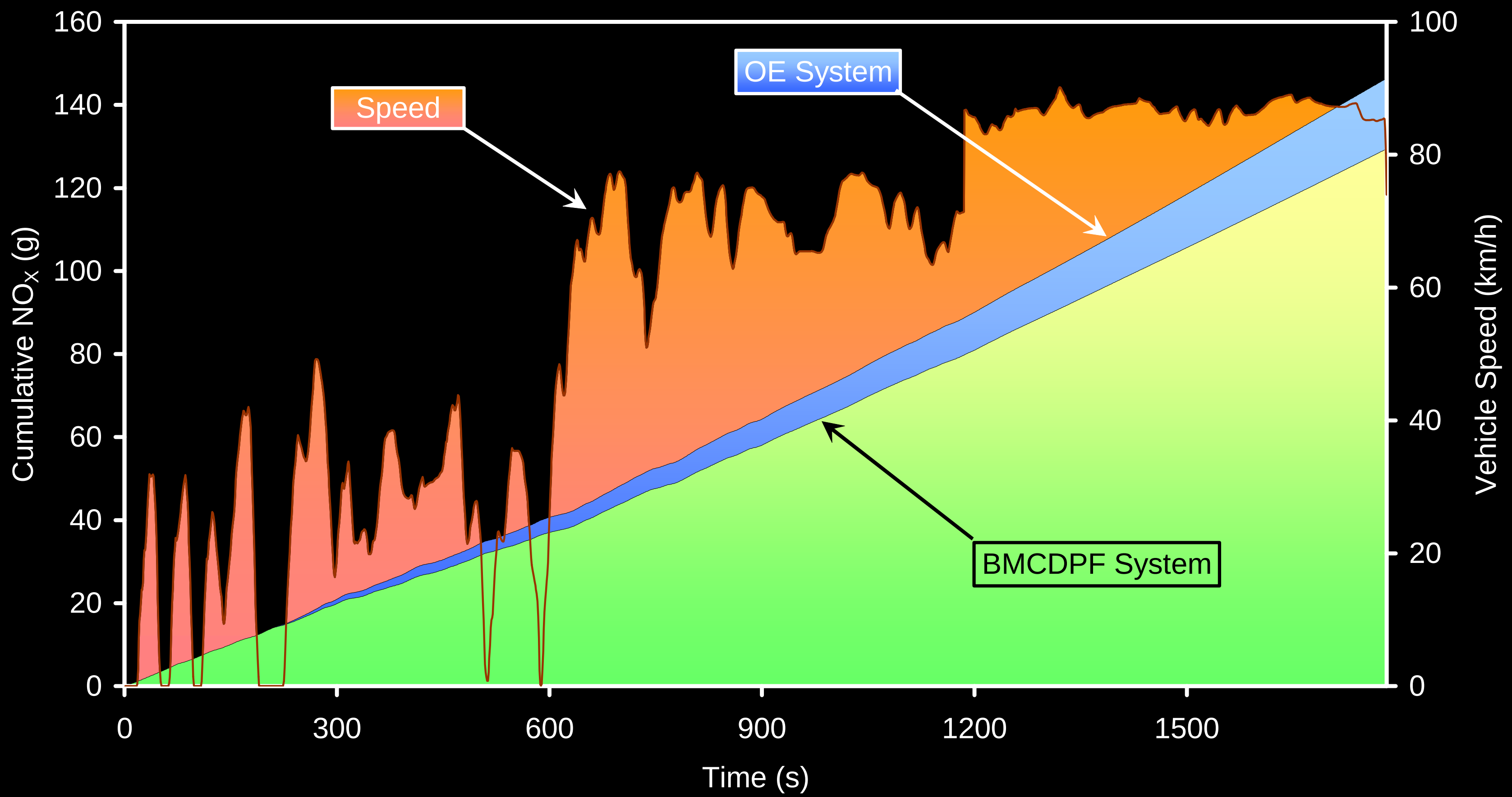
Preliminary field application - Cumulative NO_X



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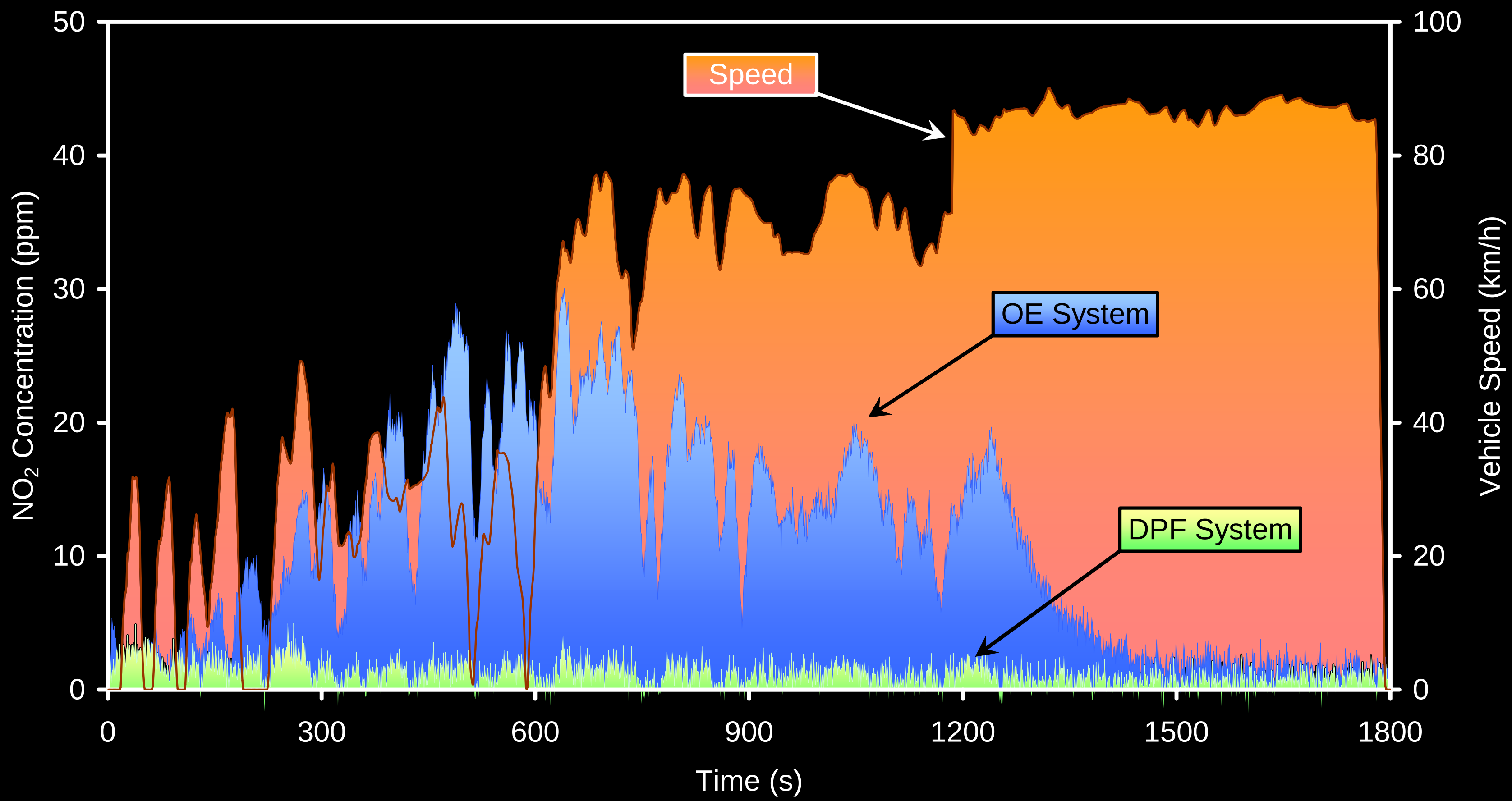
Preliminary field application - NO_2 emissions



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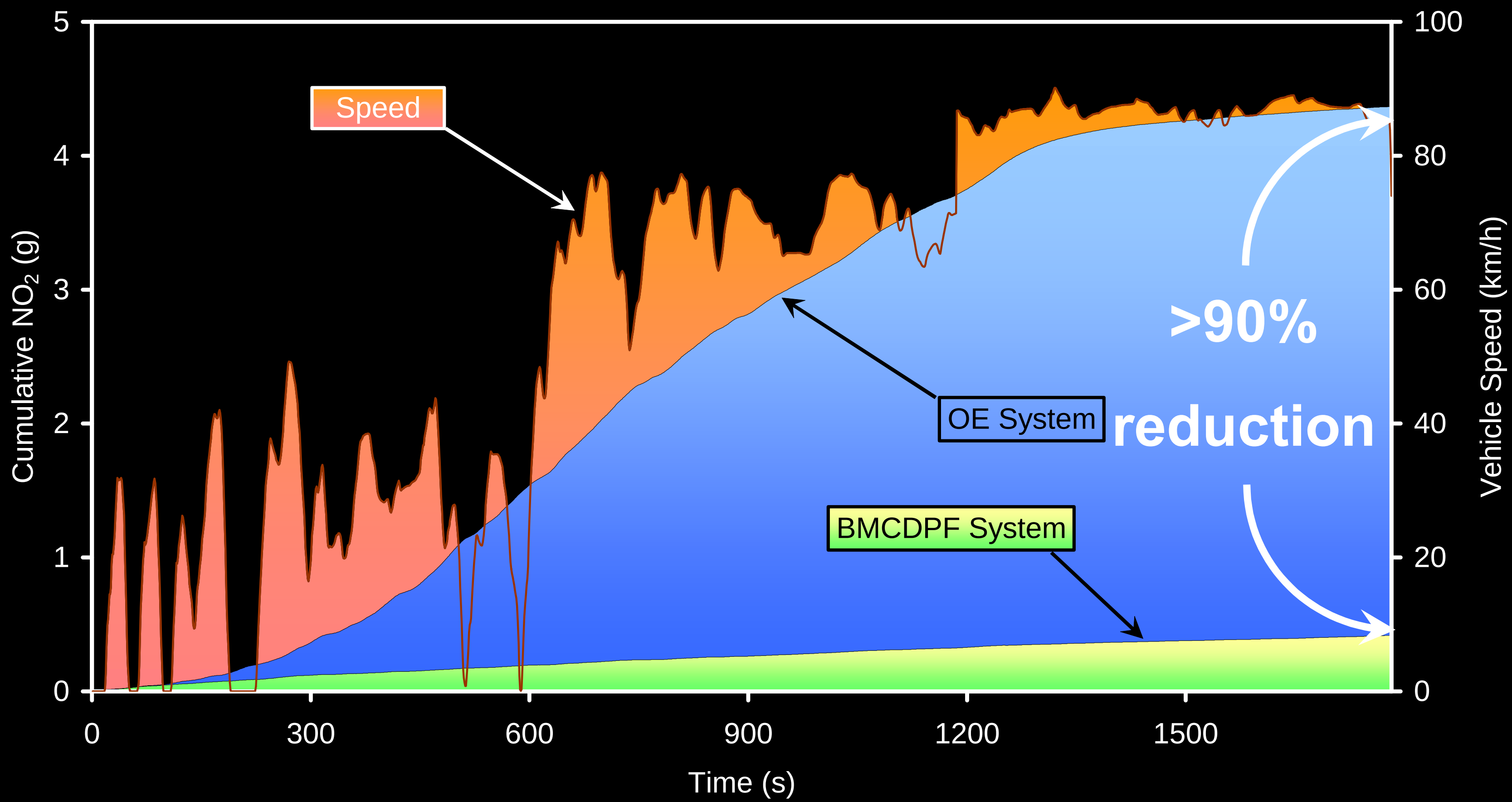
Preliminary field application - Cumulative NO_2



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Introduction

- **DPF/FBC Systems to reduce both PM and NO_2 (8th ETH Conference)**
  P Richards & J Chadderton
- Data was presented showing the effect of a base metal catalyst coated DPF/FBC system by the VERT Filter test
- Additional results were also presented confirming the significant NO_2 reduction with a base metal catalyst coated DPF/FBC system

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Further field application - City Sightseeing bus

DPF element

- Liqtech SiC honeycomb
- 25.4cm diameter
- 25.4 cm length
- 12.9 litre volume
- Base metal catalytic coating from Haldor Topsøe A/S

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Further field application - MCW Metrobus engine

Type	Gardner 6LXB
No cylinders	6 in-line
Swept Volume	10450 cm3
Bore / Stroke	121 mm / 152 mm
Compression ratio	15:1
Power	134 kW @ 1850 rev/min
Torque	727 Nm @ 1000 - 1100 rev/min

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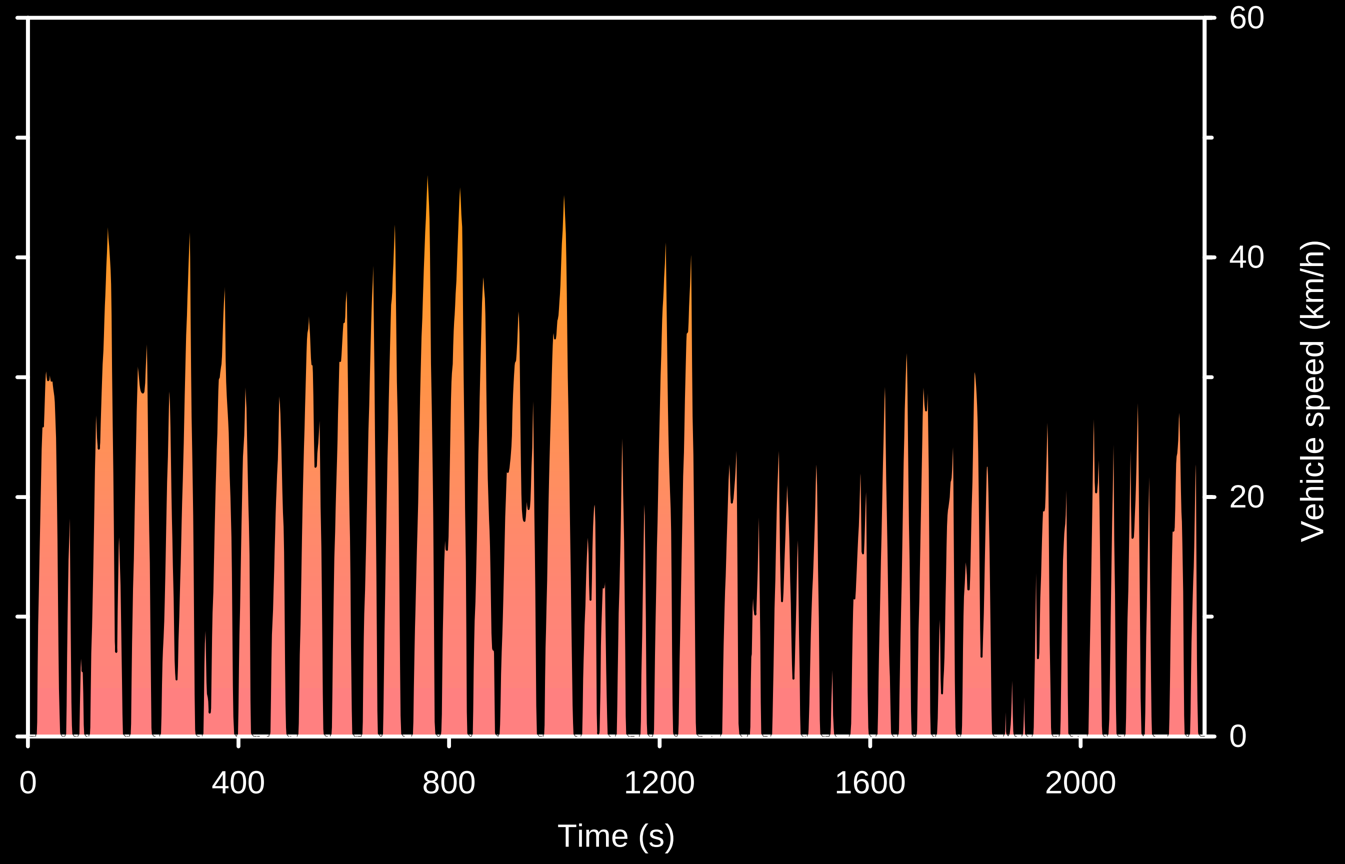
Further field application - MLBT cycle



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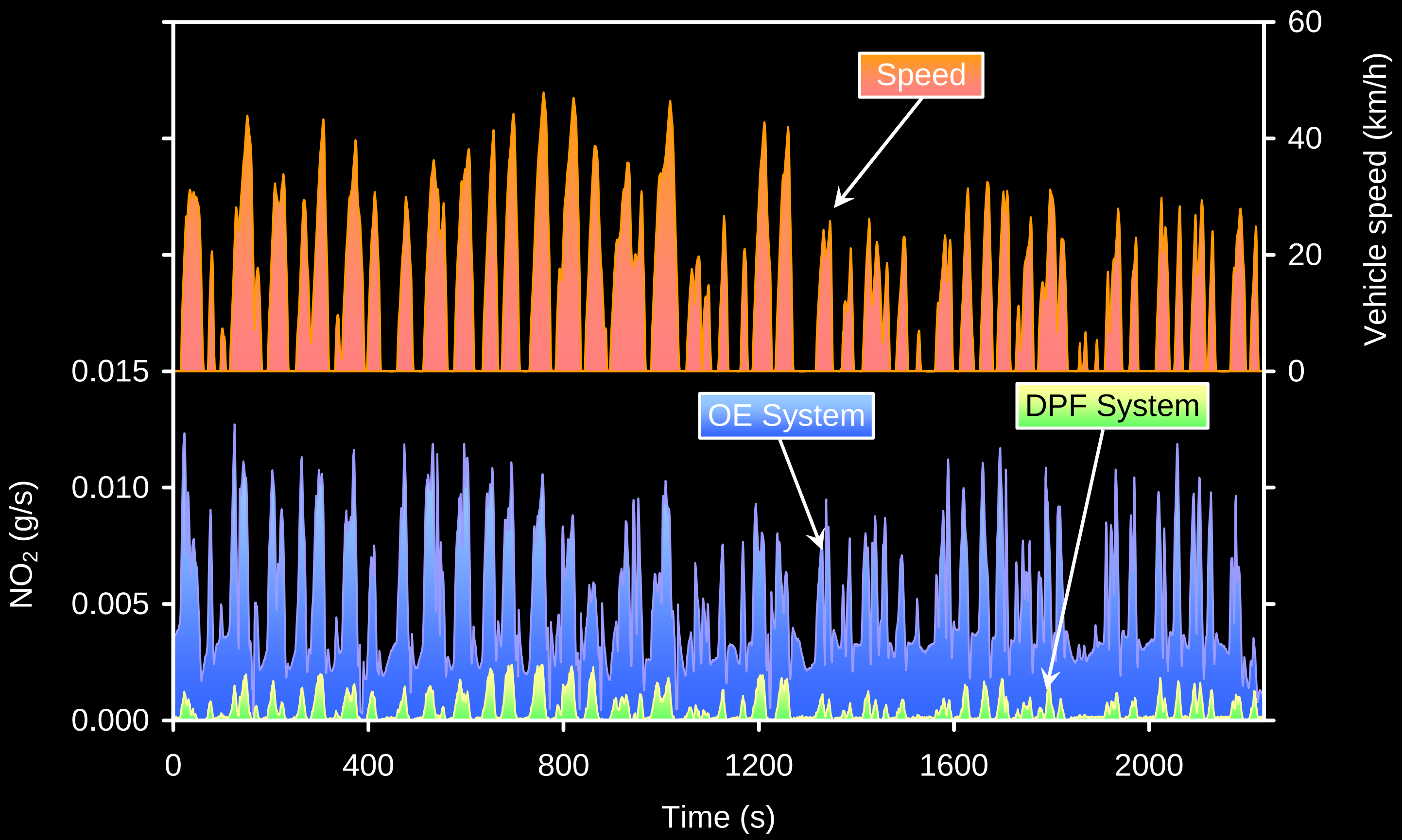
Further field application - NO_2 emissions



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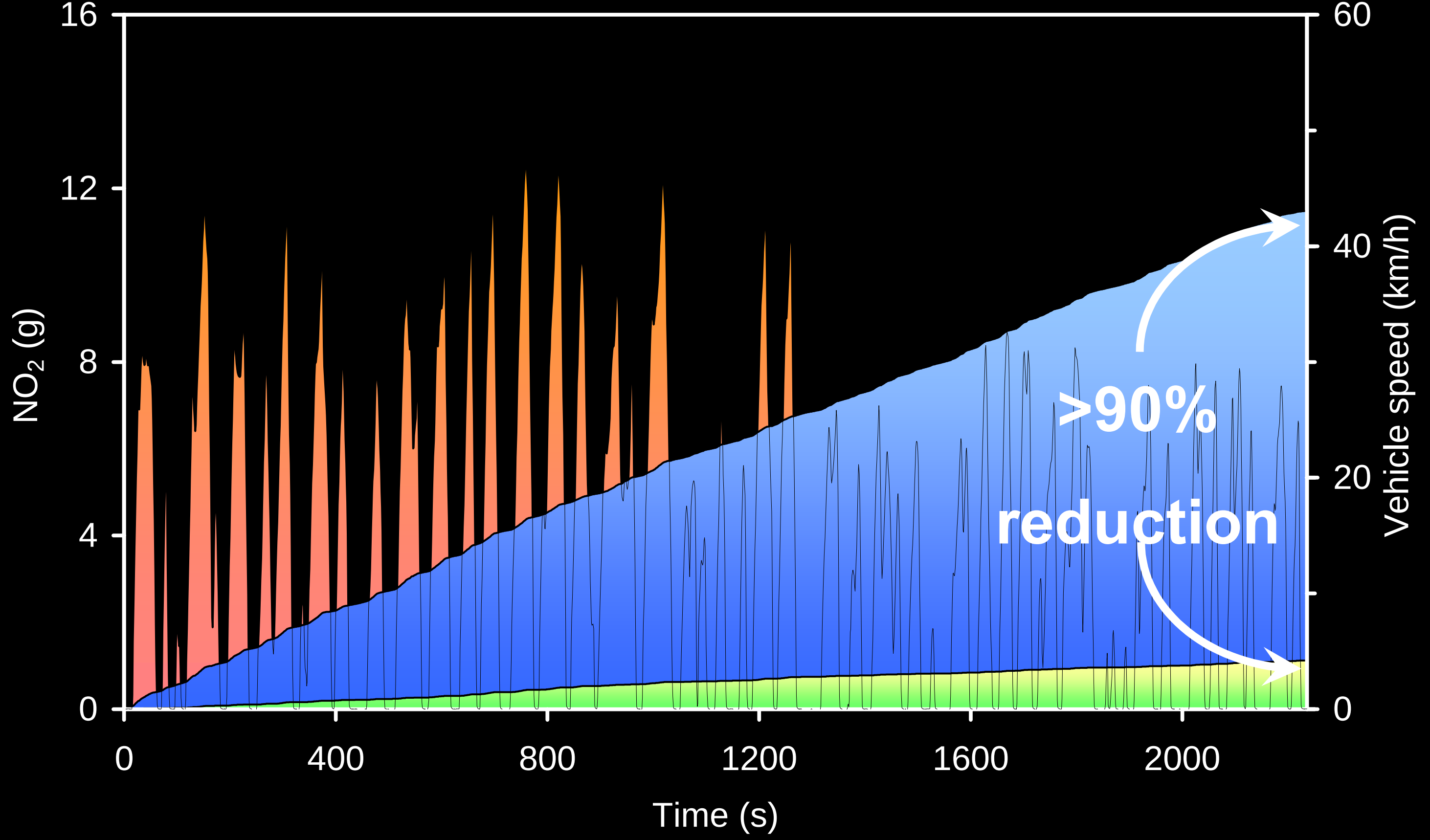
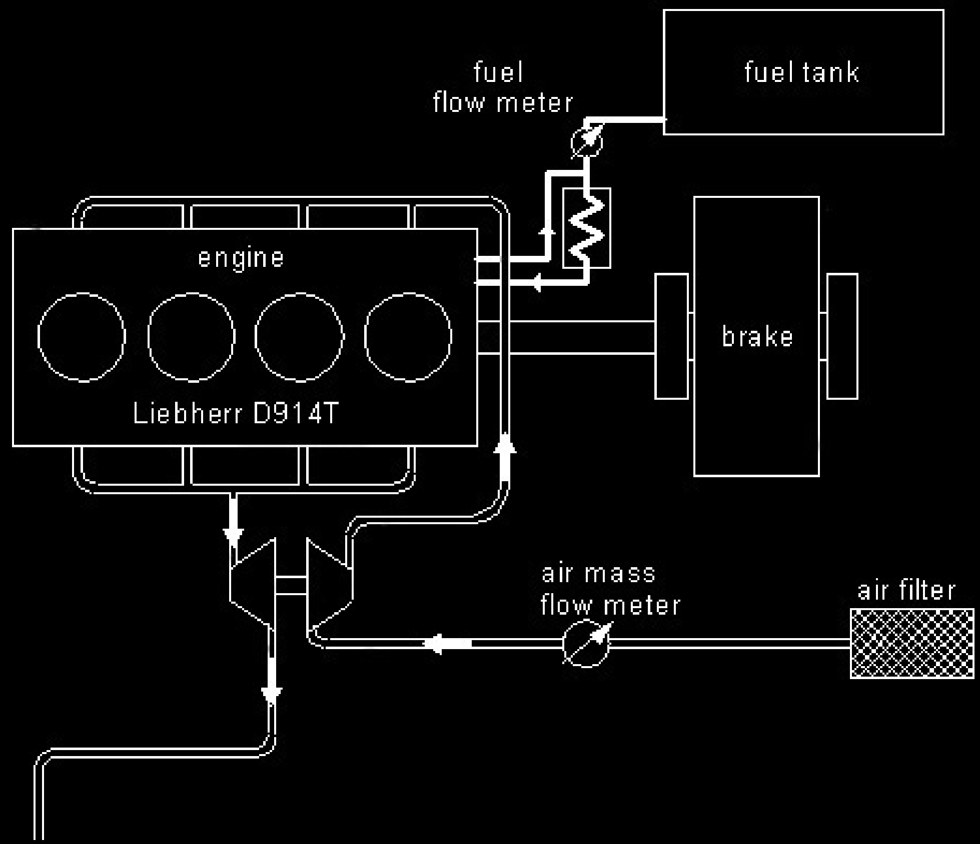
Further field application - Cumulative NO_2 emissions



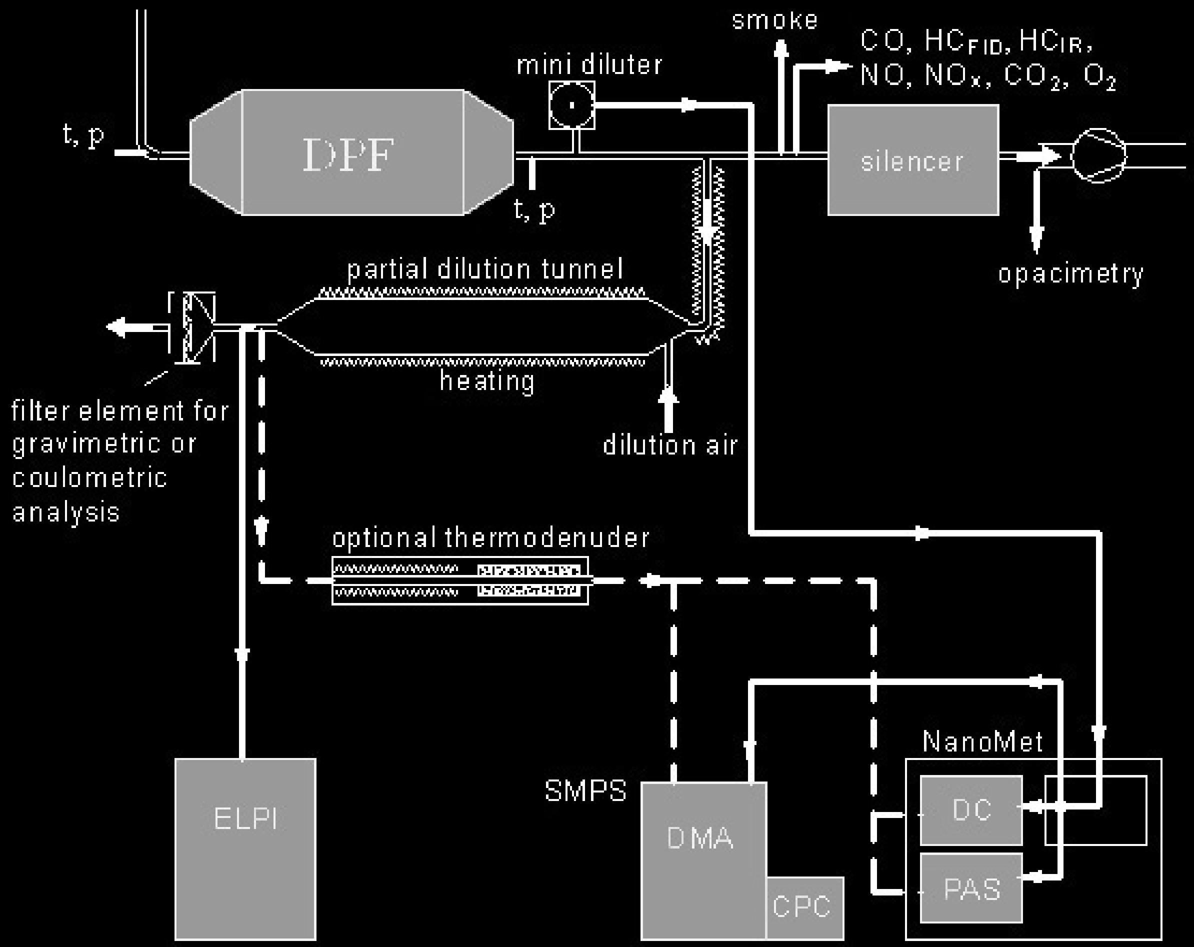
VSET testing

- Secondary emissions testing at EMPA
- Testing conducted to ISO 8178/4
- Liebherr D914T engine
  - 6.11ltr
  - rated at 110 kW @ 2000 rev/min
- Emissions of metals in FBC and on catalysed DPF

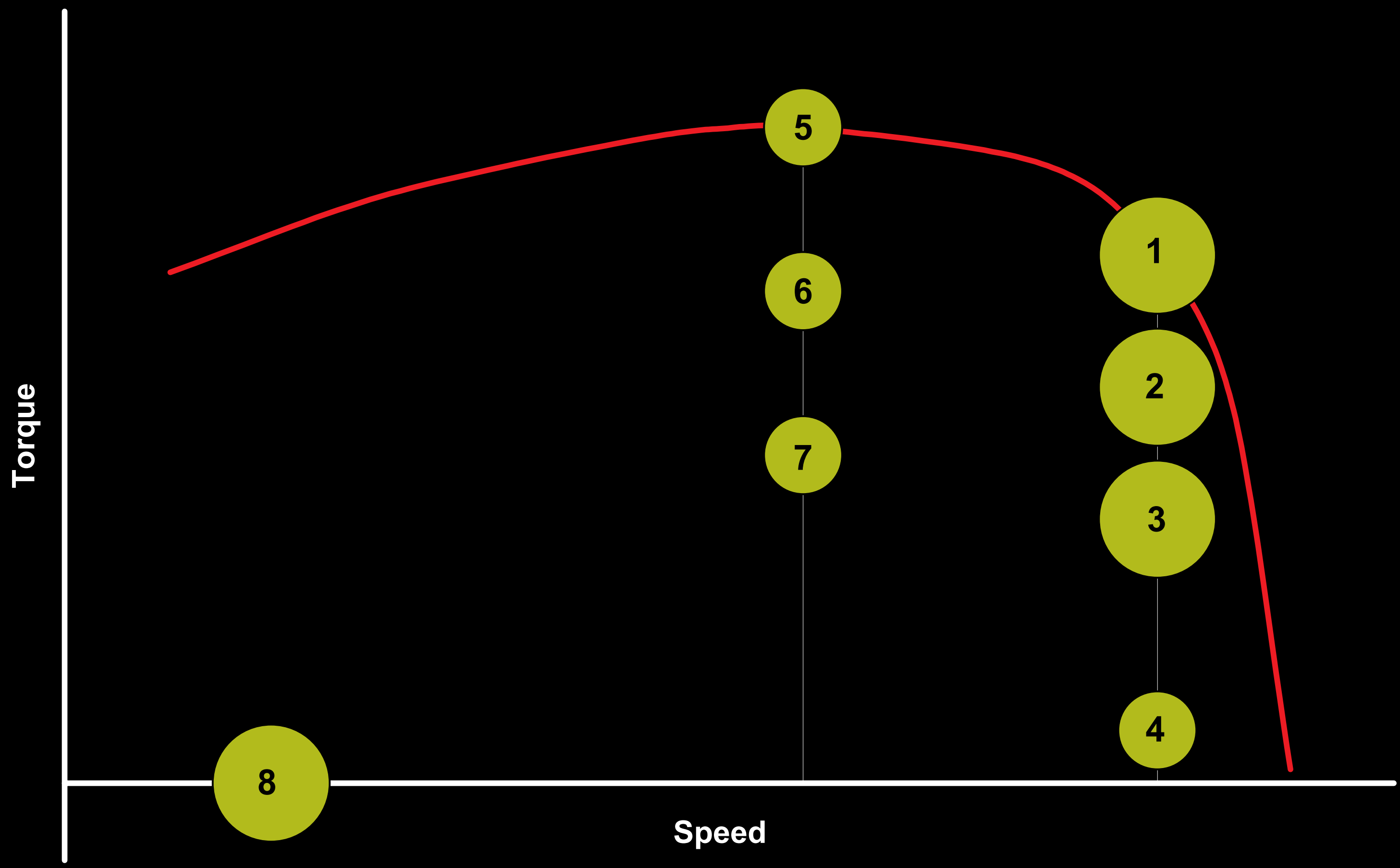
VSET – engine configuration



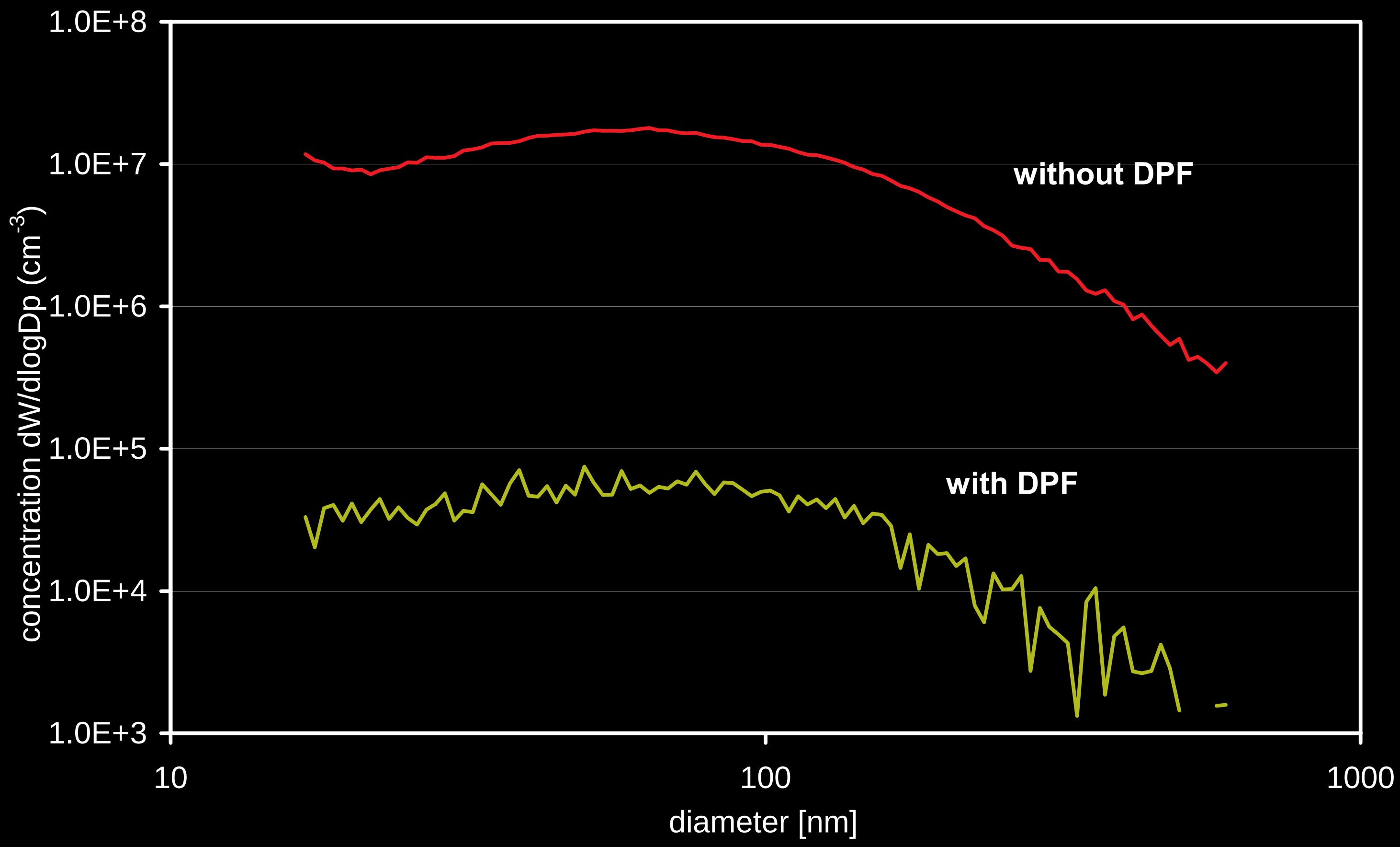
VSET – engine configuration



VSET – test conditions   ISO 8178/4



VSET testing - 1400 rev/min, full load



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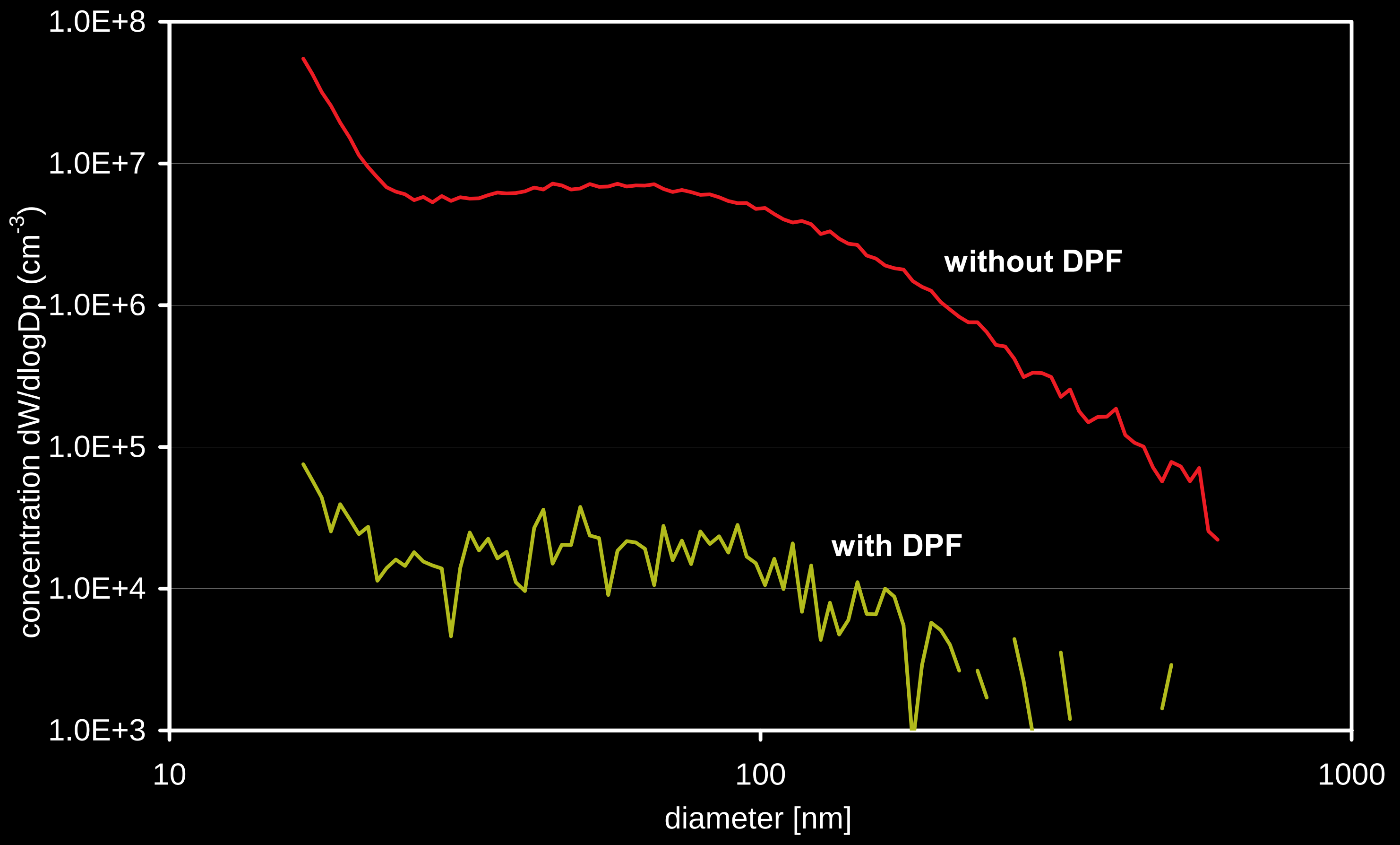
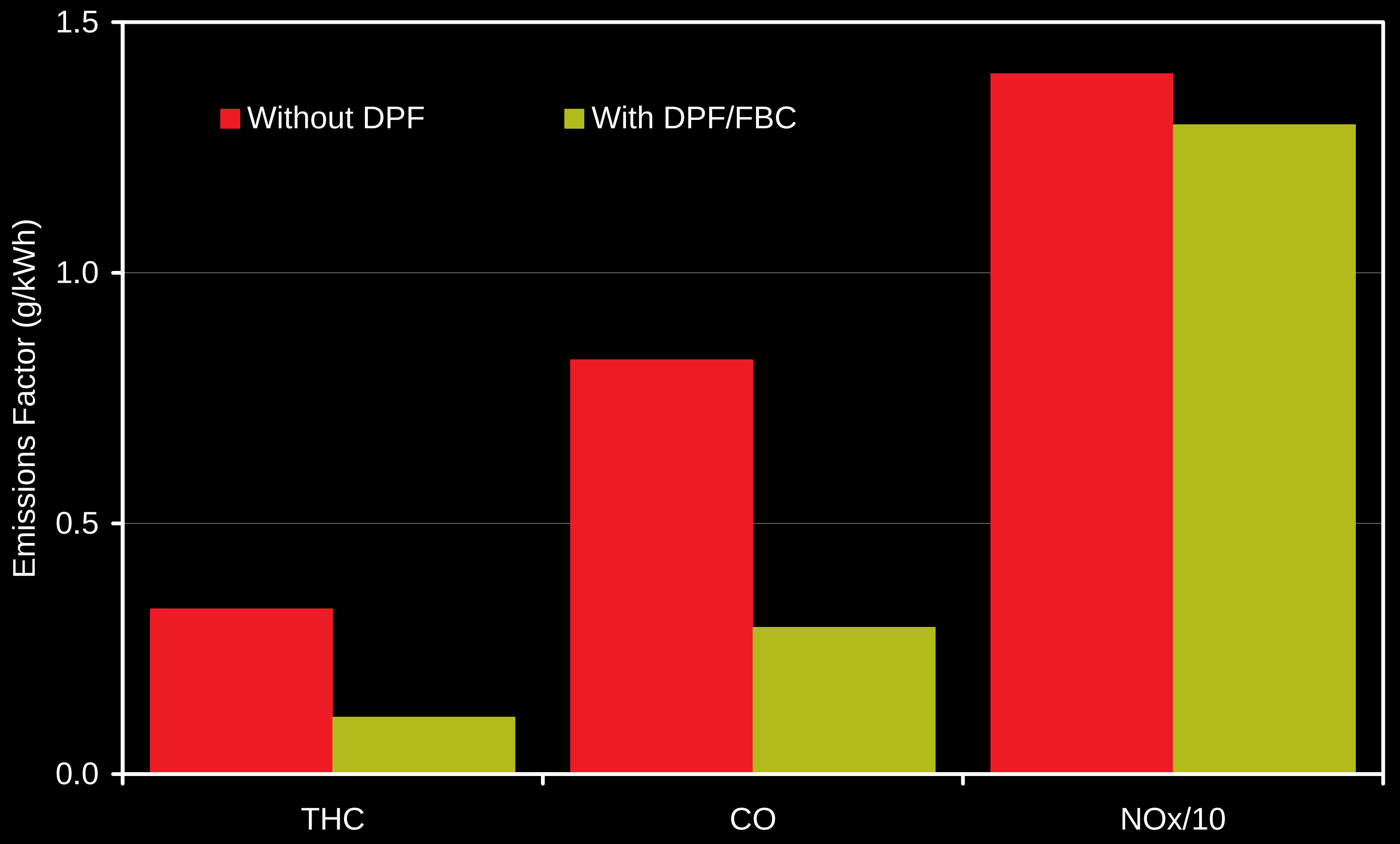
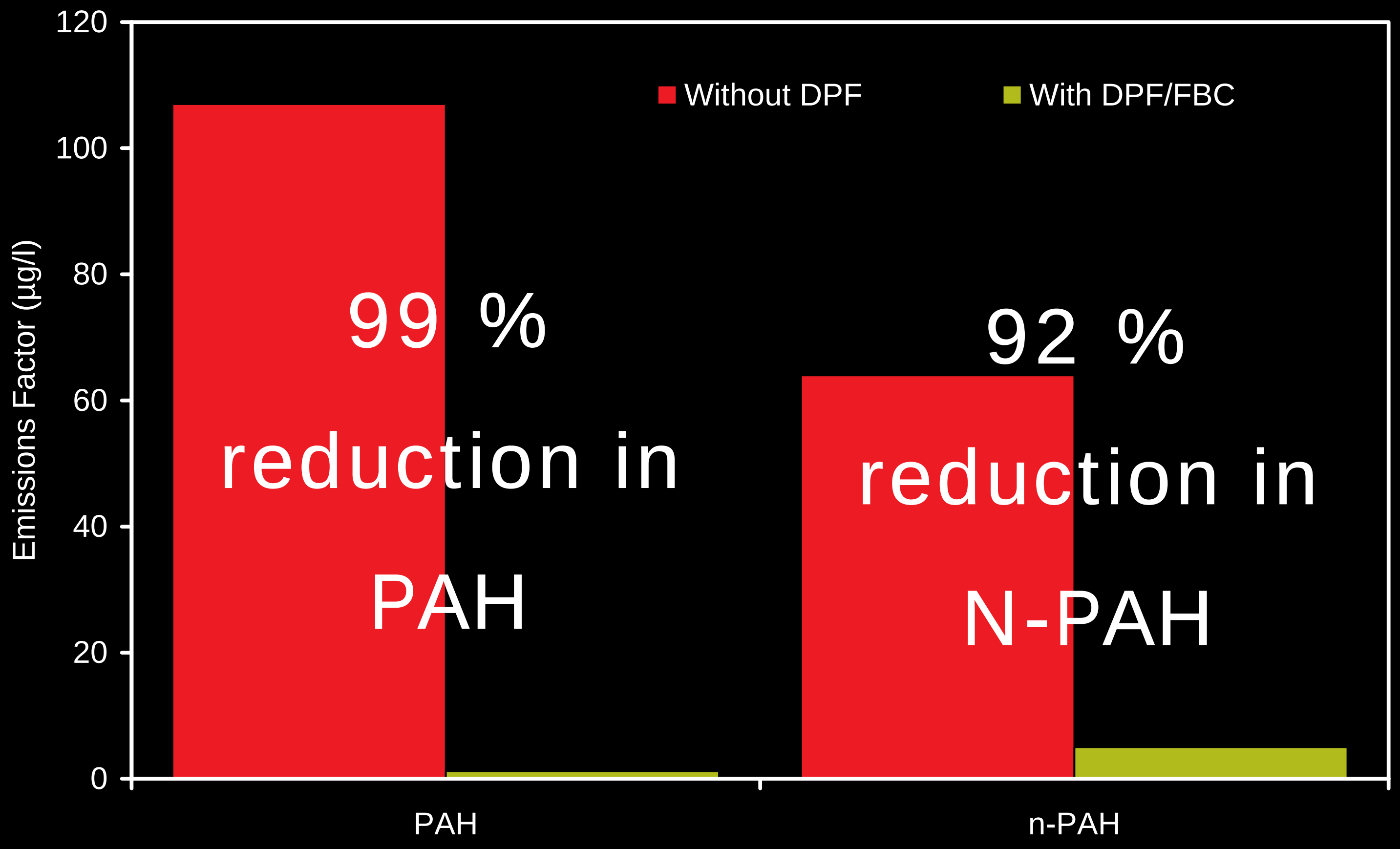
VSET testing - 1400 rev/min, 297 Nm



VSET testing - Regulated emissions



VSET testing - PAH, N-PAH emissions



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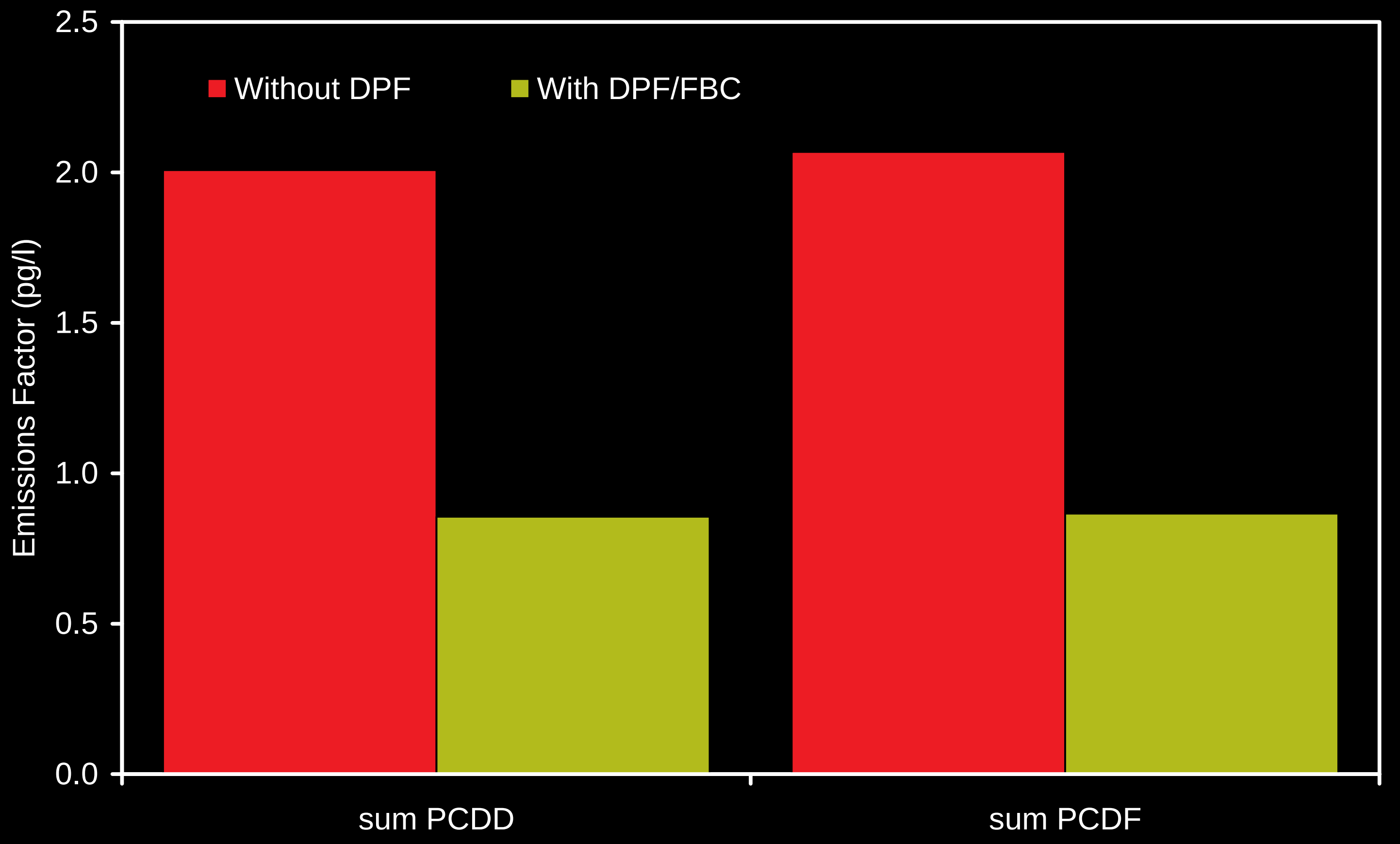
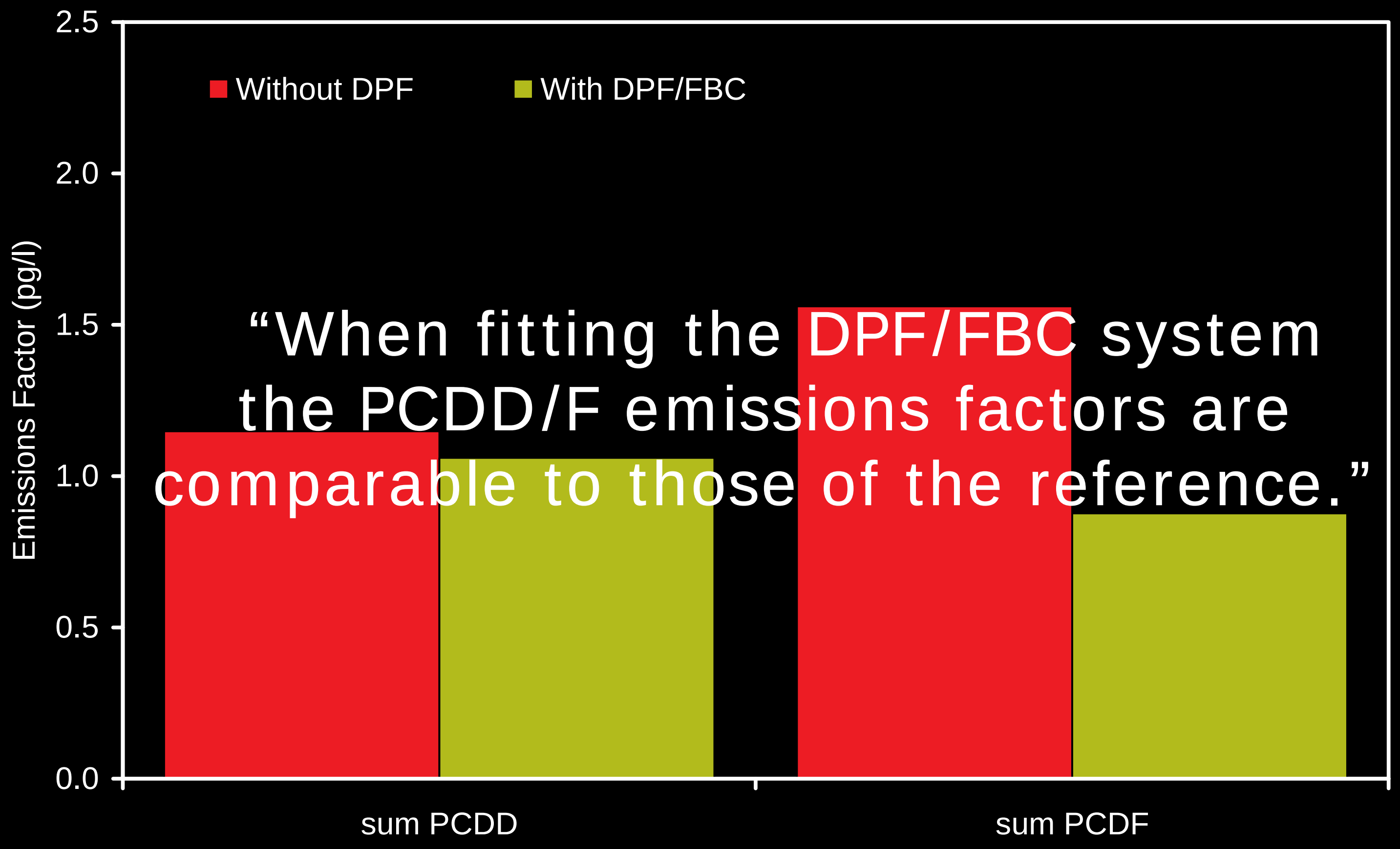
VSET testing - PCDD/F emissions



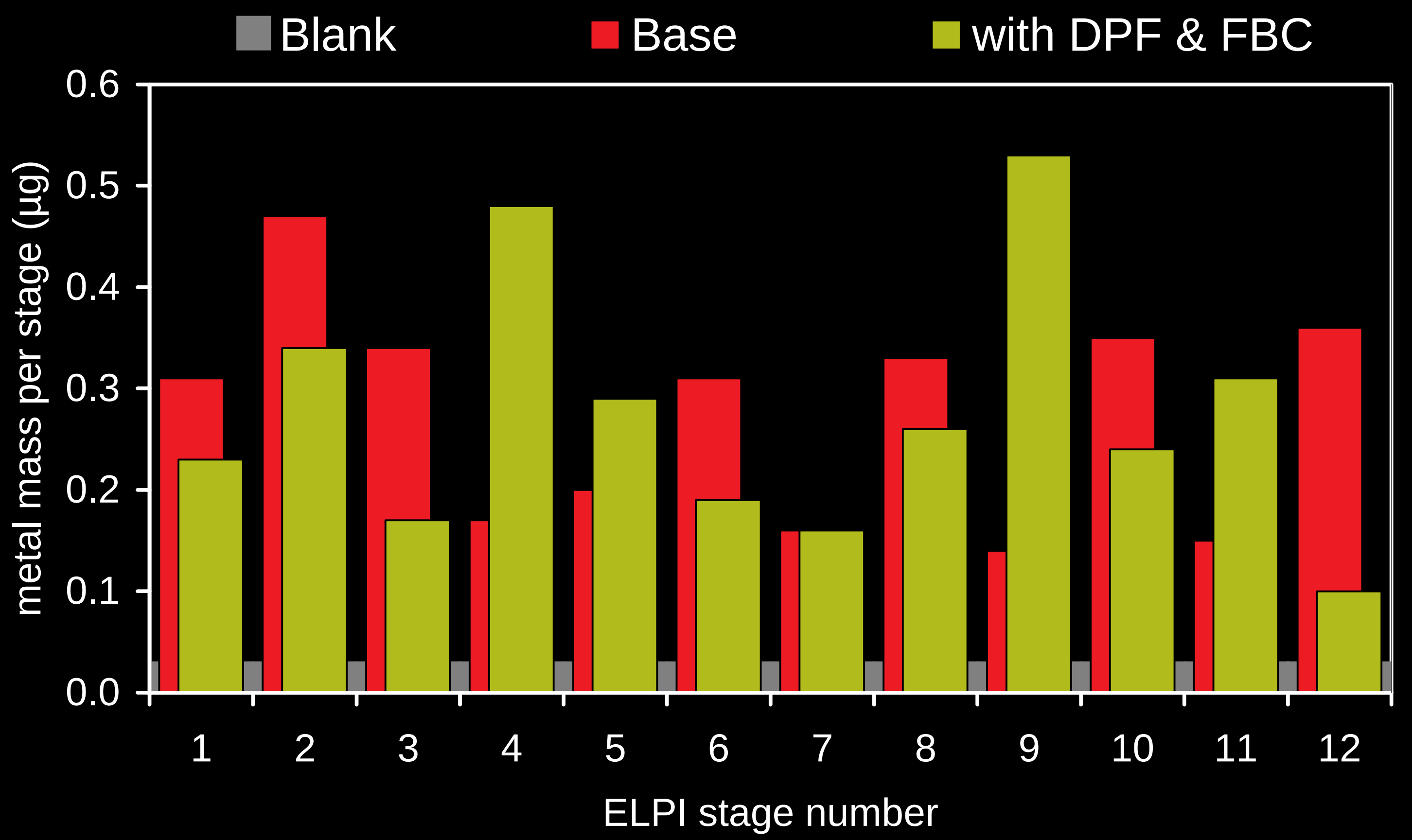
VSET testing - PCDD/F emissions



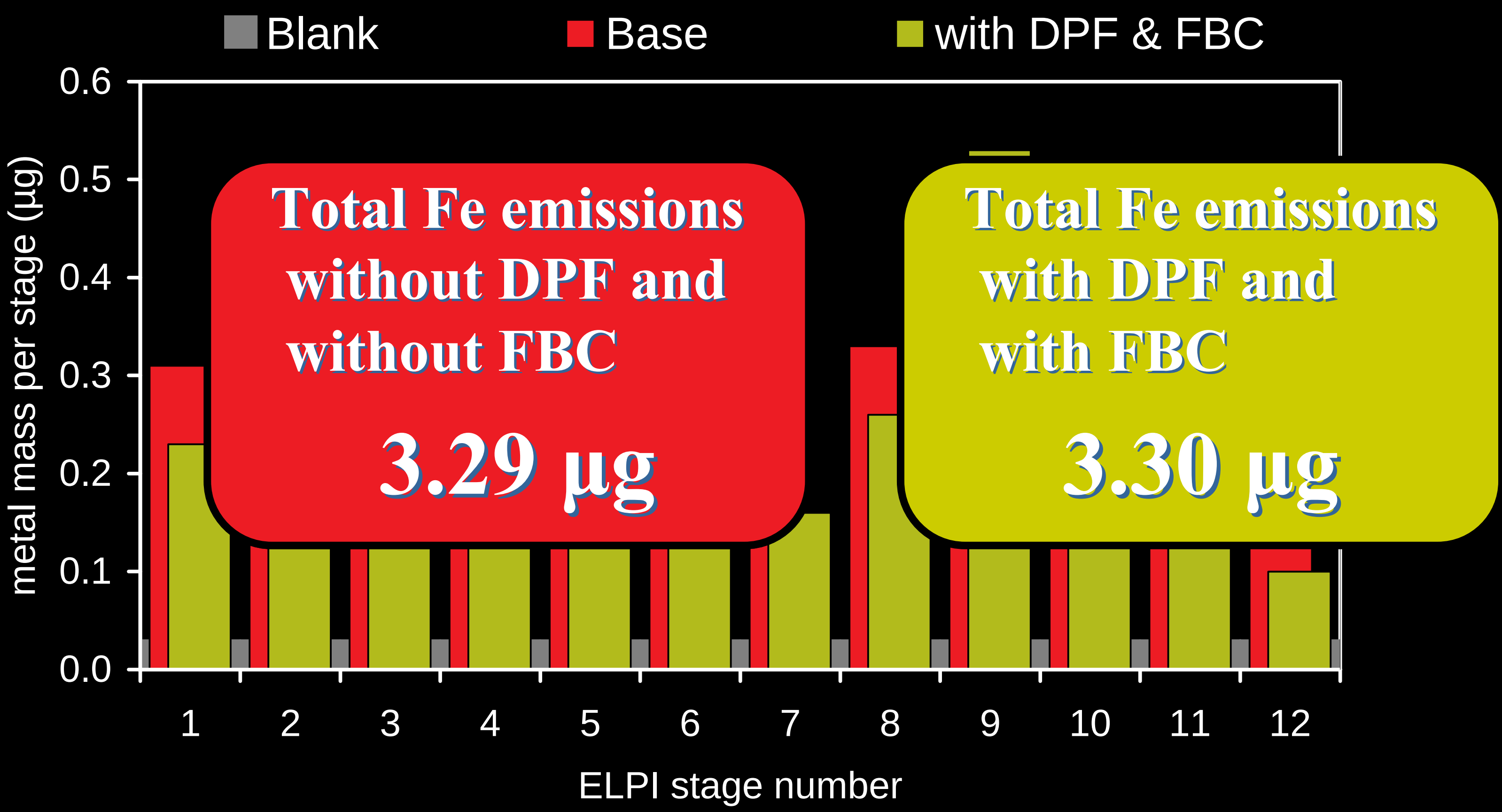
"When fitting the DPF/FBC system the PCDD/F emissions factors are comparable to those of the reference."

with Cl doped fuel

Fe emissions (40 mg/kg Fe in fuel)



Fe emissions (40 mg/kg Fe in fuel)



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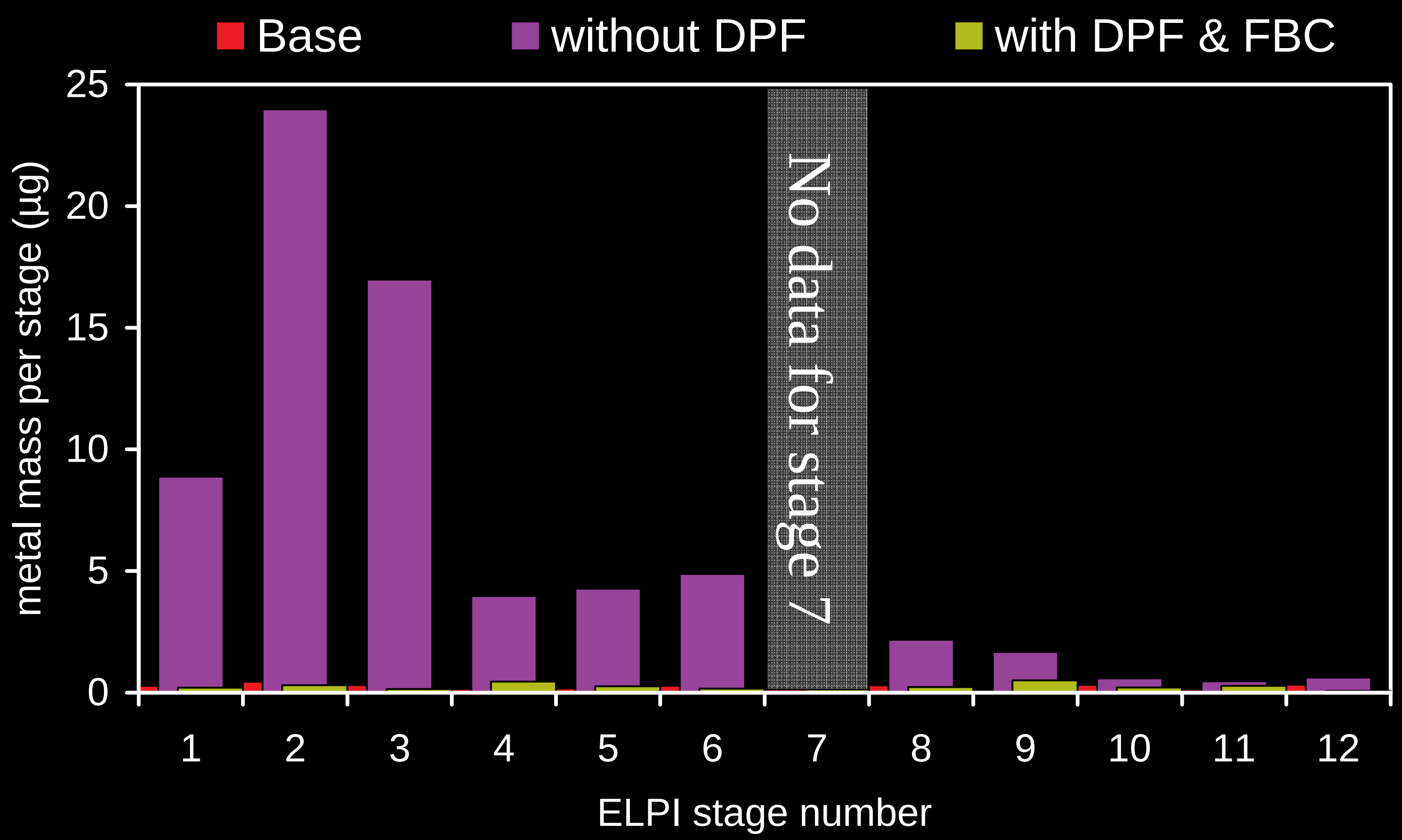
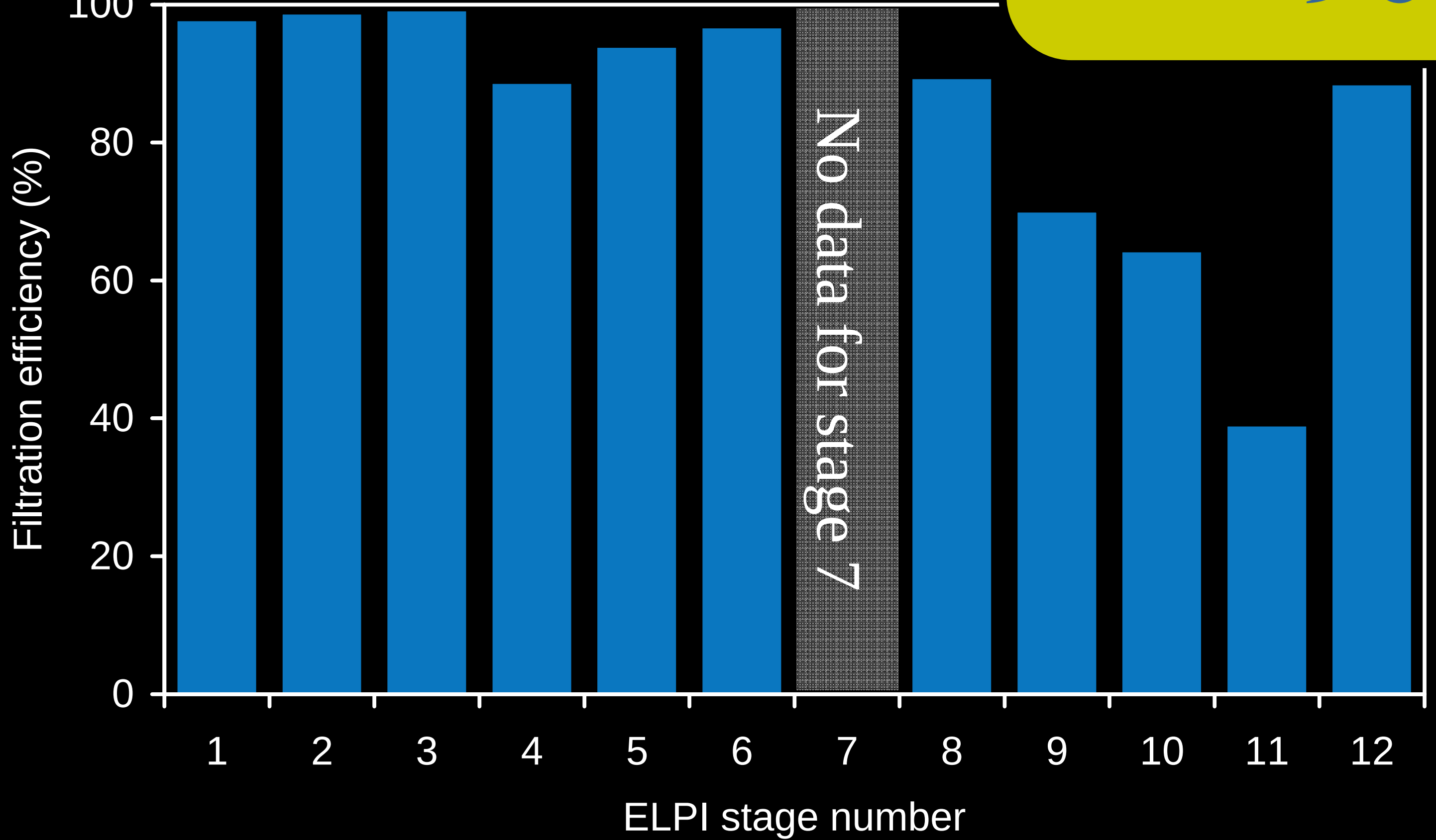
Fe emissions (40 mg/kg Fe in fuel)



Filtration Efficiency

Overall filtration efficiency for Fe

≈ 96 %



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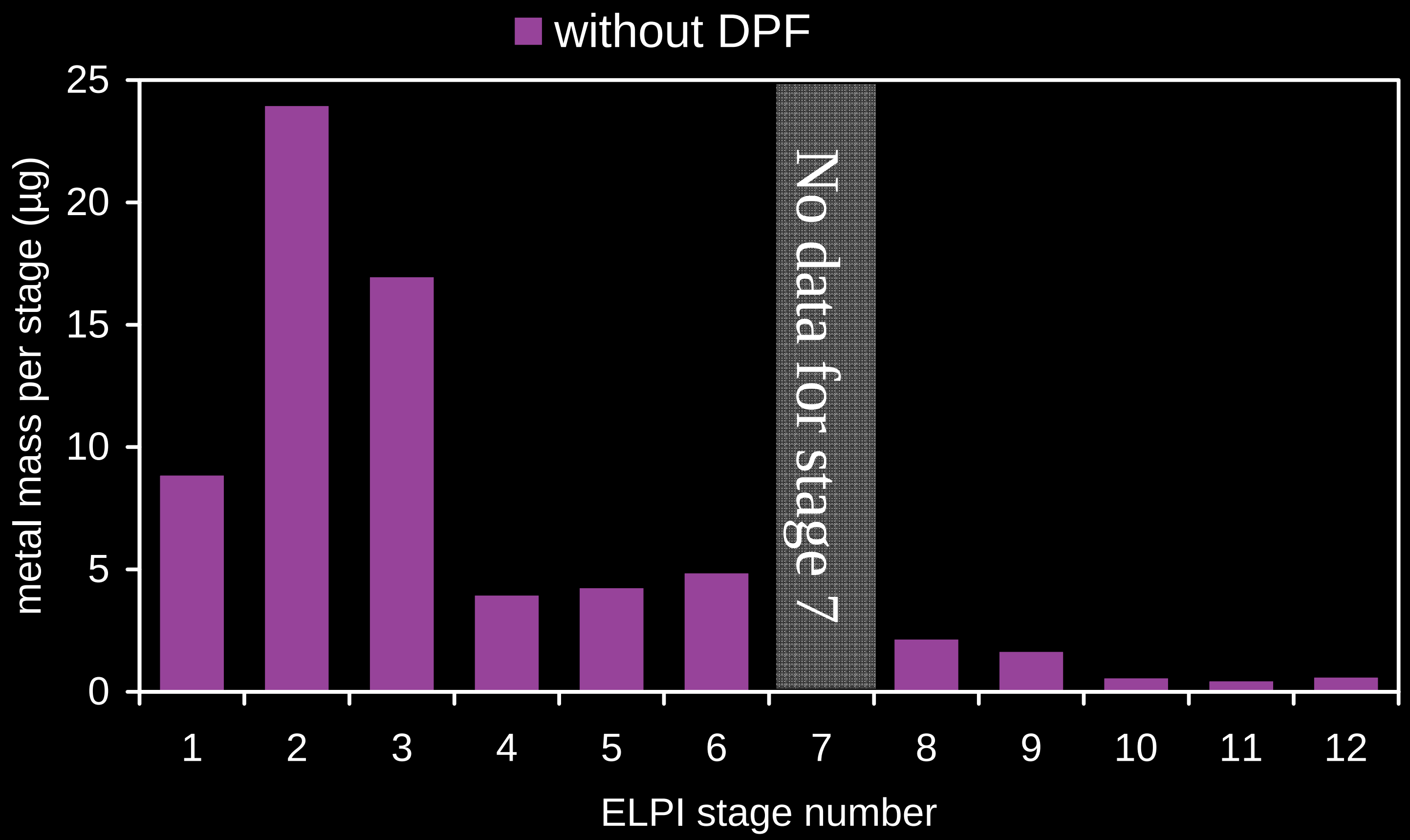
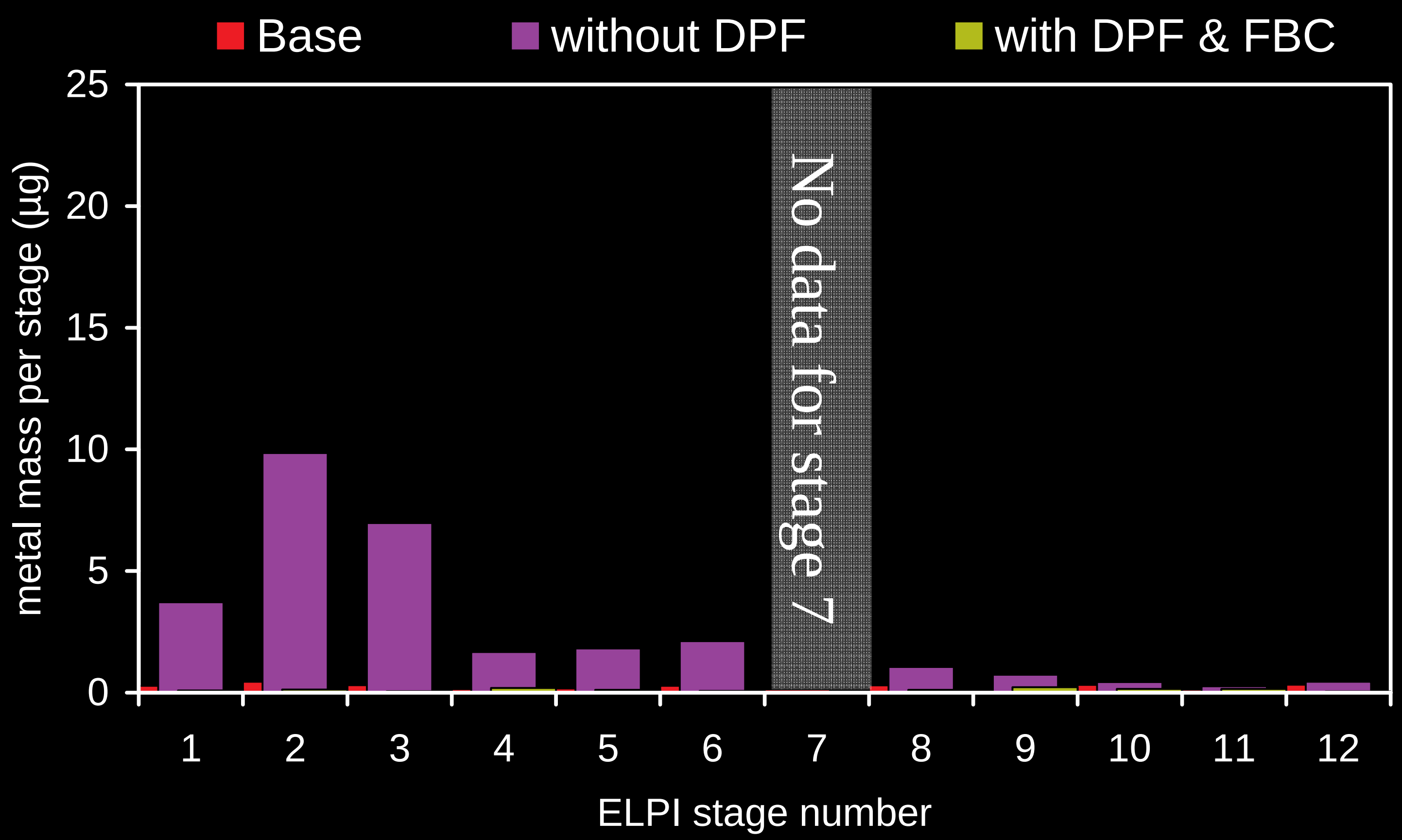
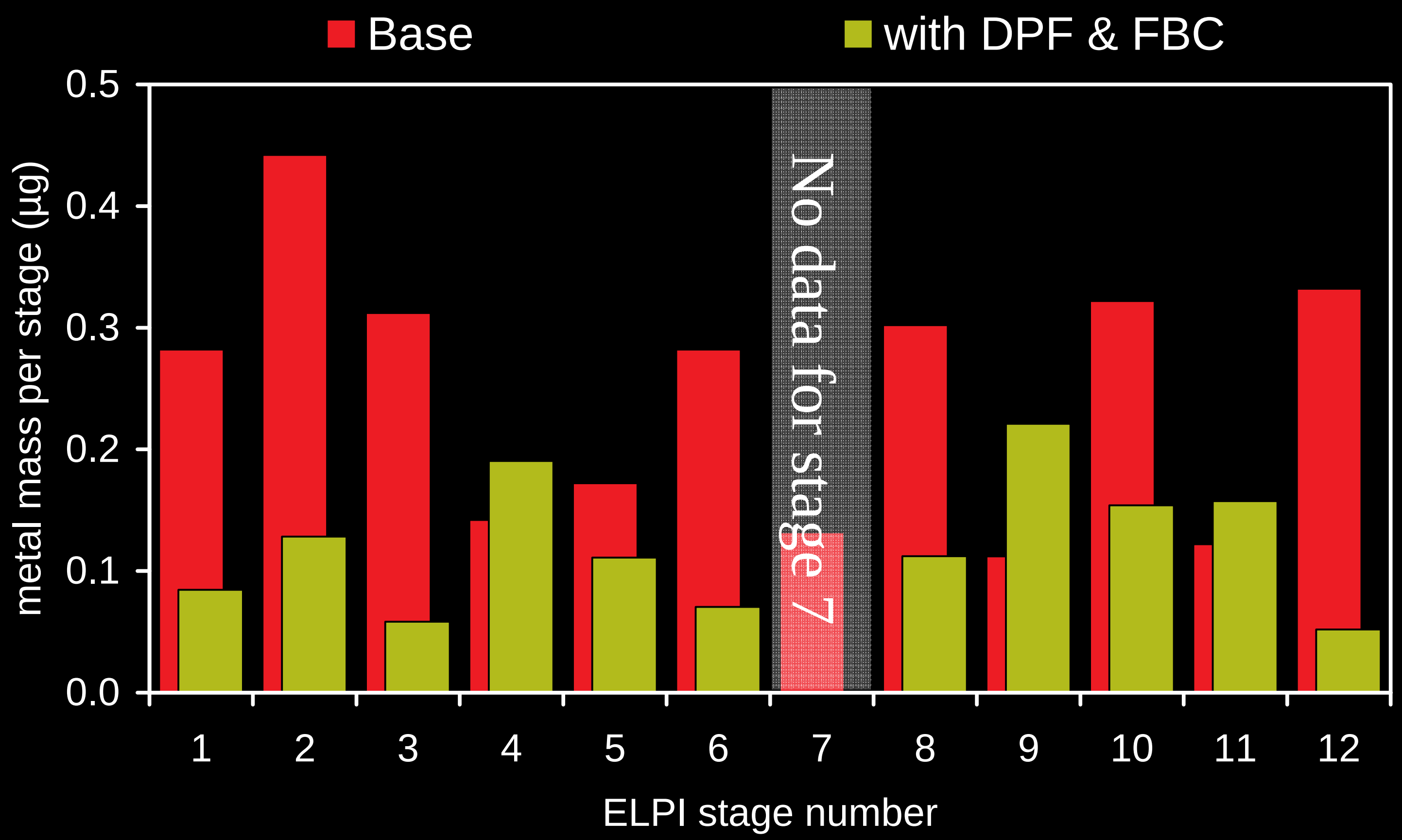
Fe emissions (40 mg/kg Fe in fuel)



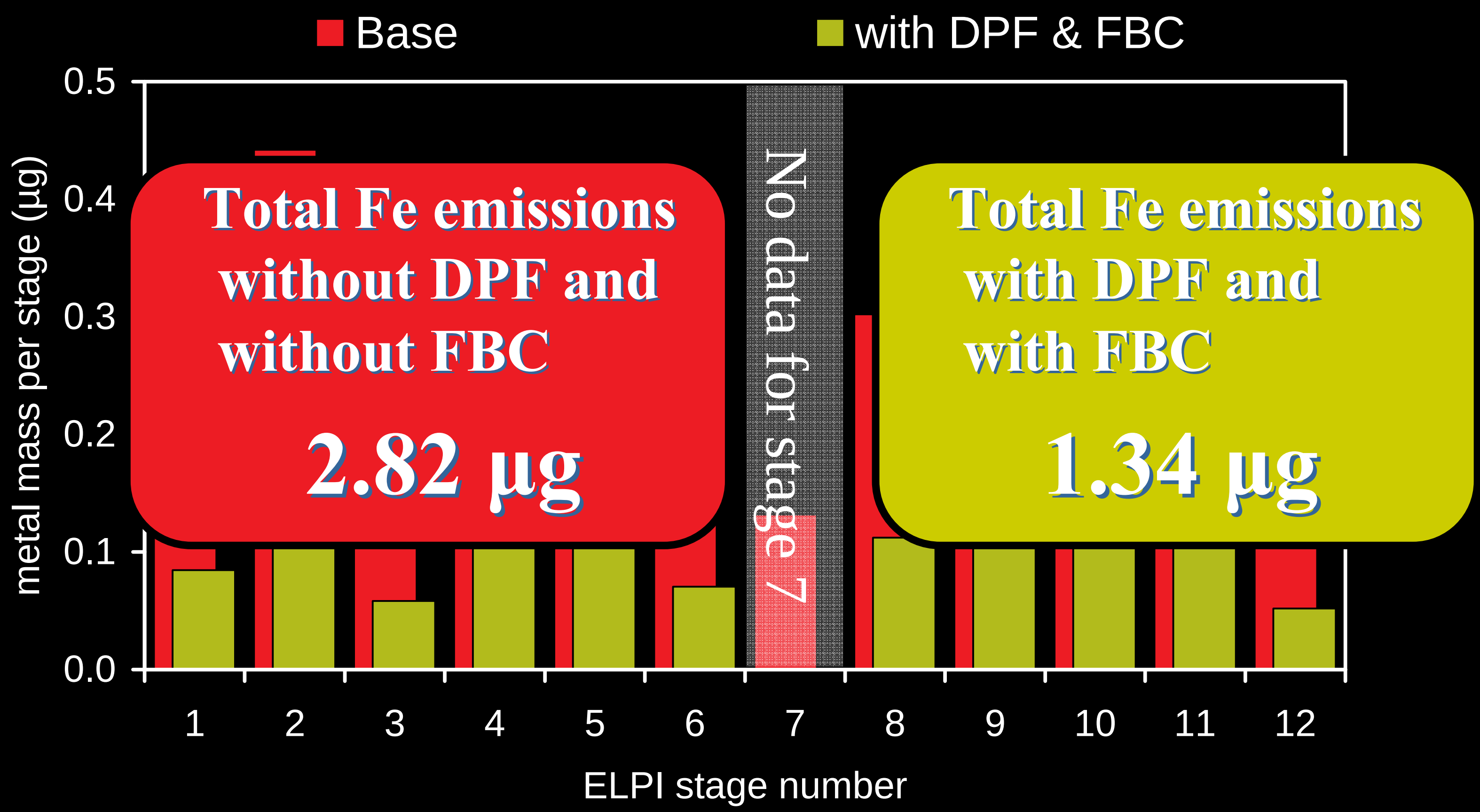
Fe emissions (16 mg/kg Fe in fuel)



Fe emissions (16 mg/kg Fe in fuel)



Fe emissions (16 mg/kg Fe in fuel)



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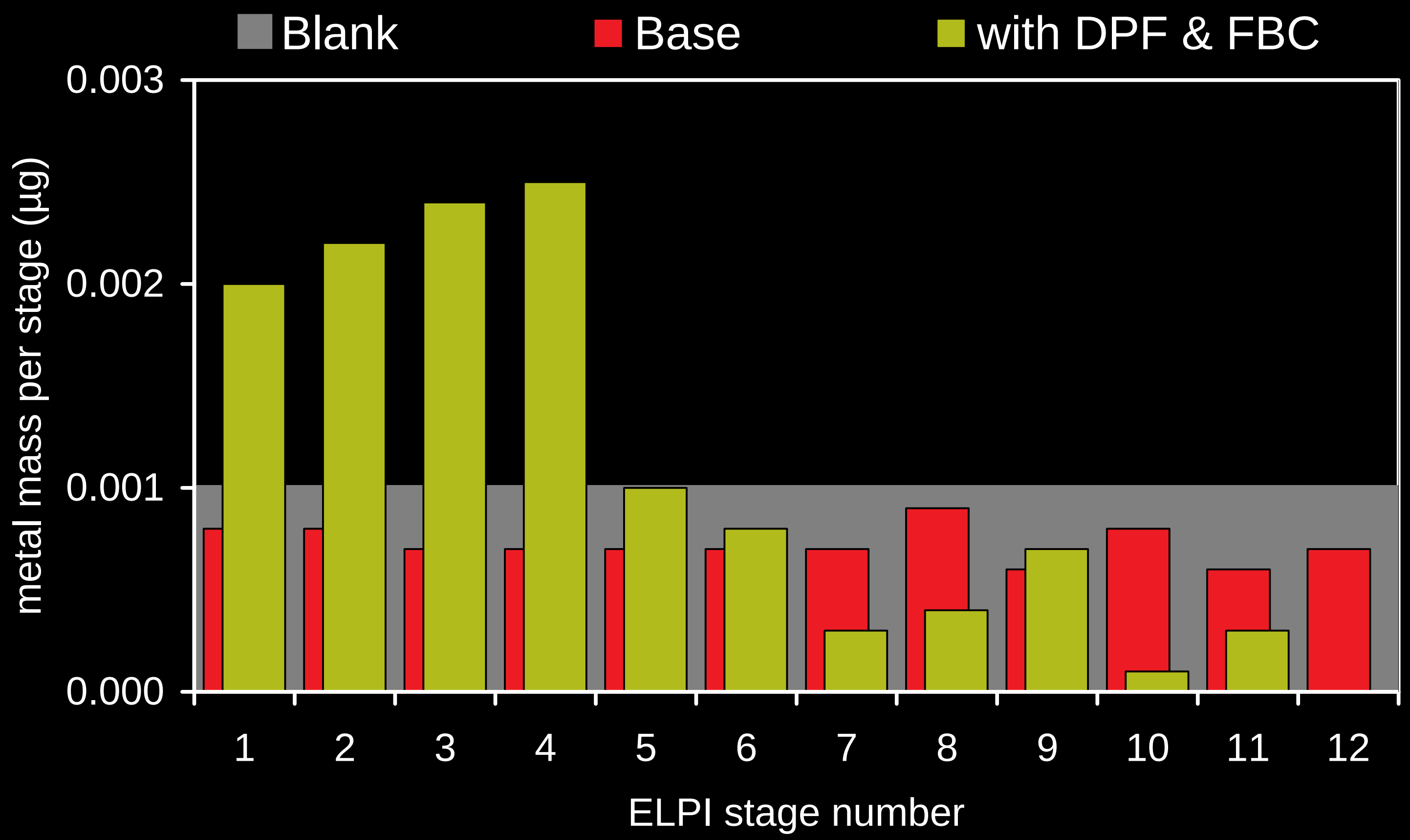
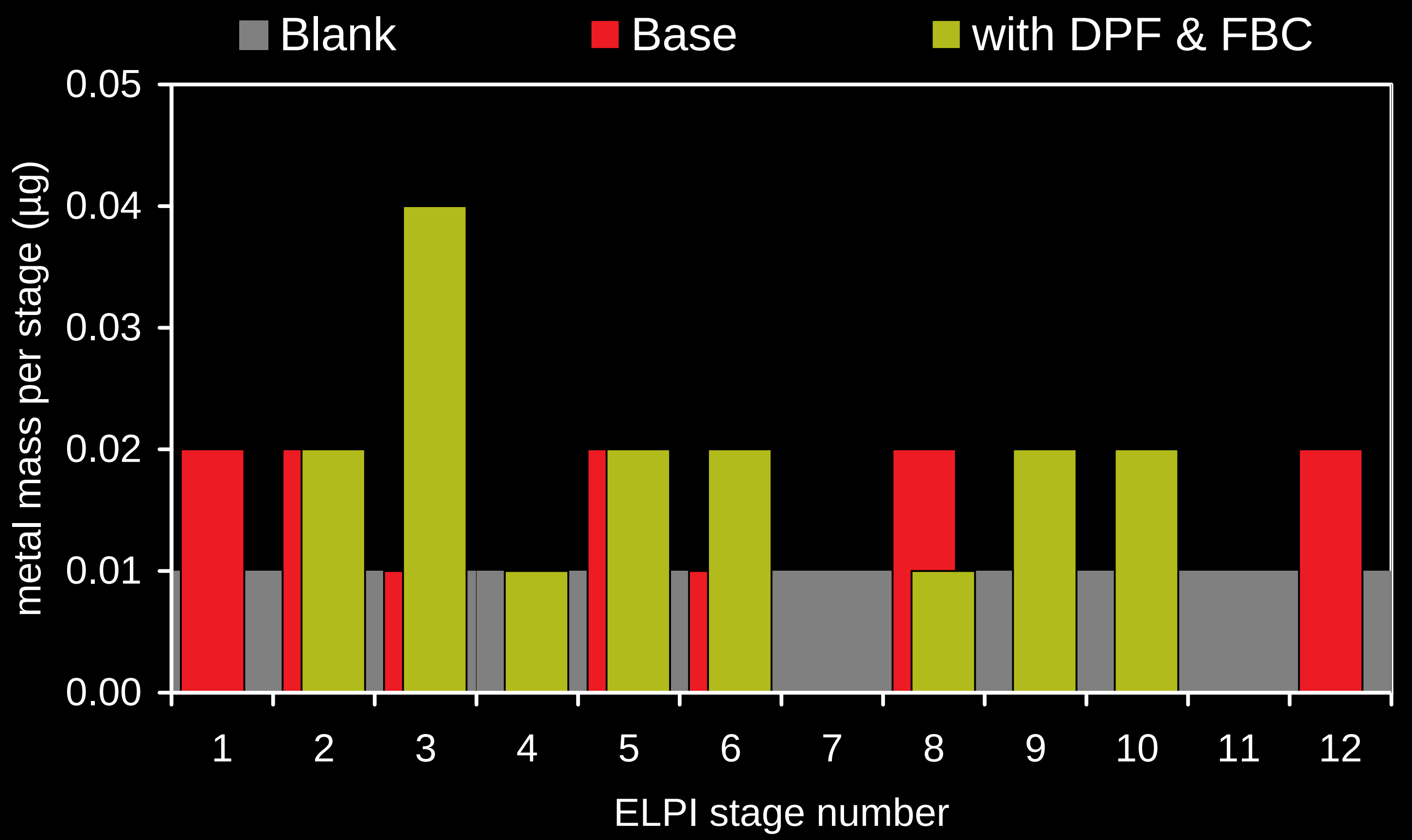
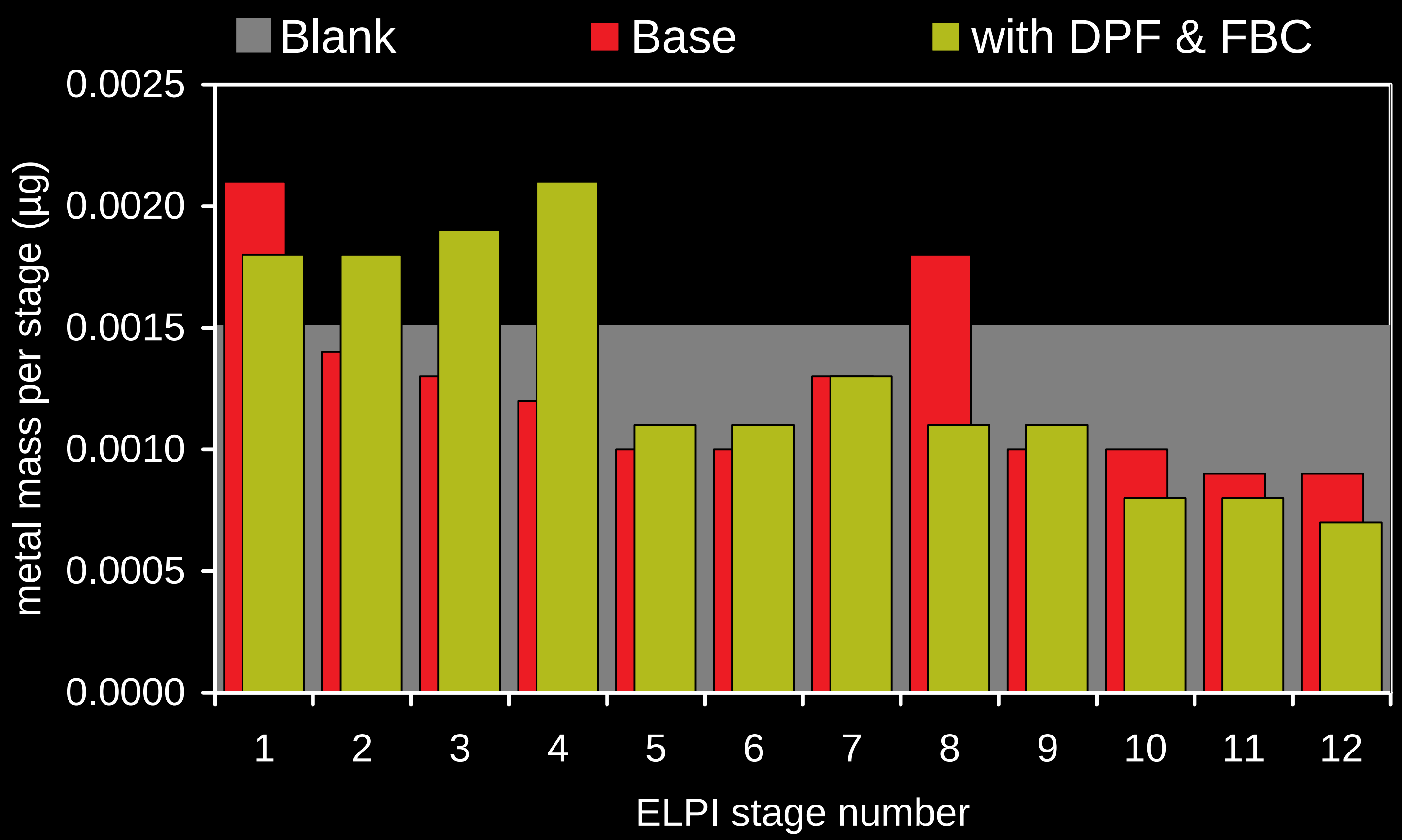
Catalyst metal emissions



Catalyst metal emissions



Catalyst metal emissions



Implications - Long distance truck field trial

- Test Vehicles
  - Mercedes-Benz Actros 1835 LS tractor units
  - Mercedes-Benz OM501LA engines, 11.95 litres , Euro 2
- Vehicles run for approximately 250 000 km each
- Fuel and lubricating oil consumption measured
- Monthly analysis of metals in the lubricating oil
- Results reported in SAE 2004-01-0074

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Implications - Long distance truck field trial

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Implications - Long distance truck field trial

- Average fuel consumption was 28.55 l/100 km
- Oil consumption was 0.048 % of fuel consumption
- From analysis of accumulated ash Fe from the FBC and Ca from the oil were being collected in the same proportion to consumption
- Collection rate indicated that 40% of what was being burned was being emitted at the tail pipe
- Results reported at
Seminar Haus der Technik in München-Ismaning

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Metal emitted (per truck per year)

Aluminium	79.9	mg
Calcium	**32.5**	**g**
Chromium	20.9	mg
Copper	129.2	mg
Lead	23.4	mg
Magnesium	121.9	mg
Manganese	9.4	mg
Molybdenum	691.4	mg
Nickel	23.7	mg
Tin	12.2	mg
Zinc	**10.5**	**g**

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Metal emitted (per truck per year)

Aluminium	79.9	mg
Calcium	**32.5**	**g**
Chromium	20.9	mg
Cop		
Lea		
Mag		
Mar		
Molybdenum	691.4	mg
Nickel	23.7	mg
Tin	12.2	mg
Zinc	**10.5**	**g**

From the VSET testing

Overall filtration efficiency for Fe

≈ 96 %

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Metal trapped (per truck per year)

Aluminium	76.6	mg
Calcium	**31.2**	**g**
Chromium	**20.1**	**mg**
Copper	**123.9**	**mg**
Lead	**22.4**	**mg**
Magnesium	116.9	mg
Manganese	9.0	mg
Molybdenum	662.8	mg
Nickel	22.7	mg
Tin	11.7	mg
Zinc	**10.1**	**g**

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Conclusions

- A DPF/FBC system will reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles, will slightly reduce NO_X emissions but has little effect on HC or CO.
- A BMCDPF/FBC system not only reduced CO, HC and PM emissions it reduced NO_X emissions and produced a significant reduction in NO_2 emissions
- The BMCDPF/FBC system will also reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles

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Conclusions

- A BMCDPF/FBC system has also been shown to significantly reduce PAH and N-PAH emissions
- The BMCDPF/FBC system does not increase PCCD/F emissions even when the fuel is doped with Cl
- No significant quantity of the metals used in the base metal catalyst are emitted from after the DPF
- The use of the FBC in conjunction with the DPF does not increase the FBC metal emissions

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Conclusions

- The high filtration efficiency of the DPF will also lead to a significant reduction in other metal emissions, including
  - Chromium
  - Copper
  - Lead
  - Zinc

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Thank you for your attention

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