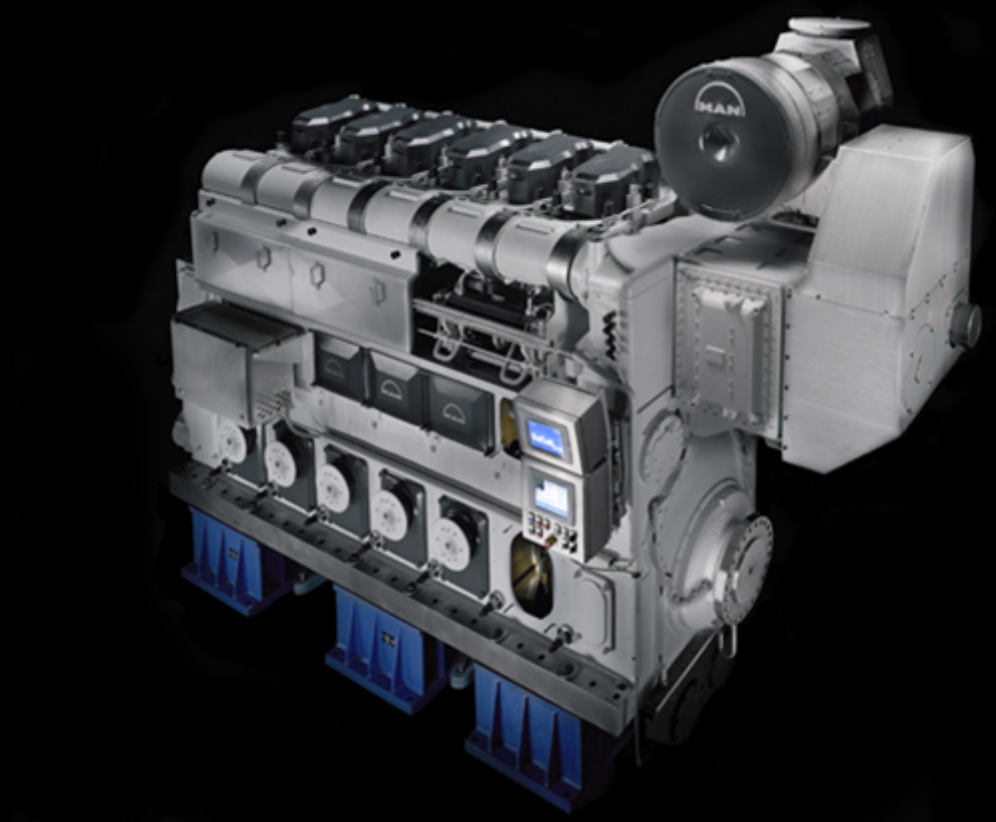

PM & Dust: Comparison and determination of EC/OC content for marine Diesel engines exhaust for different fuels

Outline

- **Motivation**
- Methods
- Results
- Conclusions
- Acknowledgements

Motivation

- **Particulate matter (PM) emissions from large 4-stroke medium speed Diesel engines show a significantly different composition compared to high speed Diesel passenger cars and trucks engines**
- **Different fuels are used in large medium speed Diesel engines**
- **Different methods exist for the determination of carbon PM content**

- **Therefore detailed measurements have been performed and different analyzing methods have been applied to determine the elemental carbon (EC) and the organic carbon (OC) content of the PM emission from large medium speed 4-stroke Diesel engines**
- **Furthermore different types of fuels have been investigated**

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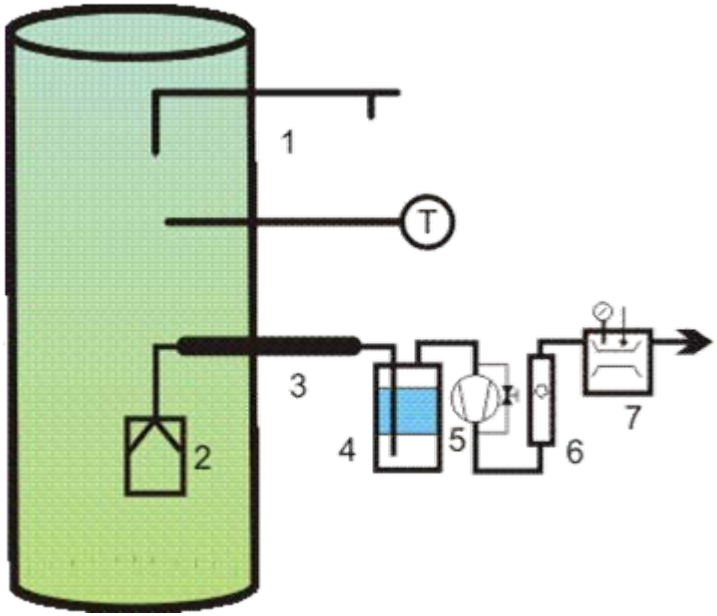
Measurement methods

- **PM measurement according to ISO-8178**
- **Dust measurement according to VDI-2066 equivalent to US EPA Method 17 / ISO-9096 / EN-13284**
- **EC determination by filter smoke number (FSN), and Multi angle adsorption photometer (MAAP) measurements by Deutsches Zentrum für Luft- und Raumfahrt (DLR)**
- **Fuel analysis performed by MAN Diesel SE and ASG Analytik-Service Gesellschaft mbH, 86356 Neusäss, Germany**
- **Analysis of the PM for EC and OC by various methods as well as sulfates (SO_4), sulfate bound water (H_2O) and ash by Germanischer Lloyd (GL), Institut für Gefahrstoff-Forschung der Bergbau Berufsgenossenschaft an der Ruhr-Universität Bochum (IGF), Institute for Applied Environmental Research -Air Pollution Laboratory- Stockholm University and MAN Diesel SE**

Dilution system for PM

- **AVL 472 Smart Sampler Modular GEM140**
- **Quartz (Pall QAO 2500) or Teflon (Pall Emfab TX40HI20) fiber filters**
- **Remark: Particulate measuring according to ISO-8178 is conclusively proven to be effective for fuel sulfur levels up to 0.8 w% only**

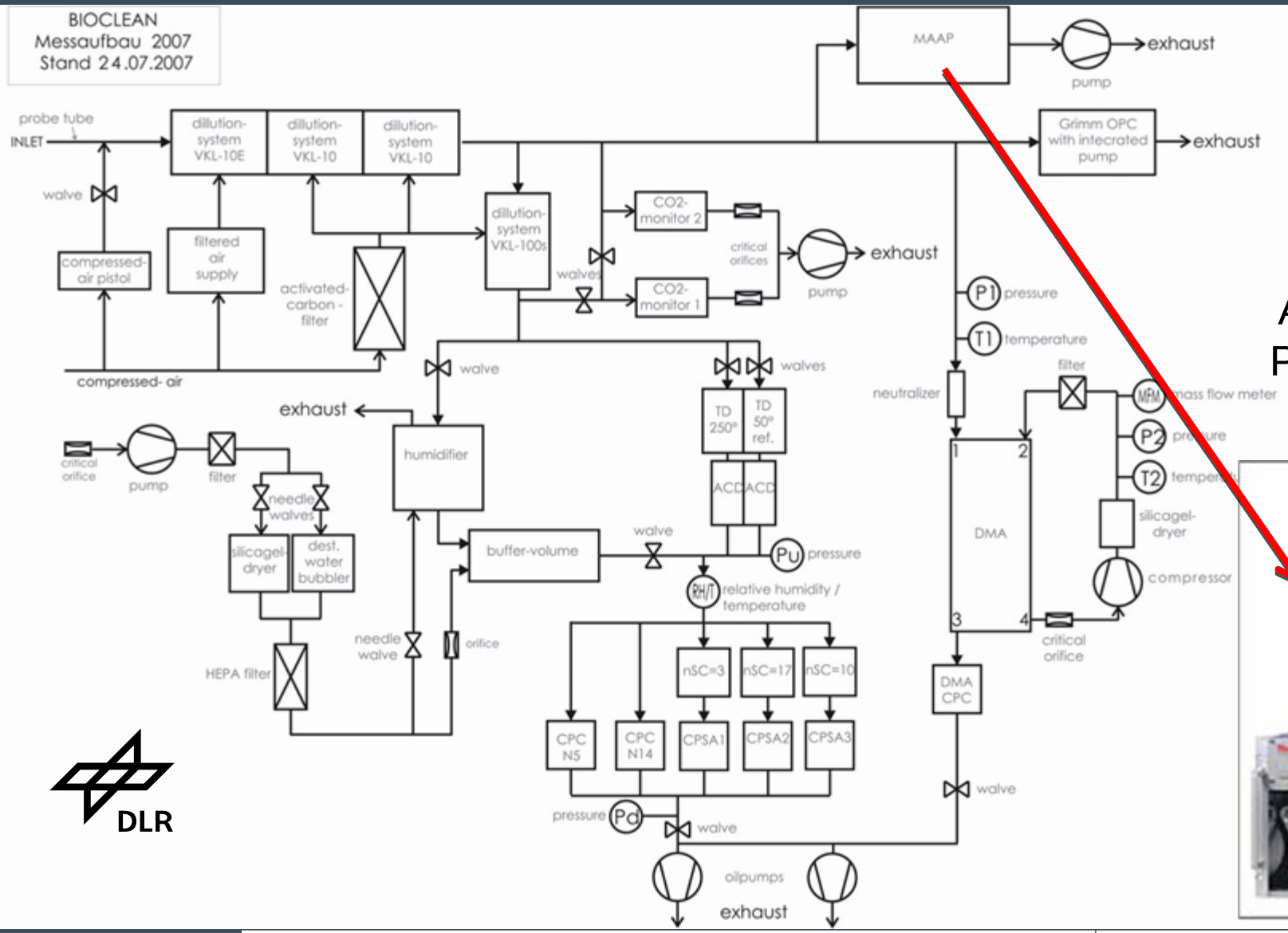
In stack system for Dust



1: Pitot tube
2: Filter device with nozzle
3: Suction tube
4: Drying tower
5: Gas tight pump
6: Flow meter
7: Gas meter

- **Paul Gothe Dust sampling system**
- **Quartz (Pall QAO 2500) fiber filters**
- **Remark: Dust measuring according to VDI-2066 is conclusively proven for dry flue gases only**

DLR
Mobile aerosol measuring system



Absorption Photometer

σ_{ap}

DLR

EC / OC analyzing methods
Part 1

- **BGI 505-44 (ex. ZH 1/120.44), Coulometric-Method**
  - **Thermo-desorption of OC @ 500°C in N_2**
  - **Thermo-desorption of EC @ 650-800°C in O_2**
  - **http://www.arbeitssicherheit.de/servlet/PB/show/1224638/bgi505_44.pdf**

- **VDI-2465 Blatt 1, Coulometric-Method with filter-split**
  - **½ filter: Thermo desorption of TC @ 650°C in O_2**
  - **½ filter: Toluene-Propanol Extraction and thermo-desorption of OC @ 500°C in N_2 and Thermo- desorption of EC @ 650°C in O_2**

- **National Institute for Occupational Safety and Health (NIOSH) 5040**
  - **multi-stage thermo-optical method**
  - **http://www.cdc.gov/NIOSH/nmam/pdfs/5040f3.pdf**

EC / OC analyzing methods
Part 2

- **VDI-2465 Blatt 2, Thermographic-Method**
  - **Thermo-desorption of OC @ 80-620°C in He**
  - **Thermo-desorption of EC @ 300-700°C in O_2**

- **In-house method GL**
  - **Improved VDI-2465 Blatt 2 after Extraction and Thermo-desorption of OC @ 700 °C and EC @ 850 °C**

- **Calculation of EC by AVL-415 filter smoke number (FSN)**
  - **EC [mg/m³] = 1 / 0.405 x 4.95 x FSN x e $^{0.38 \times FSN}$**

- **Multi angle absorption photometer (MAAP)**
  - **ambient atmospheric black carbon (BC)**
  - **http://www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_18581.pdf**

EC / OC analyzing method
Part 3: NIOSH 5040 method

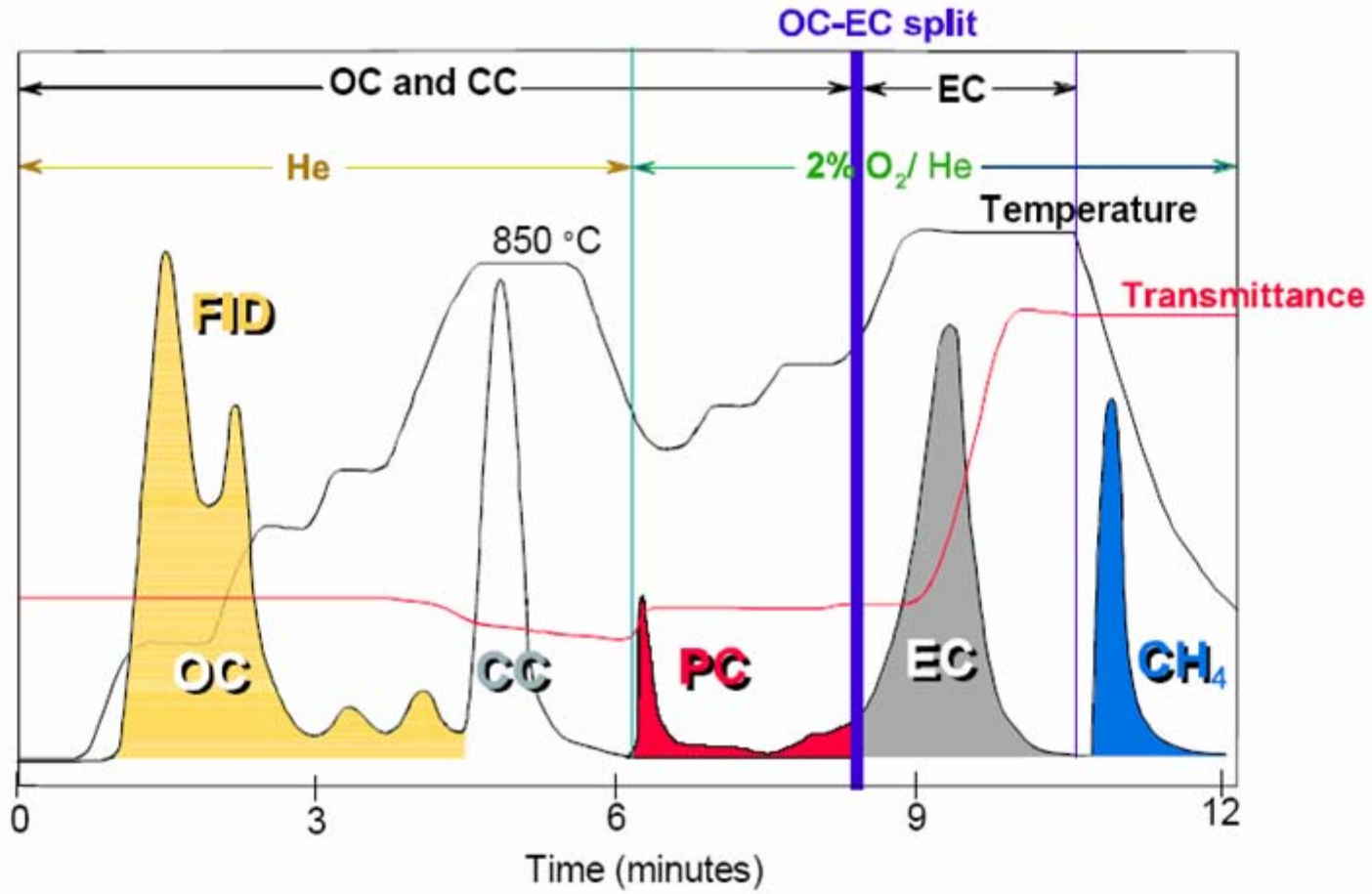


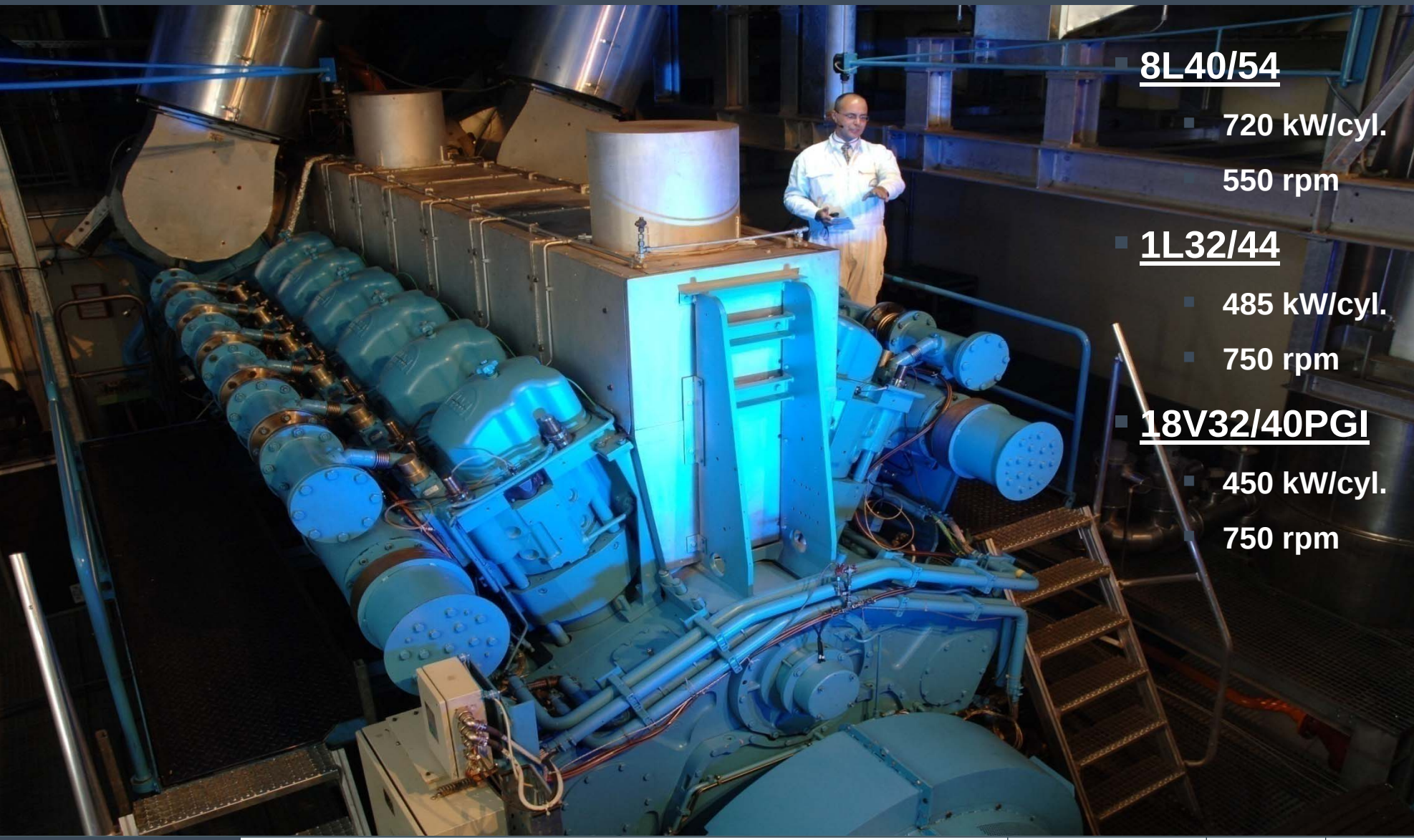
Figure 2. Thermogram for filter sample containing organic carbon (OC), carbonate (CC), and elemental carbon (EC). PC is pyrolytically generated carbon or 'char.' Final peak is methane calibration peak. Carbon sources: pulverized beet pulp, rock dust (carbonate), and diesel particulate.

Fuel properties

Fuel	Marine Diesel Oil (MDO)	Palm Oil	Animal Fat	Heavy Fuel Oil (HFO)	Natural Gas
Test engine	**8L40/54**	**1L32/44**	**1L32/44**	**1L32/44**	**18V32/40PGI**
Category	**Distillate**	**Renewable**	**Renewable**	**Residue**	**Gas**
Type	**DM-B grade**	**Vegetable**	**Animal**	**RM grade**	**Russian**
Viscosity [mm²/s]	**6.2 @ 40°C**	**29 @ 50 °C**	**31 @ 50 °C**	**719 @ 50 °C**	**-**
Density @ 15 °C [kg/m³]	**879**	**916**	**914**	**982**	**-**
Hydrogen [% mass]	**12.22**	**11.00**	**11.20**	**10.45**	**98% Methane**
Carbon [% mass]	**85.53**	**77.30**	**77.00**	**86.94**	**-**
Sulfur [% mass]	**2.15**	**7.2 ppm**	**2.8 ppm**	**2.17**	**10 ppm *)**
Nitrogen [% mass]	**0.10**	**-**	**-**	**0.42**	**-**
Oxygen [% mass]	**-**	**11.50**	**11.60**	**-**	**-**
Ash [% mass]	**0.01**	**0.0016**	**0.0017**	**0.012**	**-**
Lower Heat Value Hu [kJ/kg]	**42,077**	**37,144**	**37,292**	**40,435**	**49,030**

*) 20 mg/m³ Odorant C_4H_8S Tetrahydrothiophene (THT)

Test engines



- **8L40/54**
  - 720 kW/cyl.
  - 550 rpm
- **1L32/44**
  - 485 kW/cyl.
  - 750 rpm
- **18V32/40PGI**
  - 450 kW/cyl.
  - 750 rpm

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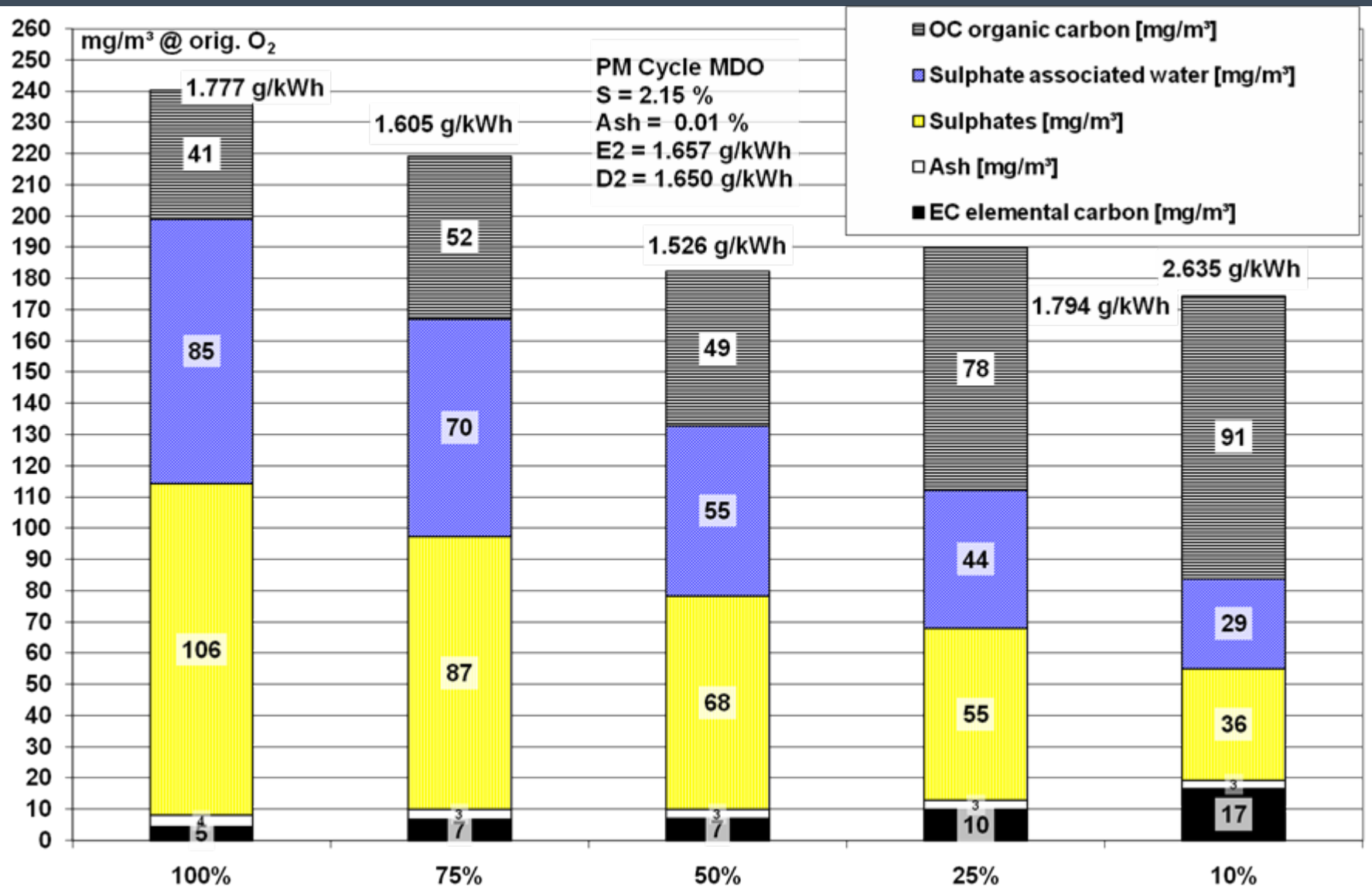
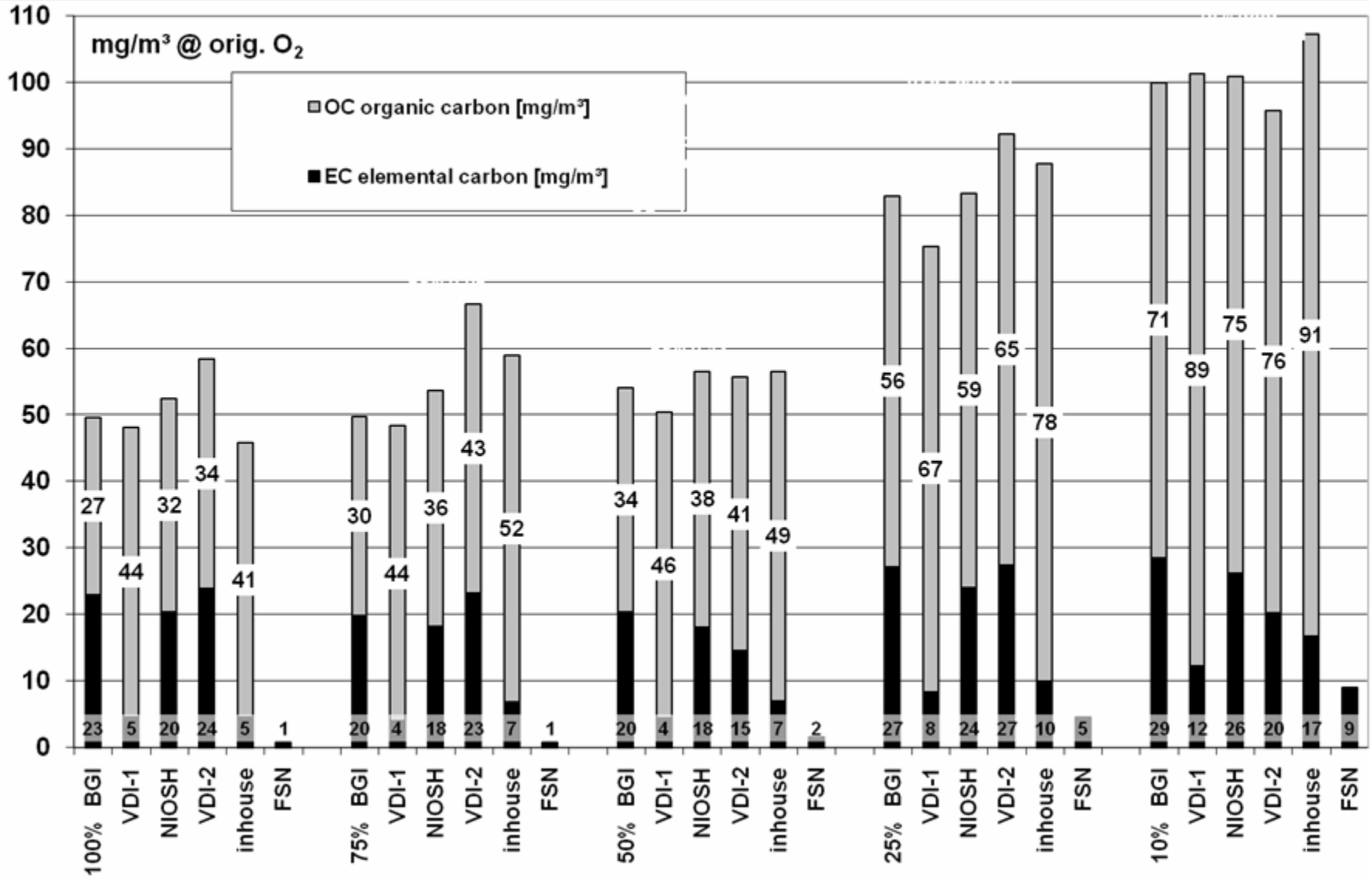
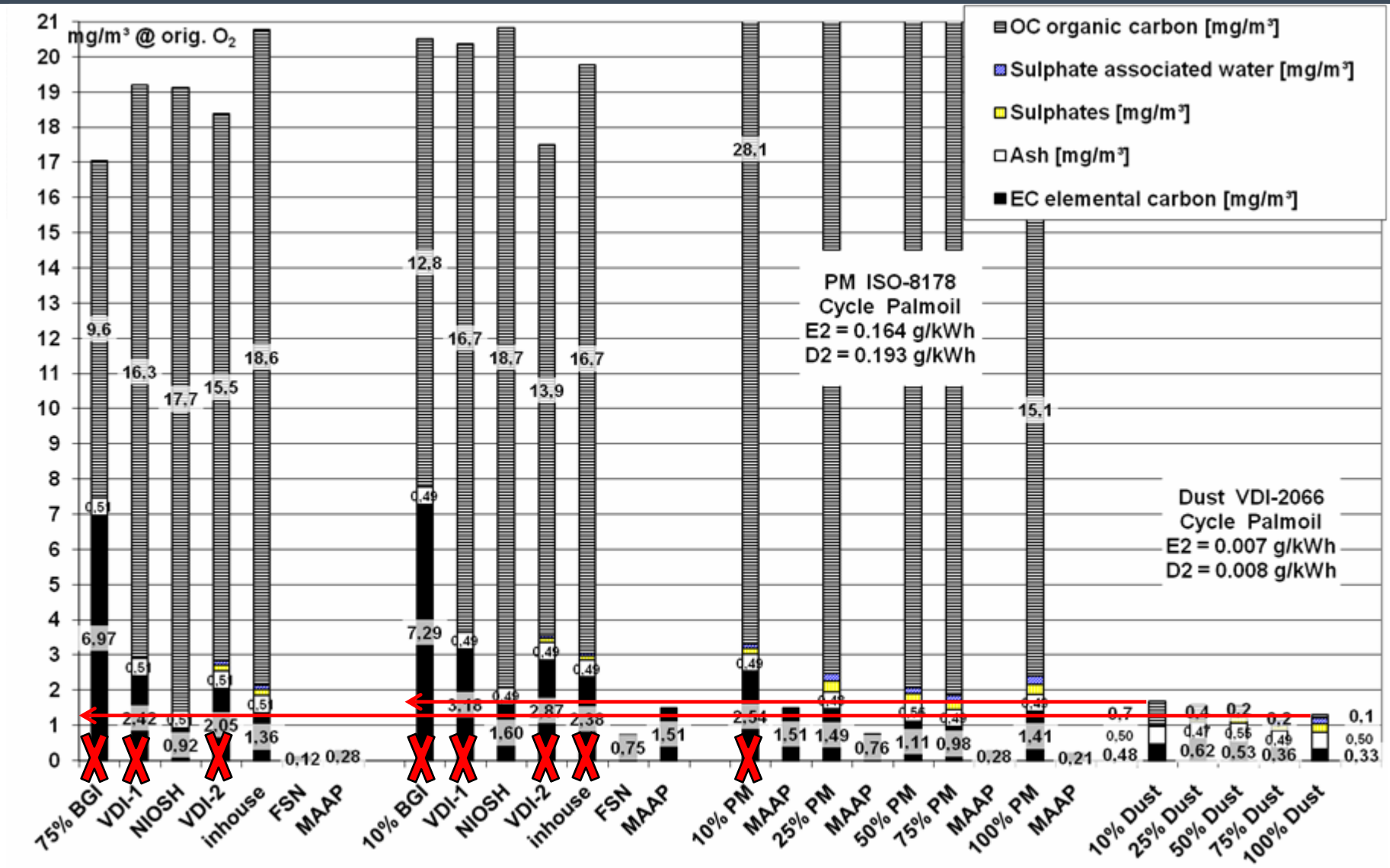
PM emission and composition
8L40/54 test engine, MDO-operation



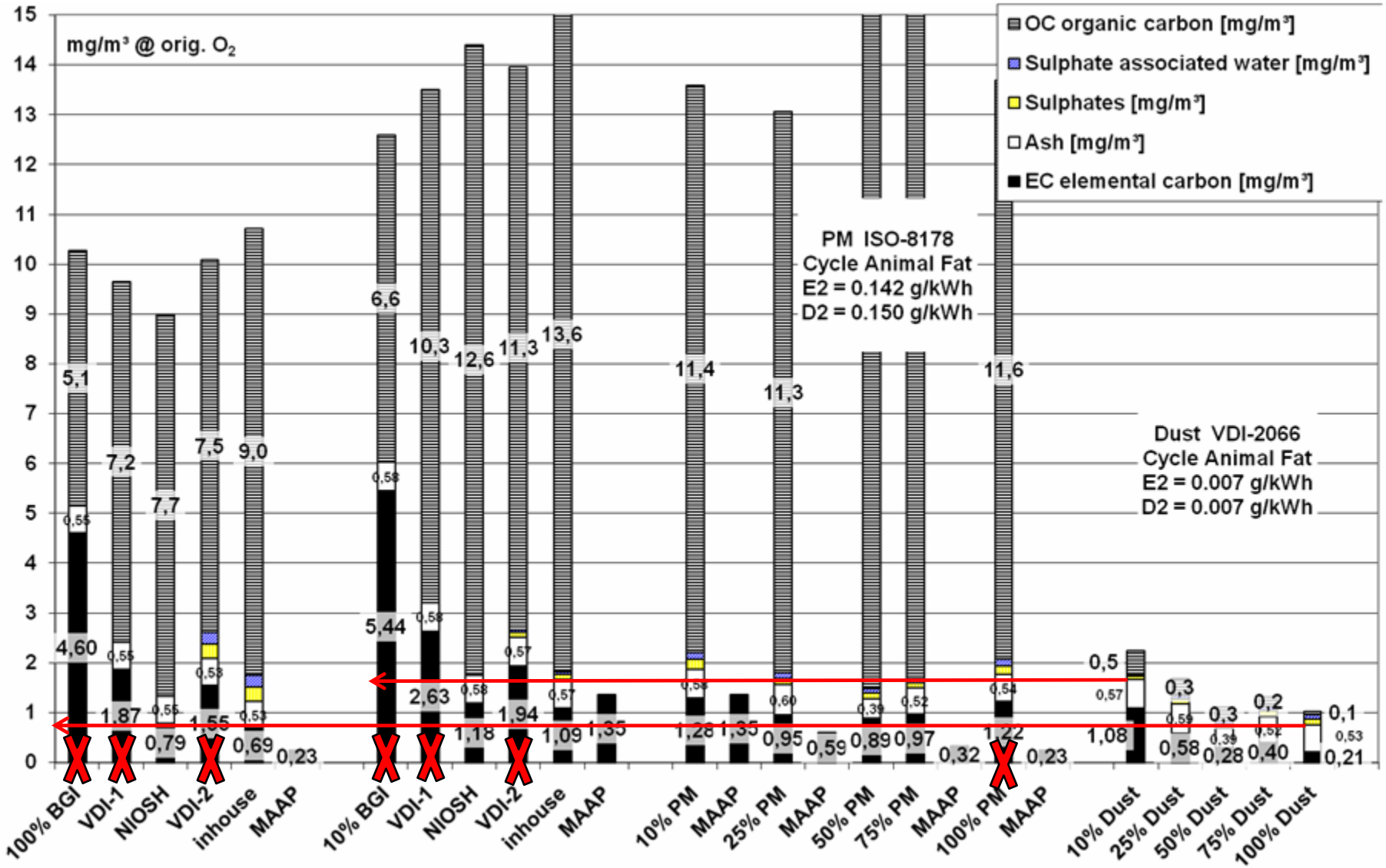
EC & OC analytical comparison
8L40/54 test engine, MDO-operation



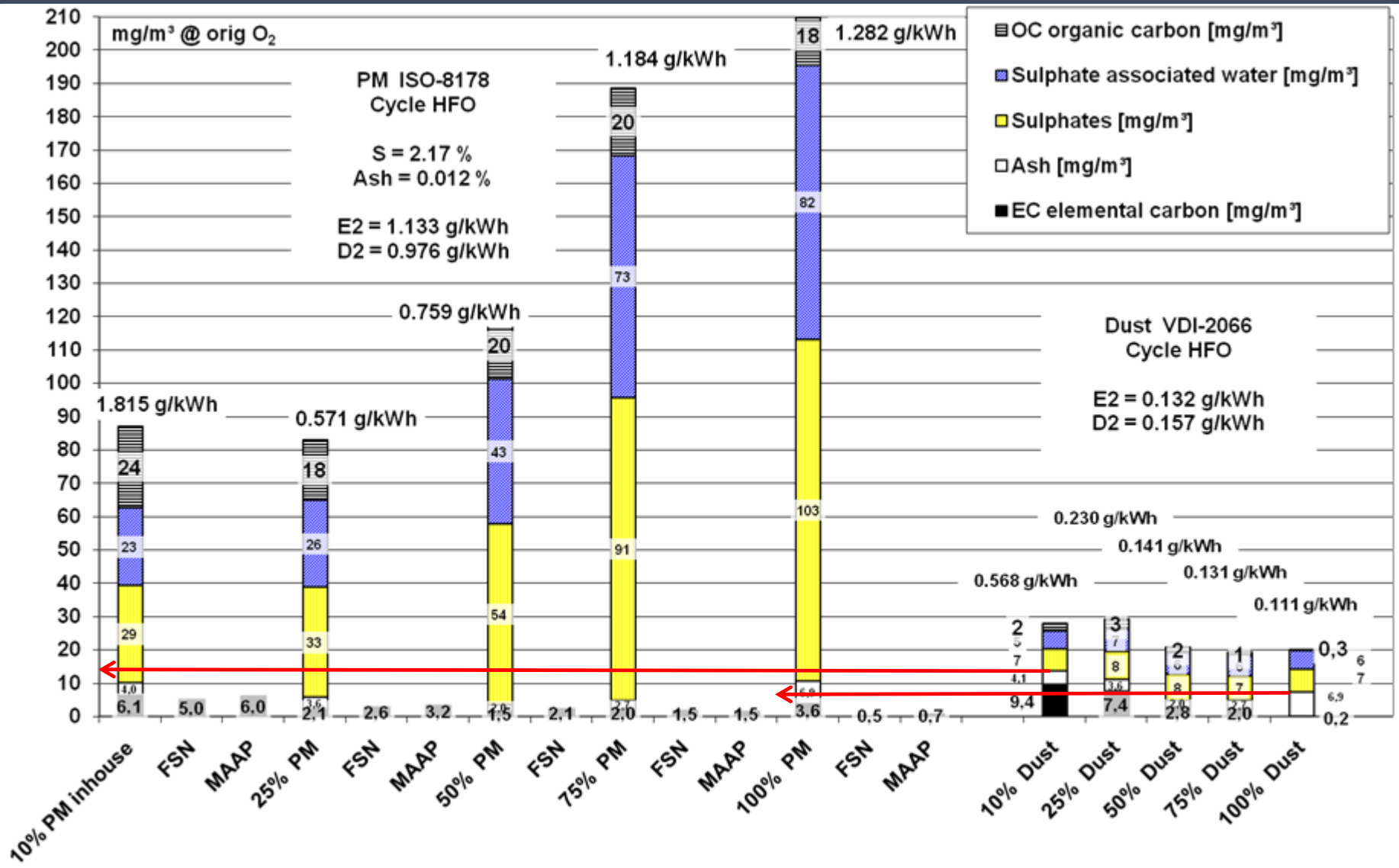
PM EC & OC analytical vs. Dust 1L32/44 test engine, Palm-Oil



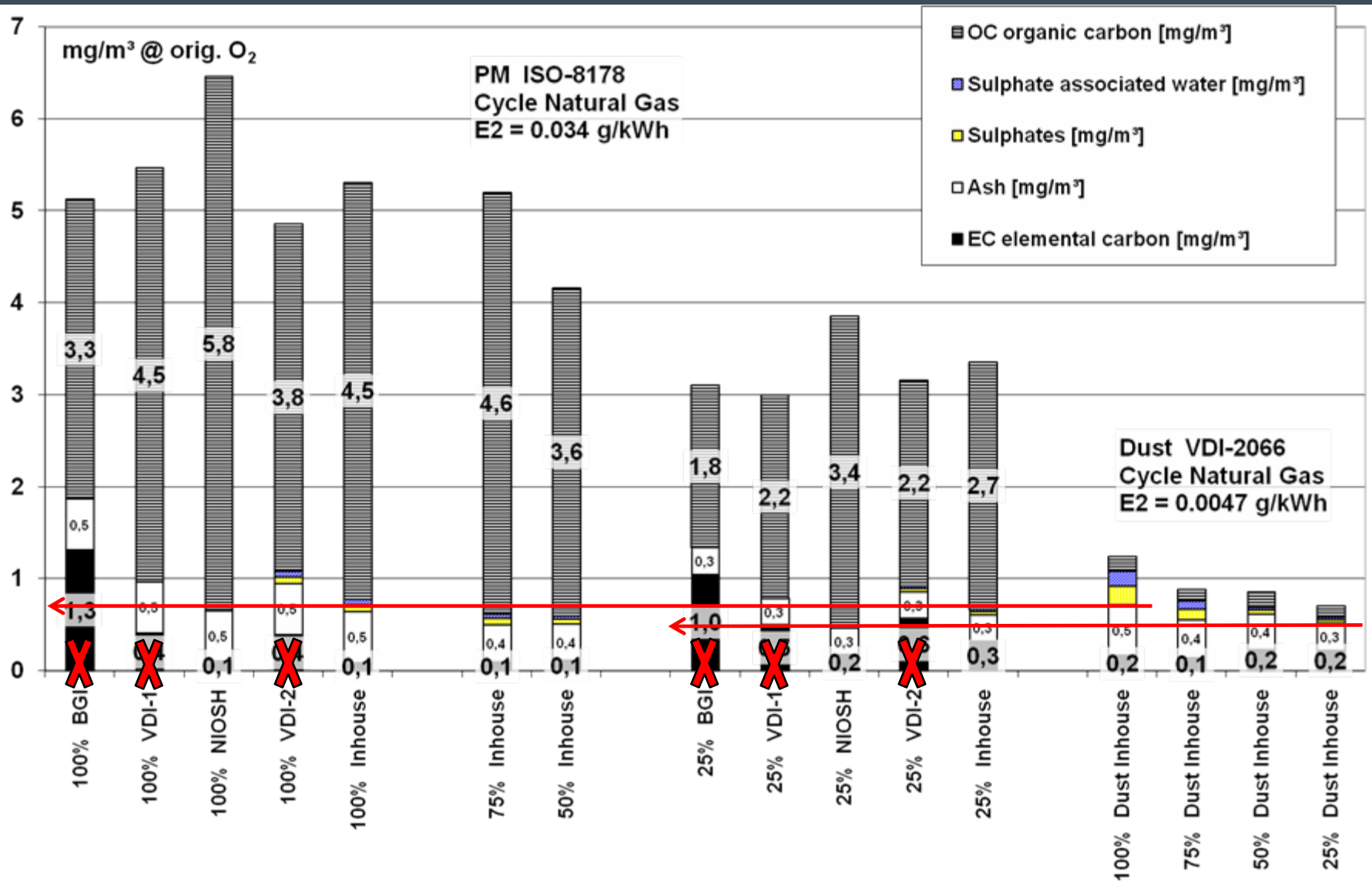
PM EC & OC analytical vs. Dust 1L32/44 test engine, Animal-Fat



PM vs. Dust
1L32/44 test engine, HFO



PM EC & OC analytical vs. Dust 32/40PGI test engine, Natural Gas



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Conclusions
Part I

- **The investigated analytical methods differ for determination on total carbon TC within a deviation of approx. 25%**

- **But the investigated analytical methods differ significantly for determination on OC up to 200% and EC up to 600%**

- **FSN and MAAP values indicate even lower EC values**

- **The following order can be given for the detection on EC**

  MDO: BGI = VDI-2 = NIOSH >> VDI-1 = In-house >> FSN
  Palm: BGI >> VDI-1 = VDI-2 > In-house > NIOSH > MAAP > FSN
  Fat: BGI >> VDI-1 > VDI-2 > In-house = NIOSH >= MAAP
  HFO: In-house >= MAAP >= FSN
  Gas: BGI > VDI-1 = VDI-2 > In-house = NIOSH

- **Dust measurement results exclude certain EC analytical values, e.g. by BGI, VDI-1 and VDI-2 methods**

Conclusions
Part II

- **Dust measurement detects a significant fraction of volatile components like sulfates, sulfate bound water and OC, contrary to its definition**
- **Dependent on the fuel, NIOSH, in-house, MAAP and FSN methods may probably provide the more realistic EC values**
- **In general liquid renewable fuels show a lower EC emission value compared to liquid fossil fuels due to a more complete combustion by the oxygen content of the renewable fuel**
- **PM emission from gas engine is supposed to originate from lube oil**
- **PM from large four-stroke medium speed Diesel engines consists mainly of volatile material like sulfates & water and OC**

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- **Acknowledgements**

Acknowledgements

- This investigation was partly supported by the BMBF Project “BioClean”, Reducing emissions of climate-active gases and particulates from large Diesel engines for ship propulsion systems and stationary power supply by the application of fuels from renewable sources
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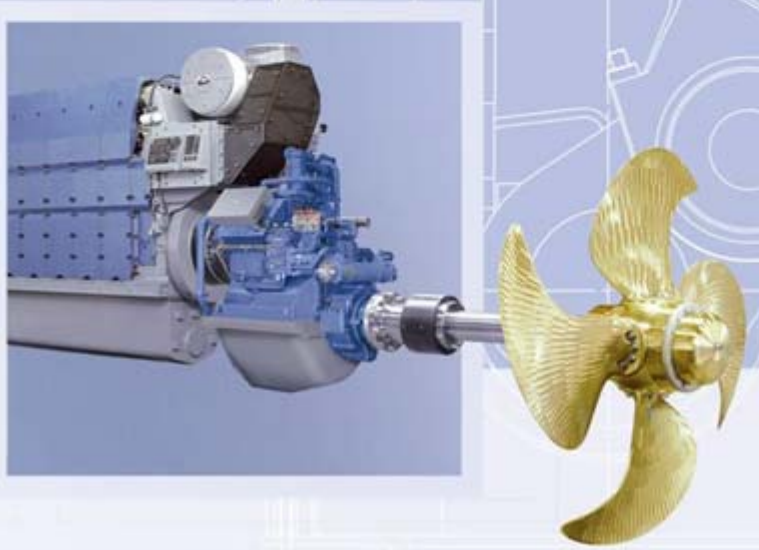
Thank you for your attention !




MAN