Marine BC measurements: Two large engine test facility campaigns

Presented by: Greg Smallwood[1]

Researchers: Kevin Thomson[1], Jens Peter Hansen[2], Jannik Pedersen[3], Flemming Bak[3], Stephanie Gagne[1]

[1] National Research Council Canada

[2] Alfa Laval Aalborg

[3] MAN Diesel and Turbo

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Research Motivations

- International Maritime Organization (IMO) has become interested in assessing the impact on climate forcing in the Arctic of Black Carbon (BC) emissions due to shipping
- Members to perform measurement campaigns involving measurements with different instrument and sampling methods, marine engines, engine conditions and marine fuels

http://www.asianews.it/news-en/Beijing-launches-Arctic-route-to-unite-the-Pacific-and-Atlantic-37271.html

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U.N. Arctic Monitoring and Assessment Programme

Research Objectives

- Evaluate the comparability of different BC measurement instruments and methods as a function of engine type and fuel type
  - Engine types:
    - large 2-stroke marine engine
    - large 4-stroke marine engine
  - Fuel types:
    - Marine Diesel Oil (MDO)
    - Heavy Fuel Oil (HFO)

MAN Diesel & Turbo research centre in Copenhagen

Test engine specification – 4T50ME-X	
Engine type	Diesel, two-stroke
Manufacture	MAN Diesel & Turbo
No, of cylinders	4
Bore	500 mm
Stroke	2200 mm
Power (MCR)	7080 kW
Max speed	123 rpm

Alfa Laval research centre in Aalborg

Test engine specification - 9L28/32H	
Engine type	Diesel, four-stroke
Manufacture	MAN Diesel & Turbo
No, of cylinders	9
Bore	280 mm
Stroke	320 mm
Power (MCR)	1980 kW
Max speed	750 rpm

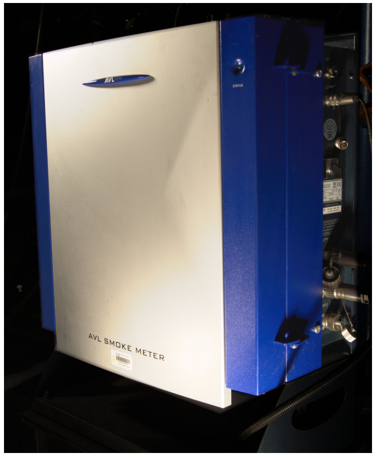
- test installation for research and development of emissions control systems
  - SCR, boiler and SOx scrubber
  - non-optimized for absolute emissions performance
  - configuration produces a high backpressure
  - results in atypical emissions levels for this engine

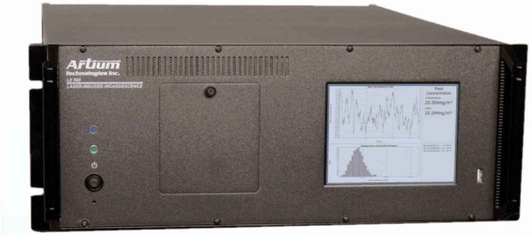
Test Matrix

- Two-stroke engine
  - MDO at 25% and 75% load (214 ppm Sulphur, 50 ppm ash)
  - HFO at 75% load (2.2% Sulphur, 200 ppm ash)
- Four-stroke engine
  - MDO at 37% and 60% load (60 ppm Sulphur, 10 ppm ash)
  - HFO at 37% and 60% load (1.9% Sulphur, 410 ppm ash)

Instrumentation

- Two-stroke engine
  - AVL 415S Smoke Meter
  - Dilution tunnel (ISO 8178) (12:1 to 25:1 dil.)
    - DMT PAX870 Photoacoustic Spectrocopy
    - Sunset Labs Thermal Optical Analysis
    - Gravimetric Filters
    - Electrostatic Precipitator onto TEM grids
  - In-stack (EN 13284-1 Dust)
    - TOA and gravimetric filters
- Four-stroke engine
  - Dilution tunnel (7:1 to 17:1 dil.)
    - DMT PAX870 Photoacoustic Spectrocopy
    - Sunset Labs Thermal Optical Analysis
    - Gravimetric Filters
    - Electrostatic Precipitator onto TEM grids
    - Artium LII300 Laser Induced Incandescence

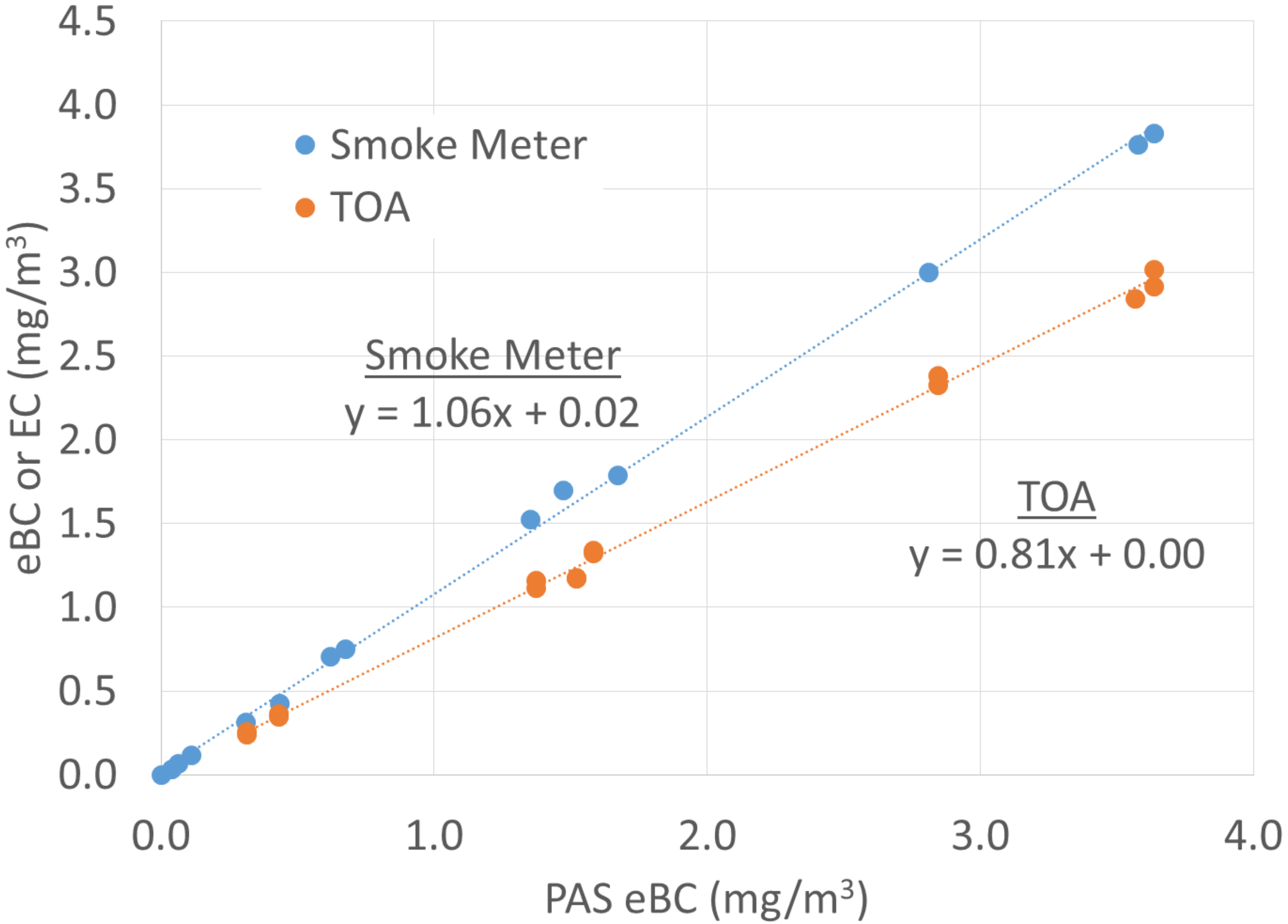




Baseline Instrument Comparison

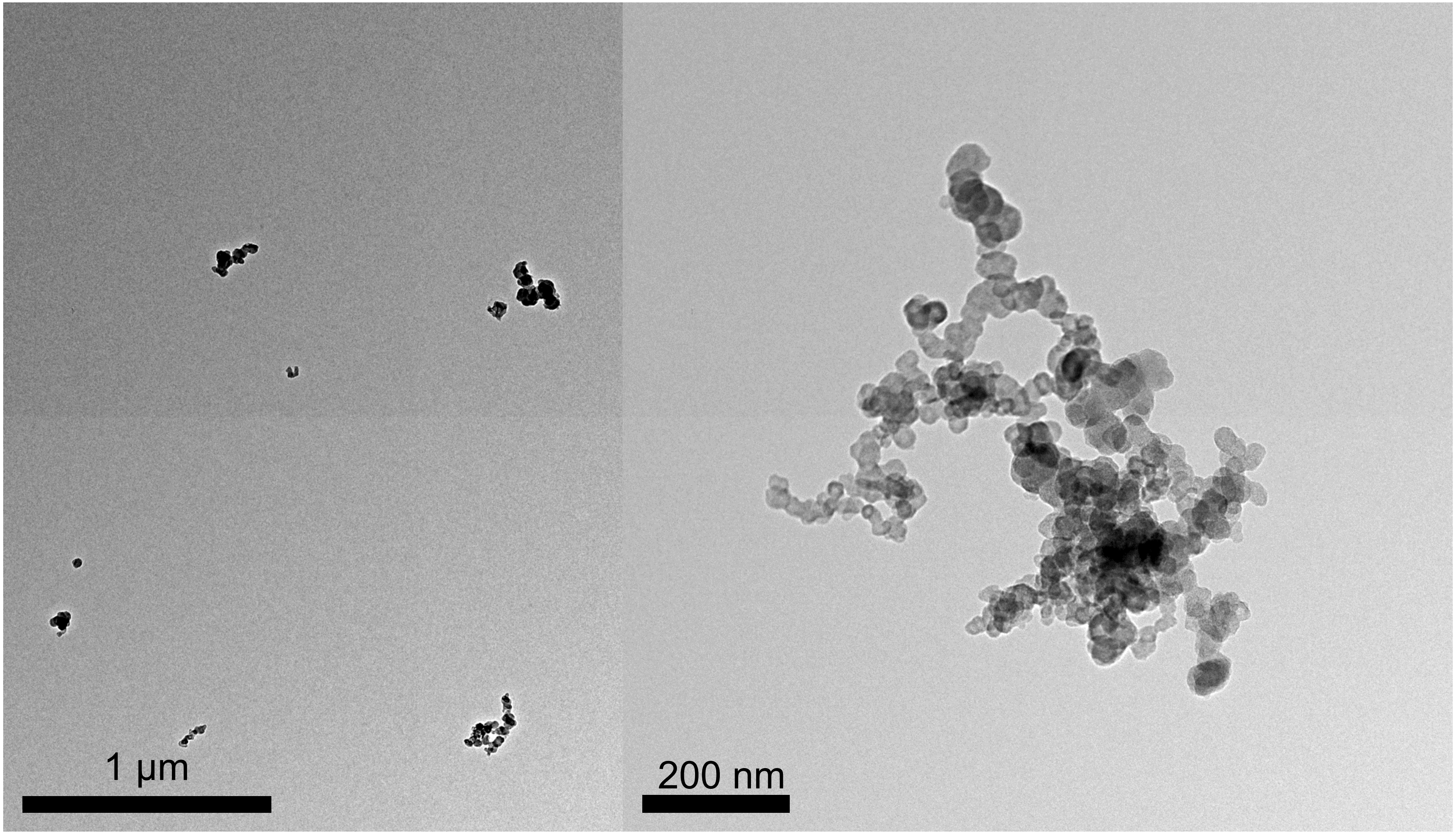
- Instruments calibrated using different methods and different calibration aerosols
- Baseline comparison made to understand the agreement (or disagreement) of instruments
- 5201c miniCAST burner operating as Set Point 1 used as source for instrument comparison
- Dilution using Dekati injection dilutor and mixing with HEPA filtered air
- Common sampling tunnel

Baseline Instrument Comparison

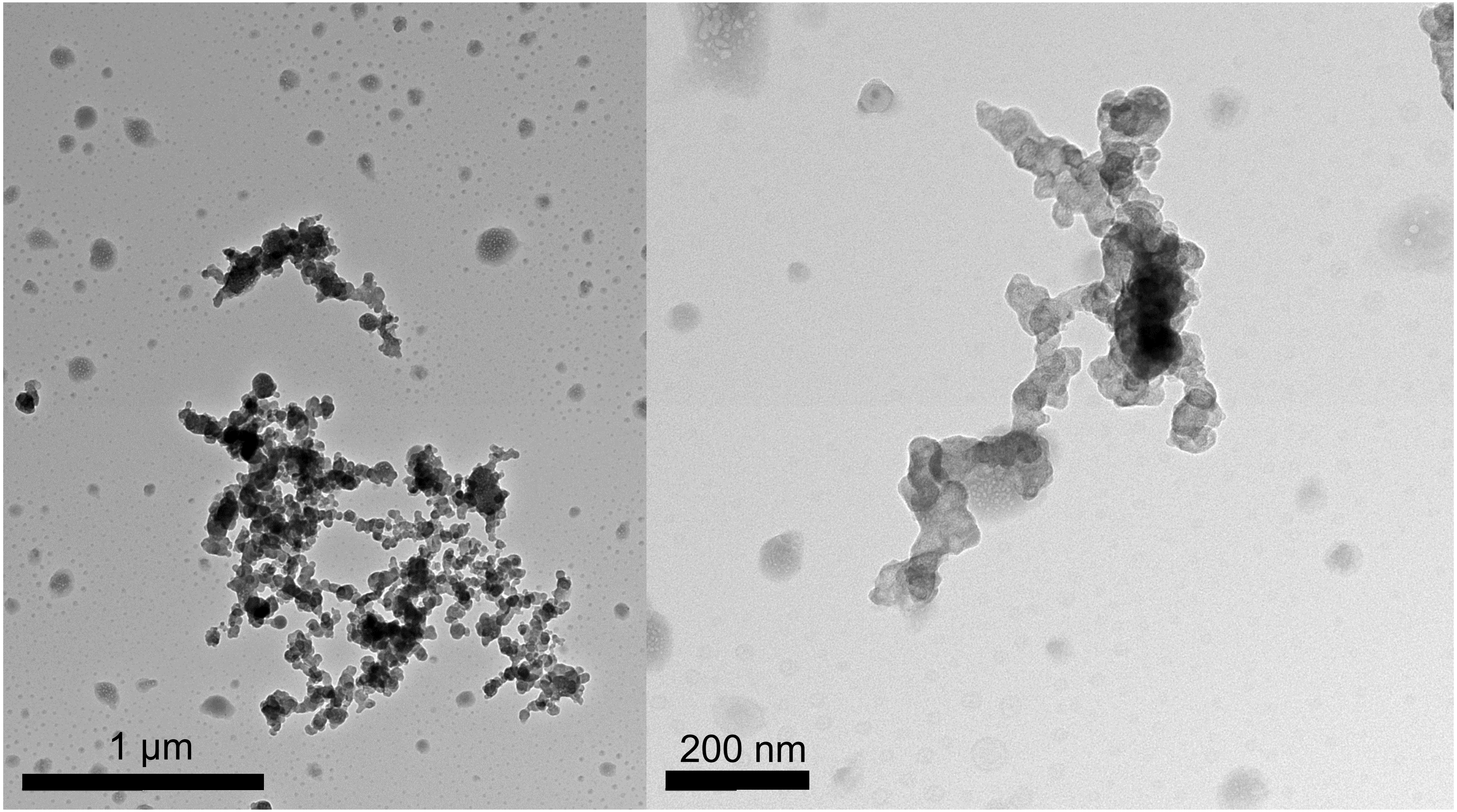


NRC·CNRC

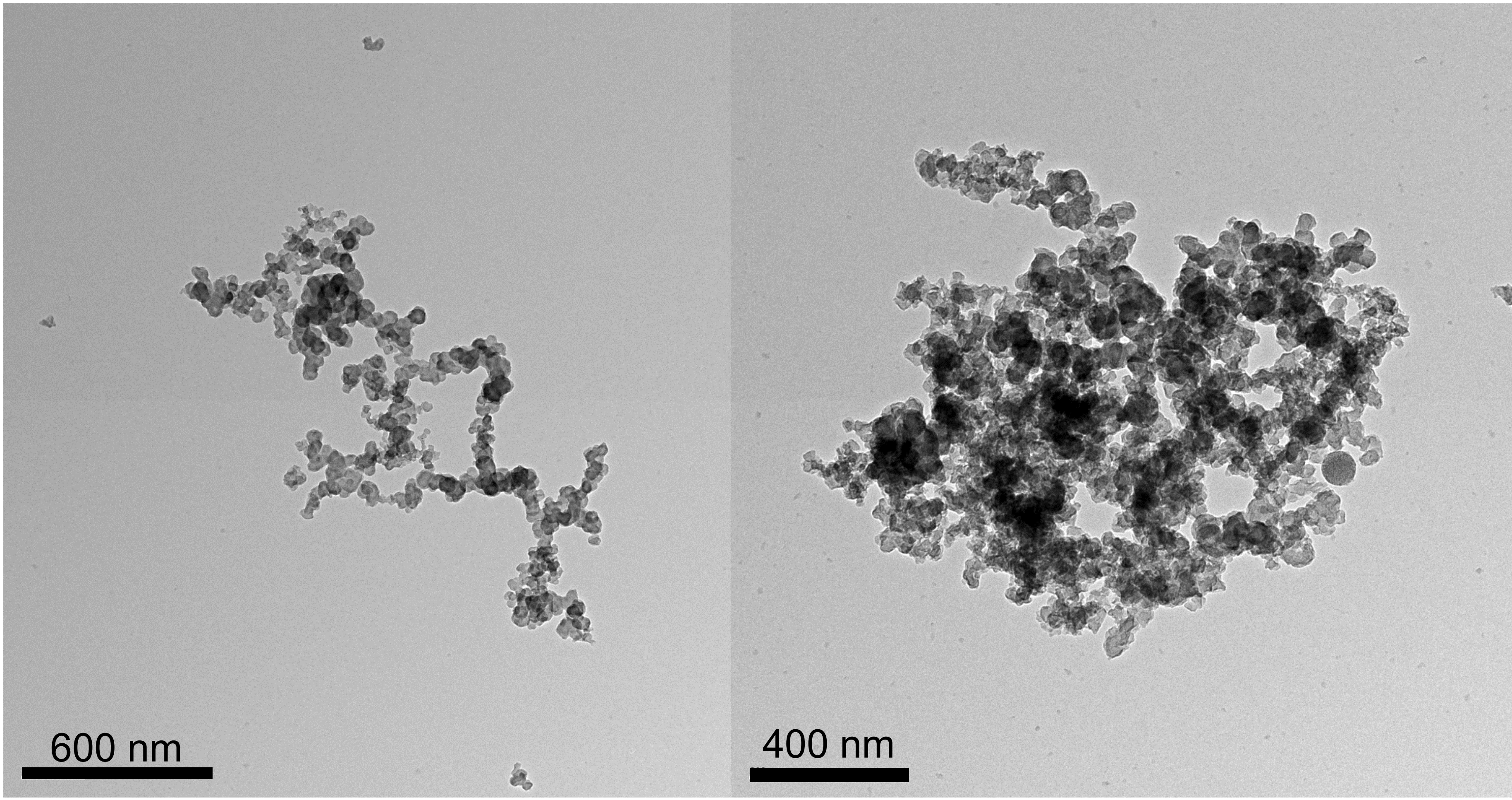
TEM Samples – 4-Stroke Engine - MDO



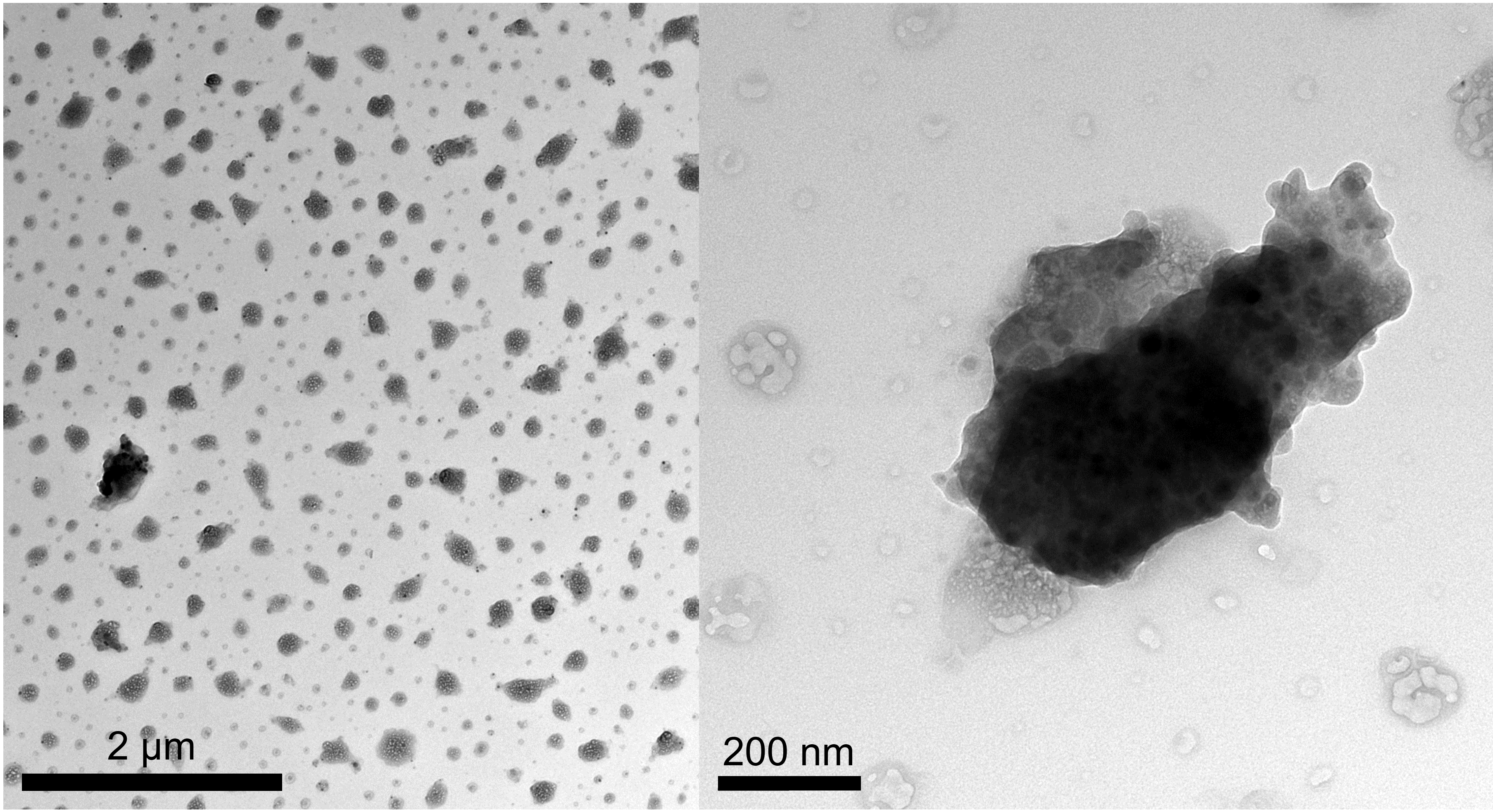
TEM Samples – 4-Stroke Engine - HFO



TEM Samples – 2-Stroke Engine - MDO



TEM Samples – 2-Stroke Engine - HFO



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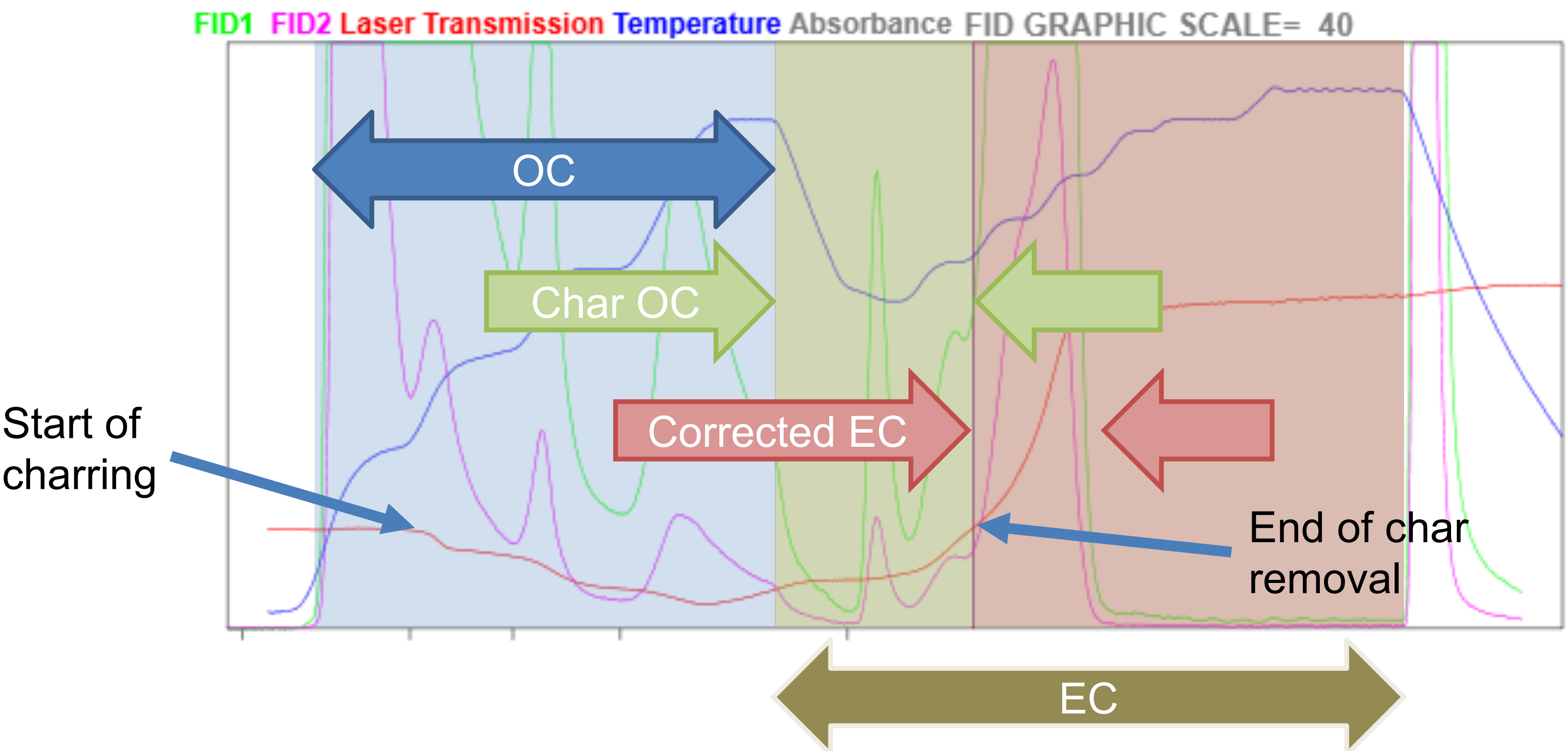
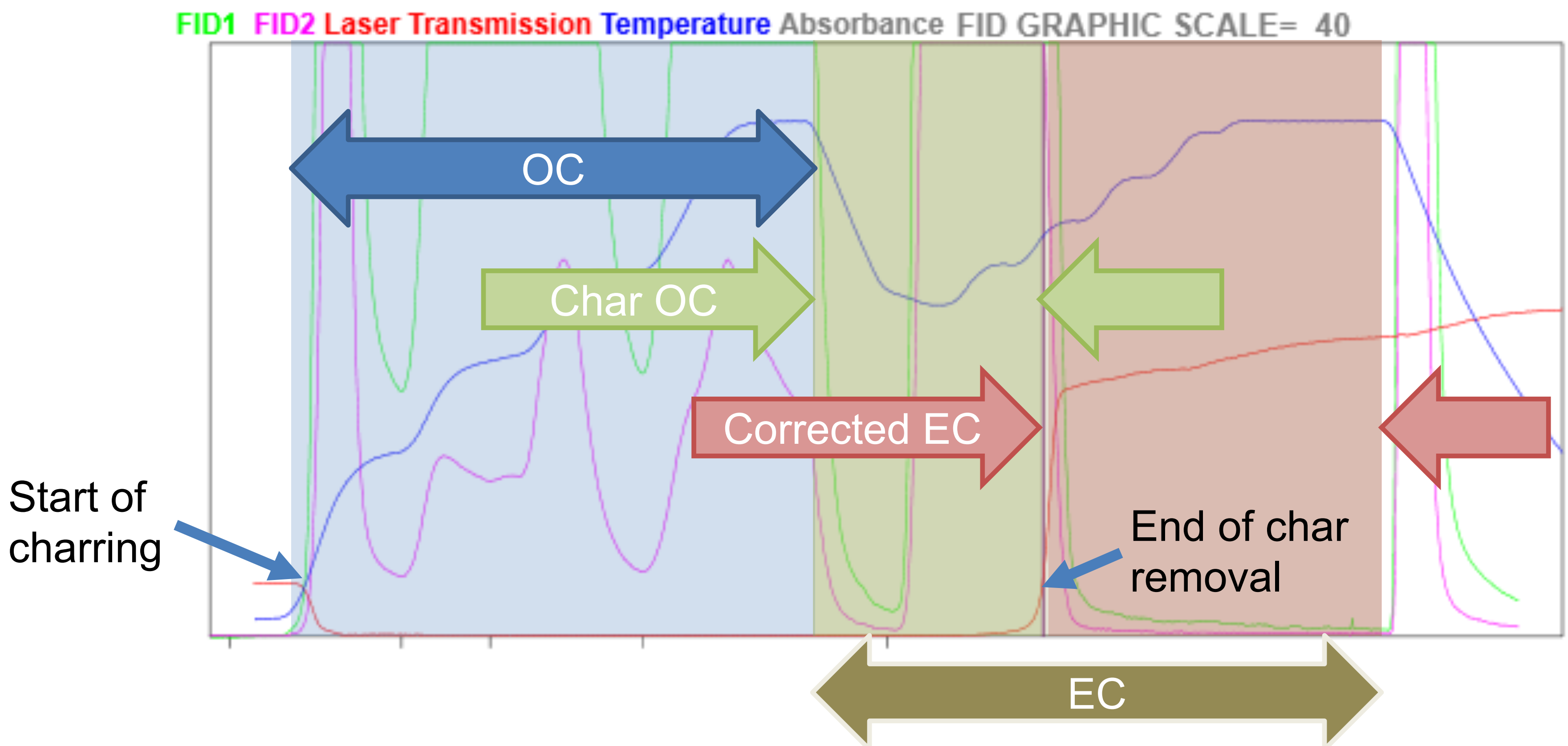
Thermal Optical Analysis Thermograms

- 2-stroke MDO, 75% load



Thermal Optical Analysis Thermograms

- 2-stroke HFO, 75% load



TOA Carbon Make-up

4-Stroke Engine

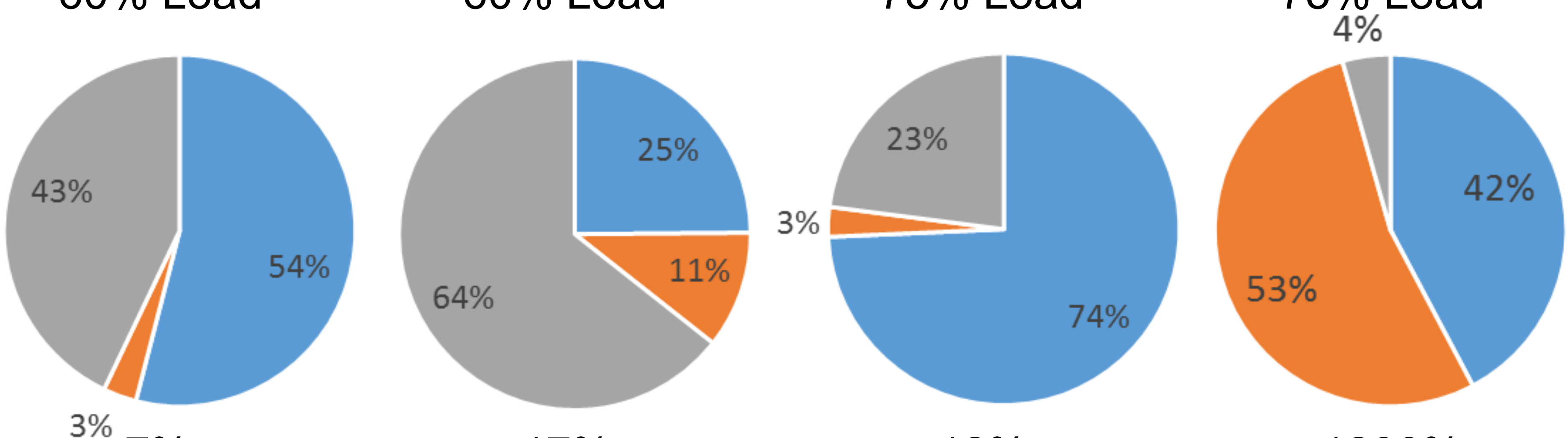
2-Stroke Engine

MDO
60% Load

HFO
60% Load

MDO
75% Load

HFO
75% Load



7%
EC correction

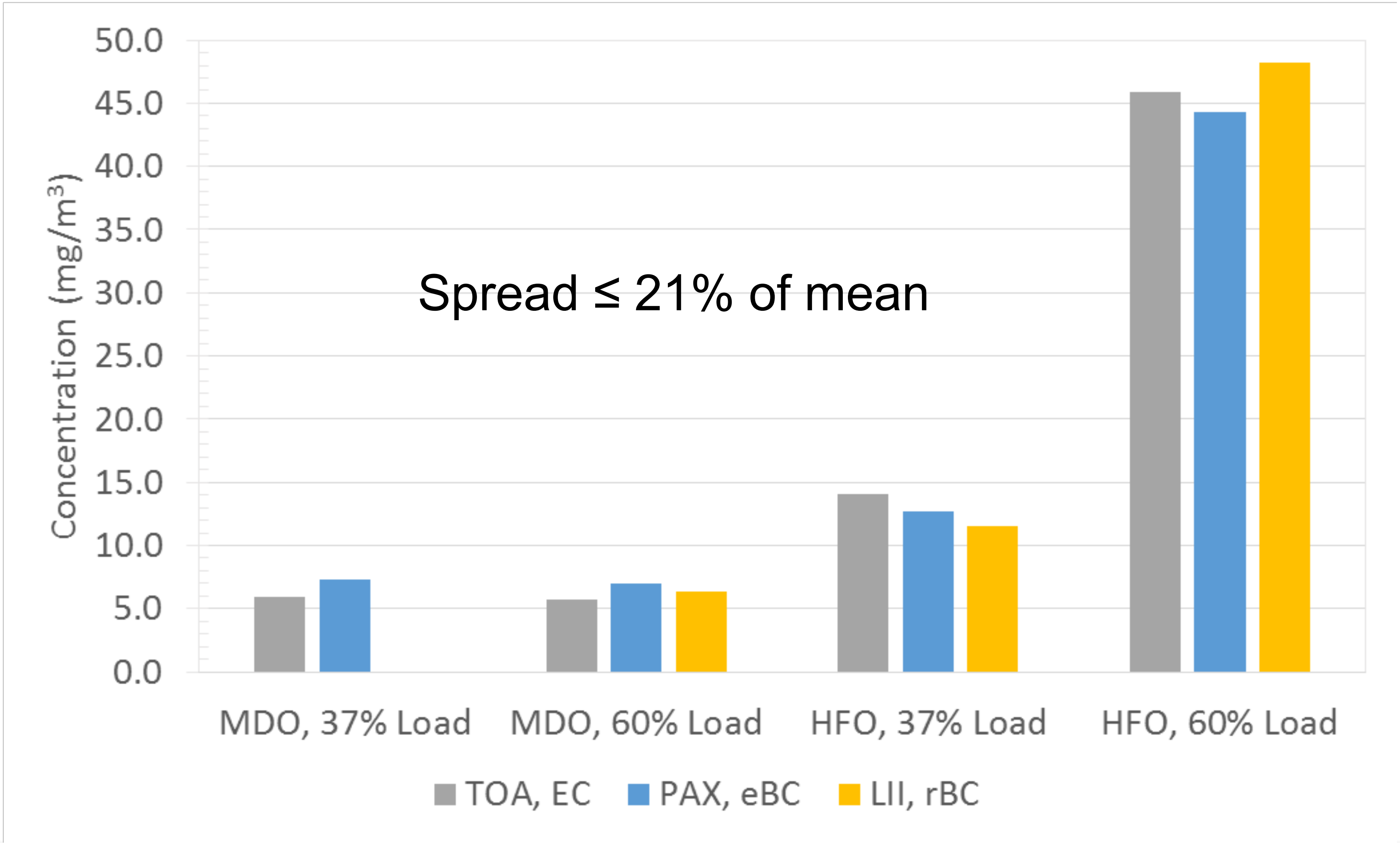
17%
EC correction

12%
EC correction

1200%
EC correction

■ Base OC ■ Char OC ■ Corrected EC

BC Results – 4 Stroke Engine



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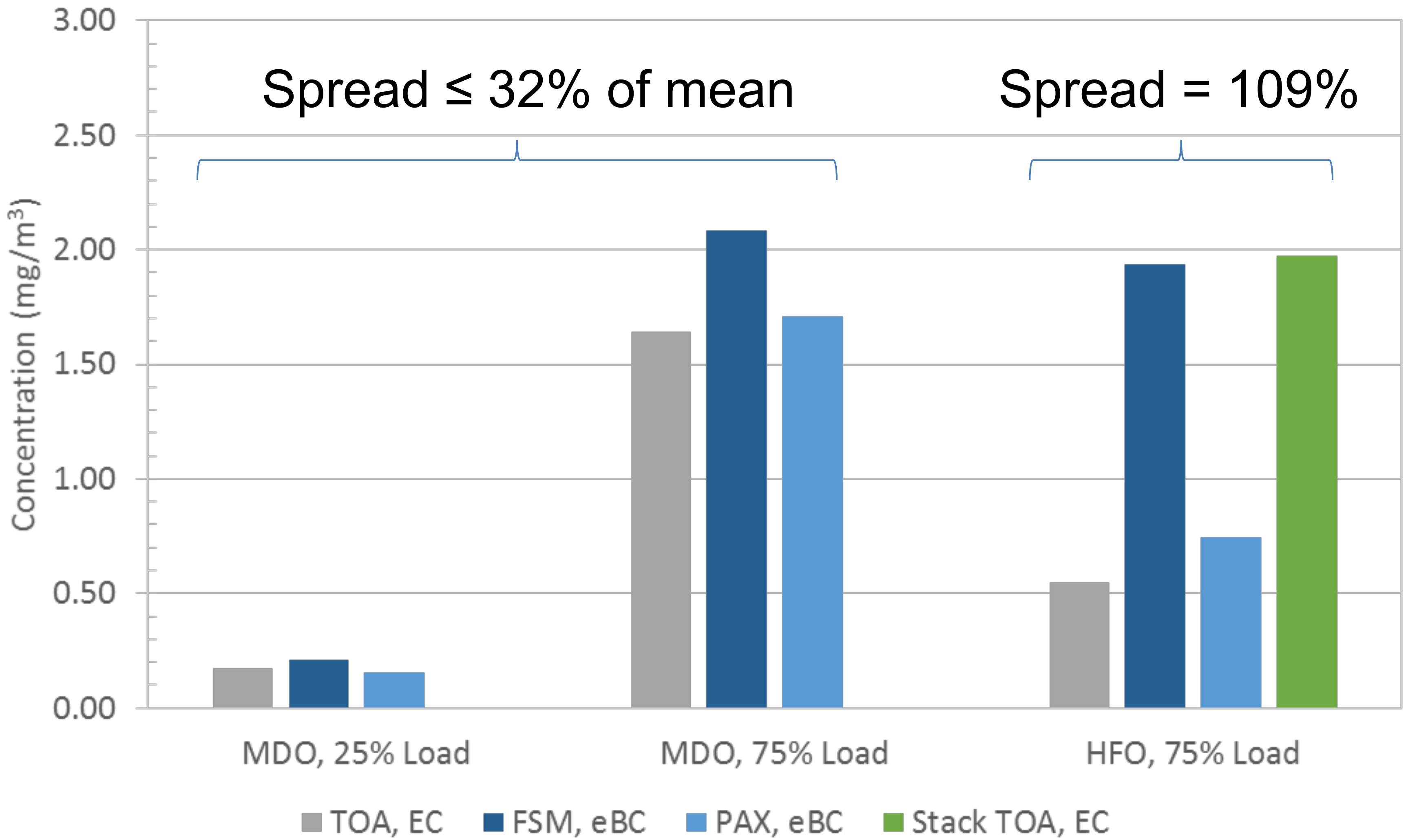
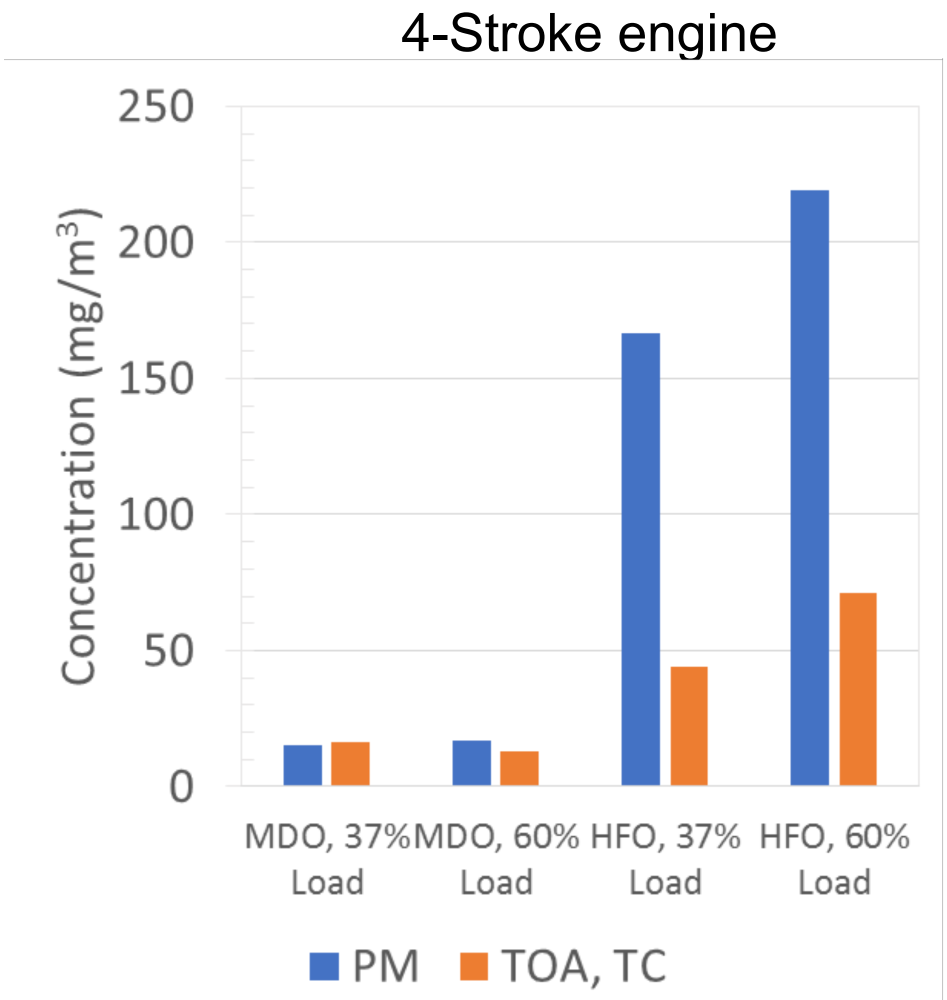
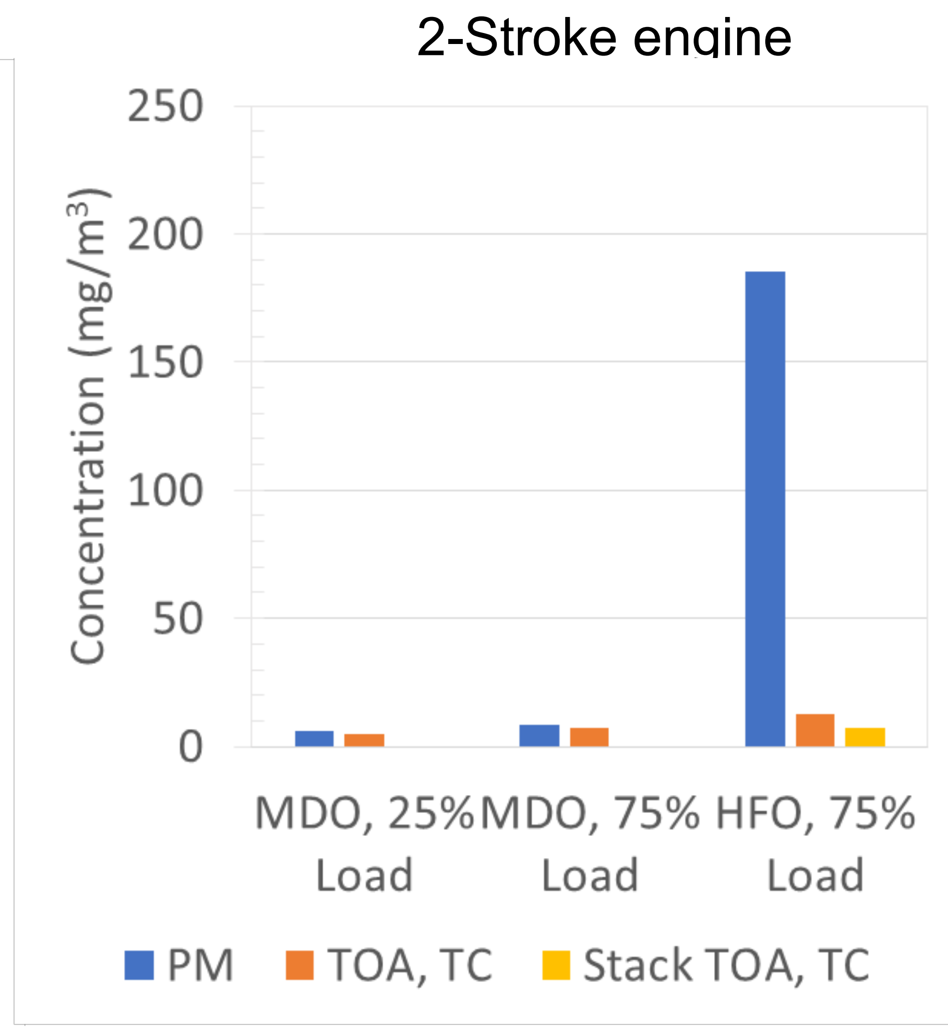
BC Results, 2 Stroke Engine



Total PM & Total Carbon





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Discussion and Conclusions

- Measurement of BC relatively consistent across different measurement technologies except for 2-Stroke/HFO
  - Spread of measurement 109% of mean for 2-Stroke/HFO
    - Non-EC particles dominate 2-stroke/HFO emissions
    - Charring may impact TOA EC accuracy
    - Coatings may impact optical eBC accuracy
  - Spread of measurements < 32% of mean for other conditions
    - Charring does not appear to impact agreement of 4-Stroke/HFO measurements
- Significant differences in PM are observed between 2-stroke and 4-stroke engine emissions and for MDO and HFO
  - Significant presence of liquid particles that char easily with HFO
  - BC/EC lower proportion of particulate with 2-stroke engine

Discussion and Conclusions

- Carbon particles dominates PM emission for MDO
- Significant reduction of PM for fuel switching
  - 4-Stroke engine - 13 times reduction at 60% Load
  - 2-Stroke engine – 21 times reduction at 75% Load
- Switching from HFO to MDO reduces BC emissions for non-optimized 4-stroke engine
  - 7 times reduction at 60% Load
- Switching from HFO to MDO has no apparent reduction in BC on 2-stroke engine
  - Same or increased BC emission

Discussion and Conclusions

- Issues with measurements
  - repeatability of limited number of experiments does not represent full uncertainty of measurement
  - sampling system not optimized or standardized
    - most measurements with dilution tunnel but not all
    - great variations in PM depending on the dilution ratio
  - TOA analysis becomes very uncertain
    - due to charring, and
    - due to extremely low EC content

Next steps

- PM, BC and eBC emissions are dependent on many factors:
  - Engine type and operating conditions including combustion pressure and temperature, nozzle SAC volume, engine load, ambient conditions
  - Fuel type, fuel composition, lube oil type, lube BN number, lubrication system
  - Possible use of emissions control system (scrubber)
    - variables include seawater scrubbing, fresh water scrubbing, salt concentration of scrubber water, temperature of scrubber water, demister type, gas-water contact in scrubber, water spraying pattern…
  - Possible use of EGR and all its variables…
  - Possible use of SCR and all its variables…
- Cooperation between engine suppliers, instrument suppliers, emissions control system suppliers, laboratories, universities and authorities is required to solve this huge challenge
  - our cooperation was dependent on support from the Danish and Canadian government, and is a good example of the path forward
- More research is needed!

Thank you

Project Sponsors:

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Transport Canada – Clean Transportation Initiative

Blue INNOship

Transports Canada Transport Canada

Kevin Thomson
kevin.thomson@nrc-cnrc.gc.ca

Jens Peter Hansen
jens.peterhansen@alfalaval.com

Flemming Bak
flemming.bak@man.eu

Greg Smallwood
greg.smallwood@nrc-cnrc.gc.ca