Assessment of an On-Board FT-IR Gas Measurement Systems for Future Heavy-Duty Regulations

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OFS
PEMS
PRESENTATION

COMPANY	IAG nG
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Presentation outline

Topics

RDE test in October 2019: Tested in Austria up to 1550 meters above sea level.

The OFS is the first onboard FTIR system that is as light and compact as other OBD systems and therefore can be mounted on hitches/tow balls or inside the test vehicle.

Who is IAG-ng?

01 Founded 2000 as part of IAG, own company since 2019

02 Located in Austria, 60km south of Vienna

03 35 Employees and Growing

04 Mainly FT-IR and TDLS (NH_3 & H_2O) focused

05 First FT-IR Bench introduced 2003

06 Over 200 FT-IR Benches Worldwide

07 First NH_3 Analyzer introduced in 2017

08 over 100 NH_3 Analyzers Worldwide

09 Strong focus on R&D: H_2 Mass Spec Bench

OFS: Technical details

General technical information

01	Dimension 23.6”x19.7”x15.7”
02	Weight 110 lbs.
03	System pressure 800 mbar
04	3-12 l/min regulated flow
05	Swagelok quick connect for span & zero gas
06	Maximal inlet pressure 6 bar
07	Up to 5m heated line Winkler quick connect
08	Power supply 115V AC
09	Power consumption 250W (without heated line)
10	Optional 160 Ah battery
11	-15°C to +40°C; up to 1800 above sea

Benefit: *Due to our new design and the given measurement physics of the FTIR principle, it is not necessary to carry any additional operation or calibration gases in the passenger compartment of the vehicle to be tested.*

FTIR: Technical details

General spectrometer information

01	Model 2030G
02	70 cm^3 stainless steel gas cell
03	5 Hz analysis frequency
04	5.11 m optical path length
05	Spectral range 500-6000 cm^{-1}
06	Detector 0.25 mm LN_2 cooled MCT
07	Gold plated mirrors with MgF_2 coating
08	Windows ZnSe
09	250 ml liquid nitrogen reservoir

Improvements Rev. G:

- *User replaceable HeNe Laser*
- *Temperature controllers integrated to boards.*
- *Improved air flow*
- *Updated power supply assembly*
- *IR source without fan cooling*

OFS System Layout

Gas-flow schematic

01 Gas Inlet

02 Heated Filter block

03 Filter

04 Pressure regulator (P. max 6 bar)

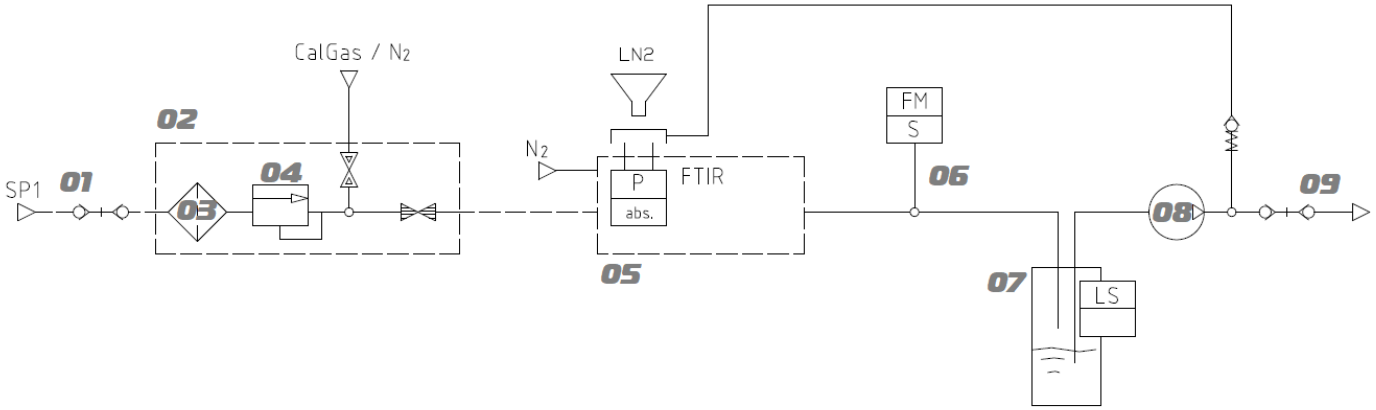
05 FTIR spectrometer

06 Flow measurement

07 Condensate trap

08 Pump

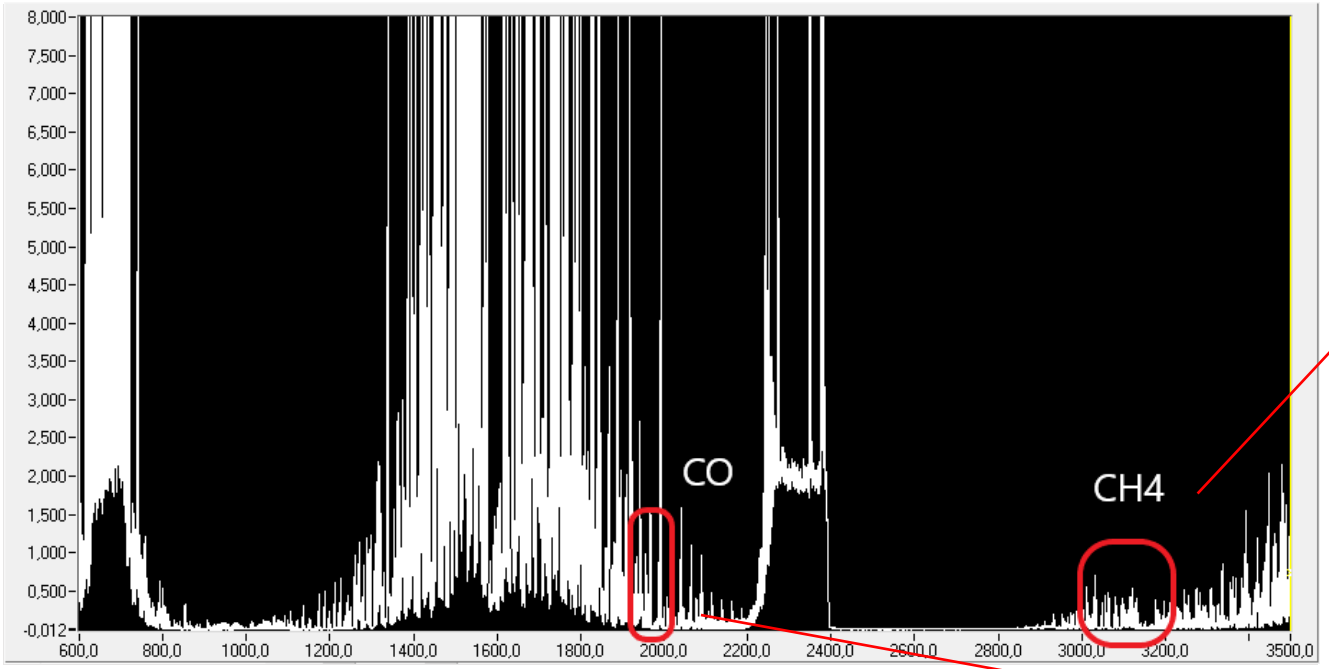
09 Exhaust



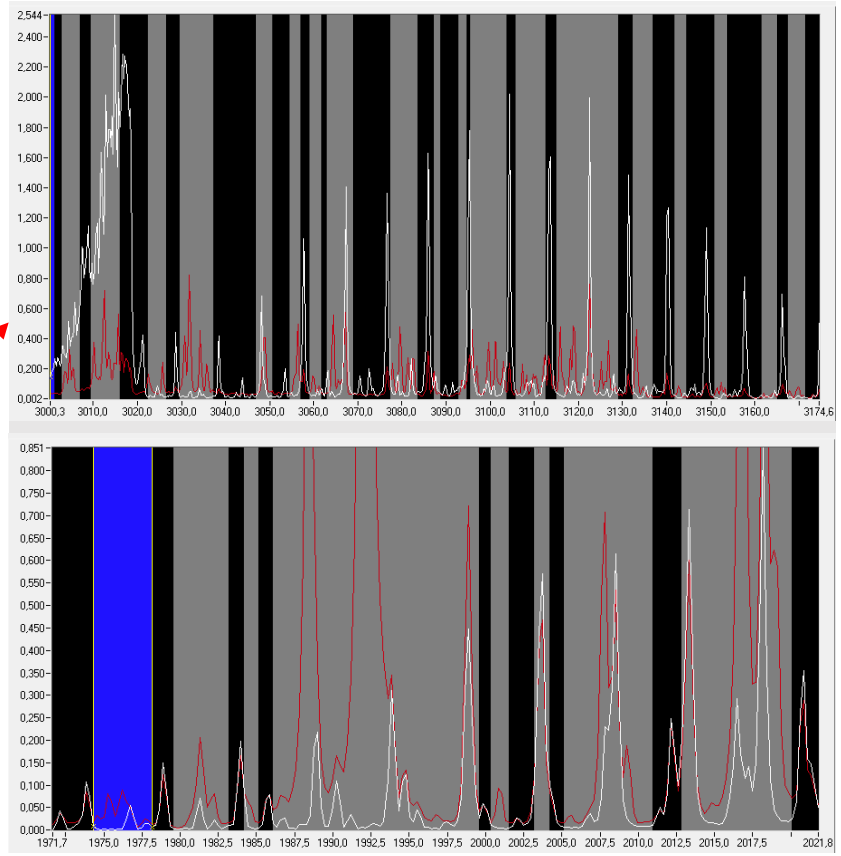
Sampling concept: *Based on vacuum extraction pump, allows sample flow extraction of 5 l/min at an altitude of 1800 m and 12 l/min at sea level.*

Dynamic*: The entire gas path of the OFS is 100 cm³. This leads to an NH3 t_{10-90} time of less than 2 sec. including a 2 m heated line. (Test was made in accordance with EPA1065)*

FTIR Line Shape Calibrations



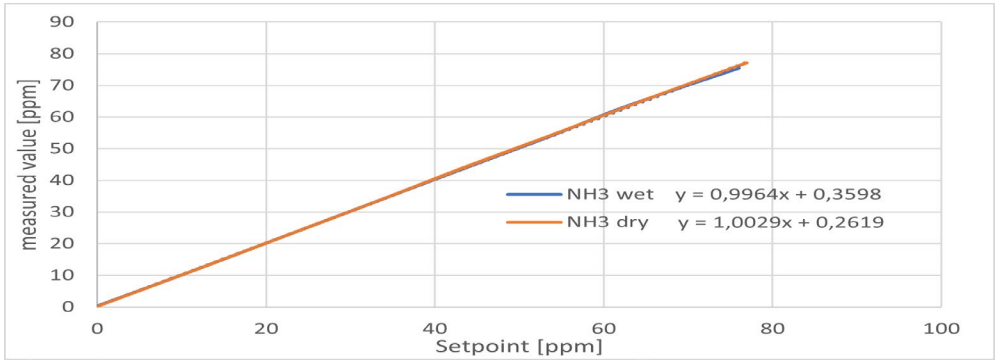
Lines relevant to the evaluation regions for the standard components: 3% CO, 9% CO_2, 550 ppm NO, 500 ppm NO_2, and 500 ppm CH_4

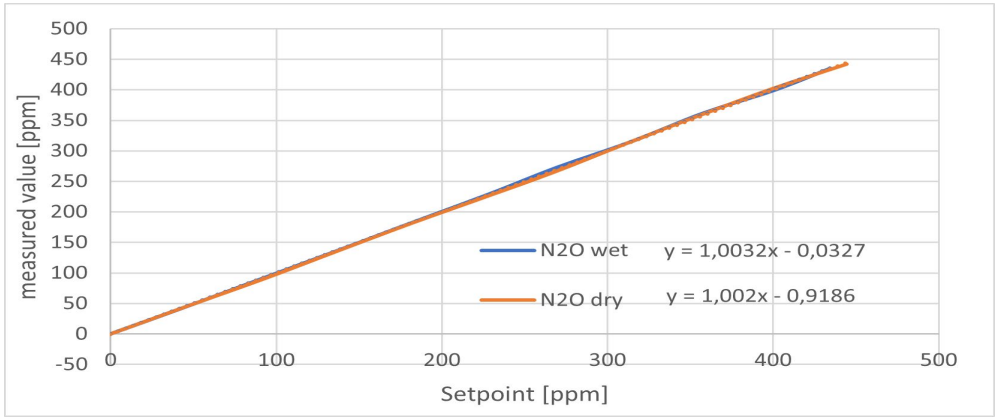


CH_4 (top) and CO (bottom) match well
Only black areas are used
White: Calibration Gas (CO or CH_4)
Red: spectrum of humidified mixed gas (left)

Accuracy: Wet & Dry

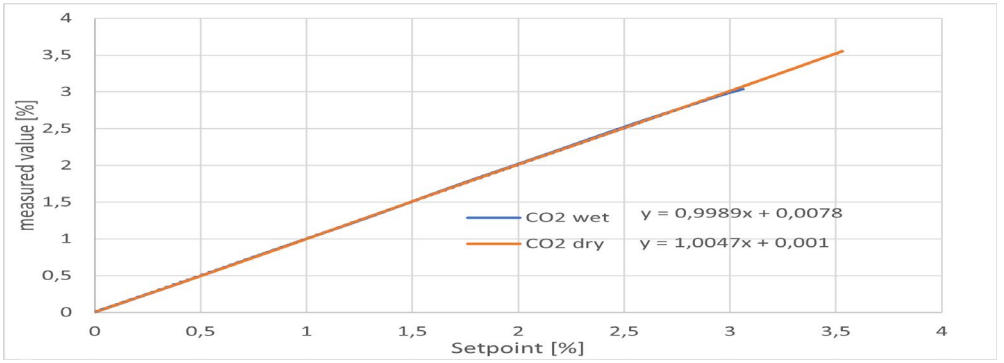
01 NH_3 & N_2O

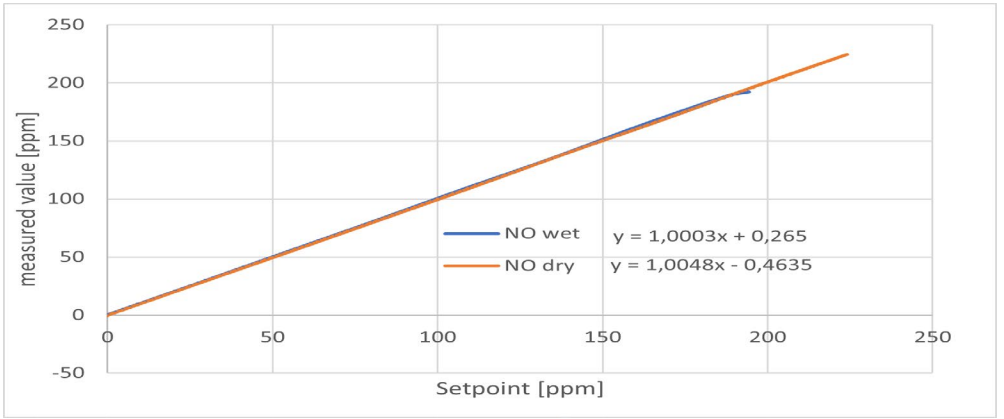




The accuracy is not influenced by 20% water, NO, CO_2, NH_3 and N_2O are shown as examples

02 CO_2 & NO





Calibration gas was humified by a HovaCal and a 2m heated line was used as a connection to the OFS.

01 Zero and dry reference gas

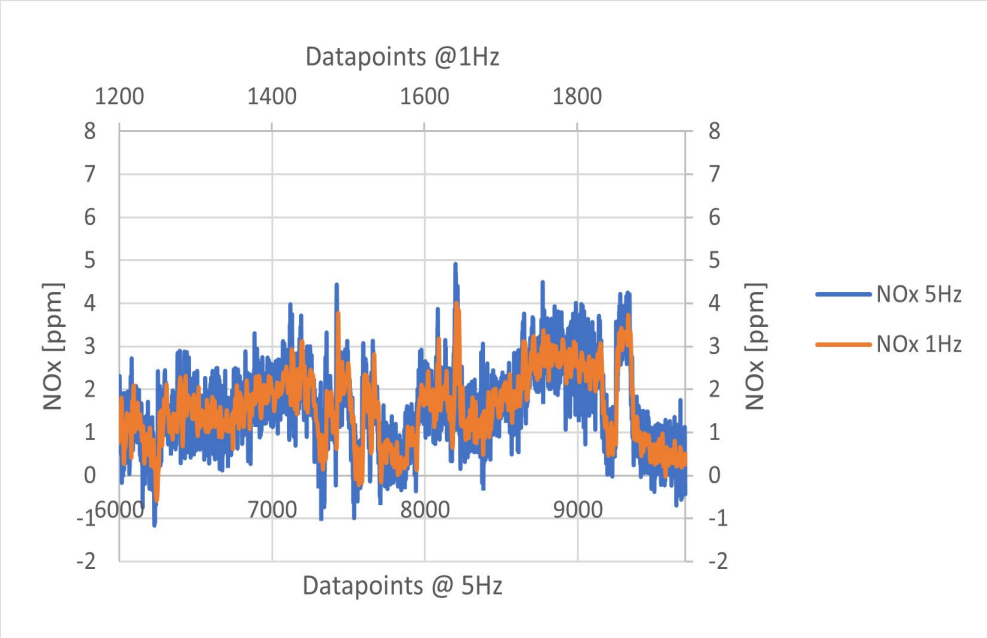
	300 ppm NH_3	500 ppm NO	500 ppm NO_2	500 ppm CH_4	200 ppm N_2O
Zero Point Drift 1h:	0.06 ppm	0.1 ppm	0.09 ppm	-0.07 ppm	0.05 ppm
Zero Point Drift 8h:	-0.07 ppm	0.09 ppm	-0.06 ppm	0.04 ppm	-0.02 ppm
End Point Drift 1h:	-0.21 ppm	0.18 ppm	0.18 ppm	-0.14 ppm	0.15 ppm
End Point Drift 8h:	0.35ppm	0.22 ppm	0.23 ppm	-0.20 ppm	0.27 ppm

02 Zero and wet (8% H_2O) reference gas

	300 ppm NH_3	500 ppm NO	500 ppm NO_2	500 ppm CH_4	200 ppm N_2O
Zero Point Drift 1h:	0.12 ppm	0.15 ppm	-0.04 ppm	0.11 ppm	0.08 ppm
Zero Point Drift 8h:	-0.10 ppm	0.11 ppm	0.05 ppm	0.08 ppm	0.07 ppm
End Point Drift 1h:	0.08 ppm	0.12 ppm	-0.11 ppm	0.09 ppm	-0.20 ppm
End Point Drift 8h:	0.14ppm	0.17 ppm	-0.12 ppm	-0.09 ppm	-0.14 ppm

Apparent FTIR Noise

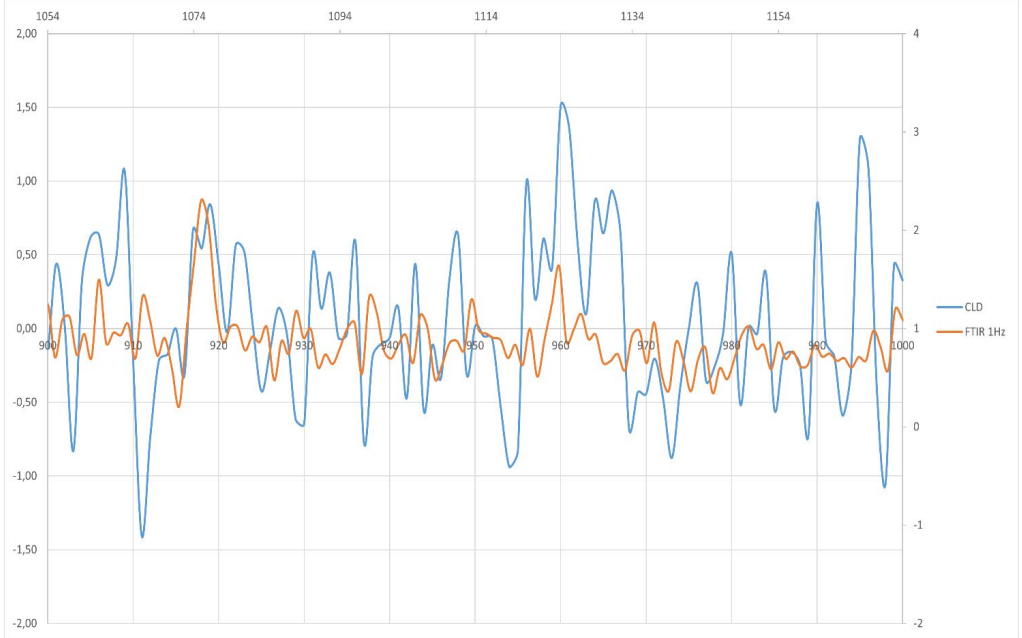
01 OFS 5Hz to 1Hz



Part of NOx values of WHVC, same raw data used to create 5Hz and 1Hz plot

This comparisons were part of a test made on a MAN truck at the TU Graz (Austria) on a chassis roller test bench on tailpipe position. A SCR cat was used.

02 1Hz OFS and 1Hz CLD

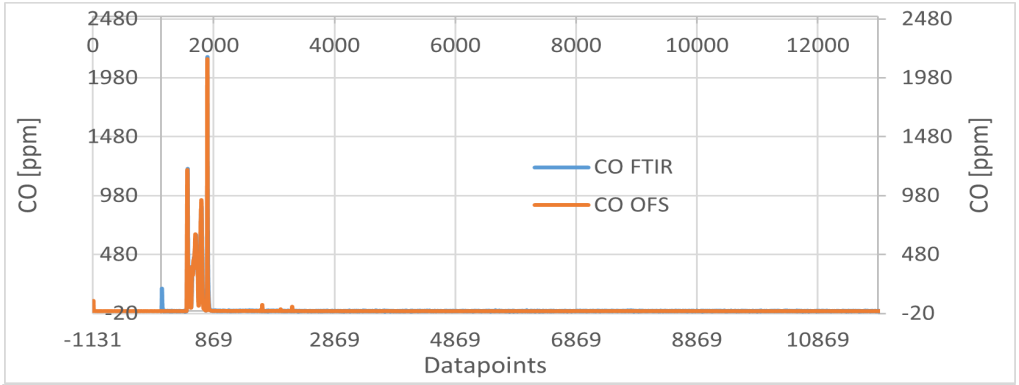


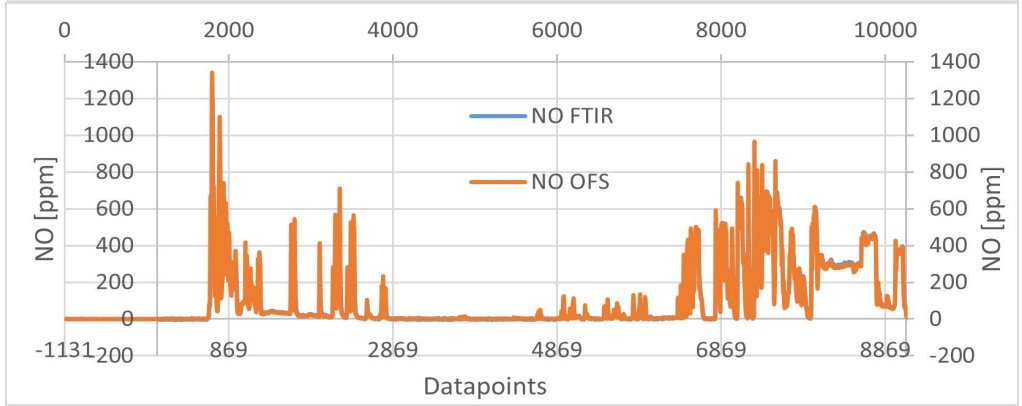
1Hz OFS and 1Hz CLD (Horiba Mexa), zero emission point of WLTC cycle

Comparison to lab FTIR

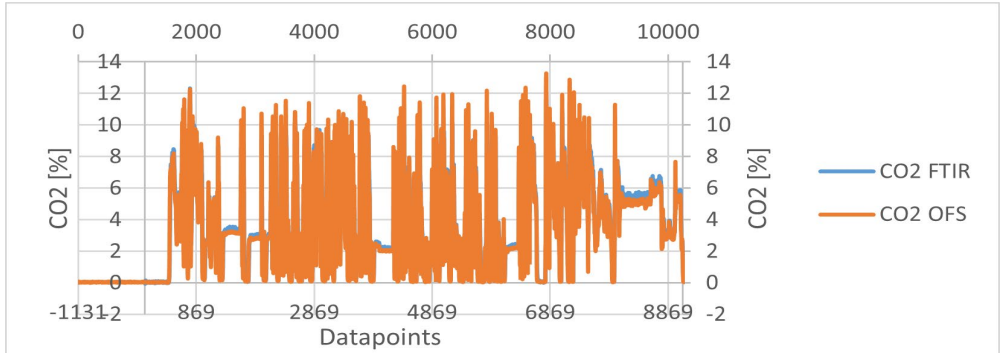
The tests were performed on a MAN truck at the TU Graz (Austria) on a chassis roller test bench on tailpipe position fitted with a SCR cat. The lab FTIR was a IAG Versa06 fitted with a MKS FTIR.

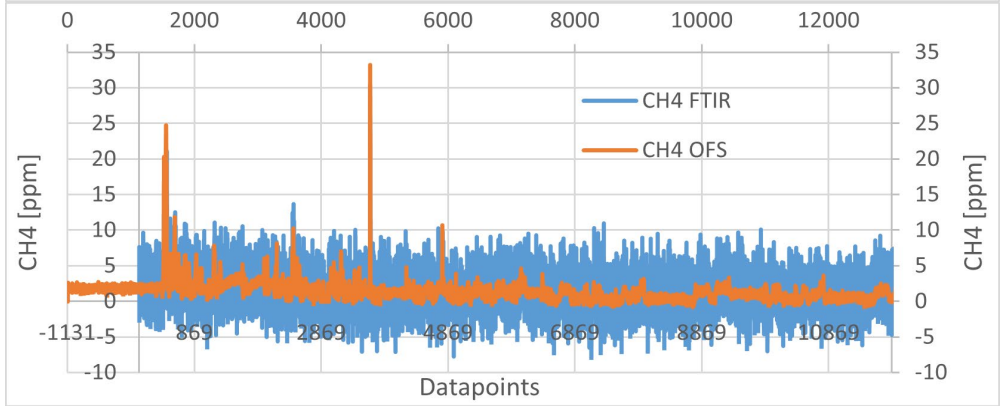
01 CO & NO





02 CO_2 & CH_4





OFS tracks NO, CO, CO_2 and CH_4 well at peaks and zero emission parts of WHVC

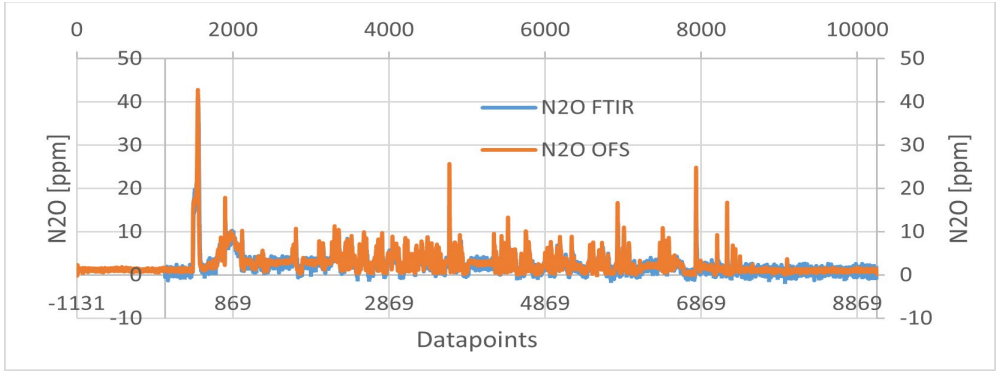
Comparison to lab FTIR

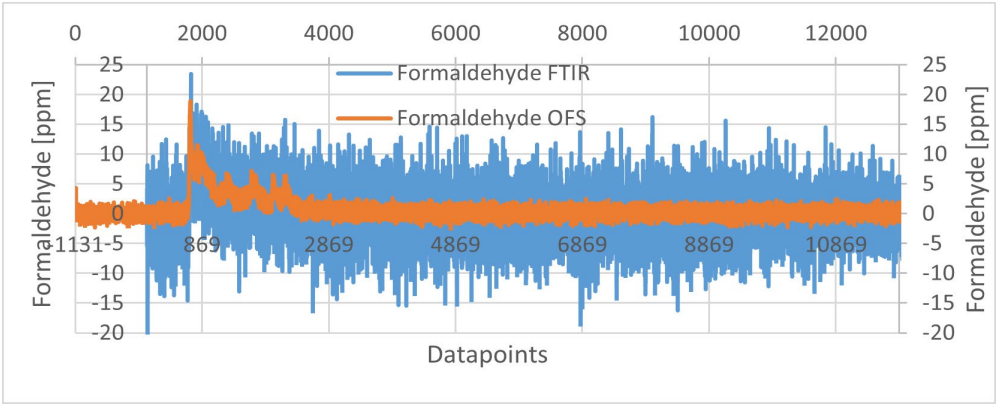
MAN Euro VI truck fitted with a SCR cat was evaluated over a WHVC .

The OFS and the FTIR were mounted at the tailpipe position downstream of all after treatment systems (SCR and DPF). The sample point was split by a T-piece.

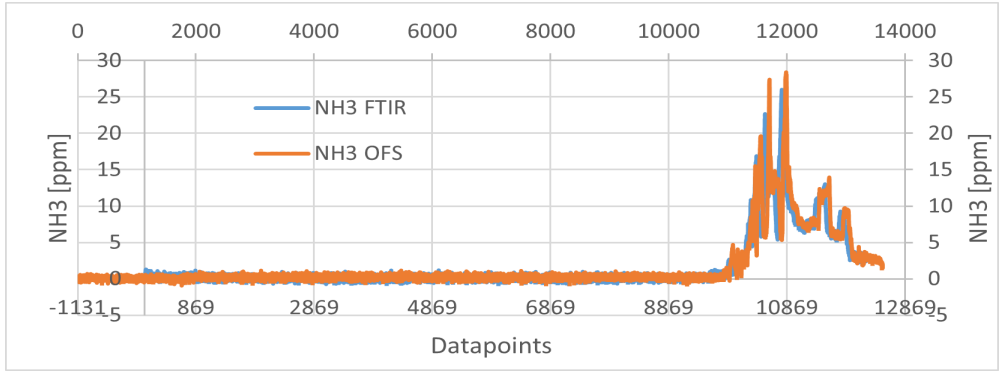
The tests were performed at the Technical University in Graz (Austria)

01 N_2O & Formaldehyde Comparison to



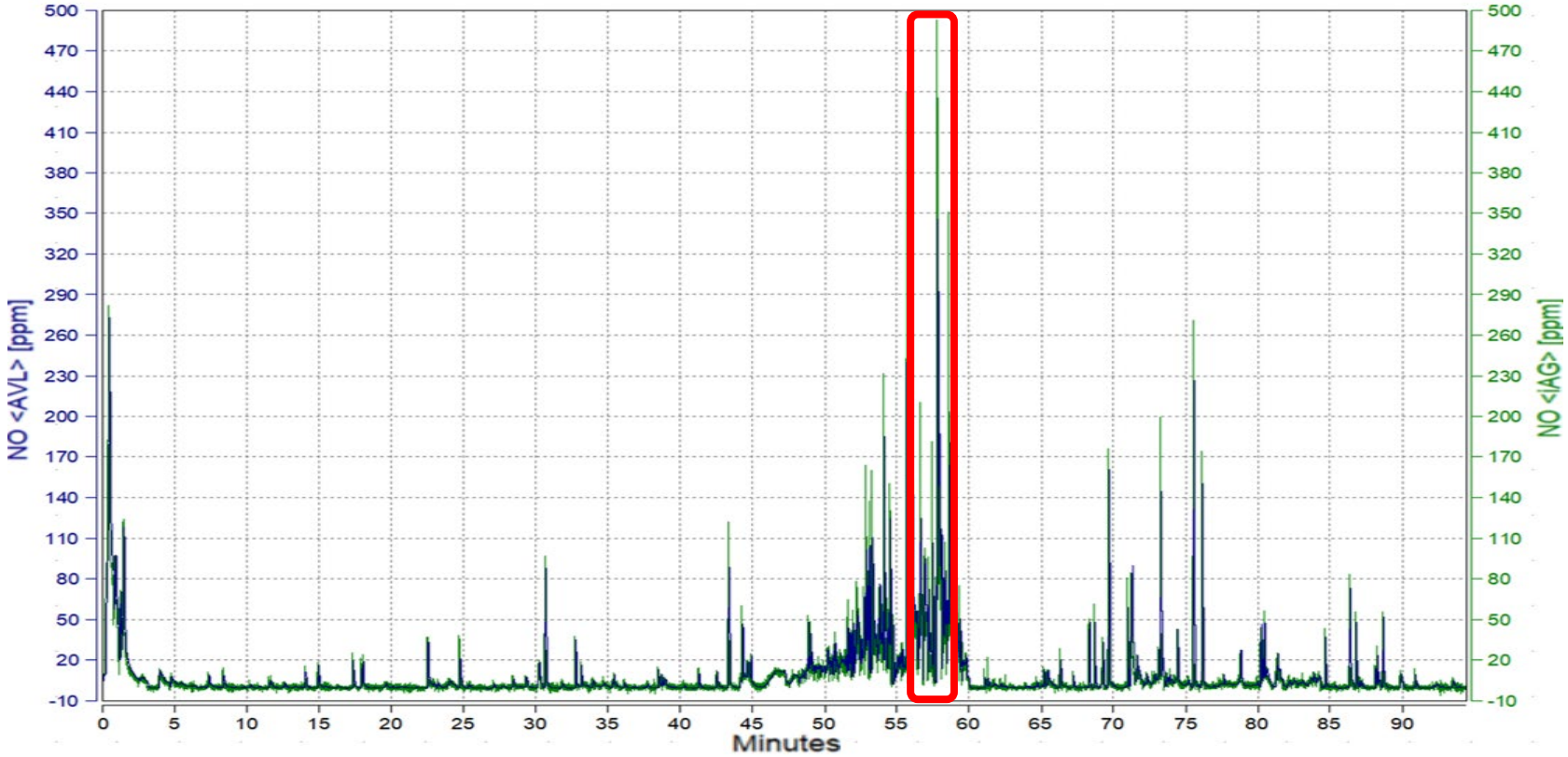


02 NH_3 Comparison to Lab FTIR



OFS tracks N_2O, NH_3, and Formaldehyde well at peaks and zero emission parts of WHVC

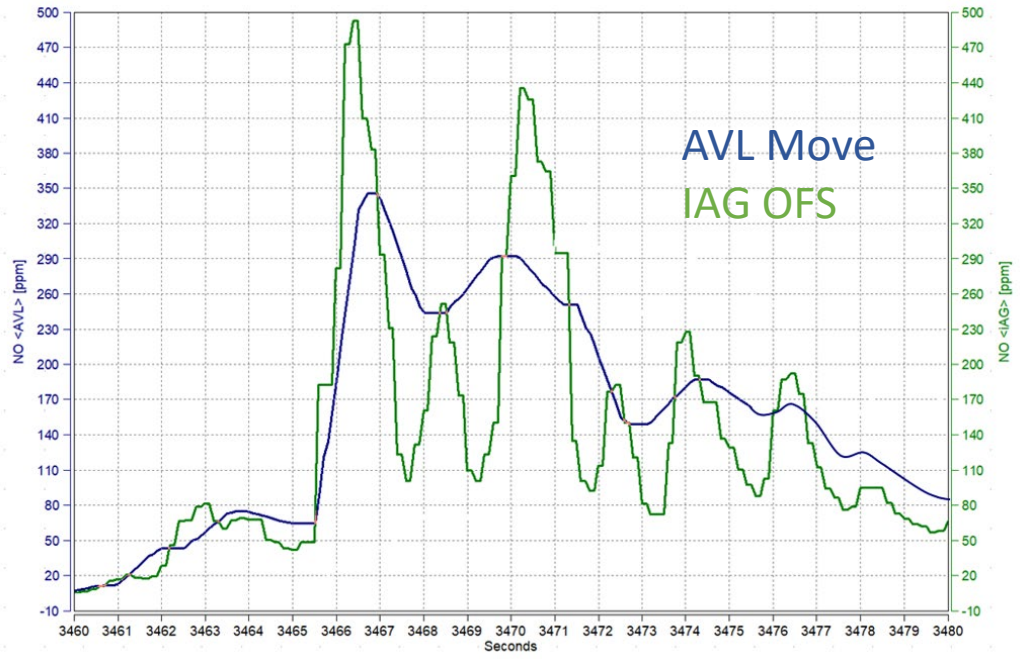
Comparison to PEMS NDUV

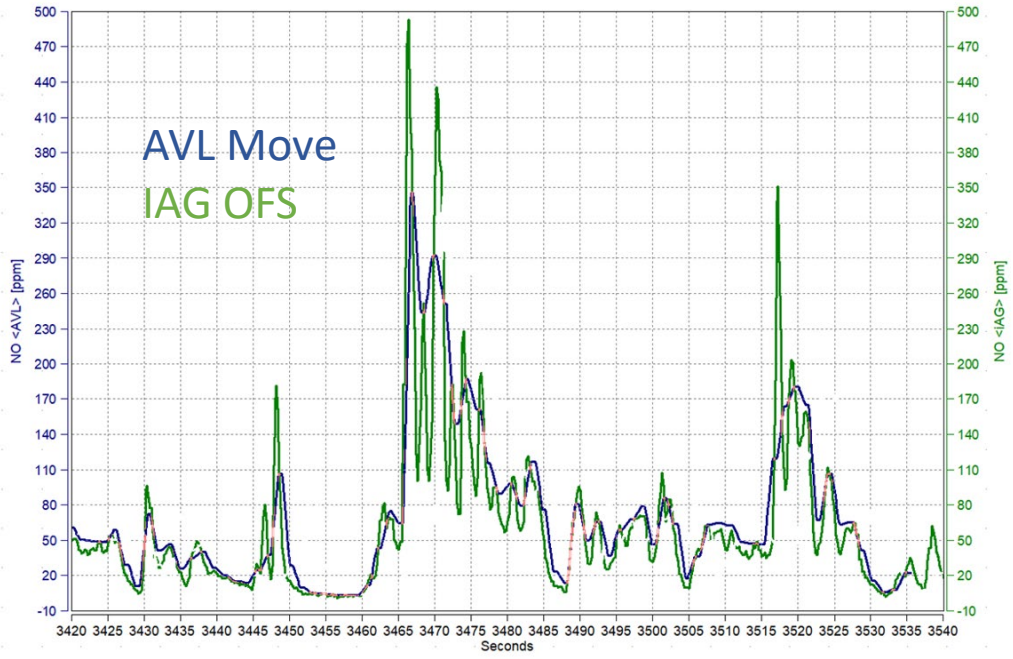


WLTC cycle of 2.0 L Diesel car, tests done by KIT (Germany) on a RDE route. An IAG OFS (green) was used together with an AVL Move (blue).

NO measurement of OFS and PEMS NDUV match very well.

Comparison to PEMS NDUV





Zoomed in regions of the previous Slide show the OFS 5Hz update frequency resolves peaks much better.

Assessment of On-Board and Laboratory Gas Measurement Systems for Future Heavy-Duty Emission Regulations. *Giechaskiel, Jakobsson, Karlsson, Khan, Otsuki, Bredenbeck, Handler-Matejka. Int J Environ Res Public Health. 2022 May 19;19(10):6199. doi: 10.3390/ijerph19106199*

Experimental Set Up

Requirement	Lab analyzers	Lab analyzers	PEMS	Lab FTIR	p FTIR #1	p FTIR #2	p QCL-IR
Manufacturer	AVL	Horiba	Horiba	AVL	IAG	A&D	Horiba
Model	AMA i60	MEXA-ONE	OBS-ONE	Sesam i60	OFS	BOB-1000FT	OBS-ONE-XL
CO_2	NDIR	NDIR	Heated NDIR	Yes	Yes	Yes	-
NO_x	CLD	CLD	CLD	Yes	Yes	Yes	-
N_2O	-	-	-	Yes	Yes	Yes	Yes
NH_3	-	-	-	Yes	Yes	Yes	Yes
Sampling line	6 m (191°C)	6 m (191°C)	6 m (191°C)	6 m (191°C)	6 m (191°C)	6 m (191°C)	6 m (113°C)
t_{10-90}	≤2.5 s	≤2.5 s	≤3.0 s	≤3.0 s	≤1.0 s	≤2.0 s	≤2.0 s
Qs (L/min)	13	13	3	10	10	10	3.3

[1] Only those assessed in this study.
CLD = chemiluminescence detection; FS = full scale; FTIR = Fourier transform infrared; NDIR = non-dispersive infrared; p = portable; PEMS = portable emissions measurement system; QCL-IR = quantum cascade laser – infrared; Qs = sampling flow rate.

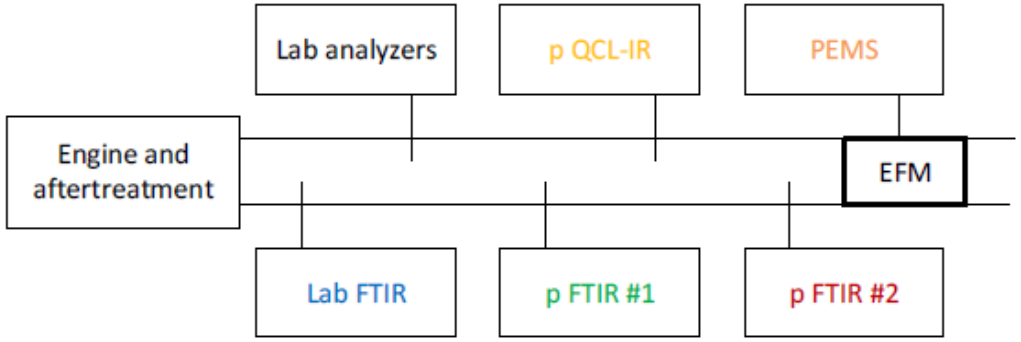
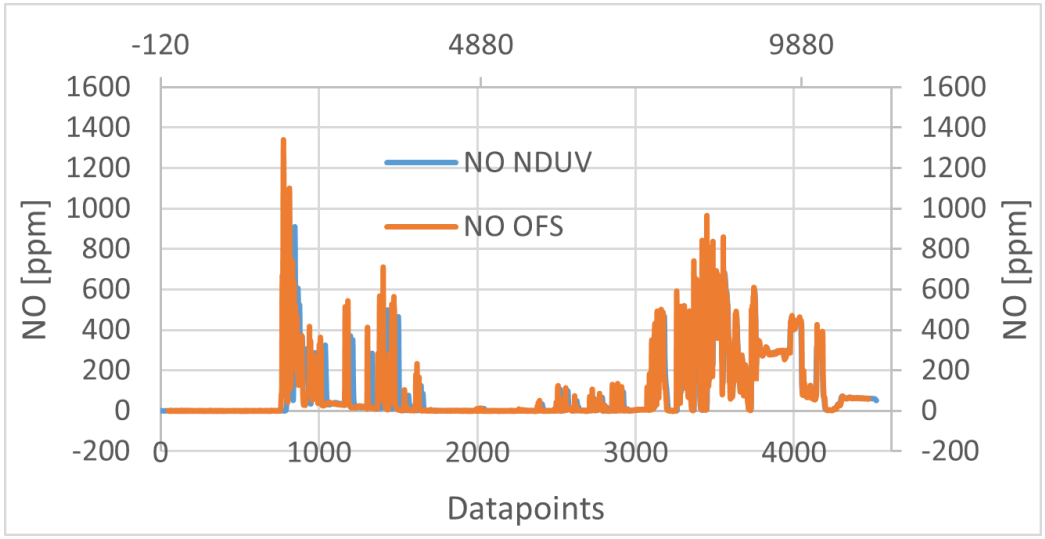


Figure 1. Schematic of experimental setup.
EFM = exhaust flow meter; FTIR = Fourier transform infrared; p = portable; PEMS = portable emissions measurement system; QCL-IR = quantum cascade laser - infrared.

Engines were the latest regulations stage, Euro VI Step E.

Test cycles included Cold/Hot WHTC, Hot WHSC, and Cold/Hot ISC

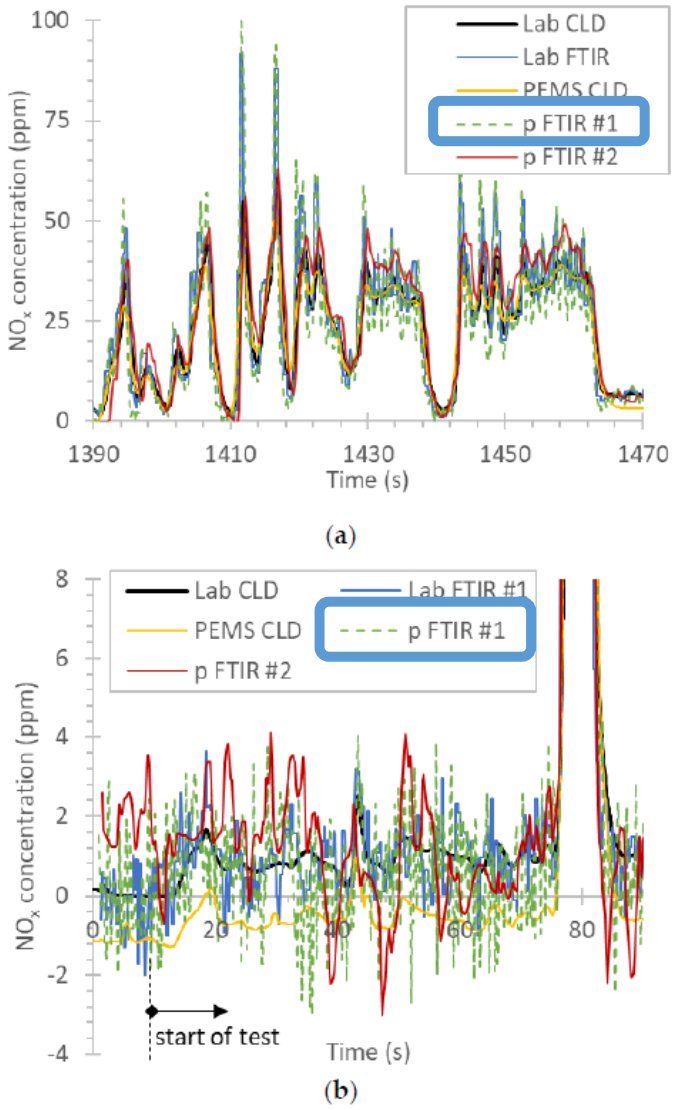
Comparison to PEMS NO



Top: WHVC shows very good comparison between OFS and NDUV

Right: Comparison done by JRC, OFS matches very well with reference CLD and FTIR

On the lower right plot the first 70 seconds show that the IAG OFS is measuring low to zero NOx as well as the lab FTIR and CLD and is not shifted to the negative as the PEMS CLD.



Mass Comparison of NOx

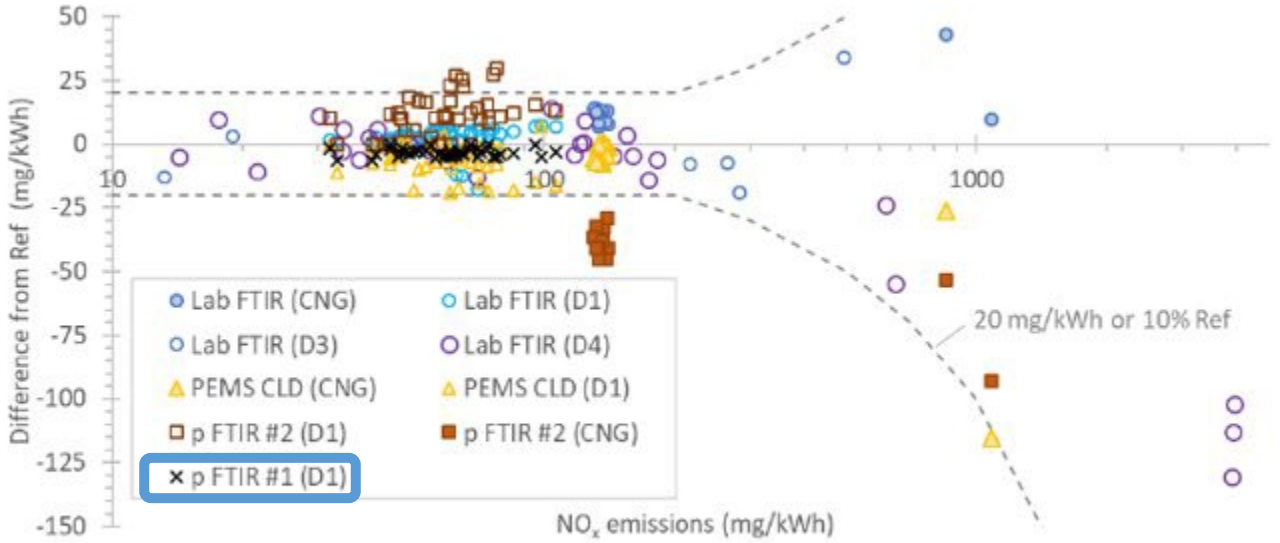
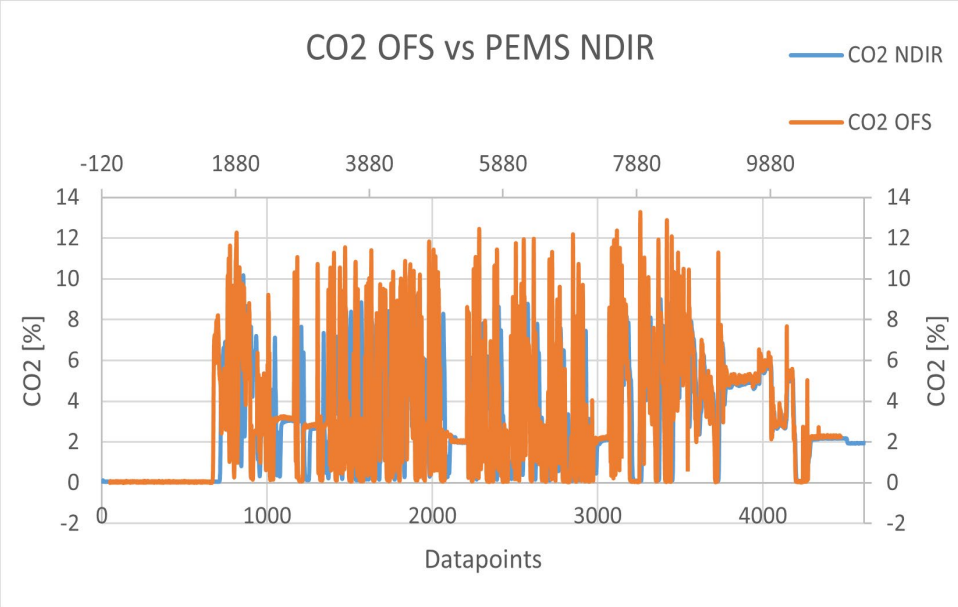
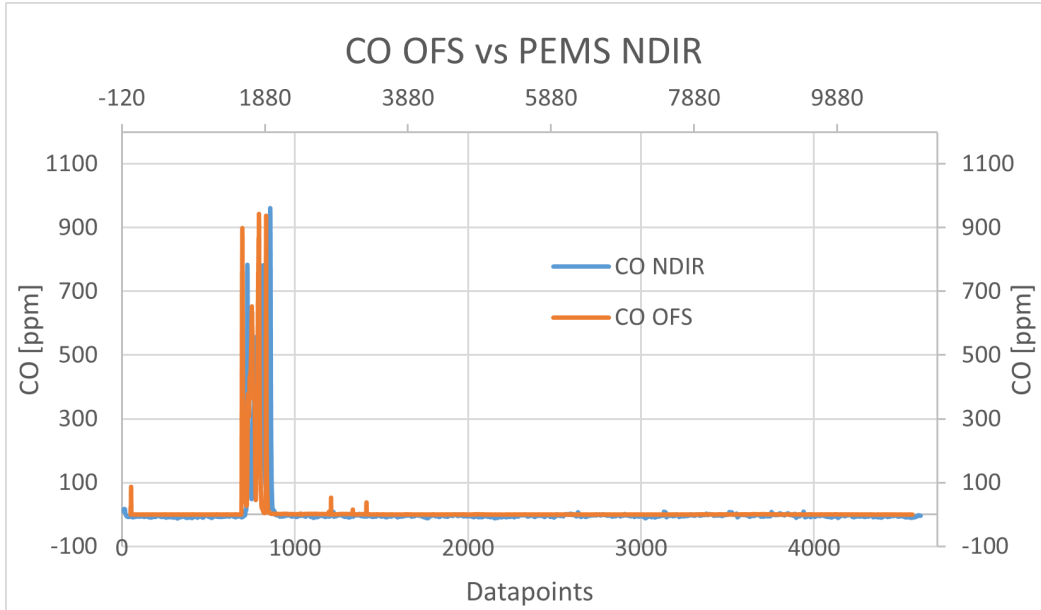


Figure 4. NOx differences of laboratory (Lab) or portable (p) FTIRs, and PEMS from the laboratory real time reference CLD analyzers. CLD = chemiluminescence detection; CNG = compressed natural gas engine; D = Diesel engine; FTIR = Fourier transform infrared; p = portable; PEMS = portable emissions measurement system.

OFS compared best relative to the Reference for NOx over the WHVC
Note: PEMS CLD reported up to 25% lower than the reference (up to 0.1 g/kWh)

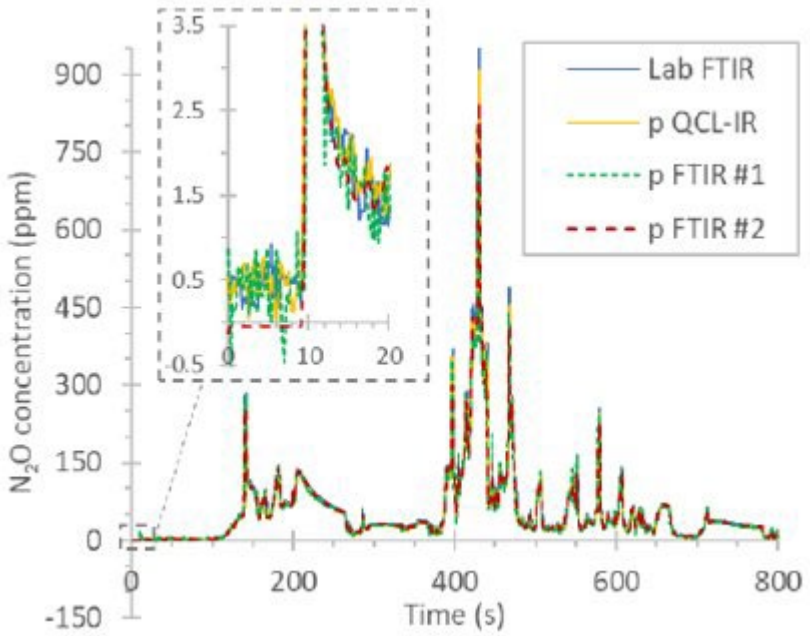
Comparison to PEMS NDIR

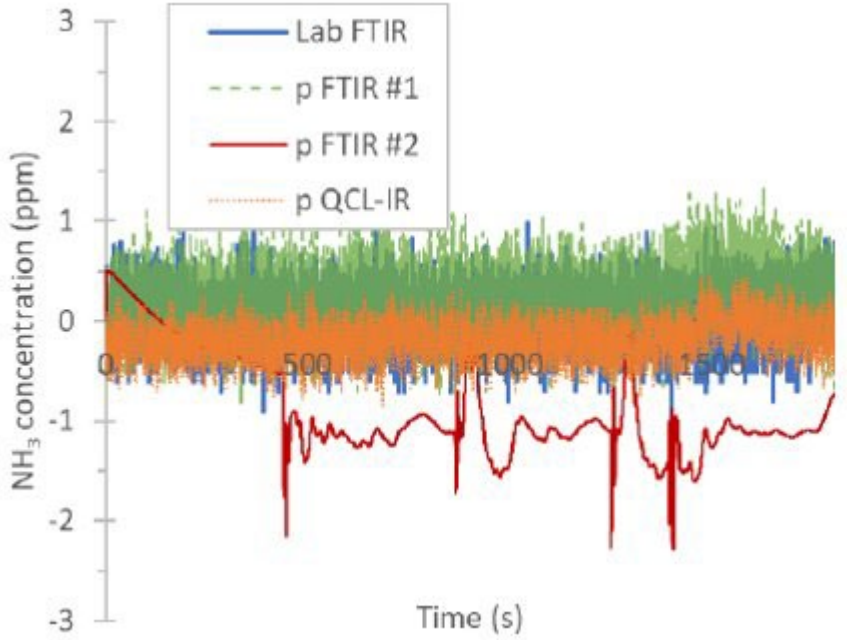




OFS compares well with PEMS NDIR on WHTC

Comparison to PEMS N_2O & NH_3

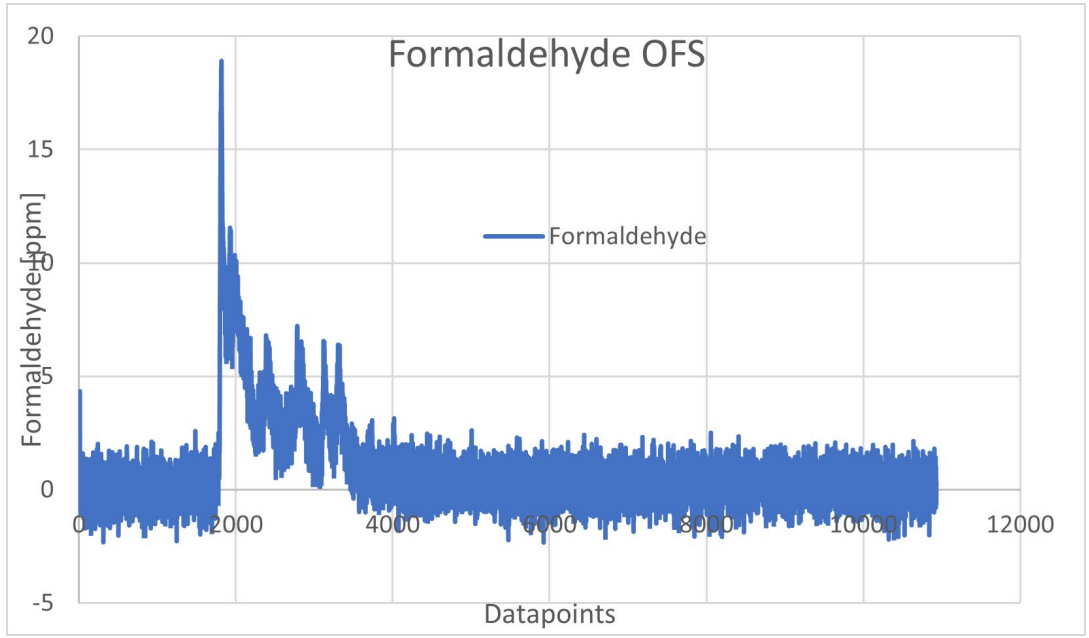




OFS shows excellent agreement for both N_2O and NH_3 emissions over WHTC.

Ammonia was essentially zero over the cycle

Results PEMS Formaldehyde



Plot of a WHVC from a MAN Euro VI Diesel truck, measured at TU Graz.

Since the OFS is the only portable FTIR there are no devices to compare.

Summery & Conclusion

01 Accuracy

Accuracy matches within ±2% compared to calibration gases, even for small concentrations.

Even with wet gas, it fulfills all existing and future regulations and is comparable to existing technology.

02 Drift

No drift was observed for 8h, no matter if wet or dry gas.

03 Plot & Mass Comparison

Peak alignment is very good, line shape and response time is comparable or better than existing PEMS devices.
Also mass is perfectly comparable to state of the art technology.

Conclusion

On Board FT-IR System performs as well and, in many cases, better than other PEMS measurement instruments for standard criteria and new criteria.

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