AVL M.O.V.E Integrative Mobile Vehicle Evaluation
PEMS – Portable Emissions Measurement Systems

AVL Tech Days 2012

21.03.2012

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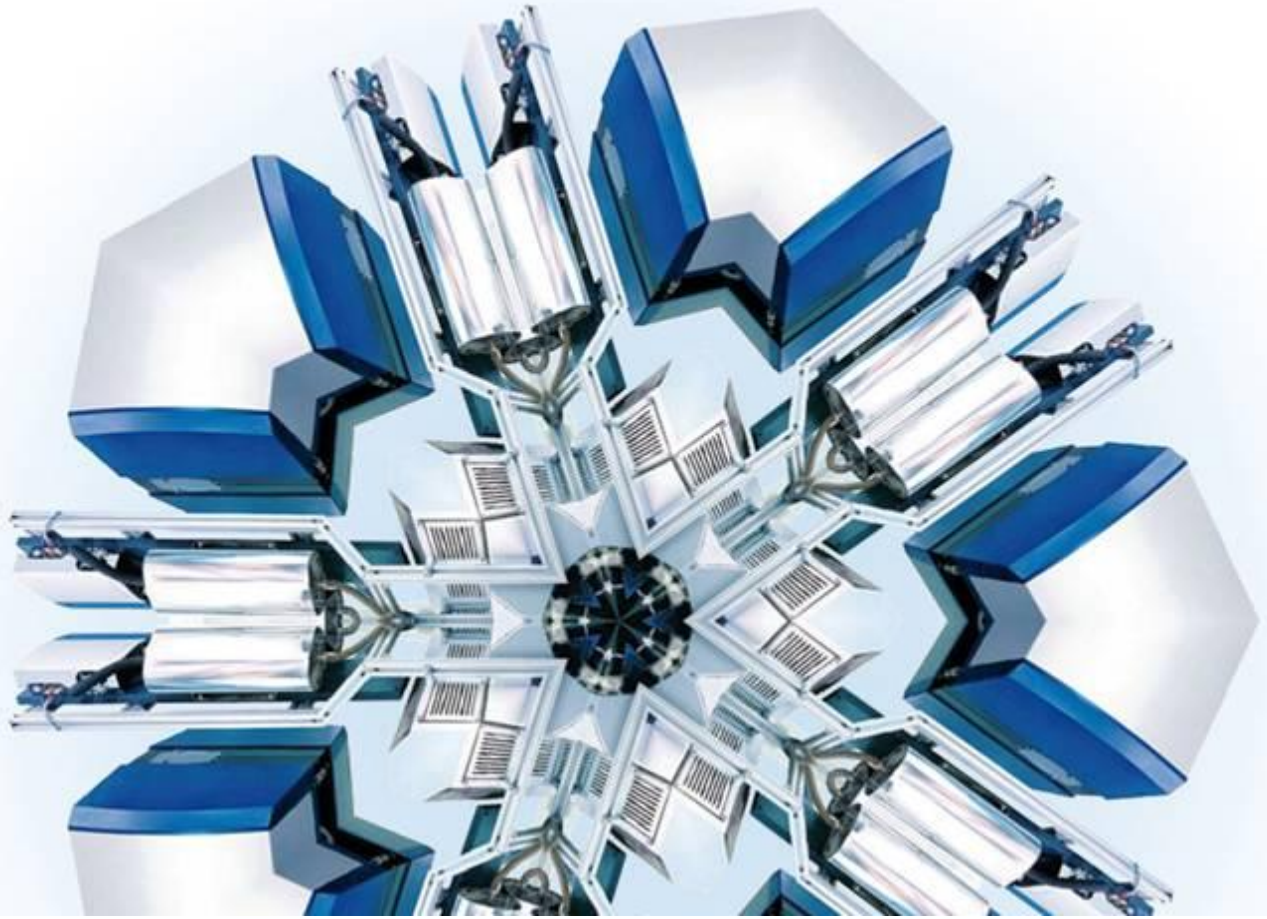


MARKET DRIVER - LEGISLATION

Since 2007

EPA

Requires heavy-duty diesel engine manufacturers to show in-use conformity to Not to Exceed (NTE) standards. Other markets to follow….

In-Use Legislation Roadmap

2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

Gaseous

PM

Gaseous/ PM

Gaseous/ PM/Soot

ASIA to follow

?

??

?????????

PEMS program (RDE) kicked off 29.9.11

Research program

Pilot program

Review & finalization

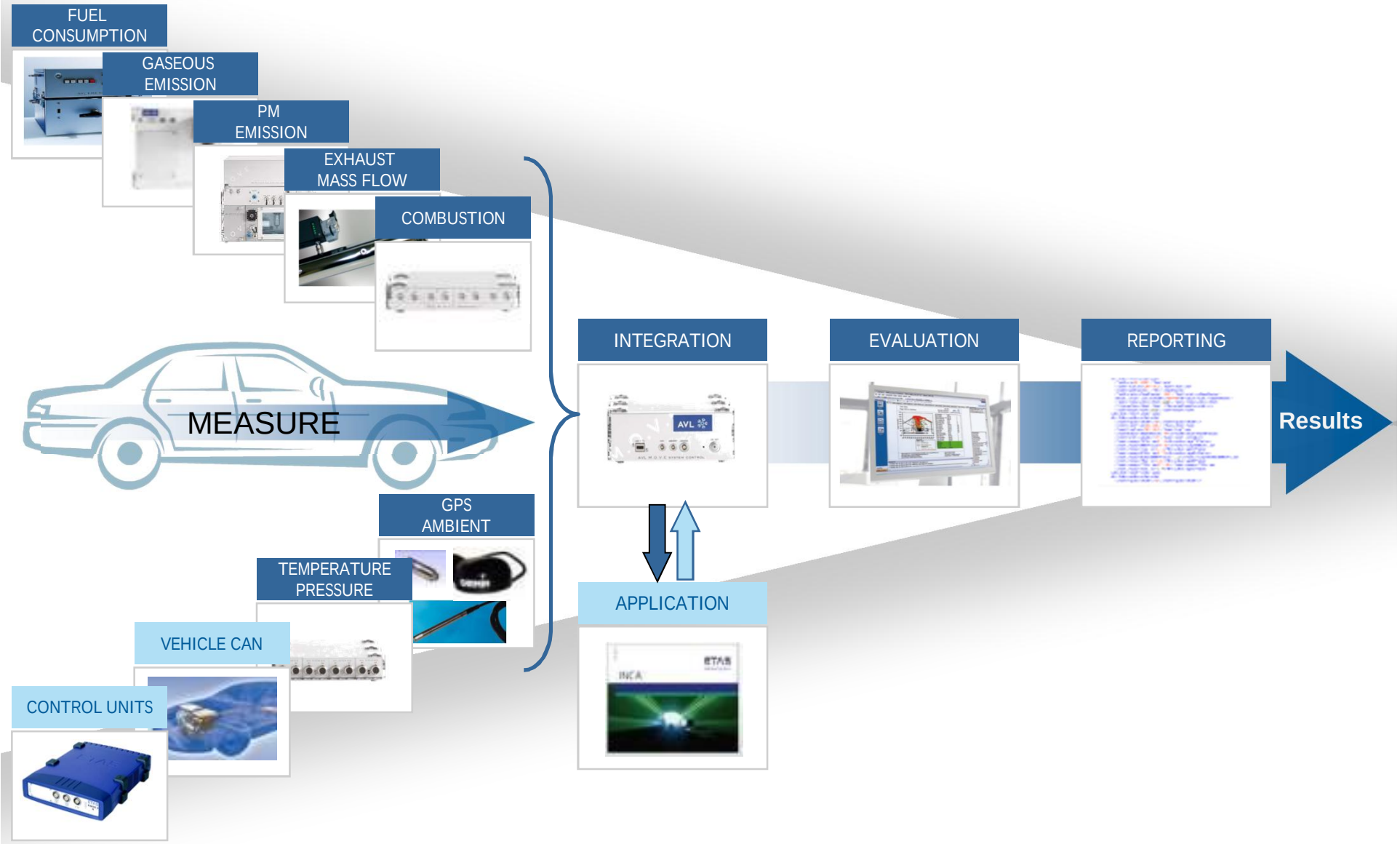
Implementation/ transition phase

Fully in force

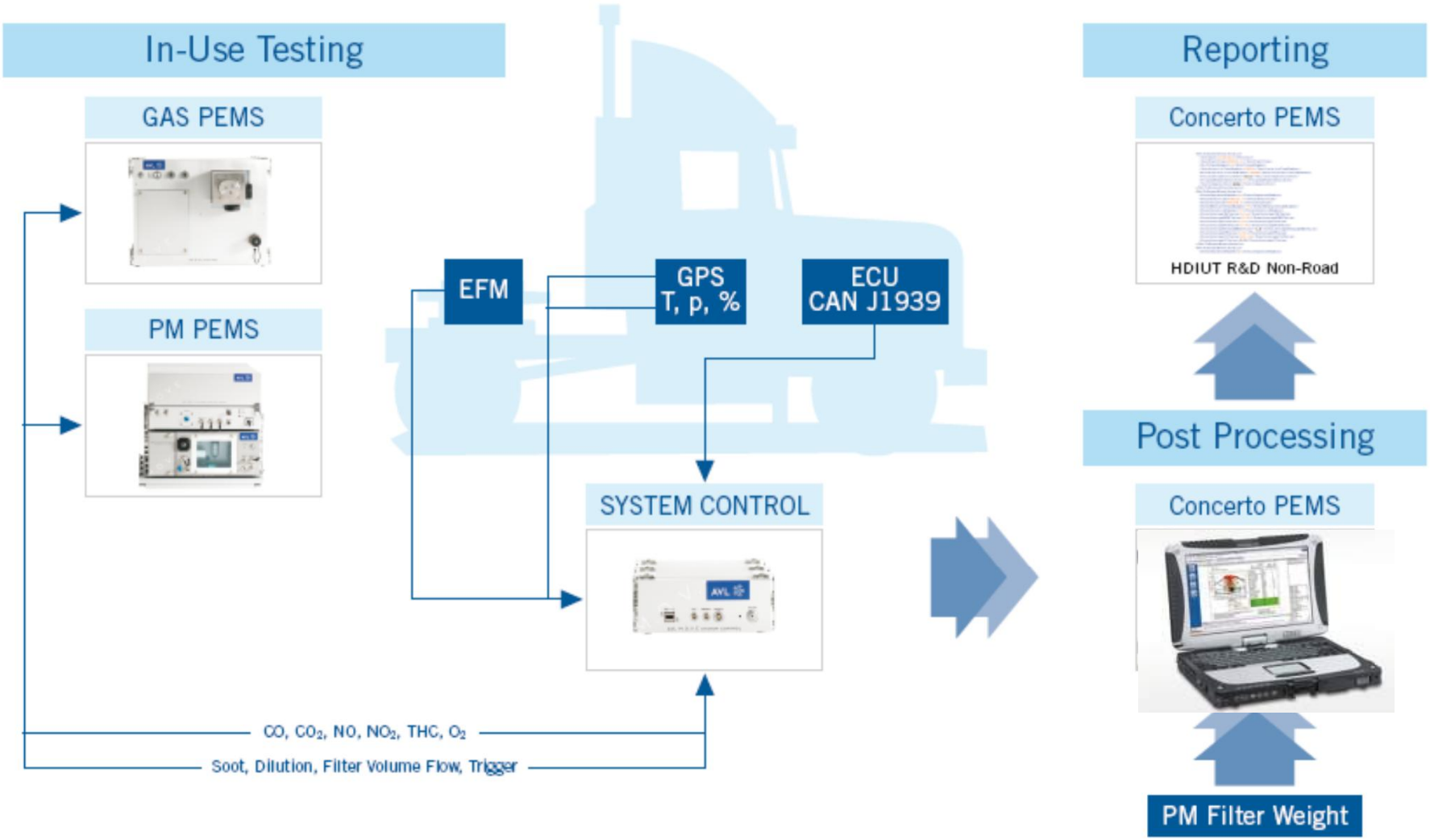
? Planed

?? Expected

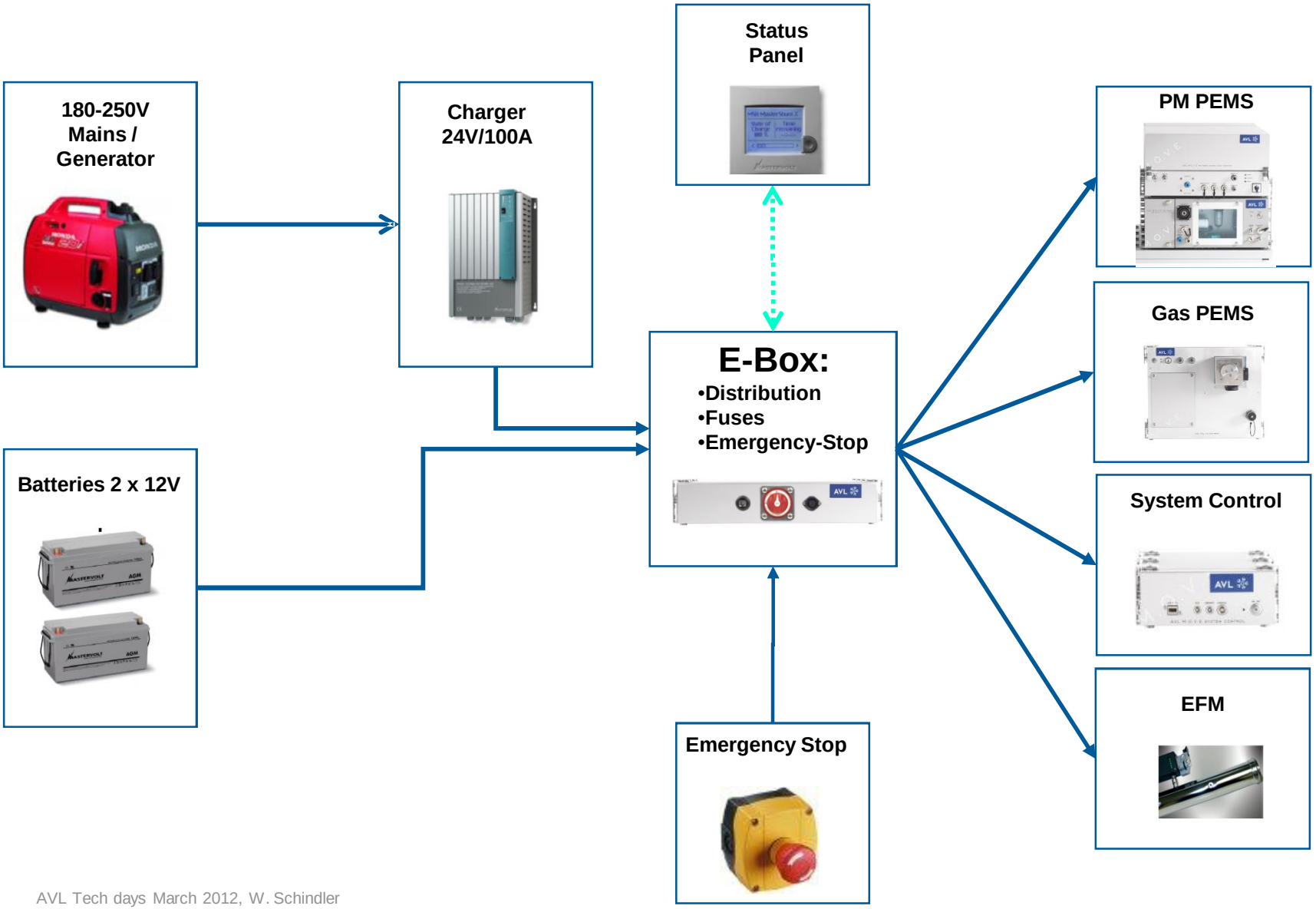
AVL M.O.V.E APPROACH – IN VEHICLE MEASUREMENT PLATTFORM



The PEMS Products - part of the AVL M.O.V.E Solution for In-Use Testing



Power Supply



AVL M.O.V.E Product Line

- AVL M.O.V.E SYSTEM CONTROL
- **AVL M.O.V.E GAS PEMS**
- **AVL M.O.V.E PM PEMS**
- AVL M.O.V.E IndiMicro
- AVL M.O.V.E SMART-FEM
- AVL Concerto PEMS
- AVL DRIVE
- AVL KMA Mobile

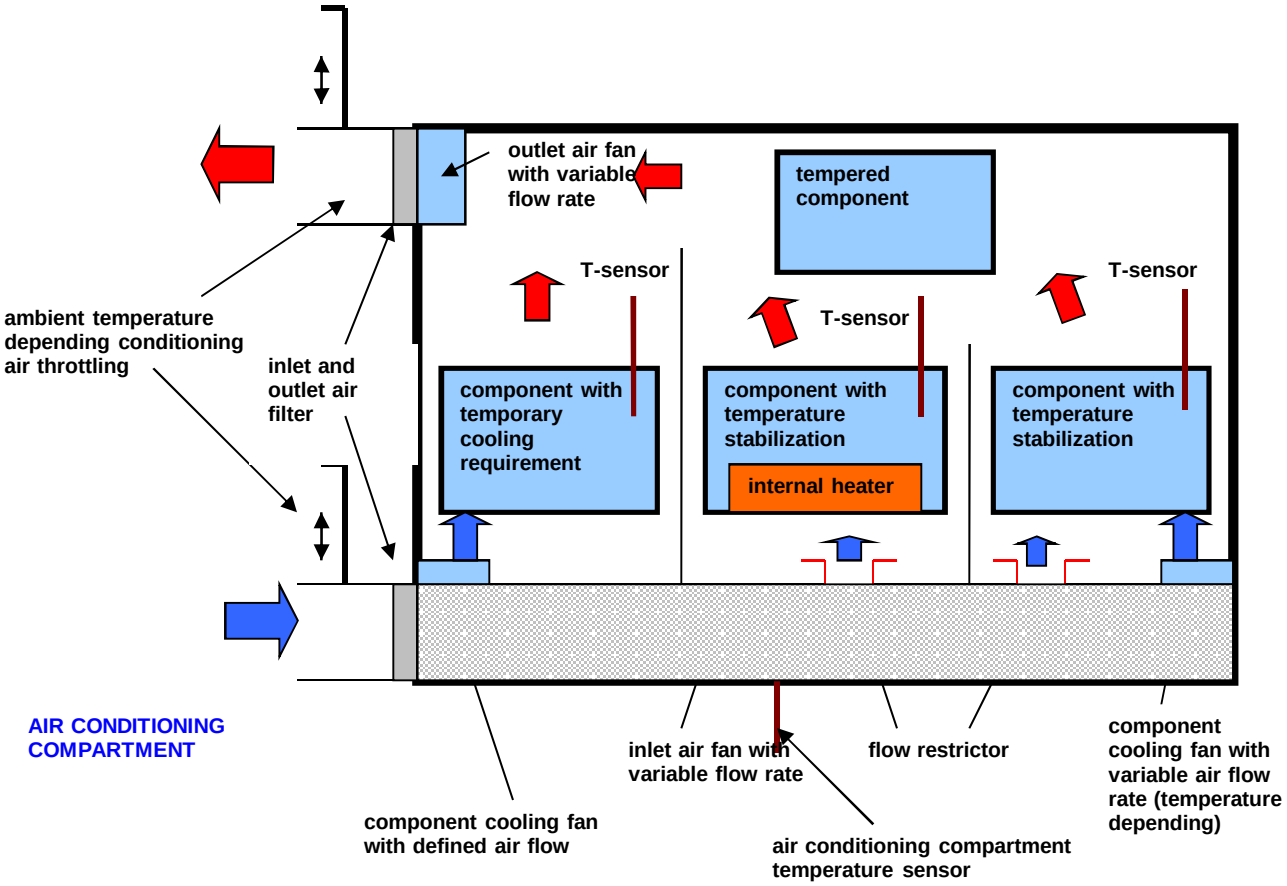
- Power supply and mounting

AVL Gas PEMS
Mobile Gaseous Emission Measurement

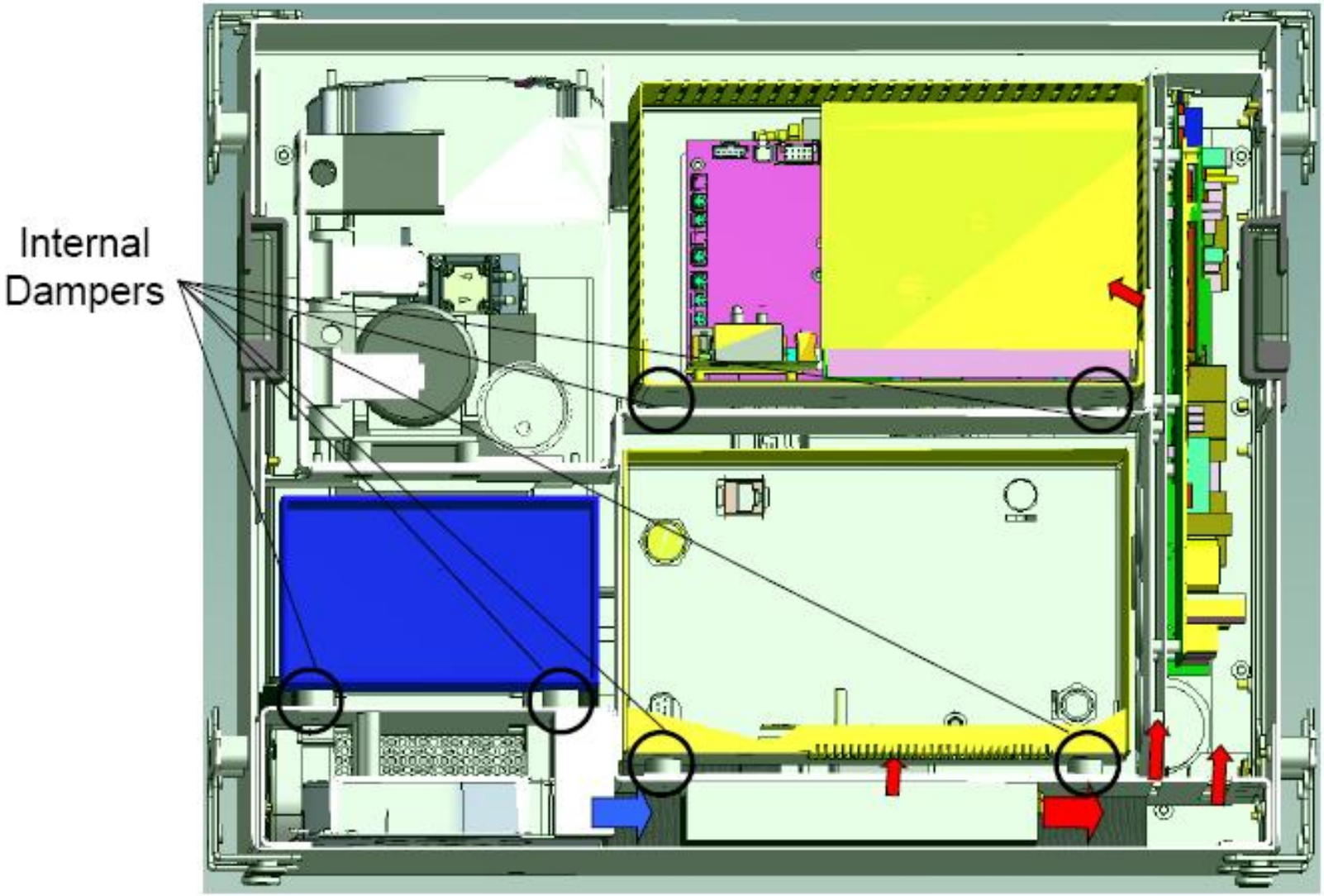
SYSTEM Highlights:

- **Measuring NO, NO_2, CO, CO_2, THC, O_2 under real-world conditions**
  - fulfilling and exceeding all requirements of CFR 40, § 1065
- **Extended operating temperature range (-30 ° C to 45 ° C)**
  - Special climate concept. (for higher temperature external cooling air can be connected)
- **Reduced warm-up time and avoidance of condensate**
  - warm-up time at 20ºC $T_{ambient}$ <1 hr
  - Special low power “Hibernate” Mode
  - Dedicated heating circuit , removing condensate before electronics switch-on
- **Robust against vibrations**
- **Compact design**

AVL Gas PEMS - Climate Concept



AVL GAS PEMS - Cross Section Front View to Conditioning and Vibration damping

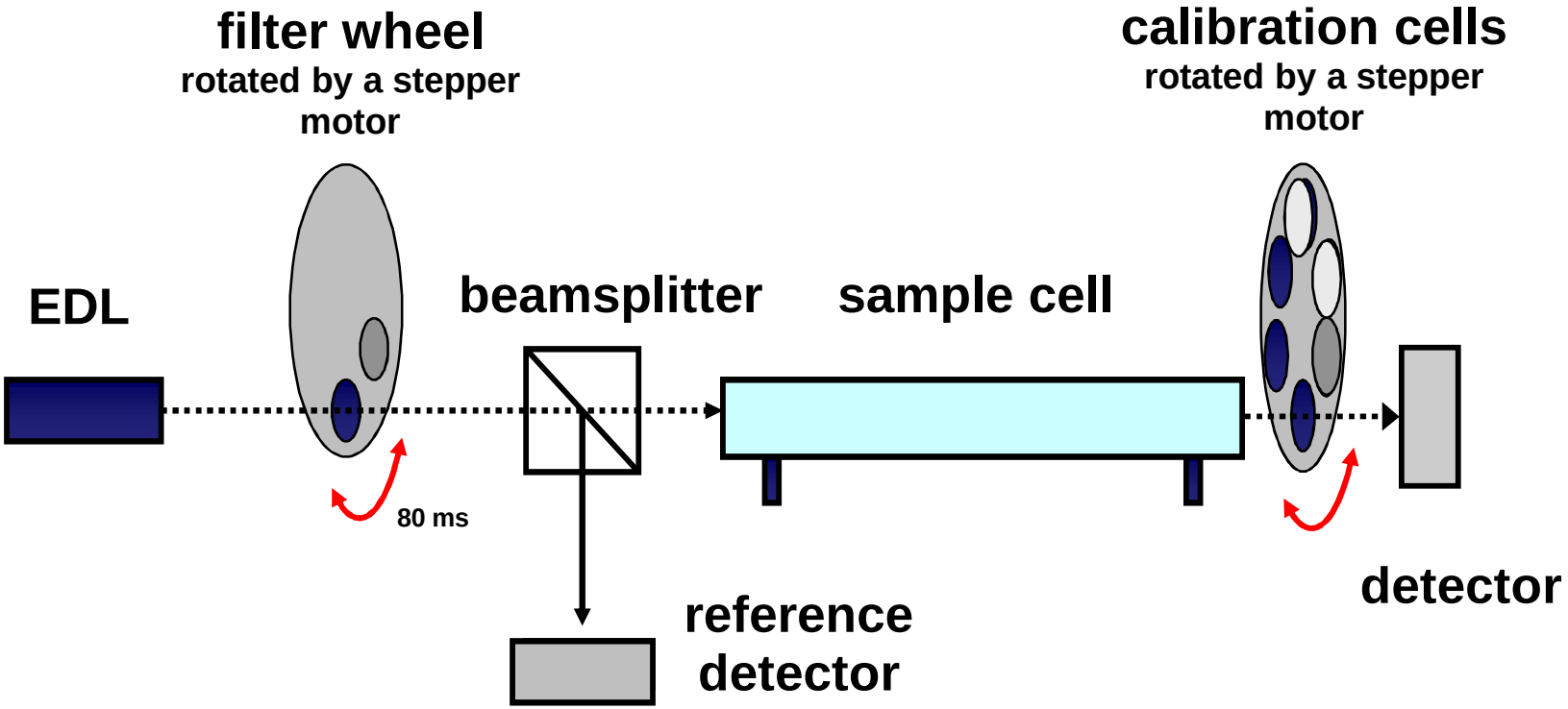


AVL Gas PEMS
Mobile Gaseous Emission Measurement

ANALYSER Highlights:

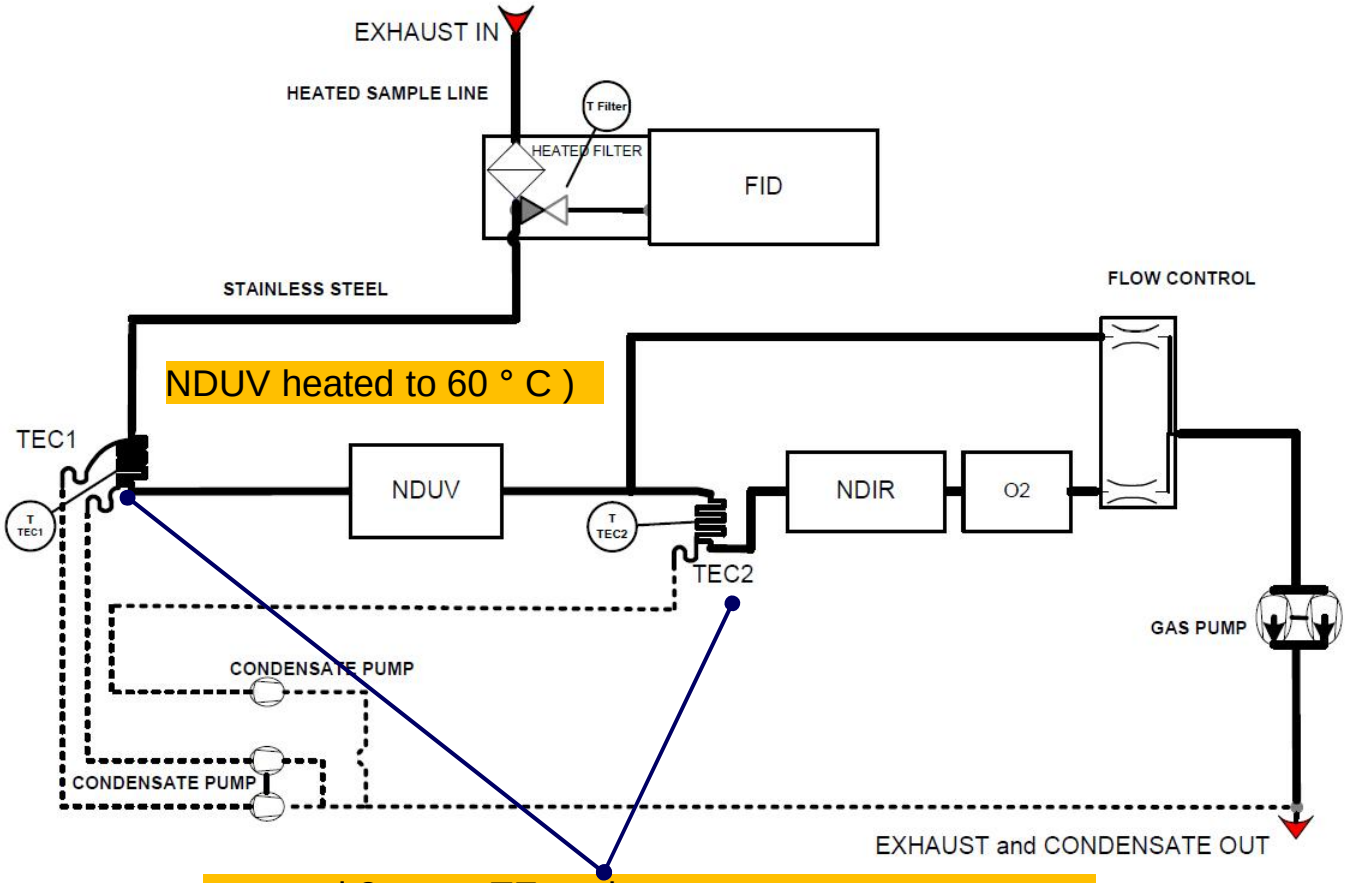
- **NDUV analyzer instead of CLD**
  - simultaneous NO and NO_2 measurement
  - no need for ozonizer/converter
- **NDUV analyzer internal calibration with gas filled cuvettes**
  - No need for a NO_2 span gas bottle,
  - only FID burner gas required for operation
- **Special exhaust gas cooling concept for low NO_2 hangup, but safe H_2O removal for CO and CO_2 analyzers**
- **High measurement accuracy, due to low zero and span drift allows accurate measurement during long tests.**
  - analyzers in temperature controlled enclosures
  - analyzers optimized for mobile use

NDUV - Non Dispersive Ultra Violet Analyzer
NO/ NO_2 - Measurement



NDUV analyzer benefits are:	• separate, but simultaneous measurement of NO and NO_2
	• No additional NO_2 bottle needed (R&D)
	• No ozone to generate and to destroy
	• lower energy consumption
	• intrinsic calibration with reference cells
	• No converter required

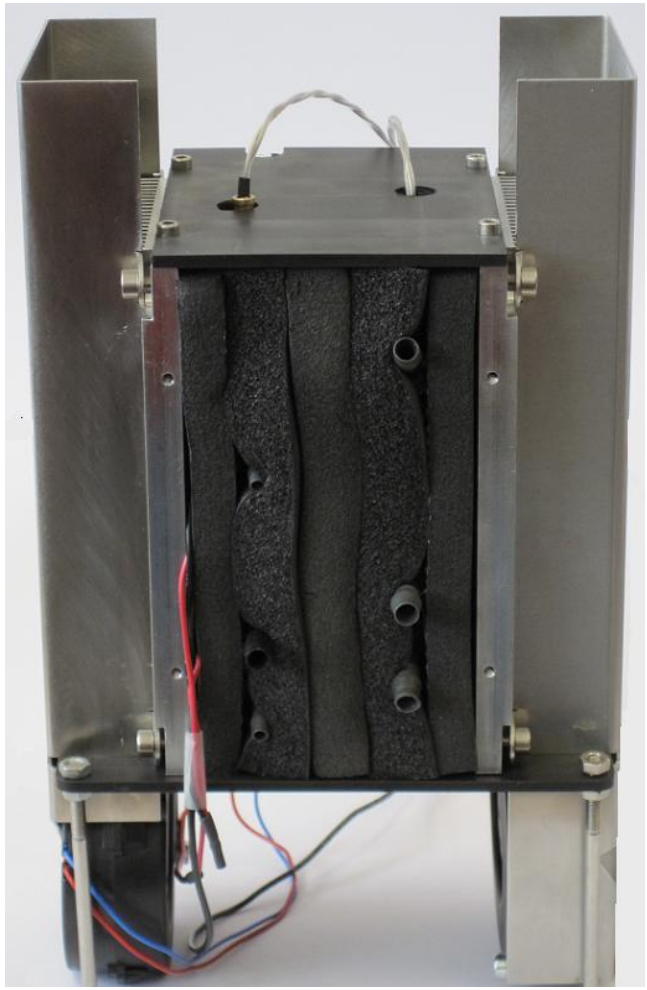
AVL Gas PEMS: Pneumatic Schematics

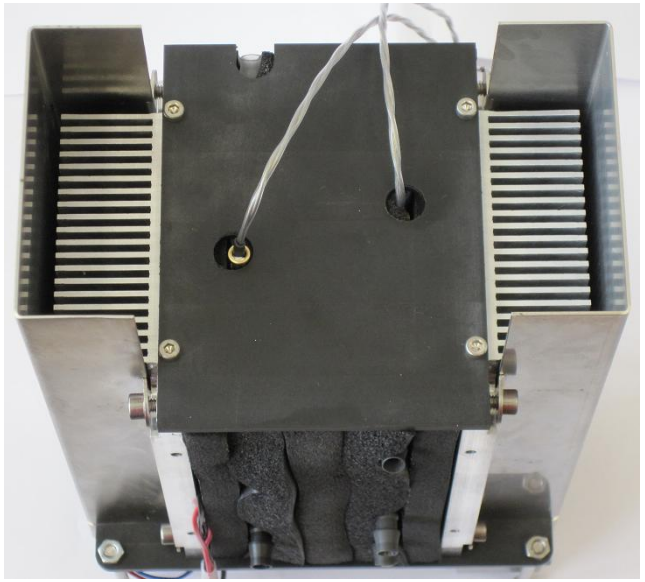


patented 2 stage TE cooler.

1. minimizes NO_2 losses: (T_{inlet} to NDUV ~ 25 ° C)
2. ensuring H_2O removal for CO/CO2 Measurement (T_{inlet} to NDIR: ~ 5 ° C)

AVL Gas-PEMS: 2 stage TEC

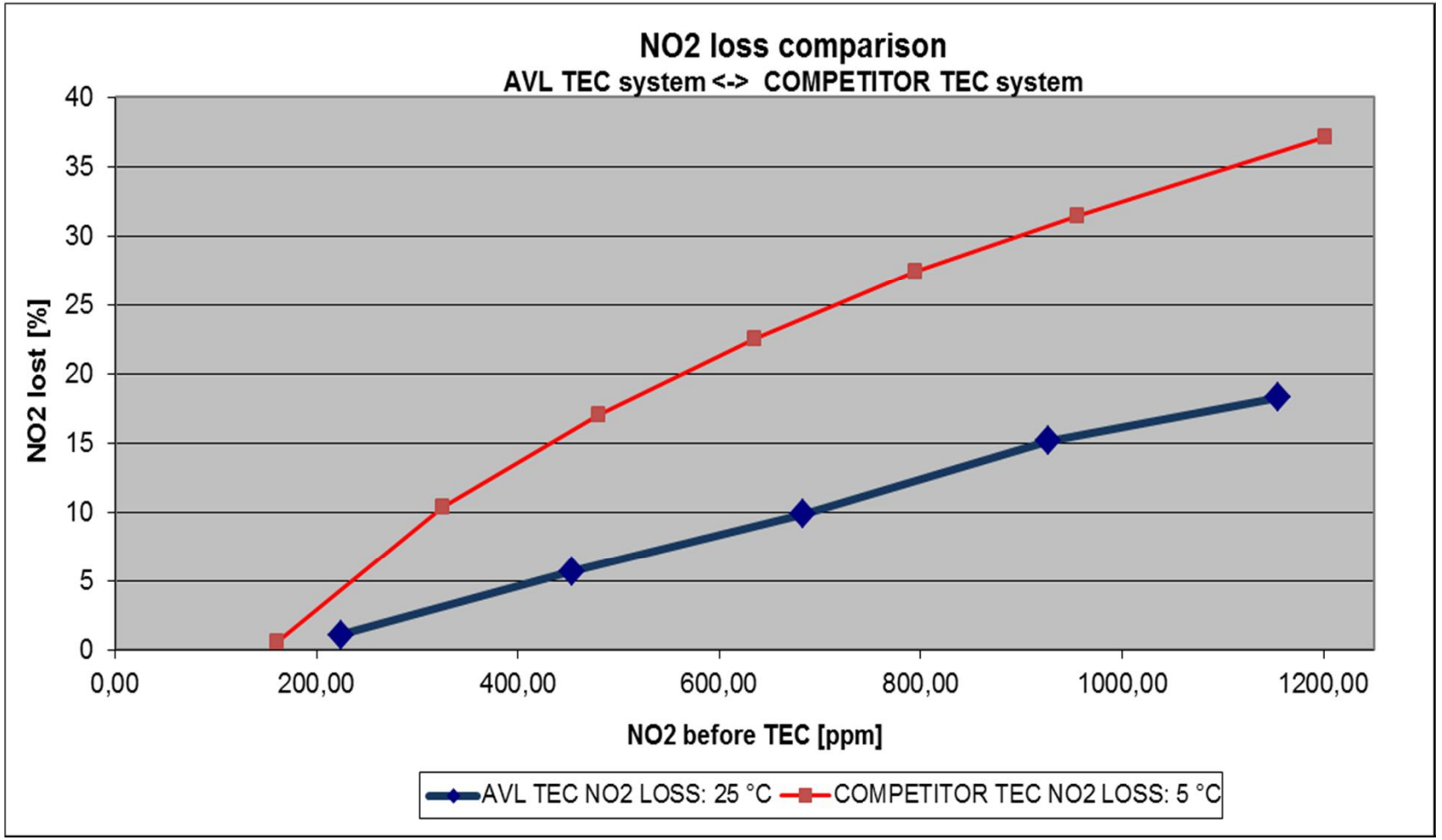




Special patented 2-stage cooling concept

- minimum NO_2 hangup,
- but safe water removal for CO and CO_2

AVL Gas PEMS
NO_2 loss dependence on the TEC temperature



AVL Gas PEMS Specifications

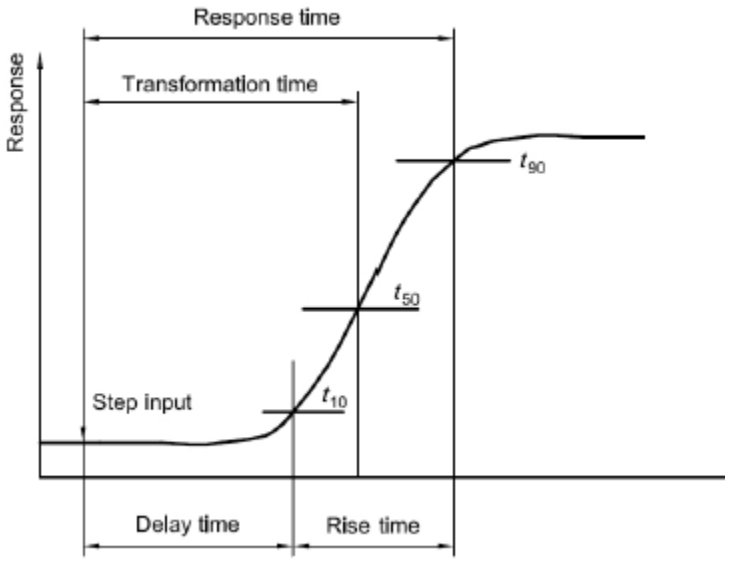
- **Measurement Range:**
  - THC: 0 – 30.000 ppm C1
  - NO: 0 – 5.000 ppm
  - NO2: 0 - 2.500 ppm
  - CO: 0 – 5 % vol%
  - CO2: 0 – 20 vol%
- **Zero Drift:**
  - THC: 1 ppm / 8h
  - NO, NO2: 2 ppm / 8h
  - CO: 20 ppm / 8h
  - CO2: 0.1 %vol / 8h
- **rise and delay times:**
  - meeting or exceeding § 1065 requirements
- **Power demand:**
  - 24 V DC
  - ≈ 450 W @ 20 ° ambient T, 2 m sample line, after warm-up
- **Pneumatics:**
  - <3.5 l/min sample flow rate (Sample gas in)
  - Input: ZERO gas, SPAN gas
  - Burner gas for HFID
  - exhaust and drain out

GAS PEMS Specifications

Operating temperature (ambient)	-30 to 45 ° C (higher temperatures can be achieved by connecting external cooling air e. g. from the temperature conditioned passenger compartment
Storage temperature	-40 to +70 ° C (Oxygen sensor needs to be removed)
Dimensions	appr. 19“ x 8 HU x 540mm (w*h*d)
Weight	appr. 50kg
Warm-up time at 20 ° C ambient temp.	< 1hr
Power demand	24V DC, appr. 450W @ 20 ° C ambient temperature (with 2m Sample Line) after warm up
Sample flow rate	< 3.5l/min
Inputs/Outputs electrical	Heated line connectors (3 heating circles with 2x PT100); 1x Ethernet (TCP/IP) 1x CAN (CAN bus monitoring) 8x Analog out, 4x Analog in 4x Digital out (DC-isolated), 5x Digital in (DC-isolated)
Measurement Range	THC: 0-30,000 ppmC1 NO/ NO2: 0-5000 ppm (NO) 0-2500 ppm (NO2) CO/ CO2: 0-5 vol% (CO), 0-20 vol% (CO2)
Zero Drift	THC: 1 ppm/8h NO/ NO2: 2ppm/8h CO: 20ppm/8h CO2: 0,1 vol%/8h
Pneumatics Inputs/ Outputs	ZERO gas, SPAN gas, Burner gas for HFID, sample gas IN, exhaust and drainage OUT

AVL Gas PEMS
Rise time and Response time

Definition of rise time and response time:



evaluated according to "EPA § 1065" under the following conditions:

- Flow rate: 3.2 L/min
- Temperature for sampling lines and FID-Filter: 191 °C
- Environmental pressure: 972 mbar

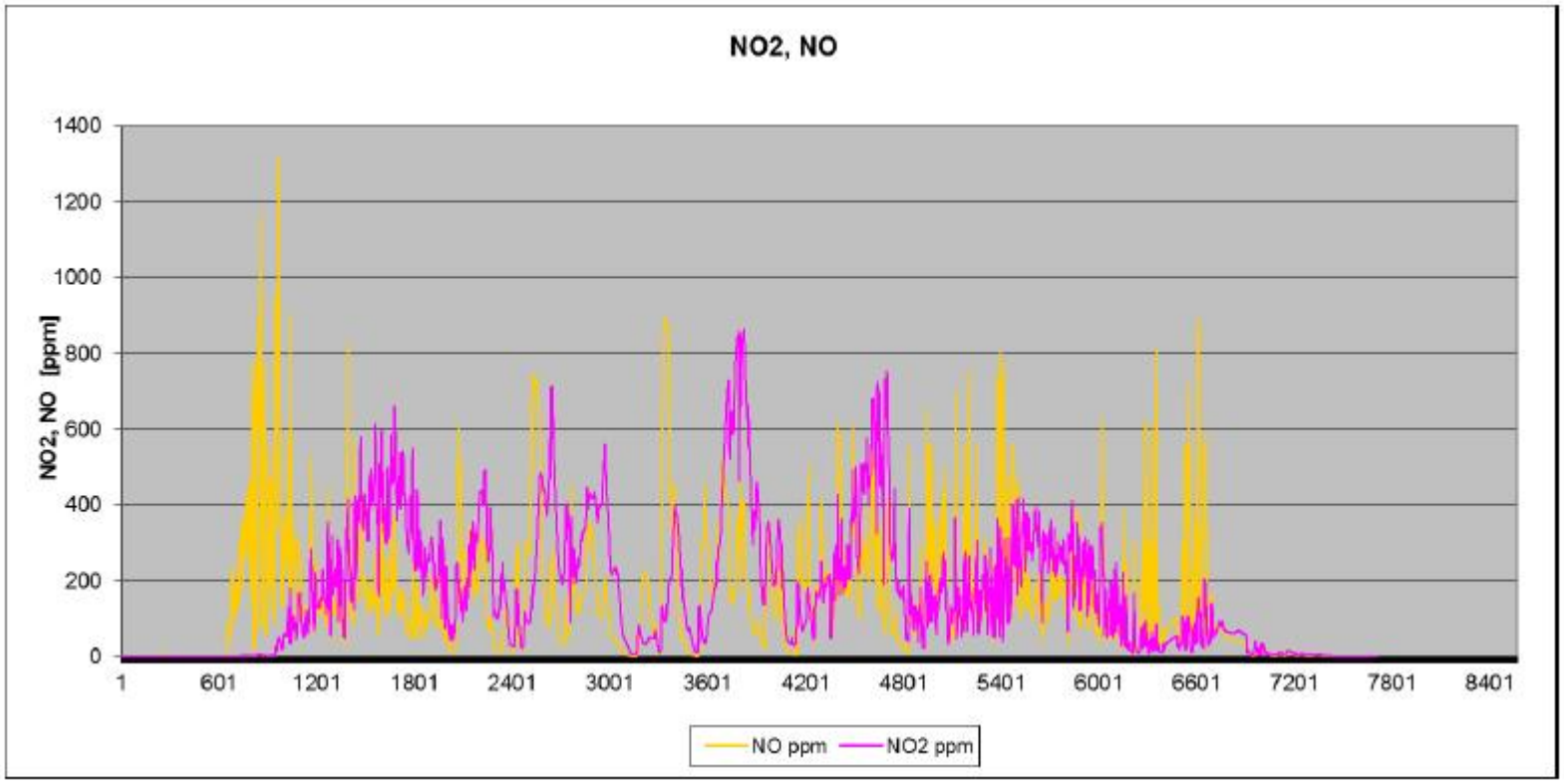
Analyser rise time: typically 3 sec

component	rise time (s)	Decay time (s)
THC	1.3	1.4
NO	2.8	2.8
NO_2	3.0	2.9
CO	3,1	2.7
CO_2	3.2	3.2
O_2	3.7	3.6

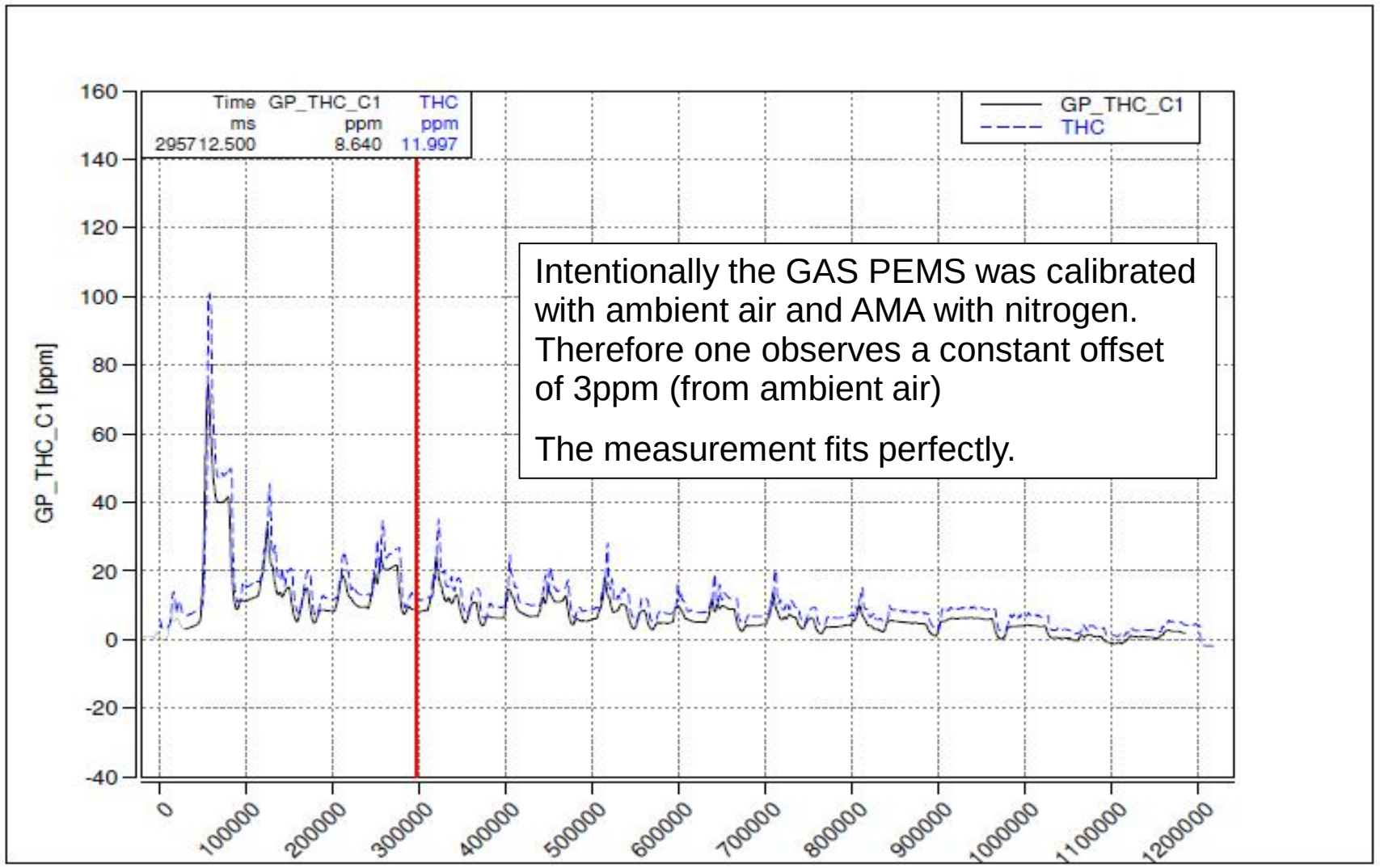
System response time with heated sampling lines [s]

component	2 m line	6 m line
THC	2.8	3.4
NO	7.4	8.0
NO_2	7.4	8.0
CO	10.5	11.1
CO_2	10.5	11.1

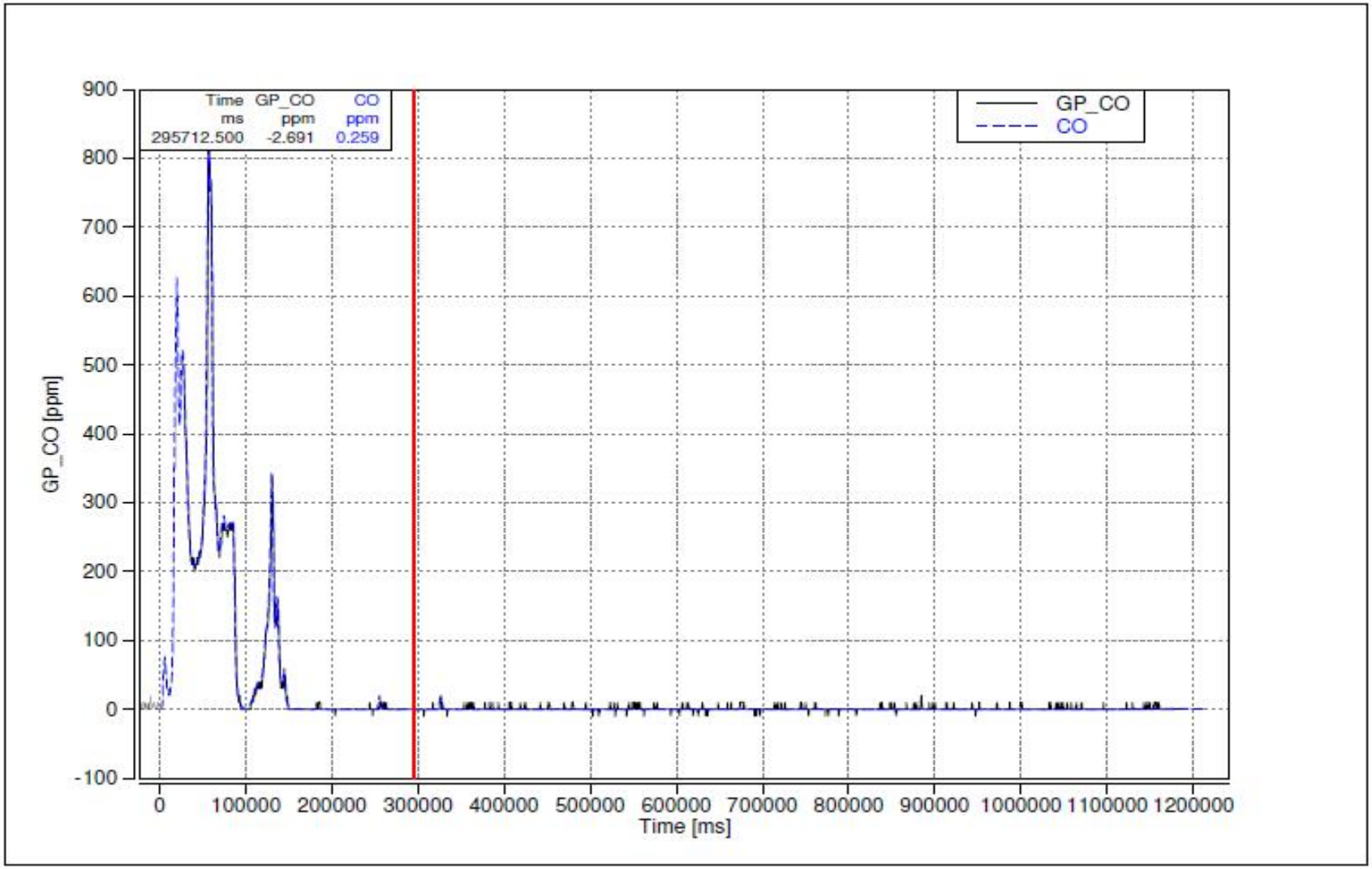
NDUV Analyser
No drift of NO, NO_2 over 2 hours



RESULT COMPARISON – AMA vs. Gas PEMS
Cold NEDC – Transient THC (raw gas measurement)



RESULT COMPARISON – AMA vs. Gas PEMS
Cold NEDC – Transient CO (raw gas measurement)



RESULT COMPARISON – AMA vs. Gas PEMS
Cold NEDC – AMA sampling from the CVS

		Chassis Dyno	AVL MOVE	AVL MOVE
		CVS/AMA 4000	GAS PEMS (1)	GAS PEMS (2)
	Unit	Total	Total	Total
THC:	**[mg/km]**	**6.819**	**5.64**	**6.21**
CH4:	**[mg/km]**	**2.717**		
NMHC:	**[mg/km]**	**4.453**		
CO:	**[mg/km]**	**43.528**	**34.61**	**38.76**
NOx:	**[mg/km]**	**195.639**	**186.37**	**200.08**
NO:	**[mg/km]**	**116.451**	**113.94**	**120.86**
CO2:	**[g/km]**	**174.036**	**(3) 175.33**	**163.87609**
AVL MOVE:				
(1) exhaust mass flow calculated from fuel flow (KMA Mobile) + C balance				
(2) exhaust mass flow from CVS				
(3) CO2 result calculated based on KMA data				

AVL Gas PEMS
GAS BOTTLE HANDLING

Before & After Testing

Before: Zero and Span Adjustment

After: Zero and Span Check

Zeroing with carbon-filtered ambient air.

Span: done manually with each bottle

3 bottles required: FID fuel, Mixed Gas, NO_2

R&D: only 2 Bottles: FID fuel & Mixed Gas. NO/NO_2 calibration is done with the internal reference cells

Gas Bottle Requirements:

- Mixed Gas:C_3H_8, CO, CO_2, NO
- NO_2
- FID fuel

Range: 80% of expected test range

Manufacturing accuracy: < +/-5%

Analysis accuracy +/- 1%

During Testing

Zero check:
is automatically initialized by the M.O.V.E System Control

Long term stability of the analyzers

è no intermediate span adjustment needed !

Only 1 bottle required: FID fuel

Gas Bottle Requirement:

FID fuel, e.g: 1l bottle; Ecocyl (picture right)

40% H_2 5.7

60% He 5.6 Ultra

Manufacturing accuracy: +/-1%

Analysis accuracy +/- 1%

AVL Gas PEMS
MAINTENANCE: Linearisation acc. to EPA § 1065

Maintenance → Testing

Linarization

- recommended monthly (market standard)
- done manually in the emissions lab
- up to 8 bottles required:

  FID fuel, CO, CO2, C3H8, NO, NO2, N2, Synthetic Air (SL)
- Gas Divider

Gas Bottle Requirements:

Linearization Gas Recommendation (based on AVL GAS-PEMS measuring ranges)

		Calibration Gas recommendation low	Calibration Gas recommendation high	Calibraion Gas Analysis Accuracy
C3H8 balance purified Synthetic Air	[ppm]	9000	9800	1%
NO balance purified Nitrogen	[ppm]	4500	4900	1%
NO2 balance purified Synthetic Air	[ppm]	2250	2450	1%
CO balance purified Nitrogen	[ppm]	45000	49000	1%
CO2 balance purified Nitrogen	[vol%]	18	19,6	1%
additional required ZERO Gas:		Synthetic Air and purified Nitrogen		

Gas Quantity for one typ. calibration	linearization
5l	30l
5l	30l
10l	40l
5l	30l
5l	30l

AVL M.O.V.E PM PEMS

Micro Soot Sensor for M.O.V.E

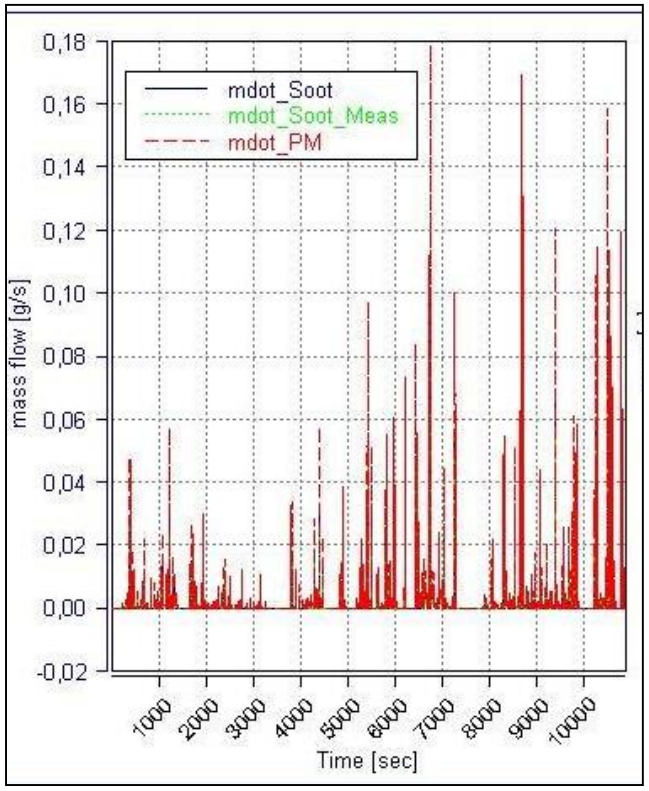
Gravimetric Filter Module

Heated Sample Line (52°C)

Heated Dilution Cell (45°C) with sample probe (<26 cm acc. to US legislation)

AVL PM PEMS
CORRELATION RESULTS – EU tests (JRC Ispra)

InUse testing requirements: PM measurement



The AVL PM PEMS uses the **soot mass emission** as continuously measured "particulate property"

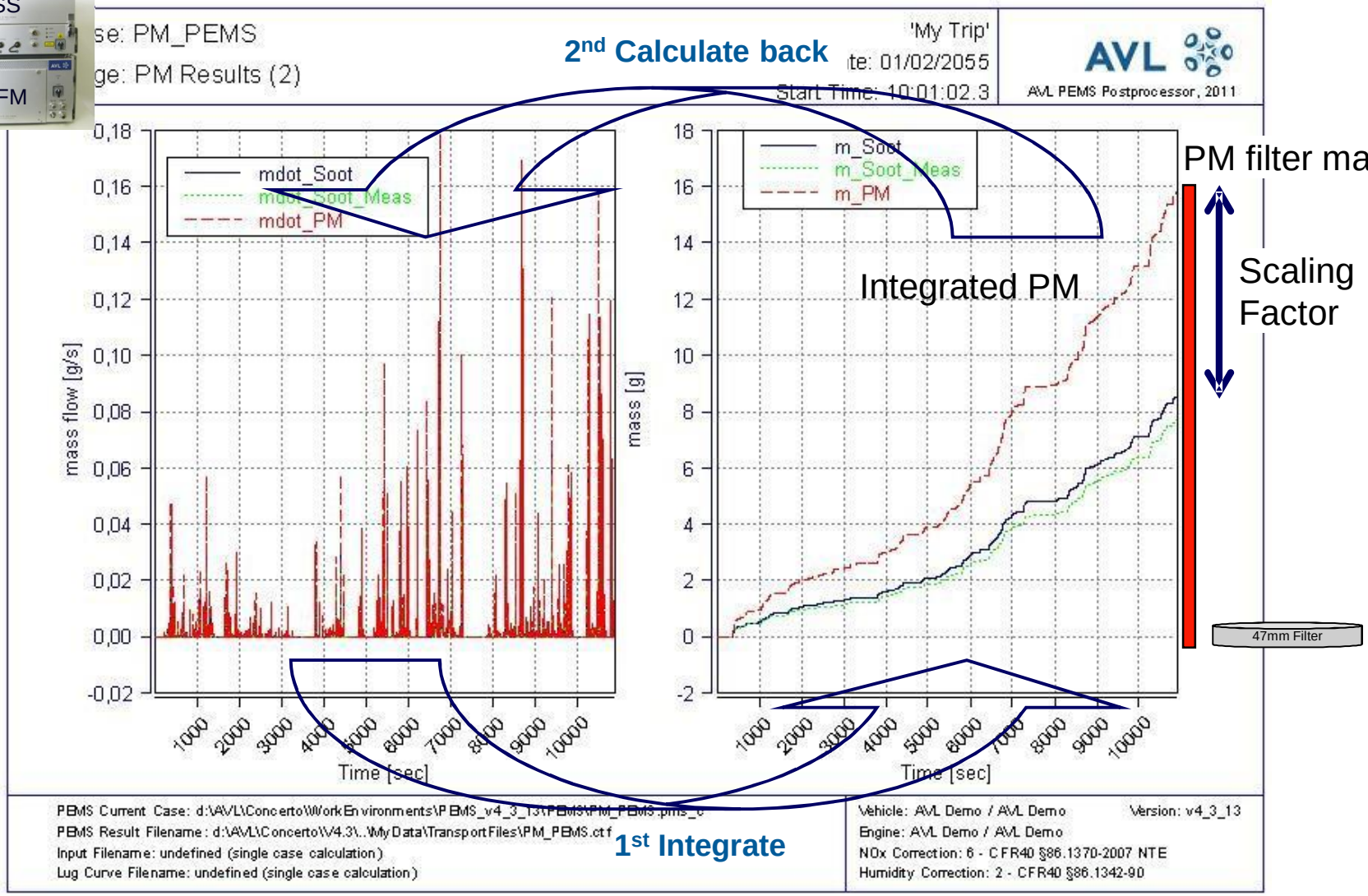
- An InUse (In-Service Conformity) test run lasts for at least 3 hours (10800 s).
- The emissions are evaluated over "events" during these tests runs. an "NTE" event (US legislation) may be as short as 30 s. A "work window" event (EU legislation) is typically between 1000 and 2000 s.

Ø The result of a batch sample – the PM filter weight gain – does not provide the information required for the evaluation of the emissions during an "event".

Ø A **continuous emissions signal** is required. Despite much effort in the last 40 years no continuous PM analyzer has been developed up to now.

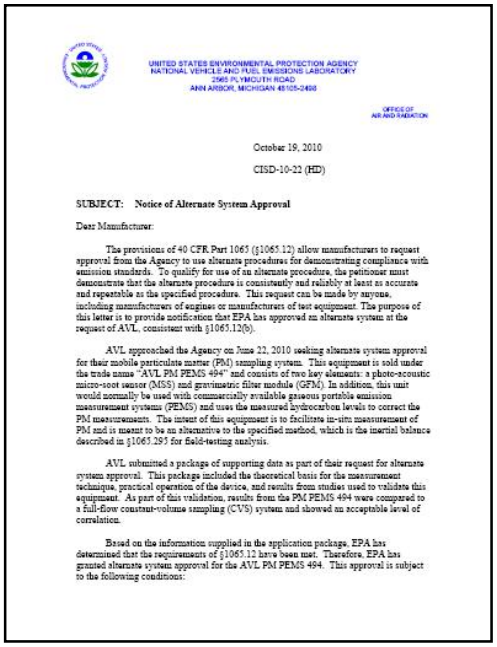
- The method of "upscaling" the continuous signal of some "particulate property" is the accepted method for In-Use PM measurement.

AVL PM PEMS – Measurement Principle



AVL PM PEMS:
US EPA APPROVAL, EU PM PEMS program acceptance

<u>On 19.10 the U.S. EPA issued a "Notice of alternate system approval"</u> *for the AVL PM PEMS (Micro Soot Sensor + Gravimetric Measurement)*



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
2565 PLYMOUTH ROAD
ANN ARBOR, MICHIGAN 48105-2498

OFFICE OF
AIR AND RADIATION

October 19, 2010

CISD-10-22 (HD)

SUBJECT: Notice of Alternate System Approval

Dear Manufacturer:

The provisions of 40 CFR Part 1065 (§1065.12) allow manufacturers to request approval from the Agency to use alternate procedures for demonstrating compliance with emission standards. To qualify for use of an alternate procedure, the petitioner must demonstrate that the alternate procedure is consistently and reliably at least as accurate and repeatable as the specified procedure. This request can be made by anyone, including manufacturers of engines or manufacturers of test equipment. The purpose of this letter is to provide notification that EPA has approved an alternate system at the request of AVL, consistent with §1065.12(b).

AVL approached the Agency on June 22, 2010 seeking alternate system approval for their mobile particulate matter (PM) sampling system. This equipment is sold under the trade name "AVL PM PEMS 494" and consists of two key elements: a photo-acoustic micro-soot sensor (MSS) and gravimetric filter module (GFM). In addition, this unit would normally be used with commercially available gaseous portable emission measurement systems (PEMS) and uses the measured hydrocarbon levels to correct the PM measurements. The intent of this equipment is to facilitate in-situ measurement of PM and is meant to be an alternative to the specified method, which is the inertial balance described in §1065.295 for field-testing analysis.

AVL submitted a package of supporting data as part of their request for alternate system approval. This package included the theoretical basis for the measurement technique, practical operation of the device, and results from studies used to validate this equipment. As part of this validation, results from the PM PEMS 494 were compared to a full-flow constant-volume sampling (CVS) system and showed an acceptable level of correlation.

Based on the information supplied in the application package, EPA has determined that the requirements of §1065.12 have been met. Therefore, EPA has granted alternate system approval for the AVL PM PEMS 494. This approval is subject to the following conditions:

Reasons:

- Mature Product
- Near Perfect Correlation to CVS, therefore a relatively small "Measurement Allowance" (In-Use emissions limit extension relative to the certification limit) can be set.
- Good on Environmental Tests.
- Passed Validation Tests of the US EPA-EMA "Measurement Allowance Program"

<u>EU PM PEMS Programs (ongoing)</u>

The AVL PM PEMS has participated in all phases of the EU PM PEMS programs, showing its applicability also for the proposed EU In-Service Compliance test requirements. It is considered one of acceptable systems by the EU "Real Driving Conditions Working Group"

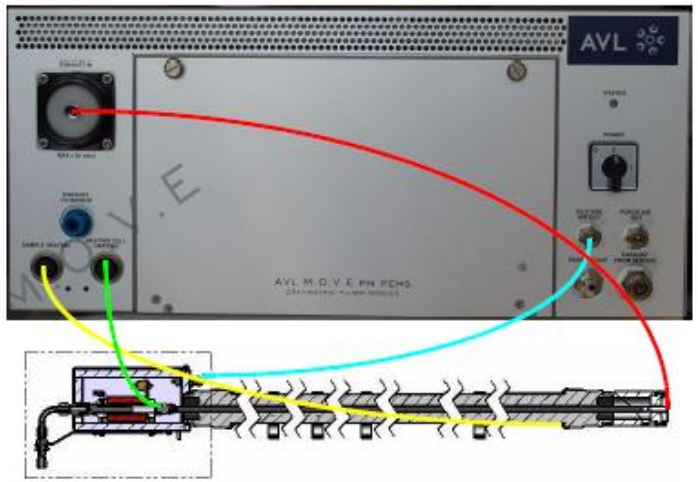
In-Use PM Testing – AVL Micro Soot Sensor

The Micro Soot Sensor has been proven to give reliable results in different evaluation programs - some of them are still ongoing

- The Ce-Cert tests for the pilot in-use program
- The US EPA measurement allowance program
- The ACES program (2005)
- The EU PEMS for gaseous emissions
- The EU PM-PEMS program (currently running)
- ...

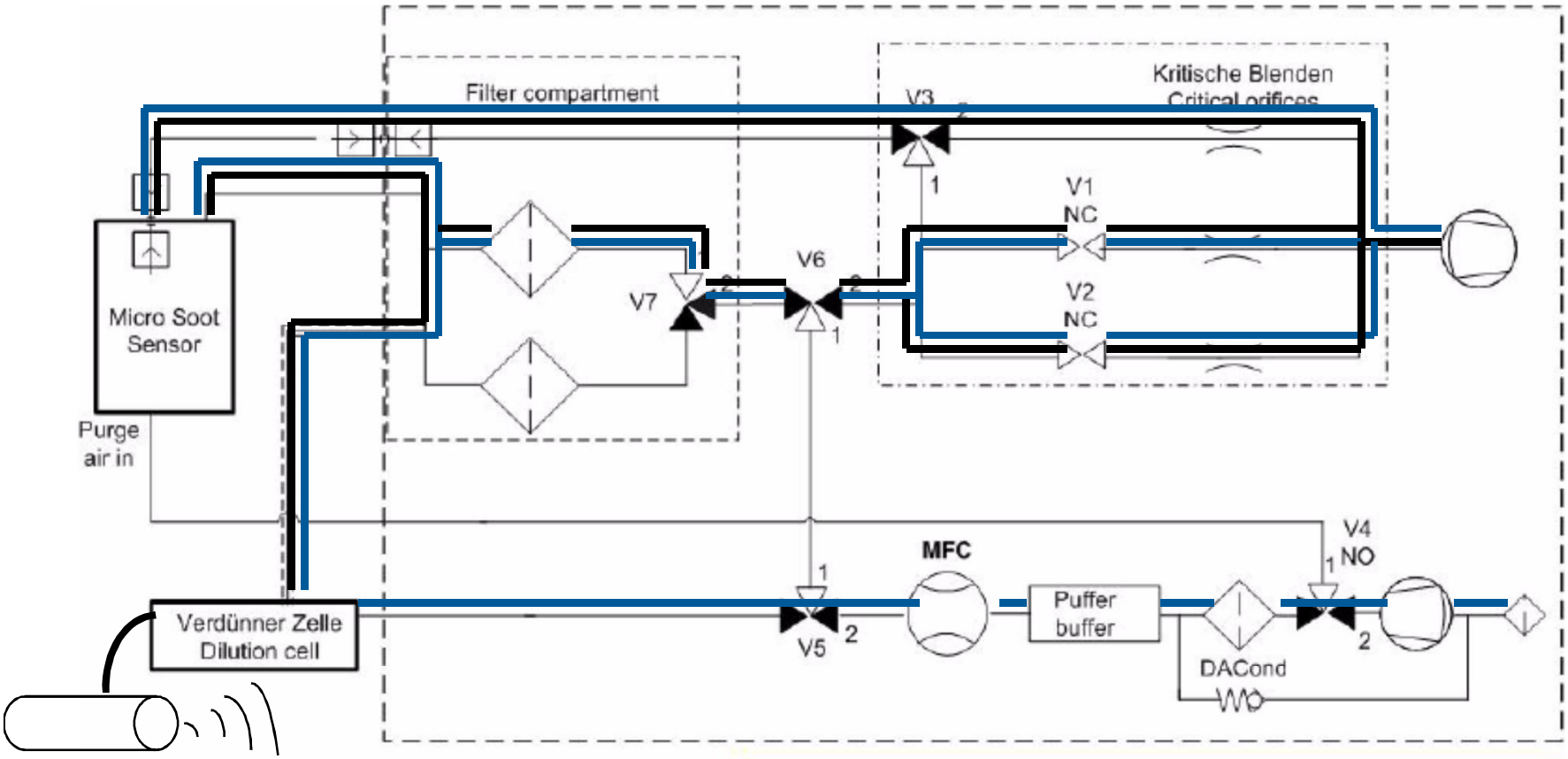
But measures soot and US EPA/ EU PEMS requires PM…

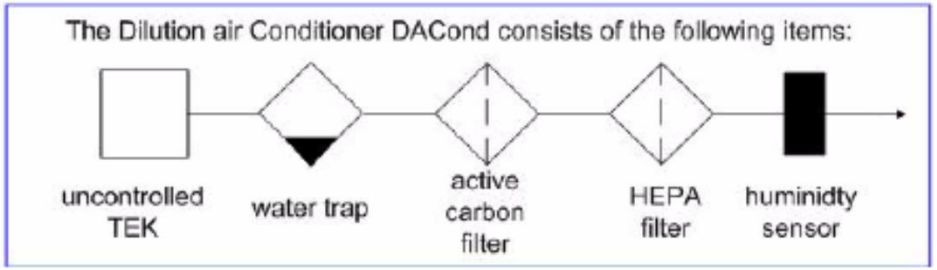
AVL PM PEMS Gravimetric Filter Module : Dilution Control and Particulate Measurement



- Constant dilution (no proportional sampling – no online exhaust flow signal required) by differential flow control.
- Flow control:
  Diluted exhaust: Critical Flow Orifices (CFO)
  Dilution air:
  Thermal Mass Flow Meter/Controller (MFC).
- High dilution accuracy due to “relative calibration” (MFC versus Critical orifice)
- Dilution air conditioning:
  TE cooler, water trap/ condensate pump, active carbon and HEPA filter
- Temperature conditioning of filters, MFD, dilution cell, heated line (52°C).
- Filter holder for 47mm particulate filters – front and backup. Specially small design with CFR §1065 compliant filter cassettes and dust protection.
- Easy access to the particulate filter,
  and to the conditioning filters during regular maintenance

Pneumatic Diagram PM PEMS





Dilution Air
Raw Exhaust Gas
Diluted Exhaust Gas

AVL PM PEMS 494 Highlights

- **Complete package for In-Use PM Testing and R&D**
  PM PEMS + Concerto PEMS (data evaluation and reporting)
- **High measurement accuracy**
  - Combination of 2 ***mass*** related measurements (no assumptions required)
  - Continuous sampling (no delay/ switching times, no data loss)
- **Compact dimensions, short installation times**

§ **Easy Integration into existing gaseous PEMS systems**
No online mass flow signal needed (no proportional sampling)

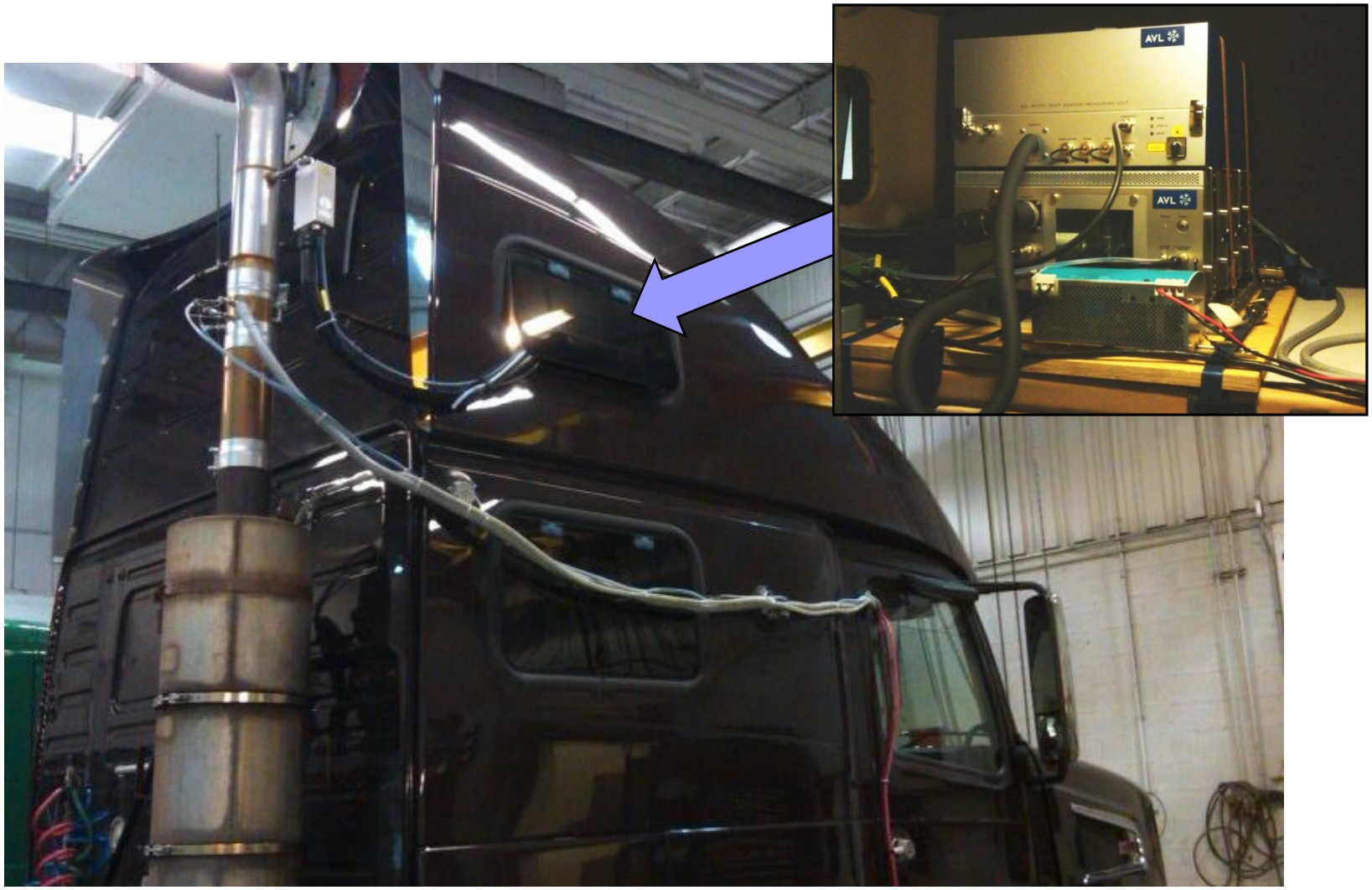
§ **Easy Operation**
Preconfigured Device Control Software with a full set of diagnosis feature, e.g. Filter overloading protection (switches to bypass if the soot mass exceeds a predefined limit)

§ **Mature product and robust design for reliable measurements**
MSS has proven its robustness in many official test campaigns

AVL PM PEMS Specifications

Sensor	Soot concentration measurement (mg/m^3)
Detection limit	0.005 mg/m^3
Measuring range	0.005 – 50 mg/m^3 ● dilution ratio
Rise time	≤ 1 sec
Exhaust pressure tolerance	-50 mbar to +50 mbar; with press. reduction up to 1 bar
GFM	**Dilution control and PM collection on a filter**
Dilution ratio	3 – 12 (default 6)
Sample flow over the filter	Nominally 5 l/min
Filter holder	47 mm (fully 1065 compliant) or 14 mm dia filters (front+backup)
System	
Dimensions	Width: 19“, depth: 450 mm, hight: 5HE(Sensor) + 4.5HE(GFM)
Weight:	22 kg (Sensor), 26 kg (GFM)
Operating (Storage) temperature	5 to 42 °C (-40 to +70 °C)
Ambient humidity:	< 95% or dew point < 35°C, whichever is lower.
Warm-up time	< 30 min
Power requirement:	24 V= or 115/230 V≈ (dual power supply), 600 W (total)
Data logging frequency	1 to 10 Hz Measurement data, 1 Hz Service data
Interfaces	TCP/IP, 2•RS232, 6•Digital I/O, 4•Analog In, 2•Analog OUt

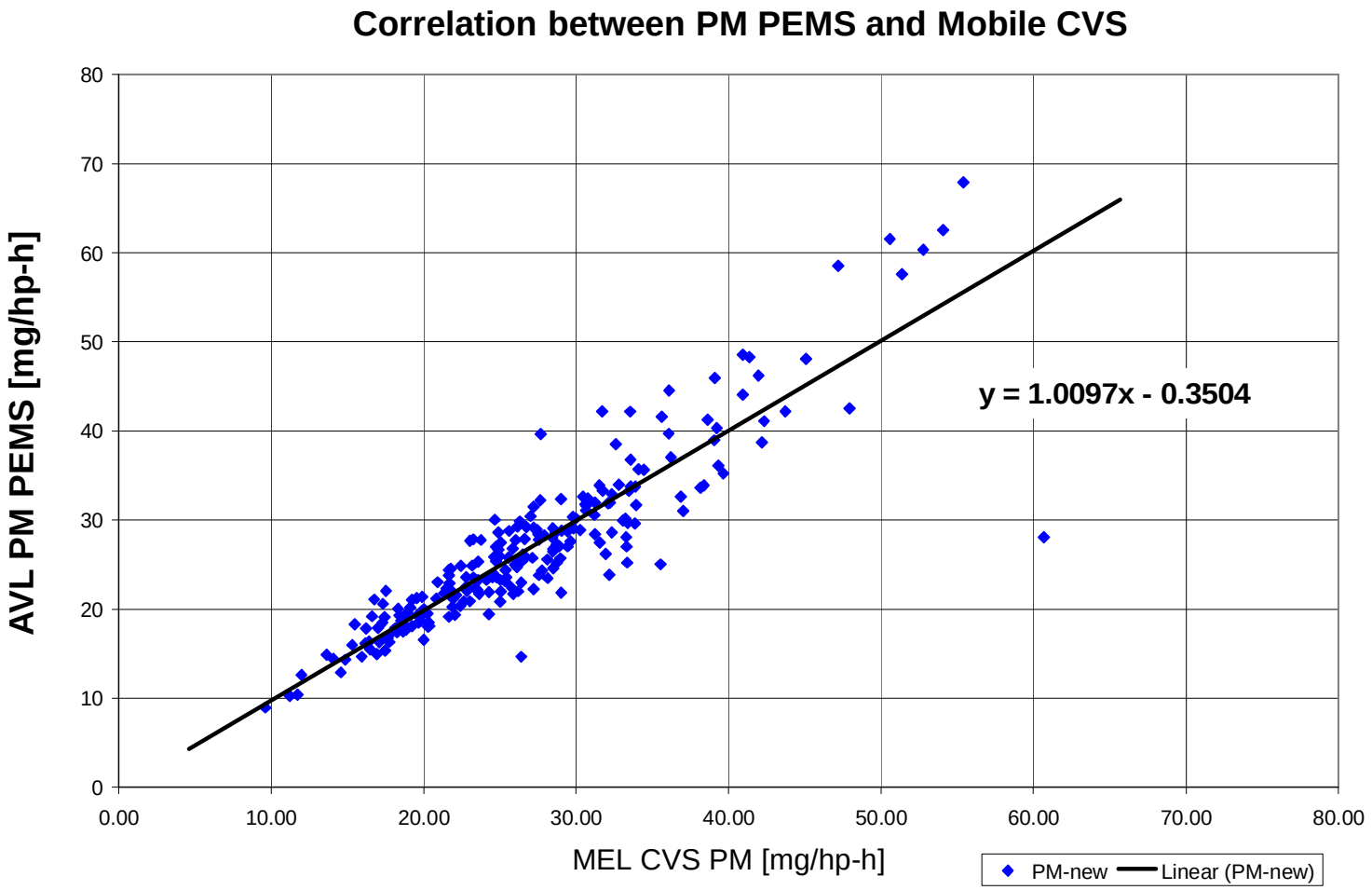
AVL PM PEMS on a Truck



AVL PM PEMS on a Truck

AVL PM PEMS on a Construction Machinery

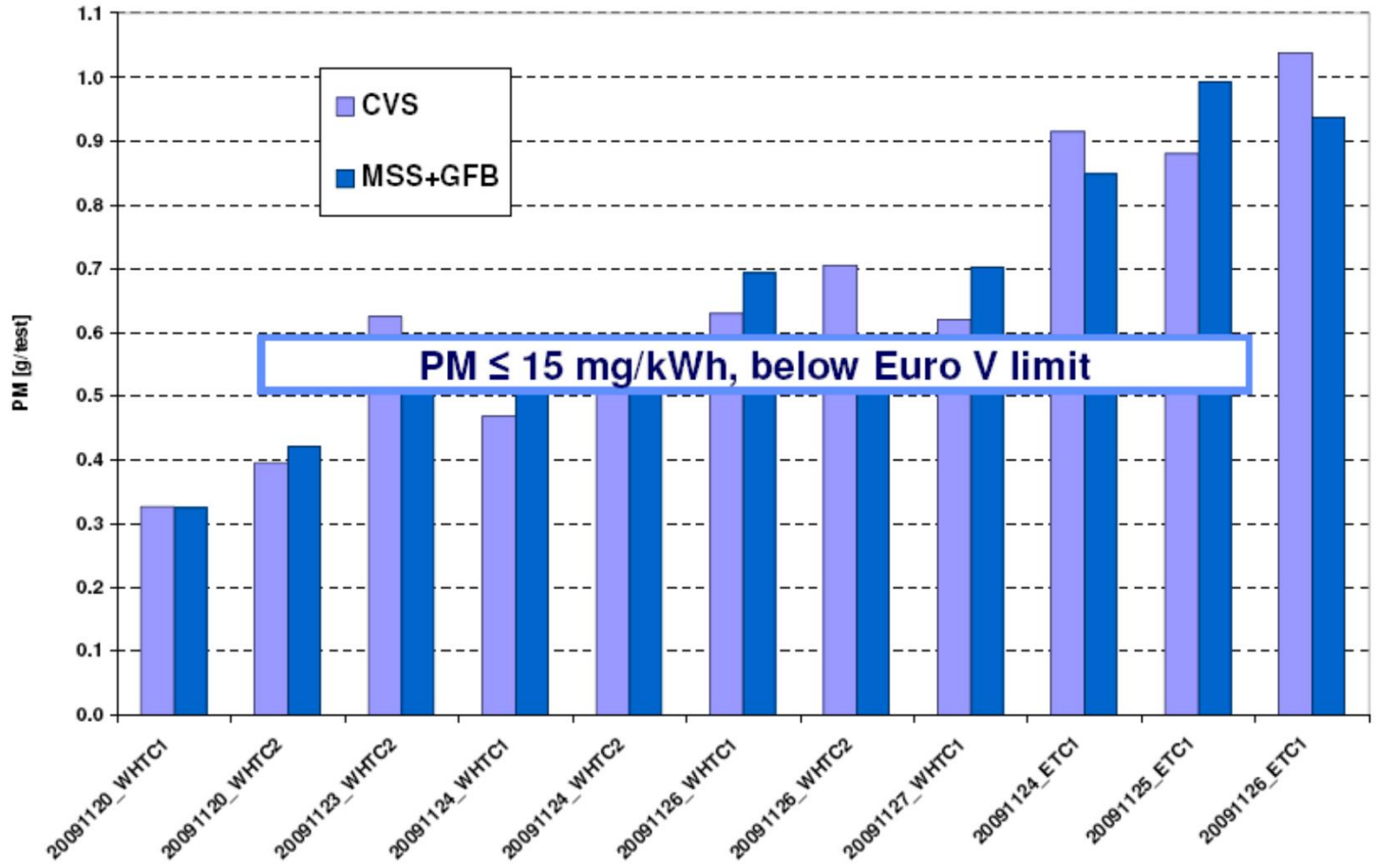
AVL PM PEMS:
CORRELATION RESULTS – US Verification tests



AVL PM PEMS
CORRELATION RESULTS – EU tests (JRC Ispra)

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Institute for Environment and Sustainability



THANK YOU
for your attention

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Karl Oberguggenberger
Marco Schöggl
Martin Rzehorska
Roland Wanker
Wolfgang Schindler
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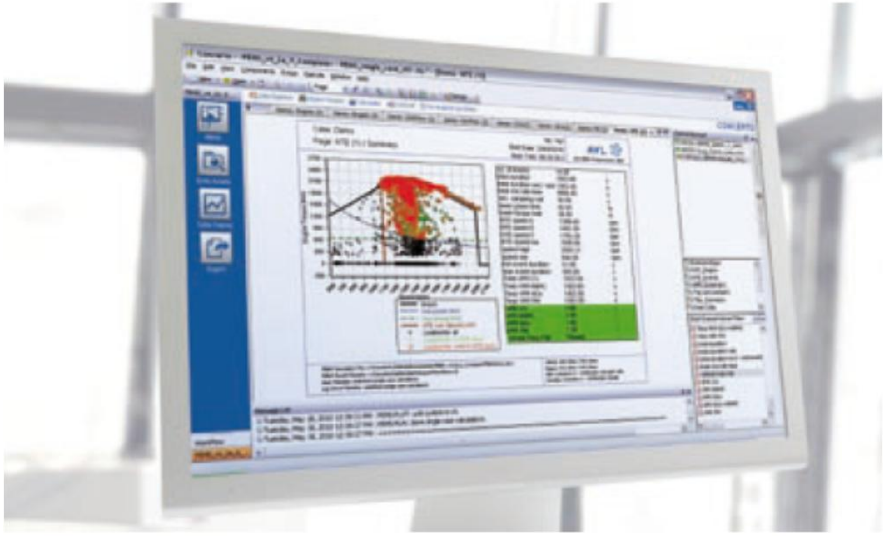
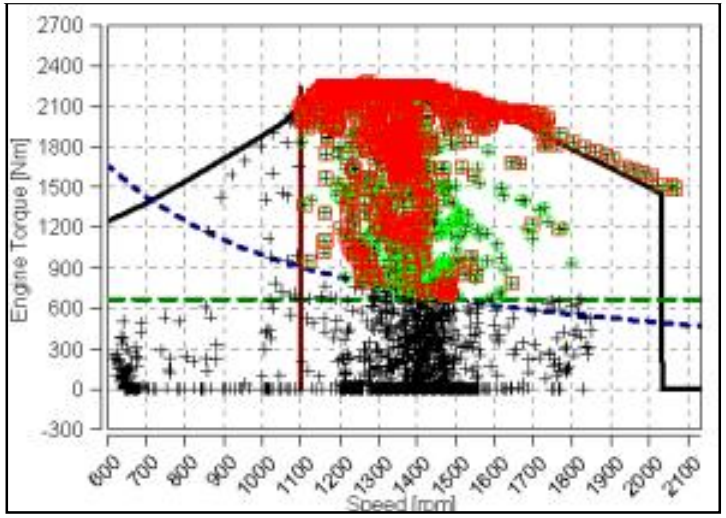
AVL M.O.V.E CONCERTO PEMS – POST PROCESSING



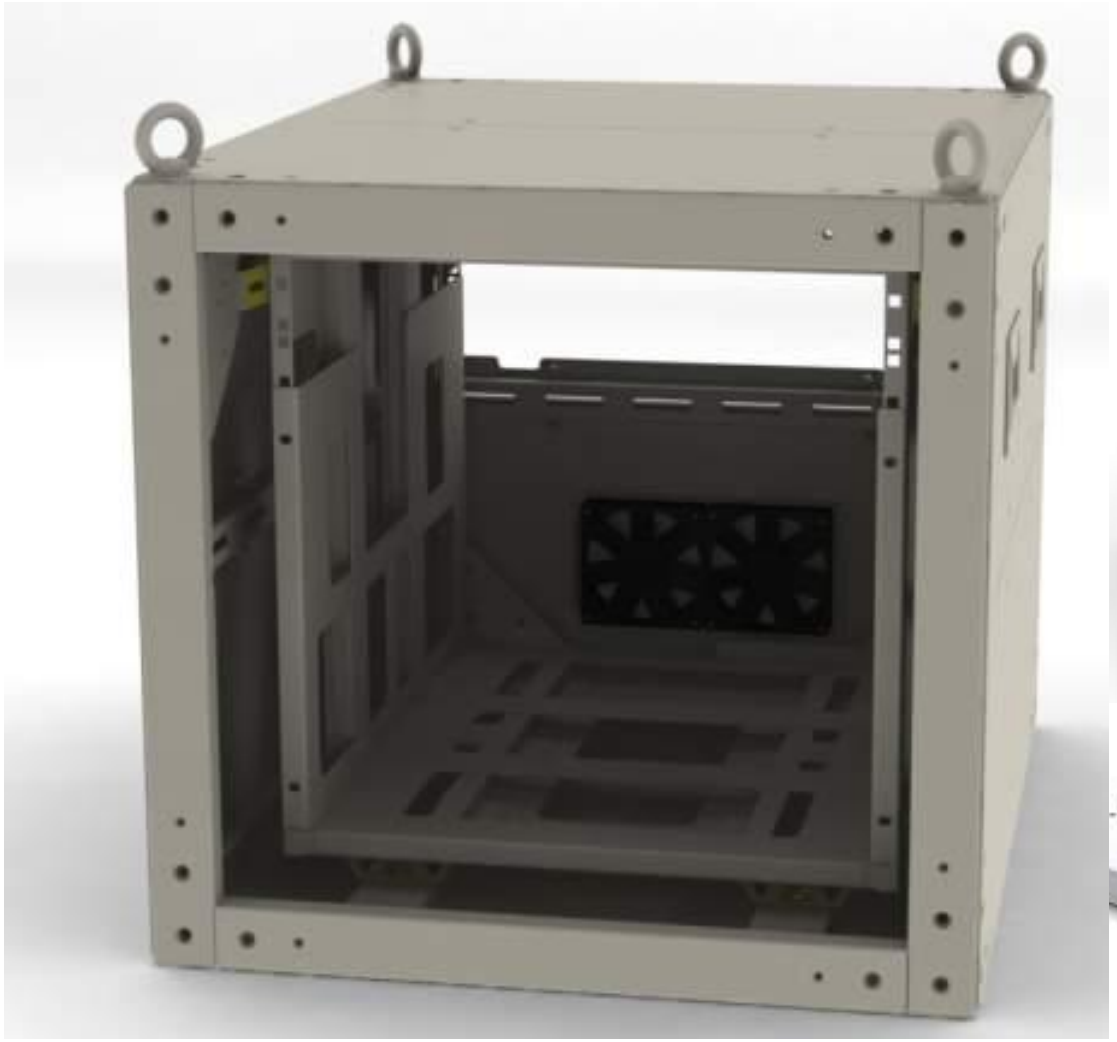


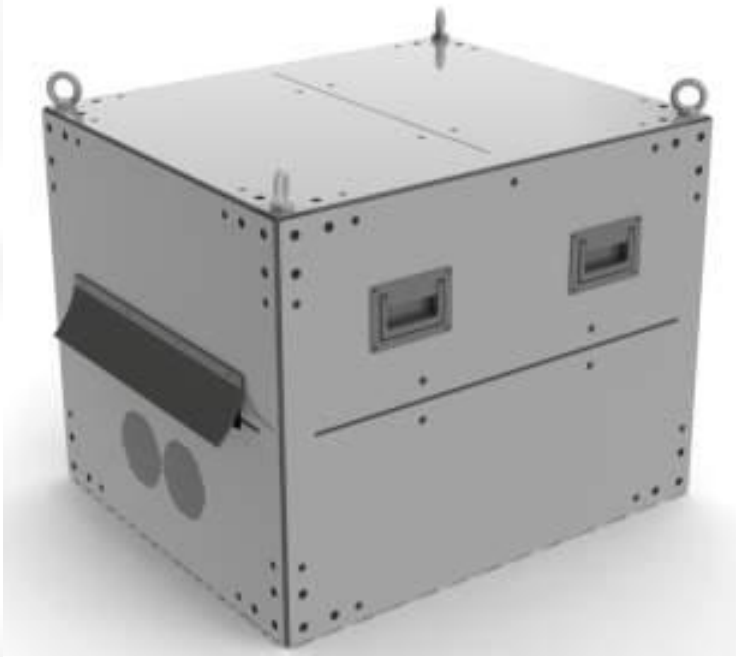
- Software to supports the user by evaluating, correlating and validating the measured data after the tests
- Predefined layouts, e.g. for legislative PEMS evaluations, complete test validation and report generation
- Import of measurement data from arbitrary sources:
  - AVL
  - SEMTECH™
  - HORIBA OBS2x00™
- PEMS Calculations:
  - US EPA (Not-To-Exceed)
  - EU PEMS (CO2 and Work Window)
- Legislative Reporting:
  - US HDIUT Program
  - …

AVL PEMS @ CRC CONFERENCE IN CALIFORNIA

AVL PEMS @ CRC CONFERENCE IN CALIFORNIA

Rugged Case/ Dampening Plate





Integration to existing Gaseous PEMS Systems

(+)

TRIGGER
Cable

+

+

AVL Concerto PEMS