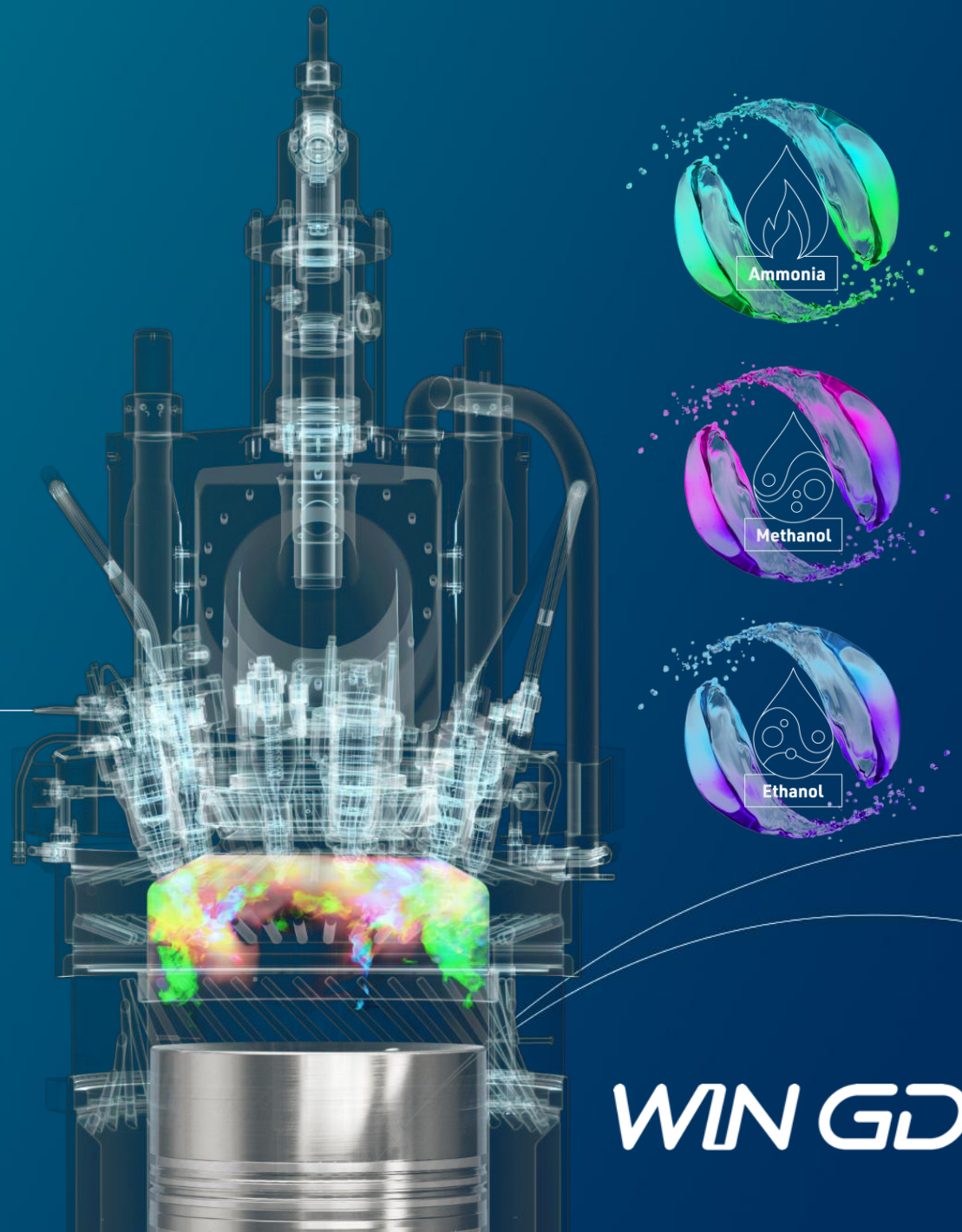
Emissions from Methanol and Ammonia engines: An OEM Perspective



Sotiris Topaloglou,
Deputy VP R&D
Head Testing & Validation

Gabriele Pisetta,
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Testing & Validation

WIN GD

Contents

Emission measurement systems for licensee testing

1	Introduction to WinGD ammonia and methanol engines
2	Measured gas species & Measurement chain
3	Measurement setup – research engines
4	Measurement setup – prototype commercial engines
5	Practical considerations
6	Data acquisition and postprocessing
7	Summary

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Introduction to WinGD Ammonia and Methanol engines



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X-DF A by WinGD Setting the Standard

Diversified ship types with Ammonia as fuel

Exmar
46’000 m³ LPG/NH3 carriers
Hyundai Mipo Dockyard



Bocimar
210k dwt Bulkers
Qingdao Beihai S/Y



CMB/NCL/Yara
1300teu Feeder
CMHI Weihai



AET/MISC
Aframax Tankers
Dalian DSIC S/Y



Engine Family	Cylinders	N° of engines
X52DF-A	6	25
X62DF-A	6	3
X72DF-A	6	12
Grand Total		40+

Amon Maritime
51’000 m³ MGC
CIMC SOE



Trafigura
45’000 m³ MGC
Hyundai Mipo Dockyard



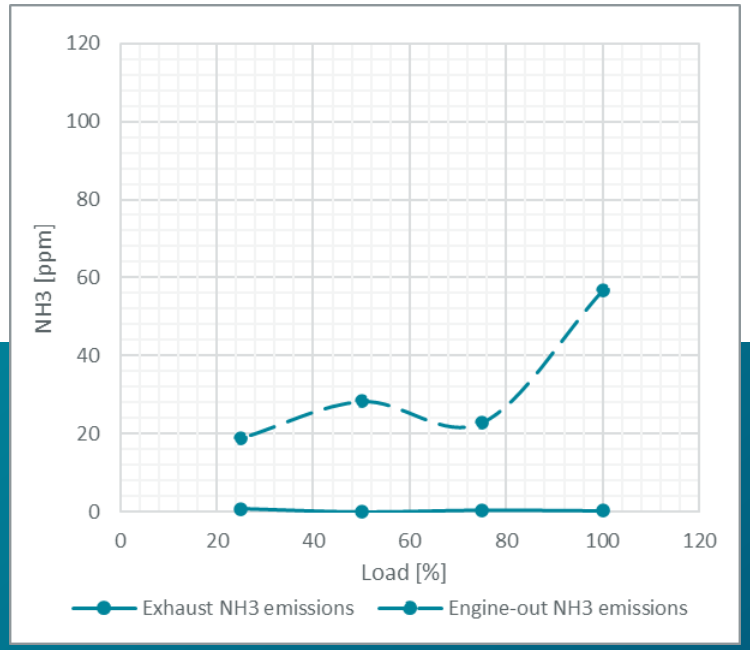
Tianjin Southwest Maritime
25k & 41k LPG carriers
Guangzhou Wenchong SY

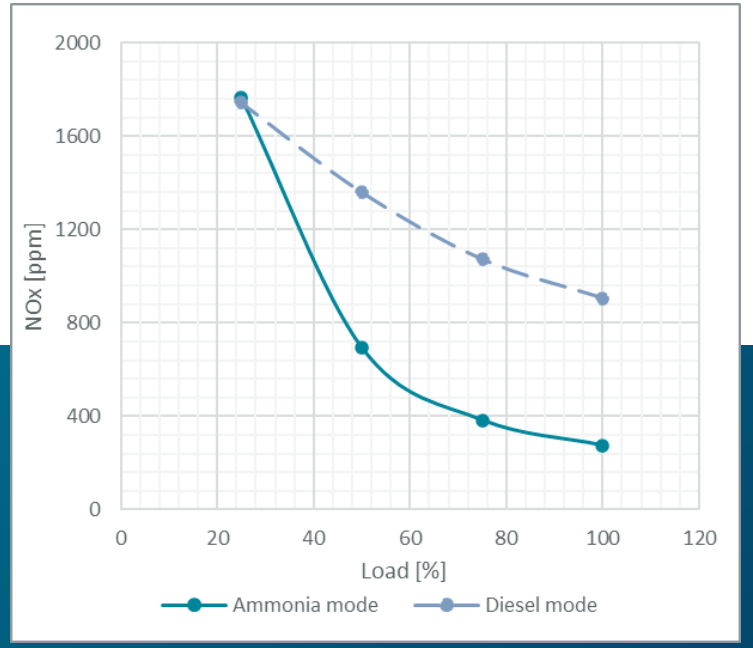


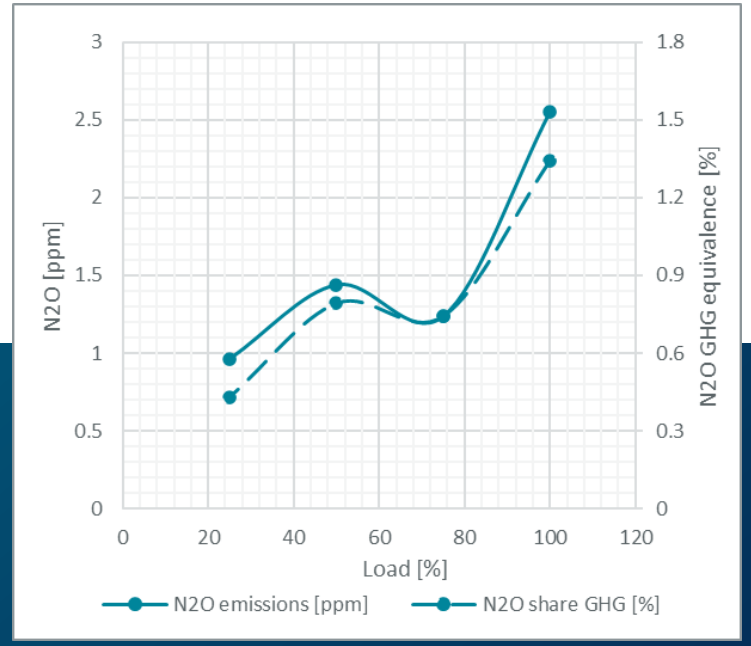
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X-DF-A by WinGD Emissions

Measured values during the official shop test







NOx: Tier II & Tier III compliant. Ammonia mode generates less NOx (<50%) than diesel mode

NH3 slip: Very low engine-out emissions, zero NH3 emissions downstream SCR

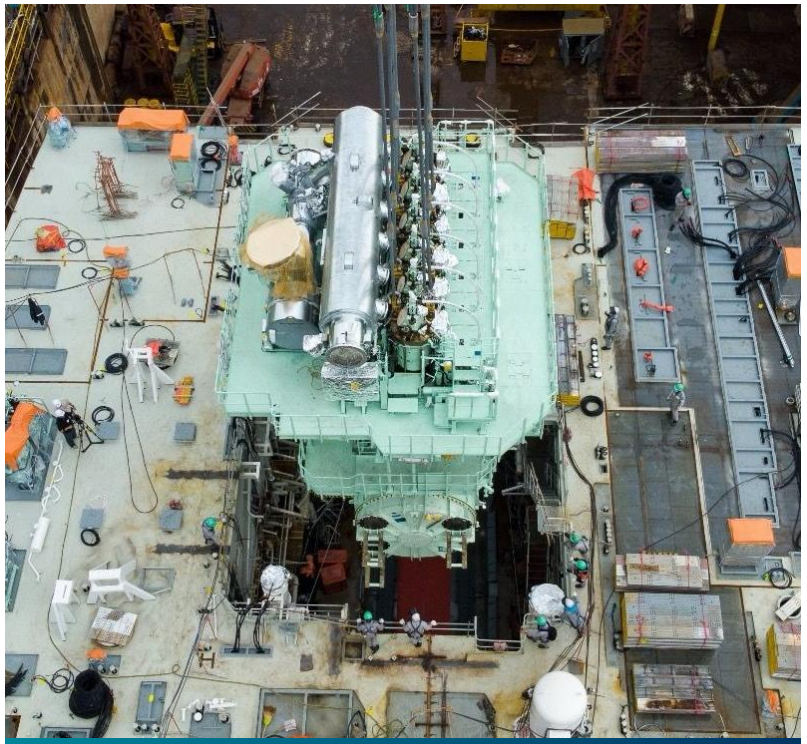
N2O: Very low engine-out emissions, no N2O aftertreatment needed

Greenhouse Gas reduction confirmed >90% with X-DF-A

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First Commercial Engine

WinGD's first ammonia fuelled engine installed on Exmar vessels

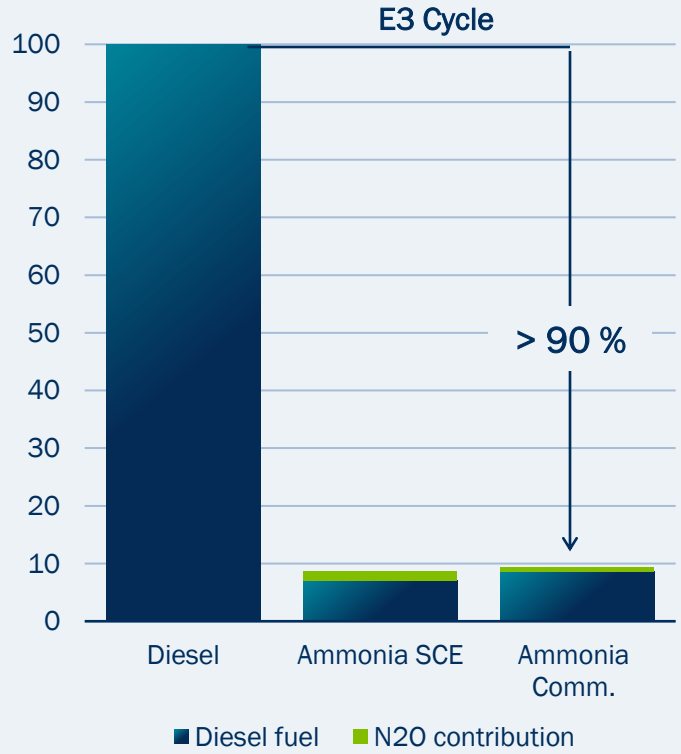


June 2025

GHG reduction consistent with Full Scale Engine Test

Performance predictions fully achieved

Measured emissions aligned with Full Scale Engine results



Installation of the X-DF-A engine on the world's first oceangoing ammonia-fuelled vessel. Photo courtesy of Exmar.

© 2026 WinGD Ltd.

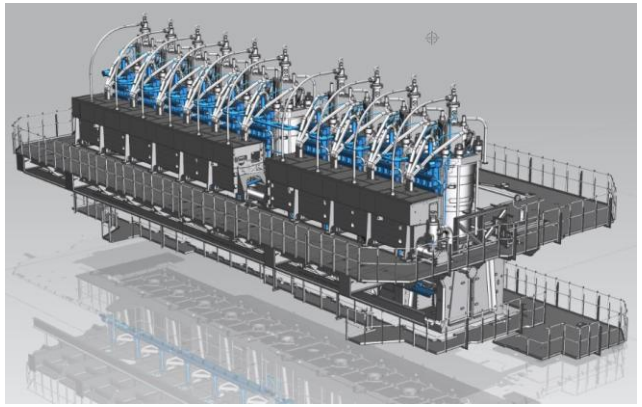
X-DF M by WinGD References, Methanol

Large range of engine types contracted for range of different vessel types

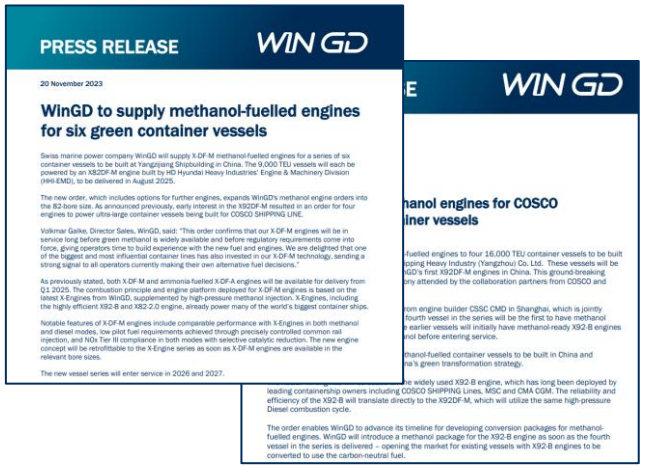
Engine type	# of sets	Ship types
X92DF-M-1.0	41	UL Container vessels
X82DF-M-1.0	22 (2 ethanol enabled)	Intermediate CV, VLOC, VLCC
X72DF-M-1.0	4 (4 ethanol enabled)	VLOC
X62DF-M-1.0	11	Aframax tankers
X62DF-M-S1.0	6	Container vessels
X52DF-M-S1.0	5	2000 CEU PCTC, Tankers
Total	**89 sets**	

Owners include:

- COSCO Shipping Lines
- COSCO Shipping Bulk
- COSCO Shipping Energy
- Maersk
- ONE
- Seaspan
- Evergreen







PRESS RELEASE WIN GD

20 November 2023

WinGD to supply methanol-fuelled engines for six green container vessels

Swiss marine power company WinGD will supply X-DF-M methanol-fuelled engines for a series of six container vessels to be built at Yangzijiang Shipbuilding in China. The 9,000 TEU vessels will each be powered by an X82DF-M engine built by HD Hyundai Heavy Industries' Engine & Machinery Division (HHI-EMD), to be delivered in August 2025.

The new order, which includes options for further engines, expands WinGD's methanol engine orders into the 82-bore size. As announced previously, early interest in the X92DF-M resulted in an order for four engines to power ultra-large container vessels being built for COSCO SHIPPING LINE.

Volkmar Galke, Director Sales, WinGD, said: "This order confirms that our X-DF-M engines will be in service long before green methanol is widely available and before regulatory requirements come into force, giving operators time to build experience with the new fuel and engines. We are delighted that one of the biggest and most influential container lines has also invested in our X-DF-M technology, sending a strong signal to all operators currently making their own alternative fuel decisions."

As previously stated, both X-DF-M and ammonia-fuelled X-DF-A engines will be available for delivery from Q1 2025. The combustion principle and engine platform deployed for X-DF-M engines is based on the latest X-Engines from WinGD, supplemented by high-pressure methanol injection. X-Engines, including the highly efficient X92-B and X82-2.0 engine, already power many of the world's biggest container ships.

Notable features of X-DF-M engines include comparable performance with X-Engines in both methanol and diesel modes, low pilot fuel requirements achieved through precisely controlled common rail injection, and NOx Tier III compliance in both modes with selective catalytic reduction. The new engine concept will be retrofittable to the X-Engine series as soon as X-DF-M engines are available in the relevant bore sizes.

The new vessel series will enter service in 2026 and 2027.

WIN GD

...nol engines for COSCO ...iner vessels

...fuelled engines to four 16,000 TEU container vessels to be built ...pping Heavy Industry (Yangzhou) Co. Ltd. These vessels will be ...GD's first X92DF-M engines in China. This ground-breaking ...ny attended by the collaboration partners from COSCO and ...

...om engine builder CSSC CMD in Shanghai, which is jointly ... fourth vessel in the series will be the first to have methanol ... earlier vessels will initially have methanol-ready X92-B engines ...nol before entering service.

...thanol-fuelled container vessels to be built in China and ...na's green transformation strategy.

...he widely used X92-B engine, which has long been deployed by leading containership owners including COSCO SHIPPING Lines, MSC and CMA CGM. The reliability and efficiency of the X92-B will translate directly to the X92DF-M, which will utilize the same high-pressure Diesel combustion cycle.

The order enables WinGD to advance its timeline for developing conversion packages for methanol-fuelled engines. WinGD will introduce a methanol package for the X92-B engine as soon as the fourth vessel in the series is delivered – opening the market for existing vessels with X92-B engines to be converted to use the carbon-neutral fuel.

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X-DF by WinGD 10X92DF-M-1.0

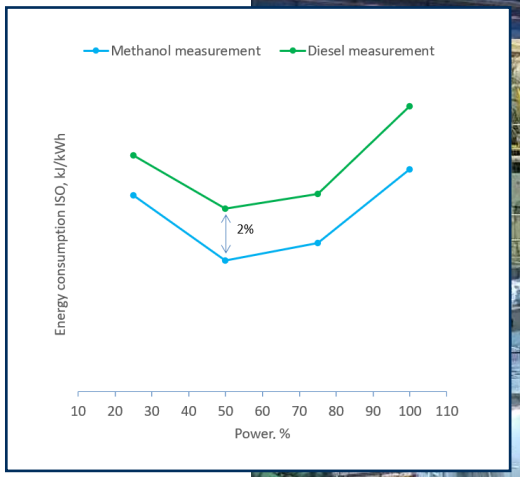
Test Results

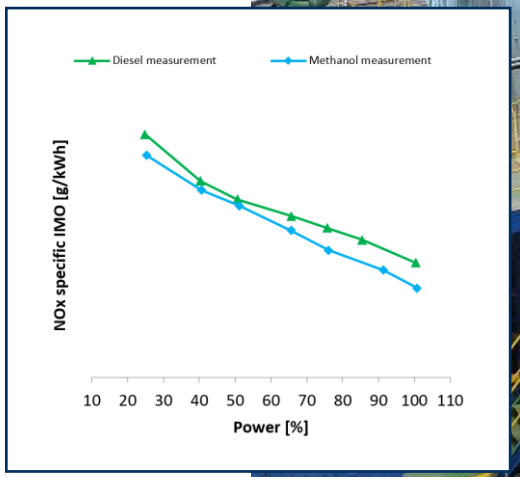
Consumption

- Best in class fuel consumption and methanol 2% lower than Diesel
- Pilot energy share <5% @100% load achieved

Emissions:

- NOx compliant with Tier II and Tier III standards, also for upcoming regulations for multiple fuel use
- CO_2 ca. 7.5% lower than in Diesel mode
- CH_2OH (formaldehyde) well below 25ppm
- HCN well below 15ppm





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Introduction to WinGD emission measurements



Introduction

Relevance of emission measurements for WinGD

Why are emissions measurements relevant for WinGD?

Decarbonisation of shipping industry through:

- Research and development of new engine types
  - Testing and validation of alternative fuels using novel fuel injection system
  - Optimisation of different engine control parameters (hardware/mechanical and software)
  - Development of WinGD own emissions abatement technologies
- Tuning of commercial engines in compliance with international regulations and contract obligations

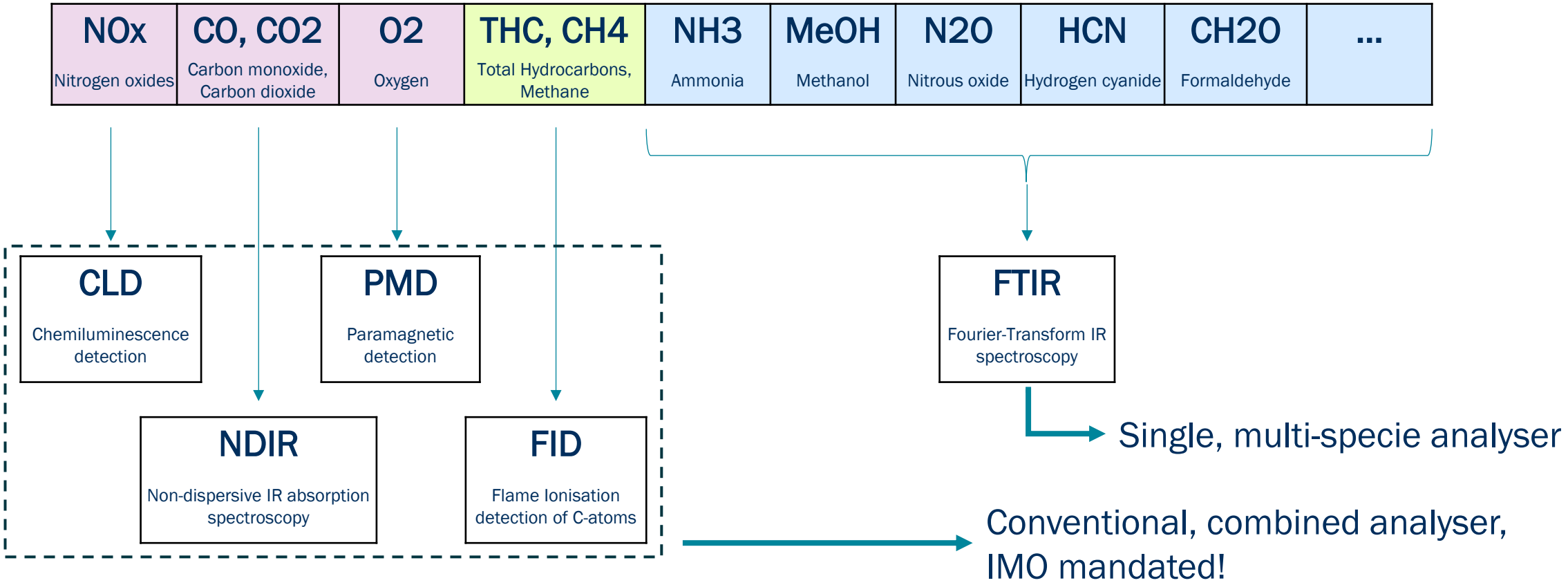
Test platforms

- Test engines – fix measurement setups
  - Engine Research & Innovation Centre (ERIC, Winterthur, Switzerland)
  - Global Test Centre (GTC Lingang, Shanghai, China)
- Prototype commercial engines – temporary, movable measurement setups

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Emission measurements at WinGD

Gas species and measurement principles



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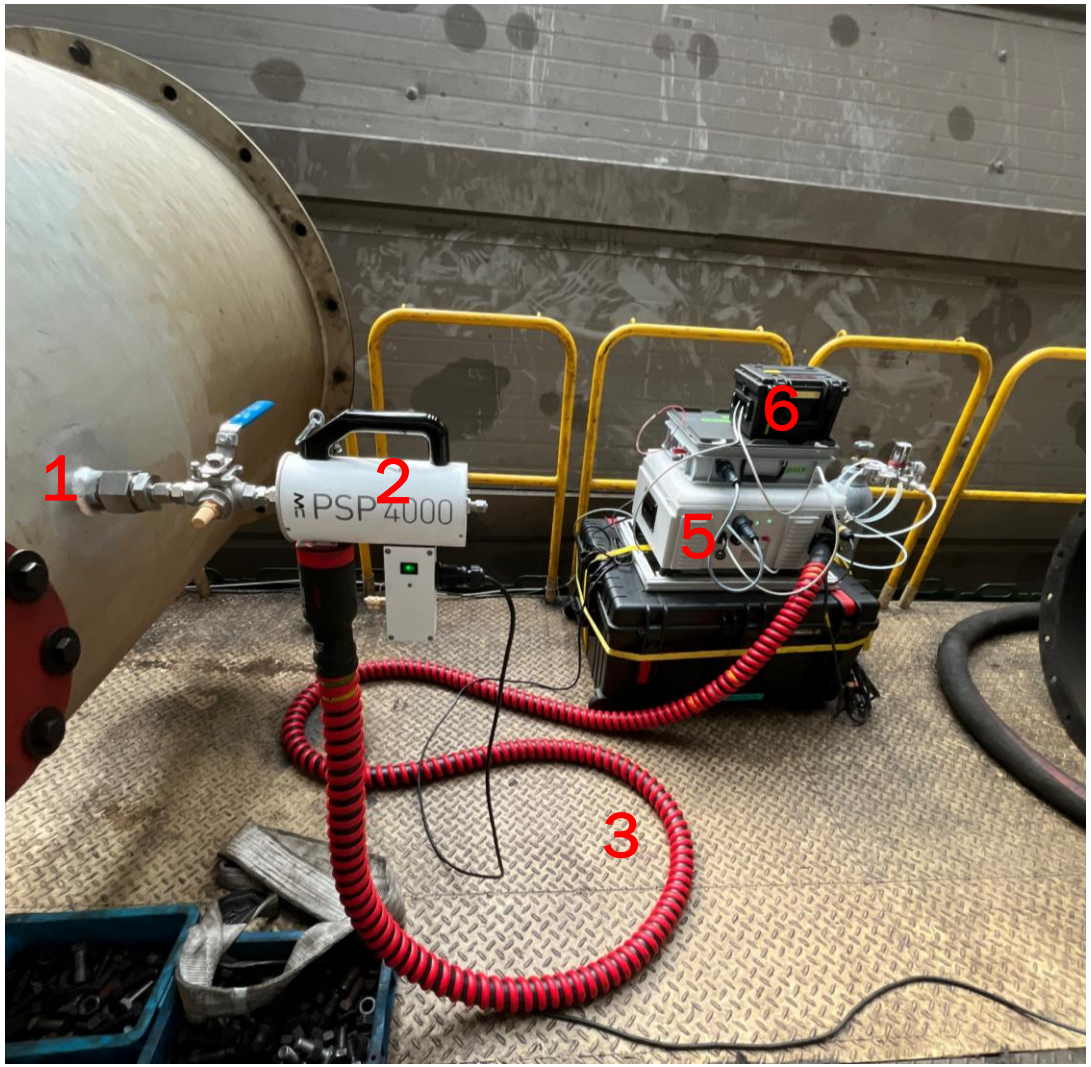
Emission measurements at WinGD

Exhaust gas conditions
160-400 degC
Large, steady-state volume flow
Solid particles (soot, lube oil, hc...)

Measurement chain

1. Sampling probe
2. Heated filter
3. Heated sampling line
4. (Gas conditioning unit)
5. Analyser
6. Data acquisition system





*measurement chain needs to fulfill IMO requirements



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Test platform

SCE 52, NH3 test engine – ERIC, Winterthur

- Single cylinder
- 52 cm bore diameter
- Power 1’500 kW
- Research engine



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Emissions setup

Measurement container

1. AVL AMA SL
   - Combines CLD, PMD, NDIR (CO and CO2), and FID
   - Integrated Gas conditioning unit
     - FID measure hot-wet gases
     - PMD and NDIR measure cold-dry
     - CLD can measure either wet or dry
   - Integrated NOx converter to reduce NO2 → NO, to measure combined NO + NO2
   - Prefilter + 10 m heated sampling lines
   - Data collection via AK-protocoll over TCP-IP
2. AVL Sesam i60 FTIR
   - Detector cooling via LN2
   - Constant purging of FTIR enclosure with clean, dry compressed air
   - Bench device (approx. 250 kg)
   - Prefilter + 10 m heated sampling lines



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Emissions setup

Portable devices

1. **Horiba PG350 + M&C PSS5** gas conditioning unit
   - Combines CLD, PMD, NDIR (CO and CO2)
   - Gas conditioning unit for cold-dry measurements
   - Integrated NOx converter to reduce NO2 ⟶ NO, to measure combined NO + NO2
   - 10 m heated sampling line + heated filter
   - Data collection via UDP-protocoll over TCP-IP
2. **CAI HFID 700**
   - THC/CH4 with integrated NMCH cutter
   - Measures also MeOH (response factor is 0.63, not actual MeOH concentration!)
   - Hot sample gas, wet measurements (wet-dry correction in post-processing)
   - 10 m heated sampling line + heated filter
   - Data collection via Modbus TCP



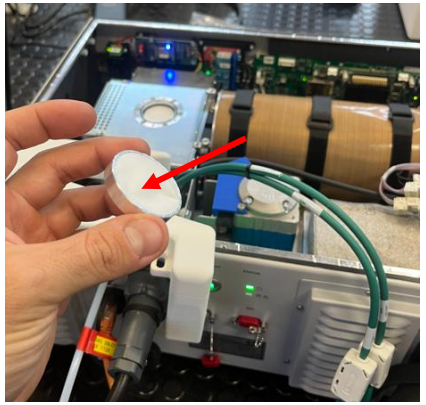
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Emissions setup

Portable devices

3. FTIR AVL MOVE FT

- Portable (about 19 kg), with integrated sampling unit
- Thermo-electric cooling of detector (no need for LN2)
- Purging CO2 and H2O from optical compartments using special tablets
- Background calibration with N2 gas
- Cannot measure O2
- 5 m heated sampling line + heated filter
- Data collection via AK-protocoll over TCP-IP





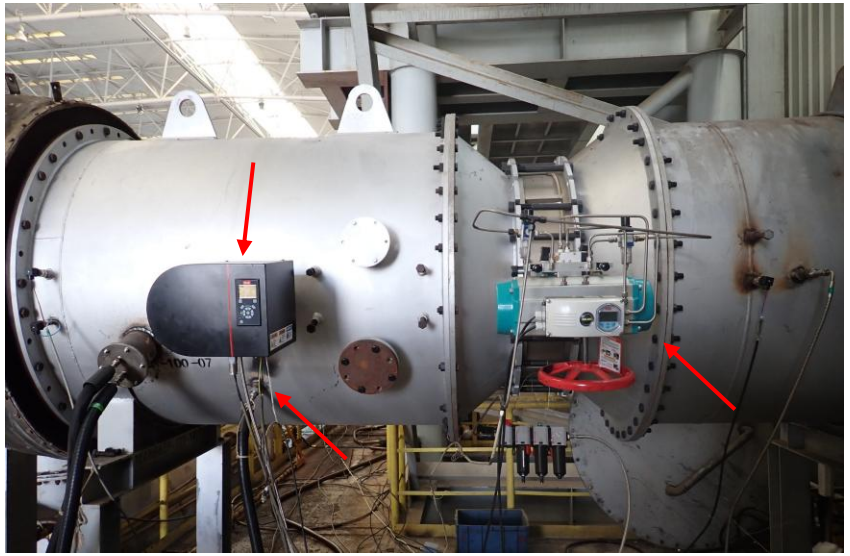
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Practical considerations

Large 2-stroke engine testing

- Accessibility to sampling point can be challenging
  - Long sampling hoses
  - Very high/low ambient temperature
- Solid particles in the gas (soot, lubrication oil, hydrocarbons…) require periodic replacement of filters
- Attention to choice of sampling point
  - Other devices might interfere









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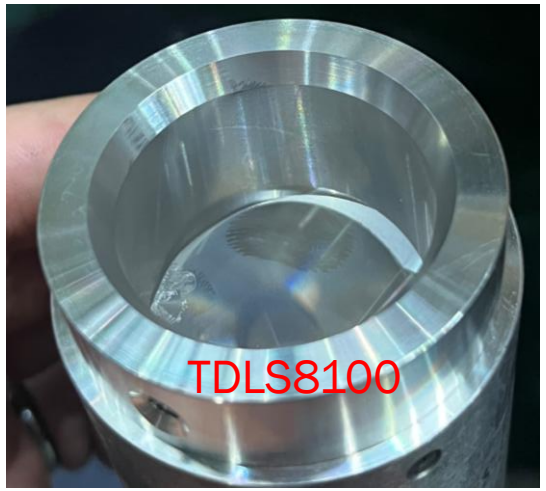
Practical considerations

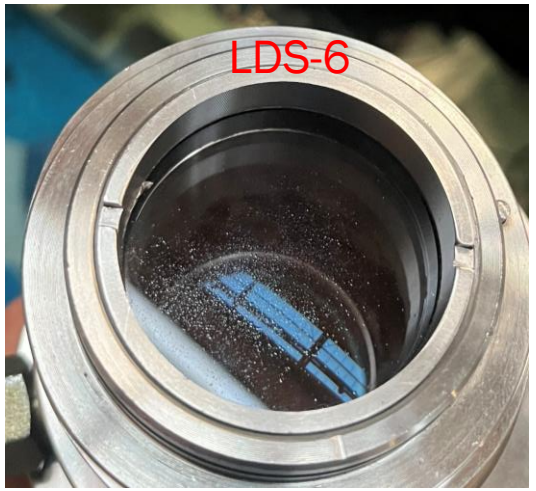
Large 2-stroke engine testing

- In-situ devices: hit-or-miss
  - Practical difficulties with Yokogawa TDLS8100 and Siemens LDS-6 (TDLS, NH3)
  - Very good experience with Danfoss IXA MES1001 (NDUV, NOx and NH3)
  - Analyser + sampling system is a safe choice









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Data collection and post-processing

Analysis of 2-stroke engine emissions

- All measurement data collected in single DAQ system
  - Engine data (power, cylinder pressure, exhaust valve stroke, injection pressures…)
  - Emission measurements
  - Fuel consumption via mass flow meters
  - Turbocharger data
  - …
- Emission data is normalised to ***specific emissions***
  - Procedure is standardised and provided by IMO (International Maritime Organisation)
  - Normalisation against engine power output, fuel consumption, exhaust mass flow, and ambient humidity and temperature

ppm or **vol% → g/kWh**

  - Resulting emissions are comparable across different engine loads, different engine sizes, and are independent of ambient conditions
  - Emissions are regulated in terms of their specific value

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Summary

Emission measurements on large 2-stroke marine engines

- Standardised measurement principles
  - CLD, PMD, NDIR, FID, FTIR
- Typical measurement chain based on analyser + sampling system (IMO compliant)
- Measurement environment poses restrictions on measurement setup
- In-situ devices require careful consideration
- Data processing is standardised (IMO mandated)

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Thank you

Propelling shipping towards a greener future

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Seeds

New IED and its implications for emission monitoring



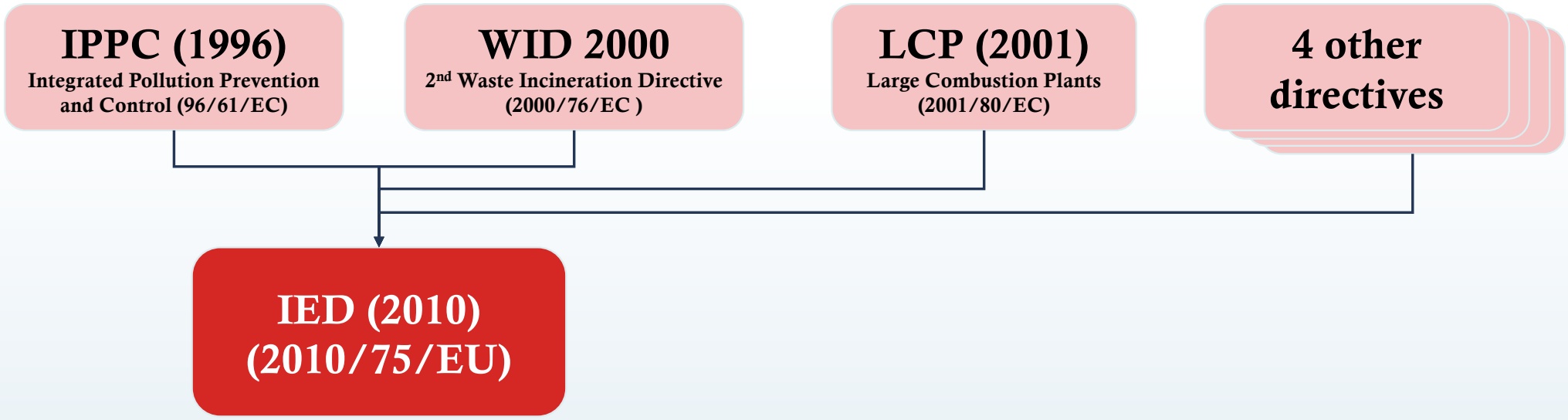
MaritimeMET, MetZeroPol, MetNH3Energy Joint Workshop, 30th September 2026

Sector-specific approaches to Emission Monitoring

01 Former Industrial Emissions Directive



How former IED came to life



Scope of IED

Some 50,000 installations across EU (Annex I activities)

Large variety of industrial/agro-industrial activities

Energy industries…

Mineral industries…

Metal industries…

Chemical industries…

Waste management…

Intensive livestock (pigs/poultry)…








Legal Framework

Principles:

- prevent and, if not feasible, reduce pollution
- high level of protection for the environment as a whole
- permit based on Best Available Techniques (BAT)

BAT are determined in a data-driven information exchange lead by a Technical Working Group steered by the JRC (EIPPCB) and documented in BREFs. The process is described in

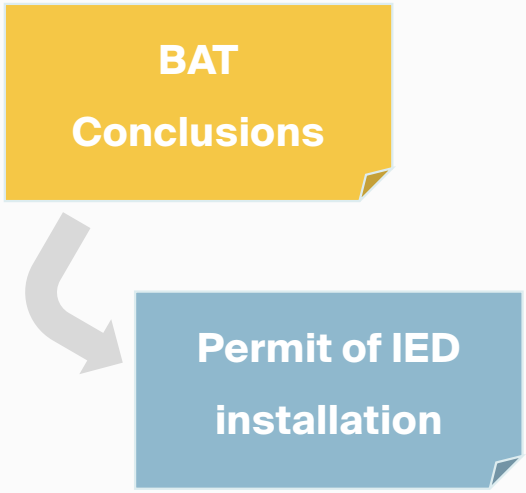
IED, Article 13
BAT reference documents and exchange of information

Legal Framework

IED ‘BAT Conclusions’ are published as **Commission Implementing Decisions and are secondary legislation** and the references for setting permit conditions for IED installations

“BAT Conclusions” contain

- Description of BATs
- Information to assess their applicability
- Emission levels associated with the best available techniques and with emerging techniques
- Environmental performance levels associated with the best available techniques and with emerging techniques
- Content of an environmental management system including benchmarks
- Associated monitoring
- Associated consumption levels
- Relevant site remediation measures (where appropriate)
- ...



IED - Compliance regime for emission limit values

Chapter II

Provisions for activities listed in Annex I

➢ Art.14.1 - *Member States shall ensure that the permit includes all measures necessary for compliance with the requirements of Art 11 and 18. Those measures shall include at least the following:*

(a) emission limit values for polluting substances […]

➢ Art.15.3 - *The competent authority shall set emission limit values that ensure that, under normal operating conditions, emissions do not exceed the emission levels associated with the best available techniques as laid down in the decisions on BAT conclusions referred to in Article 13(5) […]*

BAT Conclusions do not include rules on assessment of compliance

Chapter III/Annex V

Special provisions for combustion plants

PART 1
Emission limit values for combustion plants referred to in Article 30(2)

PART 2
Emission limit values for combustion plants referred to in Article 30(3)

PART 3
Emission monitoring

PART 4
Assessment of compliance with emission limit values

Chapter IV/Annex VI

Special provisions for waste (co-)incineration plants

PART 3
Air emission limit values for waste incineration plants

PART 4
Determination of air emission limit values for the co-incineration of waste

PART 6
Monitoring of emissions

PART 8
Assessment of compliance with emission limit values

IED - Compliance regime for emission limit values

Chapter II

Provisions for activities listed in Annex I

- Permit requirements such as Emission Limit Values have to be set on the basis of BAT Conclusions
- BAT Conclusions include reference to monitoring frequency and standards and associated emission levels (BAT-AELs)
- However, no compliance rules are included in BAT Conclusions because they are considered an implementation issue that cannot be tackled by secondary legislation



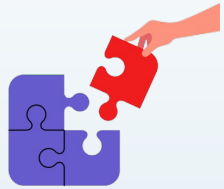
Chapter III/Annex V

Special provisions for combustion plants

Chapter IV/Annex VI

Special provisions for waste (co-)incineration plants

- Technical provisions in Annexes of IED include Emission Limit Values, monitoring requirements and rules to assess compliance against them.



IED - Compliance regime for emission limit values

Chapter II

Provisions for activities listed in Annex I





Chapter III/Annex V

Special provisions for combustion plants

Chapter IV/Annex VI

Special provisions for waste (co-)incineration plants

IED - Compliance regime for emission limit values

Chapter II

Provisions for activities listed in Annex I





Chapter III/Annex V

Special provisions for combustion plants

Chapter IV/Annex VI

Special provisions for waste (co-)incineration plants

However: BAT Conclusions were developed for sectors from Chapter III and IV too, causing a duplication of requirements....

BREF

IED ANNEX



IED - Compliance regime for emission limit values

Implementation of compliance rules, especially how to account for measurement uncertainty, was done differently at Member State level but also at local level



Summary of MS approaches for measurement uncertainty in continuous monitoring

- **Approach A**: Subtraction of maximum allowed measurement uncertainty from measured value
- **Approach B**: Subtraction of a fixed proportion of the ELV from the measured value
- **Approach C**: Subtraction of the actual measurement uncertainty of the measurement system (measured method) → i.e. use of QAL2 standard deviation
- **Approach D**: No subtraction of uncertainty
- (**Approach E**: Measurement uncertainty is reported but may be considered by the Authority only when measurements are reported above the ELV)

IED - Compliance regime for emission limit values

Implementation of compliance rules, especially how to account for measurement uncertainty, was done differently at Member State level but also at local level



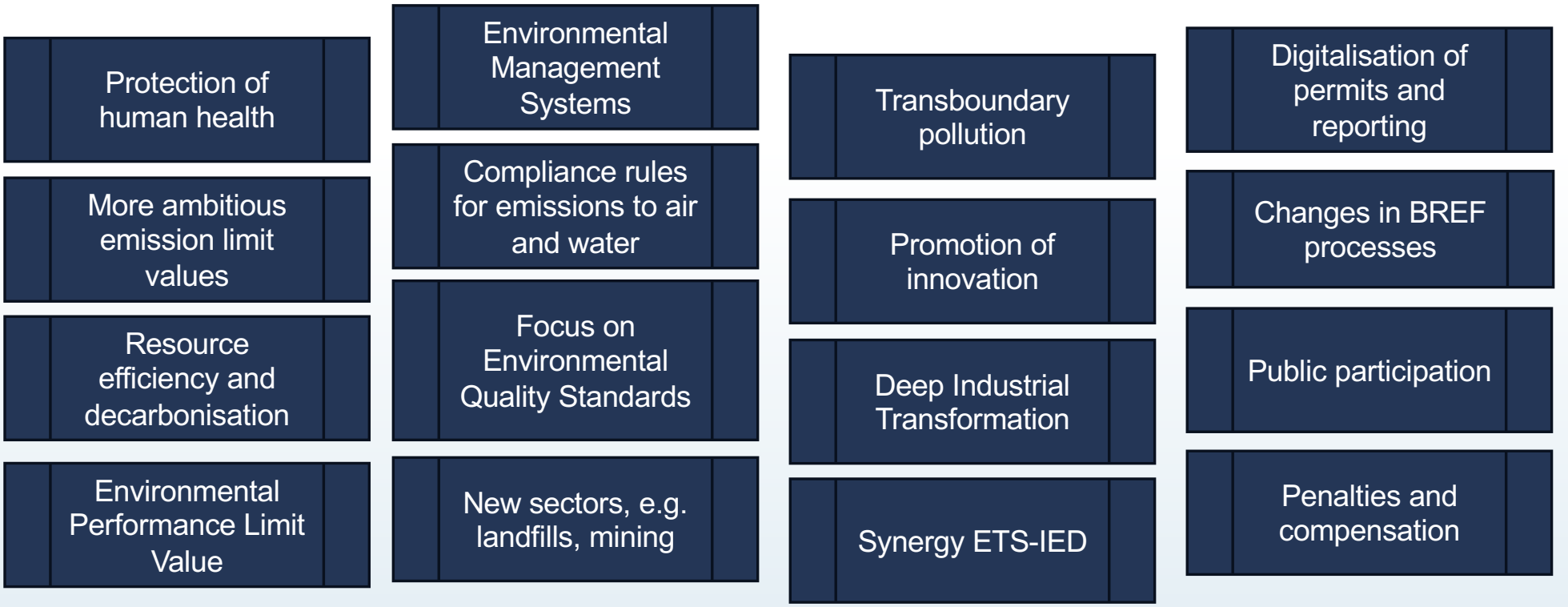
- **Approach C: Subtraction of the actual measurement uncertainty of the measurement system (measured method) → i.e. use of QAL2 standard deviation**

Strong link between implemented compliance rules for continuously monitored substances and EN standards such as EN 14181, EN 17255, …

02 Revised Industrial Emissions Directive



New Industrial Emissions Directive



BAT-AELs and Emission Limit Values

Article 15.3

CA shall set the strictest achievable emission limit values by applying BAT in the installation, considering the entire range of the emission levels associated with BAT Associated Emission Levels (BAT-AELs) to ensure that, under NOC, emissions do not exceed the BAT-AELs as laid down in BAT conclusions.

Rec.29 - Strictest end of the BAT AEL range should be accurately identified and BAT conclusions should contain information on ***circumstances allowing the achievement of lower emission levels*** *within the range of BAT-AELs set for categories of installations with similar characteristics.*



BAT-AELs and Emission Limit Values

Circumstances allowing achievement of lower end

To improve the clarity of BAT conclusions, the circumstances for achieving the strictest BAT-AEL range should include more than just specifying the technique used. For example, the circumstances might include:

- *Operational conditions: optimal temperature, pressure, or airflow conditions where the equipment operates most efficiently.*
- *Process parameters: specific conditions under which the production process operates at its highest efficiency.*
- *Environmental factors: factors such as ambient air quality, humidity, or temperature, which may affect the system's efficiency and emissions.*
- *Feedstock*

Draft revised BREF Guidance

BAT-AELs and Emission Limit Values

New BATAEL tables look quite different…

CER BREF final draft, Table 5-12 (BAT 18.2): HCl and HF emissions to air from firing

Parameter	BAT-AEL (average over the sampling period) (1) (2)	Unit	Information on circumstances allowing the achievement of lower emission levels within the BAT-AEL range
Gaseous chlorides, expressed as HCl	3 – 15 (3) (4)	mg/Nm³	Lower emission levels within the BAT-AEL range (e.g. ≤ 7 mg/Nm³) are expected with the use of raw material with a low chloride content (i.e. < 50 ppm) and a dedicated abatement technique (e.g. cascade-type packed bed sorption system)
Gaseous fluorides, expressed as HF	2 – 5 (5)	mg/Nm³	Lower emission levels within the BAT-AEL range (e.g. ≤ 3 mg/Nm³) are expected with the use of raw material with a low fluoride content (i.e. < 500 ppm), optimised heating in the kiln and a dedicated abatement technique (e.g. cascade-type packed bed sorption system, wet or dry scrubbing)

The footnotes to Table 5-12

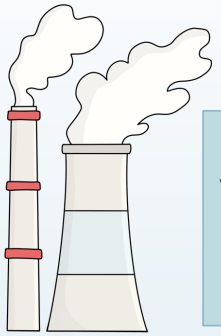
(1) The BAT-AEL does not apply for emerging techniques mentioned in Section 5.1.7.3.5. (2) The BAT-AEL may not apply when only calcined raw material is used in combination with natural gas as a fuel. (3) For existing plants, the upper end of the range may be up to 30 mg/Nm³ with raw materials of high chlorine content (e.g. > 350 ppm). (4) For plants without process waste water discharge that reuse internally chlorinated process water, and for plants using spray-dried powders produced at sites where chlorinated water is used, the upper end may be up to 20 mg/Nm³. (5) For existing plants, the upper end may be up to 10 mg/Nm³ with raw material of high fluorine content (e.g. > 1 000 ppm).



BAT-AELs and Emission Limit Values

New Article 15a – Compliance rules for emissions to air and water in EU Member States

The Commission is empowered to adopt an implementing act establishing the method for assessing compliance under normal operating conditions with emission limit values set out in the permit with regard to emissions to air and water. The deadline for adoption was 1 September 2026.



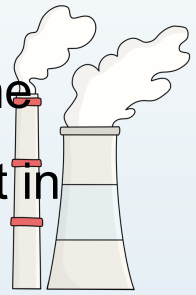
Example: Emission Limit Value set in permits on NOx emissions to air, monitored continuously

Set of compliance rules to show that emission levels are below the ELV, harmonised at EU level for all IED installations.

New Art.15a – compliance rules

New Article 15a – Compliance rules for emissions to air and water

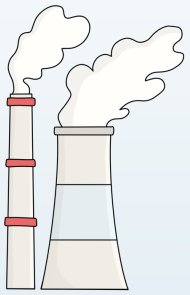
1. "For the purpose of assessing compliance **under normal operating conditions** with emission limit values in accordance with Article 14(1), point (h), the correction made to measurements to determine the validated average emission values **shall not exceed the measurement uncertainty of the measuring method**.
2. …The method … shall address, as a minimum, the **determination of validated average emission values** and shall set out how measurement uncertainty and the **frequency of exceedance of emission limit values** are to be taken into account in the compliance assessment.



New Art.15a – compliance rules

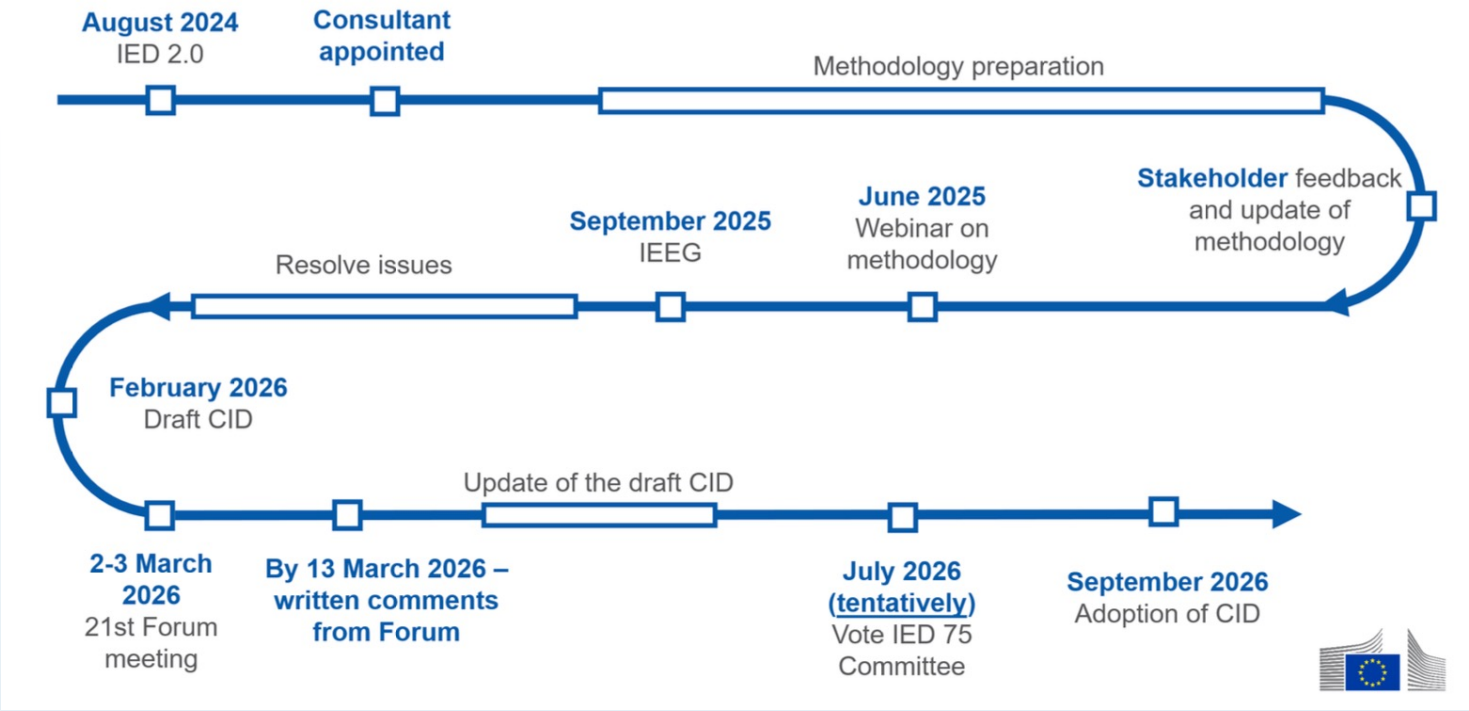
New Article 15a – Compliance rules for emissions to air and water

3. Where an installation falling within the scope of this Chapter also falls within the scope of Chapter III or IV and compliance with the emission limit values set in accordance with this Chapter has been demonstrated pursuant to paragraph 1 of this Article, the installation shall be deemed to also comply with the emission limit values set in accordance with Chapter III or IV for the pollutants concerned under normal operating conditions."



Draft Commission Implementing Decision on compliance rules

Presented at 21st IED Article 13 Forum meeting on 2-3 March 2026



Draft Commission Implementing Decision on compliance rules

Presented at 21st IED Article 13 Forum meeting on 2-3 March 2026

Content of the Decision:

- **definitions** related to compliance assessment in normal operating conditions (NOC)
- Approach **to calculation of validated average** emission levels based on a subtraction of the expanded measurement uncertainty rather than a maximum permissible measurement uncertainty.
- explanation of the role of **maximum permissible uncertainty** for compliance assessment.
- reference to standards providing **maximum permissible uncertainty** for different methods/pollutants.
- details of how the **frequency of exceedance** should be considered.

Strong link with EN standards for both emissions to air and water



Draft Commission Implementing Decision on compliance rules

Presented at 21st IED Article 13 Forum meeting on 2-3 March 2026

Dedicated annexes:

- **Annex I - method for assessing compliance**
  - Definitions and abbreviations
  - Continous monitoring of emissions to air
  - Periodic monitoring of emissions to air
  - Emissions to water
  - Documentation for assessing compliance
- **Annex II – parameters for emissions to air and water**
  - Maximum permissible uncertainty values for continuous monitoring
  - Maximum permissible expanded uncertainty for periodic measurements
  - Reference values for limits of quantification are provided as examples for maximum limits of quantification
- **Annex III – examples of calculations**

Draft Commission Implementing Decision on compliance rules

When will the new rules need to apply?

Article 3 of the amending Directive 2024/1785 contains transitional provisions, including for article 15a.

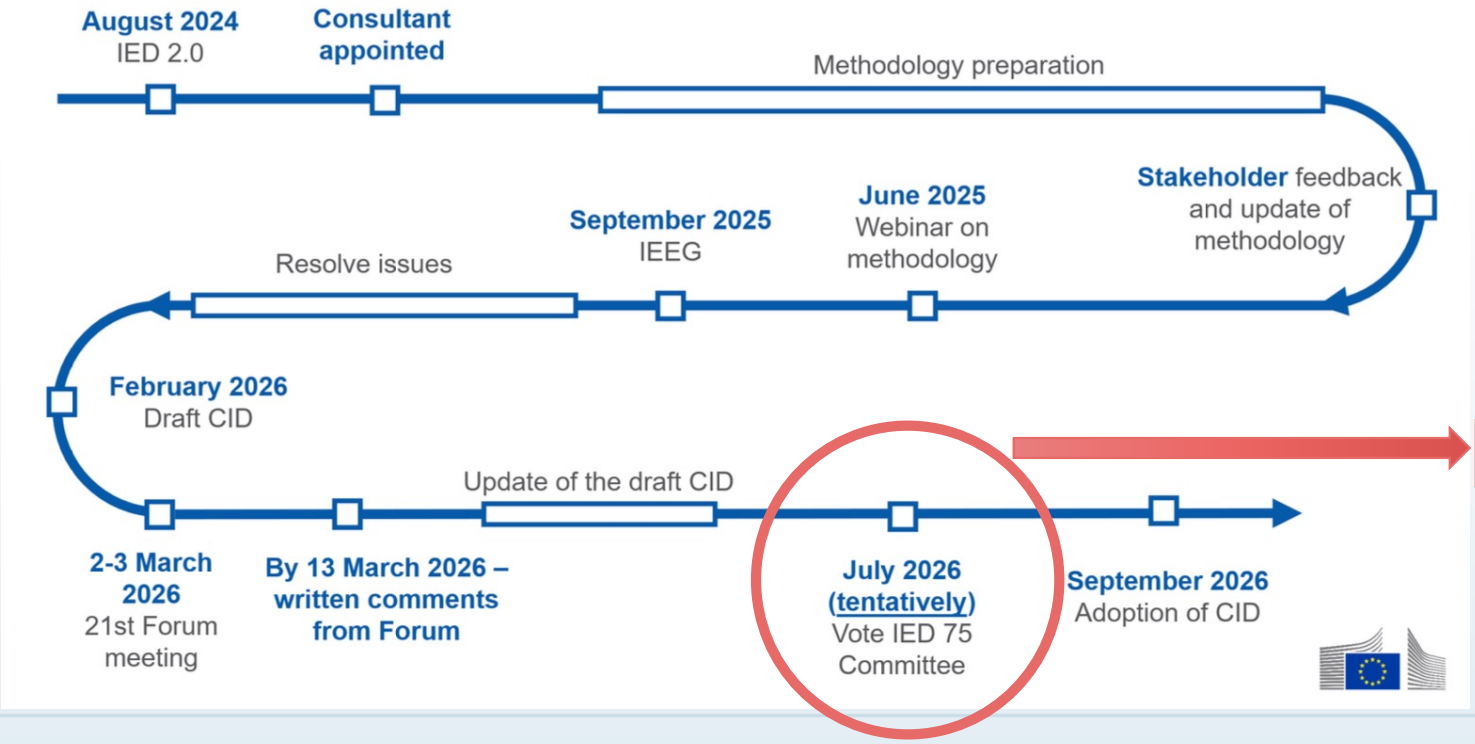
In particular for IED installations in operation and carrying out existing IED activities (article 3.2), article 15a apply :

- when the permit is granted or updated pursuant to Article 20(2) or Article 21(5)
- or when the permit is updated within 4 years of publication of decisions on BAT conclusions that have been published after 1 July 2026 or
- by 1 September 2036,

whichever is the earlier.

Draft Commission Implementing Decision on compliance rules

Presented at 21st IED Article 13 Forum meeting on 2-3 March 2026



Work in progress...





Thank you!

Any questions?



Seeds

Lighea Speziale
Lighea.Speziale@seedsconsulting.eu

NPL
National Physical Laboratory

MetZeroPol

Overview of *Metrology to Support Zero Pollution from Industrial Sources* (MetZeroPol)



Marc Coleman

MaritimeMET, MetZeroPol, MetNH3Energy
Joint Workshop: **Sector-Specific Approaches to Emission Monitoring**

30th September 2026, virtual

Key Articles in IED2.0

- The motivation for the MetZeroPol proposal is to address some of the key changes in IED 2.0
- What changes? And what issues will these exacerbate or create?
  - **Article 15 "*…The competent authority shall set the strictest achievable emission limit values by applying BAT….[operator] analysing the feasibility of meeting the strictest end of the BAT-AEL range*"**
    - **Issue:** Many SRMs are either not validated at all (CEN/TS) or not to the bottom end of respective AEL ranges
    - Nb. ~85% of all emission limits across Europe had been set at the top end of respective AEL ranges
  - **Article 15a "*The Commission shall by 1 September 2026 adopt an implementing act….. shall set out how measurement uncertainty….. taken into account in the compliance assessment*"**
    - **Issues:** How will this be implemented in practice? There is insufficient guidance in the methods for the summation of single-species and multi-species measurands (and associated uncertainties), and inconsistent use of uncertainty in compliance assessment
  - **Article 14 *"….. and for other polluting substances, which are likely to be emitted from the installation*"**
    - **Issue:** There are no reference methods for "suspected" emissions and often a lack of knowledge of exactly what is emitted and at which concentrations (e.g. PFAS)
- The MetZeroPol project is working across these 3 areas

MetZeroPol Consortium

- MerZeroPol will run from mid-2025 to mid-2028
- The project lead will be Marc Coleman (marc.coleman@npl.co.uk)

National Physical Laboratory

BAM Bundesanstalt für Materialforschung und -prüfung

CZECH METROLOGY INSTITUTE

VTT

LABORATOIRE NATIONAL DE MÉTROLOGIE ET D'ESSAIS

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

cea

TÜBİTAK

Environment Agency

INERIS

vito

uniper

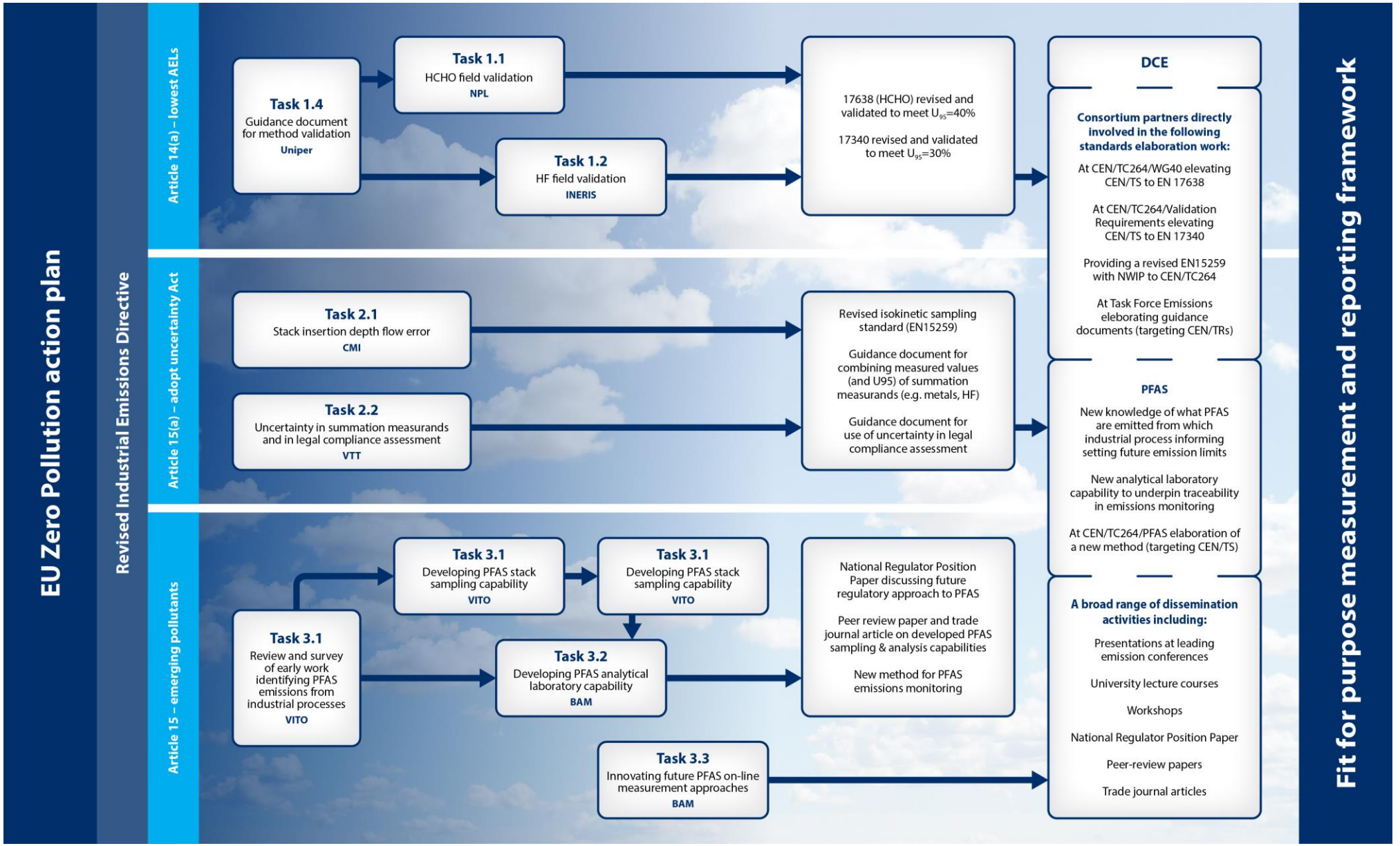
BRNO UNIVERSITY OF TECHNOLOGY

eurofins

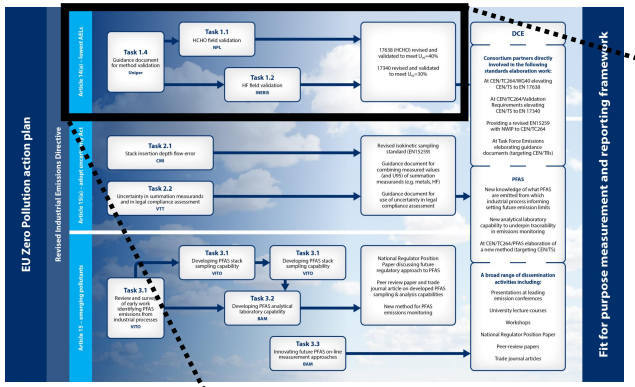
RAMBOLL

METAS Your reference.

MetZeroPol Structure

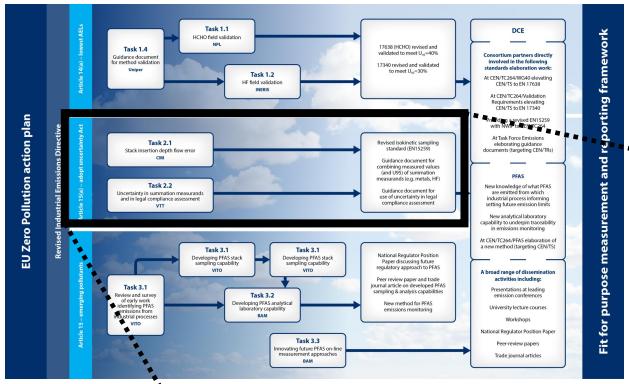


MetZeroPol Structure



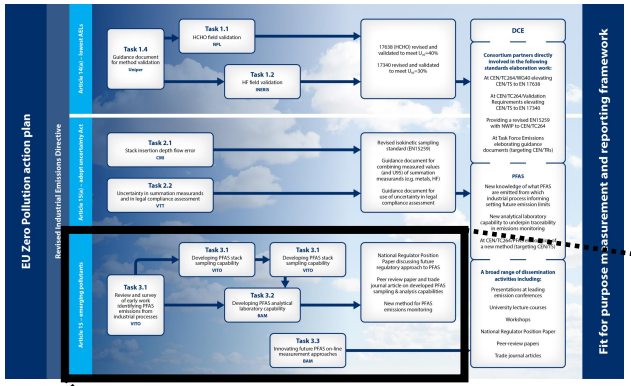


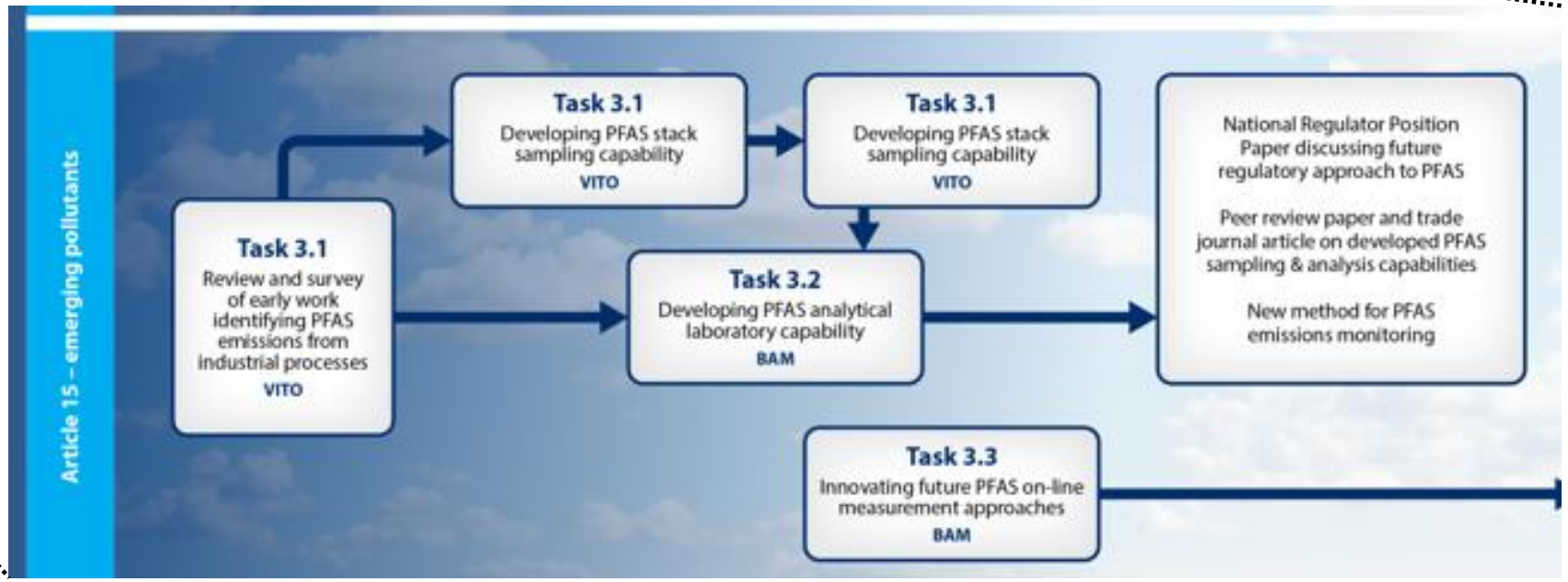
MetZeroPol Structure





MetZeroPol Structure





Thank you for you attention!



Any questions:
Marc Coleman
email: marc.coleman@npl.co.uk
www.npl.co.uk/environmental-measurement

npl.co.uk

MetZeroPoI will receive funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States

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Sicherheit in Technik und Chemie

30.09.2026

METROLOGY FOR THE ANALYSIS OF PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN INDUSTRIAL EMISSIONS

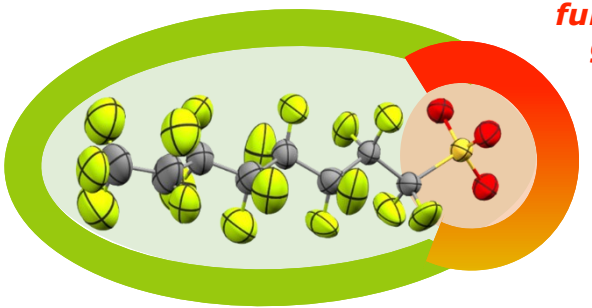
Christian Vogel, Bundesanstalt für Materialforschung und –prüfung (BAM)

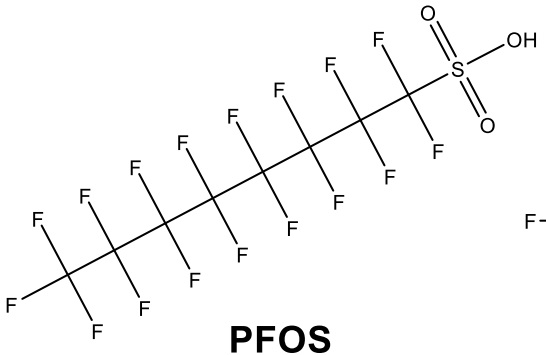
www.bam.de

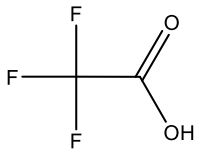
Per- and Polyfluoroalkyl Substances (PFAS)

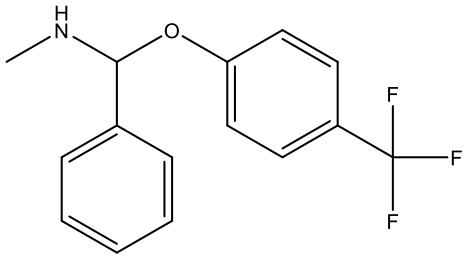
Properties of PFAS

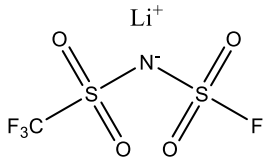
- Ambiphilic charakter
- Drastic reduction of surface tension
- Large number of more than 12,000 used PFAS: anionic, cationic, amphotic, non-ionic, polymer
- Definition: One -CF_3 or –CF_2- in the molecule











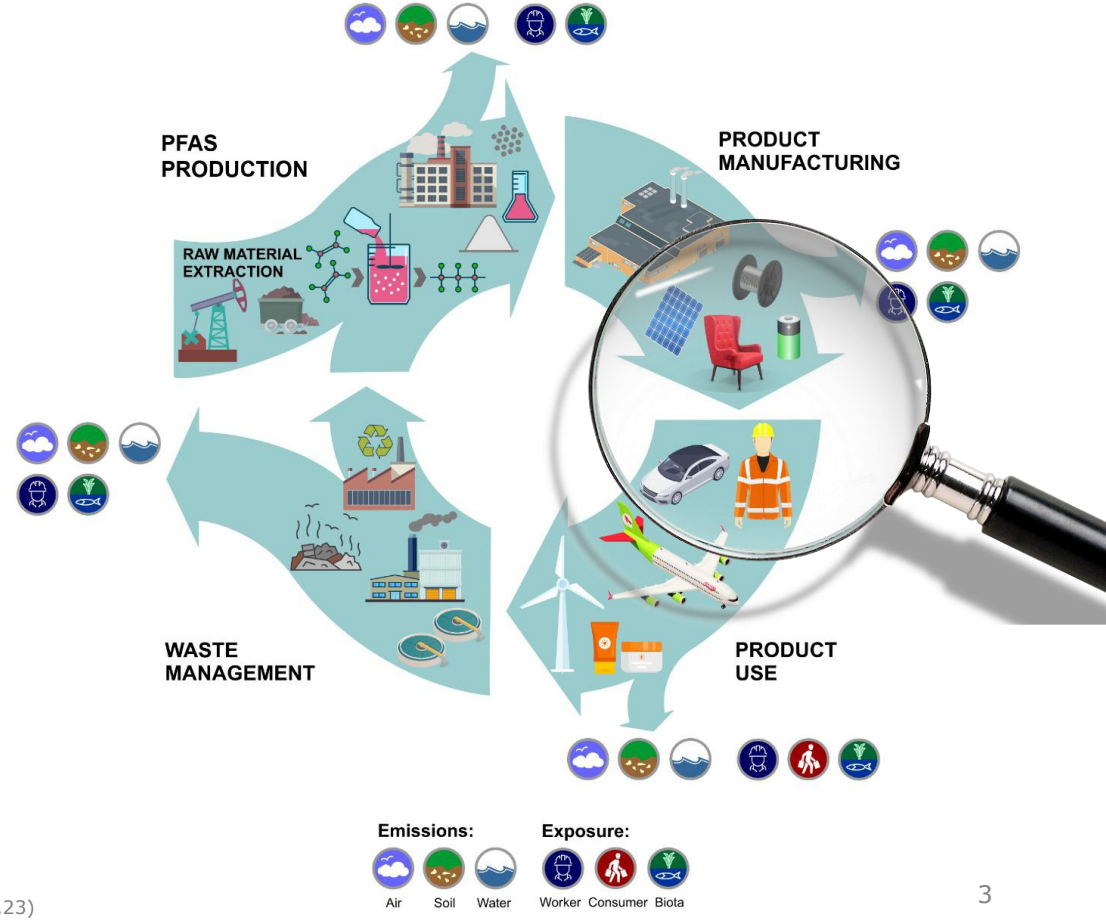
PFAS in circulation - pathways into the environment

- Primary environmental pollution through industrial emissions or PFAS exposure through direct application (e.g. AFFF)

- Secondary PFAS contamination: consumer products (e.g. outdoor clothing, textile spray) or entry into agriculture, waste stream or landfill of PFAS-containing materials

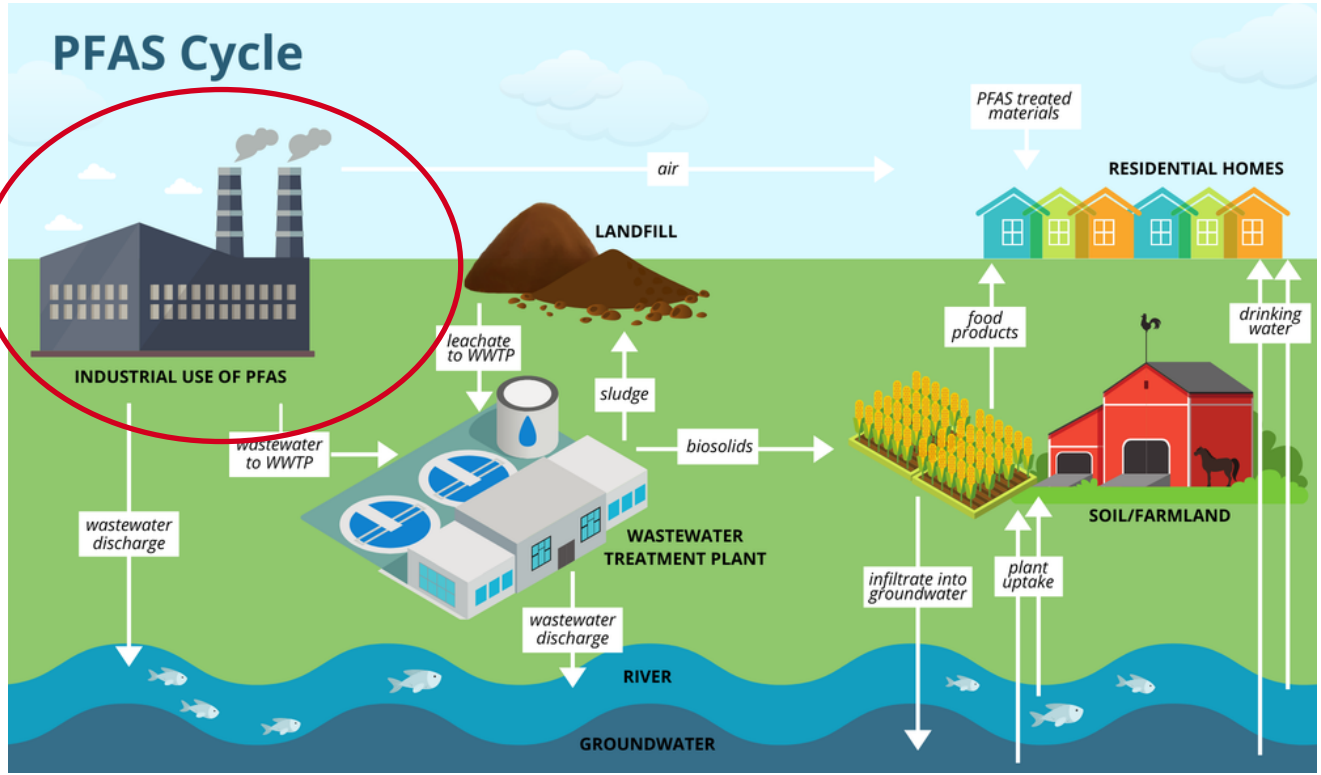
» Further development of analytical methods to assess the impact of contaminants in a variety of environmental matrices

  - Concentrations in the trace range
  - Volatile compounds
  - Poorly soluble PFAS



https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf (23.11.23)

PFAS Cycles in the Environment



https://www.ebiconsulting.com/resources_news/pfas-as-part-of-environmental-due-diligence/

Possible PFAS emissions from industrial

Available analytical methods

Solid samples, e.g. slag, filter dust:
Extraction → Target (e.g. LC-MS/MS) and sum parameter

Liquid samples, e.g. wastewater, slag water, scrubber solutions:
Pre-concentration → Target (e.g. LC-MS/MS) and sum parameter (e.g. CIC)

Gaseous samples:
Absorber (solid/liquid)– Target analysis (LC-MS/MS)

Direct measurement of gas samples by GC-MS(/MS)

Online measurements - FT-IR spectroscopy or CI-ToF-MS

MetZeroPol – WP3: New sampling and analytical capabilities for measuring PFAS emissions

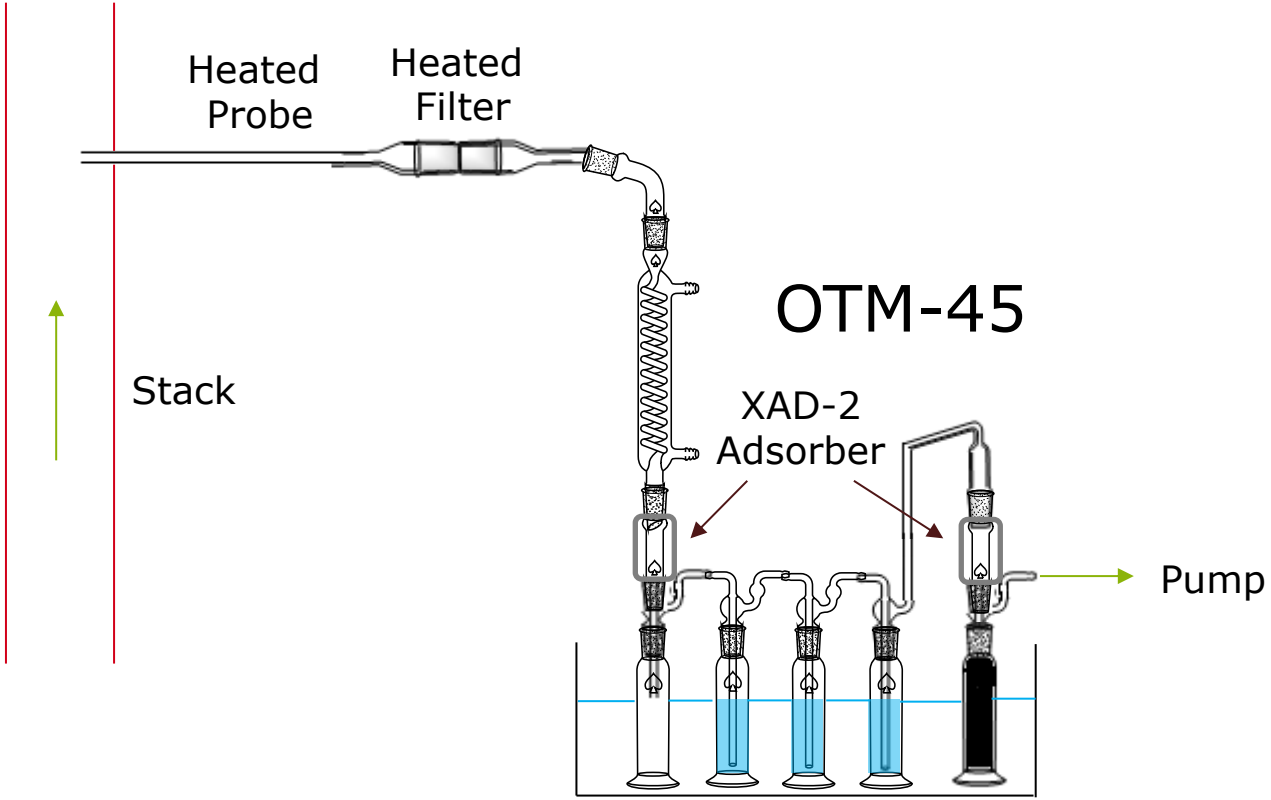
BAM

TASK 3.1: PFAS sampling from industrial process plants	TASK 3.2: Analysis of selected PFAS species in collected samples	TASK 3.3: Capability of portable instruments for PFAS online measurements
VITO, BAM, INERIS, NPL, NAB, METAS, LNE, TUBITAK	BAM, METAS, LNE, TUBITAK, VITO, INERIS, NPL	BAM, VITO, INERIS, METAS,
• Review of PFAS sampling techniques • Adapt VITO stack sim and NPL CCUS rig for PFAS • Test sampling approaches • Acquire samples from 4 different incineration process for Task 3.2	• Identify key PFAS to focus on • Develop LC-MS(/MS), GC-MS(/MS), TOPA, THPA, EOF, AOF and F-NMR capabilities • Common sample extraction and analysis procedure • Analyse field samples from Task 3.1 • Draft sampling and analysis method and provide to CEN/TS 264/WG 48	• Review on on-line techniques • FTIR for CF_4 and C_2F_6 • Raman • CI-ToF-MS

U.S. EPA - OTM-45 Method for industrial stack emissions – for C_4-C_{18} polar semi-volatile

Method for:
PFCAs
PFSAs
FOSAs
FOSEs
FOSAAs
FTS
And other replacements

In total 49 compounds

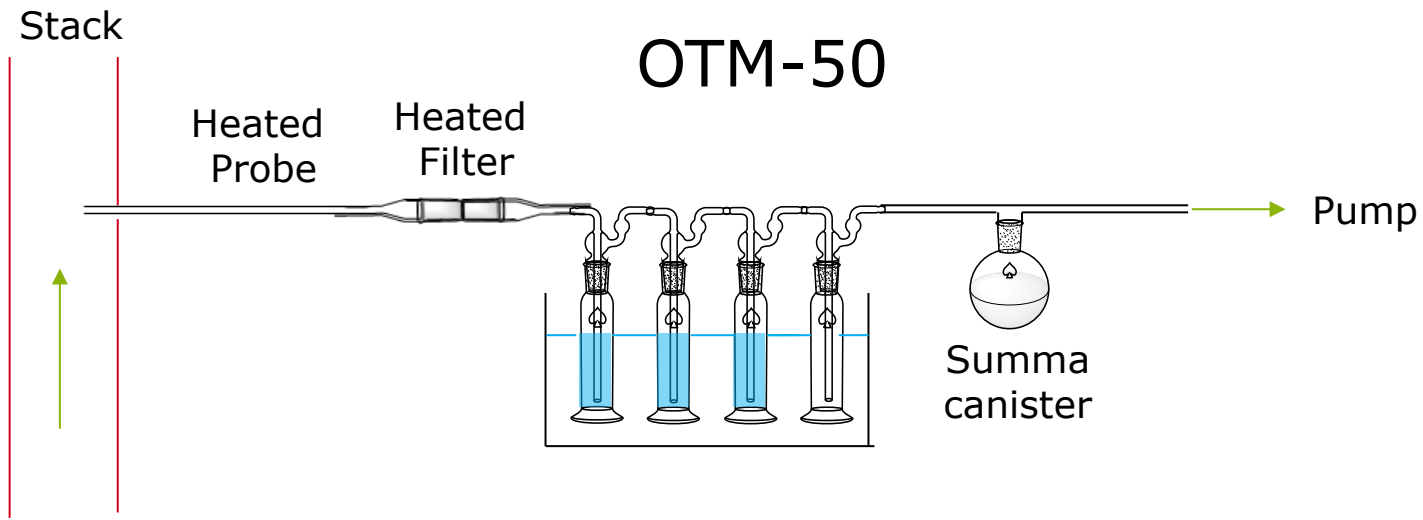


U.S. EPA - OTM-50 Method for industrial stack emissions - for C_1-C_6 non-polar volatile

Method for:

CF_4
CHF_3
CH_2F_2
CH_3F
C_2F_6
And others

In total 30 compounds



U.S. EPA – “OTM-55” Method for industrial stack emissions

Method in development for:

- Fluorotelomer alcohols and other fluorotelomer compounds (e.g. iodides, oxides)

- Fluorinated dioxins and furans



Existing Methods for industrial stack emissions

Developments in Europe – at starting point

U.S.	OTM-45	OTM-50	„OTM-55“
Belgium	LUC/VI/003		
France	XP X 43-126	XP-X 43-128 In development	
Europe	CEN/TC 264 WG 48 founded 2025		

Existing Methods for industrial stack emissions

Developments in Europe – yet

U.S.	OTM-45	OTM-50	„OTM-55“
Belgium	LUC/VI/003	LUC/VI/004 In development	
France	XP X 43-126	XP-X 43-128 In development	
Germany	VDI-EE 3499 Part 5		
Japan	Guideline 77696		
Europe	CEN/TC 264 WG 48 in progress		

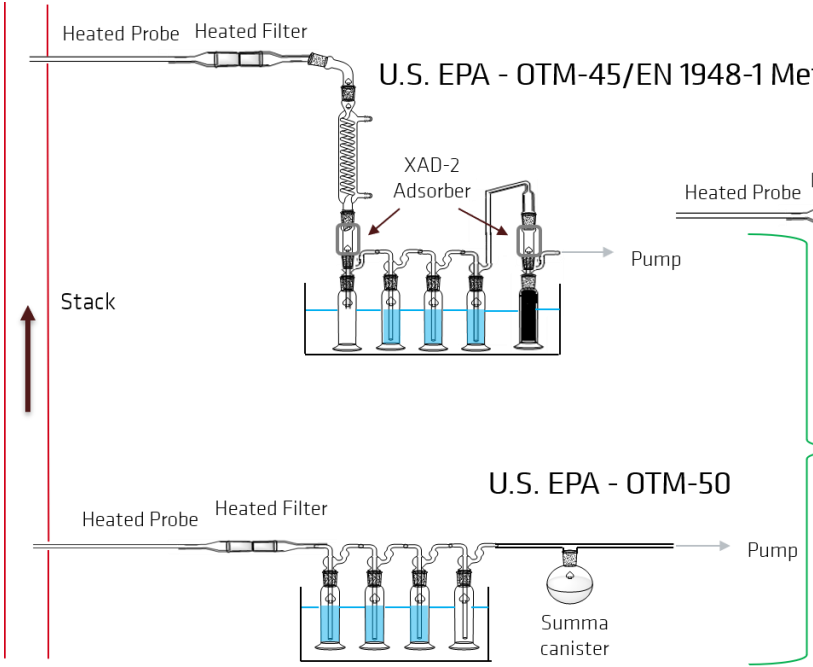
Currently available methods for different PFAS groups

C_4-C_{18} polar semi-volatile	C_1-C_3 polar semi-volatile	C_1-C_3 non-polar volatile	Fluorotelomer alcohols	Sum parameter
US - OTM-45	DE - DIN 38407-53 (TFA/water)	US - OTM-50	US - OTM-55 draft	DE – DIN 38409-59 (AOF/water)
BE - LUC/VI/003	BE - WAC/IV/A/026 (water)	FR - XP X 43-128 (in dev.)	ASTM D8591-24 (tube/indoor air)	EOF
FR – XP X 43-126	CEN draft (TFA/water)	BE - LUC/VI/004 (in dev.)	BE - WAC/IV/A/032 (water)	TOPA/THPA
DE - VDI-EE 3499-5	US – EPA 563 (water)			
by LC-MS/MS	LC-MS/MS, HILIC, IC-MS	by GC-MS	by GC-MS	CIC,GC/LC-MS

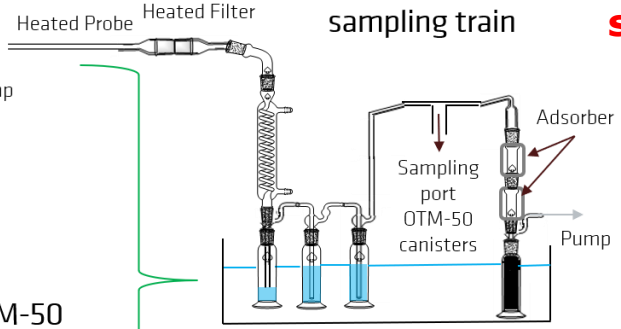
Combination of sampling trains

C_4-C_{18} polar semi-volatile

C_1-C_3 non-polar volatile



Idea on combined sampling train



C_4-C_{18} polar semi-volatile

C_1-C_3 non-polar volatile

+C_1-C_3 polar semi-volatile

(+Sum parameter)

Analytical techniques

- Mainly focusing on LC-MS/MS for the C_4-C_{18} polar semi-volatile PFAS (OTM-45)
  - Standardisation of sampling processing protocols

- Evaluation of GC-MS for the non-polar volatile PFAS (OTM-50)
- Evaluation of sum parameter techniques (e.g. CIC)
- Evaluation of fluorine NMR spectroscopy



Interlaboratory comparison and field campaigns

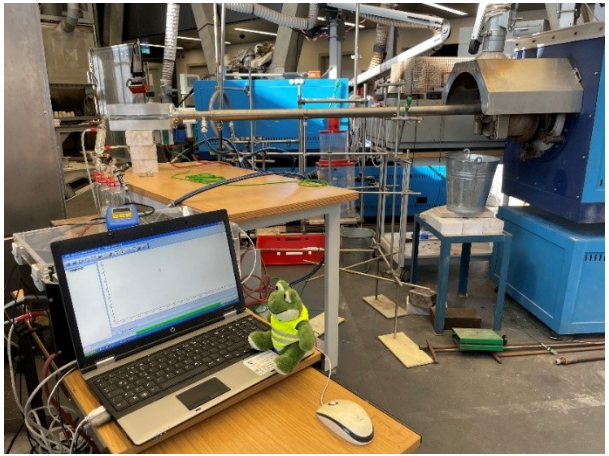
- Conducting an analytical interlaboratory comparison on the LC-MS/MS method and sample processing.

- Field campaign on 4 to 5 different industrial facilities in Finnland, Belgium, France, Germany and UK on waste incinerators and fluoropolymer plant.
  - Testing of old and new sampling trains
  - Sharing of samples for analysis

Online analysis techniques

Comparison of the following techniques for their application as online or atline instrument:

- Infrared (FT-IR) spectroscopy as online tool for gases
- Chemical ionization time-of-flight mass spectrometry (CI-ToF-MS) as online tool for gases
- Raman spectroscopy as atline tool for solid and liquid samples



Thank you for your attention.



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www.bam.de



Trace gas monitoring in industrial processes: Selecting the optimal technology for NO, NO_2, NH_3

Dr. Julian Edler, Alexandra Kirchhoff

30.09.2026

Endress+Hauser

Welcome to Endress+Hauser SICK GmbH+Co.KG (EHS)



Endress+Hauser

Welcome to Endress+Hauser SICK GmbH+Co.KG (EHS)

Solutions for greater efficiency and sustainability

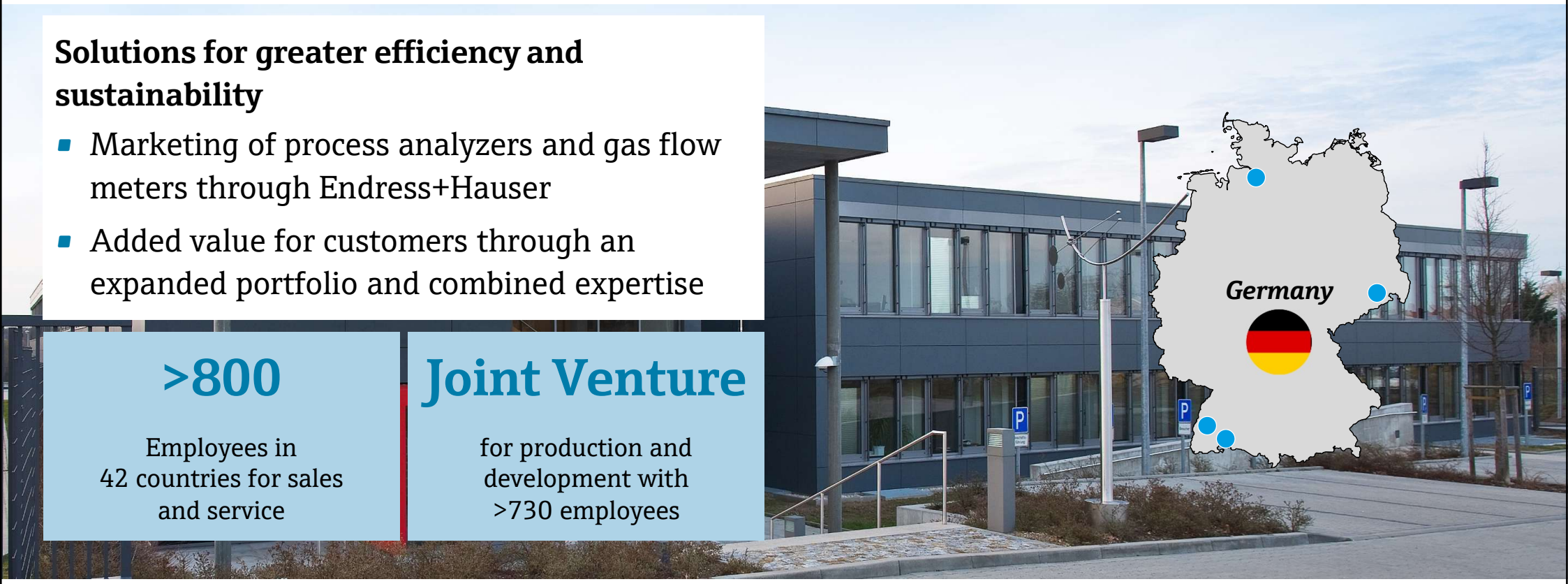
- Marketing of process analyzers and gas flow meters through Endress+Hauser
- Added value for customers through an expanded portfolio and combined expertise

>800

Employees in 42 countries for sales and service

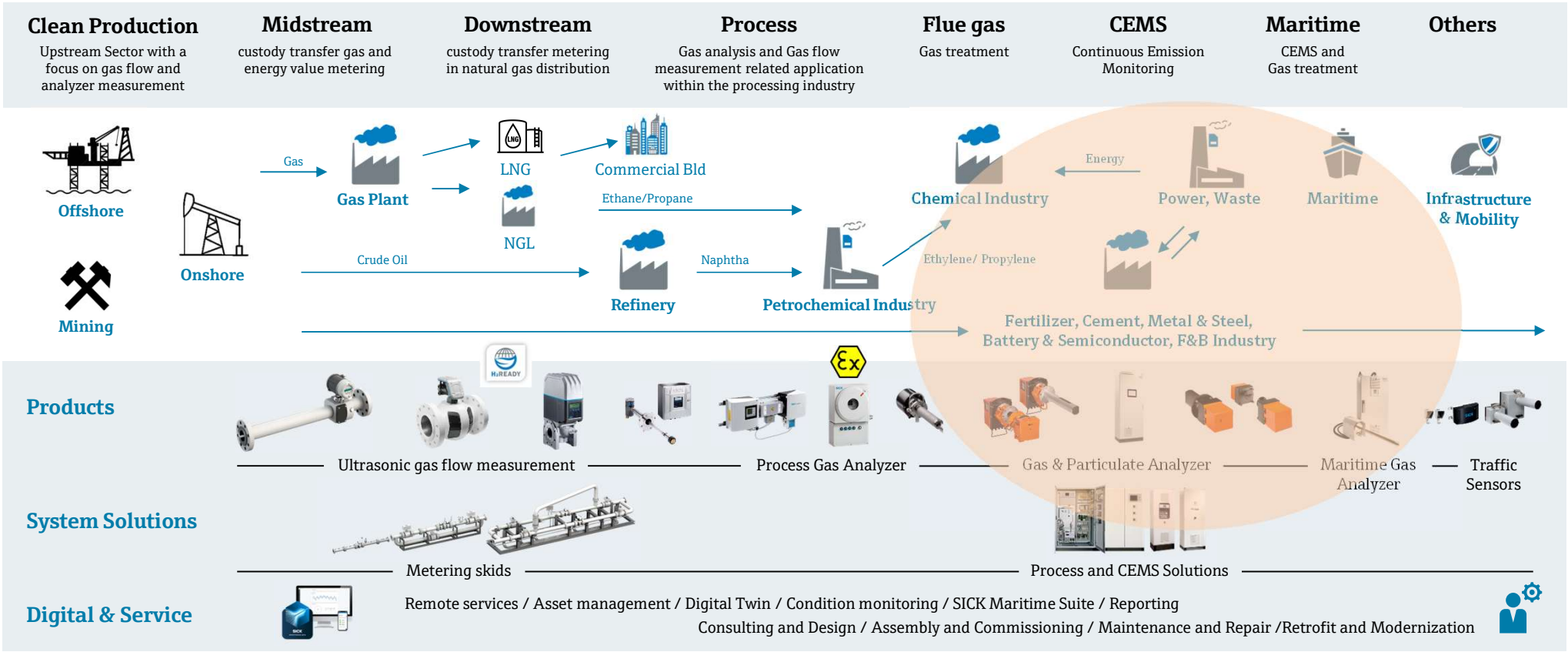
Joint Venture

for production and development with >730 employees



Endress+Hauser

Our market position | Markets, Products, System Solutions, Digital & Services

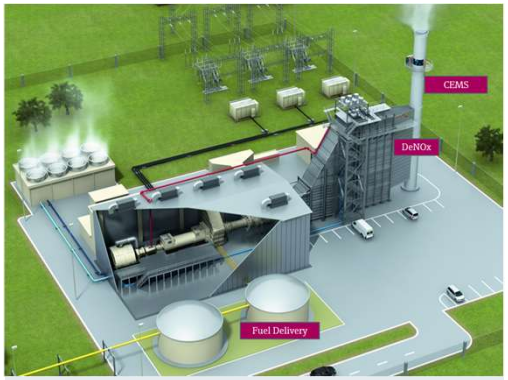


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Focus industries & applications



- DeNOx and DeSOx control: Coal/Gas/Diesel fired Power Plants and Waste incineration



- Emission monitoring: Coal/Gas/Diesel fired Power Plants and Waste Incineration



- Maritime: Measurement of SO_X at scrubber in/outlet
- NO_x measurement at SCR in/outlet



- CH_4 slip control at LNG and dual fuel engines

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DeNOx

Basic DeNOx principle:

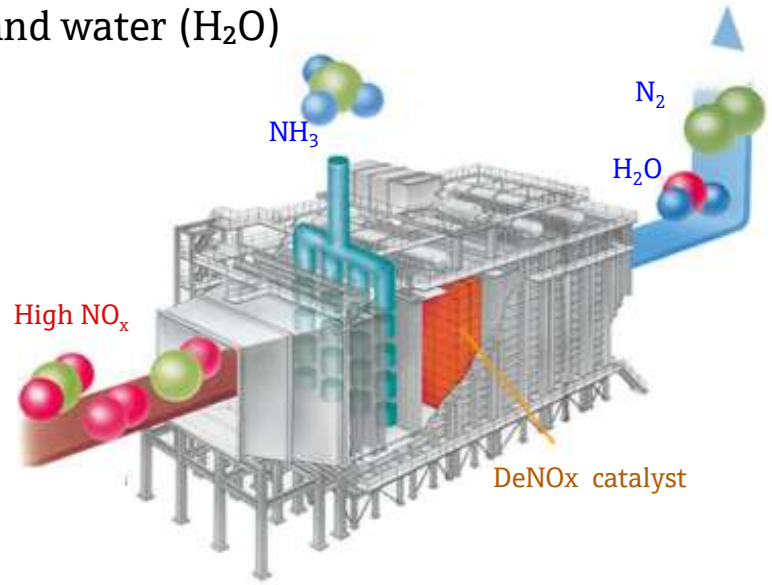
- NOx is converted into (the harmless gases) nitrogen (N_2) and water (H_2O)
- Using a reducing agent:
  - Ammonia water (NH_3)
  - Urea (which decomposes into NH_3)

Key parameters measured:

- NOx (before & after treatment)
- NH_3 (ammonia slip)

Measurements are critical for:

- Regulatory compliance
- Process control and optimization
- Ageing/damage of catalyst



$$4NO + 4NH_3 + O_2 \rightarrow 4\,N_2 + 6H_2O$$

Measuring points – example gas-fired power plant

CEMS

MCS200HW/100FT

Emission compliance

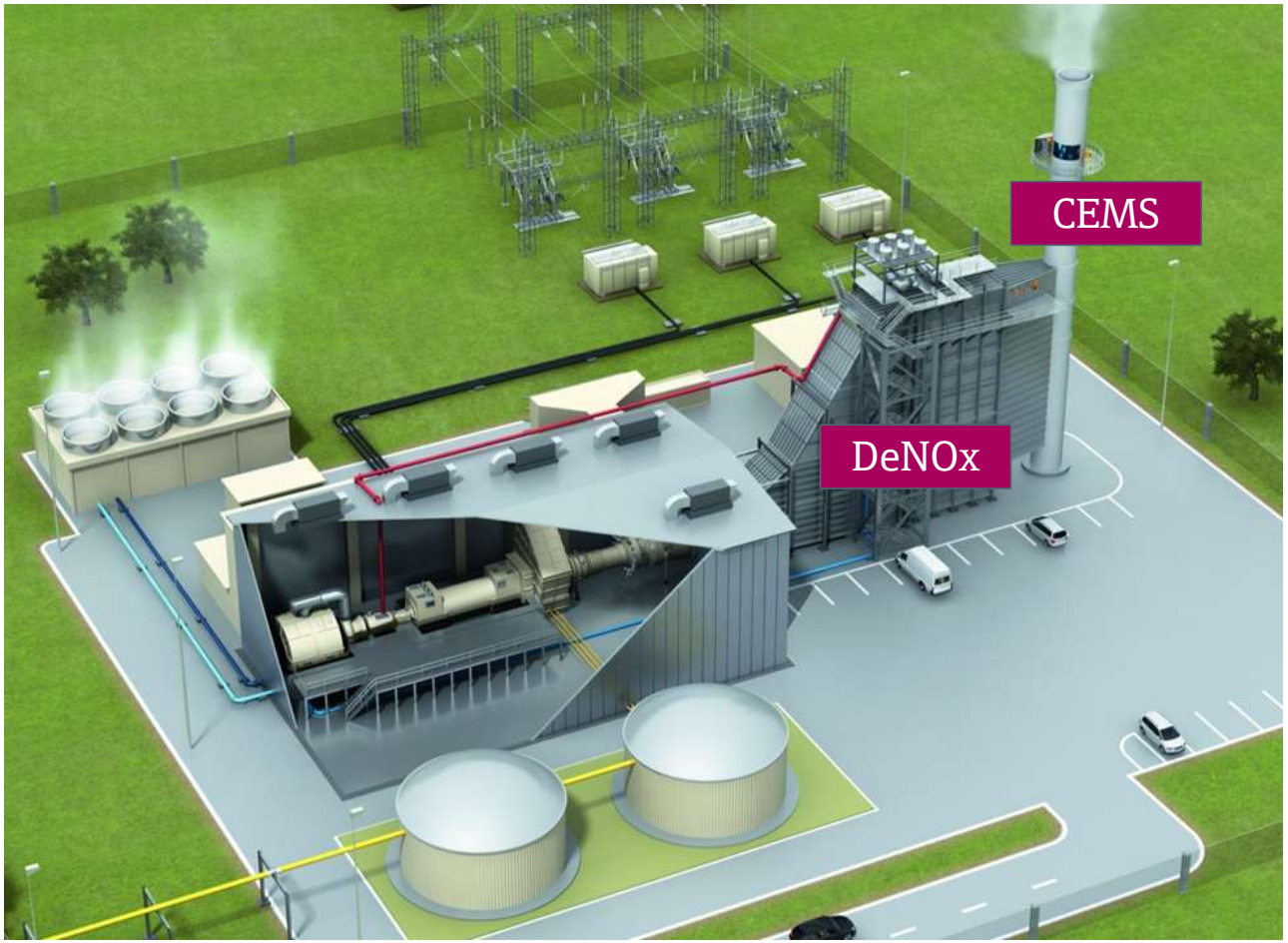


DeNOx

GM32 /GM700

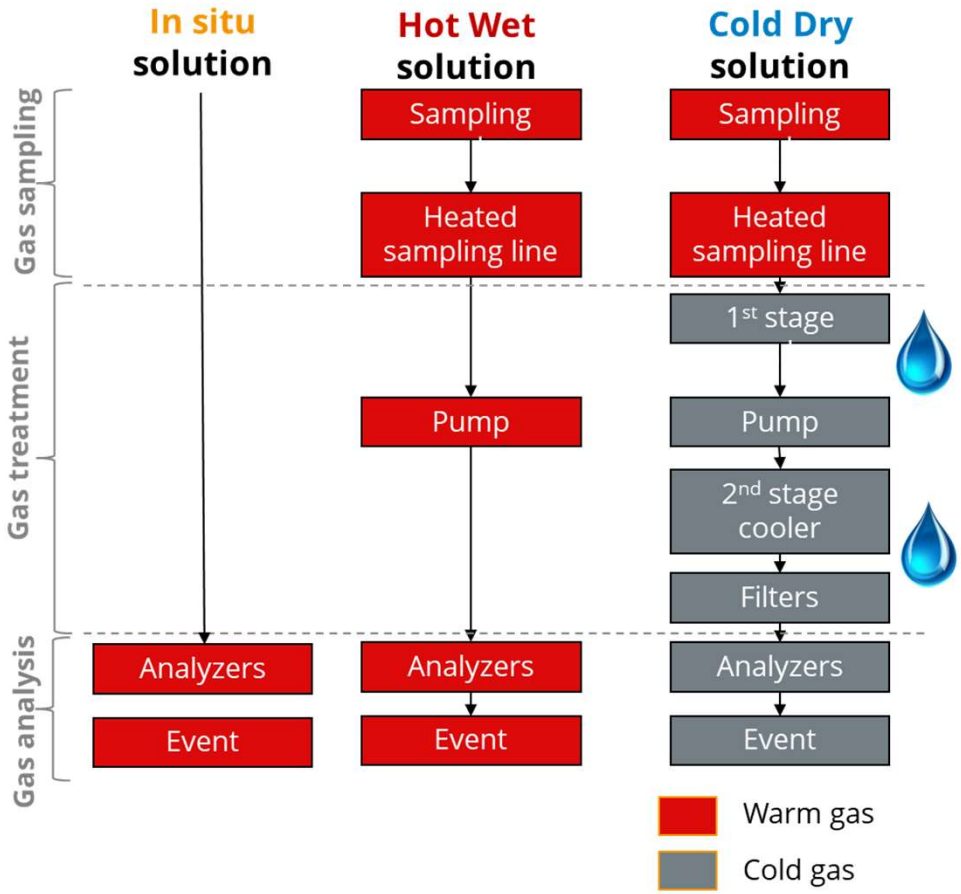
Process control

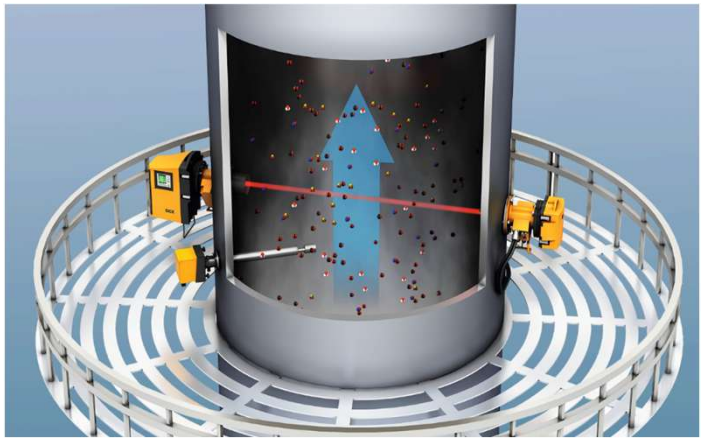




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Gas Analysis Technologies







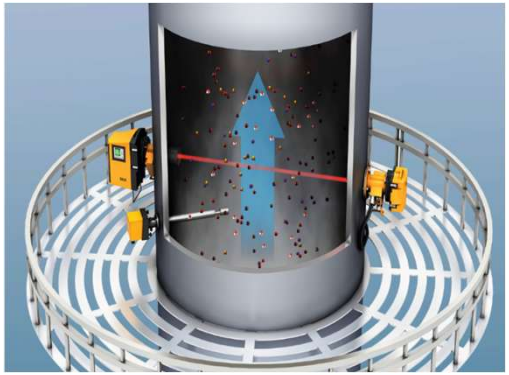
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Gas Analysis Technologies

In Situ

- Real-time gas analysis
- No gas sampling and conditioning,
- No delayed response due to adsorption
- No condensation of H2O, H2SO4, HNO3
- No condensate handling, less maintenance
- Fast measurement => control process

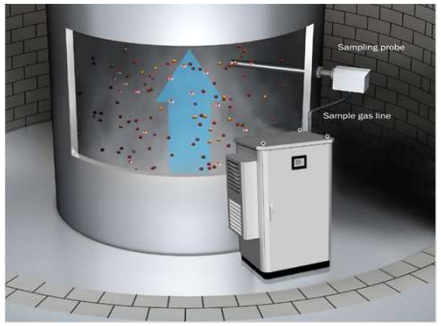




Extractive – hot/wet or cold/dry

- Enables Technologies that require ambient temperature / sensitive to vibrations
- Tailored for complete emission monitoring
- Large number of applications
- Large number of potential measuring gases
- Hot wet: no condensation of H2O, H2SO4, HNO3, no NH3 washout





Endress+Hauser

Overview | GM700

- Laser analyzer for **NH_3**, HCl, HF, CO and H_2O
- Tunable diode laser spectroscopy (TDLS)
- Direct absorption spectroscopy
- Tunable laser selectively scans the target absorption line
- Accurate, no cross sensitivity to other media
- In-situ: No sampling and preparation of gas needed
- Fast, representative measurement



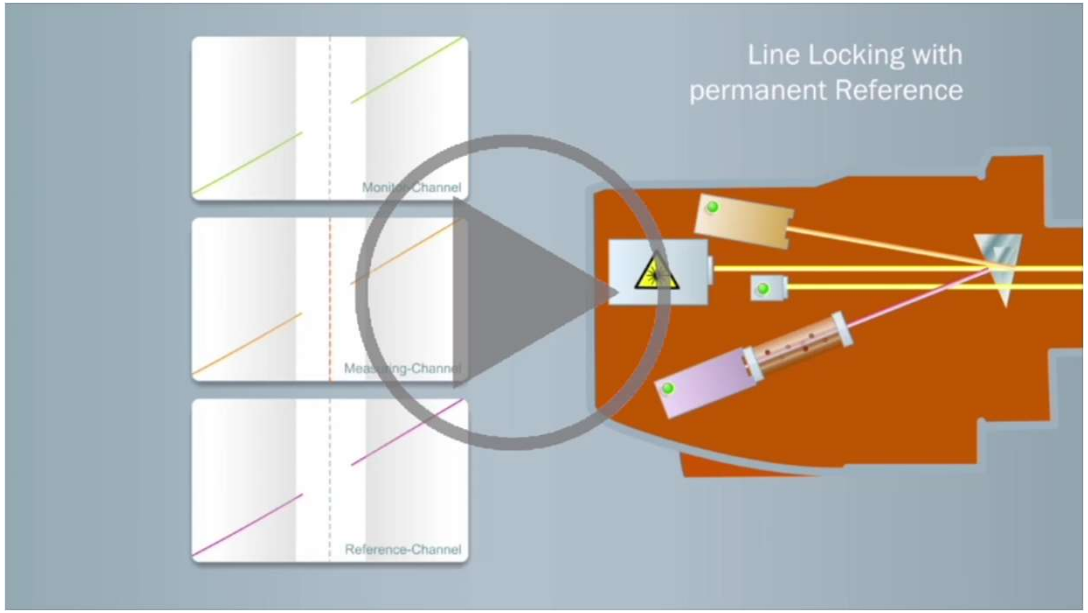
GM700 Laser Gas analyzer

- Efficient process analysis – even under difficult conditions

Details: Feature & Benefit | GM700

Without drift and calibration

- Gas-filled reference cell for long-term stability (line locking)
- Low maintenance, because it is drift-free
- No calibration with test gases is required
- No movable parts, therefore wear-free operation
- High reliability in operation



Benefit

- Low maintenance and reliable operation of the analyzer

Overview fields of application | GM700



- DeNOx



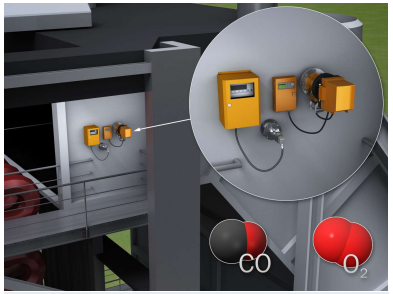
- Fertilizer production



- Aluminum production



- Raw gas measurement in waste incineration



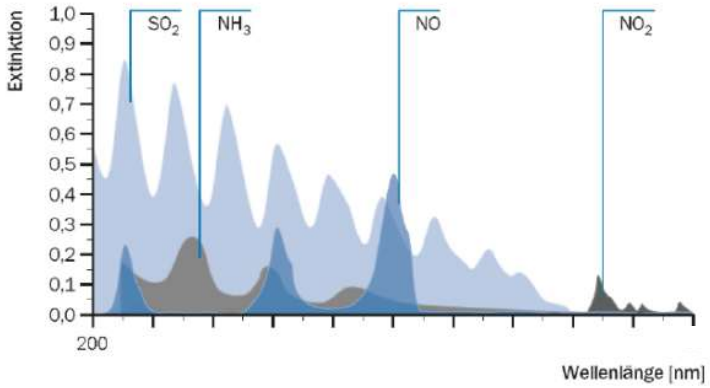
- Optimization of the Boiler output

Measuring range and accuracy	Minimal measuring range	Maximal measuring range	Certified measuring range
HF	0 … 3 ppm	0 … 2,000 ppm	0 … 5/25 mg/m³ 1)
HCl	0 … 7.5 ppm	0 … 3,000 ppm	-
NH_3	0 … 25 ppm	0 … 4,000 ppm (< 20 vol.-% H_2O)	-
NH_3 high humidity	0 … 25 ppm	0 … 100 ppm (< 40 vol.-% H_2O)	-
CO	0 … 100 ppm	0 … 30,000 ppm	-
	Measuring ranges refer to 1 m measuring path (depend on application/device version), 1) cross-duct version is suitability tested 2) depend on version		Meas. path cross-duct: 0.5 … 6 m Meas. path probes: 0.25 … 1.0 m

Endress+Hauser

Overview | GM32

- Direct and fast measurement of 4 gases
  - SO_2, **NO, NO_2, NH_3**
- UV light source & Spectrometer
- Differential optical absorption spectroscopy (DOAS)
- Low installation, operation and maintenance cost
- No cross sensitivity to other gases, dust or water





Endress+Hauser

Detail: Feature & Benefit | GM32

Measurement of raw gas spectrum

- Measurement of intensity spectra with and without gas
- Computation of absorbance spectra
- **“Curve Fit”** –gas concentrations are determined by fiting model spectra to the measured spectra
- No cross sensitivities to dust / H_20 and other gases



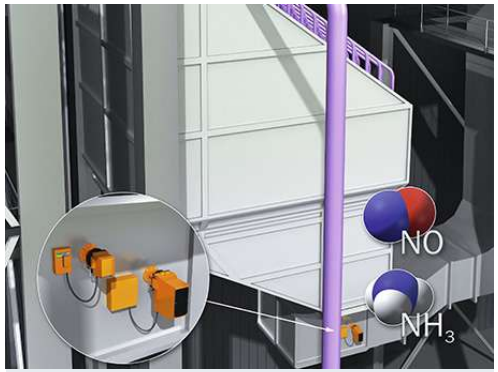


Benefit

- Direct and fast measurement of 4 components in real time!
- No cross sensitivities to dust / H_20 and other gases!
- No need for gas sampling or gas treatment!

Endress+Hauser

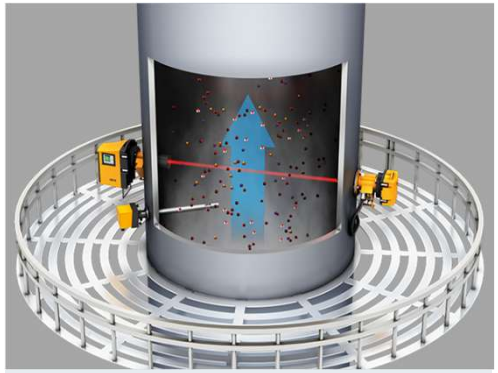
Overview fields of application | GM32



- Denitrification ($DeNO_X$)



- Desulphurization ($DeSO_X$)



- Emission monitoring

Process control in Chemistry / HPI industry

- Nitric acid plant
- Sulphuric acid plant
- Phosphoric acid plant

- Other applications

Measuring ranges and accuracy	Minimal measuring range	Maximal measuring range	Certified measuring range
NH_3	30 ppm (±2%*)	2.000 ppm	-
NO	40 ppm (±2%*)	1.900 ppm	0 ... 70 / 0 ... 700 / 0...1.302 mg/m³
NO_2	50 ppm (±2%*)	1.000 ppm	-
$LowNO_2$	20 ppm (±2%*)	1.000 ppm	-
SO_2	32 ppm (±2%*)	7.000 ppm	0 ... 15 / 0 ... 1000 / 0...2.500 mg/m³

Measuring ranges refer to 1 m measuring path. Measuring ranges depend on application and device type
* Refer to minimal full scale

Measuring path Cross Duct 1.86 m
Measuring path GMP 1,25 m / 1 m

Endress+Hauser

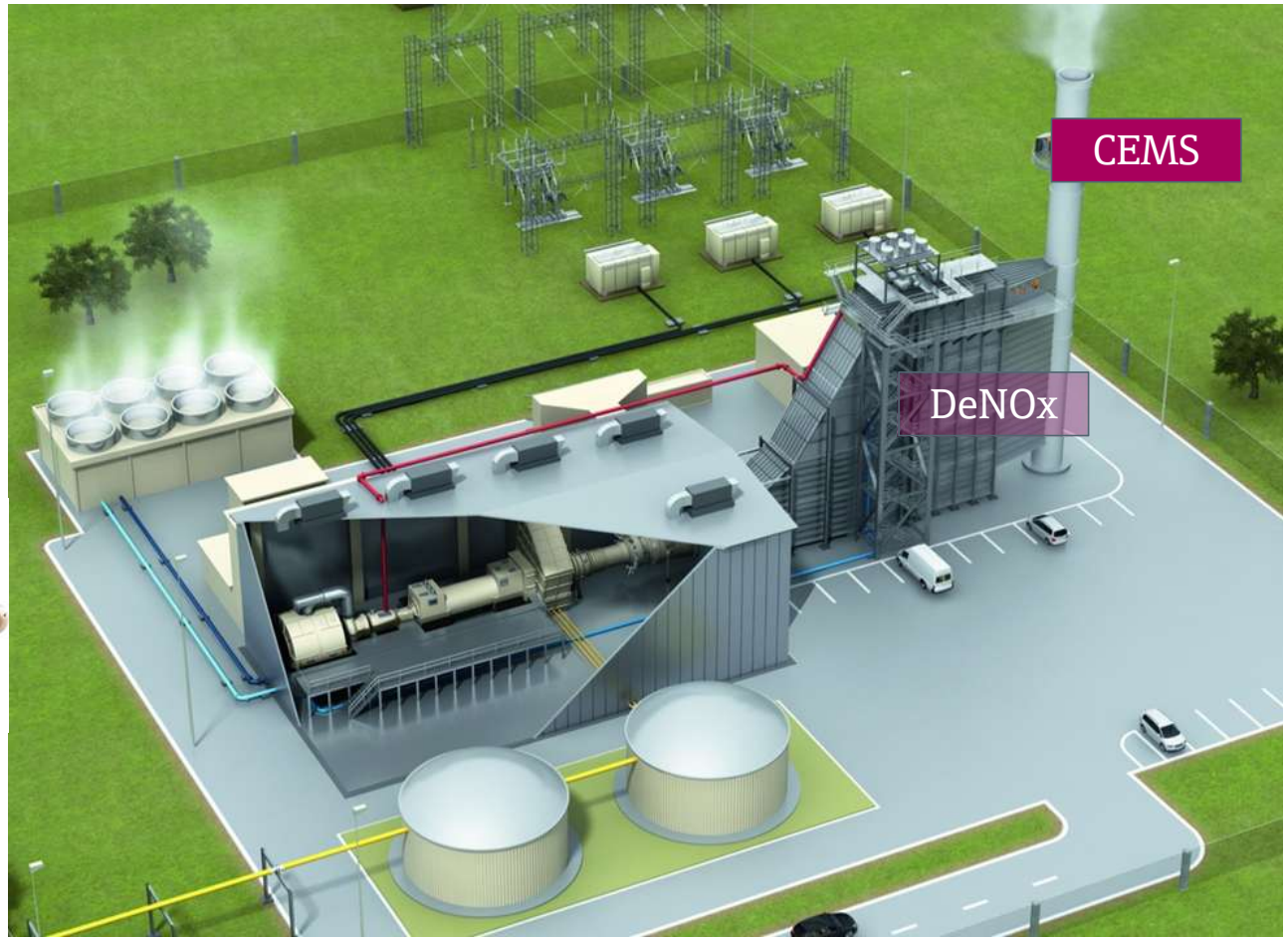
CEMS Measurement

CEMS
MCS200HW / MCS100FT



DeNOx
GM32 /GM700





Endress+Hauser

Continuous Emission Monitoring Systems (CEMS)

CEMS-Technology: hot-wet extractive

- Extracted from Stack/Process
- Analyzer in a safe environment
- No mechanical pump
- Absolute minimum maintenance
- Internal ref.-filters, no cal.-gas needed
- Highest availability





Endress+Hauser

Continuous Emission Monitoring Systems (CEMS)

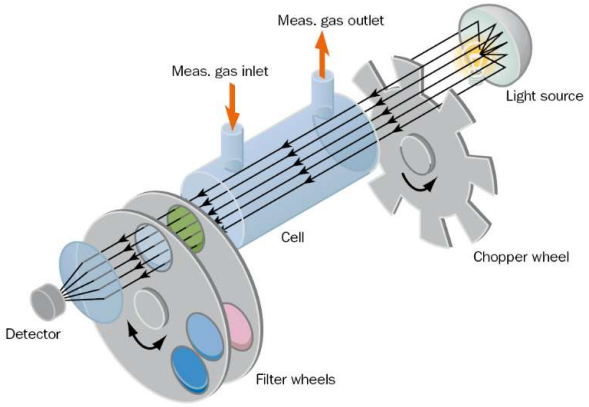
Hot Wet Extractive: MCS200HW & MCS100FT

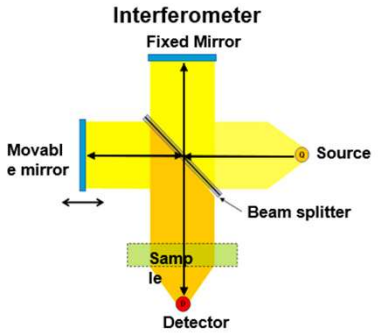
MCS200HW

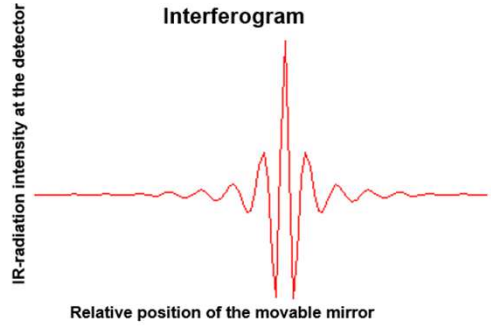
- Gas filter- and interference filter correlation
- Measuring up to 12 gases simultaneously..
- Certification acc. EN14181, EN15267-3, EPA, MCERTS
- Waste incineration, cement, power (gasturbine)

MCS100FT

- Fourier Transform Spectrometer
- Including measurement of HF, C_2H_6, C_3H_8,..
- Certification acc. EN14181, EN15267-3, EPA, MCERTS
- waste incineration







Endress+Hauser

Continuous Emission Monitoring Systems (CEMS)

Hot Wet Extractive: MCS200HW & MCS100FT

EN 15267-3 certified

MCS200HW

- Gas filter- and interference filter correlation

Component	Certified range	Additional range
H_2O	0 – 40 Vol.%	-
CO_2	0 – 25 Vol.%	-
CO	0 – 30 mg/Nm³	0 – 10,000 mg/Nm³
NO	0 – 50 mg/Nm³	0 – 2,500 mg/Nm³
NH_3	0 – 7 mg/Nm³	0 – 500 mg/Nm³
HCl	0 – 15 mg/Nm³	0 – 3,000 mg/Nm³
SO_2	0 – 75 mg/Nm³	0 – 2,500 mg/Nm³
NO_2	0 – 50 mg/Nm³	0 – 500 mg/Nm³
N_2O	0 – 45 mg/Nm³	0 – 2,000 mg/Nm³
CH_4	0 – 50 mg/Nm³	0 – 500 mg/Nm³
O_2 (ZRO_2)	0 – 25 Vol%	-
TOC (FID)	0 – 15 mg/Nm³	0 – 50 / 150 / 500 mg/Nm³

MCS100FT

- Fourier Transform Spectrometer

Component	Lowest range	Highest range
H_2O	0 – 40 Vol.%	-
CO_2	0 – 25 Vol.%	-
CO	0 – 75 mg/Nm³	0 – 1,500 mg/Nm³
NO	0 – 200 mg/Nm³	0 – 2000 mg/Nm³
NH_3	0 – 10 mg/Nm³	0 – 50 mg/Nm³
HCl	0 – 15 mg/Nm³	0 – 150 mg/Nm³
SO_2	0 – 75 mg/Nm³	0 – 1,500 mg/Nm³
NO_2	0 – 50 mg/Nm³	0 – 500 mg/Nm³
N_2O	0 – 50 mg/Nm³	0 – 500 mg/Nm³
CH_4	0 – 50 mg/Nm³	0 – 150 mg/Nm³
O_2 (ZrO_2)	0 – 21 Vol%	-
TOC (FID)	0 – 15 mg/Nm³	0 – 150 mg/Nm³
HF	0 – 3 mg/Nm³	0 – 10 mg/Nm³
C_2H_6 no type approval	0 – 50 mg/Nm³	
C_3H_8 no type approval	0 – 50 mg/Nm³	

Components and Accessories | MARSIC300 Photometer

Sampling Filter Unit

- Regulated (200 °C) heated sampling probe (0.1 µm filter)

Heated Sampling Line

- Regulated (200 °C) heated sampling line, up to 35 m

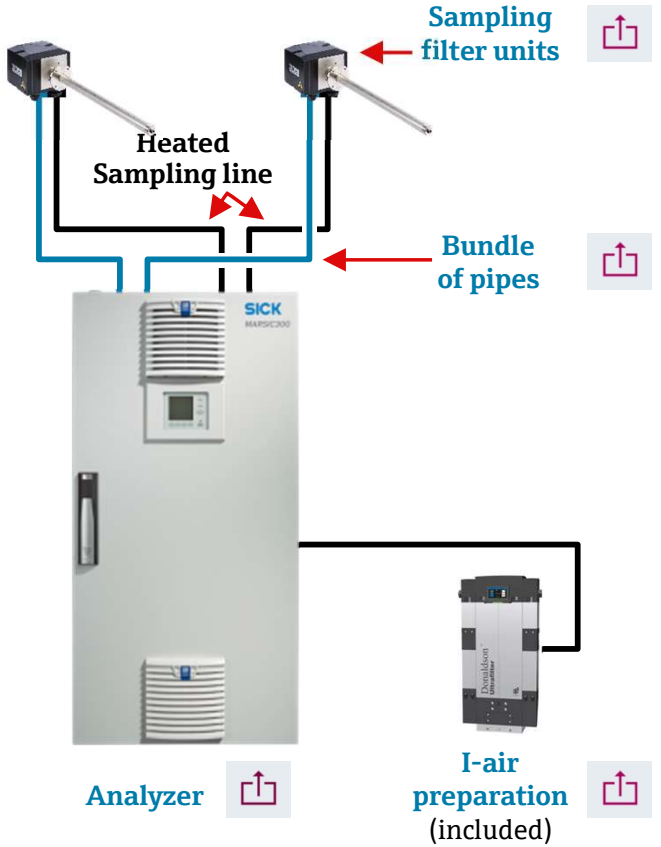
Analyzer

- Gas filter- and interference filter correlation
- Measures NO, NO_2, **SO_2,** CO_2, CO, NH_3, O_2, CH_4 + H_2O
- Humidity, flow and pressure,
- Contains ejector pump (no movable parts)

Sampling Points

- Up to 2 sampling points (optional for $DeNO_X$ up to 8 SP)



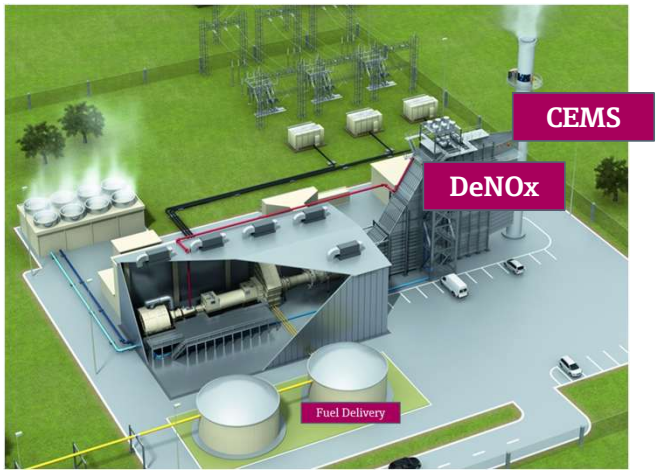


Endress+Hauser

Summary: technology for NO, NO_2, NH_3 measurement

Gas Analysis Technologies

- DeNOx & CEMS
- in situ & extractive gas sampling

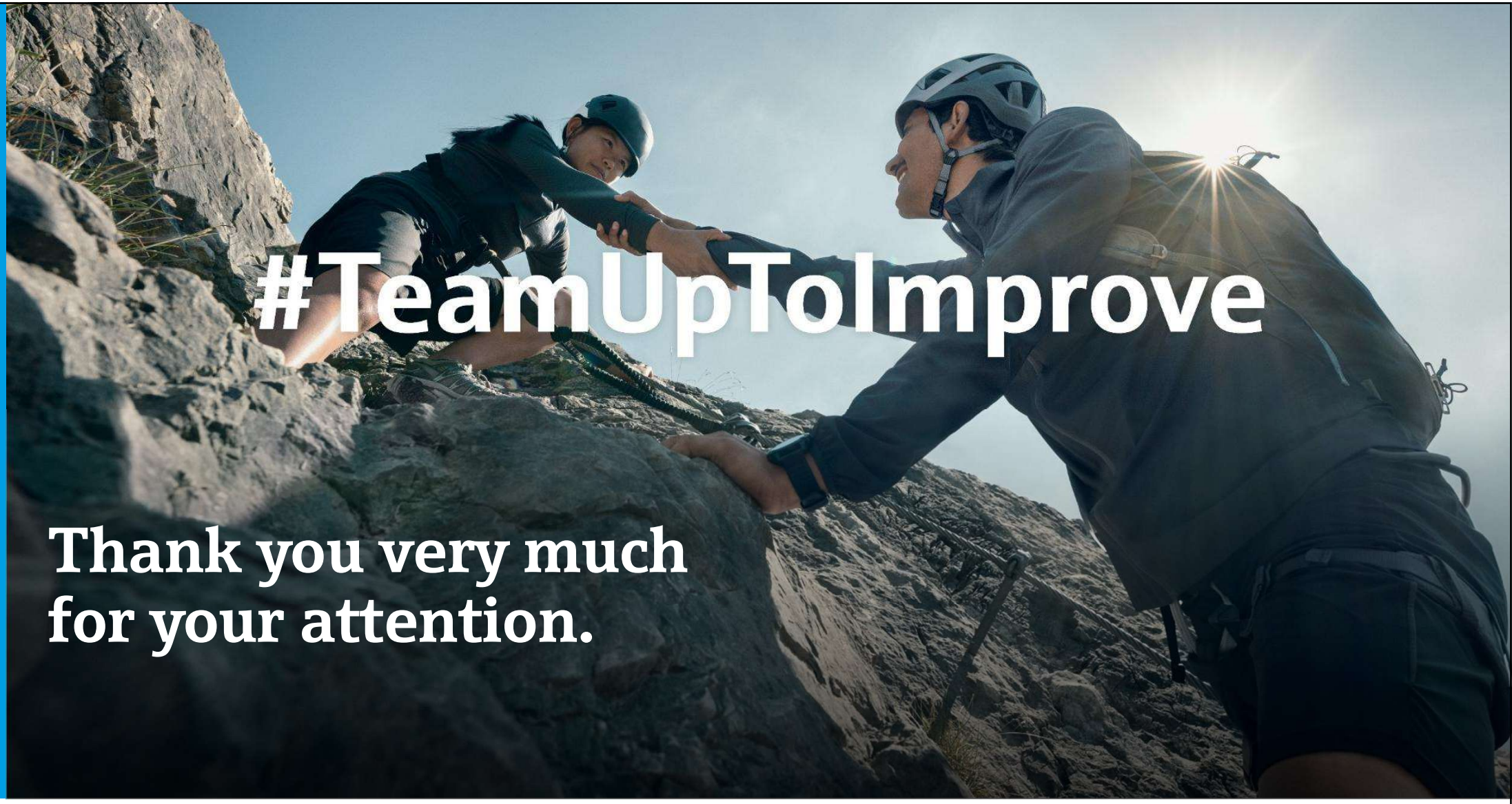


DeNOx control

- GM700-TDLS (NH_3, HCl, HF, CO) and H_2O
- GM32-UV spectrometer simultaneously SO_2, NO, NO_2, NH_3

Emission Monitoring (hot wet extractive)

- Gas filter- and interference filter correlation - MCS200 HW & MARSIC 300
- Fourier Transform Spectroscopy - MCS100FT


#TeamUpToImprove
Thank you very much
for your attention.

Industrial scale ammonia-based fuel combustion

Wp4 M14 (September 2026)

Alexander Fateev, DTU Chemical Engineering
alfa@kt.dtu.dk

MaritimeMET, MetZeroPol, MetNH3Energy Joint Workshop, on-line, Wednesday, 30th September 2026

MetNH3Energy

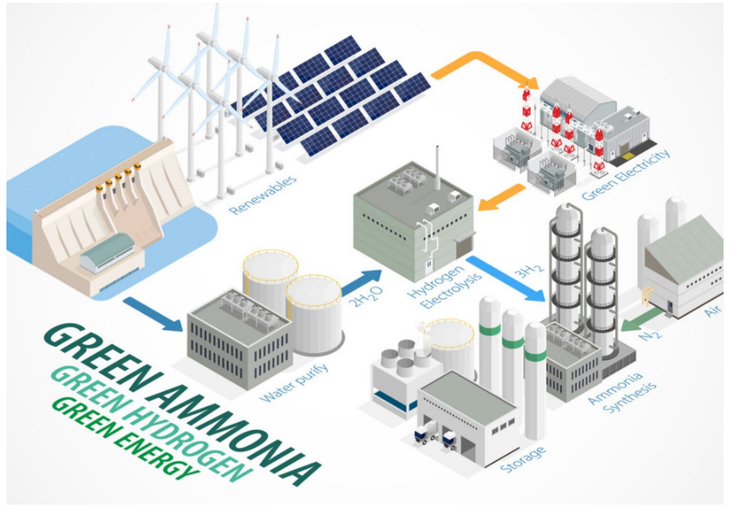
EUROPEAN PARTNERSHIP
Co-funded by the European Union
METROLOGY PARTNERSHIP
EURAMET

The project (24GRD01 MetNH3Energy) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

EURAMET Green Deal Call 2024

[Green Deal Call Scope]():

- EU Contribution – 3.5 M €
- Duration – 36 months
- Starting Date: 01 August 2025



Partners

- 24 funded + 2 unfunded beneficiaries
- 2 Collaborations partners: Alfa Laval Denmark; A*Star Singapore
- 2 Collaborations in the pipeline: INM – Columbia, INTI Argentina

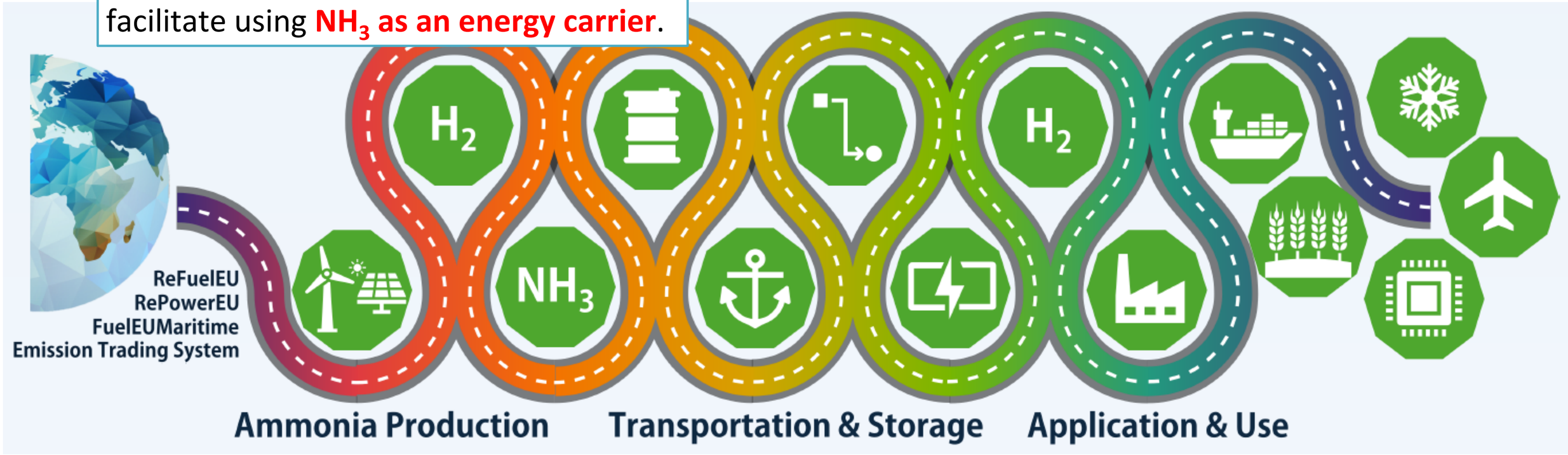
Short Name: MetNH3Energy, Project Number: 24GRD01

https://www.euramet.org/research-innovation/search-research-projects/details/project/metrology-to-support-ammonia-use-in-emerging-applications

Metrology to Support Ammonia Use in Emerging Applications

MetNH3Energy

Ensuring the **metrology infrastructure** and relevant services are in place to facilitate using **NH_3 as an energy carrier**.



WP 1: Reference Materials & Impurities	WP 2: Gas & Liquid Flow Measurements	WP 3: Leakage & Material Compatibility	WP 4: Emission Measurements & Life Cycle Analysis

Real-time emission measurements techniques and ammonia LCA

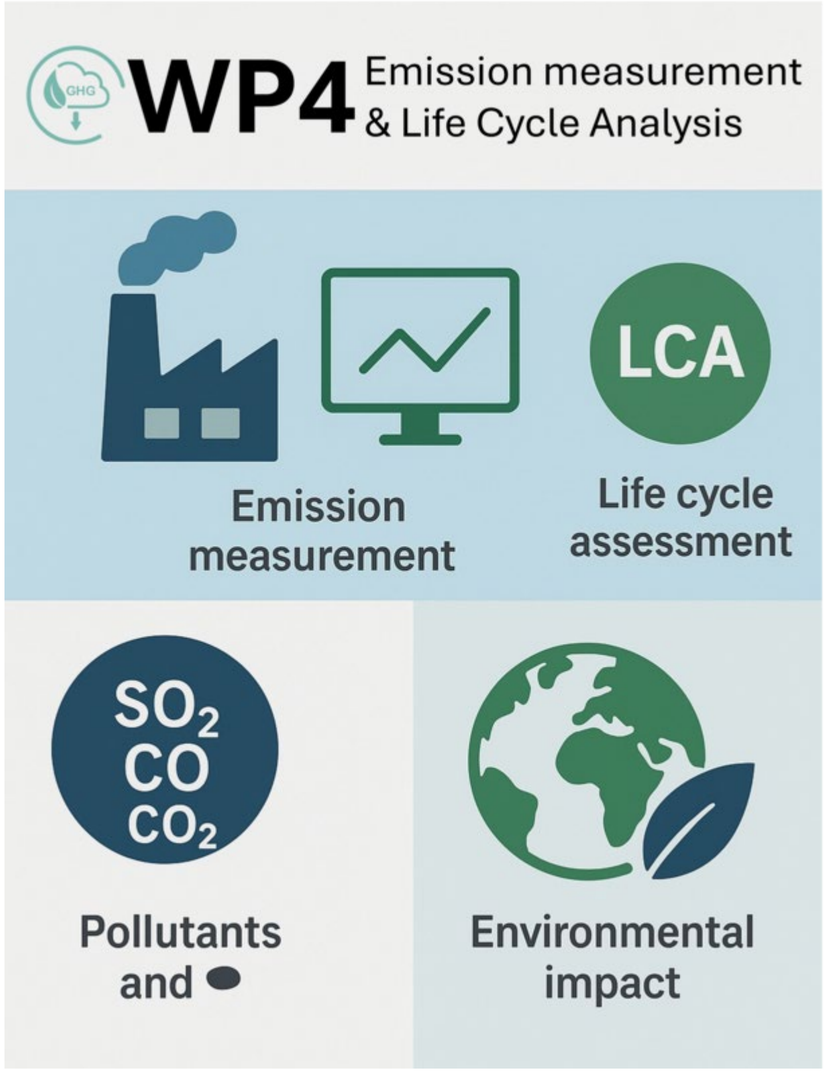
Lead by Alexander Fateev | Technical University of Denmark

Aims: to develop **traceable real-time emission monitoring** for ammonia conversion processes, supported by validated quantification methods, uncertainty analysis, and **LCA** to ensure accurate and traceable environmental impact evaluation.

📍 **Task 4.1** – Development of real-time online emission monitoring techniques

🌄 **Task 4.2** – Field tests of real-time online emission monitoring techniques

♻️ **Task 4.3** – NH_3 ex-ante techno-economic and environmental LCA



WP4
EcoLife

Task 4.2: Field tests of real-time online emission monitoring techniques: started from August 2026

MetNH3Energy

- Demonstration in practical applications:
  - an internal combustion engine (NH3/H2/gas/diesel blends): measurements in high P/T manifold at variable P/T conditions.
  - **a marine boiler operated on ammonia blends: in-flame/boiler and exhaust duct (before SCR) supplied by temperature measurements**.

- Analysis of reaction pathways to understand the effect of impurities in NH3 (H2S, CxHy) on pollutants (SOx, CO, CO2) formation.

Task 4.2: Industrial scale ammonia-based fuel combustion

Marine Testcenter

Leading Marine Environmental Tech

- The Alfa Laval Test & Training Centre in Aalborg, Denmark, is the world's most advanced test centre for environmental and combustion technology for the marine industry.
- The 2,800 m2 testing space – already equipped for today's oil and gas fuels – has now also been readied for testing biofuels and methanol.
- In 2024 the Test & Training Centre celebrated 10 years.



https://www.alfalaval.dk/industrier/marine-og-transport/marine/alfa-laval-test-og-traningscenter/

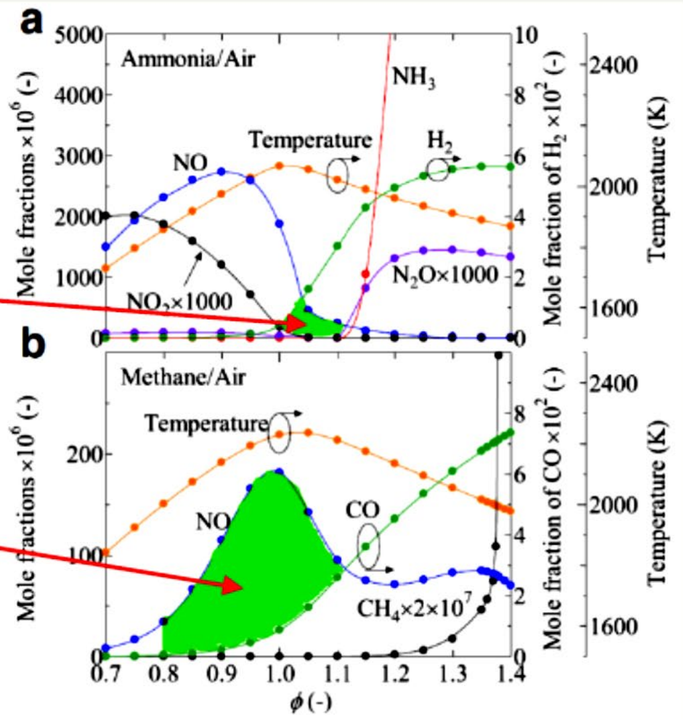
Task 4.2: Industrial scale ammonia-based fuel combustion

Combustion Properties

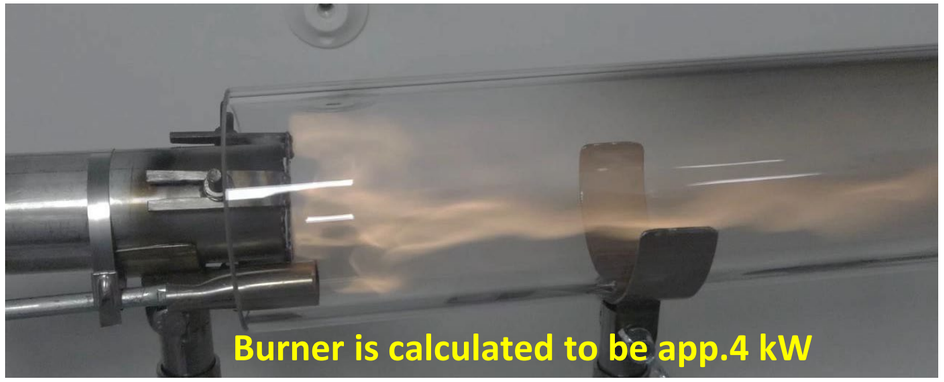
- Combustion properties comparison between Methane & Ammonia at different stochiometric mixing ratios.

Sweet spot NH_3

Sweet spot CH_4



Copy from : Science & Technology of ammonia Combustion



NH3 as a fuel in a boiler (open combustion)

- Paper study conclusions so far…
  - Ammonia burns slowly, thermal output is expected to decrease significantly on existing equipment
  - Poor Burning characteristics (Difficult to ignite & NOx/N_2O/NH_3-slip issues)
  - Extra air needed, lower flame temperature: Poor boiler performance

- Recommendations:
  - Preheat ammonia to increase flame temperature and flame velocity
  - Gas phase combustion like NG
  - Preheat Combustion Air if possible?
  - Work with excess air of "0%" (+/- 5%) N_2O or NH_3 slip?
  - Support flame may be needed for ignition or alternative flame enhancement

Task 4.2: Industrial scale ammonia-based fuel combustion

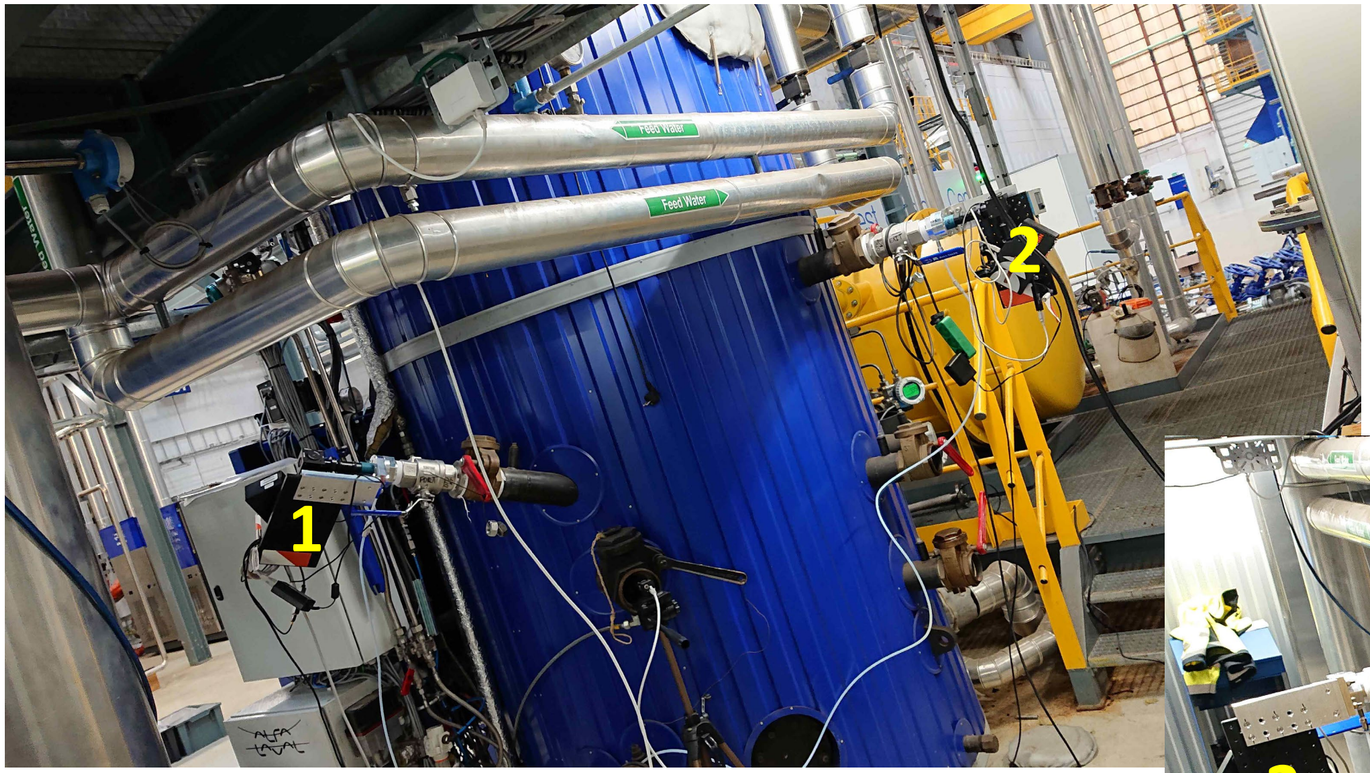
OS-TCi 2 t steam/h multifuel boiler
1.7 MW thermal



NH3 safety concerns on boiler system

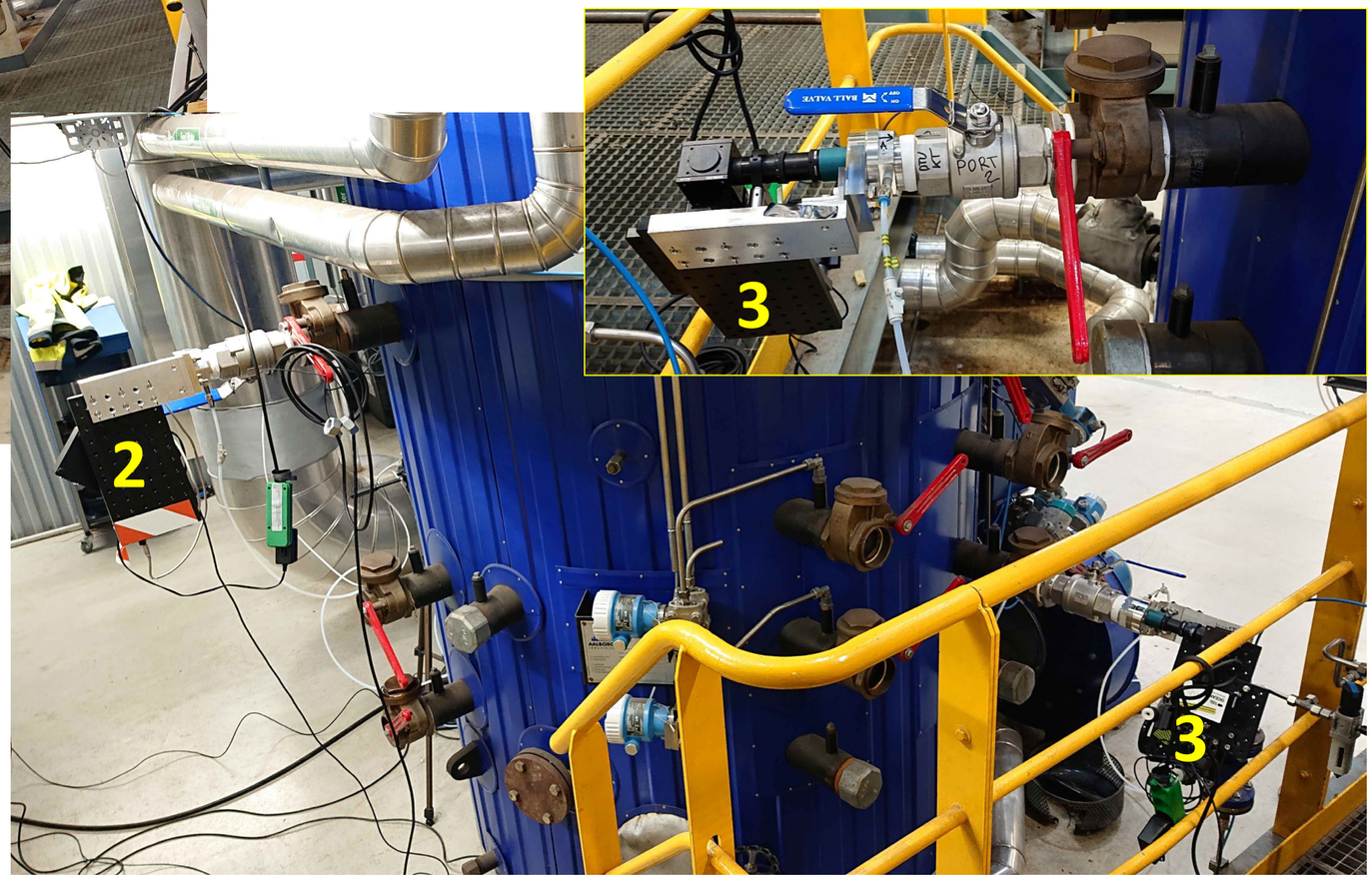
- Back blow from combustion chamber
- NH_3 slip
- NOx emissions
- Laughing gas emissions
- Ammonia leak on supply system
- Leak from exhaust gas system
- Faulty ignition
- Flame detection
- Dual fuel firing (oil+NH_3)
- Ongoing work in Test Center simultaneous to NH_3 test
- Visitors in Test Center during NH_3 Test
- NH_3 PPE
- Fire brigade assistance in worst case scenario

Task 4.2: Industrial scale ammonia-based fuel combustion

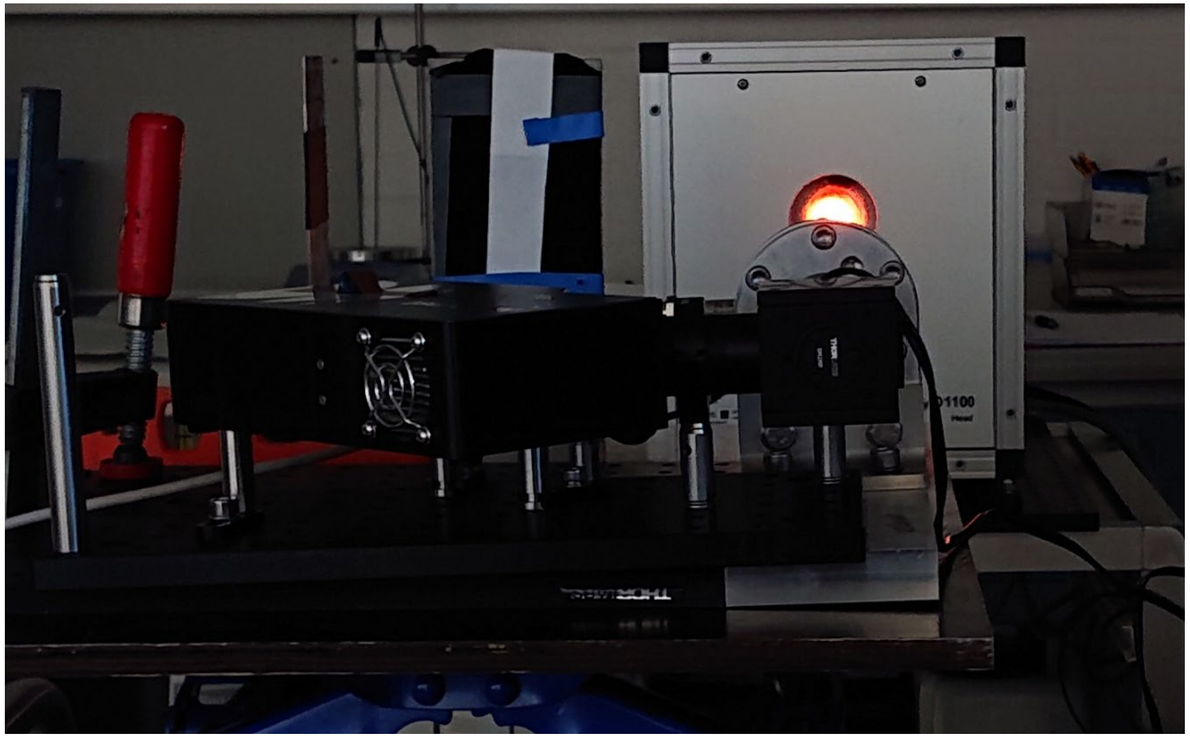


1: Flame End (NIR line-of-sight)
2: Boiler Exit (NIR line-of-sight)
1+2: continuous emission (th.radiation) measurements, 900-2500 nm, no fibers

3: Burner Exit (VIS-NIR line-of-sight, 400-1000 nm, no fibers, continuous emission (th.radiation) measurements)

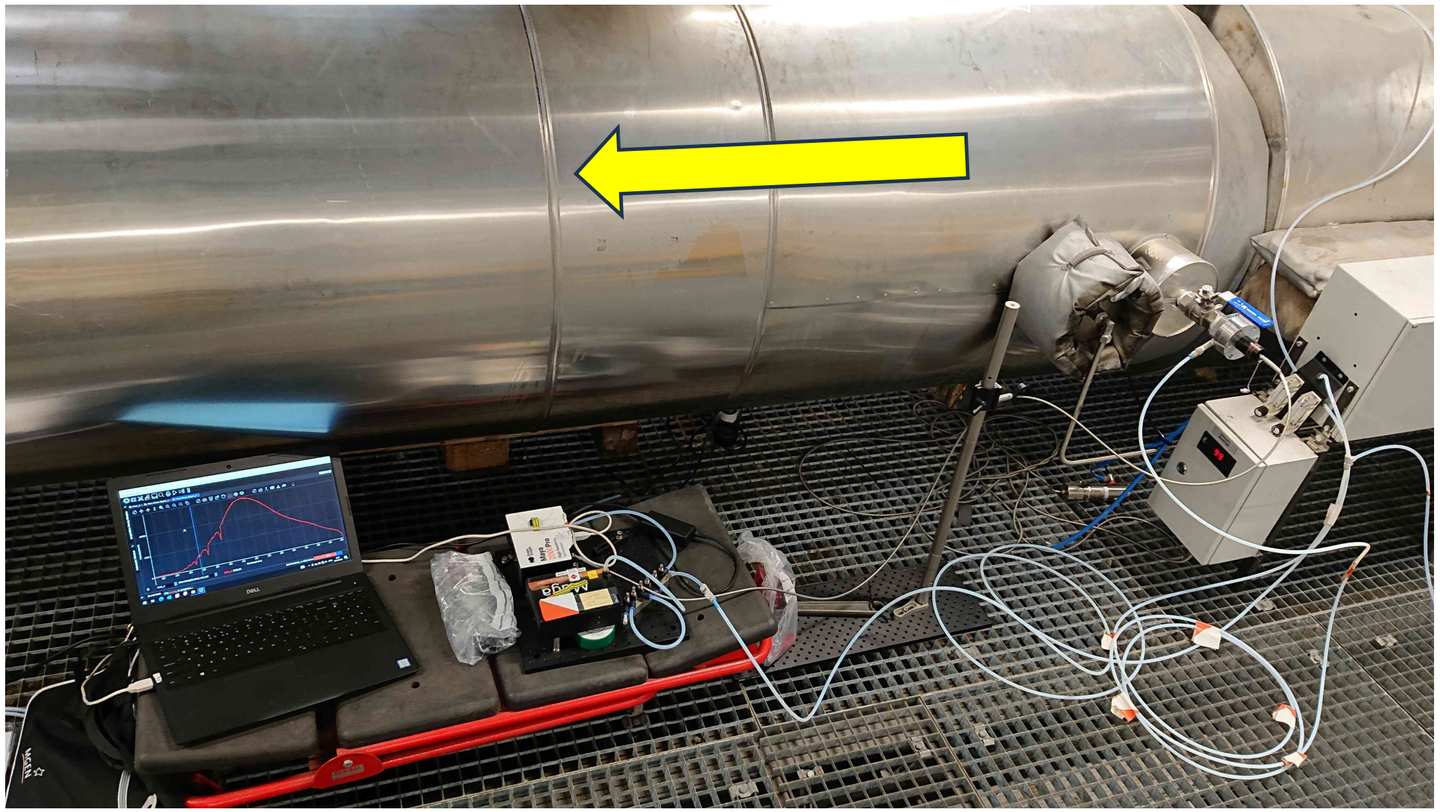


Task 4.2: Industrial scale ammonia-based fuel combustion



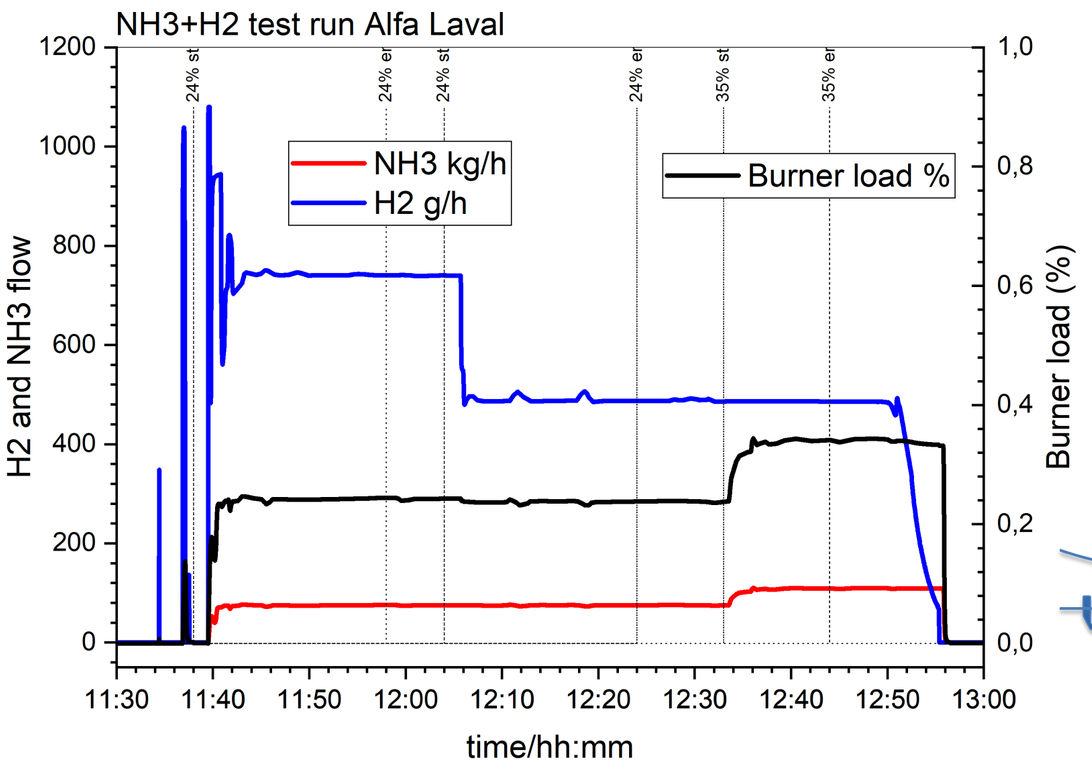
- 1 + 2 + 3 Calibration with in-house traceable BB1100 black body source @1100 °C
- Same geometry (as in the on-site measurements)
- Before/After (on-site or in lab)

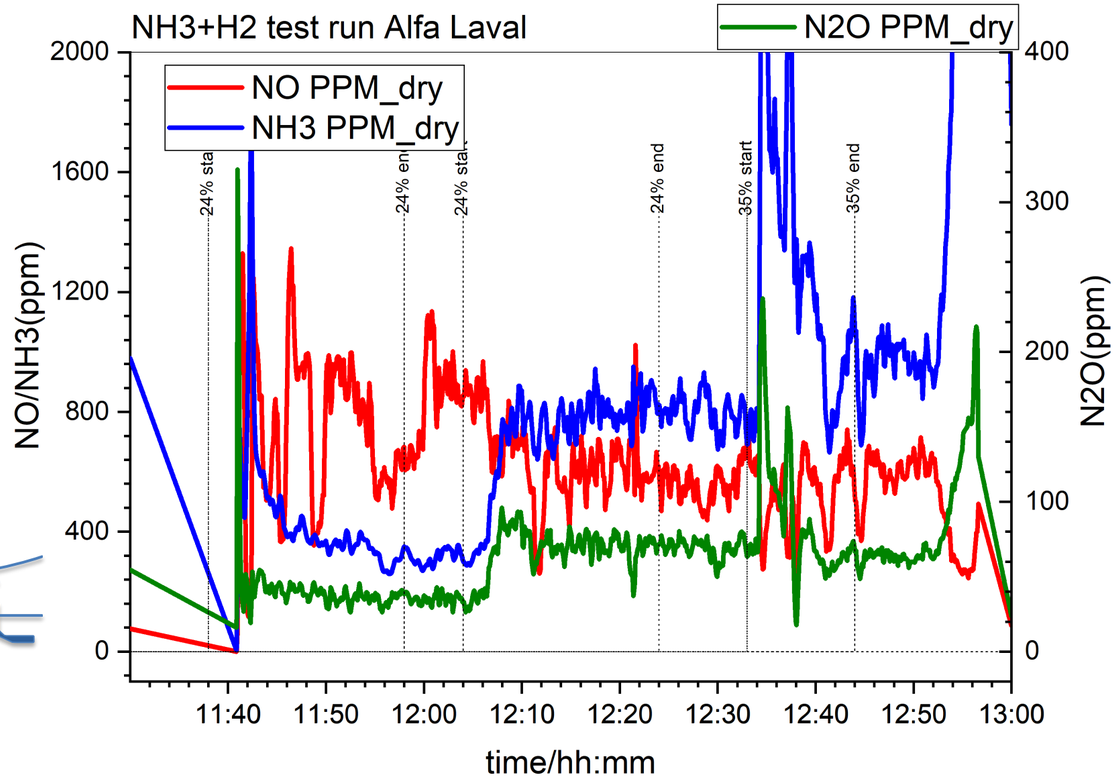
Task 4.2: Industrial scale ammonia-based fuel combustion



- ❑ Before SCR
- ❑ Use of existing access possibilities
- ❑ Transmittance measurements
- ❑ Across gas flow
- ❑ 300-350 °C gas temperature
- ❑ Negative pressure
- ❑ UV-VIS (175-400/600 nm): NO, NH3, NO2, SO2, opacity
- ❑ No concentration limits
- ❑ Continuous measurements

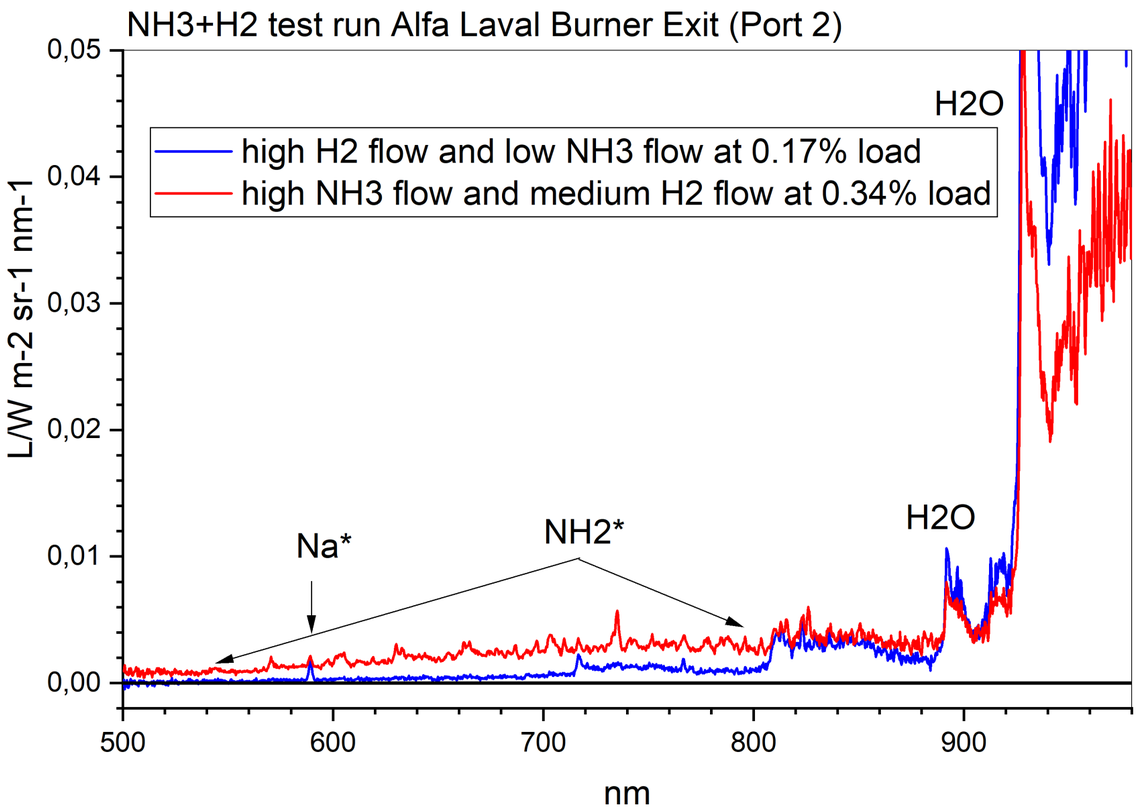
Task 4.2: Industrial scale ammonia-based fuel combustion

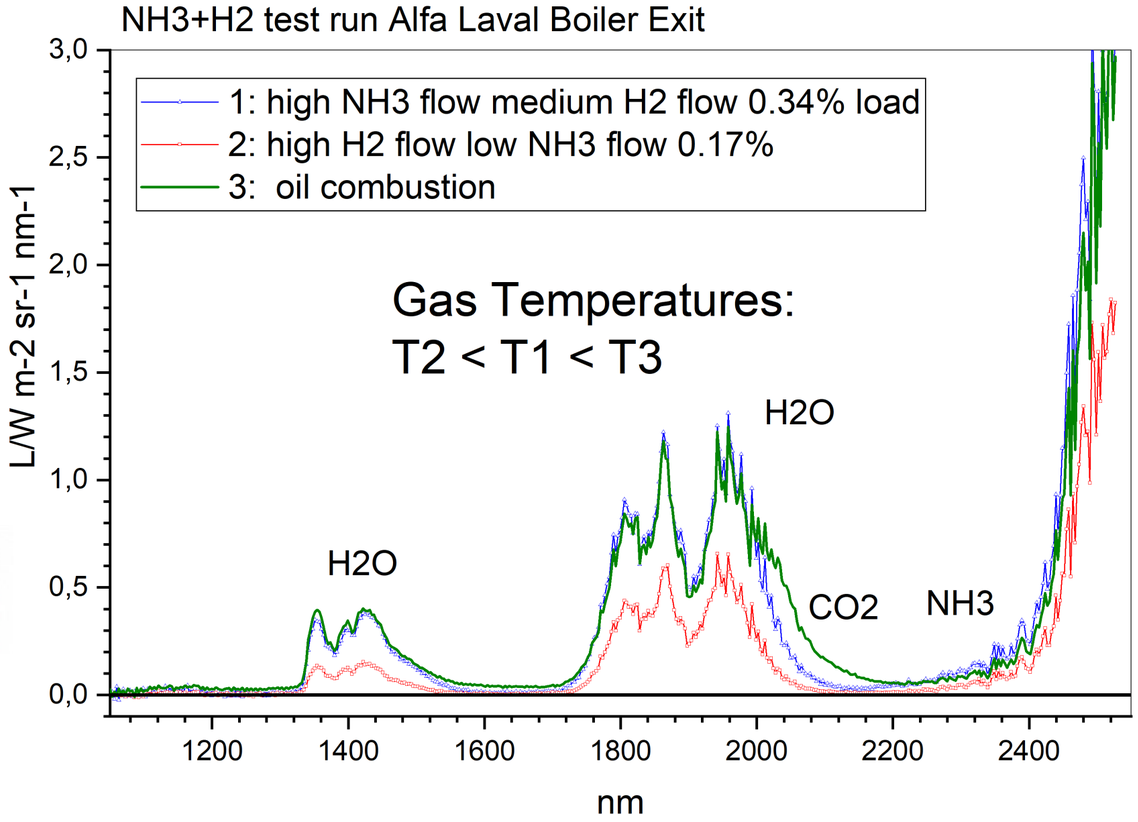




- Extractive gas measurements (after Boiler Exit)
- Unstable NO at high H2 flow
- H2 flow reduction → higher NH3+N2O emissions; “some” effect onto NO (“less”)
- Higher burner load → NO instabilities followed by NO emission increase

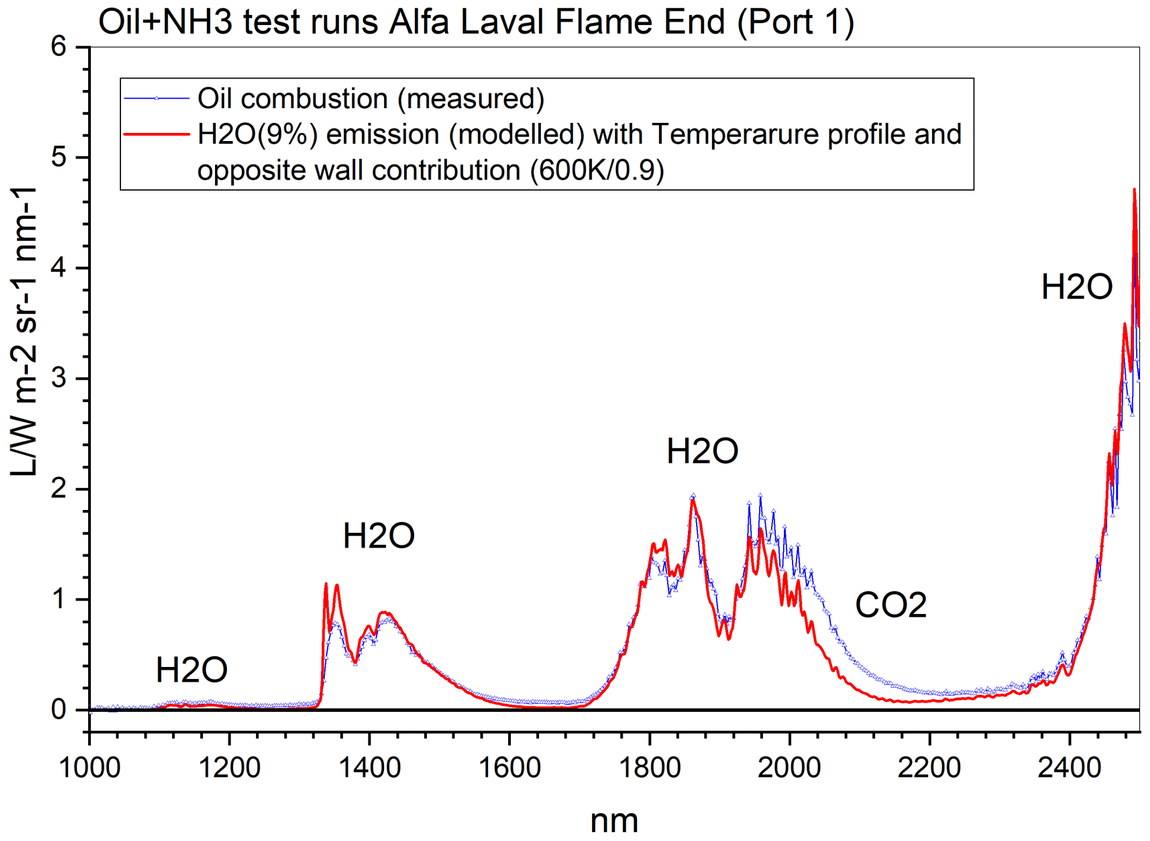
Task 4.2: Industrial scale ammonia-based fuel combustion

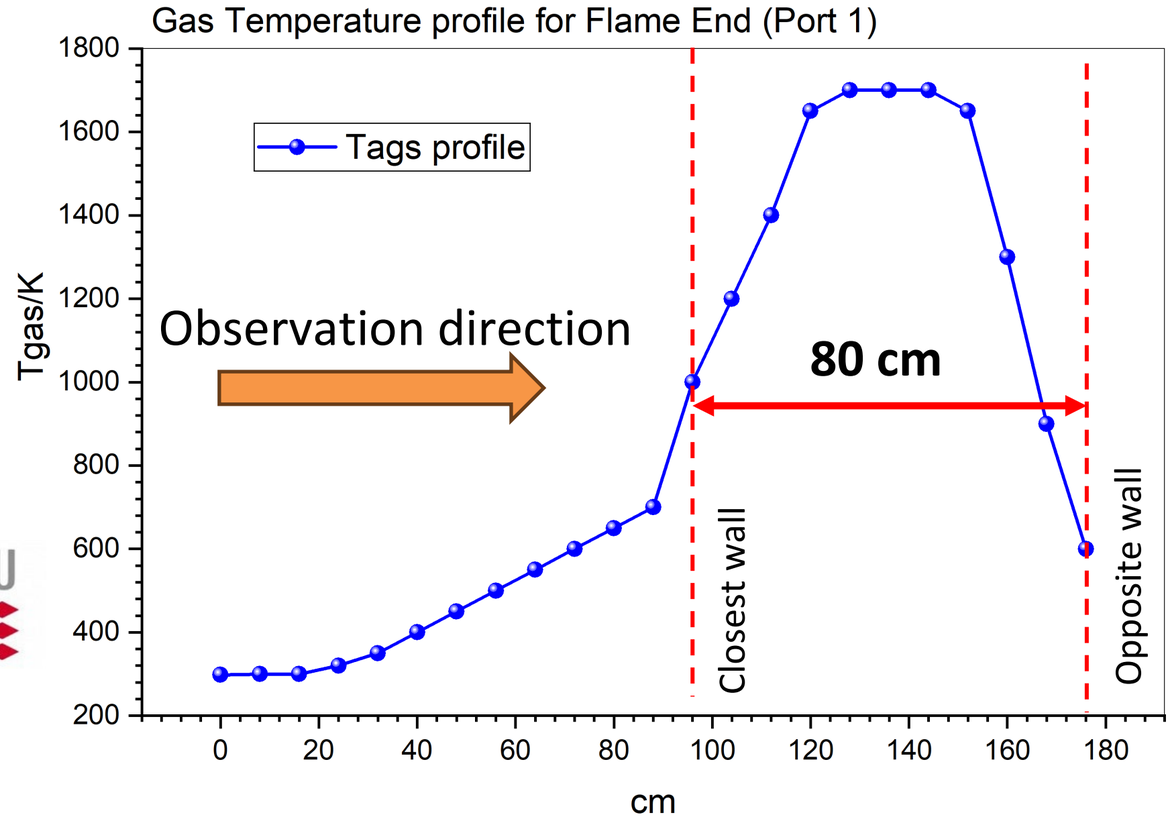




- Examples of single line-of-sight emission measurements
- Higher loads promote excited species formation
- Variations in gas temperatures (T2 < T1 < T3)
- Unburned NH3 radiation at burner start observed

Task 4.2: Industrial scale ammonia-based fuel combustion





- Example of measured emission spectrum and its modelling with given Tgas profile (oil combustion case)
- H2O dominated emission with some CO2 contribution
- Band shapes and intensity distributions (L) are T-dependent (and H2O concentration)
- On-going

WP4
EcoLife

Task 4.2: Field tests of real-time online emission monitoring techniques: started from August 2026

MetNH3Energy

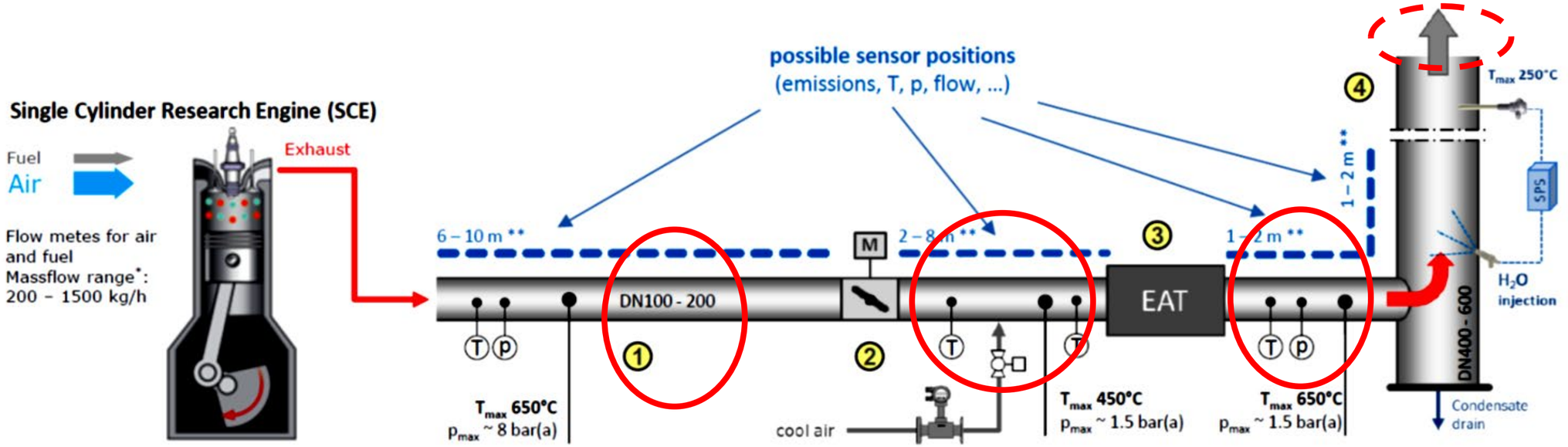
- Demonstration in practical applications:
  - **an internal combustion engine (NH3/H2/gas/diesel blends): measurements in high P/T manifold at variable P/T conditions.**
  - a marine boiler operated on ammonia blends: in-flame/boiler and exhaust duct (before SCR) supplied by temperature measurements.

- Analysis of reaction pathways to understand the effect of impurities in NH3 (H2S, CxHy) on pollutants (SOx, CO, CO2) formation.

Task 4.2: Demonstration at an internal combustion engine at LEC

NH_3 SCE test bed @LEC | WP 4.3 field test

Exhaust piping system & Chimney



* *Massflow range and exhaust gas composition depending on SCE type and operation parameters*

** *Exhaust piping geometry depending on test bed configuration*

1. High pressure (HP) section
2. Pressure control valve
3. Low pressure (LP) section including EAT system
4. Chimney with H_2O injection
   - HP and LP sampling positions
   - T, p measurement positions

In preparation (gas composition + flow):
planned for August 2027 (M25) – January 2028 (M30)

Acknowledgements to

Alfa Laval

for support, hosting and many fruitful discussions

MetNH3Energy

EUROPEAN PARTNERSHIP

Co-funded by the European Union

METROLOGY PARTNERSHIP

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Thank you very much for your attention!

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