PROJECT SUREAL-23: UNDERSTANDING, MEASURING AND REGULATING SUB-23 NM PARTICLE EMISSIONS FROM DIRECT INJECTION ENGINES INCLUDING REAL DRIVING CONDITIONS

Aerosol and Particle Technology Laboratory (APTL)

ICE2017, Capri, September 10-14, 2017

Co-financed by the European Union
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Outline

- The problem
- SUREAL-23 approach
- Project's methodology
- Advanced particle sampling/treatment
- Advanced instrumentation
- Indicative applications
- Conclusions

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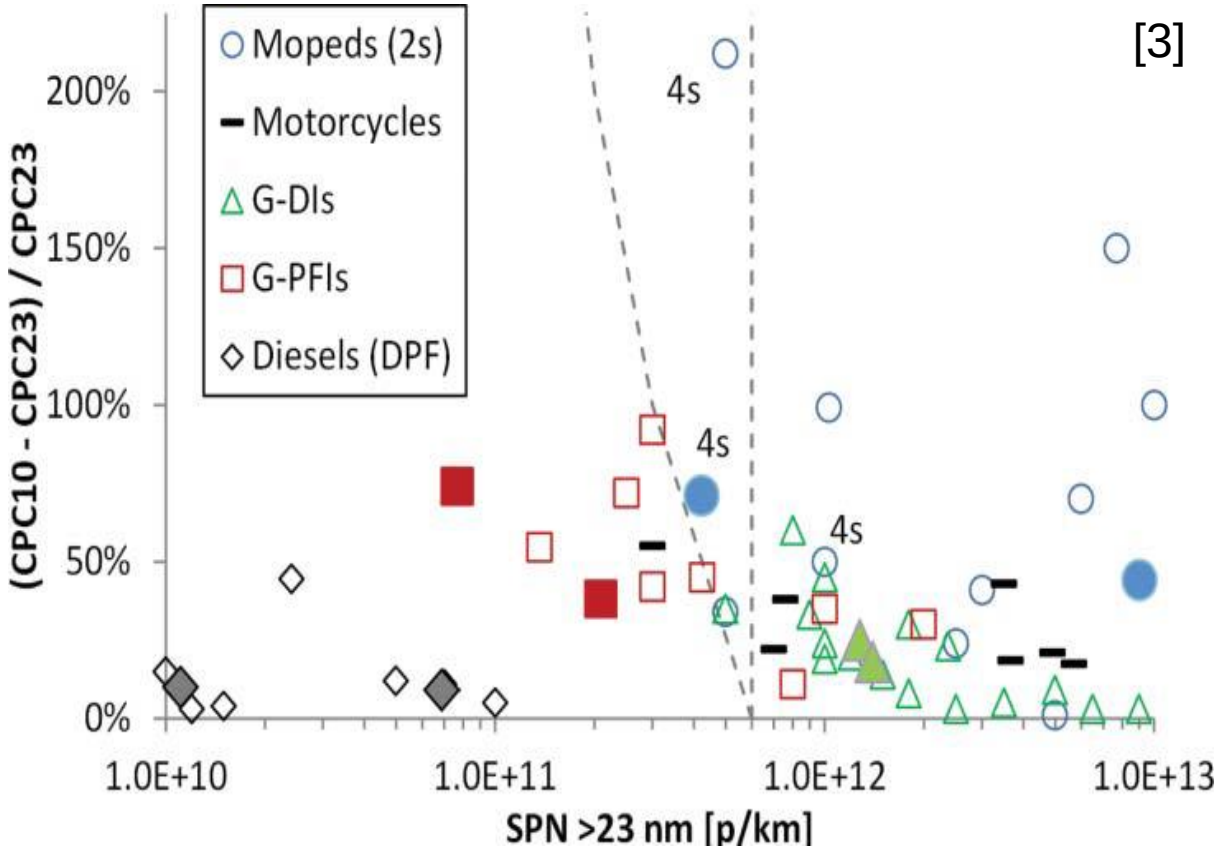
The Problem

- Vehicles are subject to regulation of **solid-only particle** number (PN) since Euro 5/6 homologation for light duty, Euro 6 for heavy duty.[1]
- Protocol developed by the PMP[2]: hot dilution and an Evaporator Tube and particle counting with **50% cut-off at 23 nm** to avoid re-nucleation artifacts.
- Initial PN regulation **aimed at Diesel**, extended to Gasoline. GDI engines have greatly increased in number.
- Evidence of significant solid PN emissions **missed** due to the 23 nm cut-off.[3]
- **Health effect significance**: enhanced deposition in the respiratory track and potential translocation.[3,4]
- **How to measure below 23 nm?**

[3]



[1] *Science of the Total Environment 408:5106–5116 (2010).*
[2] *Aerosol Sci. Technol., 42:528–43 (2008).*
[3] *Aerosol Sci. Technol., 51:5, pp. 626-641 (2017).*
[4] *Inhal Toxicol., 16(6–7):437–45 (2004).*

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SUREAL-23 Approach

Focus

The ***SUREAL-23*** project focuses on the particles, **smaller than the current regulation cut-off limit of 23 nm**, emitted from Light Duty engines (**Diesel and gasoline**).

Objectives

- **Complement and extend** existing instrumentation for particles below 23 nm.
- **Characterize** in detail the nature of the particulate emissions below 23 nm.
- **Support future emissions** compliance through technical developments in RDE.

Innovation

- **Size and composition** analysis methods suitable for transient engine emissions.
- **Novel instrumentation** for measuring aerosol particles below 23 nm, providing backward compatibility with established PN measurement technology.
- Enhancement of instrument specifications to allow operation with **less demanding sample conditioning** requirements.
- Integration of the most suitable components of the extended sub-23 nm measurement toolset into **PEMS** and verification in real driving conditions.

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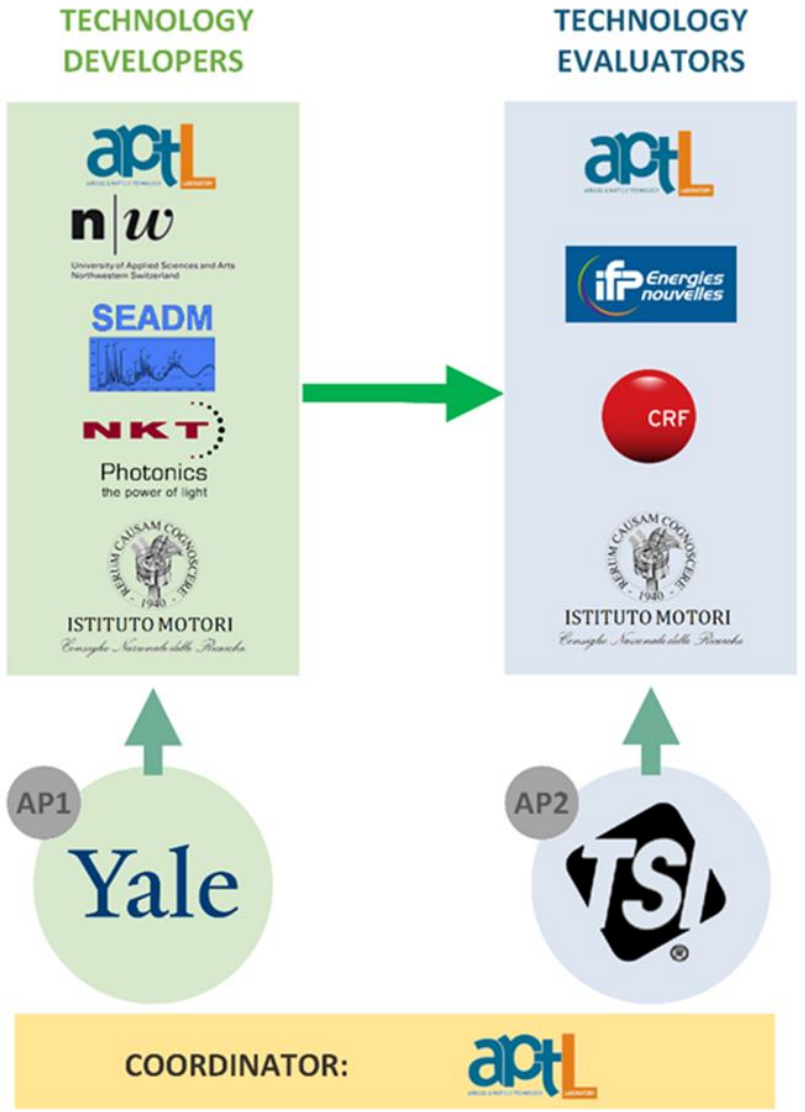
SUREAL-23 Partnership



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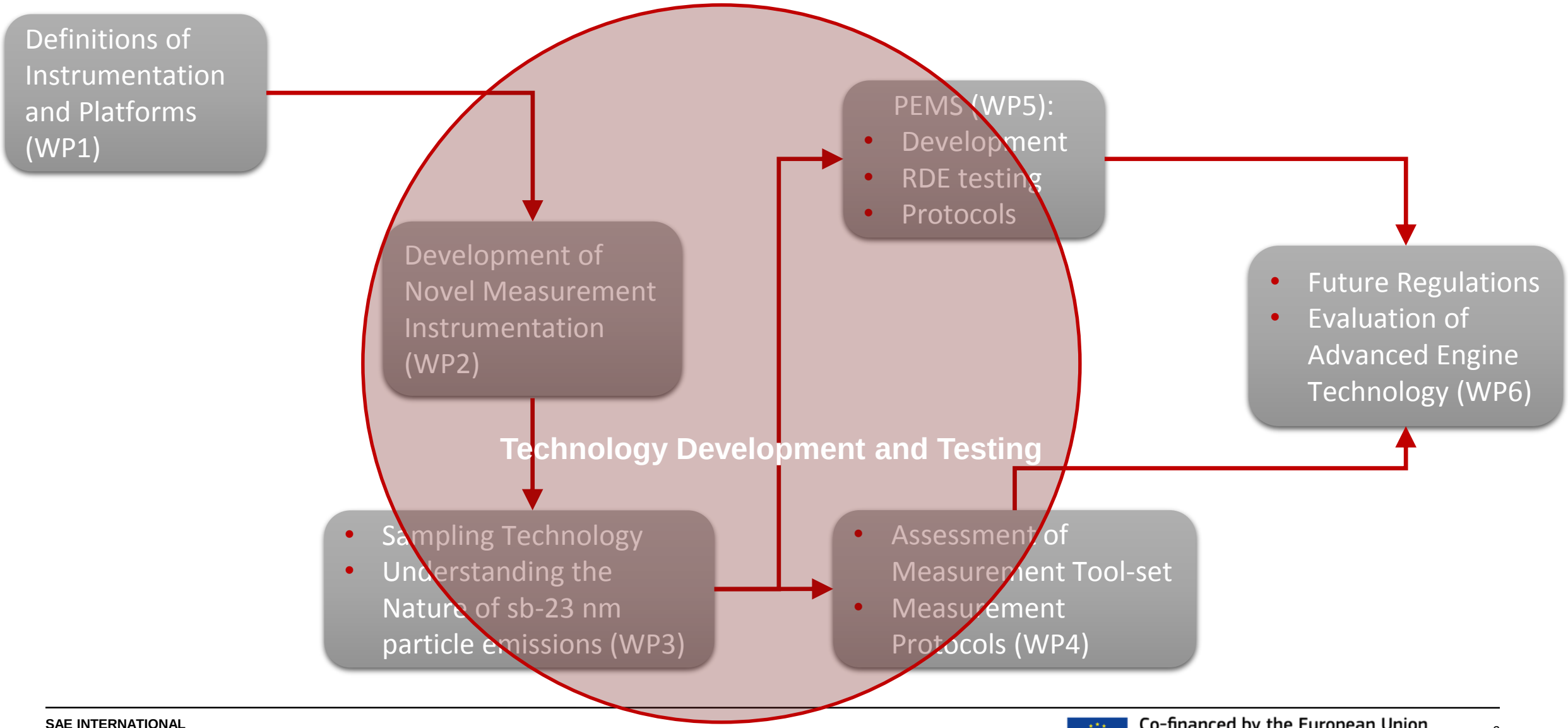
SUREAL-23 Workplan



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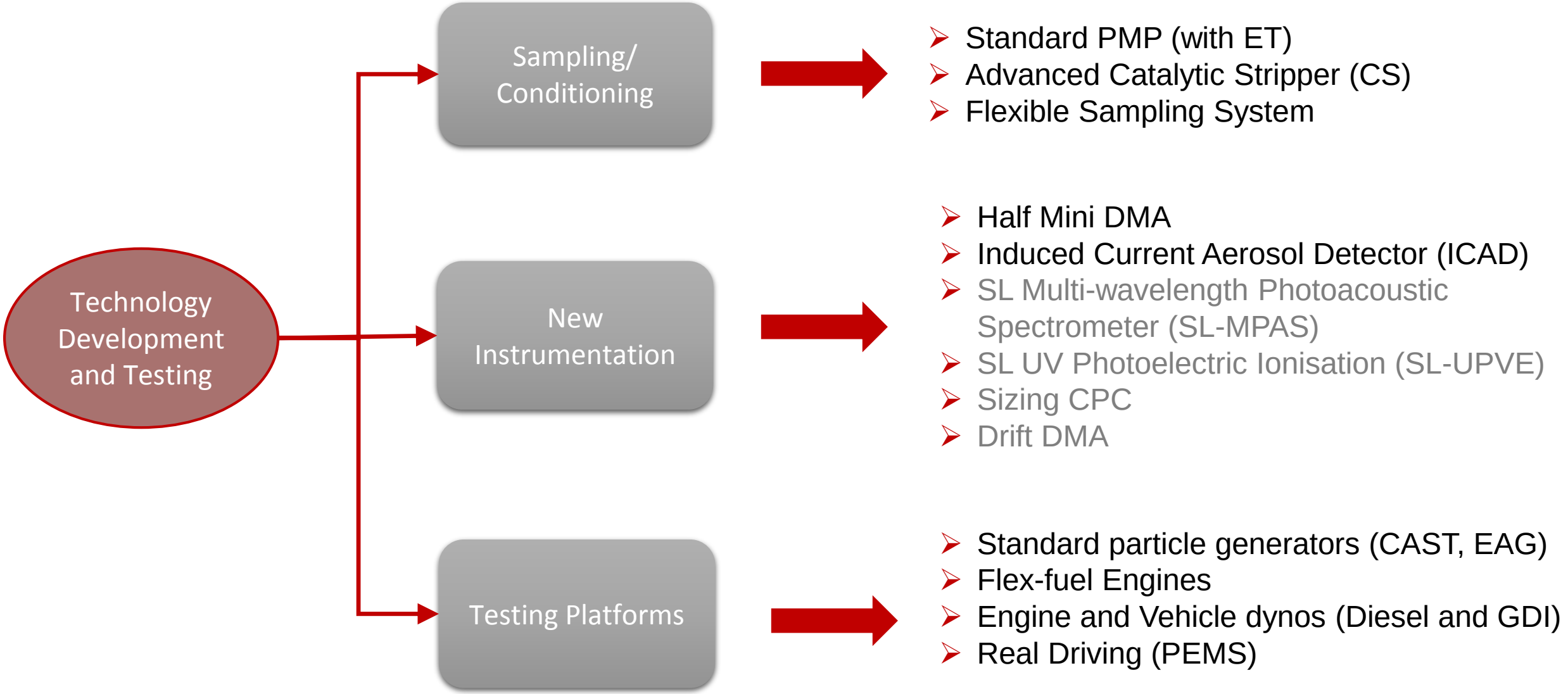
Technology Development and Testing



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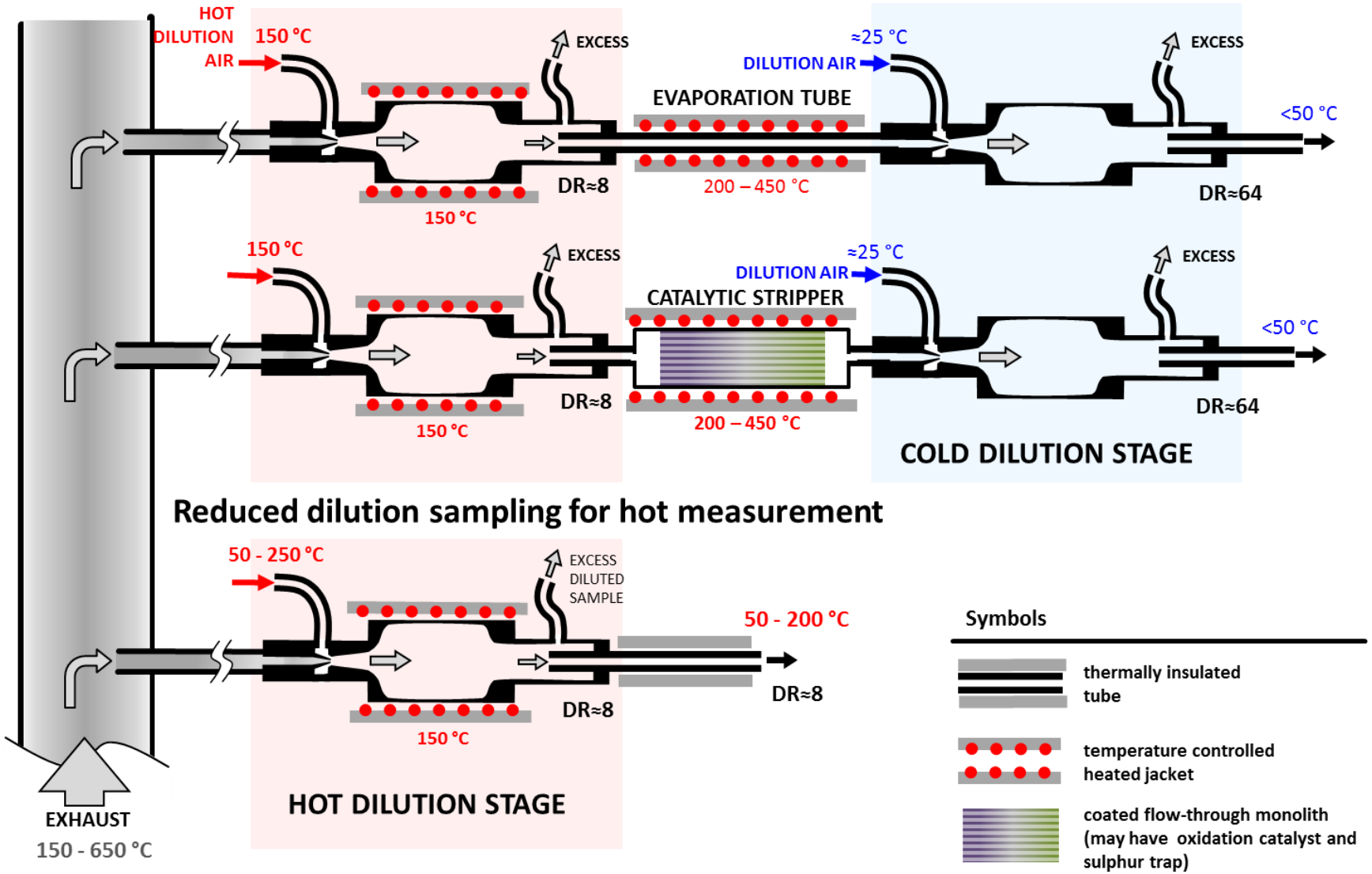
Sampling / Conditioning



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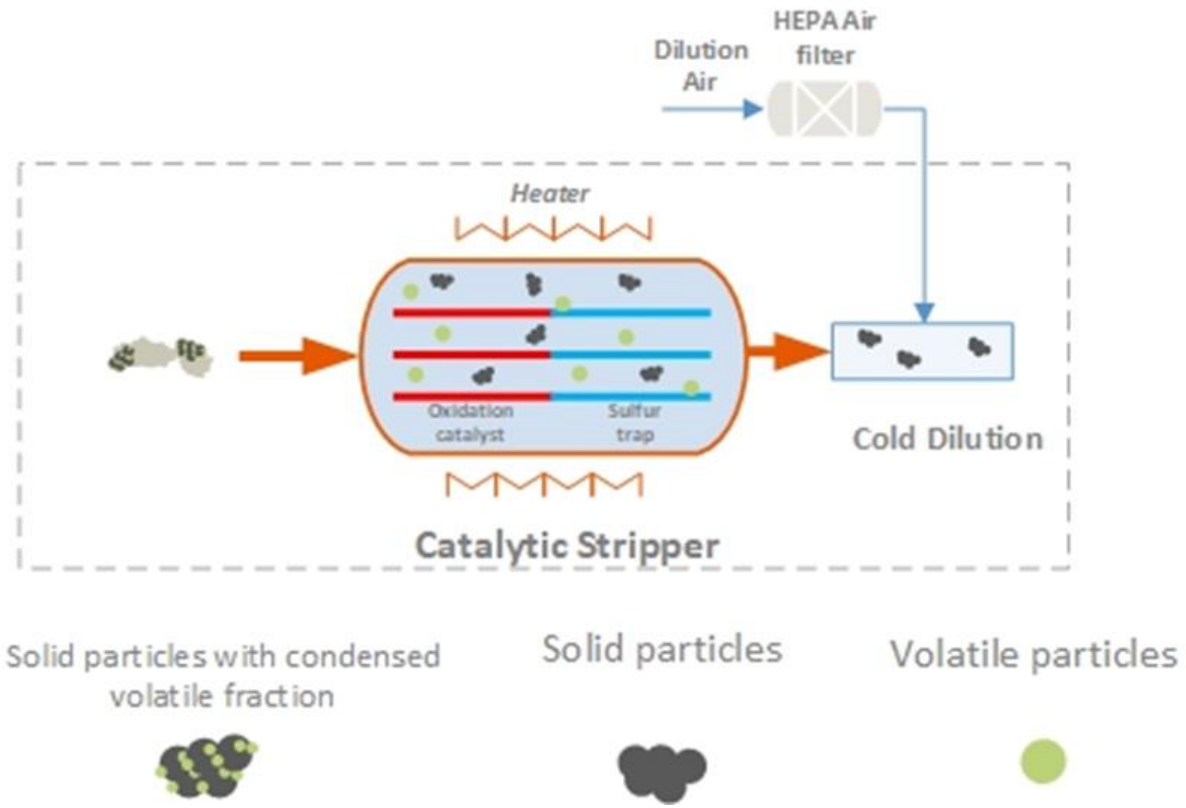
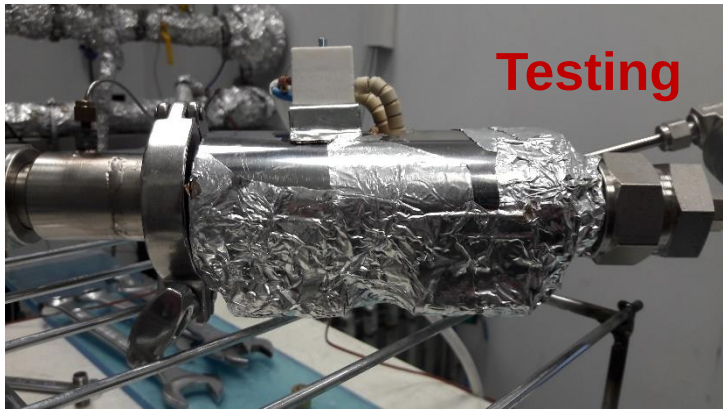
Advanced Catalytic Stripper



- A plethora of mixed oxides were synthesized and tested for their SO_2 adsorption capacity
- A double function monolith was impregnated with the most efficient powders and addition of Pt



- C40 removal efficiency
- SO_2 adsorption
- Solid particle penetration

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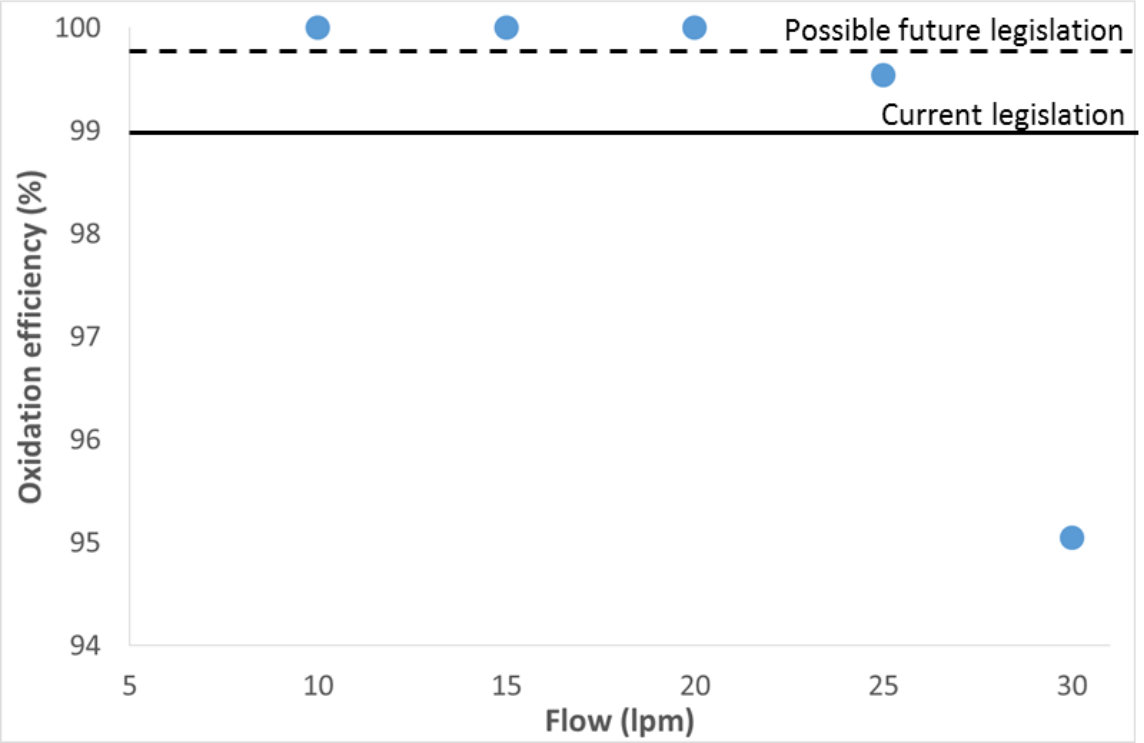
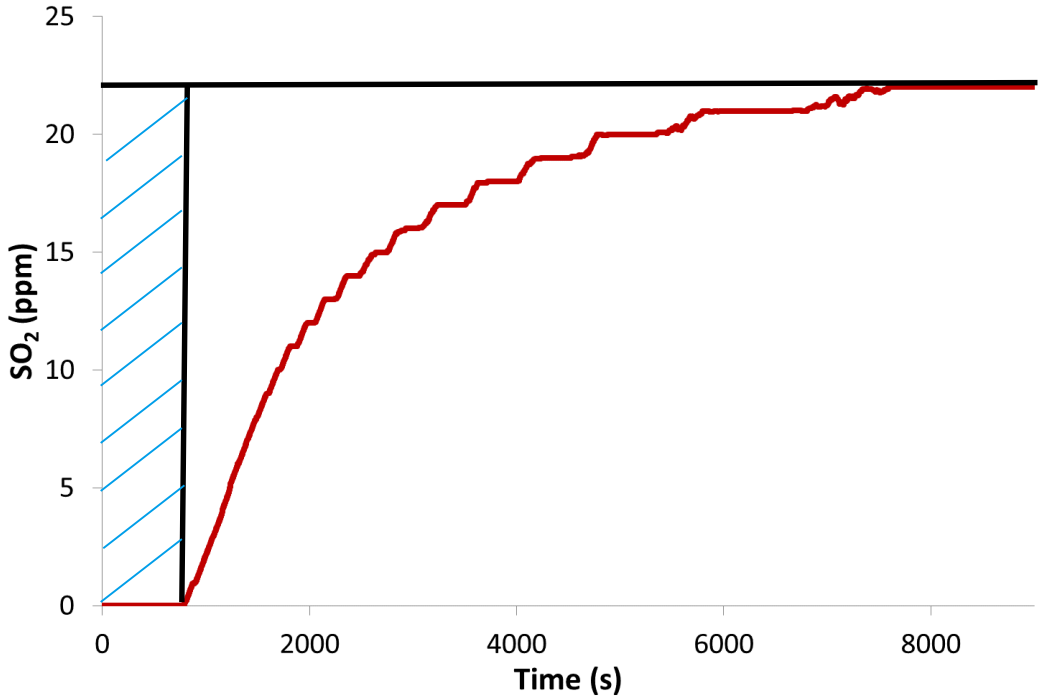
CS Evaluation





The catalytic stripper meets the current but also possible future PMP demands with **>99.9% oxidation efficiency** up to Q=20 lpm for concentrations >10^6particles/cm^3.

- The complete **S adsorption** capacity is 3.5mg or 0.27g/l of catalyst volume while the overall 11.8mg or 0.91g/l.
- CS completely adsorbs SO2 for approximately **250 NEDC cycles in raw exhaust** (no dilution).

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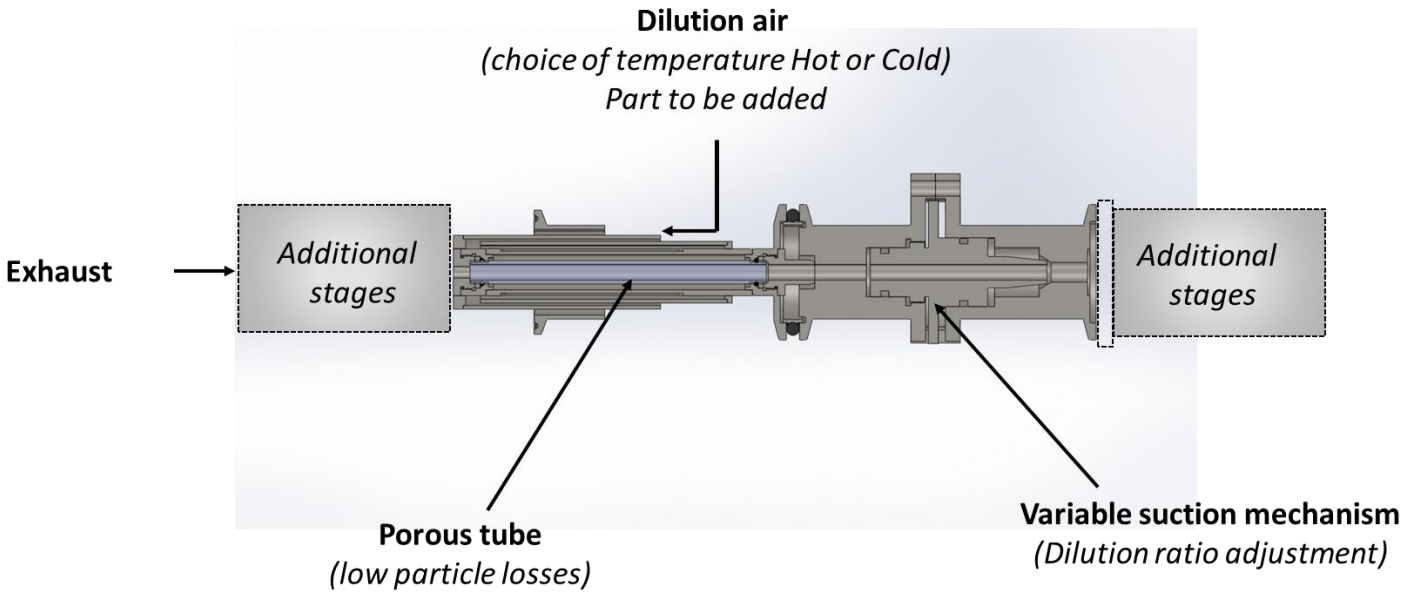
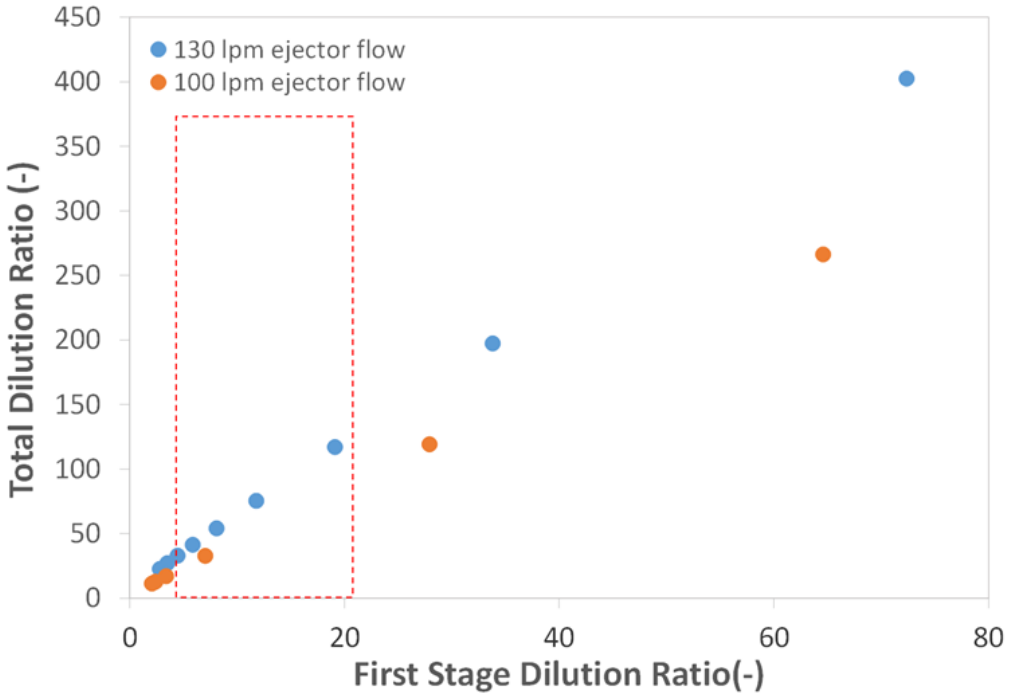
Flexible Dilution System

The system developed can operate in a wide variety of DRs (10-400) and can host additional dilution stages and/or volatile treatment devices.





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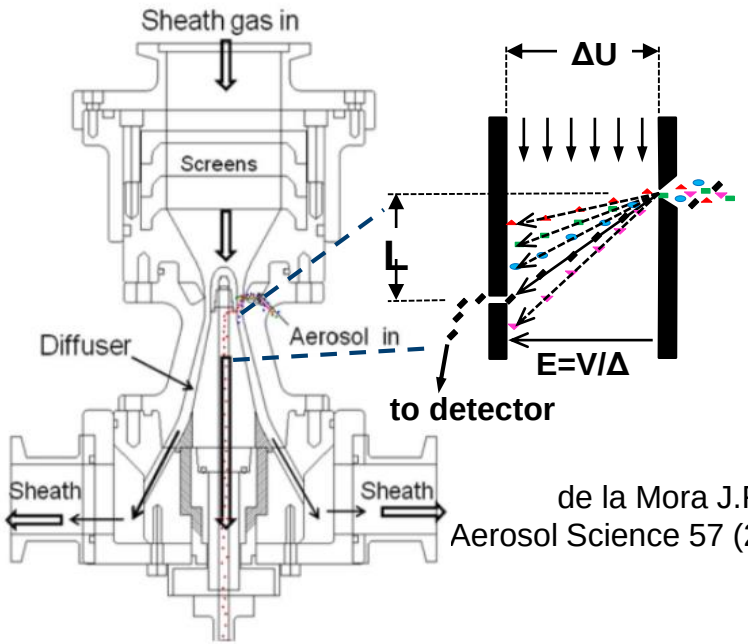
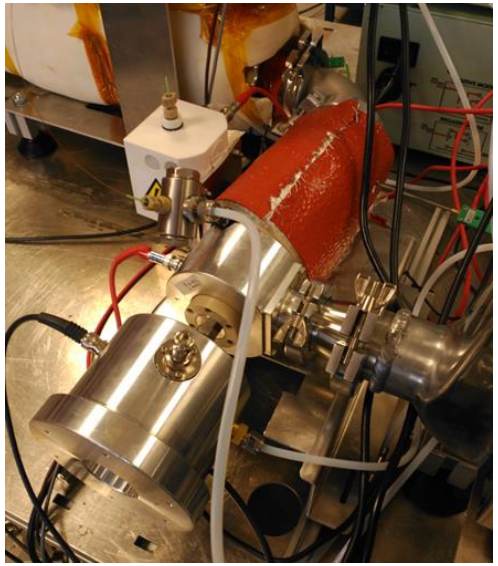
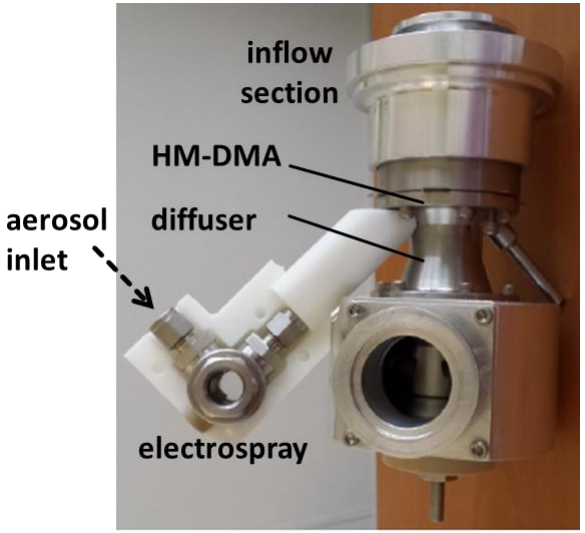
The half-mini DMA (SEADM)



de la Mora J.F., Kozlowski J., Aerosol Science 57 (2013) pp.45-53.



- Capable of operating up to 200 ° C sample.
- Components are sized for high resolution below 10 nm. Down-sizing (5 × for pump/heater) possible for region of interest 3 – 30 nm.



- **Reduced exhaust aerosol conditioning**:
  - Less dilution (cold dilution obsolete)
  - Fewer / smaller / lower power consuming devices for sample conditioning
- **Practical advantages**:
  - Easier to detect low sub-23 nm particle concentrations
  - Fewer diffusive particle losses
  - Compactness

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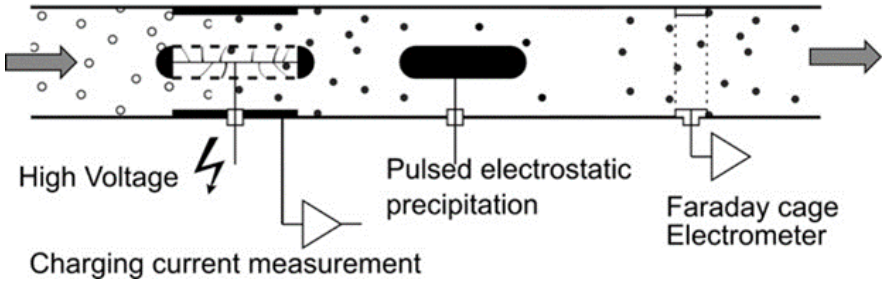
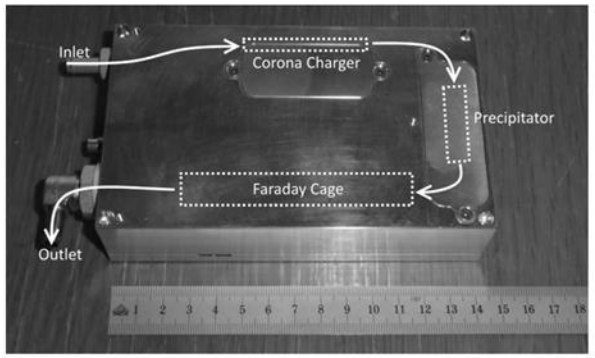
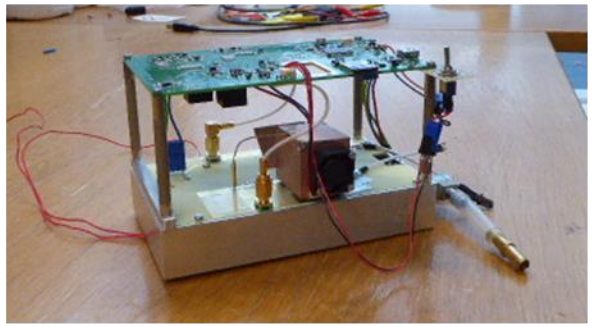
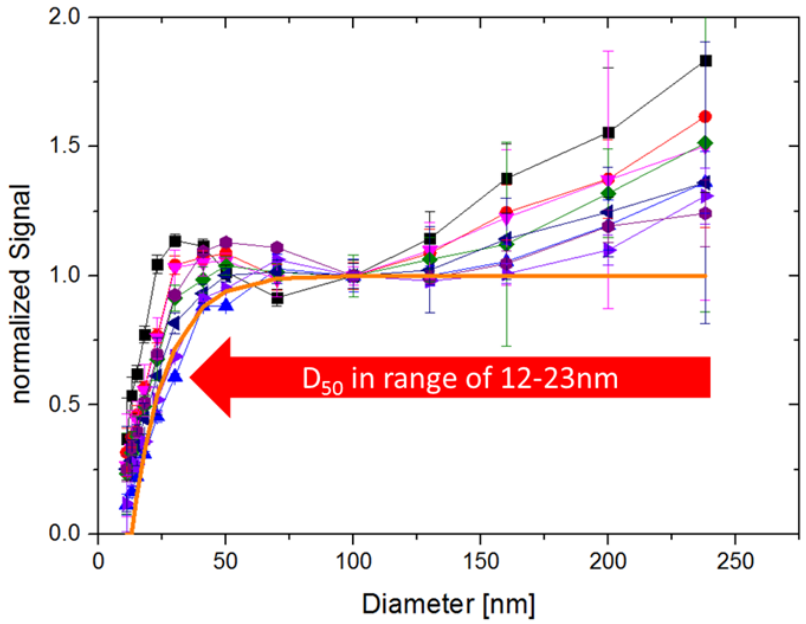
Automotive ICAD (FHNW)

The concept of Diffusion Charging



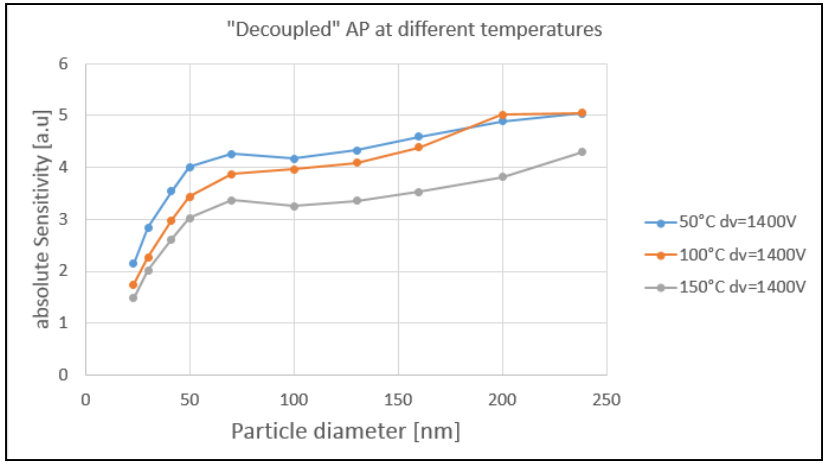






The goals achieved

- Operate at high temperature (150^{0}C) to allow minimum dilution
- 50% counting efficiency at 11.5nm
- Absolute sensitivity increased



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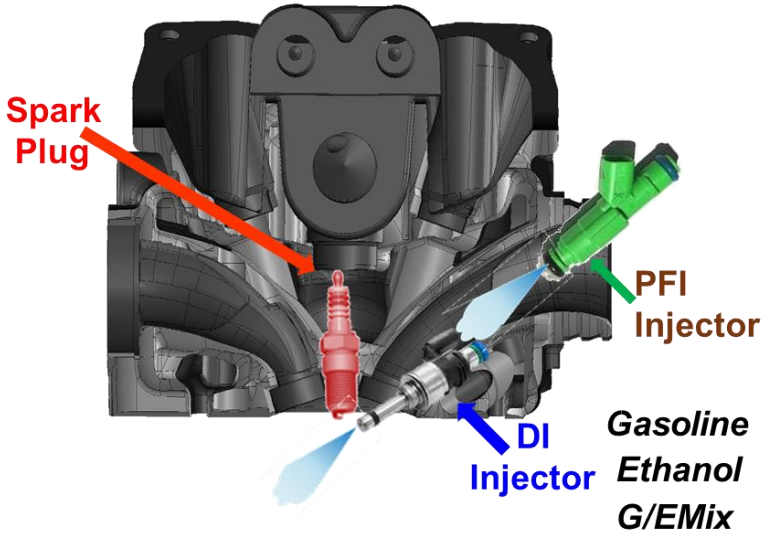
Testing Platforms (APTL, IM, IFPEN, CRF)

- **Vehicle Testing on chassis dyno**
  - Euro 6 DIESEL
  - Euro 6 Gasoline Direct Injection Engine with turbocharger



- **Vehicle Testing on road**
  - Euro 6 DIESEL
  - Euro 6 Gasoline Direct Injection Engine with turbocharger

- **Portable emissions measurement system (PEMS) instrumentation**

PSA GROUPE

EB TURBO PURETECH

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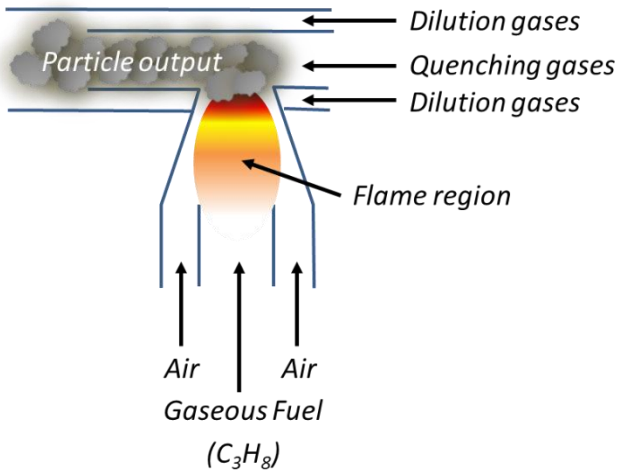
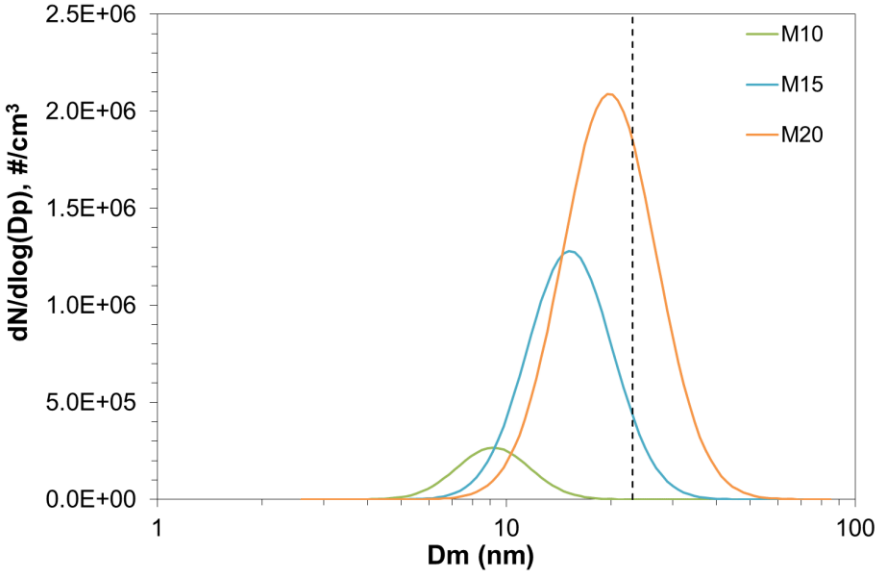
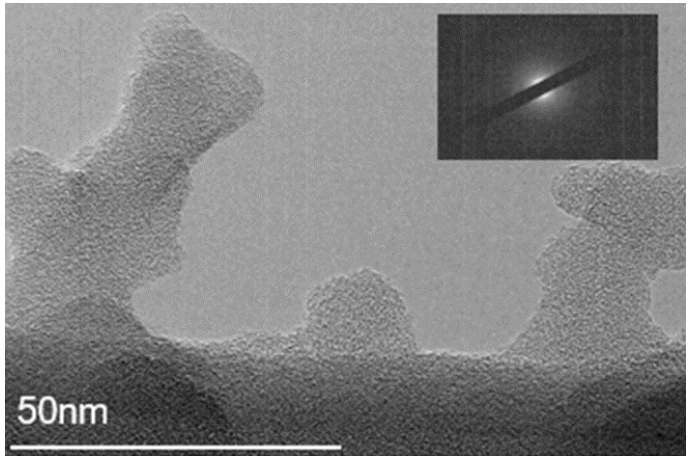
Testing with Combustion Aerosol Standard (CAST) Particle Generator

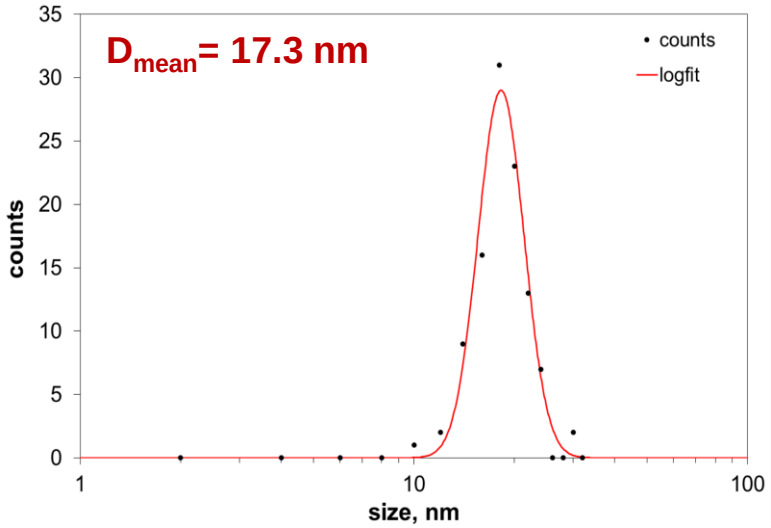
- CAST produces aerosols with user tailored characteristics by fine tuning the flow rates of the oxidation/quenching gas mix





- Nanoparticles are amorphous, lacking a well defined perimeter, exhibiting a semi-solid nature of elliptical/spherical shape
- Image analysis showed that particle sizes lie in the range of 10-30nm, with a mean value of 17.3nm





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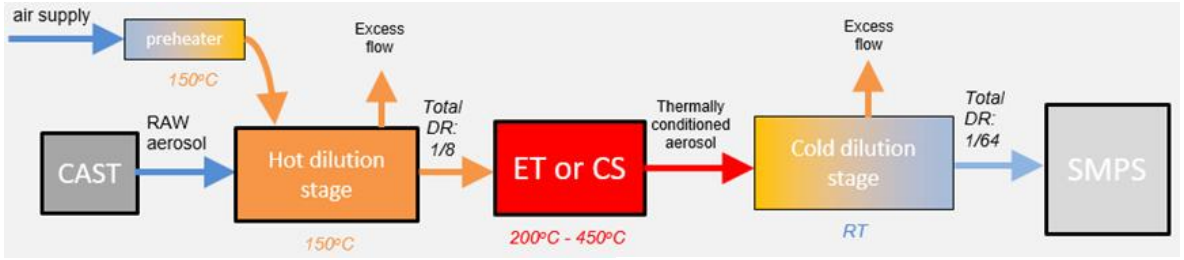
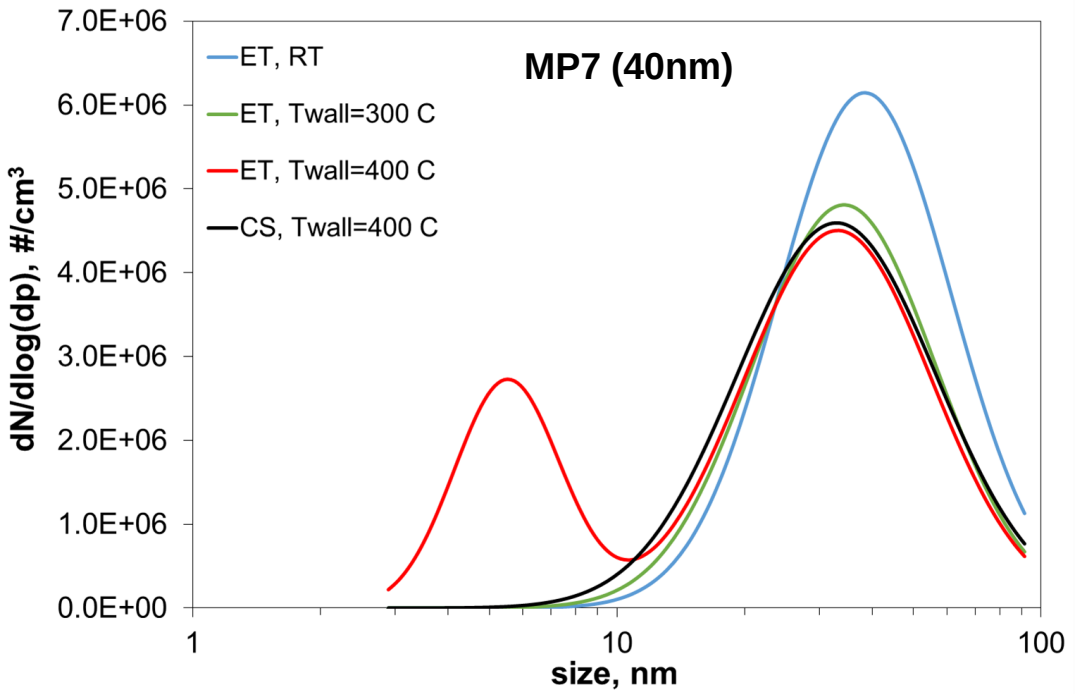
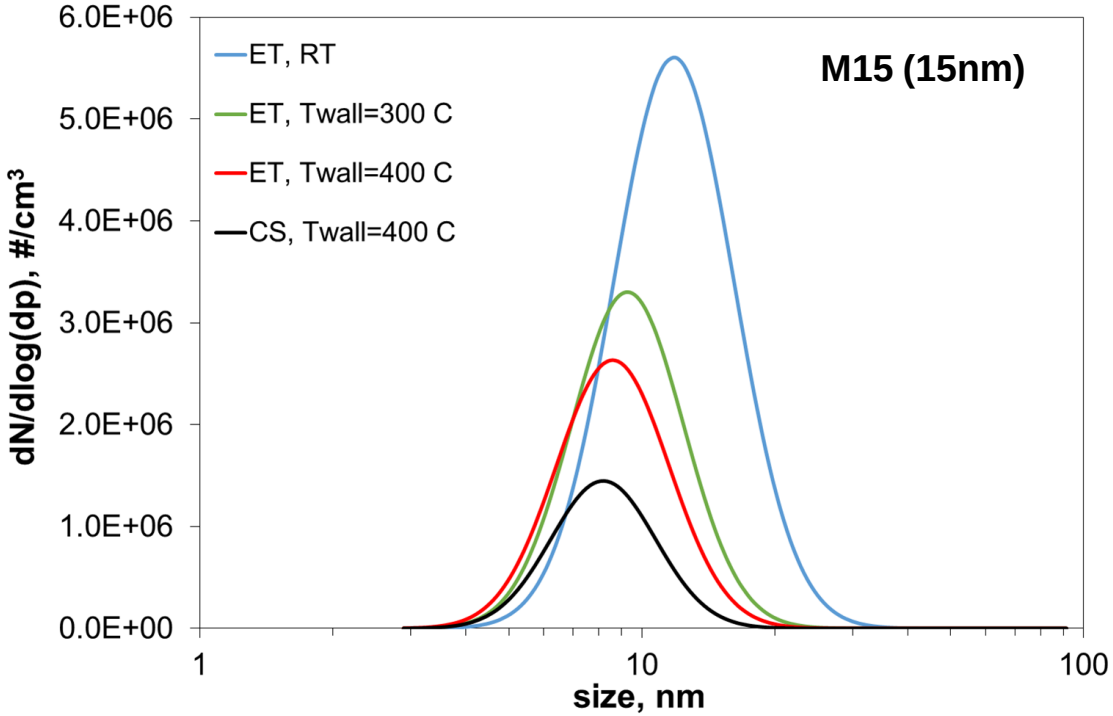
Effect of VPR Treatment on Particle Size Distributions





With ET a mode occurs at ~6nm for T_{wall}>350°C (artefact?)



More severe particle shrinkage (reach up to 1/3 of the initial particle size) than for bigger sizes

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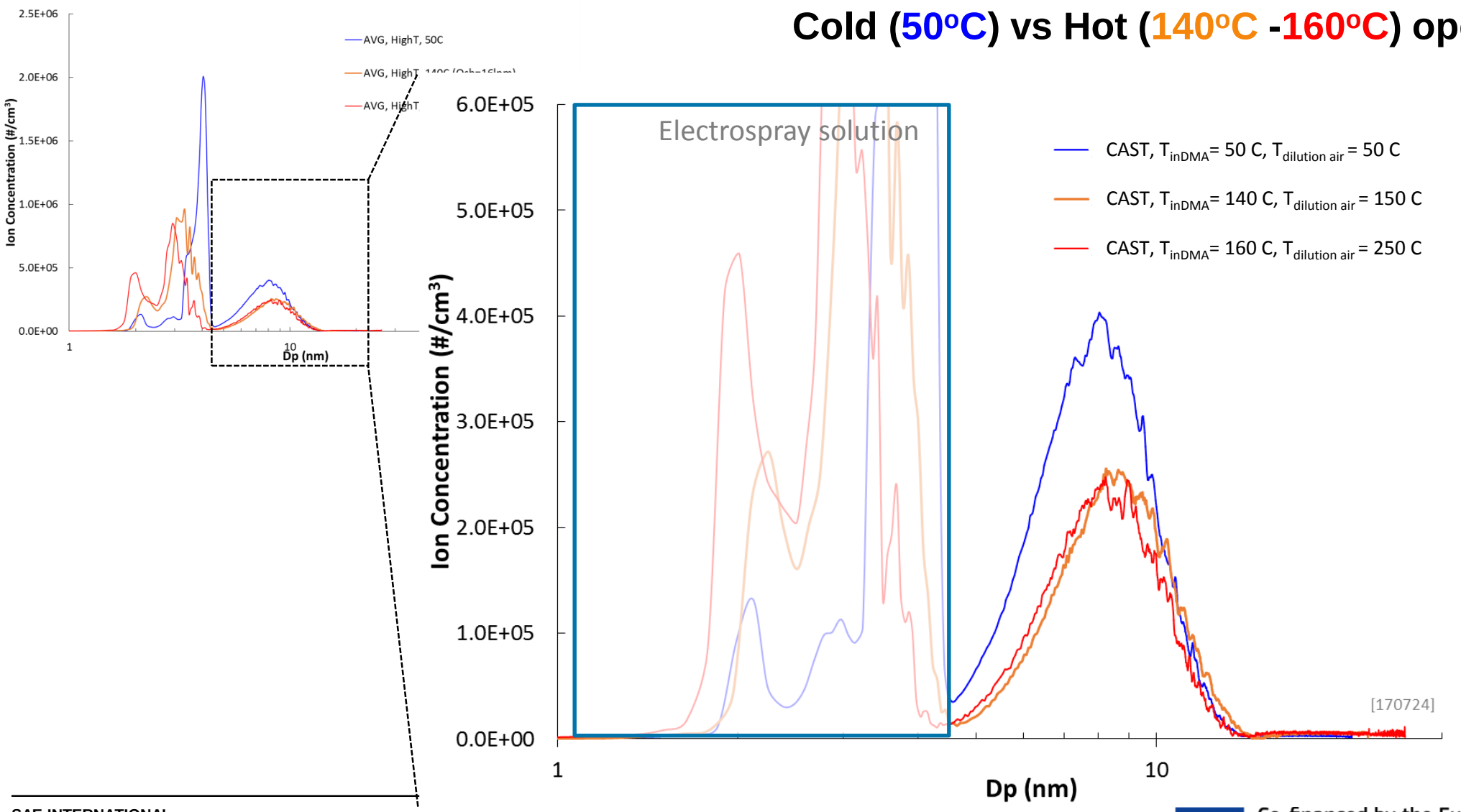
Effect of HM-DMA Operation Temperature on CAST Particles

Cold (50°C) vs Hot (140°C -160°C) operation



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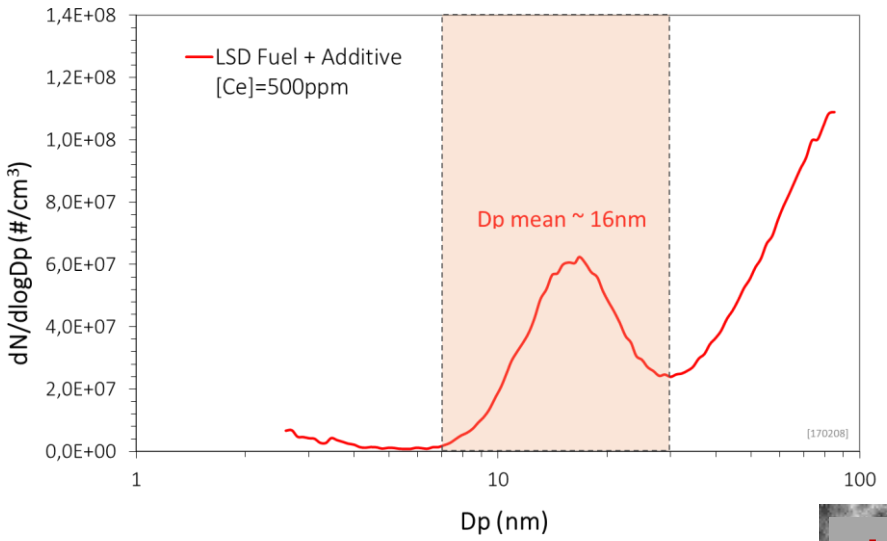
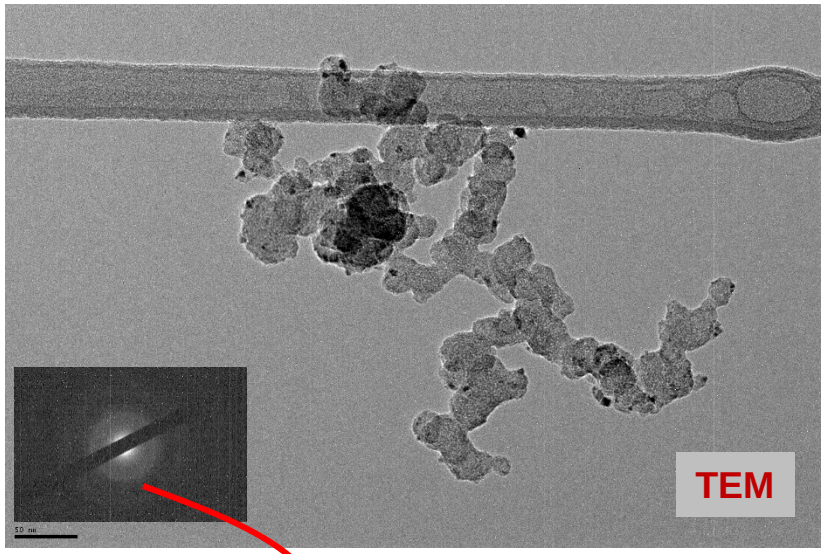
Soot from Diesel engine operation with fuel additive – TEM

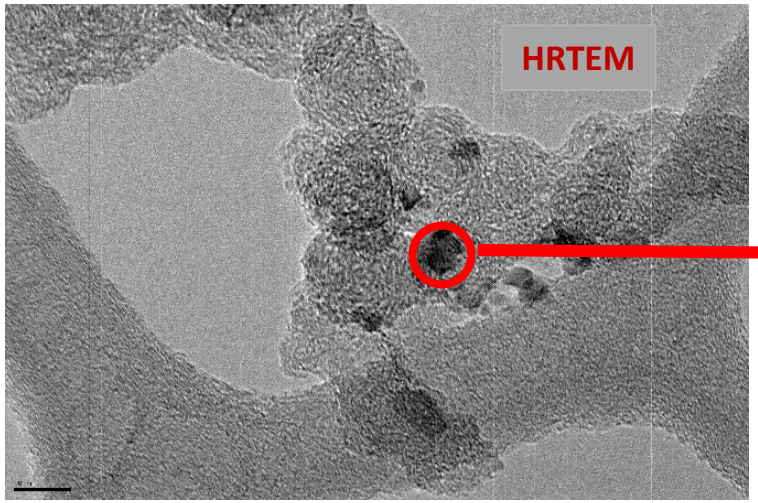


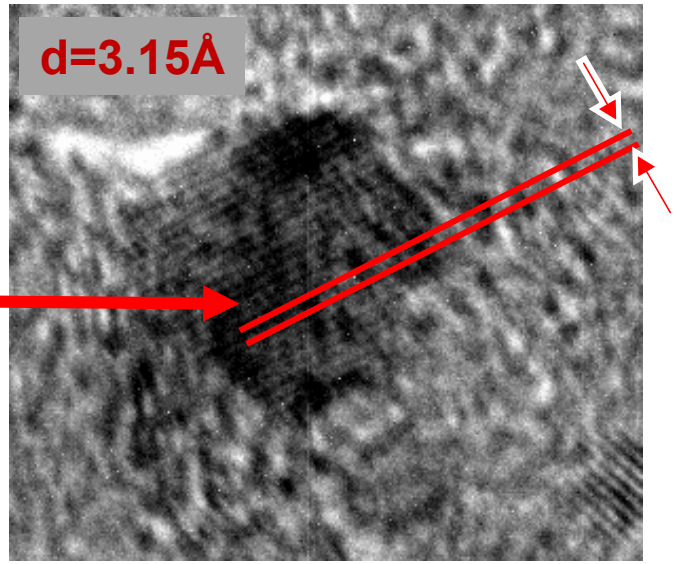
Size Selected from 7 – 30 nm with NanoDMA (3085)

$<D_{soot}>$=22.3 nm

$<D_{CeO2}>$=4.4 nm







Polycrystalinity
(mainly from soot lattice fringes)

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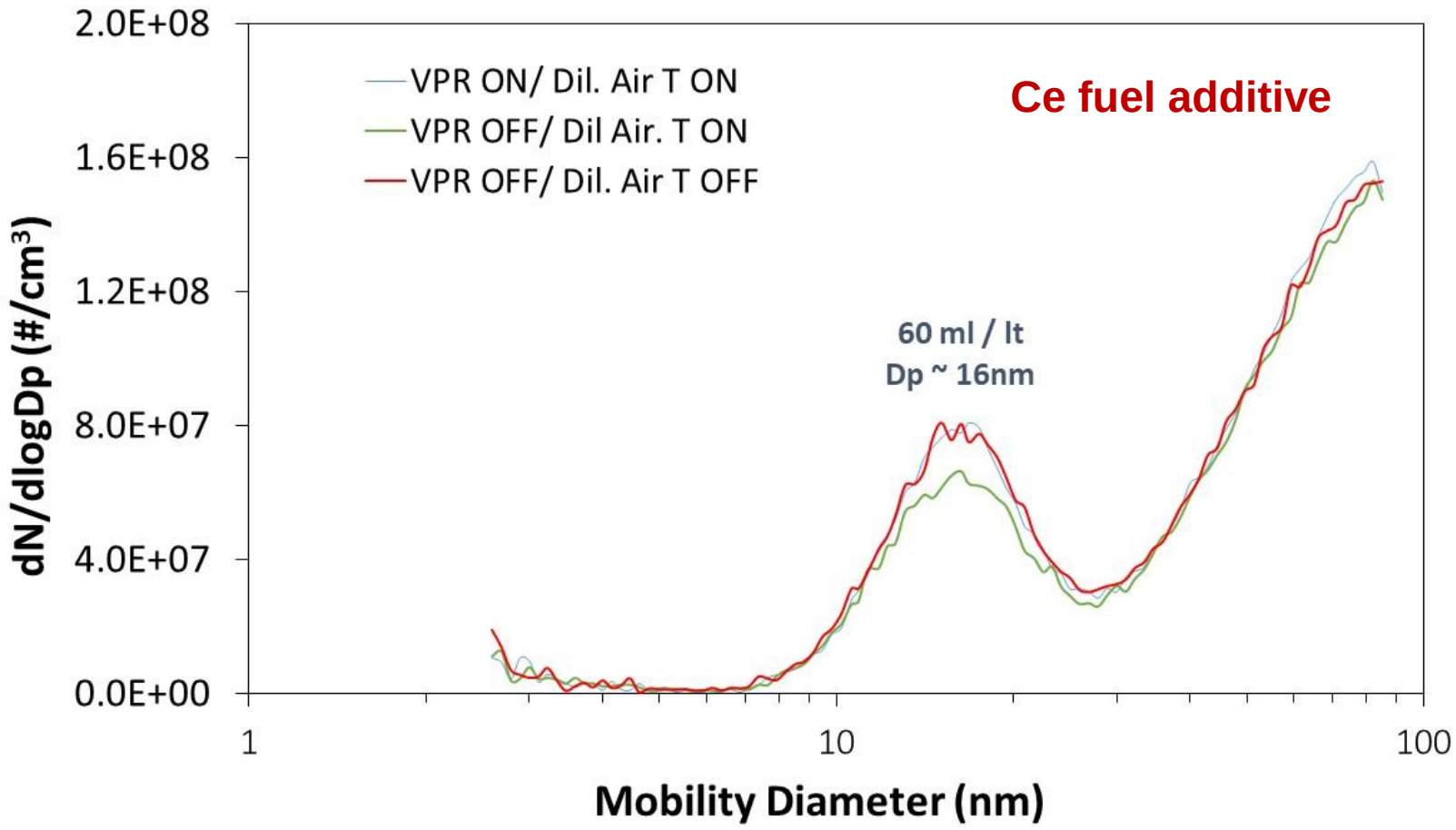
Effect of VPR Treatment on Particle Size Distributions



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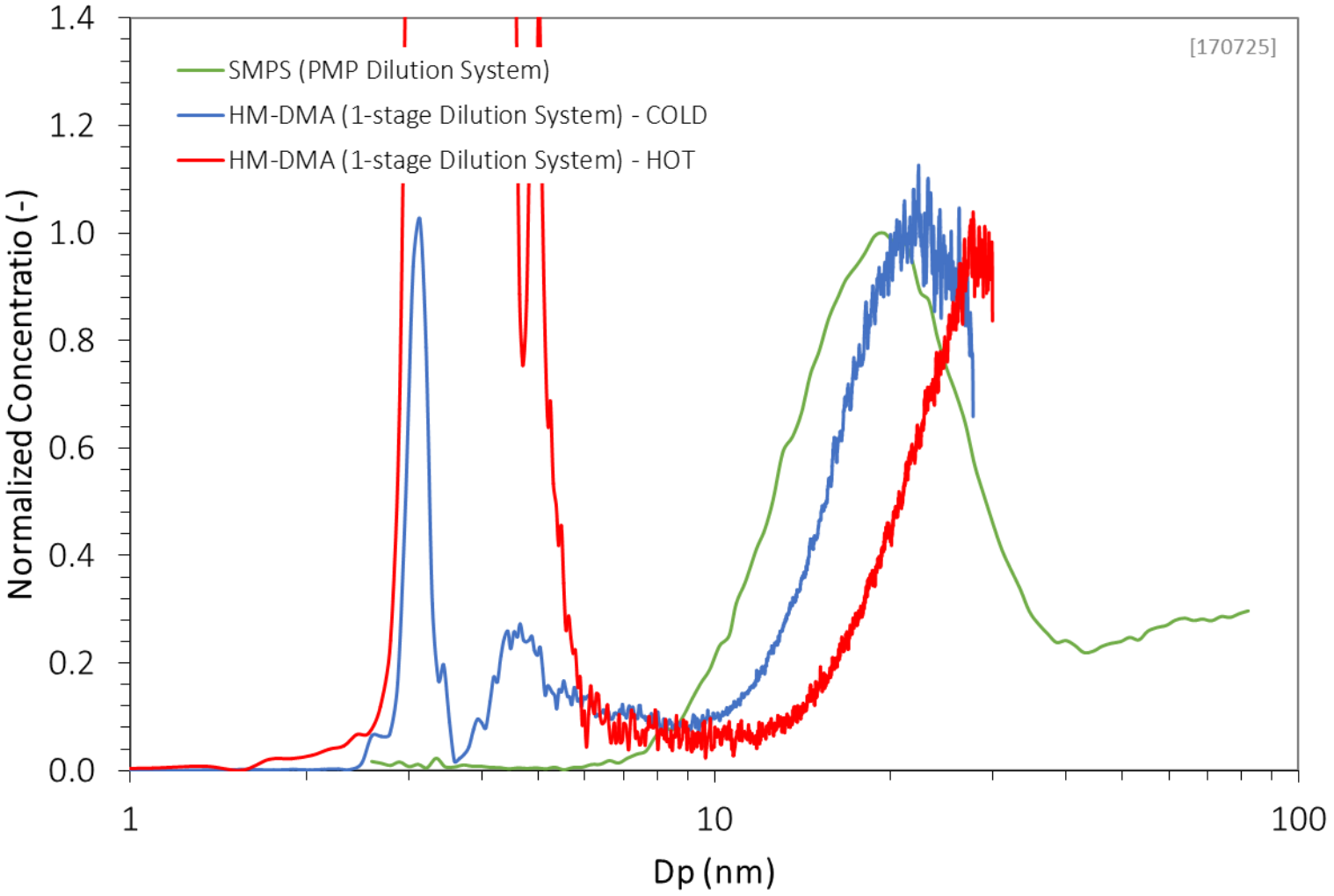
HM-DMA Measurements (Diesel with Fuel Additives)



Dilution System:

- SMPS: PMP dilution system (DR ~ 1/64)
- HM-DMA: 1-stage Dilution System (Ejector type) low DR (~1/8)

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Conclusions – Next Steps

- Advances in particle sampling / treatment / measurement systems for sub 23nm particle emissions are necessary
- SUREAL-23 proves that these are possible with:
  - Increased resolution below 23 nm
  - Advanced chemical treatment
  - Lower sampling requirements
- Next Steps:
  - Finish developments for alla proposed instruments
  - Perform measurements to a variety of testing platforms (Test Matrix)
  - Chose among best solutions for PEMS application

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Acknowledgements

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Anastasios Melas

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Thank you all

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