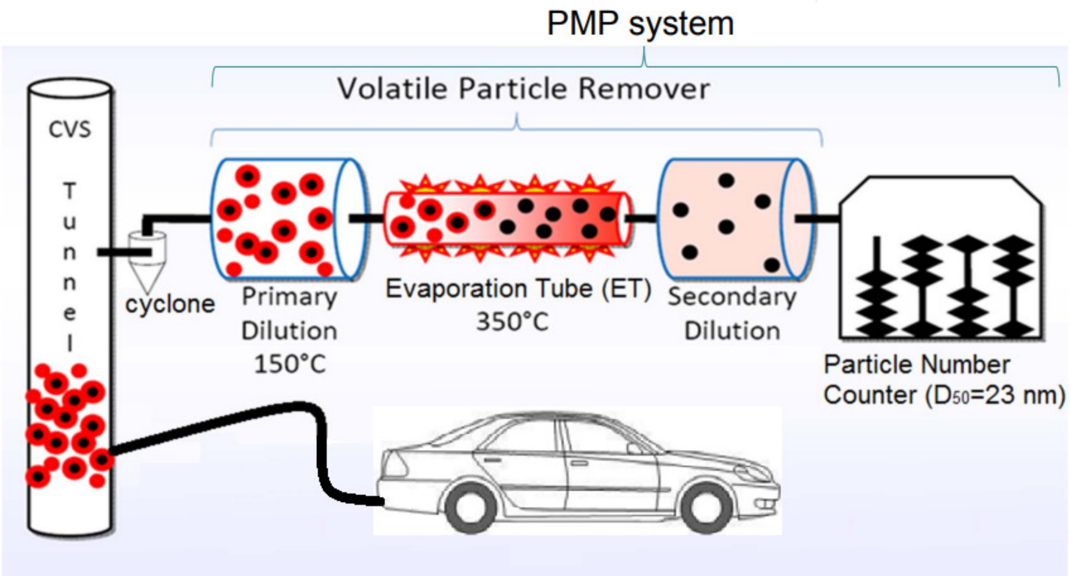
SUREAL-23 Project : Measurement of sub-23 nm particles on Gasoline Direct Injection Engine under various conditions

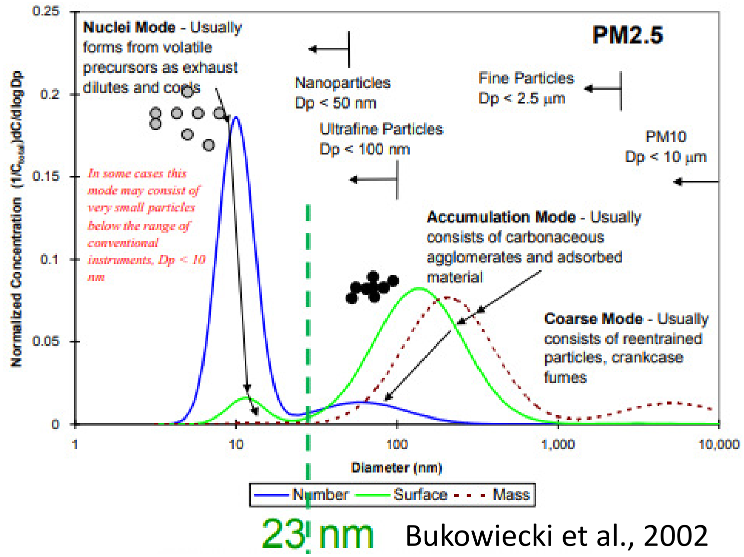
Authors : Stéphane ZINOLA (IFPEN), Mickaël LEBLANC (IFPEN), Leonidas CHASAPIDIS (CERTH/APTL) : Daniil DELOGLOU (CERTH/APTL), Penelope BALTZOPOULOU (CERTH/APTL), Anastasios MELAS (CERTH/APTL), Athanasios G. KONSTANDOPOULOS (CERTH/APTL), Tobias RÜGGEBERG (FHNW), Martin FIERZ (FHNW), Heinz BURTSCHER (FHNW), Alberto TEJERO (SEADM), Mario AMO (SEADM), Daoíz ZAMORA (SEADM)

23rd ETH-Conference on Combustion Generated Nanoparticles, Zürich, June 19th, 2019

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 724136.

- **Current Euro regulation :**
  - **PN limit at 6.10^{+11} part/km, fuel neutral, cycle WLTC + RDE limit with a CF = 1.5**
  - **PMP Protocol (chassis dyno) :**
    - **Hot dilution + Evaporation Tube + Cold dilution**
    - **Particle Number Counter with a 50% cut-off diameter at 23 nm to avoid condensation / re-nucleation artefacts**





Bukowiecki et al., 2002

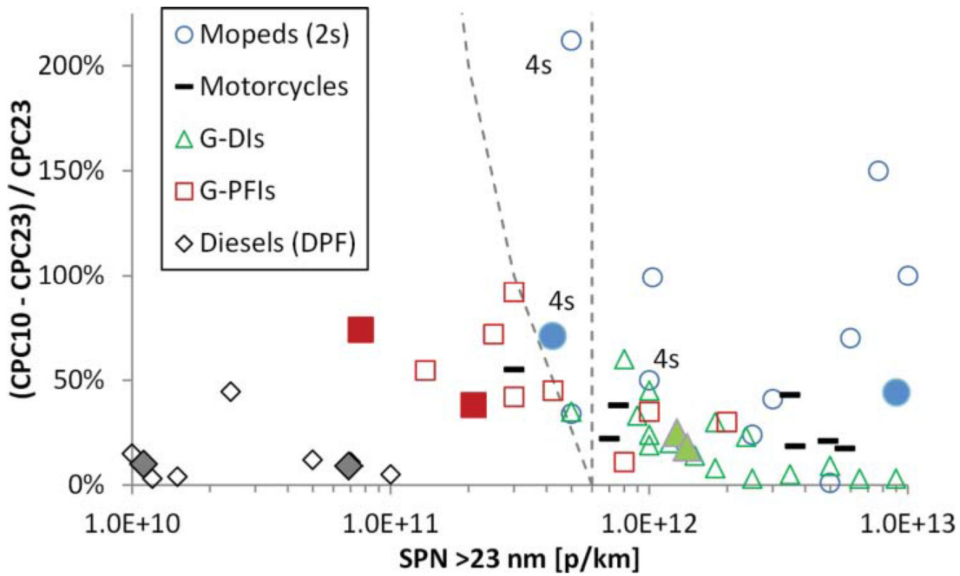
Red: Semivolatile particles
Black: Solid (mostly soot) particles

Courtesy William Robertson, CARB

INSTITUT CARNOT IFPEN Transports Energie
IFP Energies nouvelles

CONTEXT

- **Limitations of the current PMP protocol :**
  - **50% cut-off diameter at 23 nm**
  - **Solid particle only**
  - **Initially developped for Diesel engines**



B. Giechaskiel et al. (2017)

A significant part of PN emissions is missed (solid and/or semi-volatile), especially for non-Diesel applications

How to measure below 23 nm with high reliability/ reproducibility ?

© 2017 IFPEN

SUREAL-23 PROJECT

SUSTAINABLE MOBILITY

- **Focus:**
  - **Exhaust particles, smaller than regulation cut-off of 23 nm, Light Duty engines (Diesel and gasoline).**
- **Objectives:**
  - **Complement and extend existing instrumentation for particles below 23 nm.**
  - **Further understand the nature of the particulate emissions below 23 nm.**
  - **Support future emissions regulations, including the recent RDE one.**
- **Partnership:**

TECHNOLOGY DEVELOPERS

SEADM

n|w Fachhochschule Nordwestschweiz

ISTITUTO MOTORI Consiglio Nazionale delle Ricerche

apTL

NKT Photonics the power of light

TECHNOLOGY EVALUATORS

IFP Energies nouvelles

CRF

ISTITUTO MOTORI Consiglio Nazionale delle Ricerche

apTL

ASSOCIATED / ADVISORY PARTNERS

Yale

TSI

COORDINATION: apTL

INSTITUT CARNOT IFPEN Transports Energie

IFP Energies nouvelles

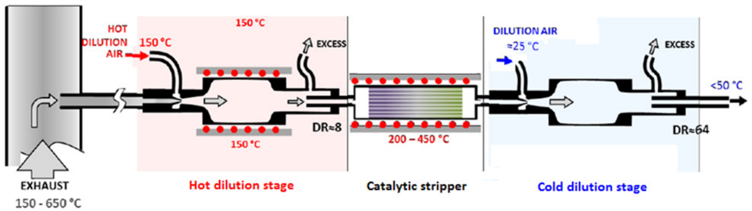
© 2017 IFPEN

IFPEN EXPERIMENT

Objective:

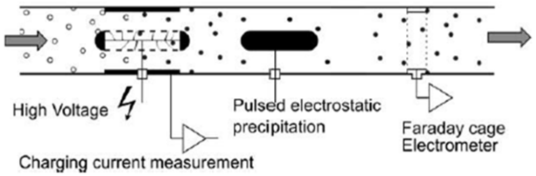
Evaluation of the new instrumentation for particles below 23 nm on GDI engine

Dual-stage diluter



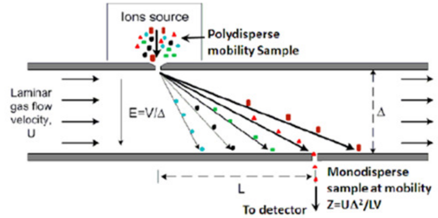
- Variable dilution ratio: 30 → 120
- CS with Sulfur Trap
- CS conv. eff > 99.9% @ 20 l/min
- Penetration 75% @ 10 nm

ICAD Fachhochschule Nordwestschweiz



- Induced Charge Aerosol Detector
- 50% cut-off diameter at ~ 10 nm
- Max operating temperature ~ 150°C
  → dilution can be reduced
- Max. PN conc. ~ 1.10^{+7} part/cm^3

HM-DMA SEADM



- High resolution Particle Size Distribution in the range 4 – 30 nm
- Max operating temperature ~ 200°C
- Fast electrometer: response time ~100 ms

Comparison with state-of-the-art apparatus

CPC 3775

CPC 3776

AE33

DMS500

CAMBUSTION DMS500 MK II

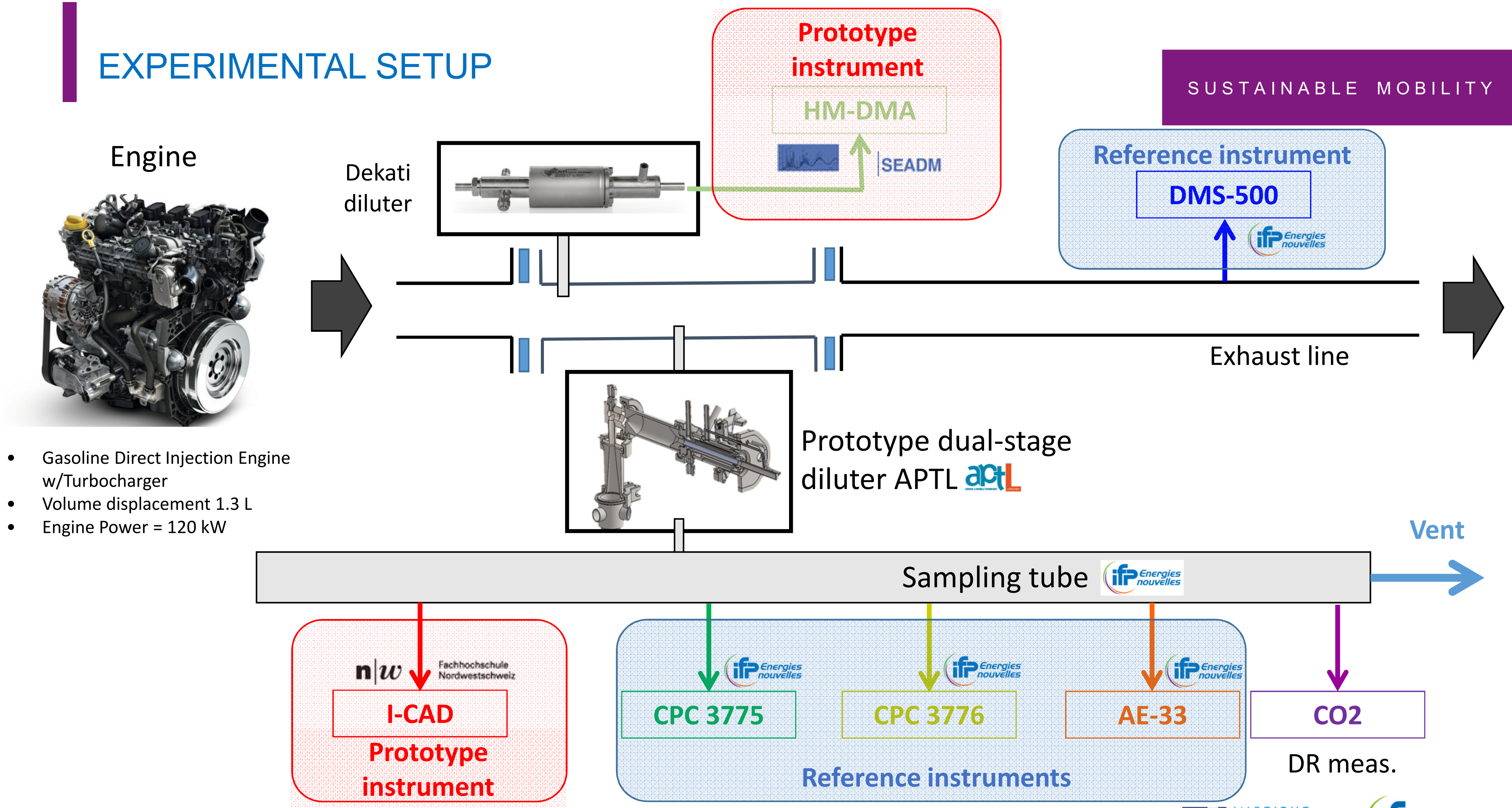
5 – 1000 nm

Determination of the < 23 nm / > 23 nm ratio

INSTITUT CARNOT IFPEN Transports Energie

IFP Energies nouvelles

EXPERIMENTAL SETUP

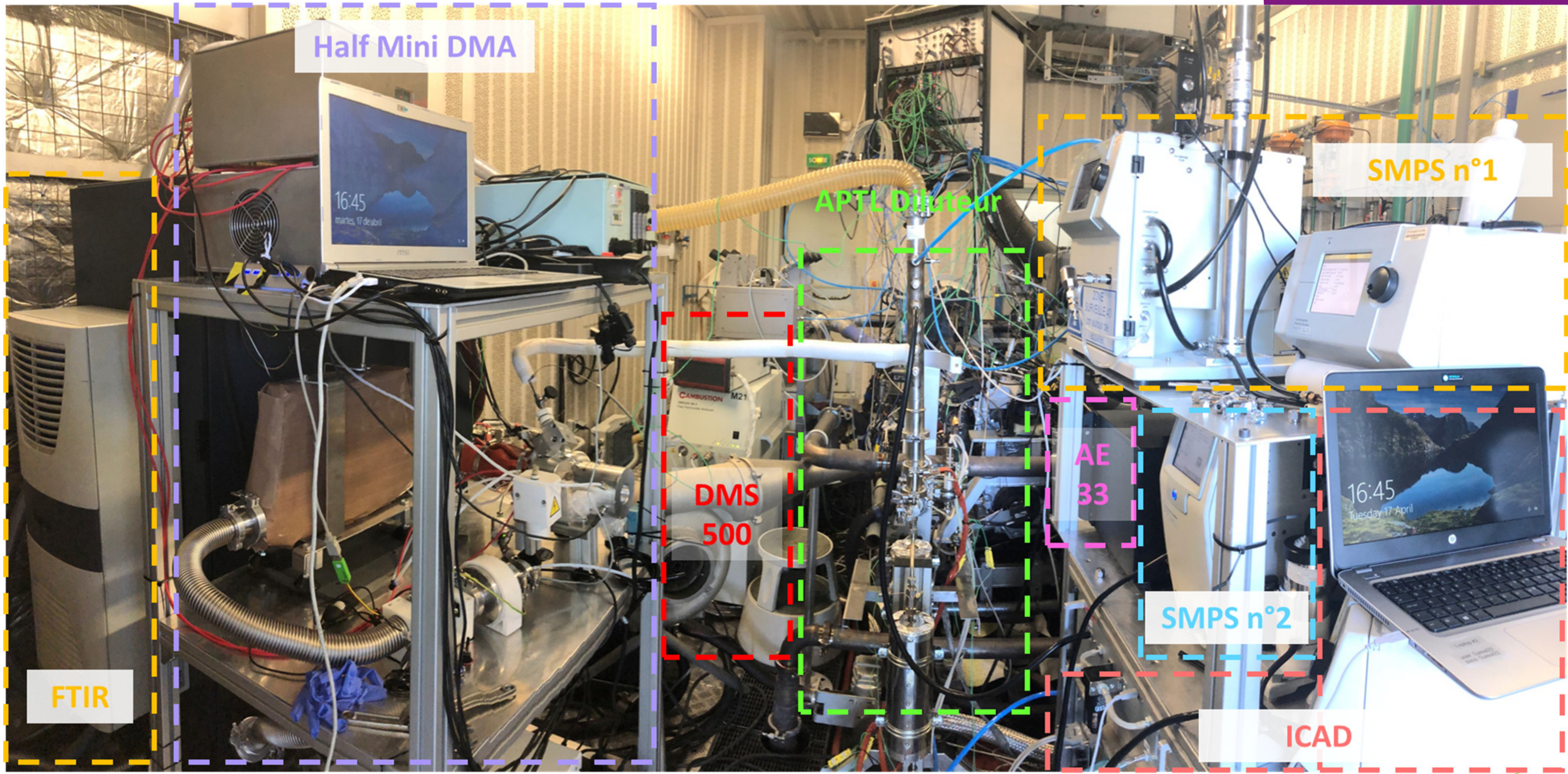


- Gasoline Direct Injection Engine w/Turbocharger
- Volume displacement 1.3 L
- Engine Power = 120 kW

SUREAL-23 | INSTITUT CARNOT IFPEN Transports Energie | IFP Energies nouvelles

© 2017 IFPEN

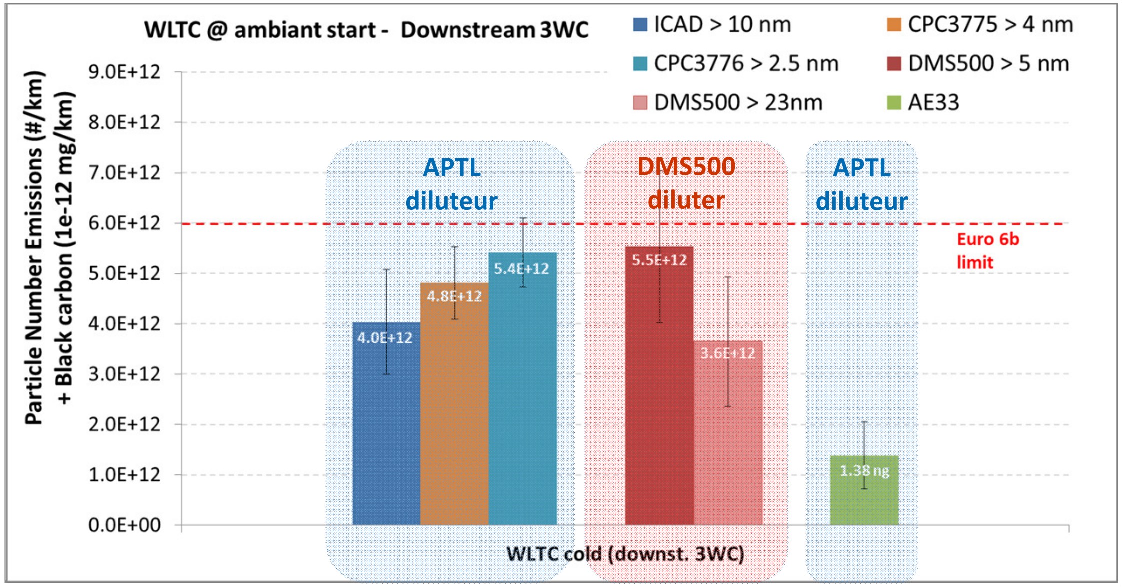
EXPERIMENTAL SETUP IN THE TEST CELL

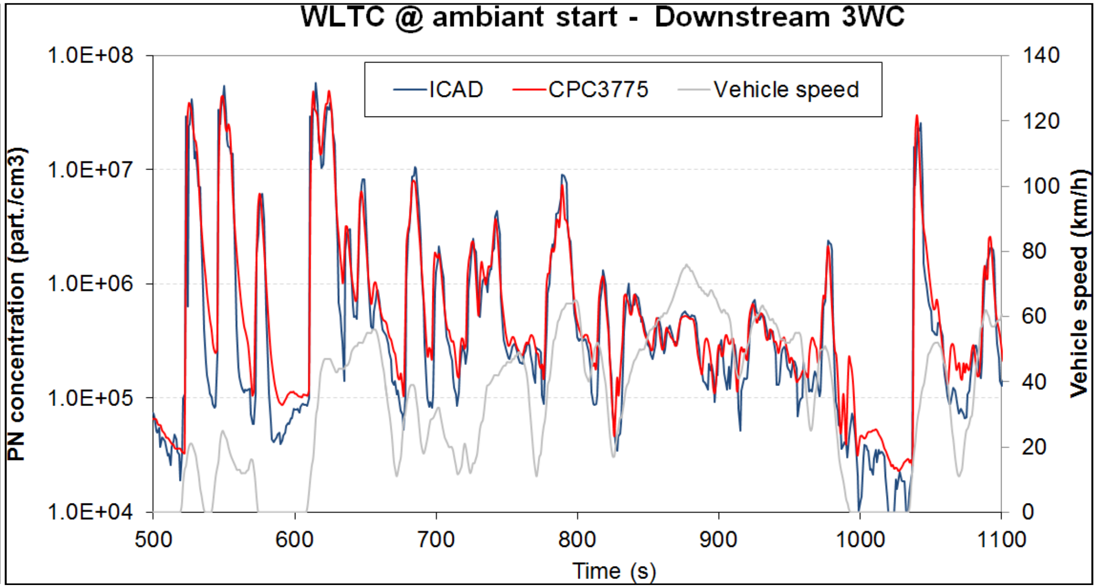


© 2017 IFPEN

RESULTS: ICAD AND APTL DILUTER VALIDATION

- **PN measurement on WLTC cycle from ambient temperature (~ 23 °C) (tailpipe) :**
  - **Cycle representative of the EU regulation**





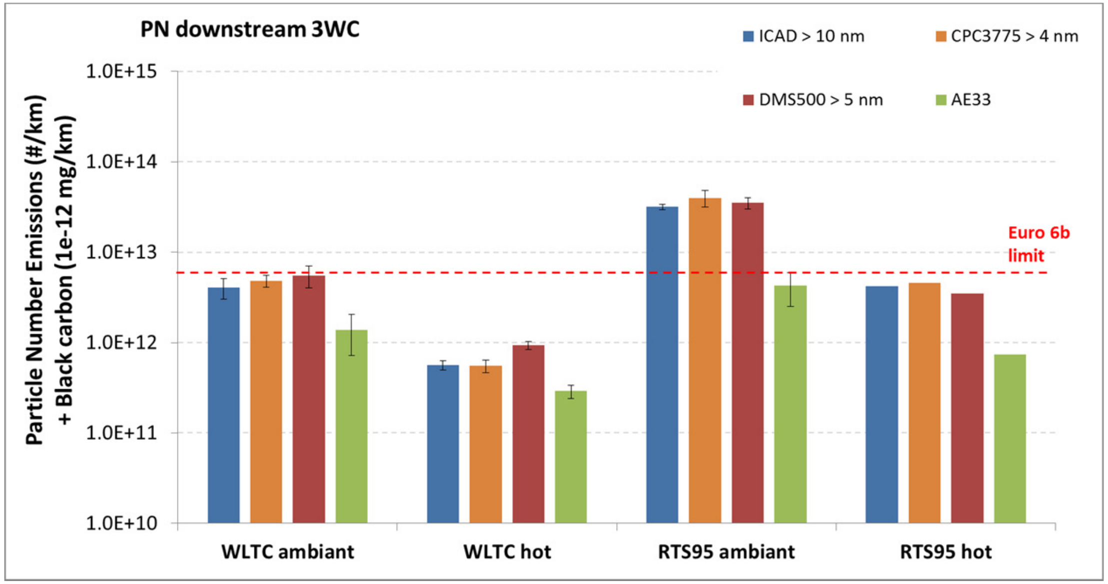
- ➢ The APTL diluter, with a Catalytic Stripper, is relevant to measure PN with various diameters cut-offs
- ➢ The ICAD device exhibits consistent results compared to the reference devices

 | © 2017 IFPEN

RESULTS: EFFECT OF DRIVING CYCLE AND START TEMPERATURE

SUSTAINABLE MOBILITY

PN measurement on various cycles and start temperatures



< 23 nm / > 23 nm	WLTC ambiant	WLTC hot	RTS95 ambiant	RTS95 hot
	52 %	26 %	32 %	86 %

Sub-23 nm ratio

Sub-23 nm ratio decreases with total PN increase	True for RTS95 ambiant cycle False for WLTC hot cycle
Sub-23 nm ratio increases with driving aggressiveness	True for hot conditions High PN emissions is preponderant for ambient conditions
Sub-23 nm ratio increases at lower temperature start	True for WLTC cycle High PN emissions is preponderant for ambient conditions

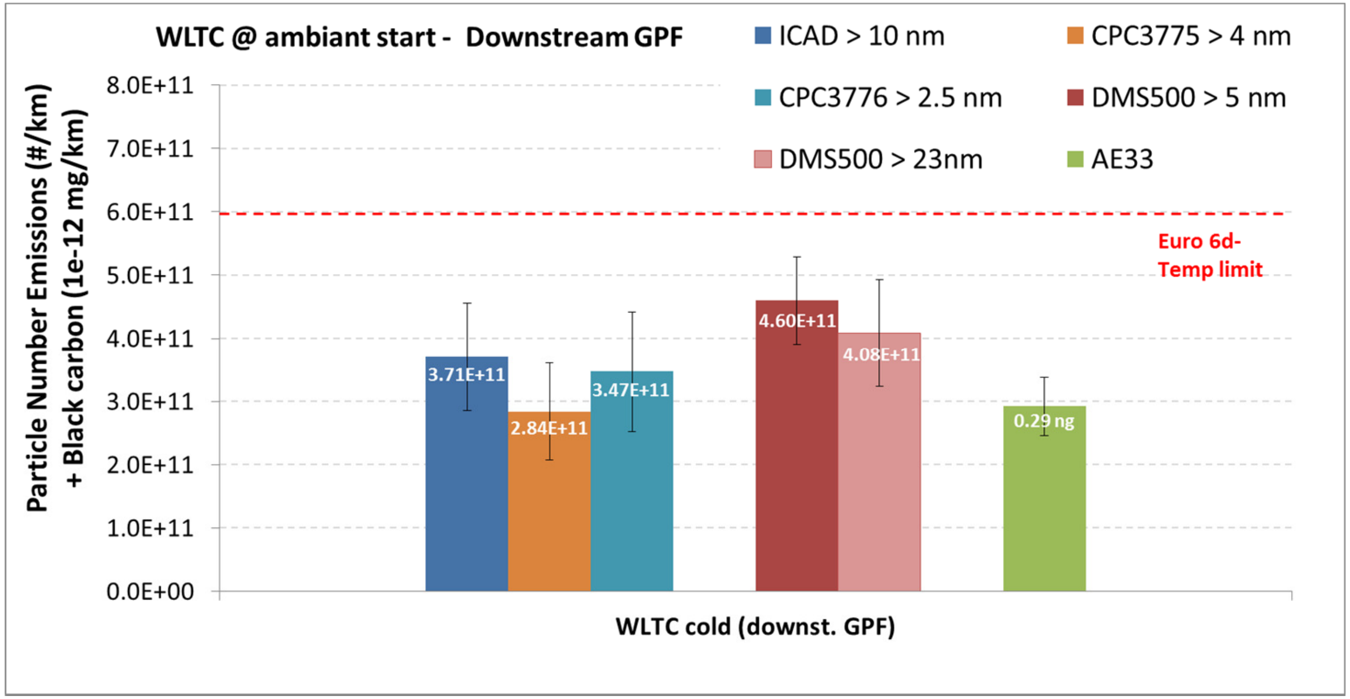
➢ **Several parameters can affect the sub-23 nm ratio – not only one parameter**

© 2017 IFPEN

INSTITUT CARNOT IFPEN Transports Energie
ifp Energies nouvelles

RESULTS: EFFECT OF THE CATALYZED GPF

PN measurement on WLTC cycle from ambient temperature (~ 23 °C) (tailpipe, w/ cGPF):



Device	Cut-off diam (nm)	GPF Eff.
ICAD	**10**	90.8%
DMS500 > 5 nm	**5**	94%
DMS500 > 23 nm	**23**	93.6%
CPC3775	**4**	91.7%
CPC3776	**2.5**	88.8%
AE33 (mg/km)	**-**	79%

- PN down to the Euro 6d-Temp limit, whatever the measurement device and so the diameter cut-off
- The conversion efficiency is about 90% regarding the number and 80% regarding the mass.
- Apparent inconsistency: the lowering of the diameter cut-off threshold does not lead to an increase of the PN

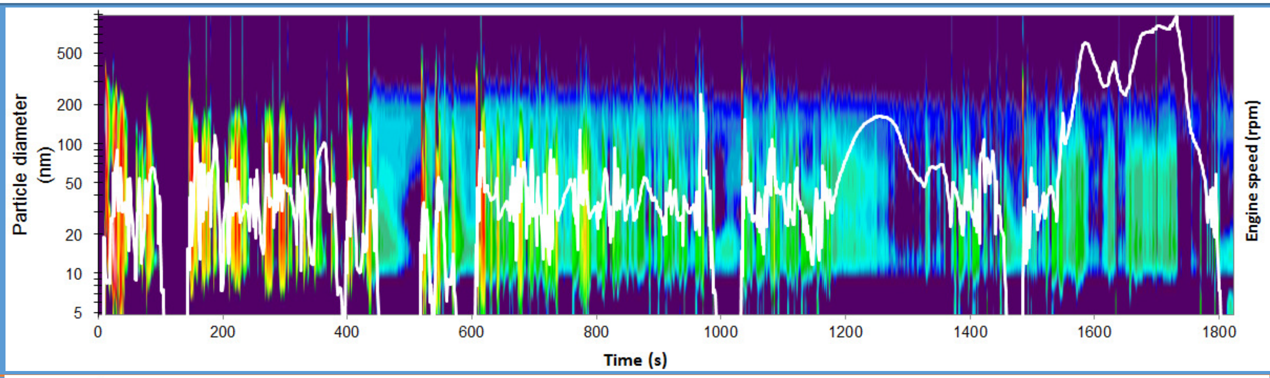
 © 2017 IFPEN

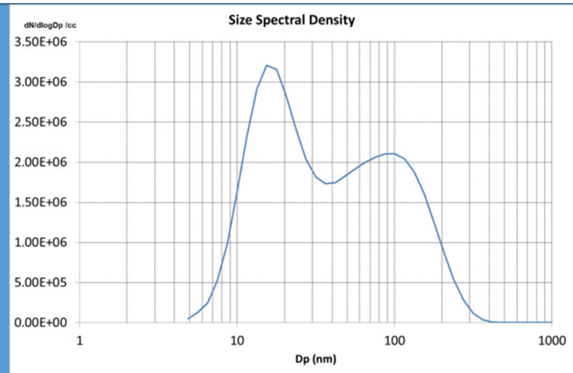
RESULTS: EFFECT OF THE CATALYZED GPF

SUSTAINABLE MOBILITY

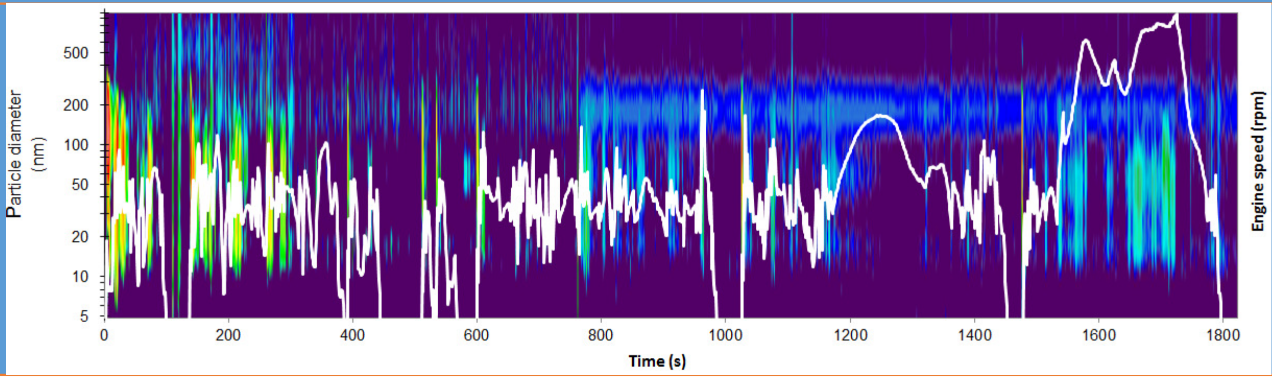
PN measurement on WLTC cycle from ambient temperature (~ 23 °C)

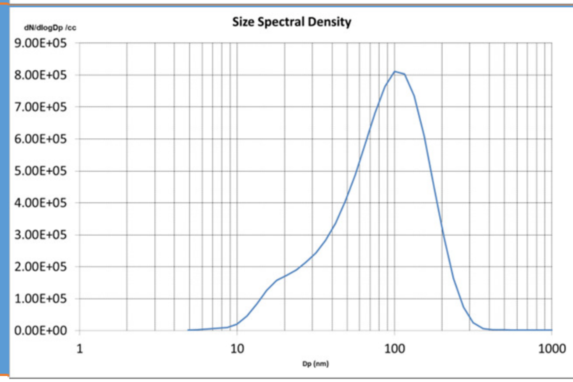
Downstr. 3WC

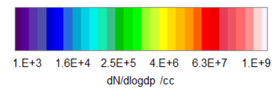




Downstr. cGPF







- PN concentration in the range 5 – 23 nm is very low downstream of the cGPF
- Possible trapping and/or oxidation of the smallest particles by the cGPF

 © 2017 IFPEN

INSTITUT CARNOT IFPEN Transports Energie

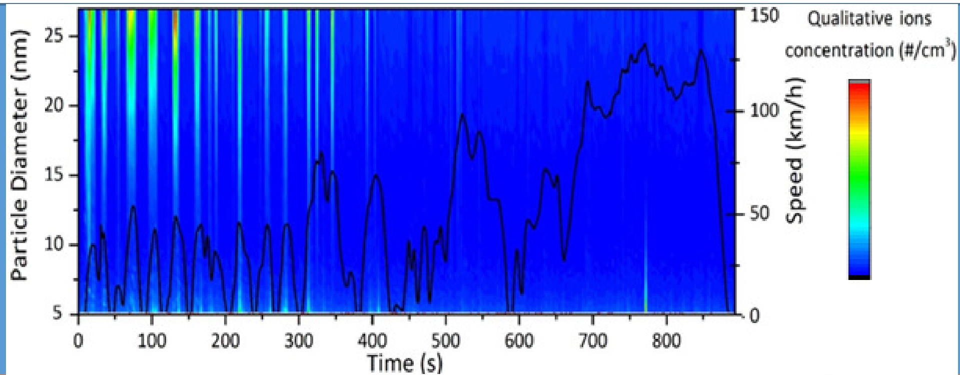
Energies nouvelles

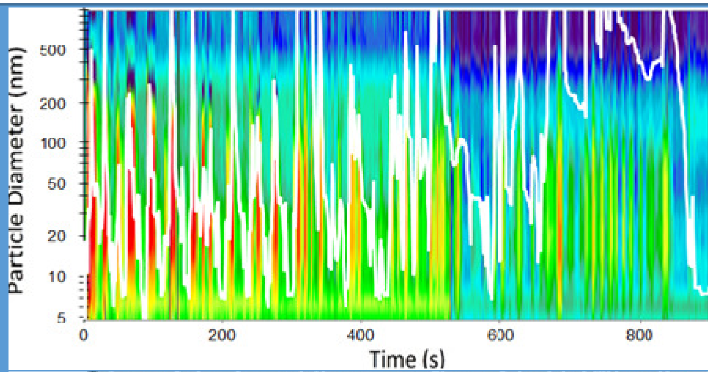
RESULTS: EFFECT OF THE CATALYZED GPF

SUSTAINABLE MOBILITY

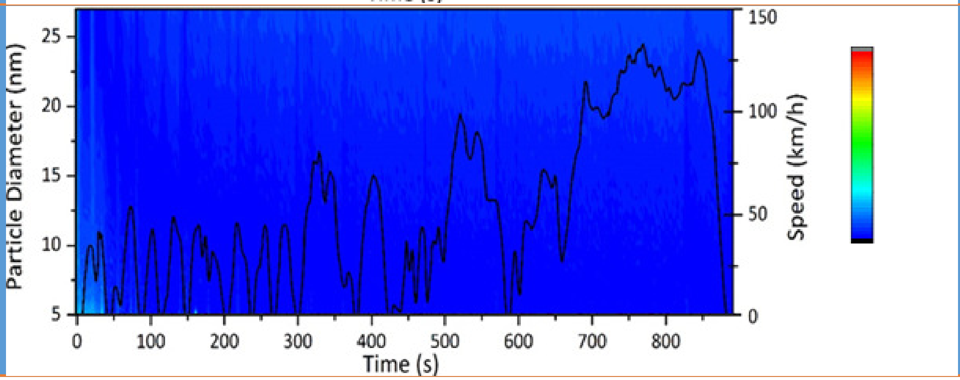
- **Confirmation with the HM-DMA measurement (range 5 – 28 nm) on RTS95 cycle from ambient**

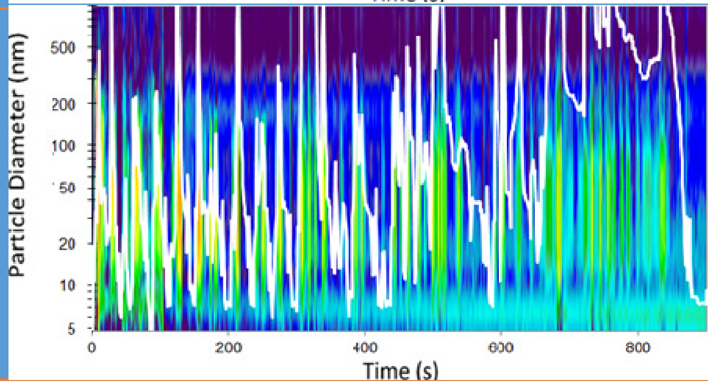
Downstr. 3WC





Downstr. cGPF





© 2017 IFPEN

HYBRIDIZATION EFFECT

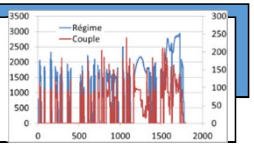
SUSTAINABLE MOBILITY

- The hybridization effect was evaluated by simulating the operation of an hybrid vehicle at the engine test bench. The Simcenter Amesim™ software was used, with the IFP-Drive library.

- Building of 2 Simcenter Amesim simulators :
  - 1 conventional vehicle + 1 hybrid vehicle

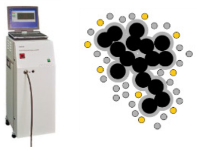
IFP-DRIVE

- Generation of engine speed + load profiles

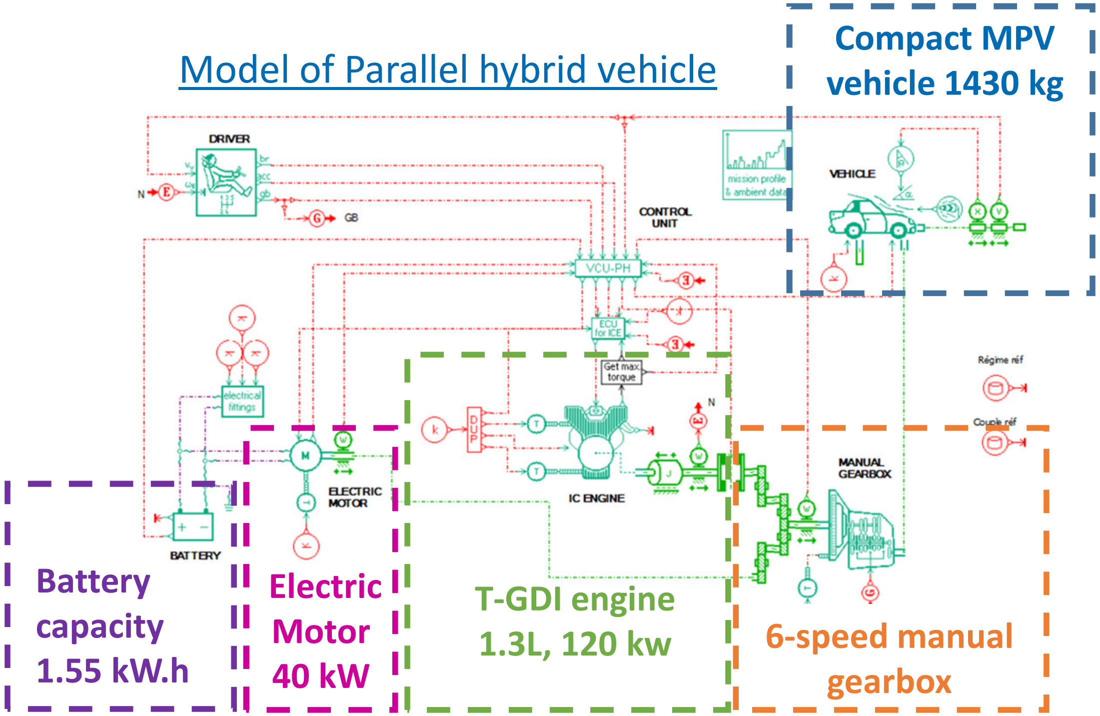


- Test bench monitoring with Morphée 2 supervisor

- PN exhaust measurement



Model of Parallel hybrid vehicle



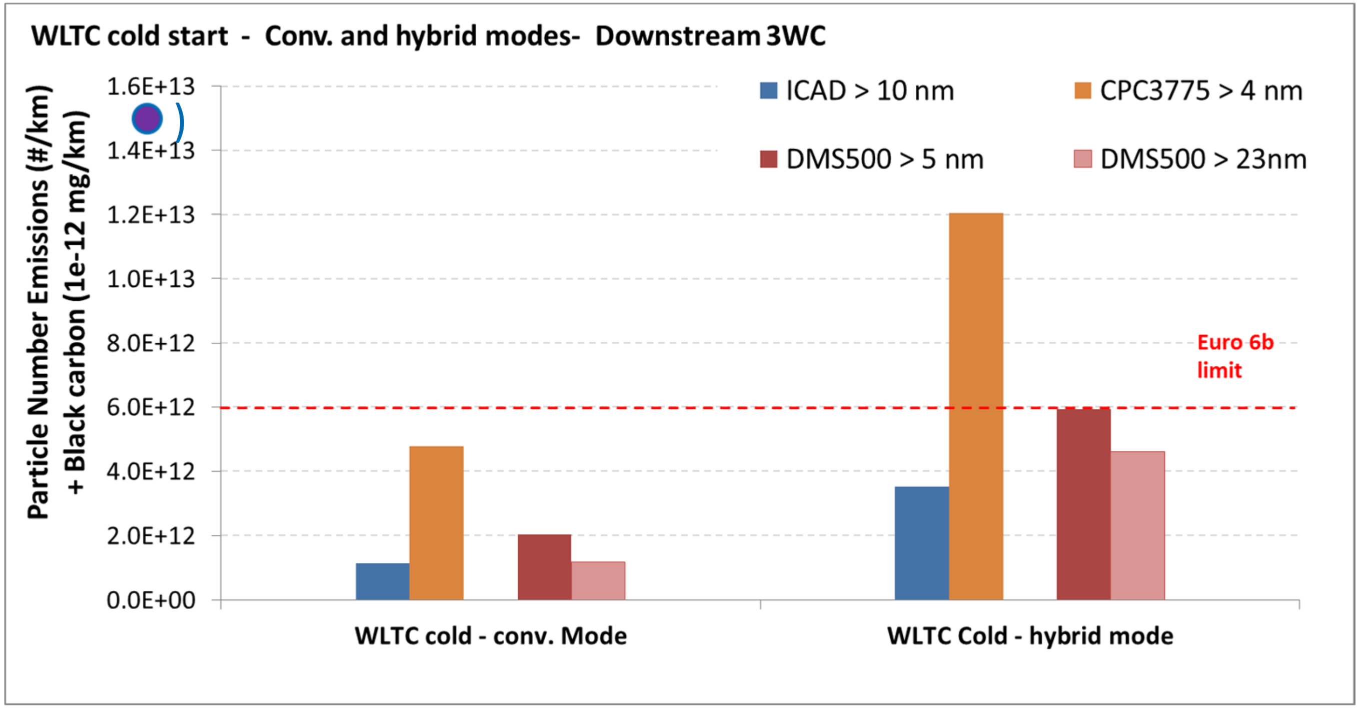
 © 2017 IFPEN

INSTITUT CARNOT IFPEN Transports Energie
IFP Energies nouvelles

RESULTS: HYBRIDIZATION EFFECT

SUSTAINABLE MOBILITY

PN measurement on WLTC from ambiant start at 23 °C (downst. 3WC) :



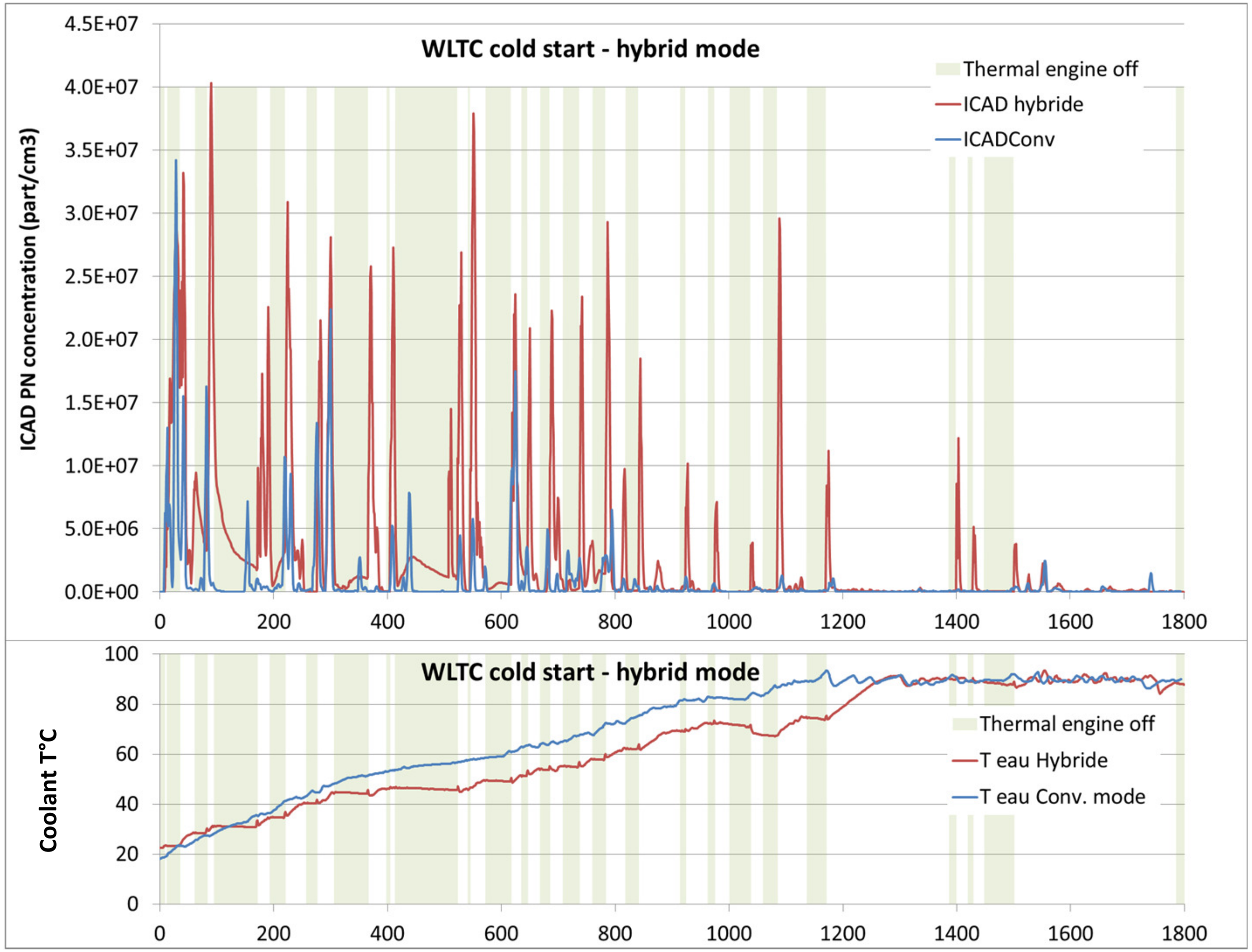
Device	Cut-off diam (nm)	Conv. Mode	Hybrid Mode	% overPN hybride
ICAD	**10**	1.13E+12	3.53E+12	212%
DMS500 > 5 nm	**5**	2.03E+12	5.93E+12	192%
DMS500 > 23 nm	**23**	1.18E+12	4.62E+12	293%
CPC3775	**4**	4.77E+12	1.21E+13	153%
Sub-23 ratio	**-**	52%	28%	-

- Significant increase of PN emissions with hybridization (from x2.5 to x4 depending on the measurement device
- Lower sub-23 nm fraction in hybrid mode

© 2017 IFPEN

RESULTS: HYBRIDIZATION EFFECT

- **Substantial PN peaks during the thermal engine restart phases :**



 | © 2017 IFPEN

CONCLUSIONS

SUSTAINABLE MOBILITY

- **Lowering the cut-off diameter from 23 nm to 10 nm leads to an increase of the total PN at the tailpipe**
  - **This increase is limited to around 10% - 20% because of the use of a Catalytic Stripper that efficiently convert the volatile fraction**
  - **This increase is not observed downstream of a catalyzed particulate filter (cGPF)**

- **Hybridization**
  - **The total PN increases from a factor x2.5 to x4 - Reduction of the sub-23 nm fraction**
  - **Efforts are required to optimize hybrid management not only regarding FC / CO_2 but also regarding PN emissions**

© 2017 IFPEN

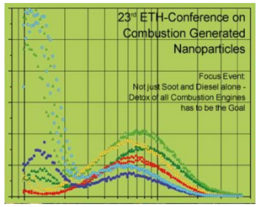
INSTITUT CARNOT IFPEN Transports Energie

IFP Energies nouvelles

ACKNOWLEDGEMENTS

Horizon 2020 research and innovation program for funding the SUREAL-23 project

The partners of the project



… and thank you for your attention. Questions?

Innovating for energy

Find us on:

www.ifpenergiesnouvelles.com

@IFPENinnovation

© 2019 IFPEN