



# Evaluation of Tailpipe Solid PN Measurement Methodologies

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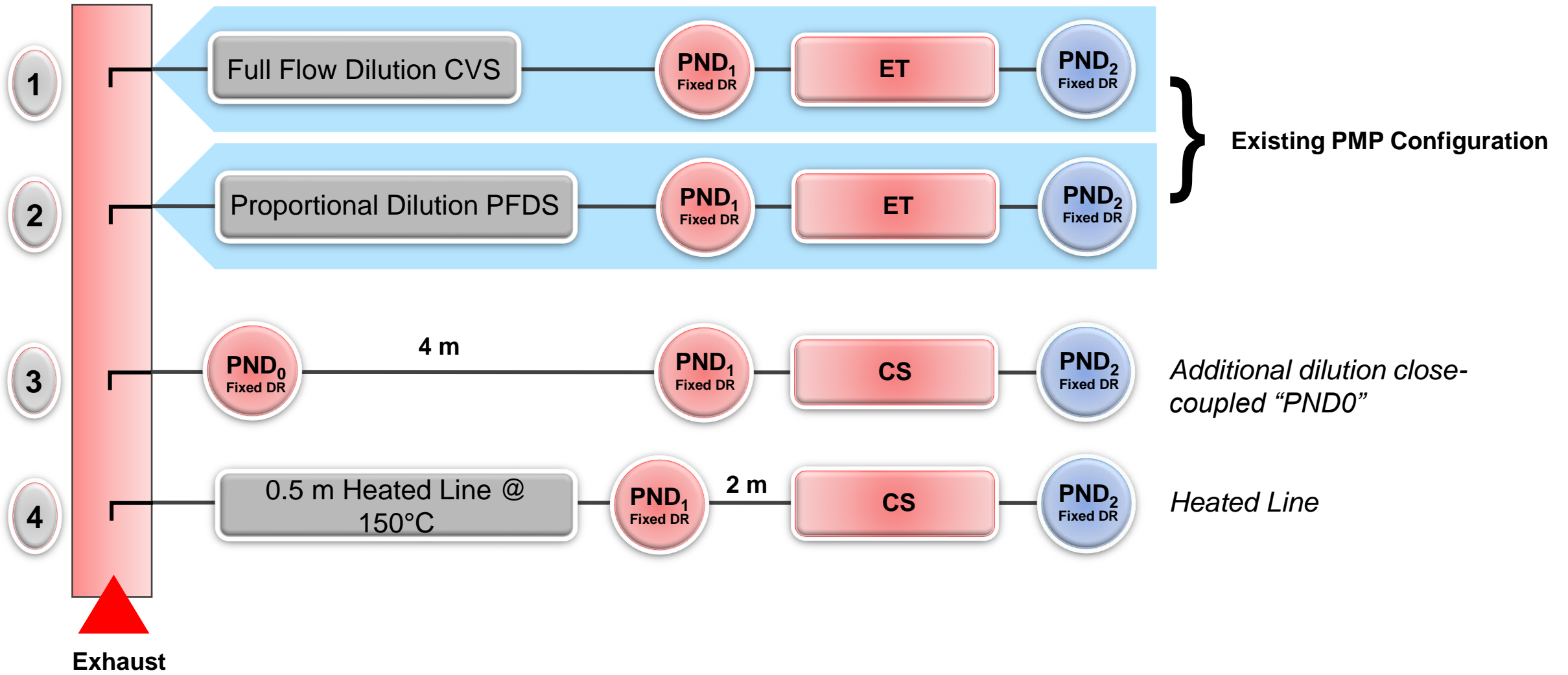
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# Approaches for PN Measurement




## Objectives:

- Comparison of two different solid PN measurement methodologies at tailpipe location
  - Use of PND0 (pre-diluter) for cold dilution
  - Use of 0.5 m heated line
- Understand the impact of sub-23 nm particles on the accuracy of tailpipe methodologies

# Test Matrix

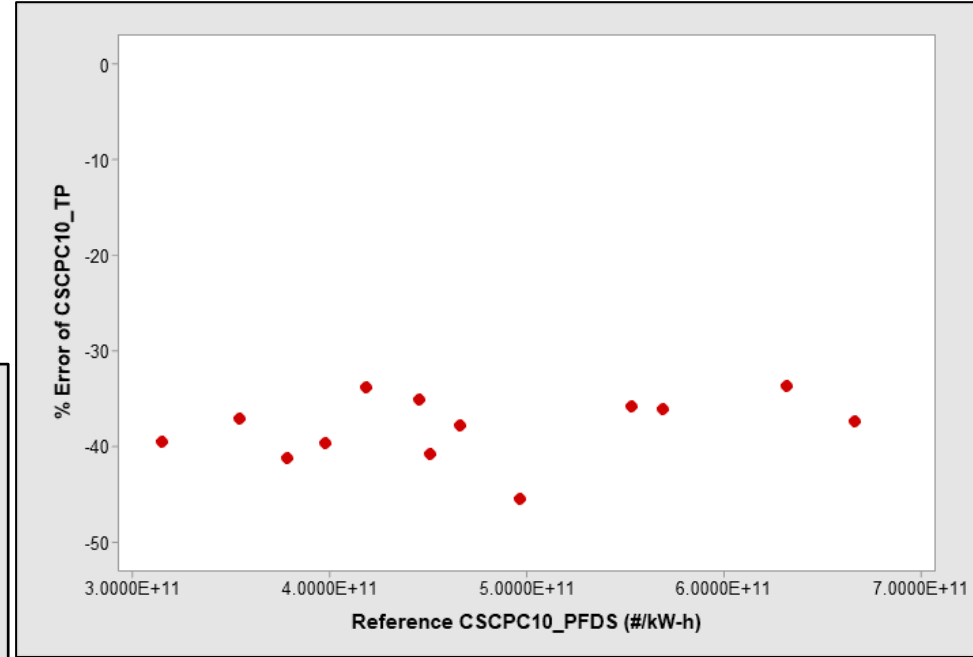
Tests Order	Test Cell	Engine	CSCPC10	CSCPC10 HL_150	CSCPC10 HL_120	CSCPC10_PD	ETCPC23	ETCPC2.5
1	1	NG1	PFDS			TP		
2	1	NG2		TP		TP		
3	1	NG2			TP	TP		
4	1	NG3			TP	TP	PFDS	PFDS
5	2	Diesel1	CVS			CVS	CVS	CVS
6	2	Diesel2	CVS			CVS	CVS	CVS
7	3	Diesel3		TP			PFDS	PFDS
8	3	Diesel4		TP		TP	PFDS	PFDS
9	3	Diesel4		TP		TP	PFDS	PFDS
10	1	NG3		TP		TP	PFDS	PFDS

**CSCPC10:** Catalytic Stripper + CPC with  $d_{50}$  of 10 nm  
**ETCPC23:** Evaporation Tube + CPC with  $d_{50}$  of 23 nm  
**ETCPC2.5:** Evaporation Tube + CPC with  $d_{50}$  of 2.5 nm  
**HL\_150:** Heated line at 150°C  
**HL\_120:** Heated line at 120°C  
**PD:** Pre-diluter  
**NG:** Natural Gas  
**PFDS:** Partial flow dilution system  
**TP:** Tailpipe  
**CVS:** Constant volume sampler

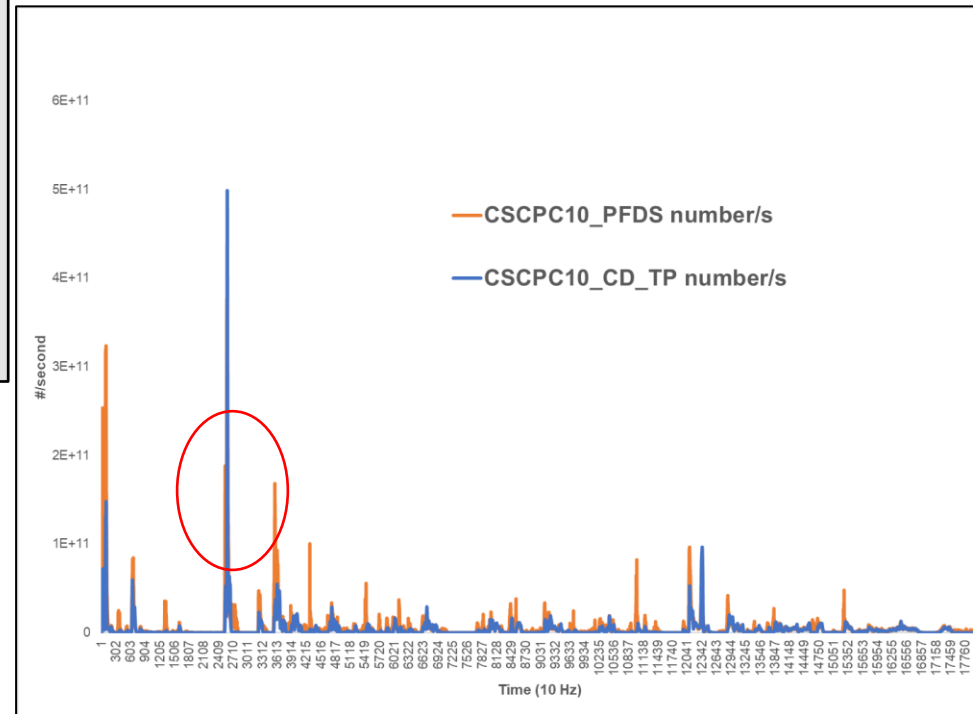

  
**One PN system but different heated line temperatures**

# Engine Type: NG1

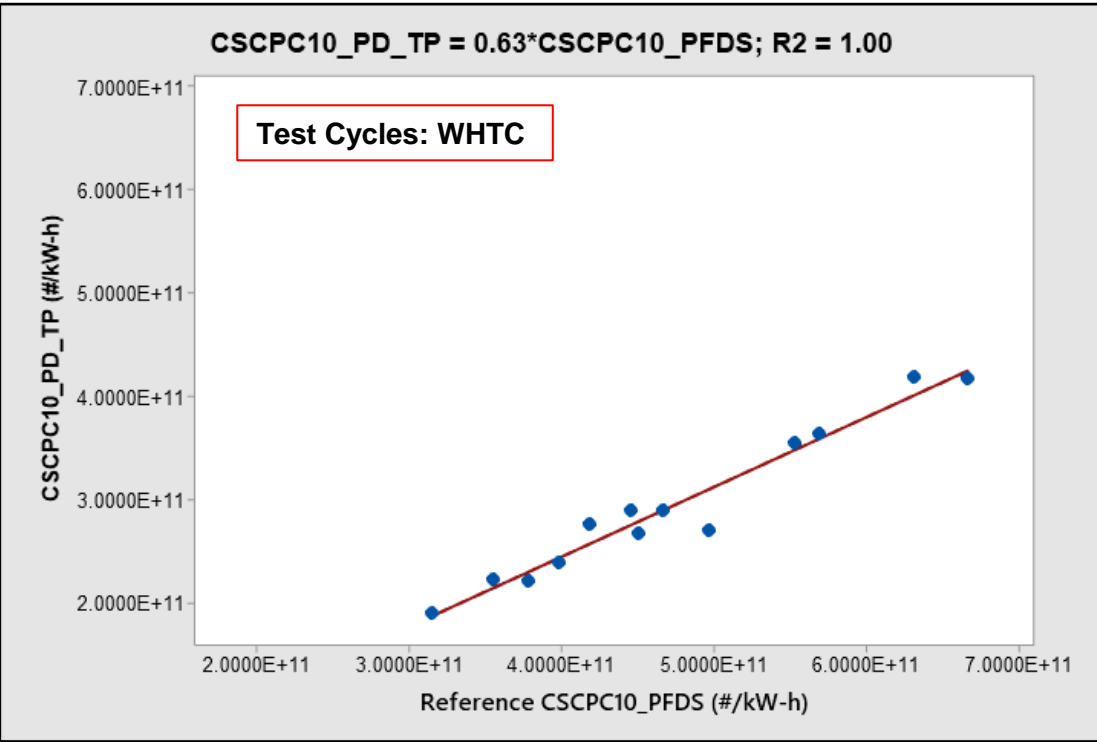
PN System	Location
CSCPC10	PFDS
CSCPC10_PD	TP



- Approximately 40% lower than reference location
- Most of the spikes are missed by the system at TP location

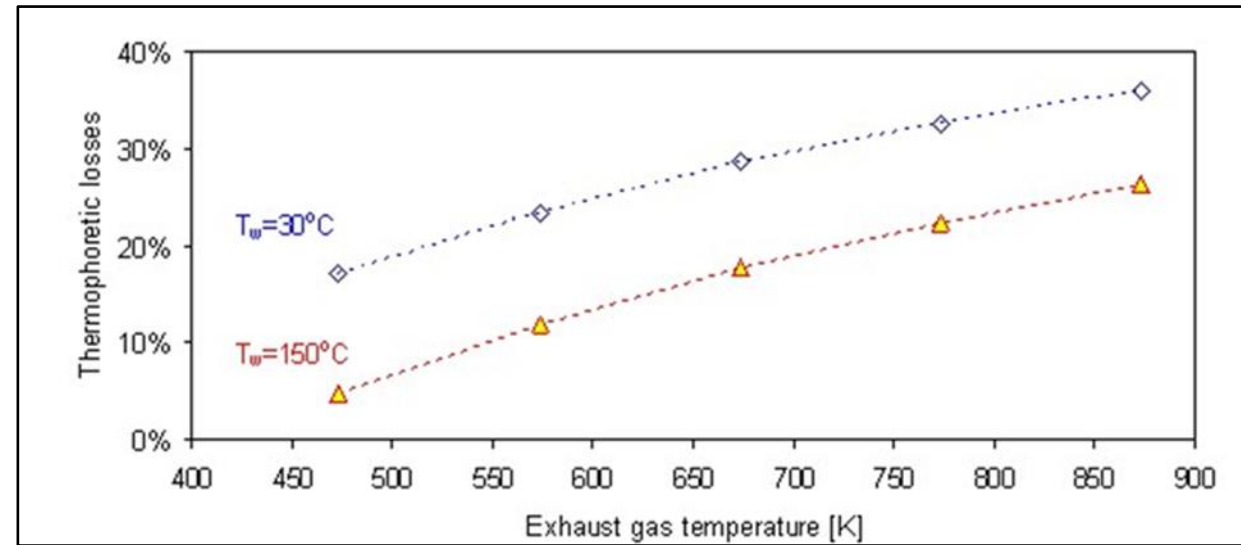
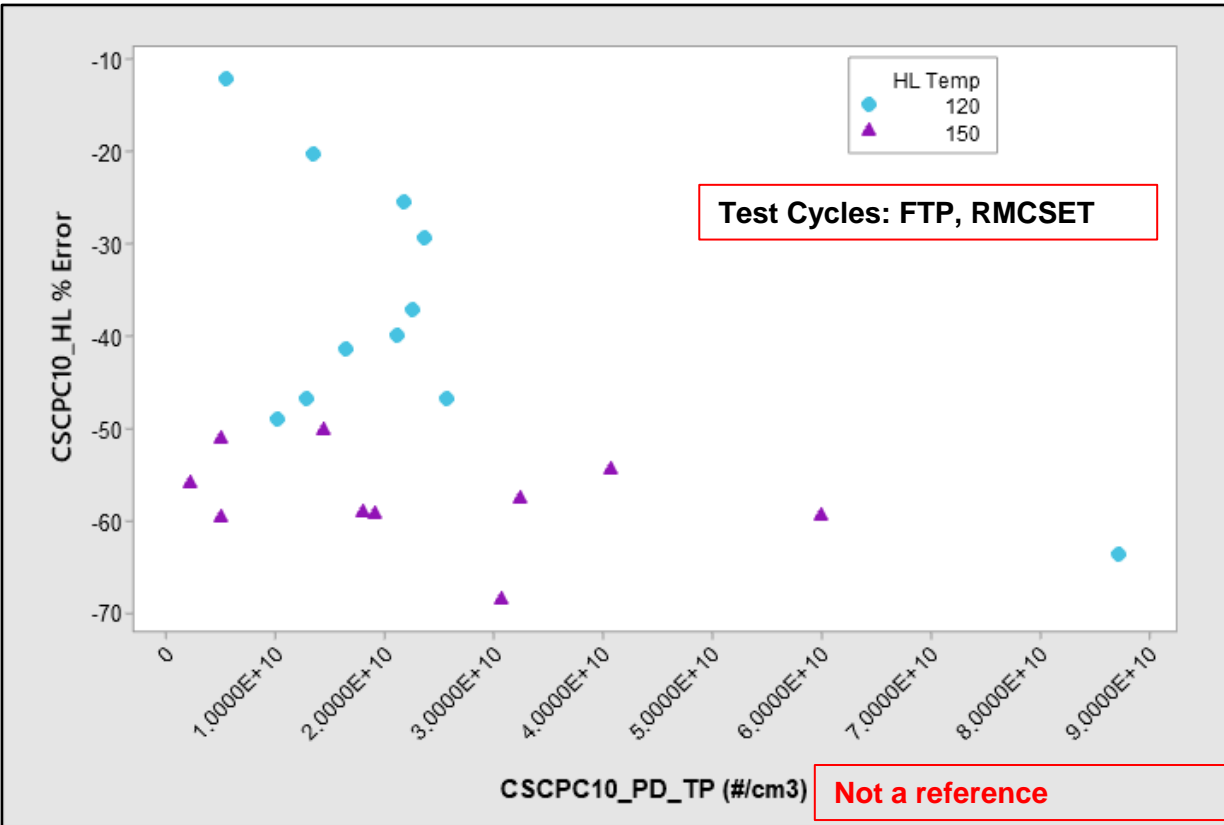


- Is that due to higher sub-23 nm fraction of particles?
- Is total PCRFF (including pre-diluter) at lower dilution ratios properly determined?



# Engine Type: NG2

PN System	Location
CSCPC10_HL_150	TP
CSCPC10_PD	TP
CSCPC10_HL_120	TP

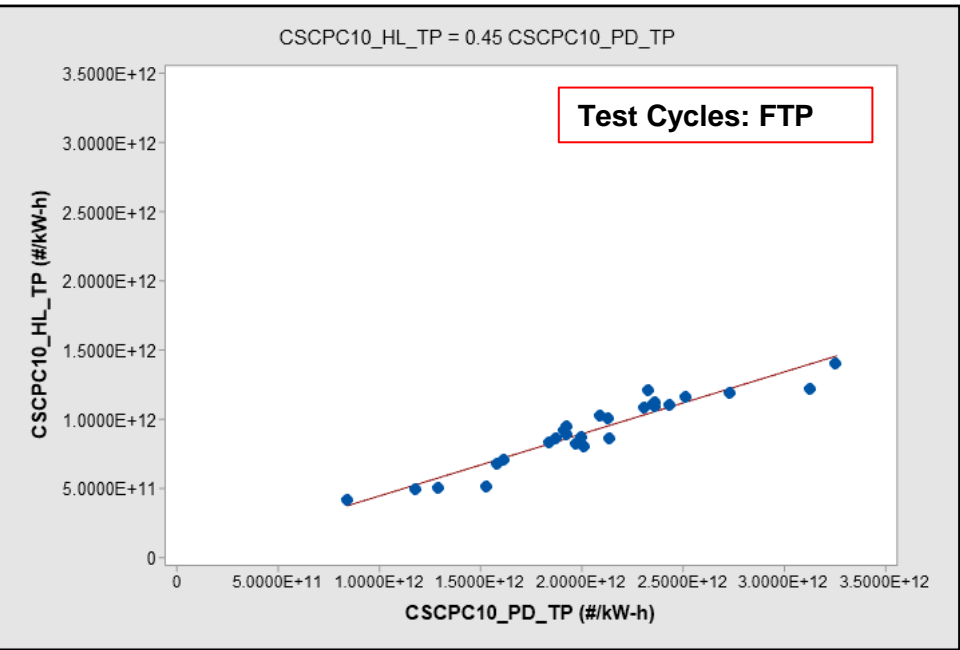


Giechaskiel, B., et. al, 2012

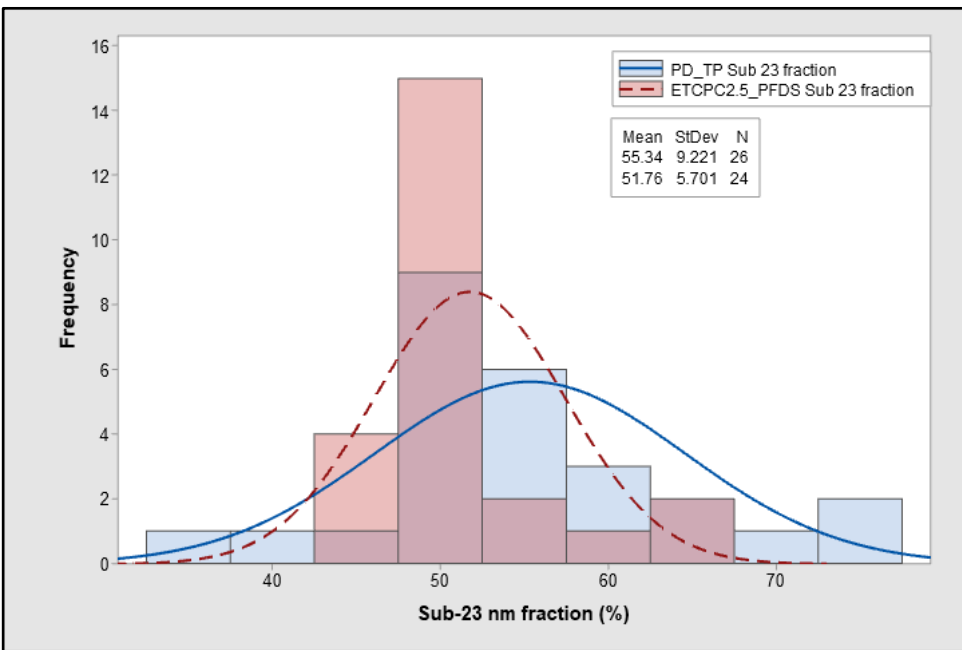
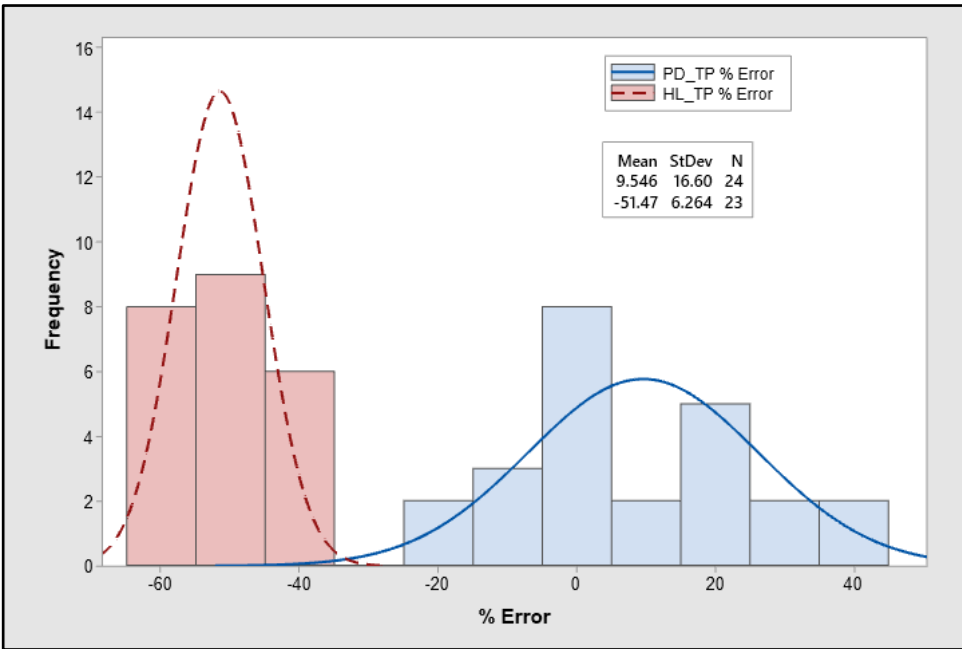
- NG engine exhibited up to 1100°C which led to higher sample temperature at PND1 (> 150°C) of CSCPC10 with heated line temperature of 150°C – note this a very rare case of calibration
- Thus, temperature of HL was dropped to 120°C
- Correlation improved but not significantly
- **Approximately ~30-40% thermophoretic losses**
- **Note** – no provision for correcting for known thermophoretic losses

# Engine Type: NG3

PN System	Location
CSCPC10_HL_120	TP
CSCPC10_PD	TP
ETCPC23	PFDS
ETCPC2.5	PFDS



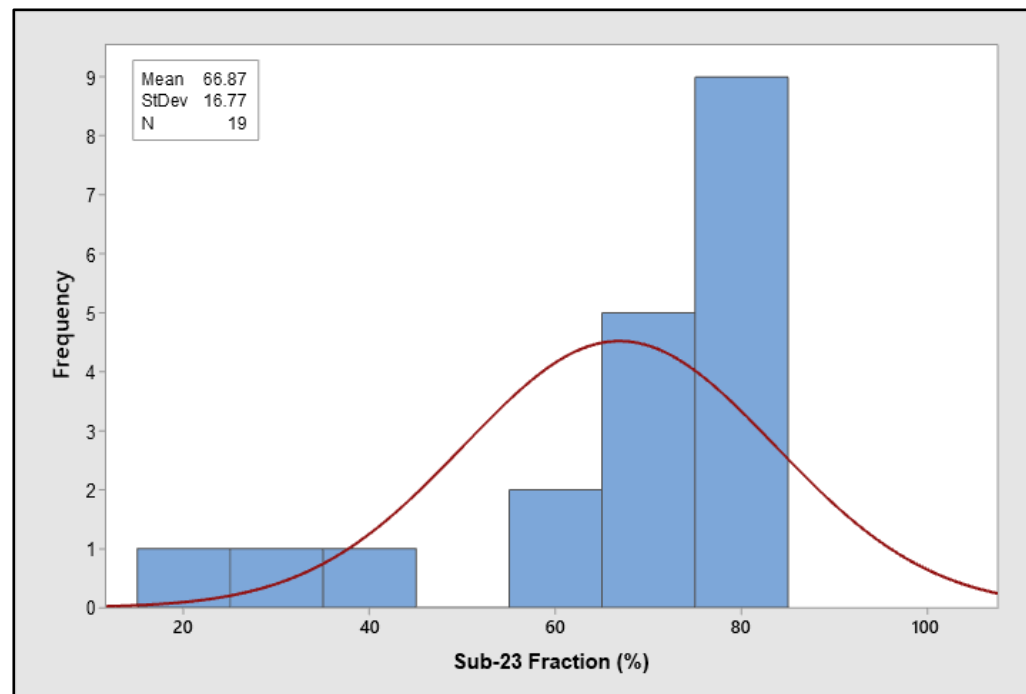
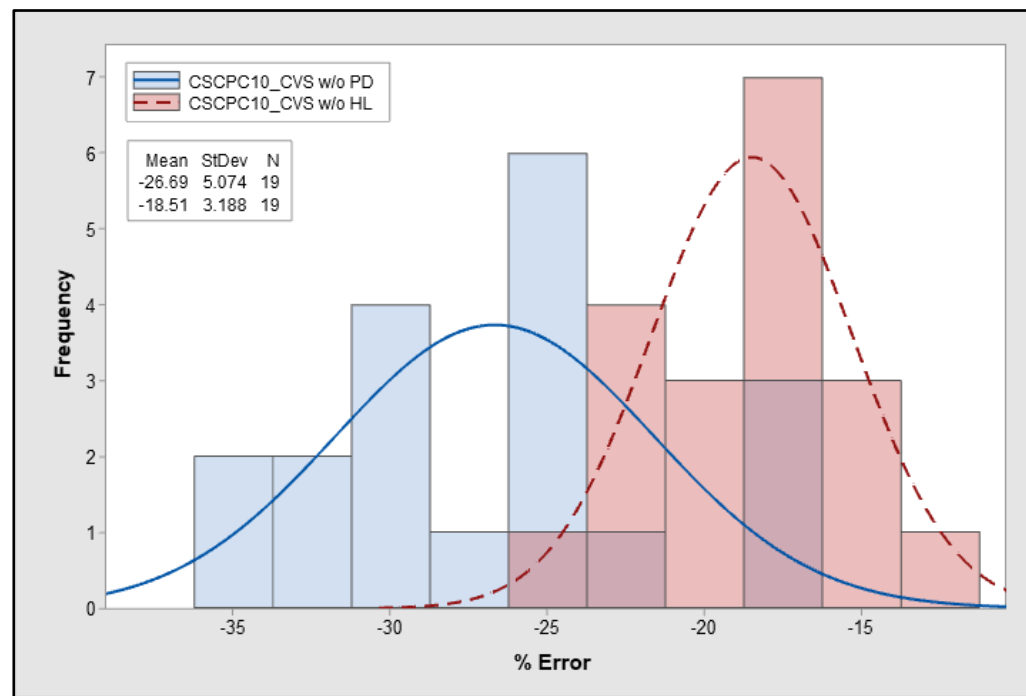
- Poor correlation between two methodologies for NG engine – **is system with HL working properly?**



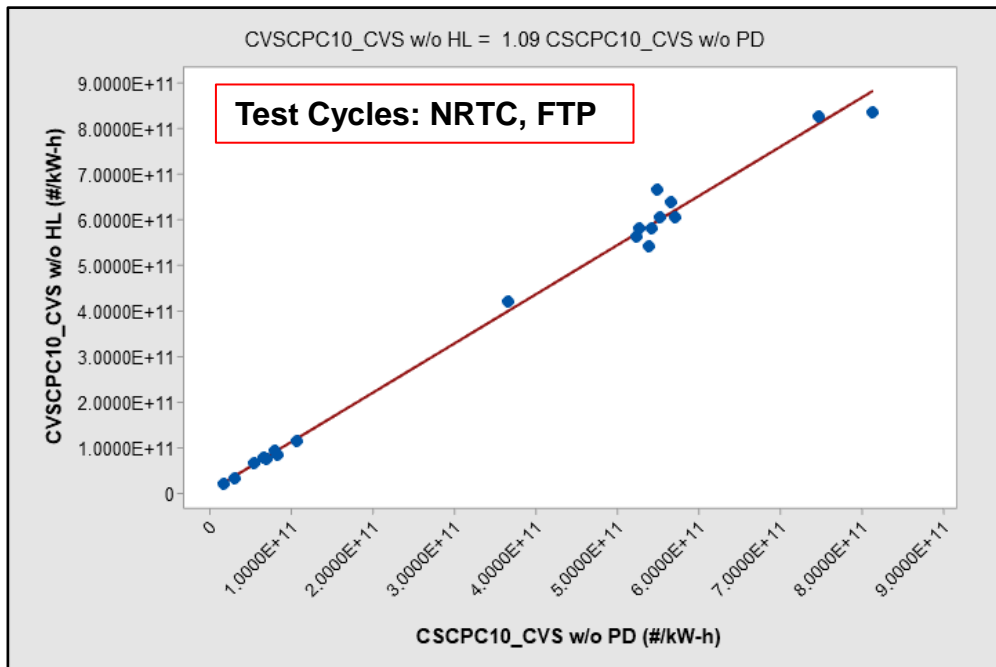
- Pre-diluter was within 10% ±17% (higher) when compared against reference (ETCPC2.5 at PFDS)
  - Lower PCRF seems to be robust for higher concentrations
- Heated line was (-51%±6%) lower than the reference
- Note that the average BSPN was ~2.0 x 10<sup>12</sup> #/kW-h
- On an average, 55% of particles were lower than 23 nm
- Thus, higher fraction of sub-23 nm does not seem to be a measurement issue for PN system with pre-diluter

# Engine Type: Diesel 1 & 2

PN System	Location
CSCPC10	CVS
CSCPC10	CVS
ETCPC23	CVS
ETCPC2.5	CVS



- PN systems reported 27% and 19% less than the reference (ETCPC2.5)
- Thus, good health of the PN systems
- Significant fraction of sub-23 nm particles (~67%), ~30% between 2.5 and 10 nm
- Seems to have no issue with sub-23 nm particles measurement without pre-diluter and heated line



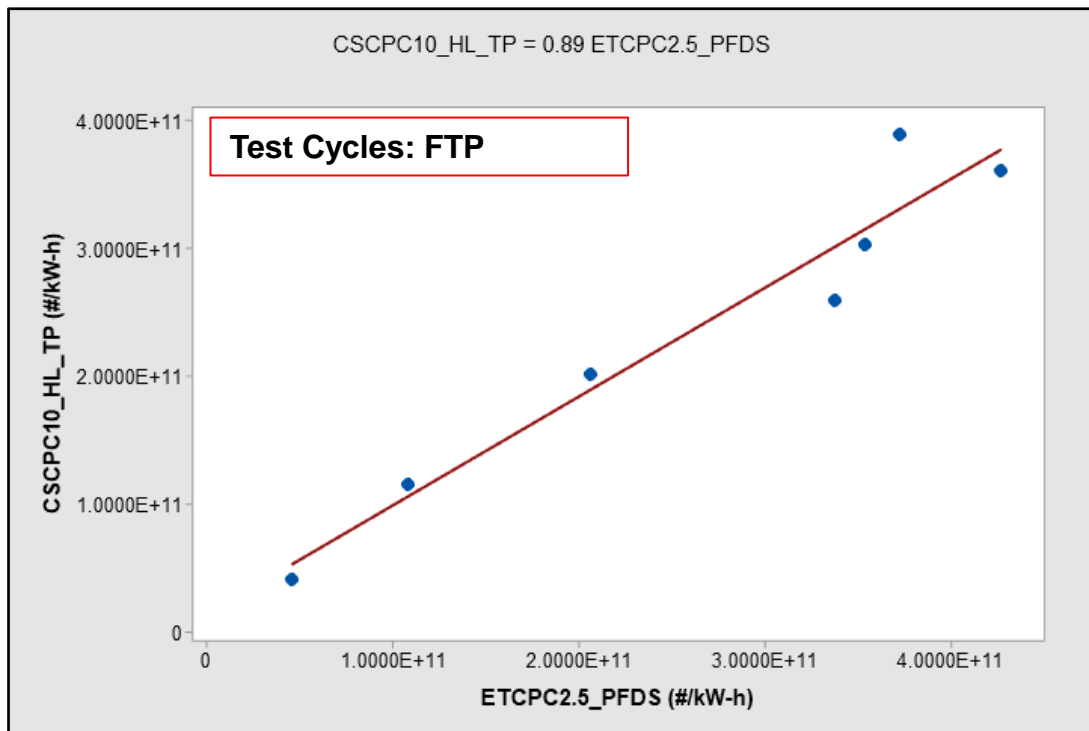
- Good correlation between the PN systems without Pre-diluter or Heated line
  - Thus, PN system utilized with HL does not have any measurement issue



# Engine Type: Diesel 3

PN System	Location
CSCPC10_HL_150	TP
ETCPC23	PFDS
ETCPC2.5	PFDS

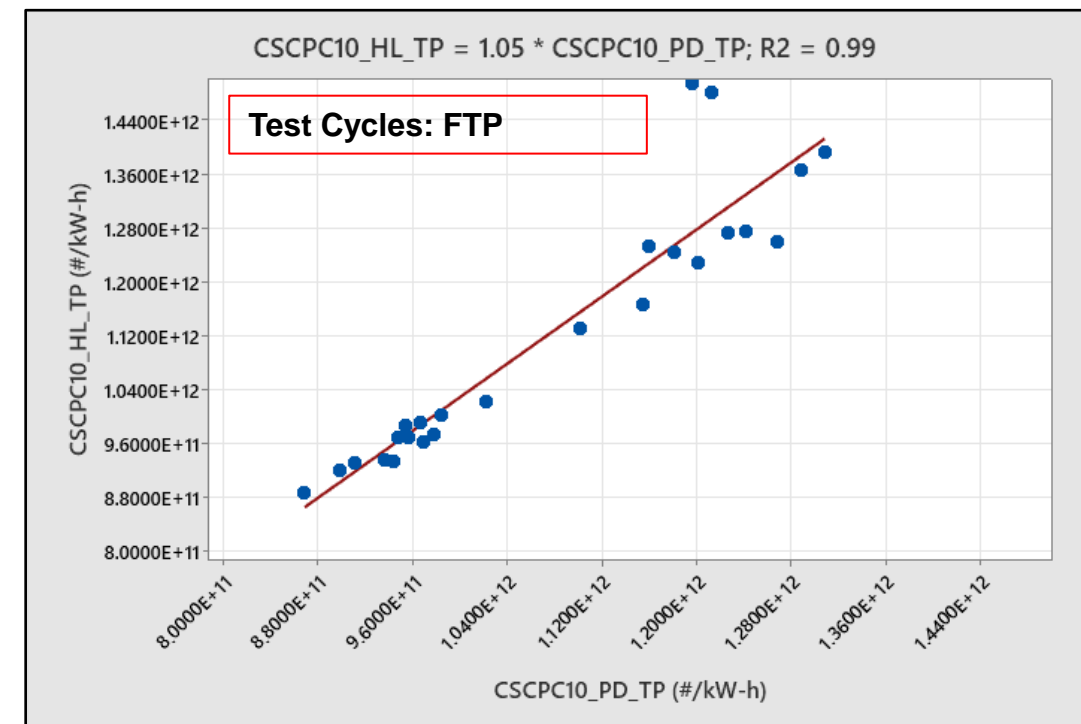
**CSCPC10\_PD  
out of Cal**



- Good correlation on the limited data set – reported ~11% lower than the reference at 10<sup>11</sup> bsPN levels
- On an average ~32% of total particle count was sub-23 nm particles

# Engine Type: Diesel4

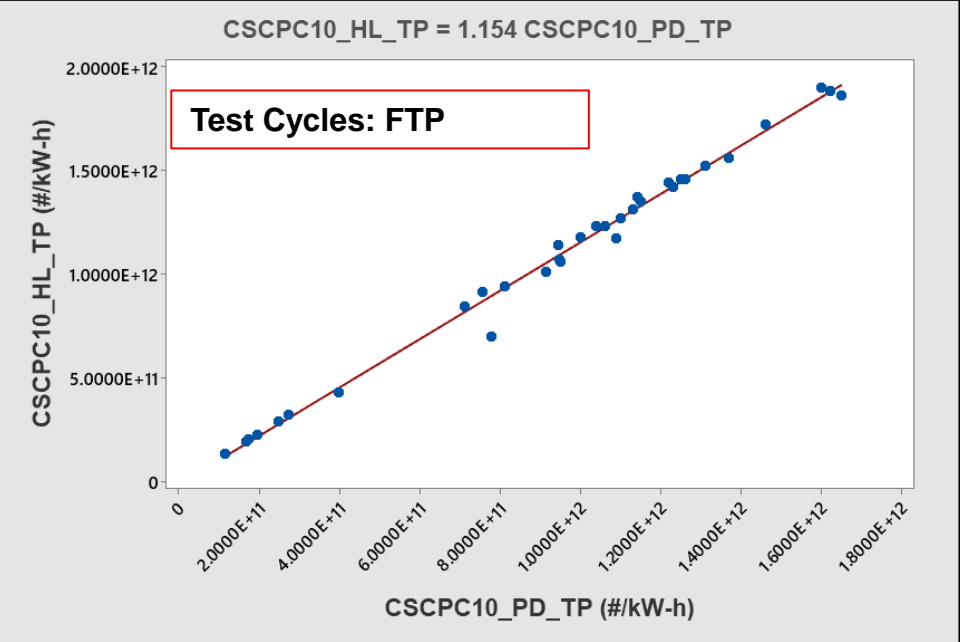
PN System	Location
CSCPC10_HL_150	TP
CSCPC10_PD	TP
ETCPC23	PFDS
ETCPC2.5	PFDS



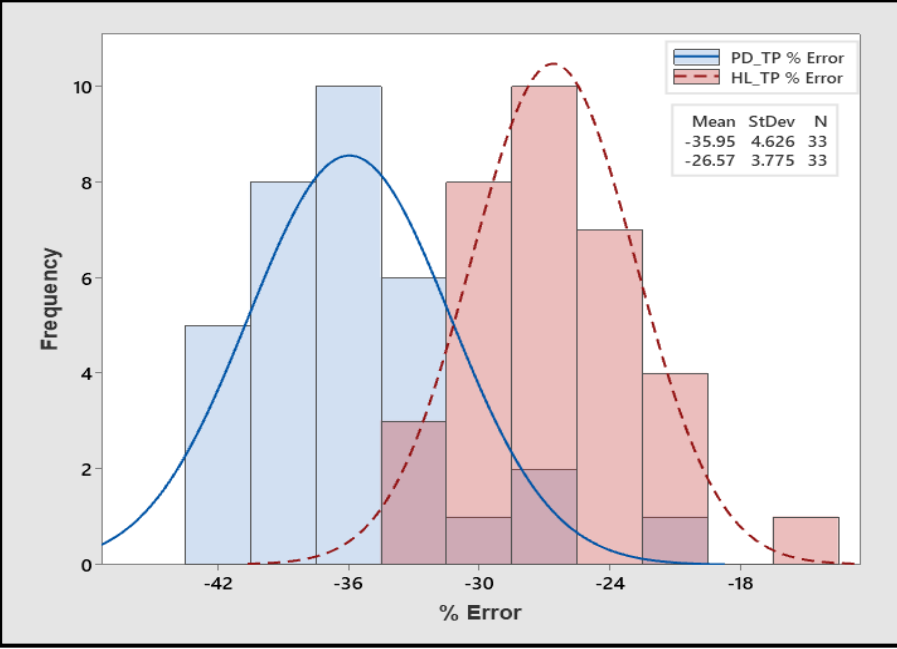
Good correlation was observed between the PN systems with Pre-diluter & Heated line. Pre – diluter & Heated Line were within 4% ± 6%

# Engine Type: NG4

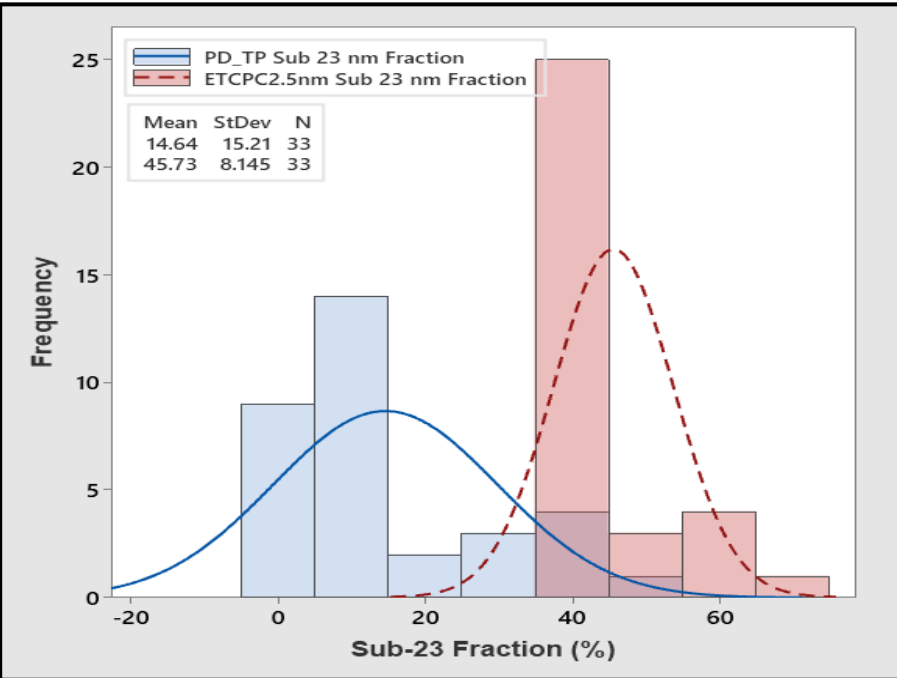
PN System	Location
CSCPC10_HL_150	TP
CSCPC10_PD	TP
ETCPC23	PFDS
ETCPC2.5	PFDS



Good correlation between the PN systems with Pre-diluter or Heated line. Pre – diluter & Heated Line were within 14% ± 5%



- Pre-diluter was within -36% ± 5% when compared against reference (ETCPC2.5 at PFDS)
- Heated line was (-27% ± 4%) lower than the reference (ETCPC2.5 at PFDS)



- Approximately 26% of particles were within 10nm and 23nm & 46% were between 2.5nm and 23 nm

# Summary

- PN system with pre-diluter was ~40% less than reference (10 nm @PFDS) for NG engine @ bsPN level of  $10^{11}$  [old calibration]
- PN system with pre-diluter was  $10\% \pm 17\%$  higher than the reference (2.5 nm @PFDS) for NG engine @ bsPN level of  $10^{12}$ 
  - After new calibration, system with pre-diluter reported 30-40% less than the reference (2.5 nm @PFDS) for NG engine at the bsPN levels of  $10^{11-12}$
  - System with heated line reported 20-30% less than the reference (2.5 nm @PFDS) for NG engine at the bsPN levels of  $10^{11-12}$
- In a rare event of high exhaust temperature, PN system with heated line at  $150^{\circ}\text{C}$  showed measurement issue due to high sample inlet temperature
  - PN system with heated line at  $120^{\circ}\text{C}$  showed poor correlation with reference (0.45 x reference). Thermophoretic losses were dominant
- Two tailpipe measurement methodologies were within 15% of each other @bsPN level of  $10^{11}$  and  $10^{12}$  for both diesel and NG engines
- Higher Sub-23 nm fraction did not significantly impact measurement of PN systems with pre-diluter and heated line
- Higher fraction of sub-23 nm particles in NG engines as reported before

Q+A

