To CLEERS 2021

NGK AUTOMOTIVE CERAMICS USA, INC.

Investigation of Diesel Particulate Filter Design Parameters to Improve Filtration Performance under Various Test Cycles

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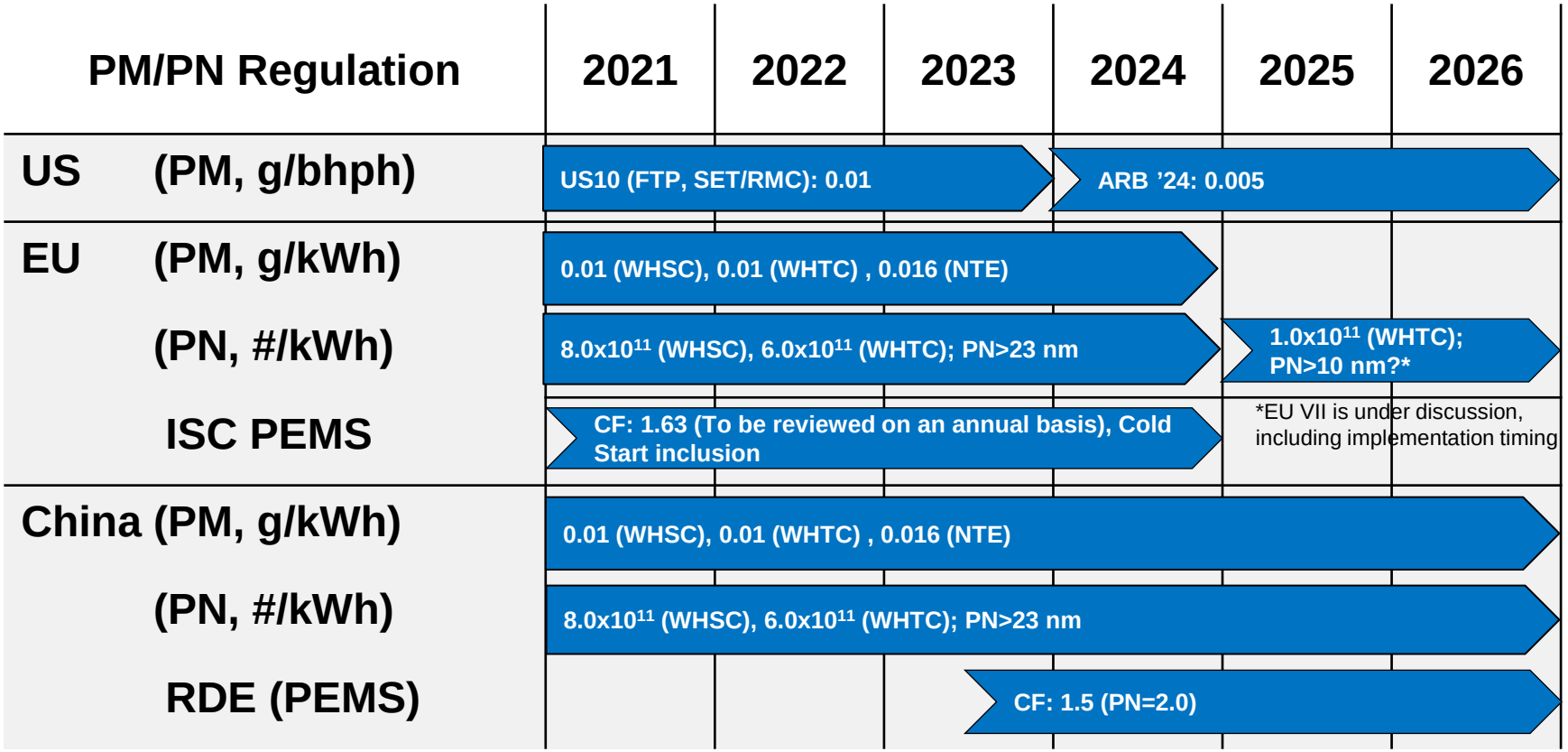
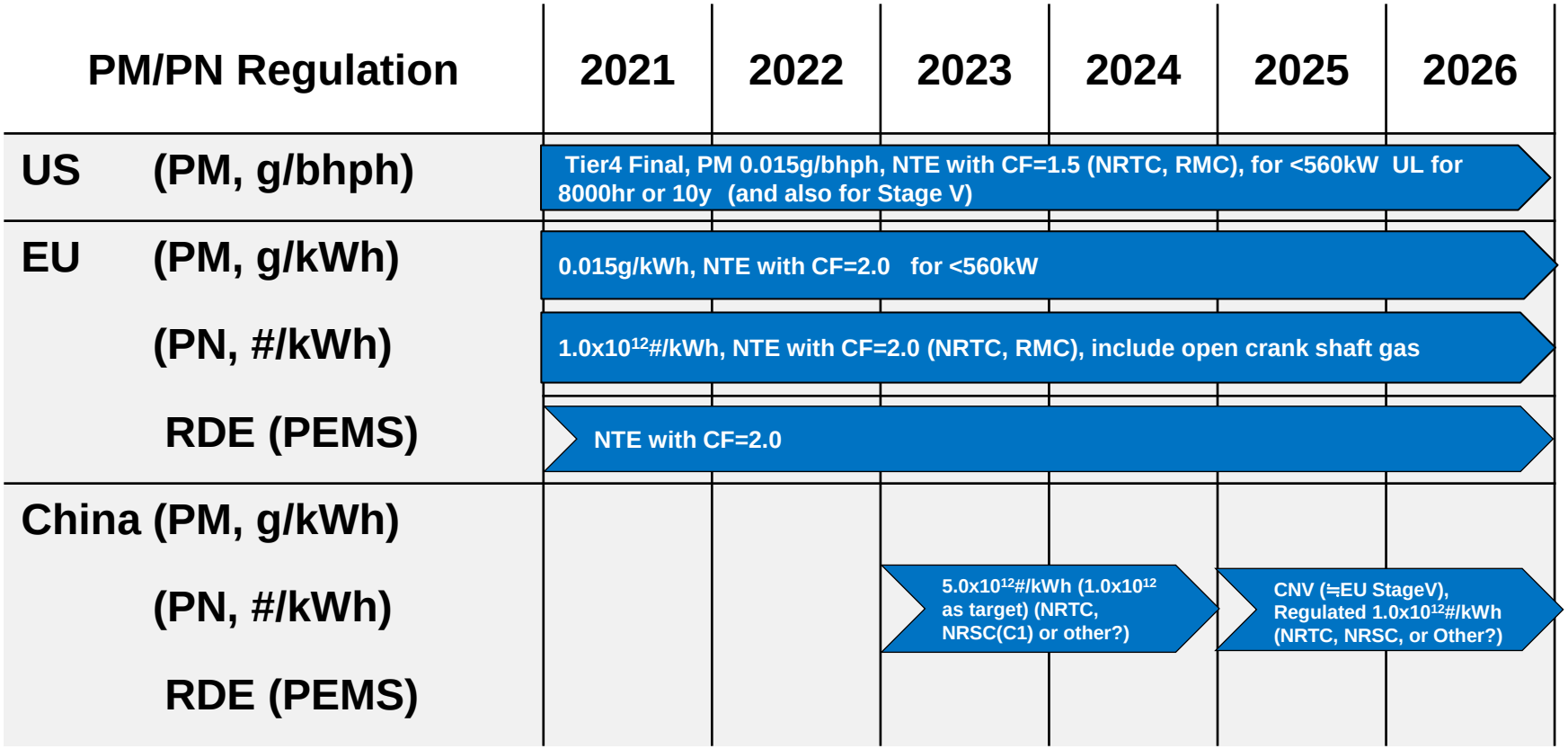
Sep 16th, 2021

On-road Regulation



- Both PM and PN are regulated in several regions of the world, future regulations may have tighter limits.
- Our goal is to design DPF to meet those regulation at different market.

Off-road Regulation



- Both PM and PN are regulated in several regions of the world, future regulations may have tighter limits.
- Our goal is to design DPF to meet those regulation at different market.

MD/HD Diesel AT System Design Improvement and DPF Trend

DOC + DPF
EPA 2007

DOC + DPF + SCR
EPA 2010

DOC + DPF + SCR
EPA 2017

DOC + DPF
Interim Tier 4/Stage III B

DOC + DPF + SCR
Final Tier 4/Stage V

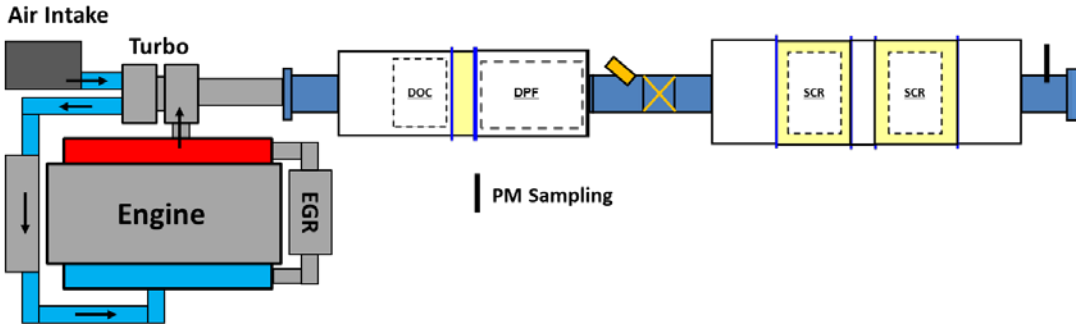
DOC + DPF + SCR
Final Tier 4/Stage V

- Cummins AT system pics are from Cummins official website
- John Deere AT system pics are from John Deere official website and John Deere CLEERS 2020 presentation

- Over the years, for the aftertreatment systems that have adopted DPF to reduce PM/PN

→ Thin-wall and downsized DPFs are developed to fit compact design while still maintaining high performance (low pressure drop, high filtration efficiency, more ash capacity, etc.)

Evaluation for PM



Test Engine:

7L on-highway EPA 2013 certified diesel engine

Test Sequence:

FTP x 2 → FTP Cold → FTP Hot → RMC 1 → RMC 2

Sampling Device:

BG-3 @ tailpipe

Test Sample:

Conventional DPF 1

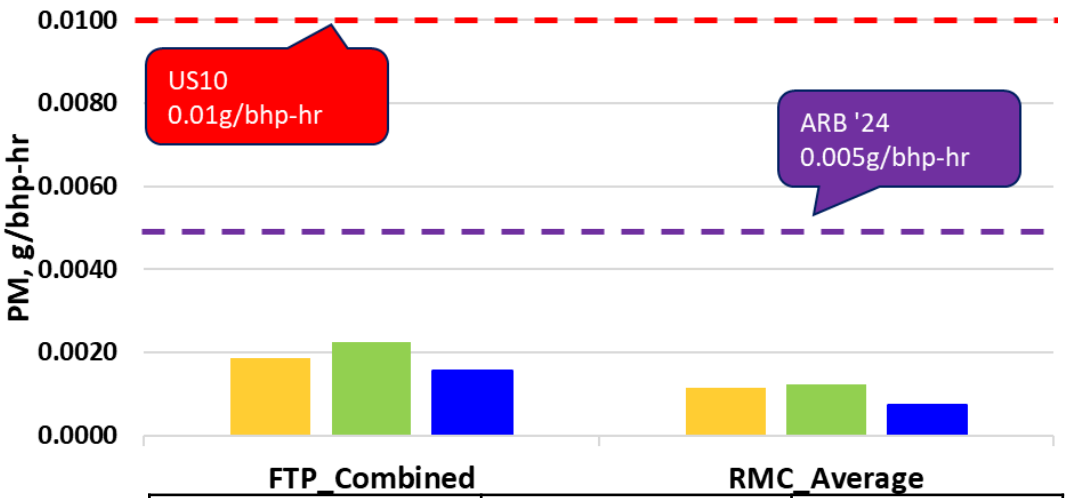
Conventional DPF 2

Advance DPF 3

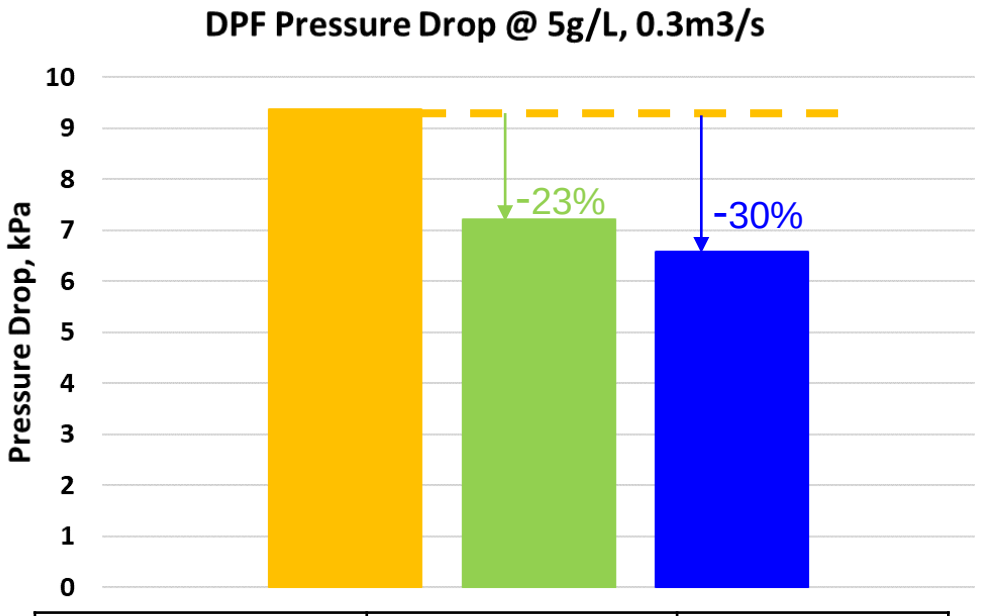
	Conventional DPF 1	**Conventional DPF 2**	**Advance DPF 3**
Wall Thickness	Baseline	Thinner Wall	
Porosity	Baseline	Higher Porosity	
MPS	Baseline		Smaller MPS

All filters were coated with a standard production catalyst at a standard PGM loading by BASF

PM Result



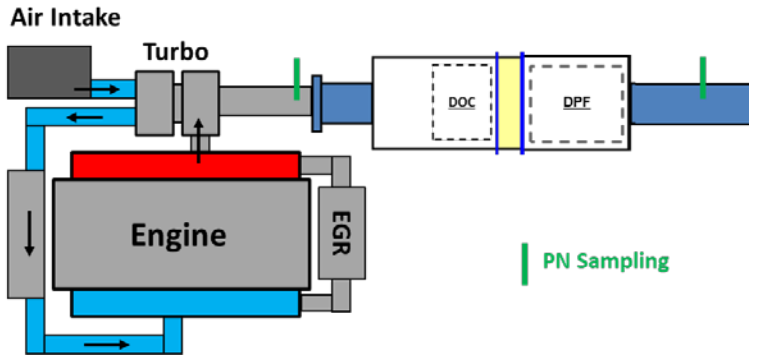
Conventional DPF 1	Conventional DPF 2	Advance DPF 3
Baseline	Thinner Wall	
Baseline	Higher Porosity	
Baseline		Smaller MPS



Conventional DPF 1	Conventional DPF 2	Advance DPF 3
Baseline	Thinner Wall	
Baseline	Higher Porosity	
Baseline		Smaller MPS

- Conventional DPFs and advance DPF are all meeting current and future PM regulation with good engineering margin.
- Advance DPF can further reduce pressure drop while meeting future PM regulation.

Evaluation for PN



Test Engine:

9L on-highway EPA 2013 certified diesel engine

Test Sequence:

Preconditioning WHTCs → WHTC Cold → WHTC Hot → WHSC 1 → WHSC 2

Preconditioning NRTCs → NRTC Cold → NRTC Hot → NRSC 1 → NRSC 2

Measurement Device:

>10nm CPC @ tailpipe

>23nm CPC @ engine out and tailpipe

Test Sample:

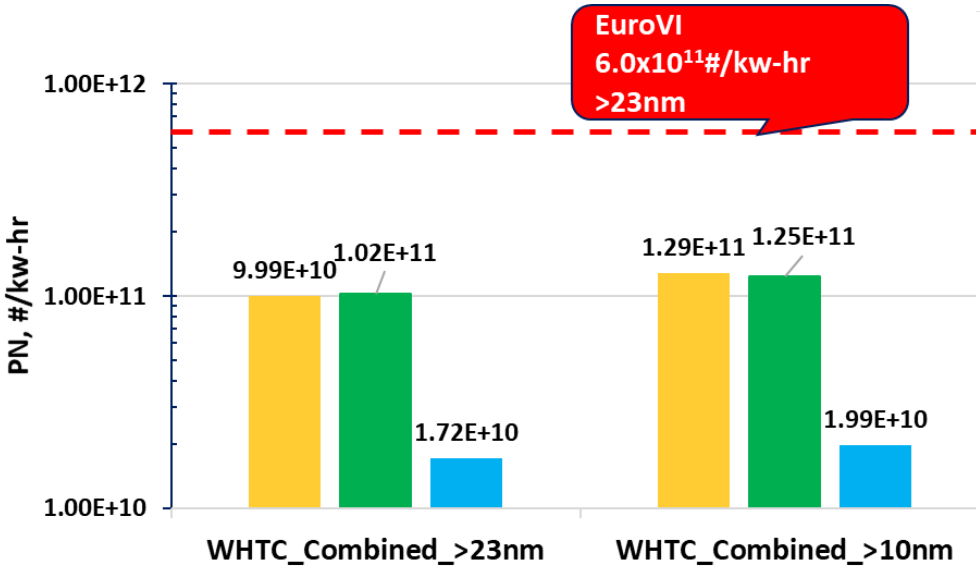
Conventional DPF A

Advance DPF B & C

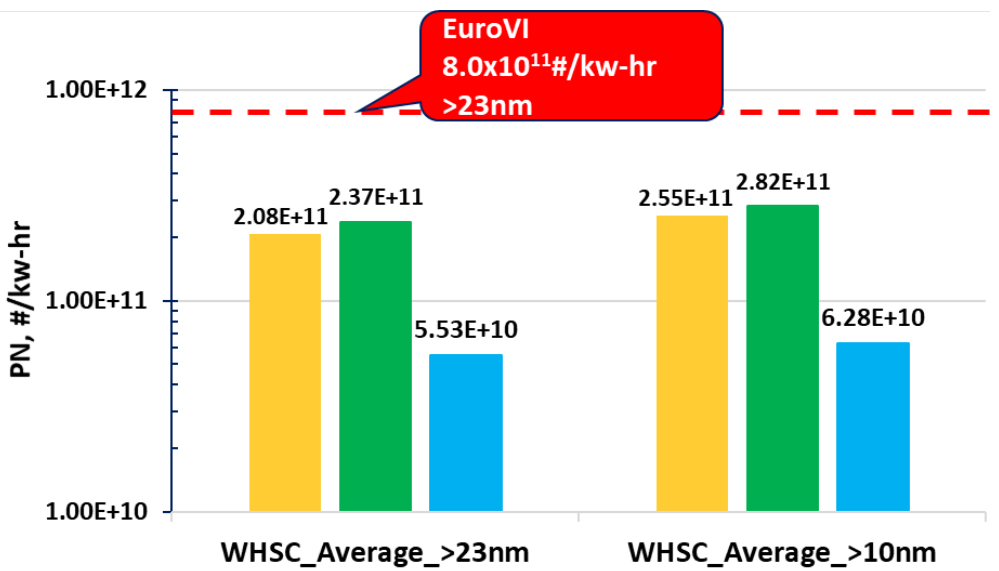
	Conventional DPF A	Advance DPF B	Advance DPF C
Wall Thickness	Baseline	Thinner Wall	Baseline
Porosity	Baseline	Higher Porosity	
MPS	Baseline	Smaller MPS	

All filters were coated with a standard production catalyst at a standard PGM loading by BASF

PN Result – WHTC/WHSC



Conventional DPF A	Advance DPF B	Advance DPF C
Baseline	Thinner Wall	Baseline
Baseline	Higher Porosity	
Baseline	Smaller MPS	



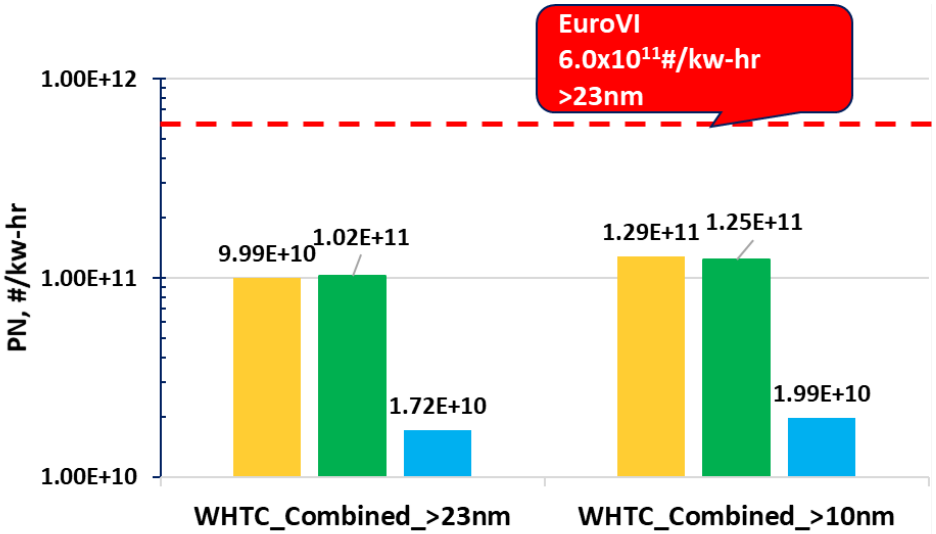
Conventional DPF A	Advance DPF B	Advance DPF C
Baseline	Thinner Wall	Baseline
Baseline	Higher Porosity	
Baseline	Smaller MPS	

- All DPFs are all meeting current PN regulation and have potential to meet future regulation.
- Sub 23nm impact:

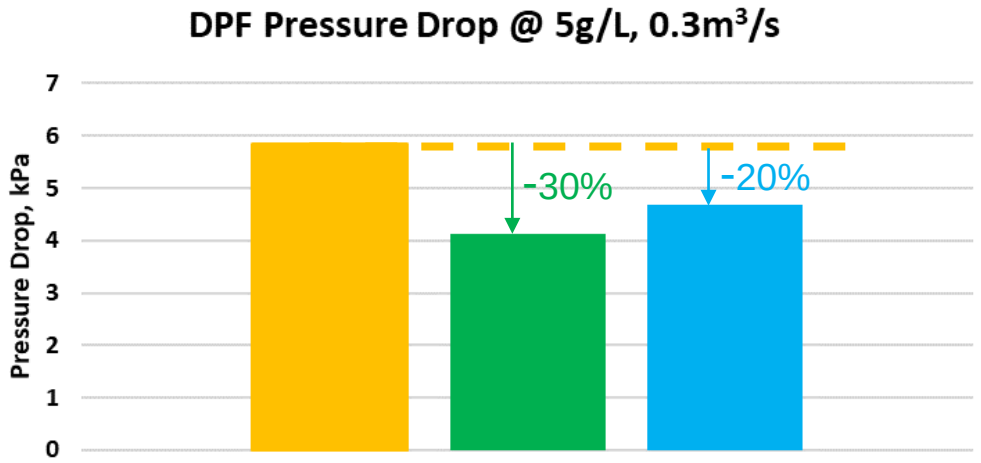
→ ~22% tailpipe PN increase on WHTC

→ ~18% tailpipe PN increase on WHSC

PN Result – WHTC/WHSC



Conventional DPF A	Advance DPF B	Advance DPF C
Baseline	Thinner Wall	Baseline
Baseline	Higher Porosity	
Baseline	Smaller MPS	



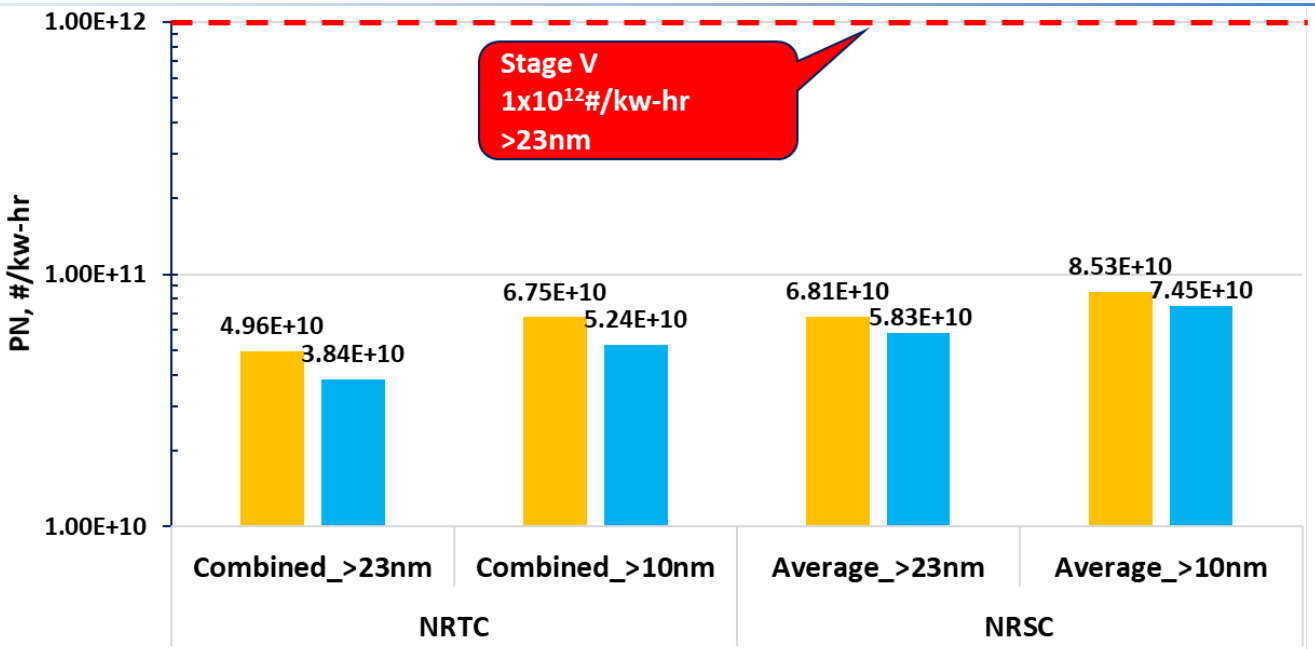
Conventional DPF A	Advance DPF B	Advance DPF C
Baseline	Thinner Wall	Baseline
Baseline	Higher Porosity	
Baseline	Smaller MPS	

- PN Performance: Advance DPF C > Advance B ≈ Conventional DPF A

→ Thicker wall, better PN performance

→ With smaller MPS, thinner wall & higher porosity DPF can have same PN performance as thicker wall DPF, an advantage to optimize pressure drop performance

PN Result – NRTC/NRSC



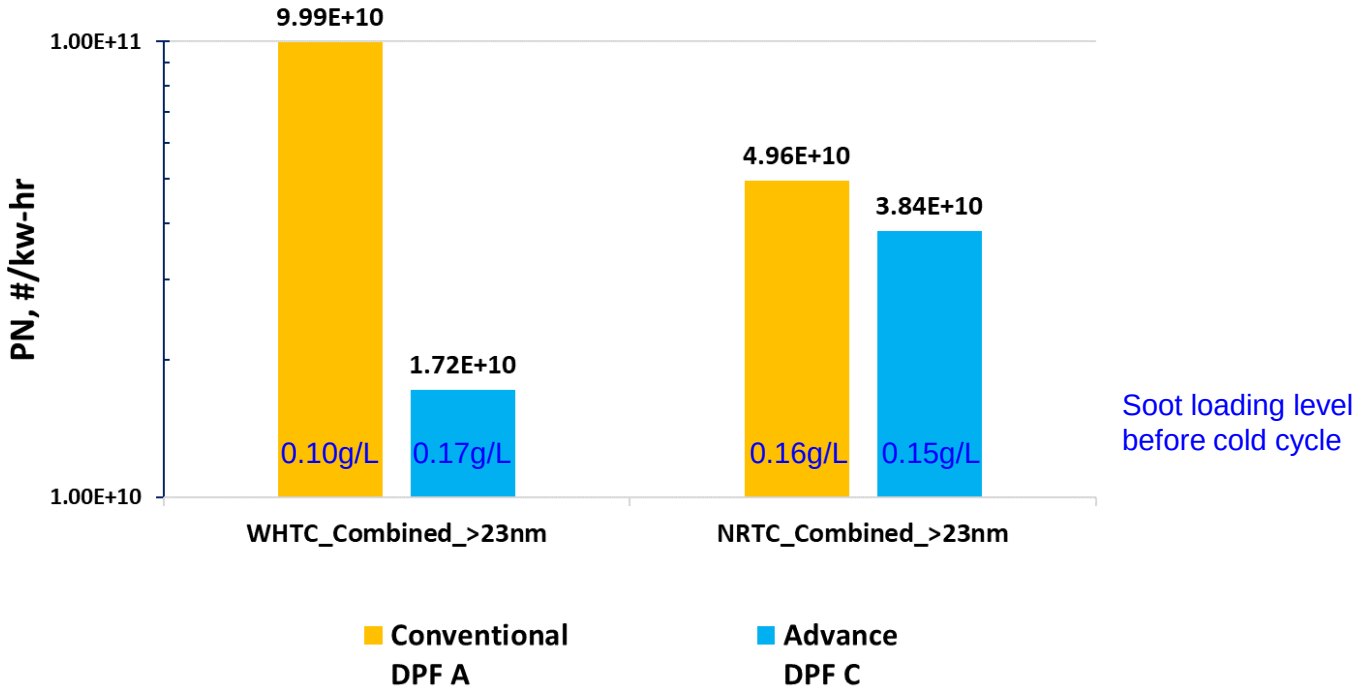
Conventional DPF A	Advance DPF C
Baseline (Wall Thickness)	
Baseline	Higher Porosity
Baseline	Smaller MPS

- Both DPFs are all meeting current PN regulation with good engineering margin.
- Sub 23nm impact:

→ ~36% tailpipe PN increase on NRTC

→ ~27% tailpipe PN increase on NRSC

DPF A VS DPF C



Soot loading level before cold cycle

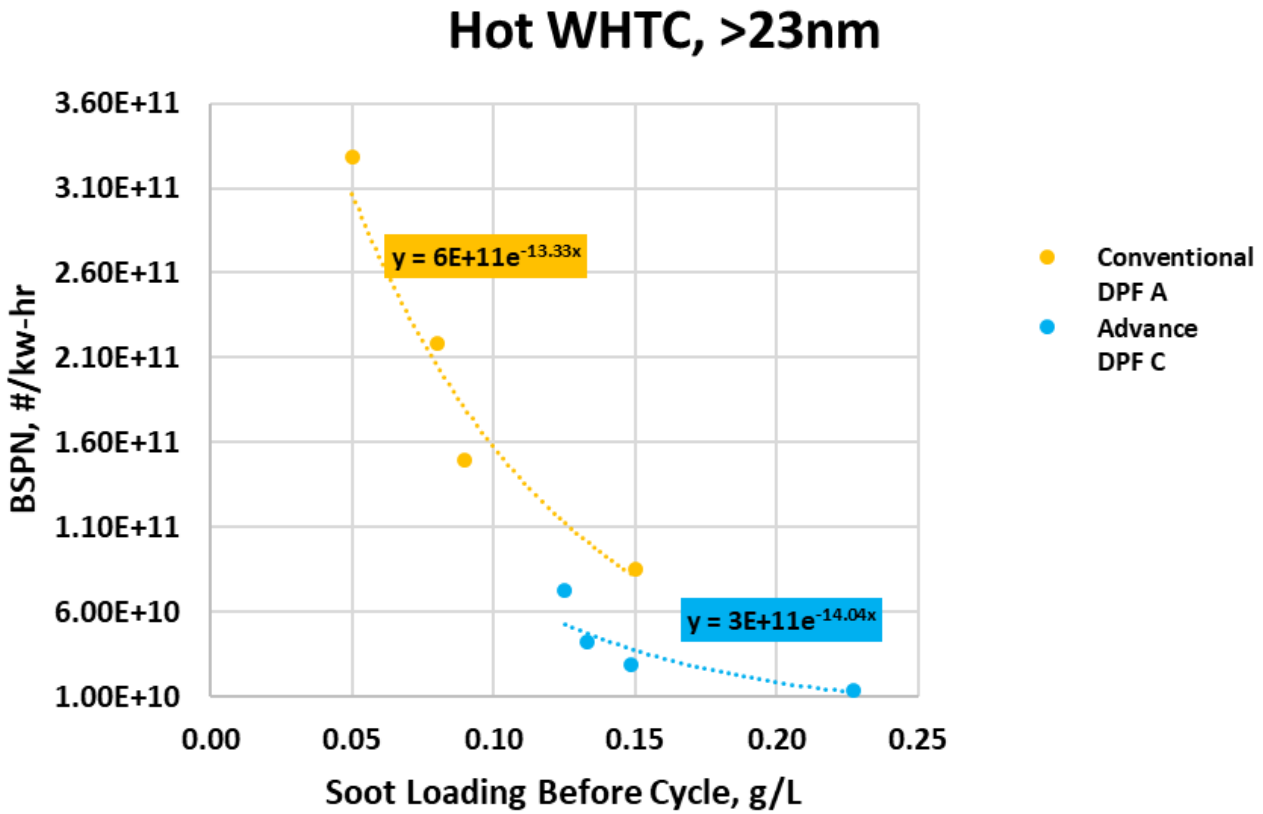
- Over NRTC, soot loading level between DPF A and C are equivalent

→ Fair performance comparison for DPF A and C

- Over WHTC, DPF C accumulated more soot than DPF A before cold cycle

→ We need to normalized PN data with same soot loading to compare DPF performance

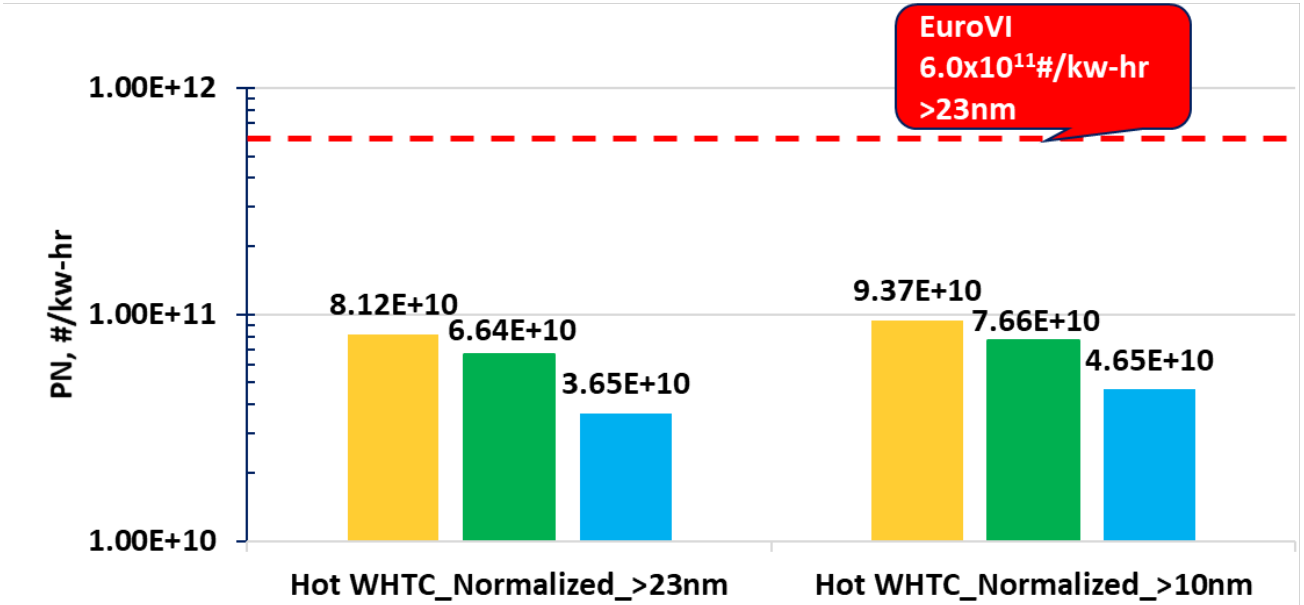
Data Normalization



- Hot cycle data were used to generate soot loading Vs PN plot

→ Based on trendline, PN data at specific soot loading level was calculated

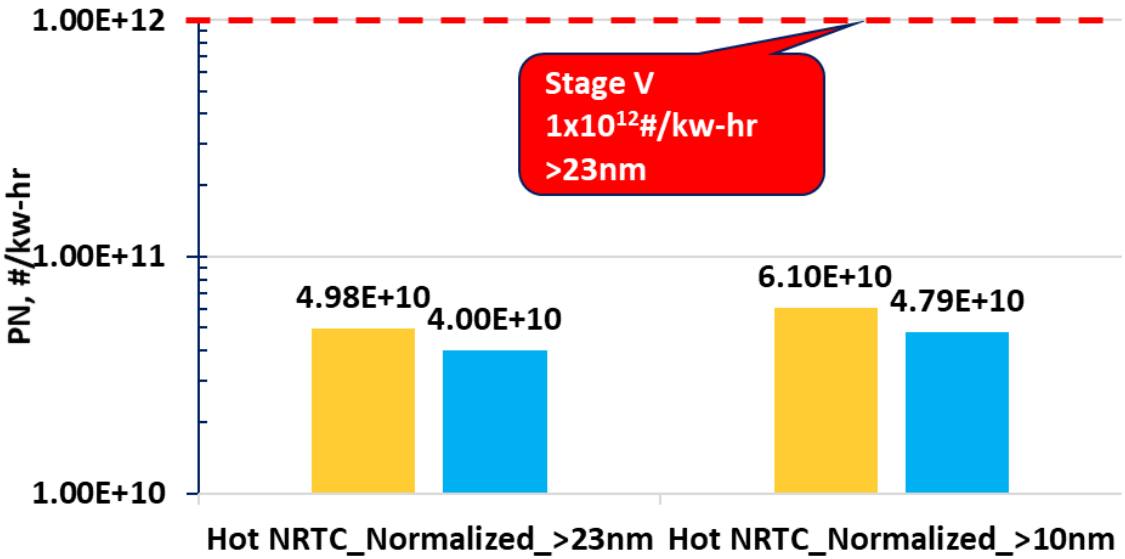
Normalized Data @ 0.15g/L - WHTC



Conventional DPF A	Advance DPF B	Advance DPF C
Baseline	Thinner Wall	Baseline
Baseline	Higher Porosity	
Baseline	Smaller MPS	

After soot loading normalization, DPF C still performs better than conventional DPF A over WHTC.

Normalized Data @ 0.15g/L - NRTC



Conventional DPF A	Advance DPF C
Baseline (Wall Thickness)	
Baseline	Higher Porosity
Baseline	Smaller MPS

After soot loading normalization, DPF C still performs better than conventional DPF A over NRTC.

Summary

- Meeting PM/PN filtration requirement will be one of major challenges to meet future regulations, especially with upcoming Euro VII (Expanding from 23 to 10 nm, regeneration and DEF impact, etc.)
- Our goal is to design DPF to meet future regulations at different market. Thin-wall and downsized DPFs are developed to fit compact design while still maintaining high performance (low pressure drop, high filtration efficiency, more ash capacity, etc.)

US Market with PM Compliance

- Conventional DPF met current and future PM regulation with good engineering margin.
- Advance DPF could achieve PM regulation while reducing GHG emissions with lower pressure drop.
- High ash capacity DPF will be desired to meet future extended warranty requirements.

European Market with PN Compliance

- Conventional DPF could meet current PN regulation until Euro VI, but additional improvement will be desired to meet tighten requirement.
- Advance DPF has significant advantage on filtration performance and could deliver potential to meet future PN regulation.
- Further investigation including system evaluation with several boundary conditions is on-going.

Acknowledgment

NGK would like to express special thanks to BASF for providing diesel particulate filter coating.

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