Potential Issues Related to the Measurement of PN During Regeneration of NRMM

A Discussion Document for the PMP WG

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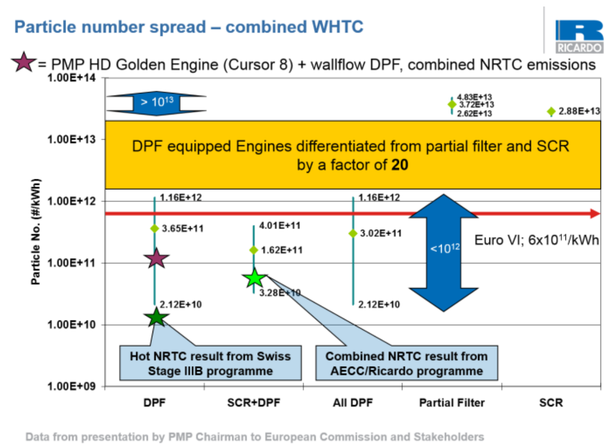
Approved	



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Introduction

- The document is produced to meet the following objectives regarding gasoline fuelled vehicles:
  - "To identify key influences and issues likely to be encountered in procedures used to measure PN from NRMM
  - Generation of diagrammatic representation of issues and/or annotated table of influences

NRMM Categories considered for PN legislation

19kW – 37kW
- Small diesel engine class; SI also included

>37kW < 56kW
- Diesel only above 37kW

>56kW – 129kW
- Dominant category in NRMM
- Technologies similar to on-road HDD

>130kW – 560kW
- Substantial applications
- Technologies similar to on-road HDD

NRMM Emissions Limits – Stages IIIA to IV

Category	Net Power [kW]	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]	Type Approval	New Registration(1)
Stage III A (V) = Variable Speed, (C) = Constant Speed							
H (V)	130 ≤ P < 560	3.5	NOx + HC: 4.0		0.2	30 Jun 05	31 Dec 05
H (C)						31 Dec 09	31 Dec 10
I (V)	75 ≤ P < 130	5.0	NOx + HC: 4.0		0.3	31 Dec 05	31 Dec 06
I (C)						31 Dec 09	31 Dec 10
J (V)	37 ≤ P < 75	5.0	NOx + HC: 4.7		0.4	31 Dec 06	31 Dec 07
J (C)						31 Dec 10	31 Dec 11
K (V)	19 ≤ P < 37	5.5	NOx + HC: 7.5		0.6	31 Dec 05	31 Dec 06
K (C)						31 Dec 09	31 Dec 10
Stage III B							
L	130 ≤ P < 560	3.5	0.19	2.0	0.025	31 Dec 09	31 Dec 10
M	75 ≤ P < 130	5.0	0.19	3.3	0.025	31 Dec 10	31 Dec 11
N	56 ≤ P < 75	5.0	0.19	3.3	0.025	31 Dec 10	31 Dec 11
P	37 ≤ P < 56	5.0	NOx + HC:4.7		0.025	31 Dec 11	31 Dec 12
Stage IV							
Q	130 ≤ P < 560	3.5	0.19	0.4	0.025	31 Dec 12	31 Dec 13
R	56 ≤ P < 130	5.0	0.19	0.4	0.025	30 Sep 13	30 Sep 14

- Introduction of PN limit at 10^{12}#/kWh (?) at Stage V

<37 kW engines currently subject to earlier stage of NRMM regulation or, for SI, none!

19 – 37kW Diesel

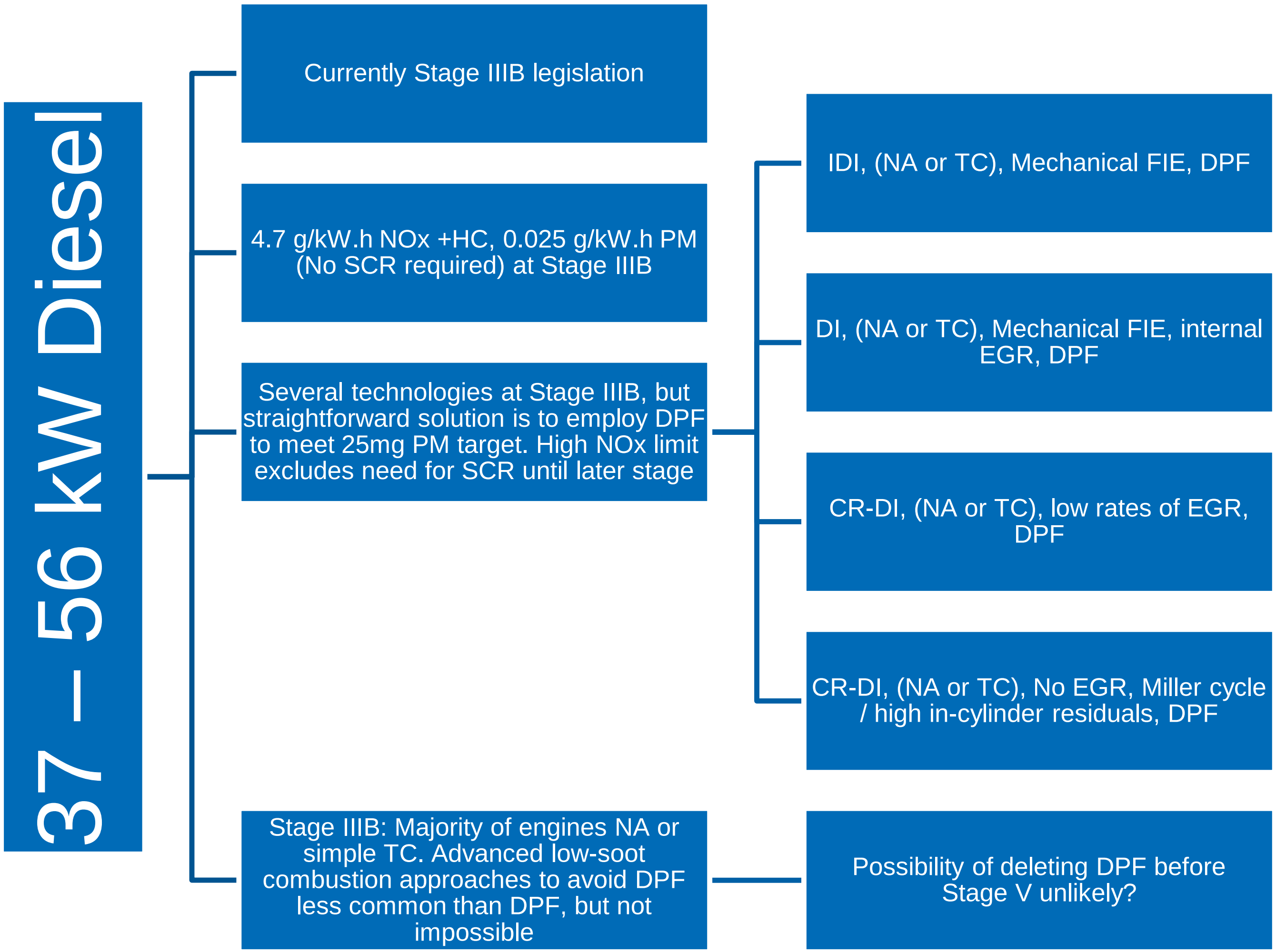
- Currently Stage IIIA legislation
- 7.5 g/kWh NOx+HC and 0.60 g/kWh PM
- 2 valves/cylinder, swirling DI, mechanical FIE, NA
- No PM aftertreatment

19 – 56 kW SI

- Not currently in NRMM regulations
- No substantial presence in Europe but could be cheap option if diesel only regulated
- Old technology, possible 'high emitters' could dominate in Europe if unregulated. Stage IV NOx at ~1.4g/kWh?
- Possible opportunity for TWC-equipped SI NRMM engines if flammability of fuel is not an issue, and FE of duty-cycle is not extreme

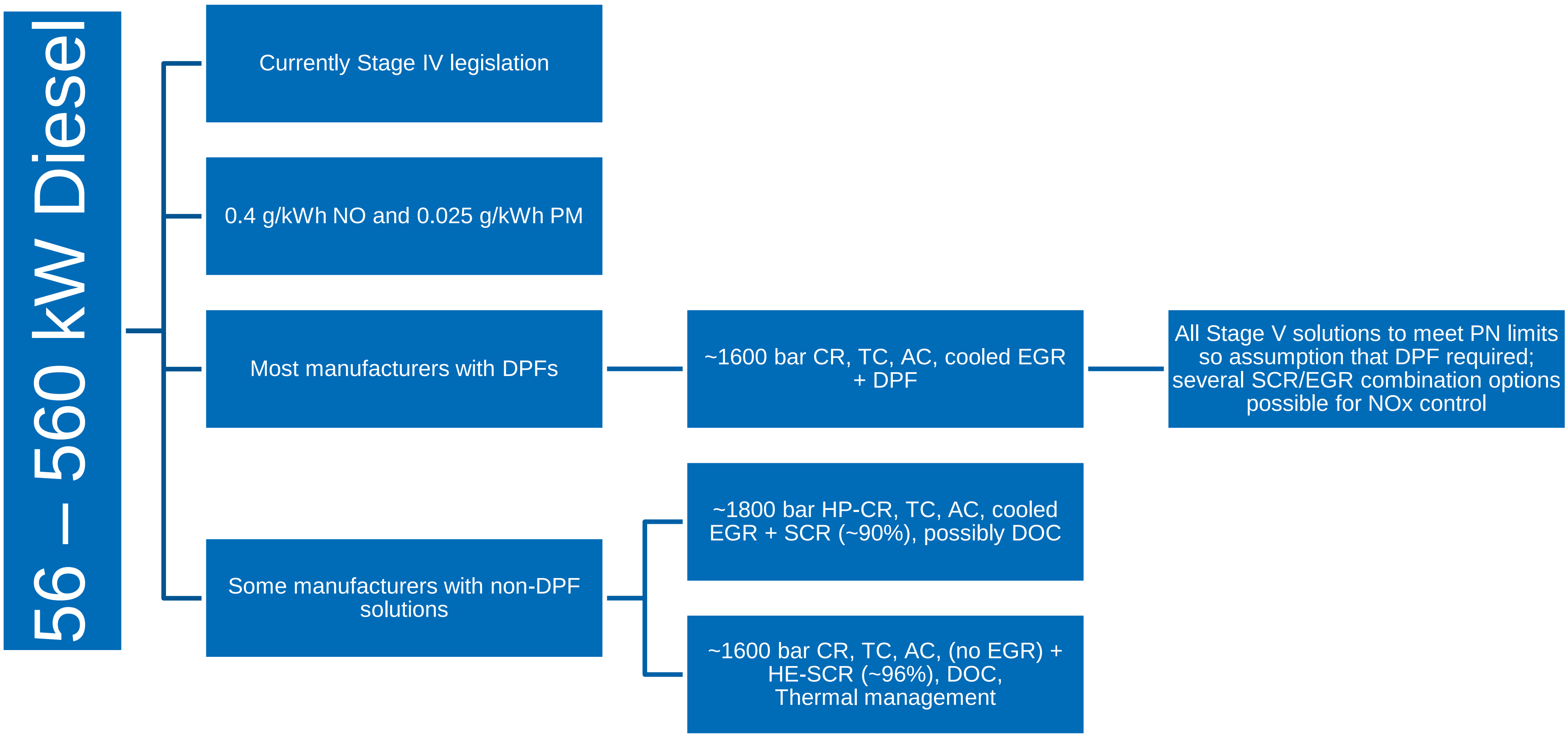
- Major technological changes and cost impact for diesel to meet Stage IV/V NOx and PM
- Potential opportunity for SI applications?
- PN data scarce for this category, especially SI

37-56kW engines encompass a wide variety of technologies, currently Stage IIIB regulations



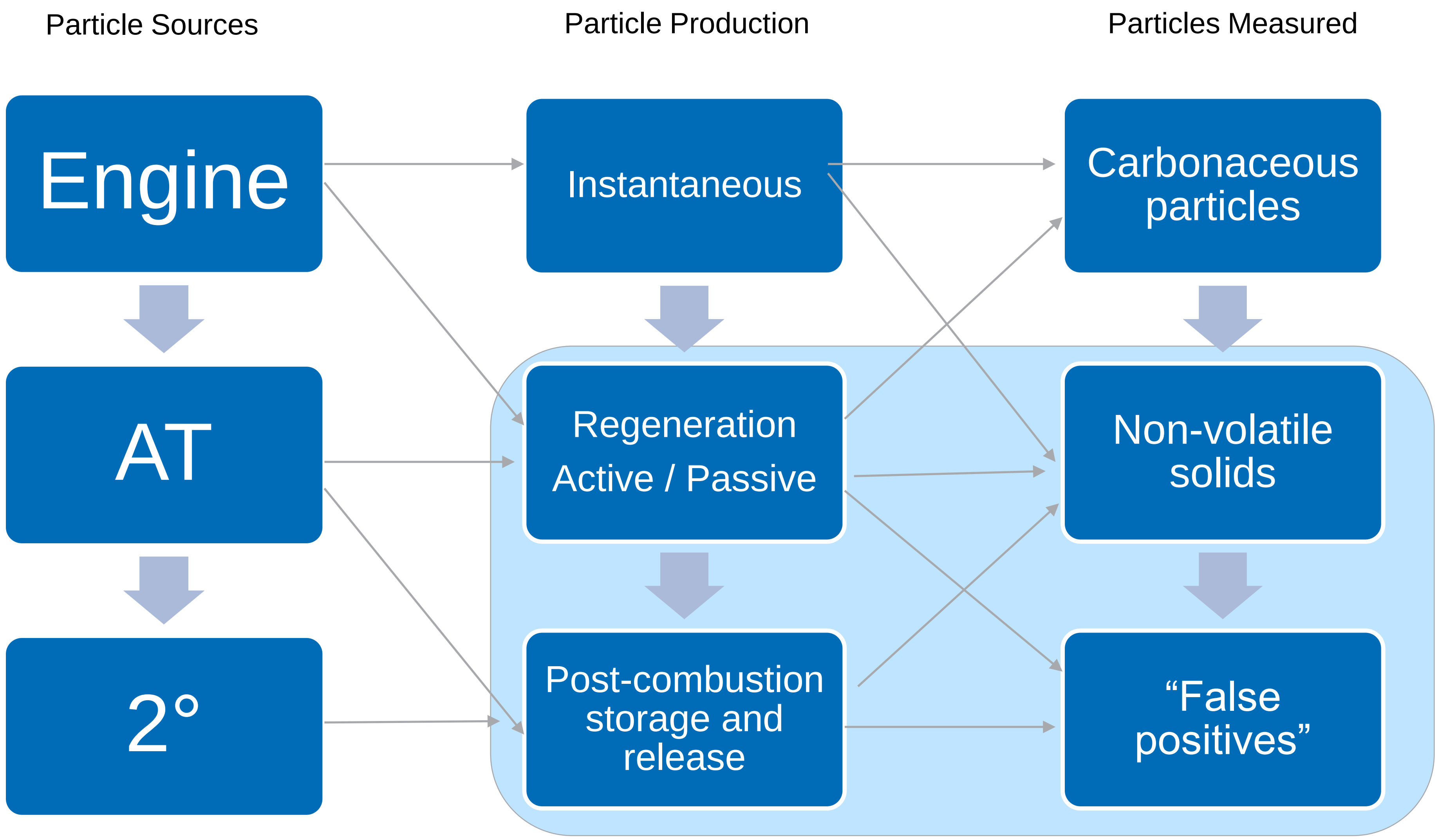
- NOx aftertreatment (SCR) requirement will be the challenge for 37-56kW at next regulatory stage; longer term technology & AT requirements to converge with higher power classes. PN data scarce

56kW to 129kW engines; 130kW to 560kW engines



- Stage V >56kW -560kW, engine and AT solutions are converging with on-road HD technologies
- Increase in hybridisation in 130kW to 560kW class; Possible OCV in 130kW to 560kW class?
- Scarce PN data >130kW class

Particles from engines – sources and influences on regulatory procedures



General influences on PN / Regenerations from NRMM

Item	Effect	Possible Outcome
Drive cycles	NRTC and NRSC hotter cycles than WHTC and WHSC	Greater levels of passive regeneration / lower frequency of active regeneration? Thermal release effects increase?
Hardware changes	All applications with DPFs. Will need a safety active regeneration strategy, even if duty-cycle is predominantly high load	Active regeneration particle impacts will be important in PN emissions of all Stage V applications
SCR impacts	SCR applications at Stage V may contribute particle precursors during active regenerations (most SCR downstream of DPF)	Combined stored ammonia, low volatility HC and sulphates may contribute solids or 'false' PN
Preconditioning	Optimum preconditioning for SCR loading may not be suitable DPF pre-con. Dependency on specific application	Potential testing with less than optimal soot-fill (pre-soot cake formation). Tendency to higher PN
Trend to higher porosity, larger bricks, lower back-pressure DPFs	Higher levels of PN emitted prior to soot cake formation, longer time for soot cake stabilisation	Higher PN emissions on application with high frequency of regenerations. Not best application to assess repeatability

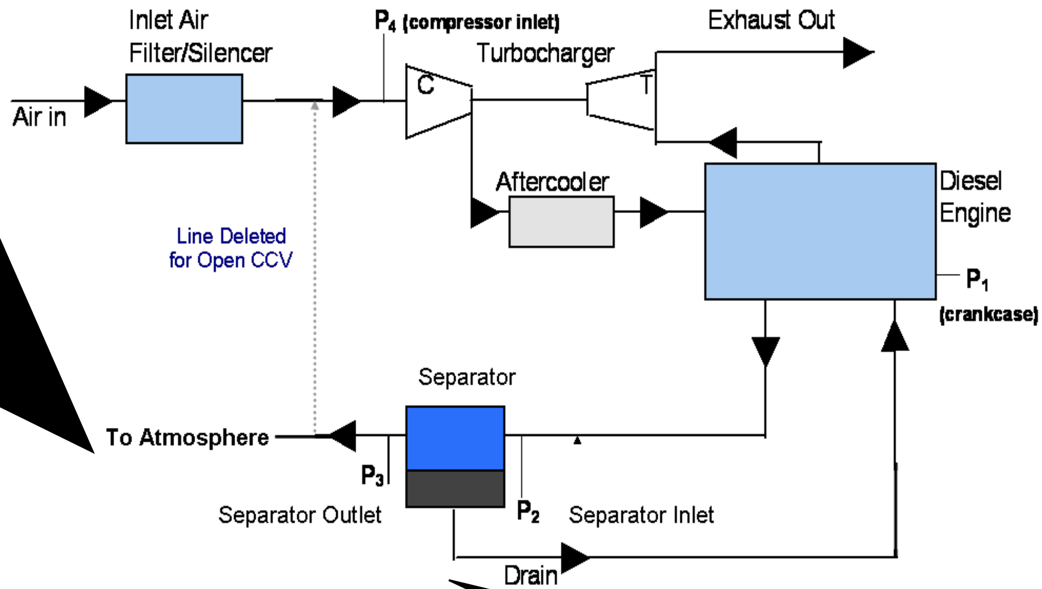
Specific influences

Item	Effect	Possible Outcome
<56kW smaller bore engines may see slightly higher oil consumption; elevated oil consumption may be seen with IDI engines	Thermal release of low volatility HC materials; loss of ash from higher porosity DPFs during passive and active regeneration	Potential for solid particle emissions increase. <10nm and challenge to VPR
Higher power engines (>130kW) might see downsizing with hybridisation.	Resulting engine operation higher load and higher temp than baseline	Greater levels of passive regeneration / lower frequency of active regeneration? Thermal release effects increase?
OCV particle emissions could be substantial (see later slide)	Solid particles in crankcase gases are not captured by the DPF and are either measured by adding back to exhaust downstream of DPF, or measured independently	Adding oily gases, soot and vapours could contaminate PN measurement system / defeat VPR.
Dilution tunnel background contributions	Observed to be very high from CVS; generally much lower from partial flow dilution systems. Difficult to reduce background levels in CVS	Implications for setting limit value through contributions to solid and volatile PN
Some engines will run EGR during cold start. This may impact the PN emissions that seem to slip the DPF during the first ~100s of the cold test	PN emissions from these engines may be higher than others, (or additional soot might 'close DPF' more quickly)	Other materials may slip DPF and deposit? Increased thermal release on regen?

Particle Transport In and Emissions from an Open Crankcase Ventilation System

RICARDO

- No influence on engine-out solid PN
- Particles lost to the environment could be as high as 50% of a 10^{12}#/kWh limit
- This should be possible to investigate experimentally



Blow-by aerosol is vented to atmosphere after filtration. If blow-by flow is 150l/min and exhaust flow is approx (1900rpm x 12 litres) 22800l/min, then PN emitted here will be ~0.7% of EO levels. So, at an EO level of 10^{14}/kWh, PN emitted will be 7×10^{11}/kWh.
These levels are similar to post-DPF exhaust levels. The efficiency of the separator for submicron particles might be as low as 50%, so vent emissions of solid particles could be as high as ~50% of a 10^{12}#/kWh limit

Assume 12l engine at 1900rpm:
Flow out of the crankcase is ~150l/min (max) and crankcase volume is c. 30 litres. Hence max residence time is ~10s. Temp drops from ~120°C to 80°C. Crankcase aerosol comprises exhaust plus oil plus headspace vapours. It has ~5s to evolve, so time for:
- Soot to combine with oil
- HC condensation
- Oil droplet coagulation
- Water condensation

CCV device / PCV valve
Entry temp is ~80°C. Pressure drop ~30mb so some revolatilisation may occur. Large oil droplets are mechanically recovered. Most particles of <500nm will remain entrained.
Aerosol exits at 60°C

Particles from NRMM gasoline-fuelled engines

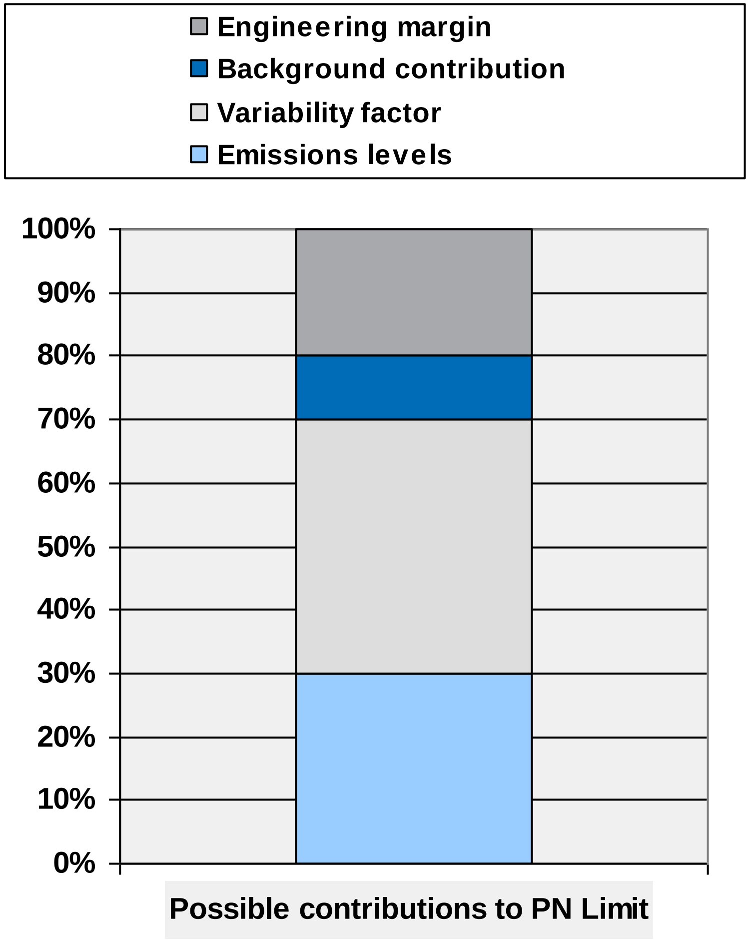
- Presumably stoichiometric with TWC
- PM/PN largely unmeasured and not well understood
- Analogous to on-road position
  - Potential for non-GPF solution?

Measurement System Influences

- Dilution systems
  - Euro VI gives partial flow and full flow dilution systems equal status, but for NRMM:
    - Impractical to use a full-flow system on a 560kW engine
    - Partial flow systems should be ok for engines down to 19kW
    - (Full flow dilution systems would be needed if <19kW engines were to be tested)
    - Better to mandate partial flow for all applications?
- Crankcase gases
  - OCV presents challenges for PN emissions and measurement
    - Vent emissions levels could be between 10^{11} and 10^{12}#/kWh before considering tailpipe emissions
    - Measurement would either
      - Recombine vent gases (soot/HC/oil mist) with exhaust downstream of the DPF
        - Potential contamination of PN system / challenge to VPR
      - Analyse vent gases independently
        - 2 sets of analysers for gases, PM and PN

Stage V limit value: What factors need to be considered?

- Emissions levels
  - Representative emissions levels from engine and emissions control technologies
  - Engine-out PN plus DPF filtration efficiency / porosity
- Variability
  - Repeatability of the engine and measurement system
  - Emissions cycle used for certification
  - DPF Regeneration / Ki factor
- Contribution of the background
- Engineering margin
- Existing regulations for other engine types



Measurement variability is a critical factor

- Data collected using the regulatory measurement approach
- Repeatability
  - Over specific emissions cycle
  - Assume no active regeneration of the DPF
  - May include passive regeneration
  - Based upon standard deviation of repeat measurements
- Active regeneration
  - During specific emissions cycle
  - Determine contribution relative to regeneration periodicity (Ki)

NRSC and NRTC to be considered

High temperature operation may lead to passive regeneration, altering the fill state of the DPF and the emissions levels observed

Active regeneration contributes particles generated in real-time as the soot combusts, and afterwards with the reduced filtration efficiency of the DPF

- Total contributions of variability factors may be greater than the contribution of the measured emissions level

Areas for further study

- Active and passive regenerations
  - Real-time PN emissions
  - Effects of thermal release of heavy HC (oil consumption etc) and other volatiles from DOC and DPF
  - Possible impacts of released SCR deposits
- Preconditioning effect on cold start emissions
- Impacts of EGR
- Effects of differences in DPF substrate filtration characteristics on PN emissions
- PN from engines with OCV: absolute levels and how to measure
- Impacts of downsized engines / hybrids
- PN from SI engines