Influence of Fuel Ethanol Content on PN and PM from Direct Injection Gasoline Engines

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Concern over particulate matter emissions from automotive engines has been expressed for decades [1]. This has lead to the introduction of both mass and number-based emissions limits for Diesel vehicles in the European Union; direct-injection petrol engines have now also had a particle number limit set, and it is likely that all automotive internal combustion engines will be subject to particle mass and number limits in the future. These limits have necessitated (or will necessitate) the implementation of measures aimed at reducing particle emissions, through changes to the calibration, fuel injectors, etc; and by implementing filtration devices (Diesel particulate filters, Gasoline particulate filters). The direct injection concept exhibits better fuel consumption and this engine type will eventually come to dominate park-ignited automotive engines. Ambitious targets for the implementation of biofuels in the European Union are slowly changing the composition of both petrol and Diesel fuels used in the EU, with impacts on particle emissions. Thus, investigations into the effect of ethanol blends on direct injection engines are of great importance for the future. A series of experiments was performed to determine the impact of fuel ethanol content and ambient temperature on particle number and mass emissions from a European gasoline vehicle featuring a direct injection engine. Testing was performed according to the EU legislative test procedure, over the New European Driving Cycle, using a chassis dynamometer, foil-backed TX40 filters for quantification of particle mass and a PMP-compliant particle counting system for quantification of particle number emissions. Tests were performed using ethanol blends E5 (i.e. 5% ethanol by volume), E10, E25 and E50 at both temperatures currently specified for SI vehicles in EU legislation: +24 °C and -7 °C. Figures 1a and 1b present particle mean number and mass emissions results obtained for the various petrol-ethanol blends.

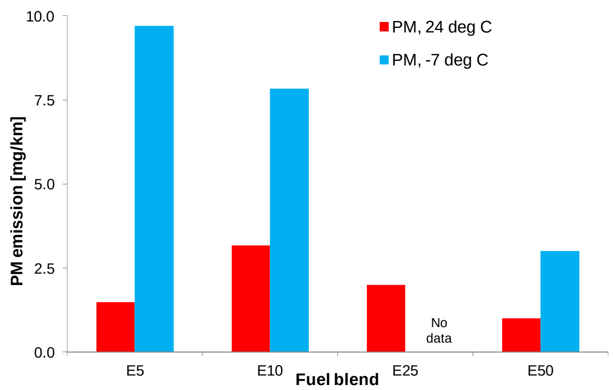

Figure 1 – a) particle mass (PM) emissions obtained over the NEDC at +24 °C and -7 °C for various ethanol blends

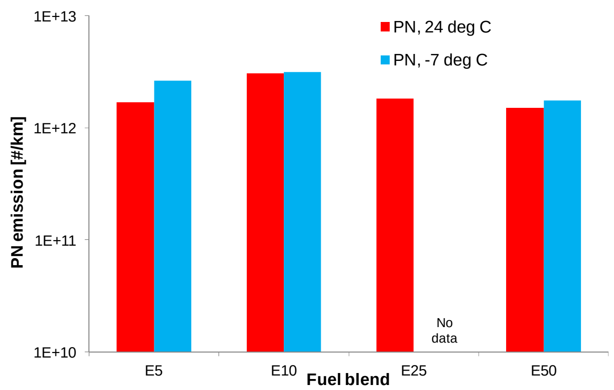

Figure 1 –b) particle number (PN) emissions obtained over the NEDC at +24 °C and -7 °C for various ethanol blends

Usage of an oxygenated fuel is generally thought to improve the combustion process and reduce particulate emissions. However, despite the increased oxygen content of the fuel, higher ethanol blends showed decreases in particle number and mass emissions which ranged from small to non-existent. The E10 and E50 blends performed well at the lower test temperature regarding their mass emissions, but showed no real advantage in terms of number emissions. Regarding comparison to the legislative limits, which are mandated for a 20-30 °C ambient temperature, the mass limit was fulfilled for all fuel blends; the phase-in particle number limit was just met for all blends, but the long-term limit of 6.00E11 #/km was exceeded for every fuel blend.

In line with previous examinations (e.g. [2,3]), the semi-log space created by co-plotting particle mass emissions (linear scale) and particle number emissions (log10 scale) was employed. While the two metrics are not directly comparable, as they measure somewhat different aspects, graphical and numerical explorations of the relationship between particle mass and number can be informative for a variety of reasons, both theoretical and practical [1]. Figure 2 presents particle number emissions plotted as a function of particle mass emissions, alongside the future legislative limits.

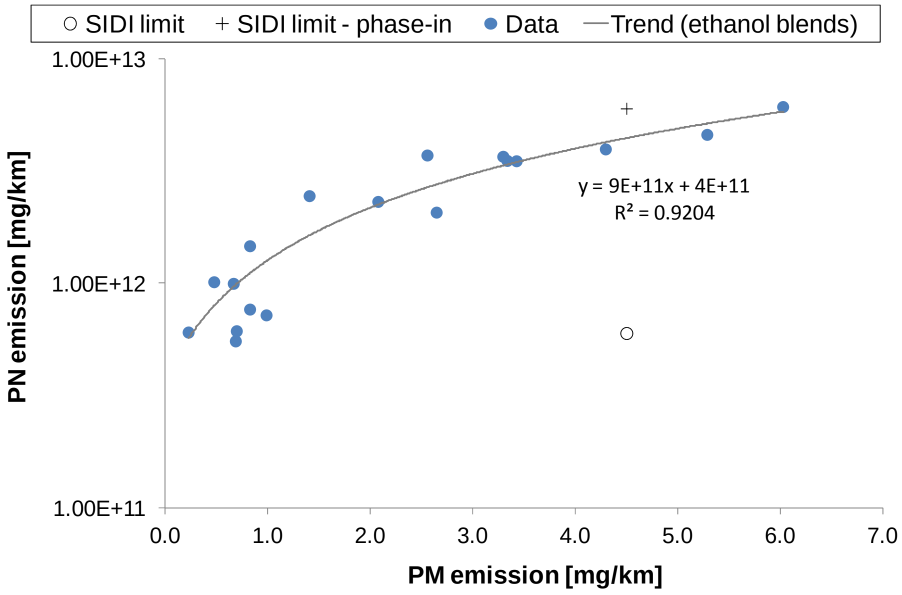

Figure 2 – a semi-log plot of particle number and mass results from one direct injection vehicle tested over the NEDC, with ethanol blends E5 to E50. Raw results (from both phases of the cycle) are presented in comparison to the EU legislative limits

The trendline's y intercept value was found to of a similar order of magnitude to the gradient, and thus the trendline was not forced through the origin. The observed PN/PM gradient is reasonably close to previously reported correlations for Diesel vehicles (with DPFs) [e.g. 2], but the large y-intercept value implies the presence of large numbers of particles of almost zero mass, in contrast to correlations observed for Diesel engines (with a DPF). Possible reasons include the physicochemical parameters of the two fuels – and the impact this has on the relative sizes of the volatile and non-volatile particle fractions, the presence or absence of a particulate filter, injection pressure, combustion temperature, etc. Fuel ethanol content was observed to correlate only weakly with PN/PM ratio (Figure 3), as previously reported in another study [3]. Further testing would be necessary to definitely determine the existence of a correlation between fuel ethanol content and this metric. In order to determine the nature of the response of PM and PN emissions to the ethanol content of the fuel blend, it would be necessary to conduct further testing with a greater number of ethanol blends of low and moderate ethanol content. Additionally, in order to further understand the effect of ambient temperature, tests could be conducted at temperatures between the two mandated EU test temperatures.

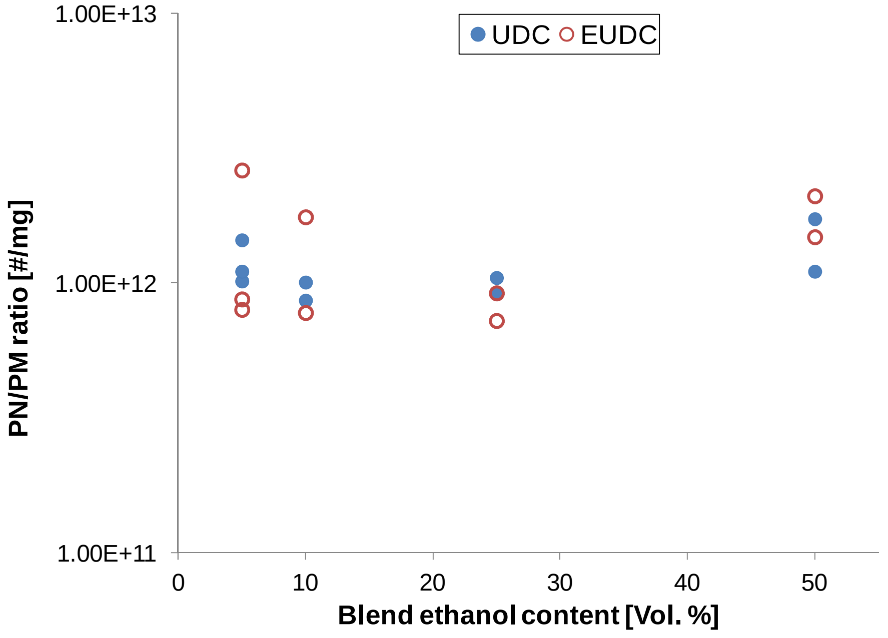

Figure 3 – The ratio of PN to PM results obtained at 24°C for various ethanol blends

Considering the concurrent trends of increasing interest in direct injection petrol engines and increasing concern over particle number and surface area, research in this area remains an intriguing necessity. Since usage of both ethanol and direct injection engines will increase in the future, the subject addressed in this research is of considerable interest regarding future emissions scenarios. Likewise, further investigations into the relative merits of each particulate matter metric (mass, number, size distribution, effective surface area) and their reliability and relevance to real world emissions are paramount.

References:

[1] Kittelson, D.B. Engines and nanoparticles: a review. Journal of Aerosol Science, 29, 5-6, 575-588, 1998. DOI: 10.1016/S0021-8502(97)10037-4.

[2] Bielaczyc, P., et al. Correlation between particle mass and number for Euro 5 compression ignition vehicles, Book of Abstracts, The 15th ETH-Conference on Combustion Generated Nanoparticles, Zurich, Switzerland, 26-29 June 2011.

[3] Maricq, M.M., et al. The Impact of Ethanol Fuel Blends on PM Emissions from a Light-Duty GDI Vehicle, Aerosol Science and Technology, 46, 5, 2012. DOI: 10.1080/02786826.2011.648780.

16th ETH Conference on Combustion Generated Nanoparticles
24th – 27th June 2012, Zurich, Switzerland

Investigations on fuel ethanol content and ambient temperature on particle number and mass emissions from vehicles featuring direct injection gasoline engines

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Presentation contents

- Research context & Experimental aims
- Introduction
- Experimental Details
- Results & Discussion
- Conclusions

Research context & Experimental aims

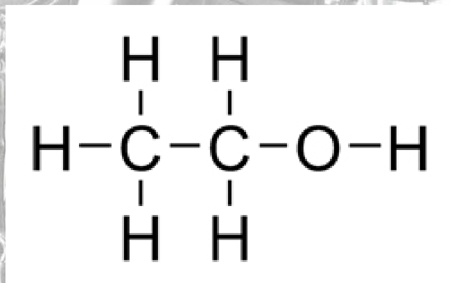
- The physicochemical characteristics of standard petrol and ethanol differ widely. The addition of even small quanitities of ethanol to petrol has been shown to affect gaseous exhaust emissions. Other studies have reported effects on PM and PN emissions.
- This study seeks to obtain further information on PM (mass) and PN (number) emissions with fuels of varying ethanol content.
- Interest in direct injection engines is increasing and this engine type will be used much more widely in the future. Interest is using greater quantities of ethanol in gasoline is also increasing. The research presented here is therefore of great importance for future automotive emissions.

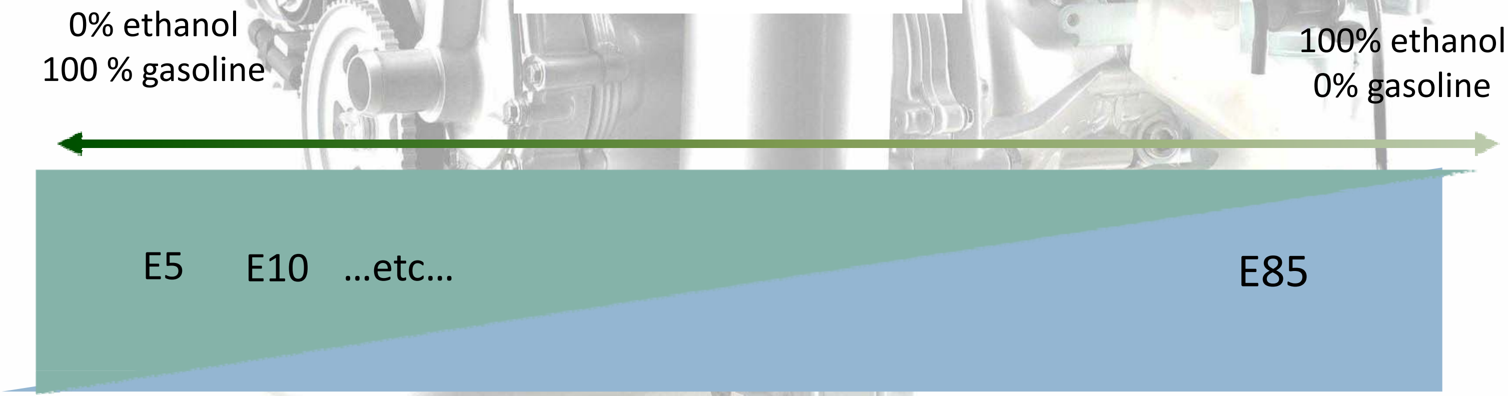
Introduction:

- Concern over particulate matter emissions from automotive engines has been expressed for decades
- This has lead to the introduction of both mass and number-based emissions limits for Diesel vehicles in the European Union; direct-injection petrol engines have now also had a particle number limit set: 6.00×10^{12} #/km (for the year 2014); 6.00×10^{11} #/km for the year 2017
- Interest is gowing in using increased quantities of ethanol in petrol fuel blends for automotive applications

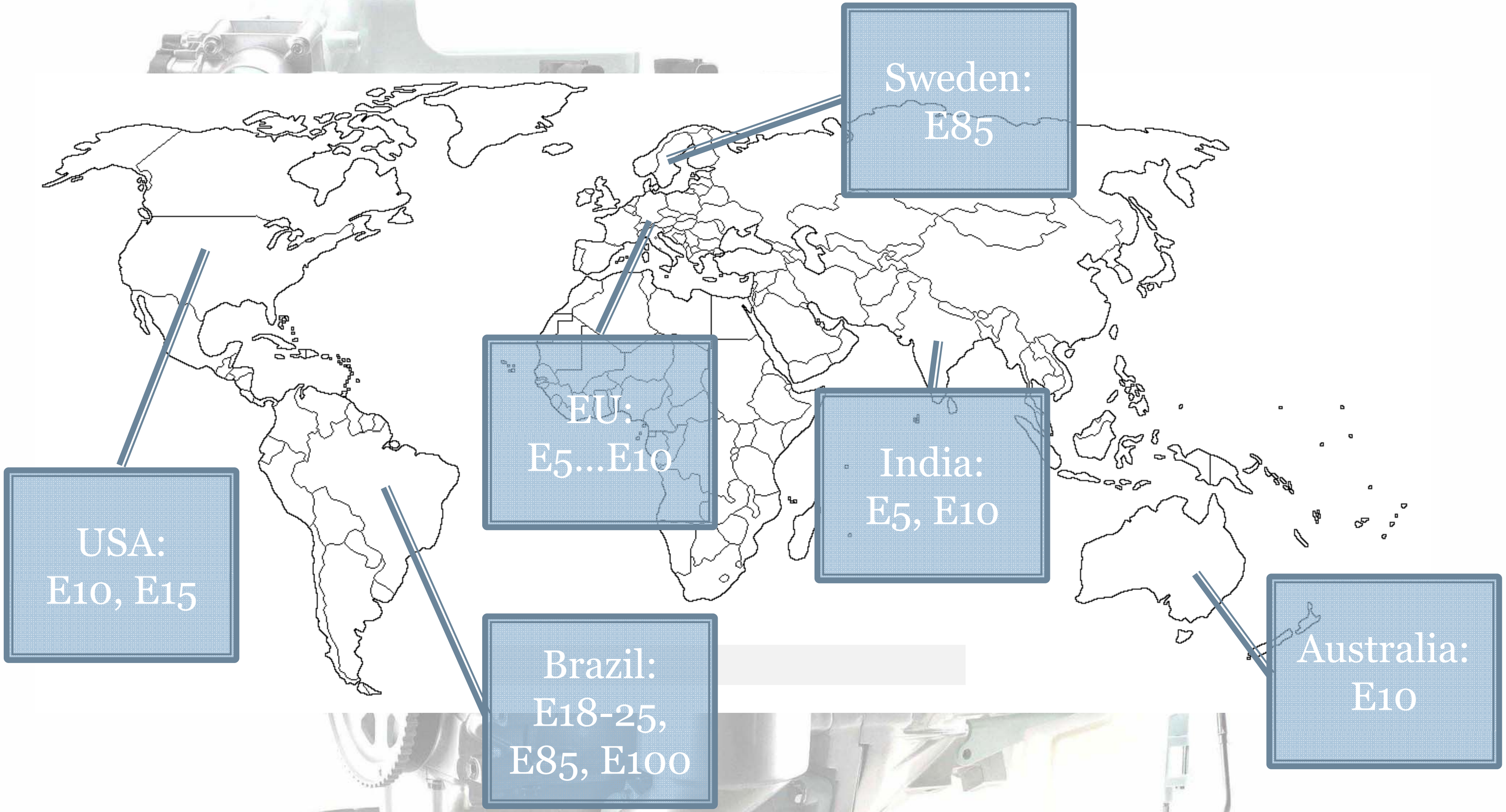
Background: ethanol as an automotive fuel:

- Using ethanol as a vehicular fuel is not a new idea
- Primary alcohol, formula C_2H_5OH
- Suitable for use in SI engines, usually blended





Background: petrol-ethanol blends worldwide

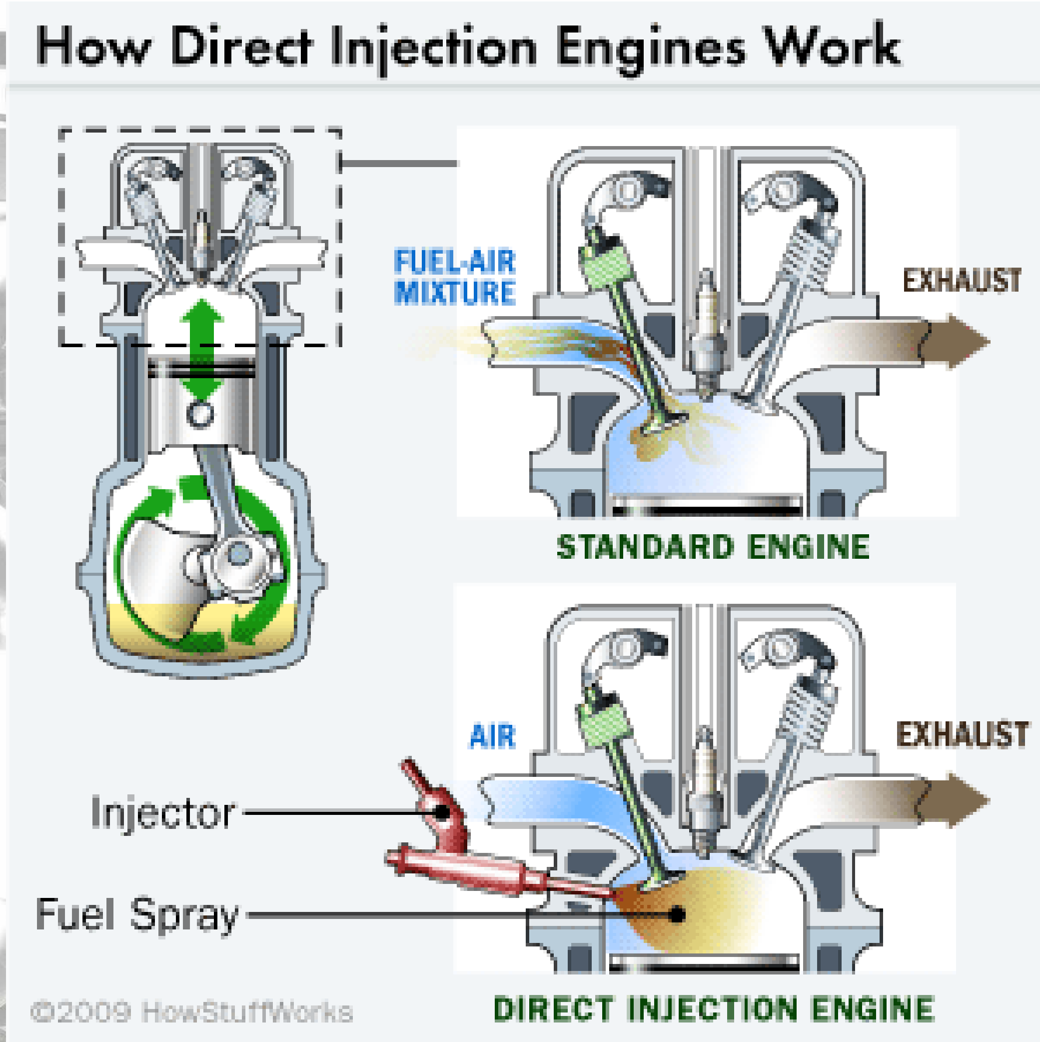


Background: ethanol as an automotive fuel:

- Interest has been growing in ethanol
- Potentially sustainable, renewable biofuel, depending on feedstock
- The EU's Fuel Quality Directive (2009/30/EC) enabled more widespread use of ethanol in petrol in the EU (blends up to E10)
- Currently the most widely-used biofuel
- All 'standard' gasoline sold in the EU is currently E5
- US EPA approved E15 for use in recent model year cars

Direct Injection Spark Ignition (DISI) engine

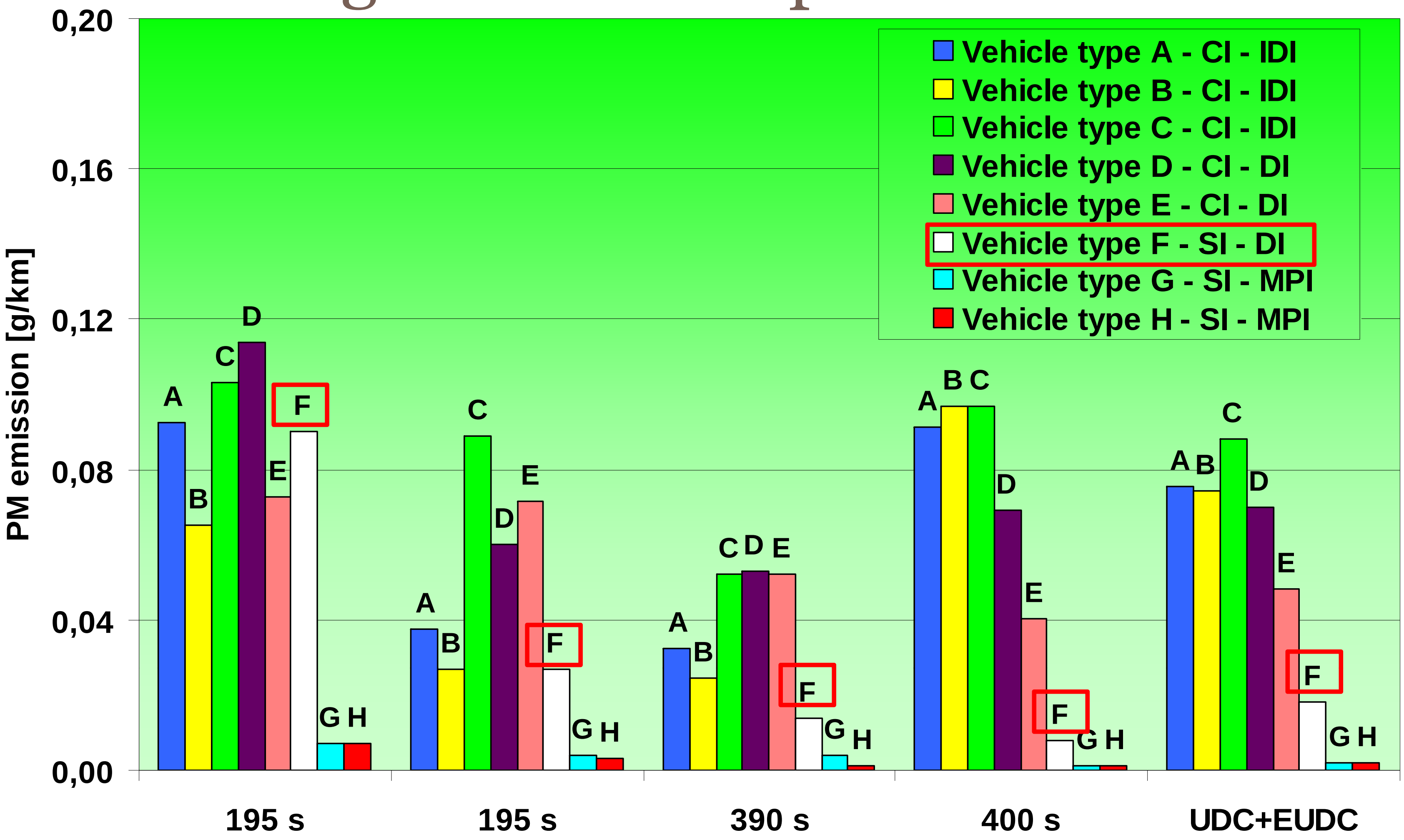
- The major advantages of a DISI engine are increased fuel efficiency and high power output
- Emissions levels can also be more accurately controlled with the DISI system
- No throttling losses in some DISI engines, when compared to a conventional fuel-injected engine



Direct Injection Gasoline engine

- Engine speed is controlled by the engine control unit/engine management system (EMS), which regulates fuel injection function and ignition timing
- High fuel efficiency is an advantage; emissions of particulate matter are a disadvantage
- The literature suggests that DISI PM emissions are higher than SI MPI PM emissions and DISI PN emissions are much much higher than SI MPI PN emissions
- DISI engines will come to have the largest market share for SI engines in the future

Background: Example emissions

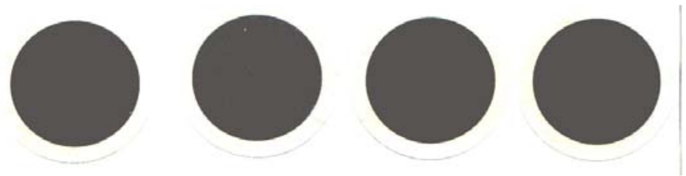


PM emissions for different vehicles with SI and CI engine

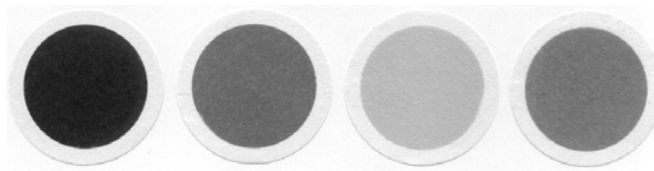
Source: Bielaczyc P., Szczotka A., Pajdowski P. EAEC Conference 2001

Background: Filter overview

CI - IDI



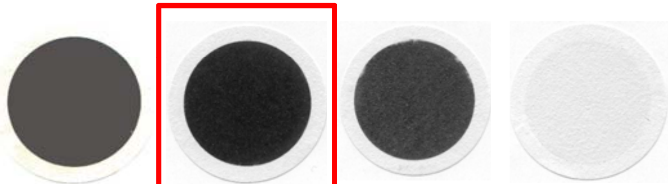
SI - DI



CI - DI

SI - MPI

Filters with particulate matters from NEDC cycle for different types of vehicles

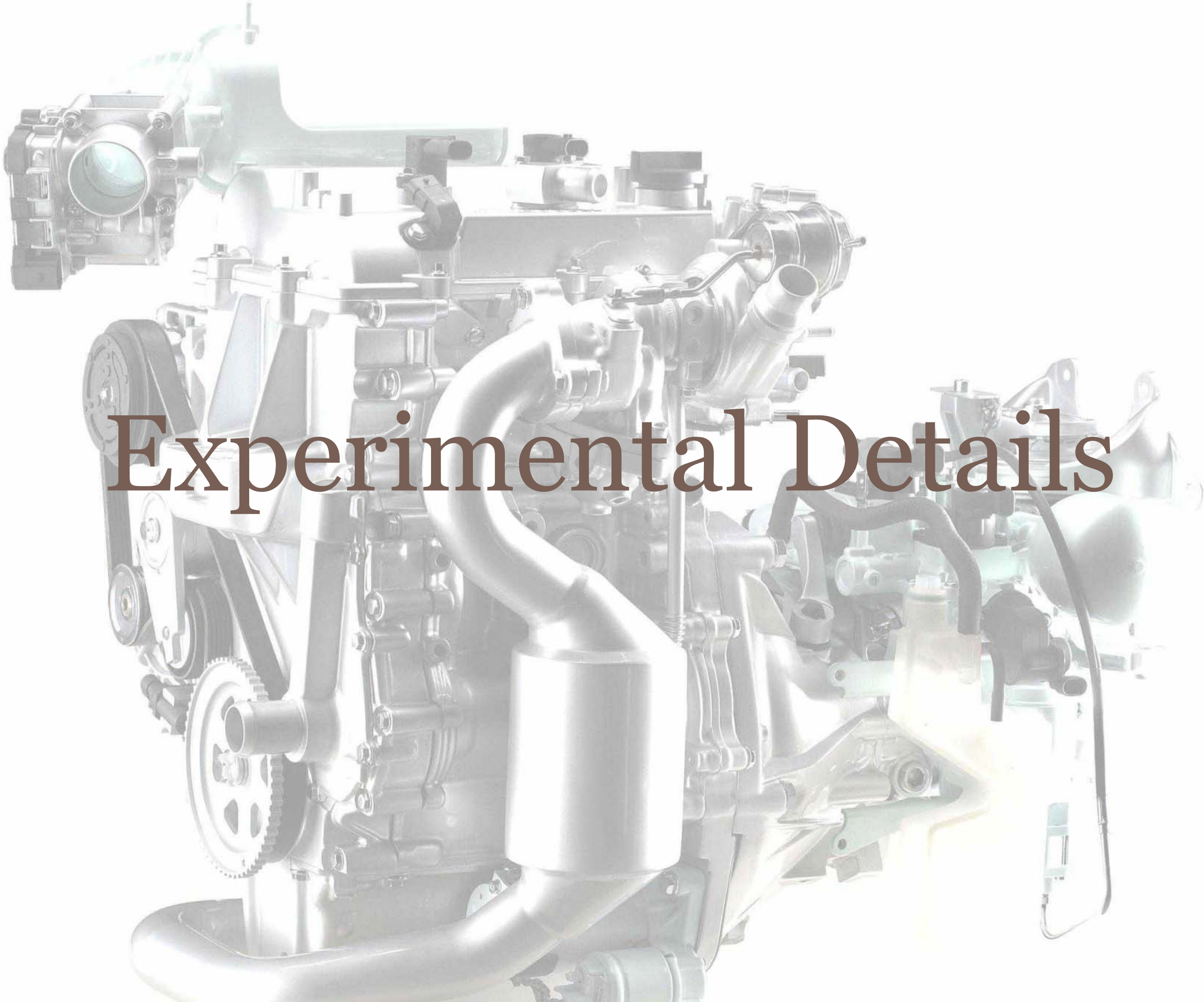


CI - IDI SI - DI SI - MPI SI - CNG

Filters with particulate matters from first 195 s of NEDC cycle for different types of vehicles

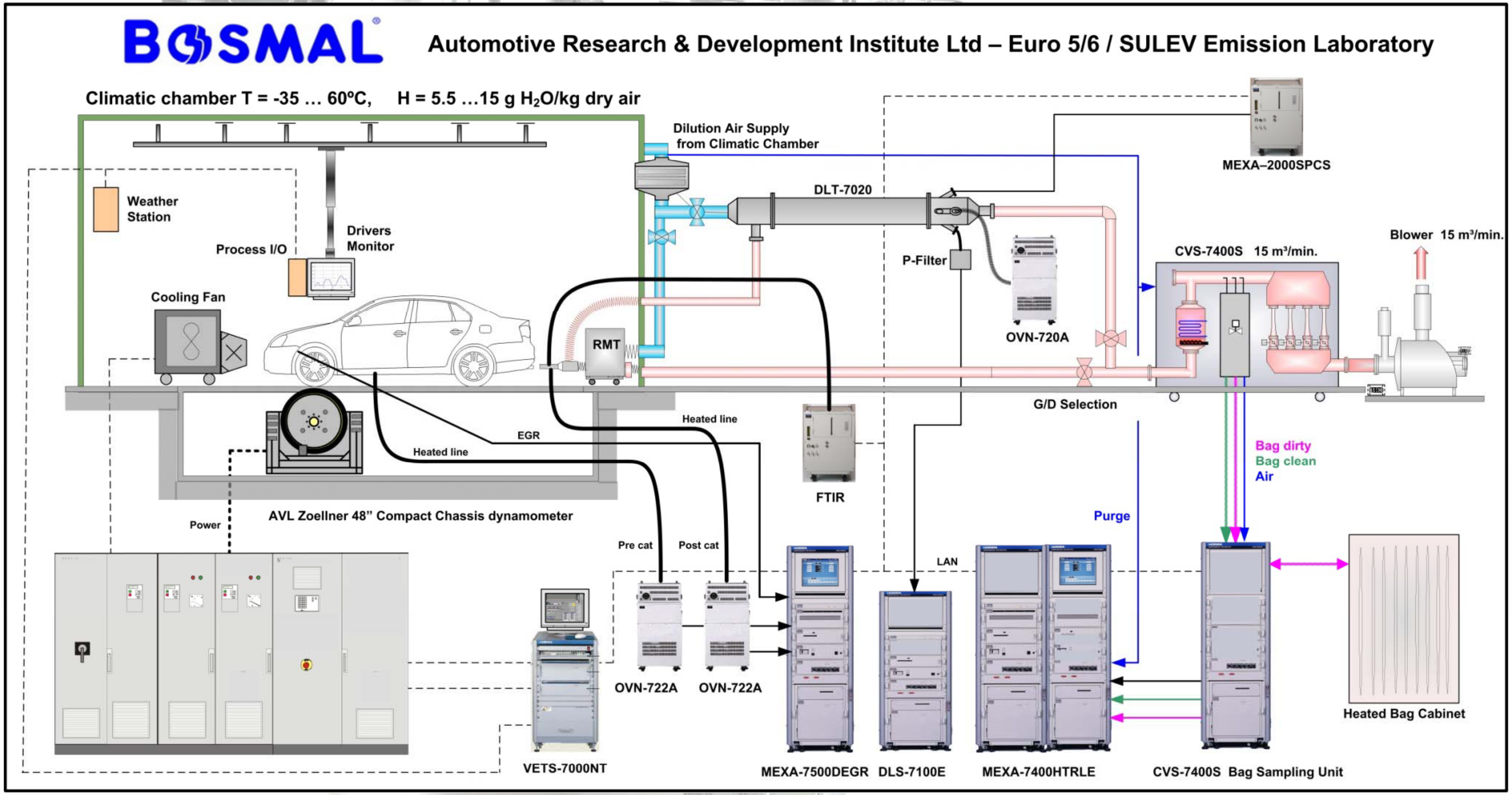
Source: Bielaczyc P., Szczotka A., Pajdowski P. EAEC Conference 2001

Experimental Details



Experimental Details : test facility

- Schematic diagram of BOSMAL's emissions measurement setup, as used to measure emissions from the test vehicles



Experimental Details : test facility

- BOSMAL's climate-controlled test chamber (-35 °C to +60 °C) housing a chassis dynamometer and windspeed fan

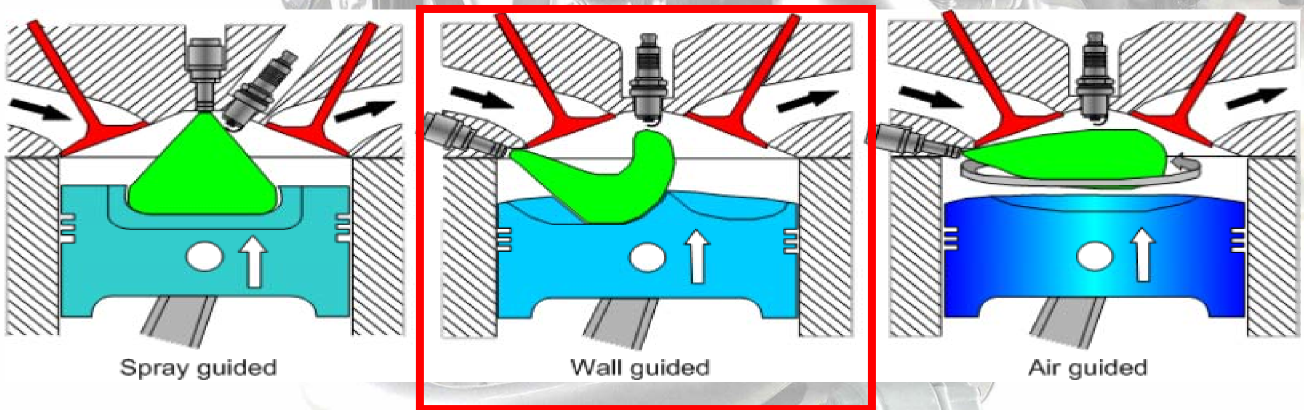
- Emissions analysers

- Dilution tunnel and particle counter

- Testing carried out in accordance with EU & PMP test requirements.
  - Test temperatures: +24 °C and -7 °C
    - Driving cycle: NEDC
- Three tests performed on each fuel (mean values plotted in graphs)
- Blends E5, E10 and E50 tested at -7 °C (two tests blend; mean values plotted on graphs)

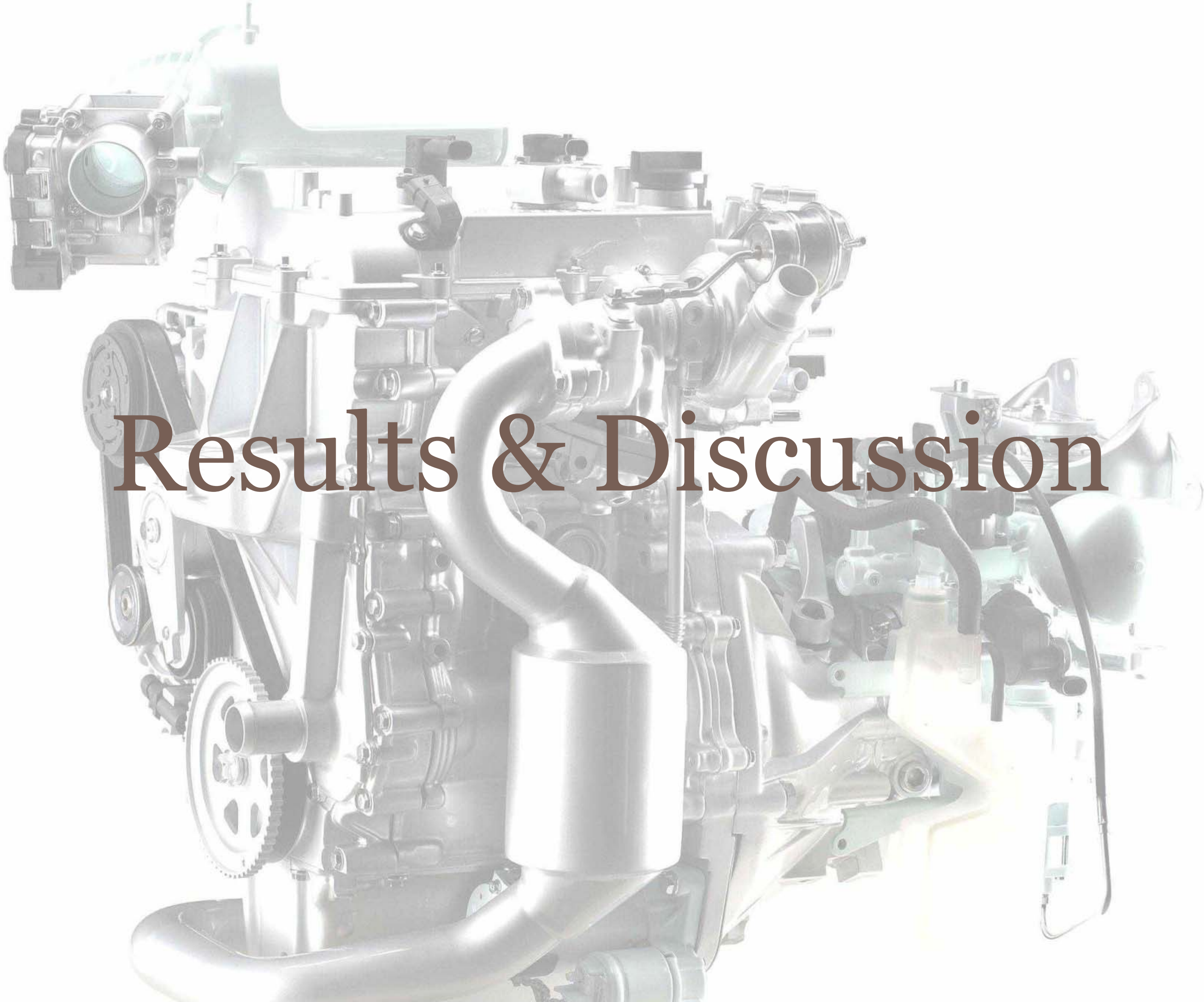
Experimental Details: Vehicle

Vehicle type	**Passenger car**
Emission Standard	**Euro 5**
Engine capacity [dm³]	**Approx. 1.4**
Max. Power [kw]	**67**
Max. Torque [Nm]	**200**
Aftertreatment system	**Close Coupled TWC**



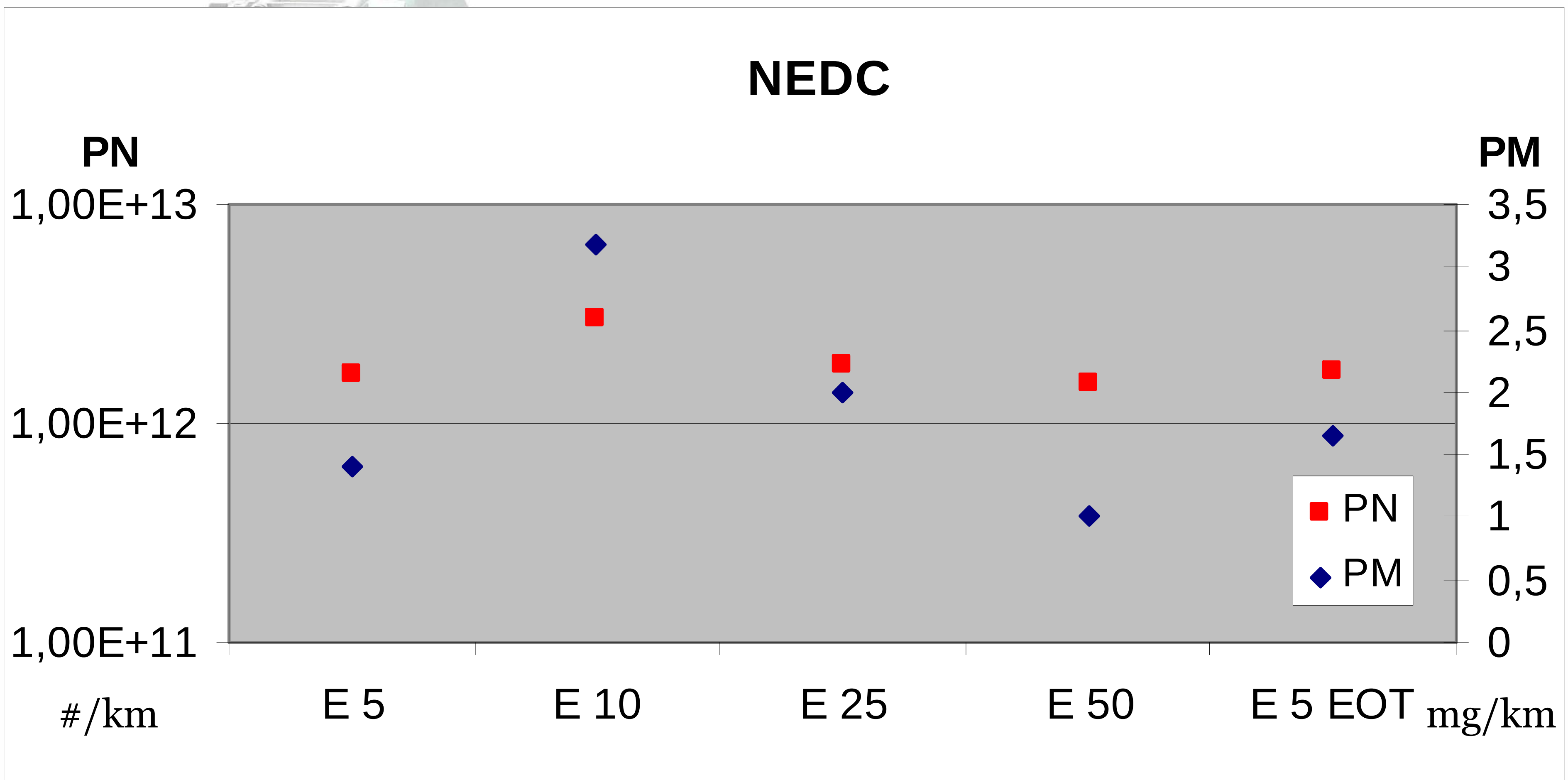
$\lambda = 1$

(stoichiometric)



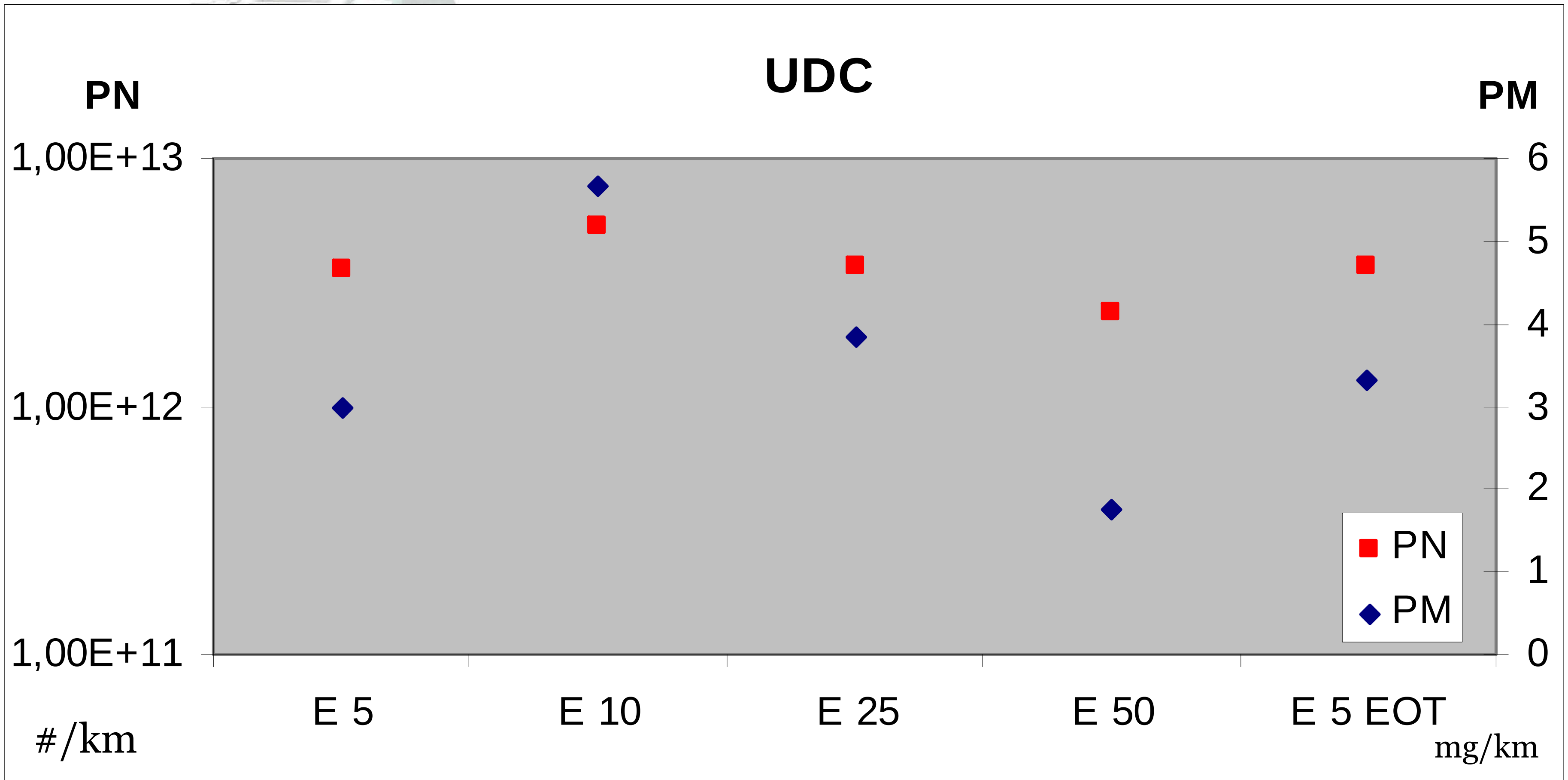
Results & Discussion

Results: PM & PN during the NEDC



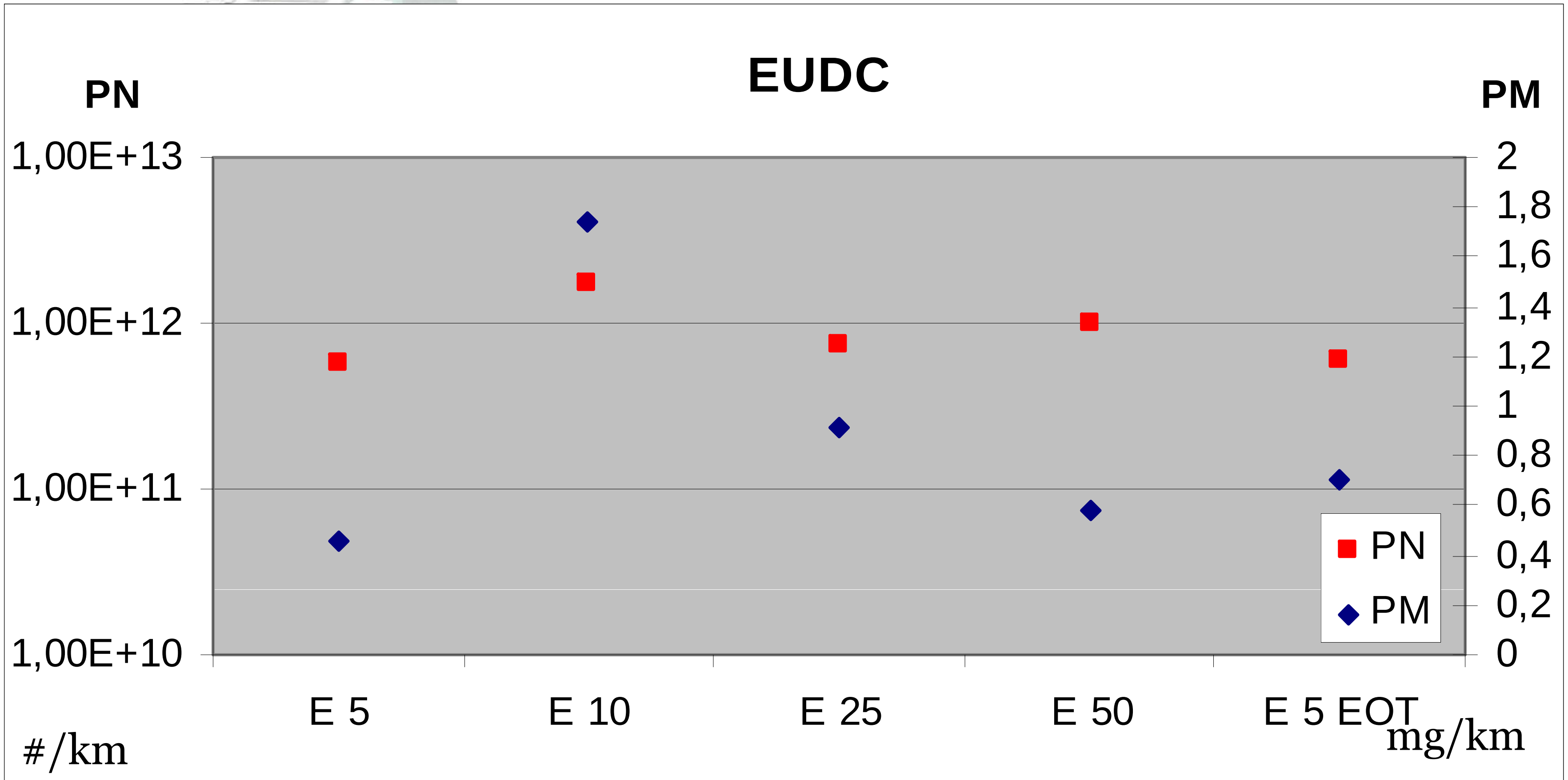
- Limited effect for PN (considering test-to-test variability); stronger effect for PM
- Mass and number emissions lowest from the E50 blend and highest from the E10 blend

Results: PM & PN during the UDC



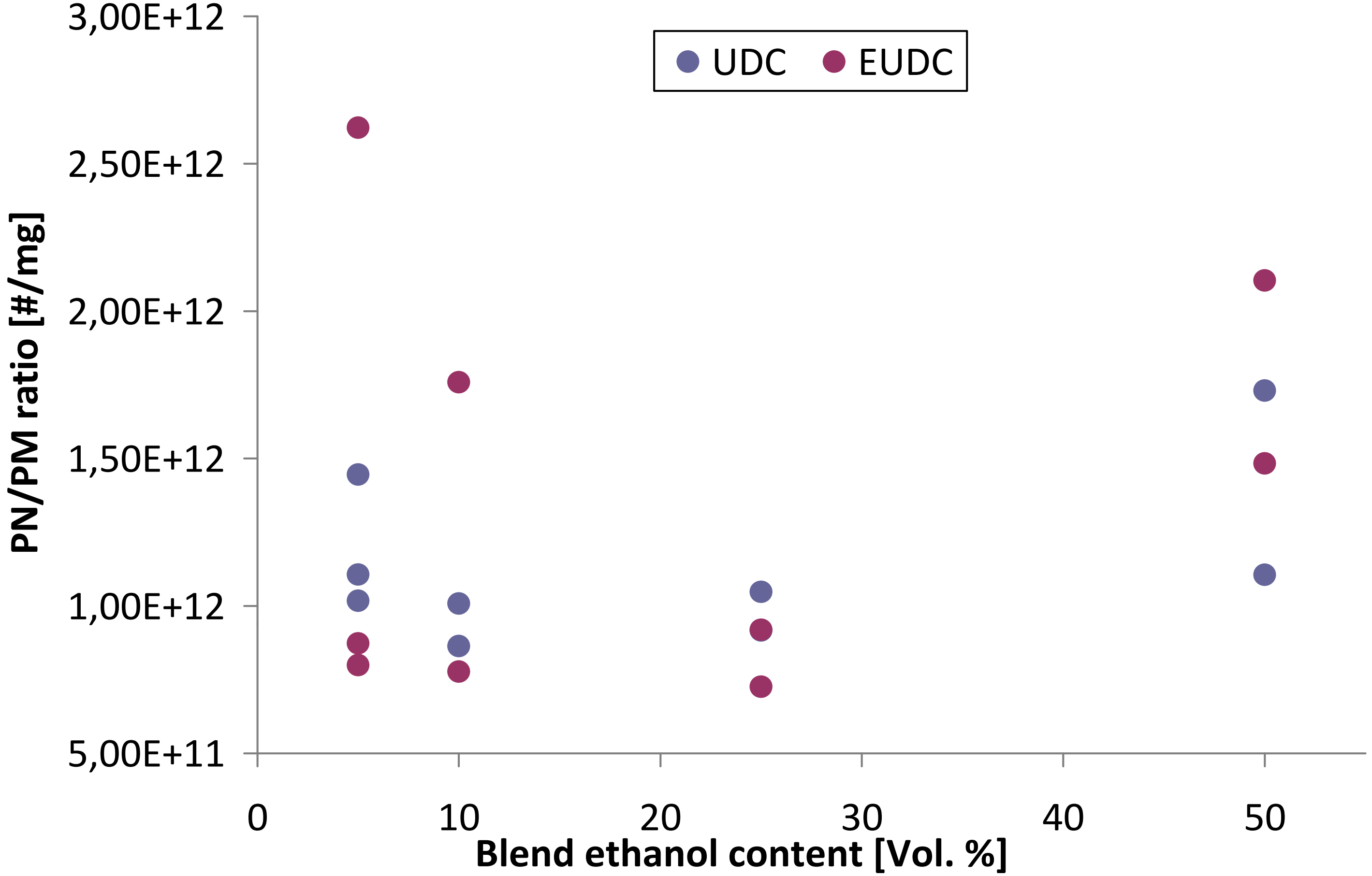
- Limited effect for PN (considering test-to-test variability); stronger effect for PM
- Mass and number emissions lowest from the E50 blend and highest from the E10 blend

Results: PM & PN during the EUDC



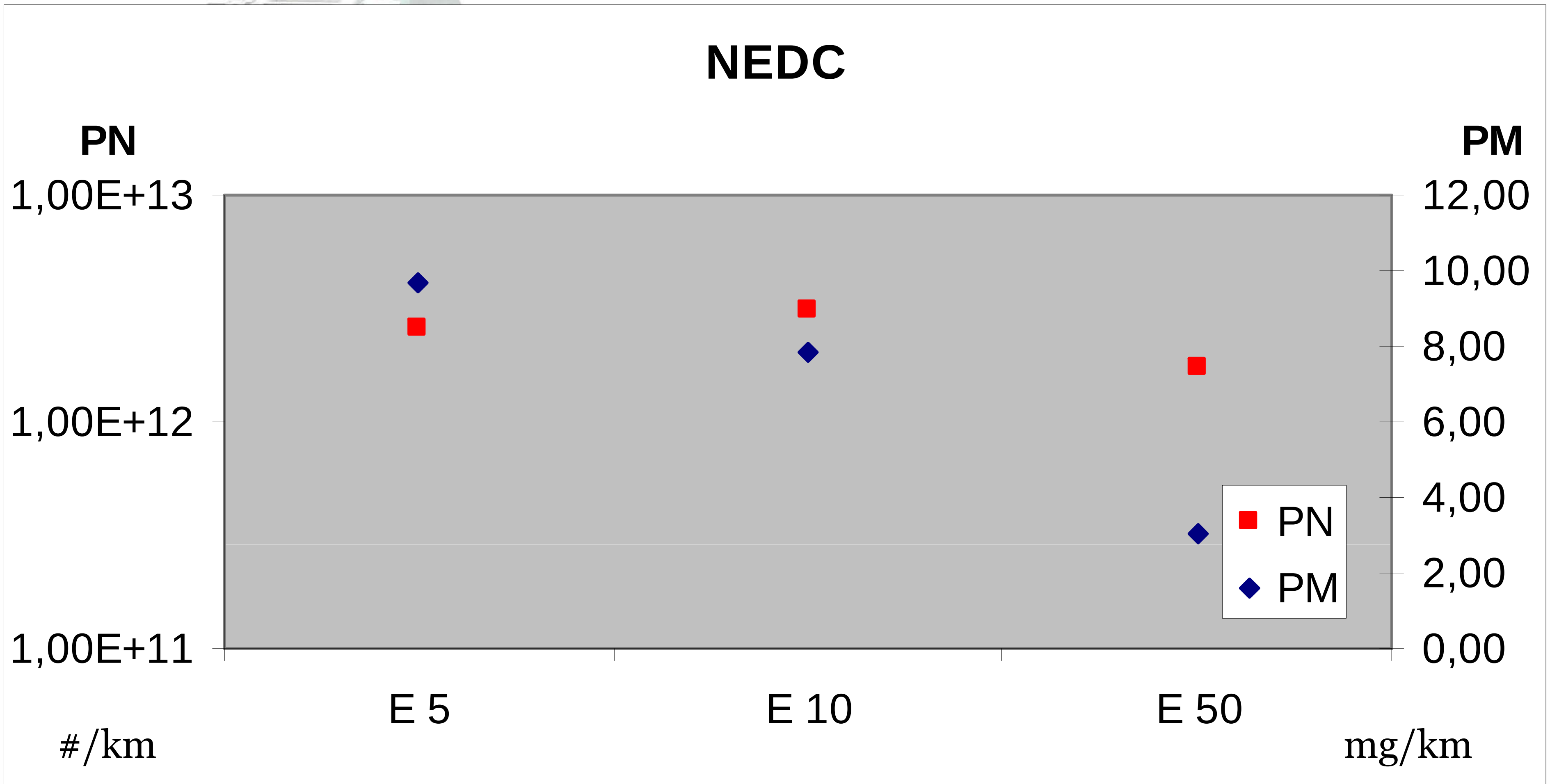
- Wide variation between blends for PM; relatively little for PN (considering test-to-test variability)
- Mass and number emissions highest from the E10 blend
- Low emissions from the E50 blend, despite a substantially increased fuel flow rate

Results: PN/PM ratios for the UDC and EUDC



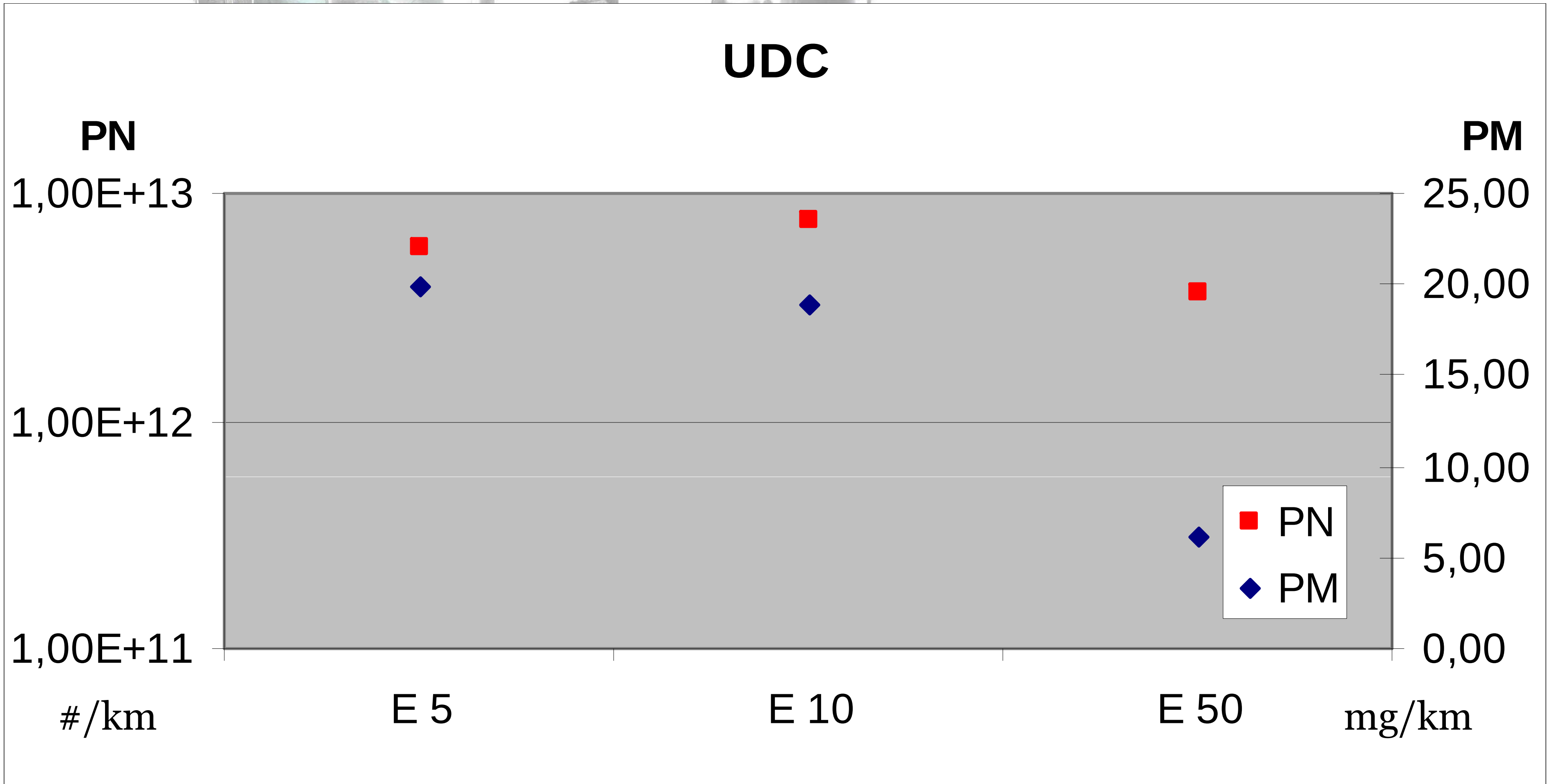
- No obvious correlation observed between ethanol content and the PN/PM ratio
- Very low repeatability

Results: PM & PN during the NEDC at -7 °C

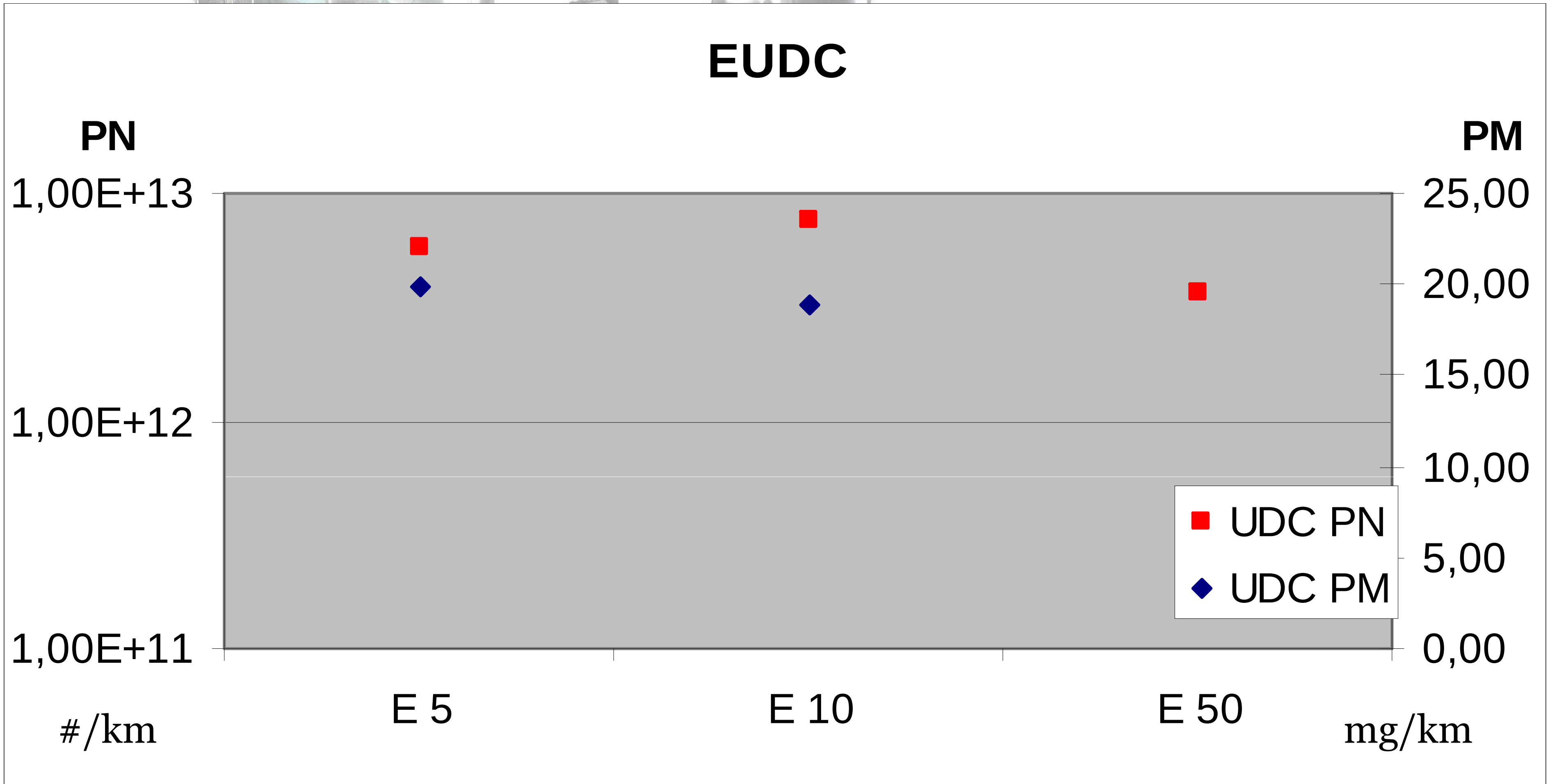


- Wide variation between blends for PM; very low emissions for the E50 blend

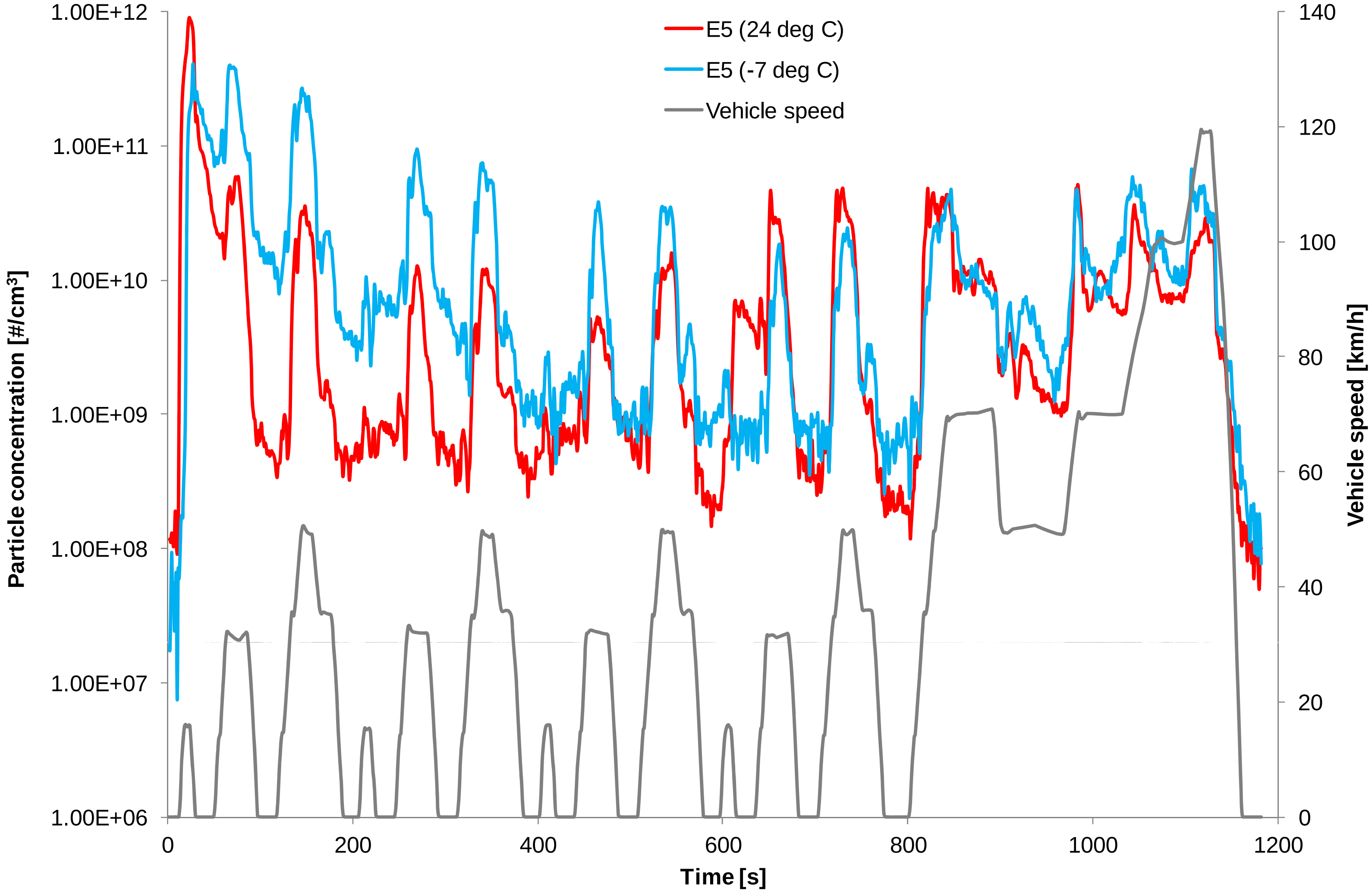
Results: PM & PN during the UDC at -7 °C



Results: PM & PN during the EUDC at -7 °C

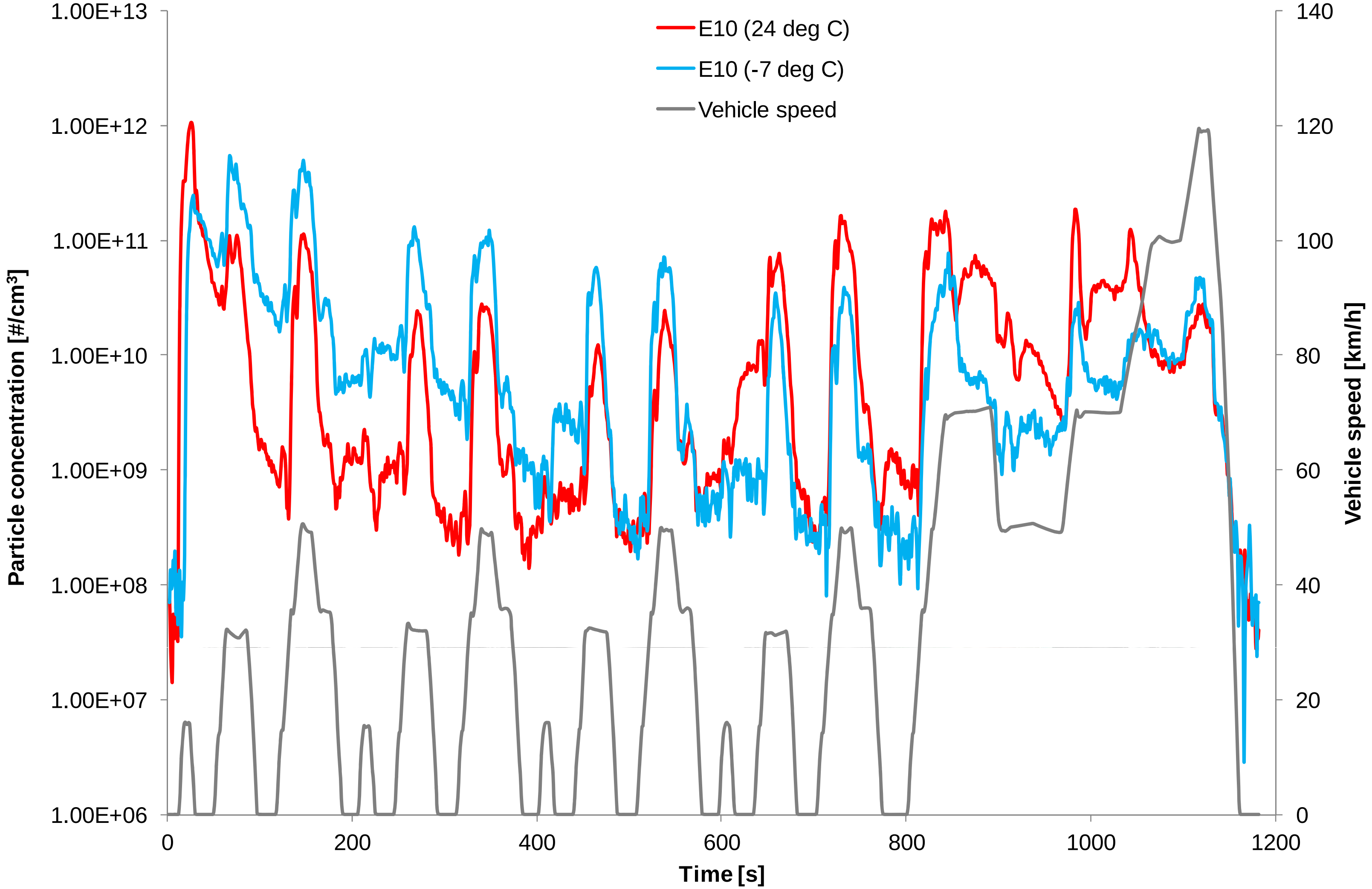


Results: Temperature influence for E5



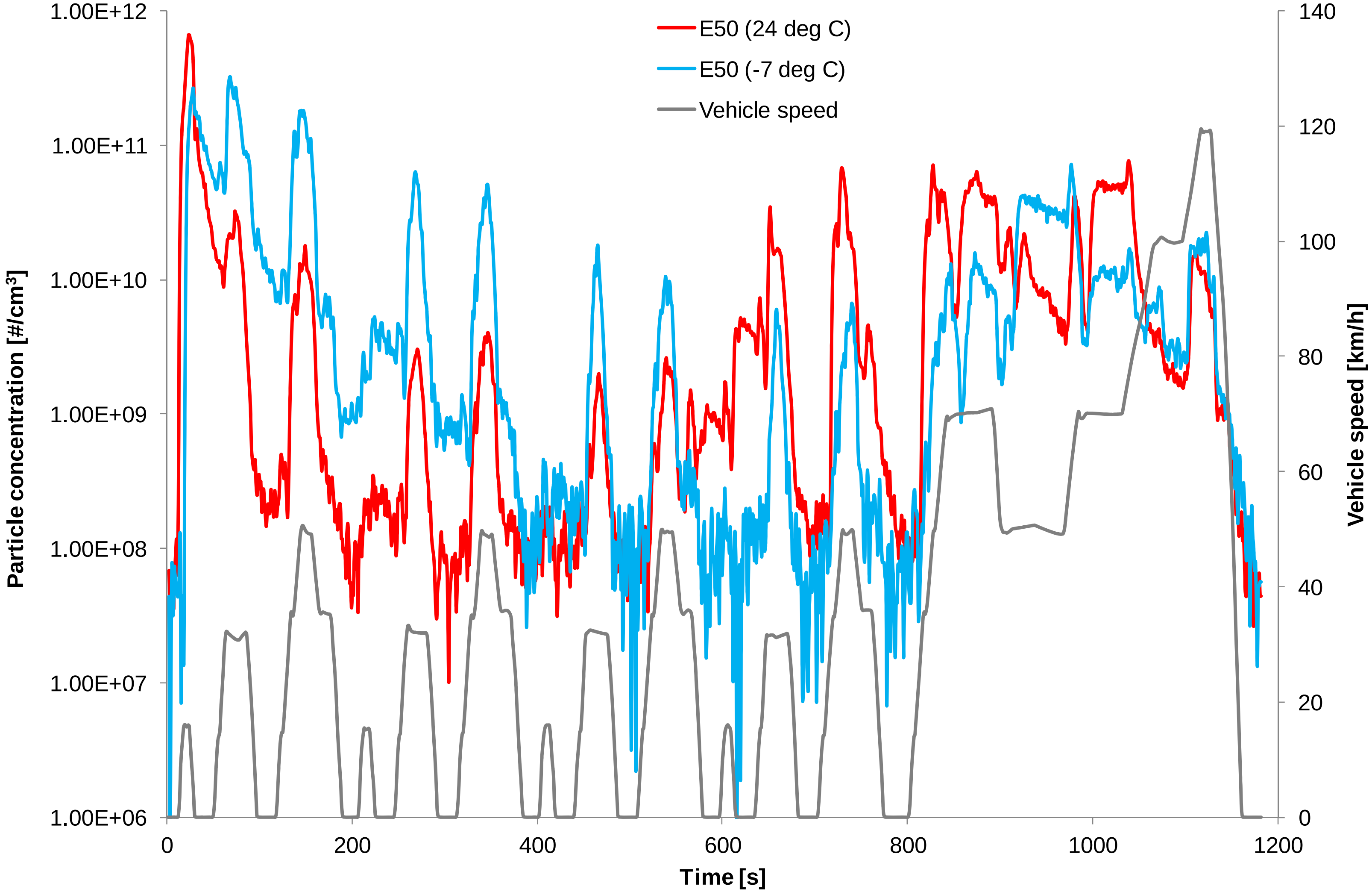
- Significantly higher emission at -7 °C for idling and transients
- Differences all but disappear after around 650 seconds

Results: Temperature influence for E10

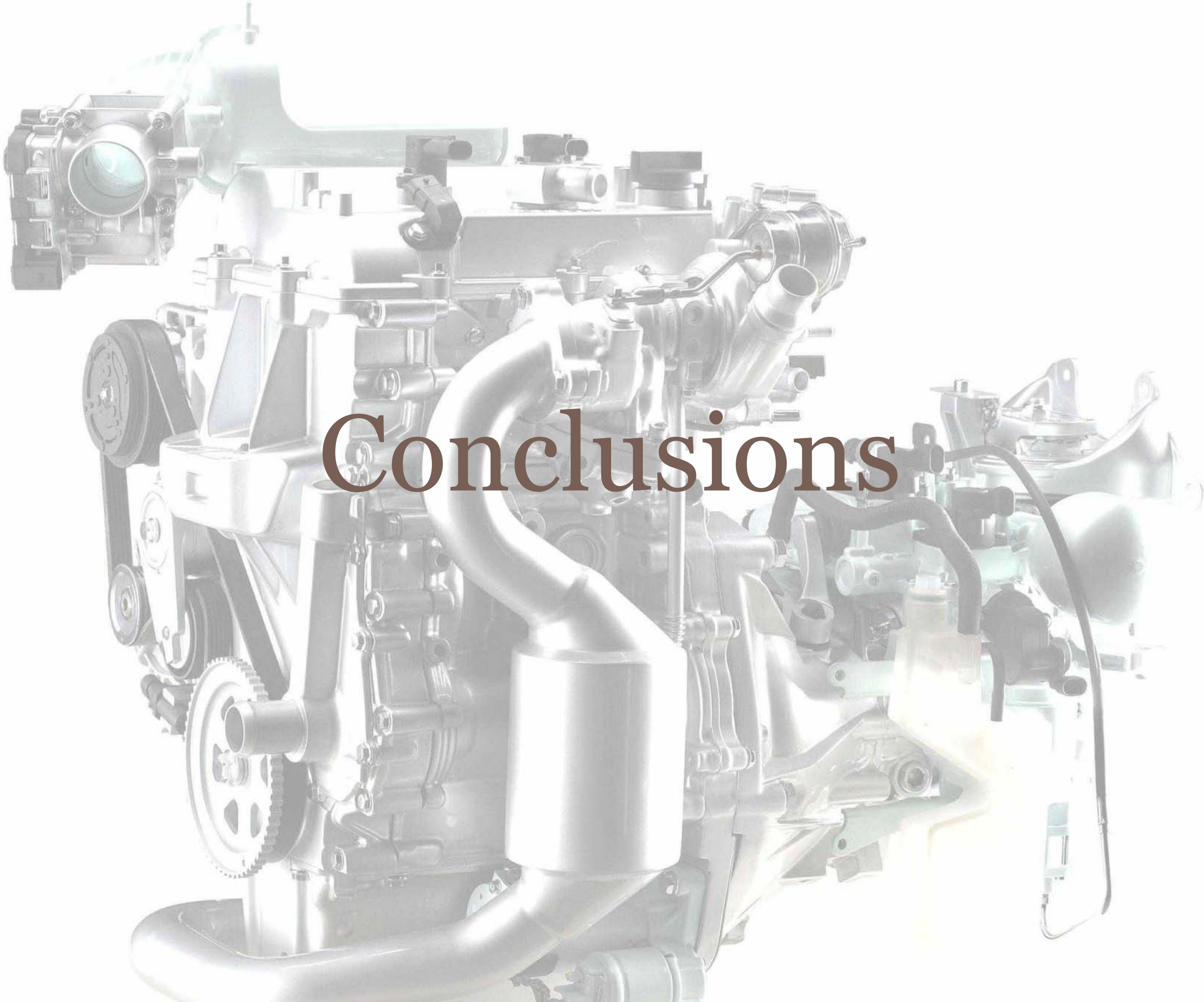


- Significantly higher emission at -7 °C for idling and transients
- Differences all but disappear after around 650 seconds

Results: Temperature influence for E50



- Significantly higher emission at -7 °C for idling and transients up to around 400 seconds
- Surprisingly, emission at -7 °C in fact lower for some portions of the cycle (550-900 seconds)



Conclusions

Conclusions (1/2)

- At 24 °C, PN emissions were high, but were (just) under the upcoming limit of 6.00E12 #/km for all test fuels. PM emissions were all well under the DISI limit.
- Emissions of PN and PM increased substantially at -7 °C, but the difference varied with the ethanol content of the fuel.
- Possible reasons include the physicochemical parameters of the two fuels – and the impact this has on the relative sizes of the volatile and non-volatile particle fractions, catalyst light-off time and the oxidation of particles in the TWC.

Conclusions (2/2)

- While considerable variation was observed, fuel ethanol content was observed to correlate only weakly with the PN/PM ratio. The results suggest that large numbers of particles of negligible mass were emitted.
- Despite the increased oxygen content of the fuel, higher ethanol blends showed limited to non-existent decreases in particle number and mass emissions, although the E50 blend did appear to perform well.

Thank you for your attention

- Any questions?

- Contact: piotr.bielaczyc@bosmal.com.pl