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ENVIRONMENTAL SCIENCE FOR THE EUROPEAN REFINING INDUSTRY

# Study of Fuel Oxygenate Effects on Particulates from Gasoline Direct Injection Cars

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**Cambridge Particle Meeting**

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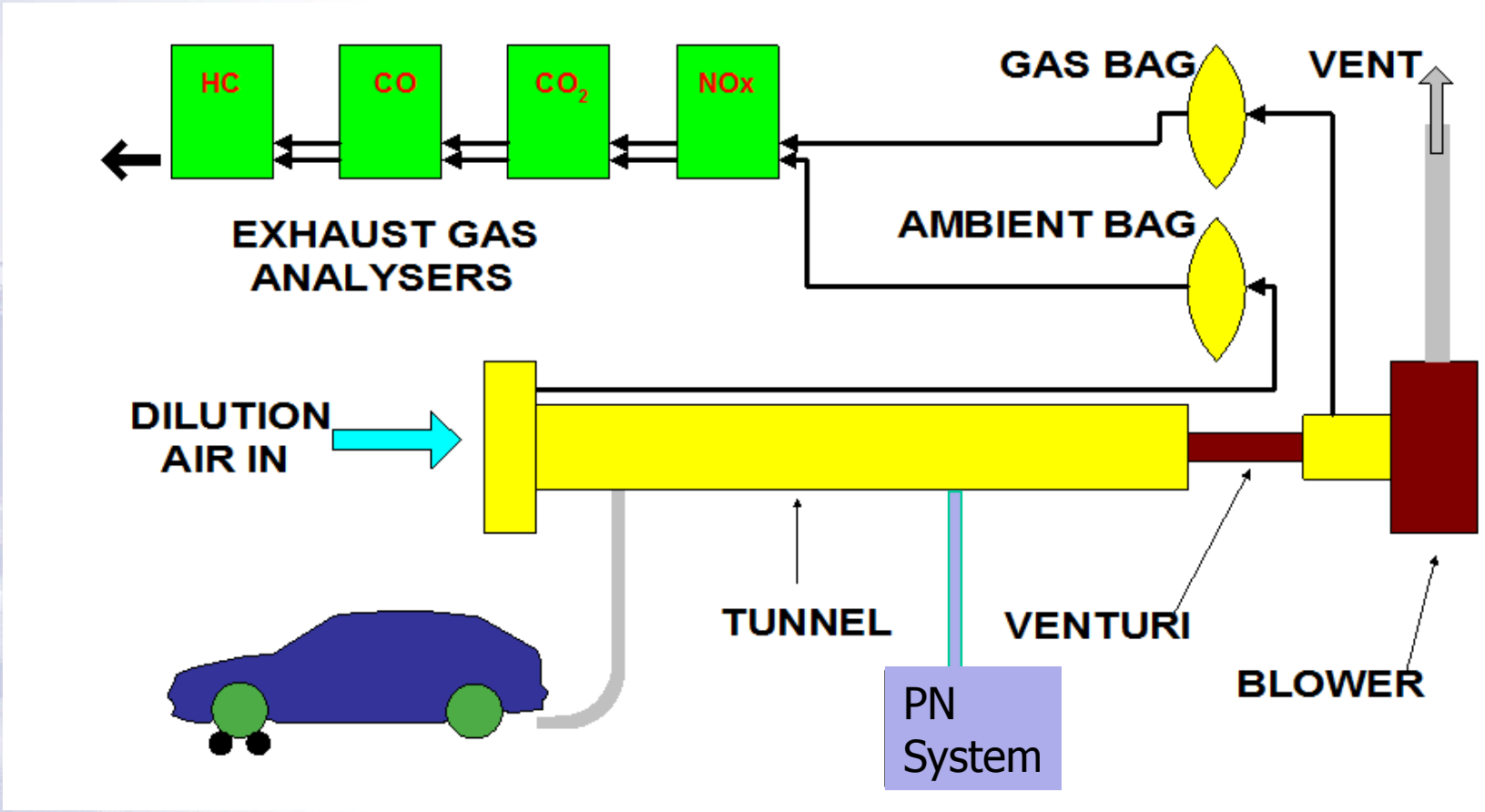
# Background

- It is well known that gasoline direct injection (GDI) vehicles produce more particulate matter than port fuel injected equivalents
- From 2014 limits on particulate number will be introduced for Euro 6 GDI vehicles which by 2017 will be equivalent to those that exist for diesel vehicles
- In addition, the Renewable Energy Directive and Fuels Quality Directive from 2009 are likely to require increased use of oxygenates
- Previous work has found the response of particulate to oxygenates to be drive-cycle dependent
  - Most studies conducted on US test cycles
  - Studies on either matched or splash-blended fuels
  - Oxygen content, distillation and fuel composition thought to be important
- Two passenger cars were tested over the NEDC test cycle for regulated emissions, PM, PN and fuel consumption
  - Scoping study using reference fuel
  - Fuel Matrix covering range of RON, oxygenate types and $O_2$ content

# Test Vehicles

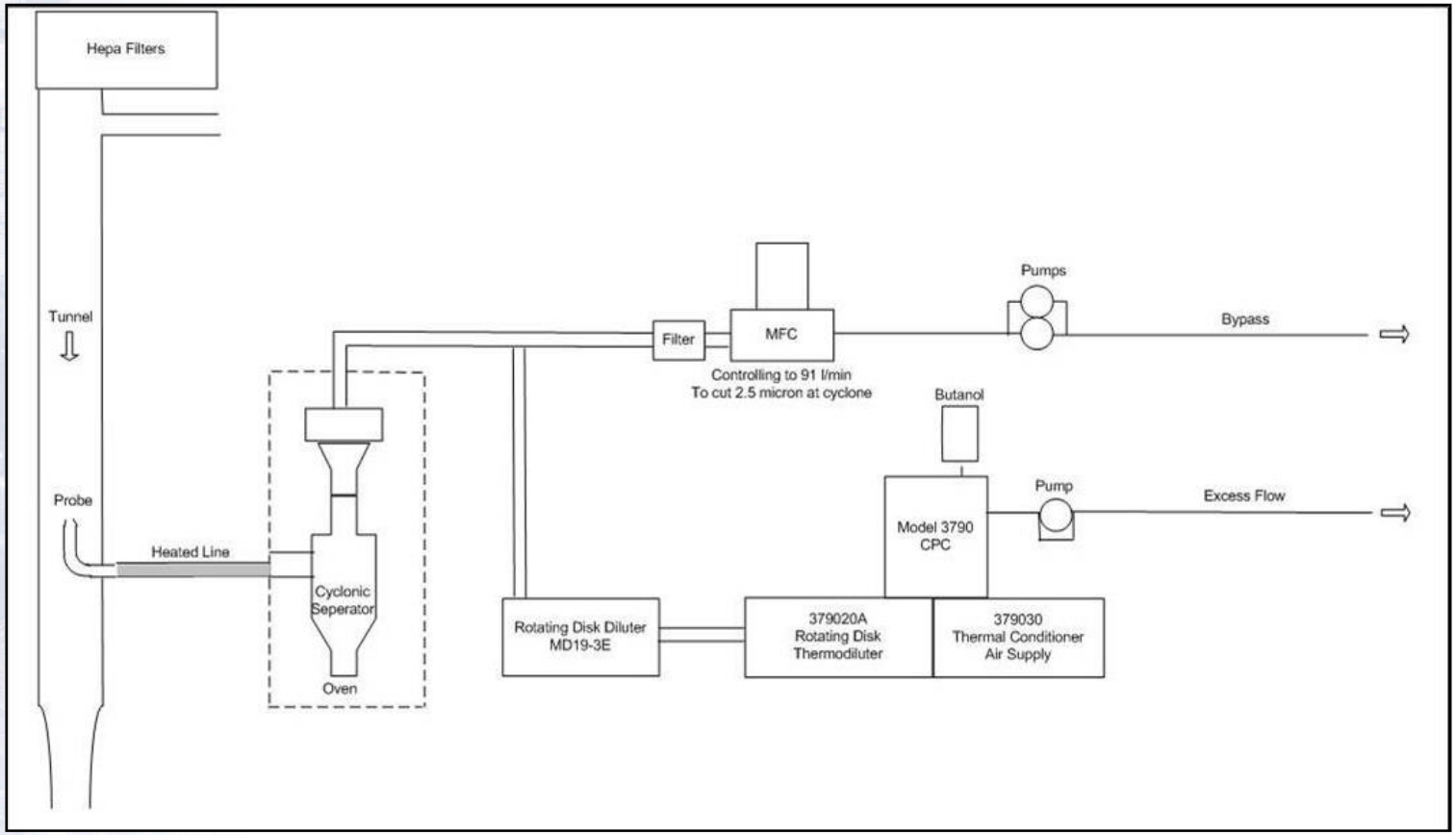
| Vehicle No. | 1 | 2 |
|---|---|---|
| Vehicle Class | Upper Medium | Medium |
| Manufacturer | | |
| Model | | |
| Category | M1 | M1 |
| Emission Standard (homologation) | Euro 4 | Euro 5 |
| Engine Displacement (litres) | 2.5 | 1.8 |
| Max. Power (kW) | 140 | 118 |
| Inertia Class (kg) | 1590 | 1470 |
| Cylinder | 6 | 4 |
| Valves | 24 | 16 |
| Aspiration | Natural | Turbo |
| Combustion Type | Homogeneous stoichiometric | Homogeneous stoichiometric |
| Injection System | DI | DI |
| After-treatment device | TWC | TWC |
| Drive | RWD | FWD |
| Transmission | Manual 6-speed | Manual 6-speed |
| E10 Compatible? | Yes | Yes |
| Registration Date | 15/06/2007 | 4/6/2009 |
| Mileage at start of test (miles) | 23,354 | 8,890 |

# CVS System



# Particulate Number System

- Particulate number and distribution measured using the PMP protocol and ELPI system



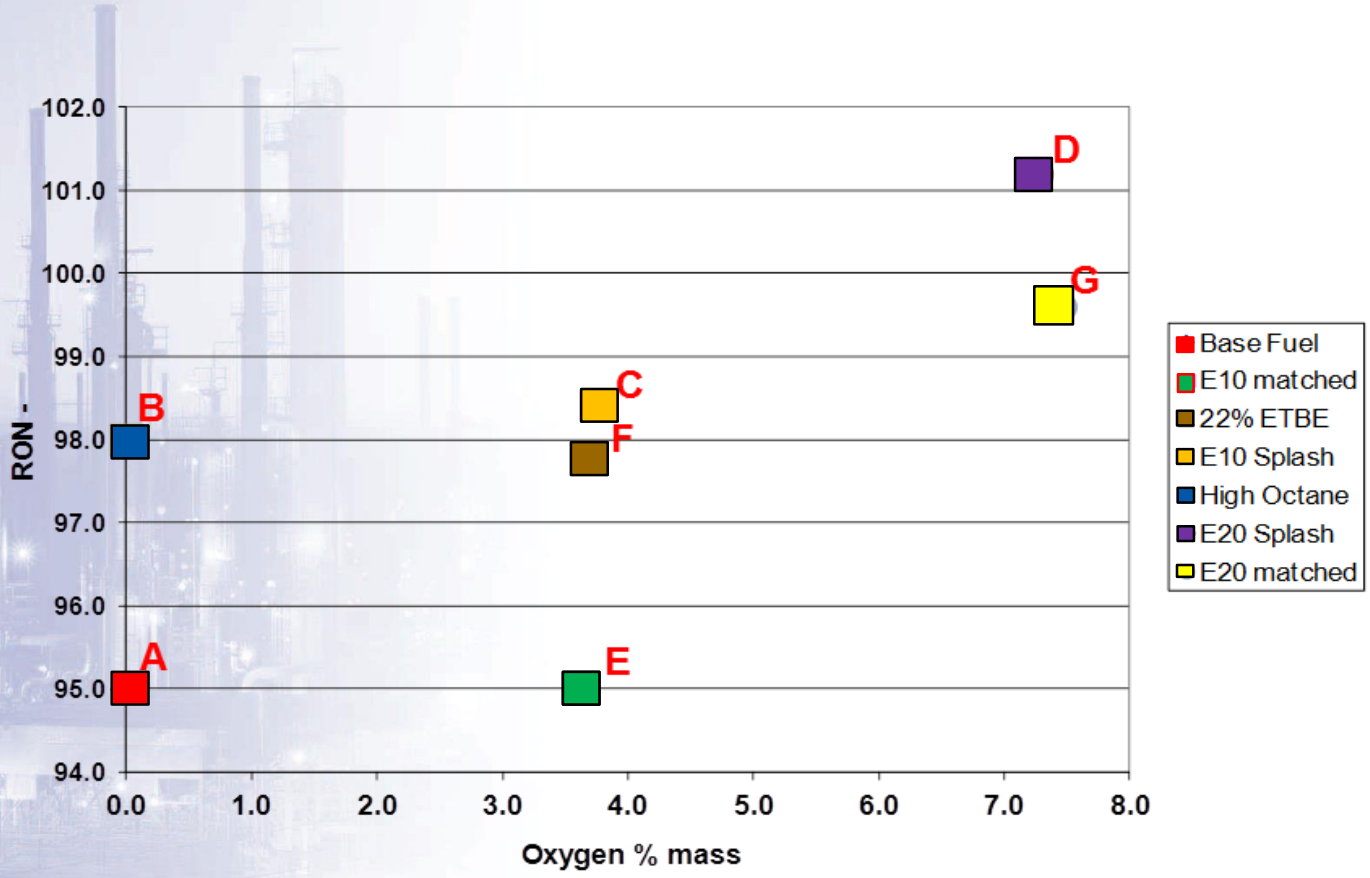
# Flush and Preparation Procedure

- Conduct fuel tank drain
- Fill with 15 litres of test fuel
- Set type pressure
- Conduct 2 NEDC cycles on the chassis dynamometer
- Conduct fuel tank drain
- Fill with 15 litres of test fuel

Carry out 2x

- Full exhaust leak check
- Tyre pressure check
- Preconditioning cycle – ECE + 2 x EUDC
- Overnight soak
- Run NEDC test (ECE + EUDC)

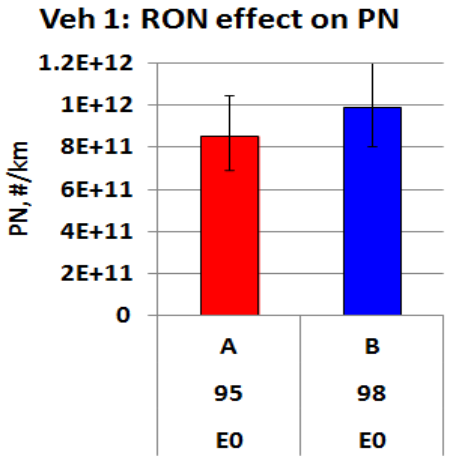
# Main Study Fuels and Testing Sequence

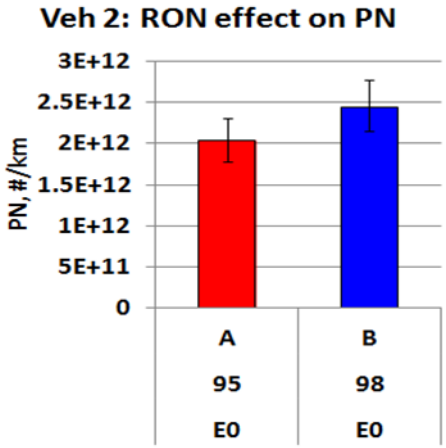


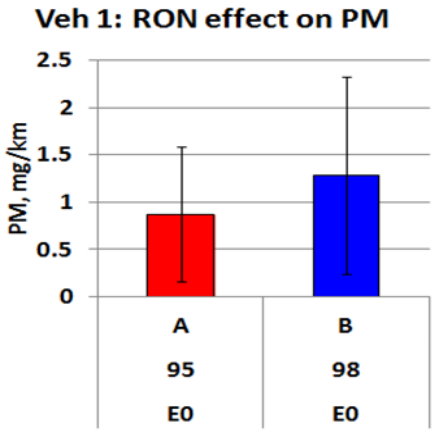

| | Vehicle 1 | Vehicle 2 |
|---|---|---|
| *Test 1* | Reference | Reference |
| *Test 2* | Fuel A | Fuel F |
| *Test 3* | Fuel D | Fuel B |
| *Test 4* | Fuel C | Fuel E |
| *Test 5* | Reference | Reference |
| *Test 6* | Fuel E | Fuel G |
| *Test 7* | Fuel F | Fuel A |
| *Test 8* | Fuel B | Fuel C |
| *Test 9* | Fuel G | Fuel D |
| *Test 10* | Reference | Reference |
| *Test 11* | Fuel D | Fuel C |
| *Test 12* | Fuel F | Fuel A |
| *Test 13* | Fuel B | Fuel G |
| *Test 14* | Fuel C | Fuel F |
| *Test 15* | Reference | Reference |
| *Test 16* | Fuel A | Fuel D |
| *Test 17* | Fuel G | Fuel E |
| *Test 18* | Fuel E | Fuel B |
| *Test 19* | Reference | Reference |

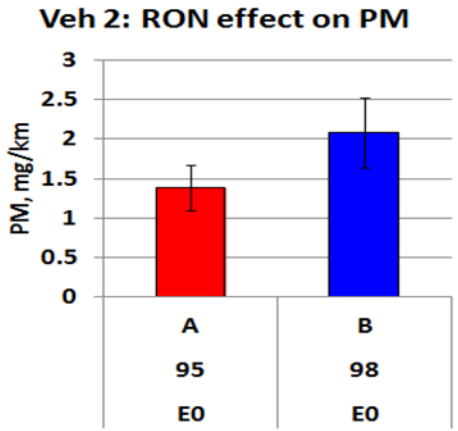
- In addition to the fuel matrix the reference fuel used in the scoping study was also run and repeated at intervals

# Octane Effects with Zero Oxygenate



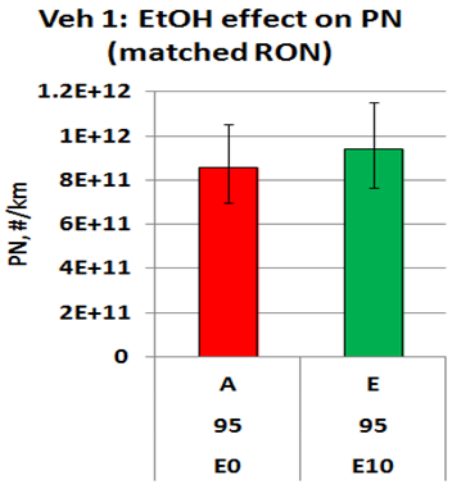



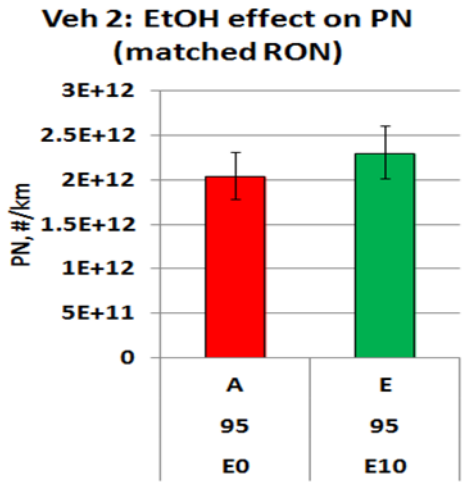



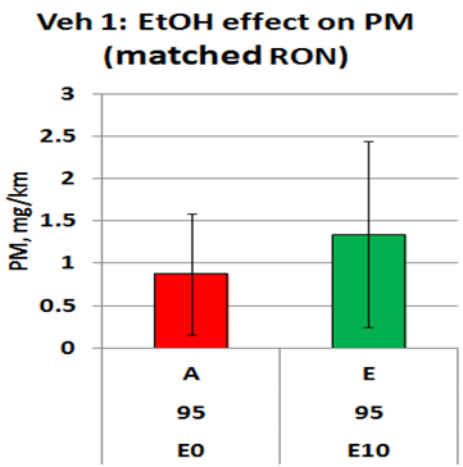



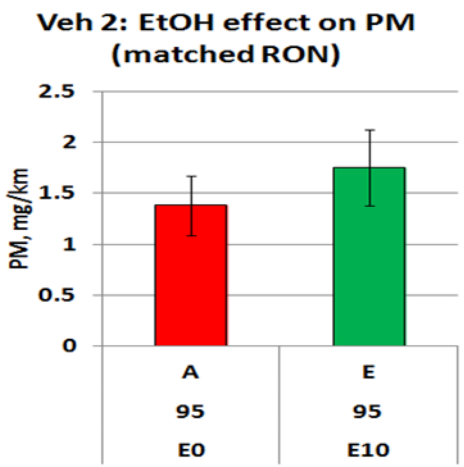

- Directionally higher PM and PN with higher RON although effects are small and not statistically significant

# Ethanol Effects on PN and PM at matched RON



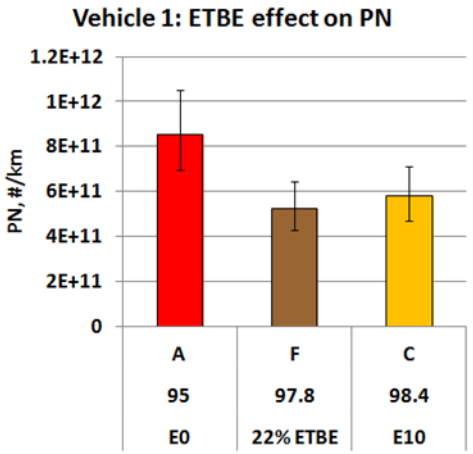



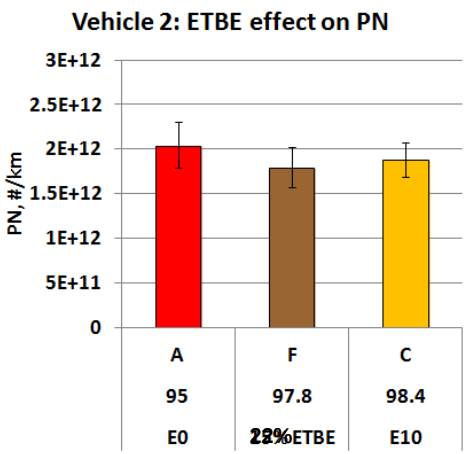



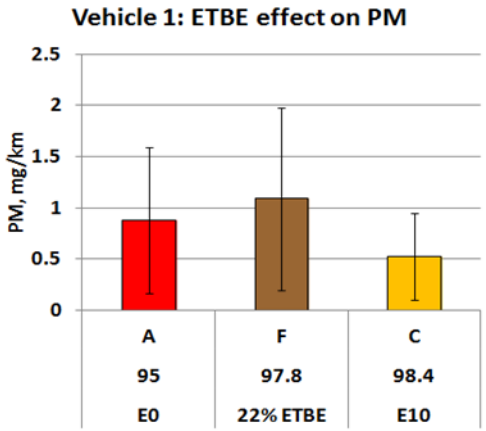



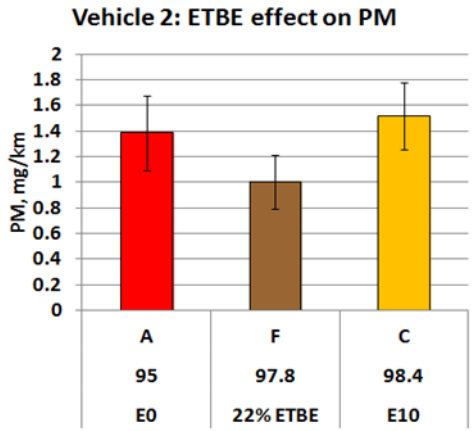

- No significant effects - directional increase in PM and PN with increased ethanol, at 98 RON directional reduction is observed

# Oxygenate Type Effects at Same Oxygen Content



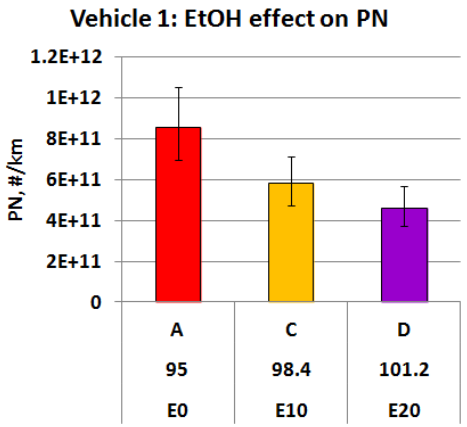



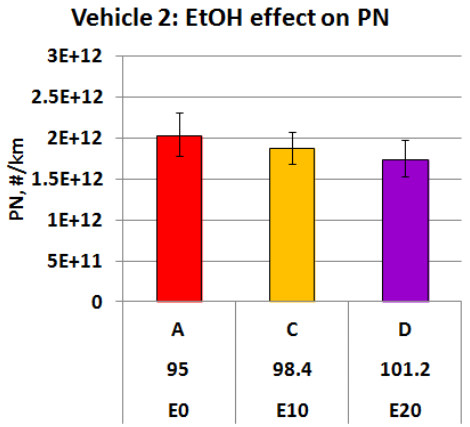



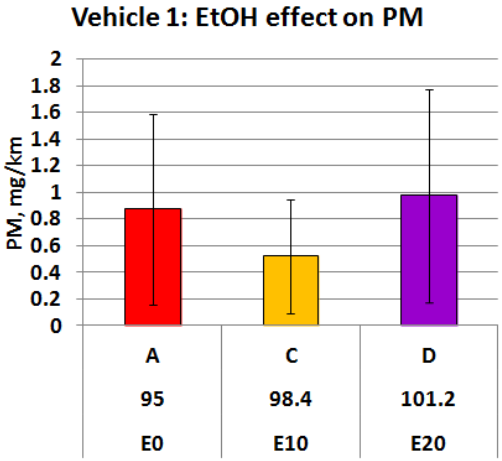



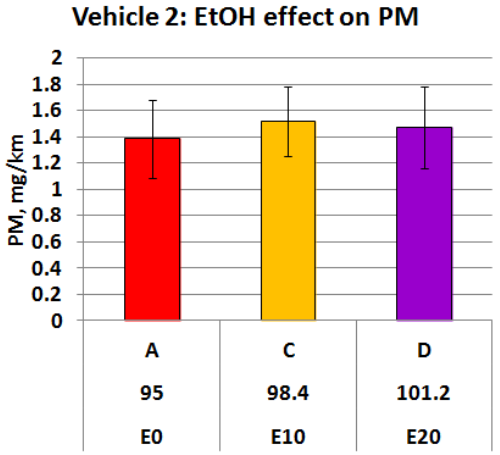

- Although some statistically significant differences between fuels, no consistent effects were observed. Both oxygenates tend to reduce PN.

# Results of Splash Blending Ethanol



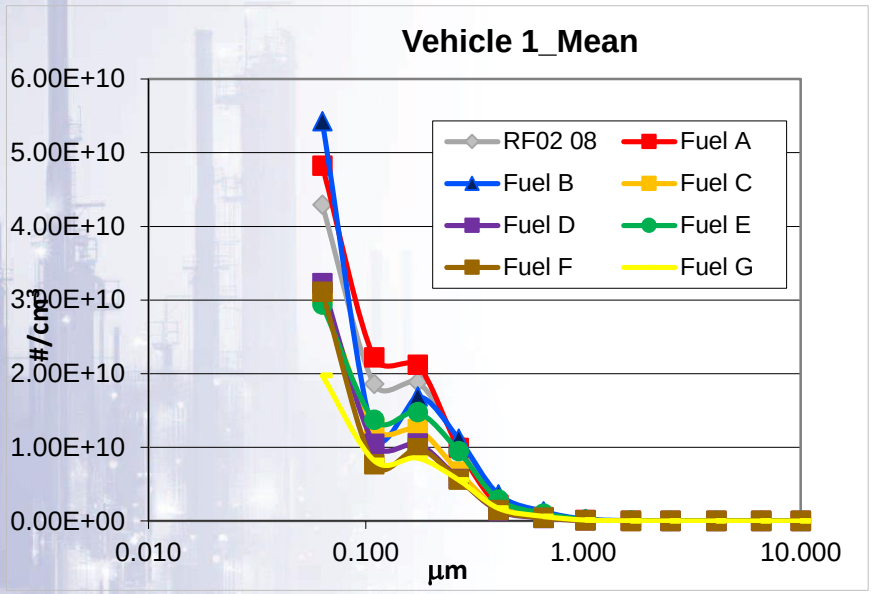



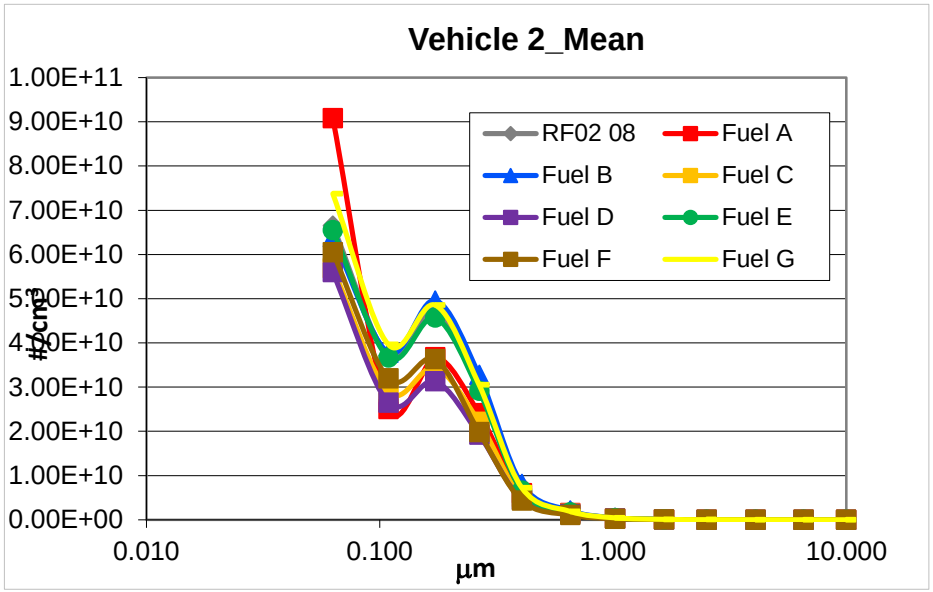




- Splash blending gave directional reduction in PN as ethanol content increases but no significant effect on PM

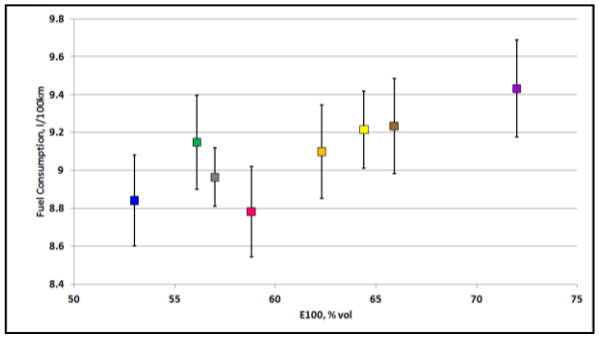
# Particle Number Distribution

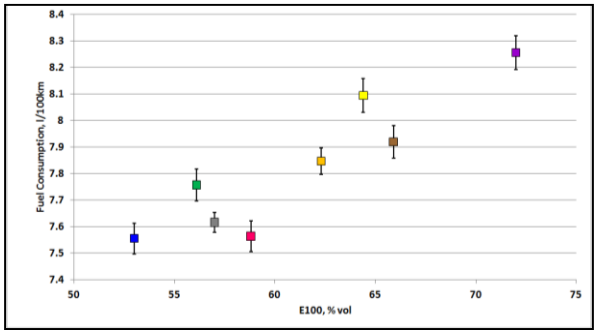


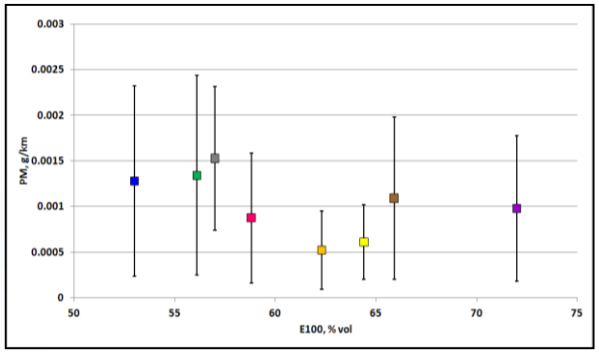



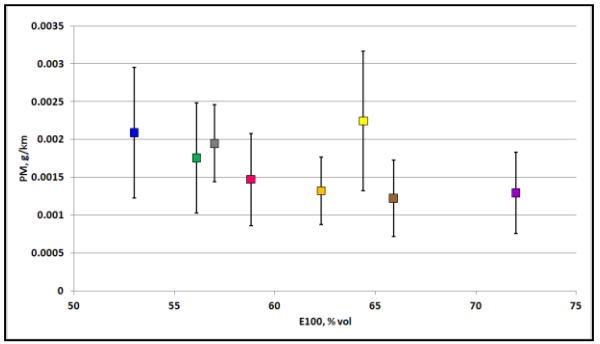

- Vehicle 2 has higher PN than Vehicle 1 for all fuels
- Bi-modal distribution was observed although limitations on the detection limit of the equipment for nano-particulate detection
- Error bars (not shown) too great to distinguish trends between fuels

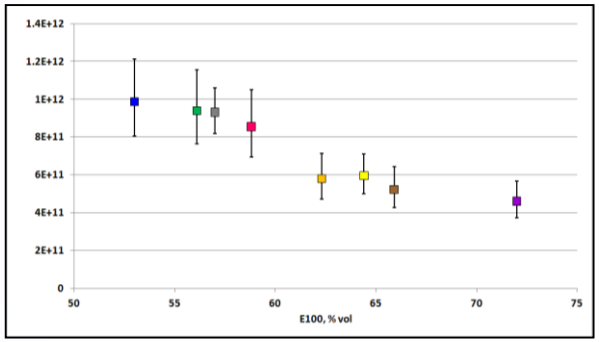
# Effect of Volatility on FC, PM and PN

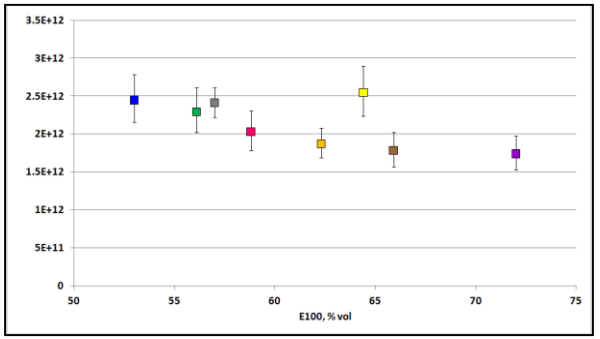


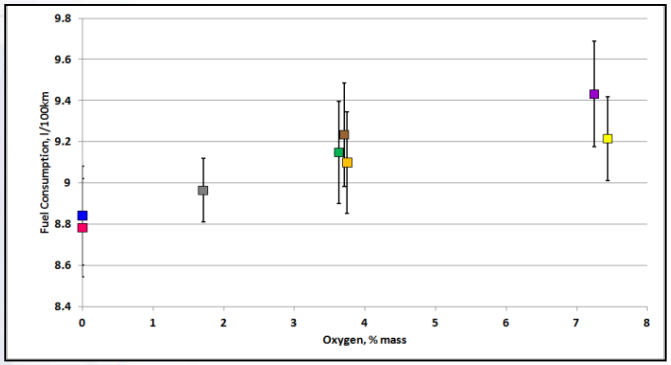



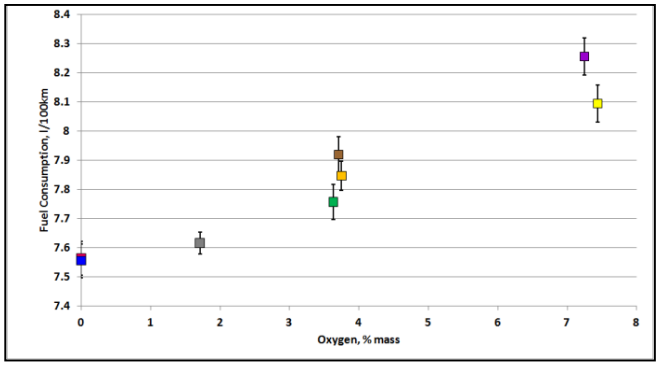



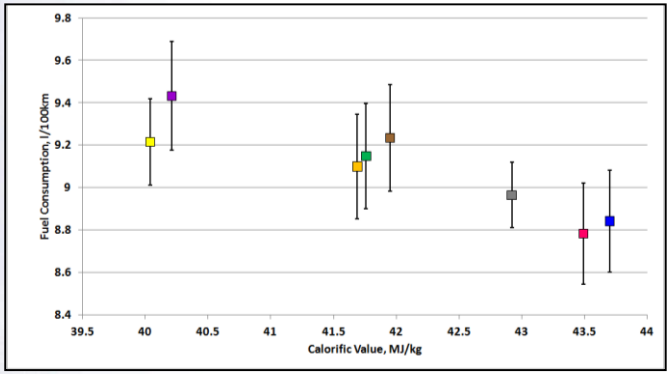


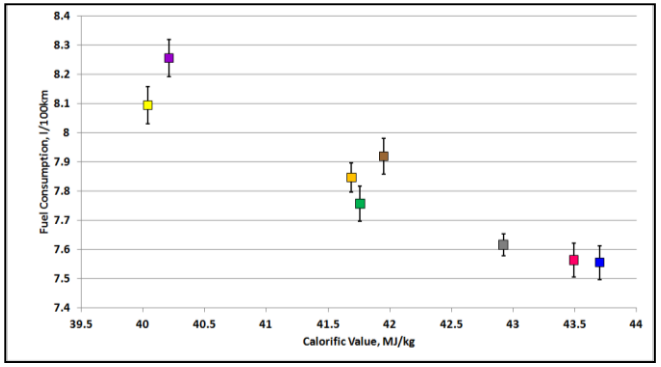

➢ Some correlations E100 dominated by oxygenate content

# Fuel Consumption vs Oxygen Content & Calorific Value




- Correlations between fuel consumption and oxygen content and calorific value were consistent with expectations

# Effects on Other Regulated Emissions

- Again fuel effects were small, although vehicle 2 seemed slightly more sensitive than vehicle 1, trends were observed as follows:
- With no oxygenates present significant increase in NOx with increase in octane was observed in vehicle 2
  - No change in vehicle 1
  - Directional decreases in CO, increases in CO2 and no change in HC
- Directional increases in NOx were observed with the use of oxygenates in both vehicles
  - E10 gave directional increase in NOx compared to E0 at equivalent RON
  - E10 gave directionally higher NOx than ETBE (at equivalent oxygen) and E20 (splash blended so higher RON)
- General decrease in CO with the use of ethanol
  - Effects were not significant in vehicle 1
  - Significant increase in vehicle 2 for ETBE which was also observed for HC

# Summary of Results

- Fuel effects appear small and on the whole were not statistically significant, directional trends present in both vehicles were noted as follows:
- When no oxygenate was present there was a directional increase in particulate mass and number with increasing RON
  - CO2 and NOx directionally increased and CO directionally decreased
- Trend toward reducing particulate number with "splash blended" oxygenate-containing fuels (increasing RON)
  - Although NO similar trend observed for PM
  - When fuel properties are matched different (although consistent) trends are observed depending on the octane level
- General trend towards increasing NOx and decreasing CO with increasing oxygenates
- Fuel consumption results reflected oxygen content and calorific value of the fuels

# Conclusions and Next Steps

- In general the results are in line with what would be expected from previous experience in diesel vehicles
- The fuel effects on emissions are fairly small compared to vehicle-vehicle calibration differences
- The PM measurements are low and at the limit of the test capability which may explain why some effects are "seen" in PN but not PM
- Fuel "leaning out" effects may explain some of the trends observed with oxygenates e.g. particulates, CO and NOx
  - Further analysis of trends versus oxygen content may help establish whether chemistry or physics dominates
- Further analysis of fuel composition and distillation results may help understand the trends in emissions especially effect of changing octane with and without the presence of oxygenates

# Thanks for Your Attention!

- Acknowledgements go to members of Concawe STF-25 and STF-20 task forces as well as Shell for providing statistical support