Department of Engineering Science

# The effect of fuel composition on particulate emissions from a highly boosted GDI engine – an evaluation of three particulate indices

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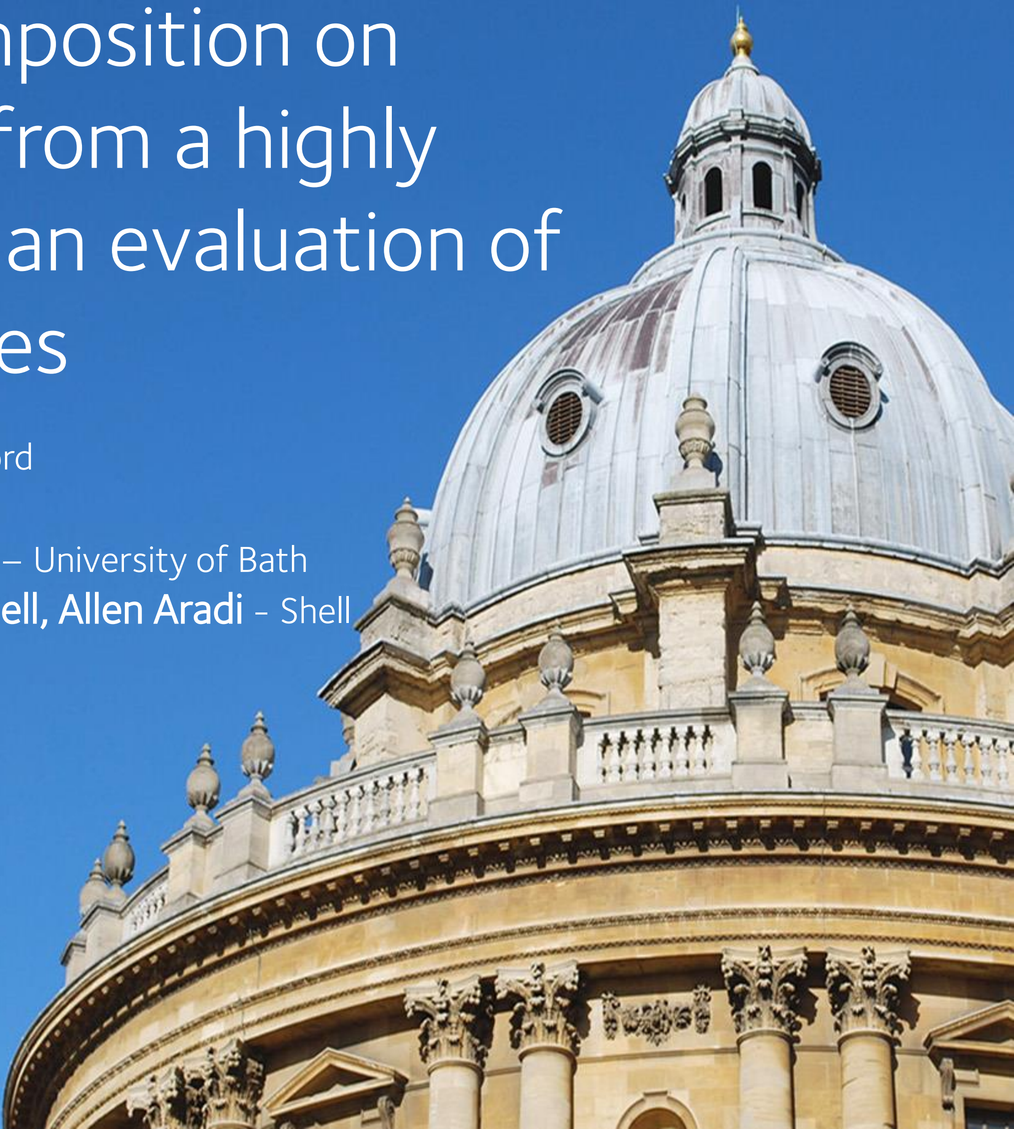
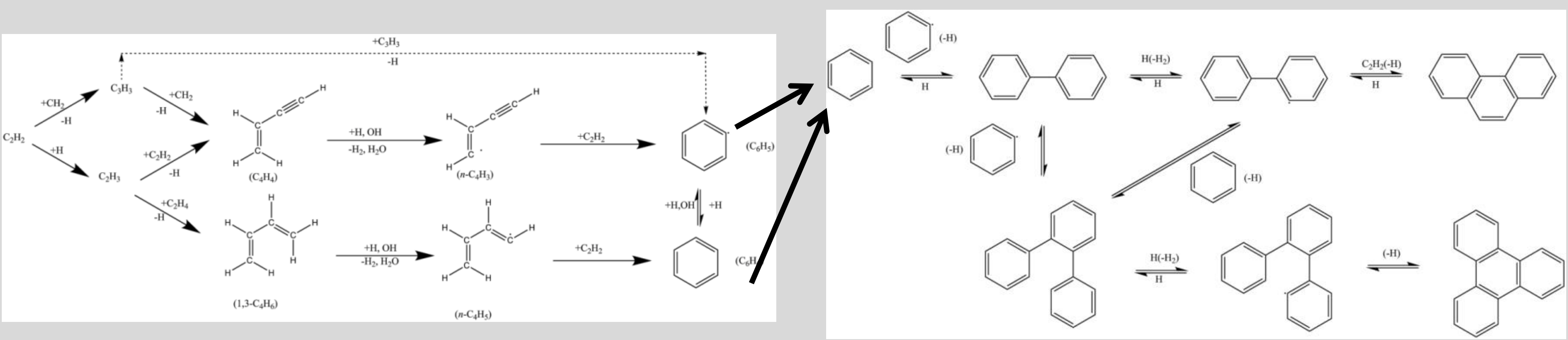
Cambridge Particle Meeting
28 June 2019



# Contents

# Background

- Boosted GDI increasing market penetration
- Fuel effects on PN
  - Dependent on mixture formation – evaporative performance of fuel
  - Avoid wall wetting / pool fires
  - Many particle formation pathways pass through aromatic / PAH components



# Background – particulate indices

- PM index (2010) – Honda – good correlation between fuel composition and PM
  - Unable to calculate PM index without detailed compositional breakdown of fuels

$$PM\ index = \sum_{i=1}^{n} \left[ \frac{DBE_i + 1}{VP_i} \right] W_{ti}$$

$$DBE = \frac{2C^\circ - H^\circ + 2}{2}$$

- PN index (2012) uses industry standard measurements
  - DVPE
  - Blending by volume

$$\text{PN index} = \frac{\sum_{i=1}^{n} [DBE_i + 1] V_i}{DVPE(\text{kPa})}$$

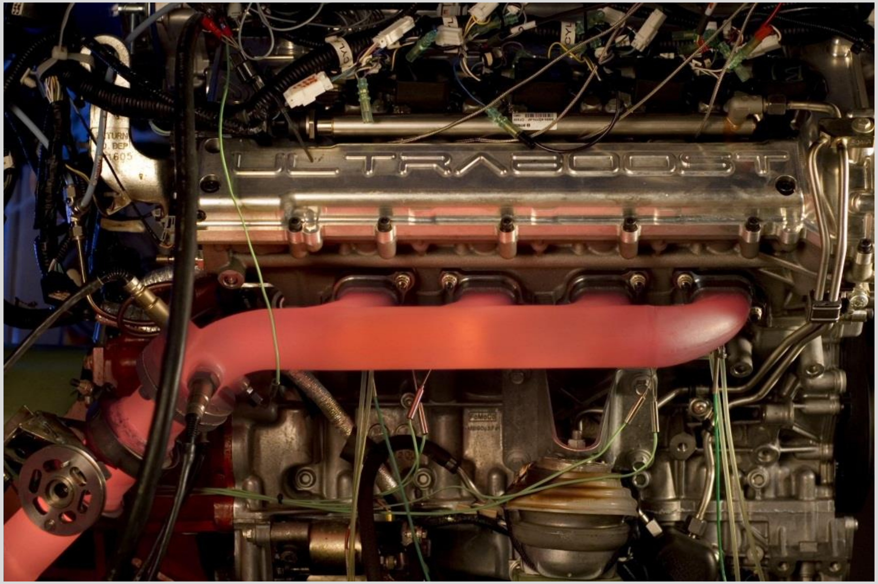
- Moriya index (2016)
  - Requires only distillation information

$$Moriya\ index = -0.0647 \times E170 - 0.0324 \times E130 + 9.92405$$

$$Simplified\ Moriya\ index = -0.0757 \times E150 + 7.8511$$

# Ultraboost engine

- Highly-boosted, heavily-downsized engine
- Torque curve and power output of the NA Jaguar Land Rover AJ133 5.0L V8 engine
- 35% improvement in fuel economy / $CO_2$ target
- 60% downsizing (2.0 litre i4)
- Driveability of the original V8 to be maintained
- Operation on 95 RON pump gasoline

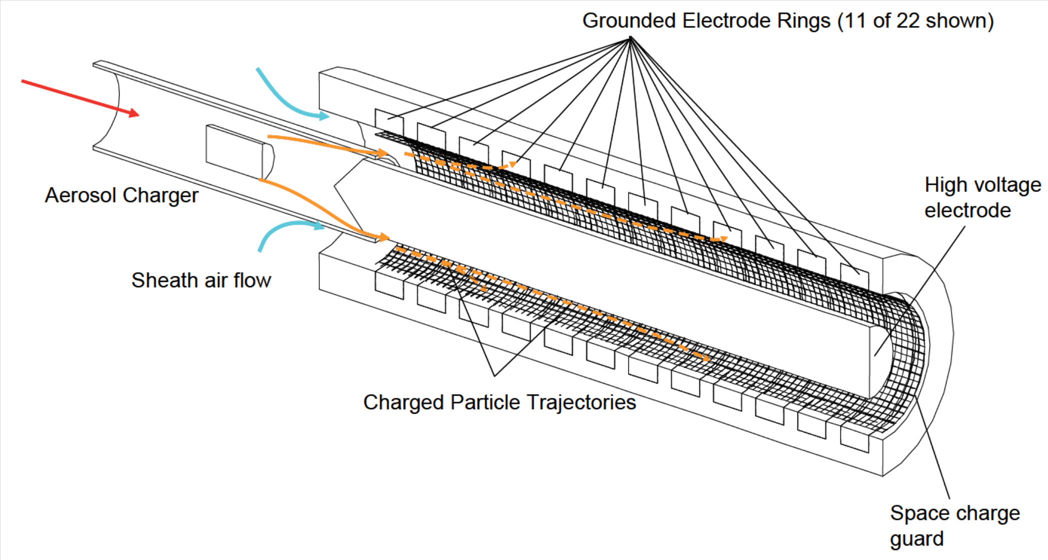



Turner et al. SAE 2014-01-1185

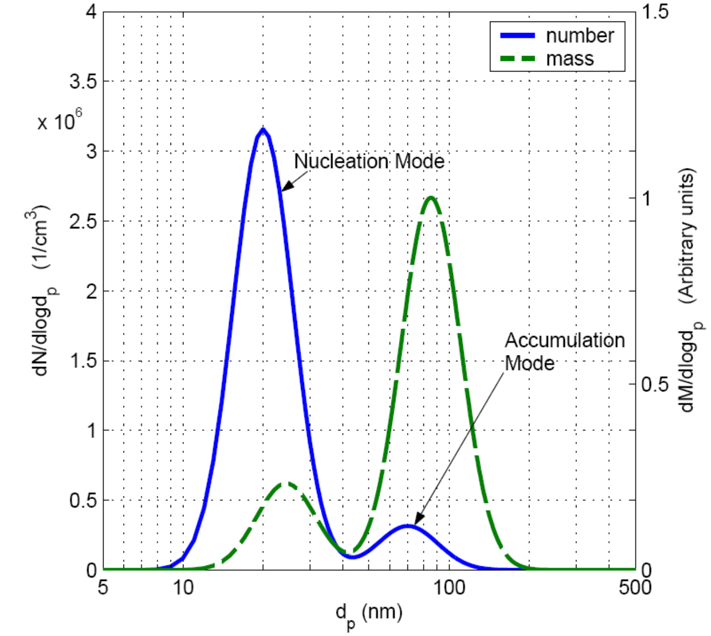
| | |
|---|---|
| **Type** | **Inline 4 cylinder** |
| **Bore × Stroke** | **83 × 92 mm** |
| **Displacement** | **1991 $cm^3$** |
| **Valves per cylinder** | **2 intake, 2 exhaust** |
| **Compression ratio** | **9:1** |
| **Maximum fuel pressure** | **200 bar** |
| **Peak BMEP** | **35 bar** |
| **Peak cylinder pressure** | **150 bar** |

# Particulate measurements

- Cambustion DMS500

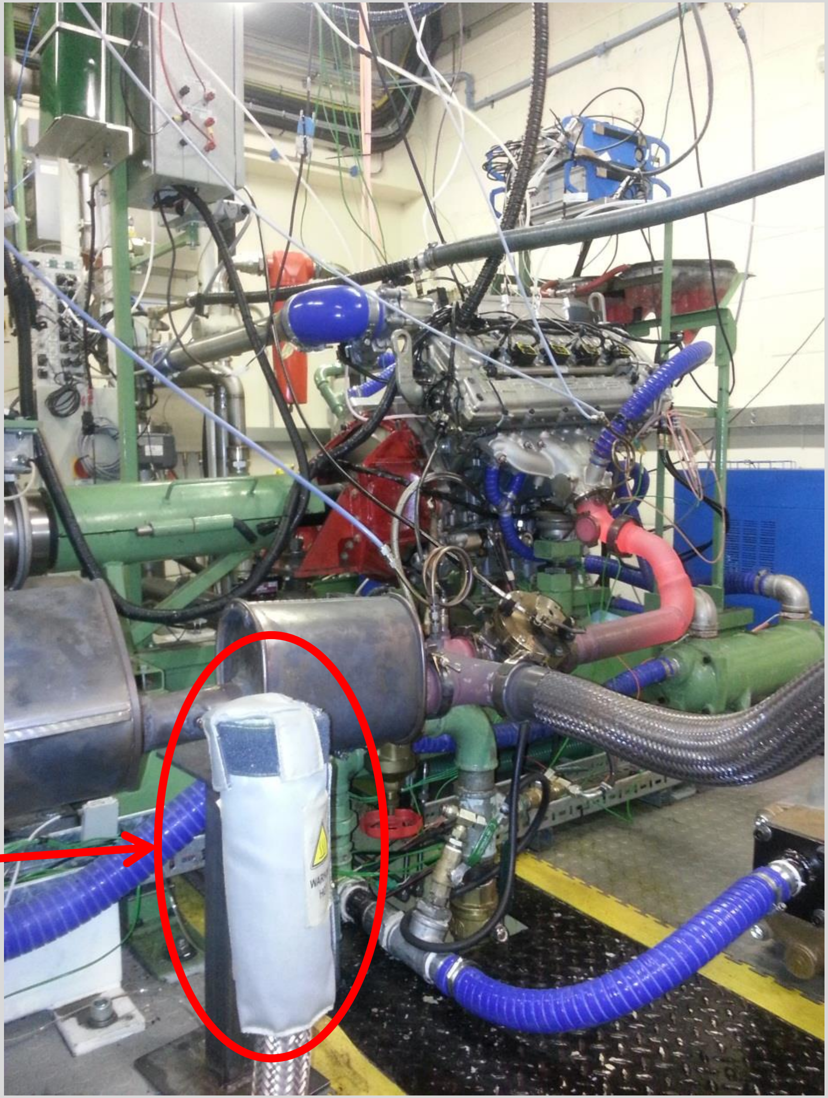



Reavell et al. SAE 2002-01-2714



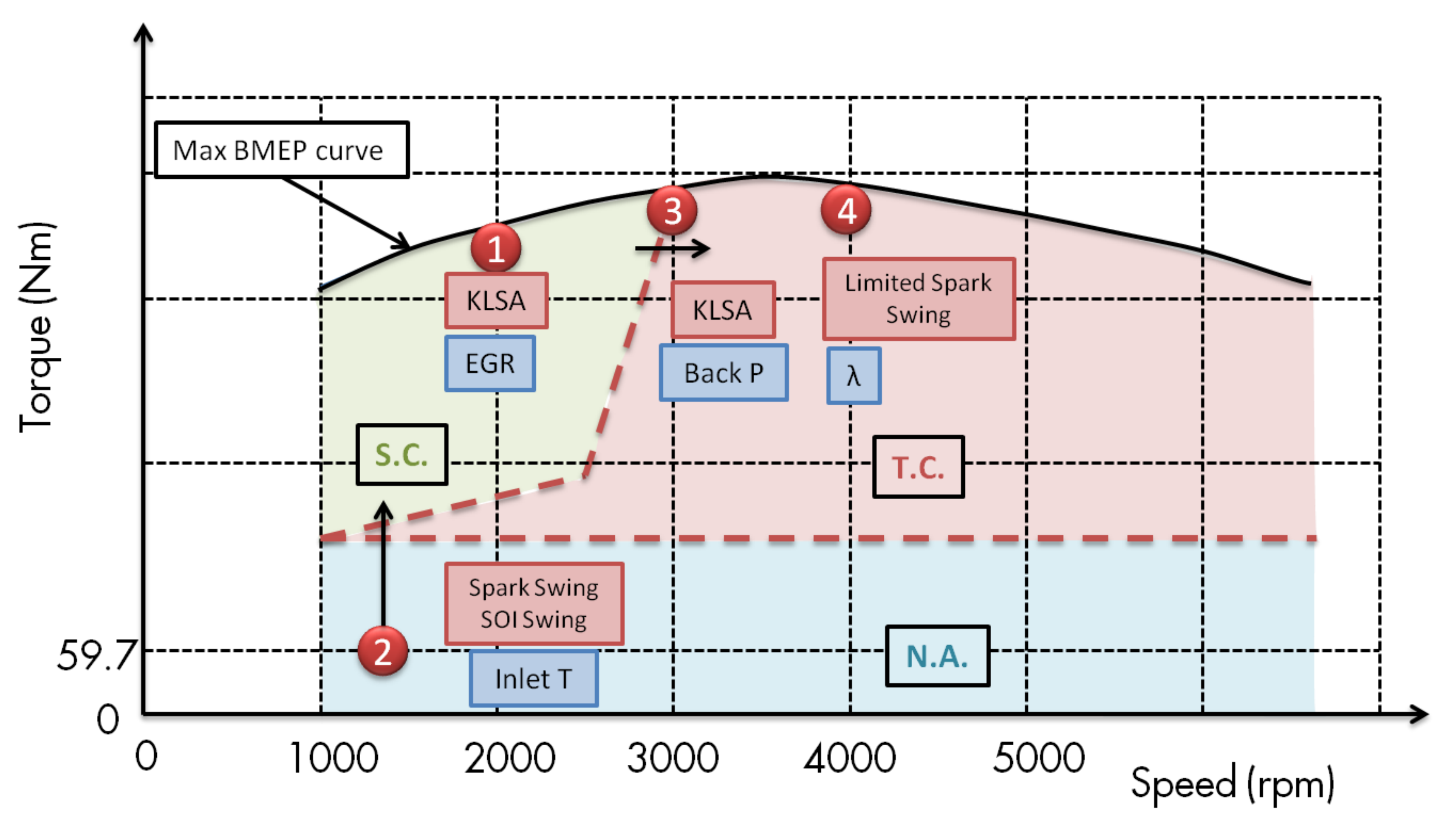
# Sampling location

- Approx 3m downstream of exhaust manifold
- Water cooled exhaust manifold
- Downstream of backpressure valve and one silencer
- No catalyst



Sampling location

# Test points


Max BMEP curve
Torque (Nm)
59.7
0
0
1000
2000
3000
4000
5000
Speed (rpm)
1
KLSA
EGR
2
Spark Swing
SOI Swing
Inlet T
3
KLSA
Back P
4
Limited Spark
Swing
λ
S.C.
T.C.
N.A.

# Test fuels

- 10 fuels tested – 3 "market", 7 "test"

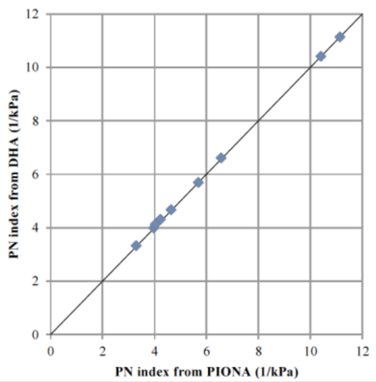
- A-D – deconvolved RON/MON matrix
- E/F – High/Low laminar flame speed
- G – Artificially boosted RON
- H – minimum EN228 RON
- I – "Winter" gasoline
- Base – standard EN228

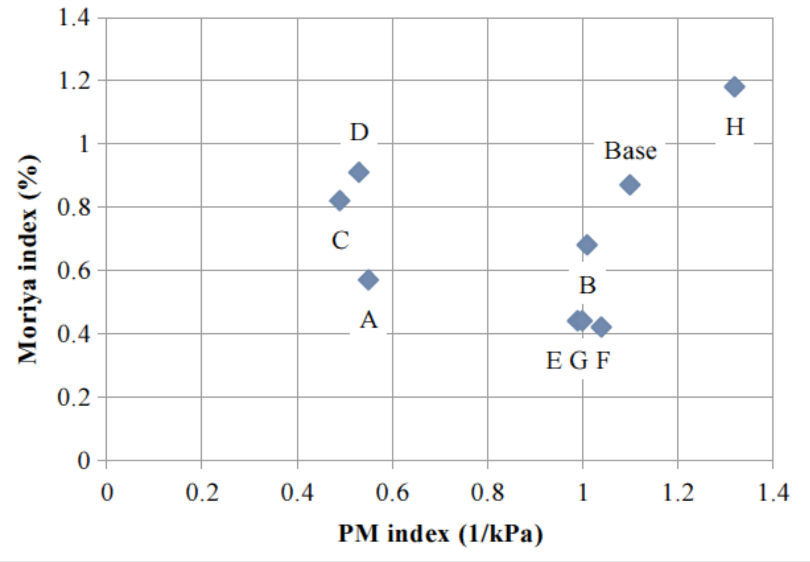
| Fuel | RON (-) | MON (-) | DVPE (kPa) | FBP (°C) | E150 (%) | C (% m/m) | H (% m/m) | O (% m/m) | PN index* (1/kPa) | PN index** (1/kPa) | PM index (1/kPa) | Moriya index*** (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 103.3 | 95 | 26.1 | 177 | 96 | 7.15 | 14.45 | 0.17 | 6.57 | 6.61 | 0.55 | 0.57 |
| B | 101.4 | 88.8 | 68.0 | 176 | 95 | 6.40 | 11.17 | 0.11 | 3.97 | 3.99 | 1.01 | 0.68 |
| C | 92.8 | 90.7 | 30.5 | 193 | 93 | 7.41 | 15.94 | 0.00 | 4.23 | 4.31 | 0.49 | 0.82 |
| D | 88.6 | 87.3 | 32.9 | 190 | 92 | 7.31 | 15.64 | 0.00 | 4.03 | 4.12 | 0.53 | 0.91 |
| E | 95.1 | 82.2 | 28.7 | 138 | 98 | 6.68 | 12.38 | 0.00 | 10.41 | 10.41 | 0.99 | 0.44 |
| F | 104.2 | 92.6 | 23.3 | 139 | 98 | 6.94 | 12.46 | 0.00 | 11.14 | 11.14 | 1.04 | 0.42 |
| G | 111.6 | 101.2 | 57.4 | 192 | 98 | 7.10 | 11.80 | 0.00 | 5.69 | 5.69 | 1.00 | 0.44 |
| H | 95.1 | 85.0 | 53.1 | 189 | 88 | 6.20 | 11.48 | 0.10 | 4.64 | 4.67 | 1.32 | 1.18 |
| I† | 98.7 | 86.5 | 97.4 | 173 | 95 | 6.28 | 11.23 | 0.00 | 2.64 | n/k | n/k | 0.66 |
| Base | 97 | 85.3 | 75.0 | 188 | 92 | 6.05 | 11.11 | 0.10 | 3.30 | 3.33 | 1.10 | 0.87 |

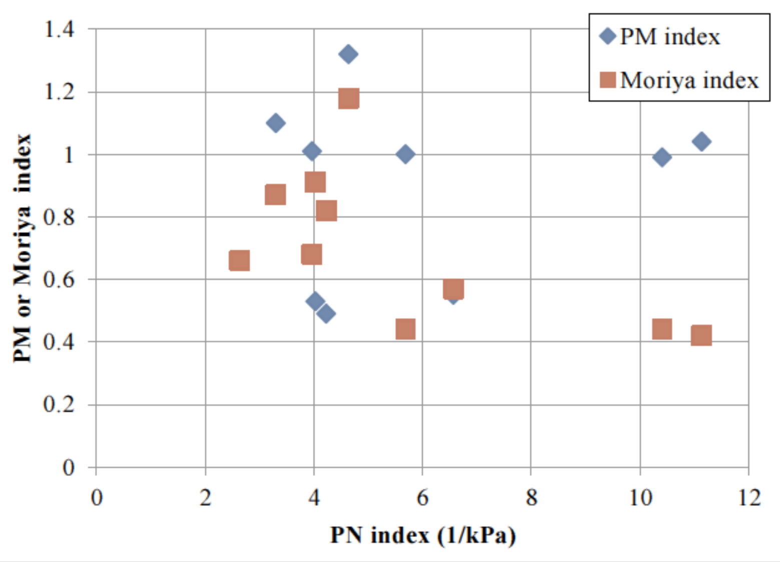
*Calculated from PIONA (ASTM D1319) analysis ** Calculated from DHA
*** Simplified Moriya index by Equation 5 † A DHA was unavailable for Fuel I

# Test fuels – spread of indices

- PN index identical (~1%) from two calculations
- Little correlation between three indices



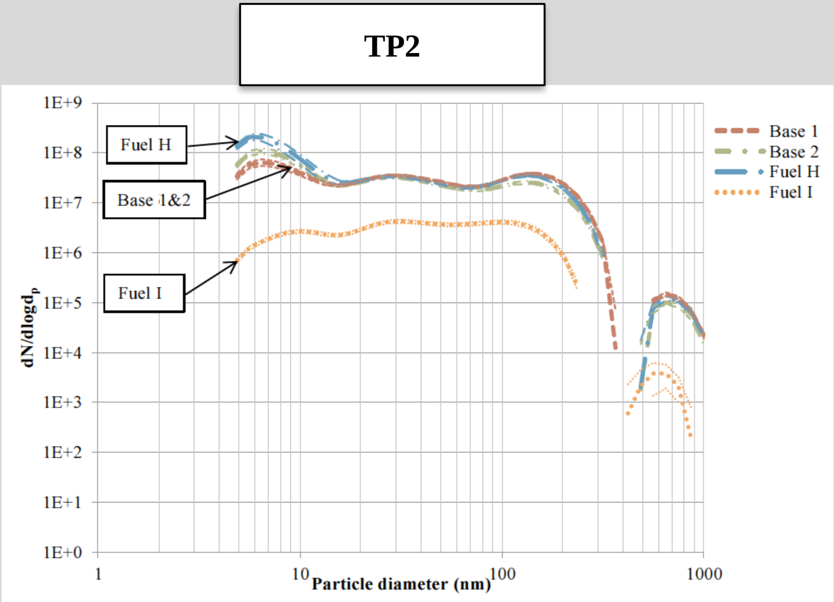
# Results – Market fuels

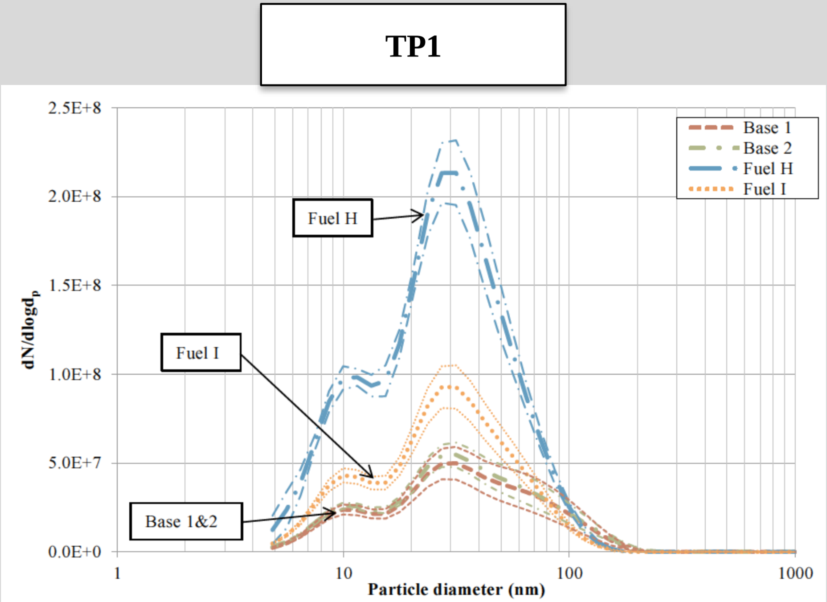
- Trends from previous work followed

| Variable | Effect on PN emissions |
|---|---|
| Engine load | Load ↑ Particulates ↑ |
| Fuel injection pressure | P ↑ Particulates ↓ |
| EGR | EGR ↑ Particulates ↑ |
| Inlet air temperature | T ↑ Particulates ↓ |
| Exhaust back pressure | Back pressure ↑ Particulates ↓ |
| λ (AFR) | λ ↓ Particulates ↑ |
| Spark timing | Ignition ← Particulates ↓ |
| Fuel injection timing | Injection → Particulates ↓ |

# Results – Market fuels

- All fuels – accumulation mode peak at ~30nm when boosted
- At part load – Fuel I (high DVPE) lowest PN
- At 2000rpm / max BMEP – fuel H highest PN
- Base fuel repeatable

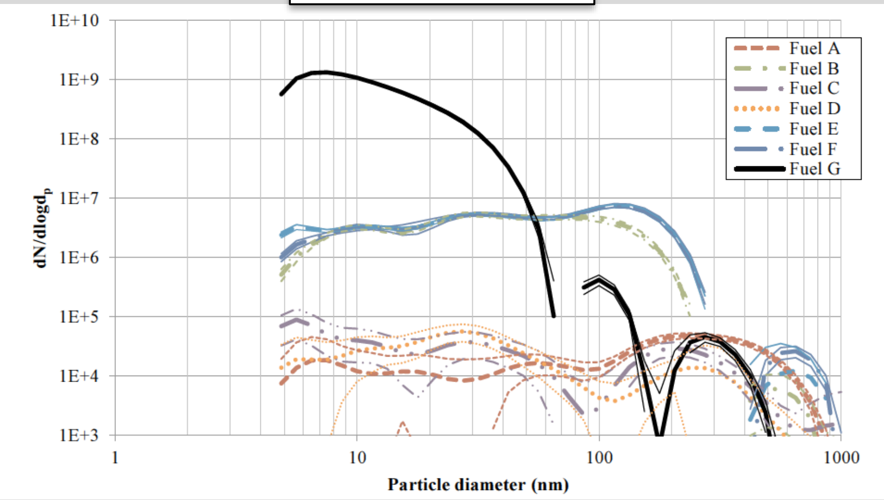


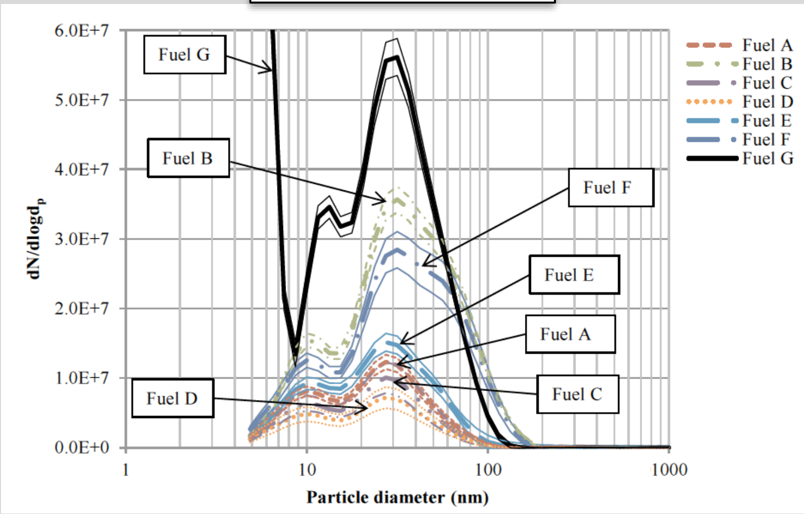
# Results – Test fuels

- Fuel G (artificially boosted RON) – v high PN + v small $d_p$.
  - Atypical distillation curve
  - High THC emissions (& BSFC)
- Fuels B & F high PN – B: high DVPE
- Fuels B&F “wide” accumulation mode (30-100 nm)

**TP2**

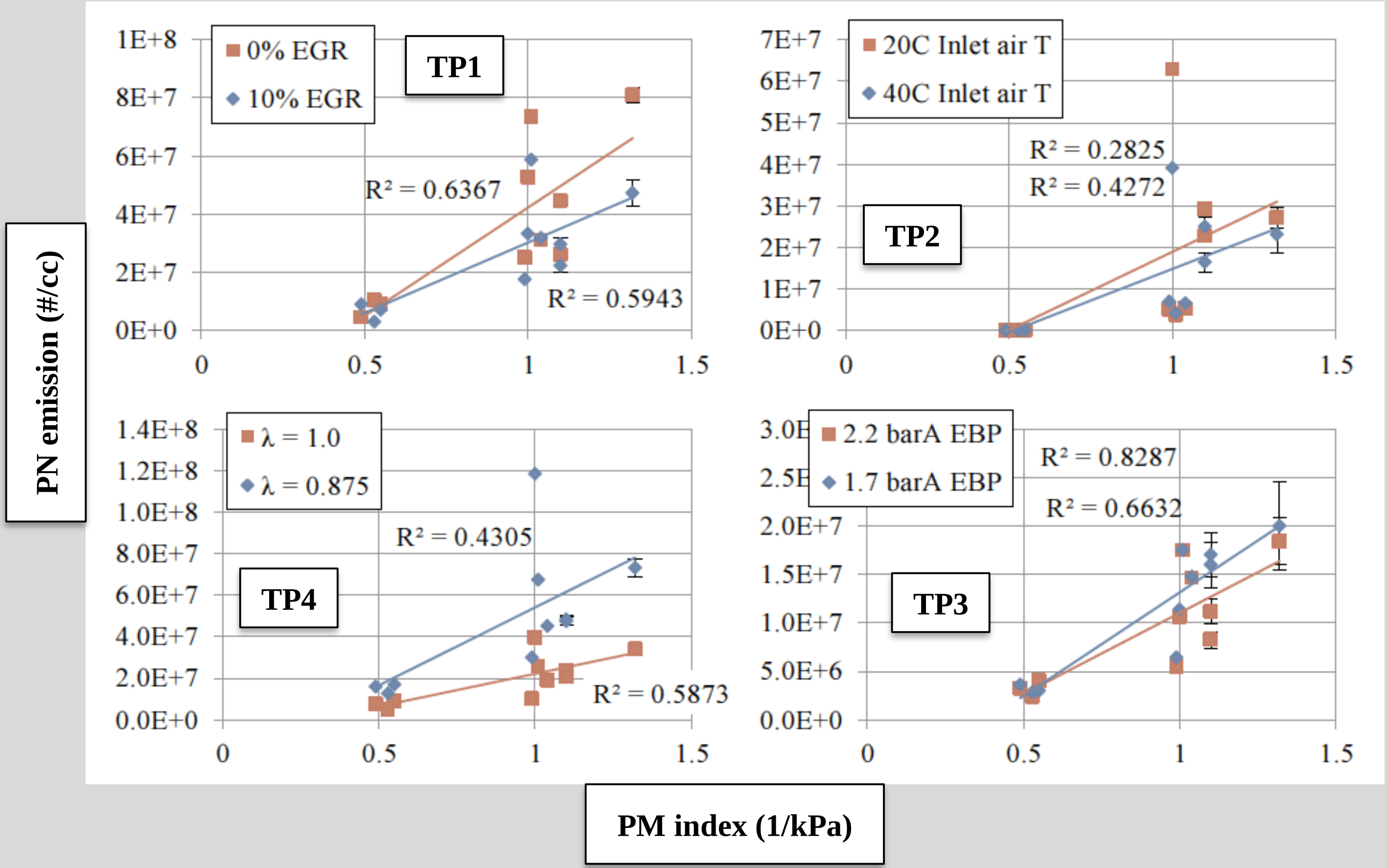



**TP3**



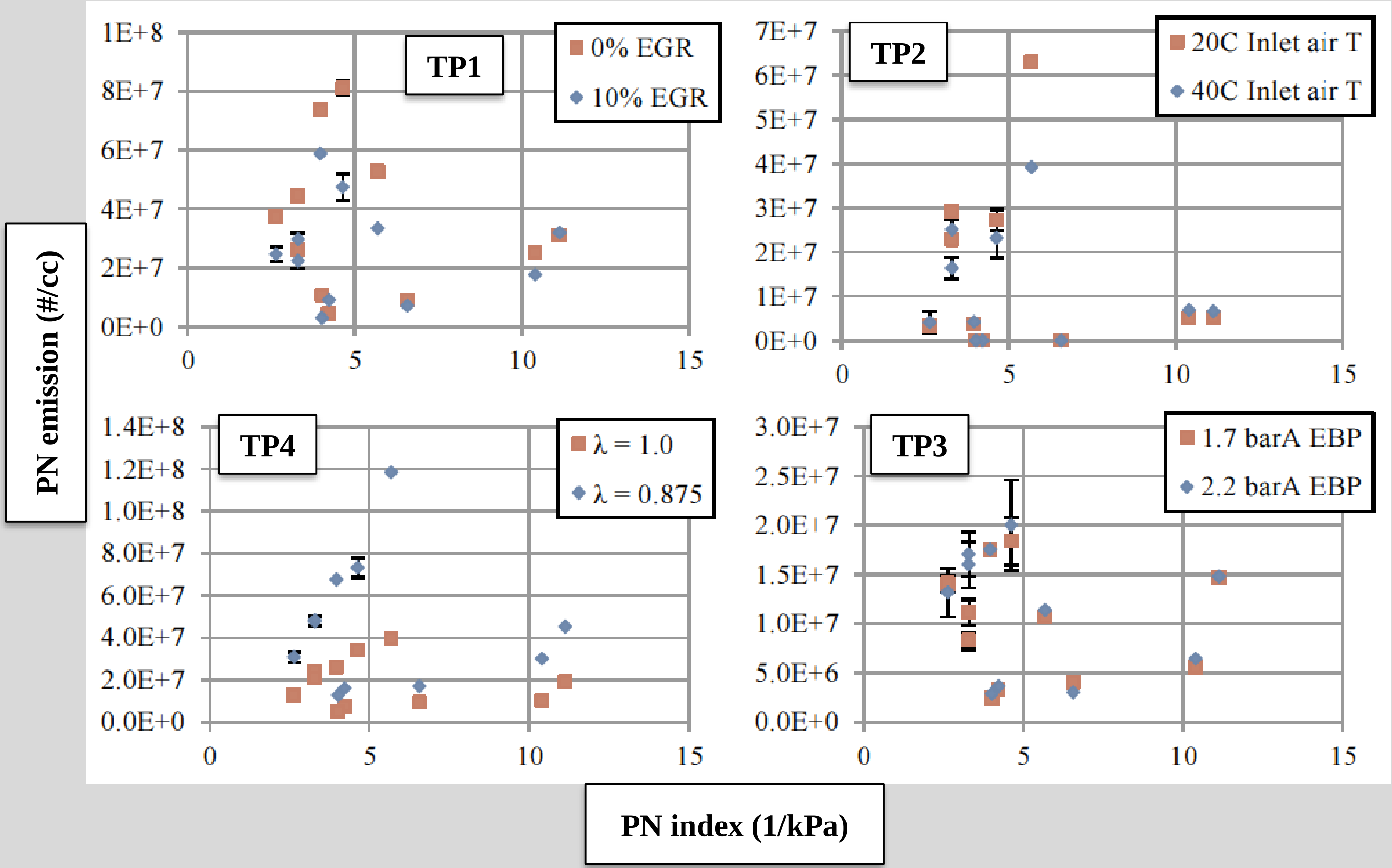
# Results – Evaluation of indices

- PM index matches fairly well for all fuels (lower correlations than seen in literature)



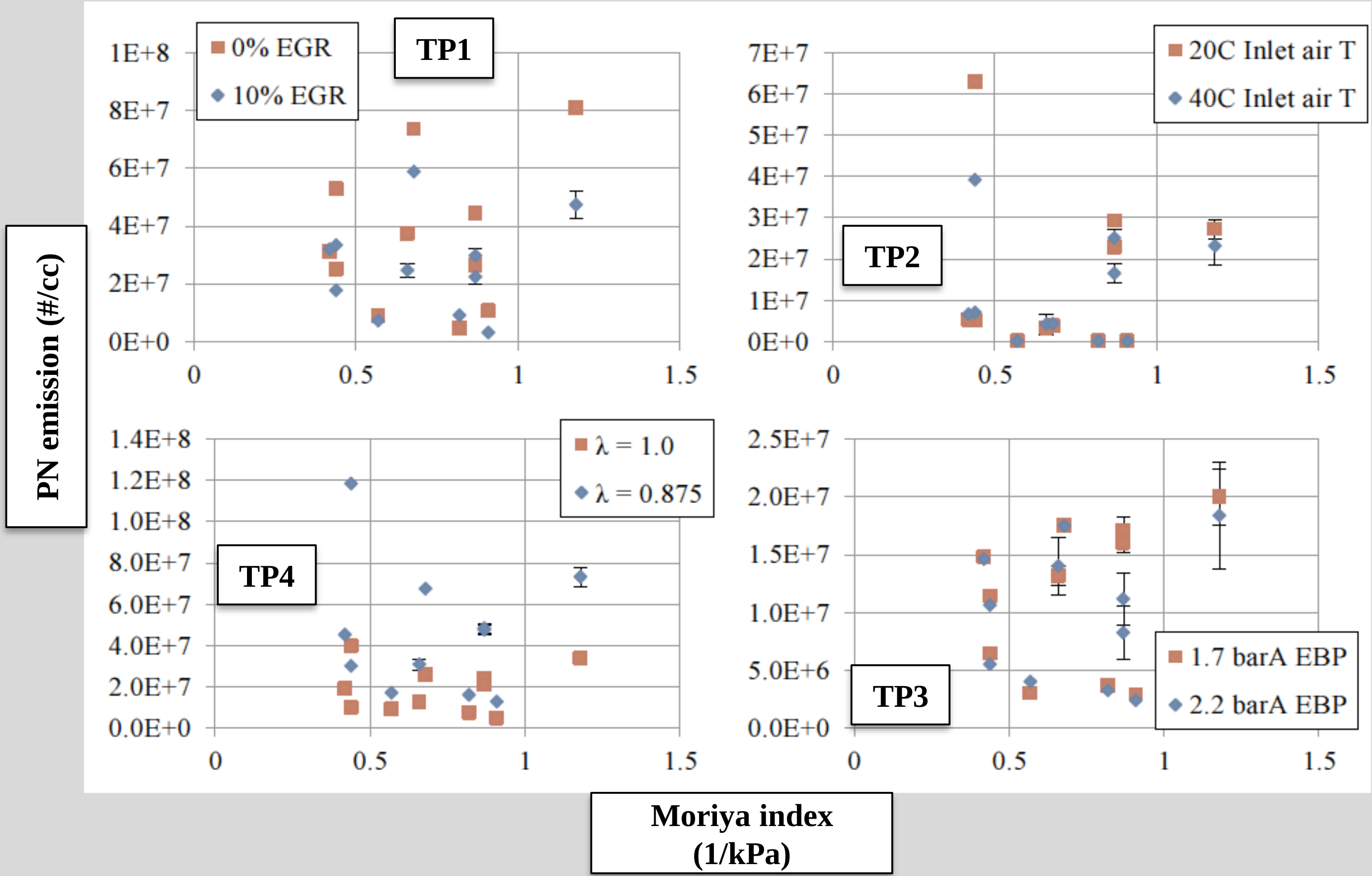
# Results – Evaluation of indices

- PN index does not match that well for all fuels



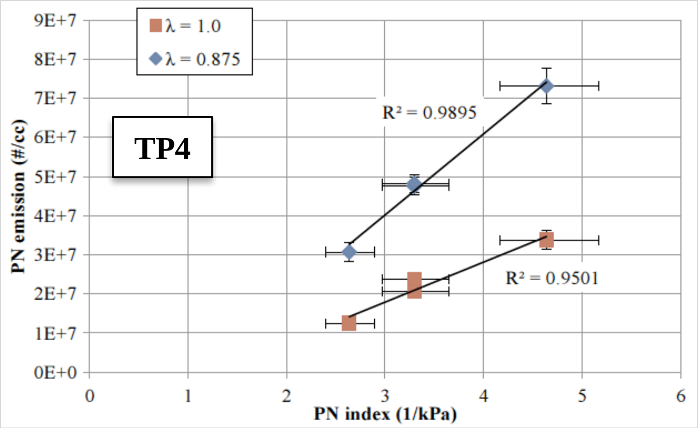
# Results – Evaluation of indices

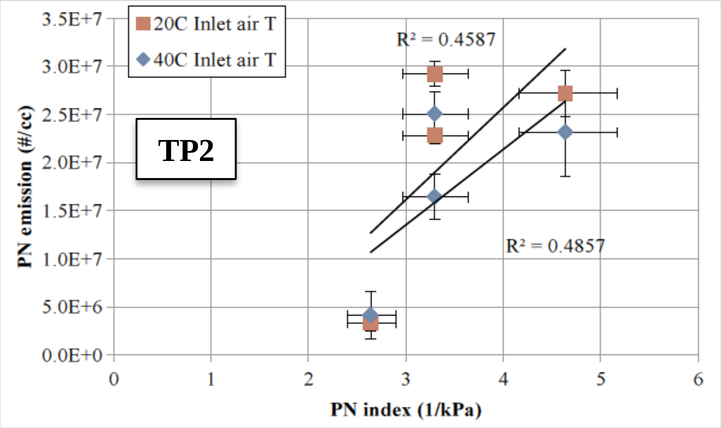
- Moriya index does not match well for all fuels



# Results – Evaluation of indices

- PN index – market fuels

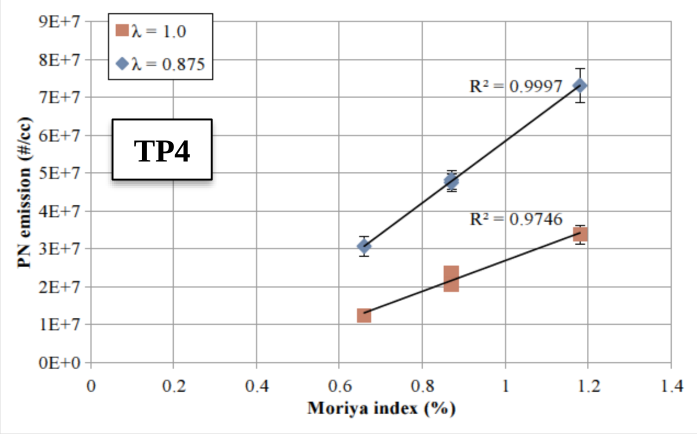


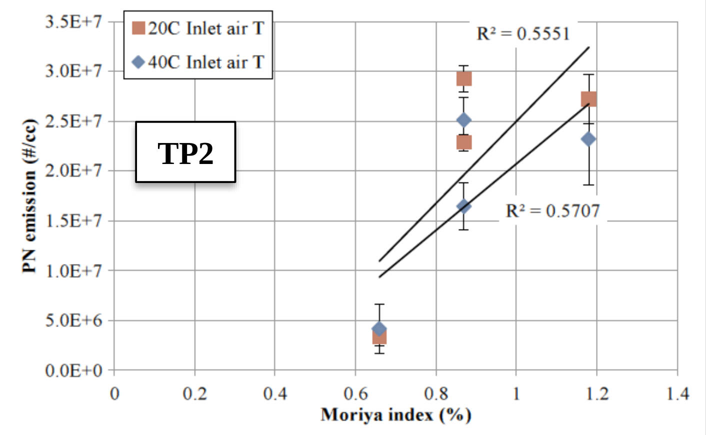




- Good(ish) correlations from PN index with market fuels – best at boosted conditions

# Results – Evaluation of indices

- Moriya index – market fuels




- Good(ish) correlations from Moriya index with market fuels – best at boosted conditions

# Conclusions

- PN emissions from 10 different test fuels
- Fuel composition remains important factor
- PM index good predictor of emissions at all test conditions
    - Heavy aromatics
- PN index & Moriya – good for market fuels in this work
- All indices strongest correlations when boosted
- More complex index ➔ better match
    - DHA very useful
- Small (~30nm) accumulation mode particles seen from all fuels

# Ultraboost consortium

ULTRABOOST

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GE PRECISION ENGINEERING

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# Thank you


- Leach FCP, Stone CR, Richardson D, Lewis AGJ, Akehurst S, Turner JWG, Shankar V, Chahal J, Cracknell R, Aradi A, “The effect of fuel composition on particulate emissions from a highly boosted GDI engine – an evaluation of three particulate indices”. Fuel, Vol 252, pp. 598–611, 2019. doi:10.1016/j.fuel.2019.04.115

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