



DfT Brake & Tyre Programme Phase 2: Impact of Regen Braking and Vehicle Mass on Brake Particle Emissions Across ICE, PHEV & EV Platforms

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Introduction to DfT Brake and Tyre Programme

UK Policy Context & Research Focus

- NEE Challenge: Brake, tyre, and road wear now major sources of PM10 & PM2.5; PN10 also Euro 7 relevant
- Knowledge Gap: Limited understanding of factors influencing non-exhaust emissions
- DfT Motivation: Inform UK policy on reducing brake & tyre wear emissions; contribute to the generation of emissions factors

Phase 2 Research Questions

- What variables affect brake & tyre particle emissions?
- How do component types and ageing influence emissions?
- What is the impact of regenerative braking and mitigation technologies?

Drivers

- NEE dominates road transport PM emissions
- Insights will support effective air quality and public health policy

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DfT Phase 1 Summary



Outcomes:

- Brake and tyre particle emissions sampling demonstrated on light-duty van using enclosure and duct-based approaches
 - Successful testing on chassis dyno, test-track, on-road urban
- Brakes - Real-time particle number and mass emissions corresponded to real-time braking events, lowest emissions were seen at lowest speeds
- Tyres - Non-volatile PN, and PM, emissions can be related to individual braking events on the chassis dynamometer, but not easily on the track or road
- Repeated aggressive braking events lead to outgassing of volatile materials from tyres

<https://assets.publishing.service.gov.uk/media/647ed40cb32b9e000ca9621d/measurement-of-emissions-brake-and-tyre-wear.pdf>

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Phase 2 Objectives

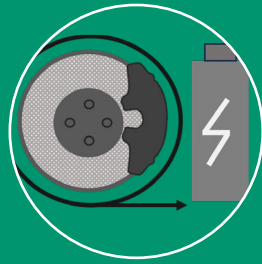
Investigate the influence of different variables affecting particle emissions from brake and tyre wear, and determine typical emissions levels to assist in developing emissions factors



Variations in brake
and disc materials

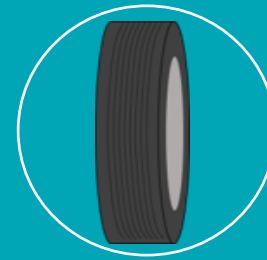
Age (mileage) of the
brake components

Driving speeds and
dynamics



Use of regenerative
braking for hybrid and
EV vehicles

Effects of vehicle
mass

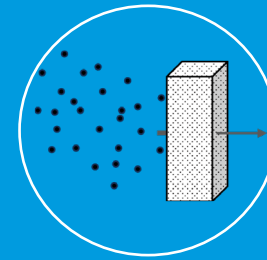


Variations in tyre
composition

Age of the tyre

Tyre sizes

Driving speeds and
dynamics



Technologies
aimed at reducing
particle emissions

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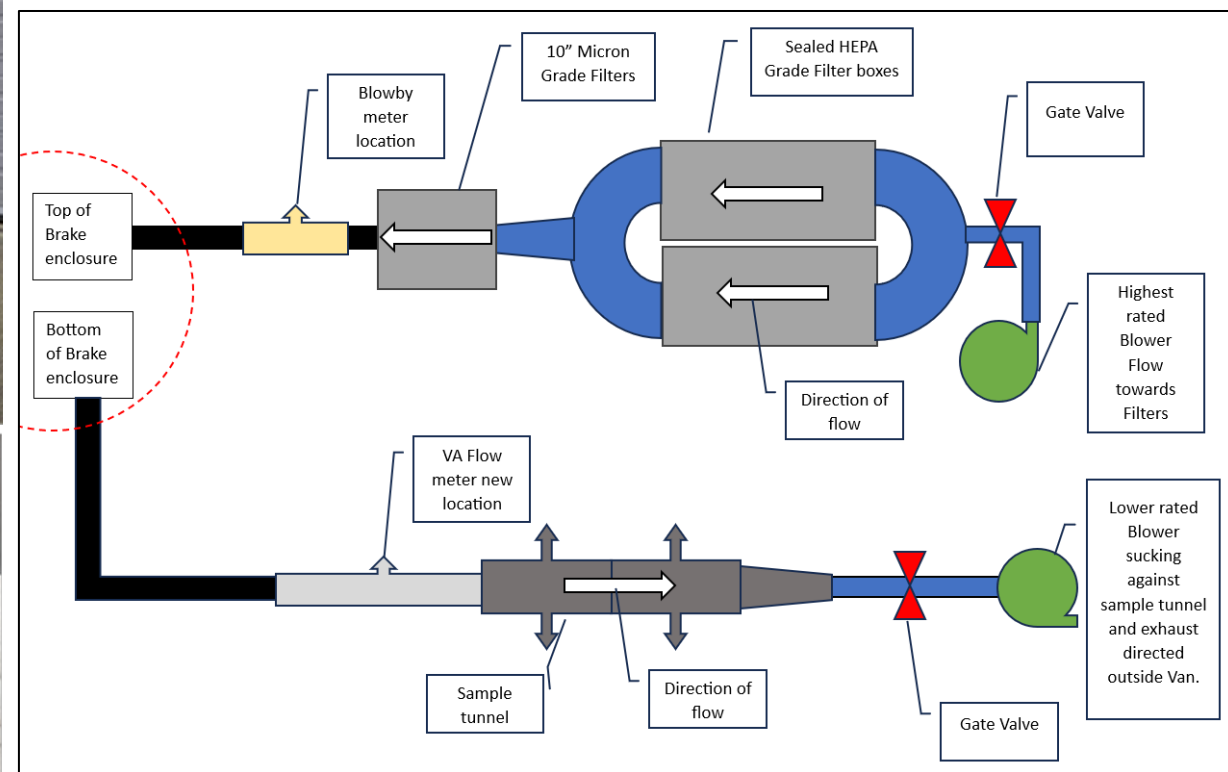
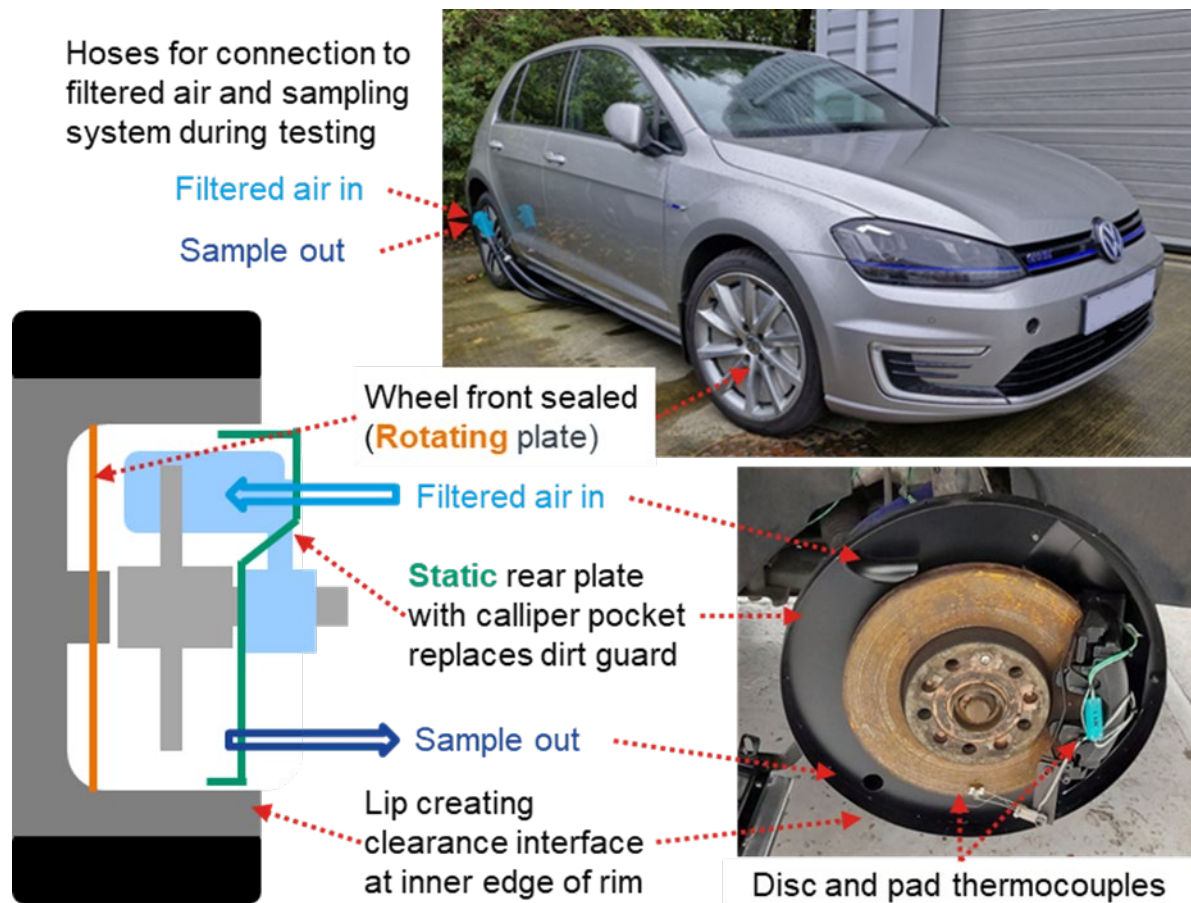
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Sampling System – Brakes (Optimised following Phase 1)



For the VW Caddy the measurement equipment could be installed on-board or tested off-board, for other vehicles the testing on chassis dyno was executed with the equipment on a trolley

Test Vehicles

- Three different vehicles were used in the comparative test work, all built on the same VW Golf platform: ICE, PHEV, EV
- Test masses
 - EV: 1700kg, 1900kg (**high regen braking**)
 - PHEV: 1700 kg & 1900kg (**moderate regen braking**)
 - ICE: 1500kg, 1900kg (**no regen braking**)
 - 1500 kg represents typical ICE gasoline Golf TSI



Regenerative
braking and
vehicle mass
evaluations

Brake pad and
disc testing
(ETH 2025)

Measurement equipment used during Phase 2 brake emissions testing

Metric	Instrument
PM2.5 in the lab/on road (real-time and gravimetric)	Dekati eFilter (PM2.5)
Non-volatile PN10 in the lab	AVL APC+ (PN10)
Non/low-volatility PN10 in the lab/on road	Dekati Hot MPEC+ (PN10)
Total PN10 in the lab/on road	Dekati Cold MPEC+ (PN10)
Particle size distribution 5nm to 2500nm in the lab	Cambustion DMS500

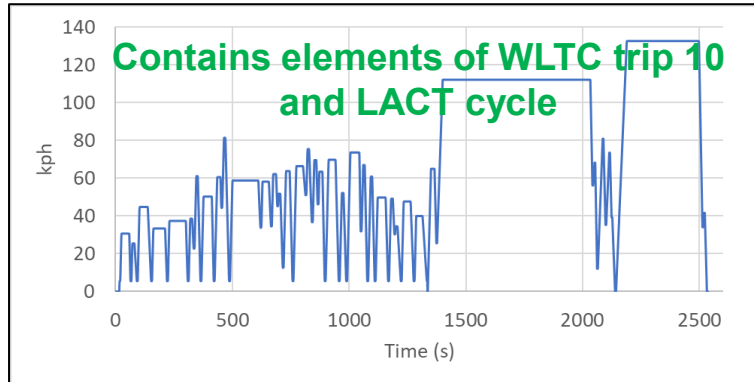
} Data shown

Additional measurements were also taken, including vehicle speed, brake fluid pressure, brake temperature, tyre temperature and air flow

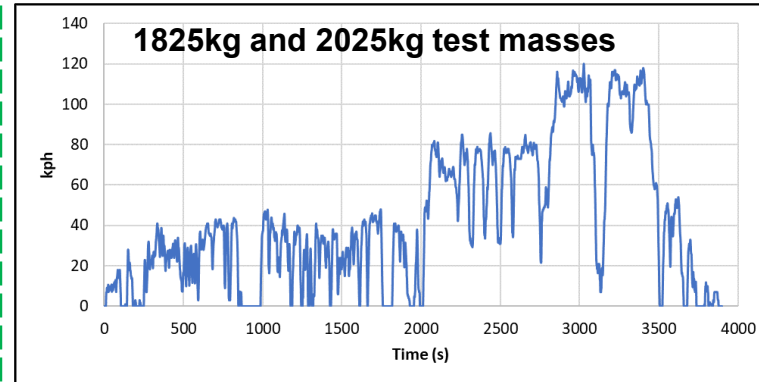
Test Cycles

Seven different drive cycles were used in the testing; here emissions results focus on the PG42 cycle & dyno RDE

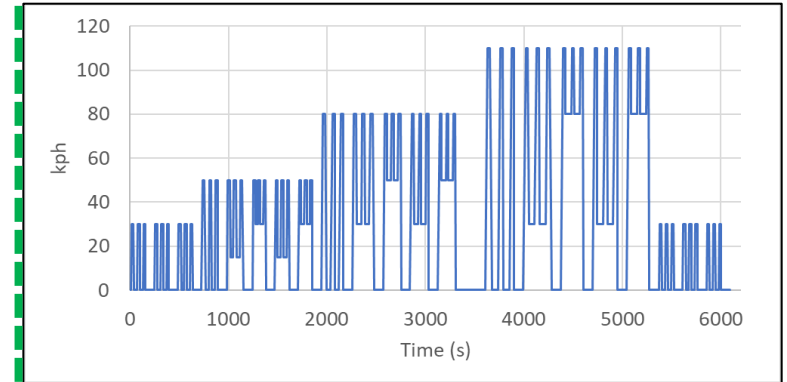
PG42 - high particle emitting cycle



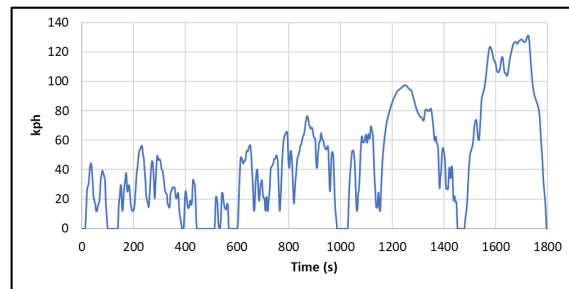
On dyno RDE - real driving emissions



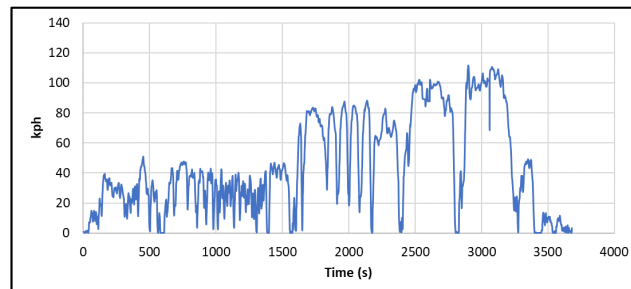
Bespoke – specified braking events



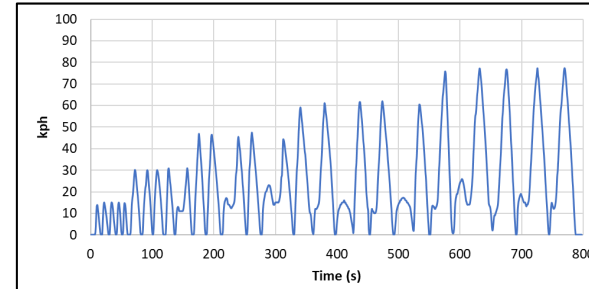
WLTC - certification cycle



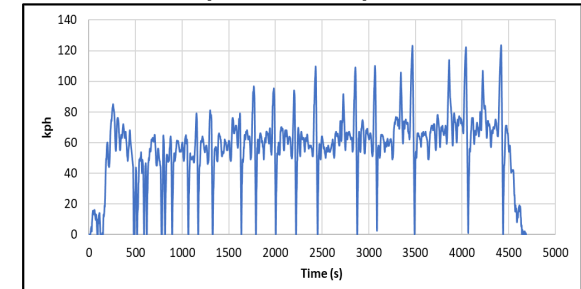
Road RDE - real driving emissions



Drive-by track - braking events up to 50 mph



High speed track - braking events up to 80 mph



Controlled Evaluation of Brake Technology and Mass Effects

- Three Vehicles on Same Golf VII Platform
 - VW Caddy (ICE)
 - Golf GTE (PHEV)
 - eGolf (EV)

Disc ref	Disc	Pad ref	Pad cost	Pad description / material
D1	"Low cost"	P1	£££	Premium brake pad

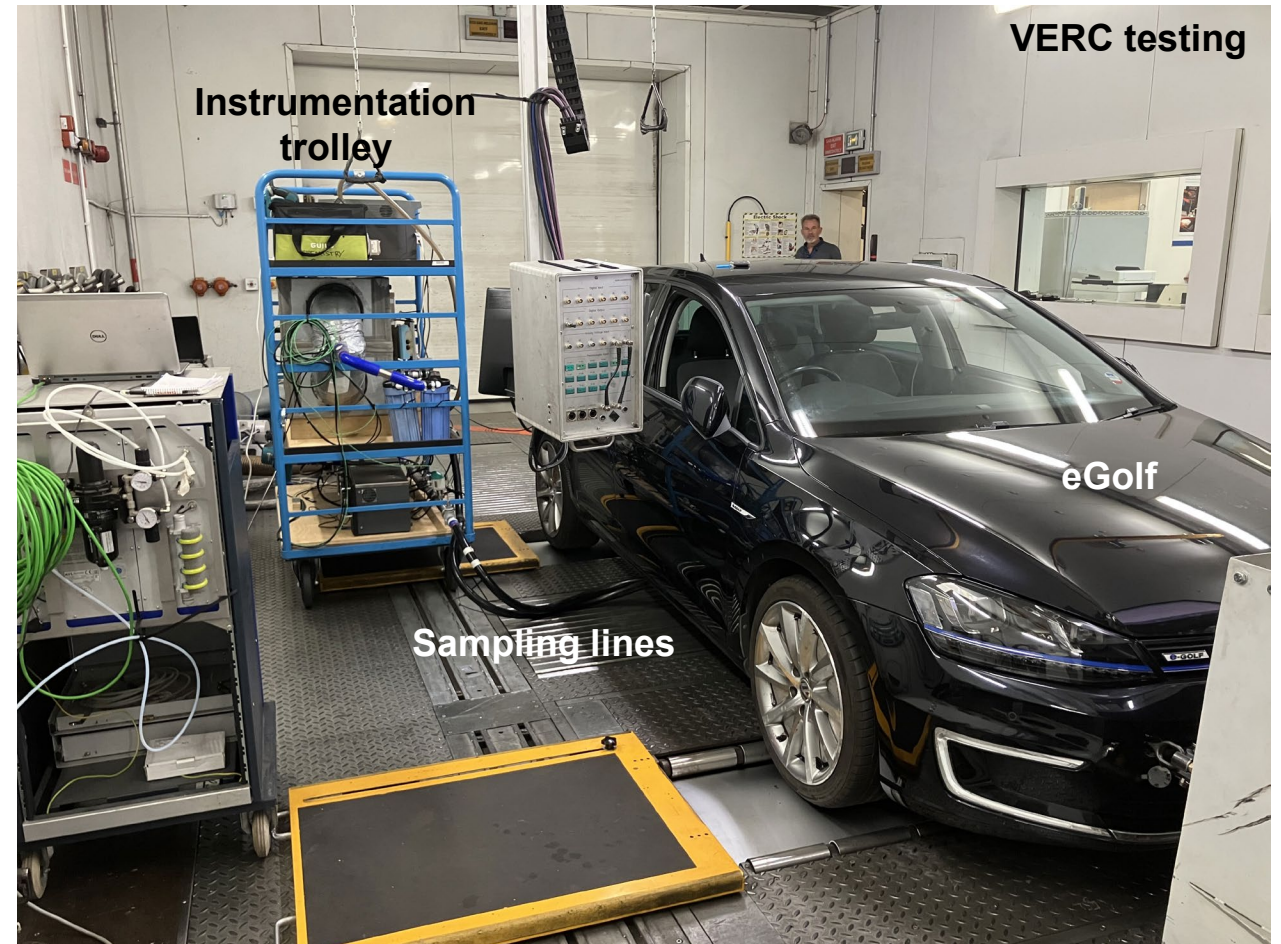
The same brake calliper, disc (D1), pad (P1), brake enclosure and wheels were used with all three vehicles



Methodology for Technology and Mass Assessment

- Chassis Dynamometer Testing
 - Controlled environment limits external variables and ensures repeatability
- Drive cycles:
 - PG42 (high particle emissions cycle)
 - RDE (real world driving, on chassis dyno)
- Objectives
 - Isolate effects on PN10 & PM2.5 emissions of
 - regenerative braking (fixed mass)
 - vehicle mass
 - (1500kg, 1700kg, 1900kg)

All results shown were measurements from a single front wheel



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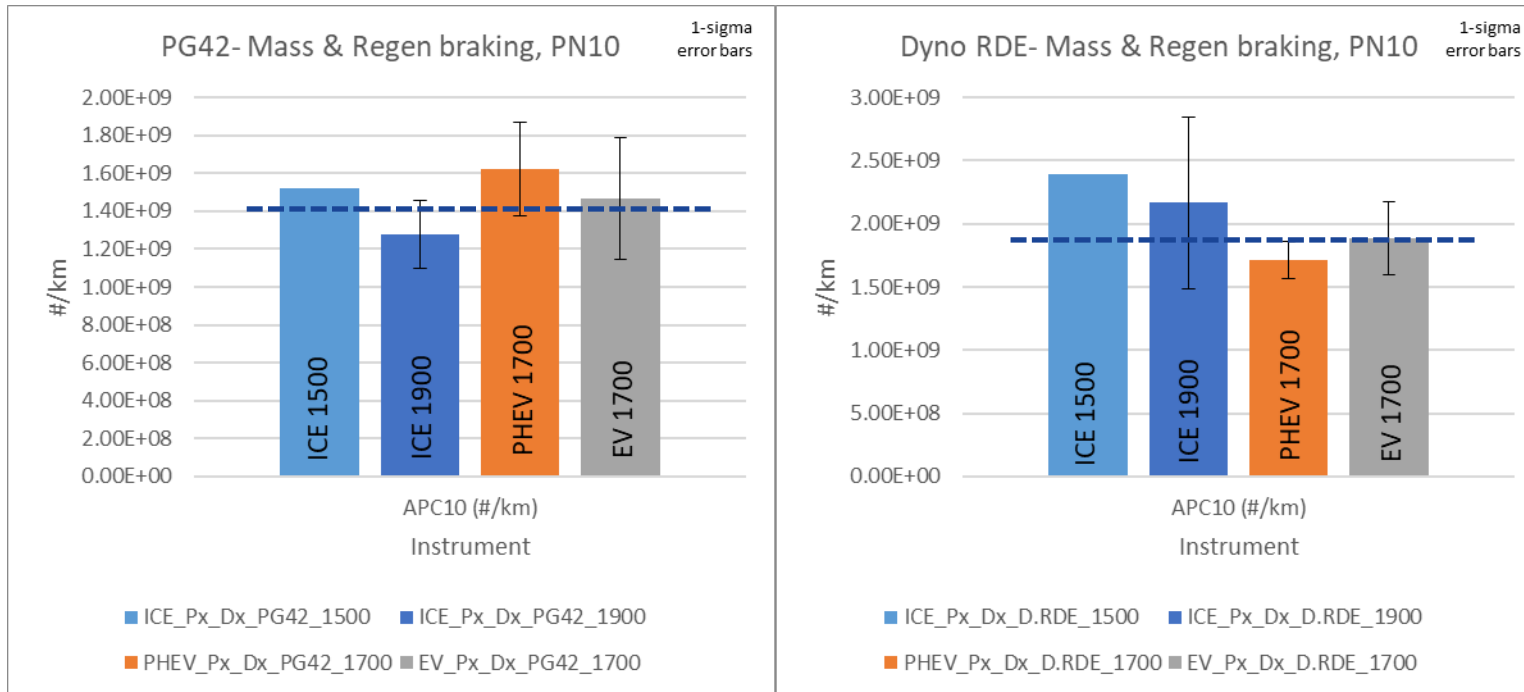
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Vehicle-to-vehicle comparisons of **PN10** emissions, representative masses, PG42 and dyno RDE

Using the same braking system pads, discs, brake enclosure and wheels



Scope

- PN10, **representative** test masses
- PG42 and dyno RDE cycles

Outcomes

- PN10 emissions similar between ICE, PHEV and EV
- No impact on ICE PN10 emissions between 1500 kg and 1900 kg

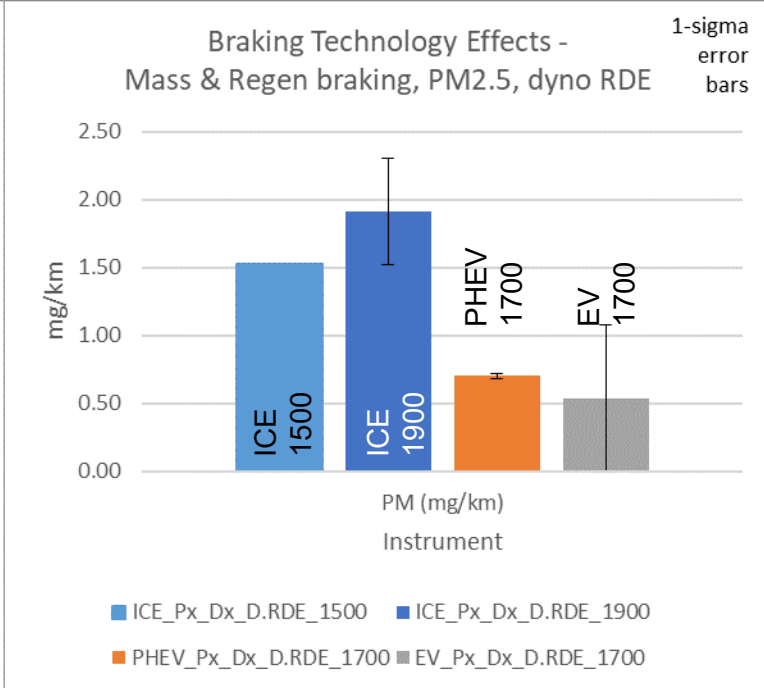
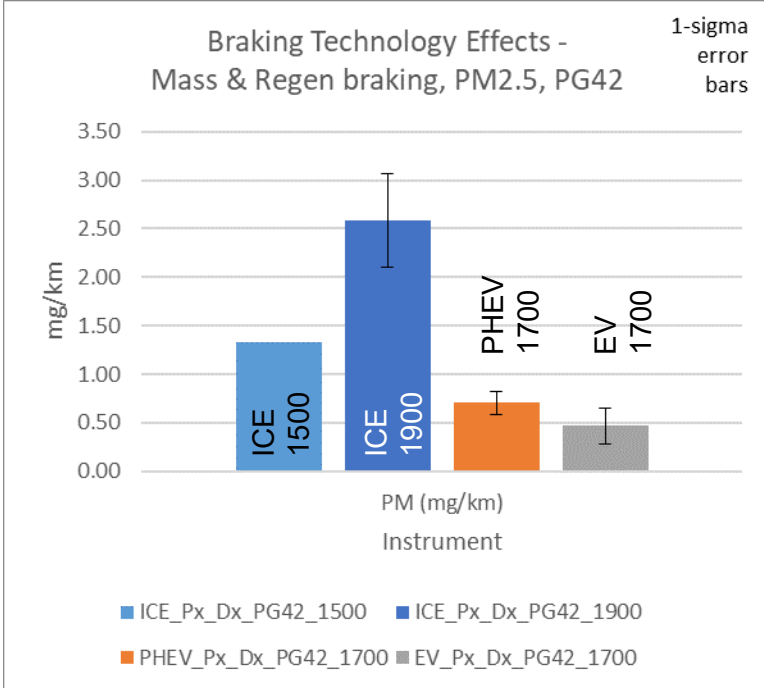
Headlines

- **Higher test mass and regenerative braking have minimal impact on PN10 emissions**

Representative masses: ICE at 1500kg, 1900kg; PHEV at 1700kg; EV at 1700kg

Vehicle-to-vehicle comparisons of **PM_{2.5}** emissions, representative masses, PG42 and dyno RDE

Using the same braking system pads, discs, brake enclosure and wheels



Scope

- PN2.5, representative test masses
- PG42 and dyno RDE cycles

Outcomes

- Highest PM_{2.5} emissions from ICE at 1900 kg test mass
- PHEV and EV PM_{2.5} emissions lower than ICE, even when ICE lighter (1500 kg test mass)
- Lowest PM_{2.5} emissions from EV, but not possible to discriminate from PHEV emissions
- PM_{2.5} differences observed, but no PN₁₀ differences, indicates volatile material effects dominate

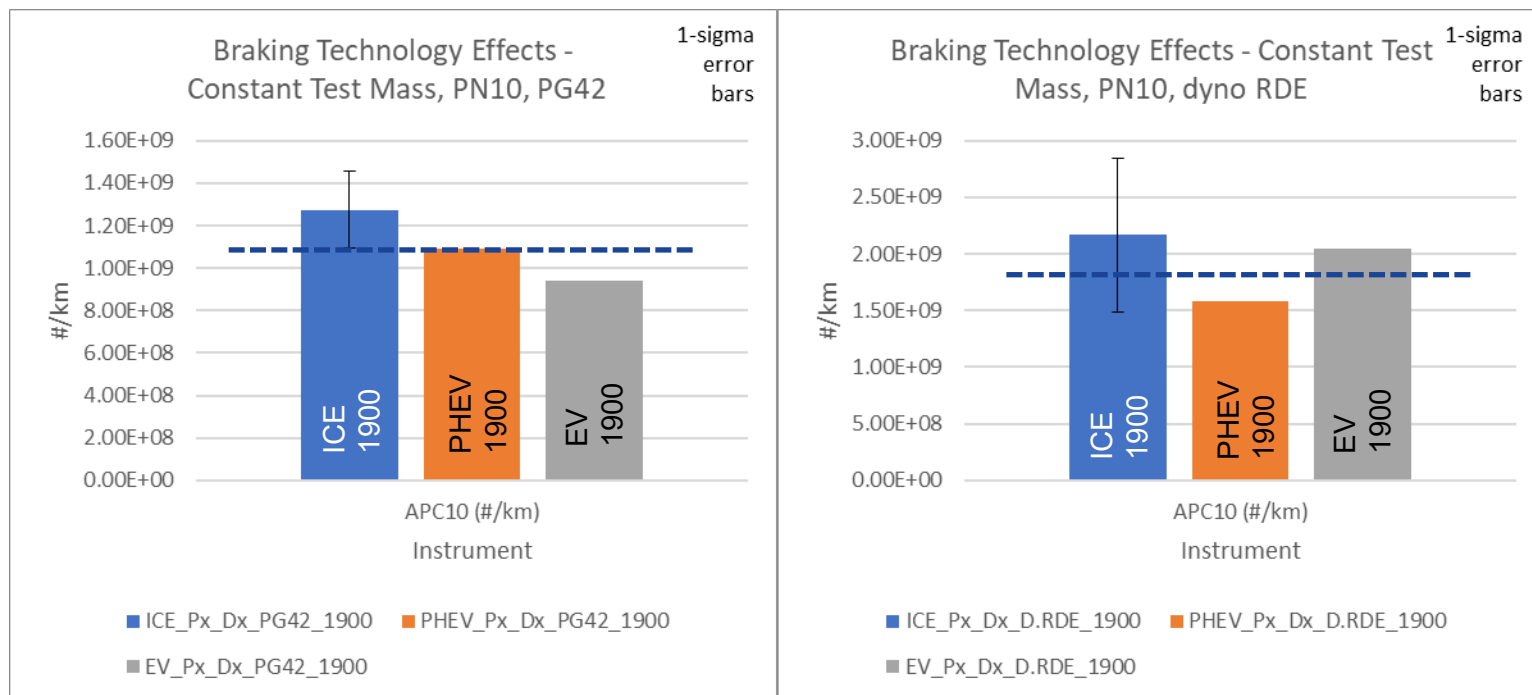
Headlines

- **Regenerative braking of EV/PHEV cuts PM_{2.5} more effectively than reducing vehicle mass by ~20% (1900kg to 1500kg)**

Representative masses: ICE at 1500kg, 1900kg; PHEV at 1700kg; EV at 1700kg

Vehicle-to-vehicle comparisons of **PN10** emissions, 1900kg test mass, PG42 and dyno RDE

Using the same braking system pads, discs, brake enclosure and wheels



Scope

- PN10 emissions, fixed 1900 kg test mass
- PG42 and dyno RDE cycles

Outcomes

- No obvious differences in PN10 emissions between ICE, PHEV and EV

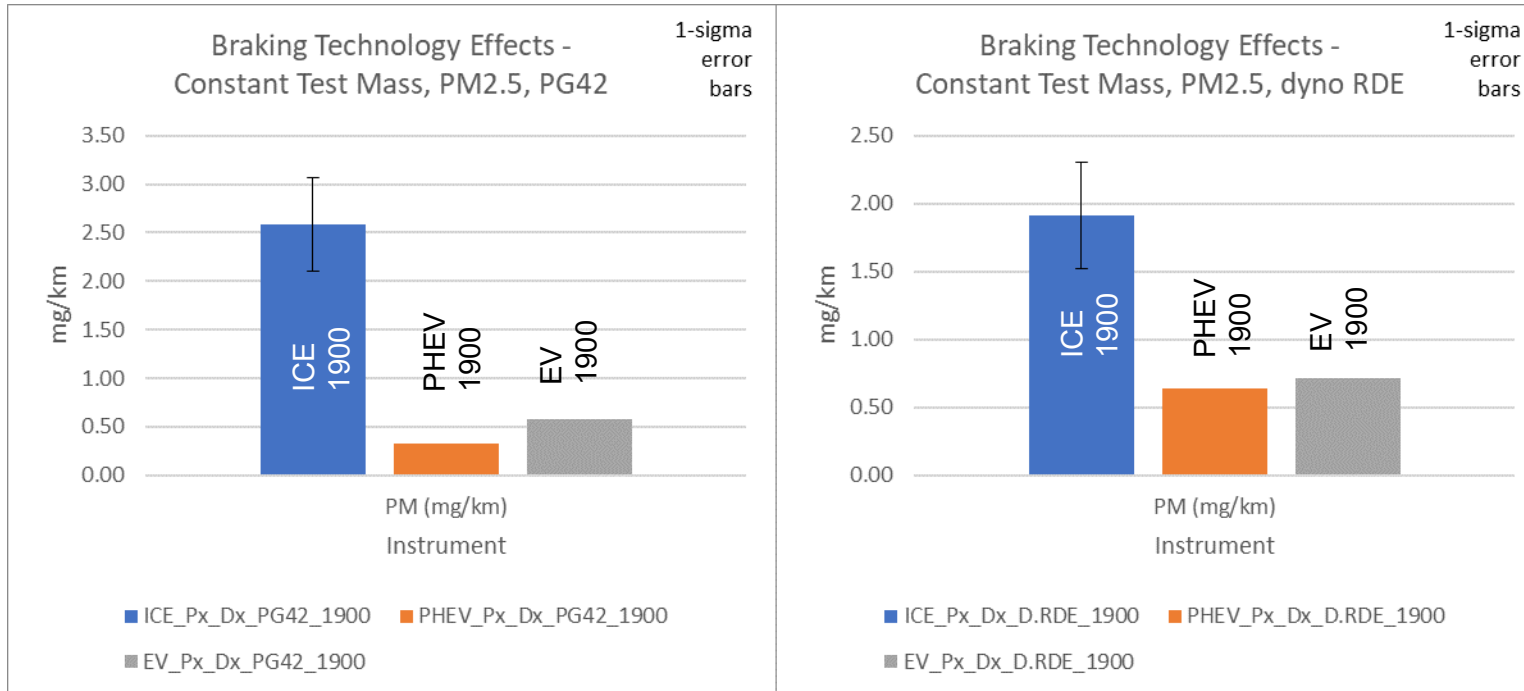
Headlines

- **No consistent effect of regenerative braking on PN10 emissions**

Fixed masses: ICE at 1900kg; PHEV at 1900kg; EV at 1900kg

Vehicle-to-vehicle comparisons of **PM_{2.5}** emissions, 1900kg test mass, PG42 and dyno RDE

Using the same braking system pads, discs, brake enclosure and wheels



Scope

- PM_{2.5} emissions, fixed 1900 kg test mass

Outcomes

- Clearly highest PM_{2.5} emissions from ICE
- Similar emissions from PHEV and EV
- PM differentiation but not PN₁₀ differentiation indicates mass differences are a volatile effect

Headlines

- **Regenerative braking substantially reduces PM_{2.5}**
 - by lowering brake temperatures and reducing volatile losses

Fixed masses: ICE at 1900kg; PHEV at 1900kg; EV at 1900kg

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Conclusions: Effects of Regenerative Braking & Vehicle Mass

- Regenerative braking substantially reduces PM2.5 and PM10 emissions
 - EV and PHEV emissions consistently lower than ICE, even when ICE is lighter
 - EV lowest PM2.5 emissions
 - Vehicle mass effect is smaller
 - ICE at 1900 kg highest PM2.5; 1500 kg has lower mass emissions but still higher than EV/PHEV
 - PM10 emissions virtually unchanged across different Golf VII models and test masses
- Key takeaway
 - Regen braking benefit > ~20% mass reduction for PM2.5 emission

Conclusions: Quantified Impacts & Reasons

- PM2.5 trends
 - ICE 1900 kg > ICE 1500 kg > PHEV ≈ EV
 - At 1900 kg: ICE highest; EV/PHEV consistent and much lower
- PN10 trends
 - Minimal impact of regenerative braking or mass differences
- Reasoning
 - Regen braking reduces friction brake use ► lower temperatures ► less volatile material loss
 - Vehicle mass increases brake load and temperature, but this has a limited effect because PN10 is dominated by non-volatile particles
- Highlights
 - For PM2.5 emissions, regen braking in EV and PHEV more than offsets the higher vehicle mass
 - For a fixed drive cycle and vehicle type, different models appear to have similar PN10 emissions

Acknowledgements

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 - Project manager: Rebecca Trebilcock



Reports of both phases of the DfT project can be found here:
[Measurement of emissions from brake and tyre wear - GOV.UK](#)

Any questions?