Particle Emissions From Brake and Tyre Wear – Results from the Phase 1 study for the UK DfT

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AGENDA

- Introduction to non-exhaust emissions
- Measurement of Brake and Tyre Wear
- System design and testing
- Results
- Conclusions

Non Exhaust Emissions (NEE)

Brake Wear
Friction between the brake disc and brake pads occur when the brake pedal is pressed – releasing particles.

~~**Tailpipe emissions, gases / particulates**~~

Road surface wear
Friction between the tyre tread and road surface

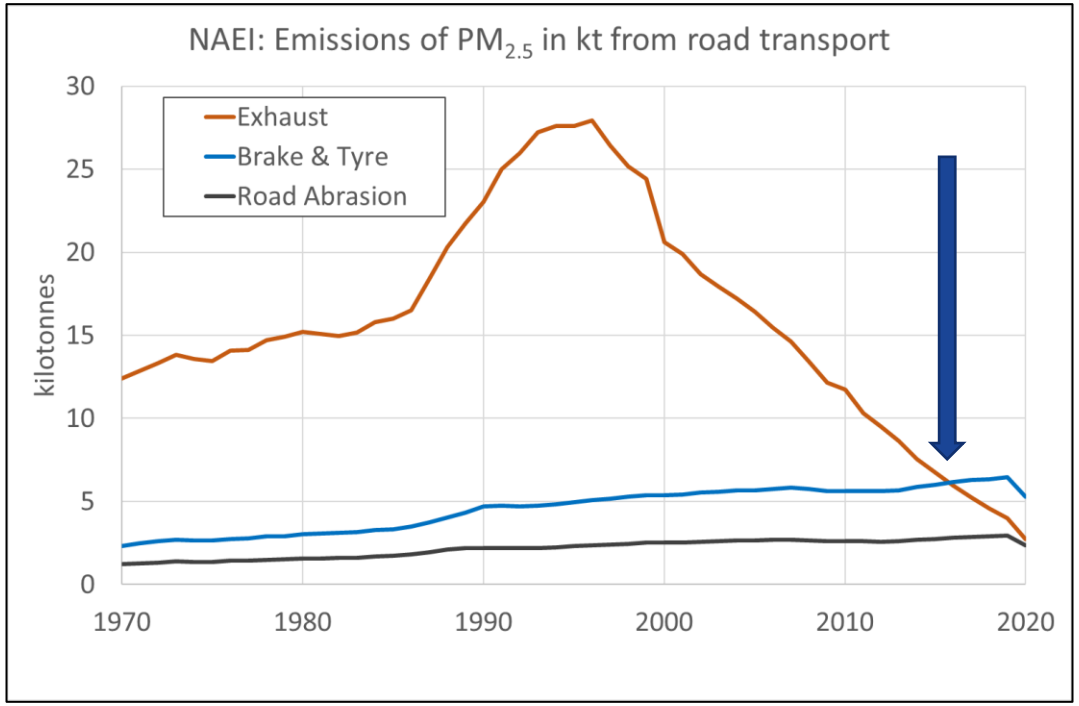
Re-suspension of road dust

Tyre Wear
Friction between the tyre tread and road surface releases particles from the tyres.

https://www.cvsltd.co.uk/car-leasing/volkswagen-caddy/

Non-exhaust emissions (NEE) in the UK

- Emissions of PM from exhausts has decreased since the mid-90s
- However, the contribution of NEE to particulate matter (PM) from traffic has increased
- In the UK, Brake and Tyre wear emissions are now the primary source of PM_{10} and $PM_{2.5}$ from road transport
- There is a transition towards zero (exhaust) emission vehicles on the road. Resulting in a need to measure, understand, and control non-exhaust emissions



Data source: https://naei.beis.gov.uk/

Non-exhaust emissions (NEE) in the UK

Department for Environment Food & Rural Affairs

Department for Transport

Office for Low Emission Vehicles

Consultation outcome

Brake, tyre and road surface wear call for evidence: summary of responses

Updated 11 July 2019

AIR QUALITY EXPERT GROUP

Non-Exhaust Emissions from Road Traffic

Prepared for:
Department for Environment, Food and Rural Affairs;
Scottish Government; Welsh Government; and
Department of the Environment in Northern Ireland

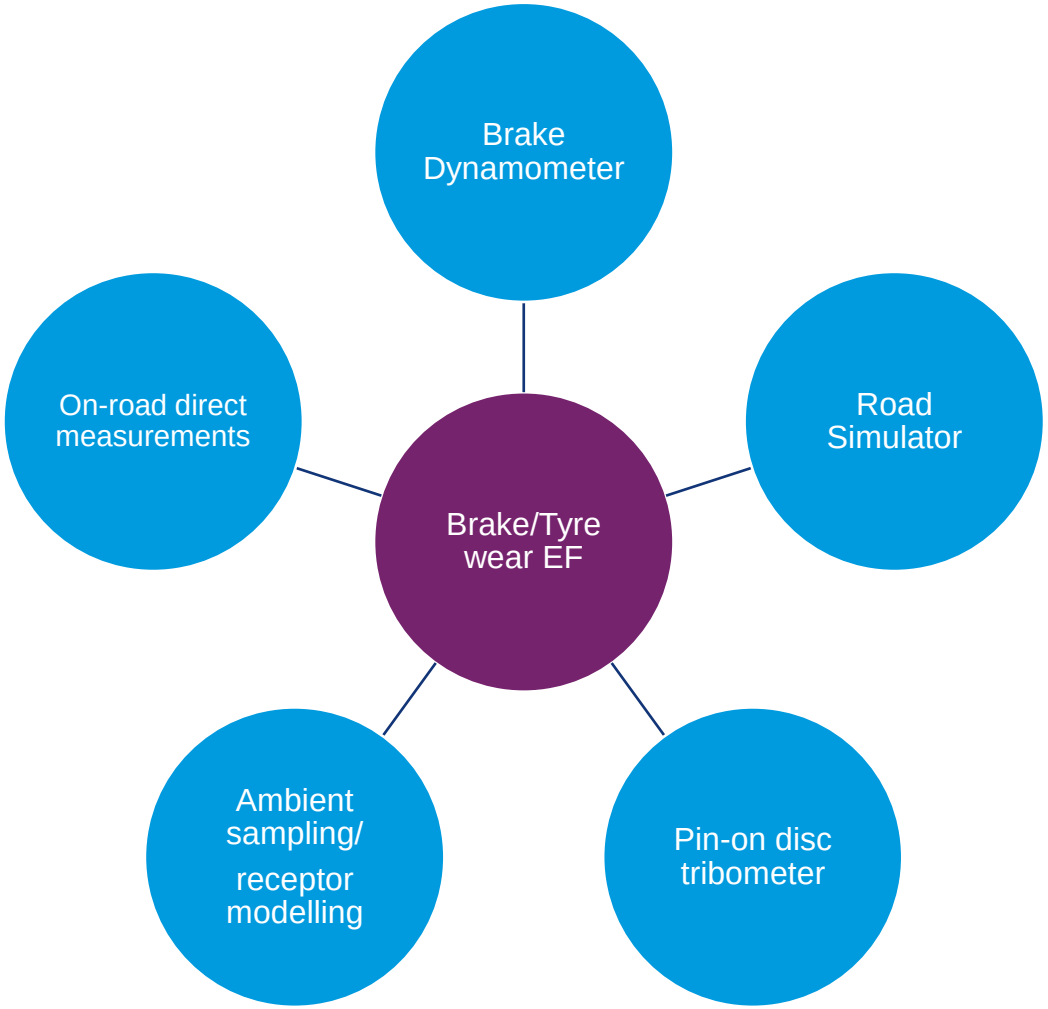
Measurement of Brake and Tyre Wear

To determine the impact of NEE on PM in the atmosphere, emission factors (EF) need to be determined. These will depend on many variables such as:

- Vehicle type
- Vehicle weight
- Driving style
- Brake and tyre materials
- Road surface
- Temperatures

Studies have used different methods to estimate NEE PM EFs and this can result in varying results.

A standard regulated method (similar to that used for exhaust emissions) is needed to assess NEE



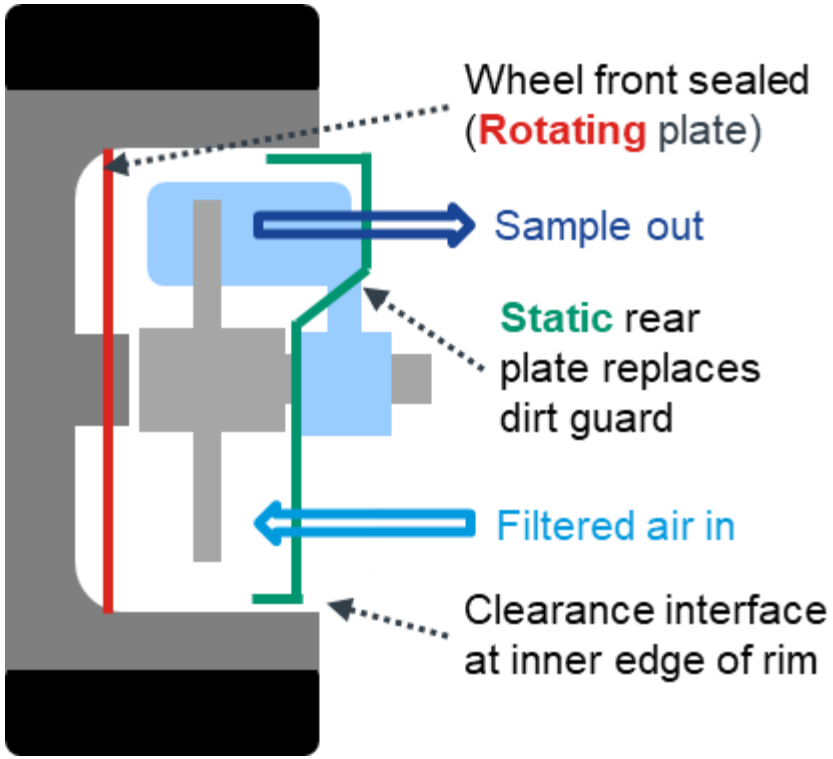
Measurement of Brake and Tyre Wear

Ricardo Energy & Environment and Ricardo Automotive and Industrial, in collaboration with the Arup AECOM consortium, are supporting the Department for Transport in the UK to develop an effective system and methodology for measuring and characterising particles emitted from brake and tyre wear under **real driving** conditions **(Phase 1)**.

In developing the system there was a need to consider:

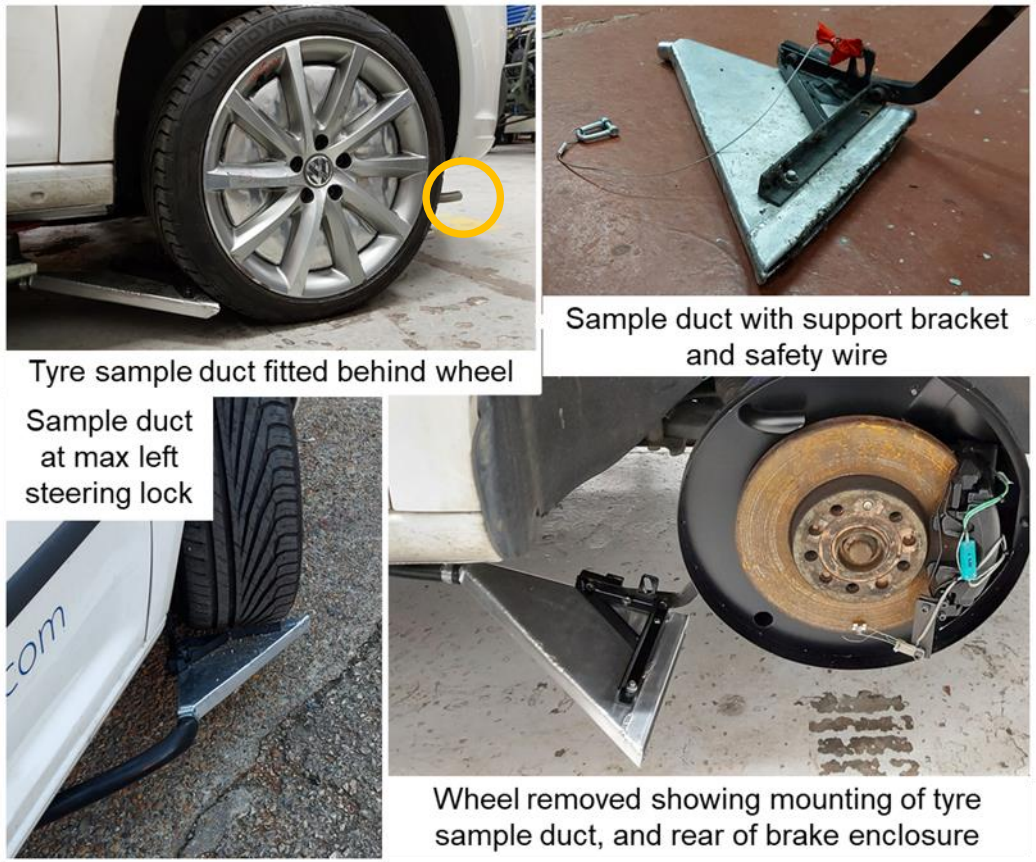
- A common sampling system and measurement equipment which can be used for both brake and tyre wear
- Representative sample collection of particles from brake or tyre wear
- Repeatable and reproducible measurements
- Careful consideration of background particles (i.e. re-suspension of road dust, tailpipe emissions)
- Power and spatial demands of the system

System Design Example – Brake Wear Sampling



3 enclosure approaches used – to explore application to different braking system types

System Design – Tyre Wear Sampling

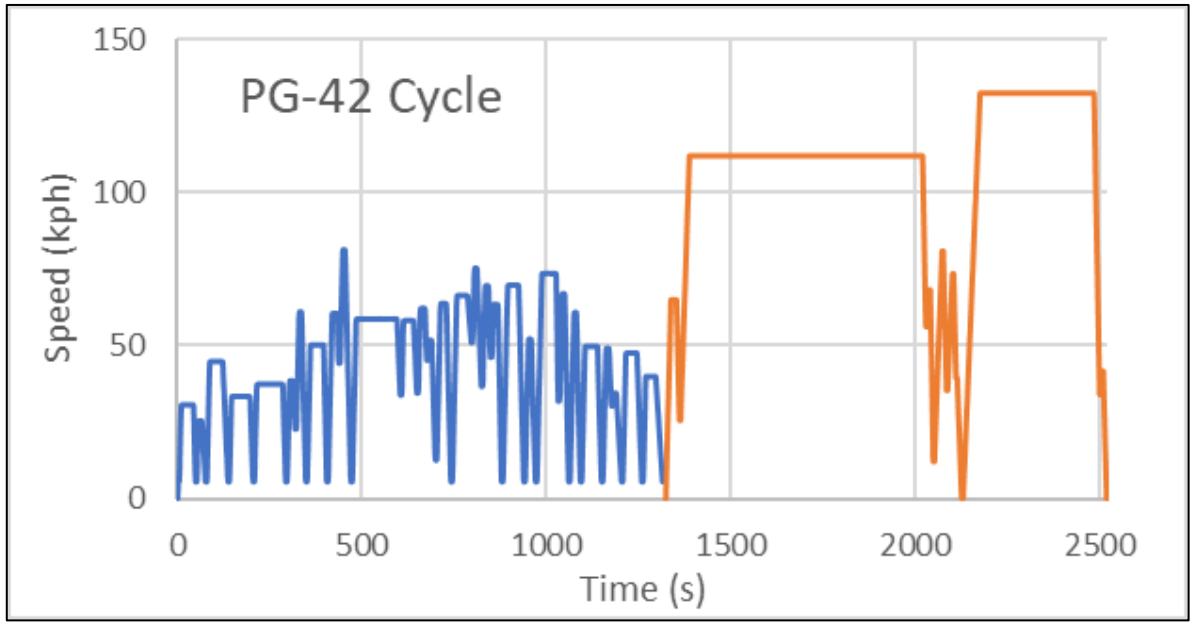


- Open duct to draw sample from behind the tyre-road contact patch into the measurement system.
- Inlet fabricated to be slightly wider than the tyre, and just above the road and angled to keep sufficient entry velocity for the sample flow and allow large material to drop out
- The duct was mounted to a bracket which in turn was fixed to the rear of the wheel hub carrier, so that the duct position is fixed relative to the wheel and swings with the wheel as it steers.
- Sample probes for monitoring background ambient particulates were fitted to the front of the vehicle

Test Plan and Drive Cycles

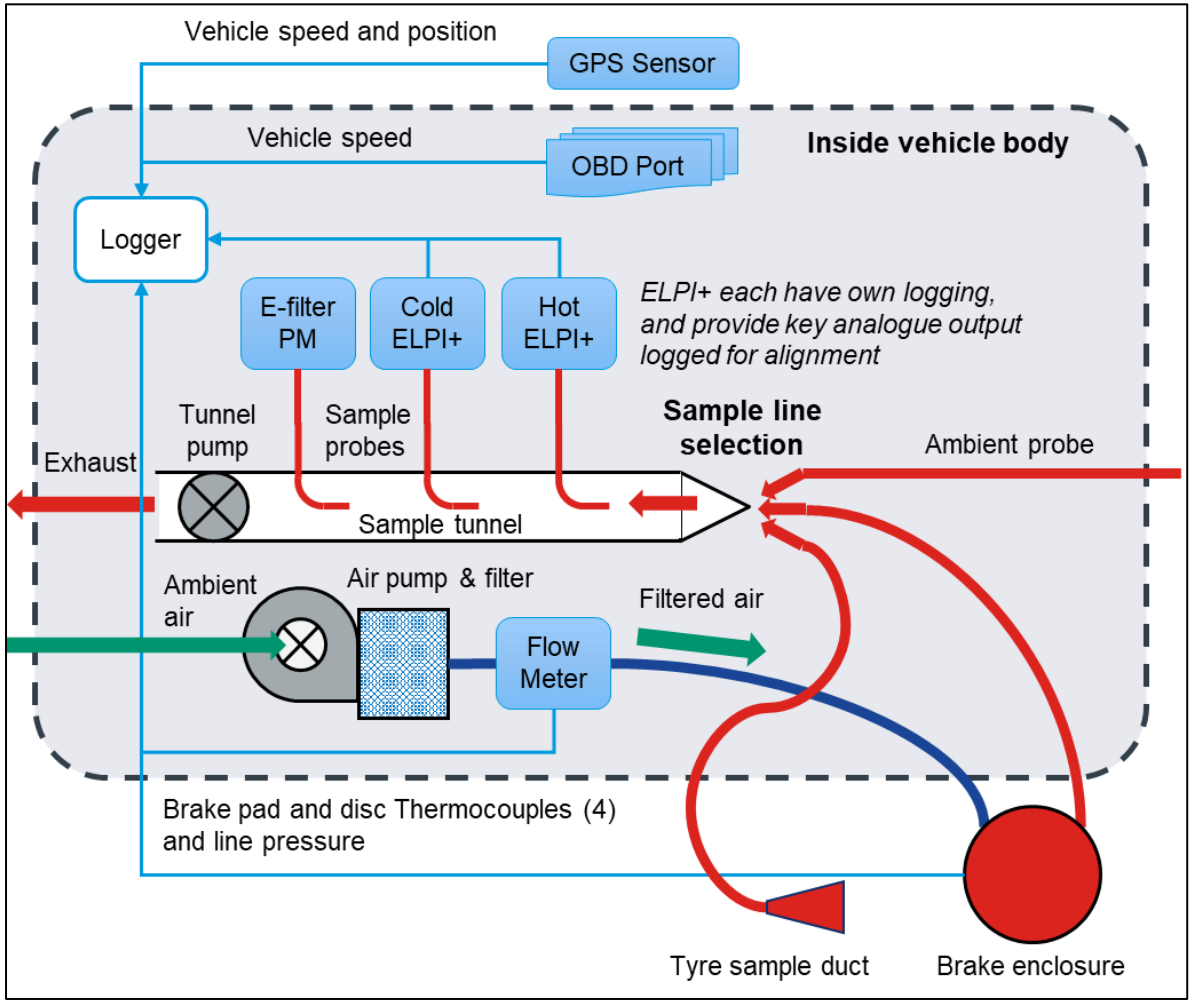
Tests	Details
Background sampling	Sampling background emissions from different inlets
Chassis Dyno	PG-42 cycles - sampling from brake and tyres
On-road/Track	Urban driving; track braking events of different magnitudes

Repeated measurements were undertaken for all tests



PG-42 - 42 minutes cycle based on high particle emitting sections of two well-known braking cycles: Worldwide Harmonized Light Vehicles Test Procedure (WLTP) and Los Angeles City Traffic (LACT).

System Design – Instrumentation

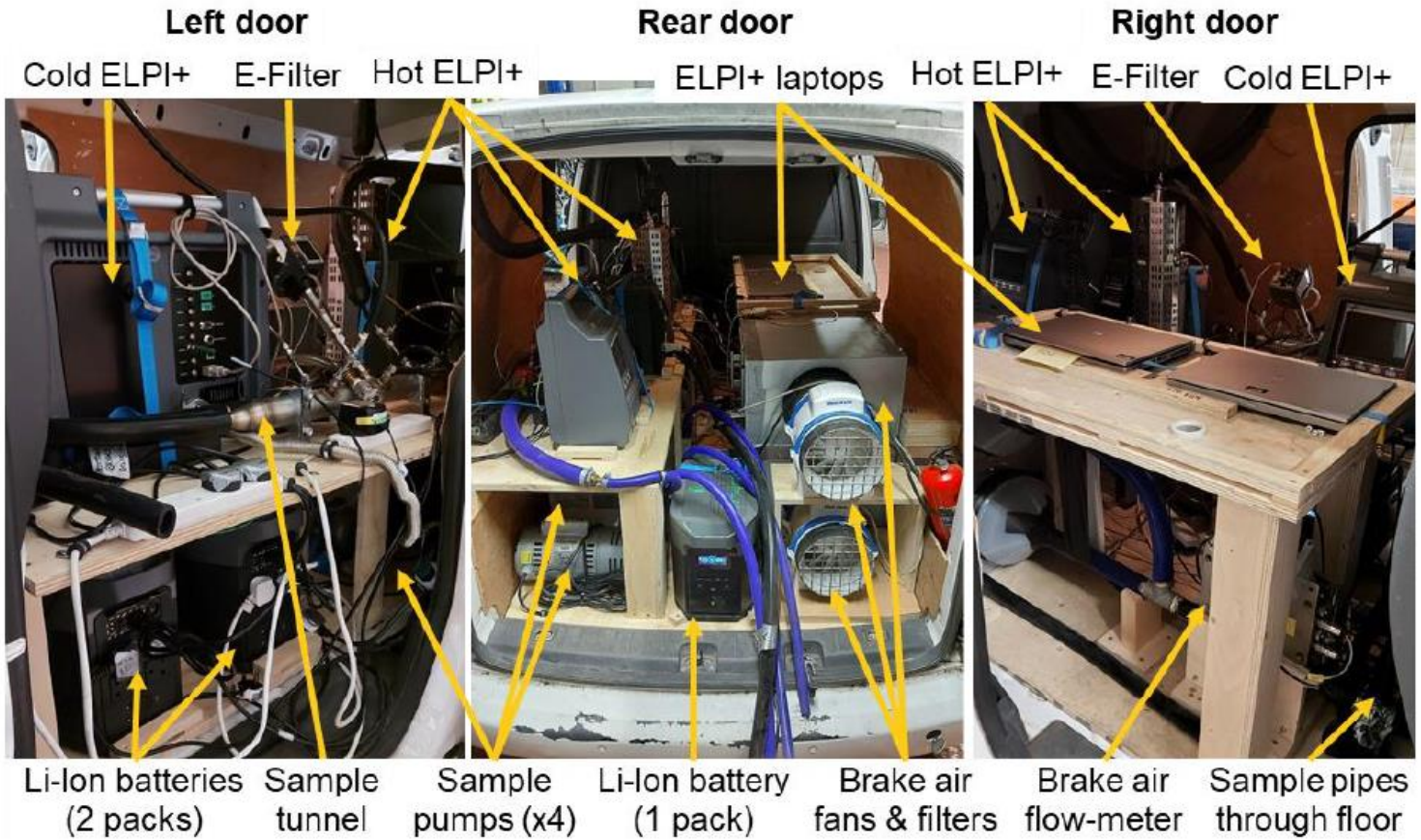


Sample analysis included:

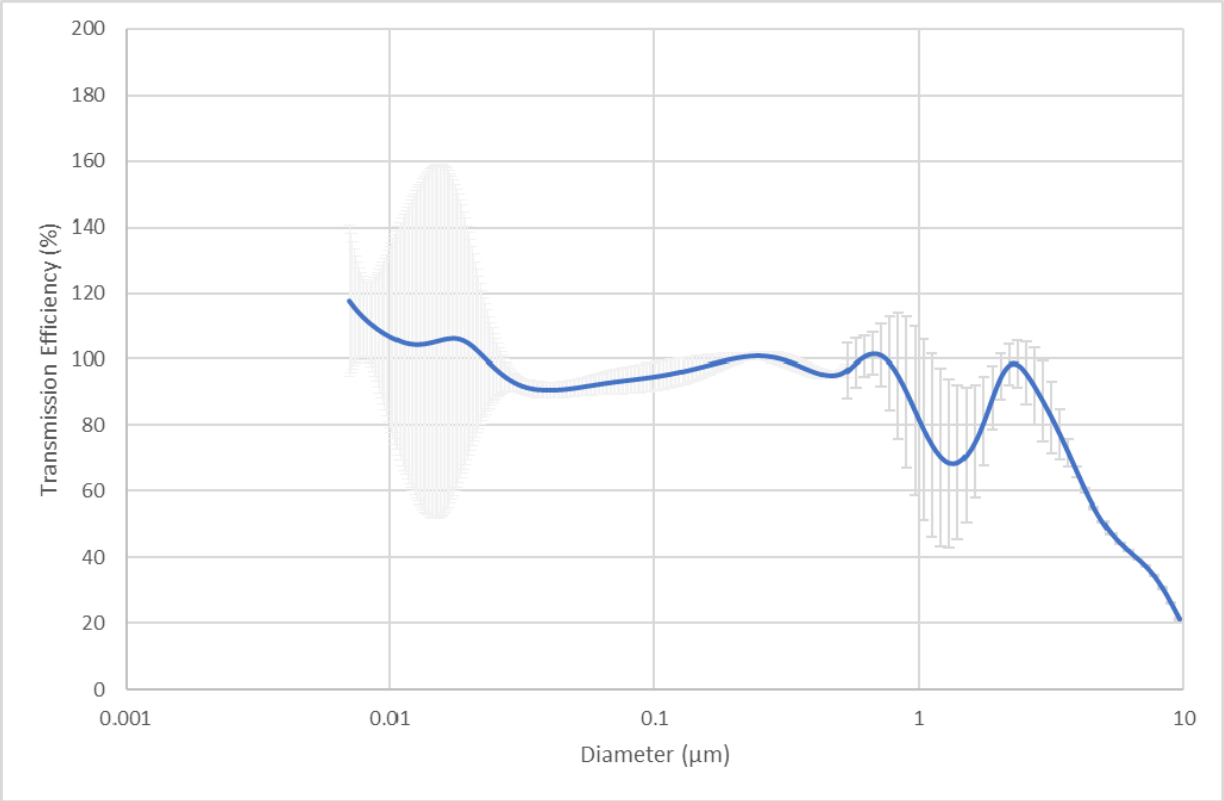
- Combination of two Dekati® Electrical Low Pressure Impactors (ELPI+) for real-time particle size distribution and concentration (size range 6 nm – 10 µm)
  - "Cold" ELPI+ measures solid and volatile particles
  - "Hot" ELPI+ includes a 180°C heated inlet to remove the volatile component of the PM
- Dekati® eFilter for real-time PM mass concentration measurements – also includes a filter for reference gravimetric determination and analysis
- PN23 system (raw) used in parallel from tunnel for lab tests

The entire system was installed to a small light duty van and measurements undertaken from the front tyre

VW Caddy vehicle

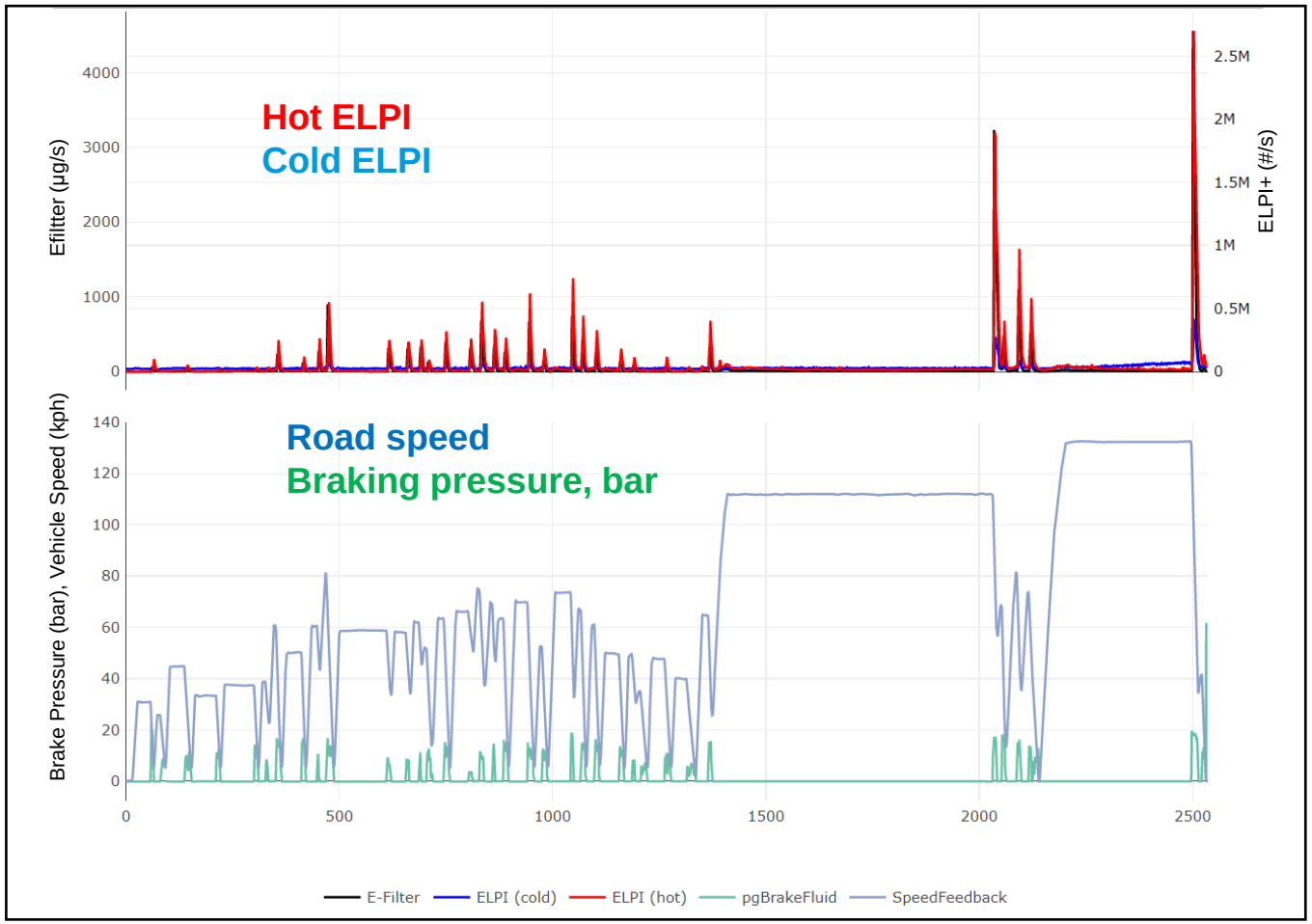


Particle penetration through sampling system



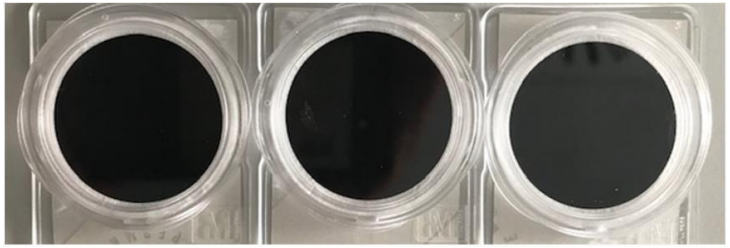
- Penetration close to 100% for particles up to ~3µm
  - Hence under-sampling of larger particles, which will have impacted PM_{10} determination by eFilter and gravimetry
  - $PM_{2.5}$ quantification likely to be more representative, and a more realistic objective for on-board sampling

Real time brake emissions – Chassis Dynamometer



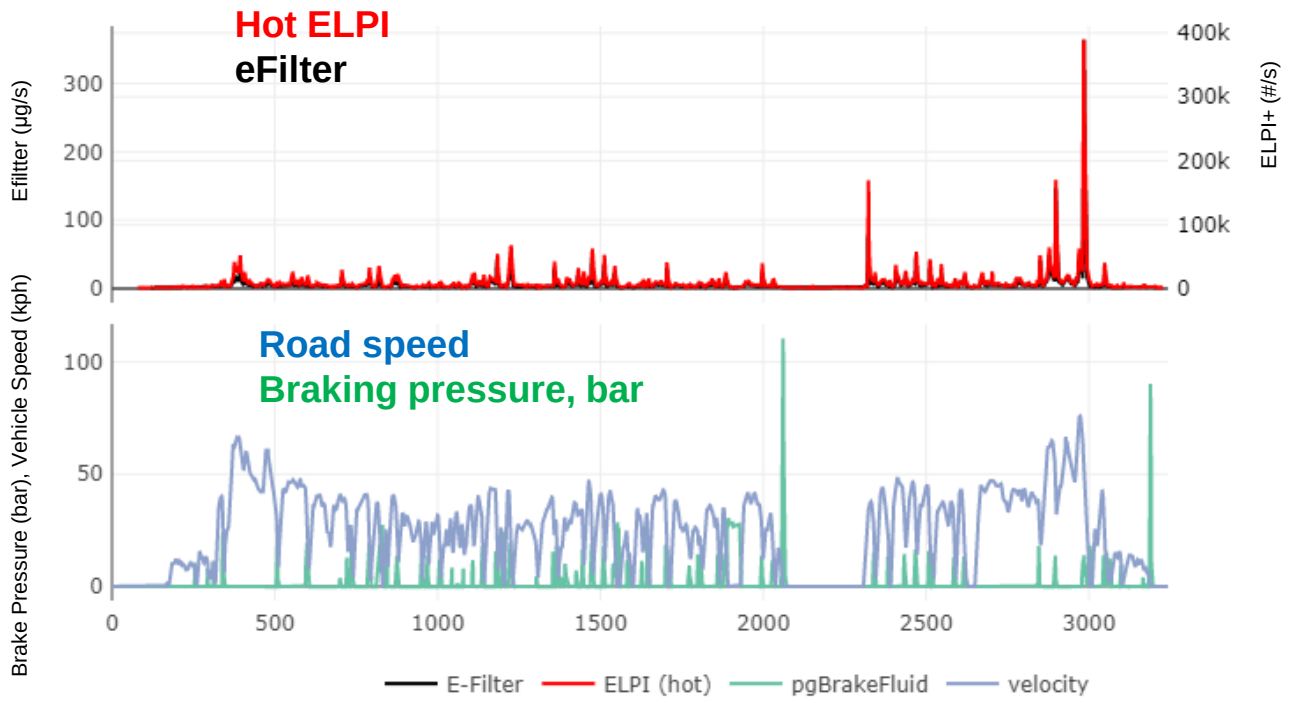
- Particle number and particle mass emissions from the hot ELPI and eFilter coincided with increased braking pressure events on the chassis dynamometer
- Emissions from the cold ELPI were coincident, but more challenging to resolve
- Hot ELPI/SPCS emissions ~ 5 x 10^9 #/km/brake, PG-42 CoV - 4% SPCS and 40% hot ELPI
- PM filter emissions ~1.6mg/km/brake

3 repeat PM filters from PG-42 brake testing



Thermogravimetric analysis of filters indicated ~95% non-volatile and non-oxidizable material

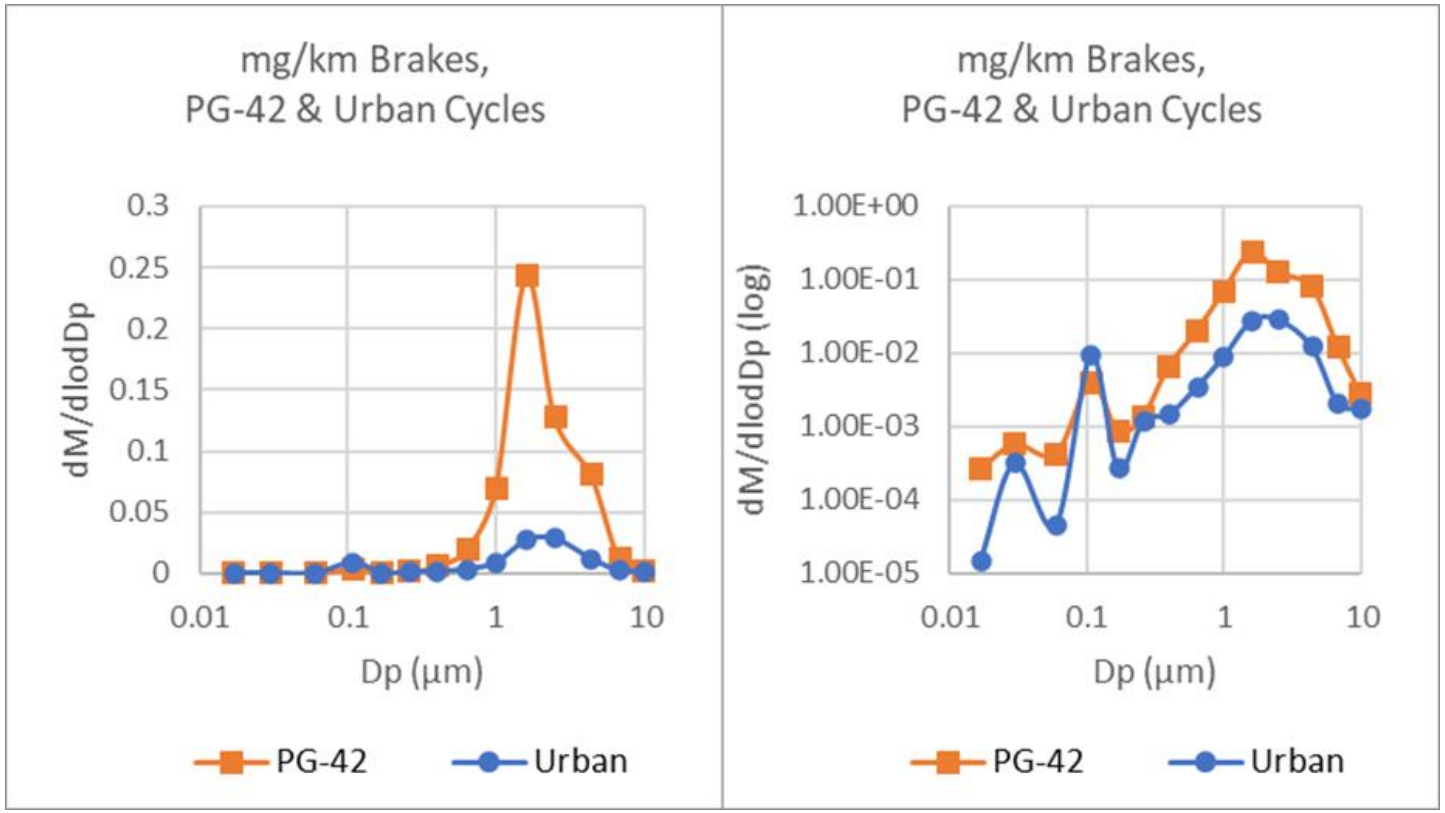
Real time brake emissions – Urban Road



- Braking events on the urban road are representative of real-world driving
- Particle number and particle mass emissions events reported from braking overlay from the hot ELPI and eFilter
- Similar to the chassis dyno tests - emissions from the cold ELPI were more challenging to attribute to specific braking events
- Hot ELPI emissions 2 to 5 x 10^9 #/km/brake
  - Cold ELPI similar
- PM filter emissions ~0.9 mg/km/brake

Real time brake emissions – particle mass size distributions

Mass Weighted Particle Size Distributions, Cold ELPI



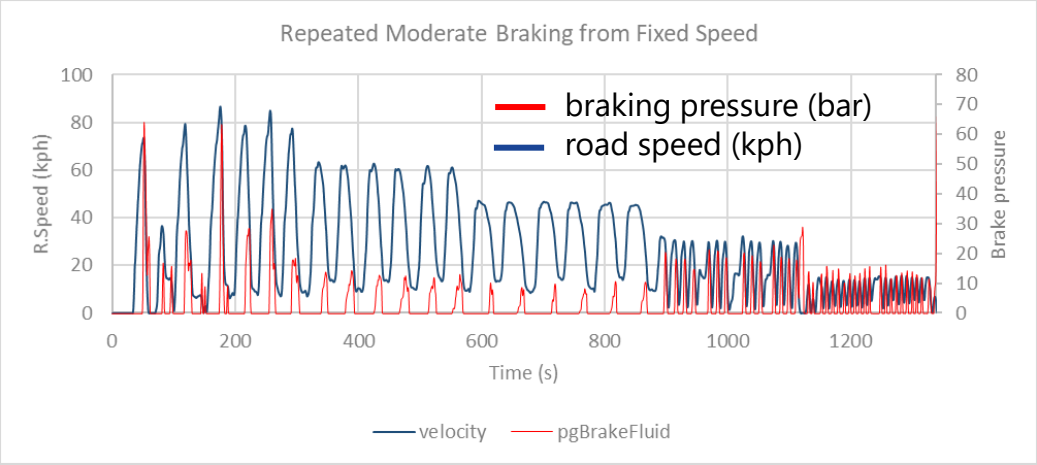
linear scale

log scale

- Mass weighted particle size distributions from the PG-42 and urban drives are generally similar
  - mass greater from more aggressive PG-42
- Two modes observed: a minor mode at ~100nm (0.1µm) and a dominant mode at ~1.6µm
- The >1µm mode is likely to be mechanically generated wear materials primarily released from the brake pad

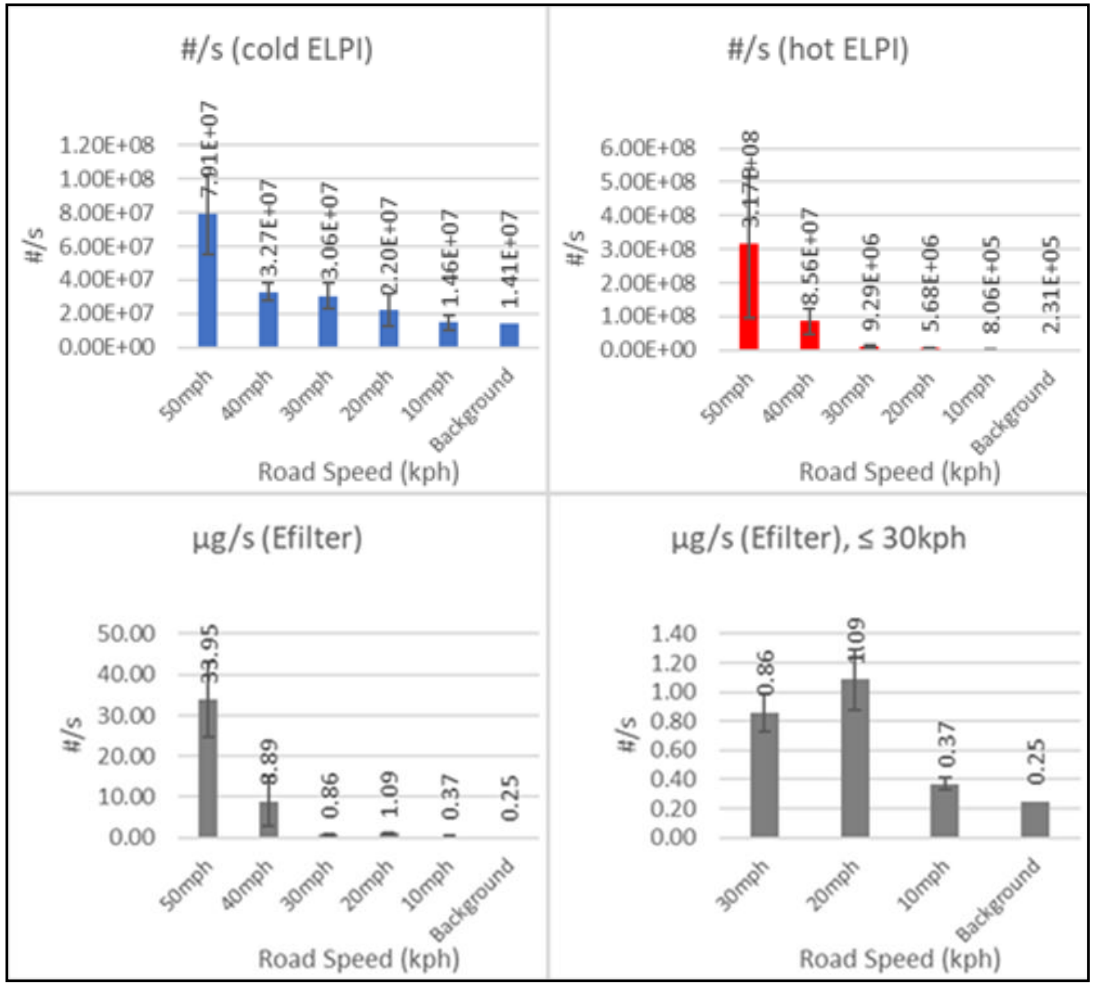
Real time brake emissions – Test Track

- A series of moderate repeated braking events were performed on the test track from several different speeds

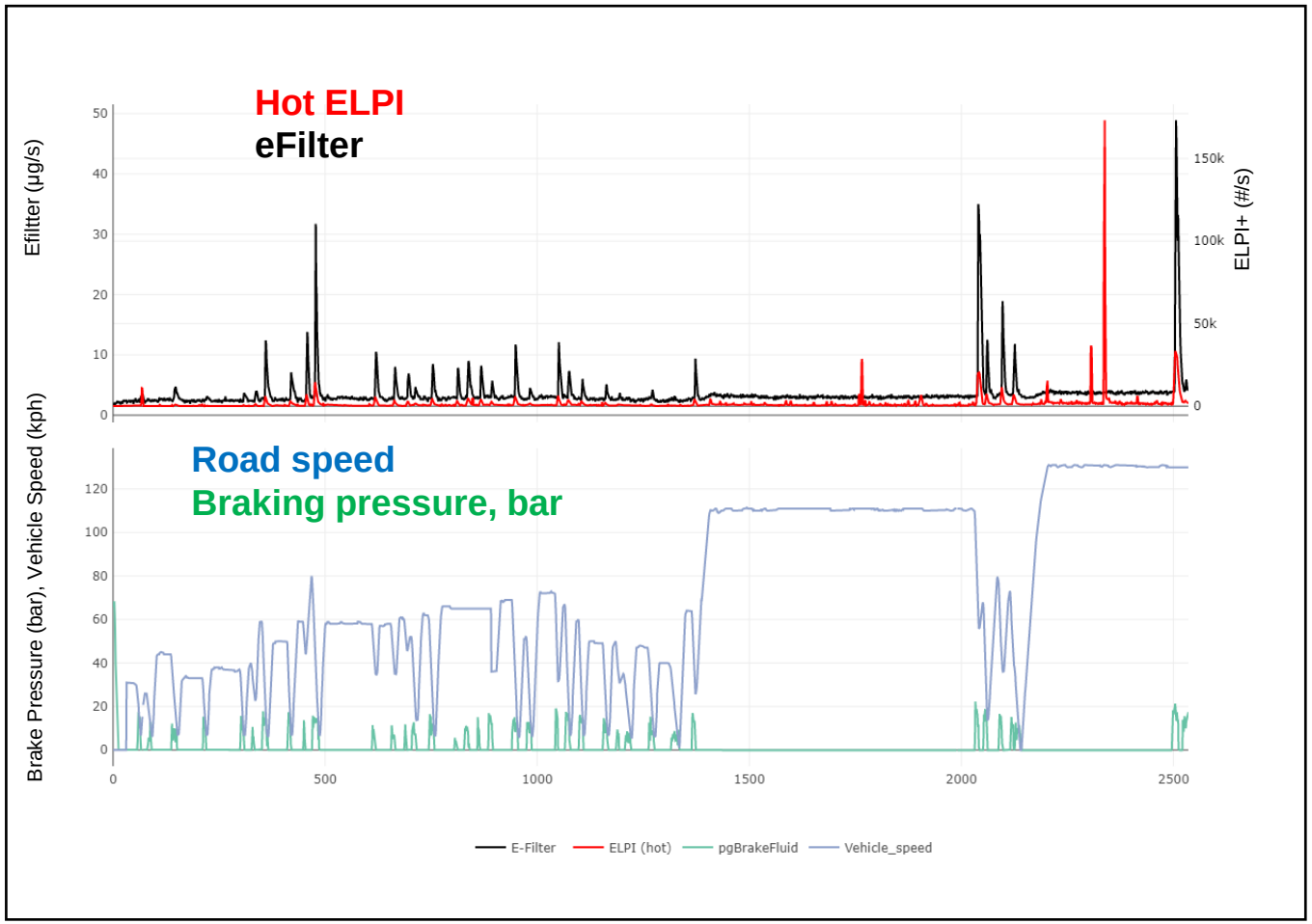


- Particle number and eFilter mass emissions increase with higher speeds
- Very low speed emissions similar to background
- Repeated very aggressive braking led to high disc and pad temps and continuous volatile emissions release

Average particle/s emissions compared with backgrounds

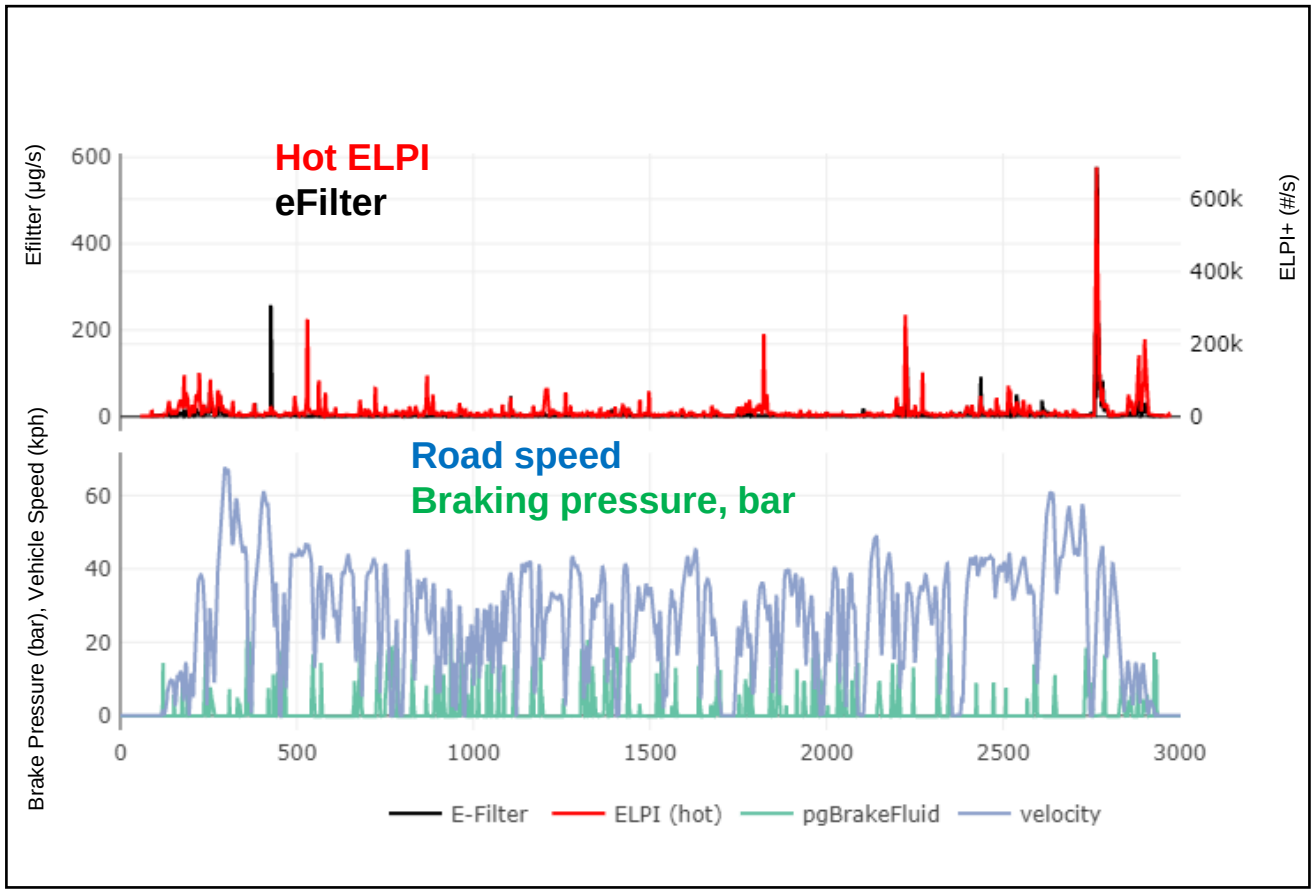


Real time tyre emissions – Chassis Dynamometer



- Spikes of particle number emissions were observed from the ELPIs, both during braking events but also during accelerations and cruises
  - Indicating particles maybe be lost following, as well as during, braking events
- eFilter mass emissions appear to be closely related to the braking events
  - Most mass is lost immediately on braking
- Masses measured were an order of magnitude lower for tyre emissions than for the brake emissions
  - The efficiency of the tyre scoop is uncertain, and is to be explored in further work

Real time tyre emissions – Urban Road

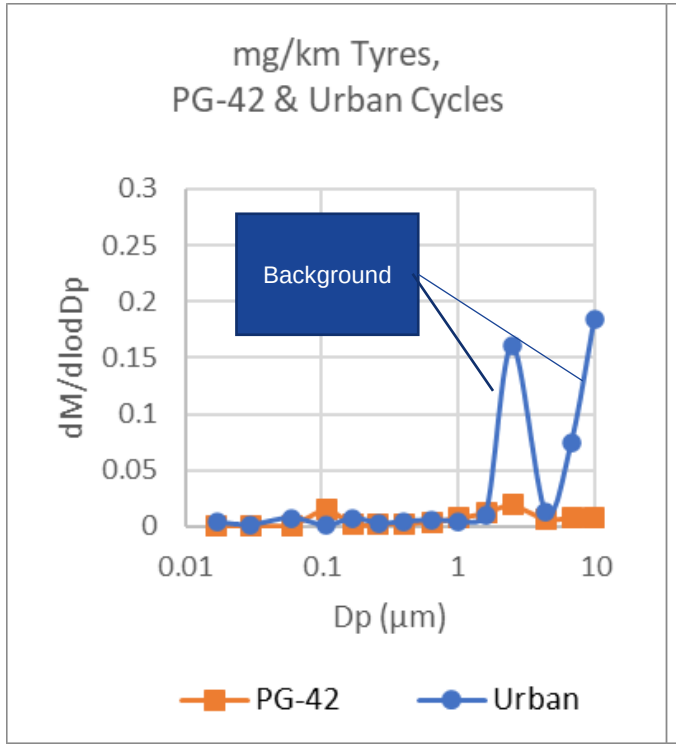


- Some urban braking events coincide with an emissions peak, however, not all do
- Peaks of both mass and number can also be observed that are not related to instantaneous braking events

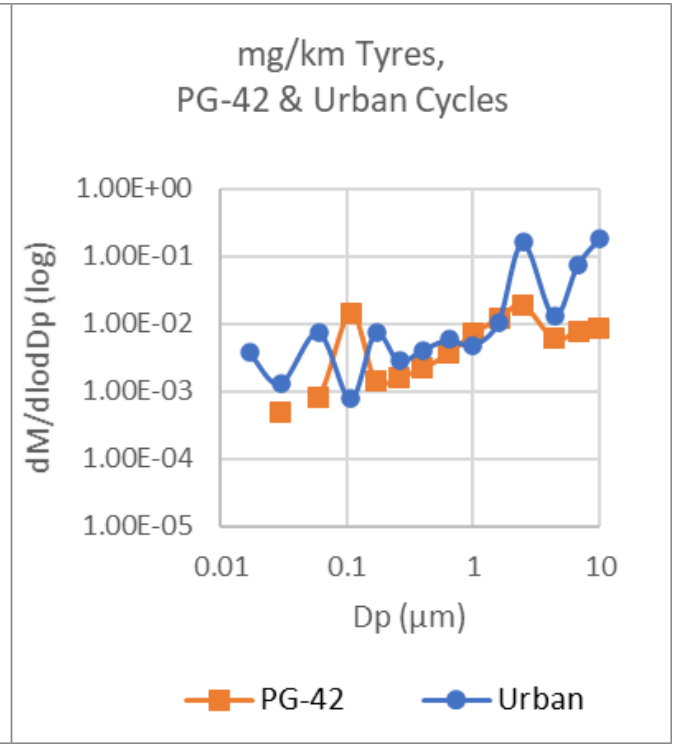
- Emissions of both mass and number were higher on the urban road, compared to the chassis dyno, despite less severe braking events
  - Substantial contribution from source(s) other than braking

Real time tyre emissions – particle mass size distributions

Mass Weighted Particle Size Distributions, Cold ELPI

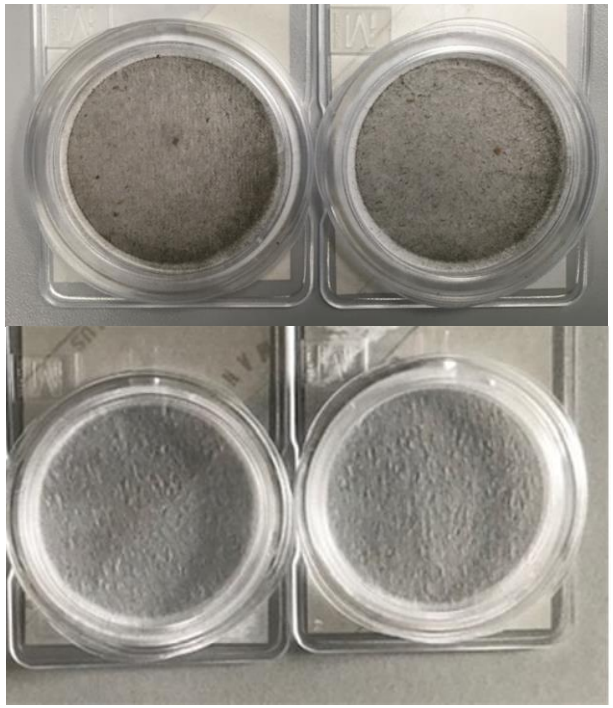


linear scale



log scale

- Chassis dyno PG-42 emissions are much lower than urban, despite the increased braking severity
  - Background contribution very high from >1µm materials

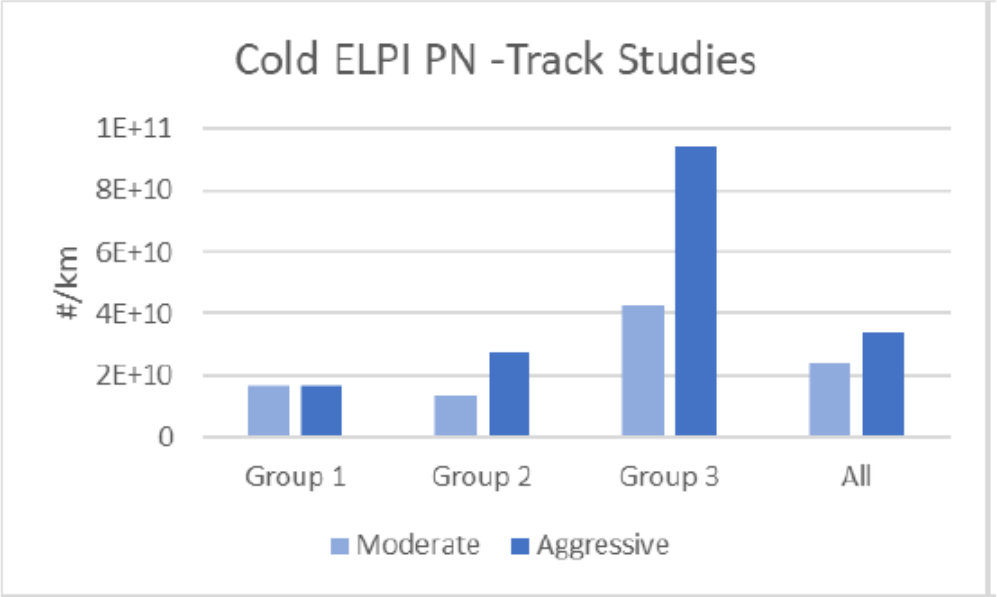


Urban testing PM filters are dirty & contaminated with discrete large particulates

Chassis Dyno filters show uniform PM material

Real time tyre emissions – Test Track

Data from three consecutive repeat sets of braking from 80kph and slower, are grouped and the integrated particle number for the cold ELPI calculated for each group.



Integrated particle numbers from moderate and aggressive tyre emissions tests

- Higher PN is measured by the cold ELPI as the aggressive braking tests proceed, than from the moderate braking tests
  - As the tyres heated up from repeated braking, an ‘out-gassing’ of volatile particles was observed
  - (*The effect is also present with the hot ELPI, though less apparent, which suggests that many of these particles are volatile below ~200°C*)

- Background contributions could be very significant to both mass and number
  - and were highly variable day to day

Summary

- An on-road system for measuring brake and tyre wear was developed and installed to a small light duty van
- Testing was successfully undertaken in a chassis dynamometer facility; on a nearby test-track; and on-road in an urban environment
- Brakes: Real-time non/low volatility particle number emissions corresponded to real-time braking events, with emissions around 2 - 5 x 10^9#/km/brake, lowest emissions were seen at lowest speeds
- Brakes: Real-time particle mass emissions responses also aligned with braking events, and mass emissions (~$PM_{2.5}$) were around 1mg/brake/km
- 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
- Tyres: Exact quantification of $PM_{2.5}$ and PN emissions is dependent on the sampling duct efficiency, which is currently unknown. This is to be investigated. Without correction, measured levels were lower than brakes on a per km basis
- Tyres: Repeated aggressive braking events appear to lead to outgassing of volatile particles from tyres, many of these particles are eliminated by the hot ELPI, heated to 200°C

Planned further work, Phase 2

- Focus on PN10 (using PN-PEMS type devices), both total and non-volatile particles
- Continue with real-time mass and a filter-based approach to enable chemical analysis and visualisation of the PM materials collected
- Optimise sampling system, e.g., for power consumption, size, flow rate …
- Explore and validate sample duct for sampling measurements for tyre wear
- Test power of the measurement system to discriminate between tyre types, brake types etc
  - Study specific influences on brake particle emissions on chassis dyno, test track and road
    - E.g., disc and pad compositions, driving dynamics …
  - Study specific influences on tyre particle emissions on chassis dyno (& tracks)
    - E.g., tyre compositions, tyre sizes …
  - Evaluate impacts of regenerative braking and emission-reducing technologies

Report of Phase 1 will be available for download from the DfT website soon

Thanks for listening!