Particle Emissions From Brake and Tyre Wear

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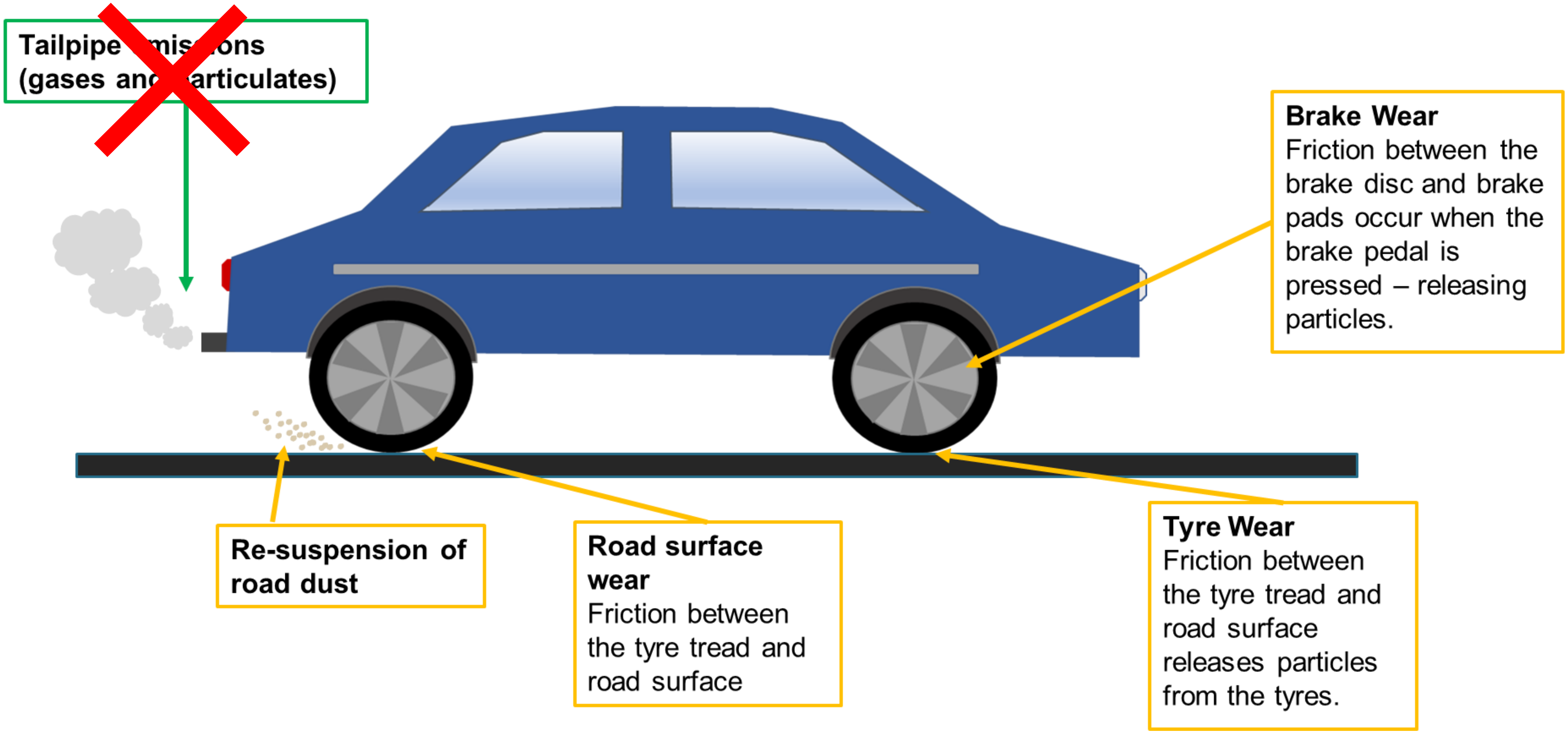
AGENDA

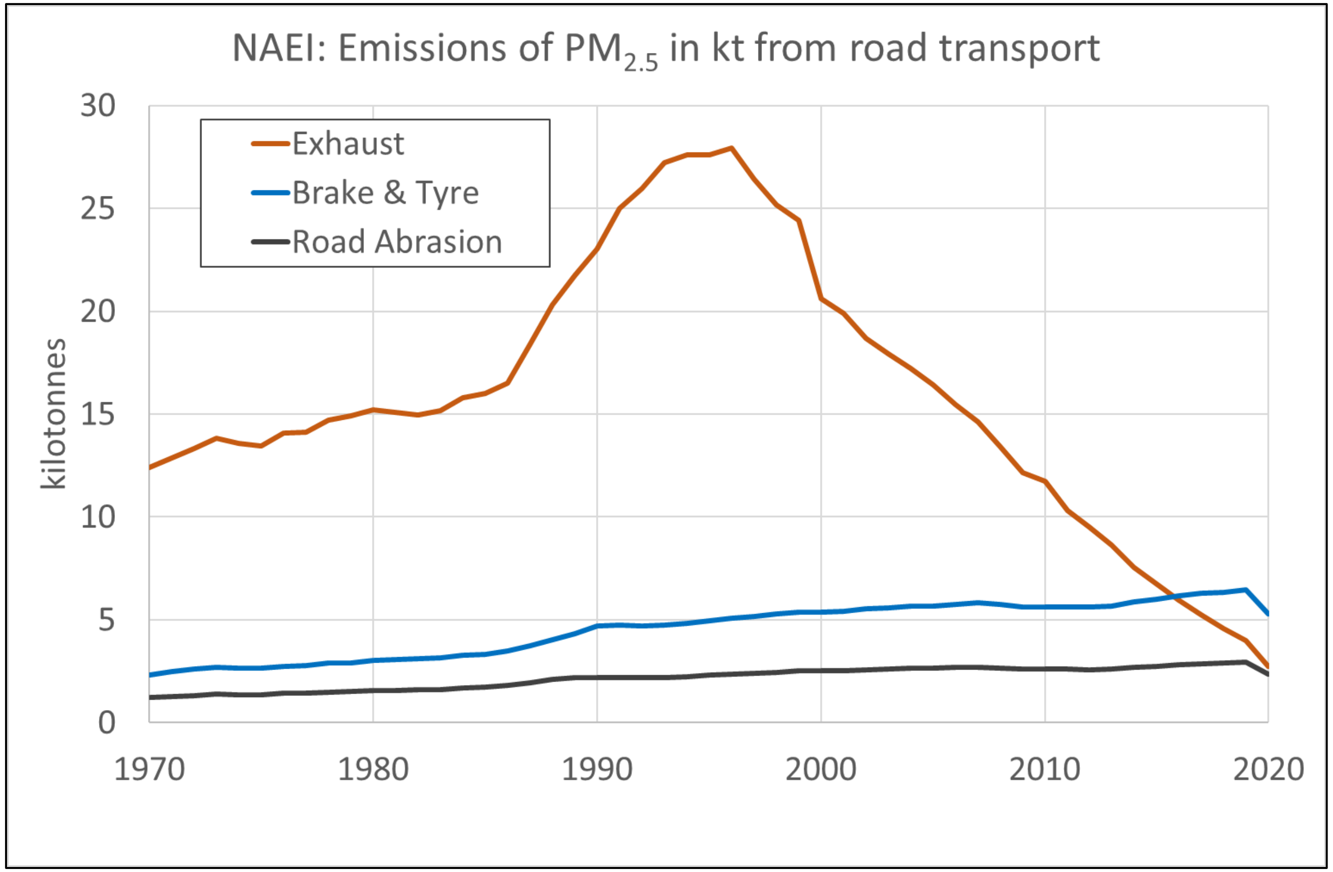
- Introduction to non-exhaust emissions
- Measurement of Brake and Tyre Wear
- System design and testing
- Results
- Conclusions

Non Exhaust Emissions (NEE)



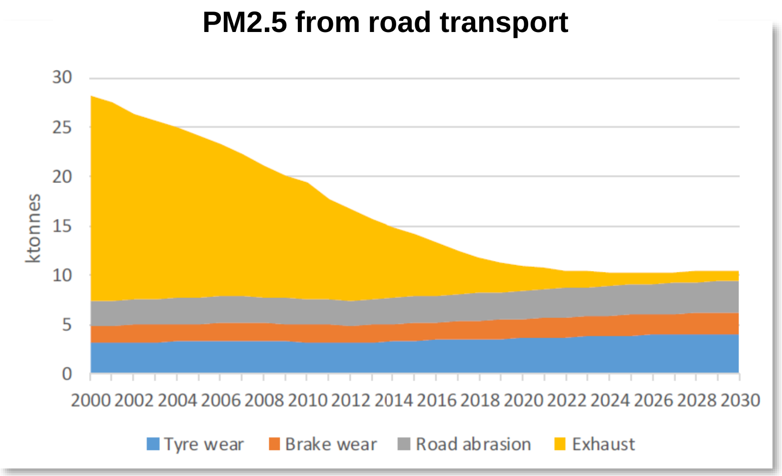
Non-exhaust emissions (NEE) in the UK

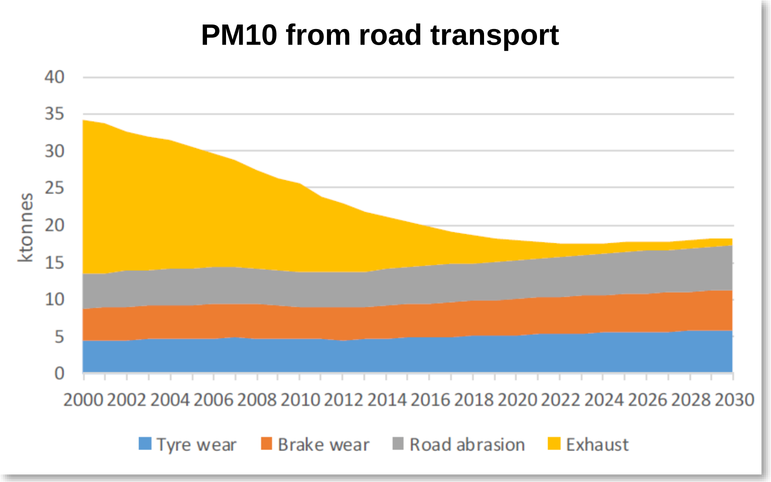
- Emissions of PM from exhausts has decreased since the mid-90s.
- However, the contribution of NEE to particulate matter (PM) from traffic has increased.
- In the UK, Brake and Tyre wear emissions are now the primary source of PM_{10} and $PM_{2.5}$ from road transport.
- There is a transition towards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

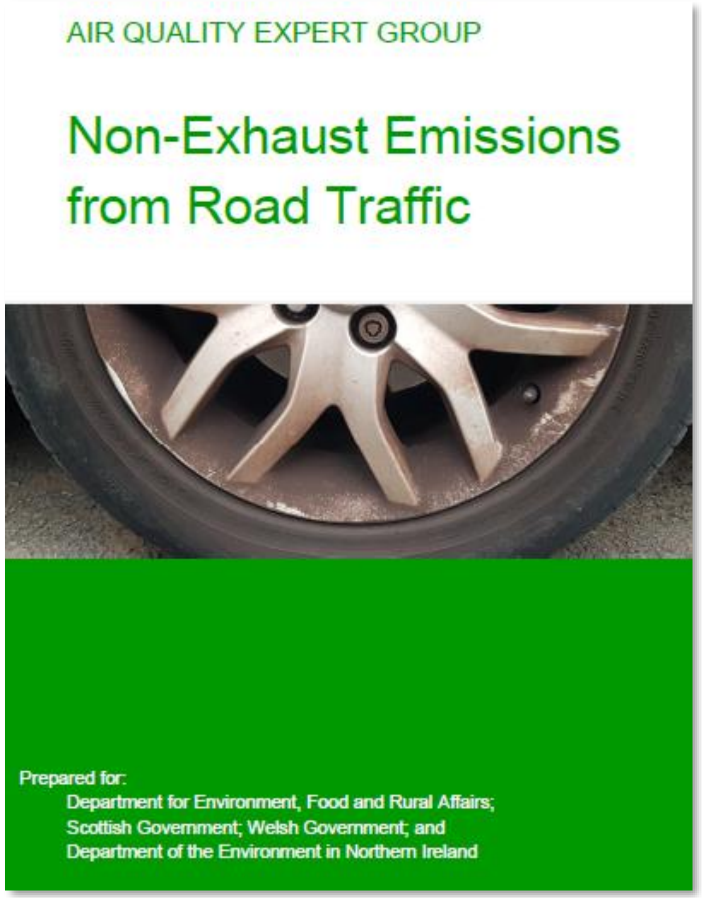


Data source: https://naei.beis.gov.uk/

Non-exhaust emissions (NEE) in the UK







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

RICARDO

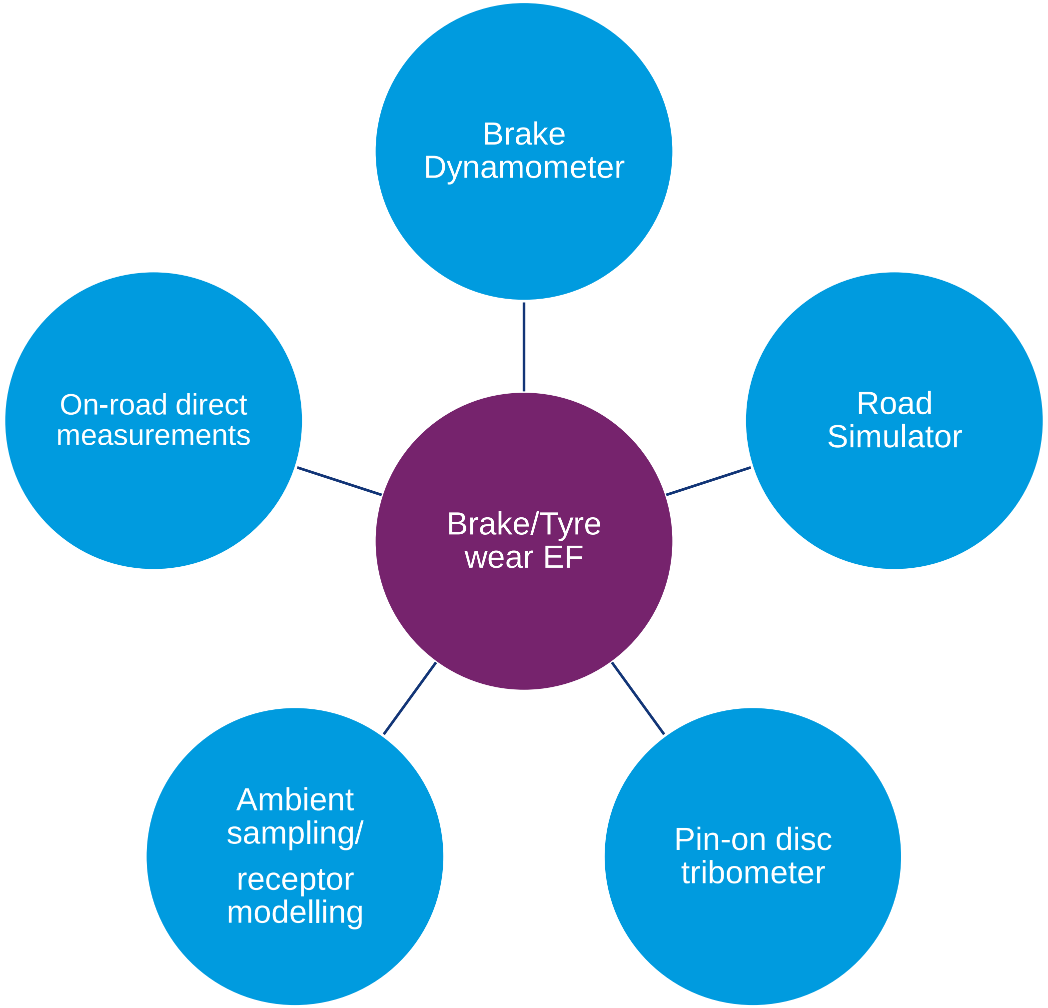
Measurement of Brake and Tyre Wear

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



International work on regulation

- UNECE is developing an **internationally recognised test procedure** to measure brake and tyre particles

- Measuring **tyre and road** wear particles is technically very complex
  - Ongoing work should lead to a test procedure and limits in regulation in late 2023

- Work on measuring **brake** wear is more advanced
  - First draft of UN regulation on test procedure (co-sponsored by DfT) is expected in early 2023
  - EU is expected to propose limits on car brake emissions this month (within Euro 7)

UNITED NATIONS
ECONOMIC COMMISSION
FOR EUROPE

Measurement of Brake and Tyre Wear

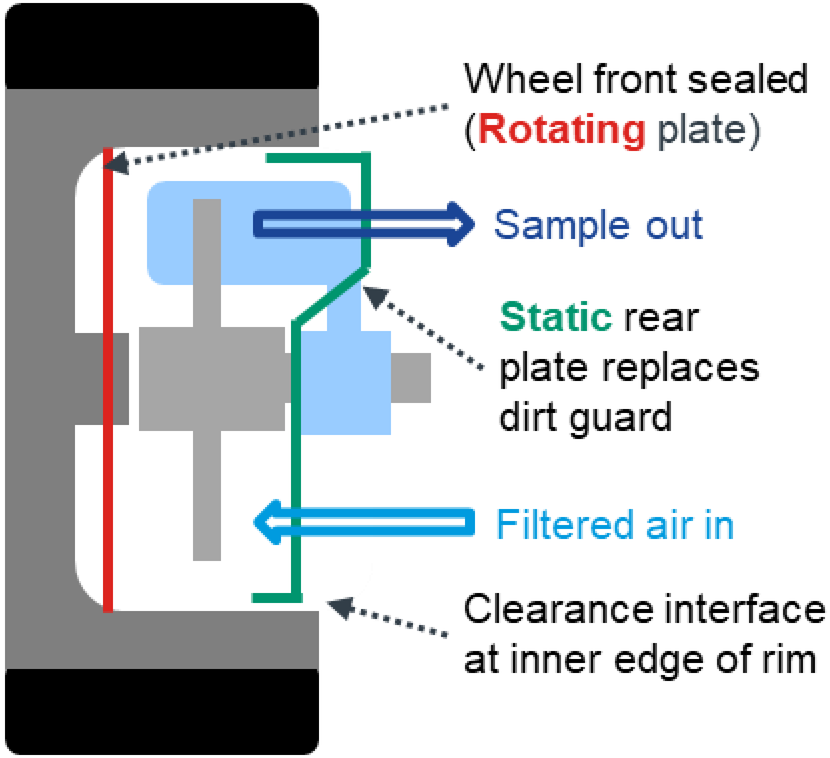
Ricardo Energy & Environment and Ricardo Automotive, in collaboration with the Arup AECOM consortium, are supporting the Department for Transport in the UK to develop an effective system and methodology for measuring and characterising particles emitted from brake and tyre wear under **real driving**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

In developing the system there is a need to consider:

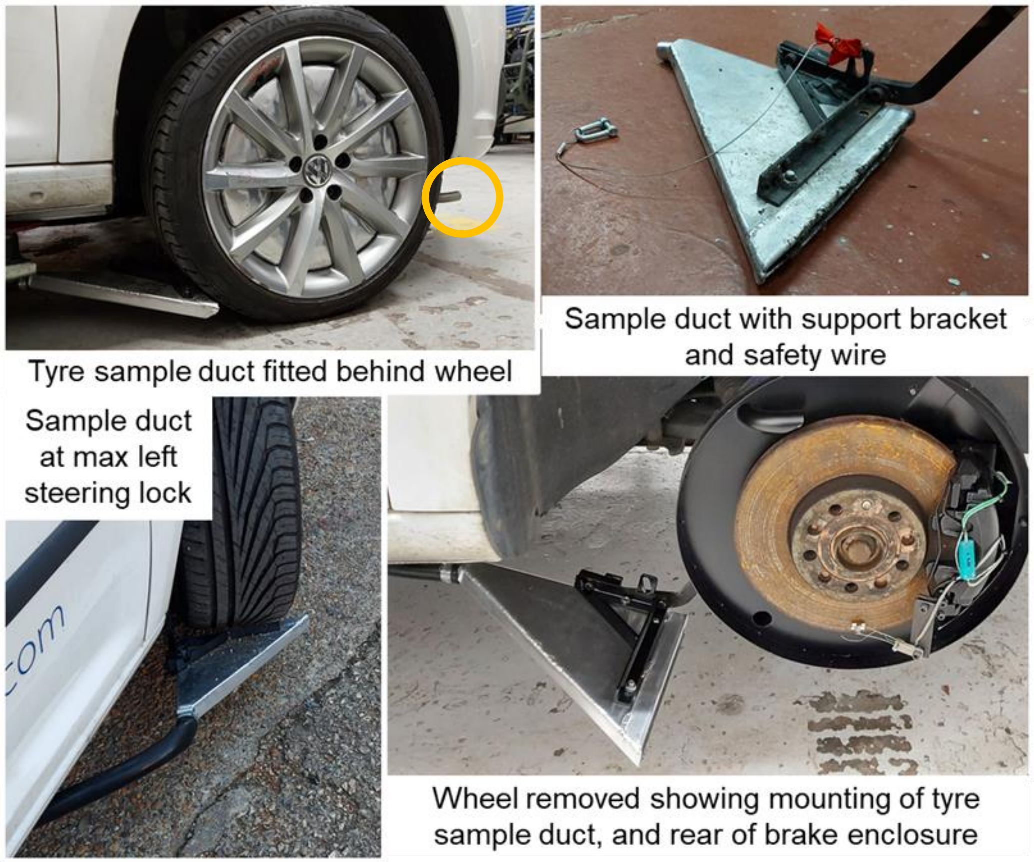
- A common sample system and measurement equipment which can be used for both brake and tyre wear.
- Representative sample collected of particles from brake or tyre wear.
- Repeatable and reproduceable measurements.
- Careful consideration of background particles (i.e. re-suspension of road dust, tailpipe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

System Design – Brake Wear Sampling

Front face of the brake enclosure



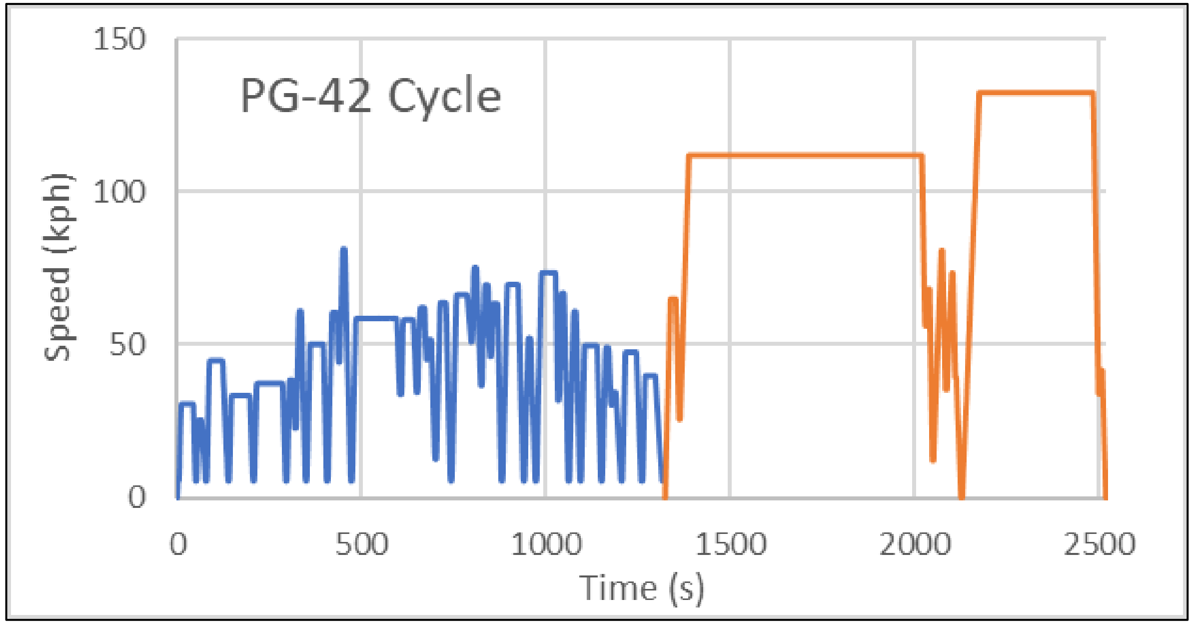
System Design – Tyre Wear Sampling



- 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

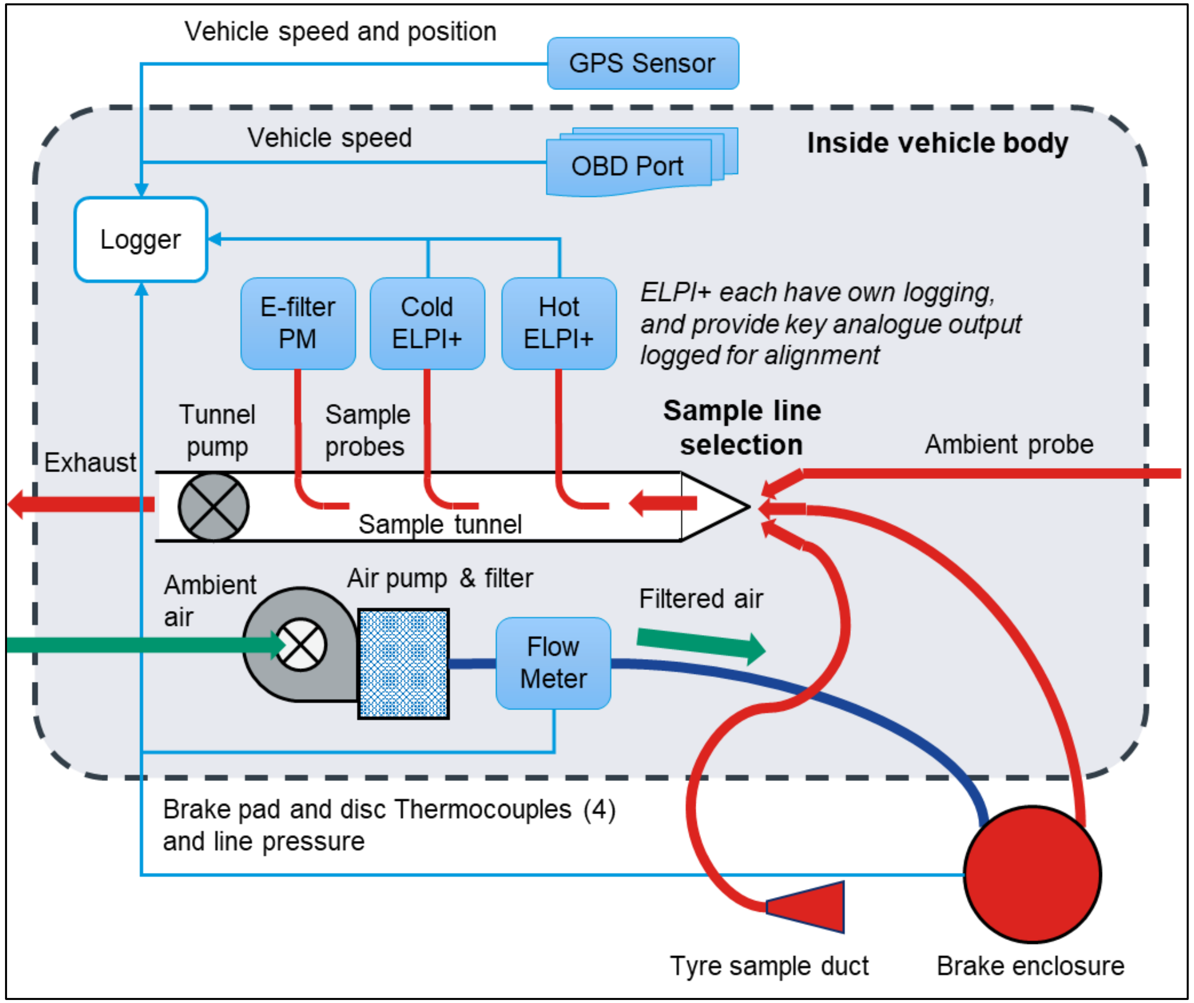
Tests	Details
Background sampling	Sampling background emissions from different inlets
Chassis Dyno	PG-42 cycles - sampling from brake and tyres
On-road/Track	Urban driving and braking events of different magnitudes



Repeated measurements were undertaken for all tests

PG-42 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

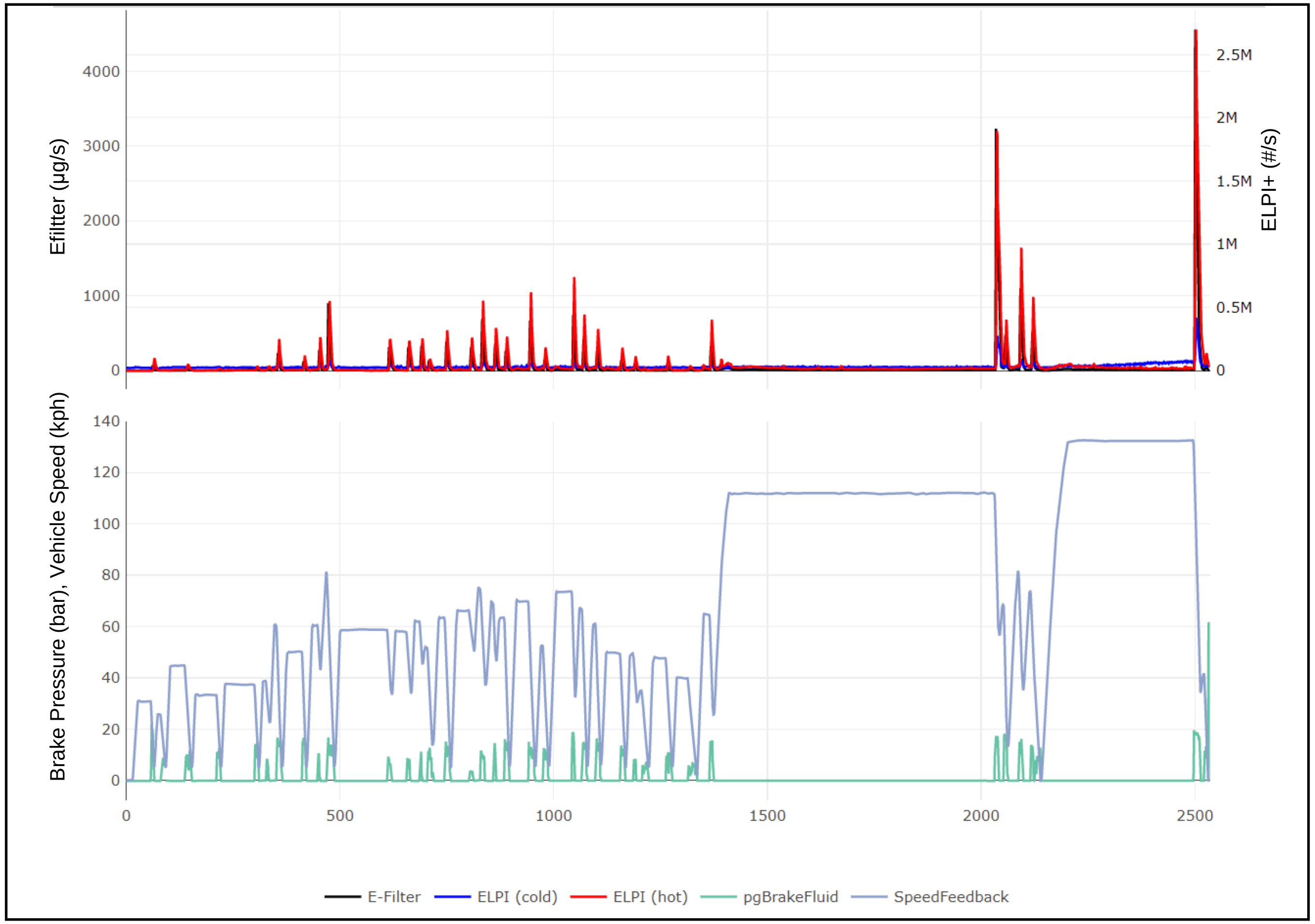


Sample analysis included:

- Combination of two Dekati® Electrical Low Pressure Impactors (ELPI+) for real-time particle size distribution and concentration (size range 6 nm – 10 µm)
  - The “Cold” ELPI+ measures solid and volatile particles
  - The “Hot” ELPI+ includes a heated inlet to remove the volatile component of the PM.
- Dekati® eFilter for real-time PM mass concentration measurements – and a filter for gravimetric analysis

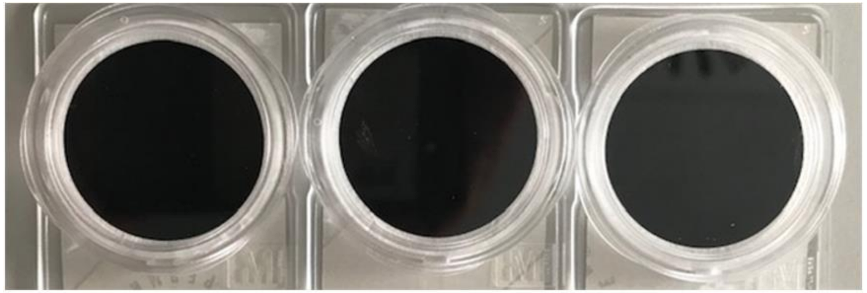
The entire system was installed to a small light duty van and measurements from front tyre undertaken

Real time brake emissions – Chassis Dynamometer



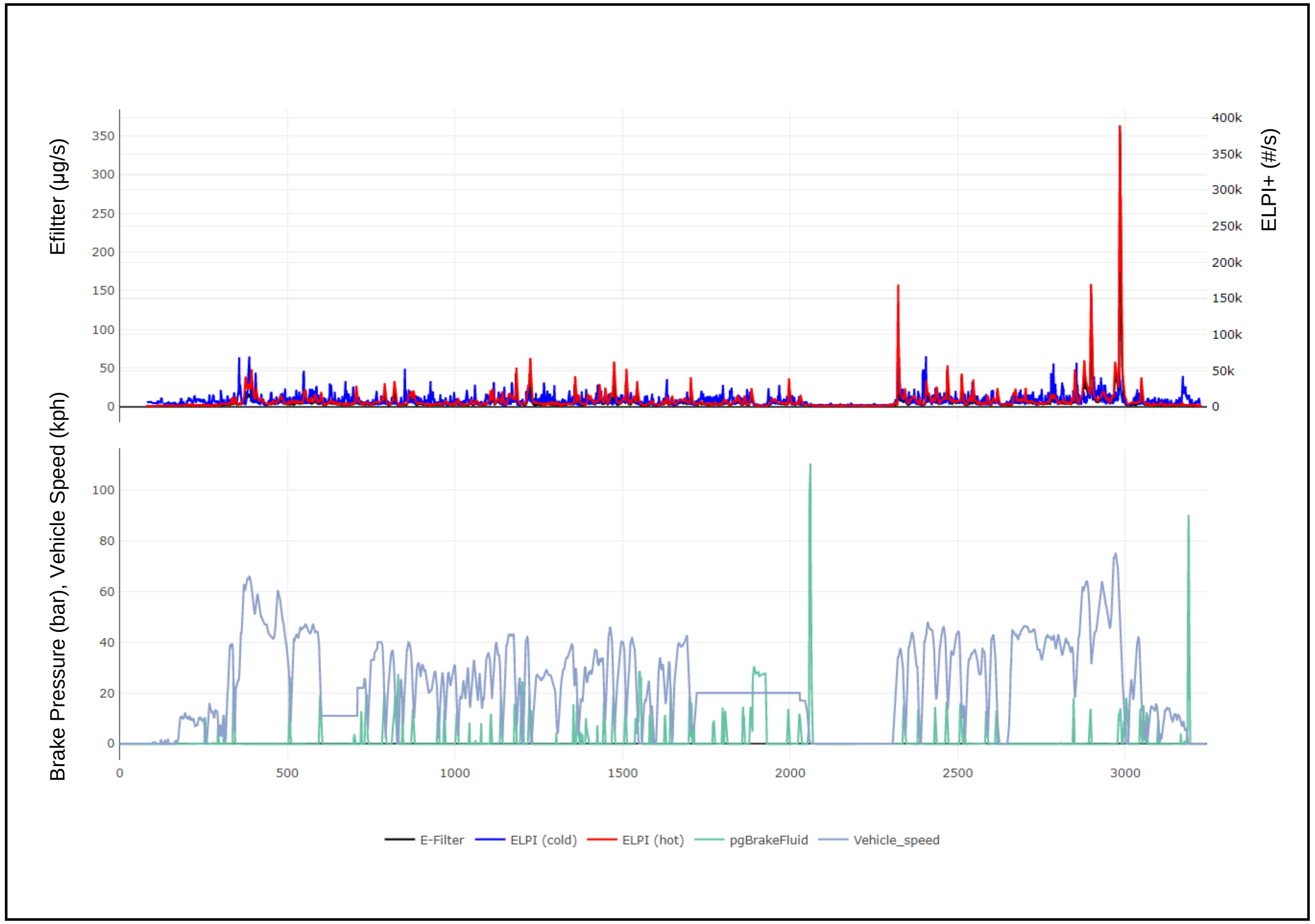
- Particle number and particle mass emissions from the hot ELPI and eFilter coincided with increased braking pressure events on the chassis dynamometer.
- Emissions from the cold ELPI were more challenging to resolve

3 repeat PM filters from PG-42 brake testing



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

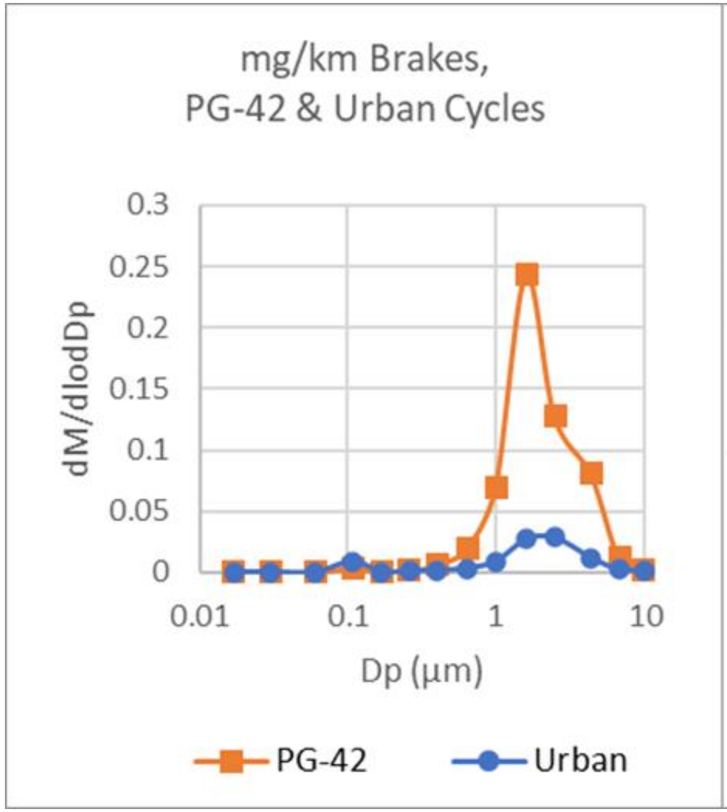
Real time brake emissions – Urban Road



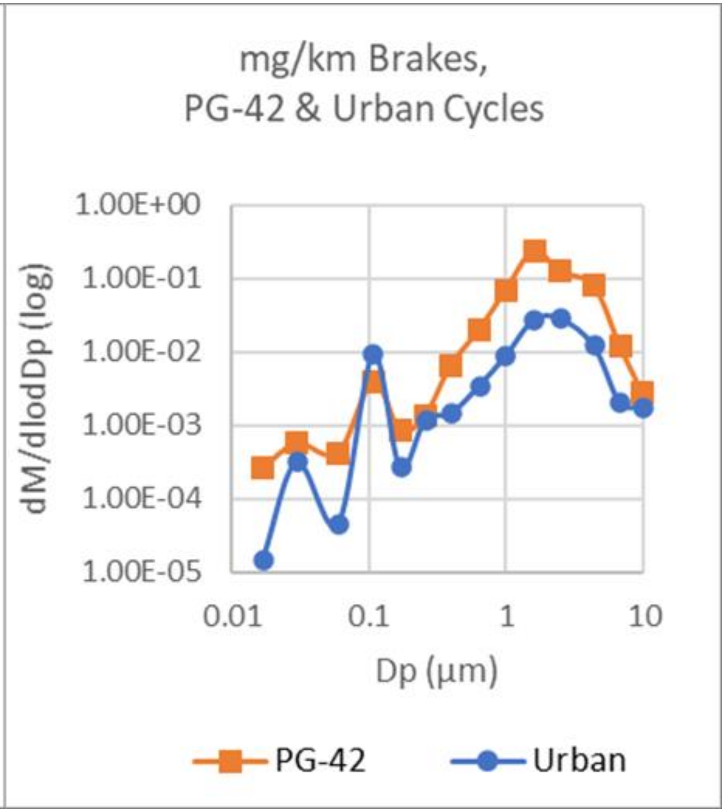
- Braking events on the urban road are representative of real-world driving
- Particle number and particle mass emissions are observed from the hot ELPI and eFilter with braking events
- Similarly to the chassis dyno tests - emissions from the cold ELPI were more challenging to resolve

Real time brake emissions – particle mass size distributions

Mass Weighted Particle Size Distributions, Cold ELPI



linear scale

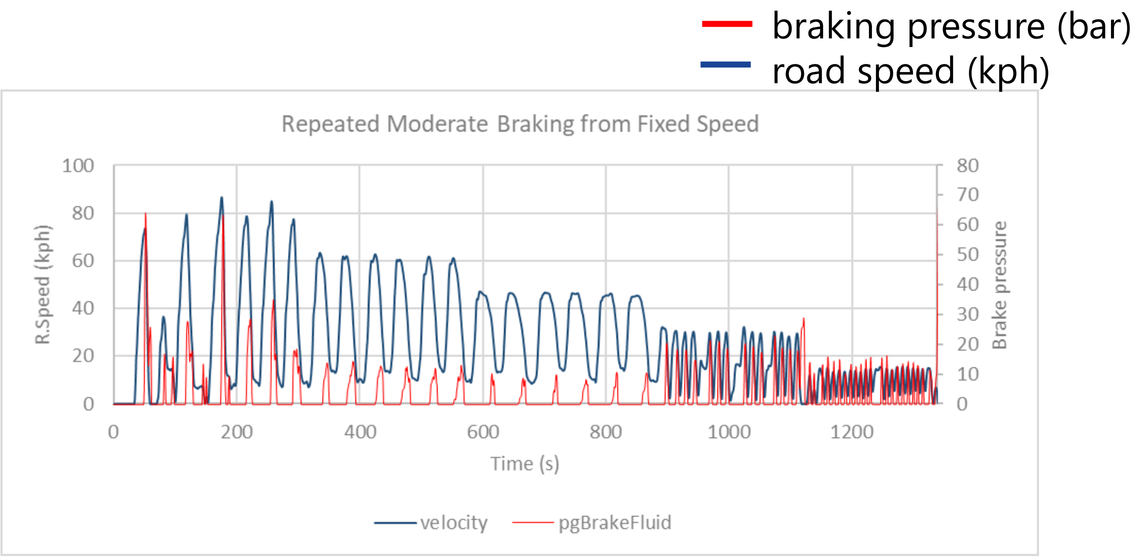


log scale

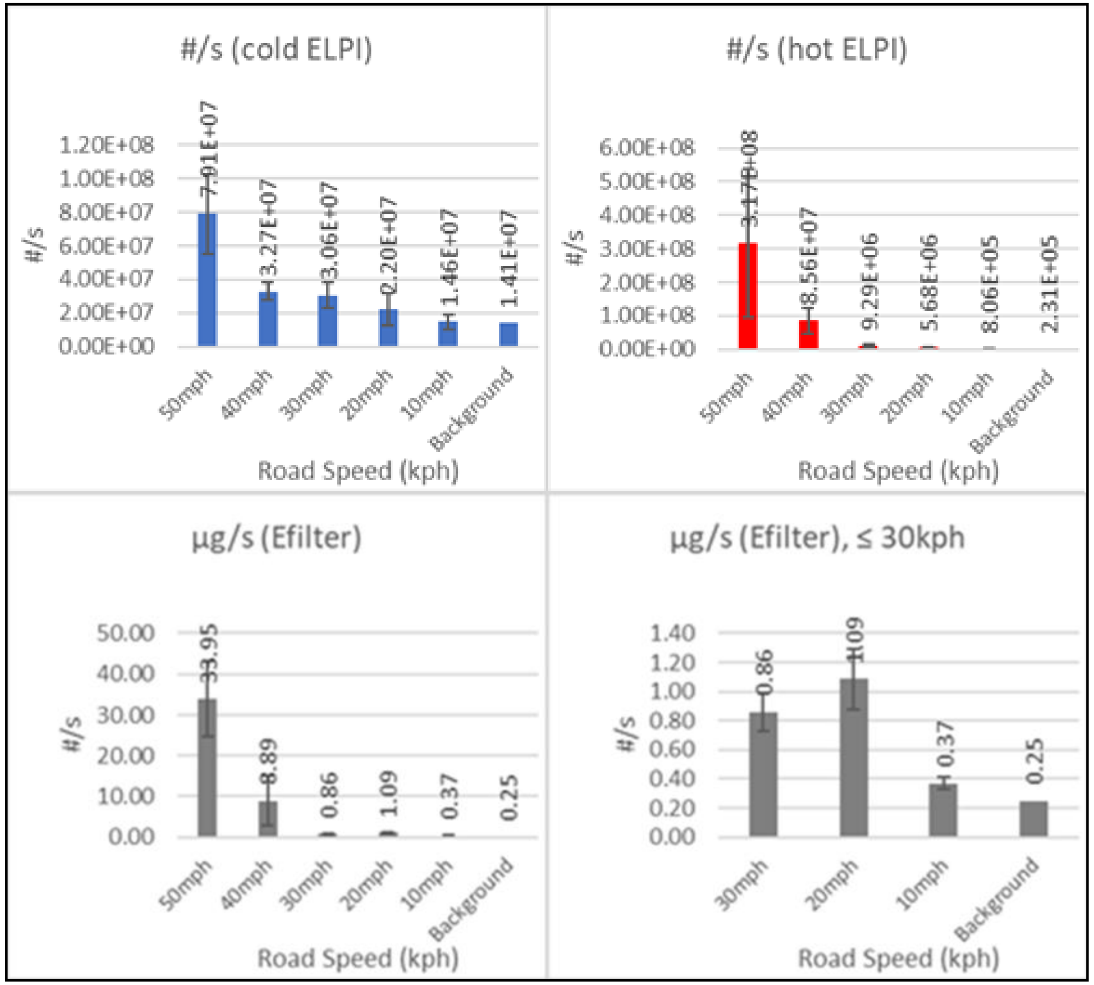
- Particle size distributions from the PG-42 and urban drives are generally similar
- Two modes observed: a minor mode at ~100nm (0.1µm) and a dominant mode at ~1.6µm
- The >1µm mode is likely to be mechanically generated wear materials primarily released from the brake pad

Real time brake emissions – Test Track

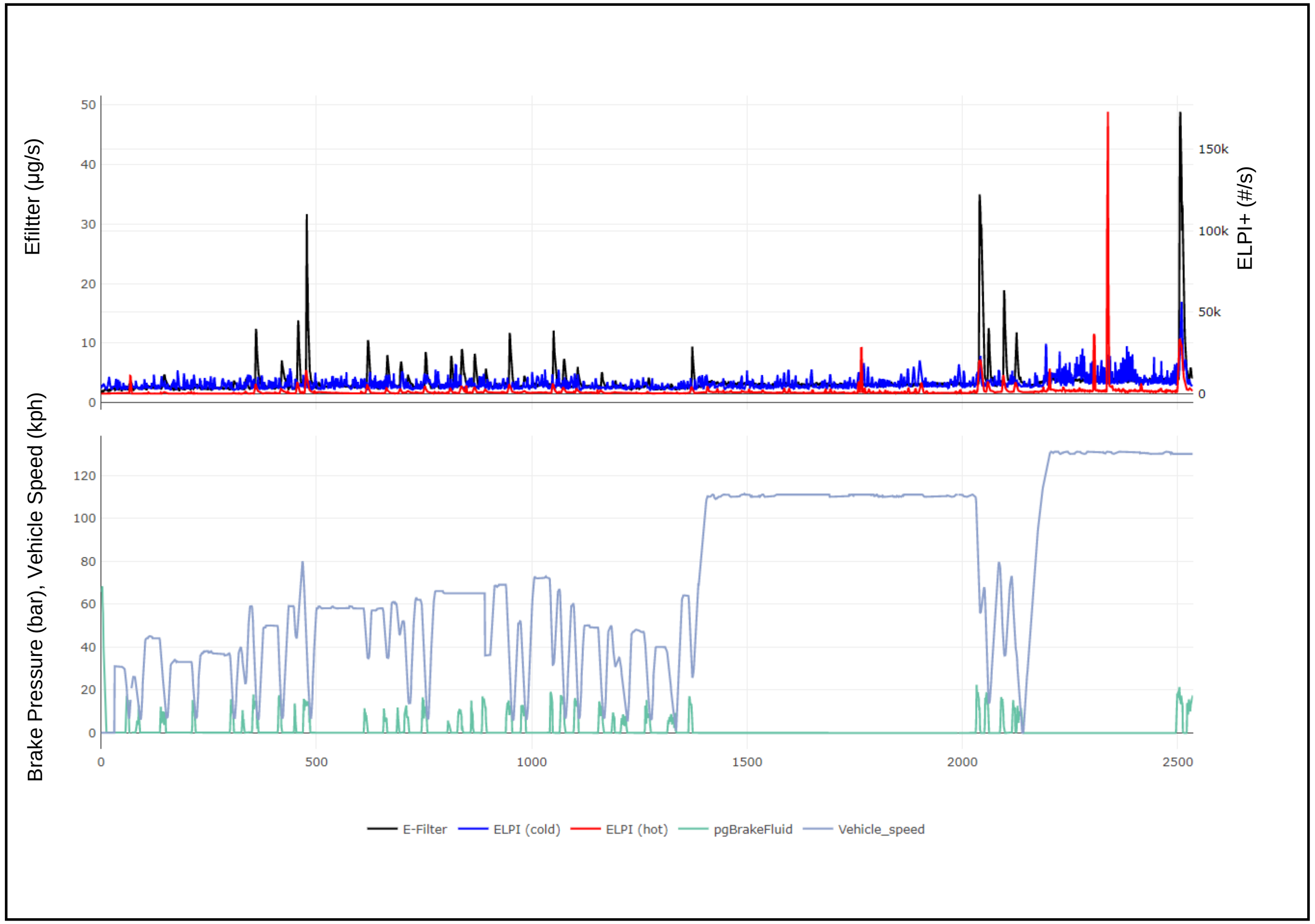
A series of moderate repeated braking events were performed on the test track from different speeds



Average particle/s emissions compared with backgrounds

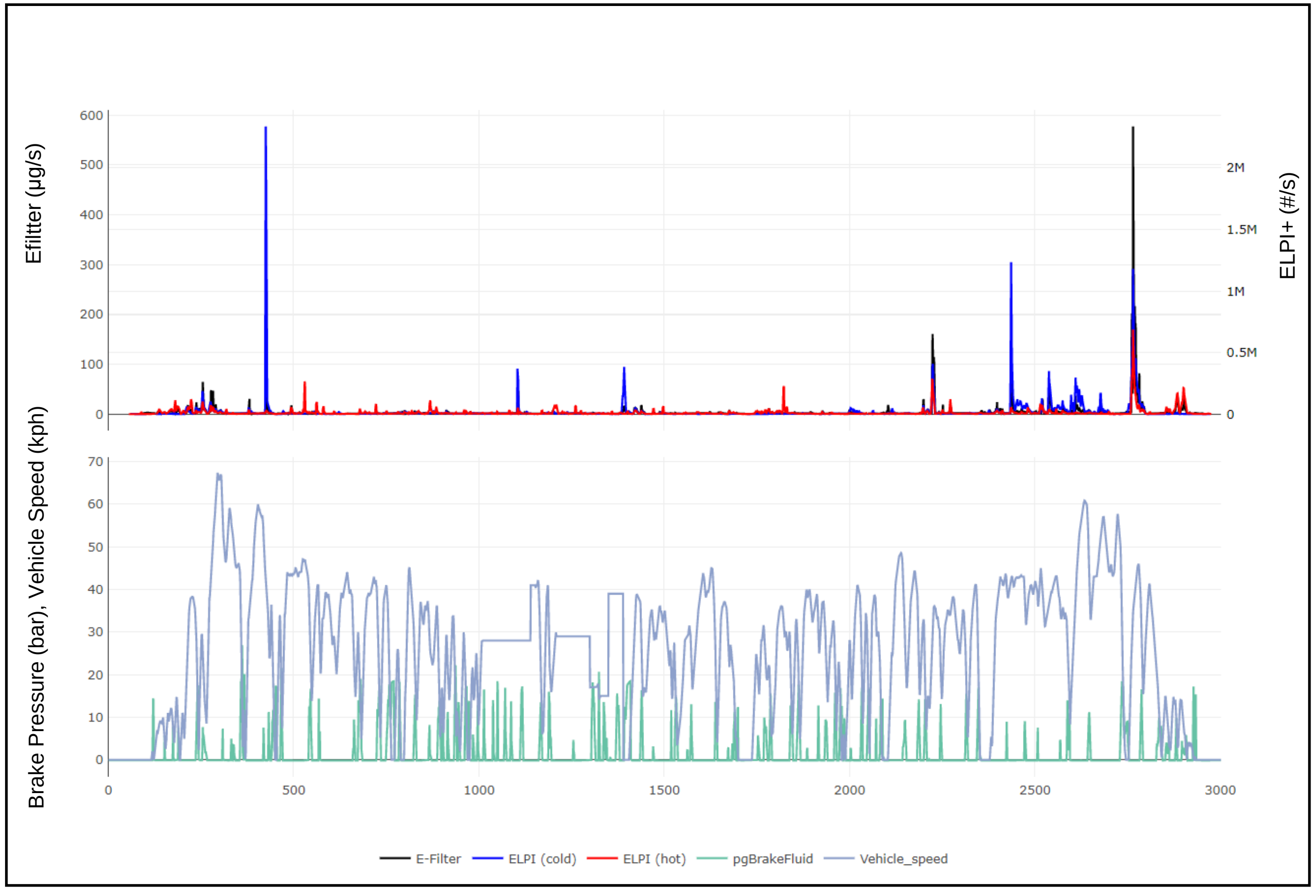


Real time tyre emissions – Chassis Dynamometer



- Spikes of particle number emissions from the ELPIs, both during braking events but also during accelerations and cruises.
- eFilter mass emissions appear to be closely related to the braking events
- Masses an order of magnitude lower for tyre emissions than for the brake emissions

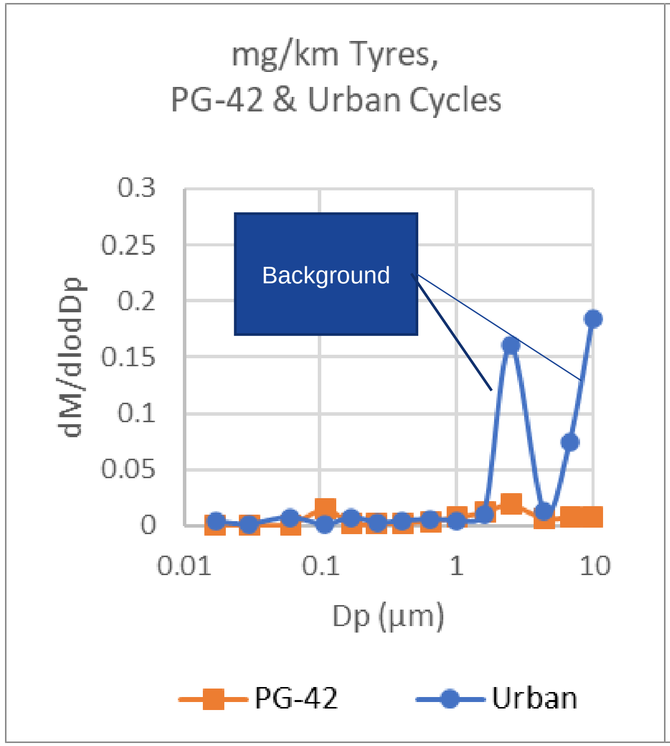
Real time tyre emissions – Urban Road



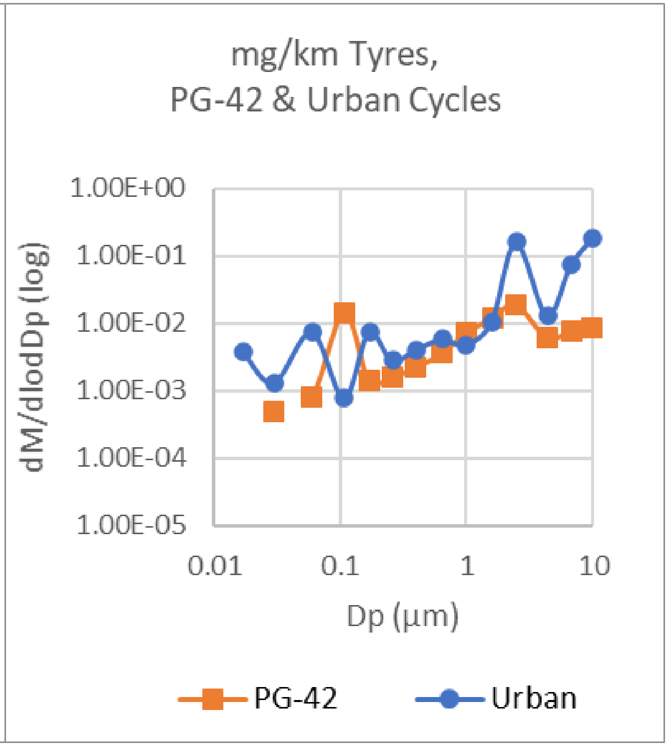
- Some urban braking events coincide with an emissions peak, however, not all do
- Peaks can also be observed that are not related to instantaneous braking events
- Emissions were much higher on the urban road, compared to the chassis dyno, despite less severe braking events.

Real time tyre emissions – particle mass size distributions

Mass Weighted Particle Size Distributions, Cold ELPI

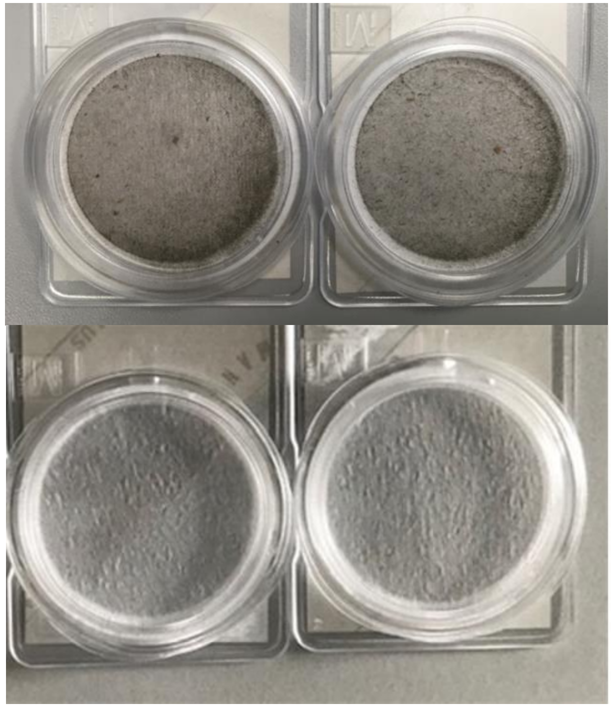


linear scale



log scale

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

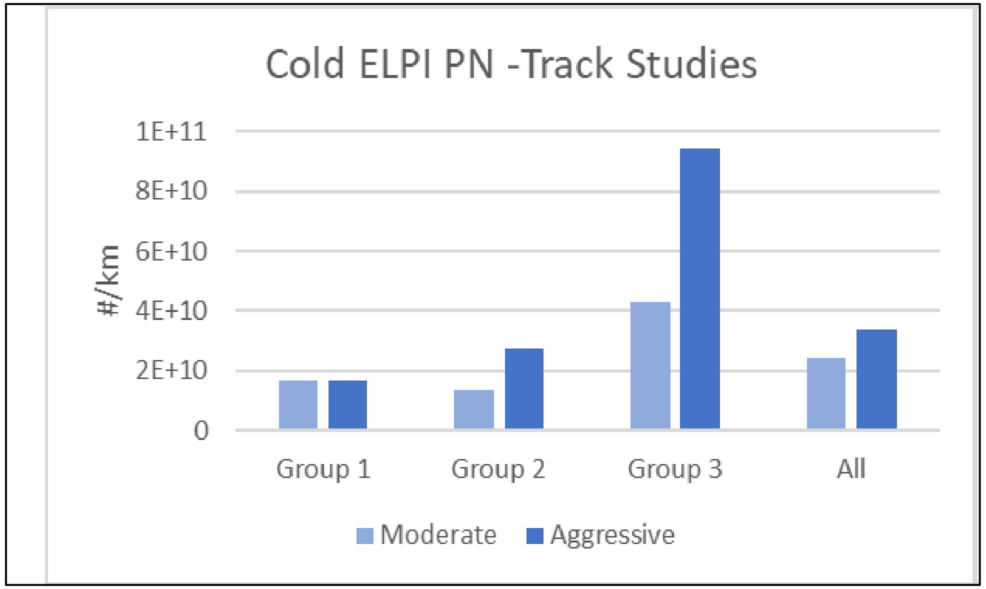


Urban testing PM filters are dirty & contaminated with discrete large particulates

Chassis Dyno filters show uniform PM material

Real time tyre emissions – Test Track

Data from three consecutive repeat sets 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 during the aggressive braking tests

Larger coarse mode of particles (>0.5µm) present in the moderate testing than during the aggressive braking testing

Likely to be from an ambient background source and contains volatile particles.

Summary

- An on-road system for measuring brake and tyre wear was developed and installed to a small light duty van - testing undertaken in a chassis dynamometer facility; on a nearby test-track; and on-road in an urban environment.
- Mass weighted particle size distributions from cold ELPI during the brake tests were similar in the chassis dyno and urban driving.
- Emissions from brake wear increased with aggressive braking events
- Real-time spikes of particle mass and particle number from tyre wear in the chassis dyno correspond to most braking events.
- During moderate braking events on the test track, particle number and particle mass emissions from tyres were not always aligned with every braking event.
- Size distributions of total particles are interesting, but unrepeatable. Heated sampling leads to restructuring of the sampled particles, and unrepresentative results, if some volatile materials remain.
- Measurement of tyre wear particle number and mass emissions is much more challenging on the test track and road using the scoop approach, due to background contributions.

Potential further work

- The favoured metric for PN measurement of brakes and tyres would be a non-volatile approach. Possibly supplemented by a parallel total particle measurement to address both volatile and non-volatile particles
- Real-time mass would be useful, with a filter-based approach to enable chemical analysis and visualisation of the PM materials collected
- Explore and validate sample duct for sampling measurements for tyre wear
- Study specific influences on brake particle emissions on chassis dyno, test track and road
  - E.g., disc and pad compositions, dynamics
- Study specific influences on tyre particle emissions on chassis dyno (& tracks)
  - E.g., tyre compositions, tyre sizes