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ERMES PLENARY 2021

Non-exhaust and Non-road Transport Emissions

PM and PN Emissions from Light-Duty Vehicle Brakes

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26 MAY 2021

Joint Research Centre

Outlook

- Short background on brake emissions
- Literature based LDVs brake PM EFs
- Development of a lab-based method
- Preliminary PMP-based PM and PN EFs
- Options to reduce brake emissions

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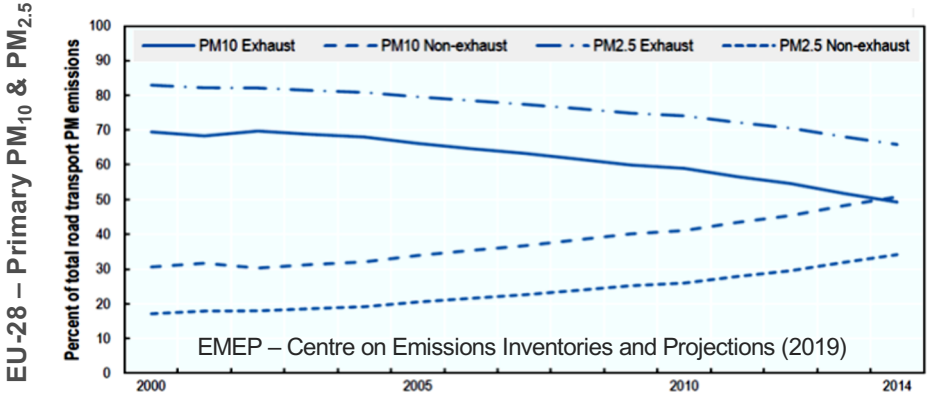
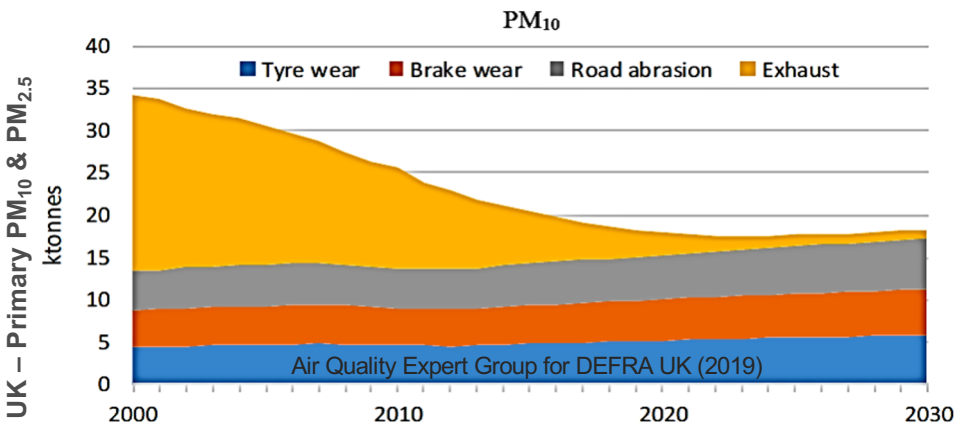
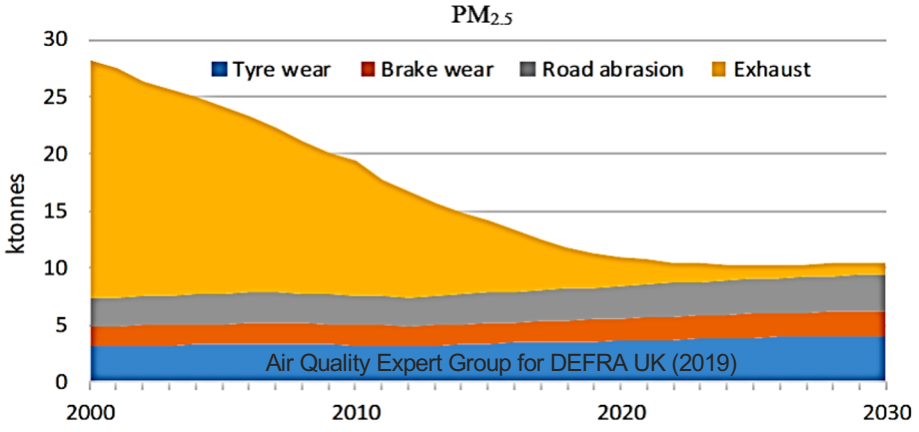
Exhaust vs. Non-exhaust Emissions



1. EFs are based on type-approval tests while real-world exhaust PM emissions are expected to be higher – Data better reflect the situation in countries with newer fleet composition

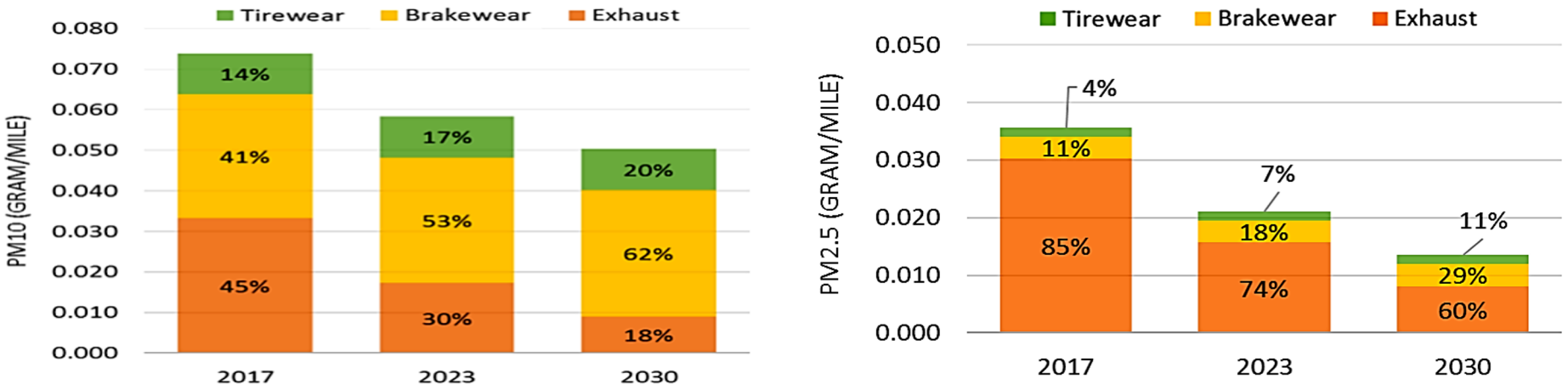
2. Question regarding the underlying assumptions – Lack of standardized methods for characterizing non-exhaust emissions





Despite the reported differences non-exhaust emissions have become much relevant for air pollution

Brake Emissions – Importance

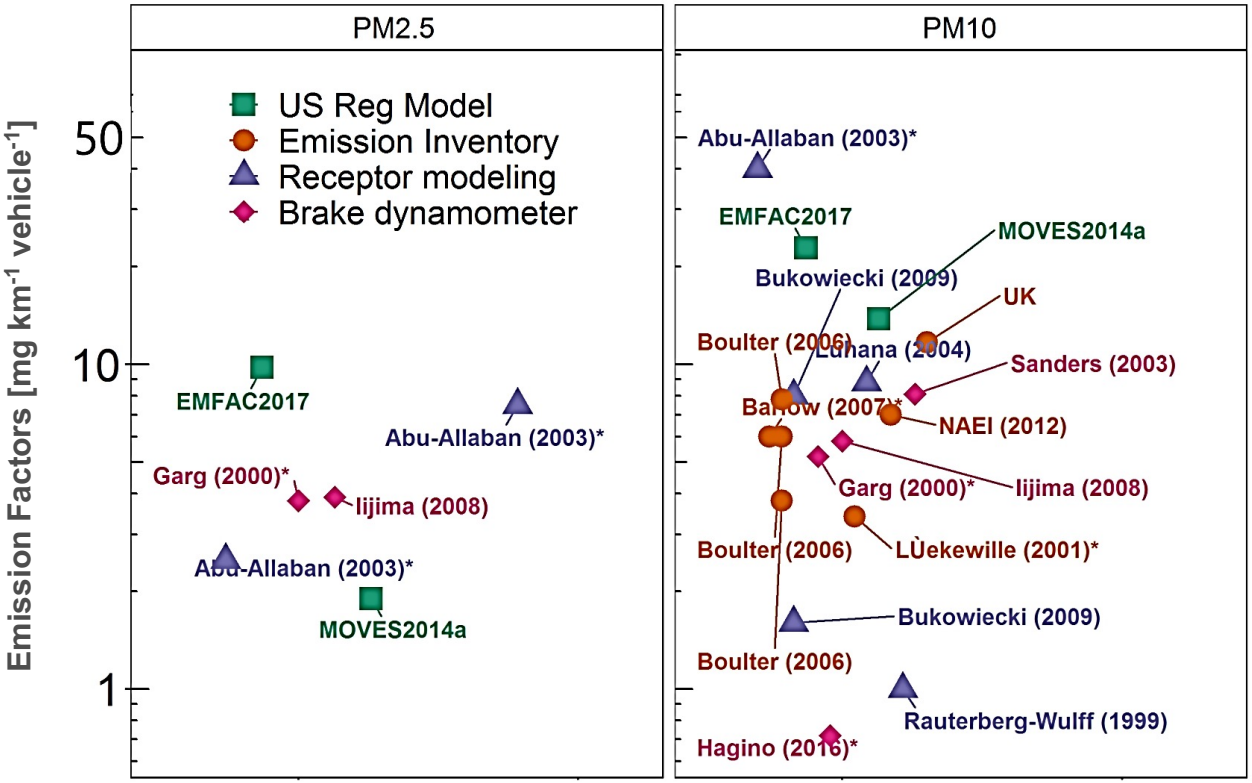


MOVES – Sonntag et al. (2020) HEI Virtual Workshop on non-tailpipe PM emissions and health

- ✓ Brake PM_{10} and $PM_{2.5}$ are approximately 3 times higher compared to tire PM_{10} and $PM_{2.5}$ (road wear not included)
- ✓ Projections show similar brake/tire emissions ratio in 2030; however, EFs have not been updated recently – Furthermore projections do not take into account technological improvements and future technologies that will heavily affect – at least brake emissions

Despite the reported differences – which reflect different methodological approaches – brake emissions make up a significant fraction of non-exhaust emissions

LDV Brake Emission Factors – Legacy



MOVES – Sonntag et al. (2020) HEI Virtual Workshop on non-tailpipe PM emissions and health

1. Emission Inventories – Require accurate emission rate input data and do not take into account differences and technologies

2. Receptor Modelling – Requires the application of unique chemical tracers

3. Brake dynamometer – No standardized or commonly accepted method available, yet

4. On-road measurement – Very challenging to isolate brake (or other non-exhaust) emissions

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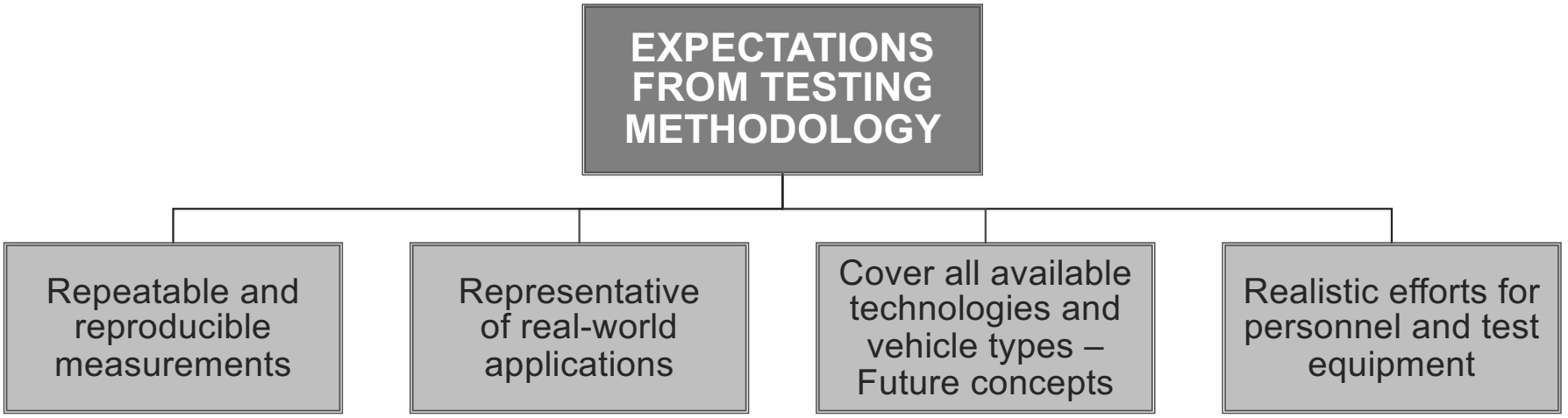
UNECE Mandate – Method Development

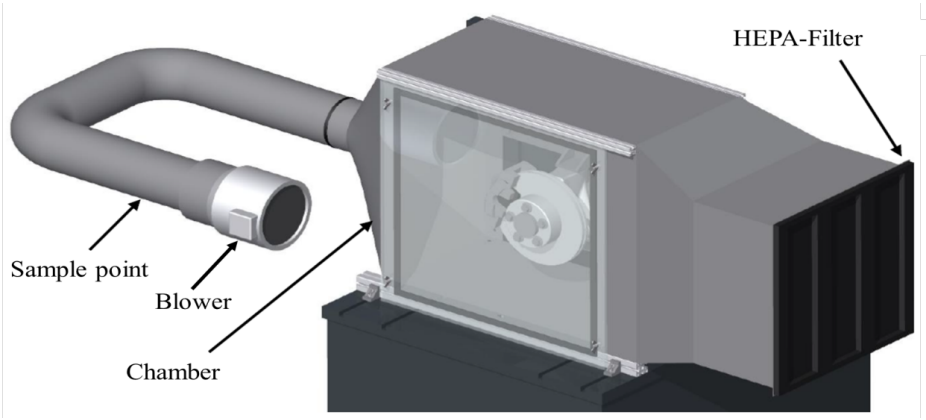
- ✓ June 2019: The GRPE approves the ToR mandating the PMP IWG to develop a lab-based method for sampling and measuring brake particle emissions
- ✓ January 2020: Several UNECE GRPE Contracting Parties request the PMP IWG to consider a possible use of the proposed method as a regulatory tool



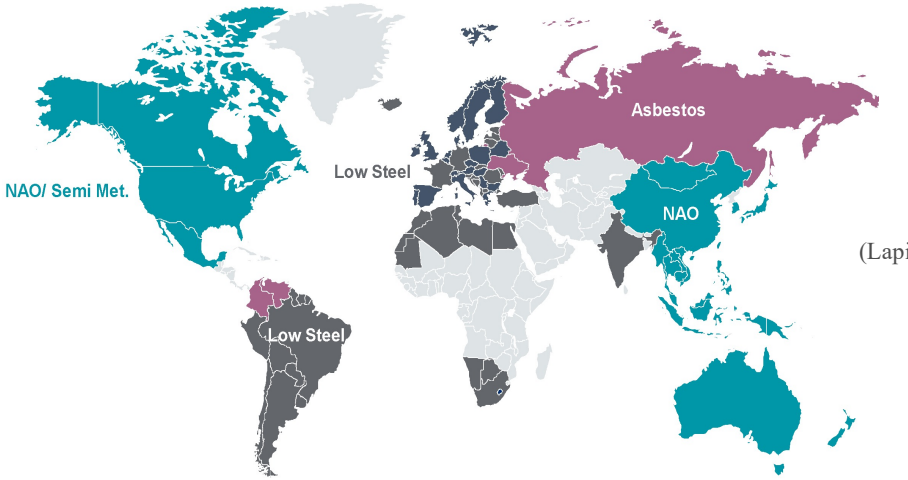
PMP Method – Fundamentals

Bandiera et al. – EuroBrake EB2021-STP-012

1. Caliper (Al + Si, Mg, Cu, etc.)
2. Disc (Cast iron, CI + Coatings, Carbon Ceramic, Al, etc.)
3. Brake pads (Low Steel (LS), Non-Asbestos Organic (NAO))



Hesse et al. 48th PMP Meeting



Prevailing pad formulations worldwide

(Lapinus - Automotive braking trends – the inside track)

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Brake Emissions Method – Main Specifications

- ✓ Novel WLTP-Brake Cycle reflecting real-world driving and braking conditions
- ✓ Dynamometer specifications and checks (i.e. background concentrations, dyno climatic controls, brake enclosure design, etc.)
- ✓ Brake specifications (temperature measurement method, defined bedding-in procedure, etc.)
- ✓ Definition of vehicle-specific parameters (test inertia based on the force distribution specified by the OEM, options for correcting for parasitic vehicle losses)
- ✓ Well defined cooling protocol reflecting real world vehicle temperature profile data
- ✓ Measurement related specifications for PM and PN (methods, instrumentation, calibration, etc.)

So far, the method development targeted brakes from ICE LDVs

- ✓ Brakes from Hybrid Light Duty Vehicles
- ✓ Brakes from Full Electric Light Duty Vehicles
- ✓ Brakes from Medium and Heavy Duty Vehicles

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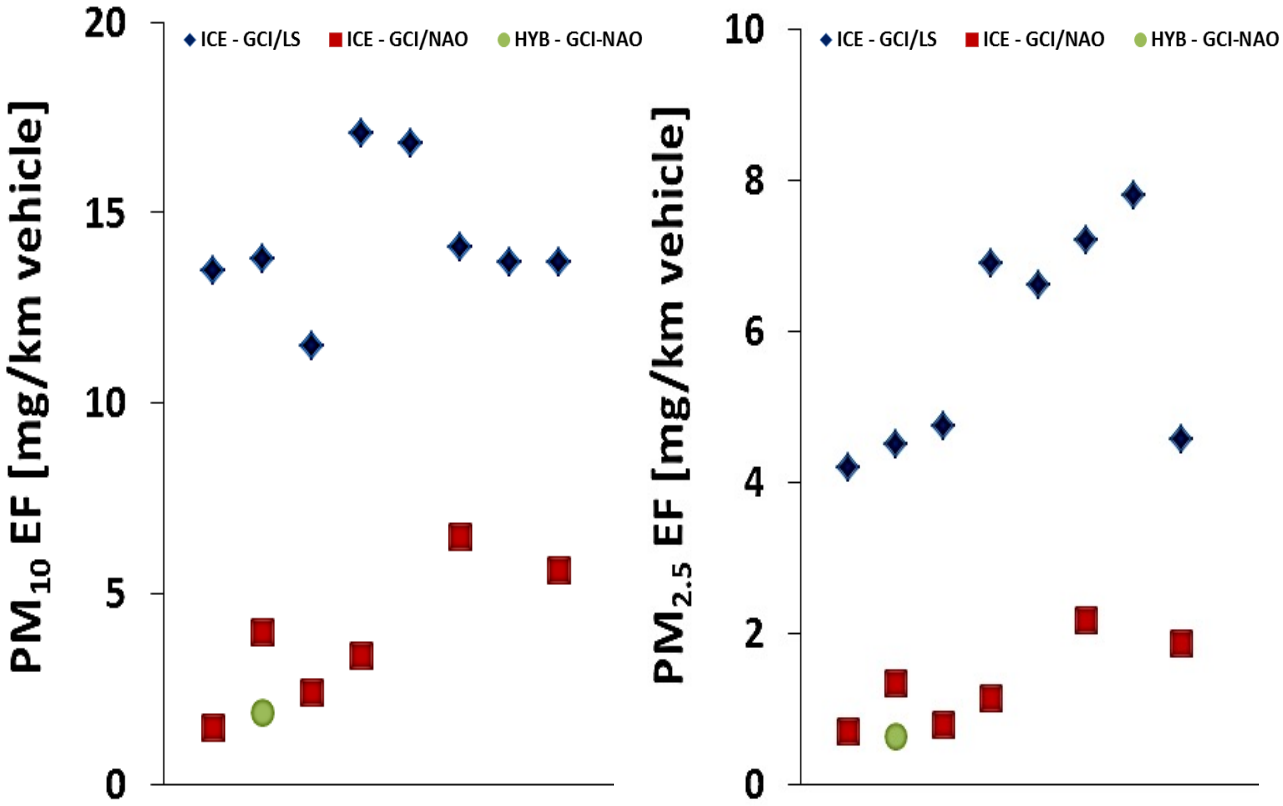
Brake PM EFs – Preliminary PMP Data



ICE Data (LS): Mamakos et al. 2019; Zum Hagen et al. 2019; Hagino et al. 2019; Agudelo et al. 2020; Mamakos et al. 2021; Hesse et al. 2021; Stanard et al. 2021, PMP TF2 unpublished data

ICE Data (NAO): Hagino et al. 2019; Agudelo et al. 2020; Stanard et al. 2021

Hybrid Data: Stanard et al. 2021

- ✓ Presented EFs are from ***a limited number*** of tests following (most of) the PMP specifications
- ✓ EFs were derived for GCI discs which are the most commonly available type in the market – Coated discs show much lower EFs (Hesse et al. 2021)
- ✓ Tested brakes cover a wide range of front applications featured in vehicles with different mass (1200-2600 kg)
- ✓ $PM_{2.5}$ is approximately a third of PM_{10} emissions regardless the type of pad
- ✓ Previously reported EFs underestimate brake PM emissions at least for LS brakes

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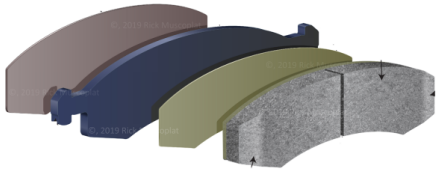
Brake PN EFs – Preliminary PMP Data

- ✓ PN EF of **2-6x10^{9} #/km** per brake have been reported when typical European brakes (LS Pad / Grey Cast Iron Disc) are tested over the WLTP-Brake cycle. Estimated overall PN emissions at vehicle level strech between the high range of 10^{9} #/km and the low- or mid- range of 10^{10} #/km
- ✓ PN EF of **1-3x10^{9} #/km** per brake have been reported when GCI – NAO brake couples are tested over the WLTP-Brake cycle or the CBDC. Overall PN emissions at vehicle level are expected to lie at the medium range of 10^{9} #/km
- ✓ A Hybrid vehicle showed the highest PN emissions (**3-4x10^{9} #/km)** among vehicles with NAO pads tested over the WLTP-Brake cycle (Agudelo et al. 2021)
- ✓ Overall PN emission levels from modern brakes seem to be relatively low compared to existing exhaust limit for solid particles

Options for Reducing Brake Emissions

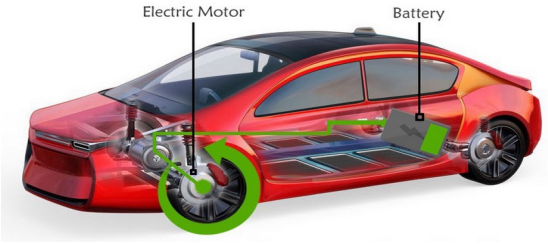
Friction Materials – LS vs. NAO

(Sin et al. – EuroBrake EB2021-EBS-012



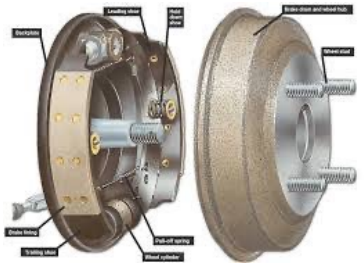
Regenerative Braking and EVs

(Picture taken from circuitdigest.com)

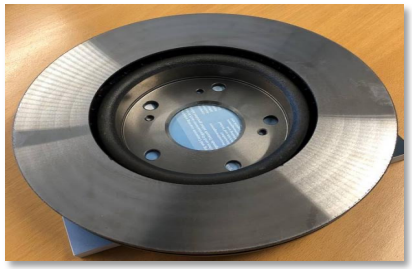


Drum Brakes

(Sin et al. – EuroBrake EB2021-EBS-012)

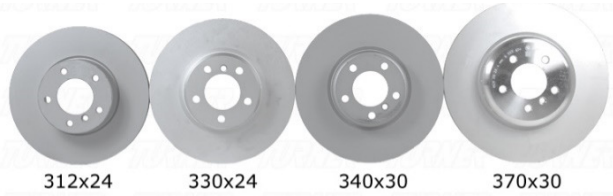


Which are the main options for reducing brake emissions?



Brake Disk Coating

(Eibl et al. – EuroBrake EB2021-MDS-003)



Brake Sizing and Temperature Control

(Sin et al. – EuroBrake EB2021-EBS-012)

Brake Filters

(Sin et al. – EuroBrake EB2021-EBS-012)

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Thank you

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