Health Effects Institute
Workshop on Non-Tailpipe PM Emissions and Exposure
November 12-13, 2020
9:45 am to 2:30 pm ET

Characterization of brake wear particles and emissions
- Current Status and Challenges -

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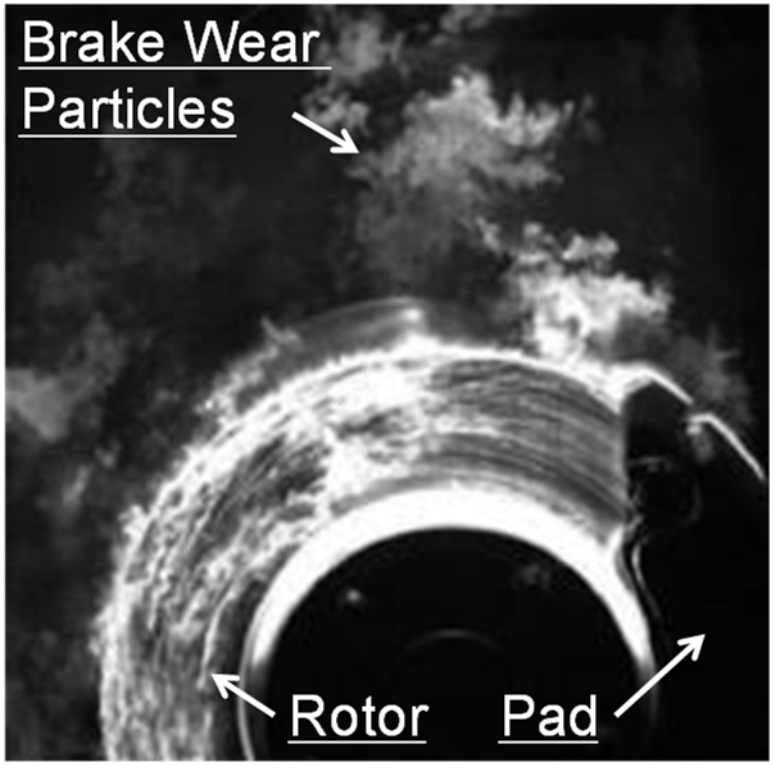
Question to Answer

- Recent total non-exhaust traffic-related PM_{10} emissions being estimated at approximately 55% in big cities and urban environments.
- Required Information : Urban Area Emissions in mg/km & Compositions for Brake / Tire Wear Particles.



Ref & Rev. : Augsburg, et al., SAE 2011-01-2345

How much Brake / Tire Wear Particles ?

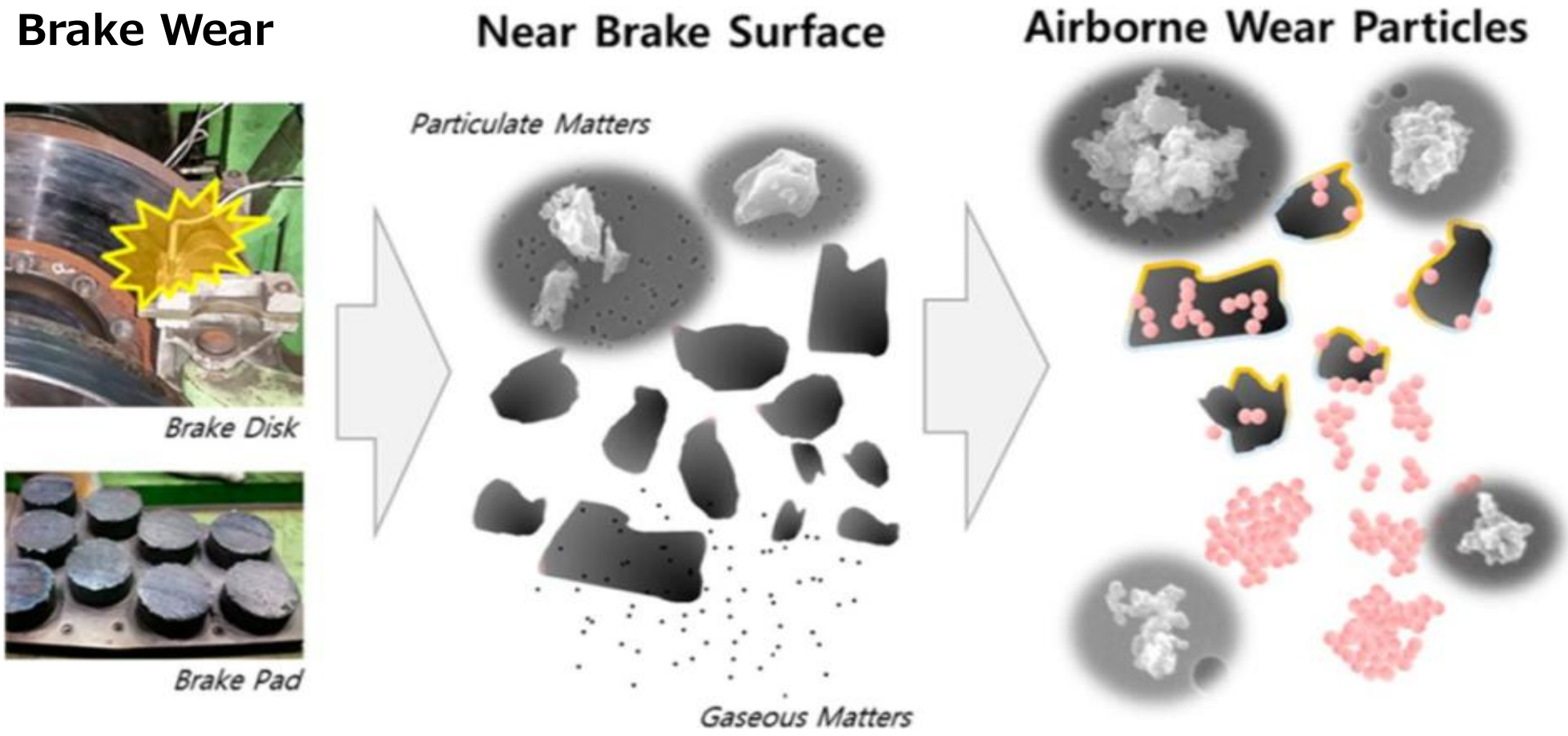
- Emission Levels in mg/km
- Comparable Tail-Pipe Emission

How important is Brake / Tire Wear Particles in Atmosphere?

- Less Contamination in Test
- Key Tracer in Atmosphere

How emit Brake Wear Particles?

- Hypothesis of Brake Particle Emission Mechanism .
- Gas and Particles can be emitted by Brake and Disc (Rotor) Wear.
- Nucleation and Coagulation of Small Particles (Adhesion on Particle) allowed.

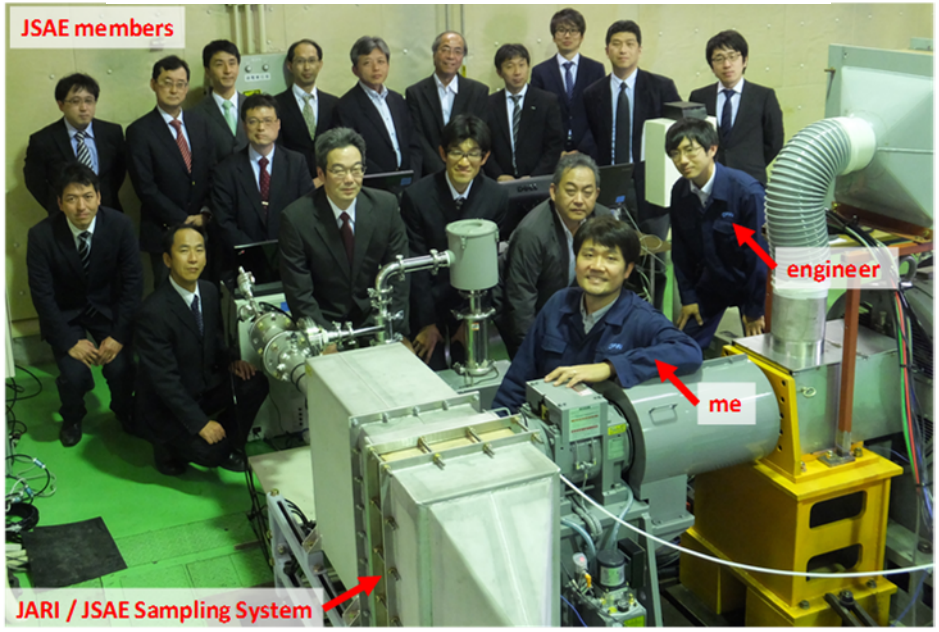


Ref: Namgung et al., Environ. Sci. Technol. 50, 3453–3461 (2016)

How do we measure Brake Wear Particles ?

- In this process, it is absolutely necessary to present choices that are as concrete as possible to the manufacture side.
- Inter-lab. test : 20% difference of $PM_{2.5}$ measurement for Five labs. using WLTP-brake cycle and JASO enclosure.

JARI-JSAE Discussion in 2017



World's first automotive standard for brake emission

JASO

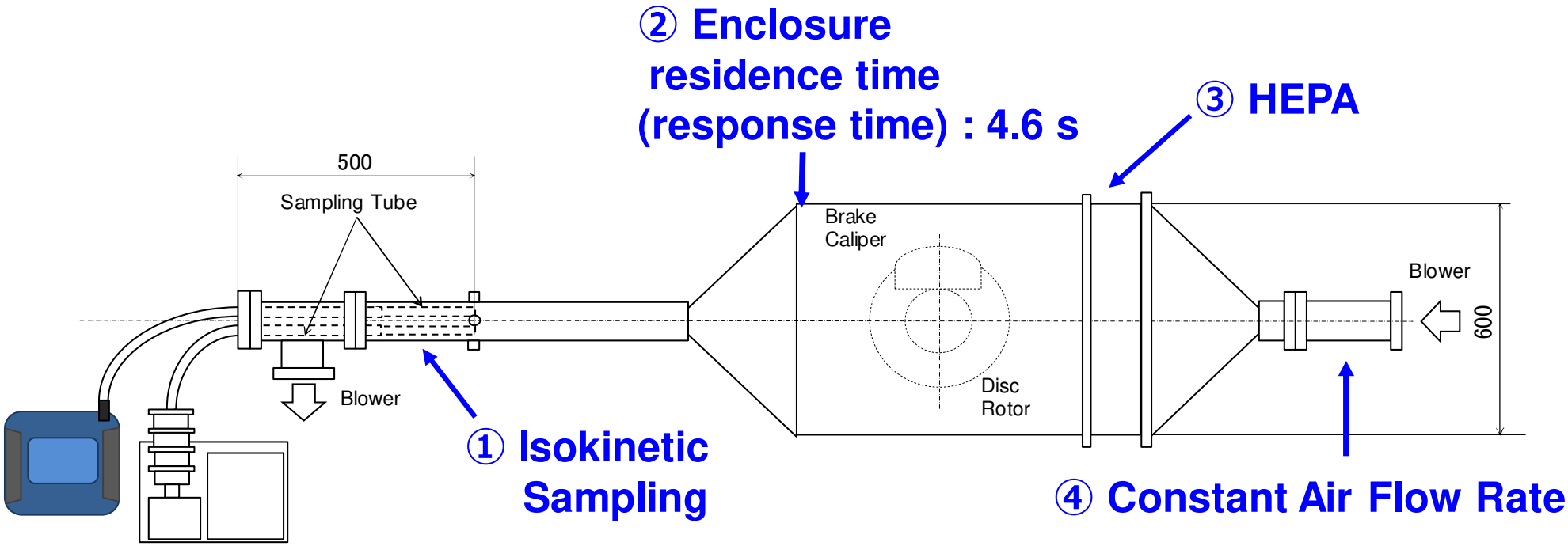
Passenger cars- Measurement method for brake wear particle emissions

JASO C 470 : 2020

JASO C470 : Passenger car - Measurement method for brake wear particle emissions
https://www.bookpark.ne.jp/cm/jsae/cat500.asp?category=502&english=on

How do we measure Brake Wear Particles?

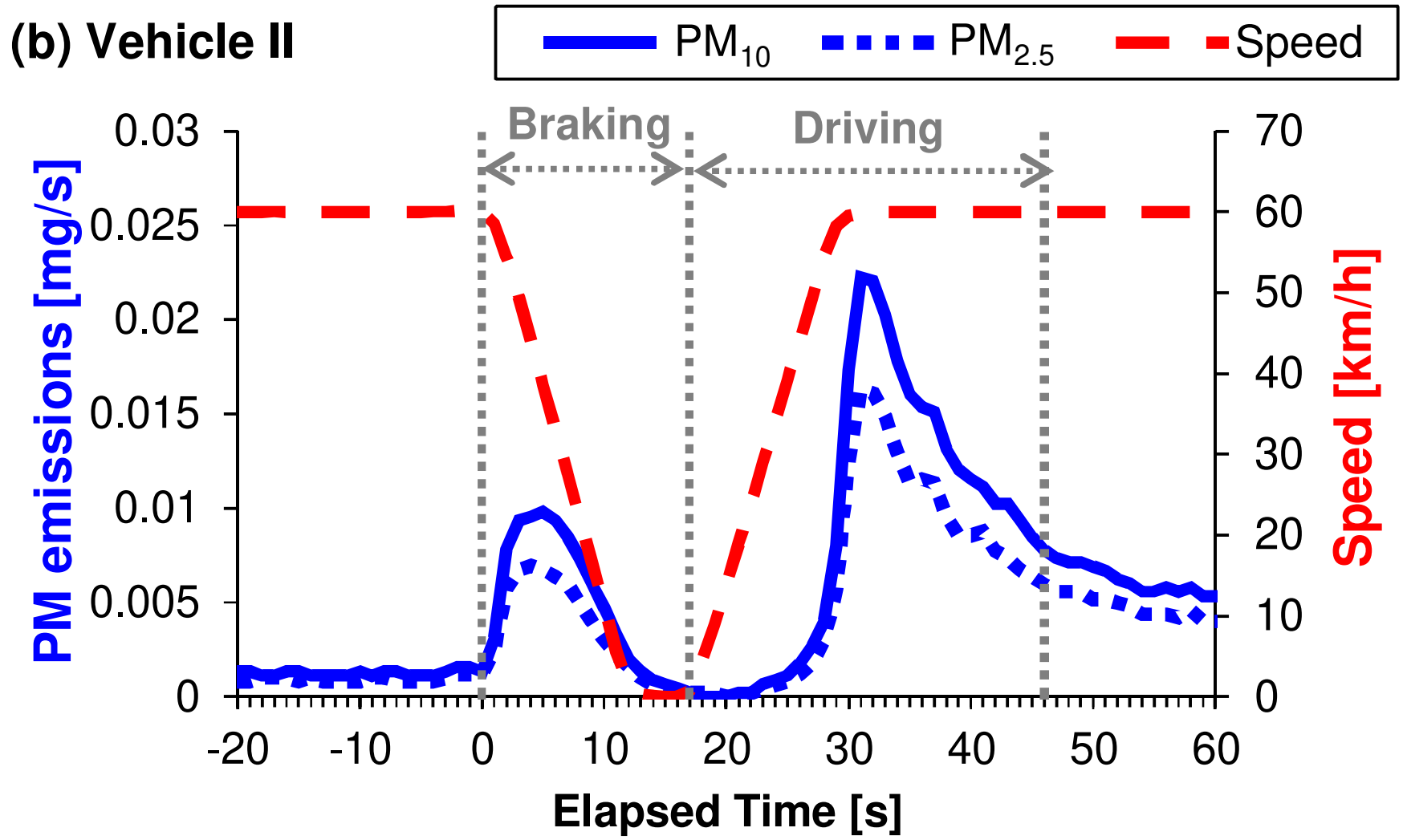
① **Isokinetic Sampling**: PM_{10} and $PM_{2.5}$ both particles measurable
② **Closed Enclosure** : Minimization of contamination
③ **Purified (HEPA filtered) Air** : Minimization of back ground
④ **Constant Air Flow Rate** : Measurable range conventional NAO brakes
(1m^3/min standard, Optional 0.5-3 m^3/min)



JASO C470 : Passenger car - Measurement method for brake wear particle emissions
https://www.bookpark.ne.jp/cm/jsae/cat500.asp?category=502&english=on

Importance of Driving Emission

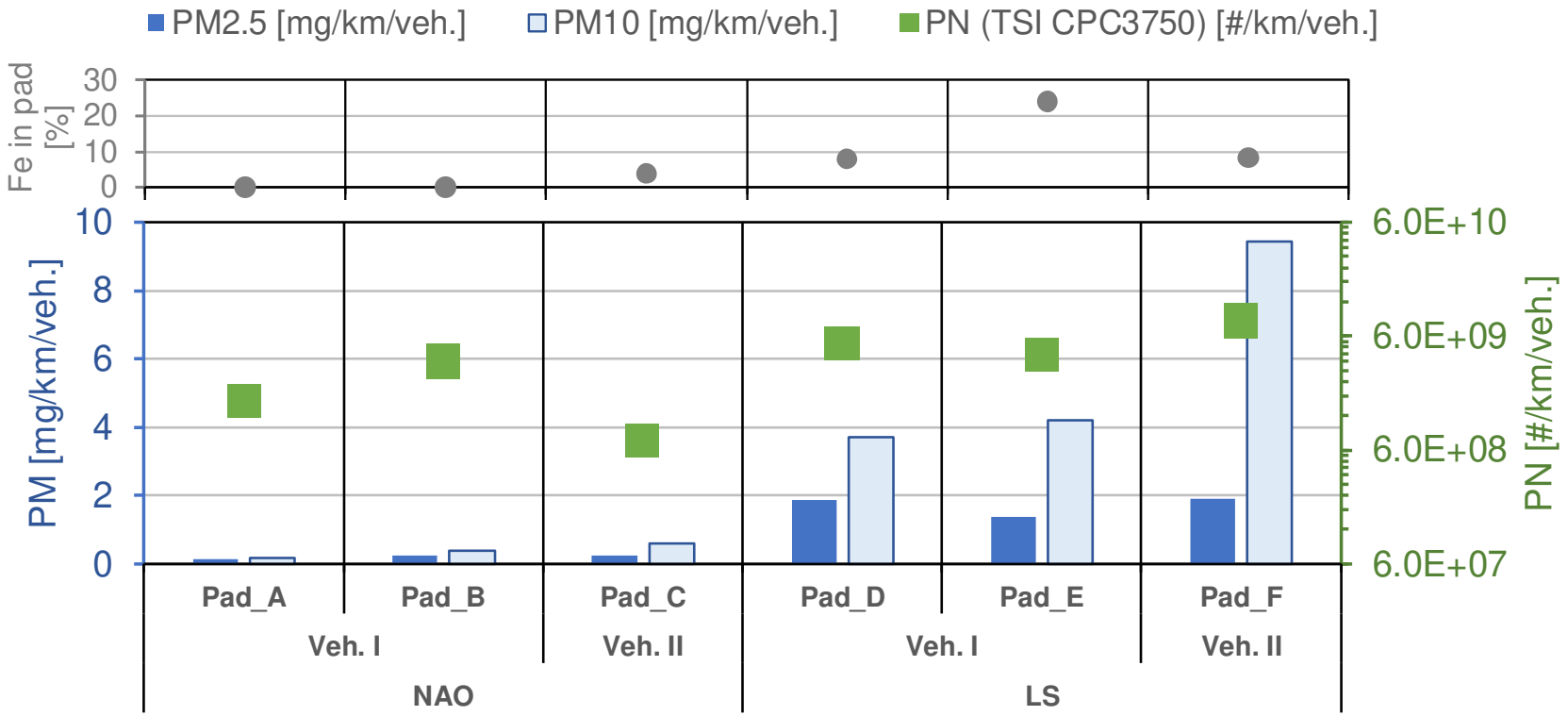
- Brake Emission should be including Braking and Driving, both !!



Ref: Hagino et al., *Wear* 334-335, pp.44–48 (2015)

How much emit Brake Wear Particles ?

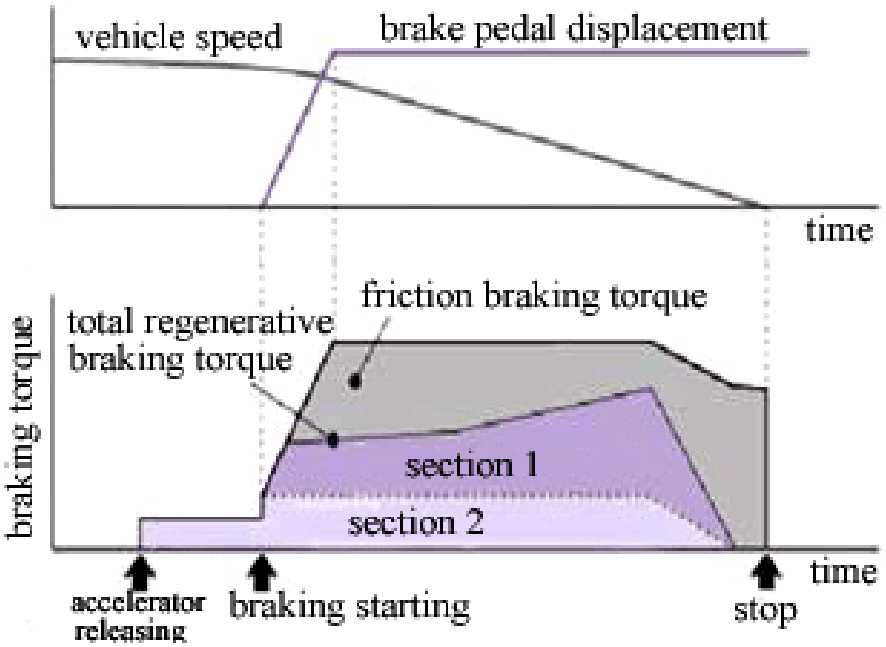
- We are demonstrating to measure PM and PN emissions from passenger car brake particles according to the WLTP-Brake Cycle (4.4h).
- There are difference brake pad materials and vehicles.



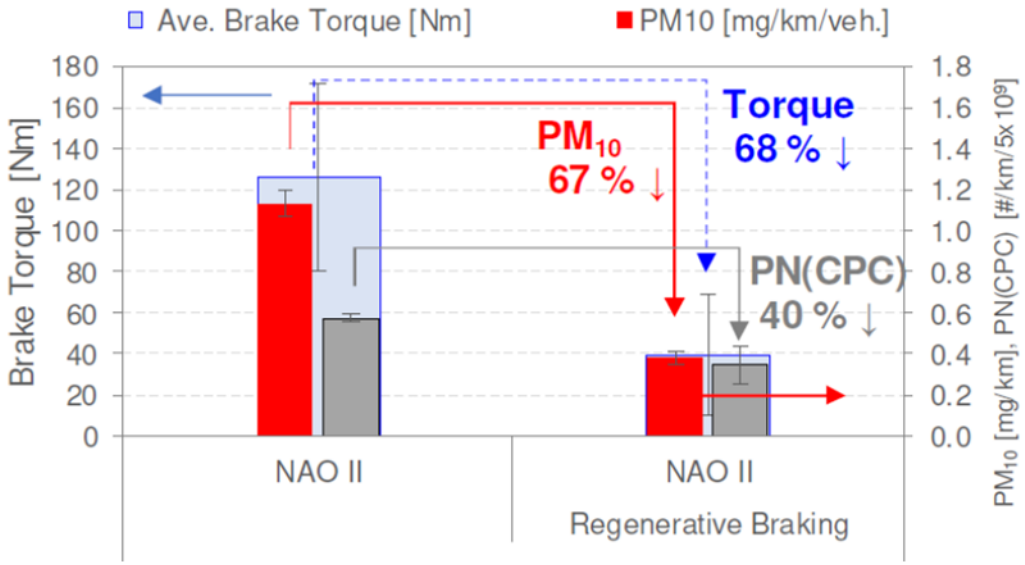
NAO: Non-Asbestos Organics, popular pad material in Japan and US
LS: Low Steel, popular pad material in Euro
Data: Hagino, *in preparation for submission*.
WLTP-Brake Cycle (4.4h) : Mathissen et al., Wear 414–415, 219–226 (2018)

How much reduced by Regenerative Brake

- 303 brake event is same as WLTP-Brake cycle.
- The brake torques profiles were defined for each brake event.
  (i.e. friction braking torque profile, regenerative braking torque profile)



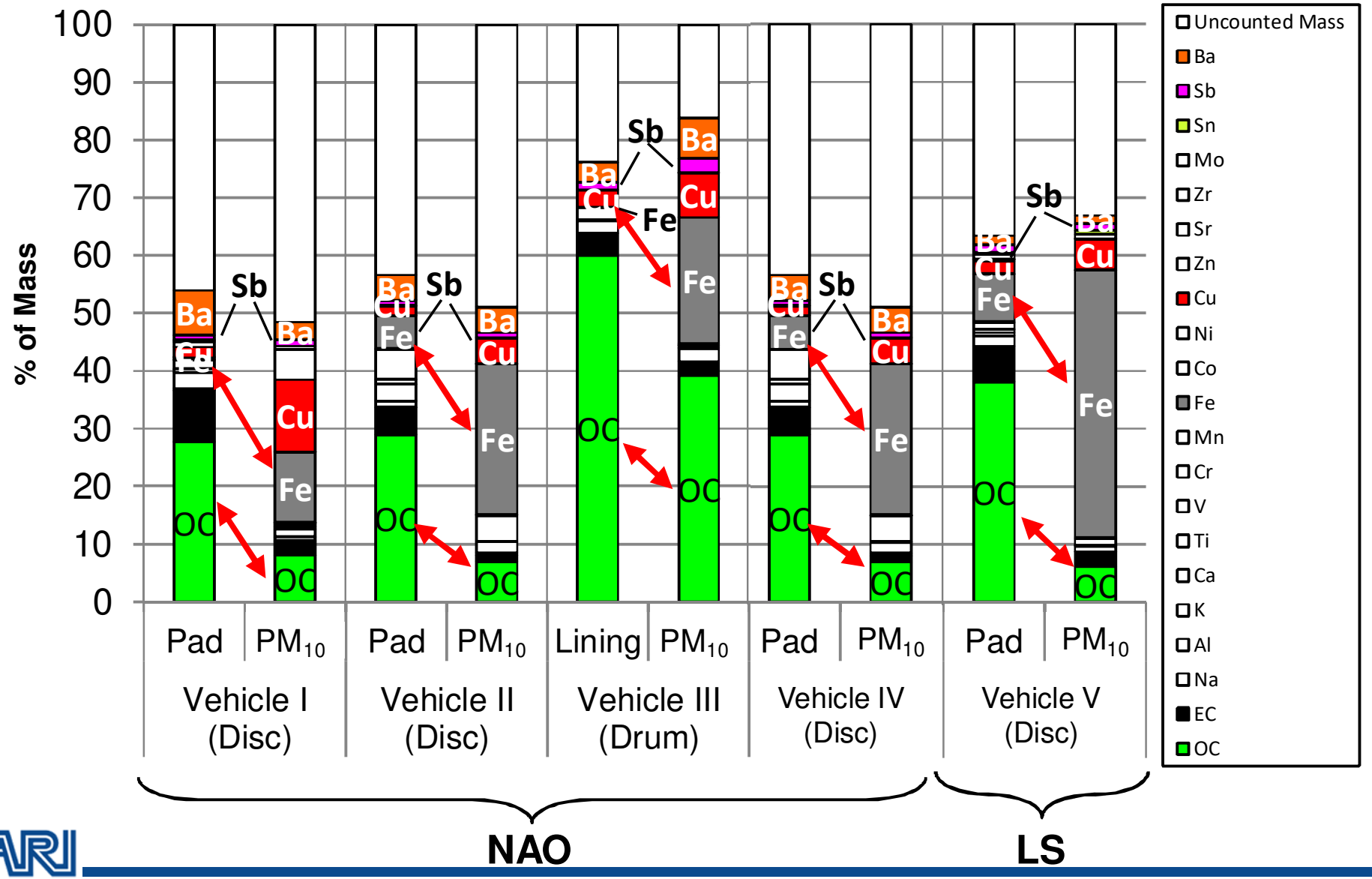
Ref. Ko et al., World Electric Vehicle Journal 6, 186-191 (2013)



Ref. Hagino et al., PMP 50th Session (2019)
https://wiki.unece.org/display/trans/PMP+48th+session

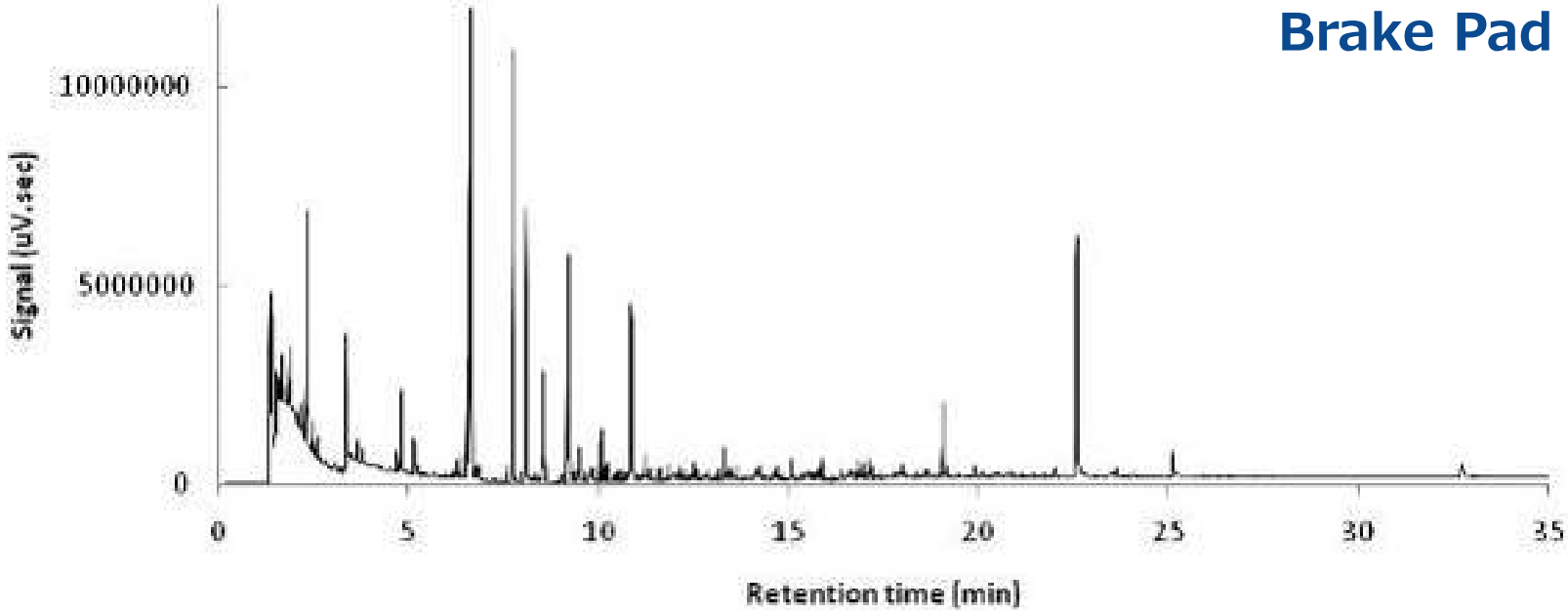
Brake Wear Particle Maker

- **Brake Wear Particle Compositions are NOT equal brake pad / lining Compositions**

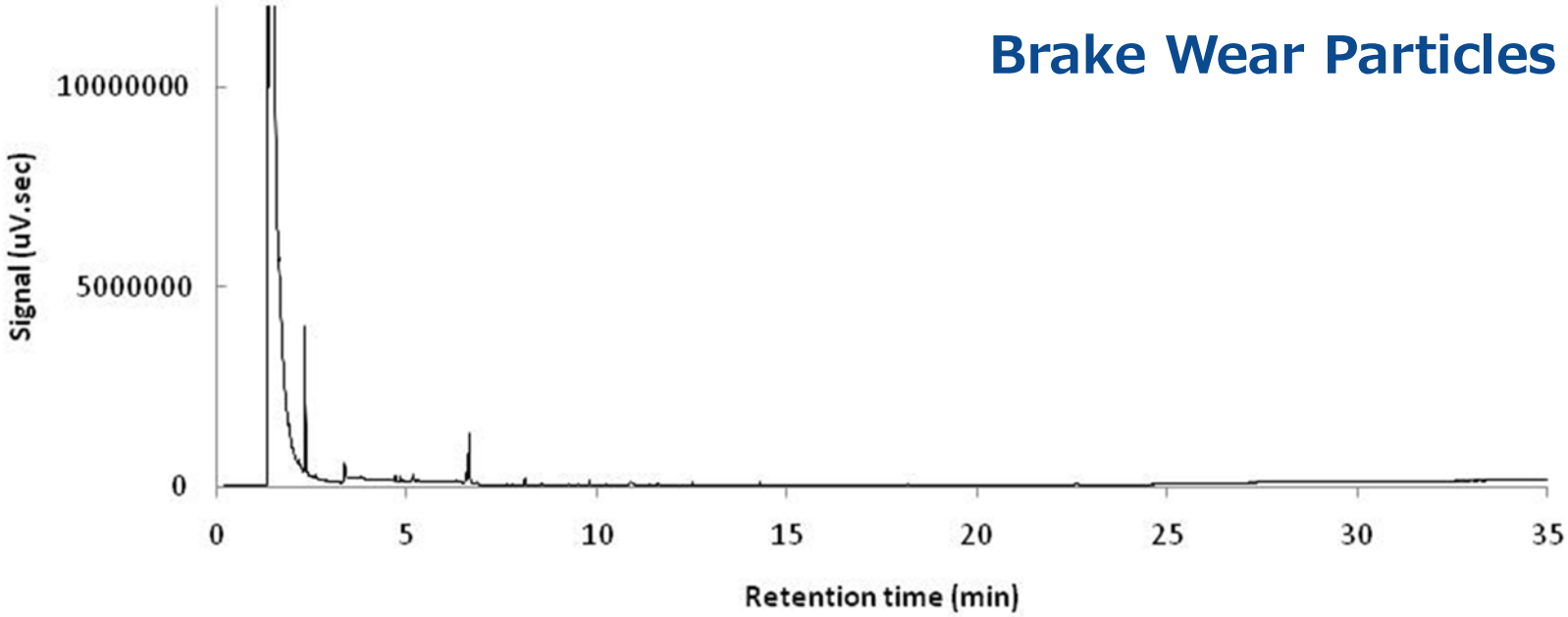


Py-GC-MS Chromatogram for OC speciation

Brake Pad



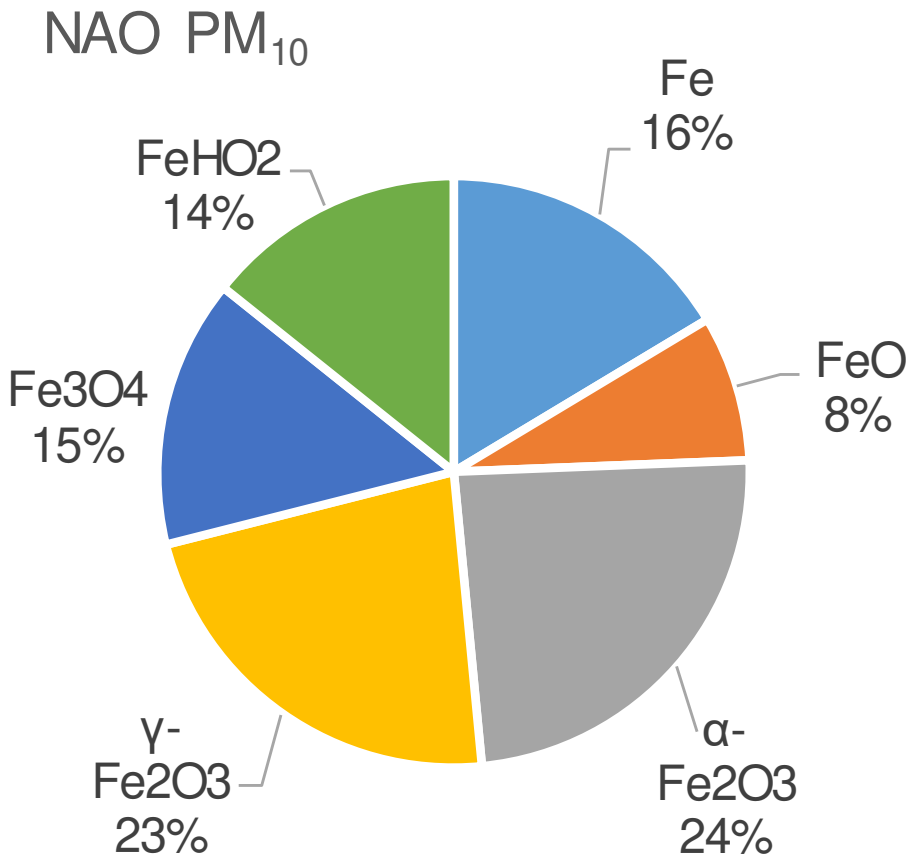
Brake Wear Particles

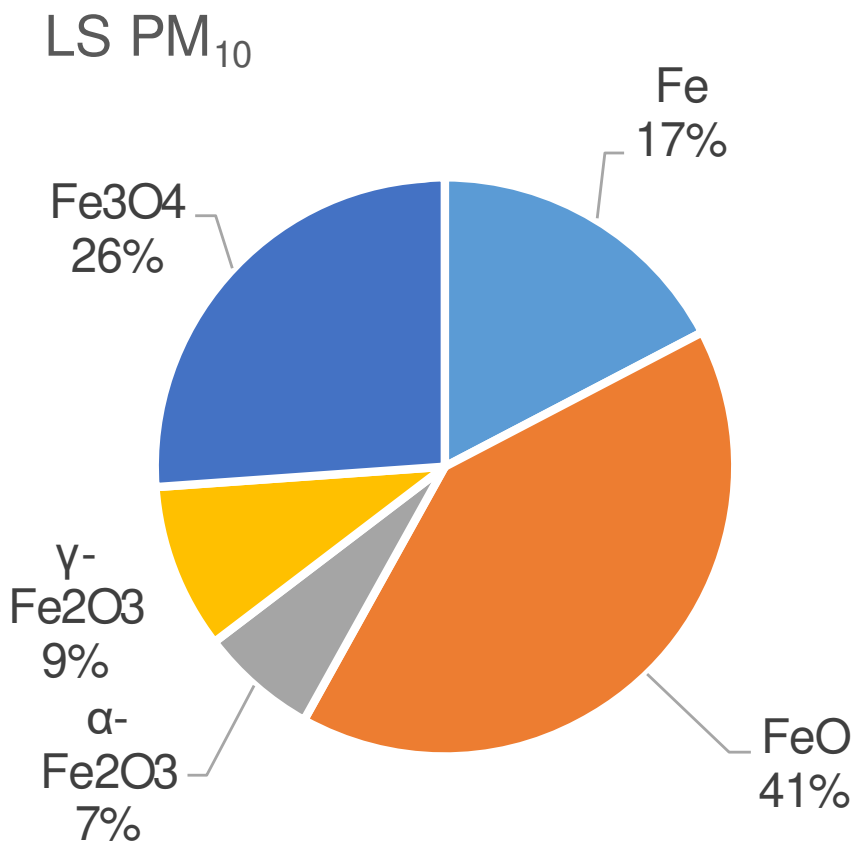


Data: JARI in 2012

Fe foam

- There was no significant different between powder and filter sample for XAFS spectrum.
- Different type of Iron foams (Fe, FeO, α-Fe_2O_3, γ-Fe_2O_3, Fe_3O_4, $FeHO_2$) were detected in Brake Wear Particles from NAO and LS pad.
- The Contributions of theses Irons were significant different and there might be different abrasive wear mechanism of pad.

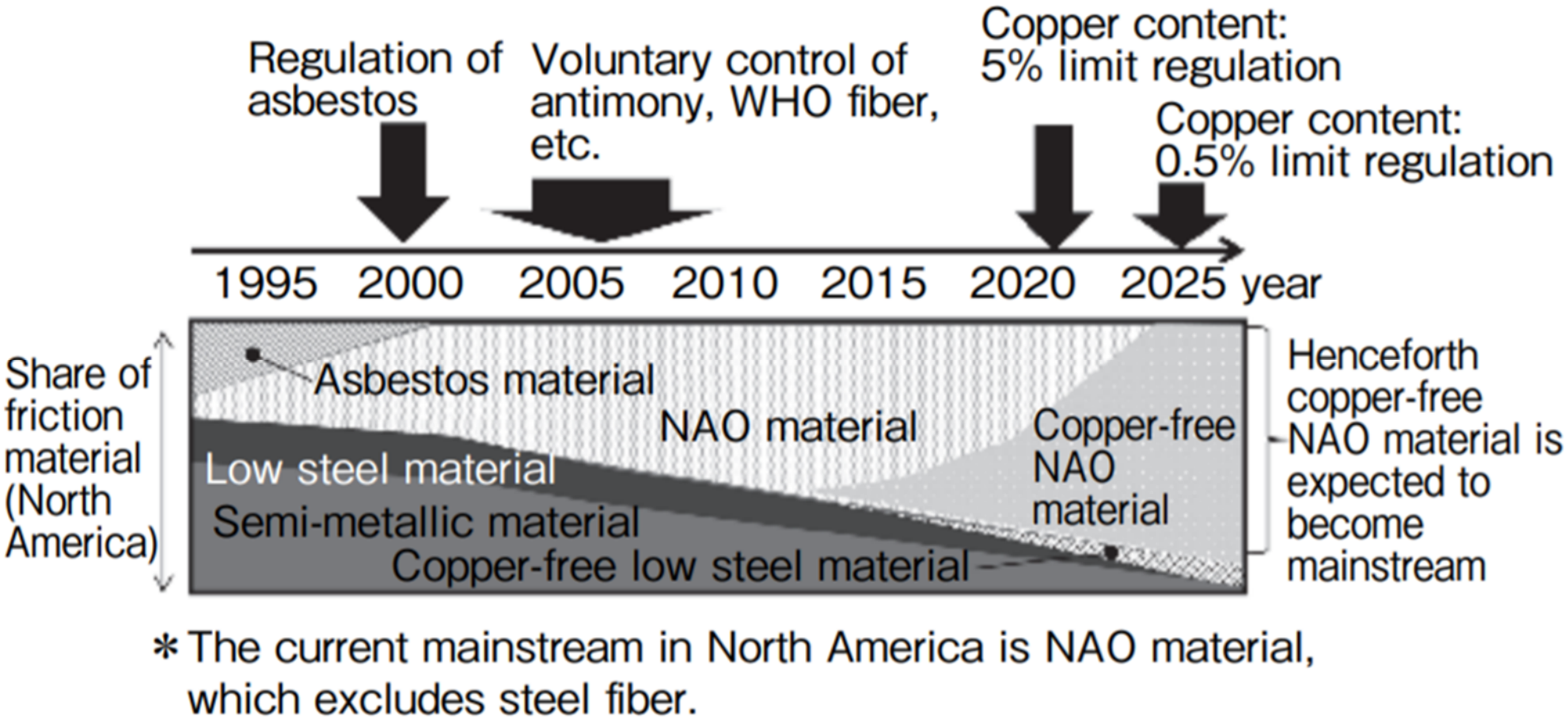




Collaboration with Prof. Okuda et al, Keio university 2019

Necessary for using modern brake materials

- **History of Changing Regulations governing chemical compounds used in automotive brake pads in North America**

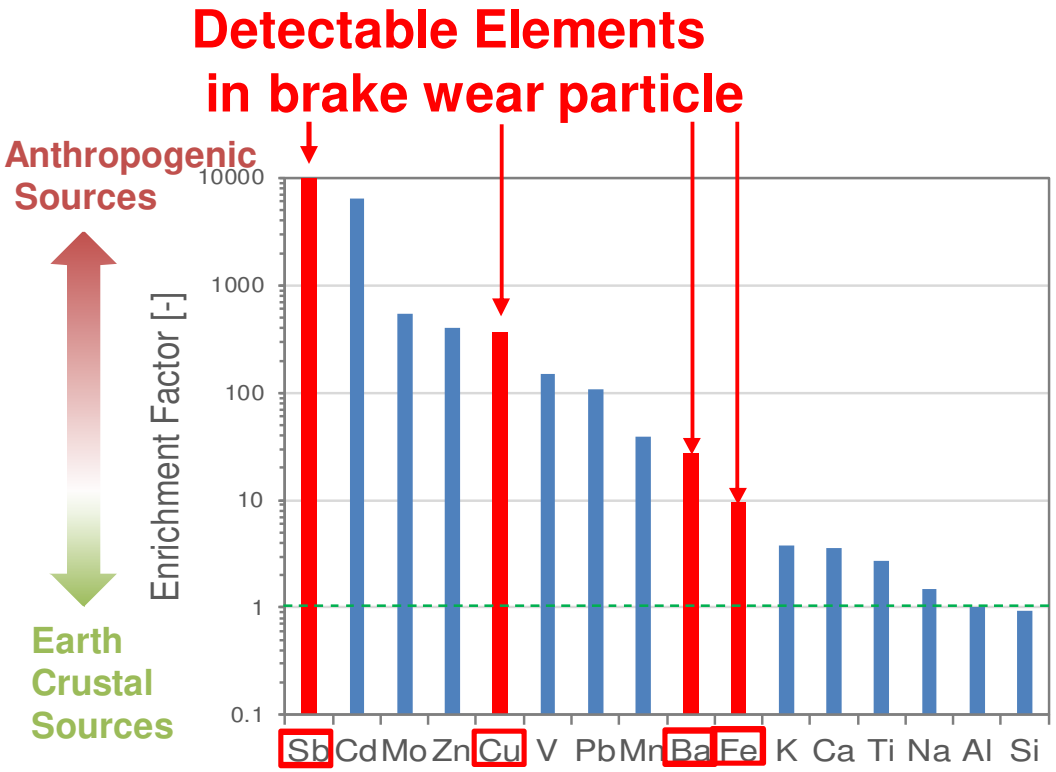


＊The current mainstream in North America is NAO material, which excludes steel fiber.

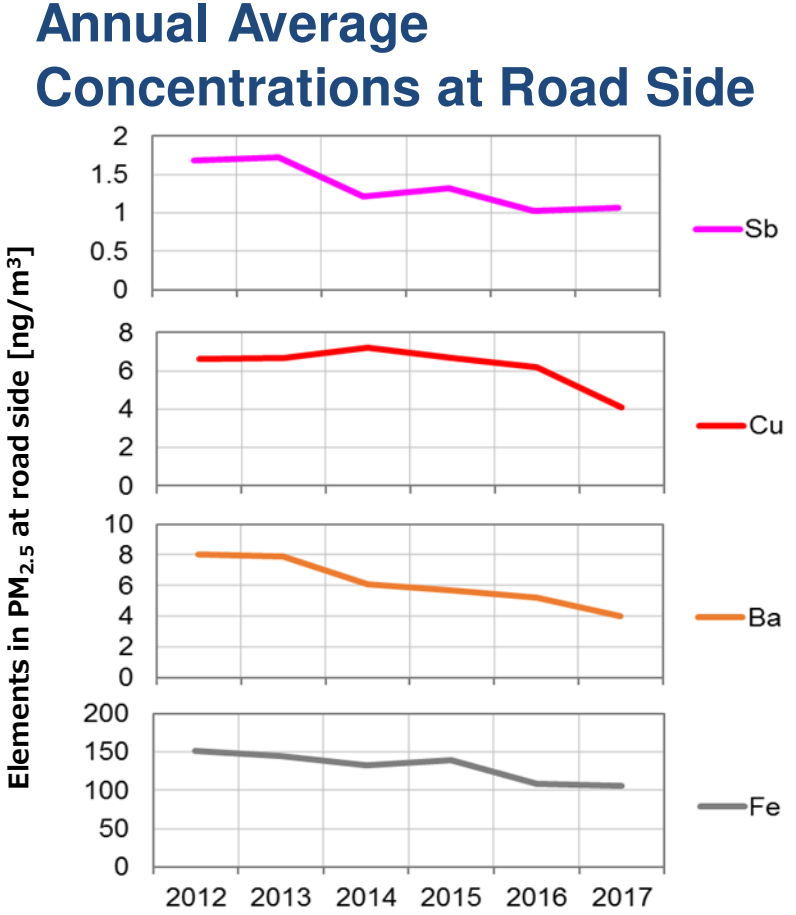
Ref : Ito, Hitachi Technical Report, NO55, pp.47-50 (2013)
https://www.hitachi-chem.co.jp/english/report/055/55_sou11.pdf

Necessary Regular updates of Ambient Data

- There were high value Antimony for Enrichment Factor in road side $PM_{2.5}$ suggesting automotive brake wear particle origin.
- The signatures have been decreasing every year.



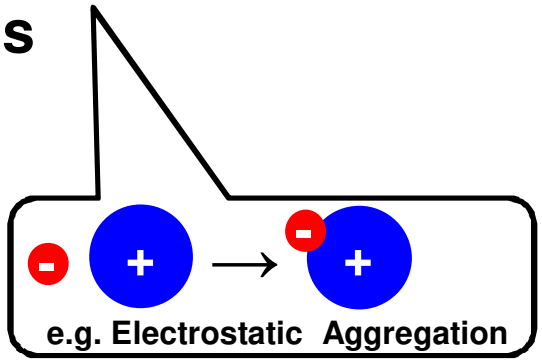
Enrichment Factor =
$([M]_{Road\ Side} - [M]_{Urban\ Background})$
$/ ([Al]_{Road\ Side} - [Al]_{Urban\ Background})$
$/ ([M]_{Earth\ crust} / [Al]_{Earth\ crust})$

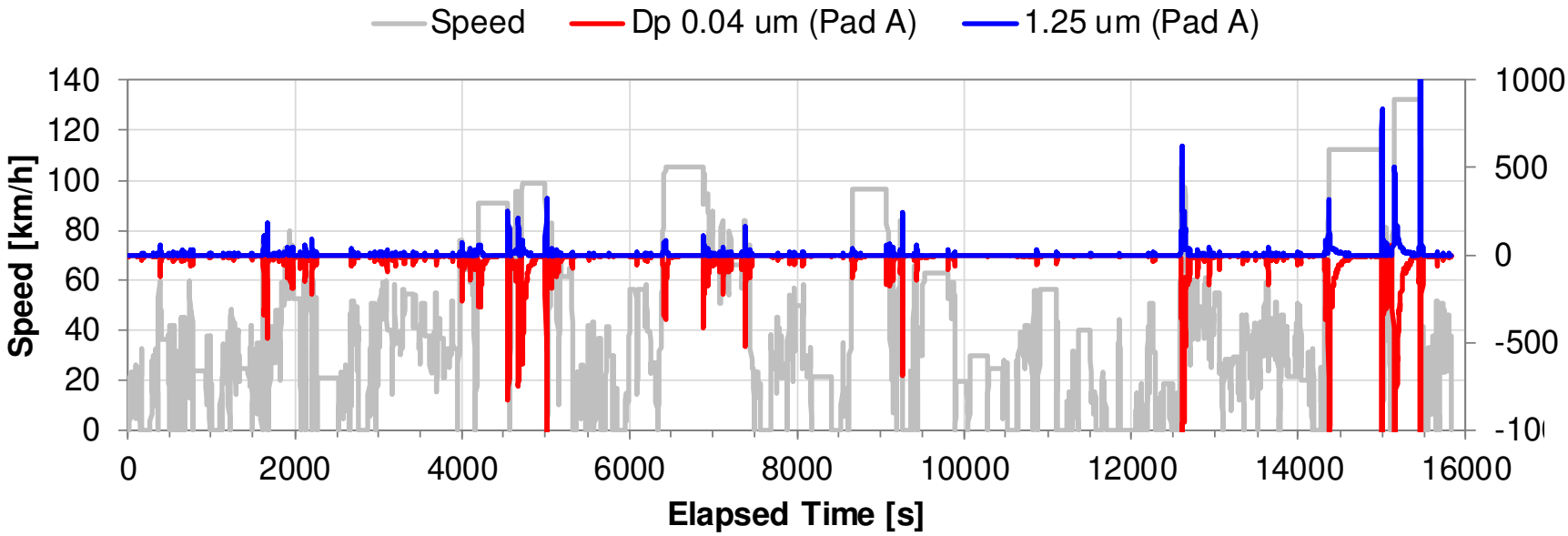


Data : MOE 2017, database (Only Japanese),
http://www.env.go.jp/air/%20osen/pm_resultmonitoring/post_25.html

Next Step for PN and toxicity test

- + and - electrically charged particles (e.g. using ELPI+) were found.
- A discussion on the electrostatic aggregation caused by the tribo-charged particles may be necessary.
- Deposition of charged particles on lung airways is 5 or more higher than neutral particles (Cohen et al., Health Phys. 1998).





Ref : Hagino, EuroBrake 2020, EB2019-FBR-016, slide only

Conclusions & Next Steps

Conclusions:

- **Brake wear particle measurement techniques were established by constant sampling system (JASO uniformed enclosure).**
- **Driving distance-based mass emission factors available.**

Next Steps:

- **Modification of PN measurement for brake wear Particles.**
- **Regular updates of Emission Factor and compositions for using modern braking materials.**
- **Atmospheric fate of brake wear particles (Characterization of Chemical / Physical / Charging state).**