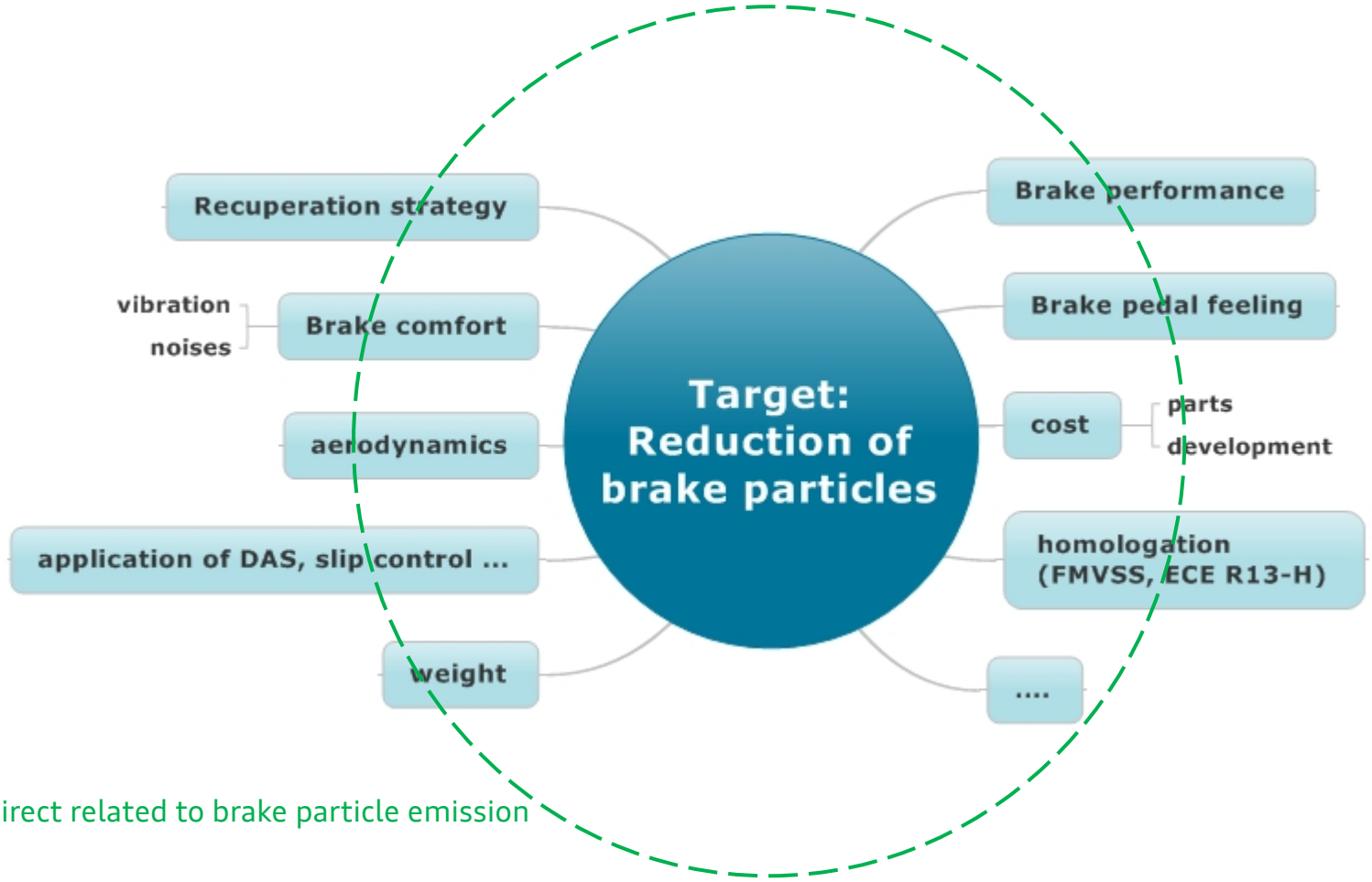
Audi
Vorsprung durch Technik

# PMP group meeting on non-exhaust emissions

Initial input of Audi to brake particle emissions

Bruessel, March 5th 2015

# General question:
# How do we evaluate „reduction of brake particles“ ?

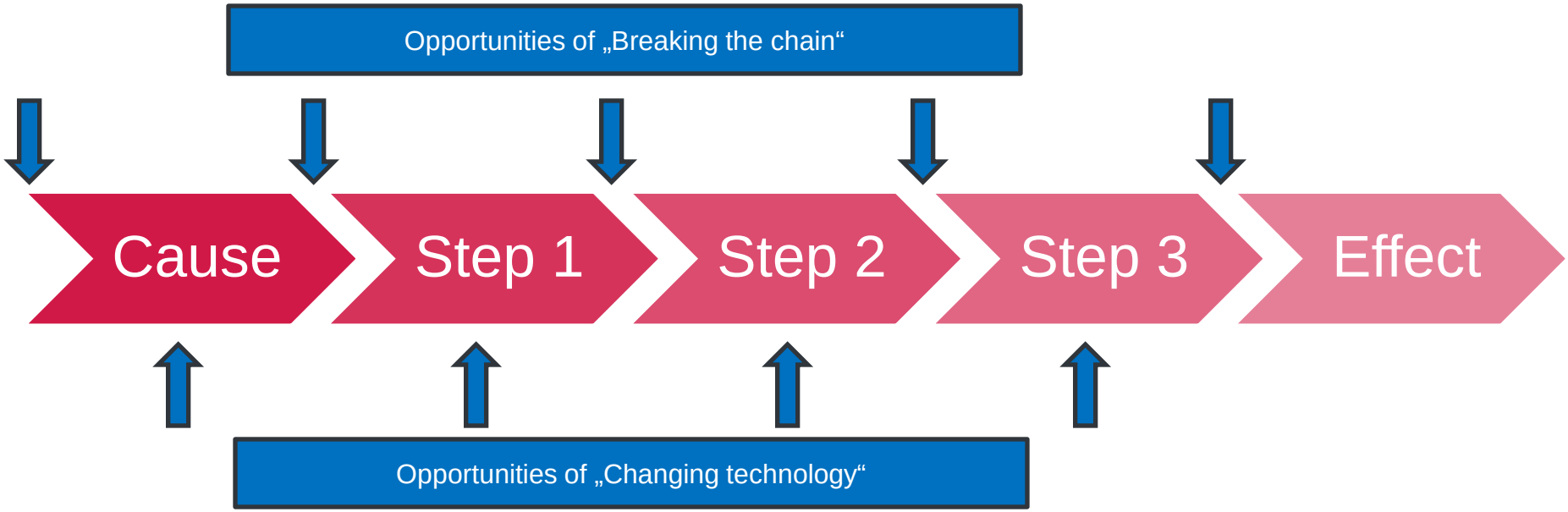



direct related to brake particle emission

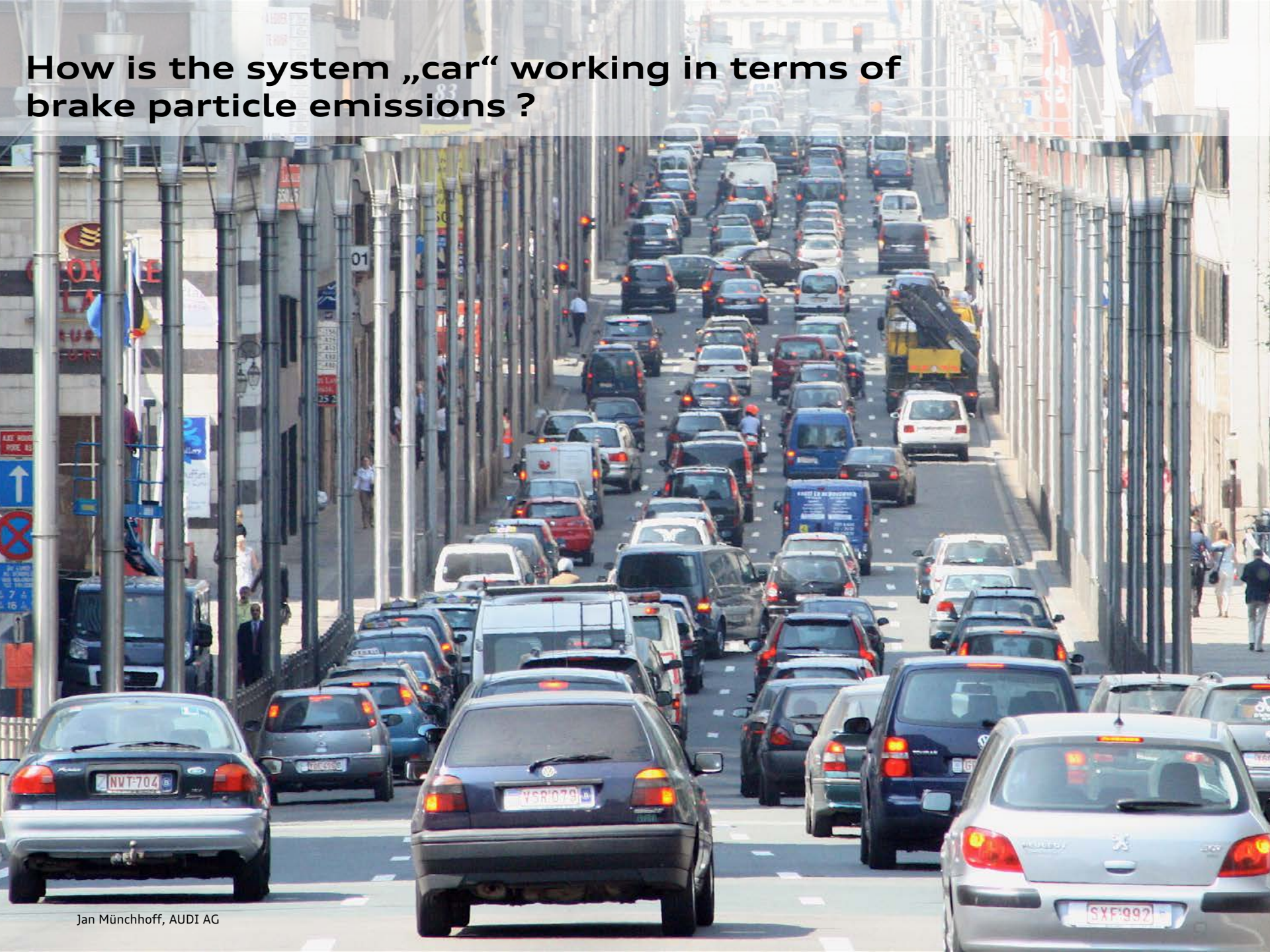
# Working of complex systems (like cars)
# General approach - Thinking about the functional chain

*Breaking the chain* means:
Talking about cause and effect studies
(in general: “Is the effect unavoidable ?”)

*Changing technology* means:
How to excute this process steps (i.e. quantity)



# How is the system „car“ working in terms of brake particle emissions ?

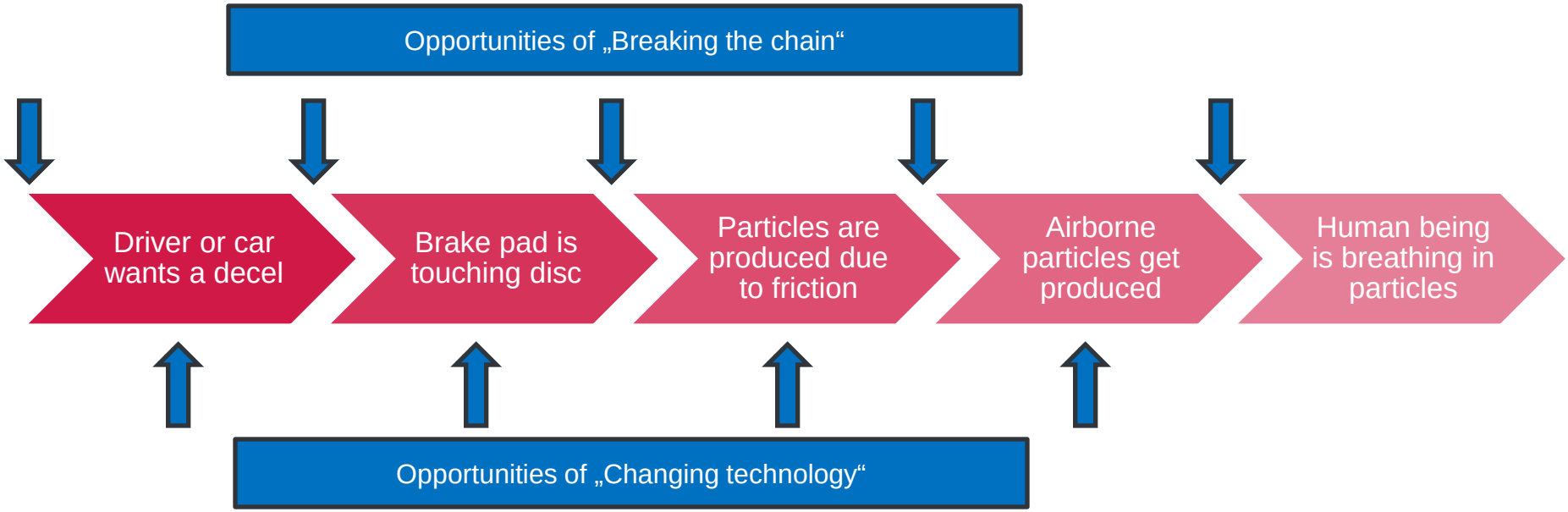


Jan Münchhoff, AUDI AG

# Thinking about the functional chain
# Example: Particle emission due to braking

Problems can't be solved anymore independent of the whole system

Efficient solution = breaking a chain (of cause and effect)



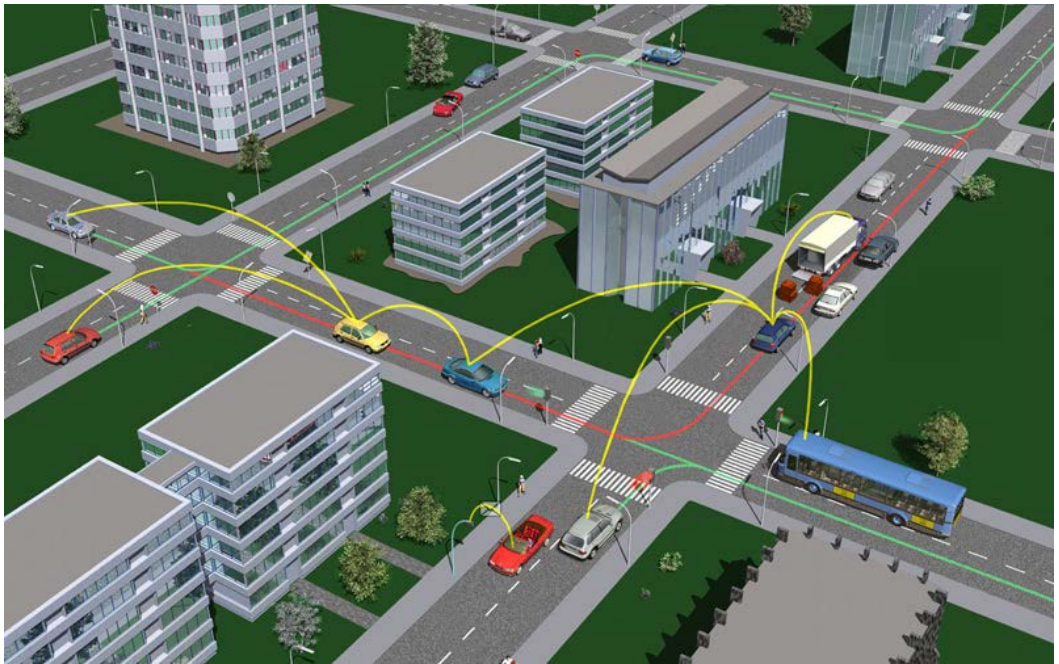
All important opportunities/effects should be rewarded to archieve the most efficient countermeasure.

# Positive impact of implementing all opportunities

- Following measures should be recognized (just examples)…
  - Special wheel covers (i.e. w/ particle filter)
  - Car-2-car and Car-2-Infrastructure communication to avoid friction braking (using non-friction brakes, wind resistance etc. instead like state-of-the-art in rail)
  - Dedicated recuperation strategies (i.e. using GPS)
  - Devices for collecting brake particles (to be recycled at dealerships during service)
  - Aerodynamic effects (for controlling particle movements)
  - …


https://www.kleenwheels.com

https://www.car-2-car.org



All important opportunities/effects should be esteemed.

What would then the best way to quantify the particle emission ?

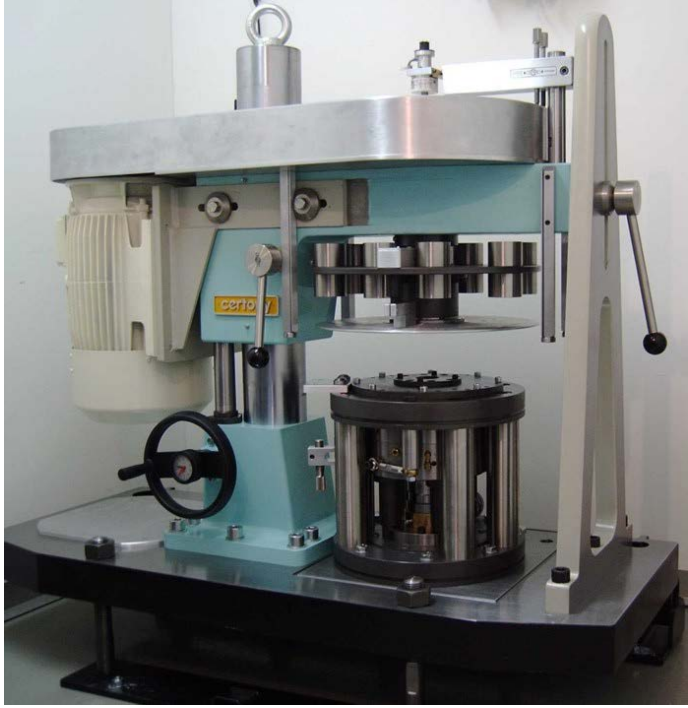
1st attempt: Referring to the last proposals in PMP group etc.

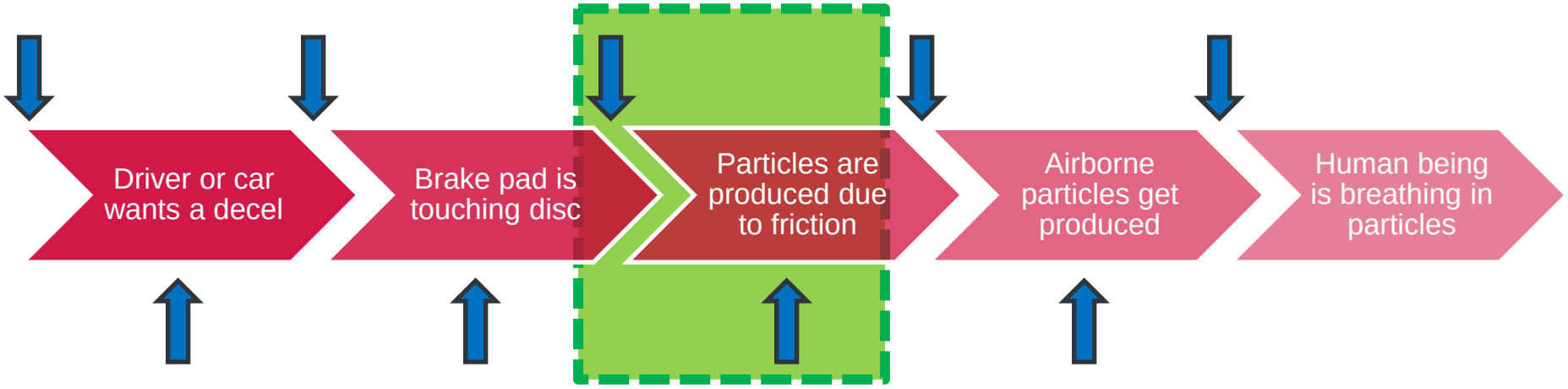
# Measuring of brake particles
# Focus of a TRIBOMETER

Most of the particle reduction measures are not visible:

- Pad shape, caliper design…
- Recuperative braking
- Collecting particles (in the car),
- Aerodynamic effects are not visible
- …

Conclusion:
Will not work for particle emission statement of a dedicated car.





# Measuring of brake particles
# Focus of a BRAKE DYNOMETER

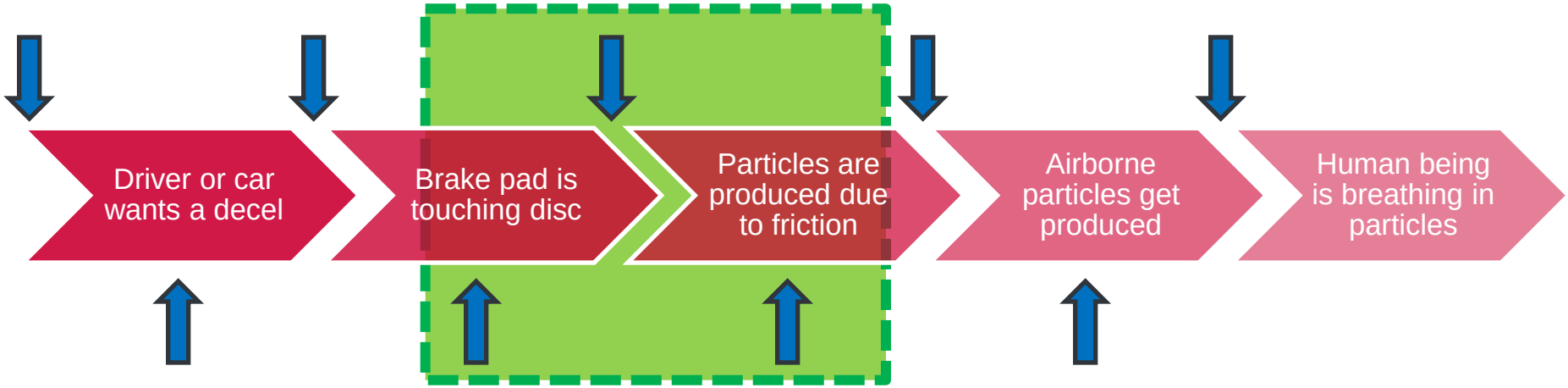
Some parts are better visible:

- Pad shape, caliper design…

Some not:

- Recuperative braking
- Collecting particles (in the car),
- Aerodynamic effects…

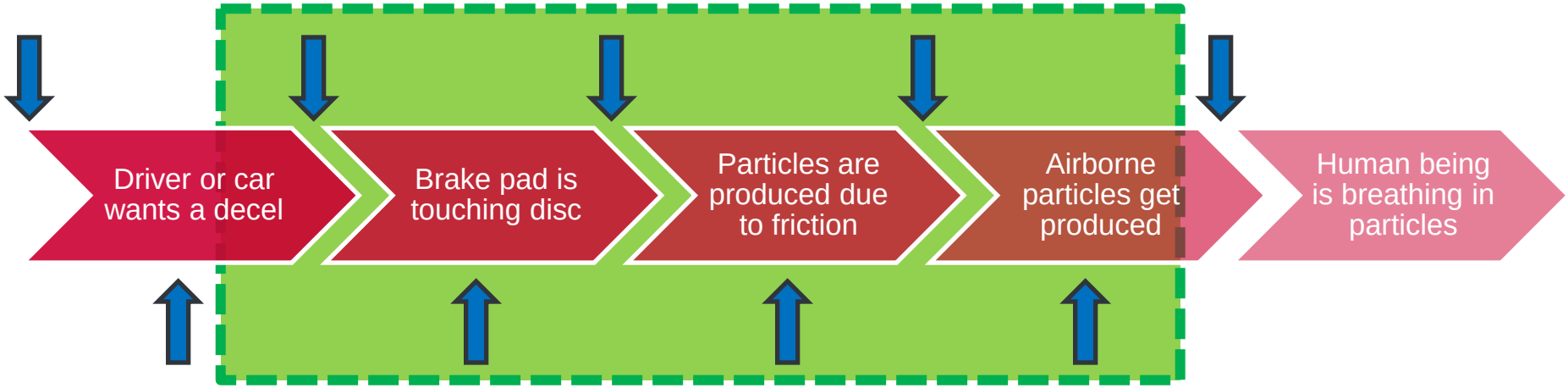
Conclusion:
Will not work for particle emission statement of a dedicated car.



# Measuring of brake particles (Potential) Focus of a ROLLER BENCH

Subjective evaluation (examples):

- Maybe the best (available) equipment in the market
- Combination of engine application and brake application effects to be implemented
- Aerodynamic not perfect (i.e. side of the car).
  → “small wind channel add-on” required
- Today seems to be no brake roller bench equipped for brake particle measurements.
- Mixture of brake and tyre emissions.



**Conclusion:**

For quantifying particle emission due to braking events a specific designed roller bench is maybe the minimum  requirement.

→ Topic for **DEVELOPMENT**.

**But:**

Even with sophisticated measurement systems (like wind tunnel) the high future potential of avoiding brake particle emissions by using (i.e.) Car-2-X communication can‘t be quantified.

→ Topic for **RESEARCH**.

**Important from OEM point of view:**

Defining the right target and limits of the measurement task is urgent and very important. Following steps could be setting milestones, defining driving profile, defining equipment etc.

→ Topic for **PMP-Group / UNECE**.

# AUDI comments on PMP working documents for the 35th PMP meeting.

# Audi recommendations on „PMP-35-02 NEPE - Working Item 1 (driving conditions)"

| | Particles from brake wear | Particles from tyre (and road wear) |
|---|---|---|
| Trip length distribution | Relevant | Relevant |
| Speed distribution in urban and extra-urban areas/highways | Relevant | Relevant |
| Acceleration rate distribution in urban and extra-urban areas/highways | Relevant (due to aerodynamic effects on particle emissions) | Relevant |
| Deceleration rate distribution | | |

**3. Approach**

One of the open issues on working item 1 is weather it makes sense to go for one single "harmonized" definitions of "normal driving conditions" or for different definitions depending on the region of the collected data. As agreed at the 33$^{d}$ PMP, both the approaches will be followed in order to compare the "typical driving conditions" of different regions. Important is to recognize, that different regions have today different brake friction couple technologies (like NAO and ECE).

# Audi recommendations on „PMP-35-02 NEPE - Working Item 1 (driving conditions)”

Additional parameters to be considered :

| |
|---|
| Slope/decent during braking<br>in urban and extra-urban areas/highways as a function of the trip length |
| Brake pressure in urban and extra-urban areas/highways<br>(μ is not constant) |
| Brake recuperation profile in urban and extra-urban areas/highways<br>(amount of engine decel) |
| Wear history of pads/discs<br>(i.e. longer parking before usage, corrosion, bedding condition…) |
| Intervention of ESC/ACC/… systems (ABS, brake wiper, electronic differential …) |
| Brake pressure distribution while stopping (as influencing factor regarding residual drag and off-brake-wear) |
| Amount of creeping situations next to standstill<br>(traffic jam situation) |
| Number of EPB/Mechanical PB application in urban and extra-urban areas/highways (as influencing factor regarding residual drag and off-brake-wear) |
| Lateral acceleration profile in urban and extra-urban areas/highways (as influencing factor regarding residual drag - pad/disc clearance) |
| Vehicle load condition in general |
| Existence of additional wear-driving substances (salt, dust, humidity) and ambient temperature i.e. derived from season and location |

# Audi recommendations on „PMP-35-02 NEPE - Working Item 3 (experts)”

Missing from AUDI side:

- Some Brake disc supplier (Buderus, Fritz Winter etc.)
- More Brake pad supplier (TMD Friction, Federal Mogul etc.)
- Specialists on brake recuperation/mechatronical systems (like Bosch, Continental, TU Ilmenau)
- Specialists on brake friction testing/simulation (like TU Braunschweig)
- Specialists on brake dynamometers (like Link Eng., HORIBA)

# Audi recommendations on „PMP-35-02 NEPE - Working Item 4 (measurement and sampling)”

***1a. Brake wear particles***

Brake wear particles generation and sampling can be performed in the laboratory by means of a roller chassis bench (Full Chassis Dynamometer), by means of a brake dynamometer or by means of a pin-on-disc configuration. Furthermore, mobile units can be employed in order to sample brake wear particles on-road under “real world” driving conditions. Table 1 gives an overview of the methods used for brake wear particles generation and sampling.

**Table 1: Overview of methods used for brake wear particles generation and sampling**

| Code | Method | Note | References |
|---|---|---|---|
| G1 | Brake Dynamometer | Open System | • Iijima et al. 2007<br>• Österle et al. 2008<br>• Österle et al. 2010<br>• Sanders et al. 2003 |
| G2 | | Enclosed System | • Garg et al. 2000<br>• Gasser et al. 2009<br>• Iijima et al. 2008<br>• Kukutschová et al. 2009<br>• Kukutschová et al. 2011 |
| G3 | Pin-on-disc method | Open System | • Mosleh et al. 2004 |
| G4 | | Enclosed System | • Wahlstrom et al. 2010a<br>• Wahlstrom et al. 2010b |
| G5 | Mobile Unit | Open System | • Kwak et al. 2013<br>• Mathissen et al. 2011 |
| G6 | Roller Bench (so called Full Chassis Dynamometer) | Open System | • |
| G7 | | Enclosed System | • |