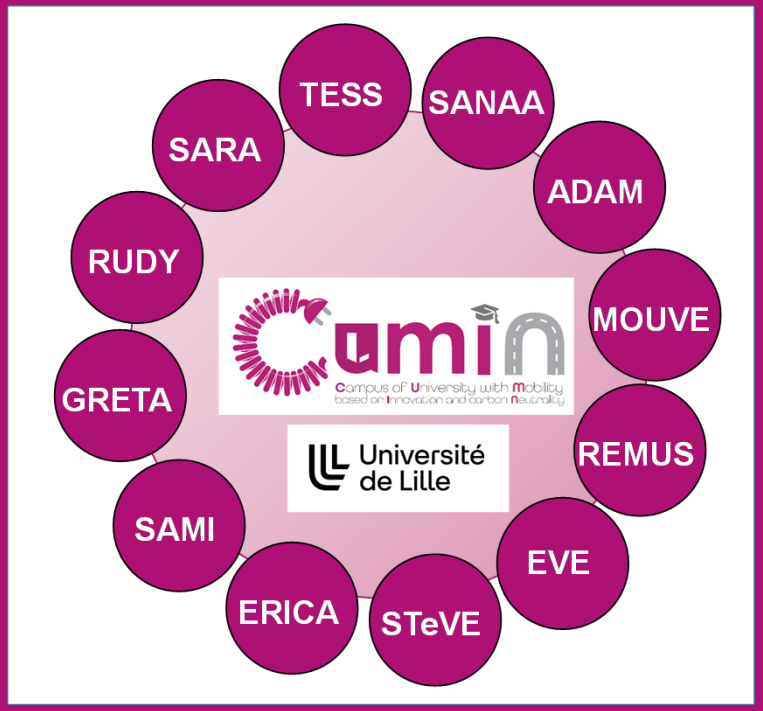
https://cumin.univ-lille.fr/



CUMIN - TIM

Consideration of mechanical braking emissions in electric vehicles

J-F. Brunel *,
P. Dufrénoy *,
W. Lhomme**,
A. Bouscayrol**

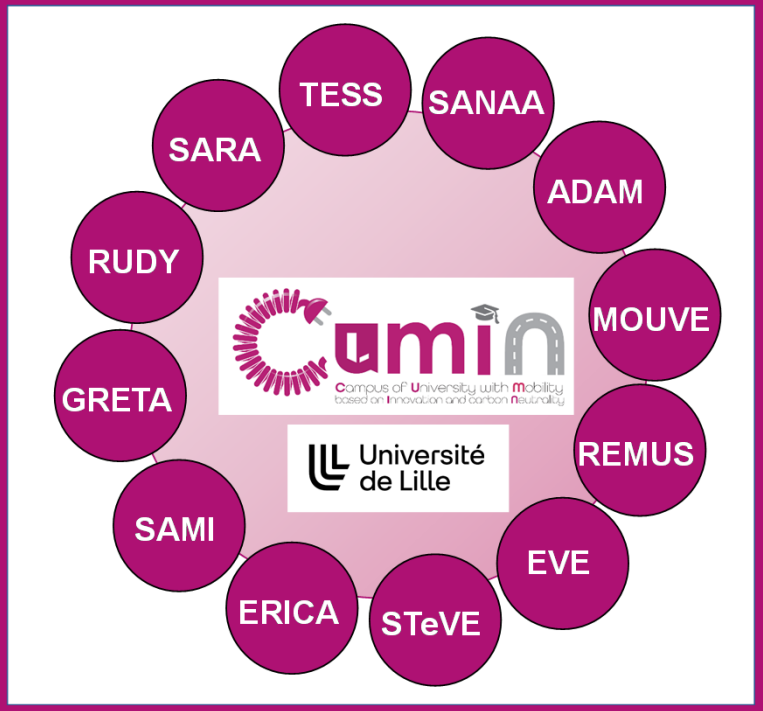
* LaMcube, Univ. Lille
** L2EP, Univ. Lille

Outline

1 **LaMcube activities**

2 **CUMIN-TIM project**

https://cumin.univ-lille.fr/

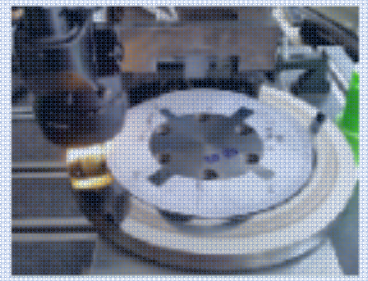


LaMcube activities

LaMcube presentation

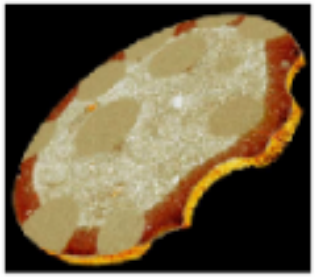
Laboratory of Multiphysics and Multiscale Mechanics

- A mixt Research Unit with CNRS since 1991 (LML) → currently UMR CNRS 9013
- Members : 37 permanent researchers, 14 technical staff, 50 non-permanent researchers (PhD+Post-Docs)
- Covering 3 institutions (Univ. Lille, Centrale Lille, CNRS)
- 4 research groups



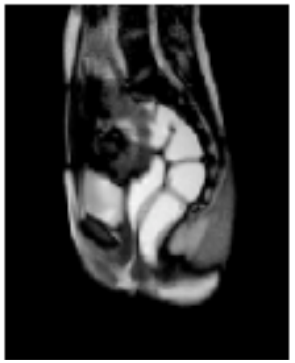
Mechanisms induced by friction & Braking

P. Dufrénoy, AL. Cristol



Behavior of geomaterials

Behavior and mechanisms of damage and fatigue



Biomechanics of soft tissues

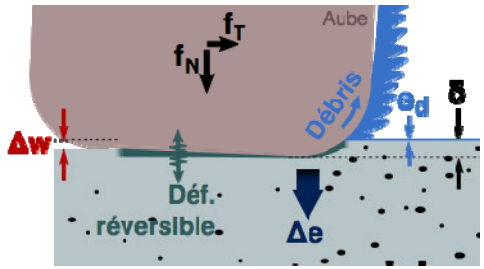
Common aspects: continuum from material elaboration to the description of systems under complex loading
consideration of relevant scales

Research team MuFrein

Mechanisms induced by friction & Braking

- **Team members**
  - Permanent staff: 8 researchers (2 Prof., 6 Ass-Prof.) + 3 Engineers
  - Non-permanent staff: 10 PhD students + 2 Post-docs

- **Scientific goals**
  - Understanding the phenomena induced by friction
    - Tribology (friction, wear, particle emissions)
    - Thermal localizations (hot spotting) and damage of components
    - Vibrations induced by friction (noise)

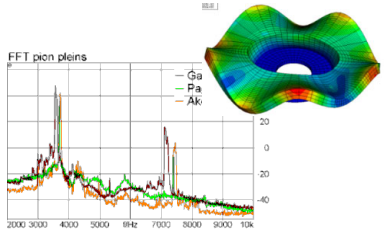


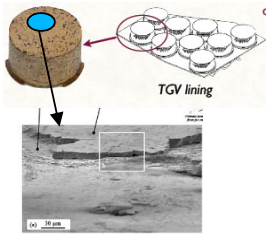
- **Difficulties**
  - Multiplicity of physical couplings
  - Diversity of scales: contact / materials / system
  - Complex and evolving materials with use

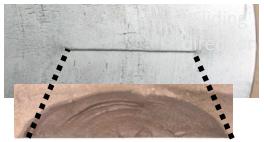
Research team MuFrein

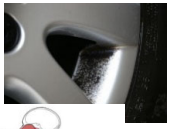
Mechanisms induced by friction & Braking

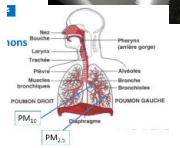
- **Societal context**
  - Goals
    - Safety: stopping distance, integrity of components
    - Material consumption: wear
    - Environmental impact: noise, particle emission
    - Reduction of energy consumption
  - Main applications
    - Braking
    - Blade-casing interactions in turbojet
    - Wheel-rail contact

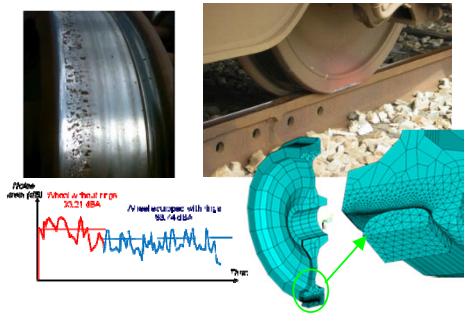


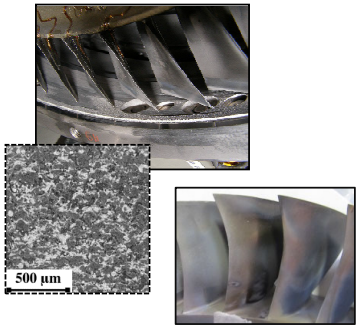








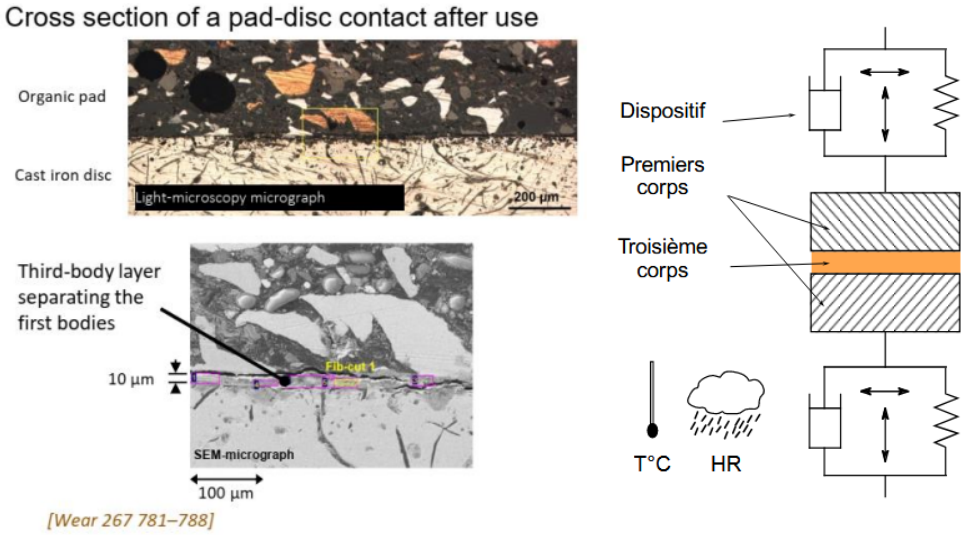




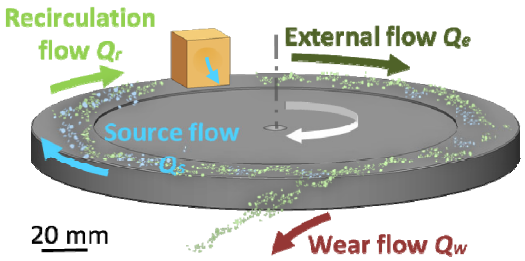
Research team MuFrein

Mechanisms induced by friction & Braking

- **How a dry contact works?**
  - Apparition of a **third body** separating the two first bodies (pad and disc) providing
    - →Load-bearing
    - →Speed accommodation
    - →Wear process



- Tribological circuit

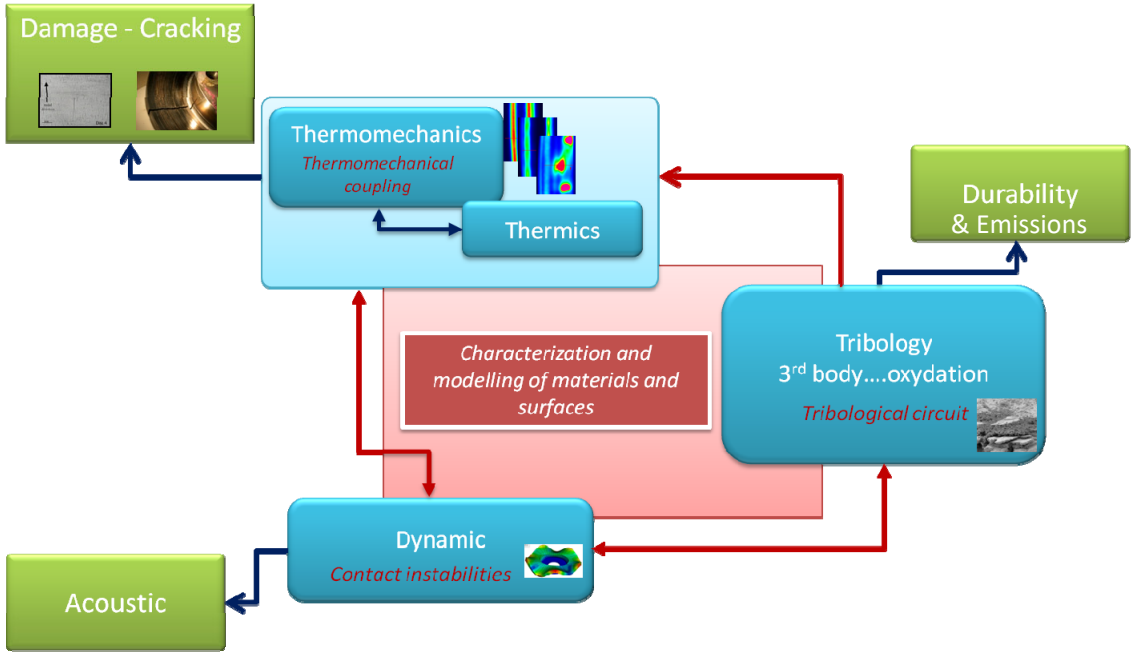


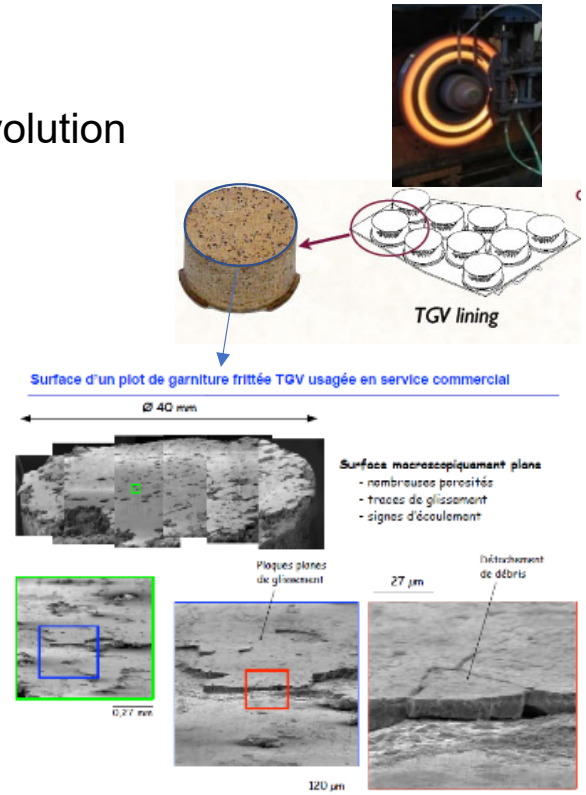
Third body flows → development of the load-bearing

Research team MuFrein

Mechanisms induced by friction & Braking

- **Strategy**
  - Considering physical-coupling
  - Considering the contact-system interactions (multiscale)
  - Studying the initiation of phenomena (source mechanisms) and their evolution





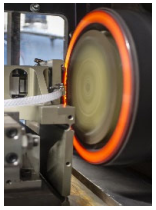
Research team MuFrein

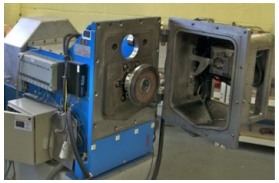
Mechanisms induced by friction & Braking

- **Strategy/Means**

Dedicated experiments with improved measurements

- Test benches from industrial partners
- Dedicated tribometers in the lab
- Improved instruments



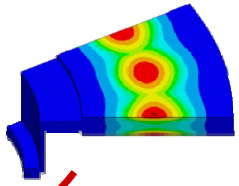
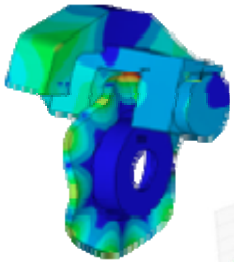
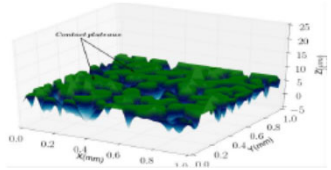


Material formulation and process

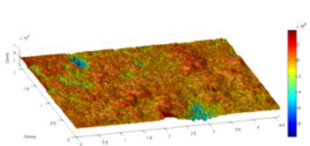
- Industrial formulations
- « Model » formulations (well-known & simplified)

Theroretical and Numerical models

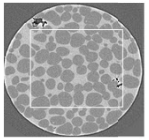
- Transient analysis
- Multiscale modelling

Analysis and characterizations of materials, surfaces and interface


Profilometry


SEM


Tomography


Particle counting

Research team MuFrein

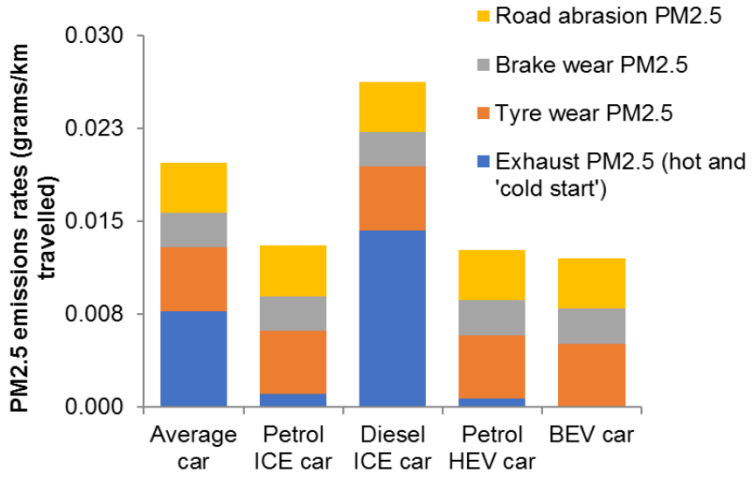
Mechanisms induced by friction & Braking

LaM CUBE
Laboratoire de mécarique, multiphysique, multiéchelle

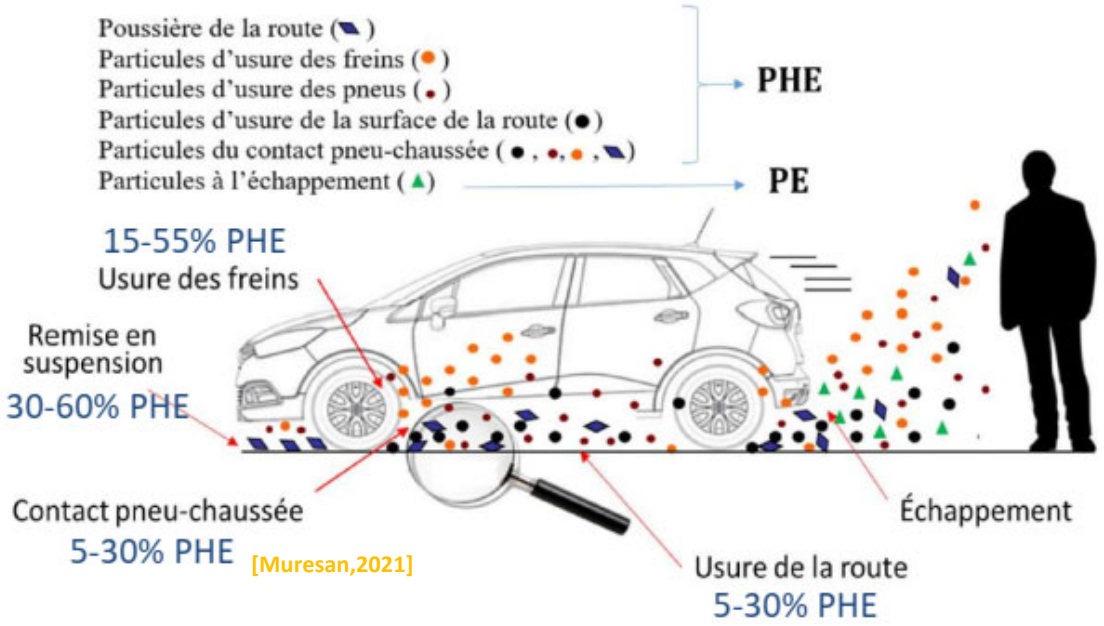
- **Some recent and current projects**
  - CPER CISIT / ELSAT2020 **/ RITMEA (basis of friction and wear)**
  - ADEME GLGV (railway braking : pad design for high performances + vibrations-squeal)
  - ADEME CERVIFER (wheel-rail contact : durability and squeal)
  - MEDEA (blade-casing interaction)
  - APERAM (disc for particle emission reduction)
  - **ADEME BREAQ (railway friction brakes : wear and particle emission)**
  - HAS (squeal of automotive disc braking systems)
  - **MESRI-BBF PI-CUBE (Physics-informed Artificial Intelligence for Cutting Brake Emissions from Electric Vehicles)**

Automotive PM emissions

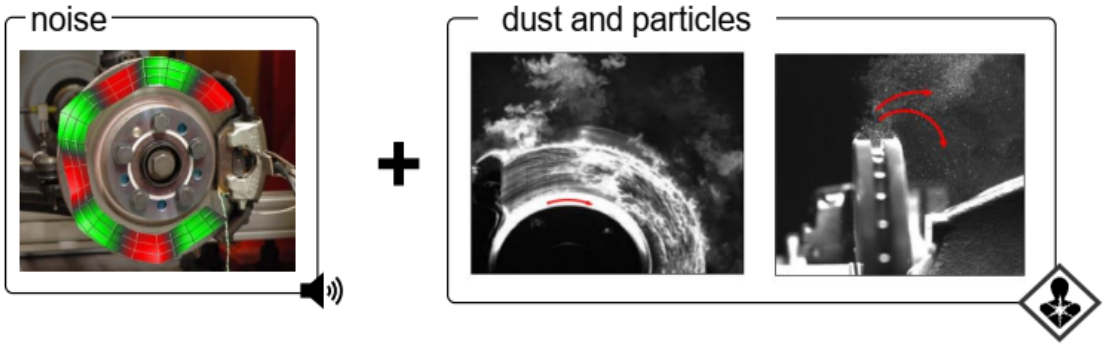
PM2.5 emissions rates by car fuel types (UK 2015)
(Fine particles with a diameter of 2.5 µm or less)



→ **Battery EV is not a "zero emission vehicle"**



Braking emissions

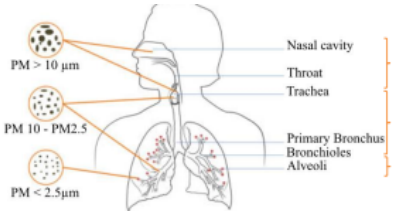


Squeal noise
Frequency > 1kHz
Noise level > 90 dB

Particles emission
15-55% of non-exhaust particles

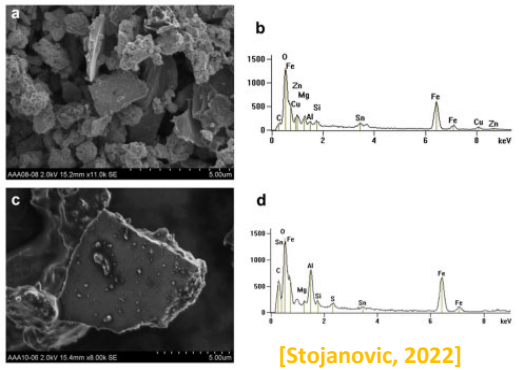
Classification of particles and influence on people's health

- Sedimentable PM (100 µm → 30 µm)
- Total Suspended Particles (TSP):
  - Coarse PM (10 µm → 2.5 µm)
  - Fine PM (2.5 µm → 0.1 µm)
  - UltraFine PM (0.1 µm → 0.001 µm)



Fine PM

Coarse PM



[Stojanovic, 2022]

Noise due to transportation in Ile de France
→ Loss of 75 000 years of heatly life/year (7.3 months/individual)
→ Stress…

[Source Bruit-parif, 2015]

Particles + VOC emission
→ 380 000 deaths/year due to transportation (6400 in France)
→ Respiratory diseases…

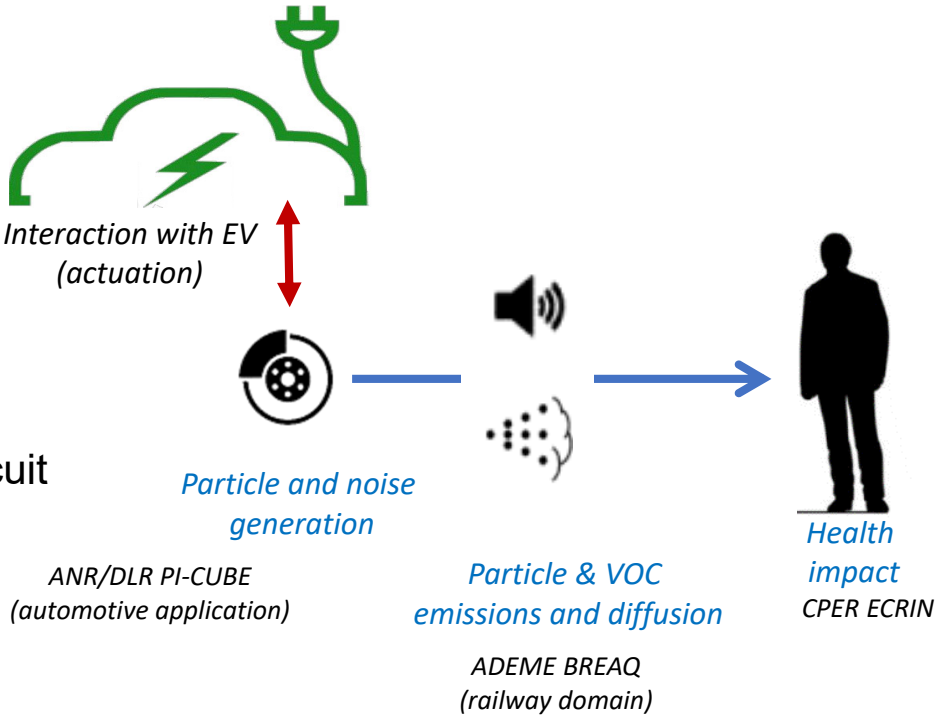
[Source ICCT, 2016]

Braking emissions

- **How to reduce the brake emissions?**

➢ Materials / Component design / Actuation

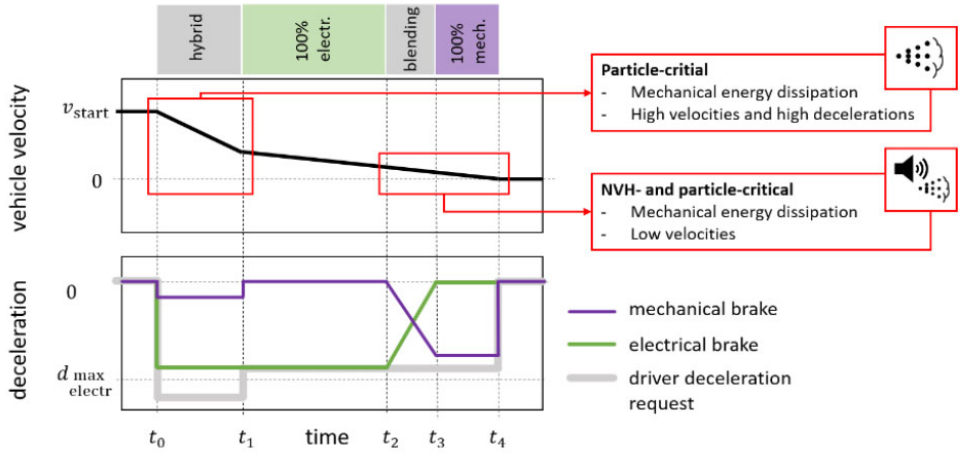
Understanding link between emissions and the tribological circuit
- tests with multimodal operando measurements
- physical models
- enhanced data treatment



PI-CUBE Project

Physics-informed Artificial Intelligenve for Cutting Brake Emissions from Electric Vehicles

- **Context**
  - ➢ Blending braking strategy between electric brake et mechanical brake

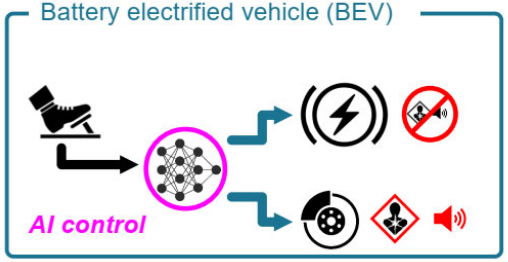


- **Objective**
  - ➢ Reduce brake emissions by optimizing the blending strategy using AI control

Braking BEVs:

Electric braking

→ AI-driven brake control
→ Emissions reduction



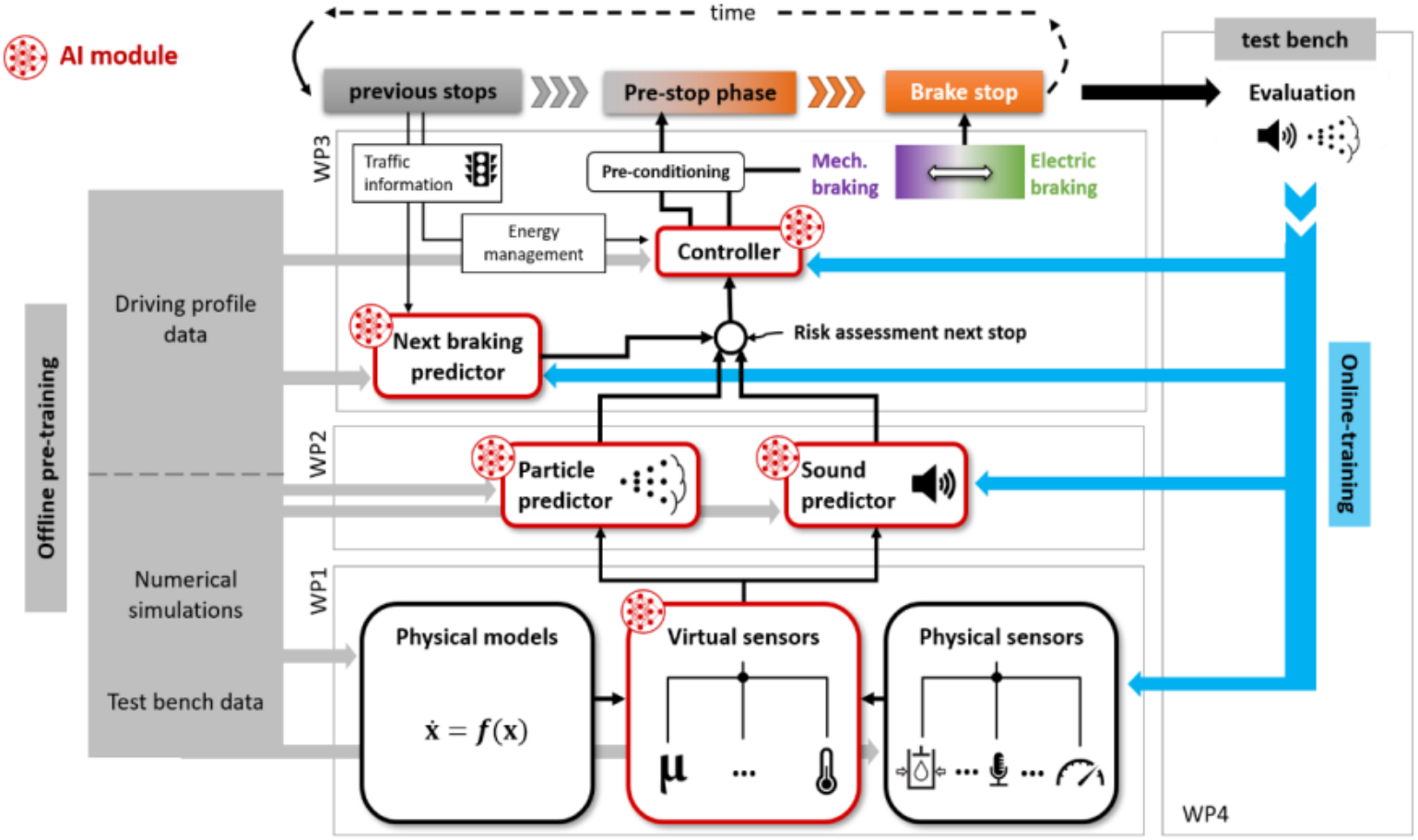
- **Outcomes**

⇨

- ✓ **Safe braking**
- ✓ **Energy efficiency**
- ✓ **Reduced particle emissions (-50%)**
- ✓ **Reduced brake noise (-50%)**

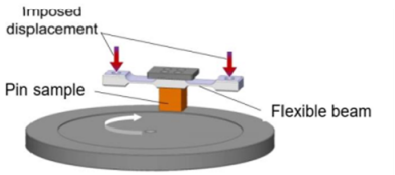
PI-CUBE Project

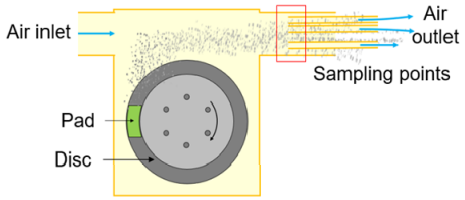
- **Strategy**

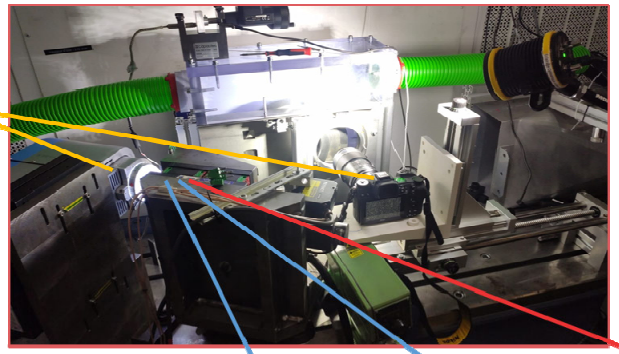


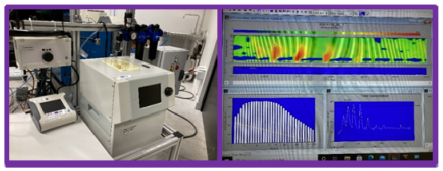
PI-CUBE Project

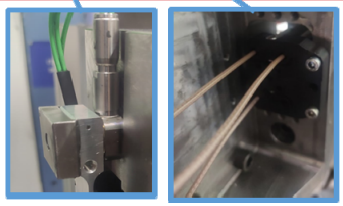
Highly instrumentalized tests on simplified set-up

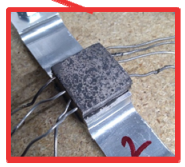












~50 channels

- **Discrete surface tracking** →Profilometry, photos
- **Particles + VOC** →Collecting box with air flow chamber
- **Atmosphere** → Humidity control
- **Mechanical** → Piezoelectric, Foucaults
- **Acoustic** → Microphone
- **Thermal** →Embedded thermocouples (pin), IR measurement

PI-CUBE Project

Highly instrumentalized tests on simplified set-up

Level 1: Data treatment from sensors

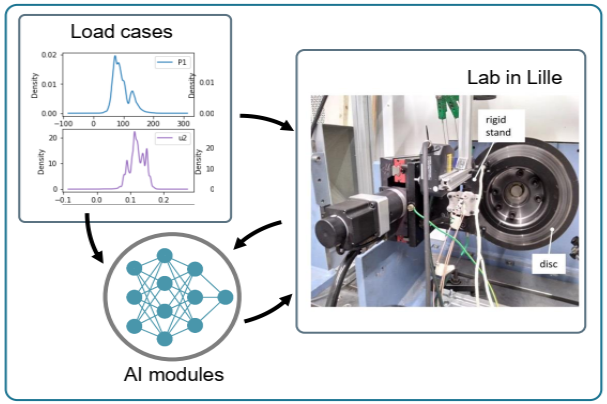
Overall trends on results

→Relevant data

→Loading macro data / in-situ data

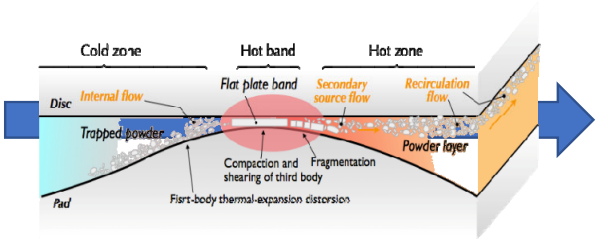
→Connections between particle / squeal emissions

→History effect, etc.



Level 2 : Physical description

- Tribology mechanisms : material thermal thresholds; scenario description of tribo circuit (matter flows); dependency of loading parameters; history…
- Importance of considering contact localizations → opening/closure
- Evolution to a stable/unstable tribological circuit (compacted interface layer) → *emissions*



--> Extension to braking system

BREAQ Project

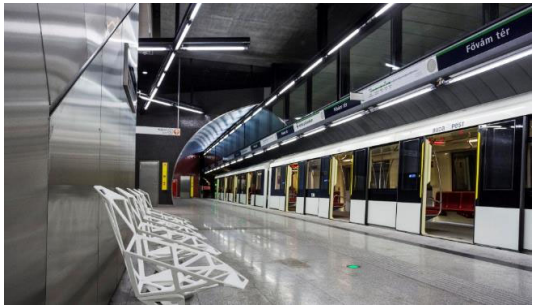
Air Quality & Healthier Mobility™_
BRaking Emissions characterisation & mitigation for Air Quality improvement

Funded by PIA
Operated by ADEME

- **Context**
  - Air quality for urban and sururban areas
  - Overshoot of limit values in metro and railway stations

- **Objective**
  - Limit quantity & hazardousness of emissions by optimizing traction/braking and developing collection system

- **Expected results**
  - Better knowledge and models
  - Air quality improvement for customers and end-users



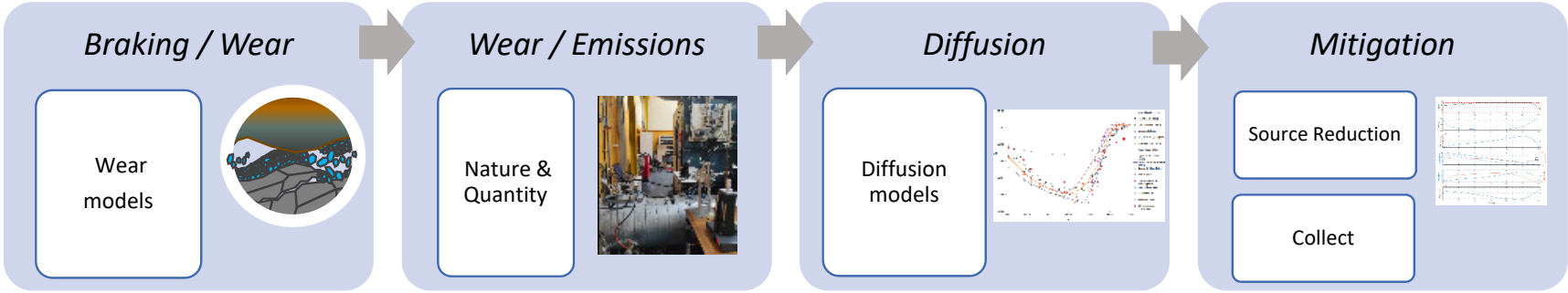
BREAQ Project

Air Quality & Healthier Mobility™

BRaking Emissions characterisation & mitigation for Air Quality improvement

Funded by PIA
Operated by ADEME

- **Strategy**

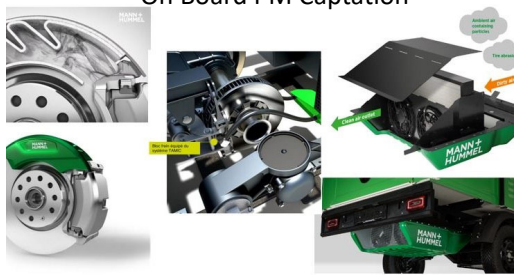


Mitigation solution development

- Optimised traction- braking function
- Optimised friction materials
- On board treatment system
- Infra collect system

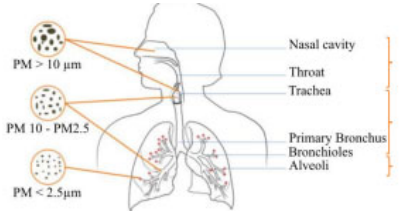
Low emitting brake pads/disc

On Board PM Captation



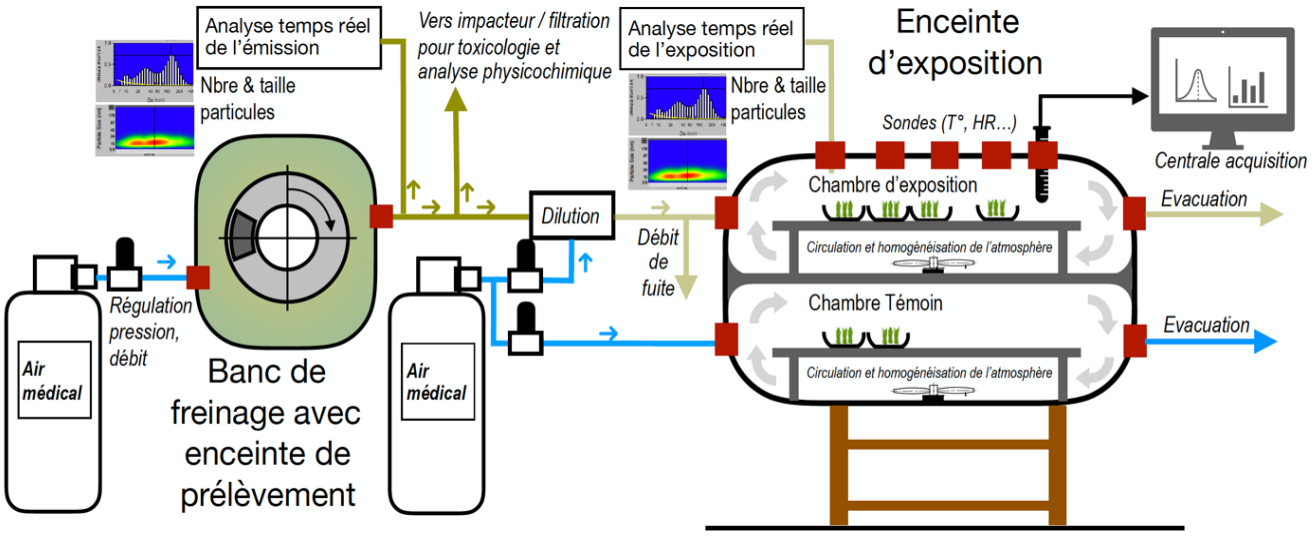
CPER ECRIN

WP1.4.4 Analyses en toxicologie, morphologiques et physicochimiques des émissions des systèmes de freinage



- **Context**
  - ➢ Toxicity of brake PM emissions

- **Strategy**



Ecotoxicity studies by comparison :

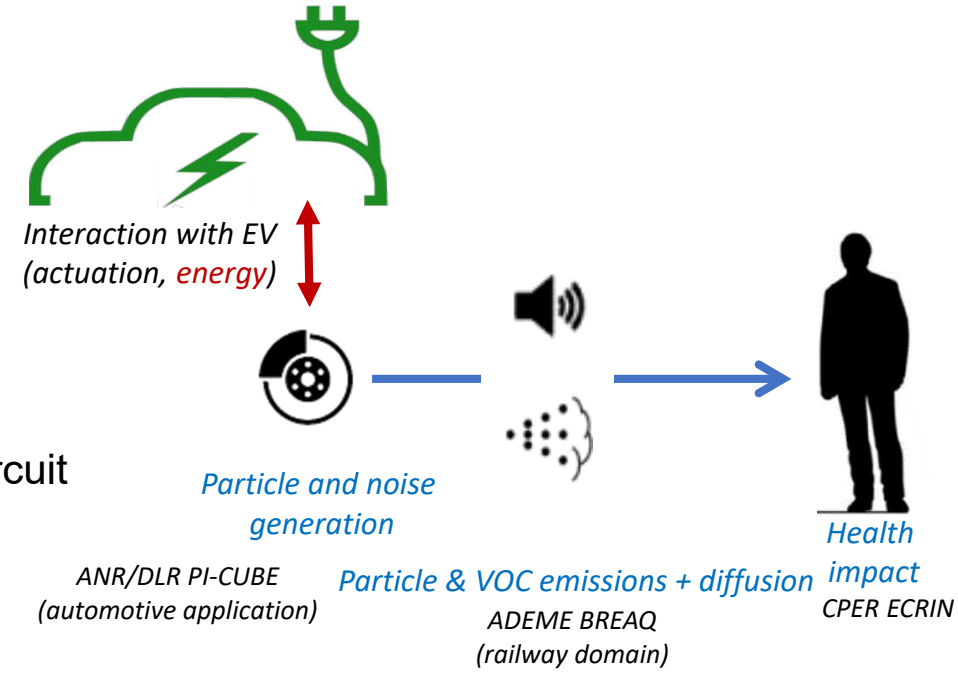
- 1 control room / 1 plant exposure room (vegetable foam as sentinel surveillance)
- 1 control room / 1 lung cell exposure room

Braking emissions

- **How to reduce the brake emissions?**

➢ Materials / Component design / Actuation

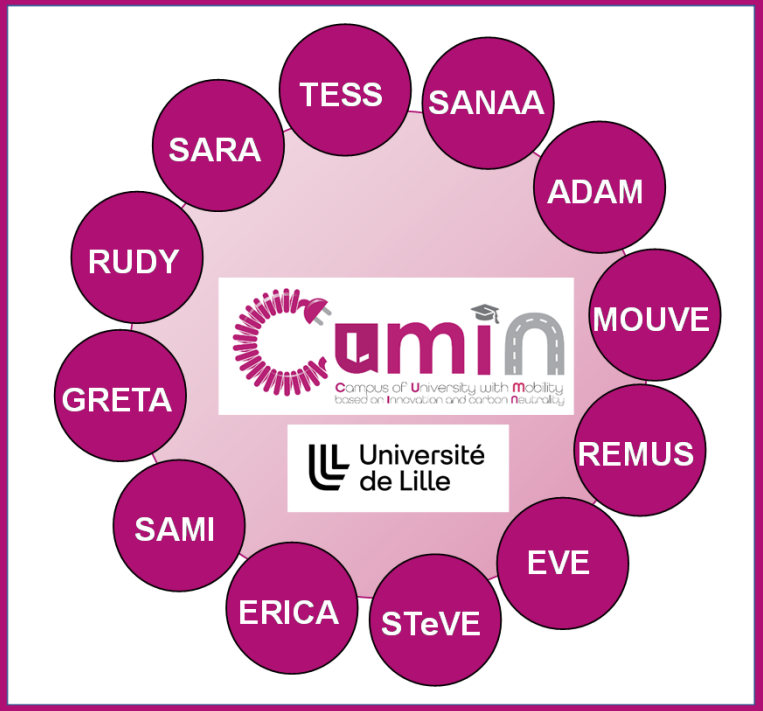
Understanding link between emissions and the tribological circuit
- tests with multimodal operando measurements
- physical models
- enhanced data treatment



➢ Optimize the use of the brake blending considering energy flows (for EV)

Project TIM CPER RITMEA

https://cumin.univ-lille.fr/



TIM Project

Traction and braking Integration in a Modular way for optimization of consumption and emission

TIM Project

Traction and braking Integration in a Modular way for optimization of consumption and emission

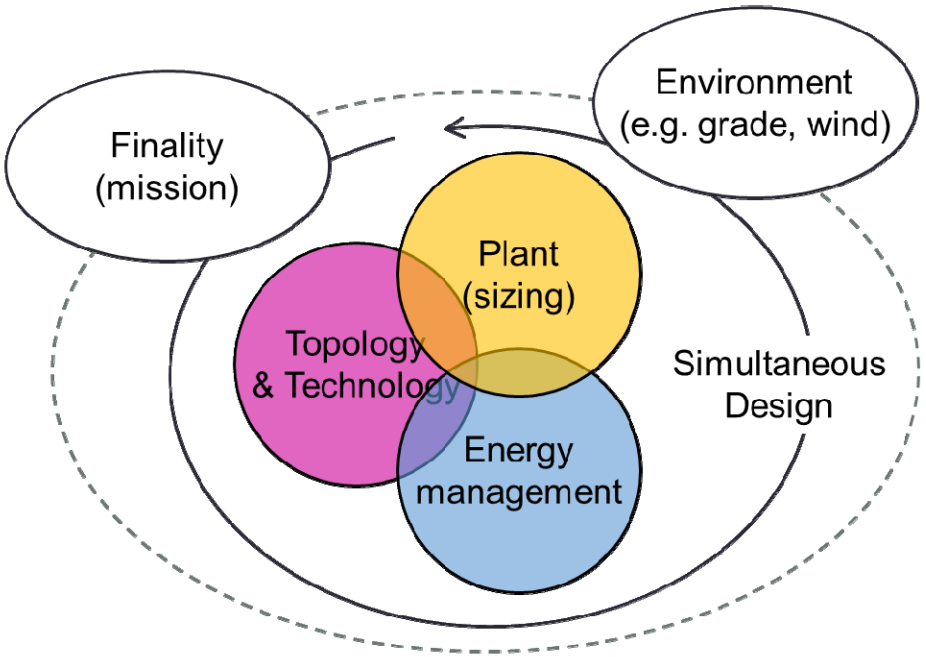
CPER RITMEA

System-level design

Applications

[Jaafar 12]
[Silvas 17]
[Kabalan 20]

Parameters



Satisfy not only a unique profile
but a class of profiles (real-time)

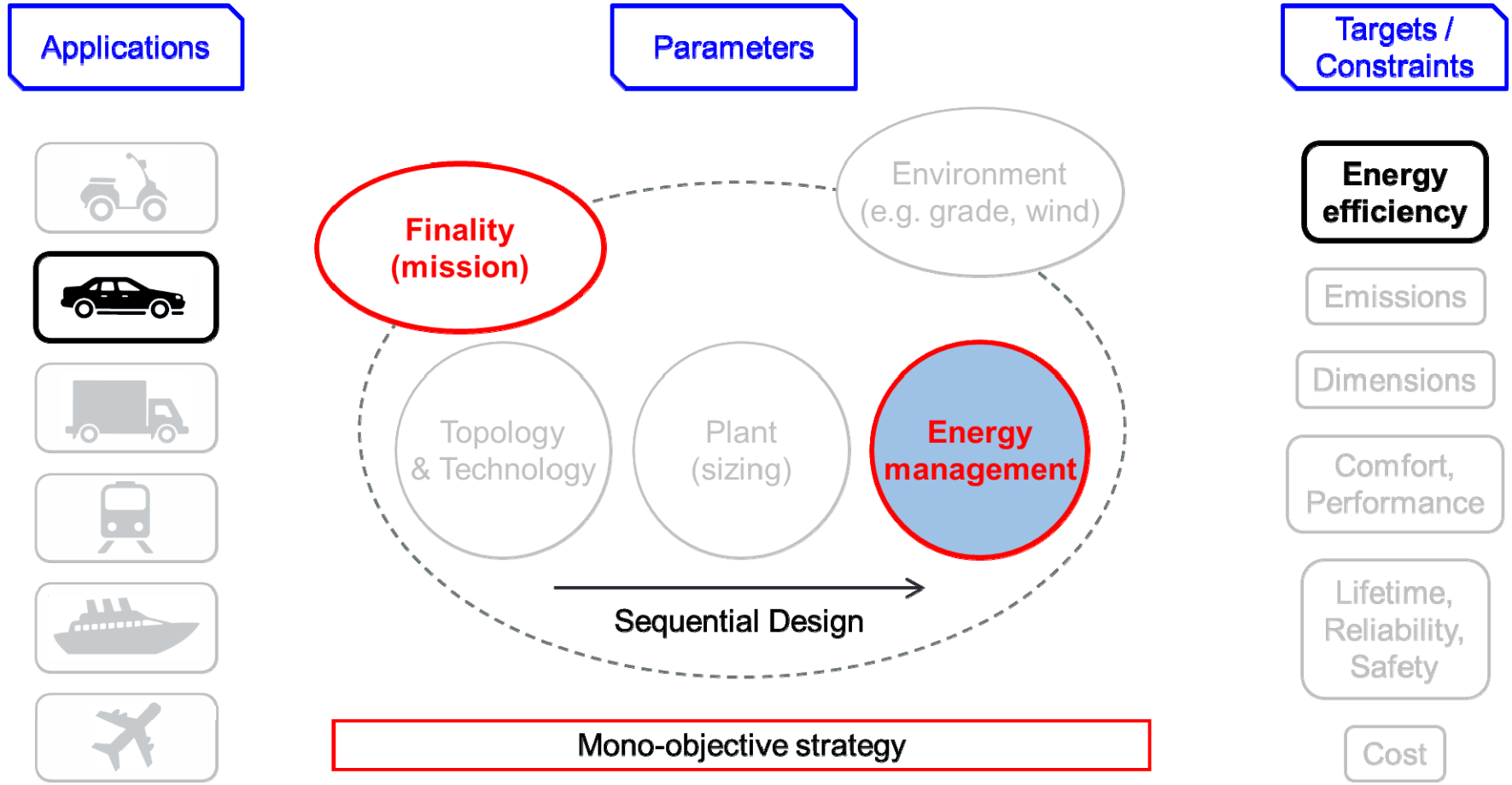
Targets / Constraints

- Energy efficiency
- Emissions
- Dimensions
- Comfort, Performance
- Lifetime, Reliability, Safety
- Cost

TIM Project

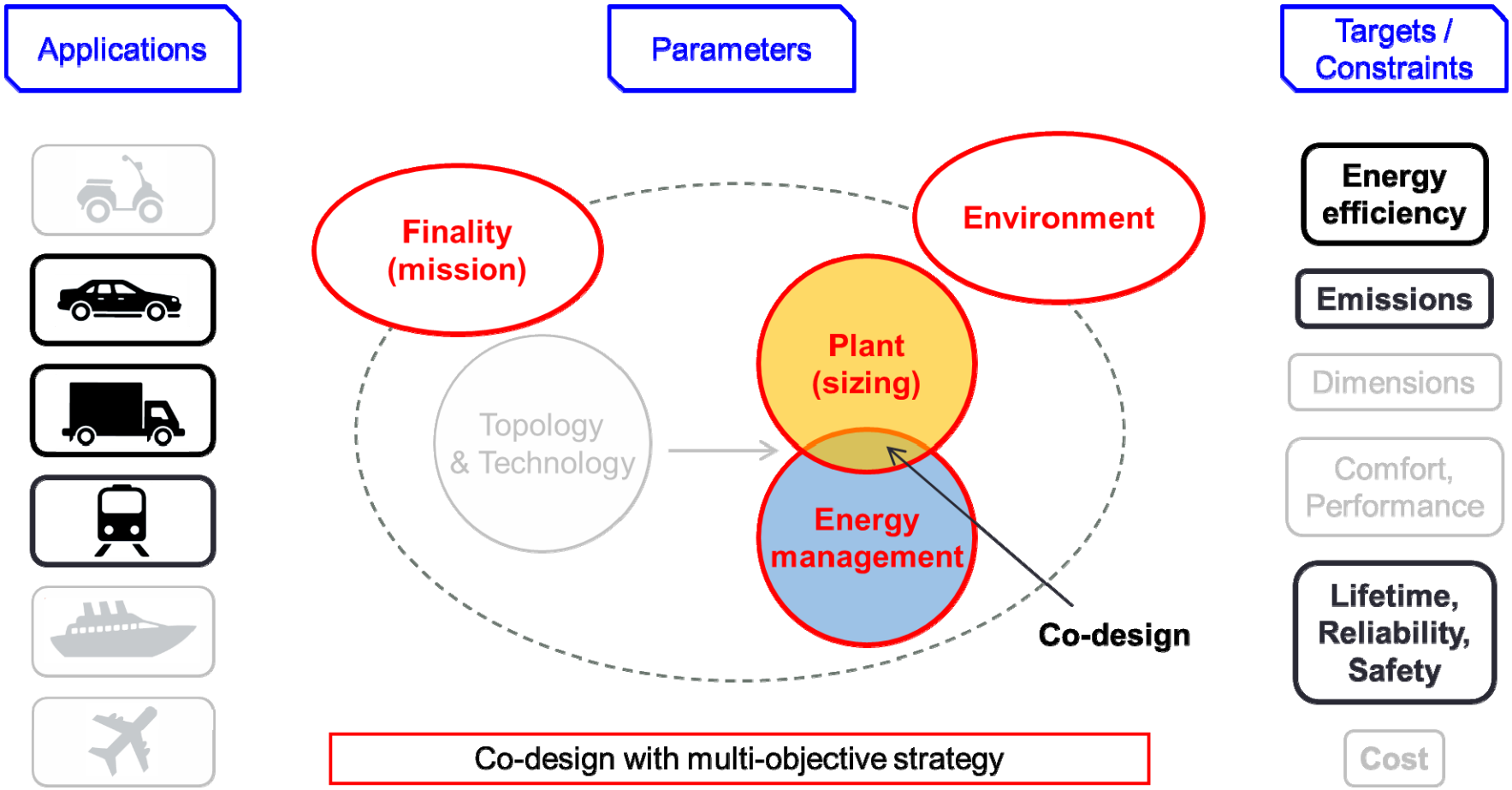
CPER RITMEA

System-level design



TIM Project

System-level design



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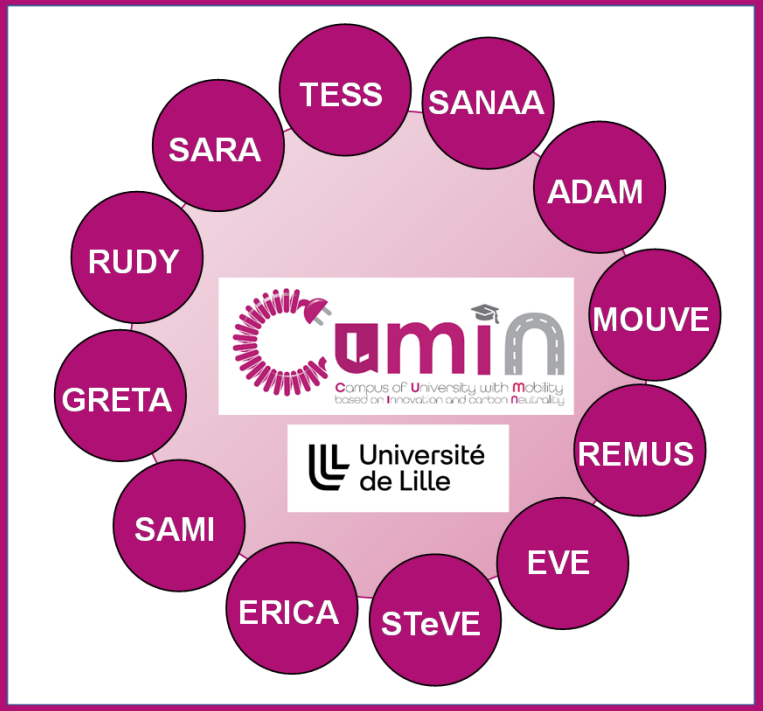

CUMIN programme

Our campus as
an exciting living lab
towards eco-cities!