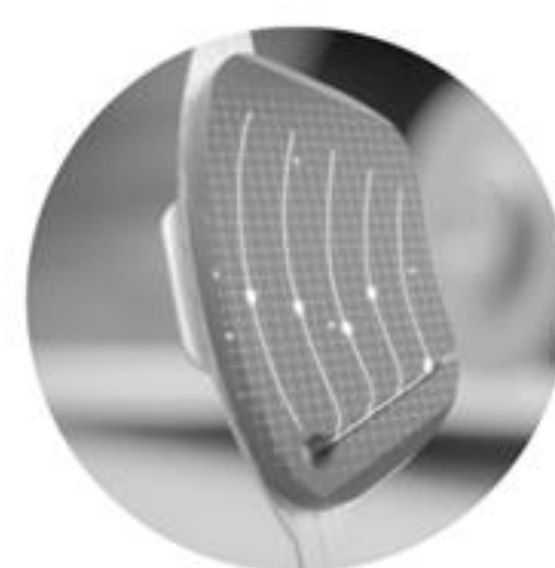
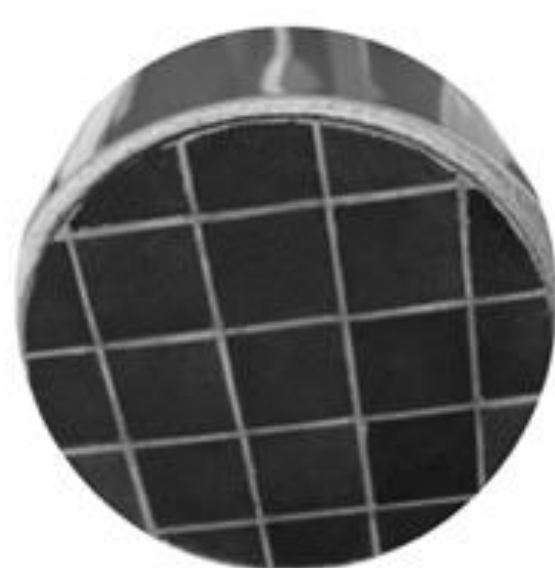
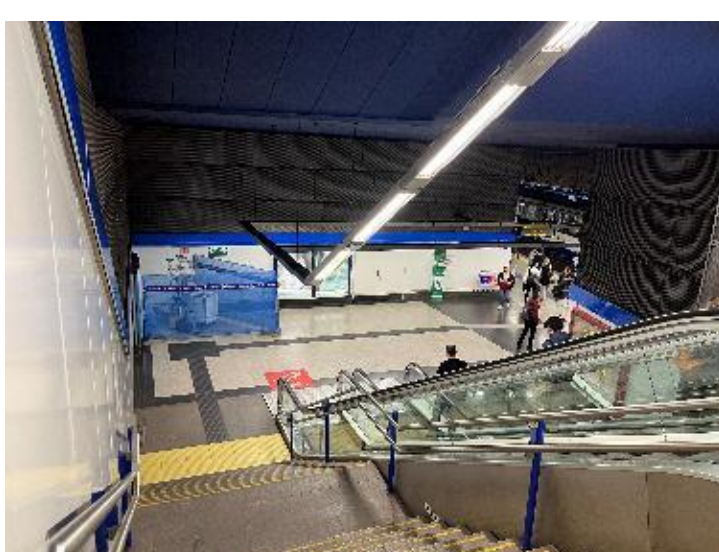
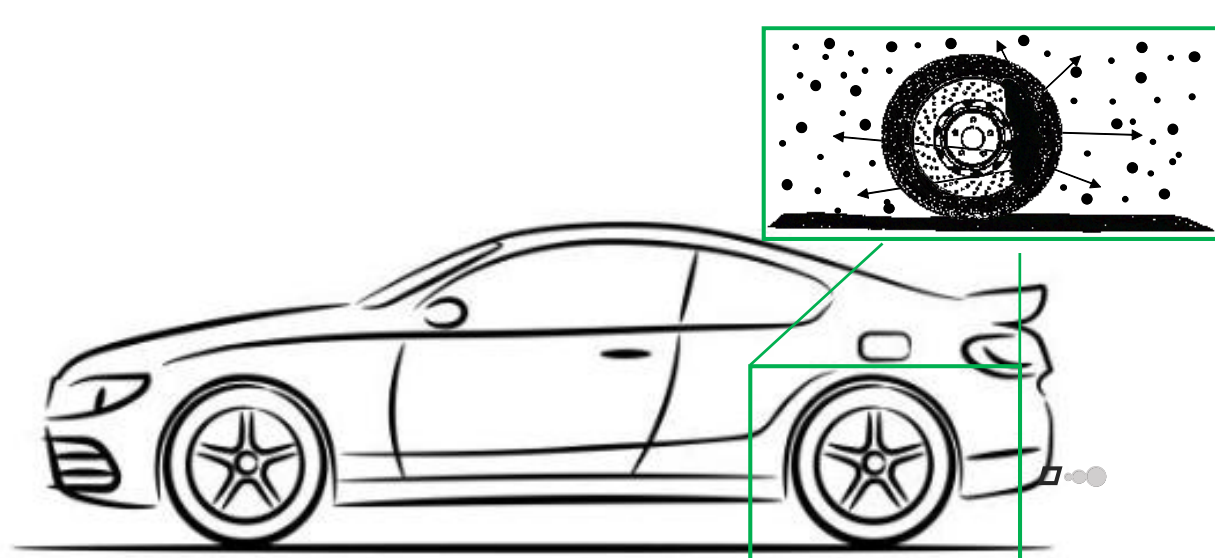




The VERA Project: Brake Retrofit Solutions

Problem

- **Brake emissions from road vehicles in EU:**
 - 280M+ vehicles in EU fleet
 - 15+ year average vehicle age
 - 30% non-exhaust emissions contribution
 - 50% urban PM from brakes
 - Serious environmental & health impacts
- **Brake emissions from underground trains:**
 - Confined, enclosed station environments
 - Limited air circulation and ventilation
 - High passenger and worker exposure
 - Accumulation of particulate matter in tunnels
 - Significantly elevated health risks compared to outdoor environments



VERA Solutions and Technologies

- **Brake Solutions >90% of particle mass reduction**

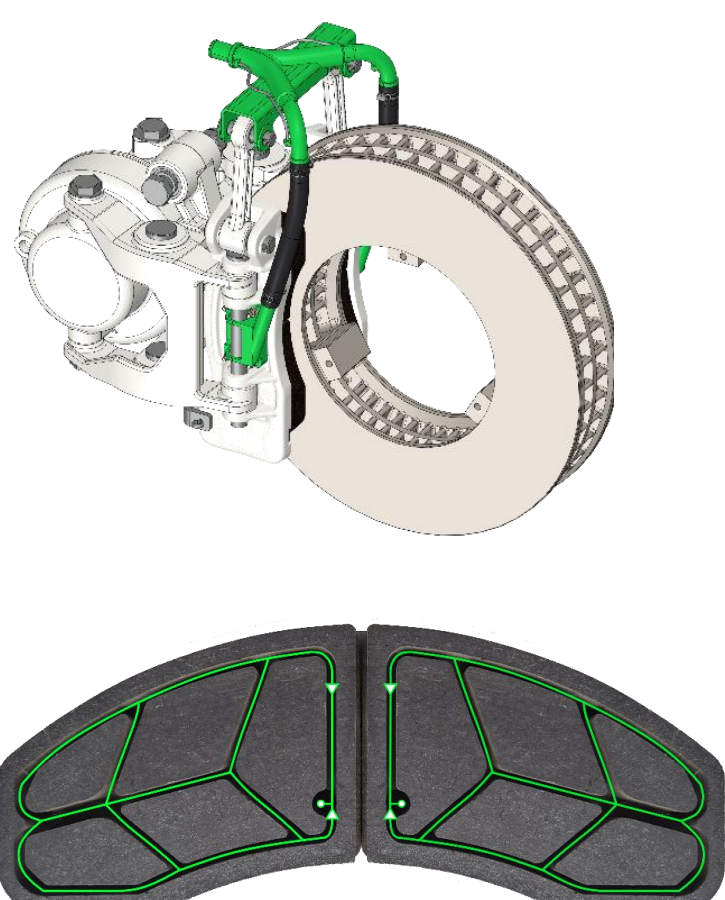
✓ 3 Final solutions integrated in Light Duty Vehicle Application:

1. **Brake Retrofit System 1 (BRS1)** combines a modified grey cast iron (GCI) brake disc with low-emission (LE) friction materials engineered by Brembo.
2. **Brake Retrofit System 2 (BRS2)** introduces an advanced coated brake disc technology paired with specifically formulated Low Metallic (LM) brake pad compositions, developed by Brembo
3. **Filtering System (OE+FS)** an innovative filtering system developed by Tallano (TAMIC) with dedicated suction grooves strategically integrated into the brake pad design, actively capturing particulate emissions at source.



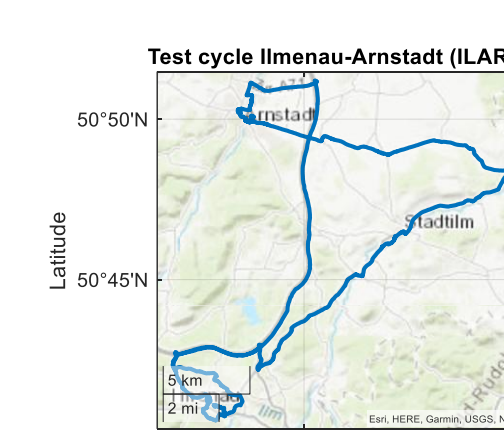
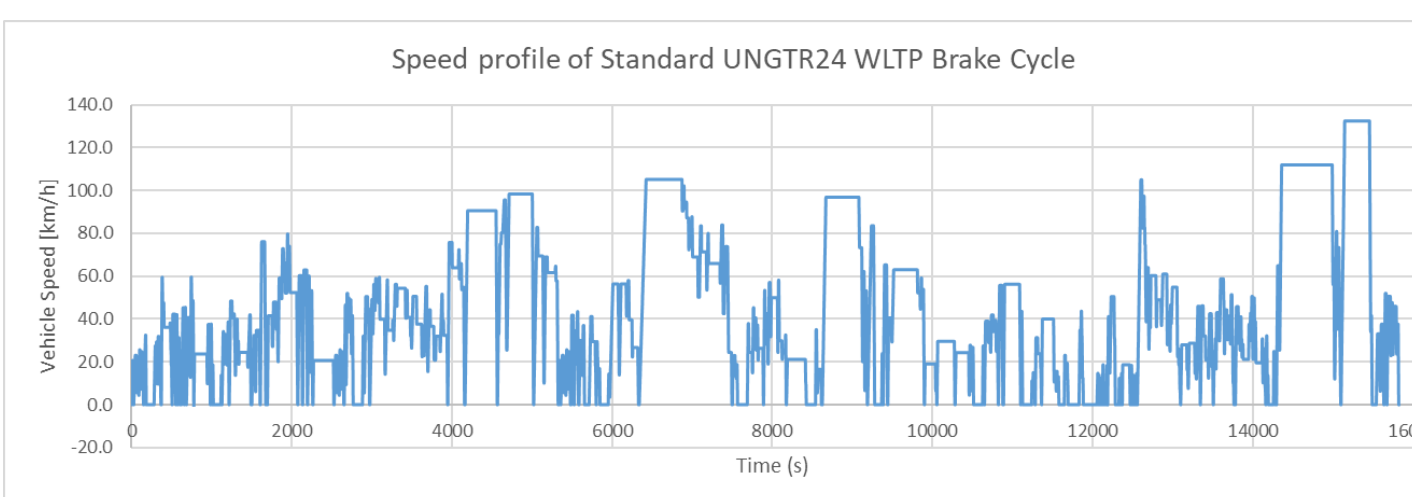
✓ 2 Final solutions integrated in Metro Application:

1. Filtration system for **Disc Brake Unit (DBU)**
2. Filtration system for **Thread Brake Unit (TBU)**

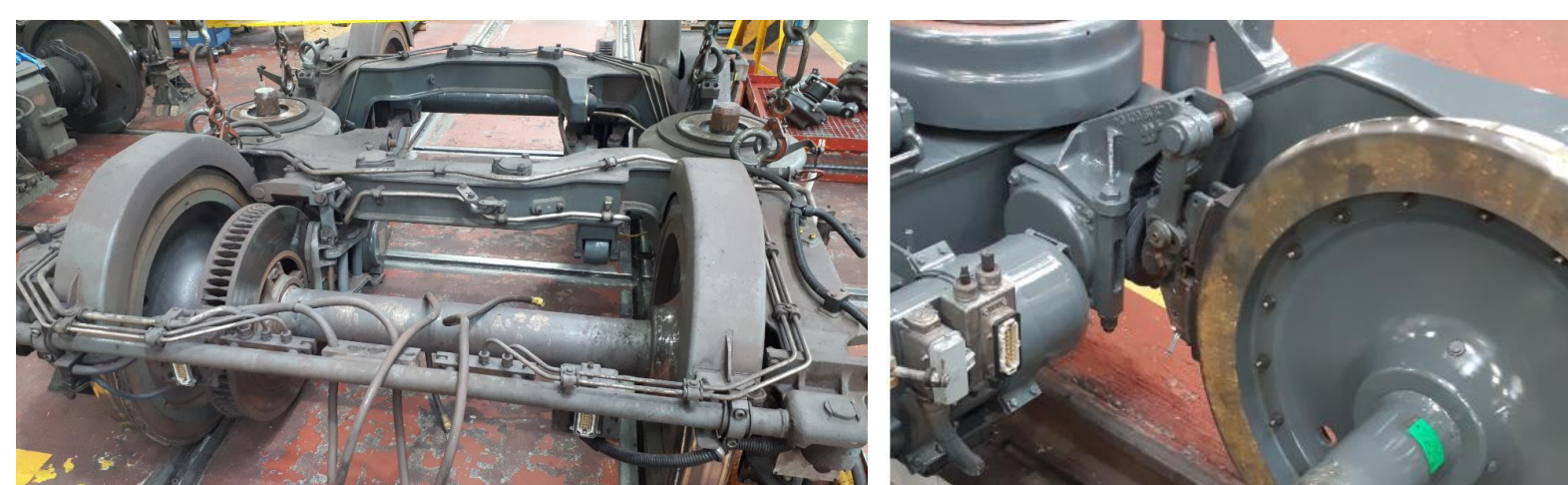


Vehicles and Testing

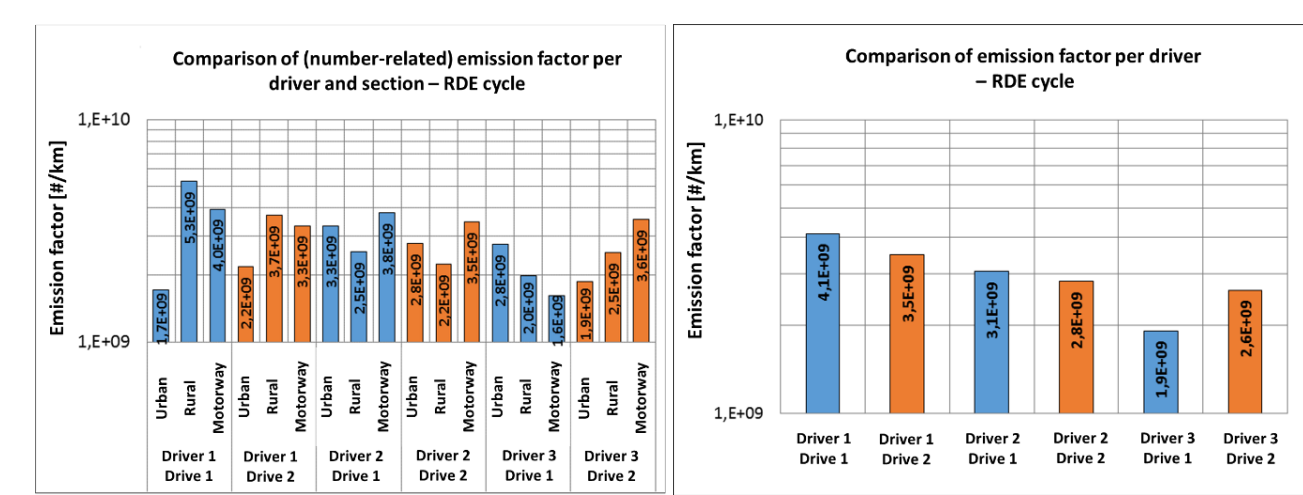
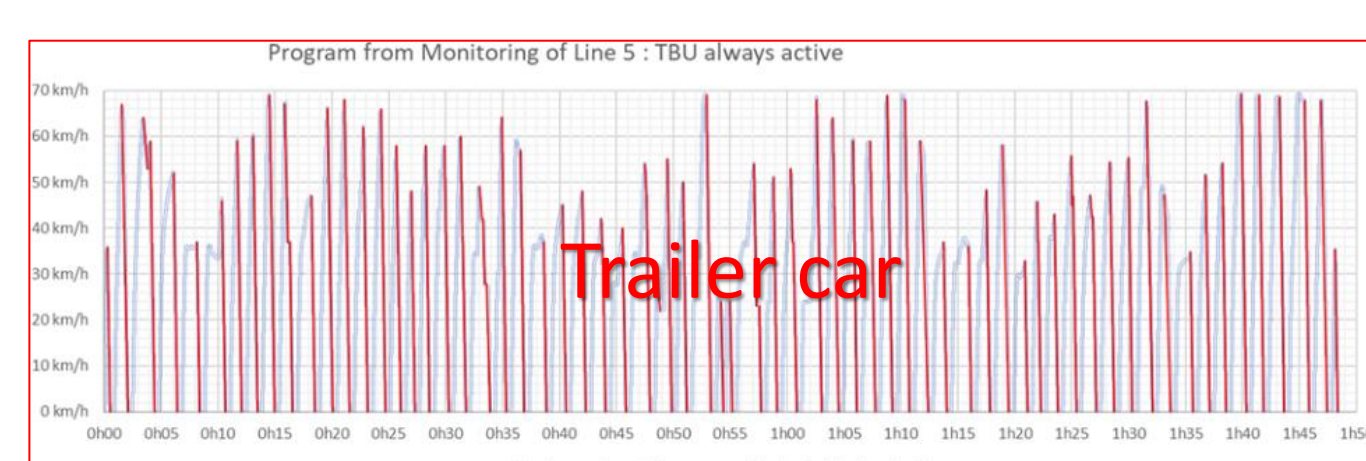
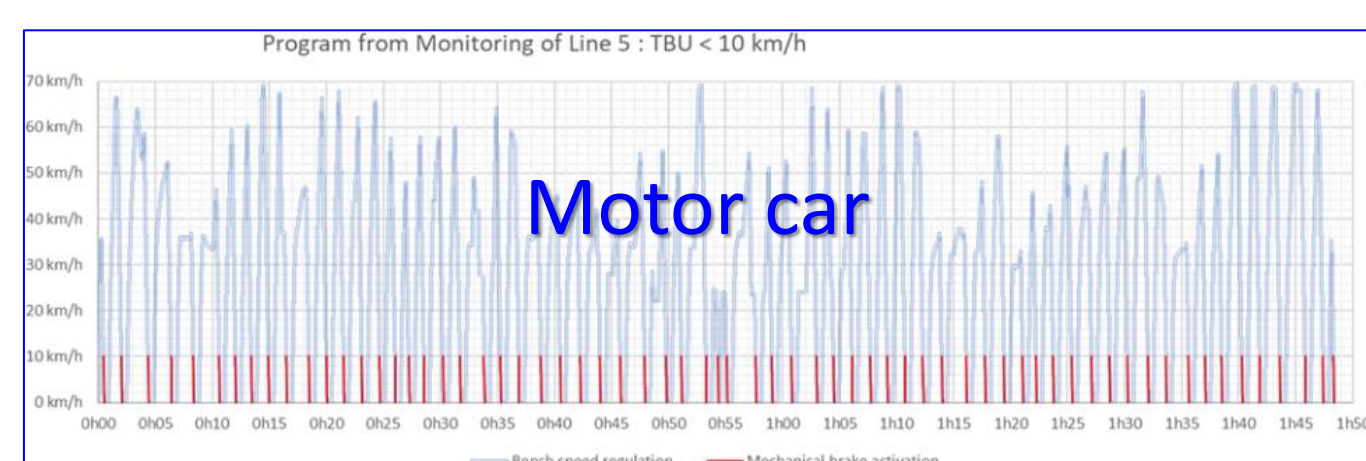
LDV Application: 3 use cases tested in lab and on road



Train Application: 2 use cases tested in lab under real operating profiles



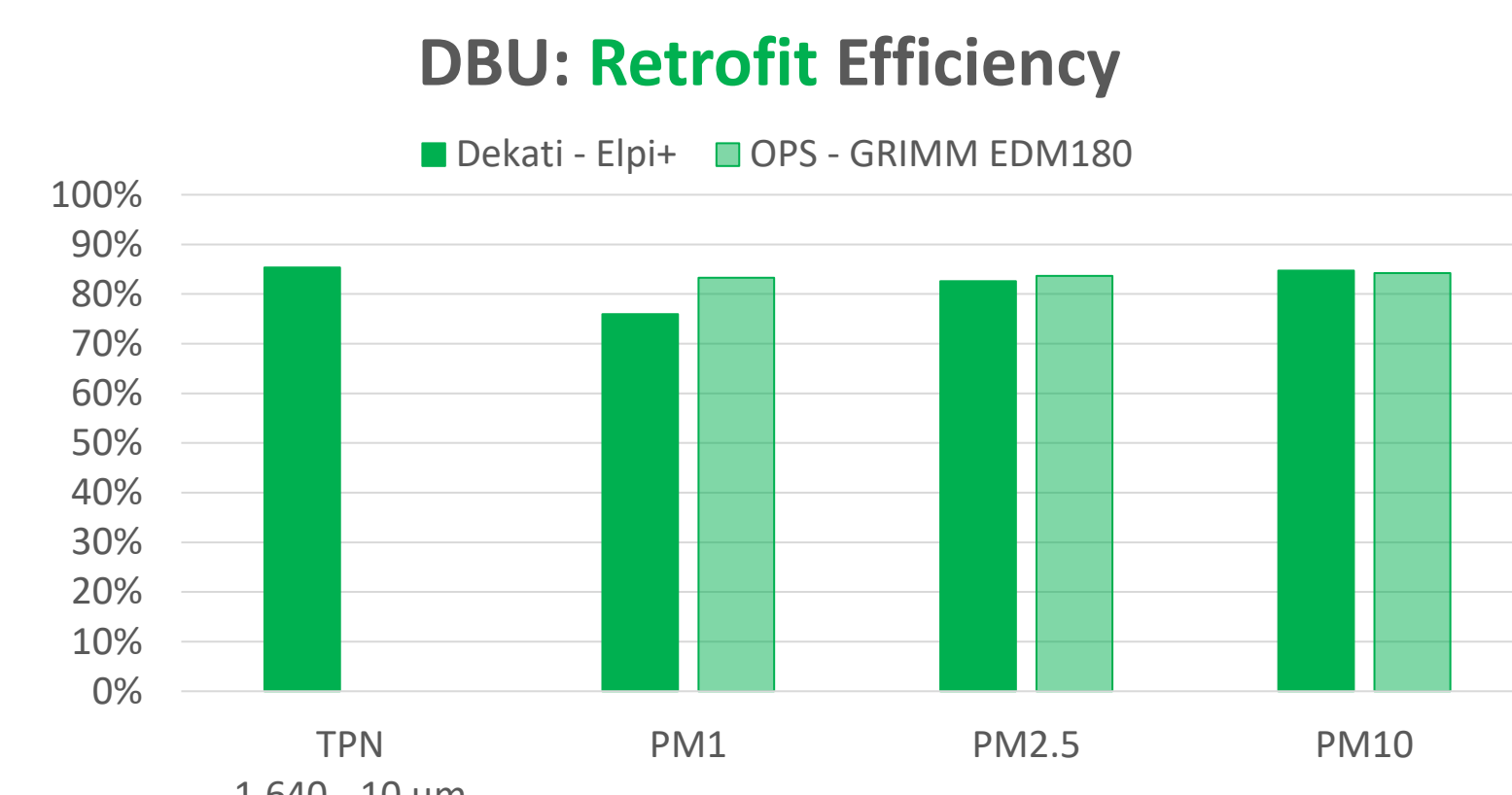
Total Brake	Initial Speed	Weight	Detail	Energy
66 x	10 km/h	Empty: 2 950 kg/wheel	Motor car	0.75 MJ
78 x	Between 20 and 70 km/h		Trailer car	23.17 MJ
66 x	10 km/h	Average: 3 762.5 kg/wheel	Motor car	0.96 MJ
78 x	Between 20 and 70 km/h		Trailer car	29.55 MJ
66 x	10 km/h	Max service: 4 575 kg/wheel	Motor car	1.16 MJ
78 x	Between 20 and 70 km/h		Trailer car	35.93 MJ



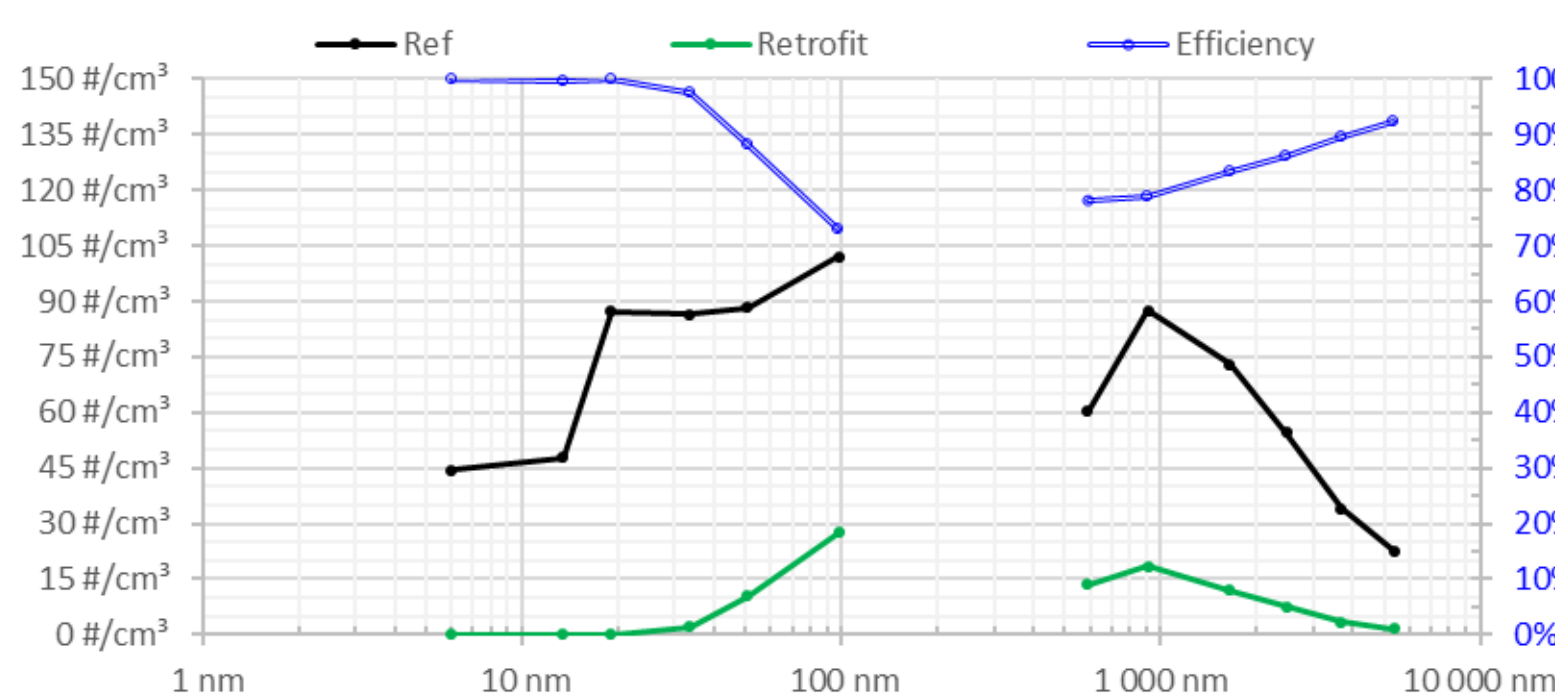
Achievements

Train Application

- High particle reduction efficiency, specially in the small fraction:
- >80% PM and PN reduction

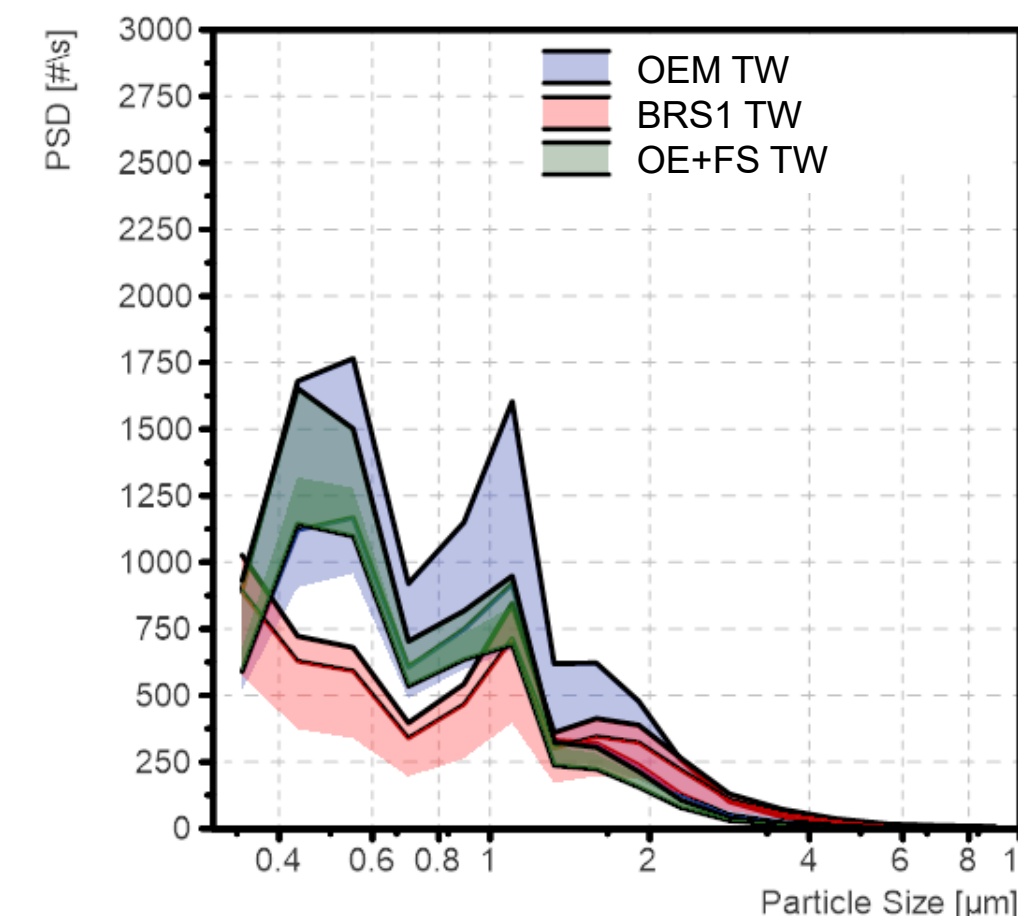
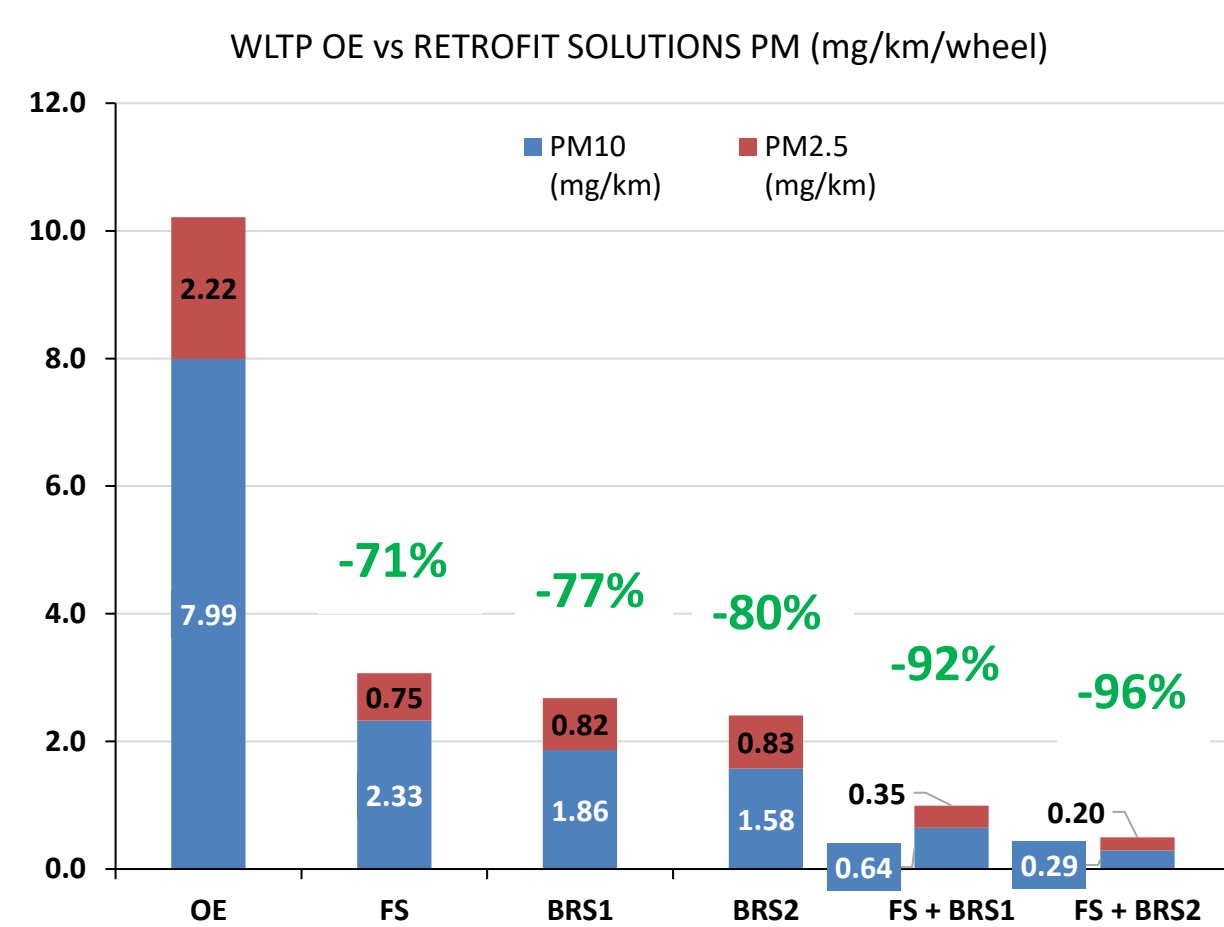


TBU: Average Particle concentration while Braking vs Particle Diameter



LDV Application

- >90% PM reduction
- Confirmed with real-world tests

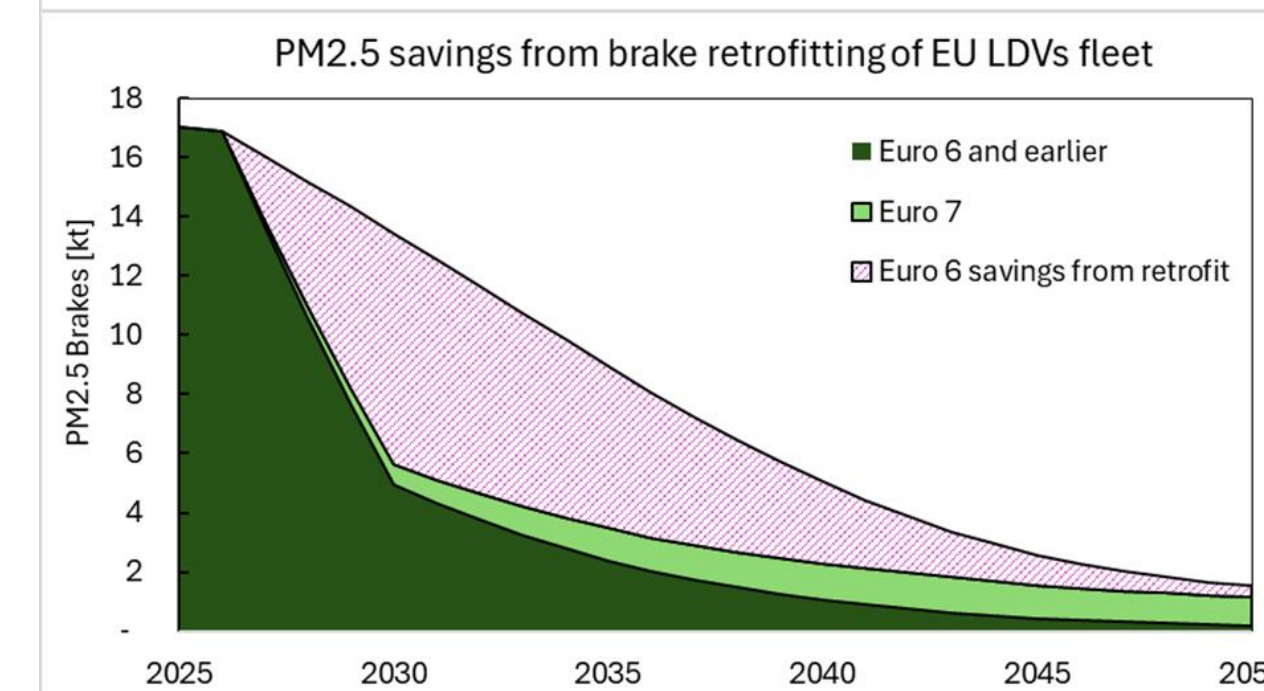
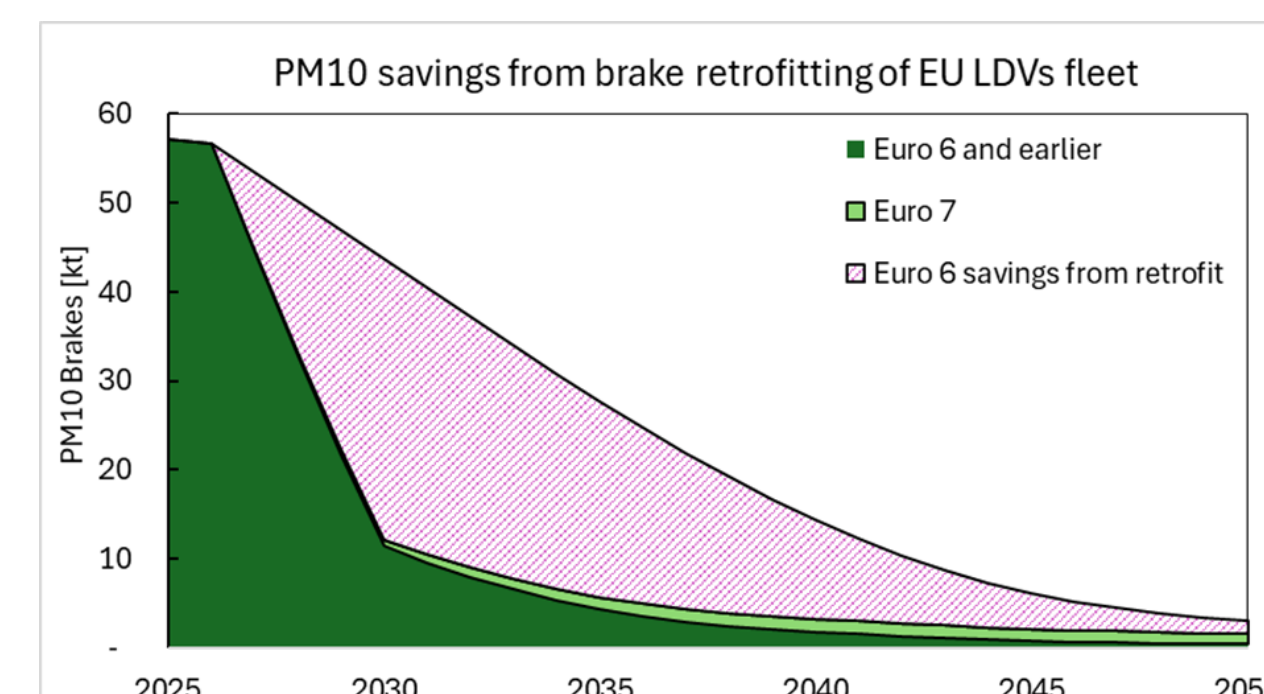
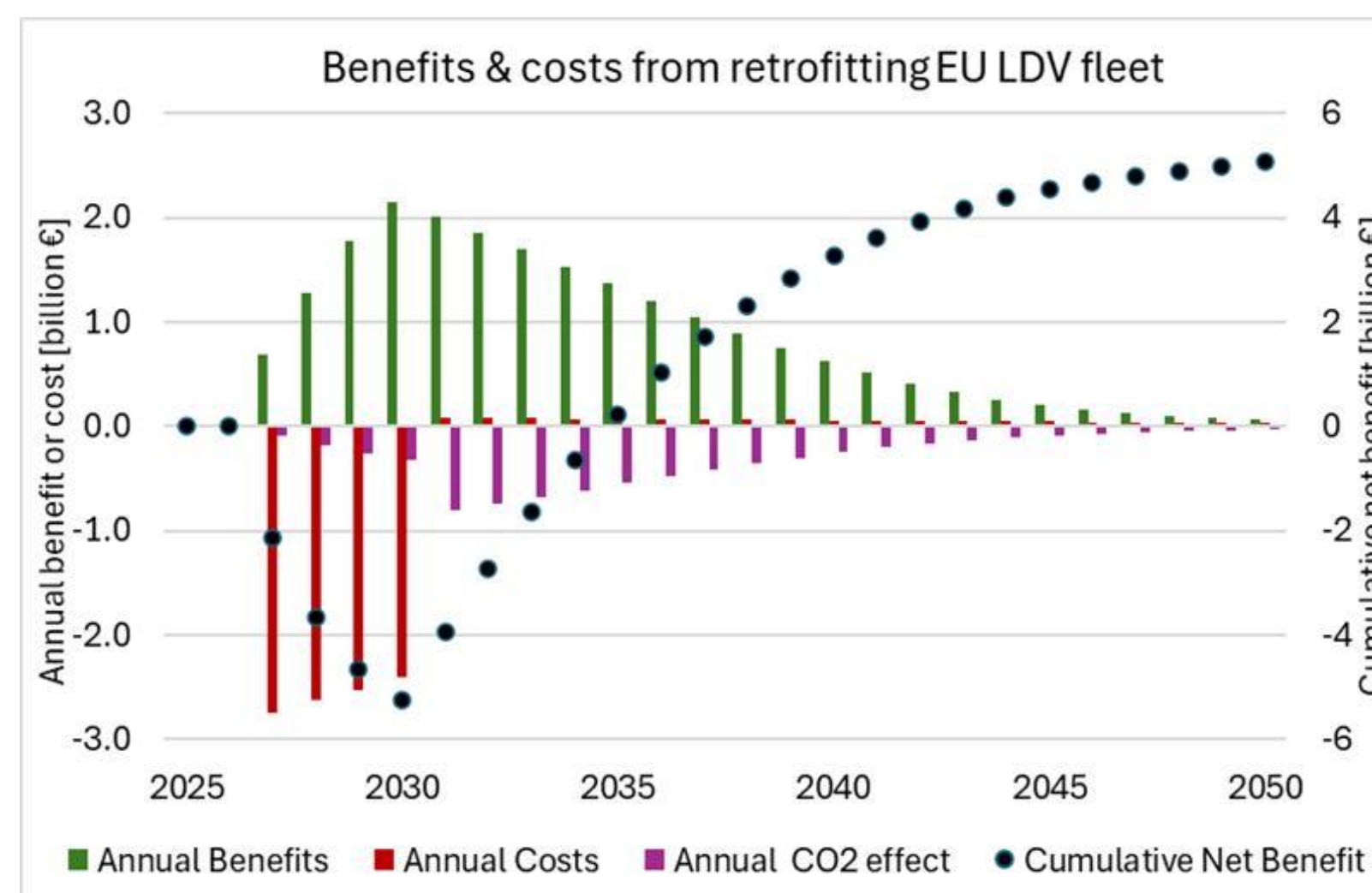


Key Advantages for Real-World Application

- ✓ **Adaptability:** Systems easily scalable across vehicle types, including HD
- ✓ **Dual-use capability:** Can be used for both retrofit and first installation on new vehicles
- ✓ **Replacement part option:** Discs and pads can serve as direct replacement for worn components
- ✓ **Low cost:** Total system cost designed to be small fraction of vehicle value
- ✓ **No performance compromise:** Solutions validated to maintain braking efficiency, safety, and comfort
- ✓ The final integrated brake systems represented a comprehensive approach combining **wear reduction** (novel materials) with **particle capture**, validated through extensive lab and real-world testing, achieving **>90% PM reduction**

Benefits

- **Positive health impacts, confirmed by toxicological analysis**
 - Lower population exposure to non-exhaust PM via substantial reductions in brake emissions from Euro 6 and earlier LDVs
 - Lowest in vitro toxicity of emitted PM based on similar mass basis
 - Highest health gains when combining BRS1+FS systems
 - Benefits reflect both **less PM mass** emitted and **lower particle toxicity** across retrofit configurations
- **Cost-Benefit Analysis (CBA)**
 - BRS1+FS applied to all Euro 6 and earlier LDVs delivers €5.5B net benefit
 - Following same approach, applying FS (TAMIC) to Madrid metro network yields a monetized net benefit of over €1M
 - The CBA updates PM damage costs using toxicological tests across multiple endpoints, e.g., cell viability, inflammatory response, oxidative stress



Policy recommendations and implications

- Strengthen the inclusion of non-exhaust emissions in policy design; multiple effective market solutions already exist
- Prioritize deployment of retrofit solutions against brake wear in existing fleet where rapid air-quality gains are needed
- Support uptake through incentives schemes

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