Mitigation of Ultrafine Particles from Transportation – **International and Domestic Policy Overview**

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Workshop on UFP Emissions from Transportation

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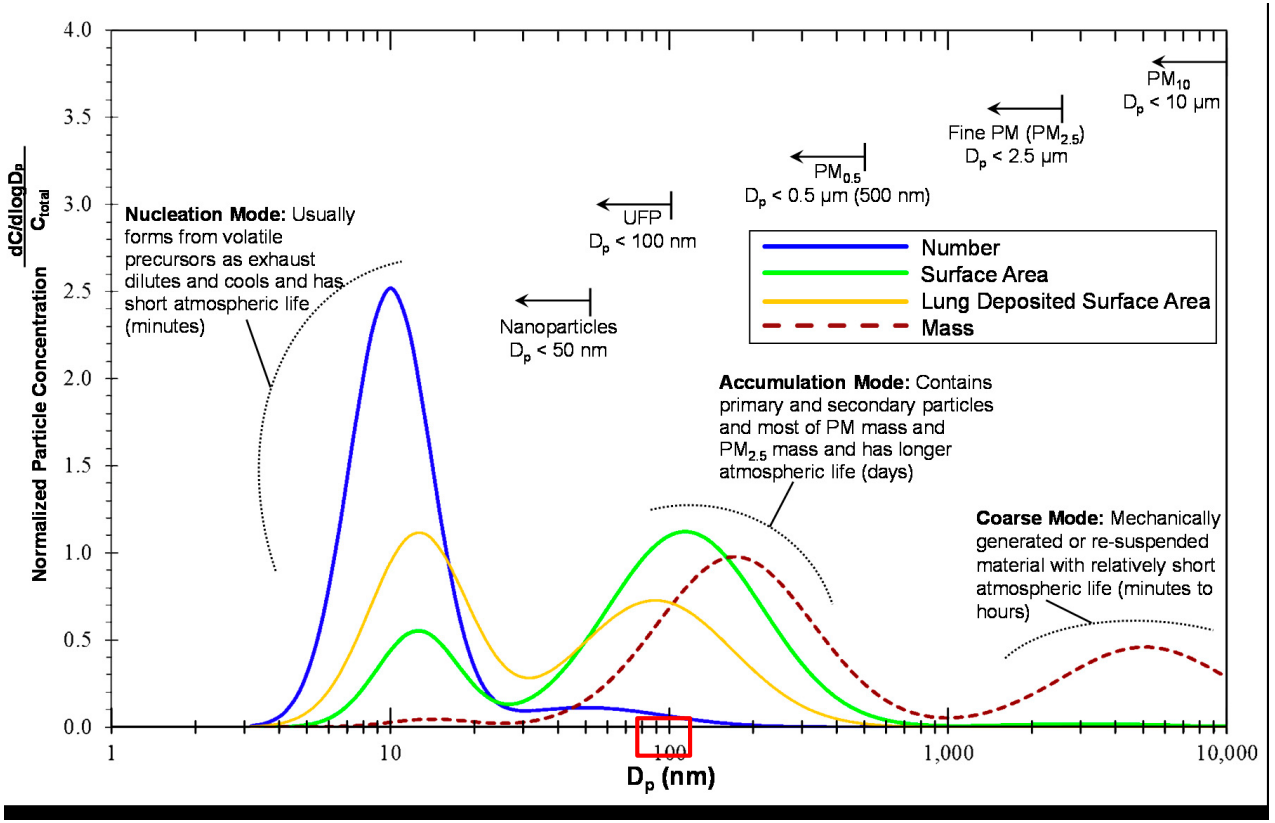
Typical Particulate Size Distributions

- Diagram shows **majority of partulates from vehicle exhaust are in UFP range** (<100 nm d)
- Majority of particulate mass lies above the UFP threshold
- So UFPs are not well accounted for by standards that focus strictly on particle mass

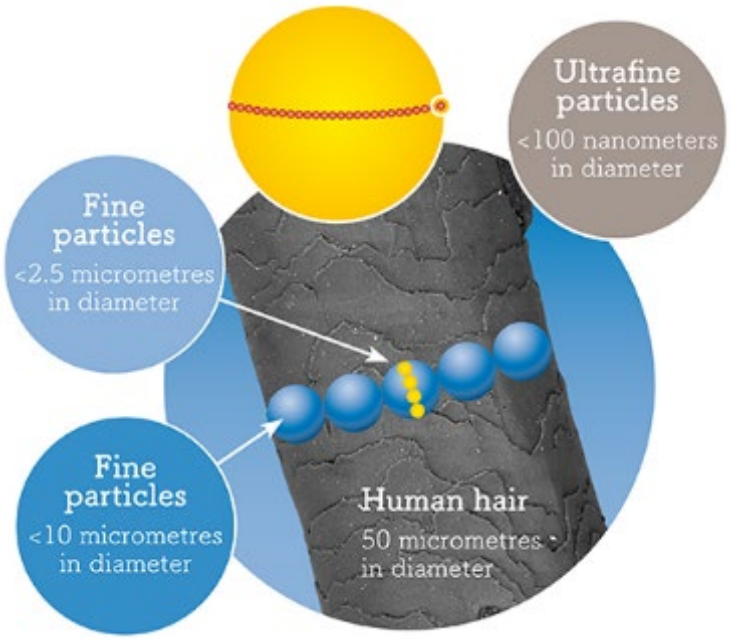


Baldauf et al., 2016

Particle Number (PN) Standards vs Particle Mass (PM) Standards

- Given the extreme small size (<0.1 micrometers in diameter), ultrafine particles (UFPs) are not a major factor in measurements of overall particle mass (PM), but they constitute the largest contributor to overall particle numbers (PN)

- **UN-Economic Commission for Europe's Particle Measurement Programme (PMP)** made recommendation to have a **solid particle number (SPN) limit**
  - Initially, recommended to control diesel vehicle emissions
  - After the introduction of gasoline direct injection (GDI) engines, SPN was recommended to control gasoline vehicle emissions



Euro 5 & 6 Vehicle Emission Standards for Light Duty Vehicles

- Based on recommendation of the Particle Measurement Programme (PMP), the European Union introduced a **Solid Particle Number (SPN)** standard to complement the **Particle Mass (PM)** standard for diesel and GDI engine vehicles.
  - SPN standard **measures solid particles >23 nm** in diameter

- The implementation of SPN standard effectively requires that diesel particulate filters (DPFs) and gasoline particulate filters (GPFs) are used in many light duty vehicles

Euro 5 and 6 Vehicle Emission Standards (Light passenger & commercial vehicles)

Stage	Implementation Date	PM (mg/km)	PN (#/km)
Euro 5b (diesel)	2011	5	6×10^{11}
Euro 6 (diesel & GDI)	2014	5	6×10^{11}

DieselNet, 2019

Euro 5 & 6 Vehicle Emission Standards for Heavy Duty Vehicles

- **Light duty vehicle:** maximum mass not exceeding 3.5 tonnes
  - **Passenger cars:** used for the carriage of passengers, with no more than 8 seats in addition to the driver seat
  - **Light commercial vehicles:** used for the carriage of goods

- **Heavy duty vehicles:** comprise trucks, buses and coaches. HDVs are defined as freight vehicles of more than 3.5 tonnes (trucks) or passenger transport vehicles with more than 8 seats (buses and coaches)

(European Alternative Fuels Observatory, 2019)

Euro 5 and 6 Vehicle Emission Standards (Heavy duty vehicles)

Stage	Test	Implementation Date	PM (mg/kWh)	PN (#/kWh)
Euro 6 (diesel & gasoline)	WHSC	2019	10	8×10^{11}
Euro 6 (diesel & gasoline)	WHTC	2019	10	6×10^{11}

DieselNet, 2019

China 5 & 6 Vehicle Emission Standards for Light Duty Vehicles

- Chinese emission standards are **based on European regulations,** and incorporate particle number as well as mass
- China 6 regulations finalized in December 2016
- China 6 limits will **apply to all light duty vehicles** (Euro 6 only applies to GDI engine LDVs)
- Also measures solid particles >23 nm in diameter

China 5 and 6 Vehicle Emission Standards (Light duty vehicles)

Stage	Implementation Date	PM (mg/km)	PN (#/km)
China 5 (diesel & gasoline)	2013 (Beijing) 2014 (Shanghai) 2016-2018 (Nation wide)	4.5	6×10^{11}
China 6a (diesel & gasoline)	2020	4.5	6×10^{11}
China 6b (diesel & gasoline)	2023	3	6×10^{11}

DieselNet, 2019

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(European Alternative Fuels Observatory, 2019)

China 6 Standards
(Heavy duty vehicles)

Stage	Test	Implementation Date	PM (mg/kWh)	PN (#/kWh)
China 6a (diesel)	WHSC	2019	10	8×10^{11}
China 6a (gasoline & diesel)	WHTC	2019	10	6×10^{11}
China 6b	PEMS	2021		12×10^{12}

DieselNet, 2019

California Low Emission Vehicle III Standards

- California Low Emission Vehicle (LEV) III standards were **adopted in 2012**
- **EU and China's planned SPN standards are more stringent,** because the SPN limit is 6×10^{11} p/km, which equivalents to 0.8 mg/mile
- The California Air Resources Board (CARB) **proposed to include the SPN limit** in LEV III to limit particulate emissions from GDI vehicles. But this was **withdrawn from the final regulation**.

California LEV III Standards
(Light and medium duty vehicles)

Stage	Vehicle Type	Phase-in Model Year	PM (mg/mi)	PM (mg/km)
California LEV III	LDV	2017-2021	3	1.86
California LEV III	LDV	2025-2028	1	0.62
California LEV III	MDV	2017-2021	8-10	5-6.2

DieselNet, 2019

U.S. EPA and Canada's Emission Standards

- **U.S. EPA's Tier 3 standard harmonized with LEV III** up to 2025, with a 3 mg/mile particle mass (PM) limit, starting in 2017
- **Canada's** On-Road Vehicle and Engine Emission Regulations **harmonized with U.S. EPA's Tier 3** limits, starting also in 2017

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(Light and medium duty vehicles)

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California LEV III	LDV	2017-2021	3	1.86
California LEV III	MDV	2017-2021	8-10	5-6.2
California LEV III	LDV	2025-2028	1	0.62

DieselNet, 2019

North American Heavy Duty Vehicle Emission Standard

- California and Canada have the same emissions standards as U.S. EPA for heavy duty vehicles

North America Vehicle Emission Standards
(Heavy duty vehicles)

Phase-in Model Year	PM (mg/bhp-hr)	PM (mg/kWh)
2007	10	13.4
2015	10	13.4

DieselNet, 2019

Closing Thoughts

- Roughly half of all light duty vehicles sold in North America now have GDI engines
- Some of the emissions from these vehicles are not being addressed by current regulations or programs
- Because the Euro 6 SPN limits only apply to GDI engines, they are failing to address some emissions from standard port fuel injection (PFI) engines

- Some experts believe that the lower range of regulated particulate size should decrease from 23 nm to 10 nm (majority of UFPs are between 2 and 23 nm in diameter)
  - If this were to happen in Europe, SPN emissions from the average vehicle would increase by 114%
  - The measurement of SPN emissions down to 10 nm is now technically feasible for legislative purposes

Thank You

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