LABORATORY OF APPLIED THERMODYNAMICS

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Urban and cold-start phase particle emissions of a gasoline hybrid and a CNG vehicle

25th ETH Conference on Combustion Generated Nanoparticles
June 21-23, 2022

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Introduction

- **Road transport contribution in EU**[1,2,3]:
  - Up to 39% (11% on average) on urban $PM_{2.5}$
  - The highest contributor on ultrafine particles in big cities

- **Daily mobility** in different EU countries:
  - **Urban trips**[4]:
    - 41-99% of all trips <300km
    - 24-88% of covered distance for trips <300km
  - **Cold start**[5]: 17-38% of all trips are started under cold conditions (after >8h parking)

→ **Urban and cold-start phase (0-5 minutes) emissions are of high importance**

[1] EEA, Air quality in Europe – 2020 report, [2] Thunis P. et al., 2021, Urban $PM_{2.5}$ Atlas - Air Quality in European cities, [3] Lorelei de Jesus A. et al., 2019, Ultrafine particles and $PM_{2.5}$ in the air of cities around the world: Are they representative of each other?, [4] Eurostat, 2021, Passenger mobility statistics, [5] Weiss, M., 2017, Including cold-start emissions in the Real-Driving Emissions RDE test procedure

Methodology

Vehicles:

	Vehicle 1	Vehicle 2	
Fuel	Gasoline Hybrid	CNG	Gasoline (back-up)
Fuel Injection	PFI	PFI	GDI
Engine Capacity [cc]	1798	999	
Engine Power [kW]	72 + 53 el.	66	
Aftertreatment	TWC	TWC	
Euro standard	Euro 6d	Euro 6d-temp (type-approved as monofuel CNG)	
Segment	C-SUV	B	
Year of man.	2019	2019	
Mileage [km]	3k	9k	

Abbreviations: CNG: compressed natural gas, PFI: port fuel injection, GDI: gasoline direct injection , TWC: three-way catalyst

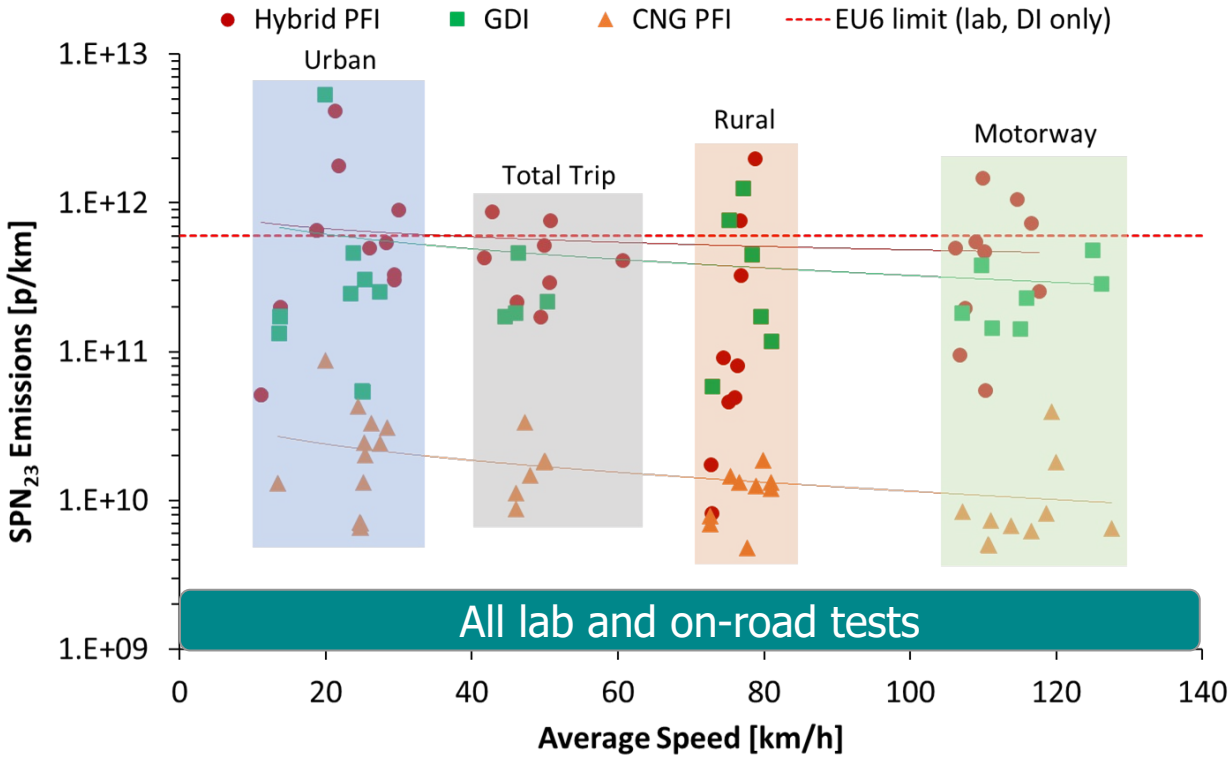
Tests and measurement equipment:

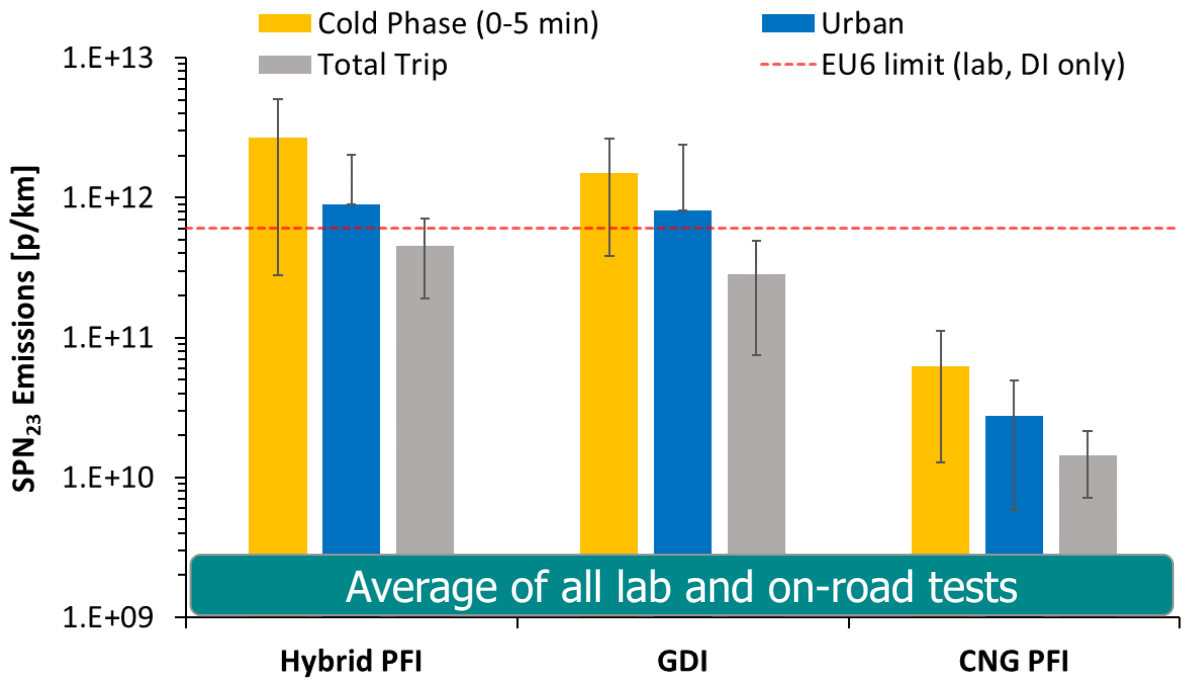
- **On-road** tests with PN-PEMS (portable emissions measurement system)
- **Chassis dyno** with PN-PEMS and laboratory PN equipment

Notes:

- PN emissions presented in the following slides refer to **SPN (solid particle number) with a cut-off size at 23 and 10nm**
- The **Euro 6 SPN_{23} limit of 6×10^{11} p/km** is provided for comparison reasons although not applicable to the studied vehicles

Emissions over the different test phases



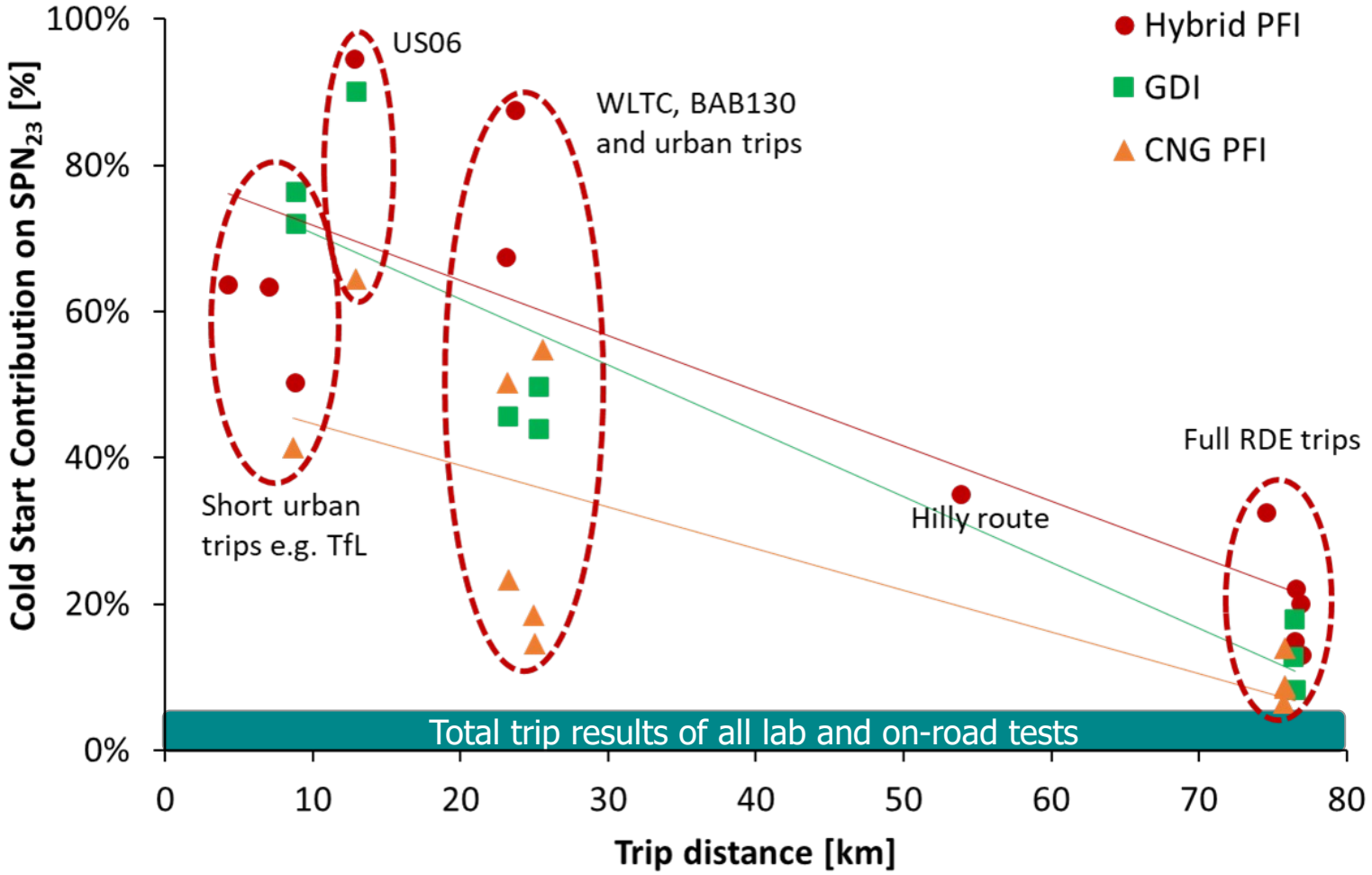


- High variation within each test phase → wide range of driving/test conditions
- **The highest emissions during urban phase**
- **CNG: overall lowest emitter,** well below 6×10^{11} p/km
- GDI and hybrid PFI at similar levels, exceeding 6×10^{11} p/km even in total trip results

→ Urban and cold phase emissions significantly higher than total trip:

	Cold/Urban	Cold/Total	Urban/Total
Hybrid PFI	3.0	5.9	2.0
GDI	1.9	5.3	2.9
CNG	2.3	4.3	1.9
Average	2.4	**5.2**	2.3

Cold start contribution in relation to trip distance

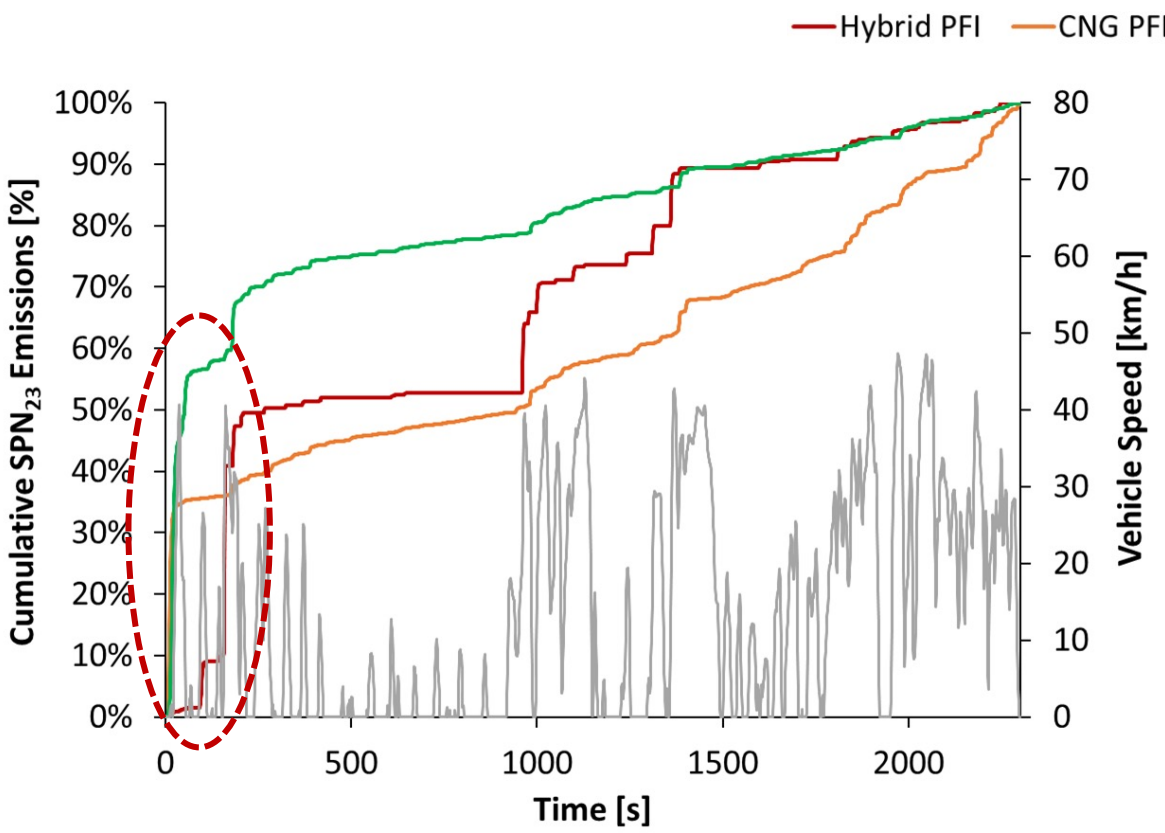


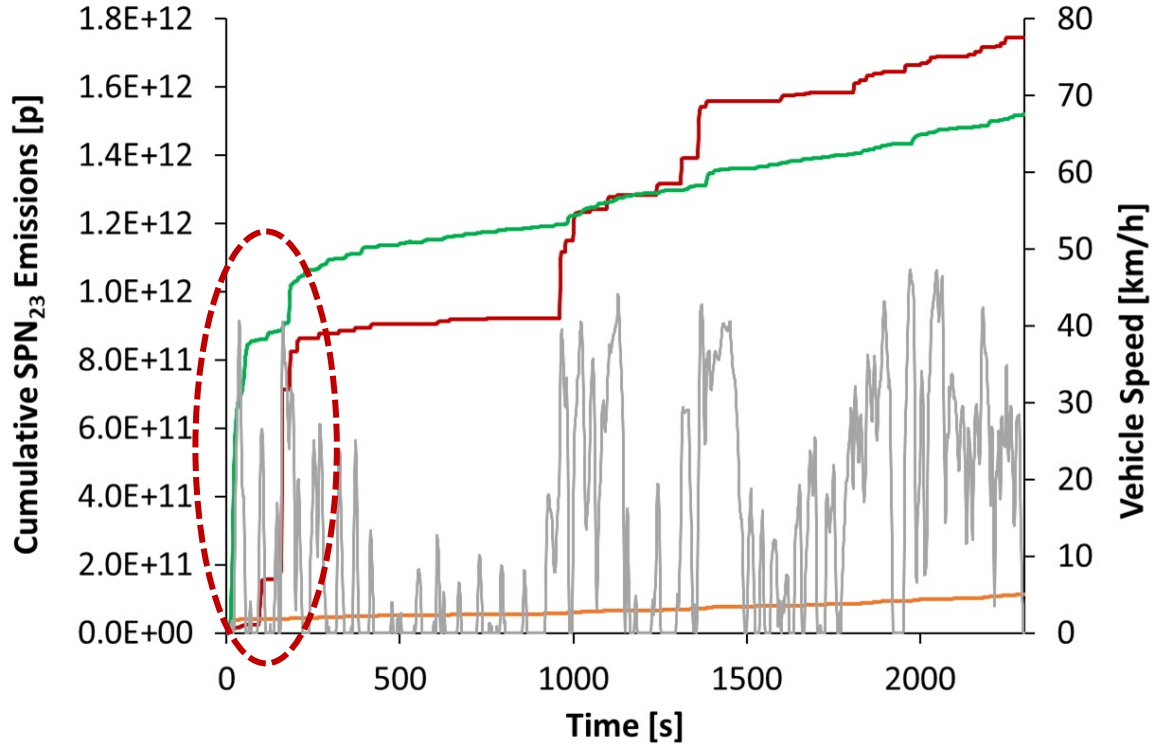
- High cold start effect in short trip distance
- **Cold start contribution on cumulative SPN_{23}:**
  - **Up to 95%** in dynamic short trips (US06)
  - **Up to 75%** in short urban trips
  - **Up to 30%** in full RDE trips
- **CNG: lowest cold-start contribution in all cases**

Note: cold start contribution refers to the cumulative SPN_{23} emissions [p] over the cold start period (0-5 min) compared to the total trip cumulative SPN_{23} emissions [p].

Cumulative SPN_{23} emissions – vehicles comparison

Cold-start TfL on dyno

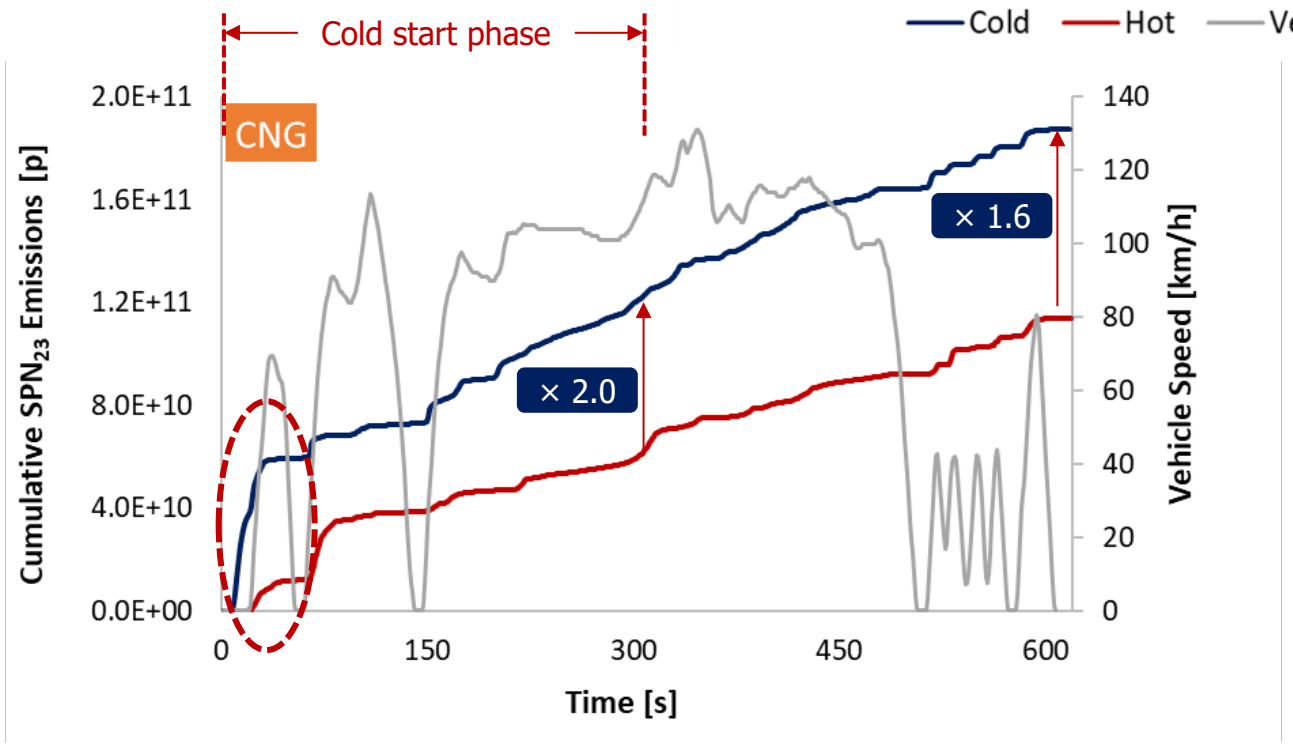


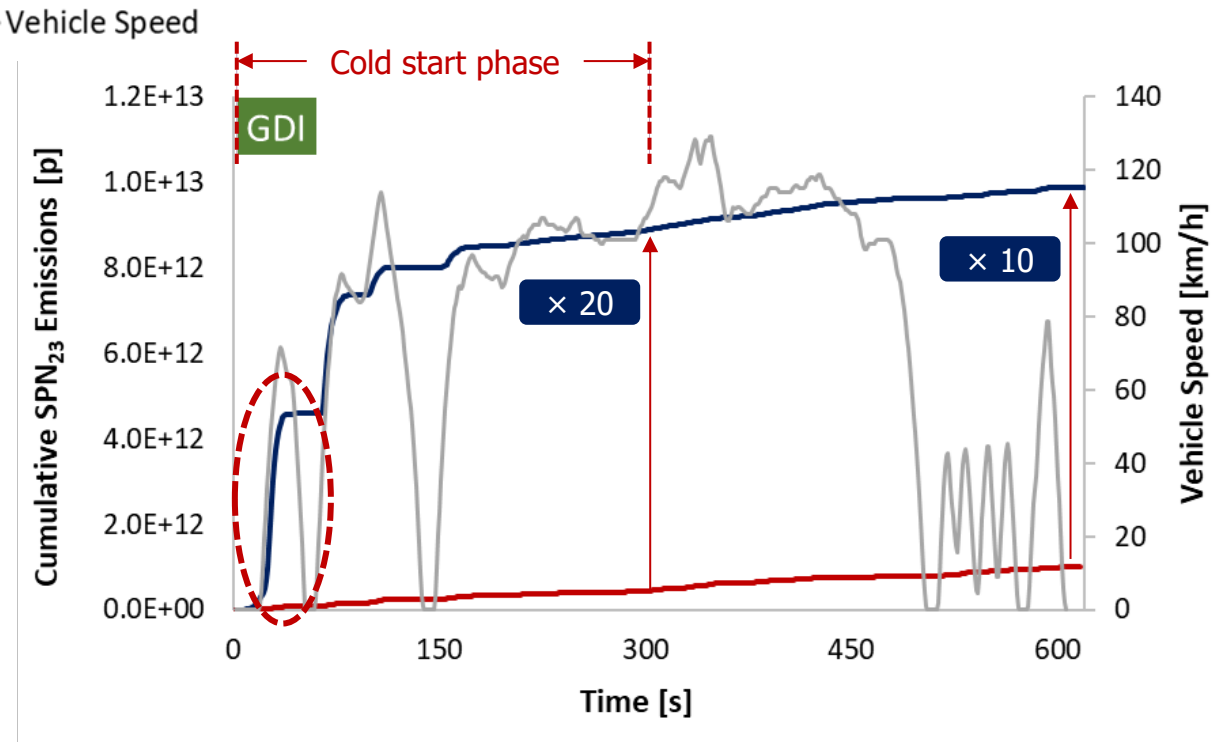


- The **highest cold start contribution in GDI**, the **lowest in CNG**
- Steep emissions increase during the first acceleration
- Long plateaus in Hybrid PFI due to engine-off events (initial battery SOC: 27%)

Cold vs Hot start tests

Cold and hot-start US06 on dyno, Vehicle 2

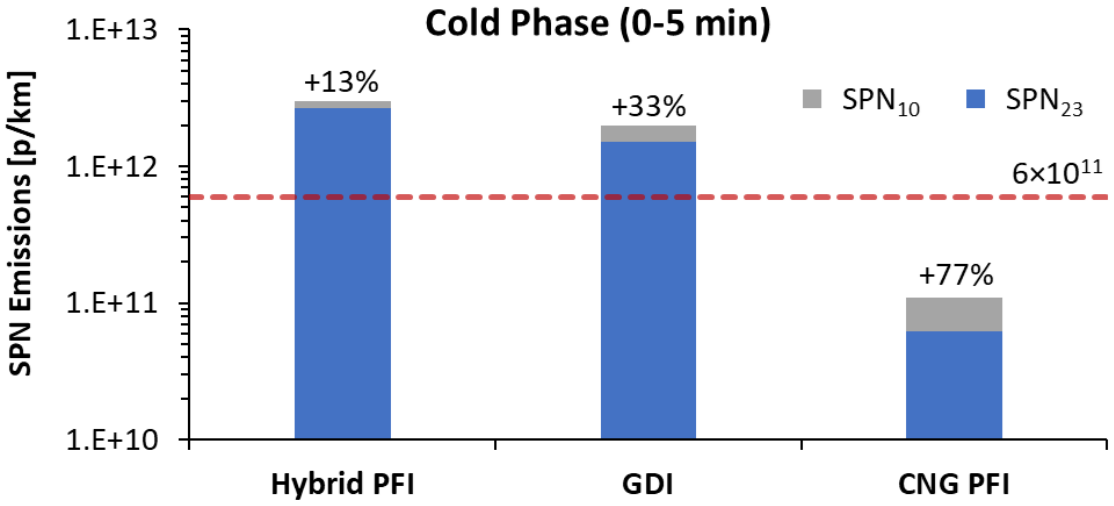


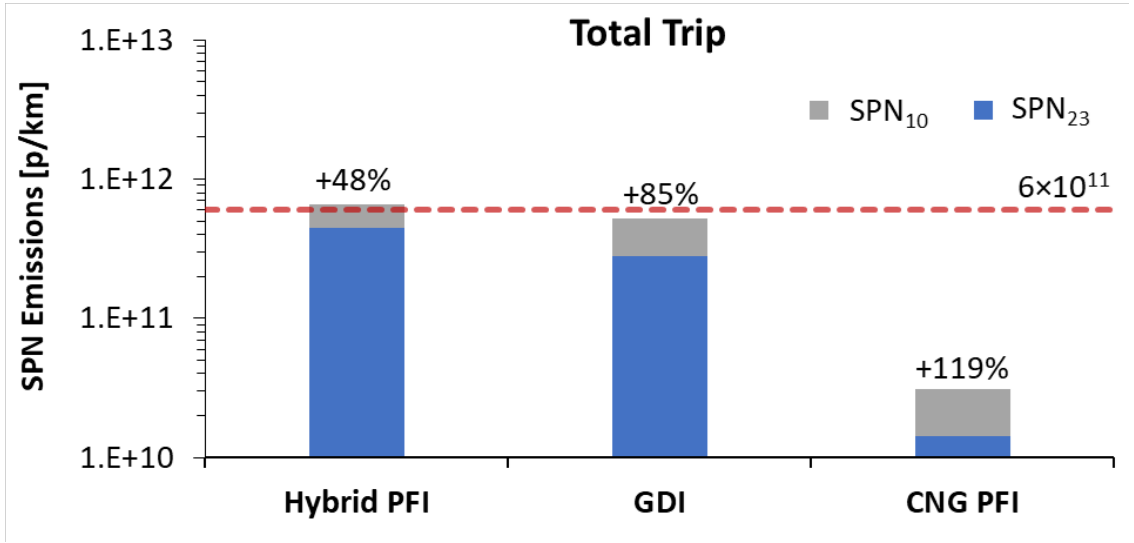


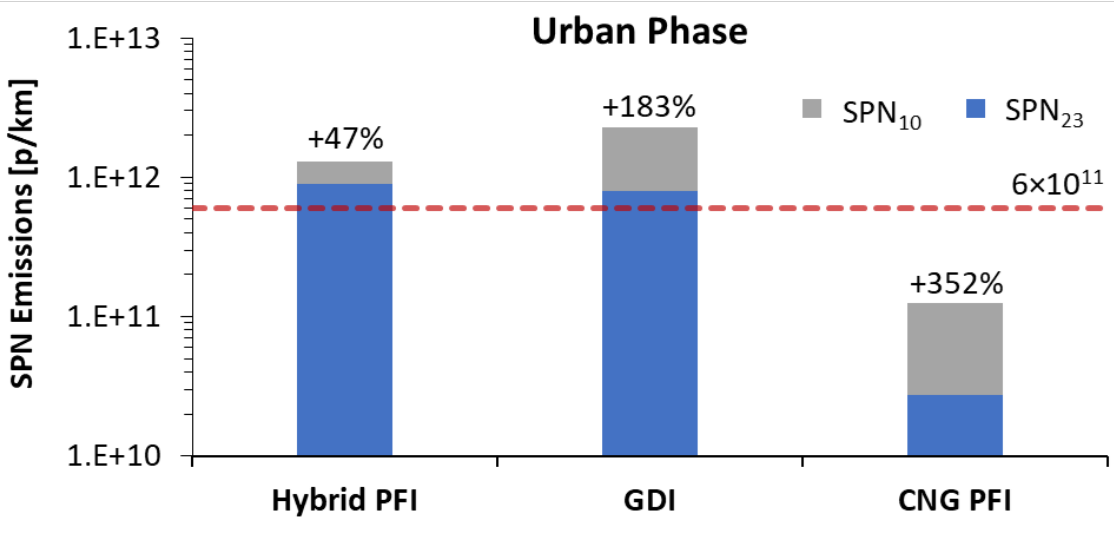
- Difference between cold and hot start cycles built mainly in the **first vehicle acceleration**
- CNG: much smaller cold-hot difference compared to GDI. Emissions also significantly lower

SPN_{23} vs SPN_{10}

Average of all lab tests







- **Low SPN_{10}/SPN_{23} ratio in cold start, high in urban**
- Highest ratio in CNG in all cases
- SPN_{10}: Small effect on compliance with 6×10^{11} p/km, only in hybrid PFI

Summary and conclusions

- **Urban and cold-start** phase (typically occurs at urban areas) **contribute significantly** to vehicle SPN emissions, especially in short trips → next regulation should address this issue

- High **SPN increase** during the very **first acceleration** especially under dynamic driving

- No significant difference between SPN_{23} and SPN_{10} emissions during cold start phase

- Ideas for **future work**: If/how these observations may change:
  - if different cut-off sizes (e.g. $SPN_{2.5}$) or total (solid+volatile) particles are evaluated
  - if these vehicles are equipped with particulate filters

Thank you for your attention.
Any Questions?

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This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Reinforcement of Postdoctoral Researchers - 2nd Cycle" (MIS-5033021), implemented by the State Scholarships Foundation (IKY).