

Review of emissions from fuel operated auxiliary heaters



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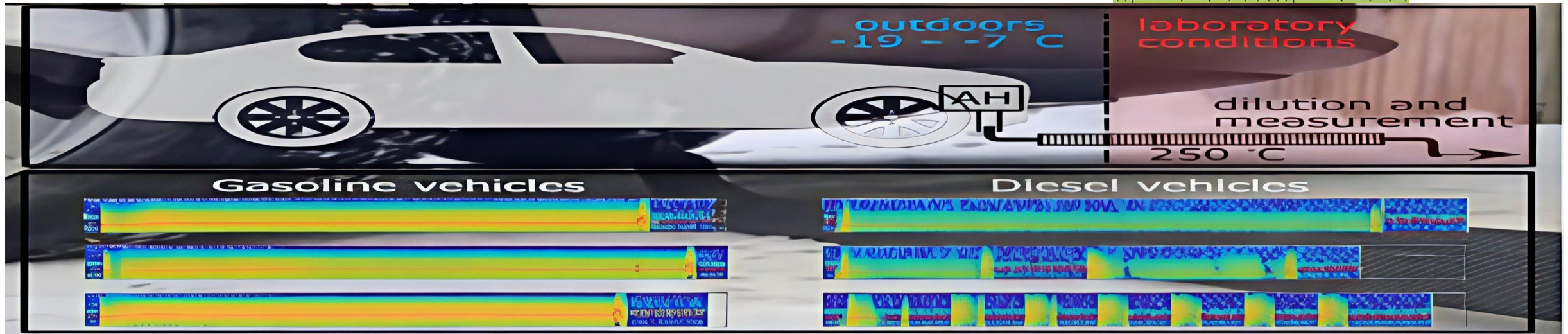
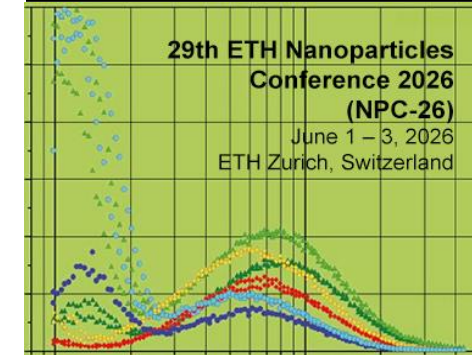
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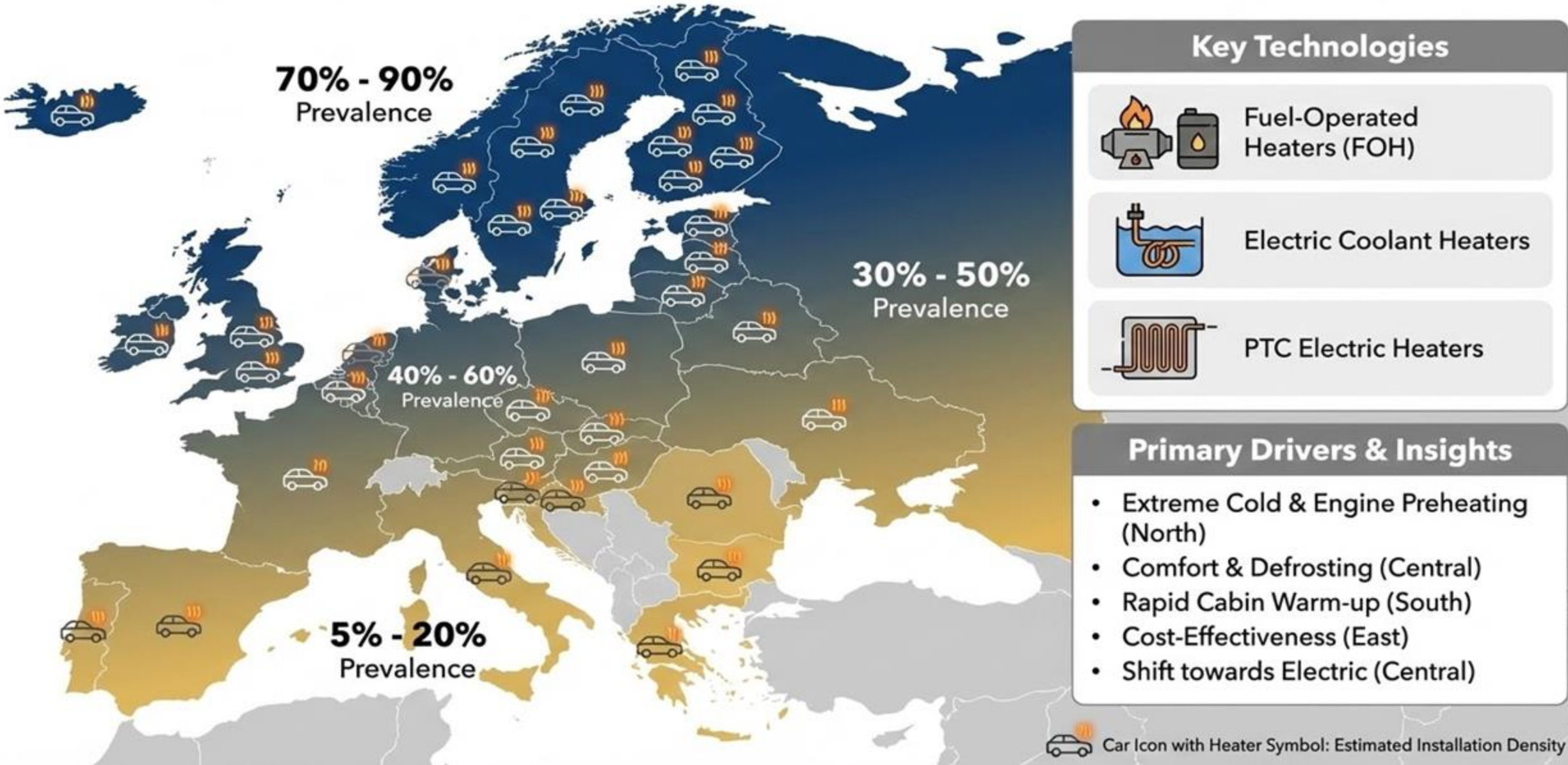
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Installed Auxiliary Heaters in European Cars



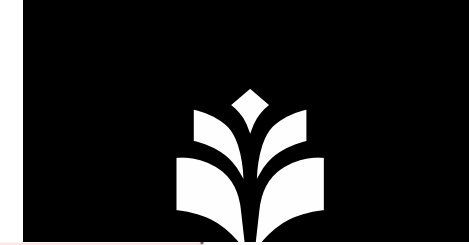
Source: Alexander Bergman, Graz University of Technology

Why are we interested in auxiliary heaters?

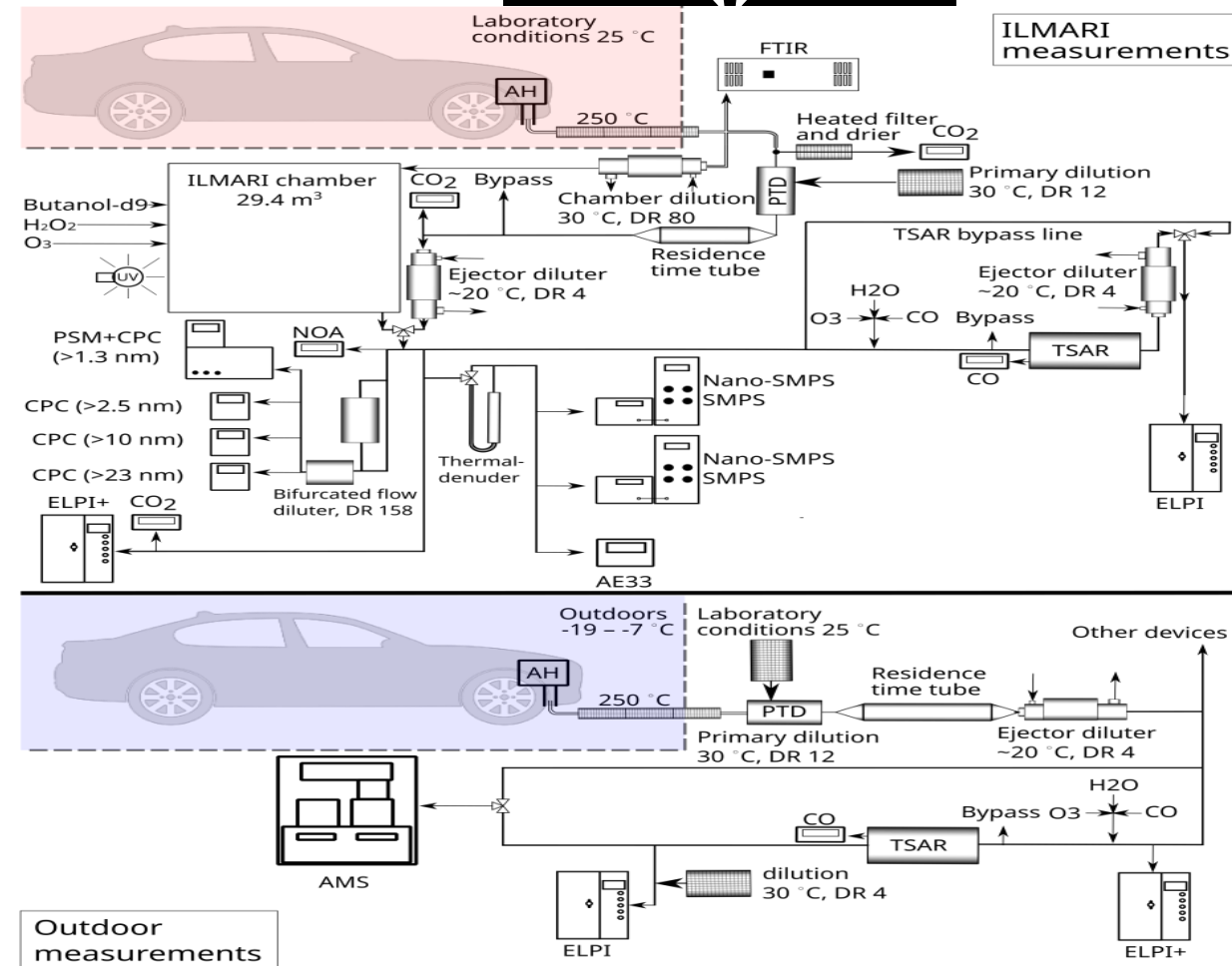


- Vehicle engine emissions are regulated and monitored (euro standard etc.) to reduce harmful effects of emissions
- Currently AH emissions are not counted as part of regulated vehicle emissions and have separate less strict emission limits (for NO_x, CO, THC)
- Notably many newer vehicles (especially diesel) need to use AH constantly during driving in cold weather

How were AH emissions measured?



- One measurement campaign consisting of outdoor measurements in Finnish winter conditions (-19...-7 °C) for 6 vehicles (3+3 diesel/gasoline)
- Further measurements in laboratory conditions for 2 of 6 vehicles with atmospheric aging chamber at ILMARI laboratory to measure secondary particles
- Also chase measurements during winter for determining effect of preheating to driving emissions



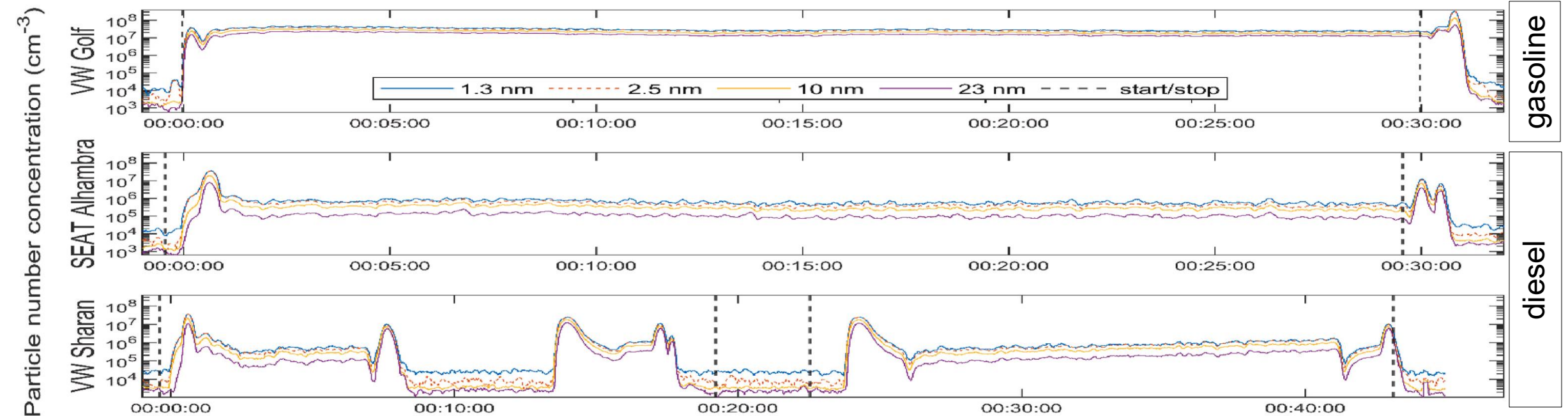
Oikarinen, H., et. al. (2025). The role of fuel and environmental conditions on the amount and composition of primary, fresh, and aged aerosol emissions originating from diesel- and gasoline-operated auxiliary heaters of passenger cars. Atmospheric Measurement Techniques, <https://doi.org/10.5194/amt-18-4271-2025>

Particle number concentrations



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- Data from CPC battery (1.3, 2.5, 10 and 23 nm cut-off diameters)
- Notable spikes in PN during beginning/end parts of heating cycle
- Gasoline AHs have higher stable period emissions compared to diesels
- ON-OFF switching observed in some AHs





Comparing AH EFs against driving emissions

- We compared PN_{23} emitted during preheating to maximum regulation values (Euro 6) for emissions per kilometer of driving
- Assuming 23 km drive (WLTC-length) after preheating, then 81%/46% of total PN emissions is produced by AH for gasoline and diesel AHs respectively
- 30min preheating produces emissions comparable to dozens of driven kilometers
- → AHs are major source of primary aerosol emissions from Euro 6 vehicles unless vehicle does not meet particle emission standards

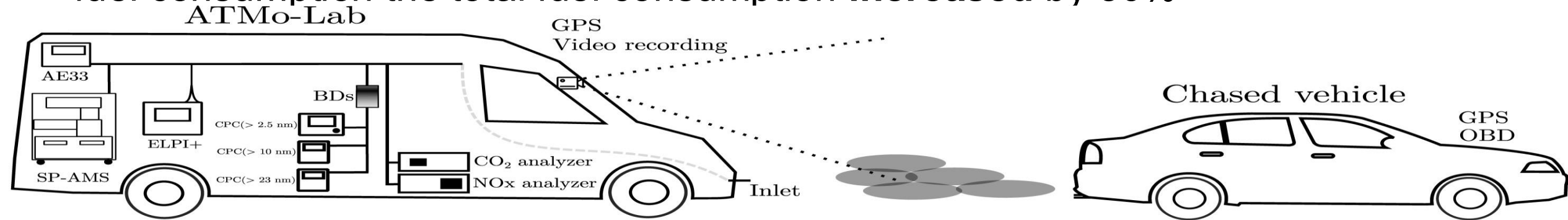
Table 2. Comparison of emissions of the number of non-volatile particles larger than 23 nm. The bold values represent the baseline assumption (driving emissions equal to the limit in European regulation). Other values represent alternative scenarios with 0.001, 0.01, 0.1, or 10 times the limit value for driving emissions.

Fuel	$10^{12}/kg_{fuel}$ emitted by the AH	$10^{12}/\%h$ (typical heating time) emitted by the AH	$10^{12}/km$ emitted by driving	$10^{12}/23.25 km$ (WLTC length) emitted by driving	Proportion of particles emitted by the AH (%)	Driving length emitting equal number of particles to the AH (km)
Gasoline	230	59	0.0006	0.014	99.98	98 000
			0.006	0.14	99.8	9 800
			0.06	1.4	98	980
			0.6	14	81	98
			6	140	30	9.8
Diesel	48	12	0.0006	0.014	99.9	20 000
			0.006	0.14	99	2 000
			0.06	1.4	90	200
			0.6	14	46	20
			6	140	7.9	2.0

Effect of preheating to driving emissions



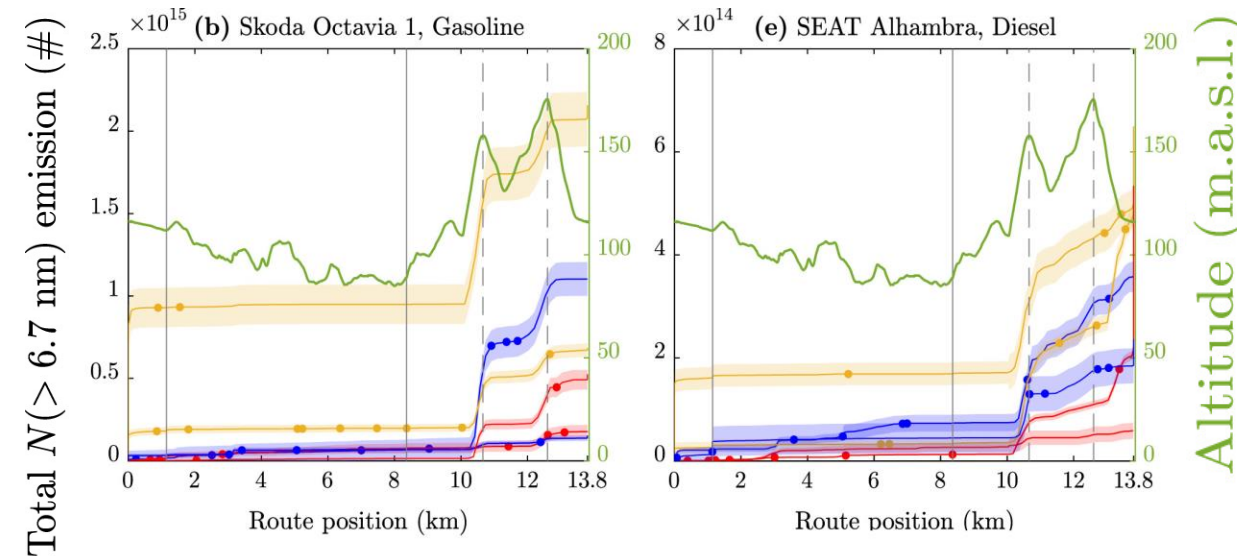
- Vehicles were driven along 13.8 km route in Finnish winter conditions (-28...-10 °C) to test how much preheating affects driving emissions & fuel consumption
- Nonsignificant reduction in fuel consumption by preheating. Accounting for AHs fuel consumption the total fuel consumption **increased** by 30%



Effect of preheating to driving emissions



- No observable reduction in PN
- Only slight reduction in PM, BC, and NOx emissions
 - Reductions mostly offset by preheating emissions
- Potential for greater reduction in driving emissions (cold vs hot starts) was observed
 - AH does not warm engine's aftertreatment system (NOx catalysts, particle filters) which does not work properly when cold (Roberts et al., 2014; Meng et al., 2024)



Olin, M., et. Al. (2023). Engine preheating under real-world subfreezing conditions provides less than expected benefits to vehicle fuel economy and emission reduction for light-duty vehicles. *Applied Energy*, <https://doi.org/10.1016/j.apenergy.2023.121805>

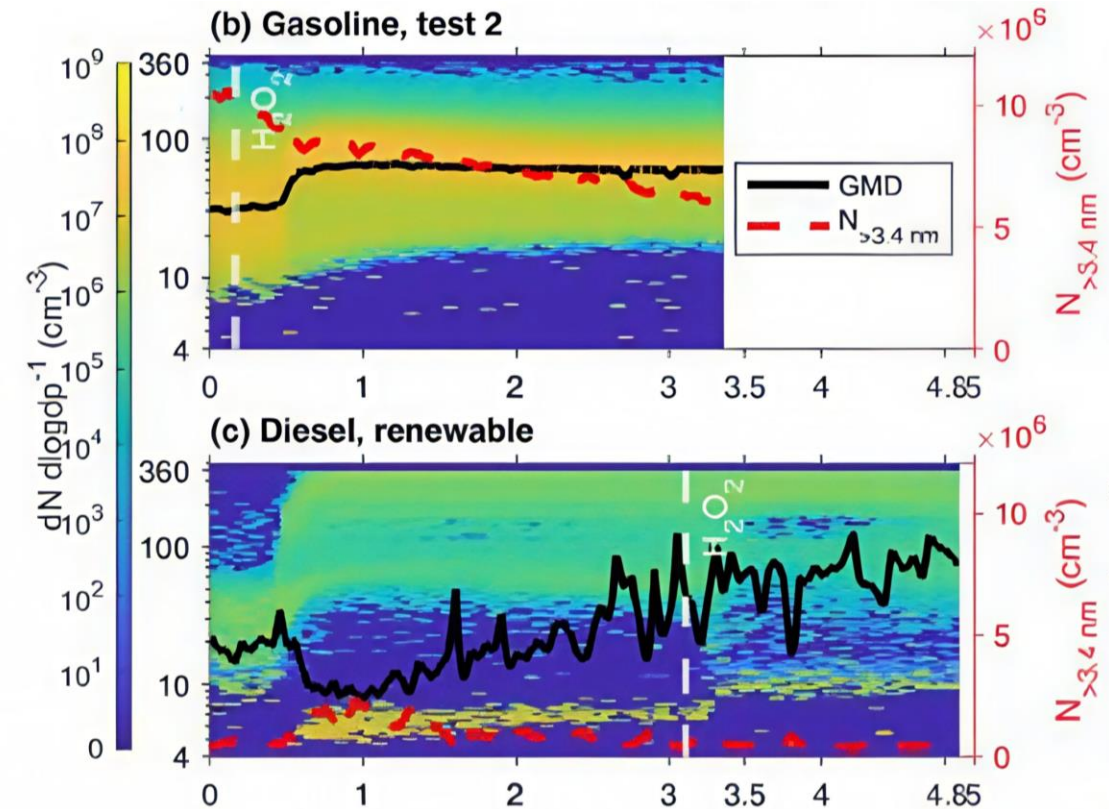
Roberts, A., et. al. (2014). Internal combustion engine cold-start efficiency: A review of the problem, causes and potential solutions. *Energy Conversion and Management* <https://doi.org/10.1016/j.enconman.2014.03.002>

Meng, Z., et. al. (2024). An assessment of the application of catalyst preheating prior to engine cold start to improve the filtration performance of CDPF on particulate emissions. *Process Safety and Environmental Protection* 182, 345–356. <https://doi.org/10.1016/j.psep.2023.12.007>

Secondary aerosol formation



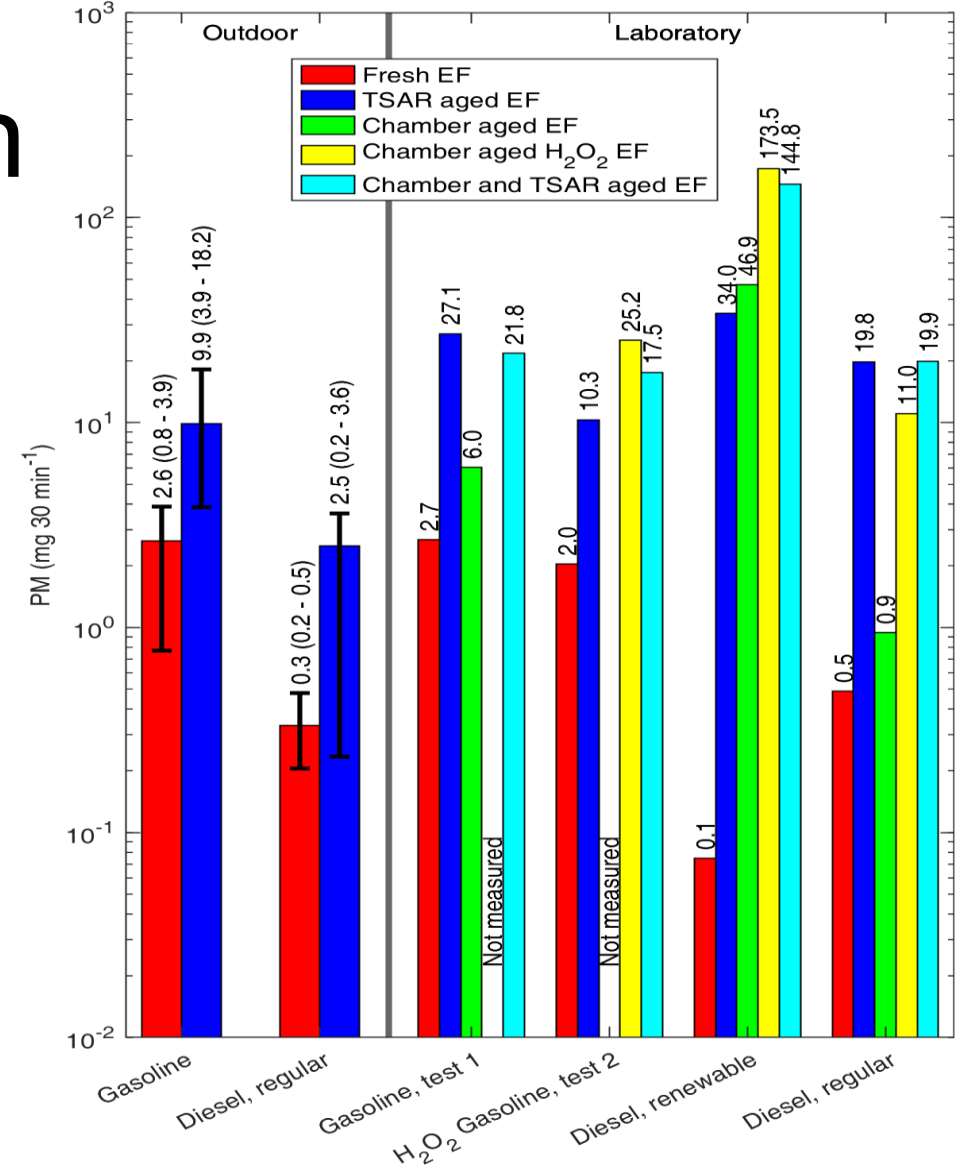
- Exhaust was aged both in ILMARI chamber for ~4 h in atmospherically relevant conditions and with oxidation flow reactor



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Secondary aerosol formation

- Secondary particles forms most of total PM released from AH
 - PM doubles when sample is aged in ILMARI without additional oxidation
 - Under more extreme aging conditions (either H₂O₂ injection or OFR) between 10 to 20-fold increase in PM
 - Low primary EF does not always correspond to low aged EF (Renewable diesel)
 - Secondary particle formation should be accounted for when measuring particle emissions from AHs
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Effect of operating temperature



- EFs from same AHs were compared between outdoor and indoor operating temperatures
- Generally, AH emissions were lower when operated at low temperatures (-19 to -7 °C compared to 25 °C)
- Current type approval tests for AHs specify temperatures of +10 to +30 °C

	PN	PM fresh	PM aged	BC	NOx
Effect of low operating temperature	↓	≈	↓	↓	↑

Conclusions



- AH emissions should be included in fleet level emission estimates at least in areas with wide scale use (Northern, and Central Europe, North America, East Asia)
- AH emissions need particle emission limits comparable to those for engine emissions, which should be tested in conditions relevant to actual use
- Despite that preheating has benefits (improve engine lifetime, passenger comfort, and enable engine ignition at low temperatures) and should not be disregarded entirely
- Possible improvements to AHs could be use of emission aftertreatment devices comparable with those currently used for mitigation of engine emissions or use of electric heaters
 - For example. integrating AHs exhaust line to engine exhaust line could both preheat the aftertreatment system and reduce AH emissions

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full dissertation on this topic is available:

Oikarinen, H. (2025) Emissions from fuel operated auxiliary heaters of passenger cars [Doctoral dissertation, University of Eastern Finland], Report series in aerosol science, 303, <http://urn.fi/URN:ISBN:978-952-7507-82-7>