# Real-Driving Emissions test programme results from a Plug-in Hybrid Electric Vehicle (PHEV)

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AECC
ASSOCIATION FOR EMISSIONS CONTROL BY CATALYST

# Association for Emissions Control by Catalyst (AECC)

AECC members : European Emissions Control companies

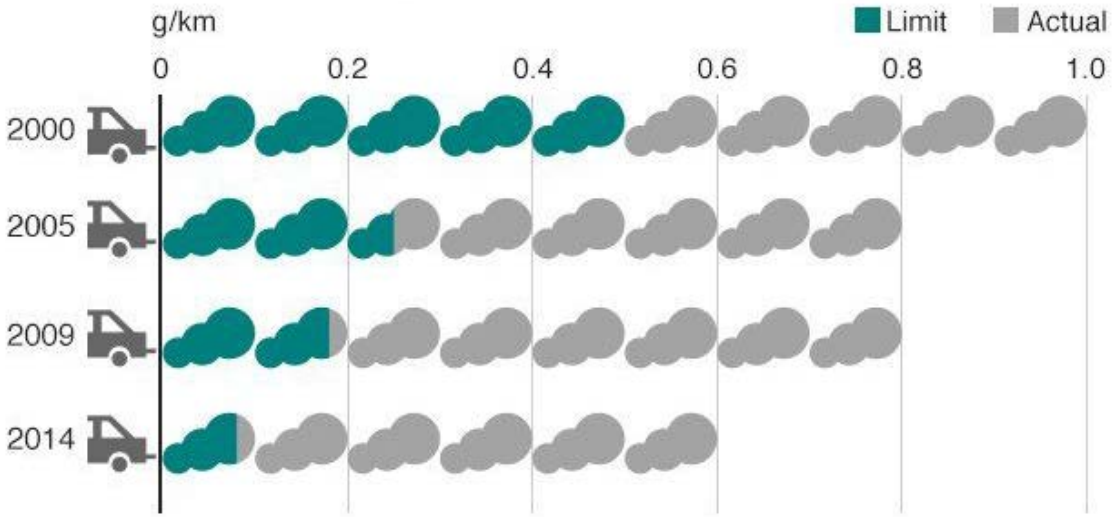

- Exhaust emissions control technologies for original equipment, retrofit and aftermarket for all new cars, commercial vehicles, motorcycles and non-road mobile machinery

# Content

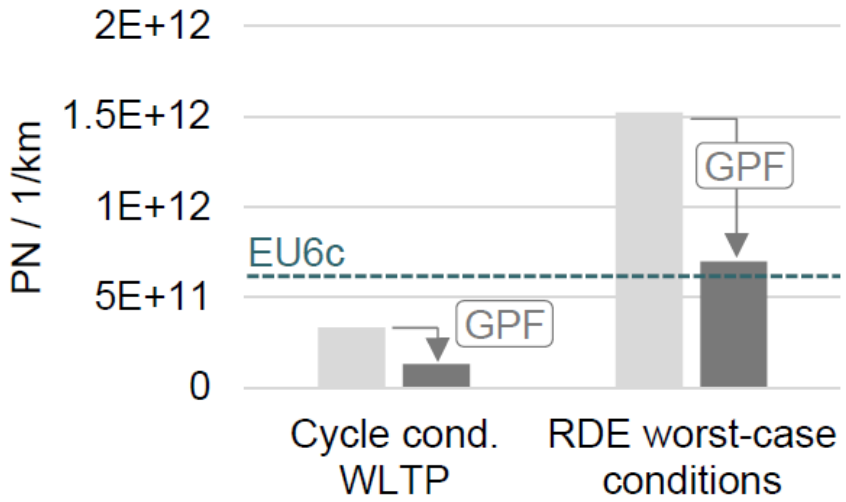
- Context
- PHEV test programme set-up
- Real-Driving Emissions (RDE)
  - PN without and with Gasoline Particulate Filter (GPF)
  - NOx
  - $CO_2$
- Conclusions & outlook

# EU RDE legislation

Aim is to close the emissions gap between lab and real-world



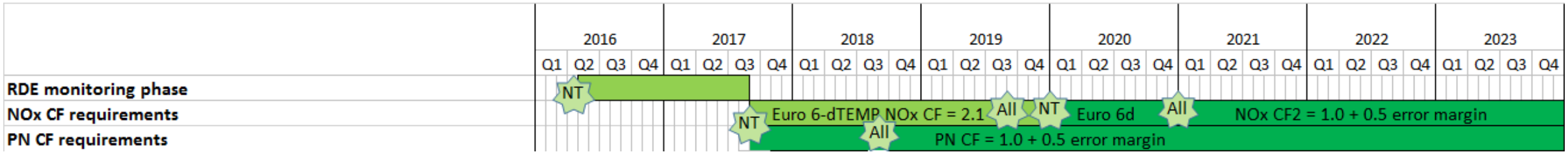

*Source: average on-road diesel NOx emissions, the ICCT*




*Source: Gasoline Particulate Filters Market and Technology Trends and their Impact on Calibration, FEV, SIA powertrain 2017*

# EU RDE legislation

- Not To Exceed limit (NTE) = Euro 6 limit x Conformity Factor (CF)
  - CF defined for NOx and PN
  - CF applies to urban part and total trip




- RDE boundary conditions define normal driving
  - Route specifications
  - Ambient conditions
  - Driving dynamics
- RDE legislation being finalised (4th legislative package under development)

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# Test programme set-up

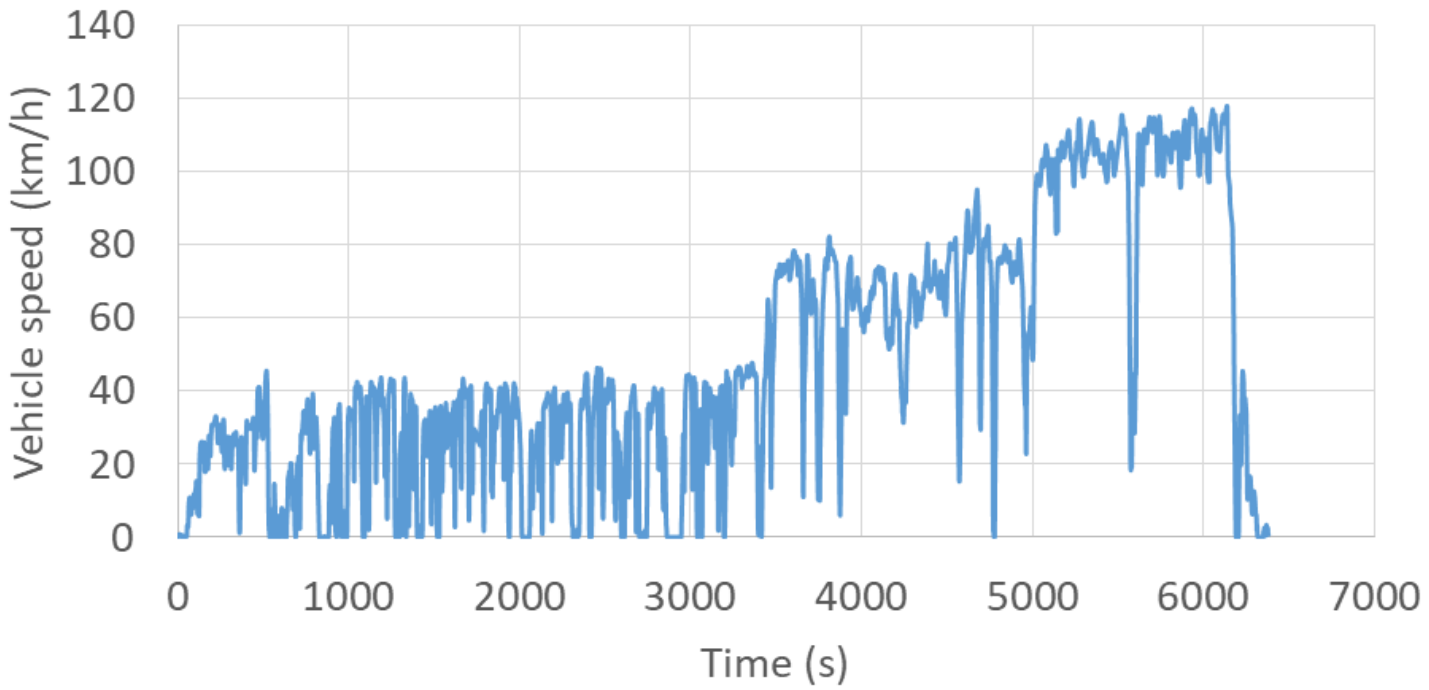
- Objective: measure the real-world behaviour of a market-representative Plug-in Hybrid Electric Vehicle (PHEV)
- Vehicle selected
  - C-segment PHEV with 1.5l class GDI engine
  - Euro 6b certified
  - Rental car ~10 000 km mileage
  - 4 Driving modes: Electric, Hybrid, Charge, and Sport
  - Official electric range: 50 km
- Emissions of PHEV are compared to similar GDI vehicle tested in 2016 test programme*

* Real-World Emissions Measurements of a Gasoline Direct Injection Vehicle without and with a Gasoline Particulate Filter, Demuynck, et al., SAE 2017-01-0985

# Test programme set-up

- Measurement details
  - At Ricardo (UK)
  - All tests on market E5 fuel
  - HORIBA PEMS OBS one: CO, $CO_2$, NOx and PN
  - Raw emissions data for urban part of RDE trip and for total RDE trip are presented, no post-processing
- Test Matrix
  - All 4 driving modes (Electric, Hybrid, Charge, and Sport)
  - Variation in initial battery State of Charge (SOC)
  - 2 tests repeated with a coated Gasoline Particulate Filter (GPF) retrofitted

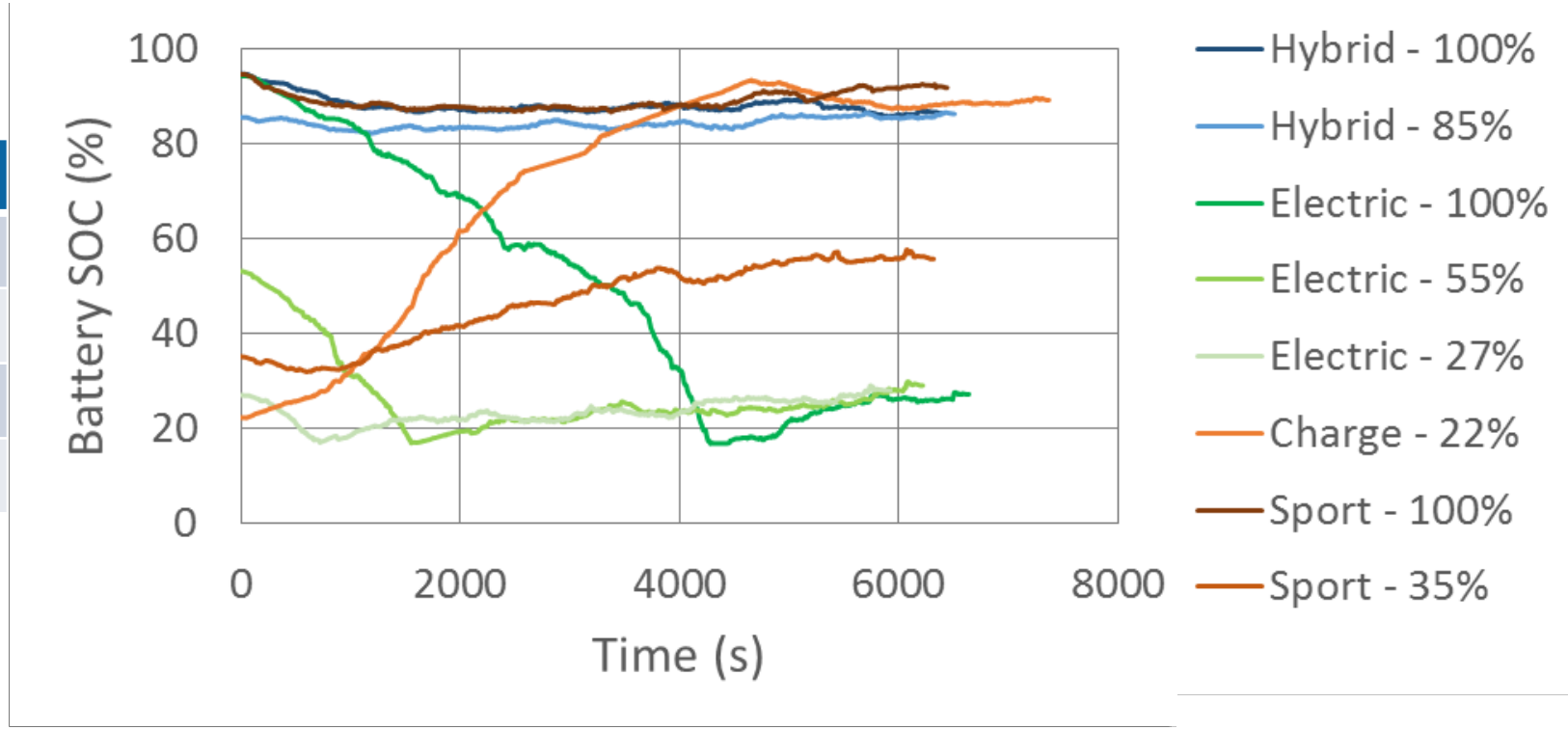
# RDE route and speed profile

# Overview of on-road measurements

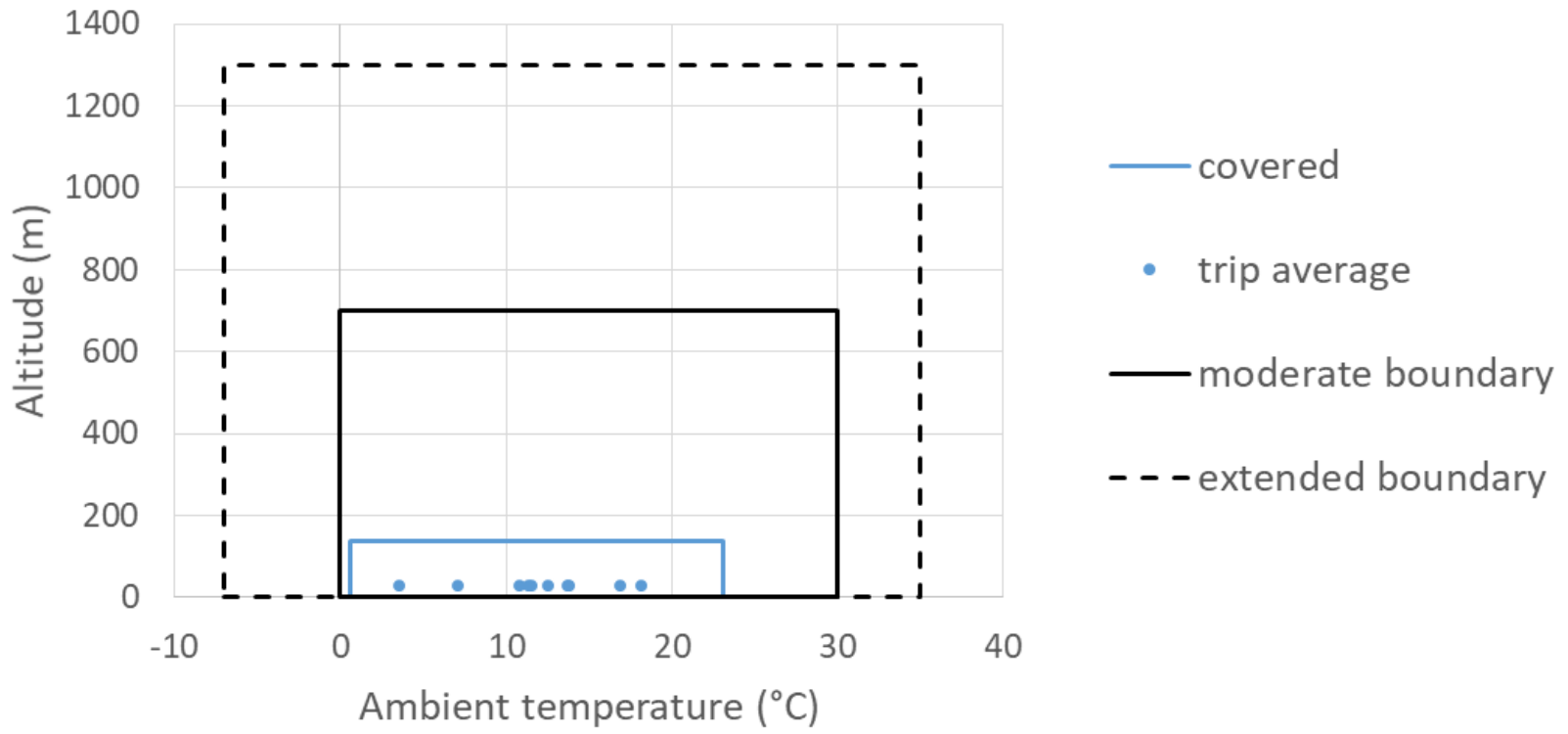
- 8 combinations of driving mode and initial battery State of Charge (SOC)

| SOC | Electric | Hybrid | Charge | Sport |
|---|---|---|---|---|
| 100% | 1x | 1x | - | 1x |
| 85% | | 1x | | |
| 55% | 1x | | | |
| 25% | 1x | | 1x | 1x |



# Overview of on-road measurements

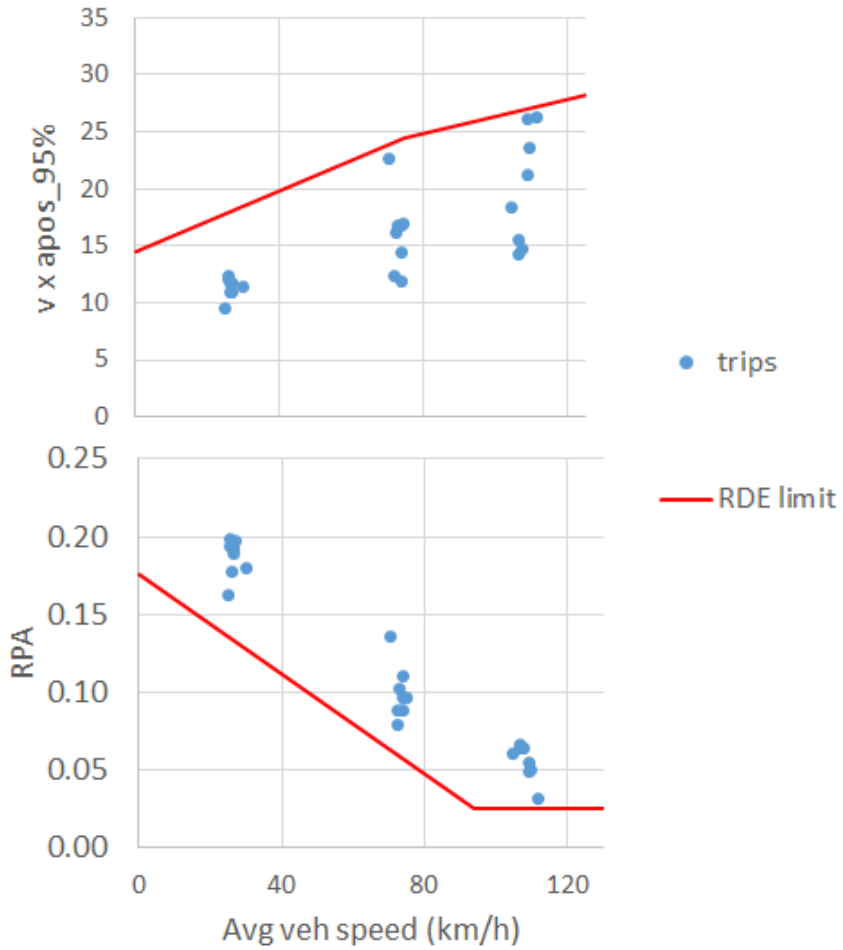
- RDE data within moderate environmental boundary conditions



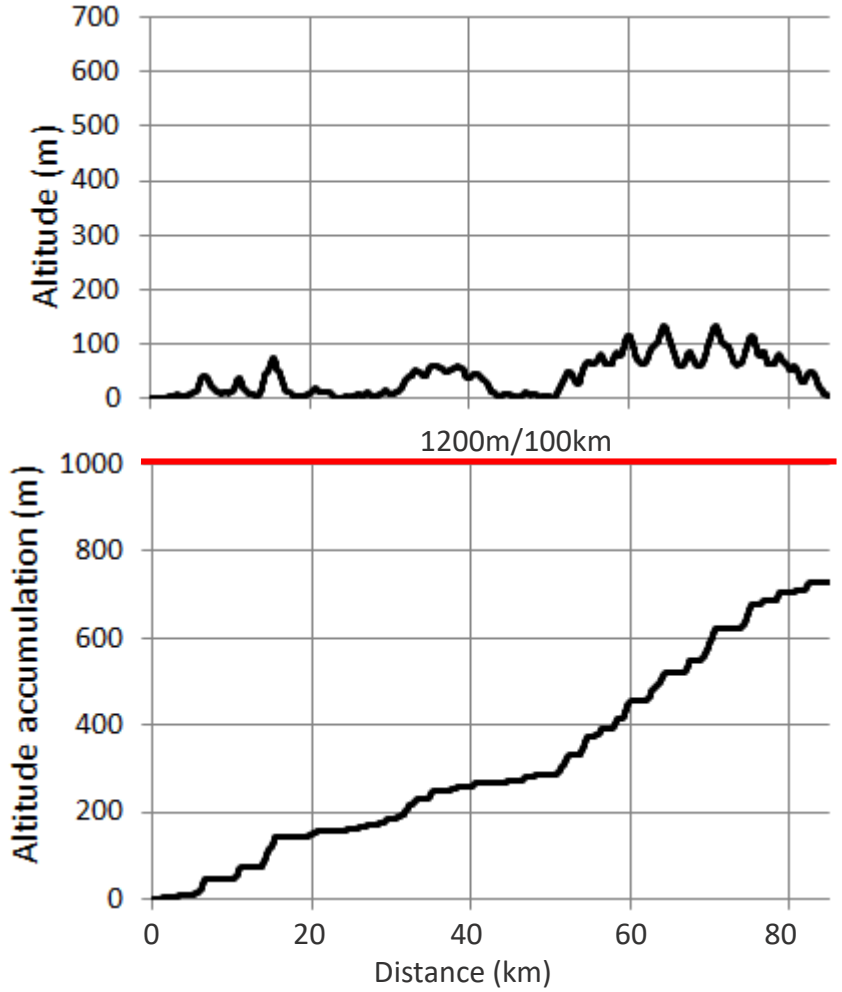
# Overview of on-road measurements

- RDE data within dynamic boundary conditions

Excess or absence of driving dynamics




Altitude accumulation



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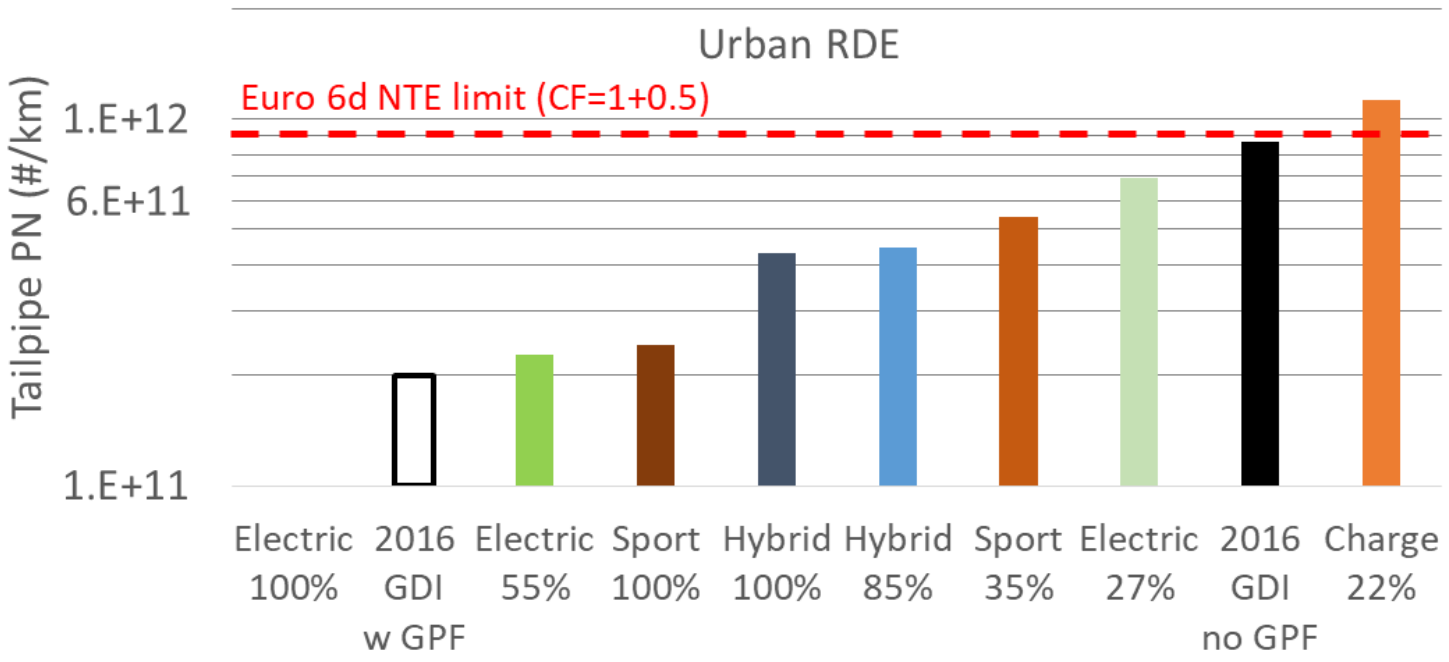
# Urban RDE PN emissions




- In Electric mode with fully-charged battery, urban part entirely run electric: zero tailpipe PN emissions in urban
- In Charge mode with empty battery, high power demand on IC engine: highest PN emissions
- PN emissions of all other tests fall in between emissions of the 2016 reference GDI with GPF and without GPF

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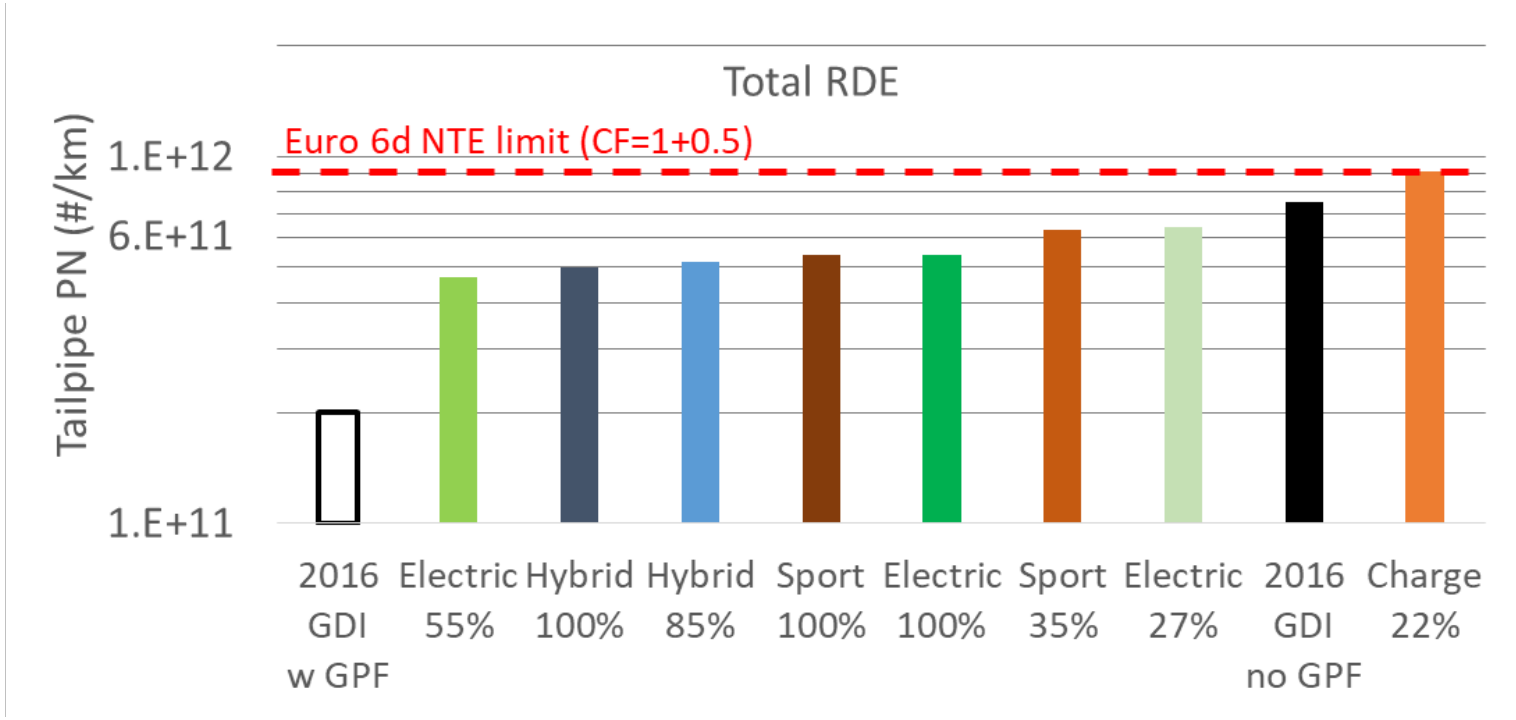
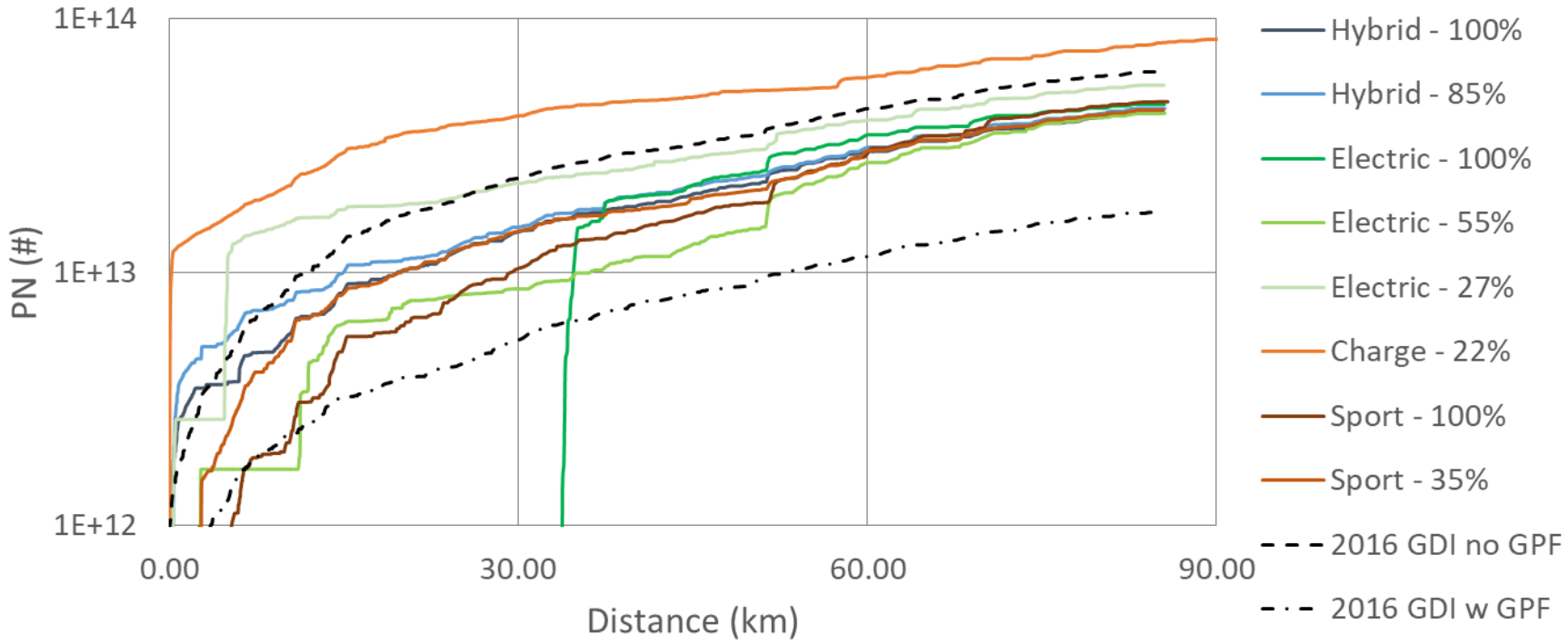
# Total RDE PN emissions




- All total RDE PN emissions below Euro 6d NTE limit
- Electric mode with fully-charged battery: PN emissions reach same level as other modes although IC engine operates only during last part of the trip

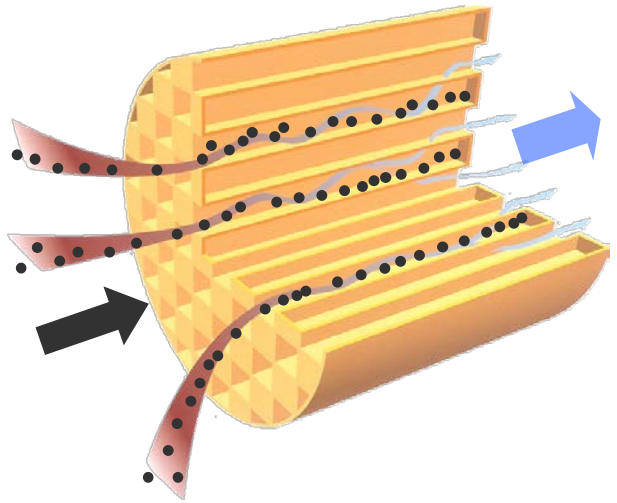
# Cumulative PN emissions during RDE trip



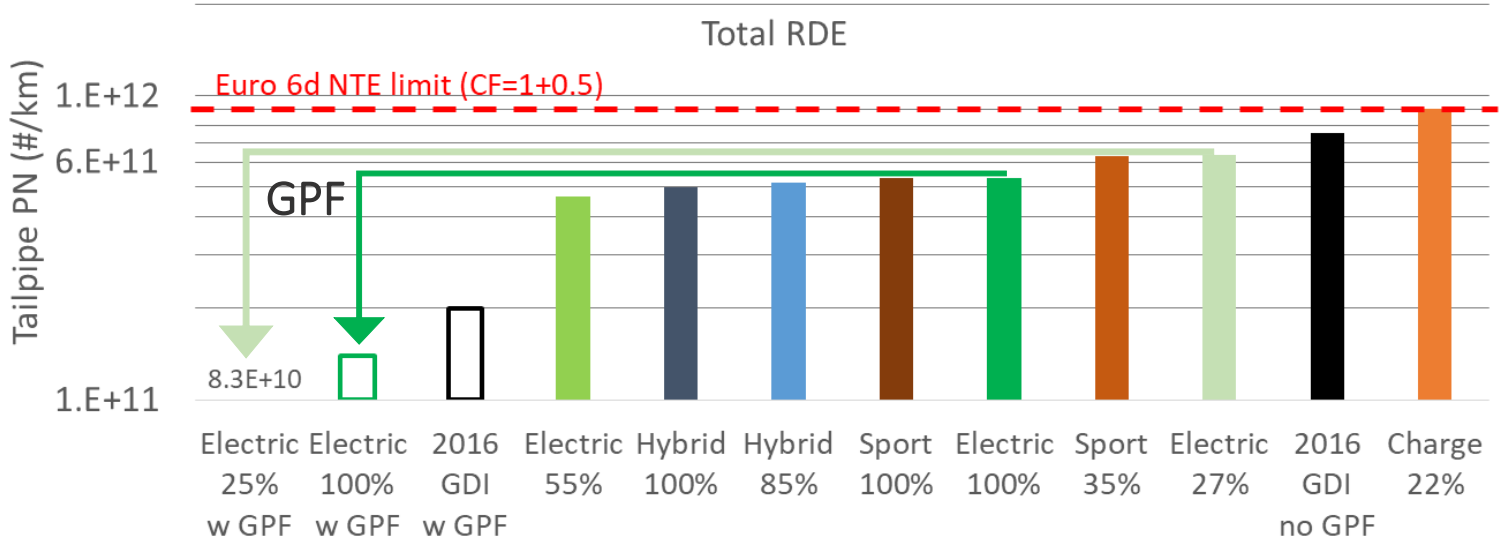

- Shows impact of cold IC engine start. PN peaks:
  - at start for Charge mode with empty battery because of high power demand
  - in middle of trip for the Electric mode with fully-charged battery because of high power demand. Overall same PN level as other modes

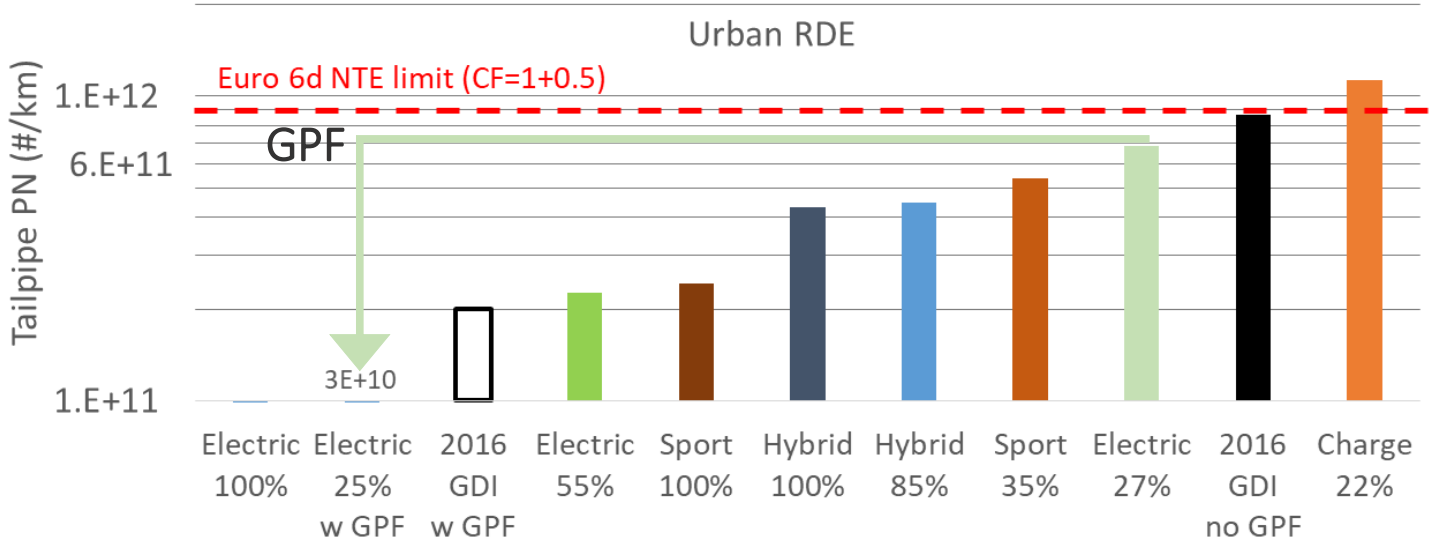
# RDE PN emissions with Gasoline Particulate Filter (GPF)

- Second (underfloor) TWC of PHEV replaced with coated GPF

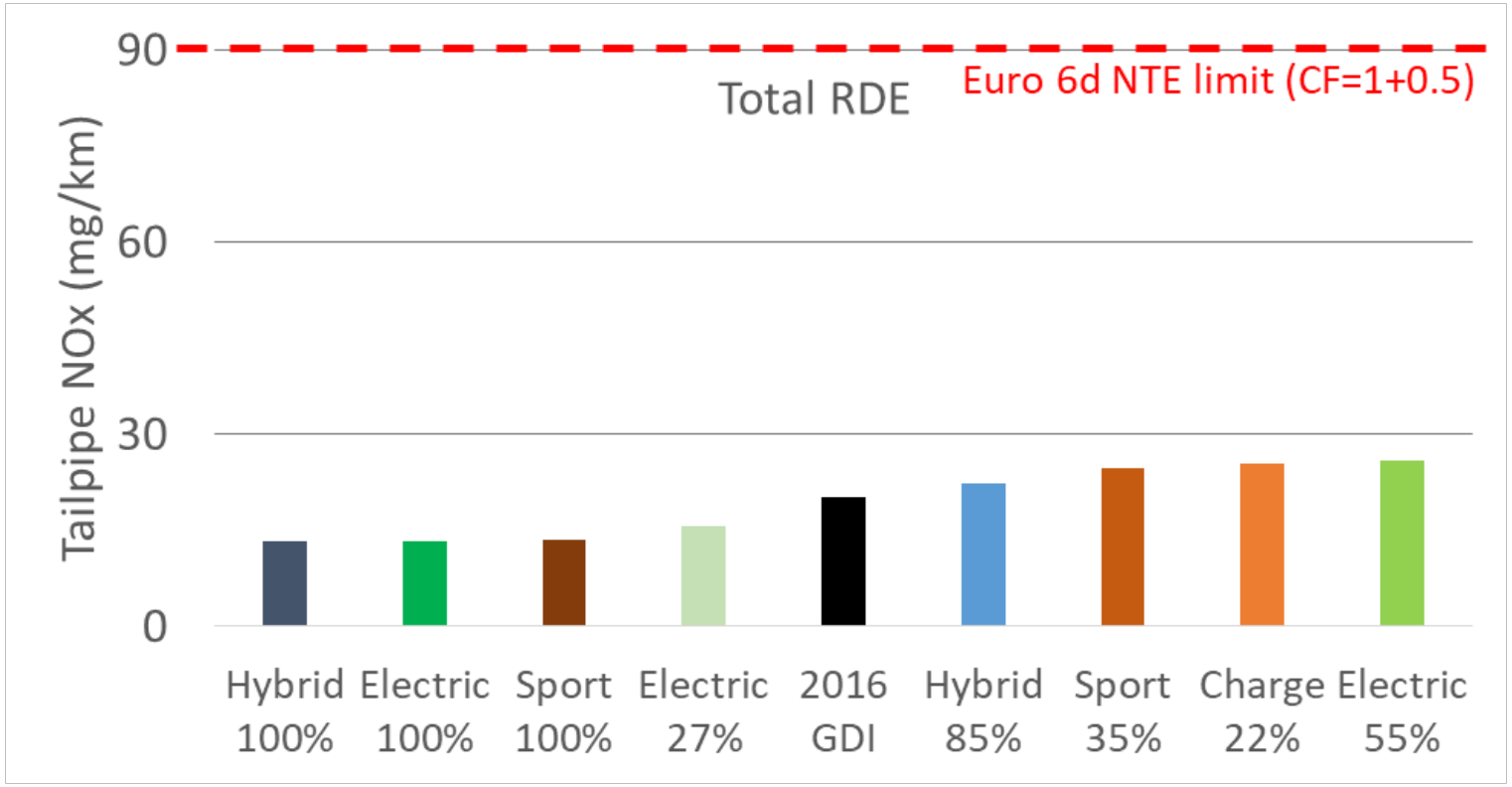


- Tests in electric mode repeated
- High PN spikes observed at ICE cold-start are well controlled by efficient GPF



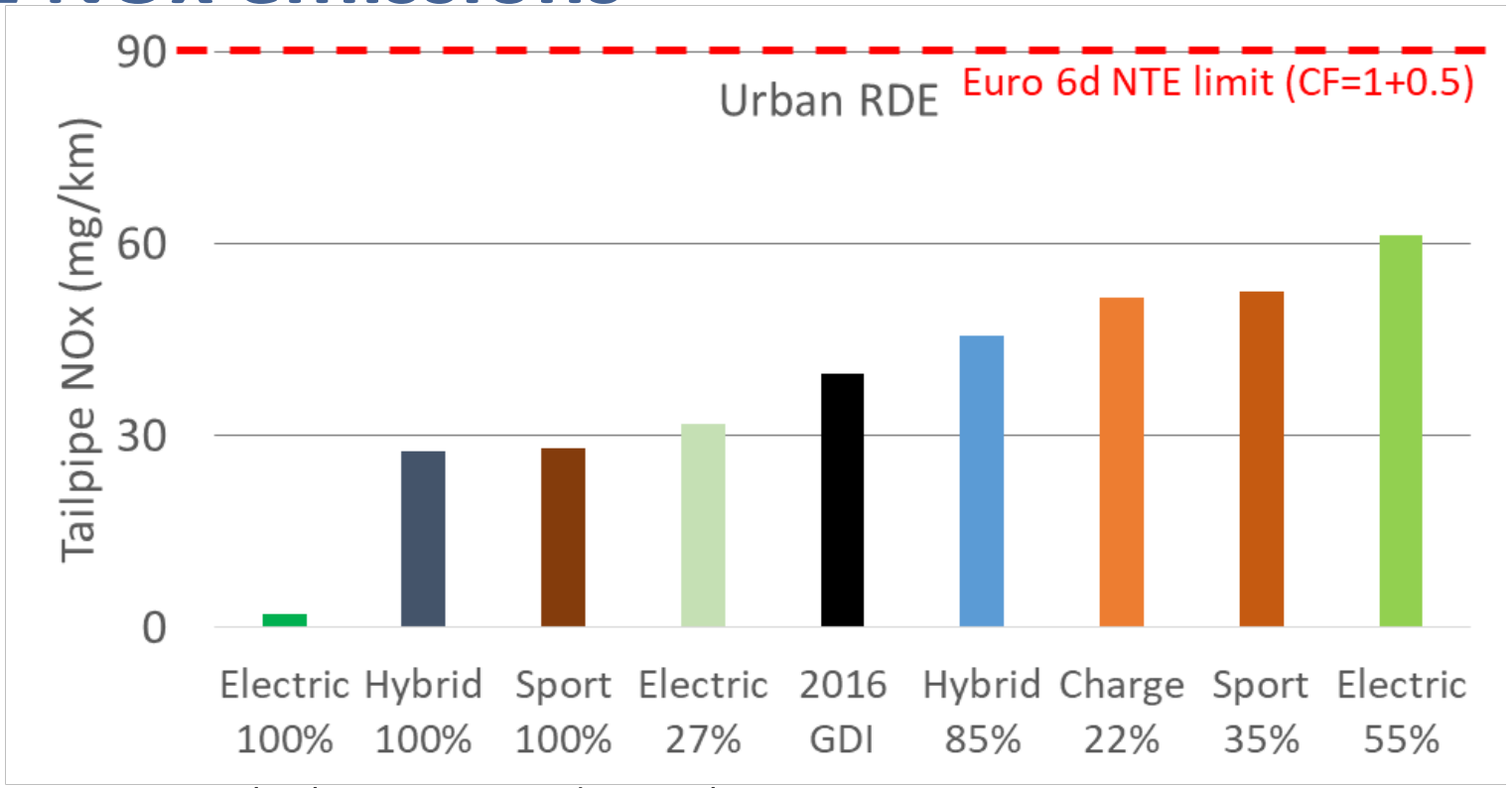



# Total RDE NOx emissions



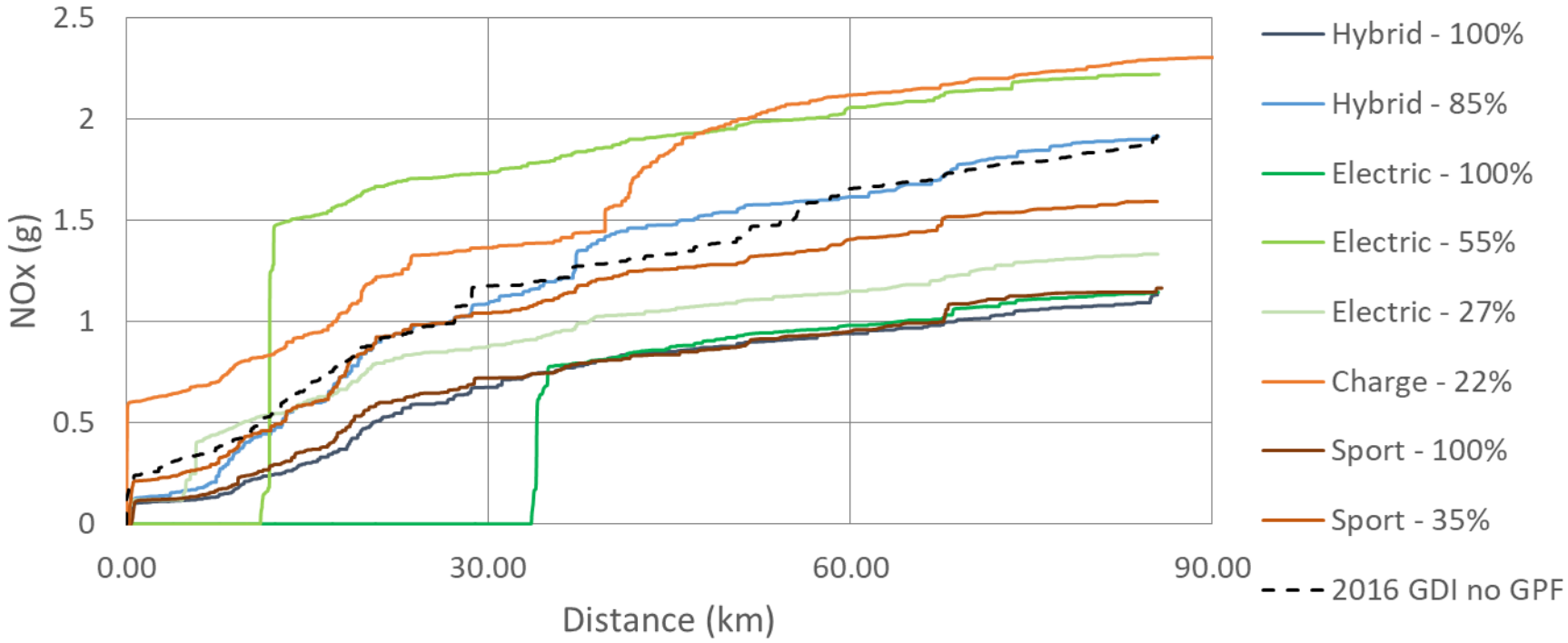

- All total RDE NOx emissions significantly below Euro 6d NTE limit
- Reference GDI result is in the middle of PHEV total NOx range
- Total NOx emissions of PHEV with fully-charged battery are consistently the lowest

# Urban RDE NOx emissions



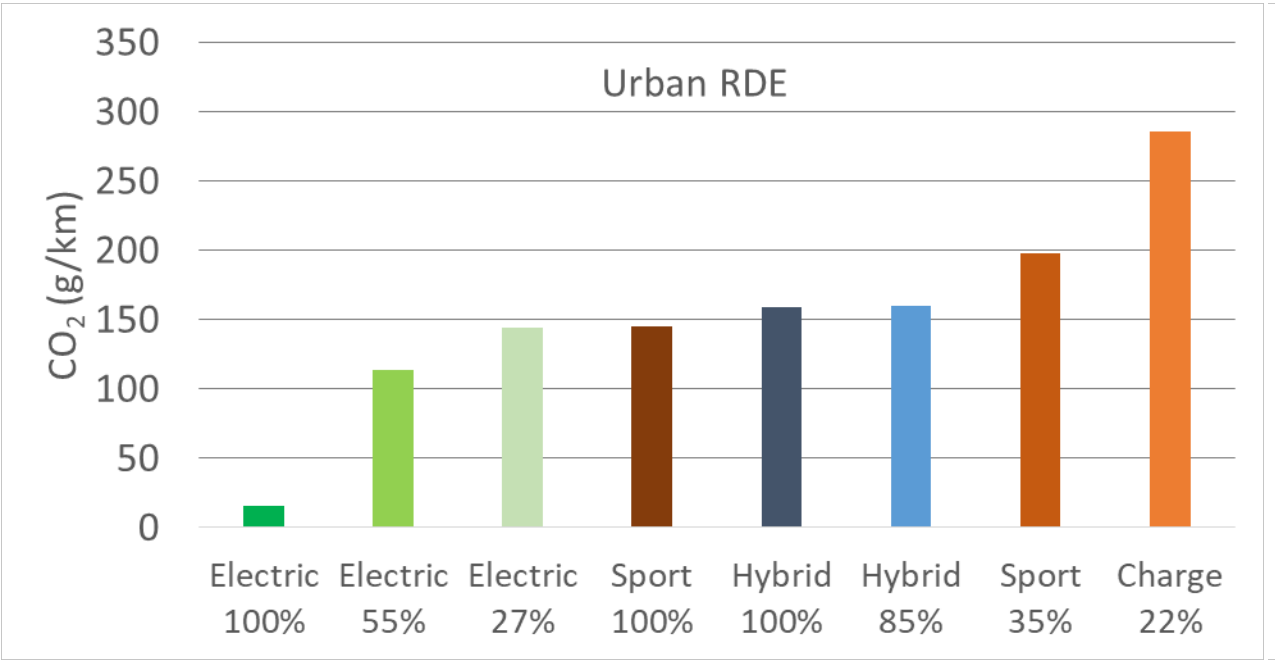

- All urban NOx emissions below Euro 6d NTE limit
- In Electric mode with fully-charged battery, urban part entirely run electric: zero NOx in urban
- Reference GDI result is in the middle of PHEV urban NOx range
- Urban NOx emissions of PHEV with fully-charged battery are consistently the lowest
- Highest urban NOx emissions in Electric mode with 55% battery SOC

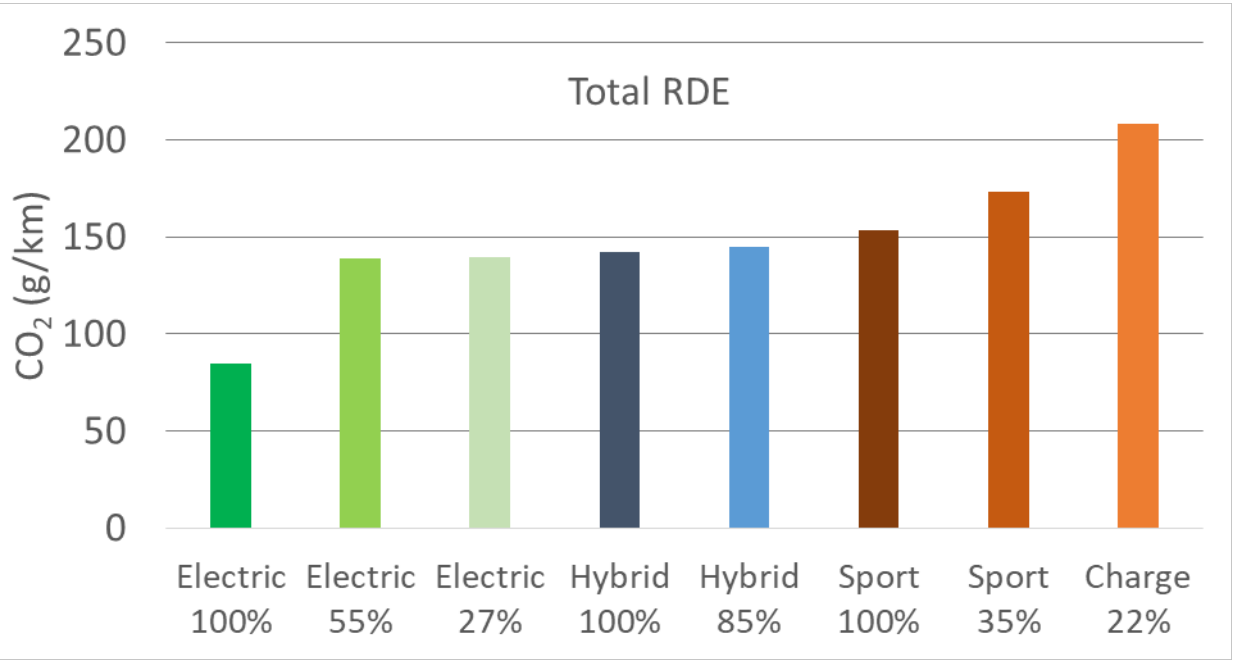
# Cumulative NOx emissions during RDE trip




- Shows impact of cold IC engine start (with cold catalyst). NOx peaks:
  - at start of RDE trip for Charge mode with empty battery
  - in middle of urban part for Electric mode with 55% battery SOC – results in highest urban RDE NOx
  - in middle of RDE trip for Electric mode with fully-charged battery – overall similar NOx level as other fully-charged tests

# Urban and Total RDE $CO_2$ emissions




- More straightforward effects than for PN and NOx emissions
  - Lowest $CO_2$ in Electric mode and increasing with decreasing initial battery SOC
  - Highest $CO_2$ when the IC engine charges the battery in Sports and Charge mode
- Electric range achieved during RDE trip: ~35 km

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# Conclusions & outlook

- AECC PHEV test programme
  - Tested 1 Euro 6b C-segment vehicle
  - Raw data is shown, without RDE post-processing (still under review in RDE package 4)
- PN and NOx Real-Driving Emissions
  - Zero-emission capability in urban RDE is ensured in electric mode when battery has been fully charged
  - NOx results are all below Euro 6d NTE limit
  - On tested PHEV, timing of ICE cold-start during RDE trip strongly impacts NOx and PN emissions
  - High PN spikes observed at ICE cold-start are well controlled by efficient GPF
  - Well integrated exhaust aftertreatment is required to control emissions under all RDE conditions, including thermal management
- Outlook
  - Investigate going to the boundaries of RDE (high dynamics, low ambient temperature)
  - Confirm benefit of GPF for removal of sub-23 nm particles

# THANK YOU!

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