



Real World Emissions and Control: Use of PEMS on Heavy Duty Vehicles to Assess the Impact of Technology and Driving Conditions on Air Quality in Urban Areas

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- **Introduction**
- Test Approach
- PEMS Results
- Conclusions

Introduction

- Regulators and local authorities have sought to reduce emissions from vehicles in order to improve air quality, through measures such as:
 - Legislated emissions limits for new engines and vehicles
 - Traffic management
 - Enforced emissions reduction technologies
- Standardised test procedures and laboratory conditions are used to demonstrate reduced emissions
- **But how effective are these measures in the real-world?**



**Emissions
reduction
measures**





Introduction & Objectives

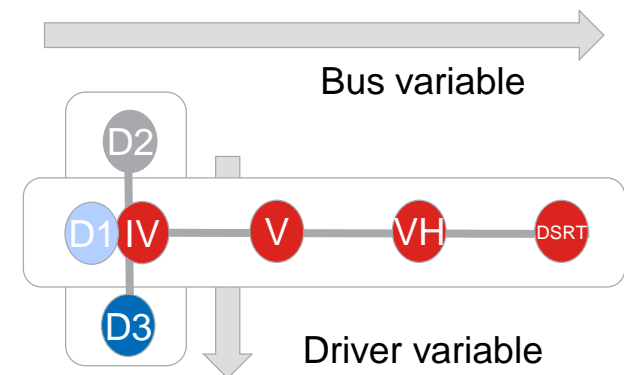
- Ricardo has conducted real world emissions evaluations using Portable Emissions Measurement Systems (PEMS), on heavy duty vehicles in the city of Brighton, UK:
 1. Euro IV, V and V-hybrid buses, and a Euro III bus retrofitted with a combined DPF and SCR system, for Brighton and Hove Bus and Coach Company
 2. Iveco Ecostralis 500 E6 truck, certified to Euro VI emissions
- Presentation objectives:
 1. Methodology for using PEMS to measure **mass** of NO_x emitted throughout operation in urban areas
 2. Effectiveness of technologies achieving Euro IV, V, VI emissions regulations and hybridisation on overall emissions and air quality in local hotspots
 3. Impact of traffic and real world factors on HDV impact on air quality in local hotspot



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Bus Supply and Preparation

- Test Vehicles:
 - Supplied by Brighton & Hove Bus and Coach Company
 - From the in-use fleet and taken out of service for 2-3 days
 - 4 double decker buses:
 - Scania Euro III DPF-SCR retrofit (**D-S-RT**)
 - Scania Euro IV (**IV**)
 - Volvo Euro V (**V**)
 - Volvo Euro V (Hybrid) (**VH**)
 - All vehicles were fitted with diesel particulate filters (DPFs)
- Vehicle Preparation
 - Loaded with ballast to represent 70% max loading => representative load on the engines, and realistic emissions control system operating temperatures
- Comparisons
 - Bus to bus comparisons were made (4 buses)
 - Driver-to-driver variations were studied on Euro IV bus only
 - D1 (Dynamic), D2 (Considered), D3 (Normal; 2nd driver)





Four buses used different combinations of emissions control devices:
Exhaust gas recirculation (EGR); Oxidation catalyst (DOC); particle filter (DPF); Urea DeNOx (SCR)

Euro IV Bus – Fleet N° 712



Engine
With EGR
 9 litre
 5 cylinder
 201kW

DOC
 (control CO,
 HC; produce
 NO₂)

DPF
 (use NO₂ for
 passive
 regeneration)

No SCR

Euro V Bus – Fleet N° 459



Engine
 9 litre
 6 cylinder
 193kW

DOC
 (control CO,
 HC; produce
 NO₂)

DPF
 (use NO₂ for
 passive
 regeneration)

SCR
 (use urea (aq)
 for NOx
 reduction;
 50:50 NO &
 NO₂ for fast
 reduction)

No EGR

Euro V Hybrid Bus – Fleet N° 442



Engine
 4.76 litre
 4 cylinder
 161kW
 E-machine
 120kW

DOC
 (control CO,
 HC; produce
 NO₂)

DPF
 (use NO₂ for
 passive
 regeneration)

SCR
 (use urea (aq)
 for NOx
 reduction;
 50:50 NO &
 NO₂ for fast
 reduction)

No EGR

Euro III D-S-RT Bus – Fleet N° 633



Engine
 9 litre
 6 cylinder
 191kW

DOC
 (control CO,
 HC; produce
 NO₂)

DPF
 (use NO₂ for
 passive
 regeneration)

SCR
 (use urea (aq)
 for NOx
 reduction;
 50:50 NO &
 NO₂ for fast
 reduction)

AMOX

No EGR



PEMS Measurements and Data Logged

GPS (not to scale) enables determination of road speed, latitude, longitude, & altitude



Exhaust flow (to allow calculation of emissions masses from concentrations) measured with pitot tube

PEMS measurements performed to a strict daily methodology, including calibration checks



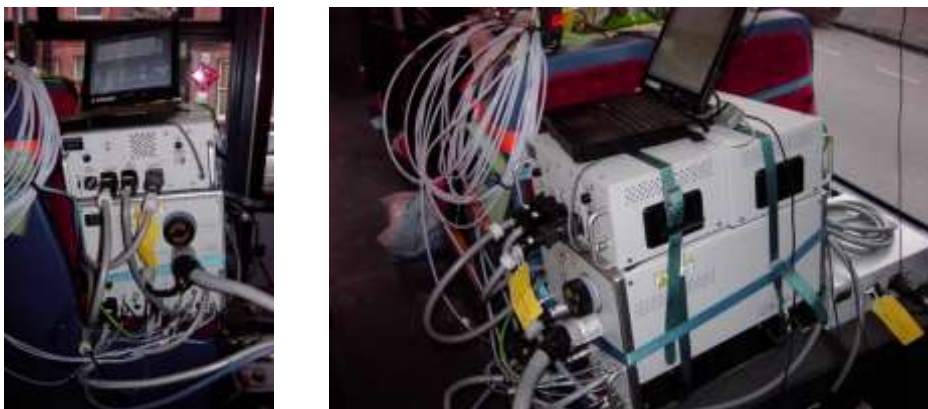
PC linked to the engine management system records operational data to laptop

Equipment installed in the rear seats of the buses tested

Horiba OBS 2200 PEMS used to measure gases from raw exhaust: CO, CO₂, NO_x, THC

PEMS Installation Photographs

Horiba PEMS Modules, strapped to seats



Service gases, crated and anchored between seats



Exhaust Pitot Flow Meter, installed at the exit of the tailpipe



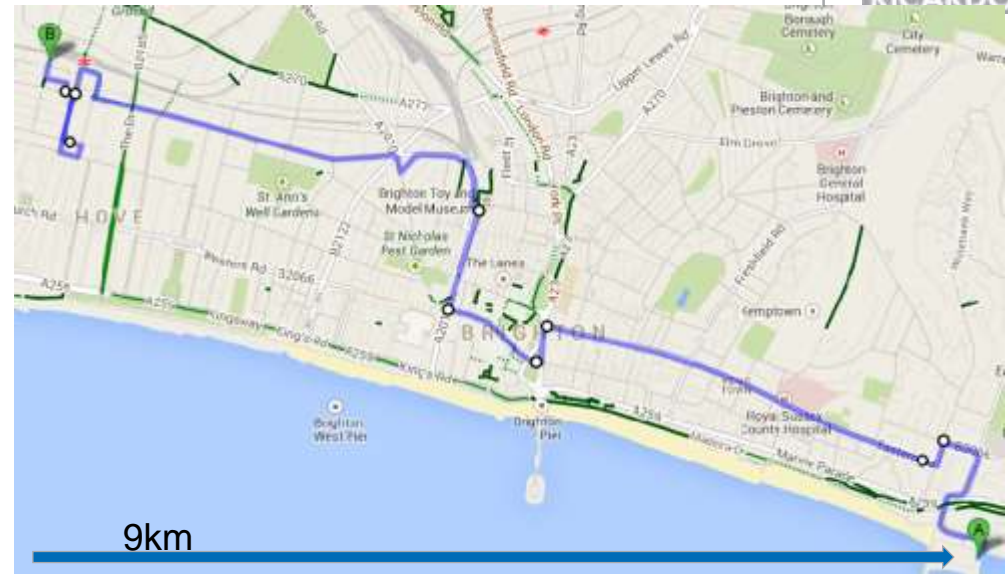
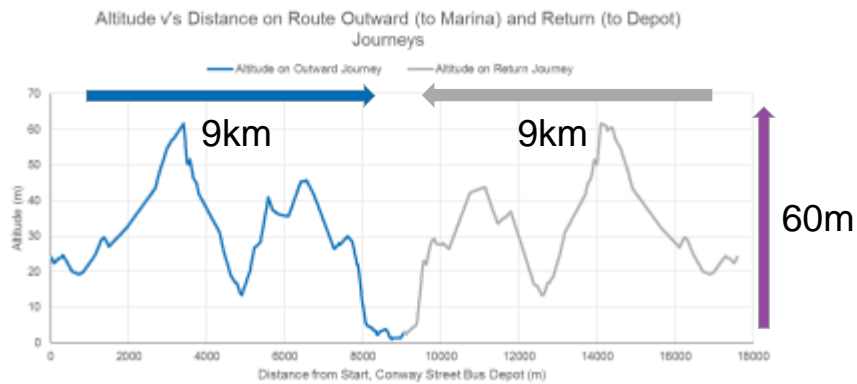
Sample Heated Transfer Line direct from exhaust to PEMS via void beneath buses' back seats



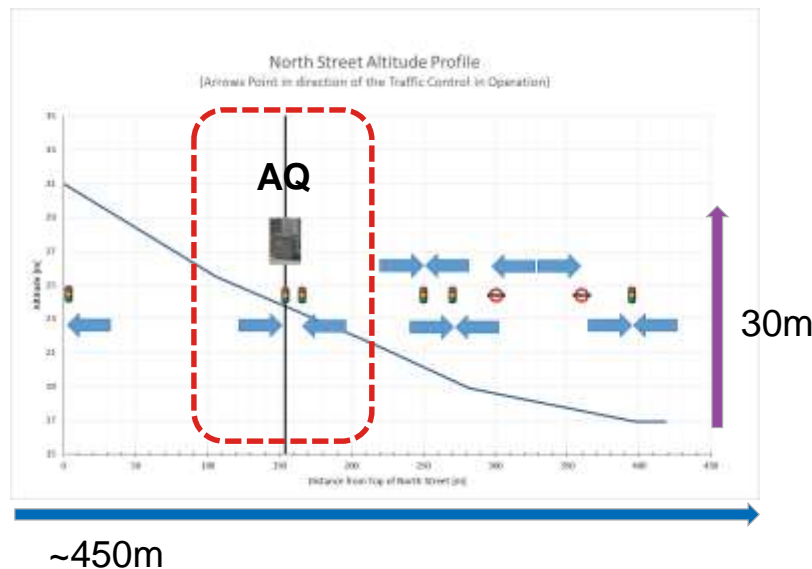
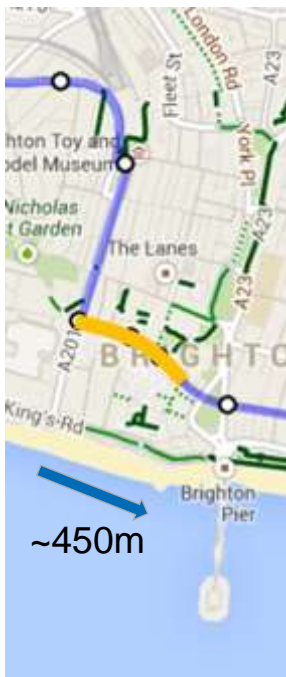


The Bus Route

Entire route – many hills; downhill outbound



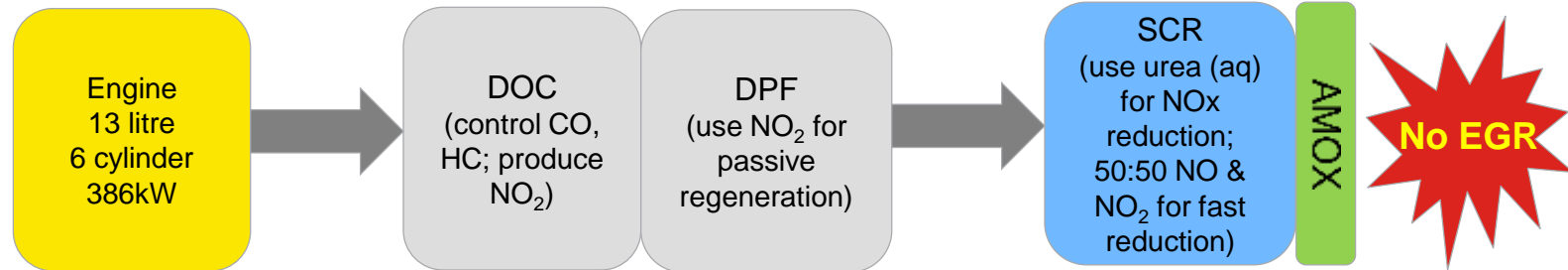
HOTSPOT North Street – downhill outbound



- Distance of entire route = ~18km
- Altitude range = sea-level to 60m; minimal flat terrain
- North Street:
 - Length = ~0.45km
 - 14m change in height, average 3% slope, minimal flat terrain
 - Contains many sets of traffic lights / pedestrian crossings
 - **Site of an air quality monitoring station**

Truck Supply and Preparation

- Test vehicle:
 - Iveco Ecostralis 500 E6 Truck.
 - Certified to Euro VI
 - Vehicle odometer reading of ~1400 km at start



Similar aftertreatment to Euro III D-S-RT Bus *BUT OEM solution*

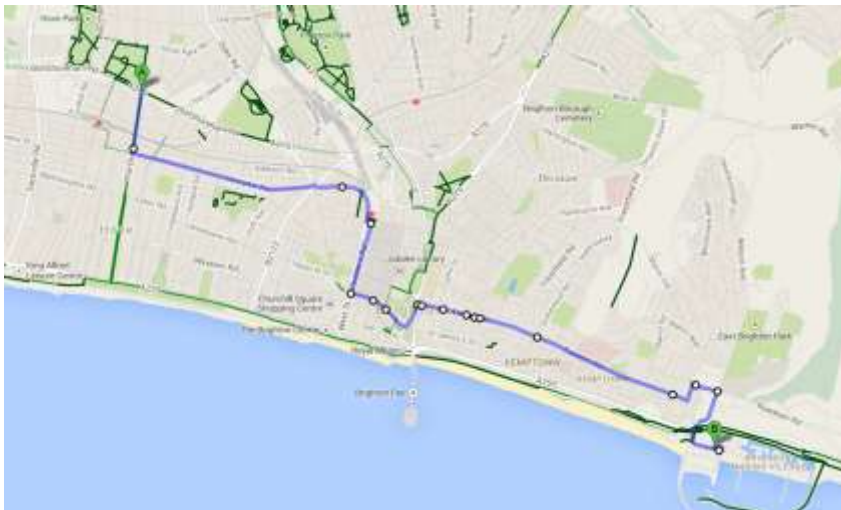
- Vehicle Preparation
 - Same Horiba OBS-2200 PEMS (Portable Emissions Measurement System) installed
 - Trailer procured to enable loading with 20 tonnes of concrete ballast

Truck Test Route

- Vehicle Testing

- Due to the length of the trailer and tractor unit a **slightly** modified “#7” route was driven
- On safety grounds, the use of any bus stops was precluded
- North Street was included in truck route (trucks normally forbidden)
- Tested in both a loaded (+20 tonnes) and unloaded trailer configuration
- PEMS data processed in the same manner as the for the buses

Modified #7 Route (Outbound) – Truck & trailer



Modified #7 Route (Inbound) – Truck & trailer



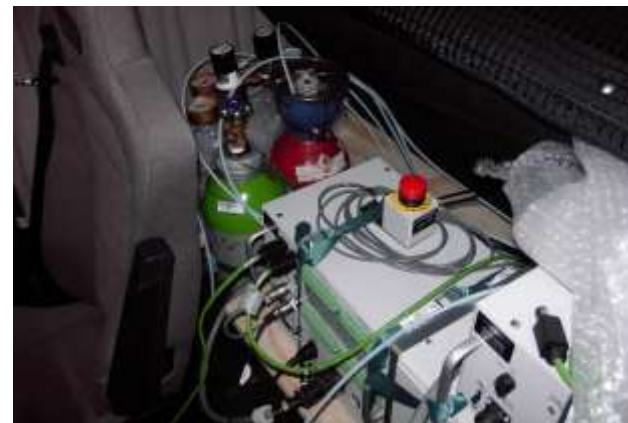


Truck Instrumentation Installation Photographs

Horiba PEMS Modules



Service gases, standing in right side storage compartment



Exhaust Pitot flow meter, installed at the exit of the tailpipe



Heated sample transfer line direct from exhaust to PEMS via left side hatch



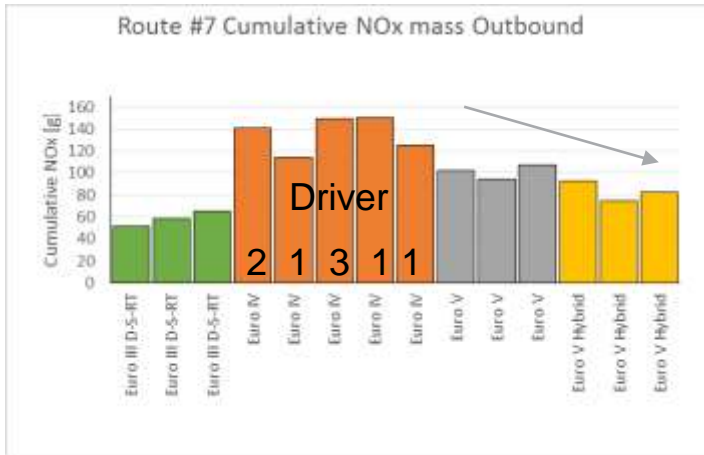


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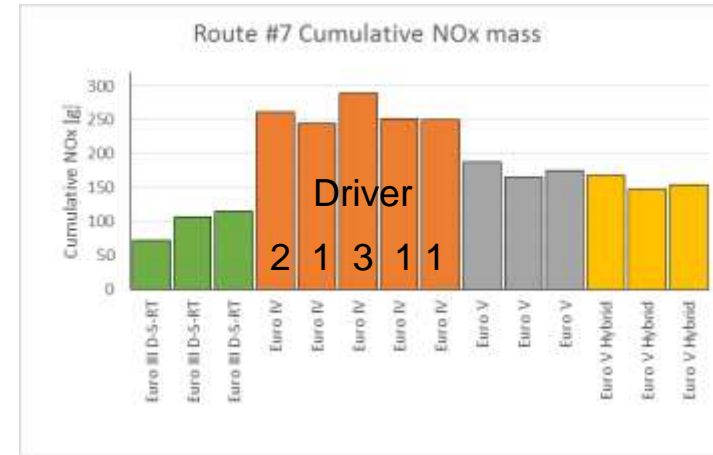


Number 7 Route NOx Levels (repeat runs) – 4 Buses

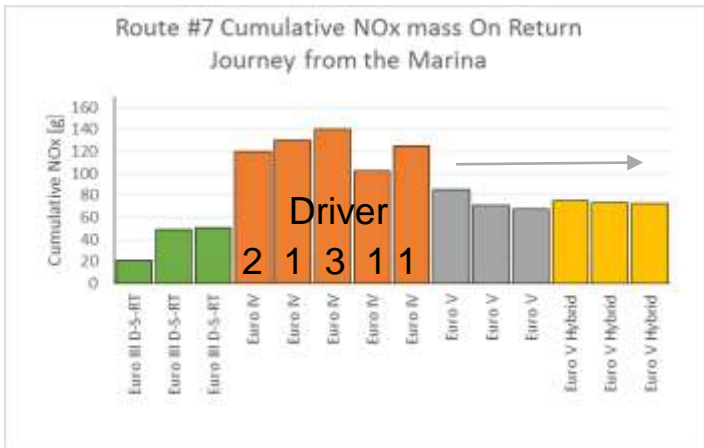
Outbound Route 7 NOx



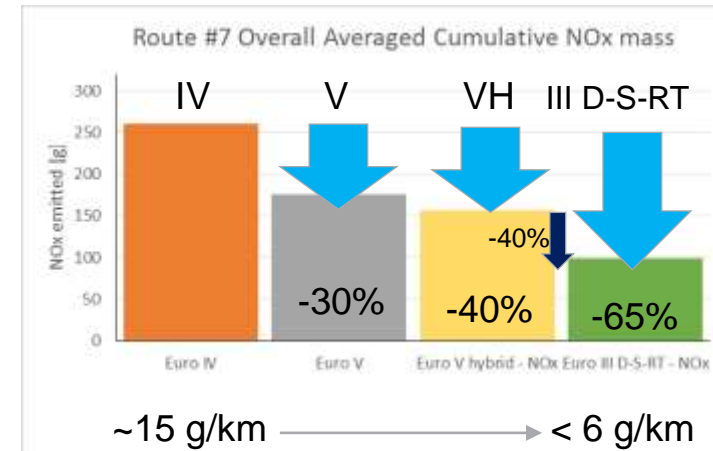
Combined Route 7 NOx



Inbound Route 7 NOx



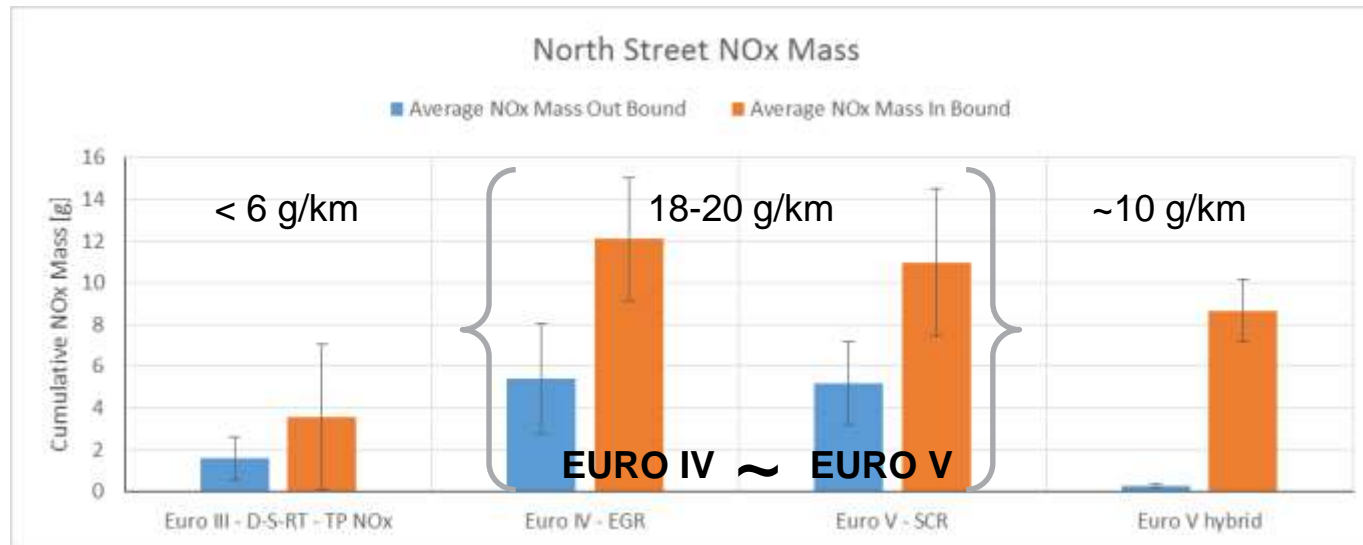
Route 7 NOx



- Overall NOx mass emissions were **Eu IV > Eu V > Eu VH**
 - But on the return, uphill, route the NOx emissions from the Euro V and the Euro VH were similar
- Emissions from the retrofitted SCR+DPF bus were lower than any of the other buses
 - Data from this bus may be more variable than other buses (related to less consistent urea dosing)
- On the Euro IV bus there was no significant effect of driver or driving style

~15 g/km → < 6 g/km

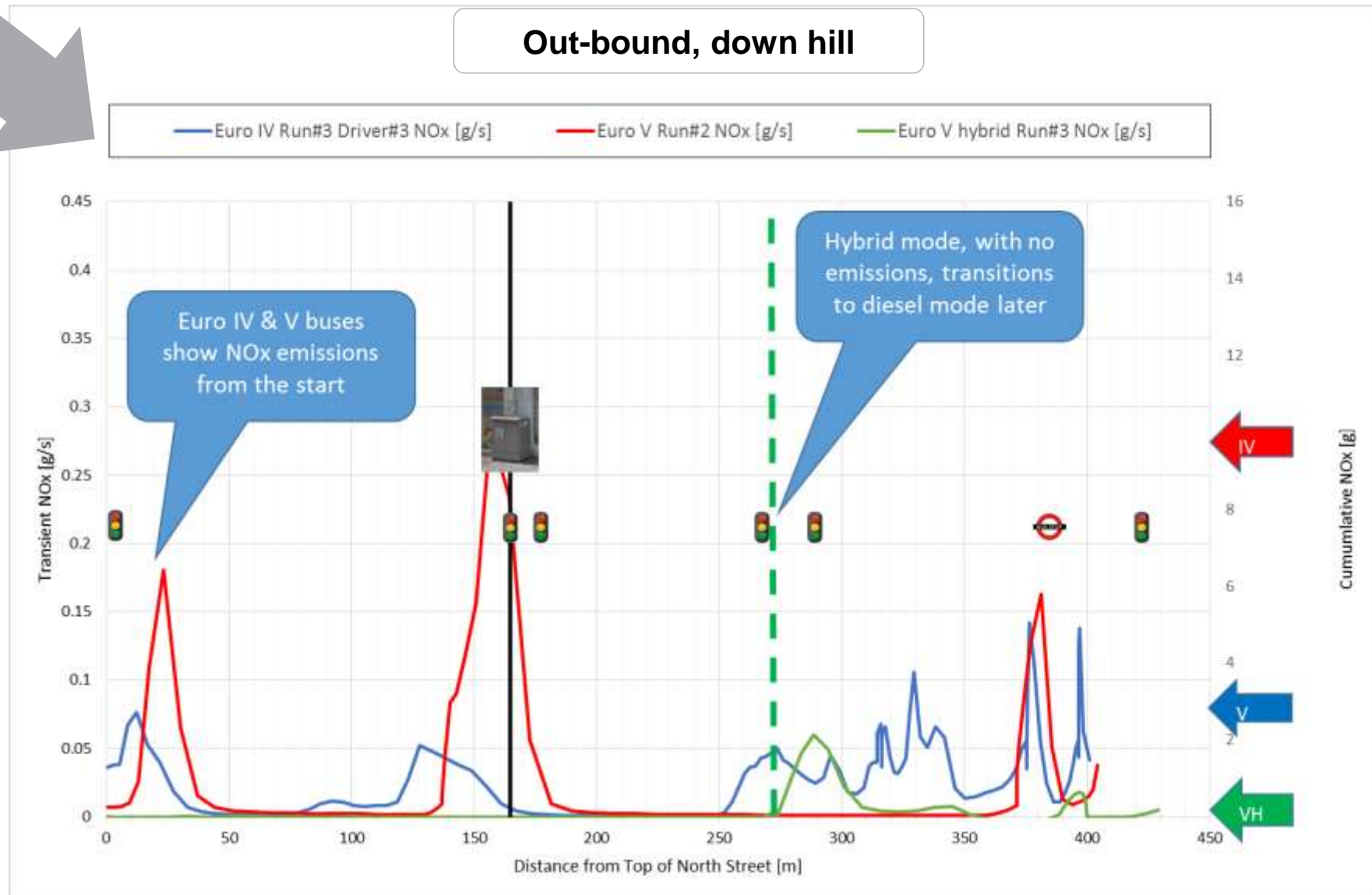
Average NOx Released in North Street – 4 Buses



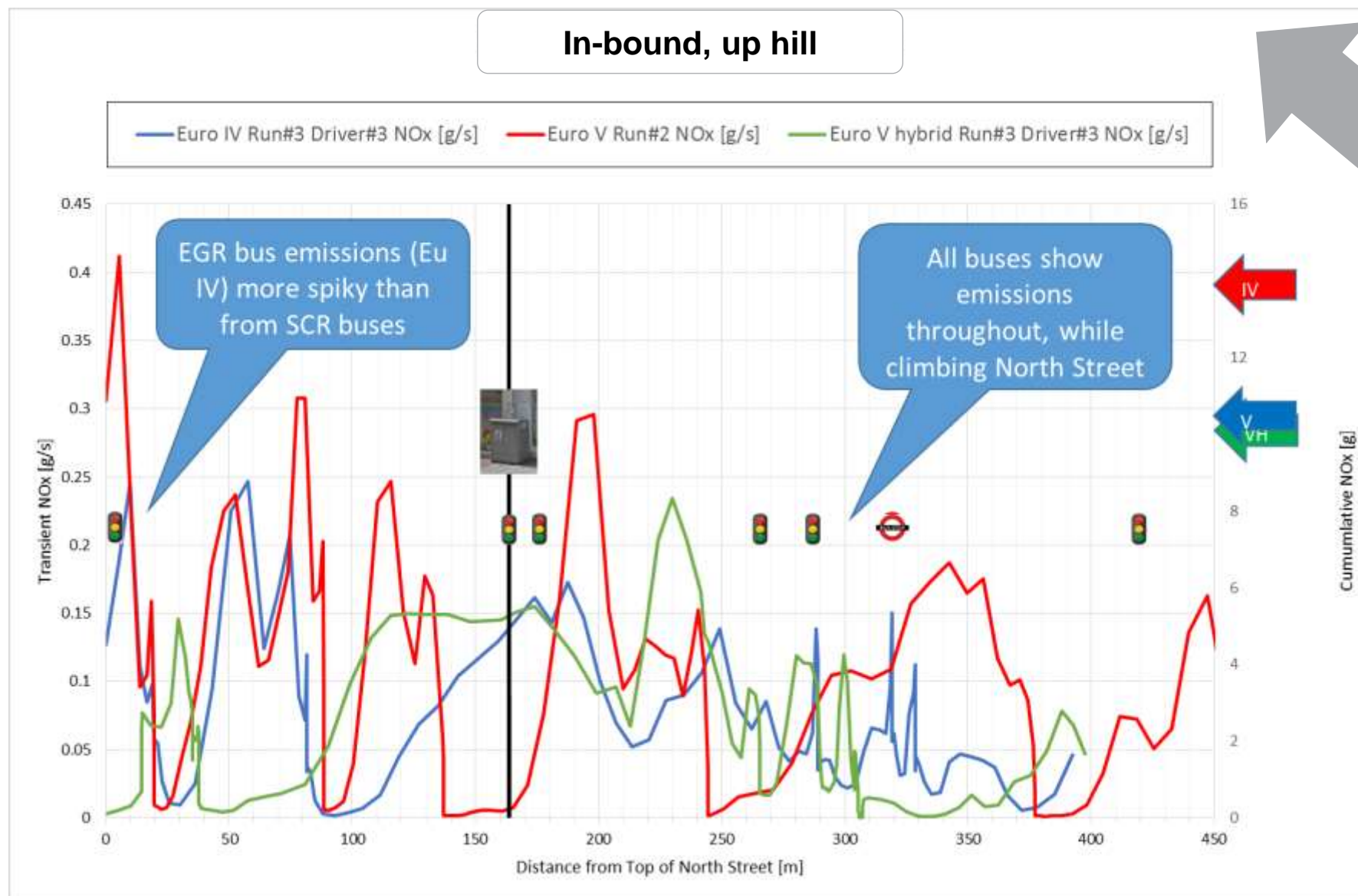
- Always less NOx emitted on the downhill route than on the uphill route
- Downhill Euro VH emissions were extremely low
 - Hybrid predominantly in electric mode and charging the battery
- Euro IV and V emissions were similar
- On the return, uphill run, emissions seemed to rank Euro III D-S-RT < Euro VH < **Euro V ~ Euro IV**
 - Interesting observation because the temperature regime of the Euro V bus was suitable for constant SCR operation - it suggests the SCR performance was suboptimal
 - Inbound DOC-in temperatures of the Euro VH would be predominantly in the operating regime of an SCR system, so some NOx reduction would be seen from the SCR
 - Improved dosing calibration/heat retention with the DPF + SCR retrofit delivers NOx benefits not seen from the OEM SCR systems
- **Comparisons of NOx emissions in North Street do not yield the same results as the overall No.7 route**

North Street, Out-bound, Down hill

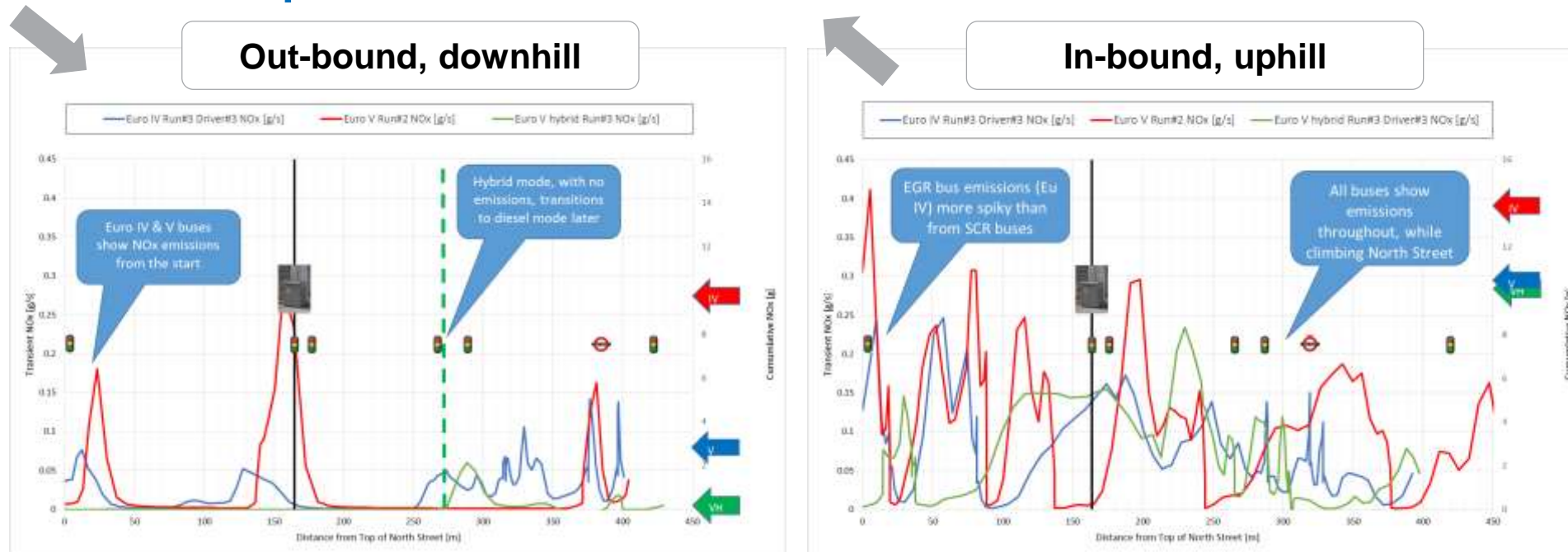
Out-bound, down hill



North Street, In-bound, Up hill



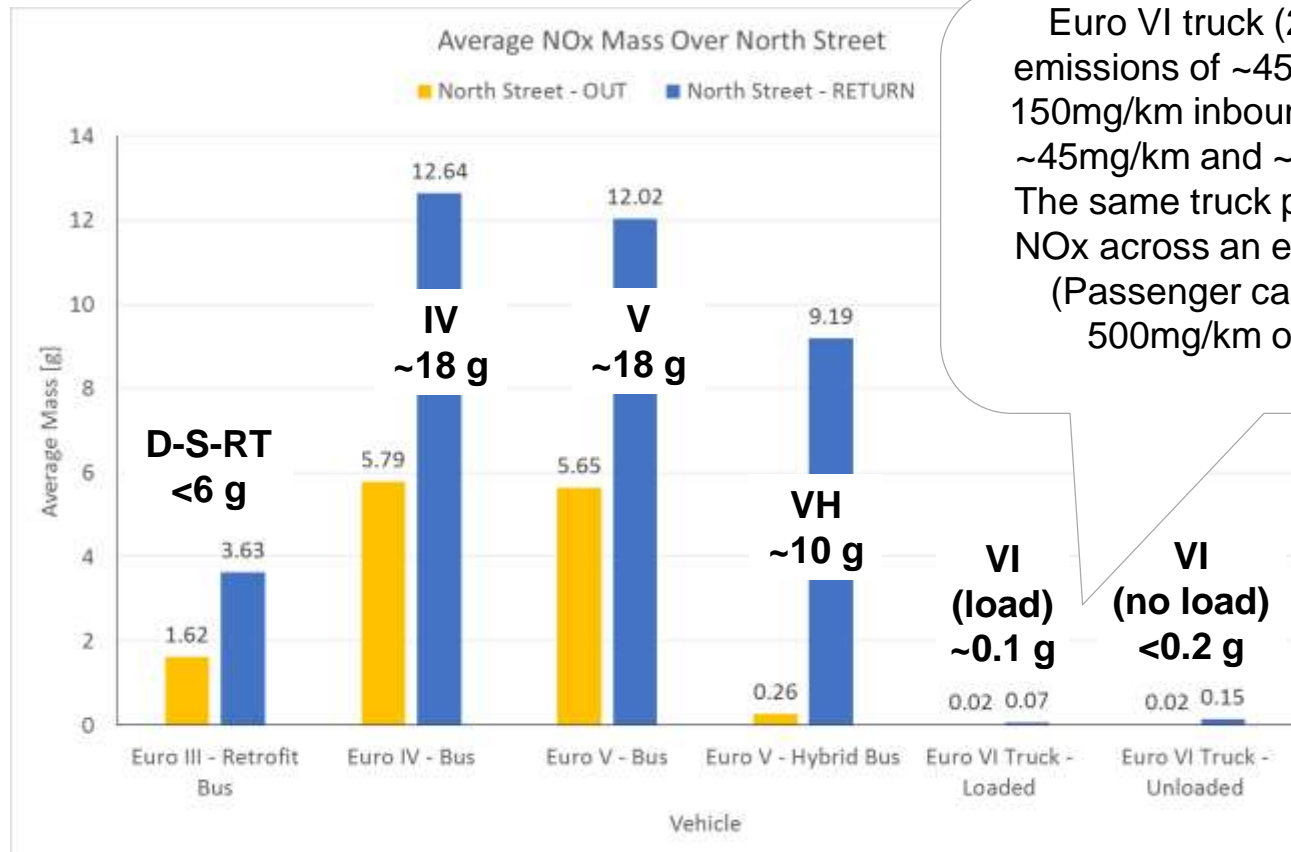
North Street Real-Time NO_x Emissions Related to Engine Transients & E-Machine Operation



- Downhill operation always produces lower emissions, for a given bus, than uphill operation.
 - The Euro VH initially shows zero emissions downhill, due to e-machine operation, until the diesel engine engages after stopping at traffic lights. The diesel engine is continuously operating during uphill transit
- Emissions spikes occur in response to accelerations, and these dominate the total NO_x released in North Street
 - The Euro IV bus EGR system is deactivated during hard accelerations to ensure good transient response
 - The Euro V and VH SCR systems dose urea for NO_x reduction, but the strategy does not seem to be optimal
- Multiple accelerations are required due to the disruptive nature of traffic, traffic control measures and pedestrian crossings in North Street

Brighton Buses & Truck Mass NO_x Emissions Comparison

- The graph gives comparative (buses & truck) mass emissions over North Street.
- Truck data is of a single run of both the loaded and unloaded trailer configuration, while the bus data has been averaged from multiple runs over the same route





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Conclusions

1. Euro VI has been more effective than previous tiers in providing a significant drop in real world emissions of heavy duty vehicles: Euro VI trucks now similar to passenger cars on g/km basis
2. Traffic management is also an important factor in reducing emissions rather than just engine and aftertreatment technology
 - Traffic calming measures do not necessarily have a positive effect
 - Slowing traffic can lead to sub-optimal catalysts performance
 - Unnecessarily stopping traffic can have a large negative impact
3. Hybrid vehicle emissions control systems need to be optimised for the operating regime to give lowest NO_x
4. PEMS gives the opportunity to understand true issues in any geographic location
 - North Street results show that localised emissions performance doesn't necessarily follow whole cycle trends, or vehicle regulatory level

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