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

Jon Andersson, Ricardo UK Ltd

Edinburgh, January 24th 2016

- **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

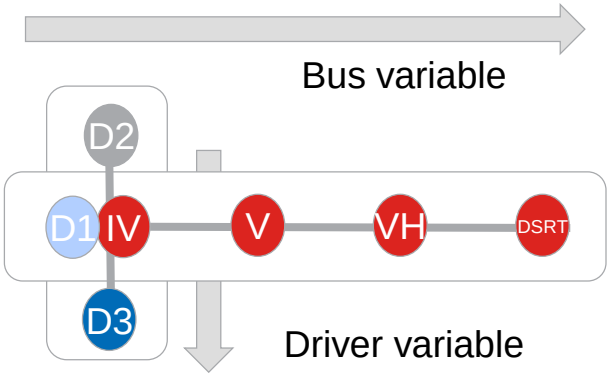
- Presentation objectives:
  1. Methodology for using PEMS to measure **mass** of NOx emitted throughout operation in urban areas
  2. Effectiveness of technologies achieving Euro IV, V, VI emissions regulations and hybridisation on overall emissions and air quality in local hotspots
  3. Impact of traffic and real world factors on HDV impact on air quality in local hotspot
  4. Comparison of real driving emissions to regulated cycle standards

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

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 Nº 712

Engine ***With EGR*** 9 litre 5 cylinder 201kW → DOC (control CO, HC; produce NO_2) → DPF (use NO_2 for passive regeneration) → **No SCR**

Euro V Bus – Fleet Nº 459

Engine 9 litre 6 cylinder 193kW → DOC (control CO, HC; produce NO_2) → DPF (use NO_2 for passive regeneration) → SCR (use urea (aq) for NOx reduction; 50:50 NO & NO_2 for fast reduction) → **No EGR**

Euro V Hybrid Bus – Fleet Nº 442

Engine 4.76 litre 4 cylinder 161kW E-machine 120kW → DOC (control CO, HC; produce NO_2) → DPF (use NO_2 for passive regeneration) → SCR (use urea (aq) for NOx reduction; 50:50 NO & NO_2 for fast reduction) → **No EGR**

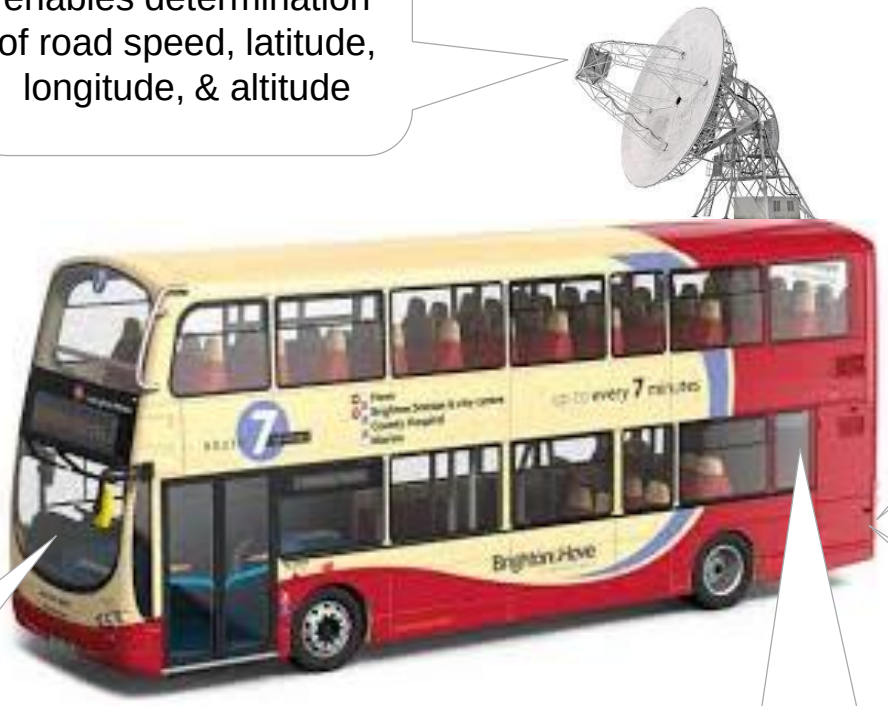
Euro III D-S-RT Bus – Fleet Nº 633

Engine 9 litre 6 cylinder 191kW → DOC (control CO, HC; produce NO_2) → DPF (use NO_2 for passive regeneration) → SCR (use urea (aq) for NOx reduction; 50:50 NO & NO_2 for fast reduction) → AMOX → **No EGR**

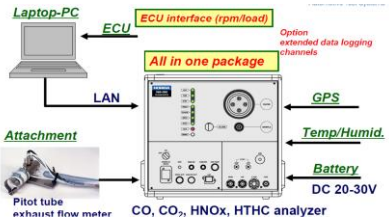
PEMS Measurements and Data Logged

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

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



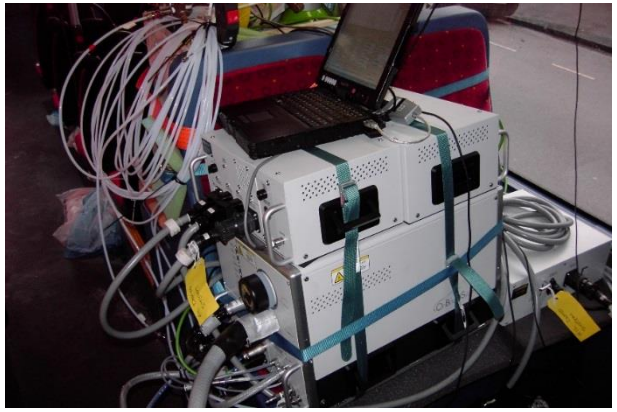
PC linked to the engine management system records operational data to laptop

Equipment installed in the rear seats of the buses tested

Horiba OBS 2200 PEMS used to measure gases from raw exhaust: CO, CO_2, NOx, THC

PEMS Installation Photographs

Horiba PEMS Modules, strapped to seats



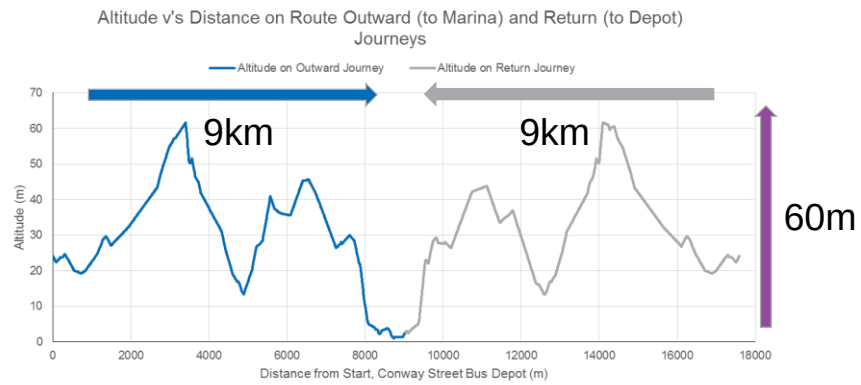
Service gases, crated and anchored between seats

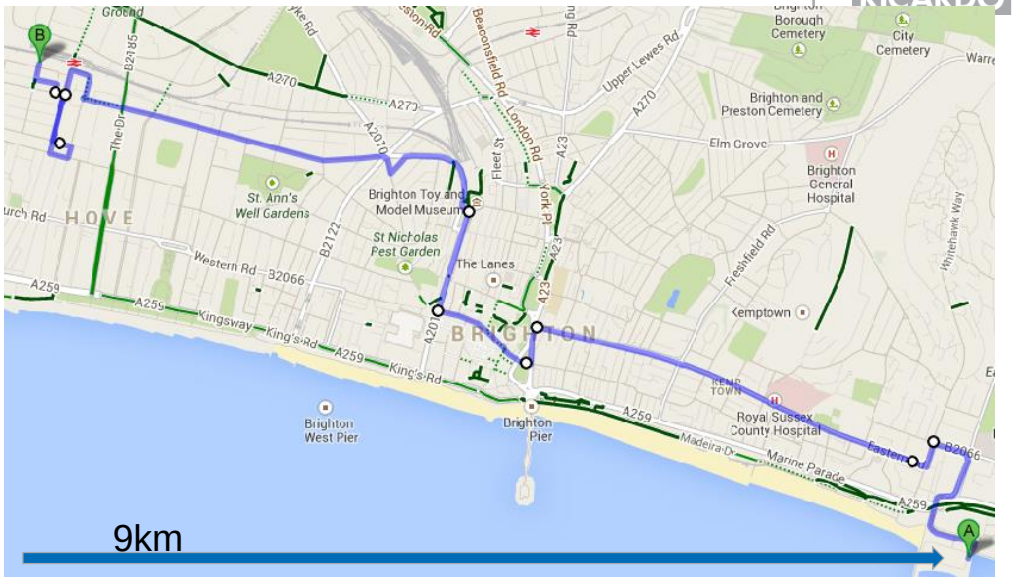
Exhaust Pitot Flow Meter, installed at the exit of the tailpipe

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

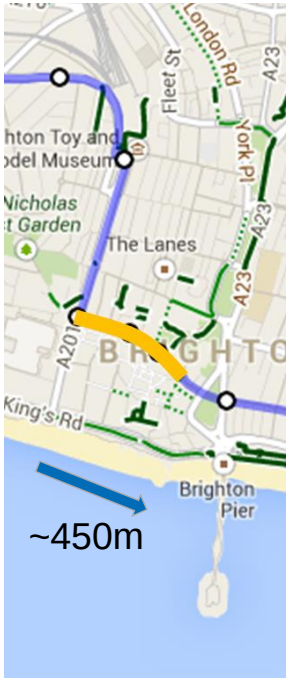
The Bus Route

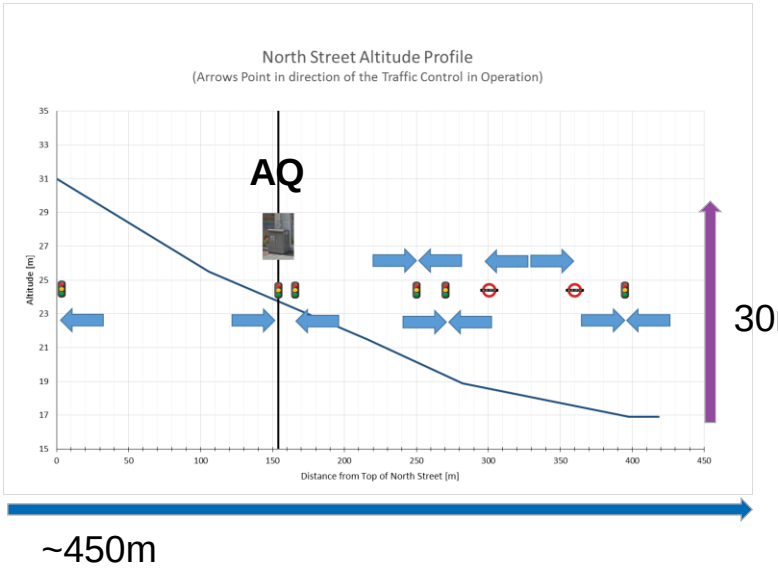
Entire route – many hills; downhill outbound





HOTSPOT North Street – downhill outbound

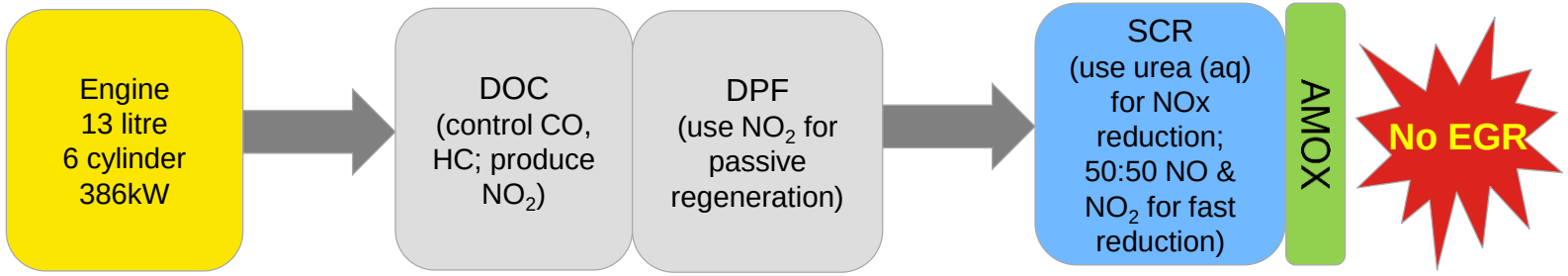




- Distance of entire route = ~18km
- Altitude range = sea-level to 60m; minimal flat terrain
- North Street:
  - Length = ~0.45km
  - 14m change in height, average 3% slope, minimal flat terrain
  - Contains many sets of traffic lights / pedestrian crossings
  - Site of an air quality monitoring station

Truck Supply and Preparation

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



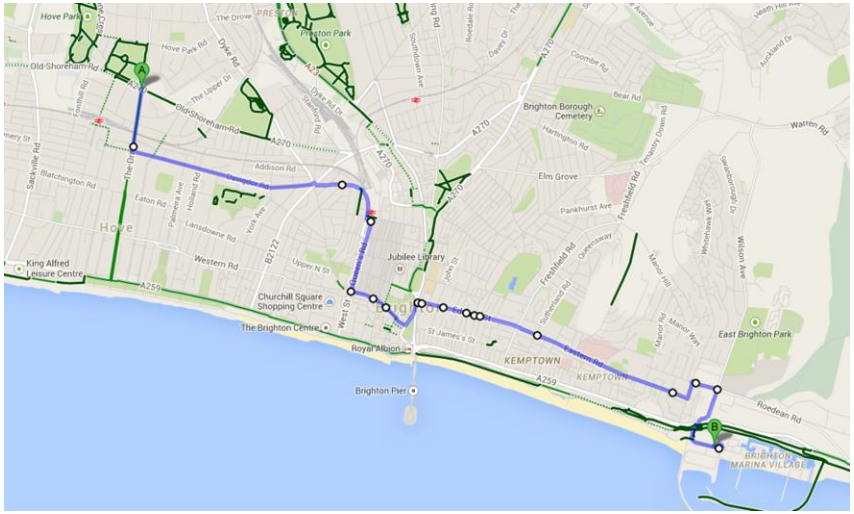
Similar aftertreatment to Euro III D-S-RT Bus *BUT OEM solution*

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

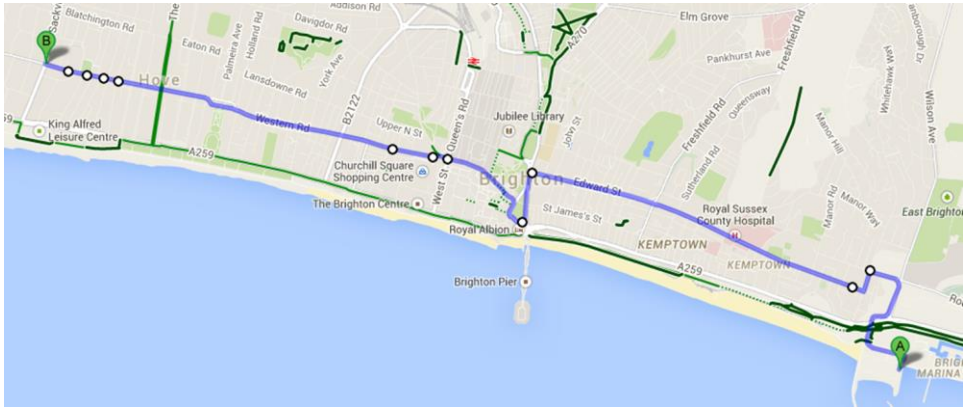
Truck Test Route

- 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

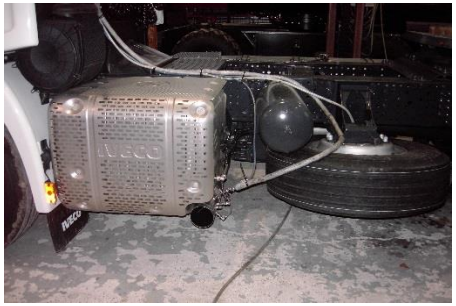


Truck Instrumentation Installation Photographs

Horiba PEMS Modules

Service gases, standing in right side storage compartment

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

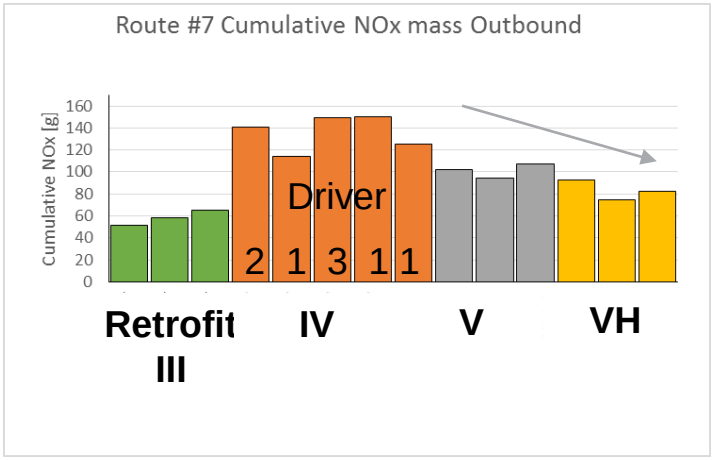


Heated sample transfer line direct from exhaust to PEMS via left side hatch

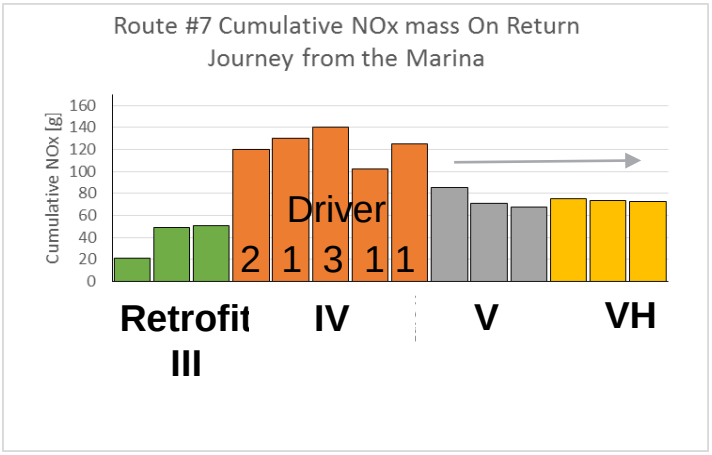
- Introduction
- Test Approach
- **PEMS Results**
- Conclusions

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

Outbound Route 7 NOx

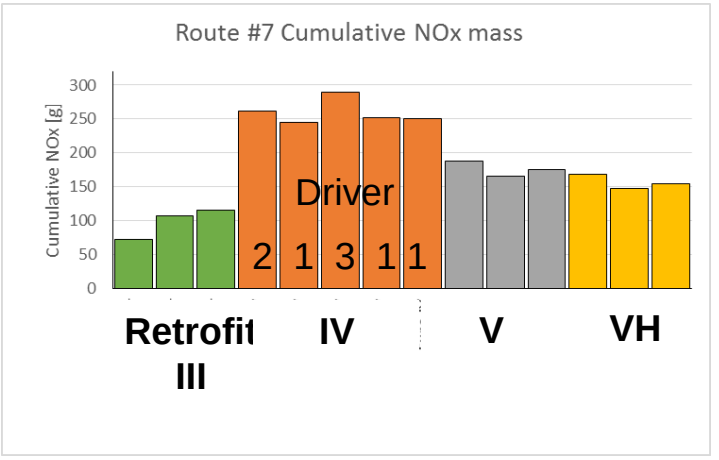


Inbound Route 7 NOx

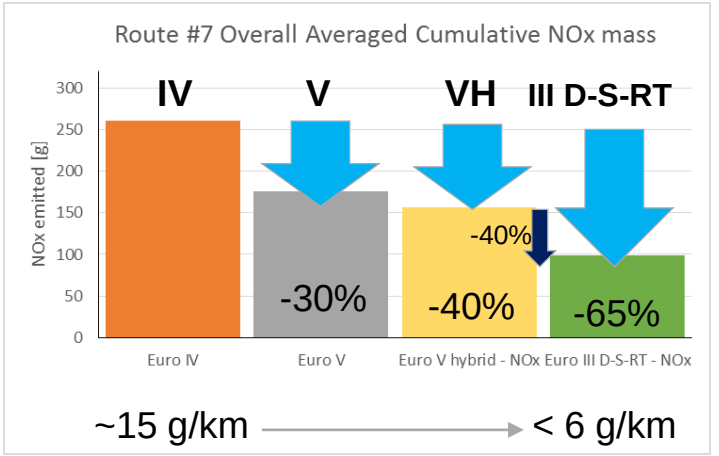


- **Overall NOx mass emissions were Eu IV > Eu V > Eu VH**
  - But on the return, uphill, route the NOx emissions from the Euro V and the Euro VH were similar
- **Emissions from the retrofitted SCR+DPF bus were lower than any of the other buses**
  - Data from this bus may be more variable than other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

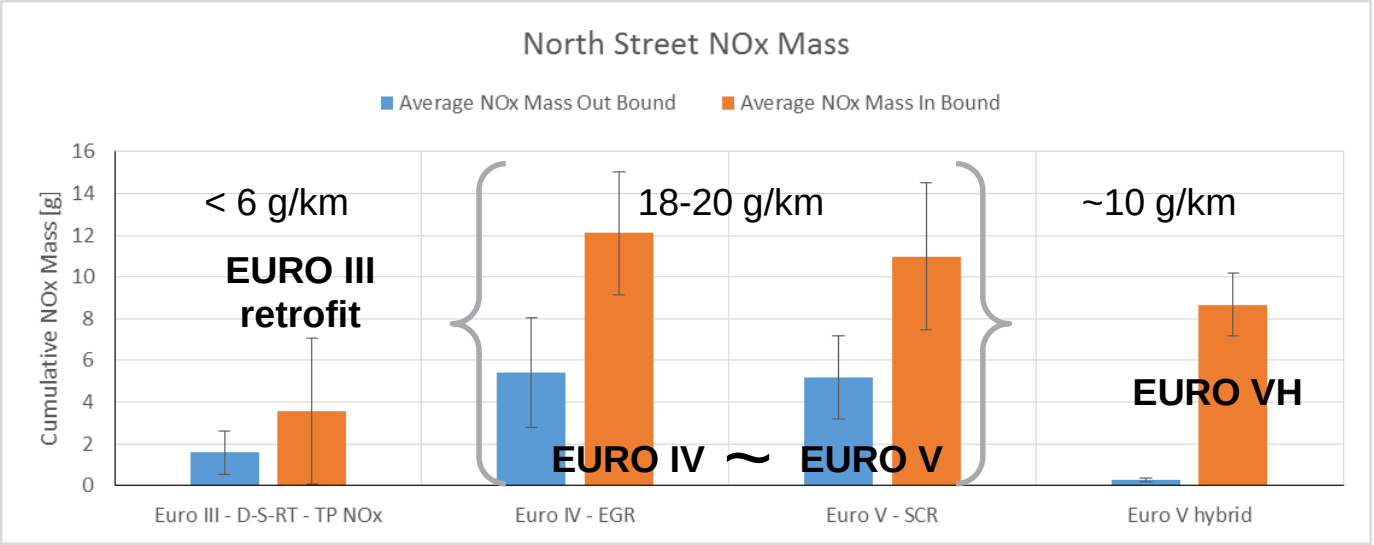
Combined Route 7 NOx



Route 7 NOx



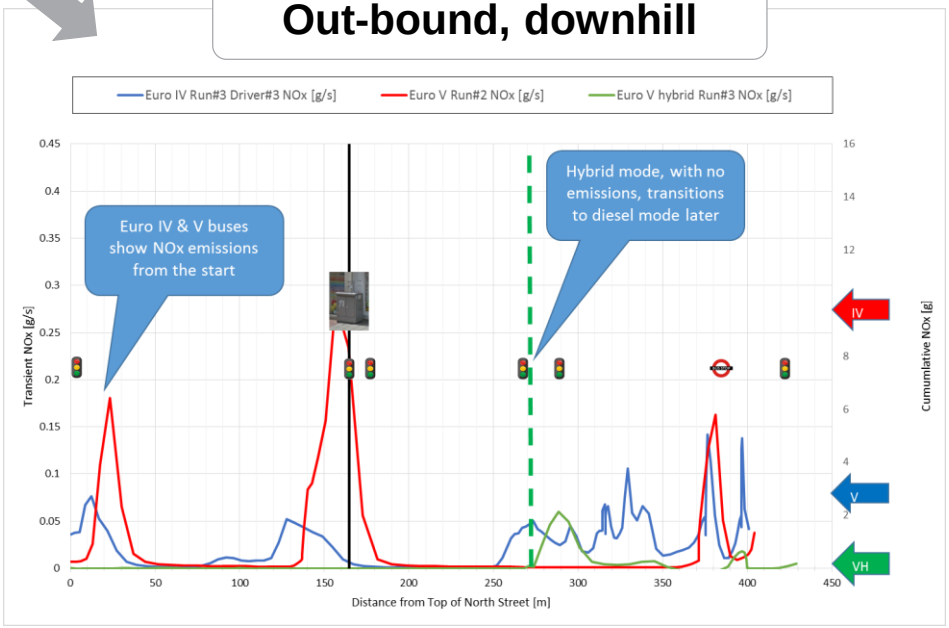
Average NOx Released in North Street – 4 Buses



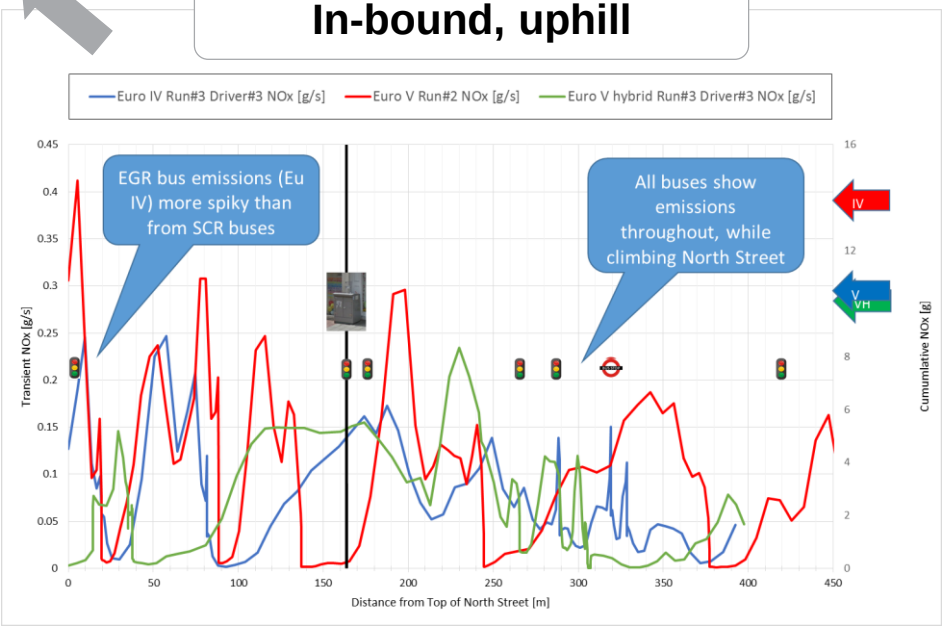
- Always less NOx emitted on the downhill route than on the uphill route
- Downhill Euro VH emissions were extremely low
  - Hybrid predominantly in electric mode and charging the battery
- Euro IV and V emissions were similar
- On the return, uphill run, emissions seemed to rank Euro III D-S-RT < Euro 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 Real-Time NOx Emissions Related to Engine Transients & E-Machine Operation

Out-bound, downhill



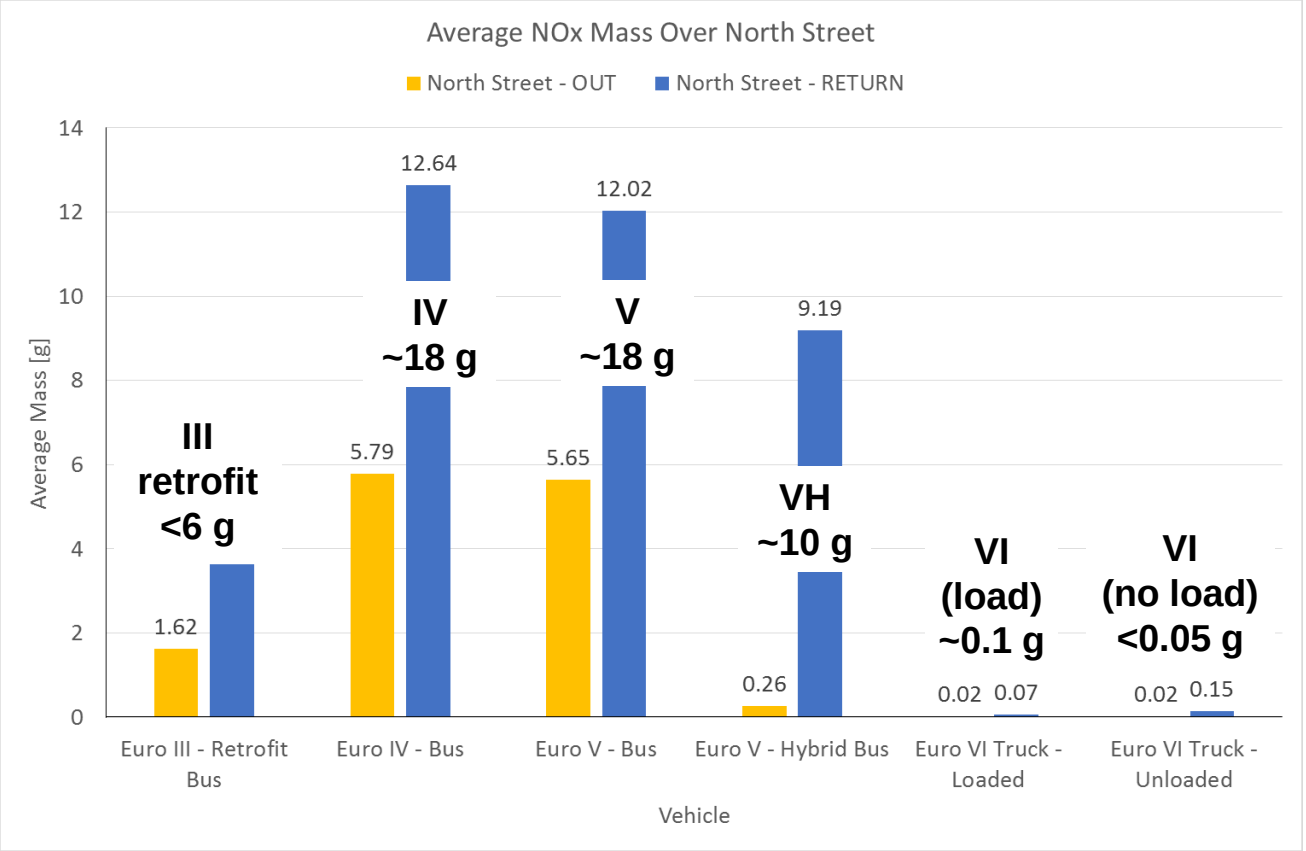
In-bound, uphill



- 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 NOx 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 NOx 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 NOx 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



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

Conclusions

1. Euro VI has been more effective than previous tiers in providing a significant drop in real world emissions of heavy duty vehicles

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 NOx

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

Acknowledgements

The authors wish to thank…

- Horiba: Salman Safdar
- Brighton and Hove Bus and Coach Company: The team at Conway Street