

London Buses Emissions Reduction

Finn Coyle

Environmental Manager, Transport Emissions

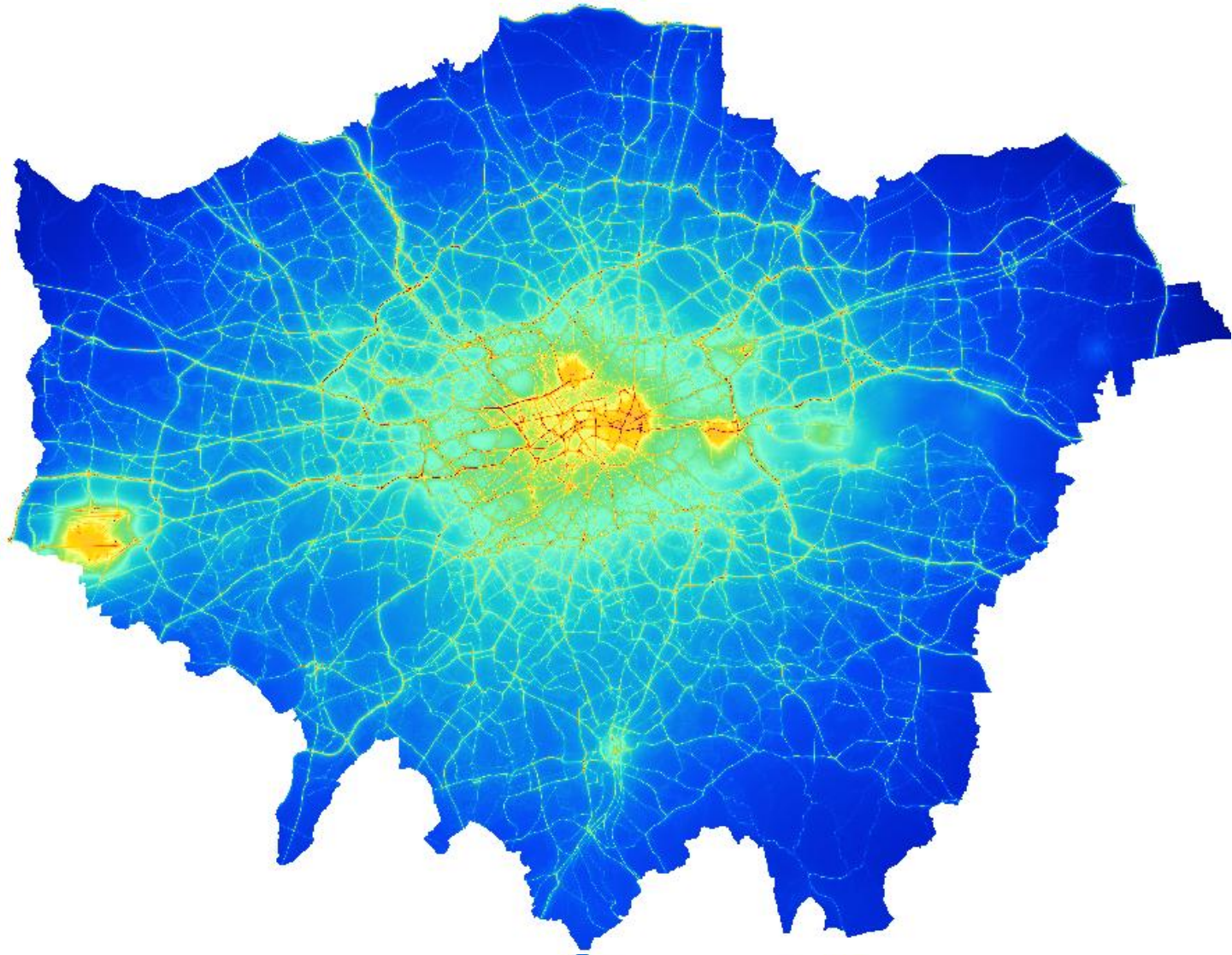
Transport for London



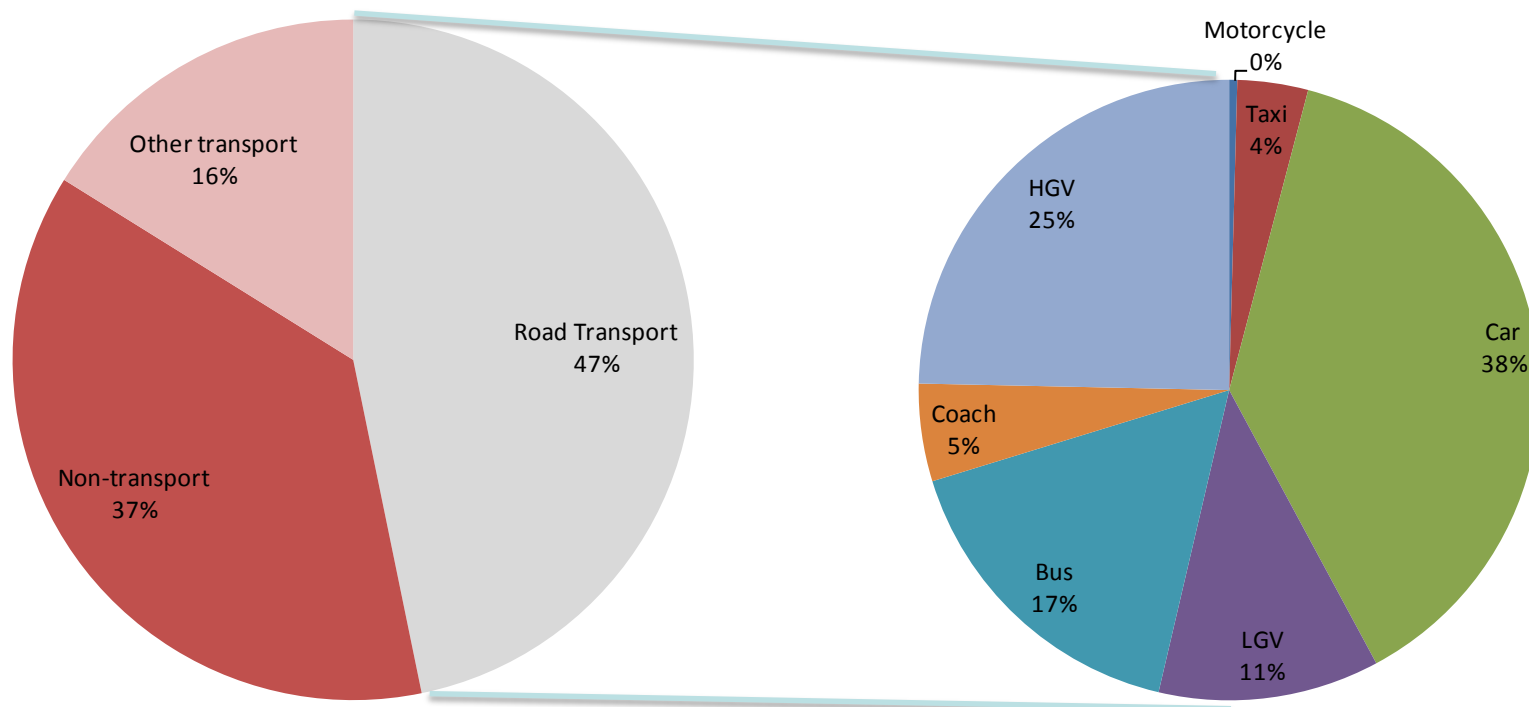
- London's NO₂ problem
- The bus network and its environmental impact
- NOx abatement retrofit and standards
- SCR development and testing
- Route selection & Monitoring
- Hybrid, electric and hydrogen buses



NO₂ Annual Mean Concentrations (µg/m³) in London (LAEI 2010)



Sources of NO_x Emissions in London - 2010

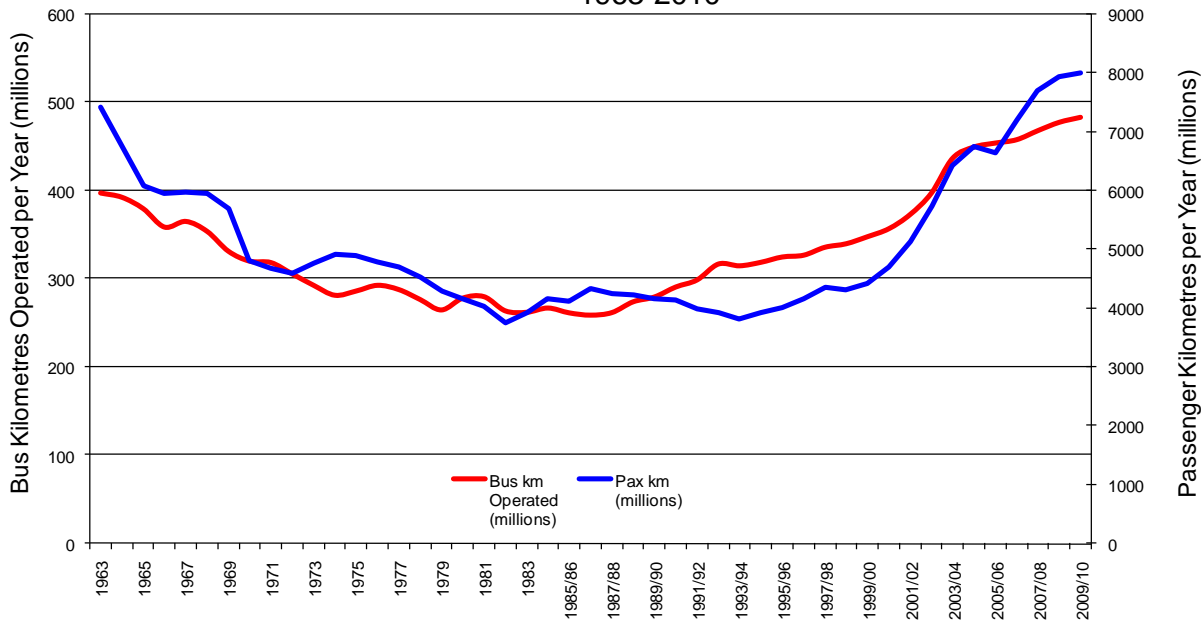


The London Bus Network

Buses operate 24 hours per day, 7 days a week

Network contracted by TfL from Private Operators

London bus network: service volume and usage
1963-2010



6.4 million journeys per week day

19,500 bus stops

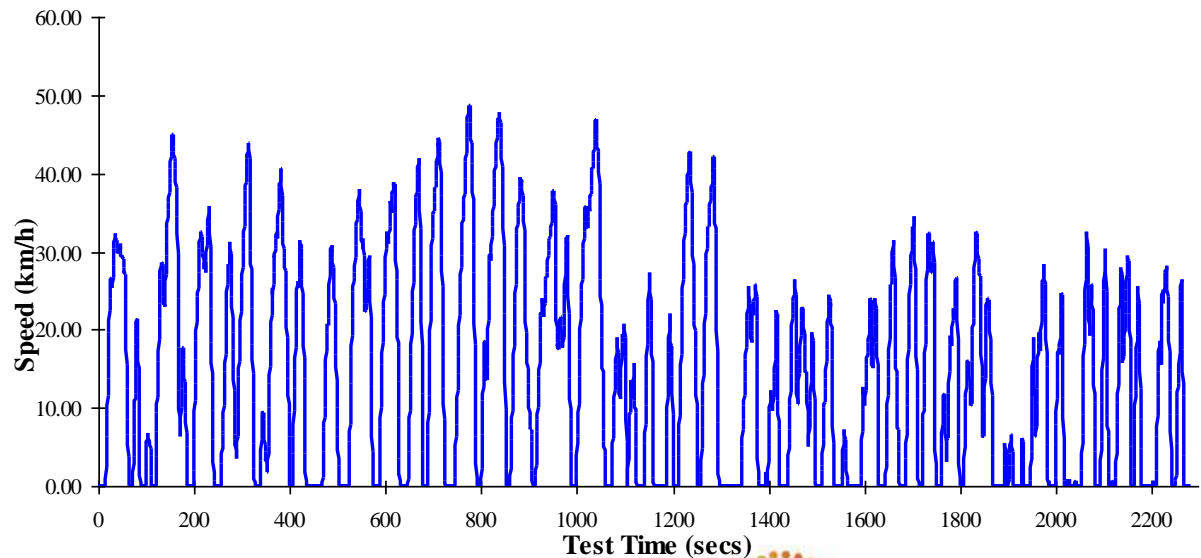
700 routes

8,500 buses

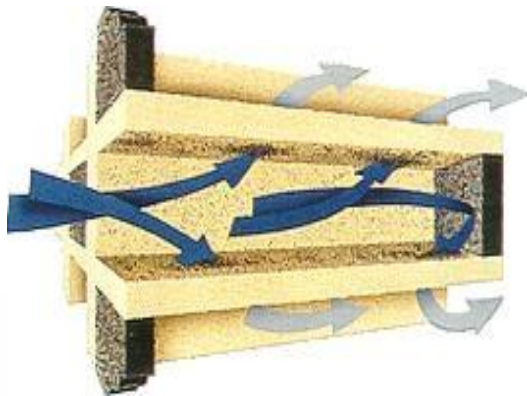
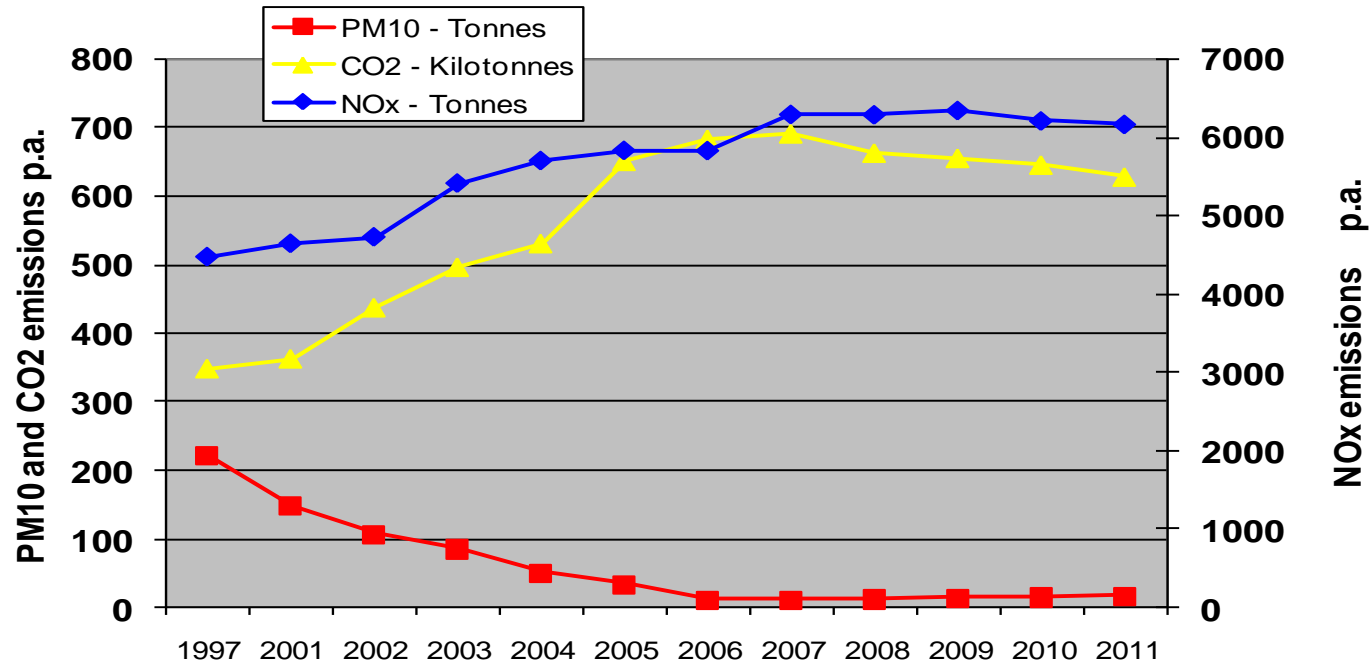


Calculating the Environmental Impact of the Bus Fleet

- TfL developed with Millbrook a 'real world' drive cycle based on Route 159 from Brixton to Oxford Street
- Every new type of bus is tested to measure CO₂, PM and NOx emissions
- Enables TfL to model the impact of the Bus Fleet on London emissions and predict the impact of interventions
- Real World test cycle with representative exhaust temperature essential for SCR development



Fleet Emission Trends 1997-2011



TfL Retrofitted Diesel Particulate Filters (DPF) on all its Euro II and III buses (6500 buses)

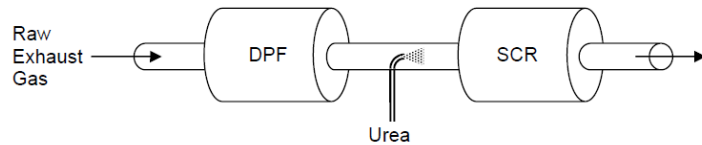


NOx Abatement Retrofit

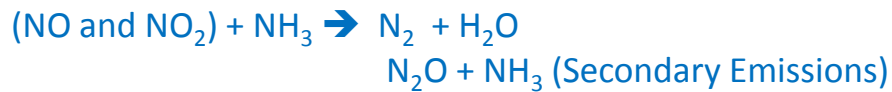
£10 million funding (DfT/TfL) to retrofit 900 Euro 3 buses with SCR

250 buses now fitted to 3 types of Euro 3 bus

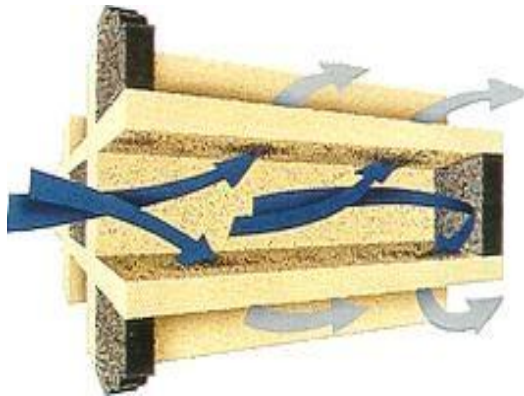
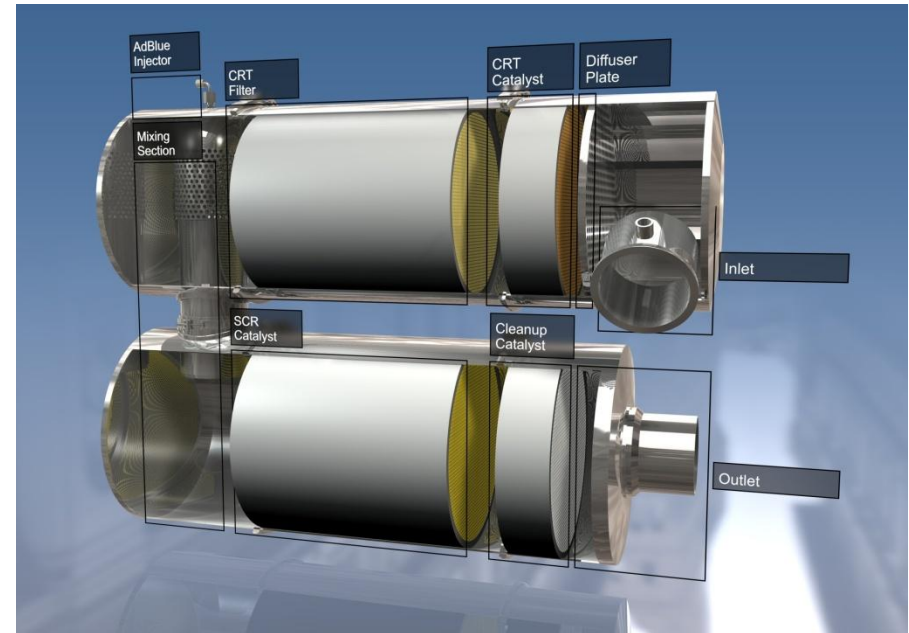
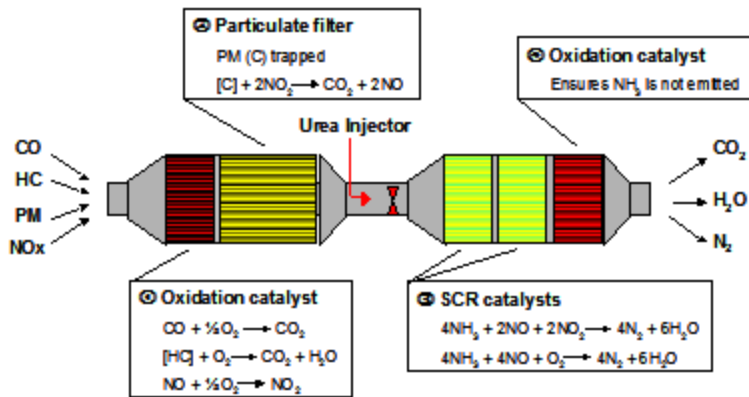
900 will be fitted by March 2014



NOx reacts with ammonia over the catalyst and reduces it to nitrogen and water



Combined DPF + SCR Systems



The fastest NOx reduction mechanism is via the path shown below:
 $2NO + 2NO_2 + 4NH_3 \rightarrow 4N_2 + 6H_2O$

Engine out levels tend to be approx 10 parts NO₂ to 90 parts NO

To utilise faster reaction, NO₂ can be increased to 50:50 with an oxidation catalyst

A 70% reduction of 50 parts is 15 – a 50% potential increase in NO₂



NOx Retrofit Standard

Primary Emissions Reduction

A 70% reduction in NOx emissions relative to baseline levels (over London Bus Test Cycle)

Secondary Emissions Limits

Nitrous Oxide (N₂O)

The CO₂eq must not increase by more than 5% of the total CO₂ emissions recorded during the test.

$$\text{CO}_2\text{eq} = 310 \times \text{N}_2\text{O}$$

Nitrogen Dioxide (NO₂)

A 50% reduction in NO₂ emissions post NOx Abatement equipment relative to engine out levels.

Ammonia (NH₃)

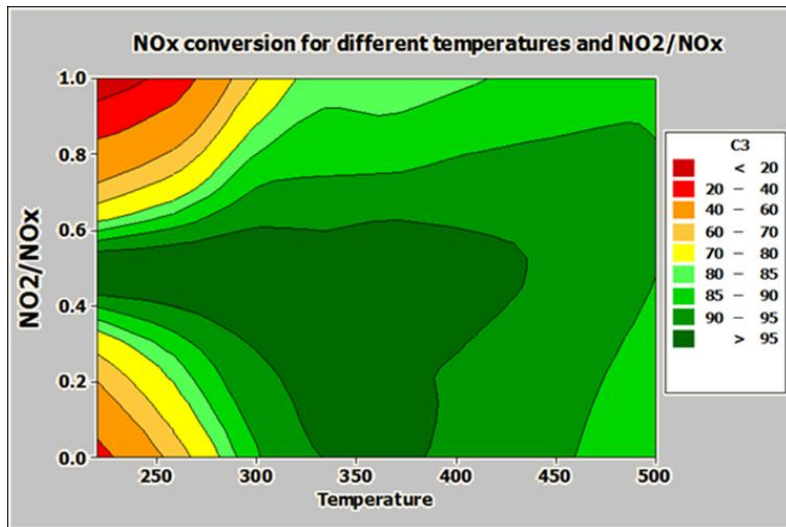
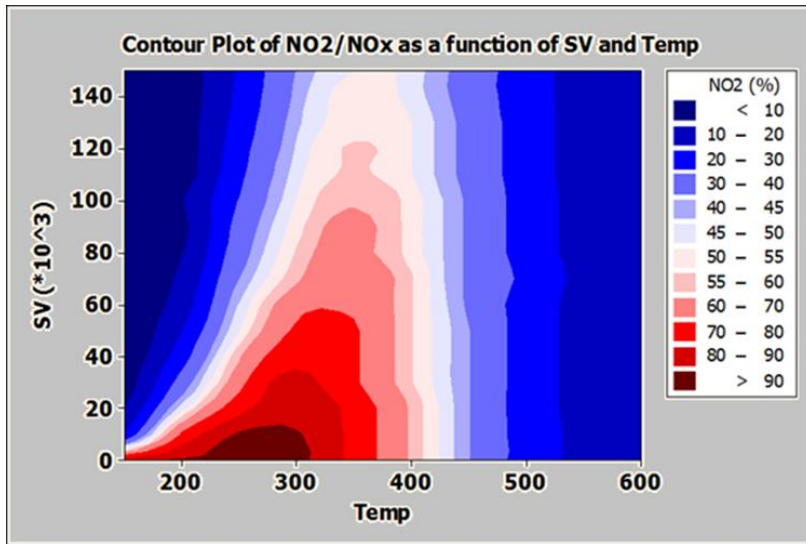
Ammonia emissions are limited to 10 ppm

Carbon Dioxide (CO₂)

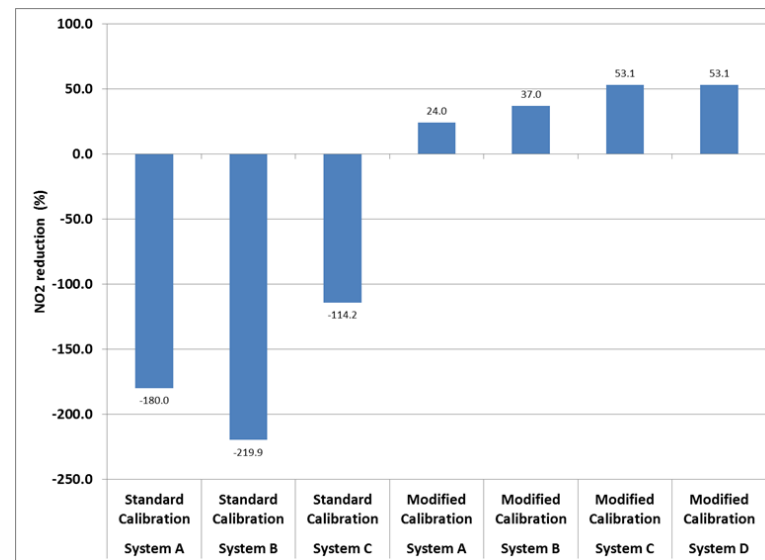
CO₂ emissions shall not be adversely affected by more than 1% (within test repeatability) by the fitment of NOx Abatement Equipment



SCR Development for NO2 Reduction



Success Criterion	TfL Standard	Compared to EU Emission legislation
PM conversion (%)	> 90	~ EU VI
NO _x conversion (%)	> 70	> EU V
NO ₂ conversion (%)	> 50	Not limited
Peak NH ₃ slip (ppm)	< 10	~ EU VI
N ₂ O formation (% CO ₂ greenhouse gas equivalent)	< 5	Not limited

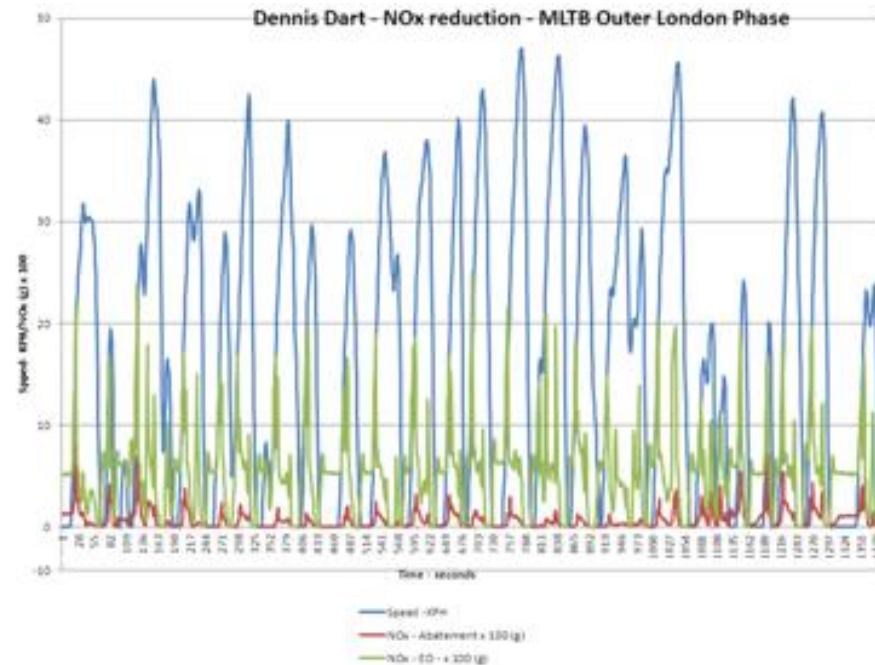


SCR Emissions Test Results

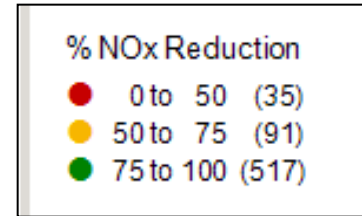
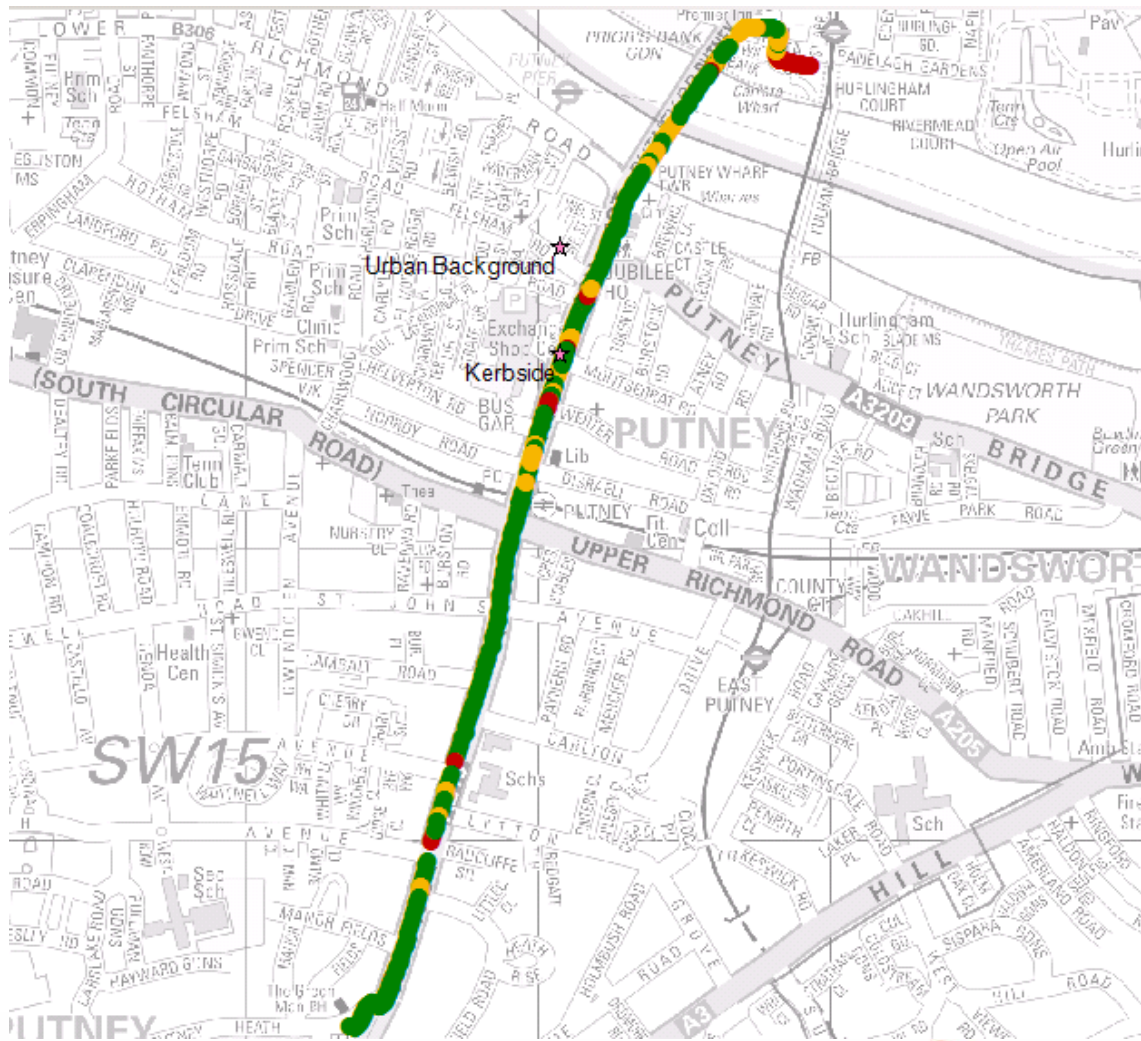
Eminox:- 88% NO_x Reduction achieved on both the Denis Dart and Volvo Double Deck

Test No 11762/63, 822/23/24		Baseline Test	
Date	15/11/11 & 1/12/11	NO _x	NO ₂
Units:		g/km	g/km
Analyser:		Bag	FTIR
Phase 1	Outer London	10.49	0.49
Phase 2	Inner London	18.43	0.84
Combined result		12.72	0.59

Test No 11775, 11827 & 829		With NO_x Abatement Device	
Date	17/11/11 & 2/12/11	NO _x	NO ₂
Units:		g/km	g/km
Analyser:		Bag	FTIR
Phase 1	Outer London	1.12	0.21
Phase 2	Inner London	2.38	0.42
Combined result		1.47	0.27
Change vs Baseline		-88.4%	-54.6%



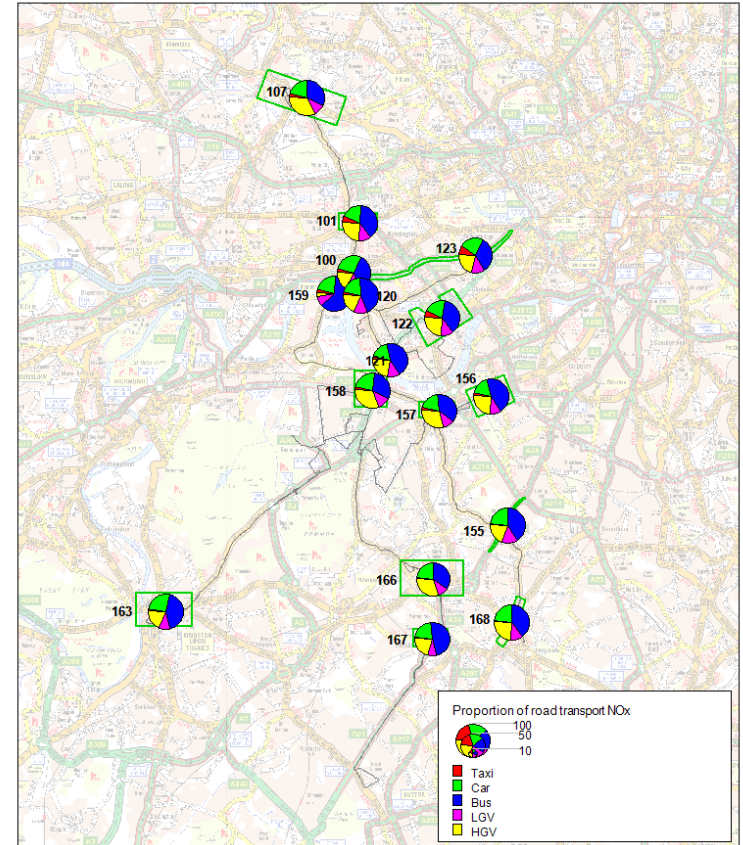
NOx Reduction on Volvo operating on Putney High Street



SCR Roll-out

Routes for retrofit were chosen based on both:

- Routes that pass through areas of high NO₂ concentrations and where buses are a large contributor to vehicle NO_x Emissions
- Routes that have the longest contract end date so that benefits are realised over a sufficient time period (3 year target)
- Routes that operate Euro III Dart, Trident and Volvo buses

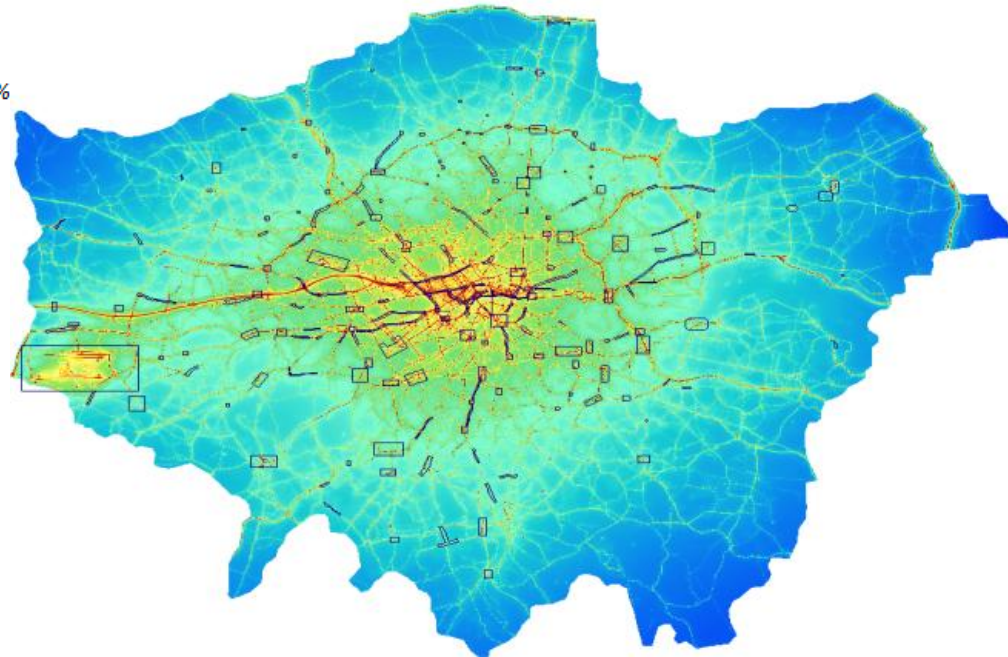


Focus Area Prioritisation

APPENDIX A – Euro 3 routes ranked by number of intersections with significant FAs

Rank (i): Rank in descending order "Number of FAs >50%", "Number of FAs > 60% and "Number of FAs >70%"

Route IDs	Number of FAs >50%	Number of FAs >60%	Number of FAs >70%?	Rank (i)
59	6	3	0	1
159	6	2	1	2
176	5	3	1	3
242	5	2	1	4
X68	5	2	0	5
243	5	2	0	6
1	4	3	1	7
68	4	2	0	8
8	4	1	1	9
91	4	1	0	10
109	4	1	0	11
55	3	2	1	12
6	3	2	1	13
188	3	2	0	14
168	3	2	0	15



NO2 Focus Areas



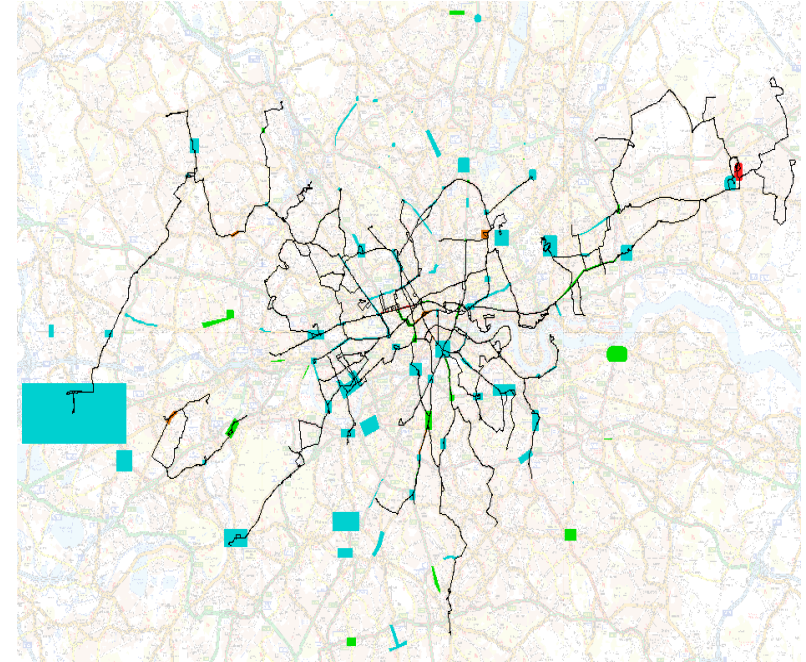
SCR Roll-out with contractual considerations

APPENDIX B: Euro 3 routes ranked by number of intersections with significant FAs and contract end date

Table ordered by *Rank Final*: The ascending order of *Rank (i)* + *Rank (ii)*

Rank (ii): Rank based on contract end date. Later dates ranked more favourably than older dates

Route IDs	Number of FAs >50%	Number of FAs >60%	Number of FAs >70%	Rank (i)	Extended contract end date	Rank (ii)	Rank Final
X68	5	2	0	5	Apr-18	13	1
68	4	2	0	8	Apr-18	14	2
128	2	1	1	26	Oct-19	1	3
159	6	2	1	2	Dec-17	28	4
172	2	2	0	19	Mar-18	16	5
9	2	1	0	29	Sep-18	6	6
390	1	1	1	32	Sep-18	7	7
193	1	1	1	33	Sep-18	8	8
6	3	2	1	13	Dec-17	29	9



Route Selection



Monitoring

- Programme with Kings College and Wandsworth using:
 - ANPR cameras
 - iBus data
 - Continuous NO₂ monitors



Short to Medium Term Strategy - Hybrid Buses

- The hybrid programme has spurred bus manufacturers to develop hybrid buses
 - 421 hybrid buses now in service from 4 manufacturers.
 - 1600 to be in service by 2016 (including 600 New Buses for London)
 - Emissions testing has shown a significant reduction in fleet average hybrid emissions compared to fleet average Euro IV:
 - 30% reduction in CO₂
 - 21% reduction in NO_x
- New Bus for London with second generation hybrid technology demonstrates even more significant benefits
- 47% reduction in CO₂
 - 78% reduction in NO_x



Electric, Plug-in Hybrid Bus & Induction Charging Trial

- TfL is planning a demonstration of a plug-in hybrid (or range-extended electric) bus
- Recharging will be by induction (wireless) charging
- Primary infrastructure will be installed in TfL bus stations at either end of a suitable route
- 2 Pure Electric Buses from Chinese manufacturer are also being introduced later this year



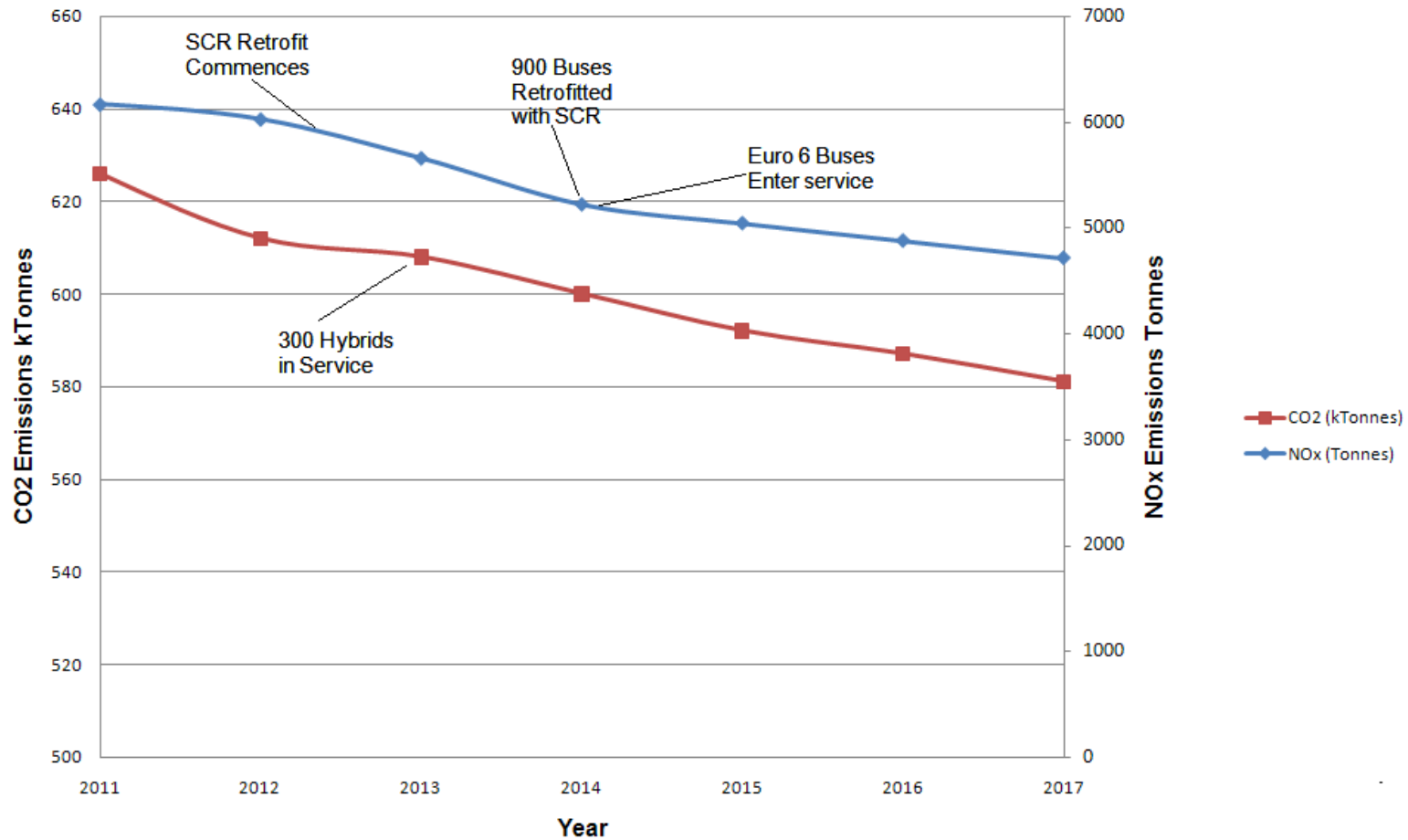
Long Term Strategy - Hydrogen Fuel Cell Buses

- Zero 'tailpipe' emission buses
- A fleet of 7 hydrogen buses are in operation (rising to eight by August)
- Aim to achieve operation as close as possible to diesel buses
- New maintenance and refuelling facility constructed within a standard bus depot



Emission Projections

Forecast Emissions



Questions?

