Air Quality and Climate Impacts of London Buses

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Energy Efficient Cities initiative

UNIVERSITY OF CAMBRIDGE

Purpose

1. Quantify the impact of transport on public health and climate
2. Inform transport policy decisions by conducting a comprehensive environmental cost benefit analysis of alternative transport technologies.

Model Features

	Current Model
Technologies	ULS Diesel Fuel, Particulate Filter, Oxidation Catalyst, SCR, EGR, CNG, Hybrid Electric
Exhaust Emissions	CO_2, PM, NO_X, HC, CO CH_4, N_2O, SO_2, BC, OC
Climate Impacts	CO_2, CH_4, N_2O, SO_2, BC, OC CH_4 leaks Hybrid battery embedded energy Catalyst embedded energy
Spatial Accuracy	50m 336,000 points 1.5% distance travelled error
Cost Analysis	Technology investment Fuel investment Social cost of carbon Health cost
Uncertainty Analysis	~100 emissions experiments Triangular distribution 1000 member MC simulation

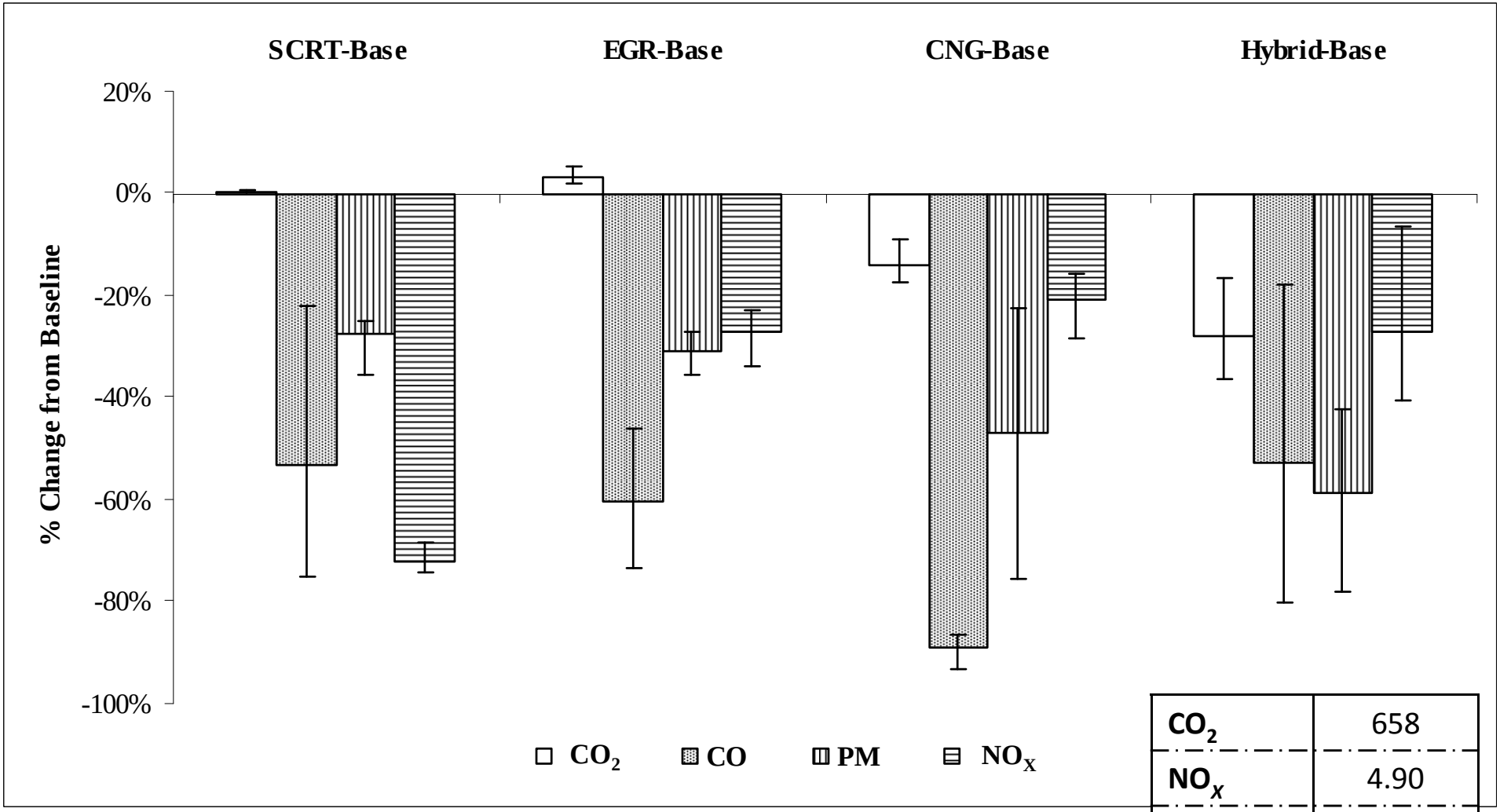
Technologies

Base Engine Level	EURO Level Composition	Baseline Scenario Exhaust Treatment	SCRT Scenario Exhaust Treatment	EGR DPF Scenario Exhaust Treatment	Hybrid or CNG Scenario
EURO II	25%	CRT	CRT + *SCR*	CRT + *EGR*	
EURO III	50%	CRT	CRT + *SCR*	CRT + *EGR*	*100% CNG or*
EURO IV	20%	SCR	SCR + *CRT*	SCR + *CRT*	*100% Hybrid*
EURO V	5%	None	None	None	

Exhaust Emissions

thousand tonnes per year	TfL or LAEI Estimate	Low Estimate	Middle Estimate	High Estimate
CO_2	646	619	658	699
NO_x	6.33	3.62	4.90	7.23
PM	0.013	0.008	0.018	0.036
CO	0.19	0.214	0.459	0.901
THC	0.07	0.0207	0.081	0.220

Exhaust Emissions



CO_2	658
NO_X	4.90
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thousand tonnes per year

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Climate Impacts (Exhaust)

Years	CH_4	N_2O	NO_X (/kg N)	CO	VOC	BC	OC	SO_2
20	72	289	-43 to 23	6 to 9.3	14	1400 to 1800	-170 to 160	-100 to -42
100	25	298	-18 to 1.6	2 to 3.3	4.5	380 to 510	-48 to 45	-29 to -12

Source: Fuglevtedt 2010

Climate Impacts (Methane Leak)

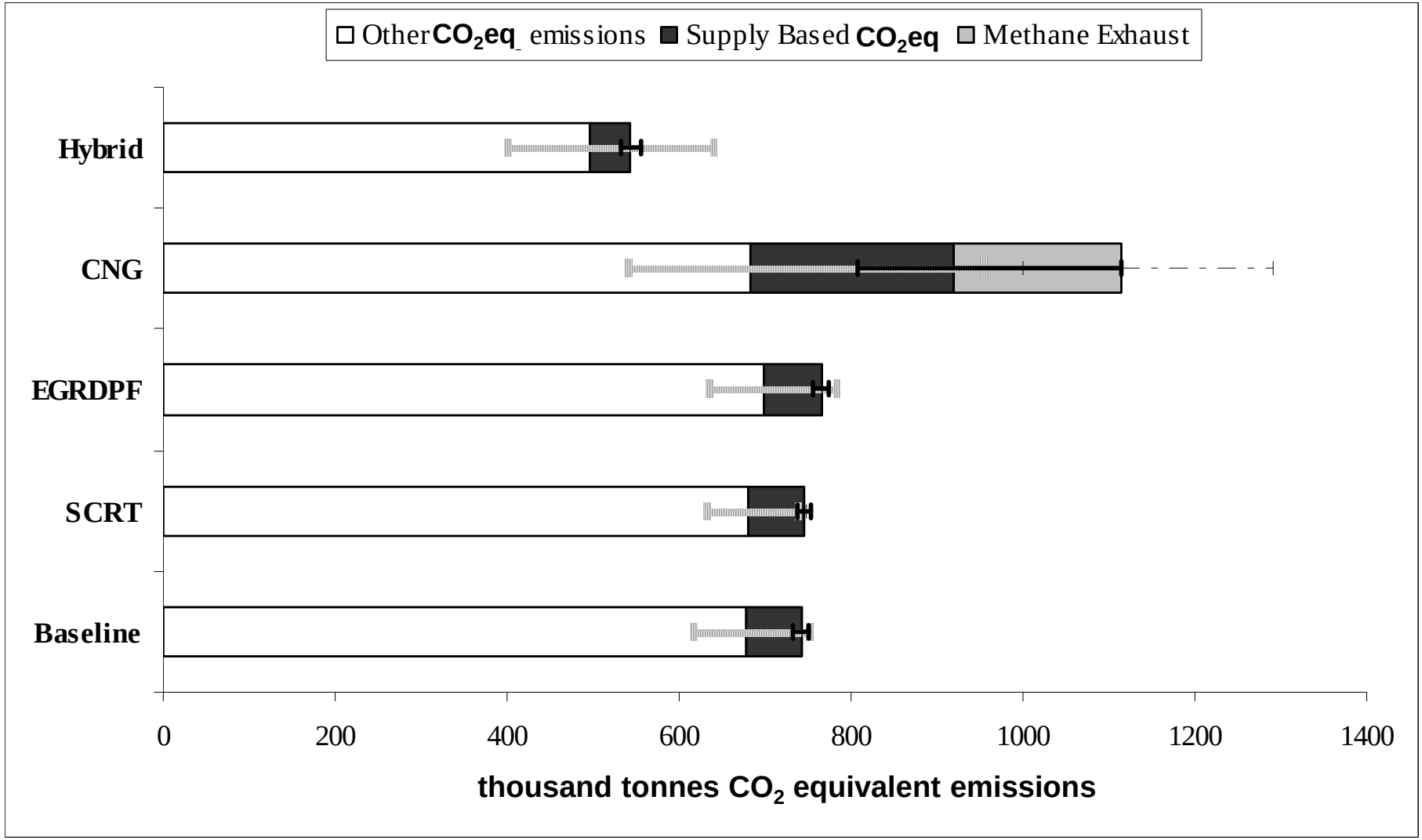
Rate at % of supply (location)	Source
0.48% (UK)	Digest of UK Energy Statistics 2010
1%-2.5% (Russia)	Lelieveld 2005
1%-2% (USA)	Lelieveld 2005
1.9%-10.8% (UK)	Mitchell 1990/1993 and Wallis 1995
1.7%-6%	Howarth 2011

Climate Impacts (Li-ion batteries)

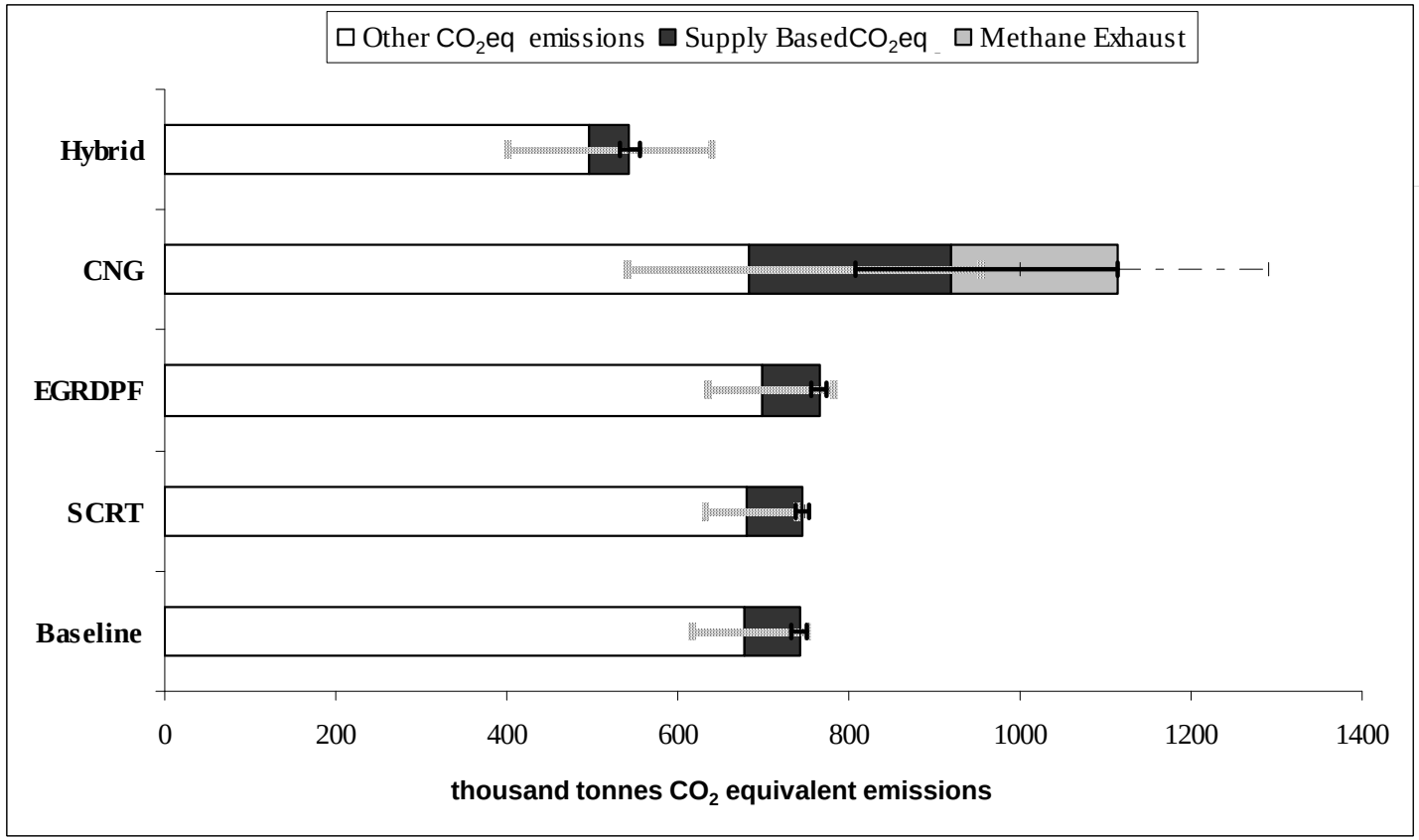
Rate (MJ-cost/kWh-batt. cap.)	Application	Source
1510-1870	Not Specific	Rydh and Sanden 2005
1700 (cites Rydh and Sanden 2005)	HEV and PHEV	Samaras and Meisterling 2008
1500 (900 without Lithium mining energy)	BEV and PHEV (assumes same chemical composition)	Notter 2010

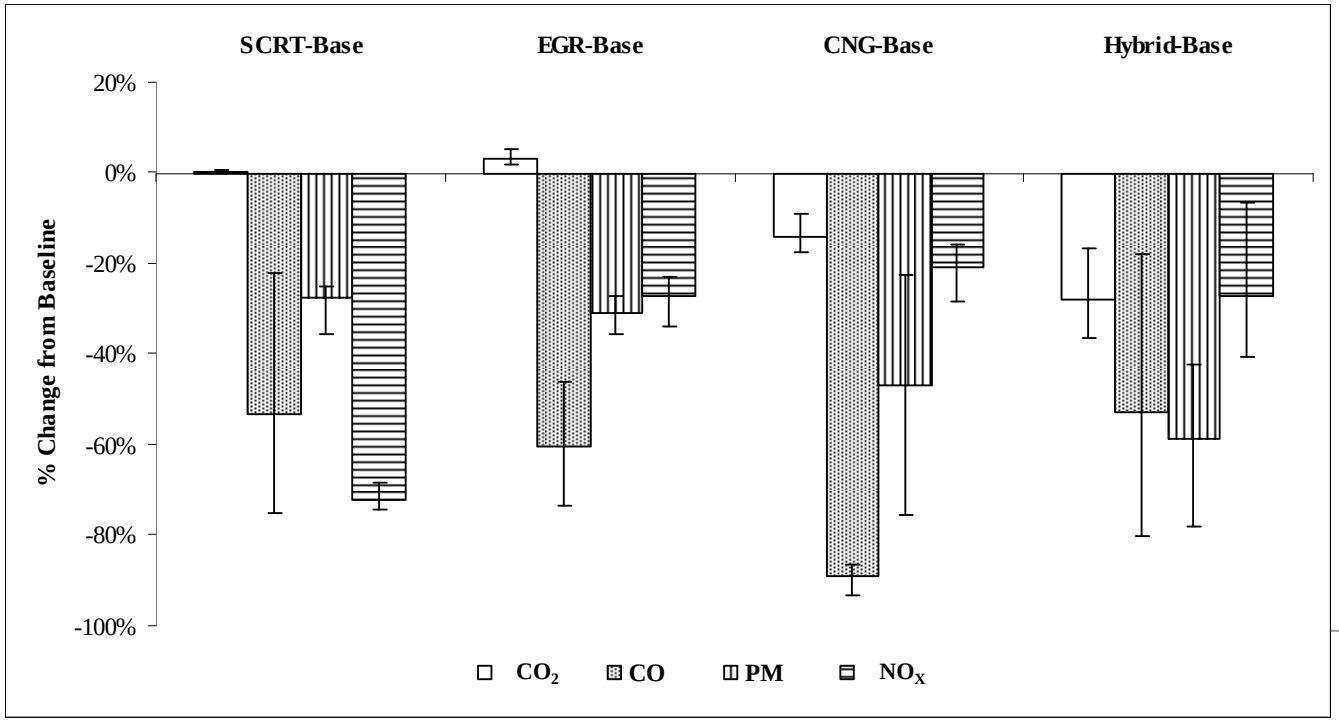
thousand tonnes of CO-eq emissions per year	Low Estimate	Middle Estimate	High Estimate
5 Year Life	4.39	6.39	9.52
6 Year Life	3.65	5.32	7.93
7 Year Life	3.13	4.56	6.80

Climate Results (CO_2 equivalent 20yrs)



Climate – Air Quality Trade-off





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thousand tonnes per year

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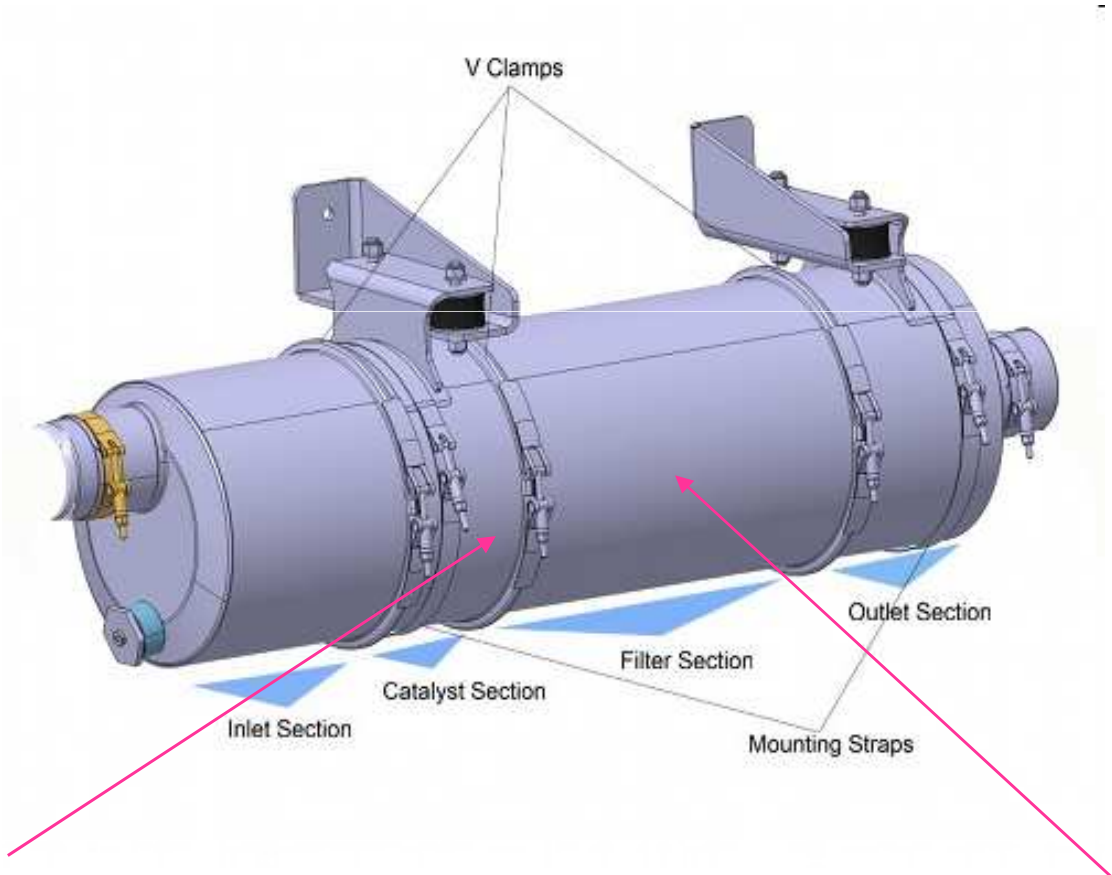
Continuously Regenerating Trap



1. Sulfur
2. Temperature
3. NO_X/PM Ratio

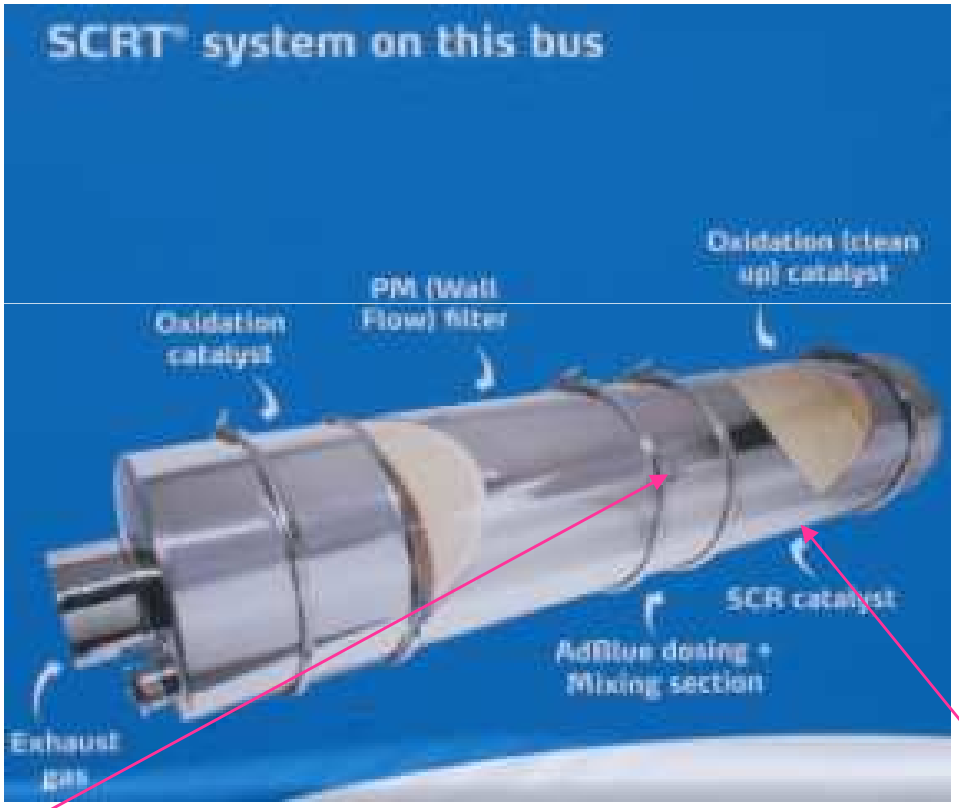
$CO + ½O_2 \rightarrow CO_2$

$[HC] + O_2 \rightarrow CO_2 + H_2O$

$NO + ½O_2 \rightarrow NO_2$

$[C] + 2NO_2 \rightarrow CO_2 + 2NO$

Selective Catalytic Reduction



$(NH_2)_2CO + H_2O \rightarrow CO_2 + 2NH_3$

+

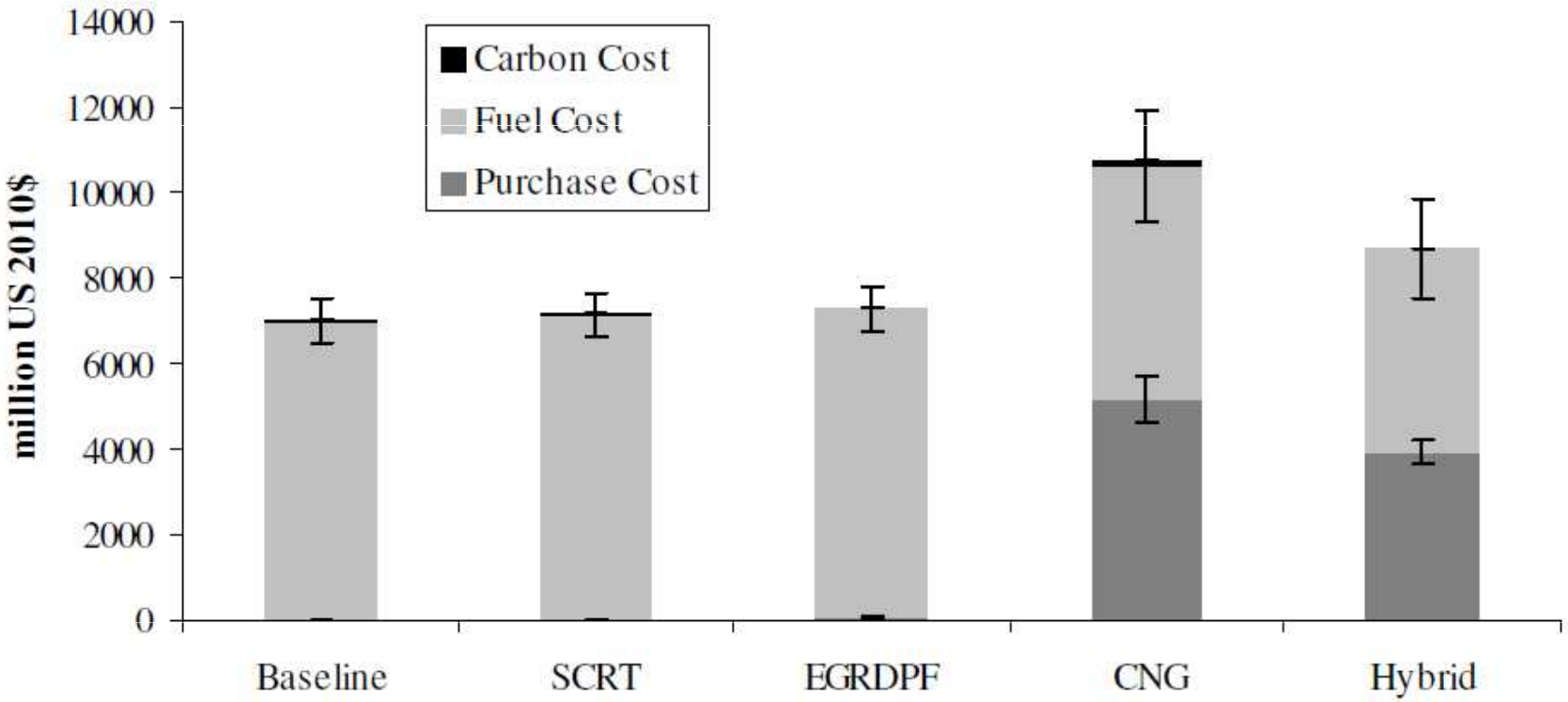
NO and NO_2 flow through

$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$

$4NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6H_2O$

$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O$

Costs



Over the course of 15 years assuming a 5% discount rate.

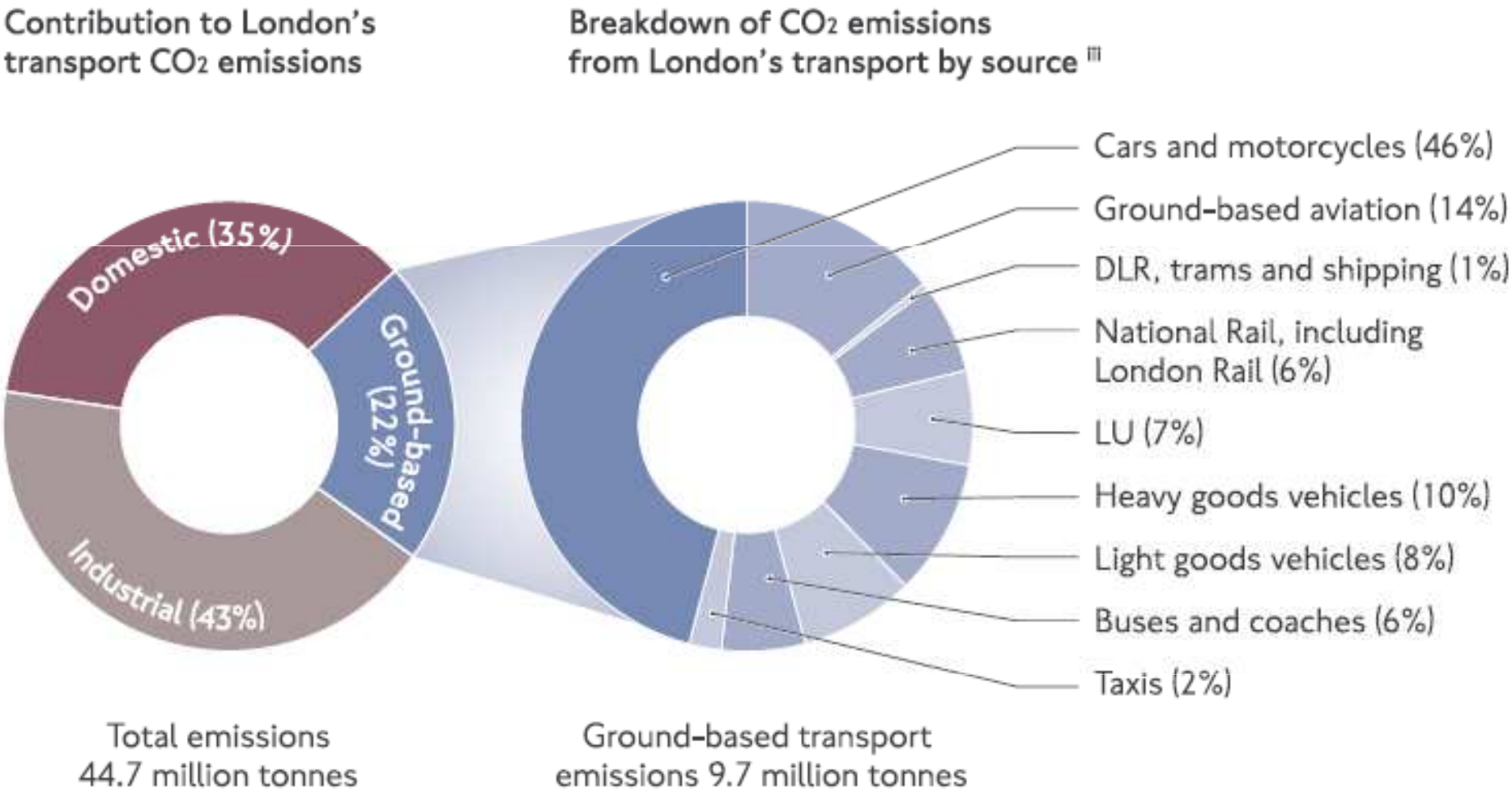
Future Work

1. CMAQ modelling
2. Cost benefit analysis

NMHC Emissions

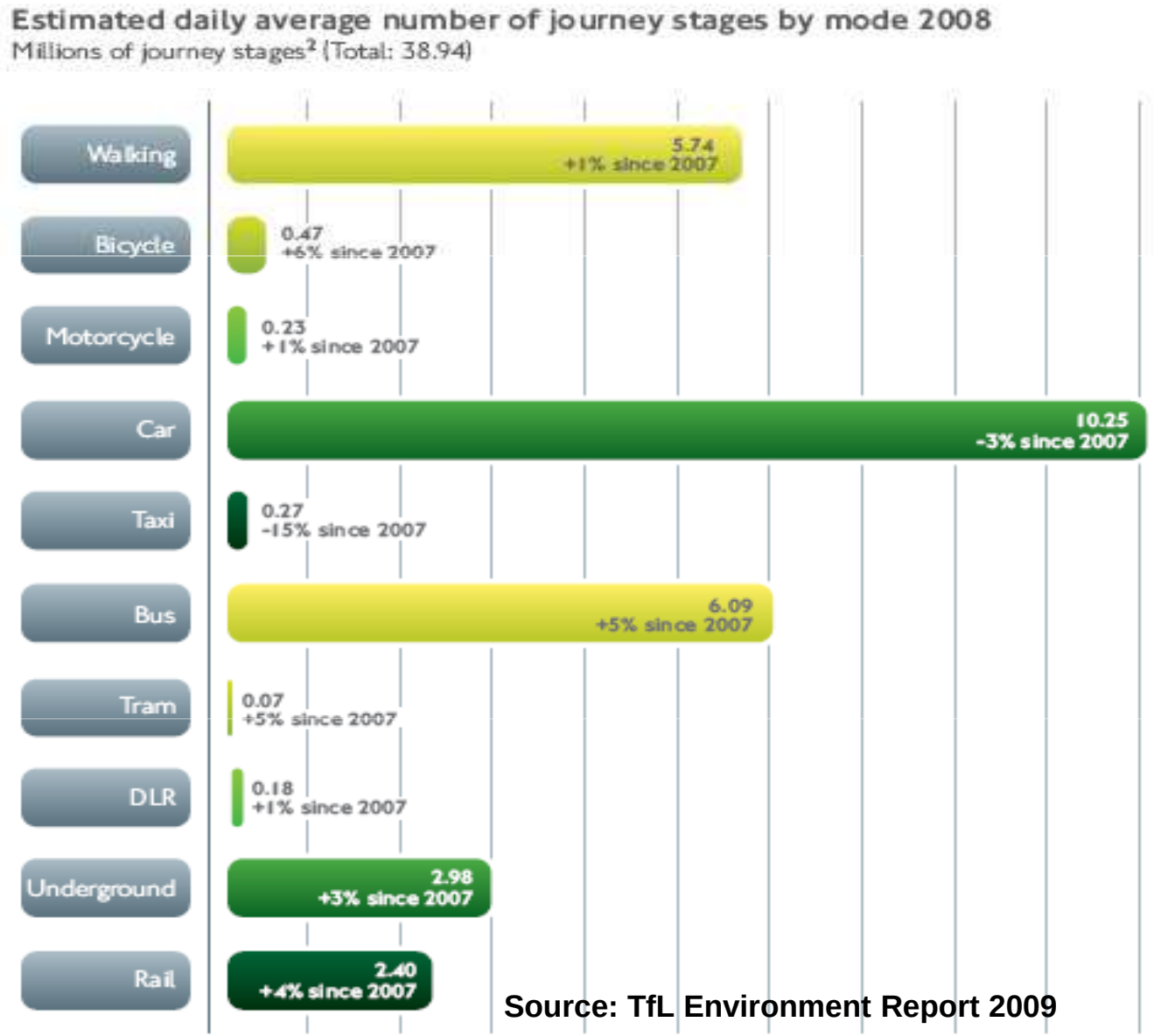
SCRT-Base	EGR-Base	CNG-Base	Hybrid-Base
-89.5%	-22.3%	3476.1%	1.65%
-80.0%	-15.5%	4979.3%	3.77%
-62.6%	-10.8%	5903.2%	9.64%

Context (CO_2 Emissions)



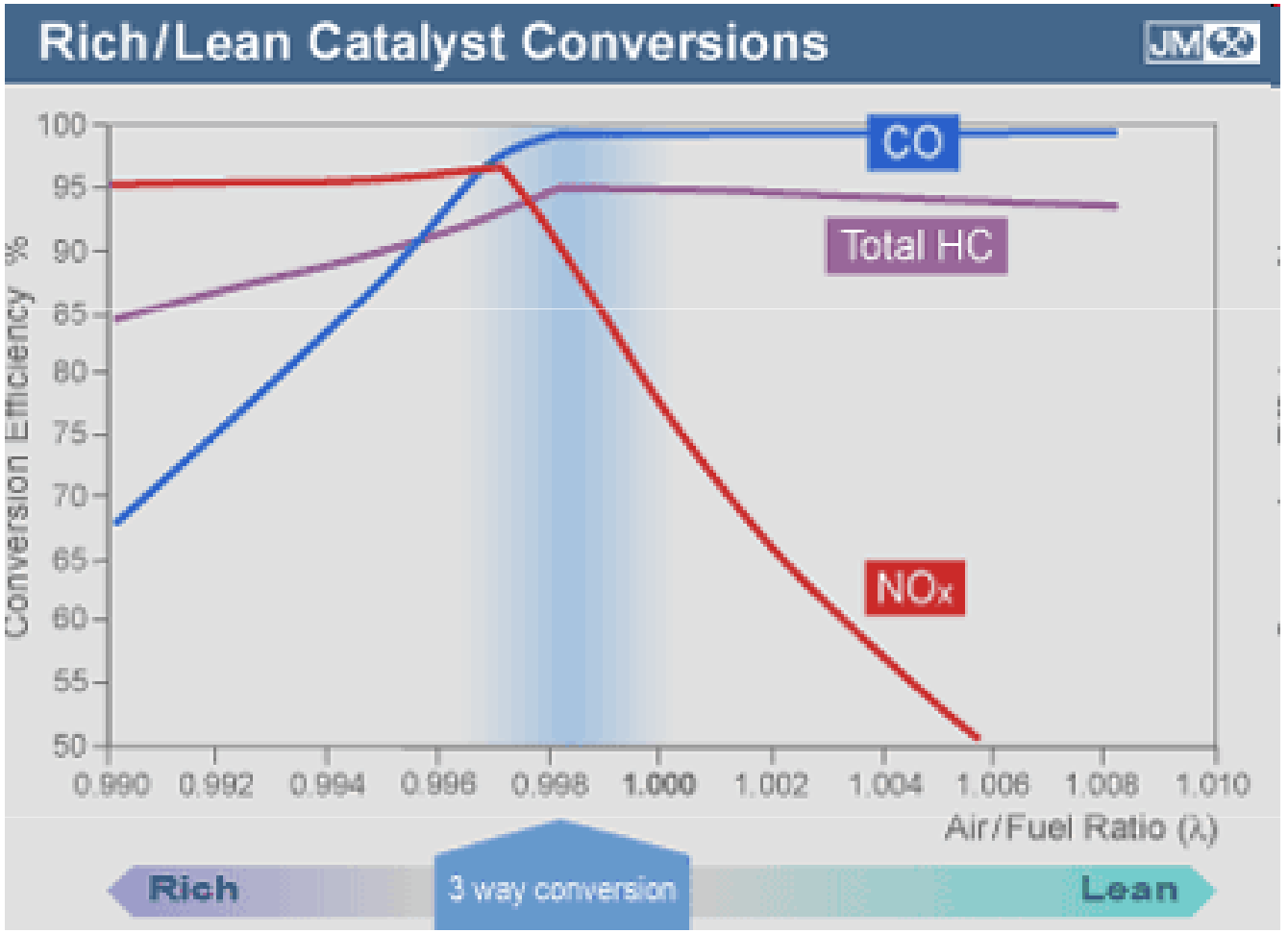
Source: TfL Environment Report 2010

Popularity of Buses



Source: TfL Environment Report 2009

Diesel versus Gasoline catalyst control



$2CO + 2NO \rightarrow 2CO_2 + N_2$

$[HC] + NO \rightarrow N_2 + CO_2 + H_2O$