Emissions performance of buses powered by engines conforming to Euro 3 emissions legislation

The Low Carbon Vehicle Partnership (LowCVP) set up a Bus Working Group to investigate how the shift to low carbon buses could be achieved. The Group's Interim Report indicated that low carbon buses could be technically feasible at a whole-life cost comparable to present buses once in full-scale production. It made recommendations on the definition, testing and certification of a low carbon bus. It recommended that initial support from Government was needed to enable the widespread early use and adoption of low carbon buses.

The UK Government's Powering Future Vehicles Strategy includes a target that by 2012 at least one in five new buses will be low carbon, with greenhouse gas emissions at least 30% below today's levels. The Bus Working Group defined the principal Greenhouse Gases (GHG) of interest to be Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). The relative "global warming potentials" for the 3 gases are 1:21:310 respectively. For current diesel bus technology, Carbon Dioxide is the main GHG constituent of vehicle exhaust, while some methane may be found in lean-burn natural gas buses.

The objectives of the Low Carbon Bus Project

The primary purpose of the Low Carbon Bus Project is to provide PowerShift grants to support fleets of low carbon buses to demonstrate their performance, reliability, operating costs and effectiveness across a range of routes. In doing so the intention is to provide the bus industry with experience of and authoritative data from the real time operation of low carbon buses, generating the confidence for bus operators to take up their use, and bus manufacturers to put them into full-scale production.

Performance specification of vehicles

The definition of a Low Carbon Bus against which applications for the project will be assessed is as follows:

- A Low Carbon Bus shall produce at least 30% fewer Greenhouse Gas (GHG) emissions than a current Euro 3 equivalent diesel bus of the same total passenger capacity. GHG emissions shall be expressed in grams of carbon dioxide equivalent and will cover "Well to Wheel" performance, thereby taking into account the production of the fuel as well as its performance from fuel tank to wheel.

- The Well to Tank (WTT) and Tank-To-Wheel (TTW) Performances shall be assessed using the reference procedures described in the Interim Report from the Low Carbon Bus Working Group. The test cycle shall be the London Buses Route 159 test cycle.

A capability to run with zero tailpipe emissions would be advantageous, particularly in urban air quality problem areas. Applications should indicate the capacity for zero tailpipe emission running where this is feasible.

Current Euro 3 diesel bus performance

A precursor to the assessment of the performance of Low Carbon Buses is the establishment of a baseline for GHG emissions generated by buses powered by Euro 3 engines.

European legislation currently only requires the determination of air quality emissions which does not include CO_2, but would include methane if the engine were fuelled by Natural Gas. Euro 3 engine emissions are measured over the European Stationary Cycle (ESC) and European Load Response (ELR) test cycles for diesel fuelled engines. Tests are also carried out over the European Transient Cycle (ETC) if a gaseous fuel fuels the engine.

None of the above test cycles factor in vehicle parameters such as mass, inertia and aerodynamic drag and only the ETC test includes acceleration and deceleration of the engine as might be experienced in “real world” operation. The ETC test is, however, based upon the FiGE truck cycle and is therefore not strictly suited to bus application.

A request for data was made to members of the Low Carbon Bus Working group for data from Euro 3 buses tested at Millbrook. The major contributions were from work sponsored by TfL and TransportEnergy although it should be acknowledged that some legislative engine dynamometer data has been submitted by some OEMs.

With respect to greenhouse gases, only CO_2 is represented within the data. Therefore further work in terms of determining levels of other GHGs would need to be commissioned for this to be represented.

Table 1 details the types of bus and their emissions levels as tested over the Millbrook London Transport Bus test cycle (Route 159). This data includes both regulated emissions and CO_2 and also represents buses fitted with exhaust aftertreatment and pre-Euro 3 buses repowered with Euro 3 engines.

Table 1: Euro 3 emissions data – Route 159 test cycle

Vehicle	HC	CO	NOx	PM	CO2	l/100km
Trident #1 DD Cummins without CRT	0.402	5.49	16.10	0.270	1461.2	55.22
Trident #1 DD Cummins with CRT	0.020	0.064	15.47	0.038	1456.0	54.66
Trident #2 DD Cummins without CRT 260 BHP	0.515	3.342	20.29	0.153	1323.5	49.94
Trident #2 DD Cummins without CRT 225 BHP	0.504	2.05	19.21	0.154	1308.4	49.34
Trident #2 DD Cummins 225 BHP with CRT	0.073	0.046	18.44	0.010	1320.8	49.59
Transbus Dennis Trident #3 DD with CRT	0.046	0.062	20.39	0.020	1372.8	51.79
Transbus Dennis Dart #1 SD Cummins no trap	0.143	1.674	15.67	0.148	1102.0	41.47
Transbus Dennis Dart #2 SD with CRT	0.011	0.064	12.35	0.010	930.3	35.73
Volvo B7TL DD with CRT	0.034	0.532	12.13	0.024	1406.0	54.03
Mercedes Citaro 12m SD with HJS CRT	0.006	0.254	12.60	0.000	1422.0	54.62
Mercedes Citaro Artic SD with HJS CRT	0.000	0.281	13.61	0.092	1585.7	59.82
DAF DB250 DD with Filter	0.133	0.066	16.70	0.008	1238.5	46.73
Leyland Olympian DD Cummins repower no trap	0.072	0.069	16.06	0.090	1288.3	48.75
Leyland Olympian DD Iveco Repower Eminox CRT	0.046	0.068	16.609	0.035	1351.9	51.00
Optare Excell Cummins ISB Re power, Std Exhaust	0.346	1.841	10.357	0.4	1118.6	42.34
Optare Excell Cummins ISB Re power, ECS Purifilter	0.031	0.103	10.566	0.015	1088.4	41.06
Optare Solo Mercedes OM 906 LA Std Exhaust	0.517	1.009	6.025	0.148	829.06	31.39
Marshall Midi Bus Cummins ISB Repower. Std Exhaust	0.16	1.08	13.34	0.09	931.12	35.20
Marshall Midi Bus Cummins ISB Repower. ECS Purifilter	0.003	0.016	13.443	0.023	968.22	36.520
Transbus Dennis Dart Dinex SCR + Trap, Urea Injection	3E-06	0.078	3.977	0.044	991.643	37.407
Transbus Dennis Dart Dinex SCR + Trap, Ammonia Injection	0.000	0.331	1.485	0.005	998.099	37.666
Transbus Dennis Dart, Dinex Trap,	0.002	0.023	11.490	0.021	996.123	37.573
Transbus Dennis Dart, OE Silencer	0.158	1.204	12.175	0.097	1030.876	38.973

At the initial first draft stage of this report it was stated that some of the data as received included information such as GVW, test inertia, number of seats, standees and total passenger numbers. This information was required in order to provide emissions figures on a gms/passenger/kilometre basis. Appendix 1 provides details of this more “complete” data set. It should be noted that the majority of vehicles within this dataset have exhaust aftertreatment and some are re-powers. A number of buses have been removed from the data set at this stage due to inertia details not being available. These include some Dennis Tridents and Darts. It is intended that these data will be included at a later stage. Comments received at the Low Carbon Bus Working Group on 4th December 2003 suggested that inclusion of vehicles repowered with Euro 3 engines might result in a data set not representative of new vehicles.

Therefore the data set which represents OEM fitted Euro 3 engines has been refined to include UVW, GVW, test inertia, number of seats and total passenger numbers. This is shown in Appendix 2.

Effect of test Inertia

The data as received were from buses which, whilst tested over the same drive-cycle (Route 159), had been loaded under different inertia setting regimes. A large proportion of buses had been tested to an inertia defined as 50% of seated passenger load, a passenger being defined as weighing 63kg. A number of the buses were tested at UVW plus 50% payload at GVW, whilst one only was tested at the recommendations of LCBWG, i.e., 50% total passenger load, a passenger being defined as weighing 68 kg. It was therefore required to normalise the effect of these load conditions before a Euro 3 CO_2 emission baseline could be determined.

By plotting the levels of CO_2 (TTW) against the test inertia of the vehicles it is possible to develop a straight-line relationship between test inertia and CO_2

The plot below shows this relationship.

Using the refined Euro 3 dataset (100% diesel powered vehicles only) the developed y = Mx + C function is:

$y = 0.0637x + 461.03$

With the above function a CO_2 level based upon a defined operational mass i.e. ULW + payload of the vehicle can be developed where:

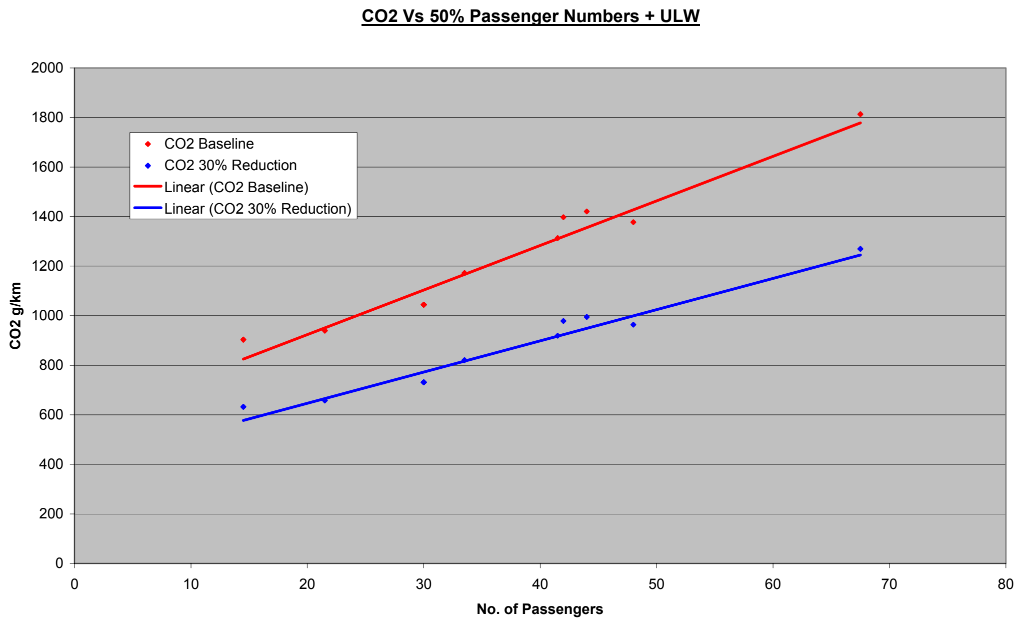
CO_2 (TTW) = 0.0637 ((number of passengers x 68Kg) + ULW) + 461.03

Determination of the baseline

The Low Carbon Bus Working Group recommended that the bus should be tested at a payload equivalent to 50% total passengers where a passenger weighs 68 kg.

The graph below shows CO_2 (TTW) in gms/km at 50% passenger loading and with the 30% Low Carbon target reduction applied

This can also be represented in terms of passenger numbers (below)



Discussion

The results presented vary slightly from the target figures initially proposed by the Low Carbon Bus Target Setting Group. These are attached as Appendix 3.

Within the data set only one bus has been tested to the LCB inertia loading condition. This is a Dennis Dart with a Cummins ISB engine. This vehicle has 31 seats with 29 standees making a total of 60 passengers.

On the 159 test, 1192 gms/km of Carbon Dioxide were measured, with zero methane and zero nitrous oxide. Tank-to-Wheel performance is therefore 1192 gms/km

45.06 l/100 km fuel consumption was measured on test. This translates into 16.18 MJ/km energy input of diesel, and the LBST study shows GHG for diesel of 10.4 gms per MJ.

Well-to-Tank GHG is therefore 168 gms/km.

Overall Well-to-Wheel is 1360 gms/km

From the Target table (Appendix 3) at 60 passengers:

Low Carbon Target is 899.8 gms/km

This represents a reduction from a measured Euro 3 powered bus of 34%, not far short of the 30% target.

From the predictive charts a bus with a capacity of 100 passengers when tested at 50% passenger loading over the 159 cycle, might be expected to produce tank to wheel CO_2 emissions in the region of 1450 gms/km. This would translate to a fuel consumption of around 54.67 l/100 km producing a well to tank figure of 204 gms/km of CO_2 i.e. an overall Well to Wheel figure of 1654 gms/km. The Low Carbon Target for a bus of 100 passengers is 1185.6 gms/km. This represents a reduction of 29%, pretty much on target for a Low Carbon Bus.

Conclusions and recommendations

- Whilst the data available for analysis has been very limited, it has proven possible to produce a relationship between vehicle mass, as tested and CO_2 emissions.
- The relationship between vehicle mass and CO_2 emissions suggest a broadly linear relationship which is not of the same characteristics as the Target Curve.
- This relationship should enable the prediction of CO_2 emissions from the full range of buses in terms of both vehicle operational mass and passengers carried.
- The original target figures proposed for Low Carbon Buses appear to be in broad agreement with those determined from this analysis. However, the target figures proposed may be argued to result in a reduction of greater than 30% at least at the lower end of the bus size range. This should be subject to discussion.
- A factor for Well-to-Tank emissions needs to be provided based upon LCVP recommendations

Acknowledgements

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Steve Bell
4 February 2004

Appendix 1: Test inertia and passenger information

Vehicle	HC	CO	NOx	PM	CO2	l/100km	Test inertia	Seats	Standees	Total
Transbus Dennis Trident #3 DD with CRT	0.046	0.062	20.39	0.020	1372.8	51.79	14222	68	20	88
Volvo B7TL DD with CRT	0.034	0.532	12.13	0.024	1406.0	54.03				
Mercedes Citaro 12m SD with HJS CRT	0.006	0.254	12.60	0.000	1422.0	54.62	13370	71	25	96
Mercedes Citaro Artic SD with HJS CRT	0.000	0.281	13.61	0.092	1585.7	59.82	18184	49	86	135
DAF DB250 DD with Filter	0.133	0.066	16.70	0.008	1238.5	46.73	13215	64	20	84
Optare Solo Mercedes OM 906 LA Std Exhaust	0.517	1.009	6.02	0.148	829.06	31.39	8530	33		43
Transbus Dennis Dart Dinex SCR + Trap, Urea Injection	3E-06	0.078	3.97	0.044	991.64	37.41	8763	31	29	60
Transbus Dennis Dart Dinex SCR + Trap, Ammonia Injection	0.000	0.331	1.48	0.005	998.0	37.66	8763	31	29	60
Transbus Dennis Dart, Dinex Trap,	0.002	0.023	11.49	0.021	996.12	37.57	8763	31	29	60
Transbus Dennis Dart, OE Silencer	0.158	1.204	12.17	0.097	1030.87	38.97	8763	31	29	60
Dennis Dart, Cummins ISB	0.206	1.423	14.73	0.154	1191.8	45.06	9114	31	29	60
Leyland Olympian DD Iveco Repower Eminox CRT	0.046	0.068	16.61	0.035	1351.9	51.00	13380			83
Optare Excell Cummins ISB Re power, Std Exhaust	0.346	1.841	10.36	0.4	1118.6	42.34	10380	41	26	67
Optare Excell Cummins ISB Re power, ECS Purifilter	0.031	0.103	10.57	0.015	1088.4	41.06	10380	41	26	67
Marshall Midi Bus Cummins ISB Repower. Std Exhaust	0.16	1.08	13.34	0.09	931.12	35.20	7090	29	29	29
Marshall Midi Bus Cummins ISB Repower. ECS Purifilter	0.003	0.016	13.44	0.023	968.22	36.52	7090	29	29	29

Appendix 2: Test inertia and passenger information – no re-powered vehicles

Vehicle	HC	CO	NOx	PM	CO2	l/100km	Test inertia	Seat	Standees	Total
Transbus Dennis Trident #3 DD with CRT	0.046	0.062	20.39	0.020	1372.8	51.79	14222	68	20	88
Volvo B7TL DD with CRT	0.034	0.532	12.13	0.024	1406.0	54.03				
Mercedes Citaro 12m SD with HJS CRT	0.006	0.254	12.60	0.000	1422.0	54.62	13370	71	25	96
Mercedes Citaro Artic SD with HJS CRT	0.000	0.281	13.61	0.092	1585.7	59.82	18184	49	86	135
DAF DB250 DD with Filter	0.133	0.066	16.70	0.008	1238.5	46.73	13215	64	20	84
Optare Solo Mercedes OM 906 LA Std Exhaust	0.517	1.009	6.025	0.148	829.06	31.39	8530	33		43
Transbus Dennis Dart Dinex SCR + Trap, Urea Injection	3E-06	0.078	3.977	0.044	991.643	37.407	8763	31	29	60
Transbus Dennis Dart Dinex SCR + Trap, Ammonia Injection	0.000	0.331	1.485	0.005	998.099	37.666	8763	31	29	60
Transbus Dennis Dart, Dinex Trap,	0.002	0.023	11.490	0.021	996.123	37.573	8763	31	29	60
Transbus Dennis Dart, OE Silencer	0.158	1.204	12.175	0.097	1030.876	38.973	8763	31	29	60
Dennis Dart Cummins ISB	0.206	1.423	14.73	0.154	1191.8	45.06	9114	31	29	60

Appendix 3: The Target Figures, as used in the Chart

Target GHG emissions in g/km by max passenger capacity

Pass	g/km	Pass	g/km	Pass	g/km
20	285.3	61	909.1	102	1196.6
21	312.6	62	918.2	103	1202.1
22	338.6	63	927.1	104	1207.5
23	363.5	64	935.9	105	1212.8
24	387.3	65	944.6	106	1218.1
25	410.1	66	953.1	107	1223.4
26	432.1	67	961.6	108	1228.6
27	453.2	68	969.8	109	1233.8
28	473.5	69	978.0	110	1238.9
29	493.2	70	986.1	111	1243.9
30	512.1	71	994.0	112	1248.9
31	530.5	72	1001.8	113	1253.9
32	548.2	73	1009.5	114	1258.8
33	565.4	74	1017.1	115	1263.7
34	582.1	75	1024.6	116	1268.6
35	598.3	76	1032.1	117	1273.4
36	614.1	77	1039.4	118	1278.1
37	629.4	78	1046.6	119	1282.9
38	644.3	79	1053.7	120	1287.5
39	658.9	80	1060.7	121	1292.2
40	673.0	81	1067.7	122	1296.8
41	686.8	82	1074.6	123	1301.3
42	700.3	83	1081.3	124	1305.9
43	713.5	84	1088.0	125	1310.4
44	726.3	85	1094.7	126	1314.8
45	738.9	86	1101.2	127	1319.2
46	751.2	87	1107.7	128	1323.6
47	763.2	88	1114.1	129	1328.0
48	775.0	89	1120.4	130	1332.3
49	786.6	90	1126.6	131	1336.6
50	797.9	91	1132.8	132	1340.8
51	808.9	92	1138.9	133	1345.1
52	819.8	93	1145.0	134	1349.3
53	830.4	94	1150.9	135	1353.4
54	840.9	95	1156.9	136	1357.5
55	851.2	96	1162.7	137	1361.6
56	861.2	97	1168.5	138	1365.7
57	871.1	98	1174.3	139	1369.7
58	880.9	99	1179.9	140	1373.8
59	890.4	100	1185.6	141	1377.7
60	899.8	101	1191.1	142	1381.7