

## Summary

This analysis compares the emissions per passenger-km and per tonne-km from the UK's national rail network with the emissions that would arise if that function were discharged by express coaches and lorries using roads occupying rail's right of way and managed to avoid congestion. The data is for the year 2002/3 and the road vehicle emissions assume Euro II standards. The reason for the year base is Network Rail's inability, or refusal, to divulge later fuel consumptions.

For passenger rail we assumed replacement express coaches would return 10 miles per (imperial) gallon with an average occupancy of 20 passengers. On that basis the replacement coaches would reduce carbon emissions attributable to rail passengers by 28%, CO by 55%: NO<sub>x</sub>, by 26% and SO<sub>x</sub>, by close to 100%. (The latter arises because sulphur has been virtually eliminated from the fuels used by road vehicles but not from that used by trains and power stations).

For freight we assumed lorries return 8 miles per gallon with an average load of 15 tonnes (30 tonnes out back empty). On that basis the replacement lorries would emit the same carbon as the trains, 23% less CO, 32% **more** NO<sub>x</sub> and close to 100% less SO<sub>x</sub>.

We also provide the emissions per passenger-km by diesel car assuming 1.5 passengers per vehicle and a fuel consumption of 45-50 miles per gallon. Under that assumption the carbon emission per passenger-km by car is double that of rail and 3 times that of the express coach cited above.

However:

- (a) The average journey by car is 8.7 miles, compared with 25 on the line haul element of a rail journey.
- (b) Where the main mode is rail the average distance traveled is 7.5 miles more than the line haul element.

Hence, if half the 7.5 miles at (b) is by car and the rest by tube (here taken as equivalent to rail in terms of emission) then the carbon emission from the rail journey as a whole will be the same as a line haul by rail of 36 miles (i.e.  $25 + 7.5 \times 1.5 = 36.25$ ). It follows that the carbon emissions per passenger journey by car are likely to be less than half those where the main mode is rail - i.e.  $8.7 \times 2/36 = 0.48$ .

## Comment

The **carbon** comparisons presented by the rail industry and by the DfT always show rail with a significantly lower carbon emission than bus, coach or lorry. In contrast we show the reverse of that for express coach and equality for the lorry. The reason will lie in the vehicle occupancy and fuel consumptions assumed. For example, a bus on a city street may return only 5 miles per gallon and carry an average of only 9 passengers. Hence those buses yield less than one quarter the passenger-miles per gallon of an express coach returning 10 miles per gallon with 20 passengers aboard. Similarly (a) a lorry suffering congestion may return perhaps 4-5 miles per gallon overall, rather than the 8 that we have used and (b) 70% of rail freight is bulk freight, leading to heavier loads than typical road freight.

Further, the official comparisons have little practical application since (a) there is little or no possibility of people in buses on city streets and cars or lorry freight transferring to trains or vice-versa and (b) the conditions that road vehicles suffer are not comparable to those enjoyed by trains. In contrast our comparisons are like for like. They are useful in that they show the reduction, or change, in emissions that paving the railways would enable.

Separately from that we note that 20% of electricity is from nuclear sources. Hence, the comparisons we, and others, present understate the environmental impact of rail by omitting (a) the effect of nuclear waste and (b) the substantial amounts of CO<sub>2</sub> required to mine and refine uranium.

## Summary procedures

We already have from Network Rail the electricity and fuel consumptions along with passenger and tonne-km for 2002/3, see Facts Sheet 5. Melanie Hobson of AEA Technology provided the emissions from diesel trains, Appendix 1. We calculated the emissions from electric traction by

multiplying the emissions from all (UK) power stations by the ratio of electricity used by the trains to total electricity supplied. The CO<sub>2</sub> emissions from power stations are available from special features Table 1 of the DTI's Energy Trends. Other emissions from power stations are from Defra's e-digest of air quality statistics.

The carbon, CO and NO<sub>x</sub> emissions from burning a litre of diesel in a road vehicle are calculated using data from the NAEI warehouse (AEA Technology) using a speed of 100 kph as input. The SO<sub>x</sub> emission is from Melanie Hobson of AEA Technology citing 0.072 gms of SO<sub>2</sub> per Kg. That data, together with fuel economy and vehicle occupancy assumptions, enabled emissions per passenger or tonne-km to be calculated.

(We here note the fuel consumptions for artics operating at 100 kph estimated by the NAEI data is 4.3 miles per gallon. That is unrealistically low according to industry sources. E.g. <http://www.tnn.co.uk/RoadTests>)

The following table summarises the results of calculations

**Table 1. Emissions: Grams per passenger-km or tonne-km for the year 2002/3**

	<b>Carbon *</b>	<b>CO</b>	<b>NO<sub>x</sub></b>	<b>SO<sub>x</sub></b>
Network South East	12.5	0.030	0.202	0.193
Regional	14.7	0.099	0.849	0.108
Intercity	16.9	0.174	0.525	0.134
<b>All Network Rail passengers</b>	<b>14.4</b>	<b>0.099</b>	<b>0.435</b>	<b>0.157</b>
Express coach 10 mpg with 20 passengers	10.3	0.044	0.319	0.001
Diesel car, 50 mpg with 1.5 passengers	27.3	0.038	0.419	0.002
Diesel car, 45 mpg with 1.5 passengers	30.4	0.025	0.456	0.003
<b>Rail freight</b>	<b>17.2</b>	<b>0.113</b>	<b>0.368</b>	<b>0.064</b>
Artic 8 mpg, 15 tonne load (30 out back empty)	17.1	0.087	0.485	0.001

\* Carbon may be converted to CO<sub>2</sub>: by multiplying by 44/12 = 3.67. Also note the carbon is total carbon

Further and referring to rail – the annual carbon emissions from table 2 total 890,156 tonnes.

#### **Electricity generation and emissions from power stations:**

Table 5.2 of Energy Trends provides a total of 395,000 GWh in 2002 of which 9,182 was imported, 17,126 used by the power stations themselves plus 3,463 in pumped storage with 29,980 lost in transmission. Hence a control total for use in factoring emissions is (395,000 - 17,126 - 3,463 - 29,980) = **344,431 GWh**. There is then the option, not here adopted, of factoring emissions up by 2.5% to take account of imports. The source for that is Energy Trends Table 5.2 [www.dti.gov.uk/files/file17410.xls](http://www.dti.gov.uk/files/file17410.xls).

Total emissions from power stations in 2002/3 were:

Carbon: 44 million tonnes

see Energy Trends Special Topics Table 1 in [www.dti.gov.uk/files/file27084.pdf](http://www.dti.gov.uk/files/file27084.pdf)

- 1 CO: 77 thousand tonnes (Defra Air Quality Table 13)
- 2 NO<sub>x</sub>: 431 thousand tonnes (Defra Air Quality Table 6)
- 3 SO<sub>x</sub>: 733 thousand tonnes (Defra Air Quality Table 8)

**To access Defra Air Quality Tables see:**

**<http://www.defra.gov.uk/environment/statistics/airqual/alltables.htm>**

#### **Rail**

In Table 2 Passenger and tonne-km along with rail's fuel consumption are from Network Rail, see facts sheet 5, and the diesel emissions are from Appendix 1 provided by AEA Technology. The emissions due to electricity used in traction are calculated by multiplying the total emissions from all electricity generation cited above by the ratio of the electricity used to the total supply, namely the **343,431 GWh**, also cited above. The emboldened data in the table was taken forward to Table 1

**Table 2. Data and emissions for rail.**

	<b>Network South East</b>	<b>Regional</b>	<b>Intercity</b>	<b>Totals/ Average</b>	<b>Freight</b>
Passenger or tonne-km (Billion)	18.9	7.8	12.9	39.6	18.7
Electricity consumption GW-h	1676	273	591	2540	95
Diesel fuel (litres, millions) Split as in 1990	28.5	104	132	264.5	265
CO2 from electricity Tonnes <b>Carbon</b> Tonnes (a)	214103	34815	75498	324477	12135
CO2 from diesel was ref. Appendix 1 Tonnes	21729	79292	142586	243607	308956
<b>Hence gms carbon per passenger-km are: (b)</b>	<b>12.5</b>	<b>14.7</b>	<b>16.9</b>	<b>14.4</b>	<b>17.2</b>
CO from electricity Tonnes	376	61	133	569	21
CO from diesel was ref. Appendix 1	194	710	2106	3010	2095
<b>Hence gms of CO per passenger-km are:</b>	<b>0.030</b>	<b>0.099</b>	<b>0.174</b>	<b>0.090</b>	<b>0.113</b>
NOx from electricity Tonnes	2103	343	742	3188	119
NOx from diesel was ref. Appendix 1	1721	6279	6028	14028	6766
<b>Hence gms of NOx per passenger-km are:</b>	<b>0.202</b>	<b>0.849</b>	<b>0.525</b>	<b>0.435</b>	<b>0.368</b>
SOx from electricity Tonnes	3577	583	1261	5421	203
SOx from diesel was ref. Appendix 1	70.5	257.5	463	791	1002
<b>Hence gms of SOx per passenger-km are:</b>	<b>0.193</b>	<b>0.108</b>	<b>0.134</b>	<b>0.157</b>	<b>0.064</b>

(a) typical calculation: Intercity:  $44 \times 1,000,000 \times 591/343,341 = 75.718$  tonnes

(b) typical calculation: Intercity:  $(75,718 + 142,546) \times 1,000,000 / (12.9 \times 1,000,000,000) = 16.92$  gms

### Road vehicles

Given the emissions per litre of diesel when burnt in a modern vehicle, plus fuel economy and occupancy data, it is a simple matter to calculate emissions per passenger or tonne-km. Here is the detail.

Item 3 within the NAEI warehouse [http://www.naei.org.uk/data\\_warehouse.php](http://www.naei.org.uk/data_warehouse.php) provides data on fuel consumptions and emissions in grams per km for a range of vehicles and speeds. We have used 100 kph. However, as noted above, the fuel consumptions for artics appear suspect in that the system gives the fuel consumption for such a vehicle as 546 grams per km, equivalent to only 4.3 miles per gallon. In reality an artic will cruise at 8 miles per gallon. For that reason we have (a) used the NAEI warehouse data to calculate the emissions per gram burnt and (b) applied those values to our own estimates of fuel consumptions for vehicles cruising on railway alignments. The detail is summarised in Table 3 below. Data from the last 4 rows was taken forward to Table 1.

**Table 3 Emissions in Gms/Kg, miles per gallon, and gms/passenger-km assuming Euro II**

<b>Emission</b>	<b>Car &lt; 2.0 l</b>	<b>Car &gt; 2.0 l</b>	<b>Bus/coach</b>	<b>Rigid lorry</b>	<b>Artic</b>
	<b>Grams per Kg of fuel (ex Table 4)</b>				
Carbon	860	860	860	860	860
CO	1.18	0.72	3.73	3.81	4.36
NOx	13.2	12.9	26.8	26.7	24.4
SOx	0.072	0.072	0.072	0.072	0.072
	<b>Miles per imperial gallon and occupancy assumptions</b>				
Mpg	50	45	10	8	8
Occupancy	1.5	1.5	20	15	15
	<b>Hence, Grams per passenger-km or tonne-km</b>				
Carbon	27.331	30.368	10.249	17.082	17.082
CO	0.038	0.025	0.044	0.075	0.087
NOx	0.419	0.456	0.319	0.530	0.485
SOx	0.002	0.003	0.001	0.001	0.001

### Typical calculation

Bus coach: carbon:

UK Gallons per passenger-mile =  $1/10 \times 20 = 1/200$

Hence Kg diesel per km = Gallons per Litre, 4.54 x Specific Gravity diesel, 0.84 x Km/miles, 0.625/200

Hence carbon grams per km =  $860 \times 4.54 \times 0.84 \times 0.625/200 = 10.24$

Table 4 cites the NAEI warehouse emissions, fuel consumptions and corresponding percentages of emissions to fuel. The values taken forward to Table 3 are emboldened. The rest are available for reference.

Separately from that Table 4 data shows lower fuel consumptions and higher carbon emissions as emissions standards for NO<sub>x</sub>, SO<sub>x</sub> and CO tighten. That is the penalty of both the higher standards and heavier vehicles (or at least heavier cars) due to safety requirements.

(In the absence of fuel consumptions beyond Euro II in the source we have set those at the Euro II levels).

**Table 4 Emissions detail**

Standard	Vehicle / CC	Emissions at 100 Kph: Gms per Km from the NAEI warehouse (a)				Calculated miles per gallon	Emissions as % fuel		
		Fuel	Carbon	NOx	CO		Carbon	NOx	CO
<b>Diesel Cars</b>									
Pre-Euro I	< 2.0 l	43.23	37.05	0.61	0.41	55.135	85.7	1.41	0.948
	> 2.0 l	51.12	43.81	0.90	0.42	46.626	85.7	1.76	0.822
Euro I	< 2.0 l	50.06	42.9	0.59	0.19	47.613	85.7	1.18	0.380
	> 2.0 l	59.98	51.4	0.56	0.1	39.738	85.7	0.93	0.167
Euro II	< 2.0 l	50.83	43.56	0.67	0.06	46.892	<b>85.7</b>	<b>1.32</b>	<b>0.119</b>
	< 2.0 l	55.89	47.9	0.72	0.04	42.646	<b>85.7</b>	<b>1.29</b>	<b>0.072</b>
Euro III	< 2.0 l	50.83		0.67	0.033			1.32	0.065
	> 2.0 l	55.89		0.72	0.025			1.29	0.045
Euro III + trap	< 2.0 l	50.83		0.67	0.033			1.32	0.065
	> 2.0 l	55.89		0.72	0.025			0.129	0.045
5Euro IV car	< 2.0 l	50.83		0.33	0.033			0.65	0.65
	> 2.0 l	55.89		0.36	0.025			0.64	0.045
Euro IV+trap	< 2.0 l	50.83		0.334	0.033			0.66	0.065
	> 2.0 l	55.89		0.362	0.025			0.65	0.045
<b>HGVs</b>									
Pre 1988	Rigids	243.99	209.1	13.53	2.52	9.769	85.7	5.55	1.033
	artics	409.8	351.2	20.7	3.3	5.816	85.7	5.05	0.805
1988 - 1993	rigids	241.74	207.17	6.66	1.94	9.86	85.7	2.76	0.803
	artics	408.15	349.78	11.16	2.52	5.84	85.7	2.73	0.617
Euro I	rigids	238.83	204.68	7.53	1.17	9.98	85.7	3.15	0.490
	artics	628.21	538.38	20.03	3.29	3.794	85.7	3.19	0.524
Euro II	rigids	233.61	200.2	6.23	0.89	10.203	<b>85.7</b>	<b>2.67</b>	<b>0.381</b>
	artics	546.49	468.34	13.36	2.38	4.361	<b>85.7</b>	<b>0.44</b>	<b>0.436</b>
Euro III	rigids	233.61		4.3	0.886			1.84	0.379
	artics	546.49		9.22	2.383			1.69	0.436
Euro IV	rigids	233.61		3.05	0.62			1.31	0.265
	artics	546.49		6.55	1.668			1.20	0.305
Euro IV +2008	rigids	233.61		1.75	0.452			0.75	0.193
	artics	546.49		3.74	1.215			0.68	0.222
<b>Buses</b>									
Pre-1988		260.06	222.87	13.22	10.34	9.165	85.7	0.0508	3.976
1988 - 1993		255.22	218.72	6.93	4.59	9.339	85.7	0.0272	1.798
Euro I		224.35	192.27	6.78	1.09	10.624	85.7	0.0302	0.486
Euro II		222.27	190.49	5.95	0.83	10.723	85.7	0.0268	0.373
Euro III		222.27	190.49	4.108	0.582	10.723	85.7	0.0185	0.262
Euro IV		222.27	190.49	2.917	0.424	10.723	85.7	0.0131	0.191
Euro IV +2008		222.27	190.49	1.667	0.424	10.723	85.7	0.0075	0.191

(a) Except SOx which is from Melanie Hobson of AEA Technology citing 0.0732 gms of SO2 per Kg of diesel or petrol, falling by a factor of 5 by 2009.

**Typical calculation of MPG.**

Invert grams per km, multiply by 1000 and be 0.84, the specific gravity of diesel. That yields km per litre. Multiply by 4.54 and by 0.625 to convert to miles per gallon.

E.g. for the first row in the table: Miles per gallon = 840 x 4.54 x 0.625/43.23 = 55.135.

## Appendix 1 Emissions in tonnes from the railway sector (diesel trains only)

Data provided by AEA Technology, May 2006.

Year	Inter-city trains				Regional trains				Freight trains			
	CO2 as C	CO	NOx	SO2	CO2 as C	CO	NOx	SO2	CO2 as C	CO	NOx	SO2
1990	129,203	1,864	6,278	633	124,893	1,304	6,322	612	231,641	1,201	2,928	1135
1991	129,276	1,865	6,282	634	125,176	1,687	6,601	613	248,436	1,154	2,938	1218
1992	133,919	1,432	4,726	625	123,582	1,852	6,648	577	277,194	2,048	6,144	1294
1993	134,418	1,438	4,744	627	123,937	1,670	6,536	578	246,148	1,819	5,456	1149
1994	127,573	1,597	5,330	536	122,742	1,126	5,656	516	217,140	1,431	4,459	912
1995	124,495	1,806	6,038	407	131,826	1,210	6,074	431	214,064	1,219	4,360	699
1996	126,919	1,841	6,155	415	134,392	1,233	6,193	439	243,035	1,384	4,950	794
1997	128,104	1,858	6,213	419	135,647	1,245	6,250	443	292,984	1,668	5,967	957
1998	142,273	2,064	6,900	465	145,046	1,331	6,683	474	293,547	1,672	5,979	959
1999	152,754	2,216	7,408	488	148,499	1,363	6,843	475	304,392	1,733	6,200	973
2000	157,219	2,281	7,625	484	151,297	1,388	6,971	466	301,796	1,719	6,147	930
2001	166,147	2,410	8,058	465	153,133	1,405	7,056	429	312,244	1,778	6,360	874
<b>2002</b>	<b>142,586</b>	<b>2,106</b>	<b>6,028</b>	<b>463</b>	<b>101,021</b>	<b>904</b>	<b>8,000</b>	<b>328</b>	<b>308,956</b>	<b>2,095</b>	<b>6,766</b>	<b>1002</b>
2003	119,948	1,390	4,420	431	88,770	725	7,057	319	312,260	2,117	6,838	1122
2004	123,307	1,429	4,544	429	90,546	740	7,198	315	341,999	2,319	7,490	1189

Note:

Regional Trains include Network South East. We have divided those emissions between the two sectors according to the diesel consumptions for those sectors available to us for 1990.

It is the emboldened data for 2002 that has been taken forward to calculations. Note that the emissions for 2004 are substantially lower. That is because diesel traction is being phased out and implies a corresponding increase in electricity use.

Also, the total carbon emission from rail in 2002 from above, namely 552,563 Kg is substantially higher than implied by the total diesel consumption of 530 million litres from Table 2 and provided to us by Network Rail. Multiplying that by the specific gravity of 0.84 and by the carbon per Kg of 0.86kg yields 382,872 Kg. Hence either Network Rail's numbers are light or AEAs are heavy.