

# Facts sheet 5(b) - Carbon emissions: high-speed rail and air compared

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### CAVEAT

The abstract of a paper by Mikhail V Chester and Arpad Horvath illustrates how vital it is to have dust to dust estimates of energy consumptions and emissions. There we see the estimates of life cycle energy inputs and emissions in the USA add 63% to the tailpipe values for road vehicles, 31% for air and 155% for rail. **Click here to see the source.**

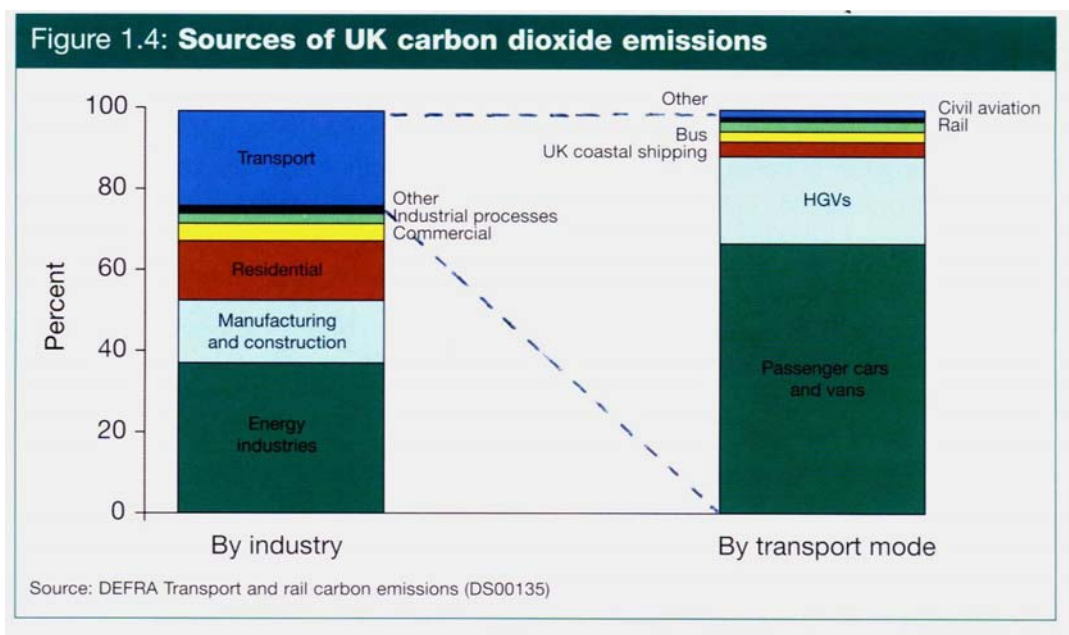
Instead of that nearly all UK emission studies deal with tail pipe emissions alone.

Consequently the conclusions of all those studies may turn out to be unsustainable along with policy depending upon them.

### Preamble

Those promoting high-speed rail make much of the supposed carbon emission saving that may result if internal air passengers transferred to high-speed rail. However, the proportion of the nation's emissions that can be attributed to air or rail is vanishingly small, see below. Hence, any transfer of passengers from one mode to the other can only have an even more vanishingly small effect.

For that reason alone the emissions argument made by those lobbying for high-speed rail should probably be ignored.



(This figure is from the White Paper, Delivering a Sustainable Railway, July 2007)

## Summary results

The carbon emissions for rail depend on whether the average emissions from the UK generating industry are used, or those relating to coal-fired generation. The reason for the latter is that large scale electrification may extend the life of coal-fired generation. In this note values for both assumptions are provided, coal-fired generation emitting twice as much as the industry average.

The emissions for high speed rail are based on a 40% load factor. The tailpipe values in grams per 100 passenger-km have the range of 4150 to 8300 for a train at 200 kph. In contrast Ryan Air may return 8475 gms per 100 passenger-km. However, if these values are inflated to provide life cycle values, as suggested in the caveat, the range for rail is 10,600 gms to 21,200 gms and the value for Ryan Air is 11,100 gms.

Against that background it seems premature to claim that high-speed rail will have substantially lower emissions than air travel when precisely the reverse may be the case.

## Data sources and detailed results

Except where stated the data which follows relates to tailpipe fuel consumptions and emissions.

Appendix 1 sourced from the BERR, provides (A) circa 150 Tonnes of carbon per GWh (550 tonnes of carbon dioxide) if we assume average emissions or (B) circa 300 Tonnes per GWh (1,100 tonnes of carbon dioxide) if emissions are related to coal-fired generation. In this note we present emission on both bases. However, the coal-fired emission rates may be the more appropriate because, as pointed out by the RSSB in its report on Traction Energy Metrics, July 2007, any large scale increase in electricity supply would prolong the life of coal-fired generation.

The emissions per passenger-km depend on occupancy assumptions. The RSSB report Traction Energy Metrics, in section 6, assigns a 40% occupancy to intercity rail. We have used that here although it is said to lead to overcrowding on some trains. For comparison the average for all trains is 30%. If for service level reasons that should be the target for intercity services then the emissions per passenger-km in Table 1 should be increased by one third.

The emissions per passenger-km for the aircraft assume an occupancy of 80%. That is above the industry average but below the 84% claimed by Ryanair. Further, emissions by air cited in table 2 are 10% above those in the source table 3 to allow for refinery energy use and the transport of the fuel to the users.

The fuel consumptions for rail in the following table are from Professor Roger Kemp. They have been converted to carbon emissions using the emission data cited above.

TABLE 1 High-speed train emissions	KW-h per 100 seat-km	Carbon dioxide Gms (A) average emissions		Carbon dioxide Gms (B) Coal-fired emissions	
		per 100 Seat-km	per 100 Passenger-km	per 100 Seat-km	per 100 passenger-km
Pendolino West Coast at 200 kph: range	3.5	1,925	4,810	3,850	9,720
	4	2,200	5,500	4,400	11,000
Class 91 East Coast at 200 kph	3.2	1,660	4,150	3,320	8,300
Eurostar at 300 kph	5	2,750	6875	5,500	13,750

(Note, Eurostar achieves a higher occupancy than used here and claims electricity from France where 80% is from nuclear. Hence in Eurostar publicity emission rates are much lower than in this table).

Professor Kemp also cited a diesel HST requiring 0.8 litres per 100 seat-km at 200 kph. The specific gravity of diesel is 0.84 and the CO<sub>2</sub> per Kg is 3,150 gms. Hence the carbon dioxide per 100 seat km is 0.8 x 0.84 x 3,150 = 2,117 gms or 5,290 gms per 100 passenger-km at 40% load factor.

Data for air is summarised in table 2. As noted above the emissions have been increased by 10% above those in the source table 3 to allow for the energy used in refineries and in transporting the fuel to the users. The data (with the exception of Ryanair) overstates the

emissions for comparison with rail because of the relatively large amounts of luggage and freight carried by passenger aircraft but not (presumably) by high-speed rail.

Table 2	Gms of CO2	
	Per 100 seat-km	Per 100 passenger-km
Ryanair	6,780	8,475
757-300	7,750	9,690
Fokker F28	19,540	24,420

### Comment

The data in tables 1 and 2 could be used to claim that, if it is emission (B), coal-fired generation, that is relevant and if Ryanair is taken as the model aircraft, then air produces the lower emissions. On the other hand if it is emission (A), the generating industry average, that is relevant, then high-speed rail may claim the lower emission.

### Radiative forcing

The emissions from aircraft are often weighted by a factor in the range 1.5 to 3 to allow for the greater radiative forcing arising from high altitude emissions. However, short haul aircraft spend little time at the altitude where the higher radiative forcing factors apply. Further ground level emissions are said to carry a radiative forcing factor that is usually omitted. Hence when comparing the warming effects of rail compared with air the differences in radiative forcing can probably be ignored.

### Sources and notes reference aircraft

The Institute of Energy (0207 467 7100) and others provided the following for aviation fuel:

Calorific value: gross = 46.2 giga-joules per Tonne, Net 46.2 x 0.935 = 43.2

Carbon dioxide: 3.15 Kg of CO2 per Kg of ATF (Jet 1)

Specific gravity range 0.775 to 0.84 providing an average here set to 0.8.

That together with the source data in Table 3 below enables the emission data therein to be calculated. E.g. Ref. the CRJ-700 first item: CO2 per 100 seat-km =  $(545 \times 3.785 \times 0.8 \times 3,150 \times 100) / (334 \times 1.6 \times 70) = 13,896$  gms.

The Aircraft Monitor data in table 3 was recommended to us by Dr Peter Morrell of the Cranfield Institute of Technology. Dr Morrell has also been kind enough to confirm that the parameters and calculations used in this table are in close agreement with his estimate for the B747-200 (the last aircraft cited in table 3).

Fuel consumptions in this table should be increased by 10% to allow for refinery energy use and fuel used in transporting the fuel to the users

TABLE 3 Short/medium haul:	Source: The Airline Monitor, August 2002 *				Carbon dioxide gms	
	US gals per block hour	Av. Seats per flight	Av miles per flight	Av mph	per 100 seat-km	per 100 pass-km: 80% load
Ryanair	776	189	611	397	6,165	7,707
CRJ-700	545	70	428	334	13,896	17,370
CRJ-100/200	365	50	442	297	14,653	18,316
ERJ-135	312	37	390	261	19,260	24,075
ERJ-140	359	44	387	284	17,127	21,408
ERJ-145	358	50	431	270	15,809	19,761
Avro 85	569	69	297	247	19,903	24,878
Bae 146	623	91	316	258	15,819	19,773
Fokker F28	664	69	430	323	17,761	22,201
DC-9-30	808	101	512	306	15,585	19,482
F-100	658	88	473	293	15,213	19,017
717-200	635	111	415	292	11,679	14,599
MD 90	927	150	811	359	10,262	12,828
737-200	910	115	522	329	14,338	17,923
737-500	704	109	600	334	11,528	14,410
A319	758	123	933	374	9,823	12,279

<b>TABLE 3</b> <b>Short/medium haul:</b>	Source: The Airline Monitor, August 2002 *				Carbon dioxide gms	
	US gals per block hour	Av. Seats per flight	Av miles per flight	Av mph	per 100 seat-km	per 100 pass-km: 80% load
737-300	730	131	610	333	9,976	12,470
737-400	786	141	663	333	9,979	12,474
A320-200	822	146	1,091	388	8,650	10,813
MD80	956	135	779	351	12,027	15,034
727-200	1281	149	766	354	14,478	18,097
737-800	836	149	1,055	382	8,756	10,945
737-900	801	172	1,075	390	7,118	8,898
A321-200	927	169	1,406	410	7,975	9,969
757-200	1091	182	1,258	402	8,889	11,112
757-300	1191	247	1,084	408	7,045	8,807
A300-600R	1743	228	1,513	413	11,035	13,793
B767-400	1661	272	1,547	429	8,486	10,607
<b>Medium/long-haul</b>						
L1011-500	2365	288	2,340	449	10,903	13,629
DC10-10/30/40	2606	284	2,575	461	11,866	14,832
A330	2169	261	3,647	468	10,586	13,232
MD-11	2160	272	3,651	488	9,701	12,126
B767-300	1476	207	2,274	450	9,446	11,808
B767-200	1459	176	2,083	436	11,335	14,168
B777-200	2134	266	3,557	487	9,820	12,276
B747-400	3429	369	4,445	505	10,970	13,712
B747-200	3536	357	3,386	480	12,301	15,377

Further a report in the Times of 8th February 2008 cites the A380 (certified to carry 853 passengers) as emitting 8,000 gms of CO<sub>2</sub> per 100 passenger-km when carrying 550 passengers on an 8,000 km trip.

**[Click here for Appendix 1](#)**

## Appendix 1 Emissions from the UK generating industry

Table A1 below and the associated notes provide:

1. Ratios of primary burn to end user consumption of (a)  $1024.8/345.2 = 2.97$  in 2005 and (b)  $1022.9/344.8 = 2.96$  in 2006; leading us to use 3.0 in other calculations.
2. A fair estimate of the corresponding carbon emission from industry as a whole is 150 Tonnes per GWh delivered to end users or 50 Tonnes per GWh of primary energy burn. Those numbers correspond to 550 and 183 Tonnes of carbon dioxide. If it is coal-fired emissions that are relevant then these emissions should be doubled.

**TABLE A1 Electricity generating industry: Energy burnt and supplied and emissions**

Fuel Source	MtC/Mtoe (a)	Mt of oe burnt (b)		TWh burnt (d)		Carbon emission Gt		TWh supplied (b)		Tonnes C per GWh consumed (e)	
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Coal	1.029	32.62	36.12	380.57	421.40	33.56	37.16	128.67	143.54	<b>293</b>	<b>289</b>
Oil	0.875	1.33	1.62	15.52	18.90	1.16	1.42	4.72	5.20	<b>277</b>	<b>305</b>
Gas	0.582	28.7	26.51	334.83	309.28	16.71	15.44	149.78	138.57	<b>125</b>	<b>125</b>
Nuclear	0	18.37	16.92	214.32	197.40	0.00	0.00	75.17	69.24	<b>0</b>	<b>0</b>
Hydro	0	0.43	0.39	5.02	4.55	0.00	0.00	4.01	3.32	<b>0</b>	<b>0</b>
Other renew	0	3.6	3.76	42.00	43.87	0.00	0.00	11.91	12.41	<b>0</b>	<b>0</b>
Other fuels		2.07	1.48	24.15	17.27	0.00	0.00	4.72	4.03	<b>0</b>	<b>0</b>
Imports		0.72	0.8	8.40	9.33	0.00	0.00	8.32	9.30	<b>0</b>	<b>0</b>
Totals/mean		87.84	87.6	1024.8	1022	51.44	54.01	387.3	385.61	<b>149</b>	<b>157</b>
<b>Final consumption TWh (c)</b>								345.241	344.85		

Notes:

- (a) These are Mega Tonnes of Carbon per Mega Tonne of Oil Equivalent as provided by Julian Prime of BERR on 5th October 2007.
- (b) Table 5.1 of Energy Trends March 2007. The Mt of oe burnt is the oil equivalent burnt by the generators. The TWh supplied is that reaching the grid.
- (c) Table 5.2 of Energy Trends March 2007. The TWh consumed is the electricity reaching users after deducting transmission losses and the generating industry use.
- (d) The calorific value of an Oil Equivalent is 42 GJ per tonne. Hence TWh here are the oil equivalent values multiplied by 42 and divided by 3.6.
- (e) Typical calculation **293** = (33.56 billion)/(128.67 million x 345.24/387.3).
- (f) The BERR and others' estimates of emissions treat the generating industry itself and sometimes the grid as end users. That leads to lower emissions per GWh delivered than we have calculated.

### **Comparison with Energy Trends**

Energy Trends, March 2007, provides 131 Tonnes of Carbon per GWh generated i.e. before generating industry use or transmission losses. The electricity generated was 408,500 GWh. The end user consumption amounted to 344.85 GWh. Hence multiplying the carbon emission per GWh generated by the ratio  $408.5/344.85$  provides the carbon per GWh used by end users. That yields 155 Tonnes which is close to the 157 Tonnes in Table A1.