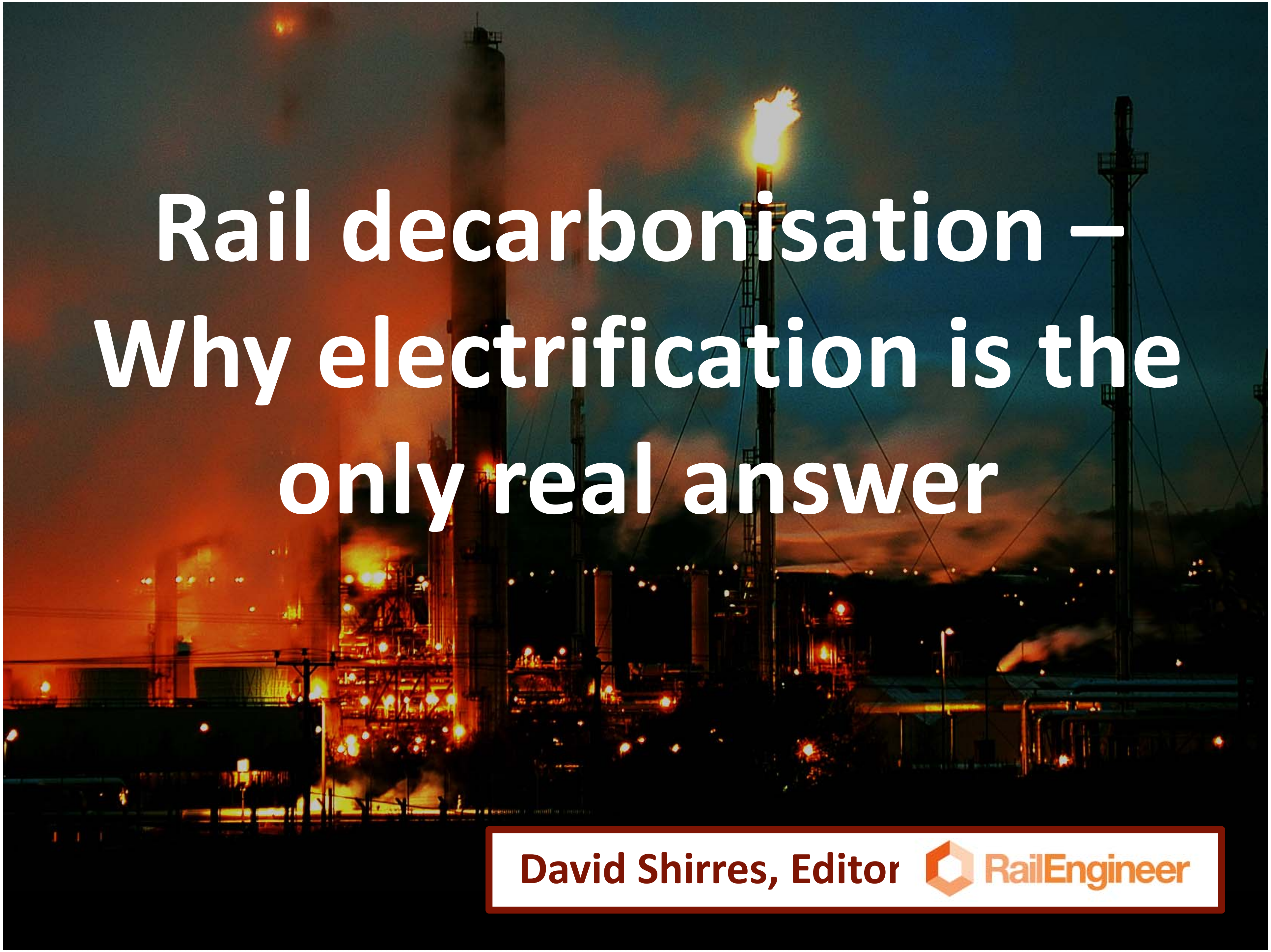
Rail decarbonisation – Why electrification is the only real answer



David Shirres, Editor RailEngineer

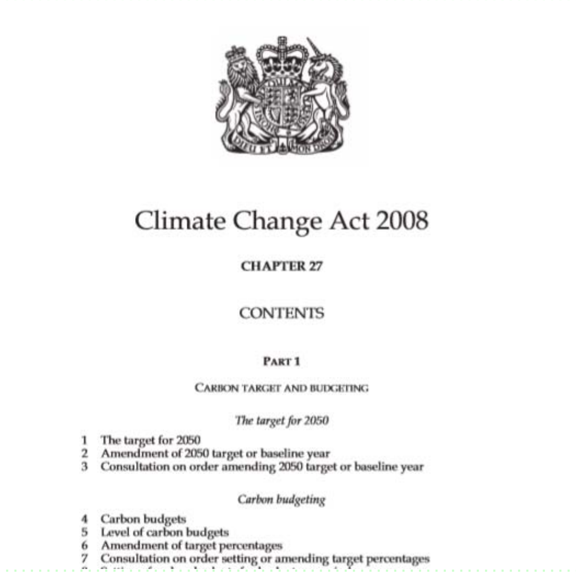
Climate change increasingly on the agenda

Edinburgh science festival charity bans fossil fuel sponsorship

Edinburgh Science faced protests from activists for taking money from oil firms

"Public concern about issues such as climate change and the impact of business on society has never been more intense than it is today, Accordingly, sustainability has now risen to the very top of the corporate agenda" Arthur D. Little

Climate Change Act 2008
– some progress



Climate Change Act 2008

CHAPTER 27

CONTENTS

PART 1

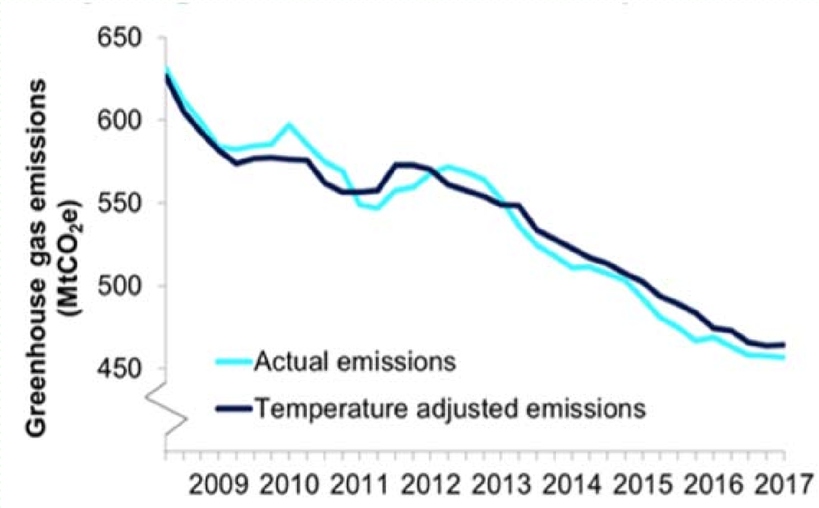
CARBON TARGET AND BUDGETING

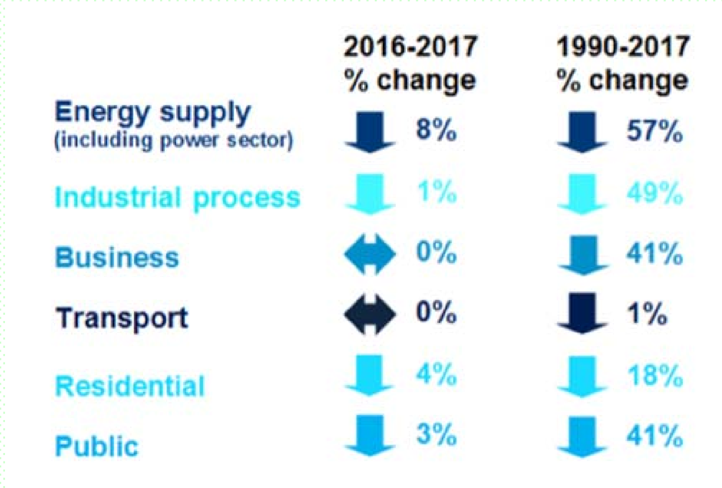
The target for 2050

Carbon budgeting

"It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline"

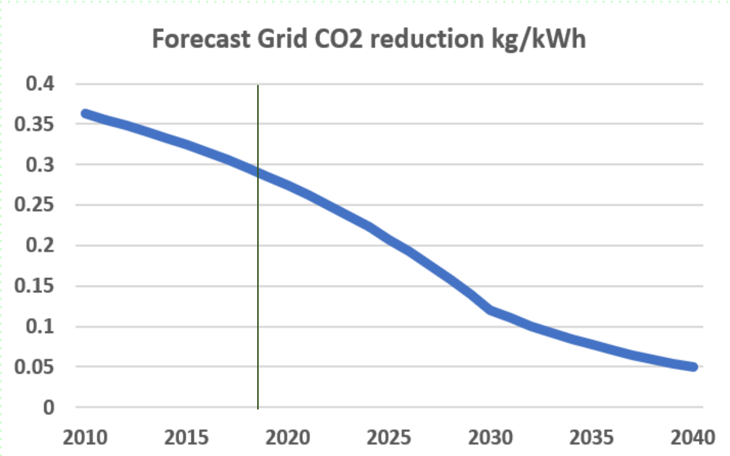
A 42% reduction so far, largely due to greening of the grid





Greening of the grid (and of electric trains)

Year	CO2 kg/ kWh
2010	0.363
2019	0.285
2040	0.050

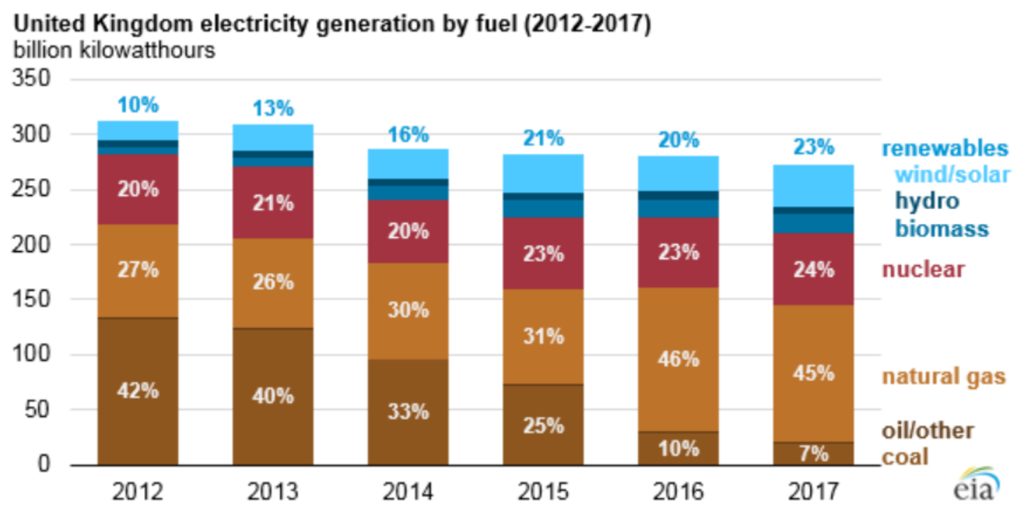


Data for Department for Transport's TAG spreadsheet

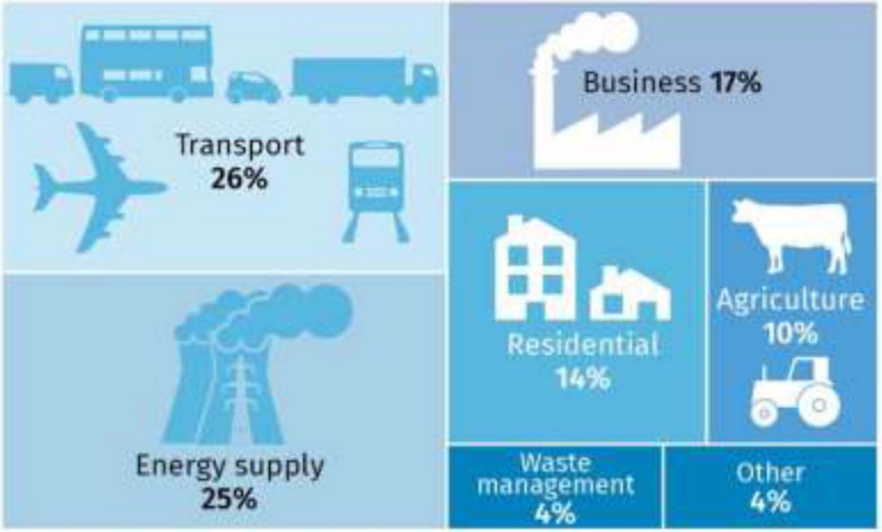
Department for Transport

WebTAG Databook November 2018 v1.11

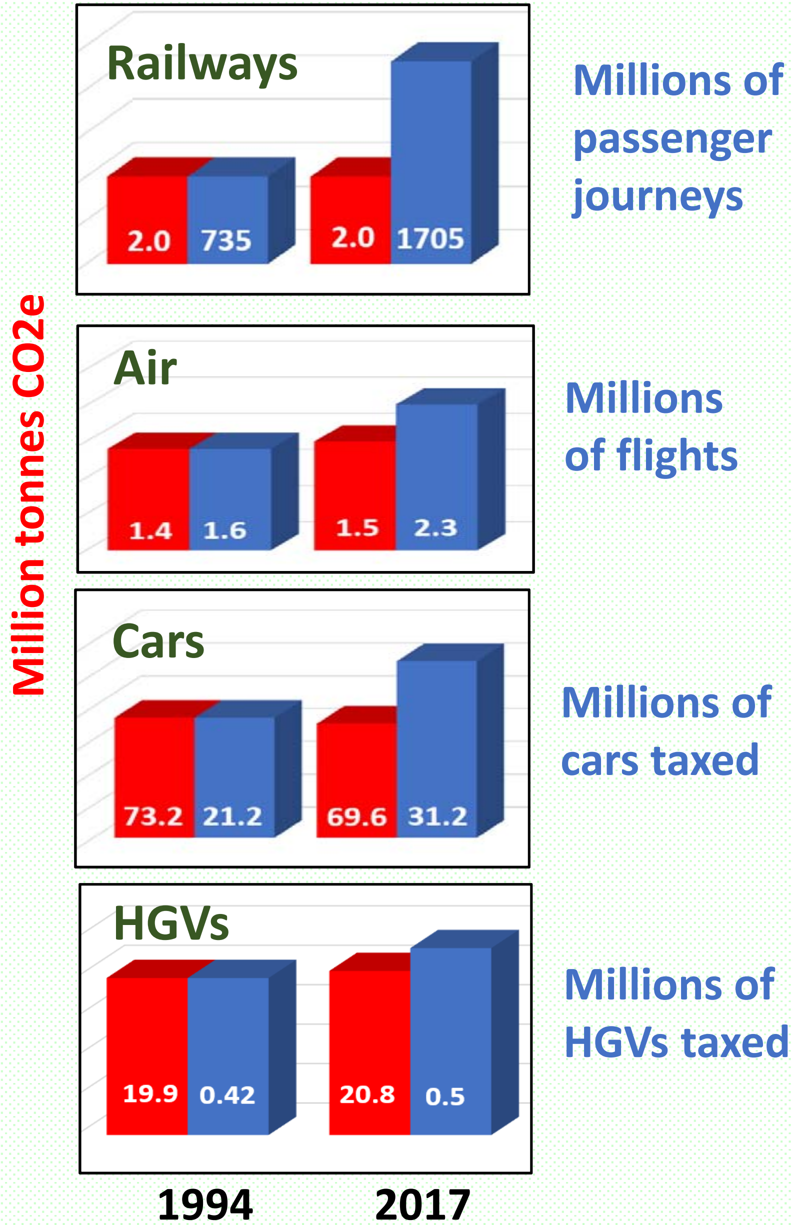
Table A 3.3: Carbon dioxide emissions per litre of fuel burnt / kWh used	
Year	Electricity Rail Kg CO2e/kWh
2010	0.363
2011	0.356
2012	0.348
2013	0.341
2014	0.333
2015	0.324
2016	0.315
2017	0.306
2018	0.296
2019	0.285
2020	0.274
2021	0.262
2022	0.250
2023	0.236
2024	0.222
2025	0.208
2026	0.192
2027	0.175
2028	0.158
2029	0.140
2030	0.120
2031	0.110
2032	0.101
2033	0.092
2034	0.084
2035	0.077
2036	0.071
2037	0.065
2038	0.059
2039	0.054
2040	0.050



But no reduction in transport emissions



	Millions of tonnes		
	1990	1994	2017
Civil aviation	1.5	1.4	1.5
Passenger cars	72.3	73.2	69.6
Light duty vehicles	11.6	12.9	19.4
Buses	5.3	5.4	3.4
HGVs	20.5	19.9	20.8
Mopeds & motorcycles	0.8	0.5	0.5
Other	0.2	0.2	0.6
Total Road	**110.5**	**112.1**	**114.3**
Railways	2.0	2.0	2.0
Shipping	8.5	10.0	5.9
Military	5.6	4.2	2.2
All Transport	**128.1**	**129.7**	**125.9**



Rail's CO2 advantage

	Rail	Road	Air
Grams CO2e per passenger - km	28.4	101.6	244.1
Grams CO2e per tonne - km	15.6	139.8	690 - 820

Source: European Environmental Agency

Indicative CO2 reduction strategies

1. Reduce rail carbon by 30% - If possible this gives savings of 0.3 x 2 million = 600,000 tonnes greenhouse (GHG) gas saving

2. Modal shift, 3% from cars, HGV and air (passenger only) would save 2.1 million tonnes GHG gases

	Current	3% reduction	additional carbon to rail	Net million tonnes
Air	1.5	0.045	0.005	0.040
Car	69.6	2.088	0.584	1.504
HGV	20.8	0.624	0.070	0.554
				2.098

Rail's greatest potential to reduce UK carbon is by encouraging transfer road and air. To do so it must offer an attractive service. Therefore any future rail traction must offer the best possible acceleration and speed.

Best possible acceleration and speed?

		Weight	Power (MW)		Power to weight ratio kw/tonne	
	Train	tonnes	Diesel	Electric	Diesel (A)	Electric
1	Class 800/3 IEP	438	3.5	4.5	7.2	10.3
1	8 coach HST	432	3.4		7.1	
1	11 coach Cl 390	567		5.95		10.5
2	4 coach Cl 385	159		2.0		12.6
2	3 coach Cl 170	140	0.93		6.0	

A. Assumes 10% is needed for auxiliaries and hotel load, not an issue for electric trains

1. Bi-mode trains
   - In diesel mode have the same power-to-weight ratio as the diesel trains they replace
   - In electric mode has power-to-weight ratio just under that of Class 390 Pendolino
   - 9 coach unit has 5 engines weighing 7 tonnes each i.e. 8% weight of train which incurs a significant carbon cost over the train's lifetime
2. Commuter trains
   - In Scotland, electrification introduced class 385 EMUs that have twice the acceleration of the class 170 DMUs they replace.
   - Such acceleration is essential for an acceptable commuter service.

Electric trains have speed and acceleration to attract passengers from other modes to reduce UK carbon emissions

The Government's plans – no diesels and no electrification

All diesel trains should be scrapped by 2040, Jo Johnson tells rail bosses

Speech

Let's raise our ambitions for a cleaner, greener railway

Minister calls for diesel-only trains to be phased out as part of new vision to decarbonise the railway.

"As battery technologies improve we expect to see batteries powering the train between the electrified sections of the network, or maybe in the future we could see those batteries and diesel engines replaced with hydrogen unit?

2017 Dft removed electrification from scope of East West Rail

East West Rail "won't be a conventional diesel-powered line in the future. It's going to be a line that has completely new generation, low-emission (battery and hydrogen) trains."

Chris Grayling

Battery trains

March 2019

- Hitachi in talks with Scottish Government to provide possible battery fitted class 385 units
- Out and back range of 30 miles possible at DMU performance

IPEMU trial – February 2015

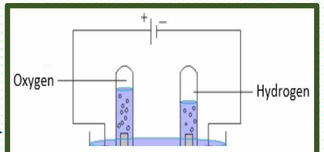
- Trial in East Anglia showed potential for IPEMUs (Independently Powered EMUs) to operated on branch lines off the electrified network
- IPEMU had an eight tonne traction battery
- Achieved out and back range of 24 miles
- Acceleration comparable with DMU

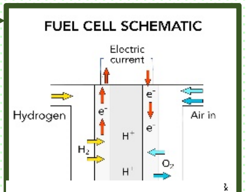
- Battery packs have 2.5 % the energy density of diesel (1.0 vs 39 MJ/litre)
- Will improve but not dramatically – UK automotive council expect it to double by 2035
- Batteries are costly and need to be replaced
- Producing and recycling batteries uses rare materials and has high environmental costs
- Unlikely to offer EMU-like acceleration

Subject to full cost and environmental assessment, battery powered EMUs have potential for branch line operation off electrified lines

Hydrogen trains – typical well-to-wheel efficiency comparisons

Hydrogen - on site production from renewable energy

Electricity from grid 3.4 kW → 

Electrolysis → Compress to 350 bar → 

Fuel Cell → Converter and Drive → Wheel 1.0 kW

Efficiency	68%	94%	52%	89%	Overall 29%

Diesel

Oil 3.9 kW → 
Extract & Refine → 
Engine → Trans-mission → Final Drive → Wheel 1.0 kW

Efficiency	93%	38%	78%	94%	Overall 26%

Electrification from renewable energy

Electricity from grid 1.2 kW → OLE Transmission → Transformer → Converter and Drive → Wheel 1.0 kW

Efficiency	98%	95%	89%	Overall 83%

Hydrogen trains – performance comparisons

	Passenger multiple unit trains		
	Hydrogen	Electric	Diesel
Power/range constraints	Up to 1,000 km limited by low energy density of hydrogen	Range – none Power – (7.5 MW per pantograph)	Diesel engine & tank
Typical kW/t	8 kW/t (iLint)	12.6 kW/t (class 385)	6.4 kW/t (class 170)
Efficiency	29%	83%	26%
CO2e	Depends how electricity is generated Currently 0.285 kg/ kWh, DfT predict 0.050 Kg/kWh in 2040		0.83 kg / kWh
Emissions	Only emission is water	None at point of use	NoX, particulates etc
Infrastructure required	Hydrogen distribution, storage and supply	OLE and power supply	Diesel storage and fuelling points

Hydrogen trains:

- require 2.4 times more electricity than an electric trains
- Only zero-carbon if hydrogen produced from carbon-free electricity (e.g. renewables)
- Have about 2/3 the power to weight ratio of an electric train

Suitable for use on rural routes, but are not an alternative to electrification

Also the view of the Institution of Mechanical Engineers


TRANSPORT

THE FUTURE FOR HYDROGEN TRAINS IN THE UK

Institution of MECHANICAL ENGINEERS

The challenges of decarbonising our energy system are becoming increasingly difficult. We have begun by addressing the easier options in the power industry, but with concerns about reducing air quality and pollution, the decarbonisation of our transport system is critical in meeting UK targets for emission reductions. When it comes to the rail industry, the Institution of Mechanical Engineers en… greater electrificatio… rail network…

1. That the UK Government rethinks the cancellation of electrification programmes and moves forward with a more innovative, and long-term approach, electrification rolling programme, that can create skills and careers, develop supply chains, and work with existing rail networks to manage projects.

… and deployment of hydrogen trains and their fuelling and servicing facilities. Creating and supporting demonstration lines and trains will help to de-risk the technologies and servicing relating to hydrogen fuels and trains.

3. That hydrogen train technology is developed in industrial areas where hydrogen production already occurs, and can support the wider transport system. For example, as well as local transport system…

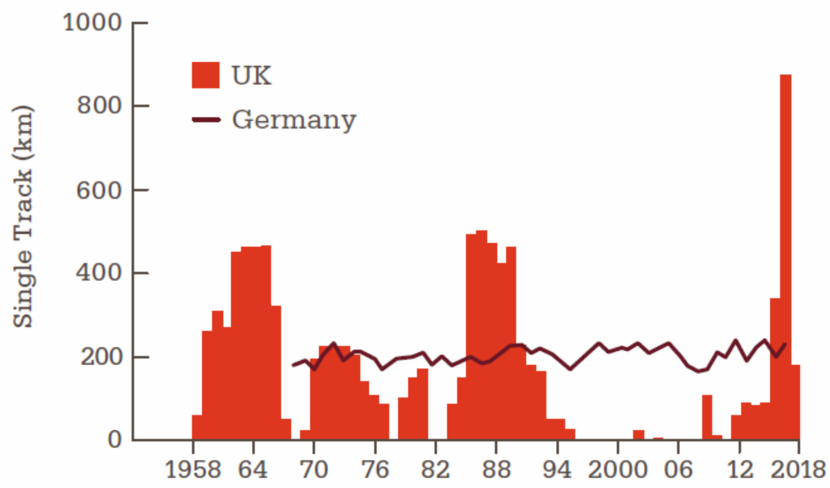
THE FUTURE FOR HYDROGEN TRAINS IN THE UK

BACKGROUND

INTRODUCTION

“That the UK Government rethinks the cancellation of electrification programmes and moves forward with a more innovative, and long-term approach, electrification rolling programme”

“There is a concern that hydrogen trains will be used by funders as a reason to avoid future electrification. Fuel cell traction should be viewed as an option only where long-term technical, environmental and/or economic factors make electrification a poor option”



Why electrification can go wrong

Electrification's carbon credentials

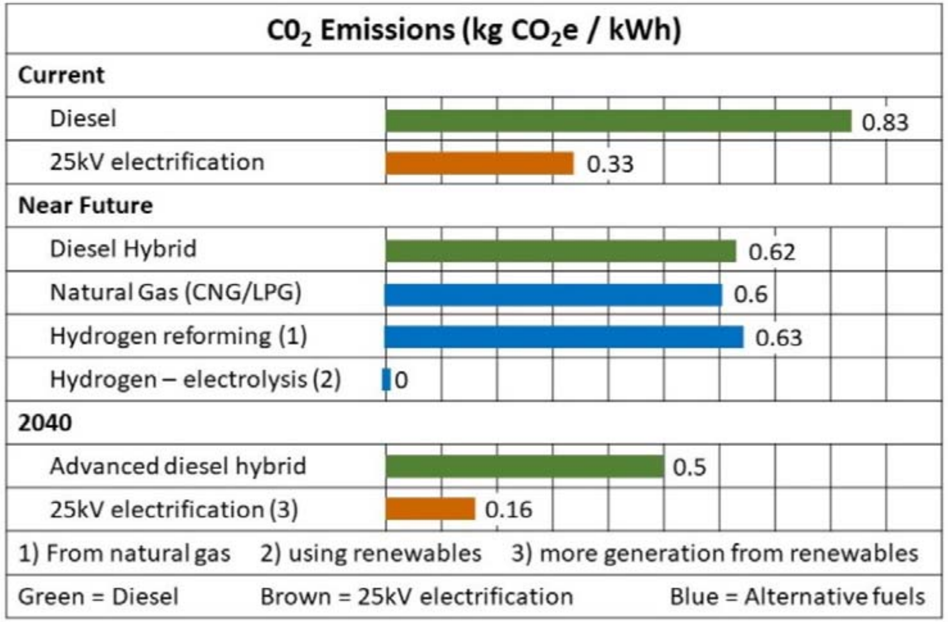
	Electric traction		Diesel traction	
2016 – 17 12 month figures	**Passenger**	**Freight**	**Passenger**	**Freight**
Fleet energy usage	3,534 m kWh	55 m kWh	501 m litres	204 m litres
Fleet emissions (million tonnes CO2e)	1,004	16	1,361	554
Fleet size	10,794	128	3,871	640
tonnes per vehicle (current)	93	122	352	866
2040 emissions using DfT predictions for CO2e from electricity generation				
Fleet emissions (million tonnes CO2e)	423	7	1,338	545
tonnes per vehicle	39	52	346	851

Electric CO2e emissions as a percentage of diesel	Passenger vehicle	Freight locomotive
2016-7	**26.4%**	**14.1%**
2040	**11.3%**	**6.1%**

Electrification's carbon credentials

Figures from RSSB T1145 report show that, per kWh, CO2e emissions from electric trains are 39.8% of diesel trains

Yet actual average CO2e emissions per passenger vehicle are 26.4% those of diesel



Figures from RSSB report Research project T1145, RSSB, Options for Traction Energy Decarbonisation in Rail: Options Evaluation

T1145 chart does not take account of energy savings from the regenerative braking offered by electric trains, or diesel consumed whilst engines idling.
Hence it understates electrification's carbon benefits

Carbon savings

Carbon savings using electric instead of diesels		
Per vehicle / locomotive	**Passenger**	**Freight**
Tonnes C02e – 2016/17	259	744
Tonnes CO2e - 2040	307	799
Average	283	771
Total over 30 years	8,490	23,130

Indicative carbon savings from electrifying all intensively used routes			
	Passenger	Freight	Total
Estimated electric vehicles replacing diesel	1,500	150	
Tonnes carbon saved per year	424,500	115,650	540,150
Tonnes carbon saved over 30 years	12.7 million	3.5 million	16.2 million

Carbon cost

HM Treasury Green Book guidance specifies that direct fuel use by non-aviation transport is non-traded sector GHG emissions for which Low, Central and High values. These values are specified in table 3.4 of DfT's WebTAG databook which provides all required data for transport appraisal

		Non traded carbon values				Discounted at 3.5%		
		Low	Medium	High	Factor	Low	Medium	High
1	2019	29.9	59.8	89.7	1.000	29.9	59.8	89.7
2	2020	30.4	60.7	91.1	0.965	29.3	58.6	87.9
3	2021	30.9	61.7	92.6	0.931	28.7	57.5	86.2
4	2022	31.4	62.7	94.1	0.899	28.2	56.4	84.5
5	2023	31.9	63.7	95.6	0.867	27.6	55.3	82.9
6	2024	32.4	64.8	97.1	0.837	27.1	54.2	81.3
7	2025	32.9	65.8	98.6	0.808	26.6	53.1	79.7
8	2026	33.4	66.8	100.2	0.779	26.0	52.0	78.0
9	2027	33.9	67.8	101.7	0.752	25.5	51.0	76.5
10	2028	34.4	68.8	103.2	0.726	25.0	49.9	74.9
11	2029	34.9	69.8	104.7	0.700	24.4	48.9	73.3
12	2030	35.4	70.8	106.2	0.676	23.9	47.9	71.8
13	2031	38.7	77.4	116.1	0.652	25.2	50.5	75.7
14	2032	42.0	84.0	126.0	0.629	26.4	52.8	79.3
15	2033	45.3	90.5	135.8	0.607	27.5	55.0	82.5
16	2034	48.6	97.1	145.7	0.586	28.5	56.9	85.4
17	2035	51.9	103.7	155.5	0.566	29.3	58.6	88.0
18	2036	55.1	110.3	165.4	0.546	30.1	60.2	90.3
19	2037	58.4	116.9	175.3	0.527	30.8	61.5	92.3
20	2038	61.7	123.4	185.1	0.508	31.4	62.7	94.1
21	2039	65.0	130.0	195.0	0.490	31.9	63.8	95.6
22	2040	68.3	136.6	204.9	0.473	32.3	64.6	96.9
23	2041	71.6	143.2	214.7	0.457	32.7	65.4	98.1
24	2042	74.9	149.7	224.6	0.441	33.0	66.0	99.0
25	2043	78.2	156.3	234.5	0.425	33.2	66.5	99.7
26	2044	81.4	162.9	244.3	0.410	33.4	66.8	100.3
27	2045	84.7	169.5	254.2	0.396	33.6	67.1	100.7
28	2046	88.0	176.0	264.0	0.382	33.6	67.3	100.9
29	2047	91.3	182.6	273.9	0.369	33.7	67.3	101.0
30	2048	94.6	189.2	283.8	0.356	33.7	67.3	101.0
						882.4	1764.8	2647.2

Department for Business, Energy & Industrial Strategy

VALUATION OF ENERGY USE AND GREENHOUSE GAS

Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government

Department for Transport

WebTAG Table A 3.4
Greenhouse Gases

This version: November 2018 v1.11 / Nov-18

Links: Contents | WebTAG Unit 3.3.5 | WebTAG Unit A 3

Parameters:
Price year: 2010
Initial fc year: 2010

Sheet Navigation:

Notes
Source: BEIS, 2018 Tat
The values in A3.4

Databook source worksheets: Use
WebTAG 1: Unit 3.3.5 (Tables 2a &

Table A 3.4: Non Traded Values, £ per Tonne of CO2e (2010 prices)			
Year	Low	Central	High
2010	26.15	52.30	78.45
2011	26.54	53.09	79.63
2012	26.94	53.88	80.83

Table 3.2 Mapping emissions to the traded and non-traded sectors

Traded sector GHG emissions
Grid electricity use by all sectors[27]
Direct fuel use and manufacturing processes by EU ETS participants (although certain GHGs are exempt)[28]
Direct fuel use in aviation[29]
Non-traded sector GHG emissions
Direct fuel use by households
Direct fuel use in non-aviation transport
Direct fuel use by private and public sector organisations from installations that do not participate within the EU ETS[30]

Over 30 years discounted at 3.5% Low, Central and High non-traded carbon values are £882, £1765 and £2,647 per tonne

Carbon cost savings

Indicative costs of carbon saved from electrifying intensively used lines			
Carbon saved over 30 years	16.2 million tonnes		
	Low	Central	High
Net present value (NPV) of a tonne of carbon over 30 years	£882	£1,765	£2,647
Carbon savings NPV (billion)	**£14.3**	**£28.6**	**£42.9**

Other savings

Operating costs from Network Rail's 2009 Electrification Route Utilisation Strategy

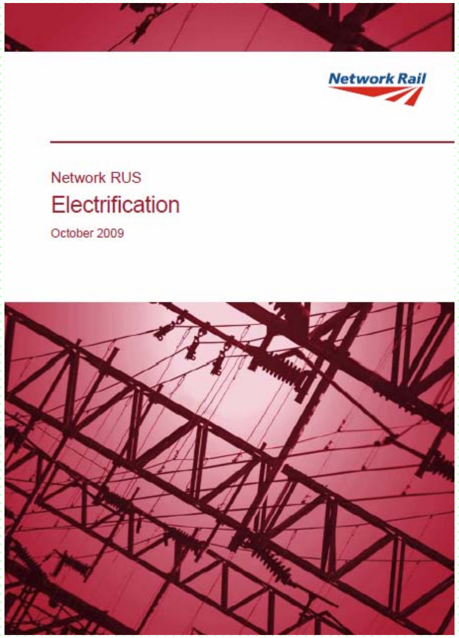


Table 3.3 – Typical operating costs of diesel and electric passenger vehicles

	Typical value for diesel vehicle	Typical value for electric vehicle
Maintenance cost per vehicle mile	60 pence	40 pence
Fuel cost per vehicle mile	47 pence	26 pence
Lease cost per vehicle per annum	£110,000	£90,000
Track wear and tear cost per vehicle mile	9.8 pence	8.5 pence

Annual average extra cost of a diesel vehicle over an electric

Miles per day	500	750	1,000
Maintenance	£36,500	£54,750	£73,000
Fuel	£38,325	£57,488	£76,650
Track wear and tear	£2,373	£3,559	£4,745
Leasing	£20,000	£20,000	£20,000
Total	£97,198	£135,796	£174,395
30 year vehicle cost (discounted at 3.5%)	£1.8 million	£2.6 million	£3.3 million

Electric trains offer lifetime savings of around £2 to £3 million per passenger vehicle

There are also significant carbon savings from reduced vehicle and track maintenance

Conclusions

- Battery and Hydrogen vehicles are only suitable for branch lines and rural routes will is a tiny proportion of total passenger miles. They are not suitable for freight
- For the same power, Hydrogen and diesel trains require three times more energy than an electric train
- Electrification is the only technology that deliver both significant carbon savings and the required train performance
- On average, GHG emissions from an electric passenger vehicle are currently 26.4% those of a diesel vehicle, by 2040 they will be 11.3% of a diesel vehicle according to DfT figures.
- This illustrates how only electric trains can deliver the huge rail traction carbon savings from the greening of the grid.
- DfT electrification decisions must take account of carbon savings as required by the 2008 Climate Change Act

Thanks for listening, let's hope the future is electric