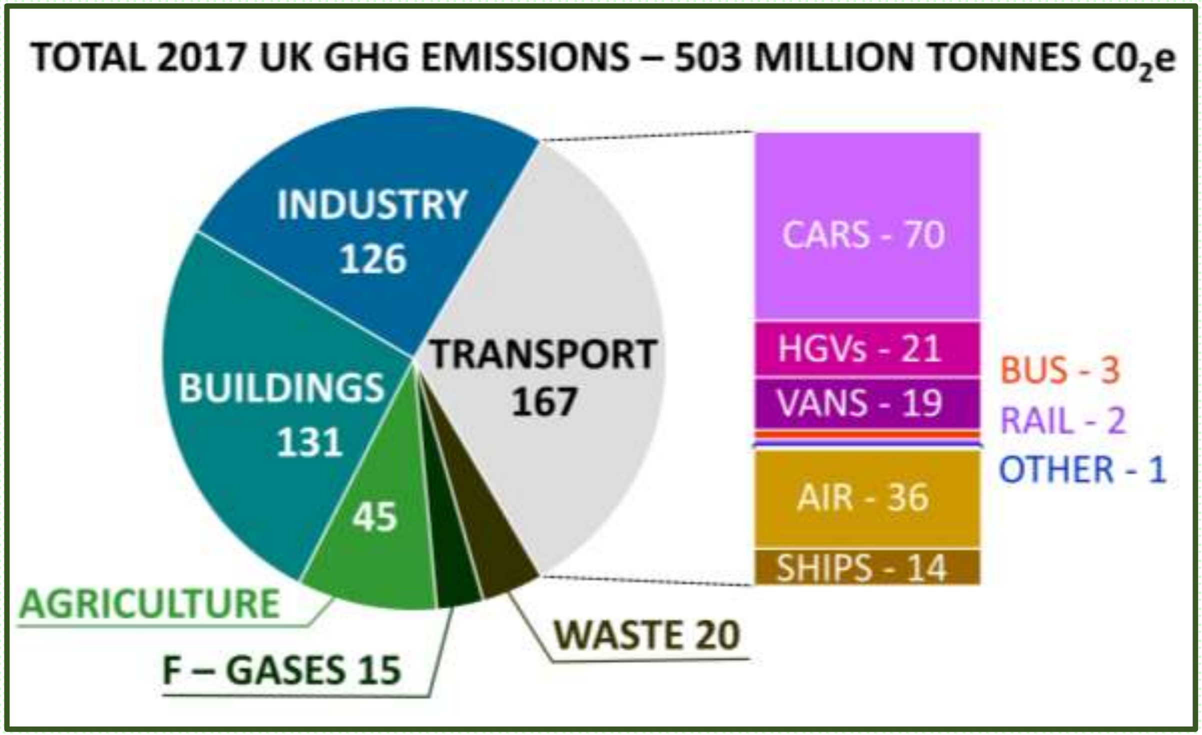
Rail (& UK) decarbonisation

David Shirres, Editor RailEngineer

The big picture

- Rail decarbonisation is part of UK strategy
- Progress to date
- Achieving net-zero by 2050 (and not before)
- Strategy for rail decarbonisation



Climate change increasingly on the agenda

Edinburgh science festival charity bans fossil fuel sponsorship

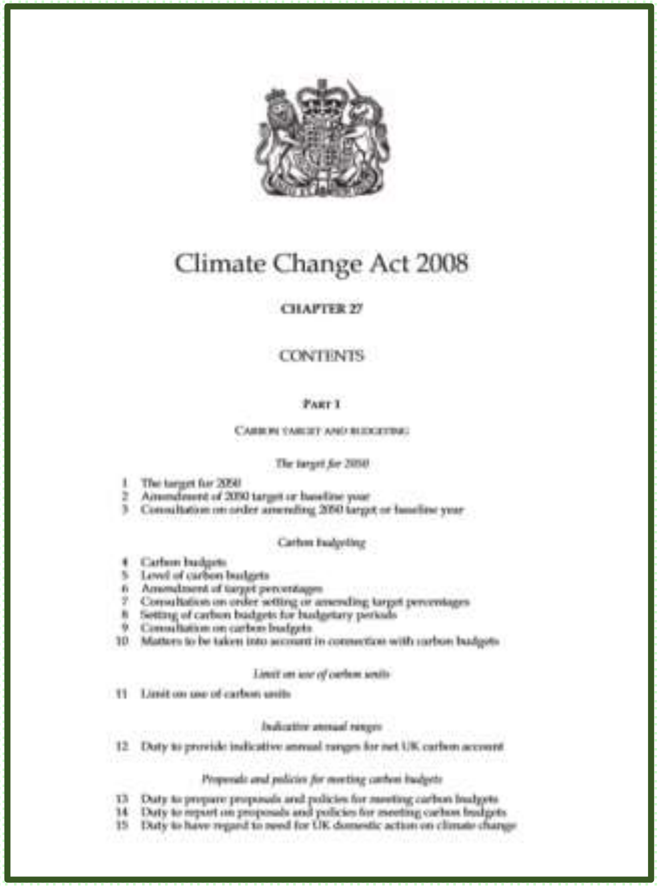
Edinburgh Science faced protests from activists for taking money from oil firms

Greta Thunberg condemns world leaders in emotional speech at UN

"For more than 30 years, the science has been crystal clear. How dare you continue to look away and come here saying that you are doing enough when the politics and solutions needed are still nowhere in sight?"

2008 Climate Change Act

- A world first
- 80% reduction of 1990 GHG emissions by 2050 – amended to net zero in June 2019
- Requires short term targets to be set and monitored
- Requires Government to set policies to ensure targets are met
- Establish Committee on Climate Change to monitor progress and advise action required


Climate Change Act 2008

CHAPTER 27

CONTENTS

PART 1

CARBON TARGET AND BUDGETING

The target for 2050

1 The target for 2050
2 Amendment of 2050 target or baseline year
3 Consultation on order amending 2050 target or baseline year

Carbon budgeting

4 Carbon budgets
5 Level of carbon budgets
6 Amendment of target percentages
7 Consultation on order setting or amending target percentages
8 Setting of carbon budgets for budgetary periods
9 Consultation on carbon budgets
10 Matters to be taken into account in connection with carbon budgets

Limit on use of carbon units

11 Limit on use of carbon units

Indicative annual ranges

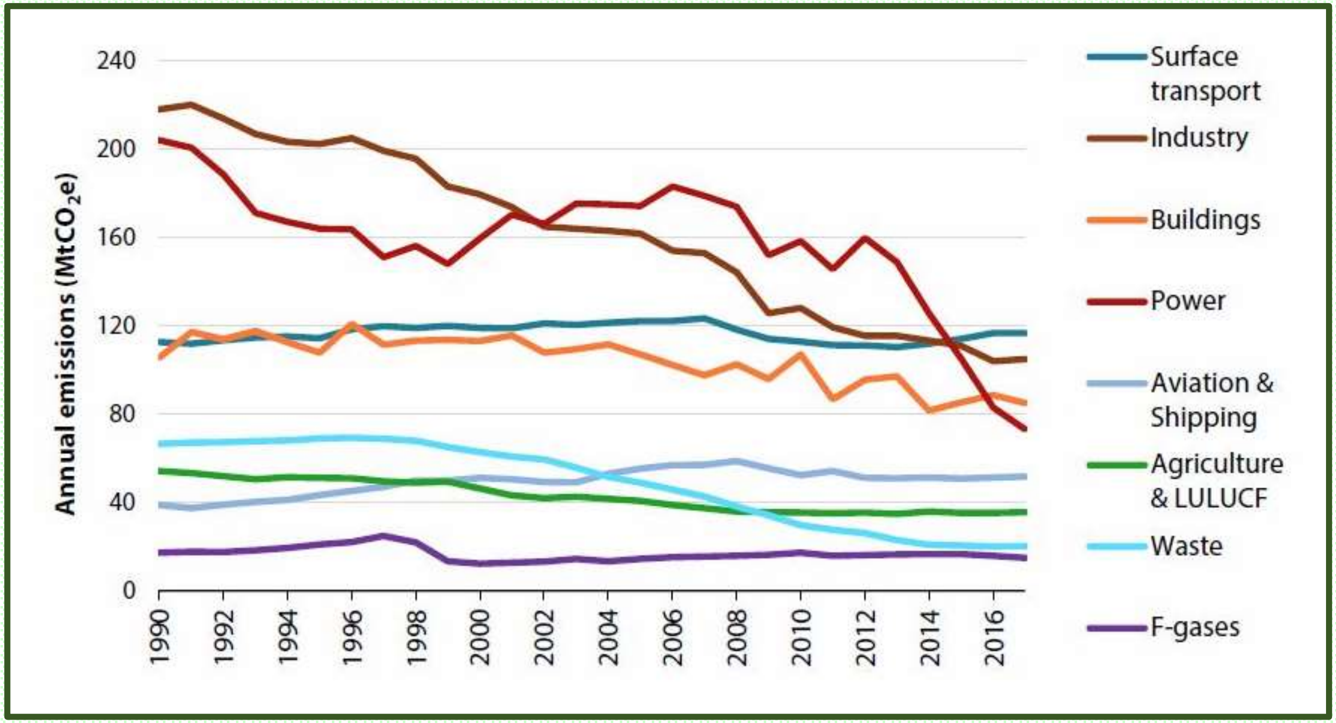
12 Duty to provide indicative annual ranges for net UK carbon account

Proposals and policies for meeting carbon budgets

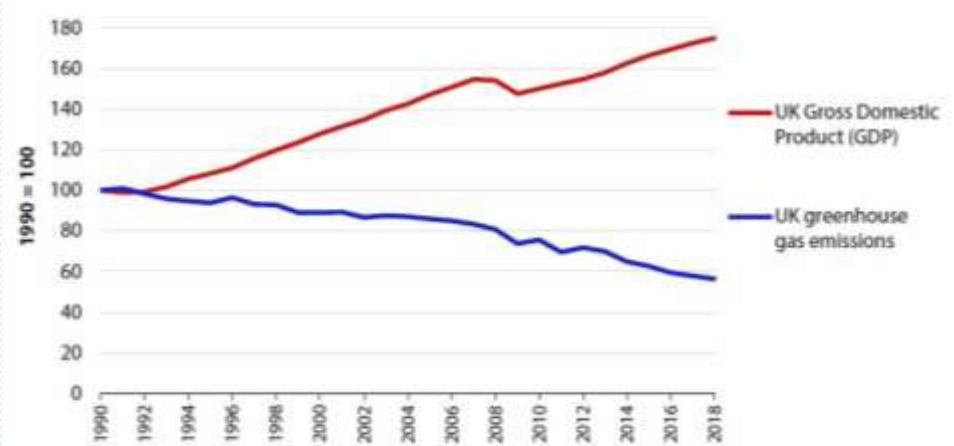
13 Duty to prepare proposals and policies for meeting carbon budgets
14 Duty to report on proposals and policies for meeting carbon budgets
15 Duty to have regard to need for UK domestic action on climate change

"It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is 100% lower than the 1990 baseline"

2008 Climate Change Act – 43% reduction so far

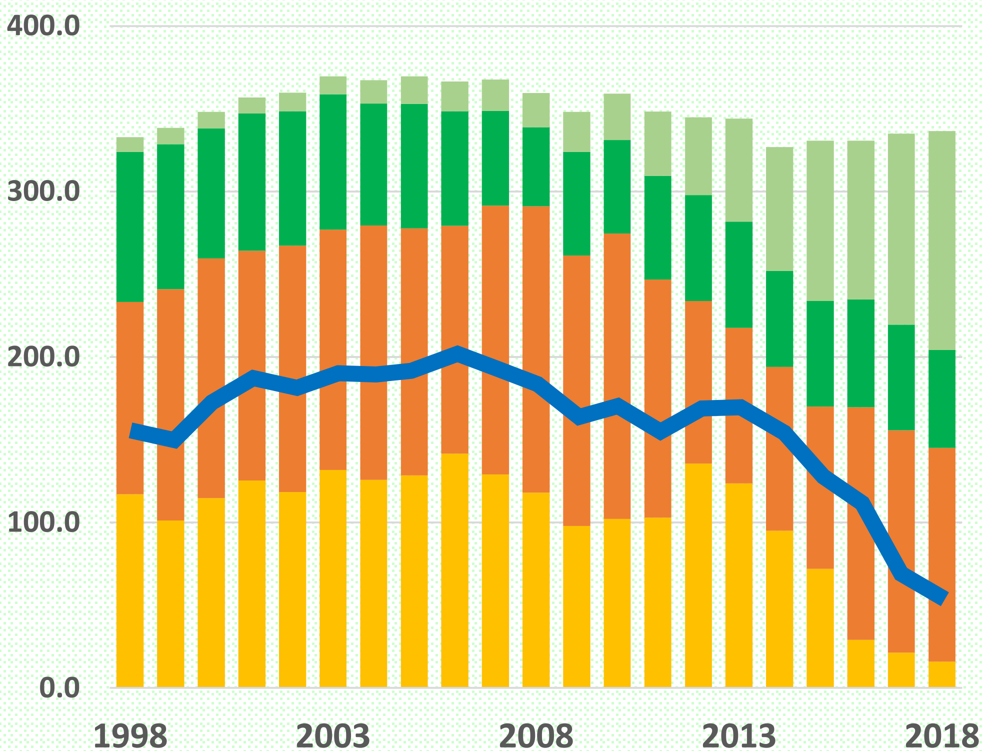


As emissions fall, GDP rises



Greening of the grid (and of electric trains)

UK Power Station Electricity Generation (TWh) 1998-2018

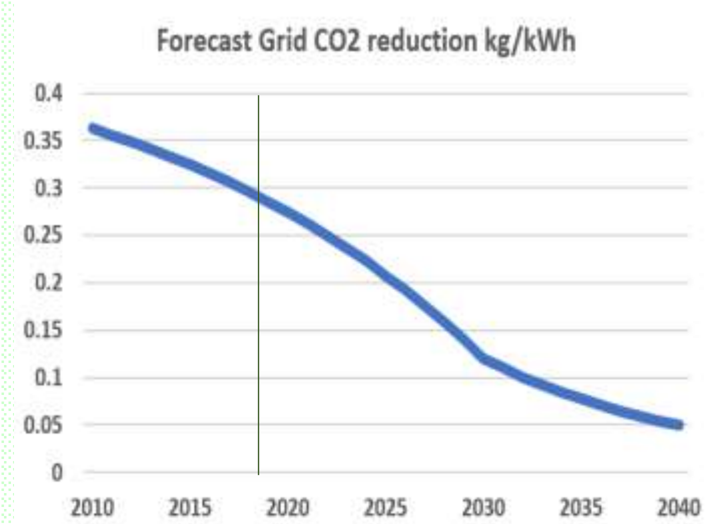


Renewables Nuclear Gas Coal

Coal and Gas emissions - 0.33 and 0.20 kg CO_2e/kWh

Emissions from Electricity Generation (Mt CO_2e)

Year	CO_2 kg/ kWh
2010	0.363
2019	0.285
2040	0.050



Data for Department for Transport's TAG spreadsheet

CO2 reduction blueprint

CCC report published May 2019

"Net-zero is only credible if policies are introduced to match."

"The technologies and approaches that will deliver net-zero are now understood and can be implemented with strong leadership from government."

"The UK must make firm plans for housing and domestic heat; for industrial emissions; carbon capture and storage; road transport; agriculture; aviation and shipping."

CCC net-zero report

Main report – Contents

1. Principals and approach to considering UK climate change targets
2. Climate science and international circumstances
3. An appropriate UK contribution to the global effort
4. Supporting increased global ambition
5. Reaching net-zero emissions in the UK
6. Costs and benefits of net-zero target for UK
7. Recommendations

Technical report – Contents

1. Introduction
2. Power and hydrogen production
3. Buildings
4. Industry
5. Transport (Cars, vans and HGVs)
6. Aviation and Shipping
7. Agriculture, land-use, land use change and forestry
8. Waste
9. F-gas emissions
10. Greenhouse gas removals

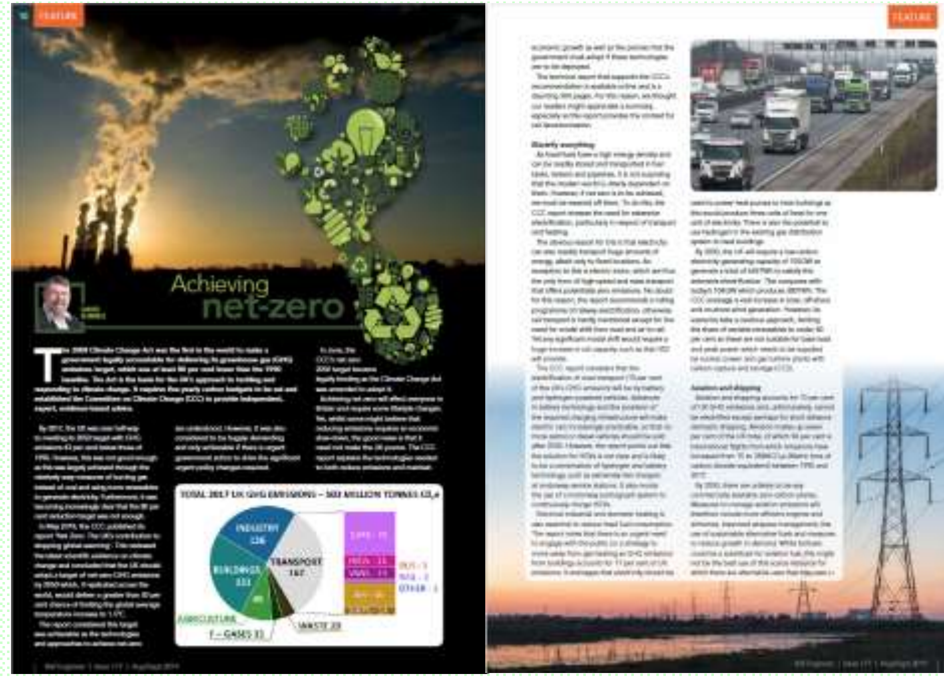
Appendix – changes to previous scenarios for the UK, Scotland and Wales

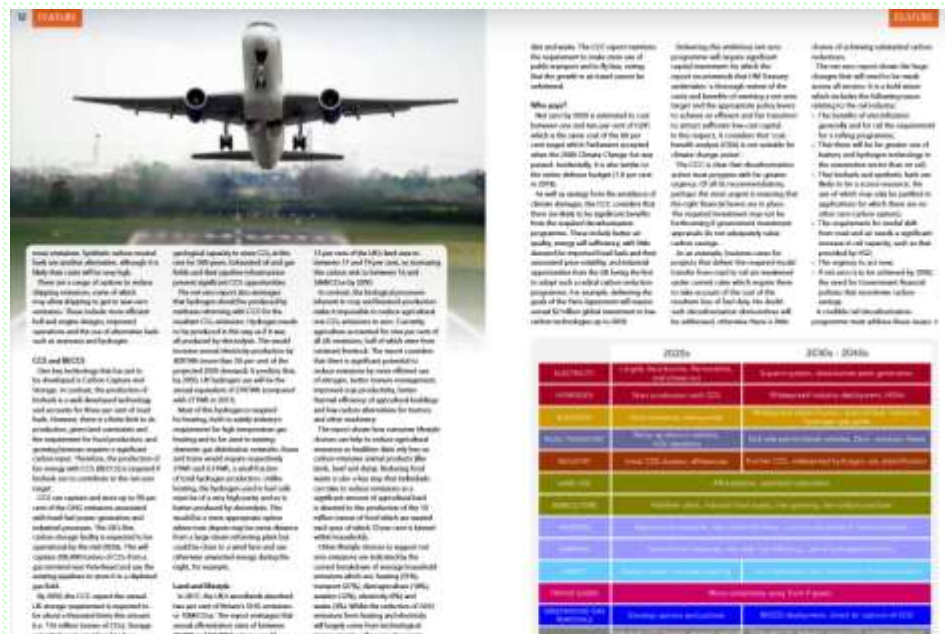
CCC net-zero report

Main report – 277 pages

Technical report – 304 pages

4 page summary in Rail Engineer, September 2019 issue





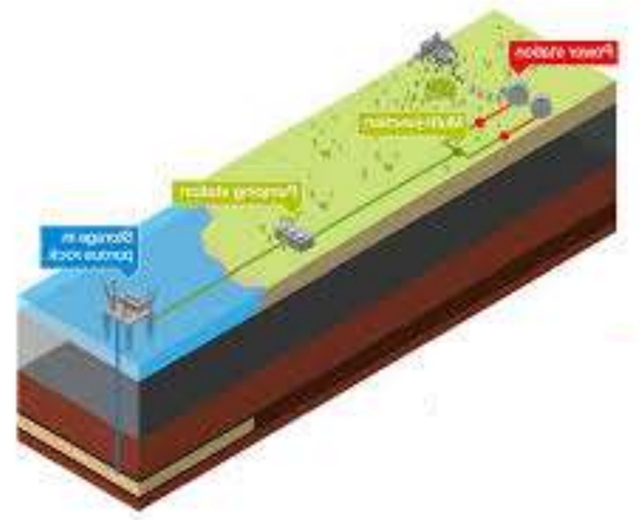
CCC net-zero report – technologies

Carbon Capture and Storage CCS)

Carbon capture from industrial processes

Pipeline transportation

Storage in depleted oil fields – estimated to provide at least a hundred year's storage

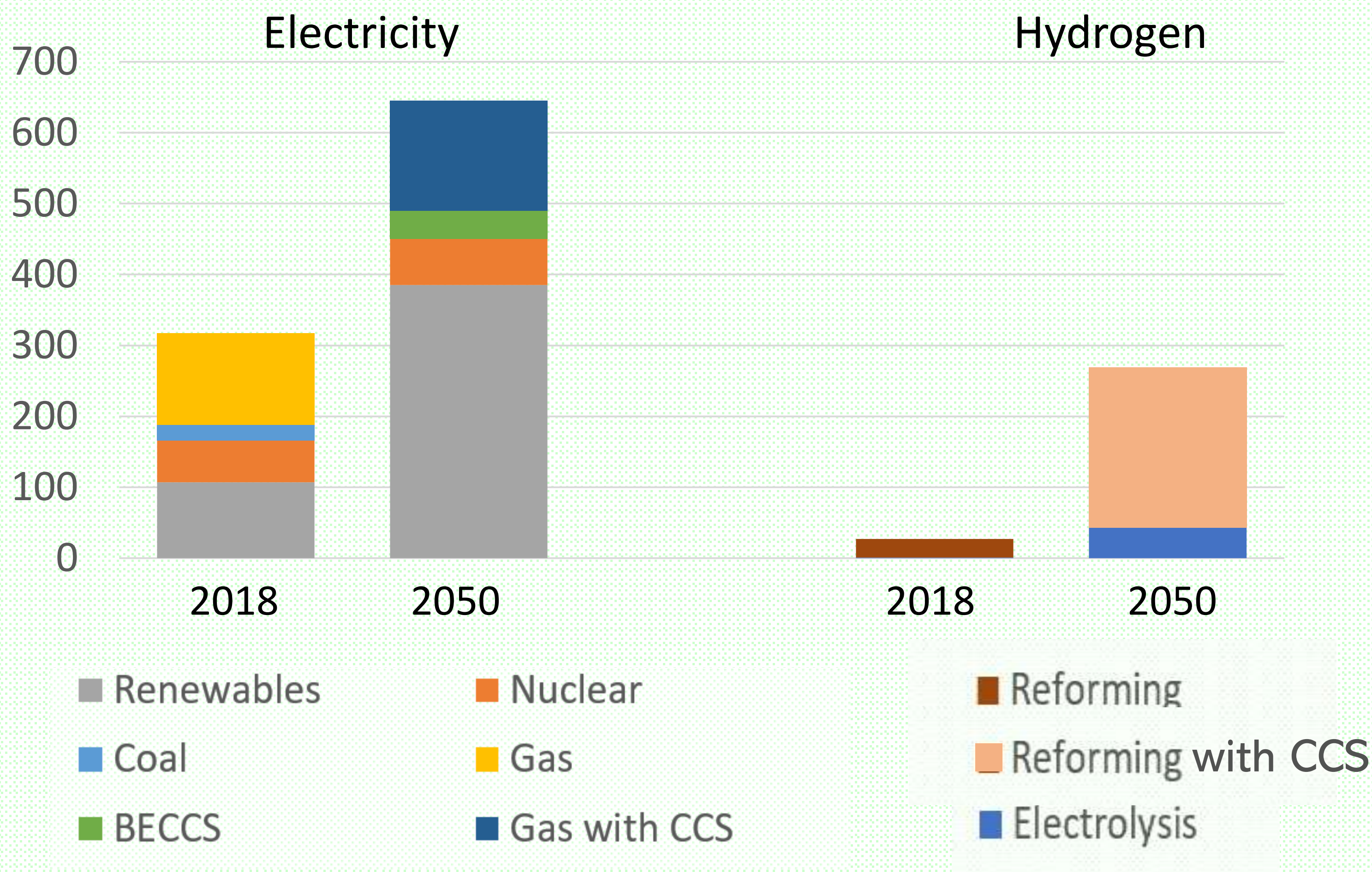


To achieve net-zero CO_2 emissions UK will need to store 171 million tonnes of CO_2 per year (i.e. 34% of current emissions)
Currently the UK has no carbon capture

2050 UK CCS requirement 171 Mt CO_2e	
Power generation	57
Hydrogen production	46
Biofuels	44
Industry	24

CCC net-zero report – technologies

Annual Electricity and Hydrogen generation (TWh)

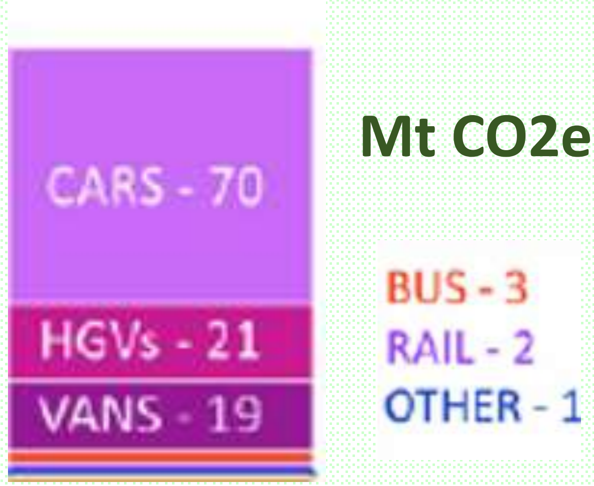


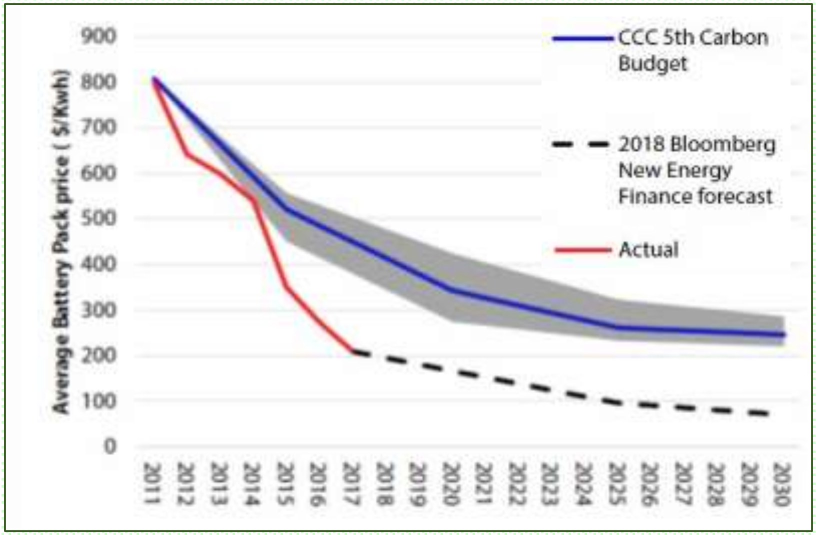
Hydrogen for surface transport: HGVs - 22 TWh, Buses - 3 TWh; Trains 0.3 TWh

CCC net-zero report – technologies

Road vehicles

- End conventional & hybrid vehicle sales by 2035
- End use of petrol and diesel vehicles by 2050
- By 2030 decision needed on best zero-carbon HGV options:
  a) Hydrogen,
  b) Electrified HGV from motorway catenary
  c) Battery HGVs with fast chargers





Actual and forecast battery costs

Required road vehicle chargers by 2050		
Type	2019	2050
22 kW	11,500	56,000
43 kW	4,400	51,000
150 kW		105,000
350 kW		2,100
Total	15,900	214,100

CCC net-zero report – technologies

Ammonia-powered ships

- Although poisonous, Ammonia (NH_3) is a practical way of storing large volumes of hydrogen (as liquid below - 33°C or when pressurised at 10 bar at room temperature).
- Can be burnt directly in an internal combustion engine with a suitable catalyst
- The volumetric energy density of liquid ammonia is 32% that of diesel and 2.5 times that of hydrogen stored at 350 bar

CCC net-zero report – technologies

Biofuels

“The level to which sustainable low-carbon biomass production can be increased is finite, given land constraints and competition from other uses (e.g. food production).

It is therefore important to pursue ways of using this finite resource that maximise its contribution to emissions reduction. This means combining bioenergy with Carbon Capture and Storage (CCS), whether for power generation, hydrogen production or production of biofuels for areas that cannot move away from hydrocarbon fuels (e.g. aviation).

Bioenergy is already used in the energy system, while CCS has been proven in a number of other countries. However, to date they have not been combined at scale.

We have assumed overall bio resource available to the UK of around 200 TWh.”

CCC net-zero report – timescales
Power, industry and buildings

	2020s	2030s - 2040s
ELECTRICITY	Largely decarbonise, Renewables, phase out coal	Expand system, decarbonise peak generation
HYDROGEN	Produce with Carbon Capture & Storage (CCS)	Widespread industry deployment, HGVs
INFRASTRUCTURE	Industrial CCS clusters, expand vehicle charging and electric grid	Hydrogen for industry, more CCS, hydrogen/electric HGV infrastructure, expand electric grid
INDUSTRY	Initial CCS clusters, efficiencies	Further CCS, widespread hydrogen use, electrification
BUILDINGS	Decide solution heat pumps / hydrogen	Widespread electrification, expand heat networks, hydrogen gas grids

CCC net-zero report – timescales
Transport

	2020s	2030s - 2040s
ROAD TRANSPORT	Ramp up electric vehicles, HGV decision	End sale petrol/diesel vehicles, Zero - emission fleets
AVIATION	Operational measures, new plane efficiency, constrained demand, limited biofuels	
SHIPPING	Operational measures, new ship fuel efficiency, use of hydrogen/ammonia	
RAILWAYS	Not specifically considered Modal transfer from cars, increased rail electrification planned on a rolling basis, Hydrogen trains deployed on non-electrified network from 2020	

CCC net-zero report – timescales
Land, waster, fridges and removals

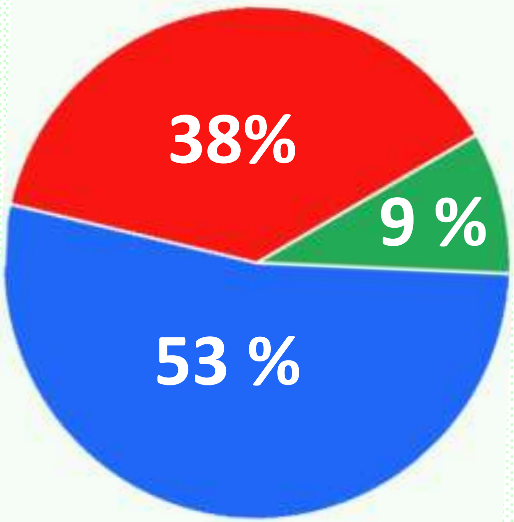
	2020s	2030s - 2040s
LAND USE	Afforestation, peatland restoration	
AGRICULTURE	Healthier diets, reduced food waste, tree growing, low-carbon practices	
WASTE	Reduce waste, increase recycling	Limit emissions from combustion of non-bio waste
FRIDGE GASES	Move completely away from F-gases	
GREENHOUSE GAS REMOVALS	Develop options and policies	Bio energy with CCS, direct air capture of CO2

CCC net-zero report –lifestyle changes required

"Success in reducing emissions so far has happened with minimal public involvement."

"If net-zero is to be achieved this cannot continue yet there is currently no government strategy to engage the public in the transition to a low-carbon economy. For example public support is vital for the switch to low- carbon heating."

CCC net-zero report – lifestyle changes required



NONE - low carbon technologies and fuels not requiring societal or behavioural changes

ENTIRELY dependant on behavioural changes required e.g. less flights and consuming less meat / dairy products

MIX of new technologies and consumer changes, e.g. buy an electric car, install a heat pump

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Climate change: Big lifestyle changes are the only answer

By Justin Rowlatt
Chief Environment correspondent

11 October 2019

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Climate change

CCC net-zero report – costs and benefits

Costs of net-zero by 2050 estimated to be 1-2 % GDP

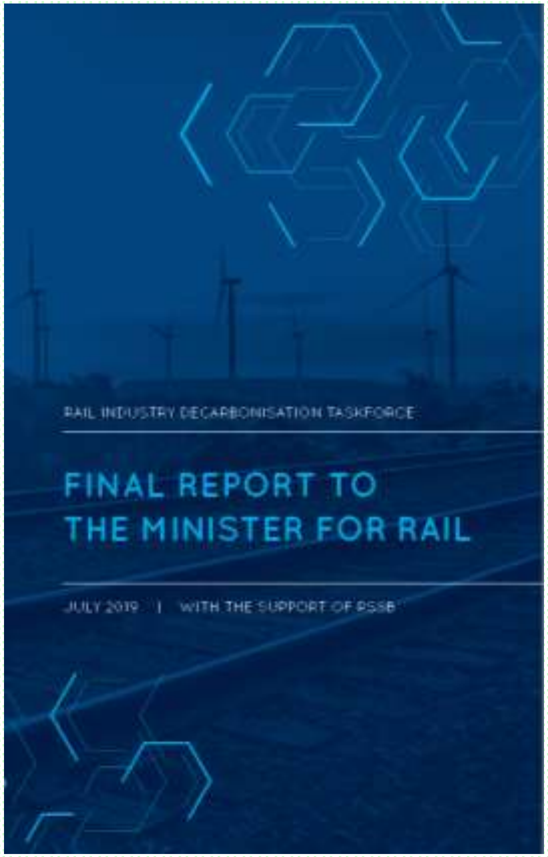
Significant benefits are:

- **Improved quality of life** – Better health (and NHS savings) from improved air and water quality, less noise, more active travel and healthier diets, enhanced biodiversity and climate change resilience
- **Lower risks from climate change**.
- **Industrial opportunities** – if UK was one of the first in some key sectors with potential benefits for exports, productivity and employment.
- **Savings from imported fossil fuels**

Estimates suggest these savings might possibly offset costs of achieving net-zero by 2050

- HM Treasury should ensure the appropriate policy levers are in place to incentivise low-carbon initiatives
- Policies need to ensure required changes do not create too many winners and losers.

Rail decarbonisation



Final rail industry task force report July 2019

Two distinct technology options

1

- Diesel only gone by 2040
- 80% carbon reduction by 2050

→

- Limited electrification
- Long term role for diesel
- Some hydrogen
- Some battery

4,000 route km of electrification

2

- Net zero carbon by 2050
- Net zero carbon by 2040

→

- Electrify all high speed routes?
- Hydrogen and battery for Cat A & B routes

4,250 route km of electrification

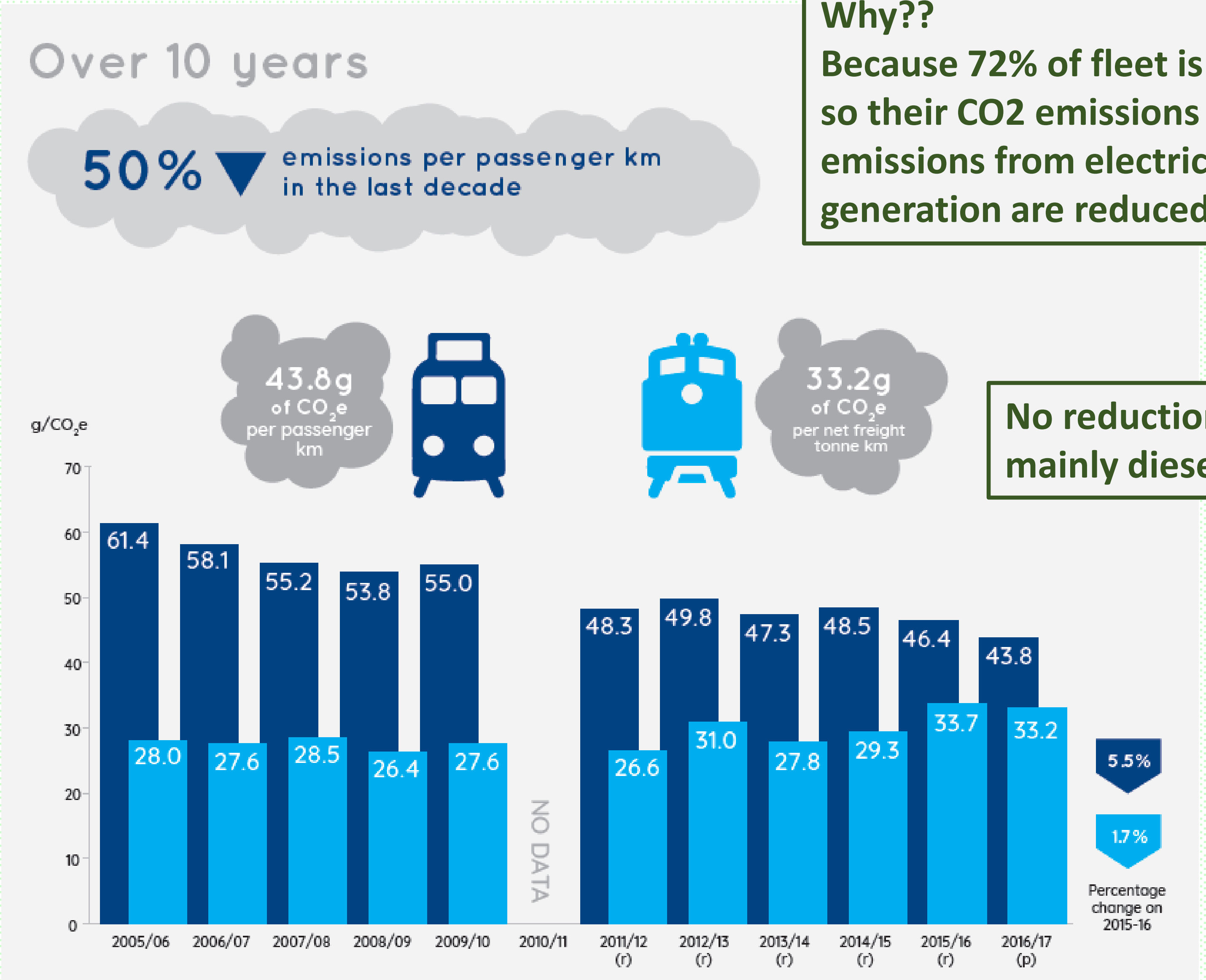
"To deliver net zero carbon by 2040 or 2050 requires a different pathway. There is no long-term role for diesel, in diesel-only or bi-mode forms, that will allow the railway to achieve net zero carbon."

Rail decarbonisation – task force report

					Electric		Autonomous Power			
Future Rolling Stock Category	Description	Total Self-Powered Range Required (Miles)	Total Max Power per Vehicle (kW)	Approx. Engine Energy Output per Vehicle per Day (kWh)	AC Electric (OLE)	DC Electric (Third Rail)	Diesel	Hydrogen	Battery	Biodiesel
A	Shorter distance self-powered with 75mph maximum speed	500	275	1,200	✓	✓	✓	✓	✗	✓
B	Middle distance self-powered with 100 mph capability	800	400	2,400	✓	✓	✓	✗	✗	✓
C	Long distance self-powered with 125 mph capability	1,100	550	4,620	✓	✗	✓	✗	✗	✓

Categorises rolling stock only by speed and distance

Rail decarbonisation – task force report



Why??
Because 72% of fleet is electric and so their CO2 emissions reduce as emissions from electricity generation are reduced.

No reduction for the mainly diesel rail fleet

Rail decarbonisation – task force report

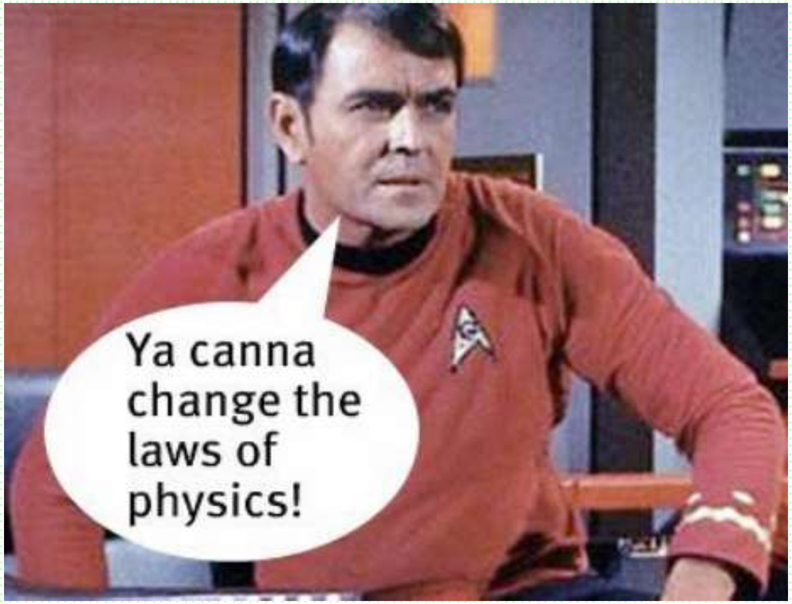
"Our focus throughout this report has been to challenge whether electrification is the best solution to achieve a net zero carbon railway"

Committee on Climate Change net zero report

Net zero will involve "extensive electrification of heat and transport"

"Rail electrification should be planned on a rolling basis to keep costs low"

Captain Montgomery Scott born Linlithgow in 2222



Rail decarbonisation – task force report

Recommendations

- **Targets** – the rail industry, including government, should support the target of net zero carbon by 2050 as proposed by the Committee on Climate Change (CCC).
- **Policy** – the whole rail industry has responsibility to contribute to net zero carbon in a cost-effective manner. To facilitate this, the government should set out clear, consistent and enabling policies.
- **Industry structure** – from the Williams Review we should have an industry structure which effectively enables, incentivises, monitors and regulates the route to support delivery of net zero carbon.
- **Delivery plan** – each key constituent of the industry eg Network Rail, TOC, FOC, ROSCO etc, should publish a long-term plan to achieve interim and long-term targets towards rail decarbonisation in support of net zero carbon by 2050. These will be reviewed, monitored and regulated by a central body.
- **Research and Development** – the industry should set out clear 5-year periodic research plans to reduce technical and implementation uncertainties.

Rail decarbonisation – task force report

Recommendations

- **Targets** – the rail industry, including government, should support the target of net zero carbon by 2050 as proposed by the Committee on Climate Change (CCC).
- **Policy** – the
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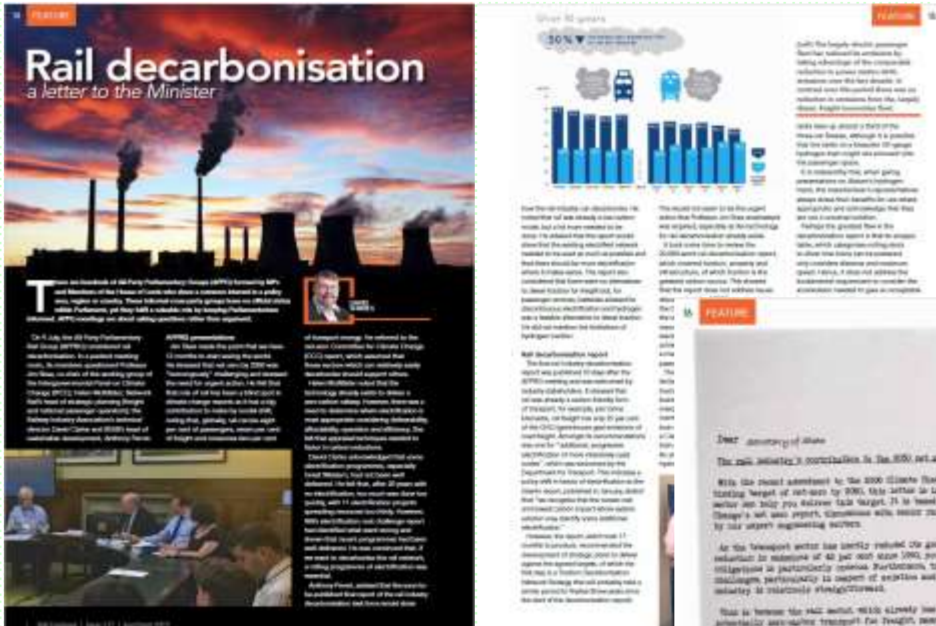
- Targets and delivery plans to be determined by a Traction Decarbonisation Network Strategy to report back in October 2020
- Traction decarbonisation reductions are entirely dependant on the power generation emissions over which the rail industry has no control
- Automotive industry will make far greater use of batteries and hydrogen than rail and already has a huge research programme.
- Emphasis on research into alternative self-powered traction which is about 5% of the solution. Proven electrification technology will provide by far the greatest emissions reduction

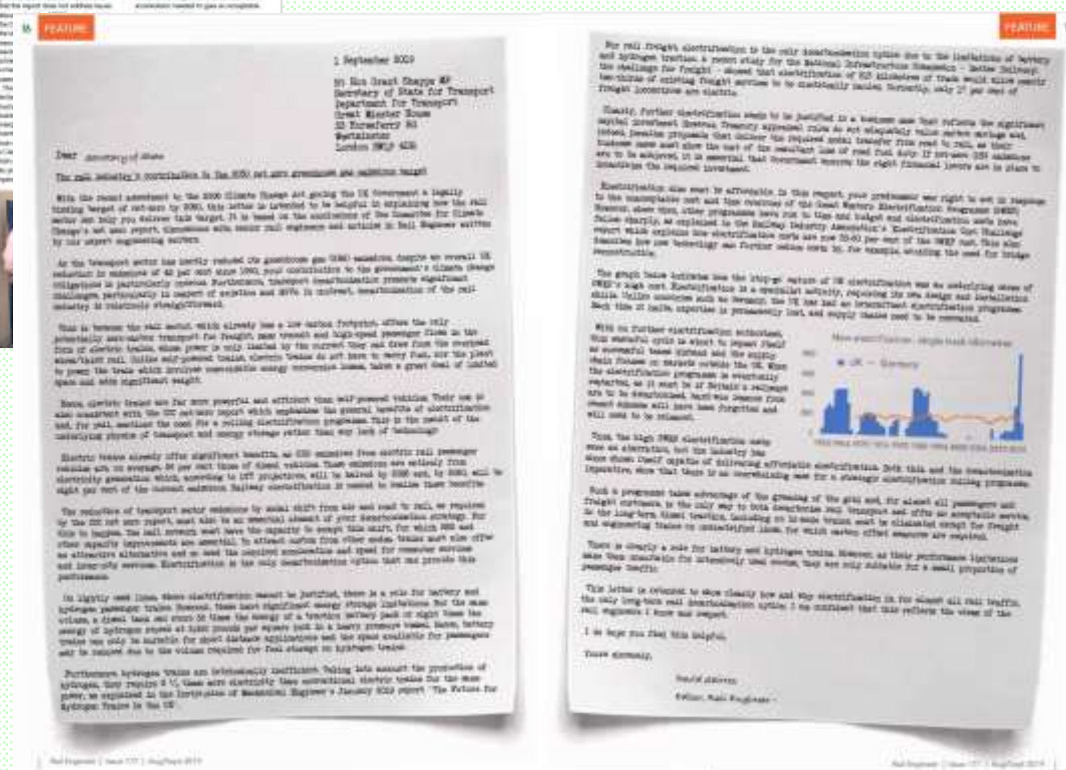
Rail decarbonisation – a short report

Rail Engineer, September 2019 issue



Background

Letter to the Minister



Rail decarbonisation – a letter to the (UK) Minister

London SW1P 4DR

Dear *Secretary of State*

The rail industry's contribution to the 2050 net zero greenhouse gas emissions target

With the recent amendment to the 2008 Climate Change Act giving the UK Government a legally binding target of net-zero by 2050, this letter is intended to be helpful in explaining how the rail sector can help you deliver this target. It is based on the conclusions of the Committee for Climate Change's net zero report, discussions with senior rail engineers and articles in Rail Engineer written by our expert engineering writers.

As the transport sector has hardly reduced its greenhouse gas (GHG) emissions, despite an overall UK reduction in emissions of 42 per cent since 1990, your contribution to the government's climate change obligations is particularly onerous. Furthermore, transport decarbonisation presents significant challenges, particularly in respect of aviation and HGVs. In contrast, decarbonisation of the rail industry is relatively straightforward.

This is because the rail sector, which already has a low carbon footprint, offers the only potentially zero-carbon transport for freight, mass transit and high-speed passenger flows in the form of electric trains, whose power is only limited by the current they can draw from the overhead wires/third rail. Unlike self-powered trains, electric trains do not have to carry fuel, nor the plant to power the train which involves unavoidable energy conversion losses, takes a great deal of limited space and adds significant weight.

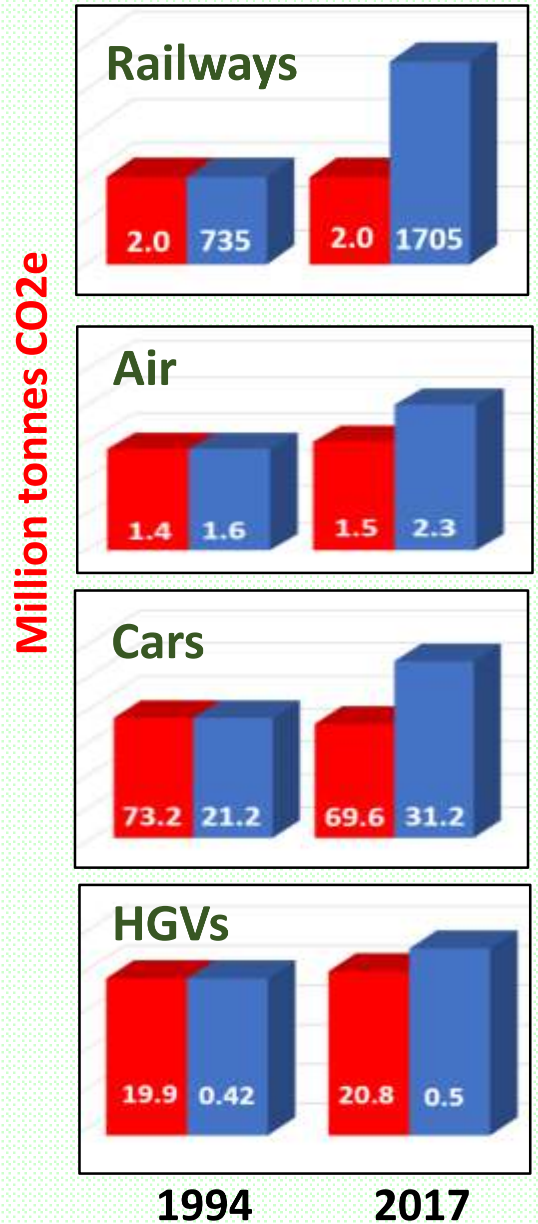
Except for rail, transport decarbonisation is particularly challenging

Rail electrification is the only potentially zero-carbon technology for freight, mass transit and high-speed passenger transport

Transport emissions –
Per unit emissions down but no overall reduction

	2016-2017 % change	1990-2017 % change
Energy supply (including power sector)	↓ 8%	↓ 57%
Industrial process	↓ 1%	↓ 49%
Business	↔ 0%	↓ 41%
Transport	↔ 0%	↓ 1%
Residential	↓ 4%	↓ 18%
Public	↓ 3%	↓ 41%

	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 decarbonisation – a letter to the (UK) Minister

Hence, electric trains are far more powerful and efficient than self-powered vehicles. Their use is also consistent with the CCC net-zero report which emphasises the general benefits of electrification and, for rail, mentions the need for a rolling electrification programme. This is the result of the underlying physics of transport and energy storage rather than any lack of technology.

Electric trains already offer significant benefits, as GHG emissions from electric rail passenger vehicles are, on average, 26 per cent those of diesel vehicles. These emissions are entirely from electricity generation which, according to DfT projections, will be halved by 2028 and, by 2050, will be eight per cent of the current emissions. Railway electrification is needed to realise these benefits.

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

Rail decarbonisation – a letter to the (UK) Minister

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Savings from use of electric traction	Passenger vehicle	Freight locomotive
Tonnes carbon per vehicle		
2016-17	259	744
2040	307	799
Electric CO2e emissions as a percentage of diesel		
2016-17	26.4%	14.1%
2040	11.3%	6.1%

Rail decarbonisation – a letter to the (UK) Minister

> The reduction of transport sector emissions by modal shift from air and road to rail, as required by the CCC net zero report, must also be an essential element of your decarbonisation strategy. For this to happen, the rail network must have the capacity to accept this shift, for which HS2 and other capacity improvements are essential. To attract custom from other modes, trains must also offer an attractive alternative and so need the required acceleration and speed for commuter services and inter-city services. Electrification is the only decarbonisation option that can provide this performance.

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

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. Net-zero by 2050 through electrification, hydrogen on rural routes, carbon offsets /capture for remaining freight/engineering locos saves 2 million tonnes CO2

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 savings 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

Modal transfer to rail is as important as rail's own carbon reductions. To attract traffic from road and air rail traction must offer the best possible acceleration and speed.
Rail must also have the capacity to accept this extra traffic, hence the need for HS2 and other capacity improvements

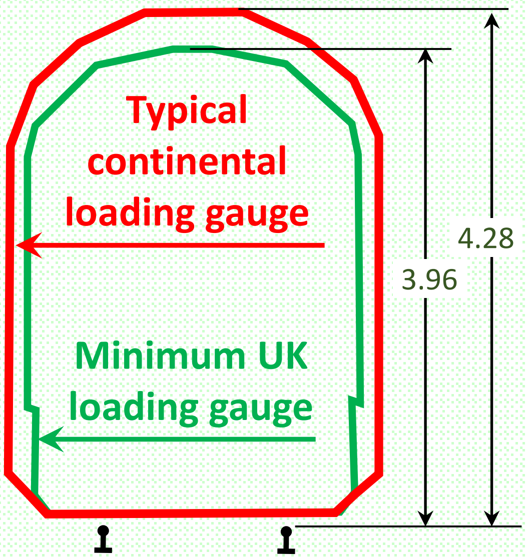
Rail decarbonisation – a letter to the (UK) Minister

On lightly used lines, where electrification cannot be justified, there is a role for battery and hydrogen passenger trains. However, these have significant energy storage limitations. For the same volume, a diesel tank can store 36 times the energy of a traction battery pack or eight times the energy of hydrogen stored at 5,000 pounds per square inch in a heavy pressure vessel. Hence, battery trains can only be suitable for short distance applications and the space available for passengers may be reduced due to the volume required for fuel storage on hydrogen trains.

Energy density	Volume (MJ/L)	Weight (MJ/kg)
Uranium	1,500,000	80,620,000
Diesel	35.8	48.0
Petrol	34.2	46.4
LPG	26	46.4
Liquid Ammonia	11.5	18.4
Hydrogen (at 350 bar)	4.6	71
Automotive battery pack	1.0	10.8
Automotive battery pack 2035	3.6 ??	43.2 ??

Alstom's UK Breeze proposal – January 2019

- Alstom's UK hydrogen train design is a conversion of a redundant electric multiple unit
- Range of 1,000 km
- Top speed of 140 km/h
- Acceleration tbc, between DMU and EMU
- Trains could be running in 2022
- Fleet operation needed to justify investment in hydrogen infrastructure
- Unlike Germany, hydrogen tanks are within motor coach taking up 25 % of the space of a 3-car train
- A purpose-built UK hydrogen train may not require internal hydrogen tanks

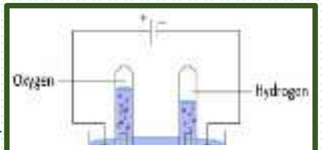


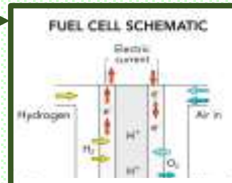
Rail decarbonisation – a letter to the (UK) Minister

> Furthermore, hydrogen trains are intrinsically inefficient. Taking into account the production of hydrogen, they require 2 ½ times more electricity than conventional electric trains for the same power, as explained in the Institution of Mechanical Engineer's January 2019 report 'The Future for Hydrogen Trains in the UK'.

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	Electrolysis	Compress to 350 bar	Fuel Cell	Converter and Drive	Overall
	68%	94%	52%	89%	29%

Electrification from renewable energy

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

Efficiency	OLE Transmission	Transformer	Converter and Drive	Overall
	98%	95%	89%	83%

Also the view of the Institution of Mechanical Engineers


TRANSPORT

THE FUTURE FOR HYDROGEN TRAINS IN THE UK

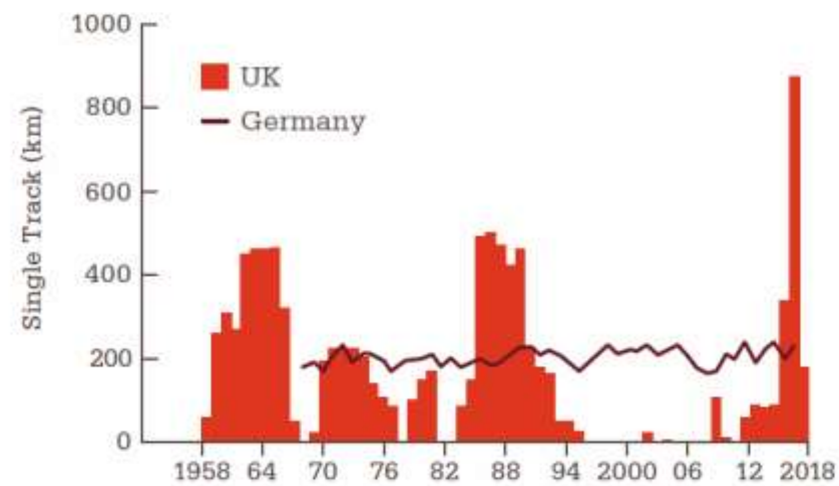
THE FUTURE FOR HYDROGEN TRAINS IN THE UK

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"



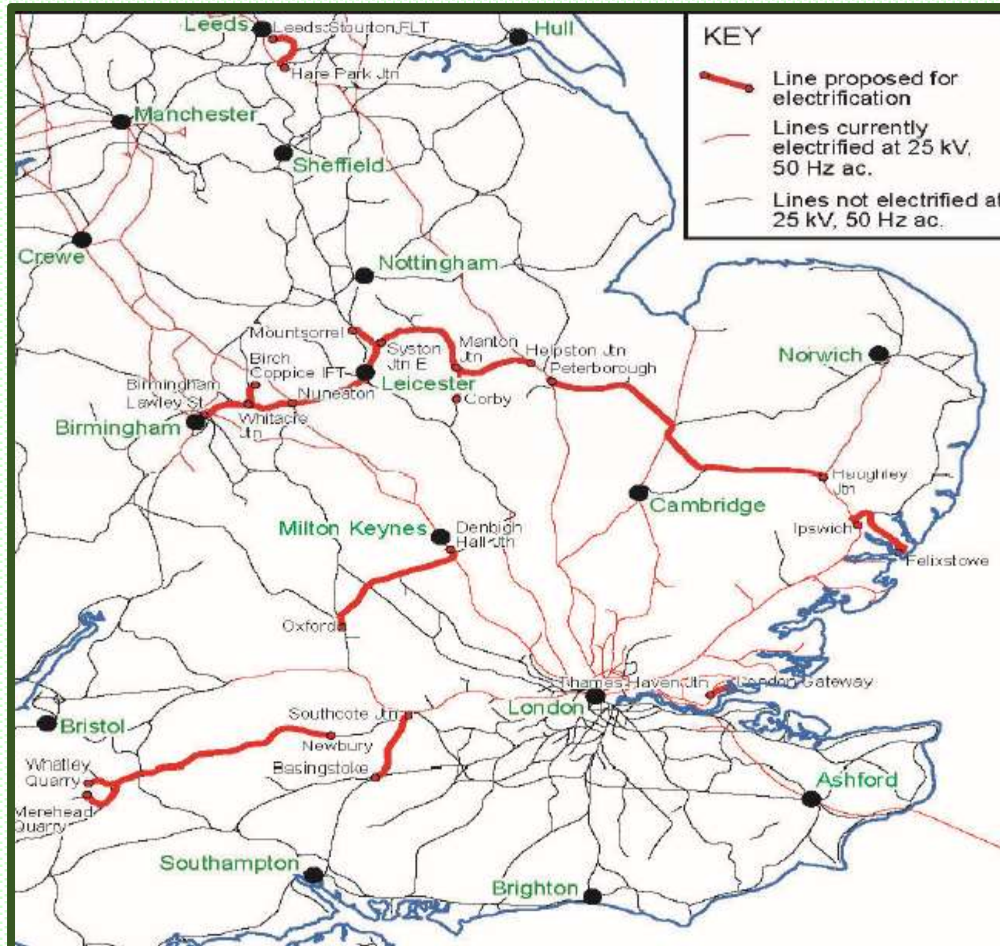
Why electrification can go wrong

Rail decarbonisation – a letter to the (UK) Minister

For rail freight, electrification is the only decarbonisation option due to the limitations of battery and hydrogen traction. A recent study for the National Infrastructure Commission - 'Better Delivery: the challenge for freight' - showed that electrification of 515 kilometres of track would allow nearly two-thirds of existing freight services to be electrically hauled. Currently, only 17 per cent of freight locomotives are electric.

CILT Rail Freight Forum has concluded that 500 km of electrification would enable 66-75% of freight traffic to be electrically hauled

Currently electric locomotives constitute 17% of the freight locomotive fleet



Rail decarbonisation – a letter to the (UK) Minister

Clearly, further electrification needs to be justified in a business case that reflects the significant capital investment. However, Treasury appraisal rules do not adequately value carbon savings and, indeed, penalise proposals that deliver the required modal transfer from road to rail, as their business cases must show the cost of the resultant loss of road fuel duty. If net-zero GHG emissions are to be achieved, it is essential that Government ensures the right financial levers are in place to incentivise the required investment.

Electrification also must be affordable. In this respect, your predecessor was right to act in response to the unacceptable cost and time overruns of the Great Western Electrification Programme (GWEP). However, since then, other programmes have run to time and budget and electrification costs have fallen sharply, as explained in the Railway Industry Association's 'Electrification Cost Challenge' report which explains how electrification costs are now 33-50 per cent of the GWEP cost. This also describes how new technology can further reduce costs by, for example, avoiding the need for bridge reconstruction.

Estimated 2040 carbon savings from additional electric vehicles with intensive electrification			
	Passenger	**Freight**	**Total**
Tonnes C02e – Annual savings per vehicle	307	799	
Estimated additional electric vehicles	2000	300	
Total annual carbon savings	614,000	239,700	853,700
Annual value carbon saved @ £136 /tonne	£83.5 bn	£32.6 bn	£116.1 bn

Carbon valuation

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

TAG Table A 3.4

Greenhouse Gases

This version:	
May 2019 v1.12	
May-19	
Links:	
Contents	
TAG Unit 3.3.5	
TAG Unit A 3	
Parameters:	
Price year:	**2010**
Initial fc year:	**2010**
Sheet Navigation:	

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

Table A 3.4: Non Traded Values, £ per Tonne of CO2e (2010 prices)

Year	Low	Central	High
2010	26.20	52.41	78.61
2011	26.20	53.28	79.48
2012	27.08	53.28	80.36
2013	27.08	54.15	82.10
2014	27.95	55.03	82.98
2015	27.95	55.90	83.85
2016	28.82	56.77	85.60
2017	28.82	57.65	86.47
2018	29.70	58.52	88.22
2019	29.70	59.39	89.09
2020	30.57	60.27	90.84
2021	30.57	61.14	92.59
2022	31.44	62.89	93.46
2023	31.44	63.76	95.21
2024	32.32	64.63	96.95
2025	33.19	65.51	98.70
2026	33.19	66.38	99.57
2027	34.06	67.26	101.32
2028	34.06	69.00	103.07
2029	34.94	69.88	104.81
2030	34.94	70.75	105.69
2031	38.43	76.86	115.29
2032	41.93	83.85	125.78
2033	45.42	89.96	135.38
2034	48.04	96.95	144.99
2035	51.53	103.07	155.47
2036	55.03	110.05	165.08
2037	58.52	116.17	174.69
2038	61.14	123.16	184.30
2039	64.63	129.27	194.78
2040	68.13	136.26	204.39
2041	71.62	142.37	213.99
2042	74.24	149.36	223.60
2043	77.74	155.47	234.08
2044	81.23	162.46	243.69
2045	84.72	168.57	253.30
2046	87.34	175.56	262.91
2047	90.84	181.68	273.39
2048	94.33	188.66	283.00
2049	97.83	194.78	292.60
2050	100.45	201.77	302.21

136.26

Other electrification savings

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

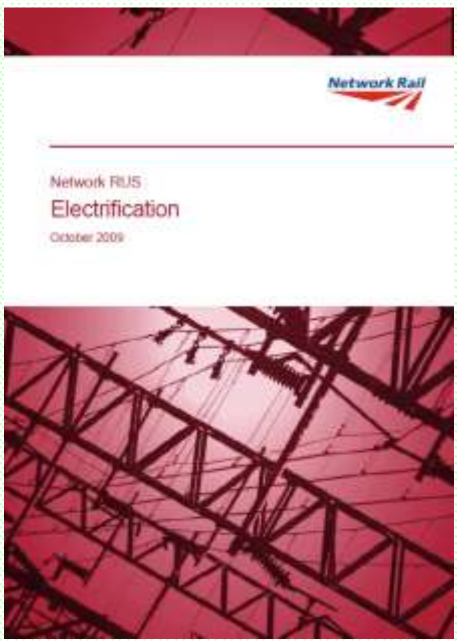


Table 3.3 – Typical operating costs of diesel and electric passenger vehicles

	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

Rail decarbonisation – a letter to the (UK) Minister

The graph below indicates how the 'stop-go' nature of UK electrification was an underlying cause of GWEP's high cost. Electrification is a specialist activity, requiring its own design and installation skills. Unlike countries such as Germany, the UK has had an intermittent electrification programme. Each time it halts, expertise is permanently lost, and supply chains need to be recreated.

With no further electrification authorised, this wasteful cycle is about to repeat itself as successful teams disband and the supply chain focuses on markets outside the UK. When the electrification programme is eventually restarted, as it must be if Britain's railways are to be decarbonised, hard-won lessons from recent schemes will have been forgotten and will need to be relearnt.

Thus, the high GWEP electrification costs were an aberration, but the industry has since shown itself capable of delivering affordable electrification. Both this, and the decarbonisation imperative, show that there is an overwhelming case for a strategic electrification rolling programme.

Rail decarbonisation – a letter to the (UK) Minister

Such a programme takes advantage of the greening of the grid and, for almost all passengers and freight customers, is the only way to both decarbonise rail transport and offer an acceptable service. In the long-term, diesel traction, including on bi-mode trains, must be eliminated except for freight and engineering trains on unelectrified lines, for which carbon offset measures are required.

Bi-modes are not a long term solution but offer significant transitional benefits

East Coast example

2019 daily diesel running - HST				2020 diesel running – Azuma bi-mode			
Between	Services	Miles	Total	Between	Services	Miles	Total
London & Aberdeen	6	523	3,138	Edinburgh & Aberdeen	6	131	786
London & Inverness	2	581	1,162	Dunblane & Inverness	2	146	292
		Total	4,300			Total	1,078
Bi-mode Azumas reduce diesel running under the wires between London and Aberdeen/Inverness by 75%							

Rail decarbonisation – a letter to the (UK) Minister

There is clearly a role for battery and hydrogen trains. However, as their performance limitations make them unsuitable for intensively used routes, they are only suitable for a small proportion of passenger traffic.

Battery trains

March 2019

- Hitachi offering battery fitted class 385s
- Out and back range of 30 miles possible at DMU performance

IPEMU trial – February 2015

- Potential for Independently Powered EMUs to operate beyond 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
- Batteries are costly and need to be replaced
- Producing and recycling batteries uses rare materials and has high environmental costs

Unlikely to be a long term solution though a potentially useful transitional technology for short runs beyond electrified routes

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:

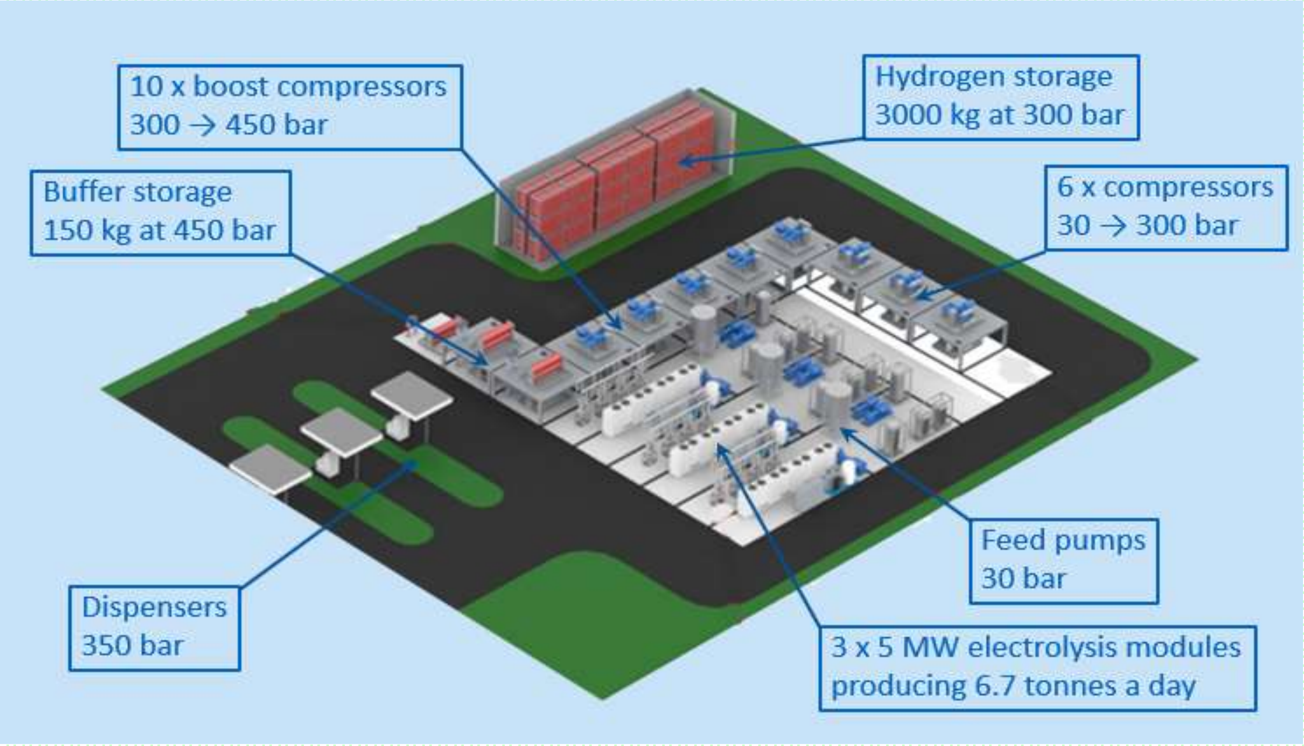
- require 2.4 times more electricity than an electric trains
- Only zero-carbon if hydrogen produced from carbon-free electricity (e.g. renewables)
- Currently have about 2/3 the power to weight ratio of an electric train though this may improve

Suitable for rural routes, but are not an alternative to main-line electrification

Hydrogen supply

- Resilient supply essential
- Reforming cheaper than electrolysis only zero-carbon with carbon capture. It also requires a large plant which may be some distance from a depot
- Hydrogen trains are only zero carbon if produced by electrolysis from renewables

15 MW plant could supply 30 trains or 300 buses



Hydrogen supply

With a range of 1,000 km, hydrogen trains on rural Scottish routes could be fuelled from hydrogen plants in Glasgow and Inverness

Hydrogen synergies

- Hydrogen trains must not be considered in isolation
- For surface transport, net zero report considers annual hydrogen requirement will be:
  HGVs - 22 TWh, Buses - 3 TWh; Trains 0.3 TWh
- Hydrogen will also replace natural gas for heating
- Hydrogen production also provides the energy storage that is needed for the required expansion of wind and solar power

UK's 19 hydrogen fuelling stations (Jan 2018)

The first hydrogen trains were bought by Lower Saxony which has an installed wind power capacity of 7,800 MW

Aberdeen's 10 hydrogen buses

Rail decarbonisation – the industry view?

This letter is intended to show clearly how and why electrification is, for almost all rail traffic, the only long-term rail decarbonisation option. I am confident that this reflects the views of the rail engineers I know and respect.

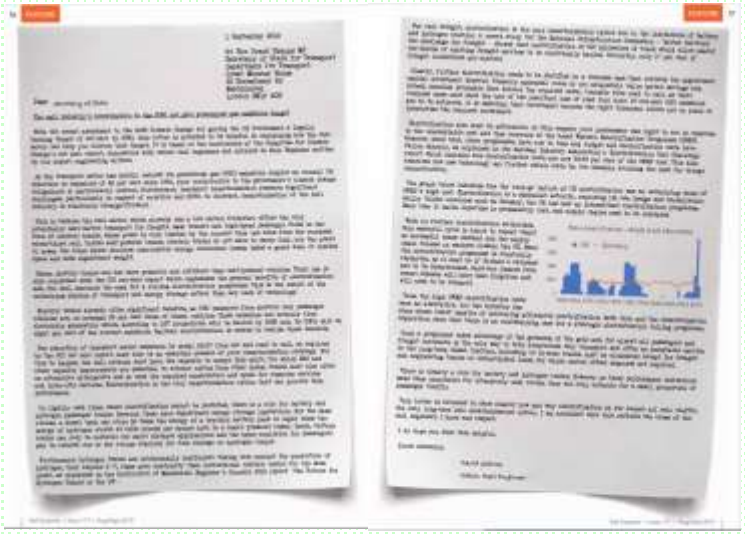
I do hope you find this helpful,

Yours sincerely,

David Shirres

Editor, Rail Engineer -

or



Conclusions – UK decarbonisation

- CCC report outlines strategy to achieve net zero by 2050.
- It also explains why this cannot be achieved by an earlier date
- UK Government has accepted this target and amended the Climate Change Act accordingly. As yet it has adopted few, if any, of the policies needed to achieve this target.
- Electrification (of surface transport and heating) is a key to reducing emissions
- It also provides the basis for a rail decarbonisation strategy

Conclusions – Net zero rail carbon

- Rail's potential for reducing UK carbon emission is both by taking traffic from road and air and reducing its own emissions.
- To attract traffic from other modes, rail traction has to offer high speed and high acceleration
- Electric trains provide such performance as they are far more powerful and efficient than self powered vehicles.
- Electric trains do not have to store fuel on board which is a particular constraint for hydrogen vehicles.
- For these reasons hydrogen is not suitable for high speed or urban services with frequent stops but do offer a suitable low carbon option for rural services which carry a tiny proportion of passenger mileage
- Battery trains offer low-carbon traction but are no substitute for long-term electrification, hence they should be a transitional technology
- Electric and hydrogen (if produced by electrolysis) trains offer zero-carbon traction if the grid can be fully decarbonised

Conclusions – Net zero rail carbon

- A rolling electrification of around 200 route km year between 2020 and 2050 would electrify all but rural lines in a cost effective manner.
- By 2050 this would give electric haulage of:
  - around 95% of passenger traffic
  - around 75% of freight and engineering trains
- Hydrogen trains could be used for the remaining passenger traffic
- There is, as yet, no practical alternative to diesel traction for freight and engineering trains. To achieve net-zero, self-powered freight / engineering trains would need carbon offsets or use biofuels produced with carbon capture
- Until the rolling electrification programme is completed, bi modes, hydrogen and batteries have a valuable transition role
- Rail's non traction energy use can be decarbonised using the technologies in the CCC's net-zero report

Thanks for listening

Let's hope for carbon-free electric traction