Future Rail Power Options

David Shirres, Editor RailEngineer

Future Rail Power Options

Covid -19

The measure of greenhouse gas emissions is grams CO_2e per passenger kilometre or per tonne kilometre. Currently UK rail passenger emissions are poor as trains are not so busy.

This presentation is based on pre-Covid statistics which are considered to be a reasonable measure as carbon reductions are a long term project

David Shirres, Editor RailEngineer

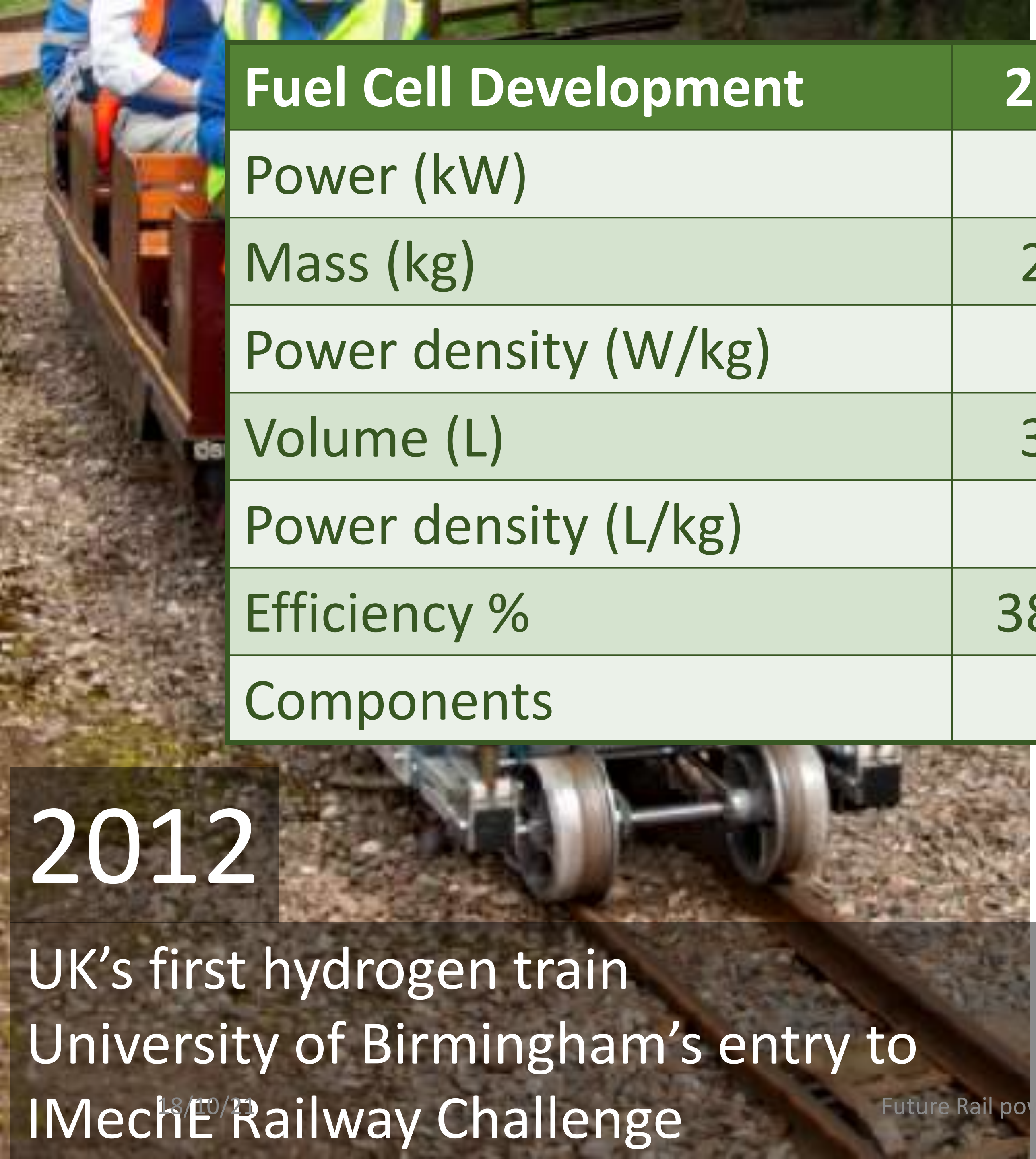
2012

UK's first hydrogen train
University of Birmingham's entry to
IMechE Railway Challenge

2017

Press visit to Alstom's German
Salzgitter plant after contracts signed
to operate world's first hydrogen train

Fuel Cell Development	2001	2003	2009	2011
Power (kW)	25	20	16.5	33
Mass (kg)	290	170	92	75
Power density (W/kg)	86	117	180	400
Volume (L)	365	180	133	125
Power density (L/kg)	68	111	124	264
Efficiency %	38-45	40 – 54	48 - 54	48 – 55
Components	25	8	6	6



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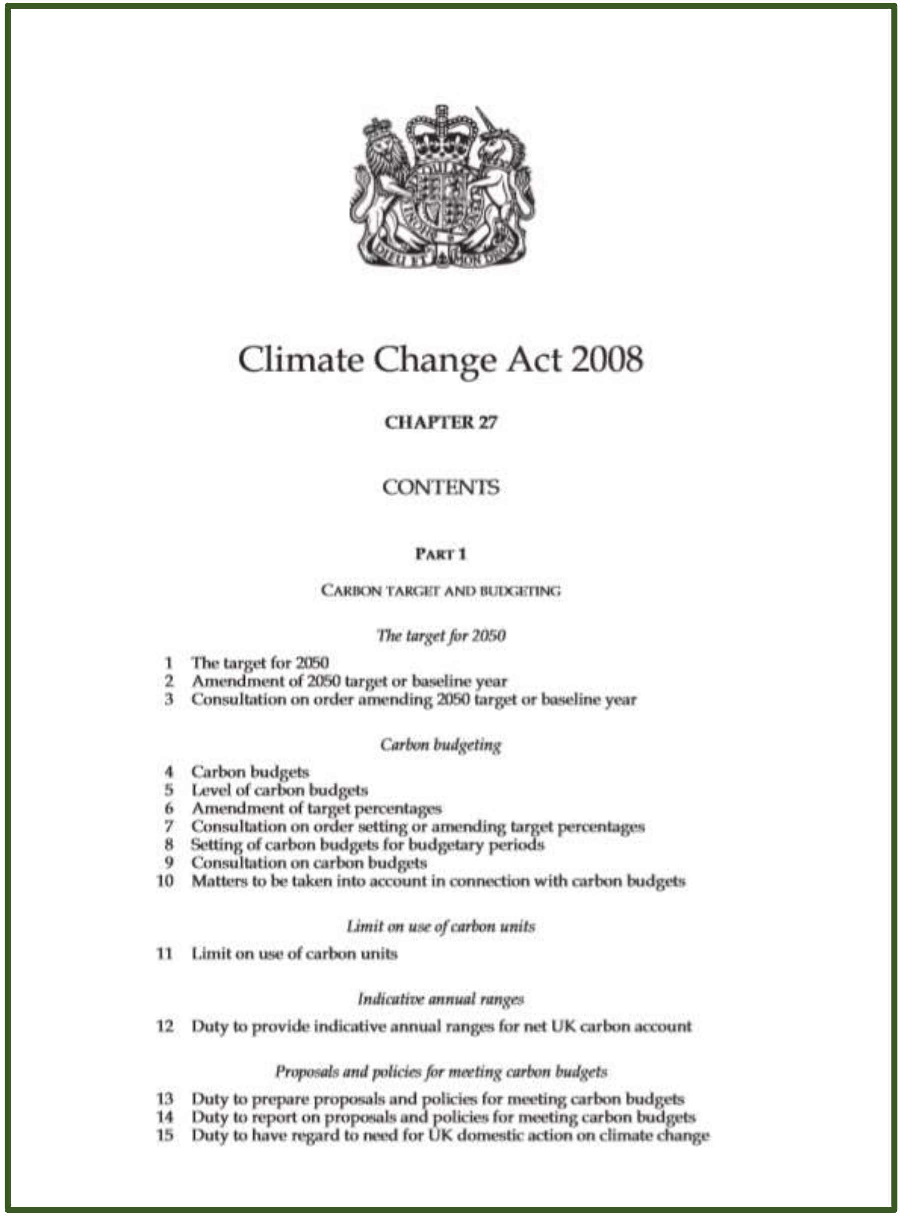
2008 Climate Change Act

- A world first
- Originally 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
- Established **Committee on Climate Change** to monitor progress and advise action required

"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"



Climate Change Act 2008

CHAPTER 27

CONTENTS

PART 1

CARBON TARGET AND BUDGETING

The target for 2050

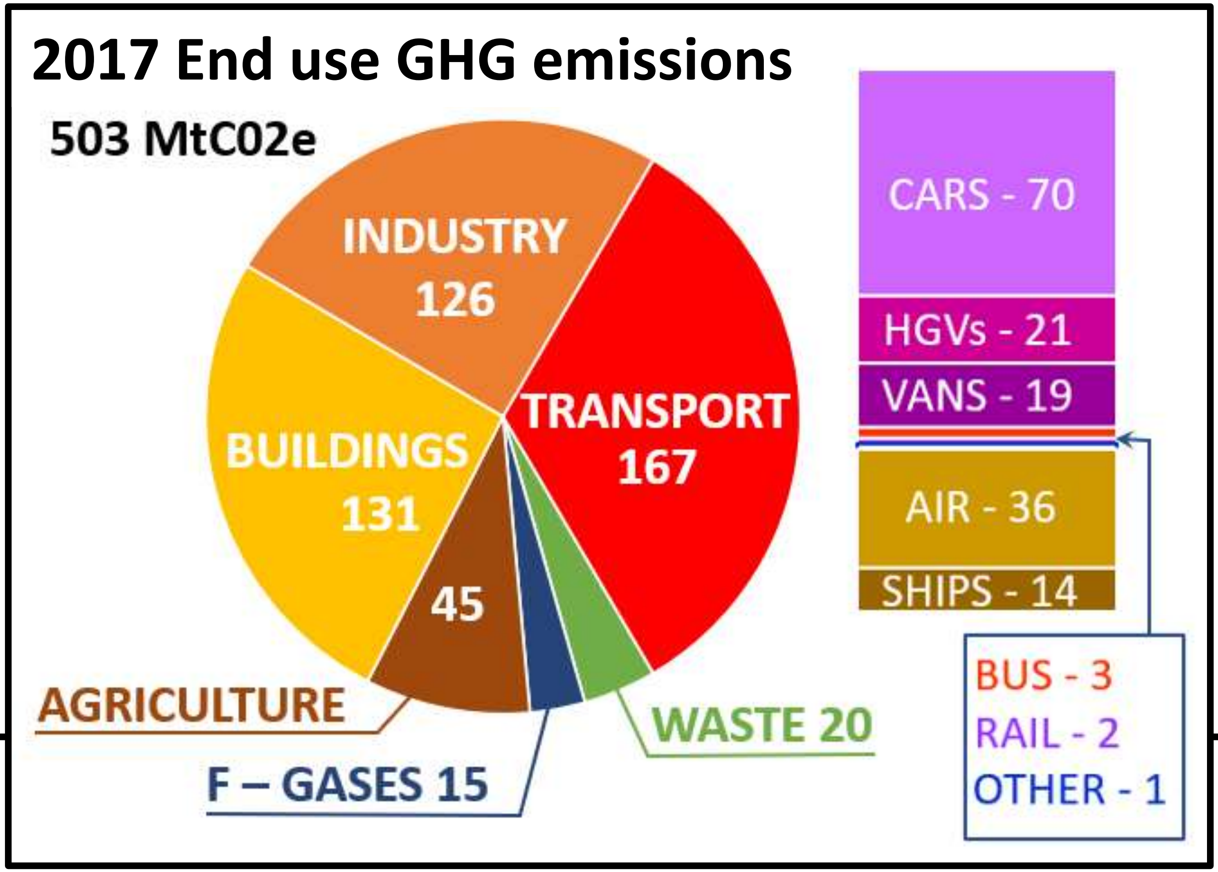
Carbon budgeting

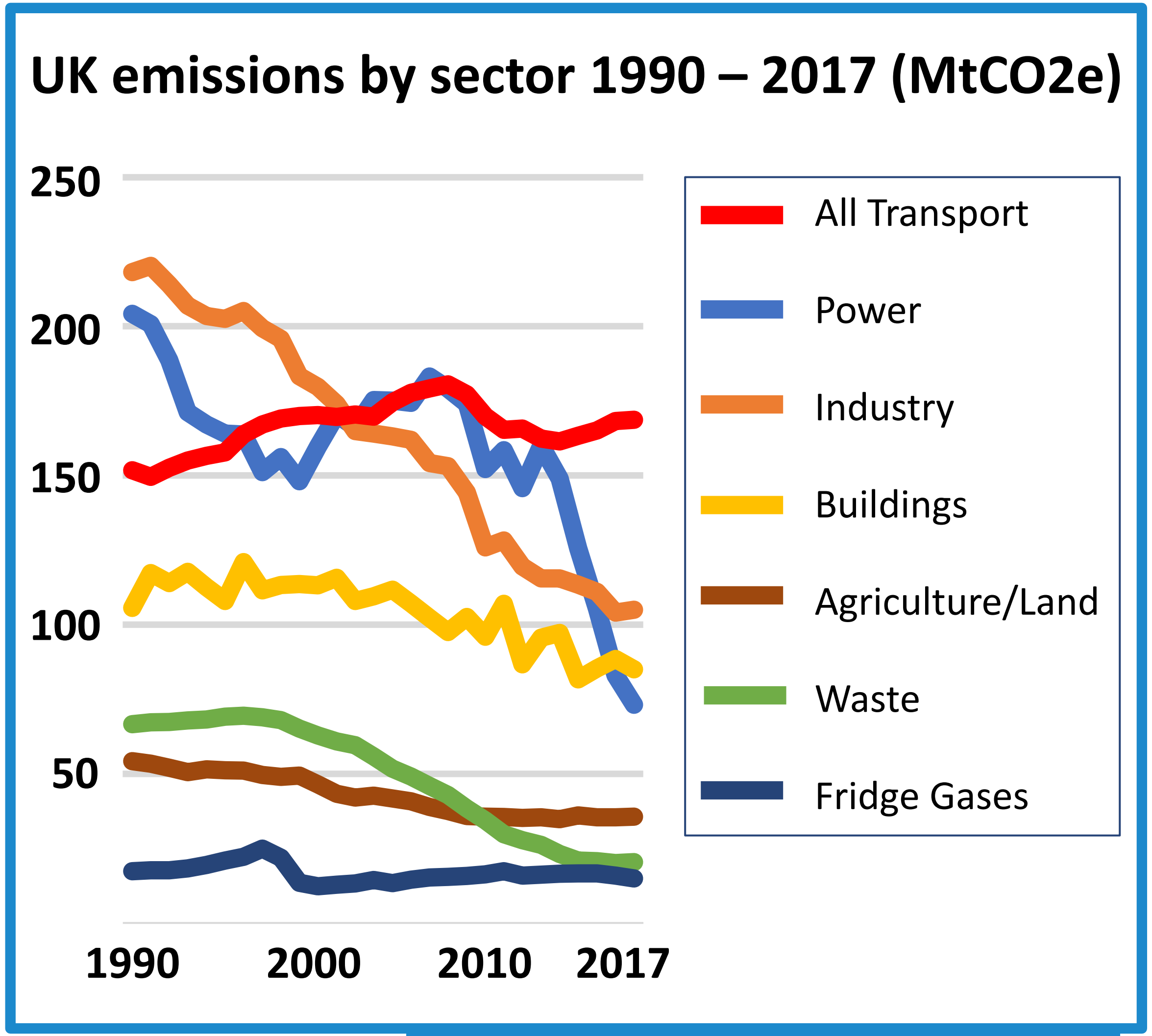
Limit on use of carbon units

Indicative annual ranges

Proposals and policies for meeting carbon budgets

Transport
- the most difficult problem





Department for Business, Energy & Industrial Strategy

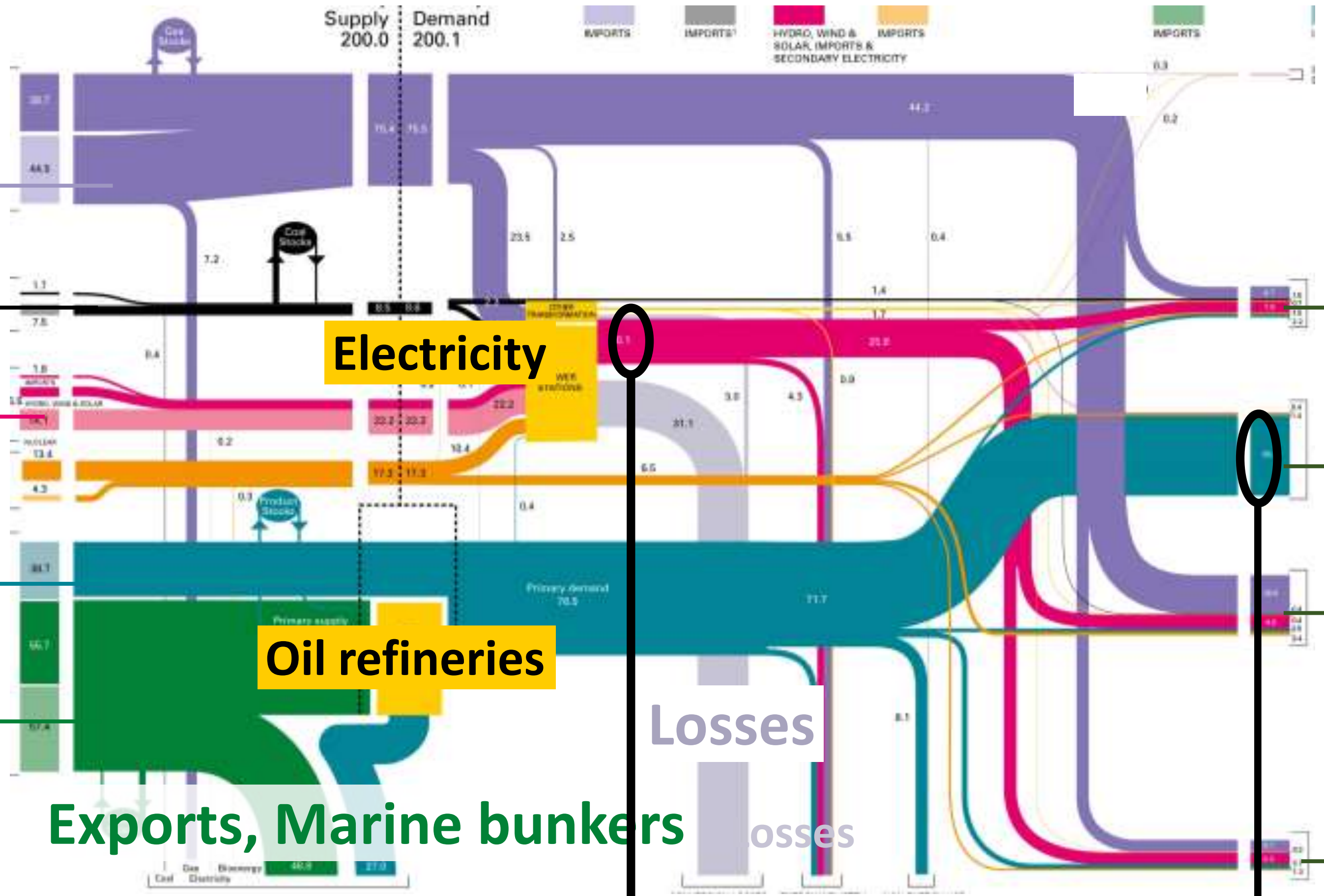
Final UK greenhouse gas emissions national statistics 1990-2017

Includes UK fuel for international aviation (35 Mt CO2e) and shipping (8 Mt CO2e) which, from 2018, this dataset no longer reports

Energy on the move – 2018 (TWh equivalent)

INPUTS - 3300

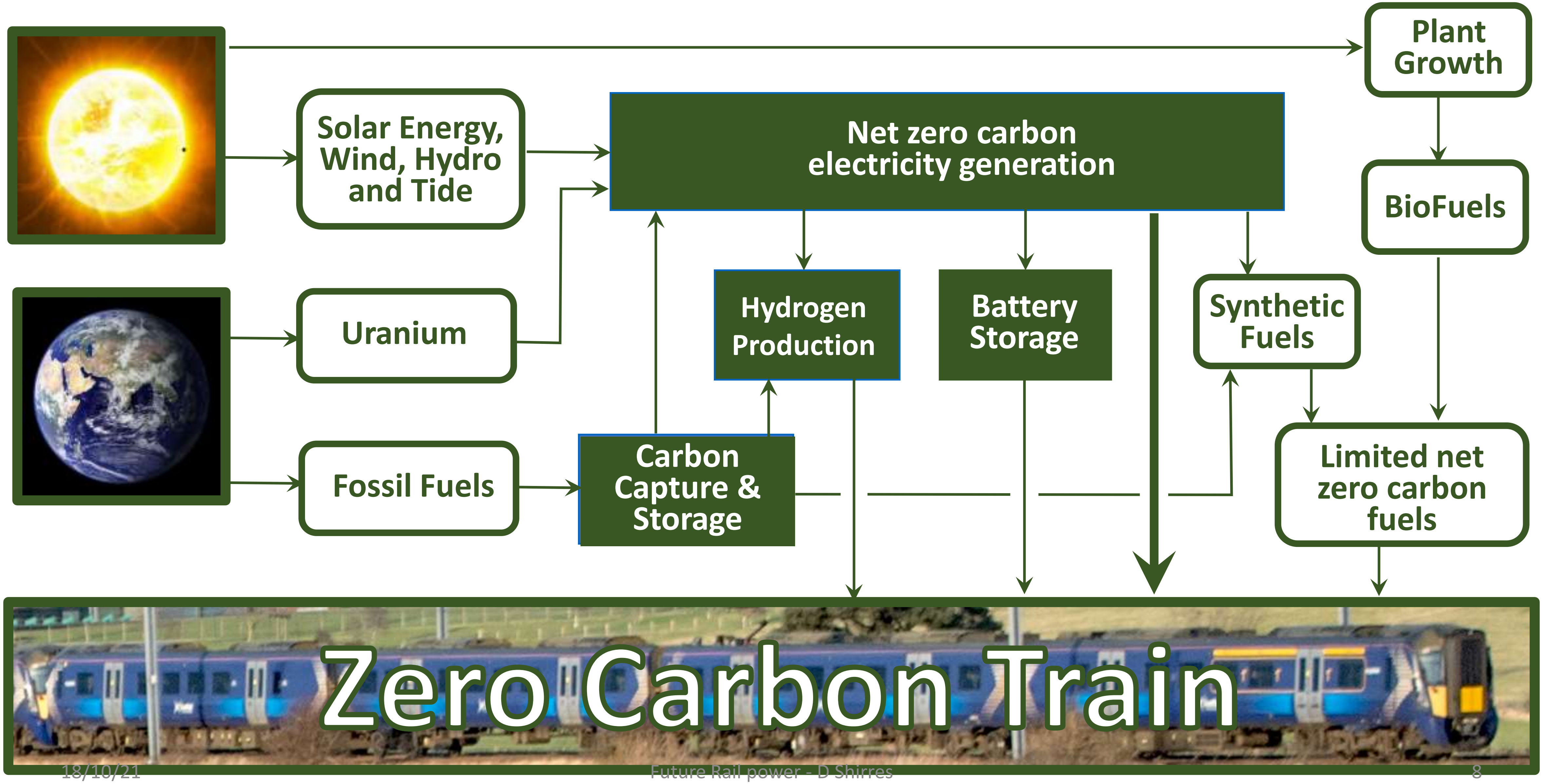
CONSUMPTION - 1760



Electricity production 350

Petroleum for transport 640

Energy on the move – 2050



Energy on the move – 2050

Electricity is the only large-scale net-zero carbon surface transport option. However:

- Electricity can only be transmitted to fixed locations and cannot be stored
- For use on vehicles, electrical energy must be converted to another form of energy for storage on vehicles
- Energy is always lost during such conversions
- Nothing comes close to the amount of energy stored in petroleum

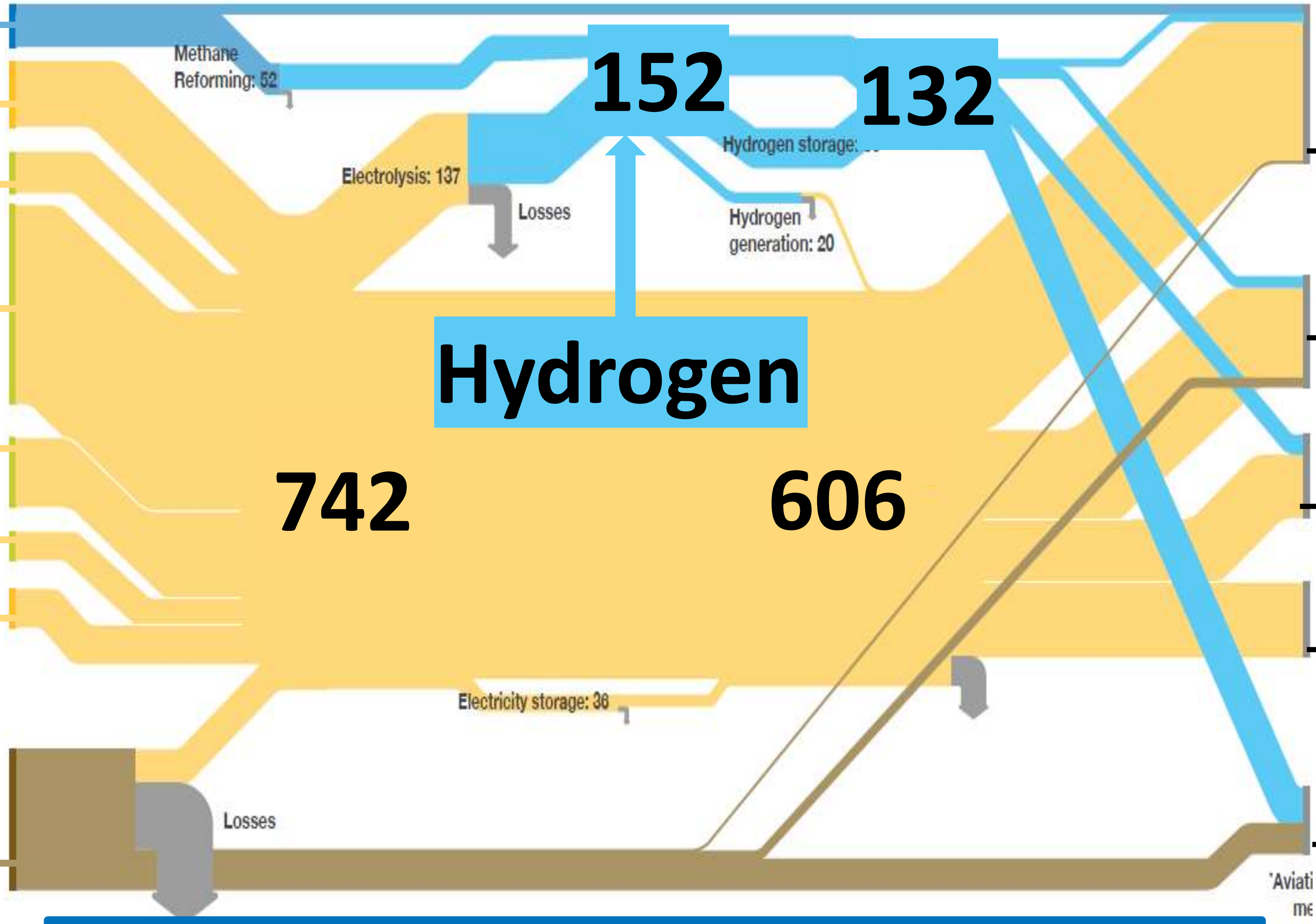
Bio-fuels

- Can have large indirect land-use emissions. Crop-based biofuels could result in food shortages and higher food prices if grown on land used for crops,
- Must be produced as part of a system of sustainable land use which makes them a finite resource which must be prioritised e.g. use where there are currently no alternative low-carbon options,
- CCC considers biofuel surface transport use should be phased out during the 2030s and that likely 2050 production scenario is 14% of current transport petroleum,
- Biofuels not likely to be a significant decarbonisation option for rail transport although they may have a small transitional or residual role,

Biomass in a low-carbon economy, Committee on Climate Change, November 2018,

Energy on the move – 2050? (TWh equivalent)

Natural Gas 64
Nuclear 101
Solar 64
Offshore 308
Wind
Onshore 108
Other 44
Imports 60
Biofuels 215



245 Industrial/ Commercial
177 Residential
129 Surface Transport
112 Export
102 Aviation/ Shipping

INPUTS - 964

Future Energy Scenarios nationalgridESO

OUTPUTS - 765

On the road

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NEWS

Home | Brexit | Coronavirus | UK | World | Business | Politics | Tech | Science | Health | Family & Education

Scotland | Scotland Politics | Scotland Business | Edinburgh, Fife & East | Glasgow & West | Highlands & Islar

Alba | Local News

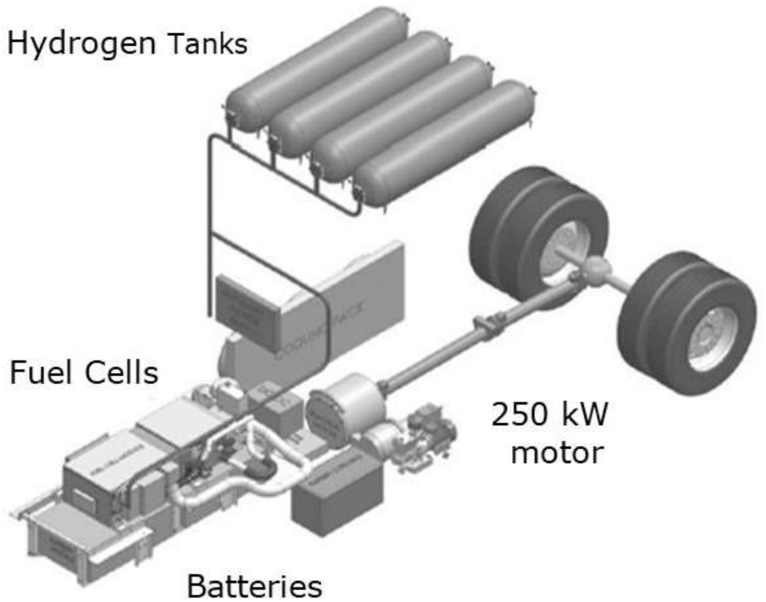
Glasgow to get fleet of 19 hydrogen-powered refuse trucks

30 September 2020

News

Aberdeen's Pioneering Hydrogen Bus Project Arrives at Major Milestone of One Million Mile Mark

Scotland: World's first hydrogen bin lorries - 2016



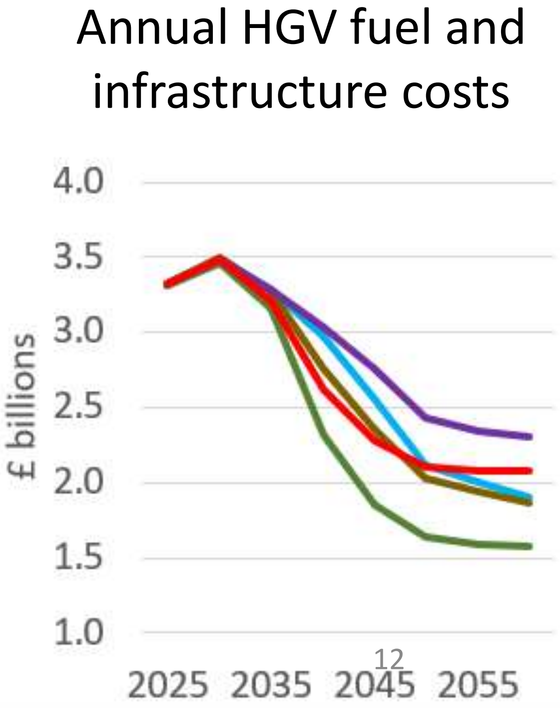
London to have world-first hydrogen-powered doubledecker buses

On the road - HGVs

- When costs of both fuel and infrastructure are considered, hydrogen only scenario appears to be the most cost-effective option for zero emission HGVs.
- By 2030, energy density of batteries and hydrogen may be the same. Hydrogen would still offer faster refuelling times battery weight might reduce payloads

Scenario	Hydrogen refuelling stations	Depot chargers (>50kW)	Ultra rapid charge points (>150kW)	ERS (km)	Cumulative Infra, cost (£ million)	Annual fuel cost (£ million)
Hydrogen	4,100	70,310	0	0	7,660	1,291
Battery	0	340,893	908	0	11,360	858
Hydrogen & ERS	2,171	139,815	0	3,761	8,510	1,209
Battery & ERS	0	256,676	0	3,849	10,390	980
Battery / HRE	2,563	254,685	0	0	11,260	1,074

ERS – Electric Road System HRE – Hydrogen Range Extender



In the air – liquid hydrogen fuelled planes

On the sea – Ammonia-powered ships

- Although poisonous, on ships Ammonia (NH_3) is a practical way of storing large volumes of hydrogen
- Ammonia is liquid below - 33°C or at room temperature at 10 bar
- Volumetric energy density of liquid ammonia is a third that of diesel
- Can be burnt directly in diesel engines with a suitable catalyst so provides long term pathway to fuel cells

Hydrogen storage

Method	Temperature	Pressure (bar)	MJ/litre	% Diesel	MJ/kg	% Diesel	Energy lost	Comment
Compressed	Ambient	350	2.9	8%	125	274%	7%	Proven technology particularly at 350 bar Cylinders use storage space inefficiently Refuelling in minutes
	Ambient	700	4.8	13%	125	274%	10%	
Liquified	- 254°C	1	9.3	26%	125	274%	35%	Space rocket use
Liquid Ammonia	Ambient	10	11.5	32%	19	41%	25%	Poisonous Requires plant to extract hydrogen, Potential fuel for existing diesel engines
	- 33°C	1						

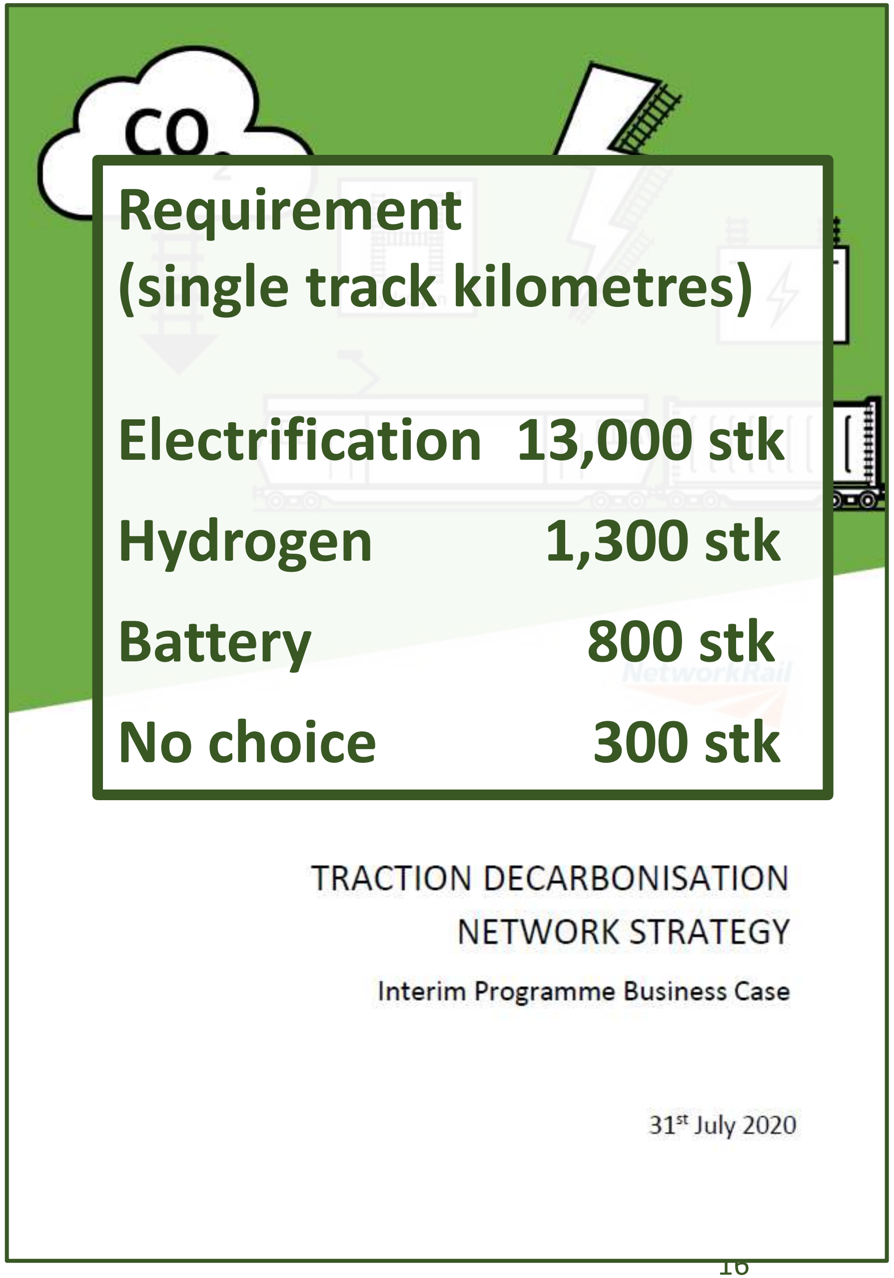
Traction Decarbonisation Network Strategy

Benefits

- Emissions reduction
- Other environmental benefits
- Modal shift from road to rail
- Passenger and freight
- Operational cost reductions
- Wider economic benefits

Business Case

- 5 pathways
- Range of costs (GW elec. highest)
- NPV range from -£2.5 to £1.6 billion
- Positive case when electrification delivered at present costs



Requirement (single track kilometres)

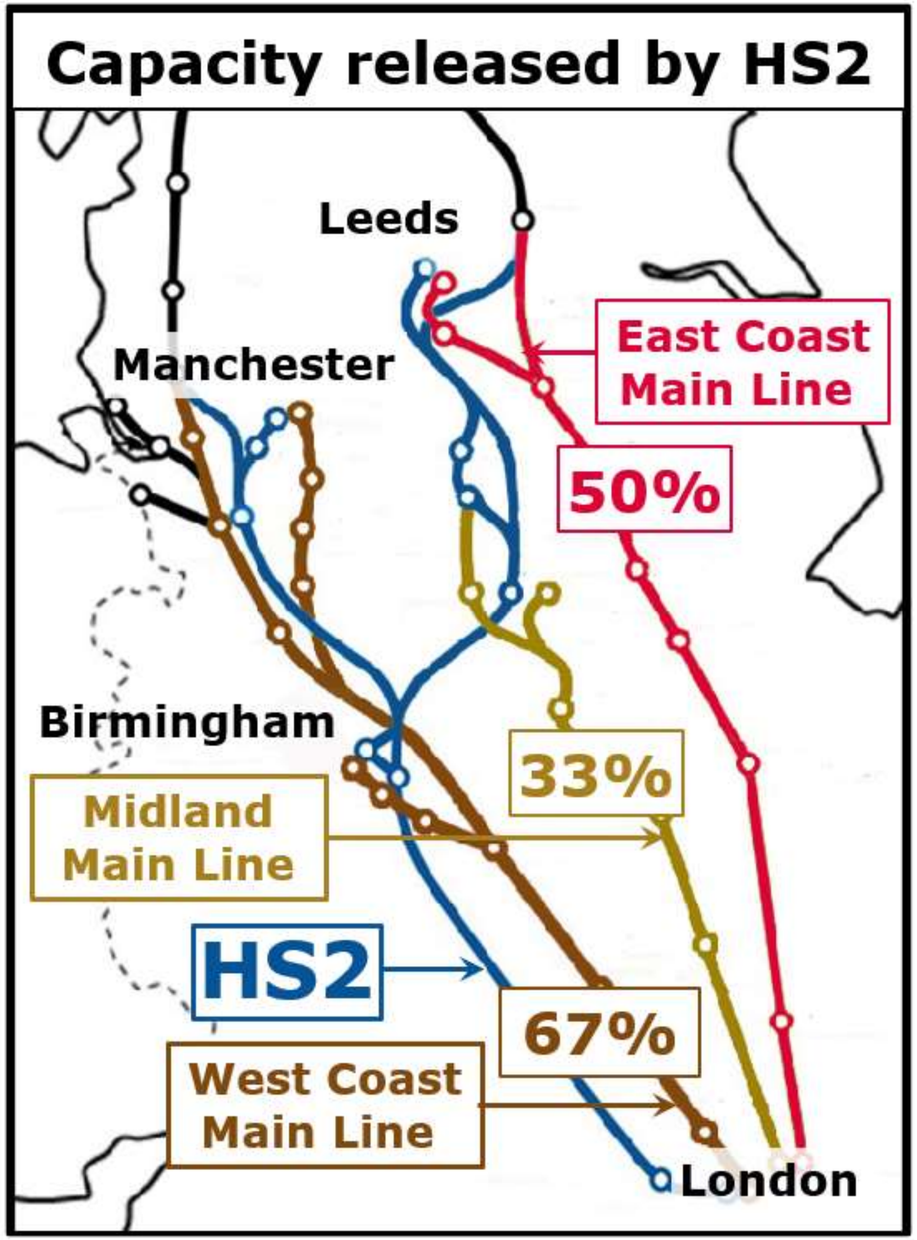
Electrification	**13,000 stk**
Hydrogen	**1,300 stk**
Battery	**800 stk**
No choice	**300 stk**

Modal shift – Rail's biggest contribution

UK road & rail transport 2018			
Passenger			
	Billion pass km	$MtCO_2e$	kg CO_2e / km
Car	678	70.7	104
Cycle	4.9	0	-
Bus / Coach	35	3.4	97
Rail	81	2.5	31
Air	9.4	1.5	160
Total	808	78.1	
Freight			
	Billion tonne km	$MtCO_2e$	Kg CO_2e / tkm
HGV	152	20.8	264
Van		19.4	
Rail	17	0.5	29
Total	169	40.7	

With modal Shift to Rail			
From Road - 5 %		From Air - 25% %	
Billion pass km	% traffic change	Emissions $MtCO_2e$	Change in emissions
644	95%	67.2	-3.5
4.9	100%	0.0	0
35	100%	3.4	0
117	145%	3.6	1.1
7.1	75%	1.1	-0.4
808		75.3	
Passenger Modal shift saving			2.8
5 % Modal Shift to Rail			
Billion tonne km	% traffic change	Emissions $MtCO_2e$	Change in emissions
144	95%	38.2	-2.0
25	145%	0.7	0.2
169		38.9	
Freight Modal shift saving			1.8
Total Modal shift saving			4.6

Modal shift – Rail's biggest contribution



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25	145%	0.7	0.2
169		38.9	
Freight Modal shift saving			1.8
Total Modal shift saving			4.6


334035
25


vivarail


LNER

Electrification

The only high-powered zero carbon transport technology

- Electric trains collect electricity on the move from fixed current collection systems
- They use electricity as it is generated and feed it into their motors without any energy conversion losses
- Their power is limited only by the current they can collect
- Thus they will always be more efficient, more powerful and cheaper to operate than any other rail traction

Cost effective electrification

Restoring Confidence

Railway Industry Association report shows how electrification can and is now being delivered in a cost effective manner

GW cost £2.2 million per single track km

Recent Scottish schemes are half this cost.

Key cost factor is historic stop start nature of UK electrification

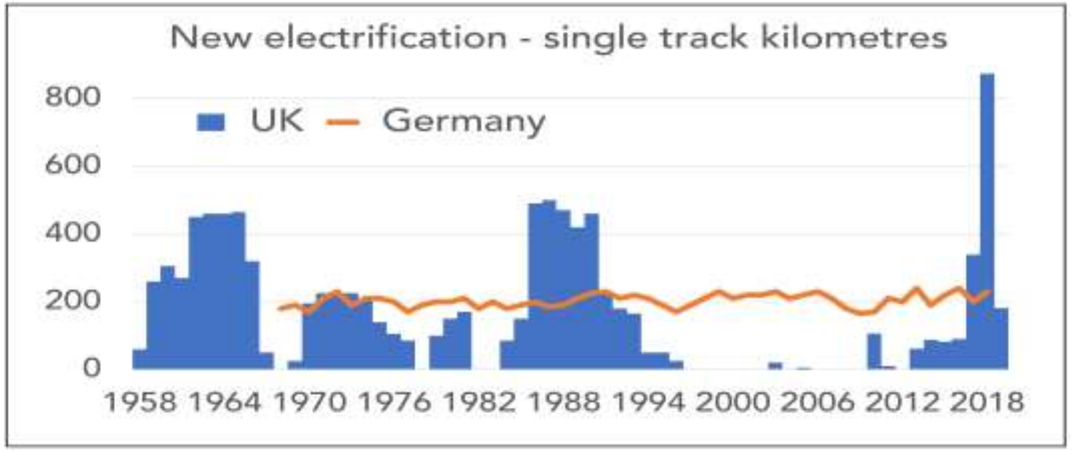
Cost saving initiatives

Fewer bridge reconstructions:

- Insulated pantograph horns,
- Ice loading clearances
- Review OLE gradients,
- Contact wire uplift assessment
- Greater use of surge arrestors.

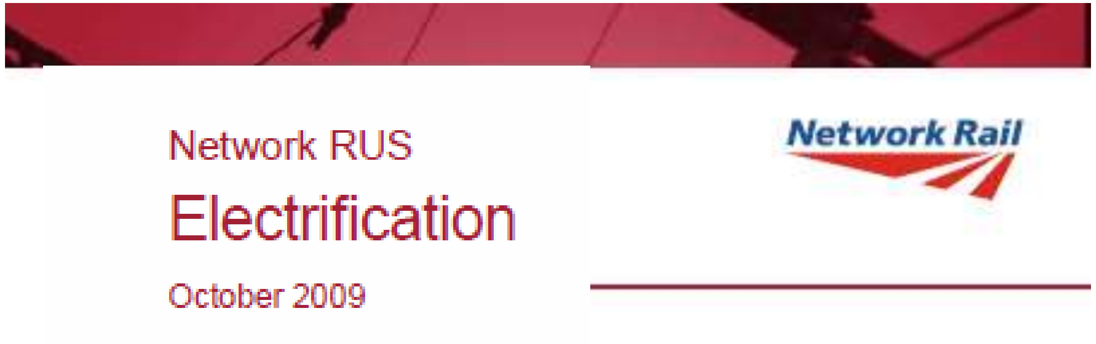
Benchmarking piling structures against EU practice

New protection technology to reduce number of substations required.



Benefits – lessons from the past

Network Rail's 2009 Electrification Route Utilisation Study



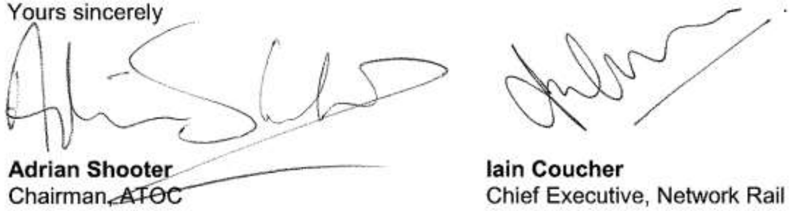
Typical operating costs		
	Diesel car	Electric car
Maintenance per mile	60p	40p
Fuel per mile	47p	26p
Lease per annum	£110,000	£90,000
Track wear per mile	9.8 p	8.5p

Cost savings of around £2 to £3 million over passenger vehicle's lifetime

2007 letter from Network Rail and ATOC to DfT

"using "diesel" trains as "mini-power" plants - to generate tractive power is both inefficient and wasteful. Given the size of trains, it is not a particularly efficient way to convert fossil fuel into power. It is, surely, better to manage this at a power station level - even after taking into account transmission losses. And this is even before one takes into account the fact that diesel trains consume significant amounts of energy to simply transport heavy engines and fuel around the network"

"we have absolutely no idea about the source of energy in the future. We can immunise the railway from changing fuel costs by an electrification programme that puts those decisions elsewhere."



Transport Select Committee 11.11.20

Given its previous high cost why should Treasury trust industry to deliver electrification at a lower cost?

Hydrogen isn't quite there yet but we have some brilliant minds working on hydrogen. How can we be sure that such technologies won't ever be better than electrification?

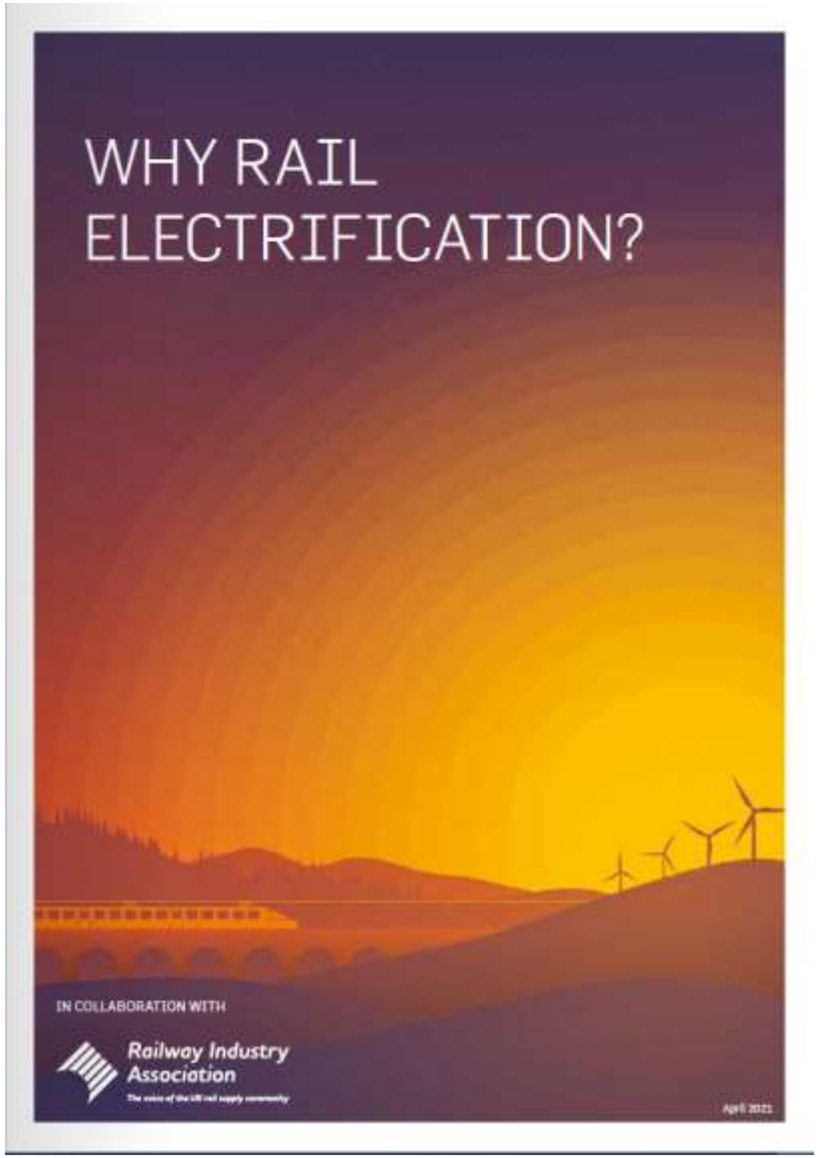
Government got diesel wrong 20 years ago so how can we be certain electrification is the right technology? Aren't we just grabbing the technology of today?

Rush to electrify rail 'risks new diesel fiasco'

Ministers urged to invest

Why is there a different approach in Scotland?

Why Rail Electrification Report



November Transport Select Committee inspired the production of the "Why Rail Electrification" report which was launched by the Railway Industry Association in April

Rt Hon Grant Shapps MP
Secretary of State
DfT, Great Minster House
33 Horseferry Road
London SW1P 4DR

22 April 2021

Dear Secretary of State,

We are writing to you today, as organisations representing businesses across the UK, as well as passengers and communities, to urge you to begin a rolling programme of electrification following the publication of a new report: "Why Rail Electrification?".

This report complements the interim programme business case of Network Rail's Traction Decarbonisation Network Strategy by explaining exactly why rail decarbonisation is only possible with large-scale railway electrification. It also demonstrates why this is a future-proof technology, with a strong business case, and why hydrogen and battery traction must have a role on the network, although they can never replace the need for a significant amount of electrification.

The attached two-page executive summary explains how these conclusions are derived from the categorical evidence in the report. We believe that they represent the view of engineers and businesses across the rail industry, as IMechE's Railway Division Chair Felix Schmid states within the report. Thus, electrification provides the Government with both good investment and a means of reaching its target of removing all diesel trains off the network by 2040. It also has benefits for passengers; improves journey times and efficiency for freight operations; and improves air quality at stations.

Claims have been made in the past that electrification can be costly, but this argument focuses on a few past projects, neglecting more recent schemes delivered to time and to budget. As highlighted by the Railway Industry Association's Electrification Cost Challenge report in March 2019[1], the industry has learnt clear lessons, including the need for a consistent pipeline of work, rather than the "boom and bust" profiles seen in the past.

We are now at a critical juncture for decarbonising our railways. To meet the legally-binding 2050 Net-Zero target, there is less than 30 years to decarbonise the UK rail network – yet there is currently no significant construction of electrification schemes in England. Furthermore, with Midland Mainline electrification up to Corby completed last year, the industry is starting to lose the skills, expertise and capabilities that ensure it can deliver efficiently and effectively. Without further work soon, we risk repeating the mistakes of the past.

On behalf of the signatories to this letter, we urge the Government to authorise a "no-regret" electrification scheme on a busy diesel railway as a start of a rolling electrification programme to contribute to the UK's green recovery. Doing so would not only support jobs, investment and economic growth, but would also show the UK's commitment as a global leader in tackling climate change in the run up to the UN Climate Change Conference (COP26) later this year.

[1] See [illegible]

Yours sincerely,

- Campaign for Better Transport
- Campaign to Electrify Britain's Railway
- Civil Engineering Contractors Association
- Electrical Contractors Association
- Institution of Mechanical Engineers
- Logistics UK
- National Skills Academy for Rail
- Northern Rail Industry Leaders
- Permanent Way Institution
- Rail Alliance
- Rail Forum Midlands
- Rail Delivery Group
- Rail Freight Group
- Railfuture
- Railway Industry Association
- RSSB
- Urban Transport Group

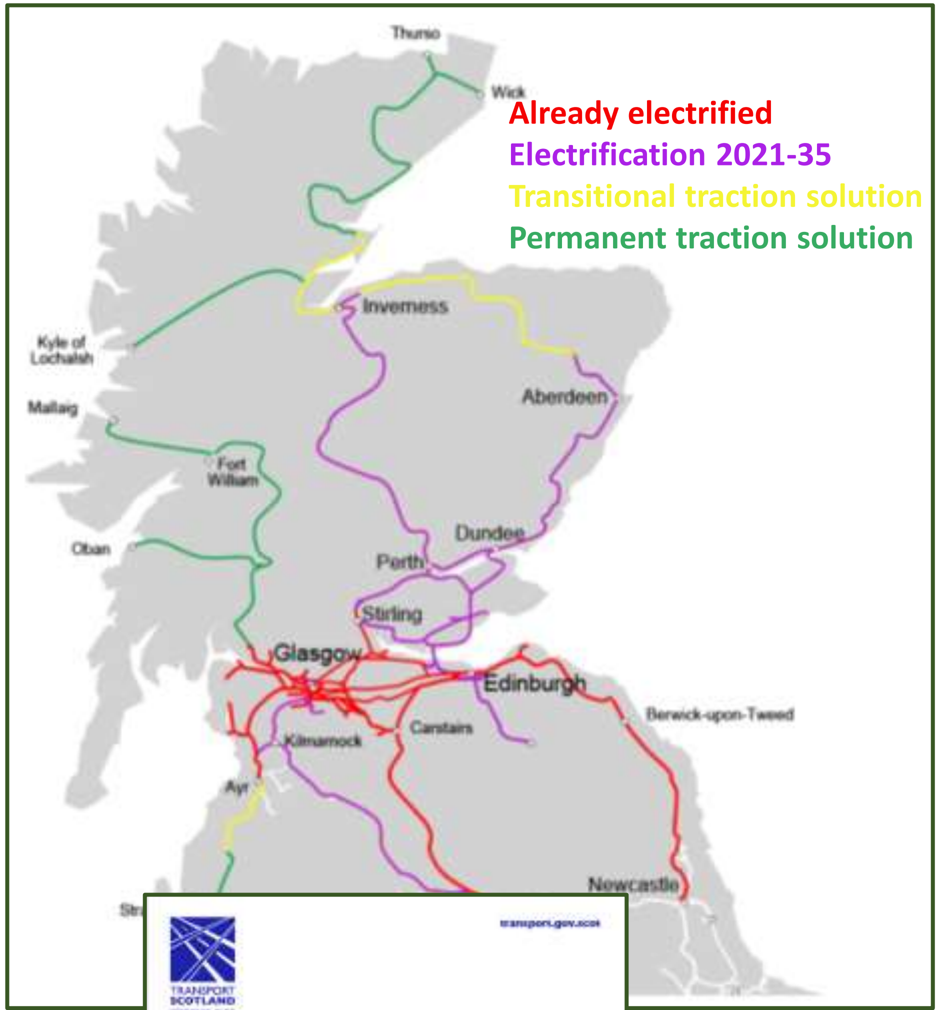
https://www.riagb.org.uk/RIA/Newsroom/Publications%20Folder/Why_Rail_Electrification_Report.aspx

Scotland's plan

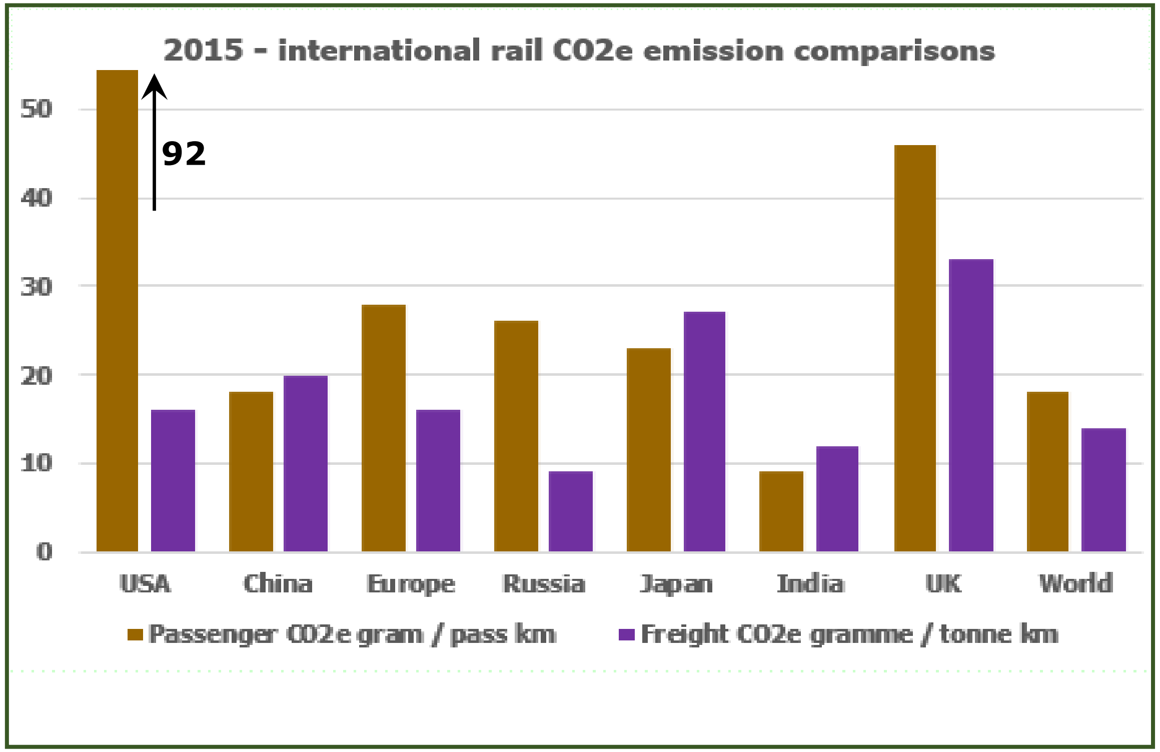
Railway professionals within Transport Scotland know that their railway can best serve the people of Scotland with electric trains that encourage modal shift by improved journey times and better reliability as well as being greener, more efficient and cheaper to operate

Response to a bad cost overrun on one electrification scheme was to find out what went wrong to make further schemes cost effective

They explained electrification to Scottish Ministers and successfully convinced the Scottish Government to invest scarce funds on a large scale electrification programme.

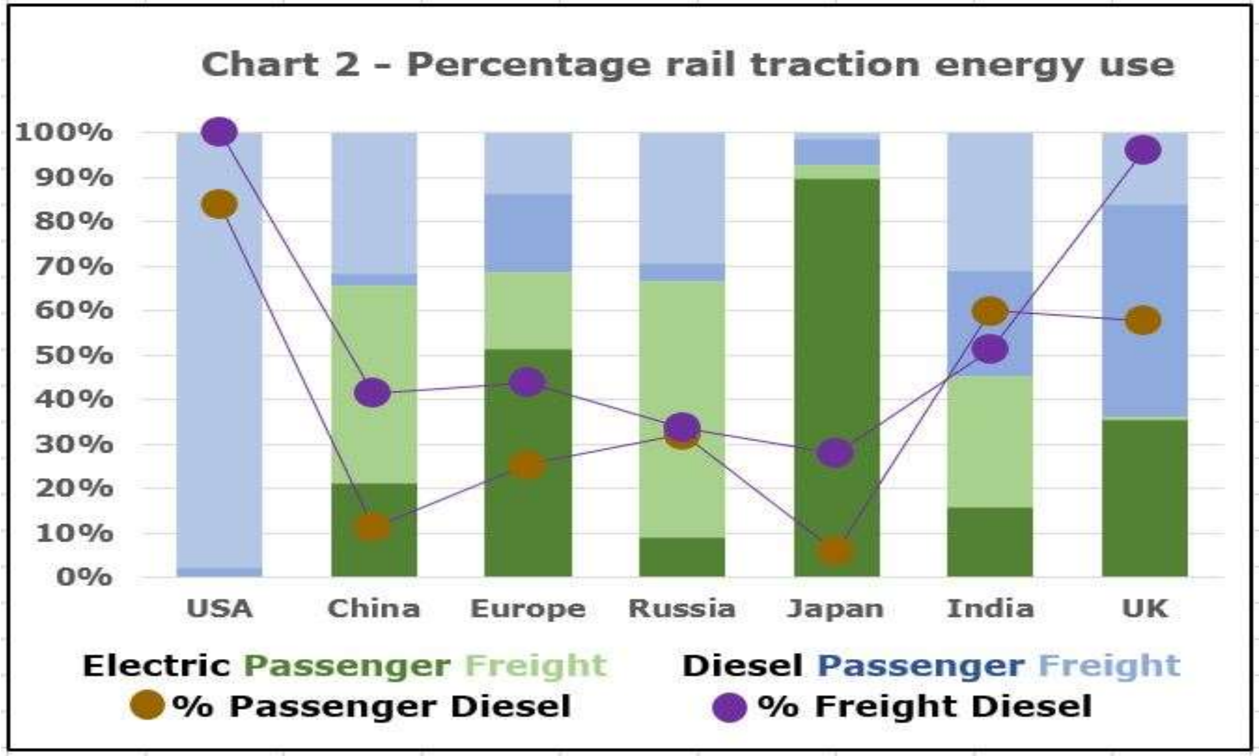


International rail comparisons



UK rail CO2e emissions are amongst the world's worst

Because diesel is a particularly high percentage of UK rail traction energy



Bi-modes

Diesel bi-mode trains

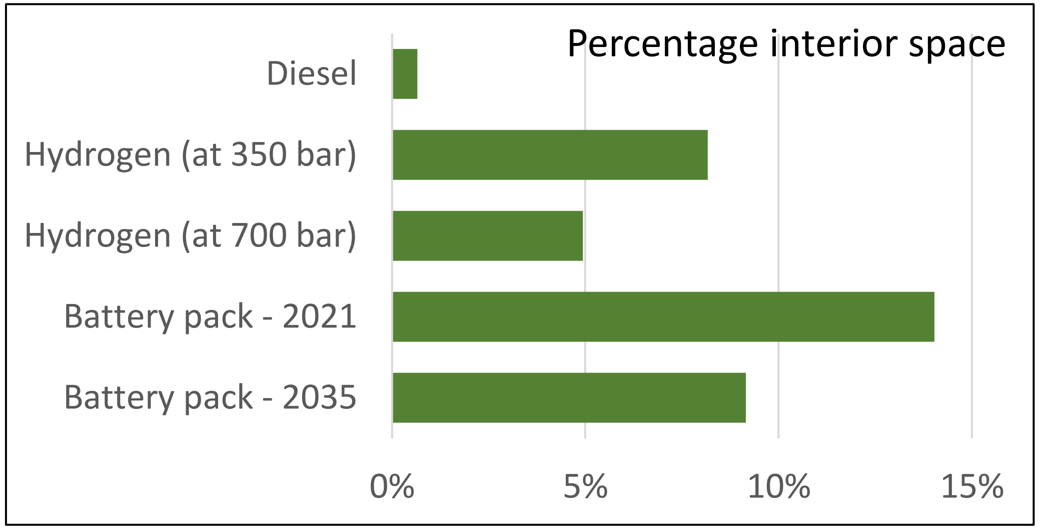
- Much less power in diesel mode than in electric mode
- LNER class 800/1 in diesel mode have less power than HSTs they replace.

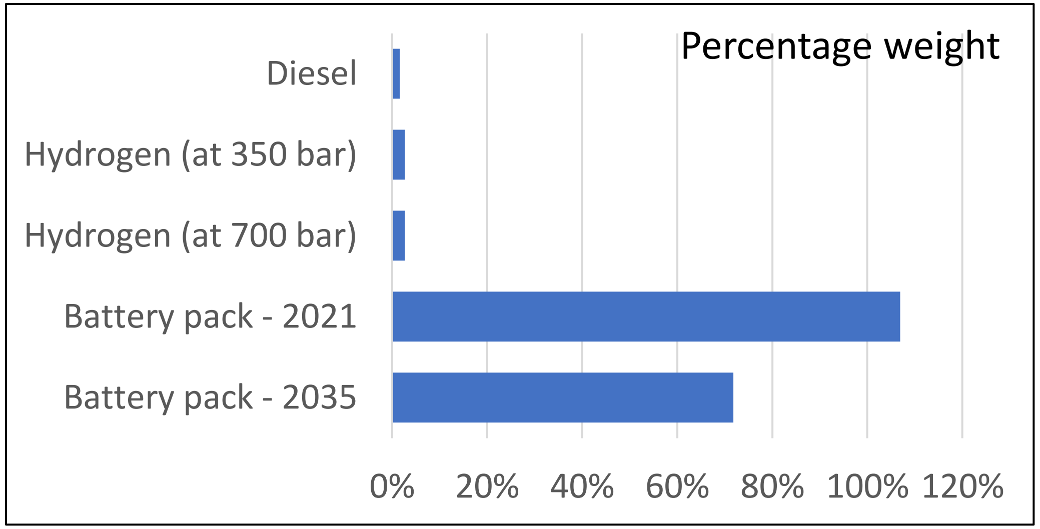
	Weight	Power (MW)		Kw/tonne	
Train	tonnes	Diesel (A)	Electric	Diesel	Electric
9 car HST	**445**	**3.0**		**6.7**	
9 car Azuma	**438**	**2.5**	**4.5**	**5.7**	**10.3**
A. Assumes 10% for auxiliaries and hotel load, not an issue for electric trains					

Carbon pros and cons	
Reduced diesel running under wires – Class 800/1 units on London to Inverness route have 33% CO2e emissions of the HSTs they replace.	9 coach unit has 5 engines weighing 7 tonnes each (8% weight of train). This incurs a significant carbon cost over the train's lifetime
Traction flexibility facilitates a rolling programme of electrification	With their diesel engines, they cannot be part of a zero-carbon railway

Storage constraints

Storing the same amount of energy on a typical rail coach diesel tank





Batteries

Battery trains

2019 - Hitachi in talks with LNER to replace Azuma diesel power pack with batteries for short distance services off the wires e.g. 17 miles off wire to Lincoln

Vivarail Class 230 – standard rafts offer hybrid and battery only trains. Battery range ~ 60 miles. Fast charging system charges batteries in seven minutes – Uses 3rd & 4th rails, specially cooled battery and recharging from trickle charged battery bank

- Suitable for branch line operation
- Battery packs have 2.5 % the energy density of diesel (1.0 vs 39 MJ/litre) - UK automotive council expect this to improve to double by 2035
- Batteries are costly and may get more expensive (over a billion cars needing batteries!)
- Producing & recycling batteries uses rare materials with high environmental costs
- Battery / EMU hybrids could facilitate a steady rolling programme of electrification

Hydrogen

Trains

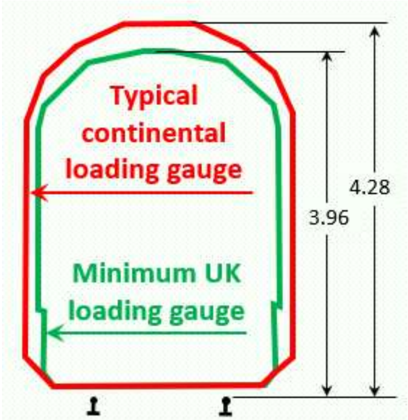
Alstom iLint in service in Germany

Alstom's proposed UK hydrogen train

Hydroflex

Scotland's hydrogen train

- Hydrogen storage constraints a particular issue in the UK
- Rail is a small hydrogen player but needs to state now with longer vehicle lives
- Can benefit from synergies with other sectors



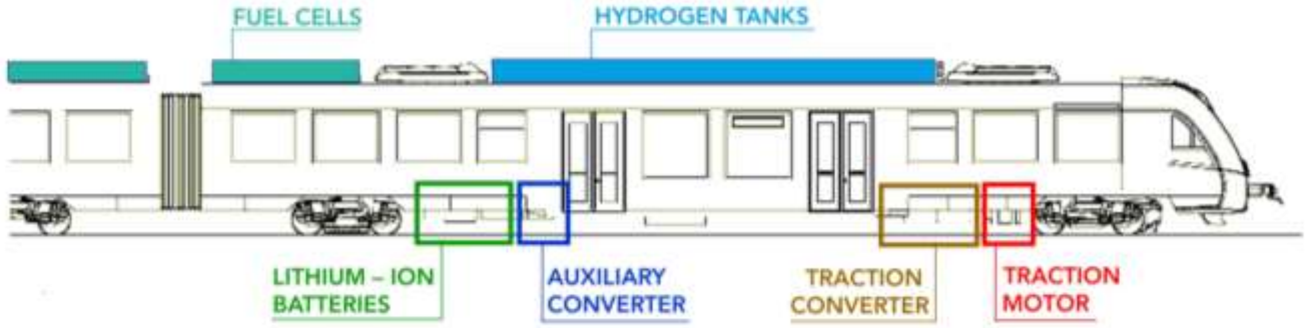
CCC view
Hydrogen demand:
Trains - 0.3 TWh
HGVs - 22 TWh,
Buses - 3 TWh;

Hydrogen trains - development

July 2012 – Birmingham University's Hydrogen loco with 1kW fuel cell at Railway Challenge

Fuel cells	2001	2011
Power (kW)	25	33
Mass (kg)	290	75
Volume (L)	365	125
Efficiency %	c42	c52

September 2018 – Alstom's 2-car unit hydrogen iLint enters service in Germany.

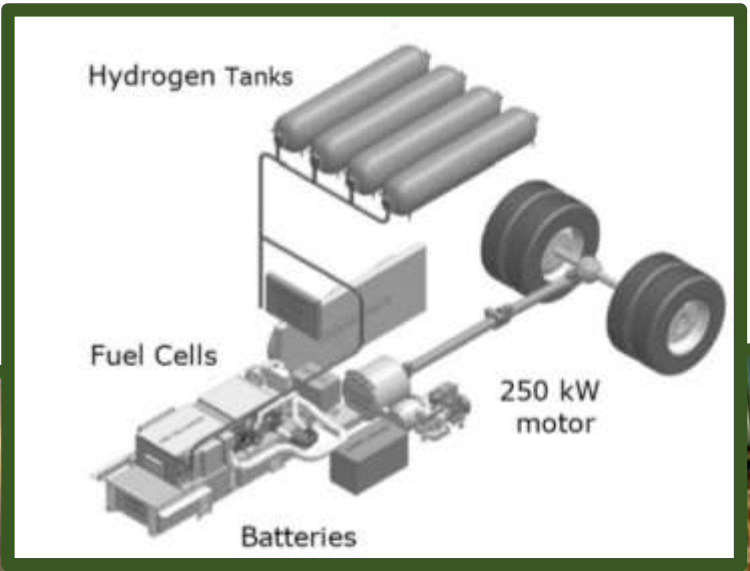


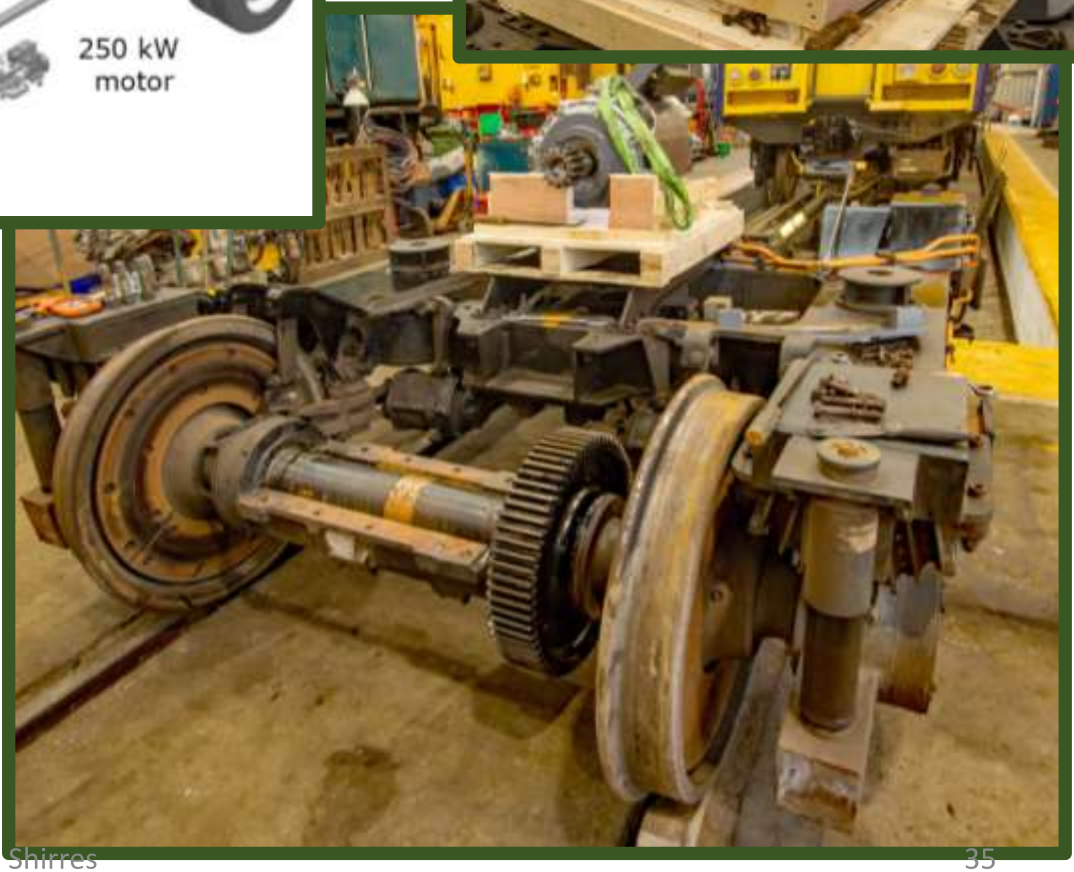
Tanks hold 178 kg hydrogen @ 350 bar to give ~700 km range; Max speed 140 km/hr; A hydrogen / battery hybrid; each car's has 200 kW fuel cell and 225kW traction battery. Peak power to weight ration 7.9 kW/tonne (25% more than class 170)

January 2019 - Alstom announce their hydrogen Breeze concept with a 1,000 km range. Due to UK loading gauge hydrogen tanks inside train

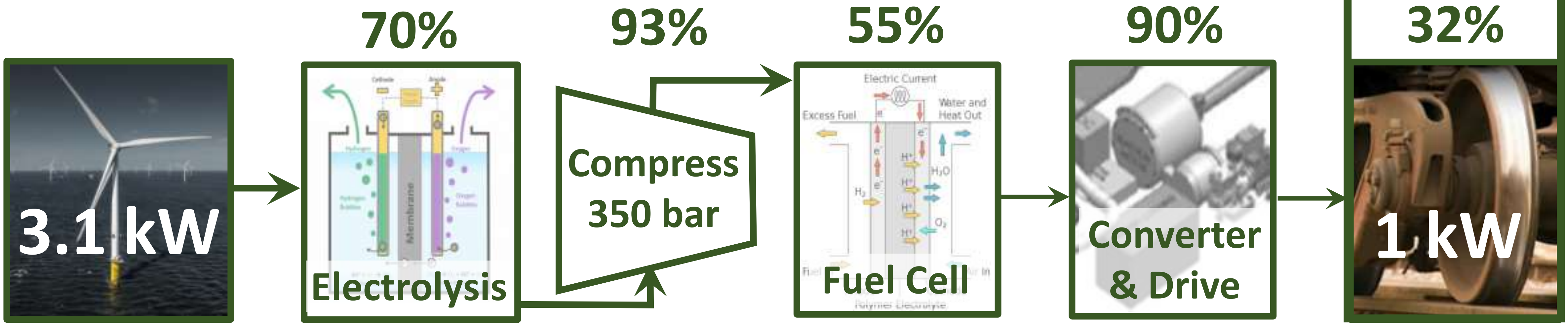
Hydrogen trains: Part of a wider hydrogen economy

Scotland's hydrogen train - technology transfer from bin lorries





Hydrogen efficiency



Is 32 % a problem ?

- Overnight wind power
- Hydrogen projects ease renewable energy investment constraints
- Price certainty – the cost of the kit

RMV's subsidiary fahma orders the world's largest fleet of fuel cell trains from Alstom

Supplying hydrogen

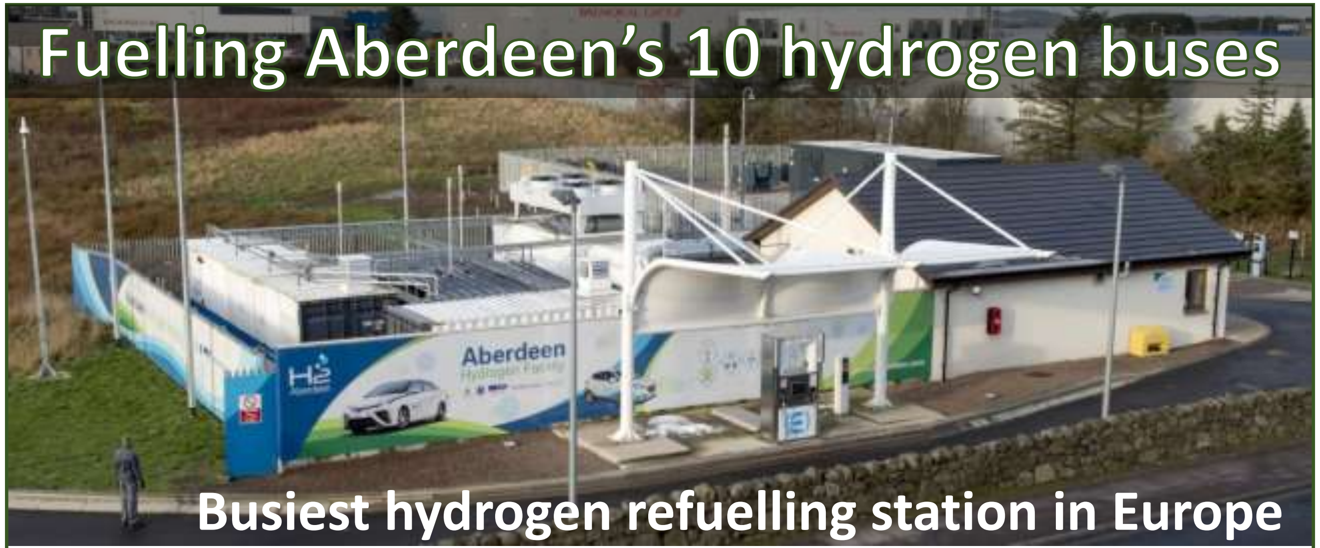
How to move hydrogen ?

a) Pipelines
b) Tankers – supply hydrogen for 5 rail cars or fuel for 60 diesel rail cars.
c) Electricity

Electricity is likely to be the answer for "back to base" operations

Aberdeen hydrogen bus pilot concluded that electrolyser plants:

- are a mature, scalable and reliable technology (99.9% over 5 years)
- prices will continue to decrease
- Offer grid balancing opportunities



£1.5 million hydrogen supply plant consisted of:

3 x Electrolysers (in 40ft containers)
2 x hydrogen compressors
2 x hydrogen dispensers
& hydrogen storage, control systems and cooling plant

1 MW electricity supply required to provide 300 kg of hydrogen per day

Modifying existing trains

Class 180 Dual Fuel Feasibility

- G-volution dual fuel system uses LNG ignited by diesel
- Fitted to one vehicle in one 5-car set
- Test results to confirm in practice
  - 20% fuel savings
  - 25-40% CO2 savings
  - 50 % particulate reduction
  - 5 year payback
  - Noise reduction
- Safety approval, depot infrastructure and refuelling logistics to consider
- Testing delayed by Covid impact on Grand Central Services

GC GRAND CENTRAL by arriva

Modifying existing trains

Angel Trains / Chiltern Railways – Class 165 Hybrid train

- Remove underframe equipment – engine, batteries, hydrostatic drive, transmission
- Replace with 2 x 120kW generator sets, 300 kW traction motor, traction batteries, controls and remote monitoring

Operational modes:

- Engine and battery
- Battery only mode - geofenced
- Regenerative braking

Planned 2021 service entry

25% reduction in C02 emissions expected

Zero harmful emissions at stations

Getting to net zero – the role of each type of traction

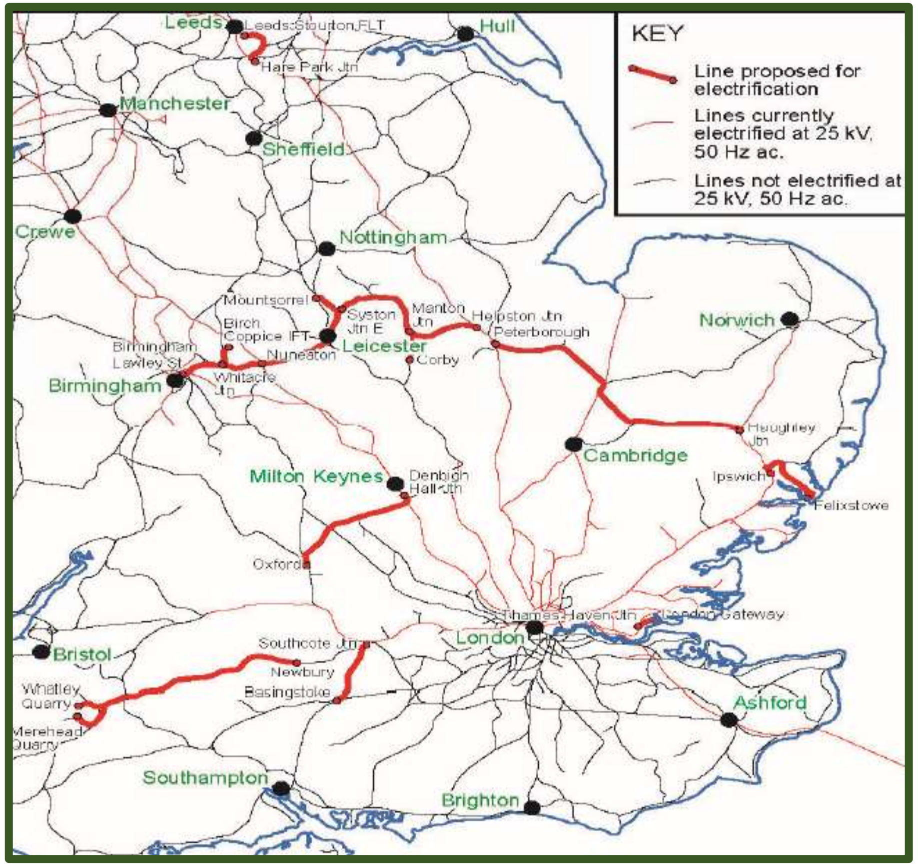
	Transition to NZR	Net zero railway (NZR)
Battery	As for NZR, also cover gaps to facilitate a rolling electrification programme	Branch line and battery / electric bi-modes on inter-city spurs, rural with 10 min stop every 100 km Last mile running for freight locos
Hydrogen	As for NZR	Passenger services that do not require high speed, long distance or frequent acceleration.
Diesel bi-mode	No diesel running under the wire. Facilitates a rolling electrification programme	No role
Dual fuel / Diesel hybrids	Lower emissions if engines burn LNG & diesel	No role
Electric trains	As for NZR	Passenger services that require high-speed or frequent acceleration (e.g. commuter services). Only solution for Freight

Passenger traffic on currently unelectrified routes

	Route km	% traffic	Description	Traction Type
Inter-City core	**1505**	**39.0**	Routes to London, NE/SW cross country services, Trans Pennine	Electric
Inter-City secondary	**1318**	**15.8**	Spurs on routes with a direct service to London, internal Scottish inter-city	Electric, possible battery on branches
Commuter	**751**	**12.3**	High frequency services into cities	Electric
Cross Country	**900**	**8.7**	Long distance services connecting town and cities that are not Inter-City	Electric / hydrogen
Urban	**722**	**7.5**	Populated area with no significant commuter flow	Electric / hydrogen
Rural	**3645**	**16**	Only traffic in mainly sparsely populated area	Hydrogen
Branch lines	**139**	**0.8**	Spurs to main lines that do not have through services onto the main line	Electric / batteries

And not forgetting rail freight

- Accounts for 29% of UK rail diesel CO2e emissions
- 96% of energy used to power freight locomotives is diesel
- CILT Rail Freight Forum concludes that 500 km of electrification would enable 66-75% of freight traffic to be electrically hauled



- **Rail is only sector with a decarbonisation heavy freight solution**
- **Significant increase in freight haulage from relatively small electrification programme**
- **Rail freight companies need a long term plan is they are to invest in electric freight locomotives**

Conclusions

1. A net-zero rail network by 2050 requires a large programme of electrification (TDNS states average 355 stk per annum).
2. It is currently not possible to specify the amount of electrification required. Current unknowns will be assessed in the ongoing development of the TDNS. For now there are clear definite electrification requirements.
3. Deployment of first hydrogen and battery needed soon to gain experience
4. Modifications are needed to decarbonise existing trains
5. Unless there are financial incentives to invest and use low-carbon technologies, such as rail electrification, the Government's net zero target is unlikely to be achieved
6. The industry has to educate decision makers

And the Future traction mix?

- Lots of electrification, some hydrogen, some batteries
- No-one knows exactly what the right mix will be
- So let's get started and find out!

Thanks for your attention