Written evidence submitted by Waxwing Engineering Ltd

Summary

Modal shift from road and air to rail supports decarbonisation of the UK's transport network. Rail is already some way down the decarbonisation road, thanks to renewable generation. Further rail decarbonisation will enable this transition to be achieved sooner and to a greater extent. A number of technologies to largely decarbonise and minimise the emissions from the current train fleet are already available and being evaluated, making the transition to a net zero railway better value.

The ways to deliver cost-effective electrification projects are already known, and the costs benchmarked; the industry has the tools to address the thorny problems created by our old and small infrastructure. Small amounts of infill electrification would enable a significant transition to electric freight haulage. Electric Multiple Units and electric locomotives have lower whole-life costs, including infrastructure costs, than the diesel, hydrogen and battery equivalents.

Electric traction can support all of the different applications, whereas hydrogen and battery can only ever be niche solutions, helpful in the transition and end game for a net zero railway, but not a silver bullet; hydrogen trains require three times the energy of an electric train for the same output, increasing the pressure on generation and the grid.

The scale of decarbonisation required of UK transport is immense. To achieve net-zero railways, stop looking for the silver bullet, introduce some policy certainty and get on with electrifying the network.

1. Introduction

1.1. Waxwing Engineering Ltd is an independent railway engineering and management consultancy, founded in 2017 by Louise Shaw CEng FIMechE. Louise has 30 years of experience in railway operation, maintenance, new train procurement, major technology projects, technical strategy and policy development, in the UK and abroad.

1.2. This inquiry started before the current health pandemic, with its changing transport demand patterns, but the science and engineering certainties are constant.

1.3. We hope this response is helpful and are ready to discuss any part of it with the Transport Select Committee at any time.

2. What role rail decarbonisation can make to the Government's wider commitments on air quality to 2040?

2.1. Rail as currently configured can provide significant support for the Government's commitments on air quality through modal shift from more polluting modes of transport; further decarbonisation of rail will create a better outcome.

2.2. Both passenger and freight by rail are significantly more carbon efficient and less polluting generally than either road or aviation. They are also much safer: in the 13 years between the recent derailment at Stonehaven, in which one passenger died, and the previous accident in which one passenger died, at Greyrigg in 2007, 22,000 people were killed on Britain's roads. To put this into context, each one of the 1700 deaths per year is estimated to cost £1.9 million, at 2012 prices[1], or £3.2 billion/year in total. If that scope is extended to include all accidents, the overall cost rises to £15.1 billion/year.

[1] RRCGB valuation methodology , source gov.uk`

2.3. Modal shift will be significantly beneficial not only in terms of carbon and safety, but in other external costs, such as road maintenance and congestion.

2.4. Rail is already decarbonising and has been doing so for some time. Electric rail is very carbon-efficient; recent greening of the electricity grid has already contributed to decarbonisation of the rail system, even without taking into account any procurement of new trains or extended electrification. Circa 375,000 tonnes of CO_2 has been saved by grid greening in the last three years alone. Over 70% of the passenger train fleet is electric.

2.5. Railfreight's use of electricity increased by 12.7% in 2017/18, whilst its diesel consumption dropped by 6.7% in the same period.

2.6. In addition, even non-electric rail is already more efficient on air quality than other modes, in terms of CO_2, NOx and PMx, so modal shift to rail will improve that efficiency, whilst reducing overall emissions. Various reports from the UK and internationally, from respected, credible sources, such as the International Energy Agency[2] and the DfT's 2017 Freight Carbon Review, support this assertion. One freight train replaces 76 HGVs on average; railfreight is four times more carbon efficient than road.

2.7. Decarbonisation has the potential to further improve that efficiency, both in the transition, and in a fully decarbonised system, through the use of green electricity generation.

2.8. It is likely that the best economic, carbon and air emission performance over time will result from a migration with a suite of measures being employed:

2.8.1. electrification, rolled out in a planned, steady, continuous basis, allowing electric trains to be brought into use, or their use widened;

2.8.2. improving the emissions performance of existing early to midlife diesel trains;

2.8.3. redeploying those improved diesel trains as electric operation is made possible on the routes they serve;

2.8.4. life-expired diesel trains are replaced by a better-performing option, according to the route's circumstances, probably hydrogen or battery powered;

2.8.5. re-opening and extending the rail network, with the choice of traction source being aligned to the prevailing circumstances, and the best whole-life, whole-system cost.

2.9. It should not be forgotten that buying a new asset creates new, embodied carbon and other air emissions, in addition to the carbon and other air emissions created during use. As with road vehicles or aircraft, the embodied carbon created during construction of a new train is significant, compared with the savings in carbon at the point of use. Upgrades to existing midlife vehicles can be delivered faster and be both economically viable and better for carbon and other emissions.

2.10. The whole-life, whole-system value of the asset should be the basis for decision-making. Life-extending and repurposing an existing asset is often a viable alternative to buying a new one.

2.11. There is yet to be a credible alternative to the diesel engine for HGVs, and the laws of physics ensure that this will continue to be the case for some time, too long to contribute to the decarbonisation target timescales of 2050 under the Climate Change Act. Batteries and hydrogen simply don't have the energy density to be able to operate with anything like the range and payload currently achieved (see below).

2.12. Road electrification experiments have been taking place in Sweden, Germany and elsewhere, but they have not been anywhere near as successful as hoped for by their promoters; such schemes are fraught with technical difficulty.

2.13. Therefore HGVs will become less capable over time, and logistics chains will have to adapt.

[2] IEA (2019), *The Future of Rail*, IEA, Paris, https://www.iea.org/reports/the-future-of-rail#key-findings

2.14. The current Covid pandemic has served to illustrate the capability and potential of railfreight to replace HGV-based logistics. Unlike HGVs, there is a direct replacement for diesel engines in freight locomotives, which is actually higher performing, all round: electricity. In addition to better carbon performance, electric locos can pull heavier trains, accelerate faster (for better capacity) and have lower whole-life costs than their diesel counterparts. They are also more track-friendly.

2.15. Small, infill, electrification schemes will enable a much greater proportion of railfreight to be hauled using electric locomotives from end-to-end. One reputable assessment suggests that construction of circa 350 miles is required for 70% of current railfreight volumes to be electric hauled - saving circa 100,000 tonnes of CO_2 every year over the next thirty years.

2.16. Modal shift would improve this CO_2 and other air emissions saving: rail is already viable at 100 miles for consumer goods and 50 miles for bulk freight, such as cement from Dunbar to Uddingston. 45% of HGV tonne miles are on journeys over 100 miles and a further 12% are bulk materials travelling 50-100 miles, so that 57% of HGV tonne-miles is potentially suitable for transfer. Not all of this can realistically transfer but 30-35% looks to be feasible.

2.17. The same assessment indicates that electrification of just 660 route-miles would achieve 90% (or more) coverage of railfreight movements. The timescale could be aligned with the economic life of the fleet of the current main railfreight diesel locomotive, the Class 66.

2.18. Aviation suffers from the same challenges as HGVs, there is presently no credible alternative to fossil fuel. For UK domestic journeys, there should be no rational reason to have a short-haul flight between the south east and anywhere south of Inverness or Aberdeen: rail often matches point-to-point times and outperforms on carbon; for passengers it also enables better use of the travelling time.

3. Whether there is adequate financial and other support from the Government for the development of alternatively fuelled rolling stock

3.1. There is already a great deal going on in this context, such as funding competitions, and public statements exhorting progress. However, whilst alternative fuels may be an attractive idea politically, the laws of physics still remain, however inconvenient that might be. The silver bullet is unlikely to exist.

3.2. That is not to say that improvements shouldn't be sought, but that in the timescales set out for decarbonisation, it makes more sense to be planning (1) to do so on the basis of what is already known, understood and established, (2) to support the search for improvements to the existing, and the alternatives, and (3) then to incorporate new knowledge and technologies as they become viable. A tonne of carbon saved yearly from today is worth 10 tonnes of saving in ten years' time, and we already have the means to do so; it is entirely possible that the answer in ten years' time will be no different, but the saving will have been missed.

3.3. A suite of policy tools which more effectively evaluates investment, coupled with a real cost for carbon would enable better decision-making.

3.4. Funding plans should incorporate electrification as the primary means to decarbonise now, complemented by mechanisms to support the transition and improve the non-electric fleet.

4. How the industry is responding to the challenge of a carbon-free transport future by 2040 and developing technologies to achieve that?

4.1. Considerable work has been undertaken to produce the Traction Decarbonisation Network Strategy, Interim Programme Business Case[3], to be followed by the final Programme Business Case later in 2020. This strategy should be the basis of rail decarbonisation planning. It proposes 13,000 single track km of electrification to all-but decarbonise the network. If this is to be achieved, in the 2040 timescales, based on 2019 benchmarks, this would cost between £0.5 billion and £0.66 billion per year. This compares quite positively with the cost of roads.

4.2. Considerable work has been undertaken to understand the technical potential for alternative traction energy sources. The industry in the UK, and across much of the rest of the world, has already concluded that the best option for decarbonisation is a rolling programme of electrification, supported by a credible rolling stock deployment plan, which incorporates the upgrading of existing trains, the redeployment of electric trains, and re-purposing of some fleets with alternative traction energy technologies. This is also reflected in the recently updated and published Rail Technical Strategy[4], Low Emissions section.

4.3. Considerable work has been undertaken to understand how to reduce the costs of electrification[5]. A rolling programme, without a hiatus after the current projects, would ensure that economies of scale are retained, and re-mobilisation costs are avoided; recent engineering, design and modelling improvements, such as incorporated at low bridges on the Great Western Main Line at Cardiff[6] and Steventon[7] will contribute to a further improvement in cost. The innovations employed at Cardiff saved between £14 million and £49 million, based on estimates of the reconstruction alternatives. Other potential for cost savings compared with previous schemes have been identified and are being actively pursued.

4.4. Technologies to improve the emissions and performance of existing non-electric and electric trains are already being actively evaluated by train fleet owners and operators to establish their emissions performance, but also their effects on train reliability, maintenance and longevity, each of which will remain important as well as decarbonisation. Such retrofits represent a credible, affordable, low-risk, near-term option in the overall strategy, since much of the technology has already been deployed in other markets.

4.5. One such development has been Eminox exhaust technology applied to a Class 159 DMU which has shown very encouraging results on emissions reduction. G-volution dual fuel technology has been applied to a Class 180 high speed train and a freight locomotive, with significant carbon reduction potential, better fuel consumption and better emissions in mind.

4.6. In-addition to improvements for diesel-only trains, some modifications to electric-only trains, to make them hybrids, are being evaluated to improve their operating range away from electrified lines. A number of providers of such technologies, train builders, owners and operators have already provided submissions to the Committee on their activity and plans.

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[3] https://www.networkrail.co.uk/wp-content/uploads/2020/09/Traction-Decarbonisation-Network-Strategy-Interim-Programme-Business-Case.pdf

[4] https://railtechnicalstrategy.co.uk/low-emissions/

[5] https://www.riagb.org.uk/RIA/Newsroom/Stories/Electrification_Cost_Challenge_Report.aspx

[6] https://railtechnicalstrategy.co.uk/case-study/cardiff-intersection-bridge/

[7] https://www.networkrailmediacentre.co.uk/news/bridge-in-oxfordshire-to-remain-in-place-following-state-of-the-art-testing

4.7. New trains, such as the Hitachi Class 800s and Stadler Class 88 freight locomotives have already been procured with the means to operate in electric and non-electric mode, to be able to take advantage of electrification where it exists, whilst still enabling the journey to be completed where it does not, albeit with reduced overall performance.

4.8. Battery trains have already been developed, demonstrated and approved for use in passenger service; hydrogen trains are in service in Germany, and a converted EMU has now had its first hydrogen-powered runs on a UK mainline.

4.9. Railways abroad have also been considering the same questions as in the UK, but they have reached the same conclusion: alternative fuels have their place, but they are only a small part of the solution.

5. What challenges there are to deploying alternatively fuelled rolling stock on the GB rail network, particularly given issues with standards and loading gauge

5.1. The challenges to deployment of alternatively-fuelled trains and locomotives in GB occur both in operation, and in depots.

5.2. The potential for these new technologies to act as an alternative to electrification should not be overestimated. They undoubtedly have their place, especially as a transition mechanism, but they are not a silver bullet. The stark truth is that for non-electric trains, nothing comes close to the amount of energy in diesel fuel, so the question of what replaces diesel is important.

5.3. Electricity is the answer, but in what form? However much the hydrogen and battery proponents seek to promote their products, they will not be able to match electrification, or diesel trains for efficiency due to the laws of physics, resulting in lower effectiveness. The inherent benefit of electric trains is in not having to carry their own store of energy, meaning that they offer range, acceleration, speed, and haulage capacity in the case of freight or high speed passenger, simply not possible with self-powered alternatives.

5.4. By way of example, prior to electrification, the Class 170 DMUs running between Edinburgh and Glasgow had a 0-60mph time of 100 seconds; after electrification, the replacement Class 385 EMUs have a 0-60mph time of 40 seconds. Looking at the Cardiff-Swansea electrification, electric trains save four minutes by faster acceleration from the route's four stops, some 7% better. These numbers matter since they are a significant component of network capacity.

5.5. Freight performance improvements are also significant. Network Rail modelling of electric freight capacity and journey times indicates 12% better journey times for trains of up to 2000 tonnes, and 23% for the heaviest trains on the network; considering haulage capacity, modelling indicates that current diesel-hauled journey times could be maintained with a trailing load some 87% higher. These are all very significant gains, and would assist railfreight competitiveness hugely.

5.6. The poorer efficiency of alternative traction energy options compared with electricity will be seen in the form of higher operating costs, additional fleet-specific fixed infrastructure, greater electricity generation and grid capacity requirements and more expense than the equivalent for electric trains.

5.7. Batteries and hydrogen have a much lower energy density than petroleum, and their stored energy can only be realised by a conversion process, in the case of hydrogen: electrolysis, compression, fuel cell, traction voltage converter, mechanical drive. Each and every time there is a conversion process, there is a loss, typically heat and sound. This means that hydrogen and battery will always be less efficient than electrification: in the case of hydrogen, it is circa 29% as efficient, or putting it another way, it requires more than three times the energy to achieve the same output as that of an equivalent electric train.

5.8. An electric train does not need refuelling at all, since all the energy it requires is supplied by the wires to wherever it happens to be, regardless of whether the train is a high speed passenger train or a freight train. Hydrogen and batteries have about 14% and 7% the energy density of diesel i.e. they require approximately seven and fourteen times, respectively, the mass of energy storage that diesel requires to undertake the same duty. This means that they will need a lot more frequent refuelling, and therefore more time not in service than the equivalent diesel train; to put it crudely, the improvement needed to match even diesel is roughly an order of magnitude, which is unlikely in the required timescales. Electric trains are much more efficient than diesel trains, requiring an even greater improvement from battery and hydrogen.

5.9. It seems unlikely that either battery or hydrogen could be a credible replacement option for freight locomotives and intercity trains, simply on the basis of the space required to store the energy to run economically viable trains. Extrapolating the analysis of much bigger trans-continental freight trains to the size of trains operated in the UK suggests that three wagons would be needed for hydrogen tanks, and six wagons would be needed for batteries - this would render the train uneconomic, due to train length and mass constraints.

5.10. One should not be completely negative about hydrogen and battery, since both will have their uses, as will bimode/trimode hybrids, in transition from the current passenger fleet to electrification and in the long-run for routes that can't justify electrification, but they should be considered as niche solutions rather than the general answer.

5.11. The Network Rail Traction Decarbonisation Strategy is a helpful step along the way, but we need to see funded electrification programmes, very soon, rather than hoping for miraculous improvements in the alternatives.

5.12. Loading gauge is a challenge; standards should not be a challenge, they should and will be an enabler to make deployment easier. They will, however, need to be developed, or some aspects of existing standards adjusted to suit the different characteristics of hydrogen in particular. Battery train charging will require standardisation, in order to avoid the current lack of interoperability seen in electric cars. One manufacturer is already working with Network Rail in this field.

5.13. There will also be challenges around:

- suitability for the purpose - transition, end game
- depot infrastructure requirements
- hydrogen electrolysis energy requirements
- battery charging infrastructure
- refuelling, range
- end of life disposal requirements
- platform lengths.

5.14. The UK loading gauge is smaller than that available in Continental Europe and elsewhere. Coupled with UK platform heights, this effectively limits the places that equipment can be installed, typically to below the floor, or at the outer ends of a train if above the floor, though one manufacturer has recently introduced a new passenger train in the UK with a power module above the floor in the middle of a train.

5.15. Battery and hydrogen trains both have significant limitations in the types of operation to which they are suited, such as speed, acceleration and train mass. Neither is suitable for freight trains, which leads directly to the conclusion that a large part of the network will need to be electrified, which undermines some of the business case for hydrogen and battery where it might otherwise have been viable.

5.16. Thus far, the size of the package that powers a commercially viable hydrogen-powered passenger train has only been seen on the Alstom iLint train in Germany. Prototypes have been produced in the UK, retrofitting to an existing train, but the focus has largely been on ensuring the technology can be evaluated, rather than putting it into a final configuration.

5.17. The limiting factors seem to be mainly about storage tank size. As has been stated above, a much bigger volume of hydrogen is required than diesel, even when very highly compressed. It seems likely that these large tanks will have to be accommodated in space that would otherwise be for passengers, or will require longer trains.

5.18. Suitability for the purpose is very important. The Traction Decarbonisation Task Force Report[8], identified the suitability of both hydrogen and battery trains for different purposes. The Network Rail Traction Decarbonisation Strategy (TDNS) has taken that a step further and identified suitability by route.

5.19. Alternative fuels of whichever sort will require new or amended depot infrastructure, to "fuel" the trains/locomotives. The equipment required to fuel hydrogen trains is likely to require significant investment, such as an upgraded electricity supply to provide the megawatts needed for electrolysis, compression and high pressure storage, and high integrity connections to the train. Piping hydrogen long distances or delivery by road tanker is not considered plausible, so local production is required.

5.20. Given the level of investment required, the centralised nature of train fleets is actually comparatively better suited for the purpose than road vehicles, and such facilities could potentially derive better economic benefit by serving several transport operations, such as buses or municipal fleets as well as trains.

5.21. Battery powered trains will require charging mechanisms. The amount of energy required per train is very significant, and is likely to require substantial charging points, at depots, or on the routes served by the trains, depending on the nature of the service being operated; battery trains can also trickle charge from overhead lines where these are available. The current view is that these charging points will be of the size of a shipping container, and will consist of a very big battery bank, itself charged from the grid overnight when other demand is low.

5.22. Alternative fuels of whichever sort will require new or amended depot infrastructure to maintain them. Battery is the simplest in the maintenance context, likely to require some battery conditioning tools; the means to change life-expired battery packs, such as forklift trucks are not new. It would be reasonable to assume that the additional maintenance requirements for hydrogen buses will also apply for trains i.e. hydrogen sensors, lighting and ventilation adapted for use in hazardous locations, along with emergency venting; training will be needed for technicians focussed on enhancing their understanding of the hybrid diagnostics systems, and of the hybrid, high voltage and gas systems; training will also be needed for emergency services focussed on risk assessment and handling hazardous materials. Diesel maintenance is mature, well-understood, with an established supply chain; this is not yet the case for hydrogen.

5.23. The range of both hydrogen and battery trains is likely to be substantially less than for diesel, requiring a recalibration of the operating plans (diagrams) and expectations. Whilst diesel marginally less efficient as a fuel than hydrogen (circa 26%), its energy density means

[8] https://www.rssb.co.uk/Research-and-Technology/Sustainability/Decarbonisation/Decarbonisation-our-final-report-to-the-Rail-Minister

that a DMU can typically do circa 1600 miles before refuelling is required. Hydrogen diagrams are likely to be circa 600 miles, battery circa 100 or less (at the most optimistic with current battery technology). This will impact adversely on both efficiency and operating cost compared with diesel and electric operation. An electric train has no range constraints.

5.24. End of life disposal is also a procurement consideration for fleet owners. Fuel cell manufacturers state that all the components are recyclable, but as yet their lifetime is uncertain. A 2016 report looking into the suitability of hydrogen for buses[9] indicated that whilst lifetimes of 6000 hours were expected, and whilst some were still operating at 20,000 hours. 6000 hours is circa one year. If the lifetimes are this short, it could be a significant part of the ongoing operating cost of the train.

5.25. Some UK station platforms are short, particularly on lightly served, rural lines, one of the notable applications being considered for hydrogen application. Whilst operated by short trains e.g. two-car DMUs, this is not a problem in most cases. Where longer trains are used, if the passenger-carrying part of the train is too long, additional measures have to be employed to ensure passengers cannot accidentally fall from the train; this is known as selective door operation (SDO), and is usually more cost-effective than platform extension. Should hydrogen modification requirements extend train lengths sufficiently, these SDO modifications may also be required, further adding to the costs of the retrofit.

6. What passenger benefits alternatively fuelled rolling stock could provide?

6.1. Electric trains can offer a number of passenger benefits. As hydrogen and battery-powered trains are essentially electric trains, these benefits compared with diesel would be shared:

- Better journey times, better capacity
- Better air quality in stations, and in areas proximate to frequent stops
- Reduced noise levels in stations and the trains
- Better reliability
- Better value

6.2. Electric trains accelerate better than diesel, they have more power and a higher power to weight ratio. As demonstrated above, this transfers into better journey times. This also helps to create better utilisation of system capacity, or put another way, more trains can fit on the same infrastructure.

6.3. Better air quality in the stations is self-evident. Less obvious, and thinking more of railway neighbours, is the areas where trains stop frequently, and power systems still run, to provide lighting/other on-board systems, such as at maintenance depots or sidings.

6.4. Diesel noise is significantly intrusive in the interiors of all DMUs. Since battery and hydrogen systems have low noise characteristics, each will provide passengers with significantly quieter environments in the trains and and for neighbours, particularly around stations.

6.5. Electric trains are inherently more reliable than diesel trains, and produce less track wear because they are lighter, resulting in lower industry costs.

6.6. Hybrid trains/locos would share some of these benefits, since they will only operate in diesel mode for a limited time.

[9] Clean Hydrogen In European Cities

7. Whether alternatively fuelled rolling stock would be cost effective compared to EMUs over a 25-40 year life-cycle

7.1. Given the comparative infancy of both hydrogen and battery-powered solutions, we simply don't know the lifecycle costs yet; battery is more mature than hydrogen, but it is still immature.

7.2. Additionally, the answer also depends on the economies of scale which can be realised in the transition. Taken in isolation, for example, if a short, isolated route were to be served, the relative cost of maintenance and operation would be higher than if several routes could be served by the same maintenance depot. But, it may still be better value overall than electrification, e.g. for the Far North Line to Wick and Thurso, where population density mitigates against electrification.

7.3. If all of these complicating factors are harmonised, and we assume that critical mass is reached for a train type, a qualitative comparison can be provided. It is highly likely that the EMU would have the lowest whole-life costs. Of the two options, it is more likely that a battery train costs would be closer to those of an EMU, since it has the least additional equipment and is only marginally more complex.

7.4. It is highly likely that the costs of the hydrogen train would be higher than an EMU, since it has more equipment and more complexity, it has lots of losses in the energy transfer from well to wheel; the cost of building and running its refuelling infrastructure is not yet widely understood at the scale needed for a train fleet. It is estimated as an order of magnitude greater than for bus fleets.

7.5. The question is further complicated by the fact that both new trains and retrofitted trains are being offered to the market. Clearly the proposers and developers of those trains consider that they have a viable product, at least for some applications, or they wouldn't be investing in their development.

7.6. Given the greater flexibility of an EMU, to go wherever there is an electric overhead wire, without range anxiety and to undertake a range of duties, with lower operating costs and high residual value, it is likely that the EMU would be more cost-effective.

7.7. We have a surplus of relatively modern EMUs at present, due to the volume of new trains ordered under recent franchises. The adaptation of these surplus trains for new uses is likely to be the best value of all.

8. What the train interior of the future needs to have to ensure continued growth in rail travel, particularly amongst young people and future generations and to be fully accessible to all

8.1. I offer no comment on this question.

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