Arguments for electrification

– towards a railway that plays its full part for environmental quality and against climate change, using clean energy through fully electric operation, and promoting good growth as an attractive, efficient and economical alternative to congested roads

This a paper is written to support the Electric Railway Charter campaign by groups spanning the Pennines, calling for a rolling programme of rail electrification across Northern England, pursuing the Northern Electrification Task Force (NETF, March 2015) recommendations which gave highest ranking to the Calder Valley Line – JSW

Summary (updated February 2019): In July 2017 three electrification schemes were cancelled in South Wales, East Midlands and Cumbria. Doubt was cast on aspects of The Great North Rail Project and the TransPennine Route Upgrade (TRU). Proposed additional through platforms at Manchester Piccadilly station, designed as part of the Northern Hub to maximise benefits of the new Ordsall Chord railway, remain on hold. The TRU will now to deliver some electrification, as well as significant capacity works, on the Huddersfield line. Disappointingly the expectation is now of significant gaps in electrification Stalybridge-Huddersfield/Leeds-York, though we hear encouragingly of a new challenge to Network Rail to wire the whole route within the budget proposed for a partial scheme. It is reasonable to demand earlier promises be honoured, with a rolling programme of full (not gapped) schemes based on the March 2015 "Northern Sparks" recommendations of the Northern Electrification Task Force (NETF).

The arguments for electrification remain clear and enduring:

- **Economic & business case** – compared with diesels or other alternatives electric trains are cheaper to build, more reliable (with less maintenance), cheaper to operate and longer-lasting. Lighter weight means more passengers can be carried; better acceleration means journey times even with relatively frequent stops. Passengers experience improved cleanliness, air quality and noise levels in stations and on trains (particularly in comparison with diesel/bi-mode units that have under-floor engines). ***The "sparks effect" makes rail travel more attractive, delivering a long-term payback on the initial capital costs of wiring. Latest evidence is that with a well-planned programme these costs will become significantly lower per kilometre than occurred on recent over-running schemes.***
- **Environment & resources** – improved air quality, reduced noise, combating climate change, reducing wastage of resources, objectives that can only ever be partially achieved with fossil-fuel based traction. Even with non-renewable electricity generation, electric trains have 20-30% lower carbon emissions than diesel, an advantage already being exceeded with the current renewables mix. As electricity generation moves towards zero-carbon, so will electric transport. ***The move towards zero-emission, zero carbon road transport by mid-century must be matched by a commitment to a zero-carbon, zero-emission railway over a similar or shorter timescale.***
- **Consideration of alternatives –** bimode trains carrying both diesel and electric traction equipment are heavier, more complex and materials-hungry; less energy-efficient; more expensive to procure and operate than pure electrics. Reliability is unproven, performance unlikely to match that of pure electrics. Diesel bimodes commit the railway to continuance of polluting technology. Hydrogen fuel-cell trains, with less efficient energy storage than modern batteries, of questionable sustainability (in carbon terms) and limitations of speed and range are an unlikely solution for heavily used strategic routes. Electrics with modest battery storage may be helpful where there are short gaps in overhead electrification. Fossil-derived sources (including both diesel and unsustainably produced hydrogen) must not be seen as an alternative. ***The preferred solution should be full electrification.***

J Stephen Waring, Chair, HADRAG: The Halifax & District Rail Action Group (Feb 2019) – www.HADRAG.com

Table 1 Comparisons of electric, diesel and bimode trains

Much of the information in this table is summarised from written evidence submitted by Roger Ford to House of Commons Welsh Affairs select committee, November 2017, on cancellation of electrification in South Wales[1]. By profession a mechanical engineer, Roger Ford CEng, IRSE, FCILT is industry and technical editor at Modern Railways magazine and founding editor of Rail Business Intelligence.

	Electric	Diesel/bimode	Remarks
Average cost per vehicle	**£1.2M** (Recent EMU orders)	**£2.36M** (Hitachi bimodes ordered for TPExpress)	Reflected in leasing costs of train operating companies (TOCs)
Performance	Best due to low mass; higher power can be installed; higher efficiency.	Bimode is worst of both worlds – underpowered in diesel mode, overweight in electric mode.	Reflected in TOC costs and revenue, fares, profitability, premium payments to DfT (or increased subsidy)
Availability (% of trains in fleet in service)	Best	Lower due to increased maintenance – larger fleet required compared with electric.	
Train maintenance costs.	Typically **33% lower** than diesel.		
Reliability (expressed as miles per 3 min delay)	Siemens 3 most reliable EMU types) **100,000** mile/3min delay	Siemens equivalent DMUs **26,000** mile/3min delay (Ford considers this creditable for DMU)	
	Hitachi IEP specification **50,000** mile/3min delay	Hitachi IEP specification **25,000** mile/3min delay	
Track wear – dependent on vehicle mass.	Hitachi IEP train mass per vehicle **41 tonne** electric…	… diesel bimode with engine and fuel, **50 tonne.**	Reflected in variable track access charge paid by TOCs to Network Rail.
Mass of diesel power pack (engine + generator)	0	10 tonne, approx.	
Energy costs	Typically **45% lower** than diesel.	Advantage of electric over diesel due to lower mass, increased efficiency. Regenerative braking on electric trains recovers kinetic energy and returns as electricity to grid, saving **15-20%**. Rail can use whatever source of energy supplies the grid.	
Environmental – local	**Zero emissions** due to traction at point of use. (Some brake dust emissions but see also remarks.)	NOx, particulates, brake dust etc	Modern electric trains with regenerative braking also have reduced emissions due to brake dust.
Environmental – global – combatting climate change	*Even with non-renewable primary energy for generation, electric **20-35%** lower CO_2 emissions than diesel. With current mix including renewables this improvement is thought to be significantly already greater. As electricity generation moves towards zero-carbon, so will electric trains –JSW*		
Cost of electrification work!	*Obviously, electrification work has a high capital cost, but with a holistic view this is recouped by reduced operating costs later. This was the rationale for a number of earlier electrification schemes including the 1985-1991 East Coast Main Line project which was paid for (£306M) on the basis of operational cost saving and increased output. This balancing of electrification costs against future saving is also explored by Prof Stuart Cole in a further item of written evidence to the HoC Welsh Affairs Committee[2] –JSW*		

[1] http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/welsh-affairs-committee/the-cancellation-of-rail-electrification-in-south-wales/written/73604.pdf

[2] http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/welsh-affairs-committee/the-cancellation-of-rail-electrification-in-south-wales/written/73840.pdf

Arguments for electrification

1 Context and background

1.1 In March 2015, the Northern Electrification Taskforce, a group chaired by Andrew Jones MP (Harrogate and Ripon) comprising an all-party group of MPs and local authority representatives from across the North of England, backed by professional input, published its report.[3] The conclusion, on operational, economic and business criteria, placed 12 northern routes in a top tier recommended for electrification during the "CP6" 2019-24 Network Rail control period. A further 20 routes were placed in Tiers 2 and 3, and the task force concluded that all these routes should be electrified in due course. On the criteria used the top-ranked scheme in Tier 1 was the "full" Calder Valley Line comprising the routes from Leeds to Manchester and Preston via both Bradford and Brighouse and Hebden Bridge. Next in rank order were the second Liverpool-Manchester route via Warrington, Southport/Kirkby-Salford, Stockport-Chester, Middlesbrough, the Harrogate Line and Selby-Hull. The full list of Tier 1, 2 and 3 NETF schemes forms an appendix to this paper.

1.2 In Summer 2017 the Department for Transport (DfT) cancelled planned railway electrification between Cardiff and Swansea; on the Midland Main Line from Kettering to Derby and Sheffield; and on the Oxenholme to Windermere "Lakes Line"[4]. These were three previously committed electrification schemes and the latter two directly affect rail development in the North of England. Midland Main Line premier inter-city trains from the early 2020s are now expected to operate on diesel power for more than half of the journey from London to Sheffield using "bi-mode" trains which will carry both diesel power packages and electric power collection equipment. The Windermere branch, including services to Manchester Airport, may now be operated from the early 2020s by trains using batteries on the branch line. This will be a step forward compared with possible continuing use of diesels or electro-diesel bimodes, but it is impossible to resist the observation that this simple branch line electrification scheme could, with a will, have been completed well before 2020.

1.3 TRU: Huddersfield Line electrification Comments by the Secretary of State for Transport quoted in the Financial Times[5] immediately after the July 2017 announcement led to the general understanding that the **TransPennine Route Upgrade (TRU)**, including electrification of the line from Staybridge via Huddersfield to York, completing an electrified intercity route from Liverpool to Newcastle, was being reconsidered and might not be electrified along the whole length. This now seems to be confirmed, though not quite publicly. Instead of running fully electric trains, "bi-modes" and some diesel-only trains will be used and indeed these trains are now close to entering service with the TransPennine Express franchise. From information that leaked into the public domain in Autumn 2018 it seems that sections to be left unelectrified, at least in the CP6 (2019-24) works, will include Guide Bridge/Stalybridge-Huddersfield and much of Leeds-York. The central Pennine Stalybridge-Huddersfield line, having significant gradients, is perhaps the very section of the whole route that would most benefit from the performance of electric trains in terms of tractive effort available for acceleration and hill climbing, and the ability to recover energy in regenerative braking. It is generally accepted that that diesel bimodes will have an inferior performance on such routes. The fear therefore is that journey time targets may only be achieved by missing out stops. In February 2019, there are hopeful signs. The Railway Industry Association is expected to release (with Network Rail and DfT) finding from its Electrification Cost Challenge. There is a possibility, indeed, that Network Rail itself may take up the challenge to electrify the full TransPennine route (Huddersfield Line) within the budget for the DfT-proposed partial

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[3] http://www.railnorth.org/news/electrification-task-force-final-report-revealed/ (original release with link to report as pdf). Also available at https://andrewjonesmp.co.uk/wp-content/uploads/2015/03/EFT_Final_Report_FINAL.pdf or at https://electriccharter.files.wordpress.com/2018/05/northern-sparks.pdf

[4] Statement by Chris Grayling MP, Secretary of State for Transport, 20 July 2017: https://www.gov.uk/government/speeches/rail-update-bi-mode-train-technology

[5] Financial Times article on-line 21 July 2017 available at https://www.ft.com/topics/people/Chris_Grayling

scheme[6].

1.4 A related issue – need for capacity works in the Great North Rail Project (Northern Hub) and TRU:

(a) There is also little sign of a go-ahead for capacity works that were promised as part of the original Northern Hub project, specifically the proposed provision of two additional through platforms at Manchester Piccadilly station to handle more frequent services that will be developed via the new Ordsall Chord railway over the next few years. The lack of capacity along the Castlefield route through the Piccadilly through platforms is an obvious and acknowledged factor in May 2019 timetable chaos and continuing difficulty in improving services. Digital signalling at some unstated future date will not be able to provide what the additional tracks and platforms offer. The two additional platforms would, given necessary dwell times, allow an increased frequency measured as trains per hour through the station, enabling greater timetabling flexibility to get best value from the Ordsall curve which was physically complete in Autumn 2017 but now because of the Castlefield issues carries no more than 2 trains per hour in each direction. The additional platforms are necessary to allow attractive and robust timetables to be devised for train services from the Calder Valley and Huddersfield lines, through Manchester Victoria and round the new line to Manchester Piccadilly and the Airport.

(b) It is understood that significant capacity enhancement will be included in TRU along the Huddersfield line during CP6. We hope this will mean restoration of 4 tracks east of Huddersfield and through Mirfield benefitting not just TransPennine Express services via Huddersfield but also Calder Valley services via Brighouse. If this is confirmed it will be good news, although the lack of complete electrification is still a major disappointment. Digital signalling is also expected, with capacity benefits, but the provision of additional tracks will provide physical capacity and opportunities for parallel running that are only possible with additional tracks.

1.5 Problems with electrification – looking towards solutions.

We concede the point that delays and cost overruns in the delivery of Network Rail electrification schemes, particularly the Great Western Main Line (GWML) scheme, and more recently schemes in the North West, have led to the present electrification programme (not to mention future schemes such as the Calder Valley) being reconsidered. Even before the July 2017 announcement electrification to Oxford, Bath and Bristol had been indefinitely shelved – so that Great Western "electrics" will continue to run on diesel power to these destinations, with negative consequences for noise and air quality locally as well as increased carbon dioxide emissions. Here are three major historic city stations where failure to electrify will continue to damage the immediate environment.

Government statements have also referred to overhead electrification structures as being unsightly (notably with reference to the Windermere branch through a national park), as well as to the existence of bimode technology making full electrification unnecessary. However, the aesthetic objection to overhead electrification does not seem to have held sway, for example, when Crewe to Glasgow electrification was completed through the spectacular Cumbrian fells, a project that took just four years from approval in 1970 to completion in 1974. Bimode "electro-diesel" technology is not in essence new or "state of the art" but carries its own inefficiencies and sources of waste. New electrification technology including innovative designs for the overhead line equipment (OLE) technology is likely to have a desirable impact on both cost and aesthetic values.[7]

The costs of GWML reportedly tripled to around £2.5 billion. To put this into historical context, between government approval in 1985 and completion to Edinburgh in 1991, British Railways electrified the East Coast Main Line (north of Hitchin) at a cost of £306M (equivalent to just under £1bn at 2017 prices). The ECML scheme was funded internally through increased productivity.[8] Aesthetic issues were appropriately addressed; for example, the

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[6] See report on by MODERN RAILWAY columnist Roger Ford in his INFORMED SOURCES e-Preview March 2019: http://live.ezezine.com/ezine/archives/759/759-2019.02.18.03.45.archive.txt

[7] See, for example https://www.mottmac.com/releases/mott-macdonald-and-moxon-unveil-prototype-for-innovative-integrated-overhead-line-structure

[8] GREEN, C and VINCENT, M: *The Intercity Story* (Oxford Publishing Co, 2013), page 35. See also letter from David Carter to the Guardian newspaper in https://www.theguardian.com/uk-news/2017/jul/24/uks-rail-network-suffering-from-lack-of-joined-up-thinking

OHLE structures on the Grade 1 listed Royal Border Bridge over the Tweed were approved by the Royal Fine Art Commission.[9] The ECML electrification scheme has been criticised for having insufficiently robust OLE (for example in high wind conditions); however there seems little obvious reason why using more appropriately robust structures need be disproportionately more expensive. Some of the structures used on the current GWML electrification do appear to be very robust, even over-engineered, and criticism on aesthetic ground is understandable. However, it does not have to be like that everywhere. There are alternatives.

The respected railway engineer Ian Walmsley, writing in Modern Railways magazine (November 2017), argues convincingly for a continuing programme of electrification including reinstatement of the cancelled Midland Main Line scheme. Walmsley cites the example of Denmark where electrification designed for 250km/h (156mile/h) was ordered in May 2015 and is already live over 121 km[10].

The Rail Industry Association seems committed to reducing the costs of electrification.[11] Again innovative technology may be deployed. In some cases there are alternatives to raising bridges or lowering the track to provide clearance for £25kV overhead line electrification (OLE) wires as at the Cardiff Intersection Bridge where an insulating coating was applied.[12] On the GWML successful electrification through the Severn Tunnel (7km) was successfully achieved despite unusual challenges. Why the doubt, then, about lines with shorter tunnels in the North? (Standedge Tunnel between Huddersfield and Stalybridge is 4.8km, Summit Tunnel on the Calder Valley Line 2.6km.)

Does it all have to be at 25kV? Innovation might extend to consideration of the electrification system itself. Modern electrification is normally with the OLE energised at 25 000 V, alternating current (25kV, ac). High voltage facilitates transmission of high power at relatively low current, reducing losses and allowing conductors to be less massive. It is the high voltage that causes the need for large clearance from earthed structures (e.g. the undersides of bridges). In approximate terms the distance required is proportional to the voltage. In some early ac electrification the ac voltage used was 6.25kV instead of 25kV, proportionately reducing the clearance needed through areas with a lot of tunnels or bridges. Might this approach be part of a future solution, where the cost of transformers to change the voltage and trains that automatically switch between different systems might be offset by savings in construction costs (including the costs of disruption)?

Scotland's central belt provides an example to emulate in Northern England and elsewhere. There are four rail routes between Edinburgh and Glasgow; all four are now fully electrified. Northward, the new electrification extends to Stirling and the branch line to Alloa. Here we see a network approach yielding wide operational benefits.

1.6 Environmental commitments: road and rail – and the IPCC challenge

As part of a statement on air quality the government announced (also in July 2017) that the sale of "conventional" petrol and diesel cars and vans (implicitly this might exclude some forms of hybrid vehicle) would cease in the UK by 2040. This was a pre-existent policy dating from 2011 also including a commitment to making road transport almost totally zero-emission by 2050.[13] Many who campaign for the local and global environment would question whether these target dates are sufficiently ambitious. Nonetheless, the future prospect seemed to be, in around two decades time, a road transport system moving rapidly forward in terms of sustainability based on electric vehicles, whilst UK rail continues to derive a significant part of its traction power from dirty diesels. Thankfully a similar commitment seems to have been made on rail, with an announcement that "diesel-only" trains will also be phased out by 2040. Again note "diesel only".

The reference in these "2040" announcements "conventional" petrol/diesel vehicles and "diesel-only" trains, seems to suggest that hybrid diesel vehicles or diesel bimodes may continue beyond that date. Transport is the major contributor to CO_2 emissions (as well as locally damaging pollution) and both road and rail must decarbonise.

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9 https://www.networkrail.co.uk/the-history-of-the-royal-border-bridge/

10 "STOP – THINK – ELECTRIFY": Modern Railways, November 2017, page 39 (Key Publishing).

11 https://www.theguardian.com/uk-news/2018/dec/11/the-need-to-speed-up-rail-electrification

12 https://glscoatings.co.uk/pdfs/GLS100R_Rail_Brochure.pdf

13 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633269/air-quality-plan-overview.pdf

It is simply not good enough to imply that carbon-burning hybrids and bimodes may continue. By 2040 any use of fossil fuels must surely be in rare and exceptional cases.

The autumn 2018 Intergovernmental Panel on Climate Change (IPCC) special report said effective action against global warming can still be taken. But the deadline is 2030.

1.7 Glut of EMUs. The current situation with franchise renewals, where there is an incentive to provide new rolling stock on lines such as Thameslink, Anglia and South Western, has resulted in an apparently glut of reasonably modern electric multiple unit (EMU) trains. For example 86 4-car Class 319 trains have been withdrawn by Thameslink: some have come to the North, some are being converted to dieselised “Flex” (Class 769) units for Northern and other franchises, and at least one is planned for conversion to hydrogen/electric bimode operation. The conversions have yet to be proven in service, with the Class 769s for Northern more than a year late. Whether all of the ex-Thameslink 319s will find use is not clear.

The TransPennine Express franchise is to replace express-standard Class 350 units that were built as recently as 2014 with new build. The released 350s are to go to the West Midlands franchise (LNWR) where, along with a larger number of new-build trains they will replace suburban-style trains of the same class. In this situation it seems illogical not to go ahead with electrification schemes that could use spare trains, new or refurbished to nearly new standard.

In a project by train-builder Alstom and leasing company Eversholt, a number of serviceable 4-car Class 321 electric multiple units may now be converted to hydrogen fuel cell operation – with a reduced maximum speed and significantly reduced capacity (4-cars reduced to three of which one will be half given over to hydrogen storage tanks). The “hydrogen multiple unit” (HMU) trains will no longer function as electrics able to draw current from the OLE. The news release states “These trains could run across the UK as early as 2022, emitting only water and no harmful emissions at all,” but do not explain that to be truly pollution-free the HMU train must be fuelled with hydrogen that has been generated without producing the main greenhouse gas CO_2 as by-product.[14]

See Section 2.3.4 for further discussion of “the hydrogen alternative”.

1.8 New and reopening rail routes. It is disappointing that initial plans for East-West rail (Oxford-Bletchley-Milton Keynes/Bedford/Cambridge) do not include automatic electrification of the route from the start. This is surely a missed opportunity and failure of future-proofing. It is hoped that this omission will be corrected and that future reopenings elsewhere will not make the same mistake. In the North of England reopening from Skipton to Colne is looking hopeful at time of writing. This would naturally be electrified as an extension of the existing electrified route from Leeds to Skipton and would tie in with electrification of the full Calder Valley Line (as recommended by the NETF) through East Lancashire to Preston.

More on electrification programme (as at mid-2017) in parliamentary briefing paper SN05907 Rail Electrification, 27/07/17.

[14] https://www.alstom.com/press-releases-news/2019/1/alstom-and-eversholt-rail-unveil-new-hydrogen-train-design-uk

2 The argument for a fully electric railway; critique of alternatives

2.1 The general arguments for railway electrification remain strong. Network Rail summarised the arguments as follows on a web page headed simply "Electrification" [15], quoted below. Note that the 20-35% carbon reduction mentioned appears to be already out of date; even with current generation mix, CO_2 emissions for overhead electrification have been quoted more recently as 0.33 kg/kWh compared with 0.83 kg/kWh for diesel – a 60% reduction (see also para. 2.3.6). We make these arguments in more detail in the following sections.

> **"Electrification of the railway allows for faster, greener, more reliable train journeys, improves passenger services and supports economic growth in Britain. Benefits of electric trains:**
>
> - More capacity for passengers: more seats than diesel trains of the same length.
> - Faster than diesel trains: superior braking and acceleration make journey times shorter.
> - Quieter than diesel trains: good news for people living near the railway – our lineside neighbours.
> - Better for the environment: their carbon emissions are 20 to 35 per cent lower than those from diesel trains, and there are no emissions at the point of use, improving air quality in pollution hot spots, such as city centres.
> - Lighter: less maintenance is needed because electric trains cause less wear to the track, so the railway is more reliable for passengers.
> - Good for the economy: faster trains with more seats and better connections with previously hard-to-reach areas improve access to jobs and services, and open up new business opportunities."

2.2 The arguments in detail – advantages of electric trains

(a) Commercial, operational and business advantages. A strong business case is likely because the operational costs, commercial benefits and economic benefits of an electric railway in the future will pay back on the capital costs of carrying out the infrastructure work. Electric railways have the following attributes:

- Reduced capital cost of rolling stock compared with diesel
- Rolling stock maintenance costs reduced by electric technology which is less complex than traction packages using fuel-burning engines (or even fuel cells). Electrics are 30% cheaper to maintain than diesels.
- Reliability of electric trains – due to mechanical simplicity (linked to previous).
- Track maintenance costs reduced (about 10%) because lower mass electric vehicles (compared with diesels) mean reduced track forces due to both weight and dynamic forces (e.g. lateral thrust due to centripetal acceleration on curves as well as vertical forces).
- Reduced energy consumption due to increased efficiency of supply and traction system and reduced mass of electric trains compared with diesels or alternative fuels) meaning less energy required to accelerate to given speed; and…
- … potential for energy recovery in regenerative braking which is now the norm on new electric trains.
- Capacity – potentially more seats on electric train compared with diesel (or alternative fuel vehicle) of similar

[15] https://www.networkrail.co.uk/our-railway-upgrade-plan/key-projects/electrification/ (Content at this link may have changed since original citing.)

mass/length/power

- **Passenger benefits leading to "sparks effect"**
  – performance (in addition to reliability), particularly on routes with frequent station stops or gradients, due to higher power/mass ratio of electric trains
  – reduced noise on train, particularly now that underfloor diesel engines are the norm, and in stations,
  – improved air quality in stations
  – linked to the above enhanced passenger perception; electric railways seen as modern; ***sparks effect*** attracting more passengers and promoting good growth

- **Network benefits:** electrifying more railways makes better use of the electric railways we have already. At present we have many diesel services operating "under the wires". Our front-page illustration is a panorama of a large electrified terminus station: of six trains in shot, five are diesels. This seems wasteful in both business and environmental terms (below).

(b) Rail electrification as sustainable technology to conserve resources, preserve the environment.

The Autumn 2018 IPCC special report[16] effectively gave the global community a deadline for action on CO_2 emissions. All sectors must decarbonise. Transport is a significant sector within the total. A measure of rail's success is modal transfer from congested roads; this means rail must decarbonise in parallel with road transport. Environmental advantages of electric railways are:

- reduced **energy consumption** of electrics as above

- **local environment** in stations and around the railway more generally
  – reduced noise
  – improved air quality; zero-emission at point of use compared with particulates and NOx from diesels; modern electric trains with regenerative braking also significantly reduce pollution from brake dust by making less use of friction brakes. These are key issues where rail must keep up with advances and environmental improvements that will be developed for road transport. For example it should be unacceptable for air quality in train stations to be poorer than that which must be demanded alongside a public road.
  – reinforces perception of railway as "green alternative" to road travel

- **global environment**, combatting climate change which is clearly linked to increases on carbon dioxide in the atmosphere.
  – even with non-renewable primary energy sources electric traction has 20-35% lower CO_2 emissions than diesel. This has already improved further given the presence of renewables in the generation mix.
    ➔ ***Electric railways have potential to be*** **zero-carbon** ***as electricity generation moves to renewables*** *(or even nuclear*[17]).

- **physical resources, reducing waste**. Electric traction equipment is longer lasting and requires less replacement of parts during lifetime leading to better conservation of physical resources. Diesel-generator sets have more manufactured components and more moving parts.

- **the visual/built environment** – whilst overhead electrification masts may be considered visually intrusive in areas of sensitive built environment (e.g, in the city of Bath) or of natural beauty (e.g. national parks), this must be compared with the visual intrusion of modern roads and of national grid powerlines and pylons, as well as the effect of roads in terms of noise and air pollution. Consider the effect of overhead wires on the 10 mile Windermere branch in the Lake District National Park, compared with the impact of the A590/A591

[16] https://www.ipcc.ch/sr15/
[17] ***To be clear:*** **This is not to suggest that all supporters of this paper or the Electric Railway Charter are supporters of nuclear power.**

dual carriageway roads in the same area. The M6 motorway passes just outside the national park boundary through an area of spectacular scenery, alongside the electrified WCML railway: which has the greater visual impact? Not all schemes will require the heavy, apparently over-engineered structures recently installed on the Great Western Main Line; better designs are possible.

- **Network benefits** (as in (a), above) make environmental as well as business sense. Operating diesel or trains using carbon-derived fuels "under the wires" is a waste of the resources previously invested in electrification.
- **A green "sparks effect".** With environmentalism increasingly part of the public consciousness, people want to make "green" choices. There is evidence that electric cars, when both running costs and purchase costs are included, are already cheaper to own and run than petrol, diesel or hybrid vehicles[18]. Rail must compete and must maintain its environmental advantage to positively attract new passengers. Nobody wants to drive an electric car to the station to catch a train that still pollutes locally and adds to global warming.

2.3 Arguments in detail: consideration of proposed alternatives to electrification

2.3.1 It has been suggested that significant lengths of the main line railway network may be left unelectrified, with the gaps to filled by use of bi-mode trains using diesel or other carbon-based fuels (including carbon-dependent hydrogen). Our feeling is that this may be appropriate for relatively minor routes but almost certainly not for strategic primary or secondary routes. A good example of a strategic secondary route would be the Calder Valley Line (Leeds-Bradford/Brighouse-Hebden Bridge-Manchester/Preston) which was given the highest ranking as an electrification scheme by the March 2015 NETF report "Northern Sparks". ***The expectation, then and now, is of a railway operated by fully electric trains.***

2.3.2 **The electro-diesel bimode alternative: a sub-optimal solution, "worst of both worlds".** The idea of an electro-diesel train is not new, although the bimode train with underfloor diesel engines as well as the electric overhead pick-up (pantograph) is relatively so. The bimode electro-diesel multiple unit trains carries fuel tanks, diesel engine and generator in addition to electric current collection equipment (visible as the familiar "pantograph" on top of the train) and transformers. It thus has greater mass or weight than either a pure electric or a pure diesel of equivalent performance. Carrying both electric and diesel-electric traction energy systems the electro-diesel bimode is the "worst of both worlds". The following points sum up the argument, supported by some quantitative data set out in Table 1. **Electro-diesel bimodes are:**

- compared with either pure electric or pure diesel, the most expensive type of train to buy. Pure electric is least expensive.
- inherently inefficient, wasteful of energy, due to additional mass to be carried "dead" over long sections (e.g. Windermere-Manchester service carrying diesel under the wires all the way from Oxenholme to Manchester; MML Sheffield-Kettering (electric transformer dead weight), Kettering-London (diesel dead weight); etc. Additional mass causes additional energy use/fuel consumption.
- increased complexity of technology – additional maintenance requirement, unproven reliability of dual technology crammed into small space.
- unsustainable in environmental terms, e.g. noise and air pollution from diesels in stations and other unelectrified sections which are likely to be more urban areas; rail must lead in combating climate change.
- Diesels are obsolescent technology. If the East Midlands franchise is required to introduce new diesel bimodes in the early 2020s these engines will still be within their useful life when internal combustion engines are rapidly being phased out of road transport.

[18] See for example https://www.theguardian.com/environment/2019/feb/12/electric-cars-already-cheaper-own-run-study

- The diesel bi-modes are almost certain to have reduced performance in terms of acceleration and hill climbing compared with pure electrics. This problem could be tackled by having more powerful diesel engines, but this would mean either larger and heavier engines being used, or uprating the power of the existing small engines (reducing reliability), in either case further increasing fuel consumption. In practice, bi-modes will have greater difficulty meeting journey time targets unless stops are omitted, which would damage services for local communities.
- If diesel engines are to have sufficient power to match electric schedules on heavy bi-mode trains, it will be more difficult for them to comply with ambitious emissions standards. Increased diesel power would mean increased pollution – both climate-damaging CO_2, and nitrogen oxides and particulates associated with diesels which damage air quality and threaten health.
- Whilst modern diesel and other internal combustion engines may have reduced emissions, they can never be zero emission, and if they rely on fossil-derived fuels can never be zero-carbon.

2.3.3 **What about partial electrification with battery, Hydrogen (H_2) or alternative fuel bimodes?** We take heart from some government announcements referring to the development of "alternative fuel" technology. But there is a need for caution:

- "Alternative fuels" are often not genuinely zero-carbon. See discussion on Hydrogen in 2.3.4.
- uncertainty over new technology for example bimodes, and conversion of existing trains to bimode operation, and how widespread its practical use might be. We are concerned at the creation of excuses for delay in proceeding with electrification of lines that need it. If it is not to be electrified (a project that could have been completed by now), the short (10 mile) Windermere "Lakes Line" could work well with battery operation, charging "under the wires" in Oxenholme station or during longer runs under direct electric power between Oxenholme and Manchester Airport. By February 2019 this was looking increasingly likely as a solution for the Lakes Line in the early 2020s, quoting a DfT news release about the awarding of funding to several rail decarbonisation projects: "Among the priority lines for potential battery hybrid trains will be the Lakes Line in Cumbria. Train operator Northern will shortly submit a business plan for it to potentially be one of the first lines to benefit from this innovative technology."[19]

General points (with a specific example of concern):

- Battery technology is moving forward driven by growth in renewables and the demand for low/zero-emission road vehicles.
- A battery/electric "independently powered electric multiple unit" (IPEMU) train has been successfully tested in Essex[20]. However, it seems unlikely that a fleet of IPEMUs with sufficient capacity to operate from Kettering to Sheffield will be built for the East Midlands by the early 2020s. The Midland Main Line needs full electrification and it will be a missed opportunity to decarbonise if diesel bimodes are ordered that could still be operating (and polluting) in 25 years' time.

2.3.4 Hydrogen (H_2) can be manufactured as a chemical store of energy using the electrolysis of water using carbon-free electricity as energy source; so trains powered by H_2 fuel cells (which use electrochemical combination of hydrogen and oxygen rather than combustion) could become genuinely zero-carbon in the future as well as zero-pollution. **But much hydrogen-production is by chemical steam reforming of methane, a fuel containing carbon, and the by-product is carbon dioxide. So claims that hydrogen fuel-cell trains are "emissions-free" may not be the whole truth.** Even hydrogen produced by electrolysis from electricity with the current mix of primary sources is not truly carbon-neutral, but will of course move towards zero-carbon as electricity generation does so. (So too of course will pure electric traction.) See also 2.3.6.

Rail applications of hydrogen in the short-medium term may be range-limited determined by H_2 fuel storage

[19] https://www.gov.uk/government/news/carbon-cutting-rail-schemes-share-in-multi-million-pound-government-funding-boost
[20] http://www.railway-technology.com/projects/independently-powered-electric-multiple-unit-ipemu-essex/

capacity on board the trains and availability of refuelling infrastructure. ***An initial report by the rail decarbonisation task force suggests trains on hydrogen power may be limited to relatively short distances with maximum speed 75mile/hr.***[21]

The Alstom iLint train under test in Germany is the first train to be powered by fuel cells using hydrogen gas stored in pressure tanks on the vehicle roof. The iLint also has batteries for storing recovered energy from braking and a sophisticated energy management system. By spring 2017 Alstom was able to claim letters of intent for 60 trains with four German regions.[22] Alstom (with train leasing company Eversholt) is now to produce the "Breeze" hydrogen multiple unit (HMU) prototype by converting an off-lease Class 321 electric. However:

- It seems the 4-car EMU train will be reduced to a 3-car HMU, and about a third of one carriage will be converted to carry the compressed-hydrogen fuel tank. It is clearly a greater challenge to install hydrogen tanks on the roofs of trains within the British loading gauge.
- A simple calculation from the above gives an estimated reduction in passenger capacity of one third (33%) compared with the original 4-car electric multiple unit.
- It appears the converted 321 train will no longer be able to operate as a pure electric.
- Both the German iLint and the British Class 321 converted train have a quoted maximum speed of 140km/hr (87mph); the original electric Class 321 was 161km/hr (100mph). Obviously, this may not be significant for secondary routes. It is not clear whether acceleration will equal that of the pure electric.

Safety? It is not immediately clear how safety issues associated with hydrogen stored on board a transport vehicle compare with those associated with other fuels. What risk assessment has been carried out against leakage of this highly flammable gas in a railway tunnel or enclosed station area? We are not suggestion hydrogen must be unsafe, but some information needs to be published on this to provide reassurance.

Distribution of hydrogen to fuelling points might be an infrastructure challenge. Or could hydrogen be sustainably generated in depots by electrolysis of water using renewably generated electricity?

Round-trip efficiency: remarkably, hydrogen fuel cells have an efficiency of no more than about 50% (meaning that 50% of the energy value of the hydrogen is converted to electricity whilst 50% is wasted as heat). A higher efficiency may be achieved by combustion of the hydrogen to generate electricity via a turbine. The overall "round trip efficiency" of storing energy from electricity (via electrolysis) as hydrogen and then regenerating electricity for traction onboard the train is therefore likely to be at best 50% in the future (with a theoretical improvement if some of the waste heat can be recovered) and is significantly lower than using battery storage with an efficiency of up to 90%.[23] As stated elsewhere, battery technology will continue to improve.

See also 3.1 in Concluding Remarks below.

2.3.5 **Sustainable liquid fuels** may be available in the future, capable of being used in an internal combustion (IC) engine similar to a diesel. Production of such fuels might employ bio-engineering techniques akin to artificial photosynthesis to manufacture biofuels. Such an energy source could be sustainable because it absorbs CO_2 from the atmosphere in production and does not involve the use of large areas of farmland to grow fuel crops. However, compared with pure electric traction systems:

- ***the IC engine (gas, diesel or petrol) will remain inherently inefficient;***
- ***will always produce additional pollution, for example nitrogen oxides, at point of use.***

Mass-production of biofuels is clearly some years in the future and should not therefore be a reason to delay electrification of strategic rail routes.

2.3.6 A recent report from the Rail Safety and Standards Board includes emissions estimates (on a per unit energy

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[21] https://www.rssb.co.uk/RiskContent/Rail-Industry-Decarbonisation-Task-Force-Initial-Report-to-the-Rail-Minister-January%202019.pdf
[22] http://www.alstom.com/press-centre/2017/03/alstoms-hydrogen-train-coradia-ilint-first-successful-run-at-80-kmh/
[23] See for example https://www.sciencedirect.com/topics/engineering/round-trip-efficiency or http://energystorage.org/energy-storage/technologies/hydrogen-energy-storage

basis), quoted with commentary in a recent RAIL magazine article[24], and shown in our Table 2 below. Even hydrogen produced by electrolysis only gives a large reduction in CO_2 emissions when electricity generation is decarbonised (the anticipated 2040 situation).

Table 2 CO2 emissions from different types of train (RSSB figures, 2019)

Energy source/fuel	CO_2 emissions per unit energy /($kgCO_2e/kWh$)
Diesel	**0.83**
Diesel hybrid	**0.62**
Advanced diesel hybrid	**0.5**
Overhead electrification 2018 [i.e. with current generation mix]	**0.33**
Overhead electrification 2040 [i.e. with expected increased renewables]	**0.16**
Natural gas (CNG/LNG)	**0.6**
LPG	**0.7**
Brown hydrogen (from natural gas)	**0.63**
Brown hydrogen (from electrolysis 2018 [current generation mix])	**0.8**
Brown hydrogen (from electrolysis 2040 [expected increased renewables])	**0.4**
Green hydrogen [assumes zero-carbon distribution]	**0**
Biodiesel [assumes zero-carbon distribution]	**0**
[*To which we would presumptuously add:*]	
[Green electrification]	**[0]**

2.3.6 In conclusion:

- ***We do not see either hydrogen-fuelled trains or trains burning carbon-based fuels as a sensible, sustainable alternative to continuous (or near continuous) electrification of strategic routes such as the Calder Valley Line and other heavily used routes across the North.***

2.4 Bridging the gaps. We comprehend arguments against continuous electrification of ***less heavily used routes or branch lines*** based on the cost and disruption associated with increasing physical clearances for the high voltage equipment. We would not oppose the idea of some short sections being left "unwired". But:

- the whole point of the above argument about bi-modes is that the continuing use of diesel engines reduces efficiency, increases energy consumption and damages the local and global environment. ***Diesel bimodes and other unsustainable fuel-based solutions must be rejected.***
- We should care where our energy comes from and should start to move rapidly away from transport, including rail, that is dependent on burning fossil-fuel derivatives in an internal combustion engine, and towards the use of sustainably generated and clean electricity.
- The widespread use of genuinely sustainable biofuels or sustainably-generated hydrogen for medium to long distance transport would appear to be, at best, some years away. ***There is a need to beware false promises.***
- The conclusion seems to be that where sections – meaning short sections – of an electrified railway are left unwired (or not live) the gap might be filled by trains with a modest amount of onboard energy storage, probably provided by batteries. This is already feasible. Battery technology will continue to improve, driven by development of renewables and indeed by demand for pollution-free road transport. There is a precedent for this approach in the electrification scheme proposed for the Cardiff Valleys in South Wales. ***However, the South Wales valley branches are not equivalent to strategic cross-Pennine routes where full electrification remains the preferred solution.***

[24] https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=25914 quoted by HAIGH, Philip: *Energy solutions to advance railway's green credentials* in RAIL 872 (13-26 Feb'2019, p84-5) (Bauer Media).

2.5 Disruption in construction? The electrification work itself need not result in excessively long periods of disruption to passengers. Much work can be done at night and with effective planning, learning from experience, with teams moving on from project to project, the need for lengthy blockades minimised. Some recent electrification work has employed long blockades, perhaps to allow projects running late to be completed, but this need not be the norm, the key surely being realistic timing, effective planning and experienced project management, all developed effectively through a rolling programme where experience is continuously gained and carried forward.

2.6 Alternative approaches. As already explored in Section 1.5 above, another approach to reducing the need for physical work to increase clearances could be the adoption of dual-voltage electrification, with some sections energised at 6.25kV instead of 25kV. Reducing the line voltage by a factor of four has a broadly proportional effect on the resulting electric field strength and required distance of live conductors from physical structures. Dual voltage electric trains are a tried and tested technology and have been in service on many railways across Europe for several decades. Additional lineside transformers would be required but this might be justified in cost terms by removal of the need for major civils work to increase bridge or tunnel clearances.

Also as mentioned in 1.5, other helpful approaches include bridge insulation and new designs for OLE supports.

2.7 Freight trains. The focus of this paper is on passenger trains. However, strategic routes across the North including the Calder Valley Line also carry heavy freight services. Poor performance by freight trains adversely affects the performance of the core passenger service, which adds strength to the argument that freight locomotives should also operate under direct electric power, in turn strengthening the case for electrification of the route.

3 Concluding remarks

3.1 ***The Future for Hydrogen Trains in the UK***[25], a report by the Institute of Mechanical Engineers, warns against hydrogen being seen as an easy substitute for electrification. Whilst supporting the idea of development and hydrogen trains and associated infrastructure, the IMechE paper's first recommendation is "***That the UK Government rethinks the cancellation of electrification programmes and moves forward with a more innovative, and long-term approach, electrification rolling programme, that can create skills and careers, develop supply chains, and work with existing rail networks to manage projects.***"

3.2 Trains are an excellent alternative to road transport in terms of their ability to carry large numbers of people over either long or short distances. Modal transfer to rail is a potentially highly effective way of reducing road congestion and improving air quality as well as reducing CO_2 emissions and will be even more effective with electric railways. It must surely be agreed that action to tackle both air pollution and climate change must be a key policy objective. Rail must be perceived as modern and also good for the environment if it is to attract more people from congested roads. We should be concerned about air quality in train stations as well as on city streets. This principle can be applied not just to commuting or business journeys but to a wide range of personal travel needs – leisure, personal business, local and longer distance journeys, urban and rural (issues caused by road transport including congestion, air pollution and noise are no longer restricted to urban areas). Electrification favours longer trains that can carry more people. Electrified freight trains will have better performance, in turn improving the punctuality of passenger trains on the same route.

3.3 The Northern Electrification Task Force recommendations should be the basis of a rolling programme of electrification across the North of England, starting with the top ranked schemes in Tier 1. Electrification of the full Calder Valley Line would naturally follow the completion of work on the Huddersfield Line (the TransPennine

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[25] http://www.imeche.org/policy-and-press/reports/detail/the-future-for-hydrogen-trains-in-the-uk

Route Upgrade). The Calder Valley Line means the routes from Leeds, via Bradford and via Brighouse, to both Manchester and Preston. Further schemes would run alongside or closely follow. The Harrogate Line – would be a relatively straightforward scheme in Yorkshire. Southport/Kirkby lines or the Warrington Central line would further a network programme the North West.

NETF said that the Tier 1 schemes should be carried out in Control Period 6 (2019-24). This no longer appears feasible, but planning should, nonetheless, start now to ensure physical works can begin before 2025. With the necessary political will this should be perfectly realistic. When physical work starts it should be carried out in as smart a way as possible to minimise disruption. If there are exceptional short gaps in otherwise continuous electrification trains can have a modest capacity of clean on-board energy storage such as batteries, eliminating the need for carbon-derived energy including "dirty diesels".

The rolling programme should build on lessons learnt from recent schemes in terms of working with contractors and project management, gaining in expertise continuously. The idea of a dedicated management team working through a series of projects seems to make sense. Skills need to be retained, maintained, developed, not lost by a stop-go approach.

To abandon electrification on grounds of apparent initial costs is short sighted in both environmental and business/economic terms. Electrification costs will be balanced and, in most cases, outweighed by savings for train operators later in terms of more cost-effective rolling stock. This was the principle on which the East Coast Main Line was electrified in the early 1980s. A similar approach based on the whole costs of running the railway is required by the DfT today. Recent reports call for re-establishment of a national centre of excellence which could support a rolling programme.

Capital costs of electrifying will be reduced. The Great Western main line electrification reportedly cost £3.5M per single-track km, compared with £1.25M to £2.0M for schemes in Scotland and NW England. European electrification schemes average around €1.0M (£880,000)/s-t km. With the efficiencies generated by a rolling programme British electrification costs should come down to significantly under £1M/s-t km. [26]

About 33% of the UK rail network is electrified. Most comparable European countries have been ahead of the UK for many years. The Netherlands, a country comparable in size with the North of England, is 70% electrified, Germany 60%.[27] On similar percentages most lines in Northern England would already be electrified. Switzerland, famous for its Alpine terrain with cuttings, bridges and long tunnels is almost 100% electrified.

The recent Intergovernmental Panel on Climate Change (IPCC) special report suggest that the global community has about a decade to take effective action against global warming.[28] Transport is perhaps the most significant emitter of CO_2 pollution. Our country must surely lead the way in decarbonising all transport including rail.

The aim should be to eliminate diesel or other carbon-based operation and create an ultra-low emission, zero-carbon, high technology railway including all existing main and secondary routes across the North of England where it will help to deal with the economic imbalance, and elsewhere. Other than for lightly-used lines this must mean a fully electric railway as envisaged by **Northern Sparks*****, the 2015 task force report.***

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[26] Discussion by Roger Ford (MODERN RAILWAYS, March 2019) at http://live.ezezine.com/ezine/archives/759/759-2019.02.18.03.45.archive.txt , quoting review of electrification costs for DfT by Prof Andrew McNaughton
[27] UIC Synopsis 2016: https:// https://uic.org/IMG/pdf/synopsis_2016.pdf
[28] https://www.ipcc.ch/sr15/

Appendix

NETF Tier 1, 2 and 3 schemes, March 2015

The North of England Electrification Task Force was Chaired by Andrew Jones, MP for Harrogate and Knaresborough. In his foreword to the March 2015 task force report ***Northern Sparks*** Mr Jones concluded: "We want a railway that meets the needs of the North. A network that is expanded, efficient and electrified. This report is the Task Force's view of where the next steps start." The task force included three MPs (Harrogate, Bolton West, Redcar) three council leaders (Warrington, Bradford, Darlington) and senior officers from the DfT and Network Rail. In section 8.3 the report prioritised schemes in three tiers (below) and commented: "We believe that ALL these routes need electrifying, starting with those in the first tier, based primarily on the scale of economic impact they will bring. This provides the core foundation for the remaining tiers." The separate schemes were given scores based on economic benefits (50% weighting), impact on services, costs and environment (20%) and providing capacity and quality (30%) the total weighted score for Tier 1 schemes are also shown below.[29]

Tier One	Tier Two	Tier Three
Calder Valley – Leeds to Manchester and Preston via Bradford and Brighouse	Manchester to Sheffield and south east Manchester local services	Barrow to Carnforth
Liverpool to Manchester via Warrington Central	York to Scarborough	Pontefract to Church Fenton
Southport/Kirkby to Salford Crescent	Bishop Auckland/Darlington to Saltburn and Sunderland	Hull to Scarborough
Chester to Stockport	Barnsley to Huddersfield	Ormskirk to Preston
Northallerton to Middlesbrough	Sheffield to Lincoln via Retford	Carlisle to Newcastle
Leeds to York via Harrogate	Chester to Crewe	Skipton to Carlisle
Selby to Hull	Burnley to Colne & Kirkham to Blackpool South	Barton on Humber
Sheffield (Meadowhall) to Leeds via Barnsley / Castleford & connections	Knottingley to Goole	Cumbrian Coast
Bolton to Clitheroe		Doncaster to Gilberdyke
Sheffield to Doncaster/Wakefield Westgate (Dearne Valley)		Cleethorpes to Thorne (Doncaster)
Hazel Grove to Buxton		Middlesbrough to Whitby
Warrington to Chester		Skipton to Heysham

Northern Sparks report March 2015
– NETF Tier 1 schemes *weighted scores*

- **Calder Valley "full"**: Leeds to Manchester and Preston via Bradford and Brighouse ***84***
- **Manchester-Warrington C-Liverpool:** ***80***
- **Southport/Kirkby-Salford Cr:** ***79***
- **Chester-Stockport:** ***75***
- **Northallerton-Middlesbrough:** ***73***
- **Leeds-Harrogate-York:** ***70***
- **Selby-Hull:** ***70***
- **Sheffield-Barnsley/Castleford-Leeds** and connections: ***68***
- **Bolton-Clitheroe:** ***67***
- **Sheffield-Doncaster/Wakefield** (Dearne Valley)**:** ***67***
- **Hazel Grove-Buxton:** ***66***
- **Warrington-Chester:** ***64***

[29] Copy of NETF report Northern Sparks will continue to be provided at https://electriccharter.files.wordpress.com/2018/05/northern-sparks.pdf