HiTrans Electric Vehicle Strategy

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WICK – THURSO BATTERY TRAIN FEASIBILITY STUDY

HITRANS ELECTRIC VEHICLE STRATEGY

WICK – THURSO BATTERY TRAIN FEASIBILITY STUDY

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1. INTRODUCTION

1.1.1 SYSTRA has been commissioned by HiTrans to assess the feasibility of operating a battery powered train to provide additional services between Wick and Thurso. The study forms part of a Work Package on Zero Emissions Vehicles and Vessels that HiTrans is leading on behalf of the Green Passenger Transport in Rural Area (G-PaTRA) consortium of partners which covers six North Sea Region countries.

1.1.2 The overall objectives of the project are too:

- Enhance the capacity for authorities to reduce CO2 from remote, rural and Island transport by embedding more zero emission vehicles in rural transport systems and improving, optimising and better integrating available passenger resources.
- Identify green, innovative, integrated transport services and new organisational and ownership models to allow transport operators to deliver on the project aims of providing a sustainable rural public transport network.

1.1.3 In addition to this the project has a number of specific goals:

- Reduced greenhouse gas emissions
- Enhanced access, mobility and social inclusion
- Reduced per passenger subsidy costs
- Modal shift

1.1.4 The service would be operated by a battery powered train, such as the Class 230 from Vivarail which has been used a reference vehicle in this study. Electricity would be supplied from renewable sources in Caithness, which is a centre of alternative energy generation.

1.1.5 The aims of the study were to:

- Produce an indicative train service specification for the service between Wick and Thurso and estimate the performance impacts of this timetable
- Determine the emissions saved versus Diesel Multiple Unit (DMU) operation
- Estimate the operating and maintenance costs of the service
- Identify the infrastructure requirements for operating the service

1.1.6 The conclusions of the study are that the use of a battery train as a viable substitute for diesel trains, in areas where overhead electrification is not viable, has significant environmental benefits. For example, a new all day service would only needs to attract **13 passengers per day** from car to completely offset its greenhouse gas emissions using a conventional mix of electricity sources. Using renewables from the Caithness area, any abstraction from petrol or diesel cars would make a positive contribution. This compares to over **300 passengers per day** abstracted from car required for a diesel powered service to offset its carbon emissions.

1.1.7 The operating costs of a battery powered train are also lower than those of diesel powered trains, through a combination of lower fuel and maintenance costs. In terms of the overall development of rail services in rural areas this is important as it implies that the use of battery trains could help lower subsidy requirements presenting the opportunity to reinvest subsidy in improving the quality of services to attract more users from car.

1.1.8 The set up and capital costs of the service are very significant. With quoted purchase costs of £2.85m, capital funding of a two car battery train would represent a significant investment, either as a capital purchase or alternatively via a financing arrangement; in addition, there would also be a need for investment in charging equipment and infrastructure at Wick. The capital costs of the train relative to its potential remaining lifespan of 15-20 years are such that if the train were to be leased rather than purchased, the annual lease cost would be comparable to a new DMU; once the need to replace the batteries every seven years are taken into account, it is clear that there is potentially a significant "early adopter" penalty for the use of this new-to-rail battery-only technology. It is likely, however, that this will reduce over time as a market develops for battery-powered vehicles, with a corresponding increase in residual value.

1.1.9 Overall a Wick – Thurso battery service would represent a useful opportunity to test the concept of battery operation in a rural location whilst simultaneously testing the market for enhanced links between Wick and Thurso, but the service would require both capital and revenue funding to operate.

1.1.10 This remainder of this report sets out the approach taken to assessing the battery train proposal and the results of the process.

2. A BATTERY TRAIN FOR THE FAR NORTH

2.1.1 Within this study we consider the operation of a battery powered train that would provide a service between Wick & Thurso in Caithness at the northernmost outpost of the UK Rail network.

2.1.2 The operation of such a train would meet a number of key objectives both in terms of improving local transport and acting as a catalyst for the decarbonisation of rail services in rural areas. Below we describe the criteria that the service would address.

2.2 Decarbonising Rail Transport

2.2.1 The Scottish Government has set a target to decarbonise the railway in Scotland by 2035. Whilst the rail sector in Scotland is a relatively small contributor to carbon emissions overall, it still needs to play its part. The rail network has seen significant investment in recent years, including the electrification of many routes in the central belt. This has contributed to a reduction in carbon emissions through replacement of diesel trains by higher-performance electric vehicles, there remain a number of unelectrified routes. Whilst some of these may well be electrified in the medium term, it is likely that the economics of electrification means a number of rural routes will remain unelectrified, and as such alternative technologies to diesel trains need to be considered.

2.2.2 The use of battery technology may at least be part of the solution to this issue. The development of a self-contained battery train service either as a trial, or as a precursor to wider investment in such technology, would provide practical experience of the strengths and weaknesses of such technologies.

2.3 Renewable Energy

2.3.1 The Wick – Thurso route is especially suitable for the development of a battery train service as it has access to an essentially carbon free electricity supply. The Caithness area and the surrounding coast are home to a number of major wind farms which supply the National Grid and which provide more than sufficient electricity supply for the local area. Such is the level of investment in renewables in the area that a new Caithness-Moray cross sea transmission link has recently been completed which is a requirement for the linking of the Beatrice and Dorenell offshore wind farms to the National Grid along with a number of onshore wind farms.

2.3.2 This density of renewable energy in the area means that any used to supply a battery train would have a much lower (potentially zero) carbon emissions compared to standard Scottish National Grid electricity. A key element supporting the suitability of battery technology in the context of the local generational mix is the ability of both the charging system and the train to store power generated while conditions are favourable, and use it when required.

2.4 The Route

2.4.1 The Wick – Thurso route is suitable for the development of a Battery Train test bed for a number of reasons. The first of these is that the route is within the current capability of battery powered trains with a return trip of around 40 miles against a range of the train of 60 miles. Although in need of modernisation, the station at Wick also has sufficient space to accommodate the facilities required to service and maintain the train, and accommodate its charging equipment.

2.4.2 The route is also relatively remote from other operations making the line for suitable for trial operations; unlike much of the rest of the rail network, track and platform capacity exists for an additional free-standing operation throughout the day,.

2.4.3 Finally the route is part of the Far North Line; this is one of the routes where there is likely to be a need to decarbonise rail without recourse to full electrification.

2.5 New Links

2.5.1 In addition, the operation of a battery train service will allow an enhancement in service frequencies between Wick and Thurso above the current four trains per day in each direction. This will provide greater opportunities for rail to be used for local trip making. It will also help to contribute towards the decarbonisation of transport by promoting mode shift from road to rail.

2.6 The Trains

2.6.1 Within this feasibility study we have specifically considered the impact of operating battery trains provided by Vivarail. These would be battery-only derivatives of their diesel powered Class 230 trains. Whilst these are the only battery-only units currently in production, it is likely that alternative vehicles, such as the Bombadier Electrostar, will soon make the transition from trial operation to production versions; this is likely to reduce the cost and improve the performance of battery technology in the medium term.

2.6.2 The Class 230 trains have been converted from former London Underground D Stock trains previously used on the District Line. Although the trains were originally built in the late 1970s/early 1980s the trains went through a major refurbishment programme in 2008 but were subsequently withdrawn earlier than originally anticipated in 2015, still with up to 25 years life left in the bodyshells and bogies.

2.6.3 Vivarail purchased the trains and have begun to rebuild them for a variety of uses. The first application was to add diesel engines and a generator to produce a small diesel-electric powered train. The first of these was introduced in passenger service on the Bedford – Bletchley line in 2019. The trains have been re-engineered to be modular allowing them to accept either a diesel generator pack or a battery pack; indeed, it is possible to operate hybrid trains with a mixture of battery and diesel power sources. The currently battery packs, at two per train, are estimated to be able to support trips of around 60 miles between charging, which can be achieved in ten-minute turn-arounds using the Fast Charge system. The energy density of battery operation provides a similar power-to-weight ratio to diesel power; the main difference is that the range is currently significantly shorter than diesel, by a factor of around 10.

2.6.4 The design of the rebuilt trains allows them to be maintained in a simple and modular way; major components being exchangeable using a fork lift truck, making the trains suitable for use at locations remote from main depots, with only limited facilities. This would have the additional benefit of supporting skilled employment locally; most maintenance tasks could be undertaken locally, and even major mechanical work can be undertaken by component exchange, meaning that it is likely the vehicles would only have to return to a major depot for a full refurbishment / C6 examination, at around 7-year intervals.

2.6.5 Although originally designed for high density metro services the trains can be internally reconfigured to meet the requirements of operators with high or low density arrangements.

2.7 Battery Charging Facilities

2.7.1 To support battery operation Vivarail have also developed battery charging equipment. Notably a Fast Charge system has been developed, with a battery bank which can be "trickle charged" continuously providing a full charge (i.e. to 80% of maximum capacity) within 10 minutes, helping to improve the viability of battery operation by allowing recharging during the normal turnaround times of services.

2.7.2 The Fast Charge equipment operates by having a series of batteries permanently attached to a 415v three phase supply that are being "trickle" fed to allow them to charge over a long period of time. When a train requires charging it sits over a charging rail which only becomes live when a train is present. The train then drains the shore supply within ten minutes allowing the train to depart. We are advised that maximum battery life can be achieved by charging to a maximum of 80% of full capacity, and not drawing currently below 20% of remaining capacity; this fits the proposed usage profile for the Wick-Thurso service perfectly.

2.7.3 Within the sections below we consider how a battery train operation might be developed on the route between Thurso and Wick.

3. SPECIFYING THE SERVICE

3.1.1 To help develop the feasibility study we have defined a specification of the service, rolling stock and operational issues associated with the service which we will then address in the following sections.

3.2 The Train

3.2.1 For the purpose of this study, we have assumed that the train will be a two-vehicle train based on the existing Class 230 design and operating only on battery power.

3.2.2 In practise it may be prudent, if the service were introduced as a trial, to operate a hybrid train with three of the four traction modules supplied by battery, with the fourth supplied as a diesel unit. This would provide resilience against failures for a train operating in an isolated location without any other trains with the compatibility to rescue it in the event of train failure or requirement to work beyond its normal limits, although one of the benefits of the VivaRail design is that each car can operate independently, allowing a failed car to be rescued by the other car.

3.3 Train Maintenance

3.3.1 It has been assumed that the train would be based at Wick. This is already the traincrew base for services in the Far North and trains already stable overnight at Wick. In addition the station site at Wick has sufficient space to accommodate the battery charging and servicing facilities required for the train.

3.3.2 Alternative sites at Georgemas Jn and Thurso were considered, but the location of the train crew base and space to stable make Wick the most suitable location.

3.3.3 Based on engagement with Vivarail it has also been assumed that the train will be permanently based at Wick, with day to day maintenance conducted by the existing Wick-based ScotRail rolling stock fitter and heavy maintenance and component exchange (bogie, batteries etc) also conducted on site using local contractors sub-contracted by Vivarail if required.

3.3.4 Notionally the home depot for the train will be the ScotRail depot at Inverness, which could hold major spare parts for the train; in practice, during a trial it would probably be better for VivaRail to remain responsible for exchange components such as batteries and bogies, with "consumable" spares for routine maintenance held in Wick.

3.3.5 The train would require a dedicated maintenance siding at Wick (for which space is available), on which a maintenance pit would be needed. This would allow all routine maintenance, including brake block replacement, to be conducted on site.

3.4 The Service

3.4.1 We have assumed that only one train will be available to operate the service and as described above it will be based at Wick. The service will be designed to supplement and support the existing Far North Line services from Inverness to Thurso and Wick by providing an enhanced service frequency between Wick and Thurso. The services will be designed, as far as possible, to provide an improved service in the morning and late afternoon period as well as additional off peak services. In addition to this the option exists to provide additional services in the evening.

4. TIMETABLING, OPERATIONS AND PERFORMANCE

4.1.1 Within this chapter we develop a timetable to address the service specification within the context of the operational planning constraints of the route. and the impact that it might have on the performance of services on the Far North Line.

4.2 Timetable

4.2.1 SYSTRA has developed a Monday – Saturday timetable for the battery train to provide an enhanced service frequency between Wick and Thurso. This has been developed around the timings of existing ScotRail services between Wick and Thurso – it has been assumed there is little flexibility in the timings of existing services and therefore the proposed service has been timetabled to avoid conflicts.

4.2.2 The timetable was also based on information provided by Vivarail including the time required for the battery train to recharge (10 minutes) and its range (approximately 60 miles). The range of the train therefore means that a charging is required after each round trip as the journey to and from Thurso totals 41 miles.

4.2.3 As defined in the service specification a low- and a high-level scenario have been considered, with the high level scenario including the operation of evening services.

Timetable Planning Considerations

4.2.4 Although the northern section of the Far North Line sees a total of only eight passenger trains per day there are a number of limitations around the development of new services that have been incorporated into the planning of the proposed service.

4.2.5 These limitations include the following:

- The time taken for trains between Inverness and Wick (and vice versa) to complete the Georgemas Jn – Thurso – Georgemas Jn – Wick circuit which typically takes around 45 minutes
- The limitations imposed by having only one operational platform at each of Wick and Thurso stations meaning that care has to be taken to avoid trains being blocked in. This is compounded by the Dock Line Siding and Ground Frame at Thurso being out of use at the current time preventing trains from being shunted. The equivalent siding at Wick would be reinstated as part of the infrastructure requirements for the battery train
- Permissive working is not currently permitted at Thurso station meaning that it is not possible to bring a train into the platform if one is already occupying the platform
- The layout of Georgemas Jn station means that it is not possible to cross trains running between Wick and Thurso.

4.2.6 These constraints mean that care has to be given to developing a viable timetable that is also attractive to potential passengers. To assist in timetable development we have made three assumptions that provide flexibility:

1. That permissive working is allowed at Thurso station, as it currently is at Wick.
2. That the currently disused platform siding at Wick is reinstated allowing the battery train to be recessed if required; this would in any case be required to provide stabling for the train
3. That full use can be made of permissive working at Georgemas Junction allowing a train from Wick to connect with services from Thurso or Inverness. This facility was formerly used regularly when Far North trains had separate Wick and Thurso portions which were joined/divided at Georgemas Jn.

4.3 The Proposed Timetable

4.3.1 Within the constraints identified above we have developed a timetable that provides the following additional services:

- Four additional return trips between Wick and Thurso during the day time
- The option of up to three additional return trips in the evening between Wick and Thurso
- Two return shuttle services between Wick and Georgemas Junction to provide connections into and out of Inverness – Thurso – Wick services

4.3.2 The table overleaf presents the proposed timetable, and shows how the additional services relate to the existing Far North Line service.

Figure 1. Indicative timetable and existing ScotRail services

Wick - Inverness	Wick	Dep	06:18	07:30	08:02	09:23	10:32	12:34	13:16	15:15	16:00	17:19	18:35	19:44	20:53
	Georgemas Jn	Arr	06:35	07:45	08:19	09:38	10:47	12:51	13:31	15:30	16:17	17:34	18:50	19:59	21:08
	Georgemas Jn	Dep	06:36	07:46	08:20	09:39		12:52	13:32	15:31	16:18		18:51	20:00	21:09
	Thurso	Arr	06:46	07:55	08:30	09:48		13:02	13:41	15:40	16:28		19:00	20:09	21:18
	Thurso	Dep	06:50		08:34			13:06			16:32				
	Georgemas Jn	Arr	07:00		08:44			13:16			16:42				
	Georgemas Jn	Dep	07:03		08:47			13:19			16:45				
Inverness - Wick	Georgemas Jn	Arr				10:45		14:10			17:36				22:06
	Georgemas Jn	Dep				10:49		14:14			17:40				22:10
	Thurso	Arr				10:59		14:24			17:50				22:20
	Thurso	Dep	08:44	09:53		11:02	13:46	14:27	16:45		17:53	19:05	20:14	21:23	22:23
	Georgemas Jn	Arr	08:52	10:01		11:12	13:54	14:37	16:53		18:03	19:13	20:22	21:31	22:33
	Georgemas Jn	Dep	08:53	10:02	10:50	11:14	13:55	14:39	16:54	17:42	18:05	19:14	20:23	21:32	22:35
	Wick	Arr	09:08	10:17	11:05	11:31	14:10	14:56	17:09	17:57	18:22	19:29	20:38	21:47	22:52

KEY
Existing service
Battery Train Low scenario
Battery Train High Scenario

Daytime Wick – Thurso Services

4.3.3 The proposed timetable provides an additional four return trips between Wick & Thurso, doubling the existing service.

4.3.4 The first two departures from Wick are designed to provide a more attractive service to Thurso for accessing work and college opportunities, with departures at 07:30 and 09:23 in addition to the existing departures at 06:18 and 08:02, doubling the morning-peak service frequency.

4.3.5 The 07:30 departure from Wick, on arrival at Thurso has to wait for around 50 minutes for the 08:02 Wick – Inverness to clear the Wick – Thurso – Georgemas Jn circuit. The knock on effect of this is that the second additional service does not depart from Wick until 09:23.

4.3.6 The other additional services provide two afternoon return trips departing from Wick at 13:16 and 15:15, departing Thurso at 13:46 and 16:45, filling in the current 3 hour 25 minutes gap in the southbound Far North Line service as well as gaps between the 11:31, 14:56 and 18:22 arrivals at Wick from Inverness.

4.3.7 To allow the afternoon services to operate there is need for the Battery Train to be recessed in the siding at Wick after arriving at 14:10. This then allows the 14:56 arrival from Inverness to enter the station before the battery train then emerges from the siding to form the 15:15 service to Thurso.

Evening Wick – Thurso Services

4.3.8 In our "high" service scenario we have included three additional services in each direction. This provides new links between Wick and Thurso, including giving Wick later departures than the current last train at 16:00; this has the benefit of providing a connection from the afternoon Scrabster – Stromness ferry.

4.3.9 Arguably such services could already be operated by the train arriving in Wick at 18:22.

Wick – Georgemas Jn Services

4.3.10 To improve the utilisation of the train we have also proposed two shuttle services linking Wick with Georgemas Jn, in both cases providing connections into northbound Inverness – Thurso – Wick services. These services would have two purposes:

- They provide services from Wick to Thurso by interchange at times when a through service is not possible due to the presence of Far North Line trains
- They provide an option for passengers from the south, heading to Wick to have a same platform interchange, reducing their journey times by 25 minutes

4.3.11 These shuttle services represent a useful compromise by providing additional services at times when the route is capacity constrained.

Additional Non-timetabled Services

4.3.12 In addition to the services described above having an additional train located at Wick may have additional benefits at times of service perturbation. For example if an Inverness – Wick service was running significantly late then the battery train could be used to shuttle passengers to Georgemas Jn to meet the delayed incoming train allowing its southbound journey to depart on time. Given the scope for poor performance and reactionary delay implied by a single line route which is increasingly busy at its southern end, this would represent an opportunity to help improve performance on the route.

4.4 Performance Impacts

4.4.1 As part of this study we have considered what the impacts on performance of a new service between Wick and Thurso might be.

4.4.2 To address this we have drawn on Network Rail *Historic Delay Data* for the year up to April 2019 (the latest available data). Looking specifically at service group *HA04 – Highland Rural* which includes Far North Line services. Whilst on other parts of the network the introduction of new services might be expected to impact negatively on the punctuality of services, notably where capacity is constrained. However the route between Wick and Thurso is relatively isolated from the rest of the rest of the network, with an existing service formed of only four trains per day.

4.4.3 The addition of a new service is, assuming that the service is carefully planned unlikely to make performance substantially worse.

4.4.4 We have used the Historic Delay Data to make a comparison of existing punctuality and reliability of services on the route between Thurso and Wick and compared this with punctuality across all Far North Line services.

4.4.5 The delay data is an extremely rich dataset and allows an analysis of the locations that delays occur at, as well as an assessment of the causes of delays. The table below presents the an estimate of the number of the level of performance on the Far North Line and on the Wick – Thurso route, based on the number of services that incur a primary delay I.e. Those services which either cause an incident directly (e.g. a train failure) or are impacted directly by an infrastructure issue (e.g. a track fault). We have also included cancellations in these figures as the dataset applies an assumed number of minutes to cancellations, making them comparable with delays.

Table 1. Far North Line Service Performance 2018-19

	FAR NORTH	WICK – THURSO
Total Delay Incidents	2818	304
Sub 10 min incidents	861	191
Over 10 min incidents	1957	113
Total Trains Operated per Annum	6188	2,600
% Services less than 10 minutes late	68%	96%

4.4.6 It can be seen that if the Wick – Thurso portion of Far North Line services are taken in isolation, then 96% of trains operate within ten minutes of right time. In contrast the Far North Line as a whole achieves a figure of only 68%. This demonstrates the relative immunity of the Wick – Thurso Line to delays relative to the rest of the route.

4.4.7 We have given consideration to what the impact *might* be on overall Far North Line performance if the levels of primary delay on the Wick – Thurso section were maintained at their current level. This is plausible IF it is assumed the train crew resources for the service are suitable and therefore that train crew shortages are no worse than at present AND it is assumed that battery services are no less reliable than the existing Class 158 units in use on the line. At the present time the reliability of the battery train itself is unknown. The sister Class 230 units introduced on the Bedford – Bletchley route have not fully settled into traffic and are still suffering teething difficulties. The battery powered version of the train will however have fewer points of failure as there will be no engine and generator sets with a battery likely to be much more reliable.

4.4.8 The new battery train service would add up to 5,616 services per annum to the Far North Line, in addition to the current 6,188 services. Assuming the 96% level of reliability on the Thurso – Wick section, then the average performance of the route as whole would rise to 81% from the current value of around 70%.

5. INFRASTRUCTURE REQUIREMENTS

5.1.1 The operation of a battery train will require investment in infrastructure on the Thurso – Wick route to accommodate a train that will be semi-permanently based on the route, and provide a mechanism for battery charging to take place and also to provide the capacity required to deliver the service. These include signalling, infrastructure and charging facilities.

5.2 Signalling Enhancements

5.2.1 To provide additional flexibility to allow the proposed service to operate there will be a need to amendment the signalling regulations in the area to allow “permissive working” at Thurso station. This would allow two trains to be present at once in Thurso station and thus allow services to be “stacked” in the platform. This would, for example, allow the battery train to arrive and terminate from Wick, then allow a service from Inverness to arrive in the station in the same platform before departing to Wick.

5.2.2 Provision of permissive working should in principle be straightforward, although it may require amendments to the RETB system. The precedent for its use has however been set at Wick where it is required each day to accommodate the two separate arrivals that stable overnight at the station.

5.3 Permanent Way Infrastructure

5.3.1 It is planned that the battery train would be permanently based at Wick with only very occasional visits to larger depots for classified overhaul. As such some additional facilities will be required at Wick to accommodate the train; at a minimum, this would require the reopening of the currently out of use siding adjacent to the platform at Wick and the development of a separate maintenance siding with an inspection pit.

5.3.2 The land to develop such a siding is currently available as much of the former goods yard area at Wick is still in railway ownership, although construction may require the removal of a number of loading banks located in the yard.

5.3.3 The specific infrastructure required would be as follows:

- Reinstatement of existing siding
- Construction of new short siding of around 40m length
- Hard standing to both sides of the siding to allow fork lifts and lorries to access the trains
- Inspection pit within the siding to allow access to bogies and other underfloor equipment
- Adjacent building to accommodate spare parts and provide staff accommodation
- Access road from Bankhead to the new siding

5.3.4 Engagement with Vivarail suggests that this type of accommodation could be provided for around **£200,000**.

5.4 Charging Equipment

5.4.1 The battery train requires access to charging facilities after each round trip to Thurso. In addition to this accommodation will be required for the quick charging system.

5.4.2 It is suggested that a minimum of two sets of charging equipment are located at Wick station. The first of these will be located around 50m from the buffer stops at Wick to allow the battery train to be charged with one Class 158 in the station. The second charging point would be located on the currently disused siding adjacent to the platform line, allowing the train to charge when the platform line is either fully occupied or otherwise unavailable. Based on the current timetable this only occurs at night when two trains are stabled at Wick.

5.4.3 The use of fourth-rail technology for charging on a segregated part of the platform, with the rails only energised when the train is actually on charge at the station, means that additional public safety risks are very low. To avoid any issues around staff safety, it is not recommend that a charging point is located on the maintenance siding.

5.4.4 The exact location of the charging equipment may be dependent on the location of a suitable three phase electricity supply. Based on the proposed locations of the charging points we suggest that it may best to locate the charging equipment close to the maintenance facility and provide a feed to the two charging points around the station, whilst keeping the equipment accessible.

5.4.5 This solution would also be suitable if a trial was to be conducted as the charging equipment could be located on an HGV trailer on a temporary basis.

5.4.6 To provide the charging equipment including two sections of charging rail Vivarail have estimated costs at around **£500,000**. This investment would however potentially have a significant residual value as the charging equipment could be used elsewhere if necessary, potentially for non-rail use as an energy store. Vivarail believes that energy storage can be progressively enhance by the recycling of life-expired traction values into lower-density energy storage use over time.

6. PROCUREMENT OF ZERO-EMISSION ROLLING STOCK

Bombardier's Electrostar IPEMU battery unit

6.1.1 There are a growing number of alternative-fuelled vehicles suitable for the proposed service between Wick and Thurso currently available, including hydrogen-powered stock, such as the Coradia iLint currently on test in Germany and the Classes 319 and 321 conversions in the UK. There are also a number of battery-powered vehicles available or in design, in addition to the Class 230 D78 tube-stock conversion from VivaRail described above, there are a range of other heavy and light rail options, including the Bombardier Electrostar conversion trialled by Anglia Railways and the CAF Urbos Tram currently being tested in the West Midlands. Further conversions of existing train types are currently at the design stage, including the Siemens Class 350 by Porterbrook Leasing and the newer CAF Class 331 by Eversholt. None of these vehicles are, however, currently ready for early trial use.

6.1.2 All the options outlined above have zero carbon emissions at the point of use, and are capable of delivering zero-carbon throughout the fuel cycle. The use of hydrogen trains or light rail vehicles would, however, require significant investment both in set-up costs for fuelling (hydrogen compression facilities and a catenary system respectively) and would also both be likely to require extensive safety approvals before unrestricted use on the route. The outline feasibility appraisal and costings below therefore focus on battery-train operation, with the Class 230 used as an example of the likely requirements, as this represents the most suitable heavy-rail vehicle currently available for use on secondary services.

6.1.3 There are two elements required for the trial; the rolling stock itself, and the charging facilities. The stock will require recharging at the end of each round trip; the physical requirements for charging at a suitable terminal platform are set out in Section 5. The equipment for this, including the shipping-container sized battery bank and control gear needed for trickle-charging with enough power to provide a rapid charge to the 230 on turn-round is supplied by VivaRail, and is therefore included as part of the rolling-stock supply in the procurement options outlined below. There will, of course, also be up-front costs for the physical installation of the system and the development and approval of a safe system of working, but these will be a relatively minor component of the overall costs of introduction for the new service.

6.1.4 The options for procurement of the stock for the trial, plus the charging system, initial spares and potentially a diesel power-pack for use vice one of the battery packs for self-move to depot, with some very high-level indicative costs, are outlined in Sections 6.2 to 6.4 below.

6.2 Capital purchase

6.2.1 The direct procurement of a two-car trainset has been quoted by VivaRail at around £2.85m; it is likely that this would rise to significantly more that £3.5m with the additional elements outlined above included. As the maintenance requirements for battery-electric vehicles are significantly lower than equivalent diesel-powered stock, and the conversion of the Class 230 from the D78 stock has been designed to facilitate component exchange, there is relatively little risk, and significant cost- and local economic-benefits, from developing a local maintenance capability, in cutting-out a rail-industry intermediary, such as a Rolling Stock Leasing Company (ROSCO), as owner.

6.2.2 There are, however, two key issues to consider; most importantly, capital funding must be available, either as a grant or from a wider funding stream. Secondly, a purchase will mean that the risk of the residual value realisable at the end of the train's operational life on the route will rest entirely with the funder; this would mean that disposal is likely to be into a "buyers' market", reducing value. Despite this, capital purchase is likely to be the best option, both for minimising overall cost and maximising flexibility of use, if a source of funds can be identified to cover at least the likely 7-year period to the first overhaul, when further major costs will be incurred through bogie overhaul and battery replacement.

6.3 Finance lease

6.3.1 A finance lease will replicate the benefits outlined above from capital funding, but will allow the costs to be spread over the lease period, reducing the up-front cost of the scheme but requiring interest and contract-management payments, likely to be between £5-10 per £100 per year on top of the capital repayments over the life of the lease. The overall annual lease costs could be reduced further by agreeing a residual value at lease-end before the start, but this would probably have to be based on scrap value unless any guaranteed life remained in the batteries.

6.3.2 A finance lease is likely to be more expensive over the life-cycle than capital purchase, for the reasons outlined above, and should therefore only be considered if the funding available for the trial is on annual rather than one-off basis.

6.4 Operating lease

6.4.1 The final option would be to lease the train for a shorter period on an operational lease from a ROSCO. This would cover not only the financing costs, but also the maintenance requirements for the period of the lease, including component exchange with the possibility of provision of alternative stock during planned or unplanned interventions. At present, this option is likely to represent the worst value-for-money of the three possibilities; this would only change significantly if other operators start to use this stock in battery-train mode and a market develops for second (third?)-hand vehicles and components, meaning that the lessor sees a "bankable" residual value in the asset. This is unlikely to develop in the short term, despite growing interest in the provision of battery-powered "final mile" capability both in the UK and overseas.

6.4.2 It is therefore recommended that, if capital funding is available for the trial, the vehicles should be purchased outright to minimise financing cost and contractual issues. If a lease is required to cover all or part of the costs over the life of the train, it is recommended that further engagement with VivaRail or a ROSCO such as Porterbrook is made; battery technology for rail is now starting to catch-up with the major developments seen in the automotive sector of the past few years, and it is likely that economies of scale and greater competition will see prices fall significantly in the short to medium term.

7. ENVIRONMENTAL IMPACTS

To assess the environmental impacts of the service, SYSTRA has considered both greenhouse gas and air quality impacts.

7.1 CO_2e emissions; Battery train

7.1.1 Although the battery-powered train would be likely to be powered by renewable energy sources generated in Caithness with zero emissions, for comparison purposed SYSTRA has estimated the total emissions using the internationally-accepted measure of Carbon Dioxide equivalent, CO_2e (covering emissions of several greenhouse gases and generating an overall figure based on the global warming potential) as if the train were to be powered by the current energy mix provided by the Scottish grid.

7.1.2 To estimate these CO_2e emissions, electricity consumption for the vehicle was calculated using information provided by Vivarail (approximately 4.39 kWh per km which equates to 280 kWh per round trip). Next, the average grid emissions (CO_2e / kWh) were acquired from the Scottish Government's *Energy Statistics Database.* The latest available figures were for 2017 at 24 g CO_2e / kWh. The table below shows the total emissions per day for both the high and low scenarios.

Table 2. CO_2e emissions per day – battery train

	EMISSIONS KG (LOW SCENARIO)	EMISSIONS KG (HIGH SCENARIO)
Scottish grid (CO_2e)	38	59

7.2 CO2e emissions; Class 158 diesel train

7.2.1 The AEA *Rail Emissions Model* report (2001) was used to acquire the emissions for a Class 158 train. This document estimates that the vehicle emits 2,793 grams of CO_2 per km.

7.2.2 However, it should be noted that the *Rail Emissions Model* only provided an estimate of CO_2 alone and not CO_2e. The breakdown of the emissions given in the *Rail Emissions Model* was not sufficient to calculate CO2e and therefore benchmarking was undertaken using assumptions from the TAG databook.

7.2.3 The TAG calculations used the fuel consumption of a Class 158 vehicle which was acquired from the *Rail Emissions Model* (0.89 kg gas oil per km) and a value of kg CO_2e per litre for rail diesel. The 2017 emissions value was used from the TAG databook to align with the latest available Scottish energy statistics. The table below shows the CO_2 / CO_2e emissions for both methods.

Table 3. CO_2 emissions per day – diesel train

	EMISSIONS KG (LOW SCENARIO)	EMISSIONS KG (HIGH SCENARIO)
Rail emissions model (CO_2)	1,003	1,565
TAG (CO_2e)	1,010	1,540

7.2.4 As can be seen in the table above, the CO_2 estimates generated from the *Rail Emissions Model* and the CO_2e measurements calculated using the TAG databook are similar. Therefore, the 2017 values from the TAG databook have been used, as these account for all greenhouse gases and the date aligns with the Scottish grid data used to calculate the CO_2e emissions for the battery train.

7.3 CO2e emissions; Car trips

7.3.1 In addition to calculating the greenhouse gas emissions of a battery powered train and a diesel train, SYSTRA has also considered the emissions generated from car trips. This has been completed to determine the number of car journeys that would need to transfer to rail to displace the greenhouse gas impact of the train service.

7.3.2 Fuel consumption parameters and fuel type proportions (for diesel, petrol and electric vehicles) were taken from the TAG databook for 2017. CO_2e emissions for 2017 were then also acquired from the TAG databook and combined with the fuel consumption information and trip length (32.8 km) to determine the average emissions for a single trip (4.517 kg CO_2e per single trip). The table below shows how many car trips would need to transfer in each option.

Table 4. Number of car trips needed to transfer per day

	EMISSIONS KG (LOW SCENARIO)	EMISSIONS KG (HIGH SCENARIO)
Battery train	8	13
Diesel train	224	341

7.3.3 The table demonstrates how effective a battery train would be at reducing carbon emissions in rural area. Even in a high timetable scenario the service would need only **13 car trips** to move to rail for the service to “break even” in terms of reducing carbon. This contrasts to **341 car trips** for the equivalent diesel service, a figure which would not realistically be achievable. This shows the overall potential that the battery and electrically powered trains have for sustainable mode shift from car.

7.3.4 The table above shows that the battery train would need to replace a relatively small number of vehicle trips each day in order to have a CO_2e benefit. For both scenarios, less than one passenger is required to transfer from car to rail for each service throughout the day.

7.3.5 In comparison, for an equivalent diesel service, far more passengers would need to transfer from car in order to have a neutral impact on CO_2e emissions. Approximately 19 passengers would need to switch from car on each service.

7.4 Air pollutant emissions; Battery train

7.4.1 The energy consumption referenced in paragraph 7.1.2 was also used as the basis for calculating air pollutant emission, however estimates of air pollutant emissions were not provided within the *Energy Statistics Database* as with CO_2e. Therefore, SYSTRA has made assumptions based on the energy production mix in Scotland and data available on pollutant emissions from various forms of electricity generation.

7.4.2 First, electricity generation by fuel type percentages were acquired for 2017 from the *Energy Statistics Database.* Next, for the energy sources which emit air pollutants, estimated emission factors were calculated for each fuel type using the European Environment Agency's *1.A.1 Energy industries* report (2016). Air pollutants were only acquired where an equivalent or similar air pollutant emission factor was available from the *Rail Emissions Model.* The average emissions calculated per kWh of electricity are given in the table below.

Table 5. Average air pollutant emissions per kWh based on Scottish energy production

	SO_X	VOCs	CO	PM_{10}	NO_X
g / kWh	0.033	0.002	0.031	0.033	0.054

7.4.3 The table below shows the estimated air pollutant emissions per day of operation for the battery powered train.

Table 6. Emissions per day – battery powered train

	EMISSIONS (KG / DAY)				
	SO_X	VOCs	CO	PM_{10}	NO_X
Low scenario	0.05	0.00	0.05	0.05	0.08
High scenario	0.08	0.01	0.08	0.08	0.13

7.5 Air pollutant emissions; Diesel train

7.5.1 Air pollutant emissions for a Class 158 diesel train were given in the *Rail Emission Model* report and are shown in the table below. It should be noted that the *Rail Emission model* provided an estimate of SO_2 and not SO_x and is therefore not directly comparable to the results for the battery powered train.

Table 7. Average air pollutant emissions per kWh based on Scottish energy production

	SO_2	VOCs	CO	PM_{10}	NO_X
g / km	3.6	2.7	2.8	0.9	28.4

7.5.2 The table below shows the estimated air pollutant emissions per day of operation for the diesel train.

Table 8. Emissions per day – diesel train

	EMISSIONS (KG / DAY)				
	SO_X	VOCs	CO	PM_{10}	NO_X
Low scenario	1.29	0.97	1.01	0.32	10.2
High scenario	2.02	1.51	1.57	0.5	15.91

7.6 Appraisal of emissions impacts

7.6.1 In order to appraise the impacts of operating a battery-powered train as opposed to a Class 158 diesel train the greenhouse gas and air pollutant emissions first had to be annualised. An annualisation factor of 312 was assumed; the results of this are shown in the table below.

Table 9. Emissions (kg) – Low scenario

	CO_2e	SO_X*	VOCs	CO	PM_{10}	NO_X
Diesel train	315,112	404	303	314	94	3,184
Battery train	11,793	16	1	15	15	26

Table 10. Emissions (kg) – High scenario

	CO_2e	SO_X*	VOCs	CO	PM_{10}	NO_X
Diesel train	480,517	629	472	489	146	4,964
Battery train	18,389	25	2	24	23	41

*SO_X refers to SO_2 for the diesel train as this was the only information available from the *Rail Emissions Model*

7.6.2 It should be noted that a battery train run on 100% renewable energy from Wick would have no CO_2 emissions impact whilst operating.

7.6.3 Following annualisation, the emissions impacts were appraised using TAG worksheets. As a lot of the data used in the analysis was based on information available for a single year (e.g. 2017 for the Scottish Grid CO_2e emissions) it has been assumed that the calculated emissions savings would remain constant over a 5-year appraisal period.

7.6.4 The greenhouse gas impacts were valued using the TAG *greenhouse gases workbook.* The workbook uses inputs of CO_2e per year for the with and without scheme scenarios and produces a net present value of CO_2e emissions.

7.6.5 The impacts of air pollutants were then valued using the TAG *Air Pollutant Valuation* workbook. The workbook uses inputs of NO_x and PM10 emissions and calculates a monetised impact as well as the number of life years lost or saved.

7.6.6 The tables below present two sets of comparisons over a 5 year period. The first set of results compares a diesel train with a battery train powered by an average Scottish grid energy mix and the second compares a diesel train with a battery train powered by renewable energy sources at Wick.

Table 11. Emissions saving comparison – Scottish grid energy mix

	HIGH SCENARIO	LOW SCENARIO
NOx Saving	£44,279	£28,178
PM10 Saving	£21,508	£11,589
CO2e Saving	£101,211	£64,906
TOTAL	£145,489	£93,083

Table 12. Emissions saving comparison – 100% renewable

	HIGH SCENARIO	LOW SCENARIO
NOx Saving	£44,305	£28,381
PM10 Saving	£21,521	£13,253
CO2e Saving	£105,172	£67,446
TOTAL	£149,477	£95,827

7.6.7 The table above shows that the battery train powered by renewables and a battery train powered by the Scottish grid would have a similar impact in terms of the monetary value of emissions and both would generate benefits in comparison to a diesel vehicle.

8. COSTS

8.1.1 We have estimated both operating and capital costs for the proposed battery train service covering both the low and high timetable scenario, and have also estimated costs for a counterfactual option using a Class 158 diesel train.

8.2 Operating costs

8.2.1 Operating costs for both trains were derived from the SYSTRA Rail Operating Costs Model. These costs account for fuel, variable track access charge, maintenance and staff. For the battery train the fuel cost was calculated based on WebTAG values and fuel consumption parameters previously calculated in the emissions assessment. The total costs are given in the table below.

Table 13. Operating Costs(Per annum)

	DIESEL		BATTERY	
	HIGH	LOW	HIGH	LOW
Variable Costs	£124,488	£79,872	£88,608	£56,784
Trains Crew	£243,048	£164,424	£243,048	£164,424
Maintenance	£75,504	£48,360	£50,544	£32,448
TOTAL	**£443,040**	**£292,656**	**£382,200**	**£253,656**

8.2.2 The table shows that the battery train would have lower operating costs than the equivalent diesel train, with both low maintenance and fuel costs contributing to this. This demonstrates that the train would have a role not just in reducing carbon emissions but also in improving the economics of rural rail services which require subsidy.

8.3 Lease costs

8.3.1 Leasing of the battery train has been discussed in section 6. More details will need to be finalised before an accurate estimate of the lease can be determined. However, the table below presents an estimate of leasing costs assuming both a 7 year lease period and a 15 year lease period. An estimated lease cost of £250,000 per year for a class 158 diesel train has been included for comparison

Table 14. Lease costs

	BATTERY TRAIN		CLASS 158 DIESEL TRAIN	
	7 YEAR LEASE	15 YEAR LEASE	7 YEAR LEASE	15 YEAR LEASE
Capital cost	£2.83m	£2.83m		
Monthly lease cost	£40,469	£19,810	£20,833	£20,833
Annual lease cost	£485,628	£237,720	£250,000	£250,000
Total lease cost	£3.4m	£3.57m	£1.75m	£3.75m

8.3.2 The table above shows that the monthly lease cost for a battery train over 7 years is approximately £40,000. The monthly cost to lease a battery train for 15 years or a diesel train for 7 years is approximately half of this. However, the total lease cost for both battery train options is similar but these are more than double the estimated total lease cost for a "second-hand" diesel train.

8.3.3 Whilst this finding represents a practical issue for the short term development of the service as train leasing costs are high relative to existing diesel trains, it should be recognised that battery train costs are likely to be similar to those of a new diesel train, particularly as DMU residual values are now uncertain beyond 2040 due to the rail networks carbon reduction targets.

8.4 Summary

8.4.1 It can be seen that the battery train has the potential to reduce the day to day operating costs of rural railways relative to diesel train, helping to both improve the financial and environmental performance of rural railways. Within the context of a climate emergency there may an opportunity to reduce the operating costs of rural routes and use the reduction in subsidy to find ways of making rail more attractive to road users, either through improvements in service quality or reductions in fares.

8.4.2 The issue of capital costs is more complex, as the Class 230 reference vehicle used for the battery train comparison has a shorter forecast life than an equivalent new train, and no market data is yet available on residual-cost values for battery technology. The impact of this is that its capital costs, if leased, would have to be recovered over a shorter period of time, with a base-assumption of no residual value. This suggests that the calculations in the study are likely to represent a worst-case scenario; in the long run, as the technology becomes established and a residual value can be applied, new trains with a 40-year life and residual value based on flexible re-use would be likely to yield a lower lease cost.

9. ALTERNATIVE ENERGY STUDY FOR RÉGION PAC

9.1.1 SYSTRA has previously undertaken a study to compare alternatives to diesel operation in the Provence-Alpes- Côte d'Azur (PAC) region in the South of France. The study examined two lines:

- Marseille – Aix en Provence
- Nice – Plan du Var

9.1.2 The aim of the study was to explore alternatives to conventional overhead catenary electrification in light of the maintenance and investment costs of this form of electrification. A study had previously been undertaken (in 2013) to examine electrification of the Nice – Plan du Var line however this project was abandoned due to cost and funding issues. The aim of this project was also to consider the environmental impacts of alternative solutions.

9.1.3 As part of this study, four alternatives to overhead electrification were considered as listed below:

- Electric hybrid
- Battery train
- Hydrogen fuel cell
- Natural gas

9.1.4 A comprehensive assessment of the feasibility of each option for both lines was undertaken. This assessment considered:

- Rolling stock acquisition and maintenance
- Infrastructure and equipment required (depots, storage centres and linear infrastructure)
- Operational feasibility including safety
- Environmental impact

9.1.5 Whilst the study concluded that in the long run the best solution would still be overhead electrification, the use of a battery train represented the most realistic and sustainable option in the short to medium term. The use of hydrogen was felt to be impractical based on current technologies, whilst alternatives such as natural gas would still generate carbon emissions. A feature of the proposed battery operation was that it involved recharging of the train on route, using short sections of electrified line. Due to the journey length, however, full charges for the train were still required at each end of the route, incurring a time penalty against other power sources.

9.1.6 It is encouraging that a battery train is seen as the best alternative to either or overhead electric operation. The main difference between this and the option considered in this study is that the quick charging equipment had not been assumed, meaning that additional time would be required for charging, reducing stock utilisation significantly.

9.1.7 The study concluded that overhead line electrification was the best solution in the long-term but a battery solution is a good alternative in the short-term particularly in comparison to Hydrogen.

10. CONCLUSIONS

10.1.1 This report has considered the issues surrounding the introduction of a battery train service between Thurso and Wick. The operation of such a service would provide the opportunity to use trains supplied by VivaRail to provide practical experience of using a technology that is likely to have some role in the operation of the rural rail services in a zero carbon environment, whilst also improving connectivity in Caithness.

10.1.2 There are number of strengths and weaknesses of these proposals which we summarise below:

10.2 Strengths

10.2.1 The proposal has a number of strengths including the following:

- The potential for genuinely zero carbon emissions through the use of 100% renewable electricity.
- The service would need only 13 passengers per day abstracted from car before it made a positive contribution to carbon emissions, even if running on the current Scottish Grid mix of electricity.
- Battery trains have a lower day to day operating cost than the equivalent diesel trains, potentially improving the viability of rural services more generally
- The route being considered is relatively isolated from the rest of the rail network making it suitable to test new modes of operation
- Local economic activity will be supported by train maintenance being undertaken in Wick rather than Inverness.

10.3 Weaknesses

10.3.1 The proposal does however have number of weaknesses:

- The service has significant set up costs to provide maintenance and charging infrastructure at Wick
- The capital / leasing costs of the train are high, both the high purchase cost of the train and charging equipment and the relatively short lifespan of the Class 230 train used as a reference vehicle, meaning its costs have to be recovered over a shorter period of use.

10.4 Recommendation

10.4.1 Based on the above we recommend that if a Thurso – Wick battery train is to be pursued then it should be done so on the basis of acting as proof-of-concept with a view to battery technology having a wider role across railways in Scotland, treating the investment required as a research and development exercise, albeit one with significant benefits to the economy and environment in Caithness.

10.4.2 A trial of this relatively proven technology could also be considered for routes with higher ridership potential, e.g. new local services around Inverness, and / or the proposed Park and Ride service between Oban and Dalmally, on the same basis as the Wick-Thurso trial.

10.5 Next Steps

In the longer-term, the battery train concept has the potential to act as a zero-emission (at point of use) "bridge" between the current diesel operations and the electrification of the Highland rail network. A key enabler for this would be discontinuous electrification, where relatively short stretches of overhead (or third rail) power lines provide sufficient current for electric train operation whilst charging the train's batteries for autonomous operation on unwired sections.

This method of operation is especially suited to an extension of battery train operation to the Highland Main Line, as outlined below;

- The route has long sections of track with steep gradients, where electric traction would provide significant performance benefits
- There are long sections with very few overbridges or other structures, minimising capital costs for overhead electrification
- The southern sections of the route are already electrified, further reducing up-front costs
- The Siemens class 350 units would be a significant upgrade from current rolling stock on the route

The Inverness station area could be electrified at relatively low cost if the proposed refurbishment goes ahead; this would support the extension of discontinuous electrification to the Far North and Kyle lines, allowing the proposed battery train trial between Wick and Thurso to be extended to progressively provide all-electric operation of all services north of Inverness.

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