TRANSPORT SCOTLAND
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Rail Services Decarbonisation Action Plan

Transport Scotland

Contents

1. Ministerial foreword

The global climate emergency is an existential issue. Although this action plan comes as Scotland and other nations take immediate action to protect lives in response to the coronavirus (COVID-19) health pandemic, the effects of climate change have not gone away. That is why this Rail Services Decarbonisation Action Plan is being published, to build on our substantial efforts to reduce emissions in transport, while helping contribute to a green economic recovery following the health pandemic. In Scotland, we have ground-breaking, legally-binding climate change targets. Meeting these targets requires ambitious actions and difficult decisions. We have to do things differently now as we enter an unprecedented period of change. This requires courage, commitment, and collaboration.

Michael Matheson MSP
Cabinet Secretary for Transport, Infrastructure and Connectivity

Transport is a significant contributor of greenhouse gas emissions, but within the transport mix, Scotland's railway is a success story, with around 76% of passenger and 45% of freight journeys already on electric traction. We must build on this success by converting more passenger and freight journeys to this environmentally sustainable mode, a key element of our new National Transport Strategy. Through investment in electrification and complementary traction systems we will decarbonise the traction element of domestic daytime passenger rail journeys in Scotland. It also demonstrates our approach to investment in green technologies and our commitment to creating a greener, more environmentally just economy with growth in greener, more sustainable sectors.

This plan builds on our substantial recent electrification programme and since the recent devolution – at my request - of Network Rail's planning and development functions to Scotland, I am pleased that Network Rail, after a two year hiatus, is now re-focused on a rolling programme of electrification. New dynamic management directly aligned to Scottish Government priorities is now making a positive difference.

Electrification has many benefits ranging from faster journey times for passengers and freight, improving connectivity between our cities, and creating additional capacity, to lowering industry operating costs, helping to meet our environmental targets, and improving air quality. All of these benefits will support modal shift from private vehicles and heavy goods vehicles to rail increasing the operational, societal, environmental, and economic benefits. Our vision is for Scotland to have the best air quality in Europe with our transport system contributing to make this happen.

I am proud to present our decarbonisation action plan for Scotland's railway network. This plan is designed to be dynamic and flexible and, as such, will evolve over time. We commit to regular updates and to engage with interested parties in pursuit of our shared objectives.

Michael Matheson MSP

2. Executive summary

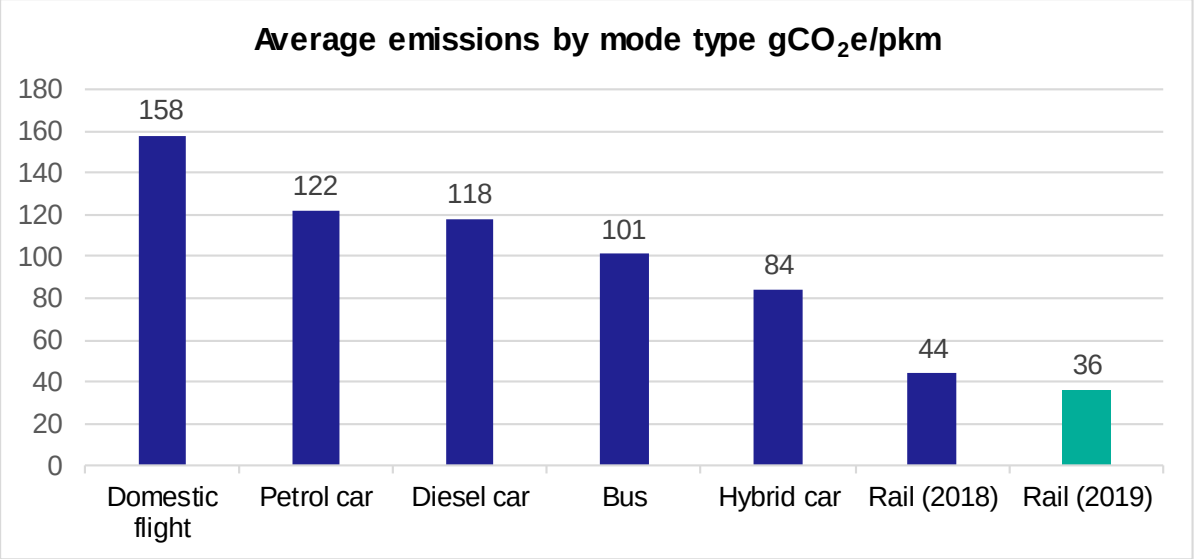
Broad context

Climate change is a global issue, addressing it is at the forefront of environmental public policy around the world. In Scotland, we have emissions reduction targets set in law to reach net-zero greenhouse gas emissions by 2045 with interim supporting targets. Following the COVID-19 health pandemic, the progression of a green and just economic recovery will be central to how the Scottish Government takes climate action, whilst also accelerating the drive to a fairer and more inclusive society. Therefore, reducing emissions across Scotland's transport system and taking economic action to harness a green recovery is essential.

Transport emissions

Rail is already a very low carbon form of transport for passengers and freight and in 2017 rail accounted for just 1.2% of all transport emissions in Scotland[1] and between 2012 and 2018 (UK) emissions per passenger kilometre fell by 24% for rail compared to 8% for petrol cars, 4% for diesel cars and 10% for buses.

The graph below shows emissions by mode type, per passenger kilometre (UK data).[2] Rail continues to improve and performs very well with average emissions of 36.6 gCO_2e per passenger kilometre in 2018-2019.



Average emissions by mode type (blue 2018, green 2019)

[1] https://www.transport.gov.scot/publication/carbon-account-for-transport-no-11-2019-edition/
[2] https://www.transport.gov.scot/publication/carbon-account-for-transport-no-10-2018-edition/5-efficiency-of-transport-modes/

Rail emissions

Rail traction is the single biggest source of rail carbon emissions; and the part of the industry where the greatest change is possible within our targets, provided that plans are agreed and steps taken immediately. Encouraging progress has been made to date and recently the Office of Rail and Road reported that in 2018-2019, whilst there had been increases in the amount of electricity consumed by passenger and freight trains, the resulting CO_2e emissions per passenger km and per tonne km had fallen, mainly due to a transition towards renewable energy sources in the electricity sector:

- passenger train emissions were 36.6 gCO_2e per passenger kilometre (a decrease of 10.3% compared to 2017-18)
- freight train emissions were 25.3 gCO_2e per tonne kilometre (a decrease of 4.1% compared to 2017-18)

Additionally, Scotland's National Transport Strategy[3] sets out the need to reduce travel by unsustainable modes and promote greener public transport. The benefits of faster journey times and improved connectivity that electrification can bring enable it to be a more attractive travel choice to prospective passengers.

The challenge

This action plan focusses on decarbonising transport through modal shift to rail, and decarbonising rail traction energy through the removal of diesel passenger trains from the Scottish network by 2035. As we take this forward we will:

- maximise all opportunities for modal shift to rail from private vehicles and heavy goods vehicles
- continue to provide reliable services
- optimise how we use our rolling stock creating more seats and services for passengers
- plan for a railway system where power use can be decarbonised efficiently

Our solution

The recent rail industry decarbonisation taskforce report[4] established that, alongside the electrification of the rail infrastructure (benefitting freight and passenger services), the two technologies that are likely to be sufficiently mature to make a significant decarbonisation impact (for passenger services) in the future are hydrogen and battery powered trains. Currently these are expensive and limited in power output and performance, but they are flexible and can be used independently,

[3] https://www.transport.gov.scot/media/47052/national-transport-strategy.pdf
[4] https://www.rssb.co.uk/Research-and-Technology/Sustainability/Decarbonisation

for some types of train service, in conjunction with discontinuous electrification, or as a valuable transition measure prior to the full electrification of a route.

This action plan sets out an initial, indicative programme of interventions which will secure benefits towards our climate change objectives, our local environmental objectives (including air quality) and for our rail network and rail users. We know that additional benefits will be realised through modal shift to rail as passengers and freight customers take advantage of the improved journey times and additional services secured through electrification. Wider greener economic benefits could also be realised and it was recently identified by the Committee on Climate Change[5] that a 5% shift in travel from cars to other modes (such as rail) would result in a monetised benefit of 0.5% of GDP in 2030.

Our plan builds on work undertaken as part of the Strategic Transport Projects Review 2 (which will inform transport investment in Scotland for the next 20 years)[6] together with a series of influencing factors or drivers and takes account of route characteristics (including diversionary routes), service types, city-connectivity, train fleet inter-working and fleet expiry dates, projects which are already in development, power requirements, technical capabilities of alternative technologies, supply chain capability, operational flexibility, and overall network impacts.

System complexity/plan delivery

Our railway is a complex system with many operational interactions and a successful, efficient decarbonisation programme can only be delivered if all its factors – route, rolling stock, power supply, structures and service operations – are recognised and addressed in an integrated manner. A detailed programme will be designed and delivered by a multi-disciplinary team establishing and maximising close working relationships across the industry.

Cost

This plan does not set out detailed cost information by route: that analysis has yet to be undertaken but as planning progresses and becomes more developed and comprehensive we will, in line with our financial appraisal process, produce thorough costs and benefits for routes, and projects, which in aggregate provide more certainty at the strategic plan level. Although the COVID-19 health pandemic has unavoidably led to a level of uncertainty in future government measures and associated investment, we will aim to maintain our previous level of commitment to rail investment. As with all long-term government action, spend in this area will be aligned with future Capital Spending Review and Infrastructure Investment Plan cycles.

The 2045 date aligns with the wider Scottish Government net-zero greenhouse gas emissions target date. With ambitions of such magnitude regarding rail

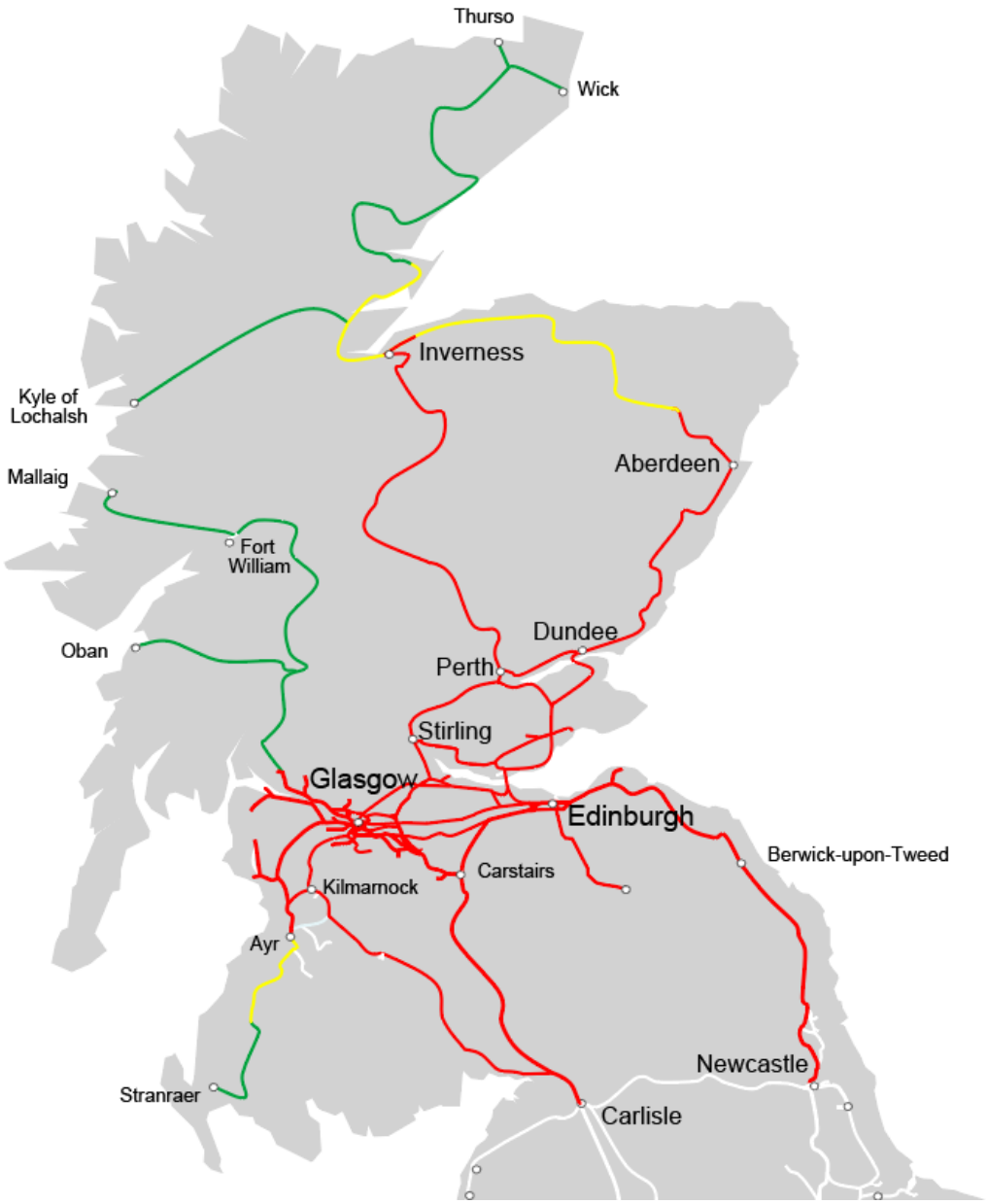
[5] https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf (page 240)
[6] https://www.transport.gov.scot/our-approach/strategy/strategic-transport-projects-review-2/

decarbonisation, it is imperative that there is a relentless focus on cost and delivery efficiency, and maximising benefits, allowing us to achieve more, sooner.

Plan updates

Our plan - shown on the following map - is dynamic and subject to continuous improvement; it will be updated and refined as necessary. We are determined to provide a high degree of investment certainty for the industry so that the supply chain can plan, recruit and make resources ready with confidence. In doing so we hope to achieve a constant work bank and engender confidence within the rail sector. Accordingly, we do not envisage our first review until spring 2023 and for that review to cover the next two five-yearly rail control periods, at which point we will also be able to identify and reflect the impacts of coronavirus (COVID-19) on emissions data across transport modes, given reporting cycles, and assess, hopefully, a post-COVID environment.

The plan: our decarbonised rail network in Scotland, 2035



Map of decarbonised rail network in Scotland, 2035

The maps in this document show the rail network in Scotland; as there are no rail lines on the islands they are not shown.

- Electrified network (some 1,616 kilometres (single track kilometres) to be electrified, sections of route could potentially include discontinuous electrification) and the electrification of some freight only lines may be subject to review
- Alternative traction - transition solution (e.g. partial electrification and/or the use of alternative technology prior to electrification)
- Alternative traction - permanent solution (i.e. the use of battery or alternative traction)

3. Background and introduction

Climate change

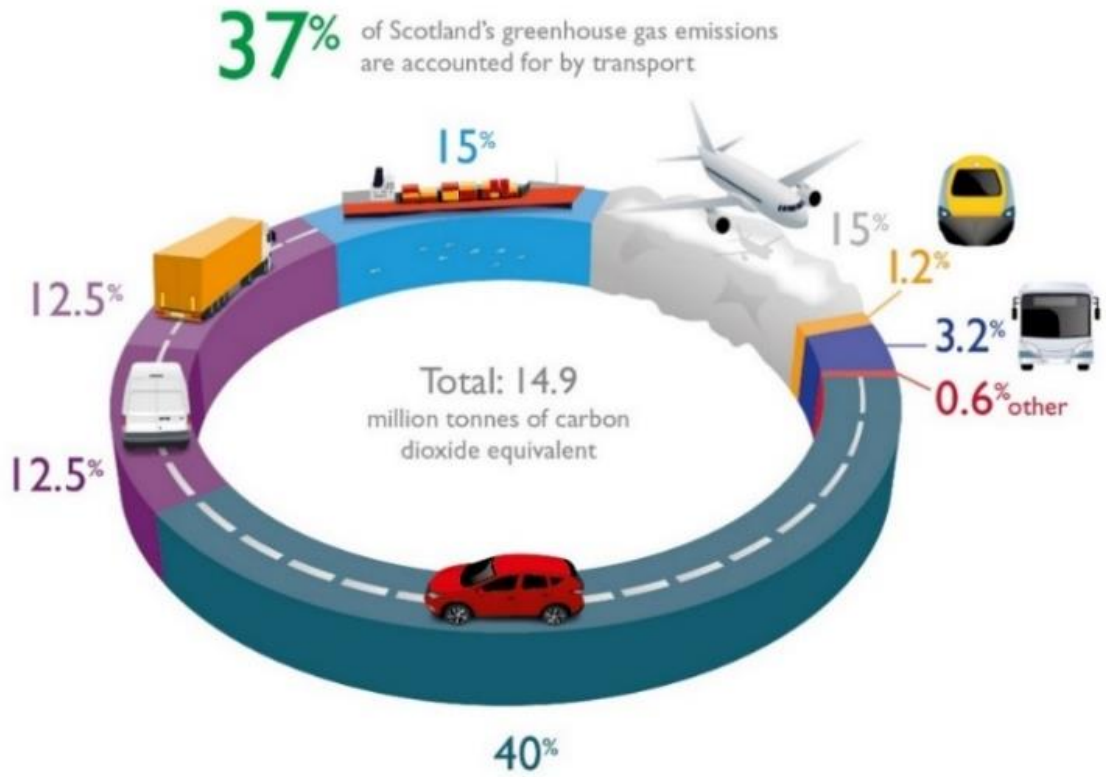
Climate change is a global issue, addressing it is at the forefront of environmental public policy around the world. In Scotland, our Climate Change (Emissions Reduction Targets) (Scotland) Act 2019[7] sets in law a target to reach net-zero greenhouse gas emissions by 2045 with interim emissions reduction targets to reach net-zero of: 56% in 2020, 75% in 2030 and 90% in 2040. Achieving these targets will be challenging, requiring different and, in many cases, more difficult choices than has been the case to date, including looking at how we travel.

For over a decade, the Scottish Government has had in place a policy of electrification of the rail network, recognising its environmental, operational, societal and economic benefits. The global climate emergency, challenging statutory emissions reduction targets, and our Programme for Government commitment on rail traction decarbonisation[8] have crystallised our thinking; this action plan is our response. While the Climate Change Plan update has been recast in light of the coronavirus (COVID-19) outbreak, with a later publication date and the dual role of helping enable a green economic recovery, the Scottish Government is fully committed to tackling the global climate emergency and to updating the plan to reflect our ambitious net zero targets.

Transport and greenhouse gas emissions

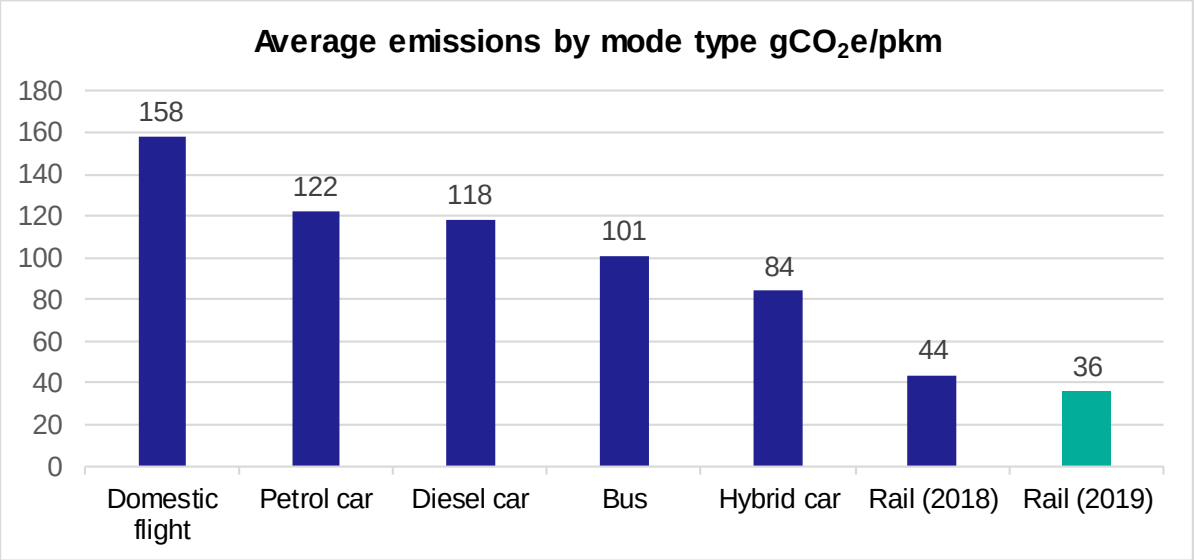
Transport is Scotland's biggest emitting sector and greenhouse gas emissions from transport have been rising. Reducing emissions from all parts of the transport system is therefore essential and is at the core of the National Transport Strategy[9] and our air quality ambitions. Rail is already a very low carbon form of transport, 1.2% of transport emissions in 2017[10] (for passengers, 1.0% and freight, 0.2%).

[7] http://www.legislation.gov.uk/asp/2019/15/enacted
[8] https://www.gov.scot/programme-for-government/
[9] https://www.transport.gov.scot/media/47052/national-transport-strategy.pdf
[10] https://www.transport.gov.scot/publication/carbon-account-for-transport-no-11-2019-edition/



Share of greenhouse gas emissions by mode in Scotland 2017

The graph below shows average transport emissions by mode type per passenger kilometre (UK data). The figures for rail cover both diesel and electric rolling stock. Other than coach travel, rail was the most efficient means of transport in 2018, however, if more trains were electric, and even more renewable energy sources were used, rail would perform even better.



Average emissions by mode type (blue 2018, green 2019)

Reducing rail emissions

There has been a reduction in average emissions per passenger rail kilometre due to the increased electrification of the rail network, improved fuel efficiency and increased capacity.[11] With the proposed interventions set out in this plan the average emissions for rail per passenger kilometre will decrease, as more electric units are introduced to the network. With modal shift to rail our total transport emissions will reduce.

Modal shift to rail

There are benefits to be gained simply from mode shift from air or road to diesel rail and these benefits are increased further from an additional shift to an electric or non-diesel rail service. As we take forward our actions we shall use all opportunities to strengthen services and provide additional seats for passengers and potential passengers.

Freight

The National Infrastructure Commission, (December 2018)[12] report advised that per tonne kilometre, rail emits only about a quarter of the CO_2 of road freight. Across the UK, in 2017, the heavy goods vehicle (HGV) sector contributed around 25 $MtCO_2e$ per year. The entire UK rail sector contributes around 3 $MtCO_2e$ per year.[13] Accordingly, a 10% modal shift of HGV traffic to rail would reduce almost as much annual CO_2e as the entire rail industry emits. Electrification of the network would extend the capability of existing electric-traction rail freight and encourage conversion from diesel rail freight which, if allied to network improvements such as connections to ports and expansion of freight depots, could make a substantial contribution to achieving modal shift and significantly improving the health of the environment.

Passenger

Newly electrified passenger railway lines often show what is known as a 'sparks effect' - a term coined to describe experience in Britain which noted that if a line was electrified patronage increased. The reasons for the increase are due to newly electrified lines often utilising modern rolling stock which is smoother, quieter and faster with the latter altering the relative accessibility of locations to work, leisure and retail destinations.[14]

Additionally, electrification often stimulates wider infrastructure interventions and timetable changes which deliver significant benefits to users, for example, at Bathgate the station was expanded and relocated at the time of electrification and

[11] https://www.transport.gov.scot/publication/carbon-account-for-transport-no-11-2019-edition/3-efficiency-of-transport-modes/
[12] https://www.nic.org.uk/publications/3730/
[13] https://data.gov.uk/dataset/9568363e-57e5-4c33-9e00-31dc528fcc5a/final-uk-greenhouse-gas-emissions-national-statistics
[14] https://www.sciencedirect.com/science/article/abs/pii/S0047272799000857

passenger numbers between Bathgate and Edinburgh (with consequent doubling of services from two to four trains per hour) increased by 87% from four years prior to electrification to four years post electrification, compared to a ScotRail-wide figure of 25% for the same 2010-2018 period. The wider Airdrie-Bathgate improvement project has also been instrumental in delivering modal shift with a substantial shift from private car to public transport. In the most recent evaluation of services,[15] some 19% of sampled rail users stated that in the absence of the rail improvement, they would travel by car, and a further 2% stated that they would use the car for part of their journey. Rail can have a significant role in modal shift and associated emissions reductions.

Rail emissions data

Work is on-going to update emissions data covering all parts of the rail industry, the last in-depth exercise was undertaken over 10 years ago. More recently, the ORR (the rail regulator) reported in its 2018-2019 rail emissions statistical release[16] that whilst there had been increases in the amount of electricity consumed by passenger and freight trains, the resulting CO_2e emissions per passenger km and per tonne km have fallen, predominantly due to a transition towards renewable energy sources in the electricity sector in GB. The ORR reports that passenger train emissions were 36.6 gCO_2e per passenger km (a decrease of 10.3% compared to 2017-18) and that freight train emissions were 25.3 gCO_2e per tonne km (a decrease of 4.1% compared to 2017-18).

Electricity emissions

Emissions from electricity generation have decreased significantly in Scotland and electrification has become an increasingly positive decarbonisation option. In 2017, each kilowatt hour of electricity generated in Scotland added an estimated 24 grams of carbon dioxide into the atmosphere (gCO_2e/kWh), a sizeable drop from 150.9 gCO_2e/kWh in 2015. This has been driven by both the increase in low carbon, renewable generation (in 2018 the renewable share as a proportion of energy in gross final energy consumption was 76.24%) and the closure of Scotland's last coal power station at Longannet in early 2016.

Wider strategic objectives

The benefits of rail traction decarbonisation align with the Scottish Government's purpose and objectives as set out in the National Performance Framework (refreshed in 2018).[17] Decarbonisation helps to achieve many of our National Outcomes, in particular those relating to the economy, communities and the environment. This plan therefore complements and supports our new National Transport Strategy's vision and outcomes (published February 2020), promoting more sustainable public transport.

[15] The Airdrie to Bathgate Stage 2 Evaluation Report, due 2020, Transport Scotland website
[16] https://dataportal.orr.gov.uk/media/1531/rail-emissions-2018-19.pdf
[17] https://nationalperformance.gov.scot/

Priority: reduces inequalities
How rail can impact: rail provides accessible transport which connects communities across Scotland

Priority: takes climate action
How rail can impact: decarbonising rail will help Scotland reduce transport emissions

Priority: helps deliver inclusive economic growth
How rail can impact: rail connects people and delivers goods

Priority: improves our health and wellbeing
How rail can impact: greener rail services can improve air quality and enhance health and wellbeing

Wider strategic objectives and rail's role

Our vision in the National Transport Strategy

Key electrification facts

As of early 2020 around 40.7% of Scotland's railway track is electrified.[18] In terms of the proportion of total vehicle kilometres under electric traction, however, the figure is far greater and constitutes 76% of all passenger journeys. The routes to all our main rail freight terminals in Scotland's central belt are electrified, and around 45% of Scottish rail freight journeys are electrically hauled from origin to destination. A significant proportion of freight is cross-border so it is important to synchronise electrification plans with those in England to ensure they are fully electrified from origin to destination.

Whilst Scotland currently has a lower proportion of its network electrified compared to the rest of Great Britain, and other European countries, significant progress in recent years and a continued commitment to electrification in Scotland has seen this improve at a faster rate than anywhere else in Britain. Through the implementation of this action plan this proportion will increase further.

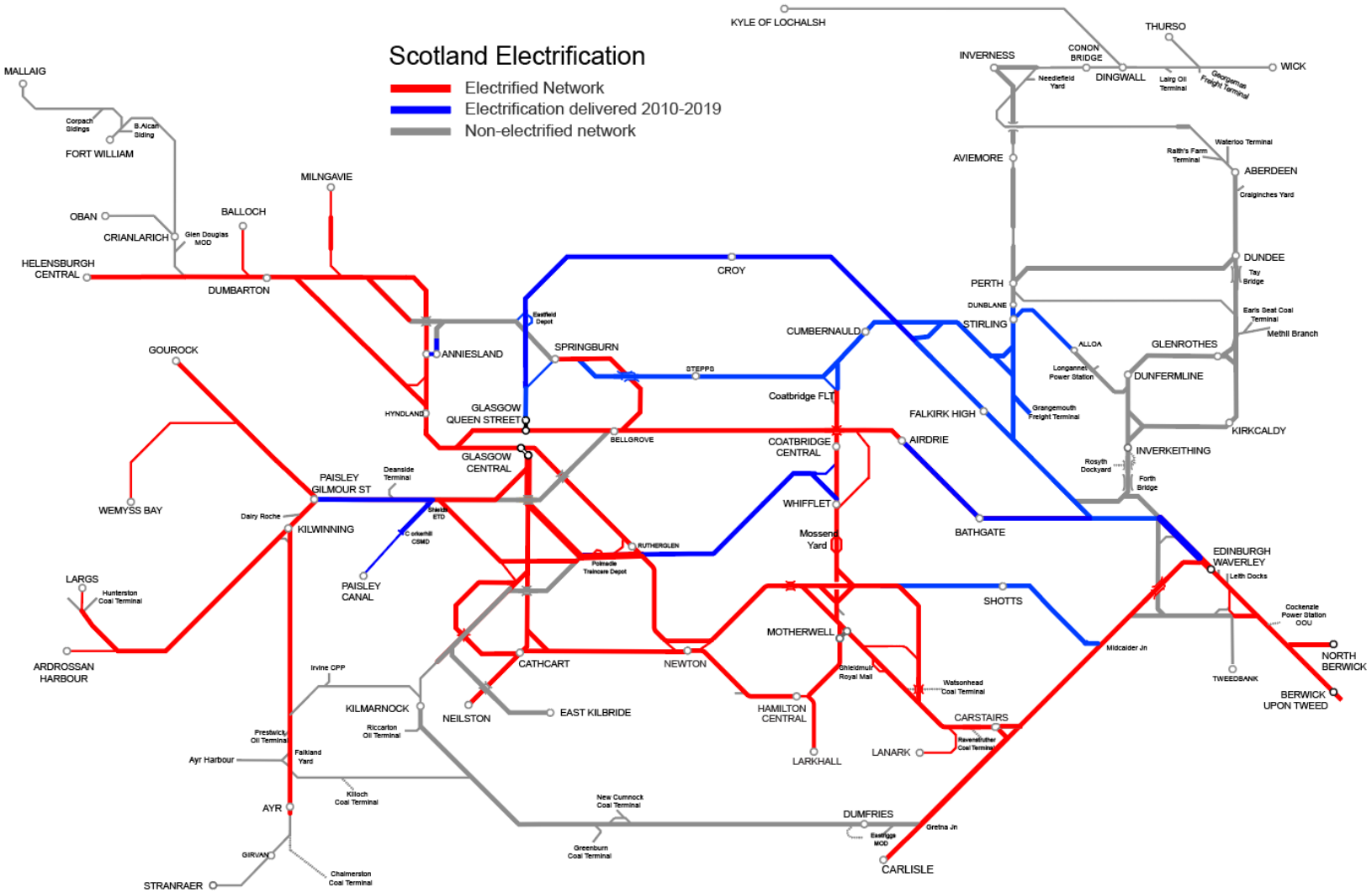
Progress in the last decade

The Scottish Government has maintained a consistent policy of investment in electrification and in the last ten years in Scotland we have invested around £1 billion in some 441 (track) kilometres of electrification and associated infrastructure improvements directly benefiting over 35 million passenger journeys each year. Both the Stirling-Dunblane-Alloa (100 single track kilometres) and Shotts (76 single track kilometres) projects were brought into use/passenger service within 12 months of each other. In the last two years the number of ScotRail passengers carried on electrified services has increased by around 23%, as a result of the electrification projects completed over this period. The lines electrified in the last ten year period include:

- the new Airdrie to Bathgate route
- lines of route from Glasgow Central to Paisley Gilmour St
- the Paisley Canal line
- the Cumbernauld line
- the Whifflet route between Rutherglen and Coatbridge
- the Stirling-Dunblane-Alloa route
- the main Edinburgh to Glasgow route via Falkirk High
- the Edinburgh to Glasgow line via Shotts

[18] 40.7% single track rail kilometres are electrified, however the Scottish Government uses a different measurement, total track length of the Scottish rail network. Around 29% of the total track length on the Scottish rail network is electrified.

The diagram below shows the extent of electrification work completed between 2010 and 2019.



Map showing extent of electrification work completed between 2010 and 2019

Consolidating experience

In response to the Scottish Ministers' specification (High Level Output Specification, July 2017[19]) in March 2019 Network Rail completed an internal report '*enabling efficient electrification in Scotland*' which crystallised lessons learnt from recent electrification projects and set out a future approach to electrification. The rail industry and its supply chain now have the benefit of considerable recent and relevant experience.

Aim and objectives

The purpose of this action plan is to set out the opportunity, identify the optimal transition plan, and establish an initial indicative programme - based on a whole systems approach - of how we will decarbonise Scotland's railway network and the wider transport system through the:

1. electrification of the rail infrastructure

The electrification of the rail infrastructure requires a number of elements:

- an adequate (decarbonised) power supply/source
- overhead wires to supply electricity direct to a train equipped to use it
- appropriate rolling stock - electric trains/locomotives

2. use of alternative traction technologies:

- electric units with batteries installed – one type of bi-mode train
- the use of non-diesel units/alternative traction types (battery or hydrogen)
- the provision of infrastructure for the storage and supply of hydrogen to trains

At times electrification and alternative traction will be used together and on other occasions sequentially. Our evidence base includes the work of the GB-wide rail industry decarbonisation taskforce,[20] and Network Rail's recent internal report – '*enabling efficient electrification in Scotland*'. We have also used a range of factors and drivers in our consideration of the phasing of programmed activity. This plan will aim to ensure that maximum benefits and efficiencies can be derived from the rolling programme through the phasing and use of non-diesel, independently powered and bi-mode rolling stock. Introduction of bi-mode non-diesel trains can secure early benefits as an interim measure when electrification of individual routes is delivered in discrete sections.

[19] https://www.transport.gov.scot/media/39496/high-level-output-specification-hlos-for-control-period-6-final.pdf
[20] https://www.rssb.co.uk/Research-and-Technology/Sustainability/Decarbonisation

Bi-mode and alternative traction types (including hydrogen)

Electric units with batteries can run on both electrified lines as well as non-electrified lines (where diesel trains currently operate). They are known as battery-electric bi-modes. They have normal electric train equipment as well as battery packs installed and their traction system means that they can use overhead power from the lines when available and battery power when on non-electrified lines. As such they can be used to fill gaps between electrified sections on the rail network, avoiding or postponing the need to adapt difficult structures, and in effect can extend electric operation beyond the limits of wherever the infrastructure electrification has reached at any time. The batteries require to be charged either whilst the train is running on an electrified section or during layover periods through specially installed facilities at terminus stations.

The rail decarbonisation taskforce report identified that the two technologies that are likely to be sufficiently mature to make a significant decarbonisation impact (for passenger services) in the future, are hydrogen and battery powered trains where their performance capabilities meet journey-time requirements. Hydrogen for example could be used on routes with 75 miles per hour maximum speed.

A hydrogen fuel cell works by changing chemical energy into electrical energy by combining hydrogen and oxygen, the electrical energy charges batteries and these in turn power the electric traction motor. Hydrogen fuel tanks can be recharged very quickly (same timings as current diesel trains).

Traction comparison

A rolling programme of electrification is essential to achieve journey time savings, lower operating costs and reduce emissions on more busy, high speed or heavy haul routes. The alternatives to full electrification will have a role for lightly used routes and on some long distance routes, where full electrification is not financially justified. The alternatives will also have a valuable role in the transition period until the optimal electrified network can be completed.

Battery-electric trains have potential to offer operating cost savings (along with zero emissions) when compared with diesel power without the capital cost of full electrification infrastructure, though the capital and operating costs of battery electric vehicles are higher than standard electric trains. They can be brought into service relatively soon. They are currently considered effective for lower-intensity services of up to around 55 miles. Recent estimates suggest adding battery capability to electric trains adds around an additional 25% to their capital cost.

The cost-effective viability of hydrogen is expected to improve over time as usage volumes increase noting that the cost of diesel may increase as less diesel is required for road transport. Hydrogen fuel cells do have the potential for services over longer distances, though the comparatively low energy density of hydrogen requires large fuel storage volume on trains for longer ranges. Initially hydrogen-fuelled trains are expected to have higher capital and operating costs than diesel trains.

Emissions with the use of hydrogen fuel depend on how the hydrogen is generated, but will be substantially lower than diesel use. The opportunity is to focus on using hydrogen from renewable sources for zero emissions compared with diesel trains. Already in Scotland significant investment in production and distribution for hydrogen fuel is taking place and this is expected to become a major energy source for rail as well as domestic/industrial gas supply and other forms of transport.

The rationale for electrification

It is widely recognised that electrification of the rail network is a key strategic investment for Scotland's railways, and increased benefits will accrue through further modal shift to rail. Rail electrification is a tried and tested technology which uses energy efficiently and reduces rail CO_2, NO_x and particulate emissions.

There are significant additional benefits from electrification and from connecting all of Scotland's seven cities together through an electrified rail network. These benefits include:

Local environmental benefits:

- improved air quality, reduced noise and vibration

Direct passenger/freight customer/user benefits:

- journey time reductions/ better connectivity and access to markets - through superior acceleration which will generate particular benefits on more hilly routes such as the Highland Main Line and towards Aberdeen from the south, and on services with frequent stops such as the East Kilbride line

- improved network capacity - as journey times for passenger and freight trains are improved by electrification overall capacity on key routes is improved; when combined with suitable signalling systems, electrification can often contribute significantly to improving the overall capacity of the network – this can allow the release of additional paths and increased services

- improved network resilience - through the electrification of diversionary routes – improving the network's performance and reliability

- substantial freight benefits - higher power allows heavier trains to operate faster and at lower cost, and makes it easier to operate more freight trains between passenger trains. Options for electrification of freight sidings, if appropriate, and terminal requirements will be reviewed during the design phases

Operational benefits:

- rolling stock strategy synergies – medium to long-term planning and certainty allows for more coherence in rolling stock strategy procurement

- lower rolling stock costs – electric trains are lighter and cheaper to build and to maintain

- improved reliability/availability/efficient use of rolling stock - as more routes are electrified, electric traction/trains in the long-term can be interchanged more easily, currently 60% of the fleet is electric

- infrastructure operating costs – economies of scale can be achieved through operating more of the same type of infrastructure

- industry fuel costs – electric grid power is around 50% less expensive than diesel, and further benefits can be realised through the use of renewable/low carbon or innovative direct feed energy for overhead line supply

New class 385 electric trains

ScotRail's new fleet of 70 class 385 electric trains have outperformed in terms of the industry standard (miles run per technical incident – MTIN) and are already proving to be twice as reliable as the diesel trains they have replaced. Electric trains have significantly less weight than diesel trains which results in a reduction in the level of wear on the tracks.

While electric trains continue to be abundantly cleaner than those using diesel, class 385 trains across the central belt are also more energy efficient than the class 170s they replaced.

Power supply

Ensuring 25 kV **power feeding** is a key workstream to support the increase in electric traction and expansion of the electrified network. There are significant lead times associated with the programme to install new feeding stations, alignment with National Grid and the overall programme needs to be considered.

Careful consideration will also be required on traction feeding technology options and future innovation/research initiatives. At all times we will maximise the benefits of decarbonisation by using Scotland's low carbon energy sources through ordinary grid connections, or innovative "direct feed" solutions.

A guide to rail power supply

Power needed to move a train is traction power. The power is drawn from the National Grid and supplies the Overhead Line Equipment (OLE) via switching stations (including feeder stations) which take the voltage and convert it. Power supply is limited across Scotland – more capacity (storage) needs to be built - and it has to be available where it is needed (distribution).

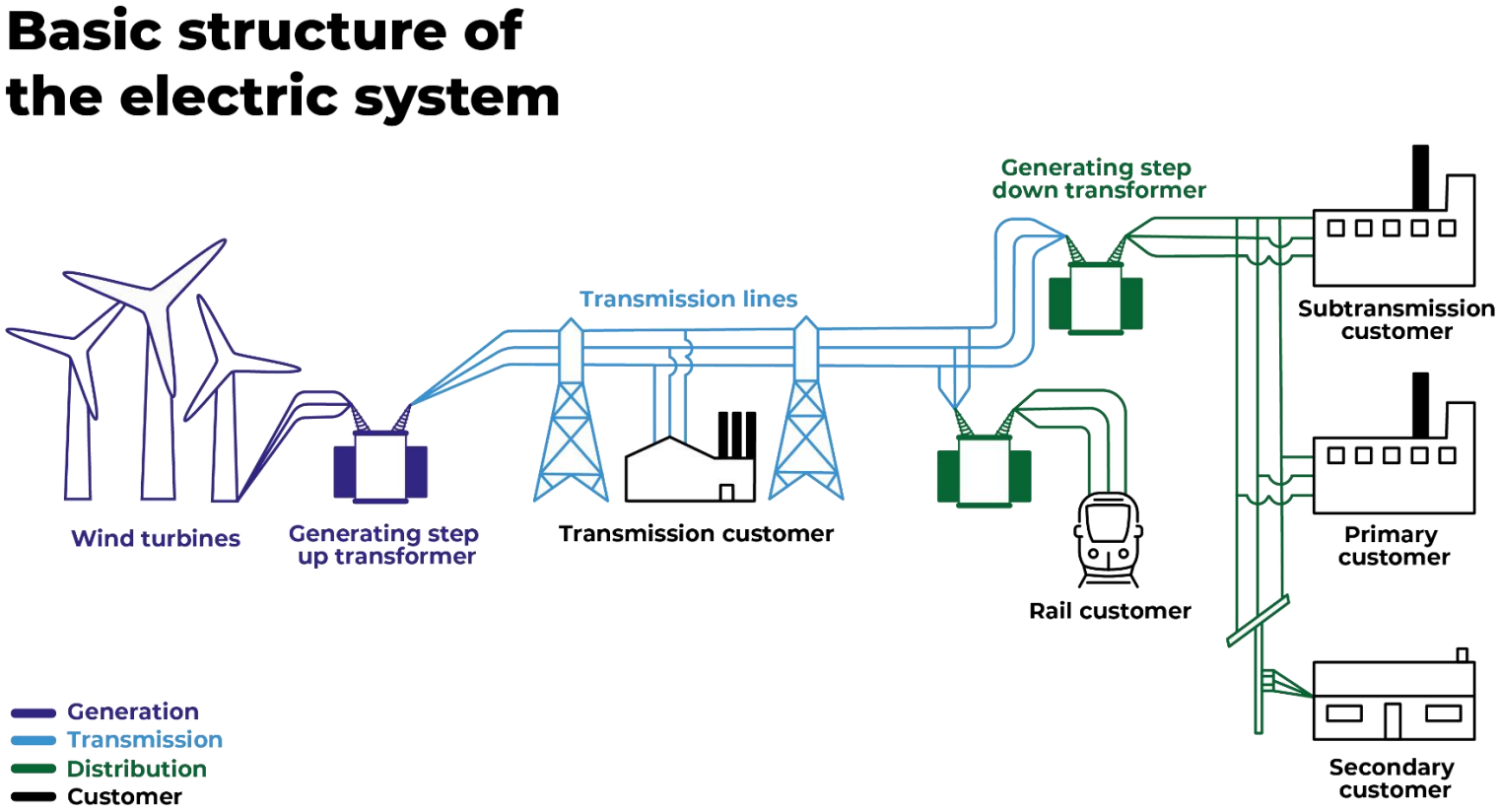


Diagram showing the basic structure of the electric system

Power resilience: A robust power supply also acts as an insurance policy for electric services across the network. It provides resilience in the event of temporary problems with any one power supply point.

The rationale for alternative traction models

In line with the findings of the rail industry decarbonisation taskforce report we have been working closely with industry and academia to develop new modes of propulsion, such as battery-powered electric trains, and we are exploring the potential for rail to utilise fuel cell technologies. This is an area where advances have been made in recent years and one where the market could mature significantly within a short timeframe, helping to boost jobs and skills development linked to a green recovery for Scotland in the context of the COVID-19 health pandemic. Whilst there are acknowledged challenges in scaling up alternative fuel production such as hydrogen, there is a clear opportunity to expand Scotland's growing hydrogen economy which is developing in the North East.

Alternative traction options will be needed to provide passenger services either before full electrification can be delivered on some lines or on other predominantly rural lines, where full electrification may be inappropriate due to cost or environmental factors.

Scotland has an opportunity to stimulate innovation within the train manufacturing industry, and wider supply chains, potentially creating skilled, sustainable employment in Scotland.

In Germany hydrogen powered trains are a feature of the railway – with two trains working reliably in local passenger service in Lower Saxony with 40 more on order.

Alstom iLint hydrogen fuel cell powered train, Lower Saxony 2019

Aberdeen Hub

Aberdeen has established itself as a centre of excellence for hydrogen fuel cell technologies, with a range of initiatives implemented in recent years, largely informed by the Aberdeen City Region Hydrogen Strategy and Action Plan (2015 – 2025). Highlights are:

- Europe's largest fleet of fuel cell buses and refuelling infrastructure, operating with very high availability levels since 2015
- introduction of fleets of light duty fuel cell vehicles into the Councils' fleet and a car sharing club
- trials of hydrogen-fuelled municipal vehicles (refuse trucks, road sweepers)
- commissioning of an industrial-scale (1 megawatt) stationary fuel cell

With existing and future plans there is a requirement for new low cost, low carbon hydrogen supplies for Aberdeen. Rail could potentially create the levels of demand that will reduce the costs of hydrogen fuel to support the long term sustainable growth of the sector in the region.

Alternative traction in Scotland

We have started to focus on and investigate opportunities for alternative traction models both for predominantly rural/scenic lines in Scotland and in areas where a policy of discontinuous electrification could be applied as an interim or transitional measure. Bi-mode trains (electric and battery bi-mode, for example) will be useful in unlocking the passenger and operational benefits from the use of electric traction earlier in the roll-out.

We acknowledge that, although work has started, the processes are not yet complete with the industry and the regulator. We understand that alternative fuel technologies are part of an ever changing, and fast-paced industry, accordingly the rail industry in Scotland will need to adapt quickly to maximise the benefits that these technologies will bring. The main benefits from accelerating decarbonisation through alternative traction are:

Local environmental benefits:

- environmental noise and vibration reduced
- local air quality improvement
- compliance with local environmental zone restrictions
- opportunity to use zero carbon renewable energy for fuel production

Direct passenger benefits:

- considerably less infrastructure along the track required, minimising service disruption during construction
- can be used on less intensively used routes, more rural/scenic lines to decarbonise without the need for electrification infrastructure/wires
- earlier benefits for passengers with improved traction performance and modern on-train facilities being experienced prior to electrification works

Direct railway benefits:

- ability to operate independently in the event of a power outage in the overhead electrification, enabling discontinuous electrification on routes with limited structural clearances, and obviating the need for catenary and high-voltage cables in depots with a safer working environment for rail staff

Innovation:

- wider benefits to Scotland's economy because the use of alternative traction provides an opportunity to build a Scottish supply base with expertise in innovative technologies

Many of the benefits are amplified through modal shift to rail.

Longannet Rail Research Hub

We intend to establish an international rail cluster in Scotland to unlock supply chain opportunities from this action plan. We want Scotland to be a leader in the innovation and manufacture of net-zero rail products, services and solutions, including integration of circular economy principles into efficient design, supply, maintenance and end-of life use within the rail sector.

The cluster, which we aim to establish at Longannet, will be built around existing strengths in rail in Scotland and will seek to enhance the innovation and supply chain in the decarbonisation of our rolling stock and wider network.

Services and rolling stock strategy

The decarbonisation of domestic Scottish daytime rail services is at the core of this plan. Fundamentally, achieving this will depend on:

- what services are provided for passengers now
- what services are planned for the future to meet current and forecast demand

- what services are facilitated for freight
- what rolling stock and traction locomotives are used to provide these services
- what power is available/required and where

We have considered the anticipated end of life dates for the current leased ScotRail fleet and when decision points should occur. At the end of 2020 there will be 148 diesel-only trains, with 394 carriages, and 203 electric units, with 649 carriages leased by ScotRail. The diesel units have a range of anticipated end of life dates (depending on class type) between 2025 and 2035. The way fleets are operated mean that certain classes of fleet are used on set routes, for example the current diesel (2-car) class 156s and class 158s operate on the West Highland Lines, Far North Line and the Kyle Line, which means when we look at how to decarbonise the passenger railway we need to take into account these operational considerations.

The volume of passenger rolling stock replacement is significant between 2020 and 2035 and as we undertake the actions this will form a key and integrated workstream. Lead times for refurbished stock, stock brought in from elsewhere or new rolling stock to operate on the Scottish network ranges from two to four years. It is also important to understand – and build in an allowance of time for - issues with fleet introduction including for approvals, acceptance, route proving, driver training, and the provision of depot and stabling infrastructure.

Different factors will affect the details of our rolling stock procurement strategy but key elements are stability in the pace of rolling stock replacement and orders alongside the ability to be responsive. As we undertake more detailed work on the actions we will ensure there is the flexibility around carriage length formations so that trains can match infrastructure and demand. We will align the timing of the procurement of non-diesel, independently operated units.

Modal shift in action

Edinburgh is the fastest growing city in Scotland and one of the fastest growing parts of the UK – with growth outpacing even that of London. GVA per head in the City of Edinburgh was £44,250 in 2017. The economy of Edinburgh and its wider-region (which includes areas such as Fife, Midlothian, East Lothian and West Lothian) is also one of the fastest growing city regions in Europe. Constrained by its size and green belt, transport links into and out of Edinburgh are vital.

We are aware of the demand for rail services in the surrounding regions and know how busy peak trains currently are on the Borders and Fife routes. Our decarbonisation action plan gives us the opportunity to cascade diesel rolling stock whilst we electrify the initial lines to strengthen other services (such as the Borders or Fife) providing an immediate and better offering for passengers, and securing early environmental benefits for transport.

The diesel dilemma

Pending full rail decarbonisation in 2035, diesel trains will continue to have an important contribution to make to overall transport decarbonisation. This is because emissions per passenger mile or freight tonne mile of diesel trains are already significantly lower than private cars or heavy goods vehicles. Consequently, there is a significant environmental bonus to be gained by reallocating diesel trains from routes which have been electrified to other routes still pending electrification. On routes such as the Borders, Fife Circle and Aberdeen suburban, demand for rail is suppressed by the current shortage of diesel carriages. New diesel carriages are quickly filled as they are redeployed to these services. Therefore it will be important to pursue technologies that reduce emissions from diesel trains during the transition to electrification. Accordingly, we will take steps to improve and reduce the environmental impact of these diesel trains until they are phased out by:

- utilising battery technology for initial traction power (with diesel engines) improving air quality in stations
- optimising the formation size of diesel trains to increase occupancy on lightly used services and minimising empty rolling stock movements
- reducing diesel emissions by the use of technologies which reduce harmful emissions such as compressed natural gas mixed with diesel or the application of exhaust treatment measures

Depot and stabling strategy

We are also developing a depot and stabling strategy which will ensure the optimum location for train depots in Scotland in order to maintain the trains required on the network. This is being informed by service specification and rolling stock strategies. The significant future programme of rolling stock procurement also provides an opportunity to engage with suppliers in relation to maintenance and stabling depots. Additionally, we are seeking to use/locate depots more strategically on the network to reduce the incidences of empty coaching stock movements which takes up capacity on the network. This work is ongoing and part of an iterative process, as such it will be regularly refined in line with taking forward the proposals in this action plan.

Relative energy efficiency of traction types

An **electrically powered train** is the most energy efficient form of traction. For every 1kW of power through its wheels it requires about 1.2kW from the National Grid. The small amount of energy loss is due to transmission from production to the traction motor via the National Grid, sub-stations, the overhead line equipment and on-train equipment. This loss means that in terms of power to create and power used in its drive an electric train has an efficiency of over 80% and there is the potential of a zero-carbon option particularly if the electricity is generated by sustainable sources (e.g. wind, hydro, tidal or solar).

A **battery train** is 12% points less efficient in its operation than an electrically powered train because of the constraints of the battery i.e. its capacity to store and release energy, which, together with the weight of the battery, has a bearing on its range and capabilities. An electric train by contrast with unlimited access to electricity has a higher power range and thus has the capability to operate more efficiently in challenging situations such as inclines. Additionally, the cost of a battery adds about one third or more to the capital cost of a similar electric train powered via a catenary system.

A **hydrogen fuel cell train** currently has some advantages over a battery train in that it can typically operate over longer non-electrified routes than a train with battery traction. Additionally, refuelling with hydrogen is fast, though hydrogen fuel occupies some seven times the volume as diesel for the same amount of energy. However, with hydrogen, 3.4kW of power is required to generate 1kW of drive via electrolysis and compression to the on-train fuel cell and converter. This gives an efficiency rating of less than 30%. It is expected that technology advancements will be made in the coming years to improve the efficiency of hydrogen fuel cells however it remains a considerable way behind electrification. That said it will have a role particularly on those lightly used routes where catenary systems may not be appropriate or cost effective and where battery would not have the range.

A **diesel train** is the least energy efficient source of traction as 3.9kW of oil via extraction and refining before being stored on train for delivery to the engine and transmission is required to deliver 1kW of drive. This delivers an efficiency of about 26% which is the lowest of all fuel types and fails to take into account the noxious gases and particulates produced in its use.

Deliverability/acceptability

Electrification, like any significant track infrastructure work, necessitates a key early activity around railway route clearance. Our recent policy statement on railway line-side vegetation management '*Building a greener railway, lineside vegetation management for nature and people in Scotland*'[21] supplements broader requirements and sets out our expectations for Network Rail in Scotland with particular regard to

[21] https://www.transport.gov.scot/media/46998/building-a-greener-railway.pdf

current and future electrification-related infrastructure projects. There is a specific focus on:

- best practice
- engagement with line-side neighbours
- safety
- ecological surveys and minimising ecological impacts
- improved biodiversity
- visual amenity

Market capability

We have considered and discussed with industry representatives the capability of the rail industry and supply chains to deliver our plan and will work with them as we take forward the actions. The plan provides a unique opportunity to build on current capability and associated contractor supply chains, with solid, stable and high quality employment opportunities.

More manufacturers have entered the GB rail rolling stock supply market which opens up additional opportunities for our rolling stock strategy.

Land-use planning

National Planning Framework 3[22] and Scottish Planning Policy[23] align with a range of wider Scottish Government policy and form the Scottish Government's suite of national level planning policy, setting out the direction for Scotland's long term development. They have informed regional (strategic) and local development plans.

The policy can be material in making decisions on individual planning applications. In the transition to the new planning system under the Planning (Scotland) Act 2019, the next National Planning Framework (currently in preparation) must contribute to a range of outcomes including meeting greenhouse gas emissions reduction targets, it will also align with and facilitate a wide range of Scottish Government policy and strategies. The significance of the work involved by the rail industry in taking forward this action plan requires support from – and should be reflected in – our land-use planning frameworks.

[22] https://www.gov.scot/publications/national-planning-framework-3/
[23] https://www.gov.scot/publications/scottish-planning-policy/

4. Decarbonisation: routes and services

General

This action plan is based on a high-level, first stage assessment of the un-electrified network. Each scheme (proposed traction change for a route/service) will be synchronised with current rail improvement projects and rail renewal activities and will be subject to further standard industry appraisal aligning with our processes for capital investment in rail.[24] Our investment decisions will look in considerable detail at the costs, benefits, risks, timescales and choices around procurement strategies and delivery mechanisms before making an informed determination.

Our rolling programme of decarbonisation considers a range of key factors and drivers such as:

- route characteristics (track length, structures/structural clearances)
- service types (commuter/local, intercity, regional, freight, scenic)
- connectivity between all of Scotland's seven cities
- fleet design and economic life expiry (the current train fleet and timescales for renewal)
- an assessment of diesel trains operating on electrified routes
- whether electrification enables a diversionary route
- previous development work
- projects in the planning stages and current and future rail renewals
- passenger and freight benefits
- power requirements
- overall network impacts/flexibility (interworking of fleets)
- operational flexibility
- supply chain capability
- technical capabilities of new and emerging alternative technologies

[24] These are articulated in the Rail Enhancements & Capital Investment Strategy, 2018

Costs

> ...development of an efficient electrification technical specification optimised for Scotland that, in support of the Investment Strategy, can deliver an efficient and affordable rolling programme of electrification with appropriate plant, staff and resources based in Scotland to deliver the outputs and maximise the benefits to Scotland, including through the supply chain.
>
> **The Scottish Ministers' High Level Output Specification 2017**

This action plan does not set out detailed cost information by route: that analysis has yet to be undertaken. Additionally, there are costs of traction which are attributable to this plan (some 148 diesel-only trains, with 394 carriages which would need to be replaced by 2035), nor does the plan make efficiency assumptions. With ambitions of such magnitude regarding rail decarbonisation it is imperative that there is a relentless focus on cost and delivery efficiency. Network Rail Scotland is currently taking positive steps to improve the efficient delivery of electrification projects in Control Period 6 (2019-2024), as specified by the Scottish Ministers in the HLOS.

Network Rail Scotland has demonstrated its ability to deliver at scale with the successful introduction of a number of significant electrification projects within Control Period 5. However, if we are to see continued, sustained reductions in unit costs then we must have a rolling programme that provides a constant, sustainable design and delivery work-bank, both for Network Rail and for contractors securing employment in Scotland both directly and indirectly. In addition to economies of scale, that will provide the supply chain with the confidence to invest in research, resource and talent thus supporting continuous efficiency improvement and providing direct and additional dividends for the wider economy.

Our railway is a complex system with many operational interactions and, accordingly, a successful, efficient decarbonisation programme can only be delivered if all its factors – route, rolling stock, power supply, structures and service operations – are recognised and addressed in an integrated manner. Consequently, we expect the detailed programme to be designed and delivered by a multi-disciplinary team that establishes close working relationships across the industry. It is by approaching matters holistically that we will ensure the comprehensiveness of the programme and efficiency of its delivery.

We know at this stage that other infrastructure works are likely to be required to capture fully the benefits on each of the route sections that feature within the action plan. Accordingly, we will assess each line of route, based on current and forecast future capacity requirements for both freight and passengers.

The major infrastructure cost components of electrification are:

- clearance of structures
- installation of overhead line electrification
- power feeding and sub-stations
- development, design and project management

The costs associated with those components can be considerable and can vary significantly depending on the length of track, number of loops, the amount of double or single-track, number and complexity of structures (tunnels and over-bridges) or the extent of enabling works. It is important, therefore, that these capital costs are brought closer to international norms by applying the lessons from recent problem projects such as the recent electrification of Great Western main line in England where, due to extraordinary escalating costs, the project had to be de-scoped with consequential implications for operations and rolling stock (i.e. the purchase of electric trains fitted with diesel engines).[25]

We are aware that electrification is being delivered more efficiently both in cost and time in some parts of Europe than is the case here in Britain. In Denmark, for instance, it is suggested that designers there have more freedom to design the system to meet output specifications and are able to be innovative as well as challenge long-established standards.

We believe that if Network Rail Scotland is wholly responsible for cost, safety and delivery but has a degree of freedom to determine designs appropriate to the needs of Scotland's network, it should be able to deliver pragmatic, effective electrification solutions that adopt and adapt best practice from here in Britain and across Europe at an increasingly efficient price. We will frame our requirements of Network Rail both in terms of defined outputs (i.e. track kilometres within a given period of time or route) as well as outcome measures (i.e. impact on Climate Change targets and passenger mode conversion from private vehicle to rail). This should ensure a holistic response by Network Rail with close engagement with industry and particularly operators in driving positive outcomes.

[25] https://www.riagb.org.uk/RIA/Newsroom/Publications%20Folder/Electrification_Cost_Challenge_Report.aspx

Innovation will be key in reducing industry costs and Network Rail is proactively progressing several workstreams on innovation and research and development alongside bodies such as the RSSB (Rail Safety & Standards Board) and the RIA (Railway Industry Association).

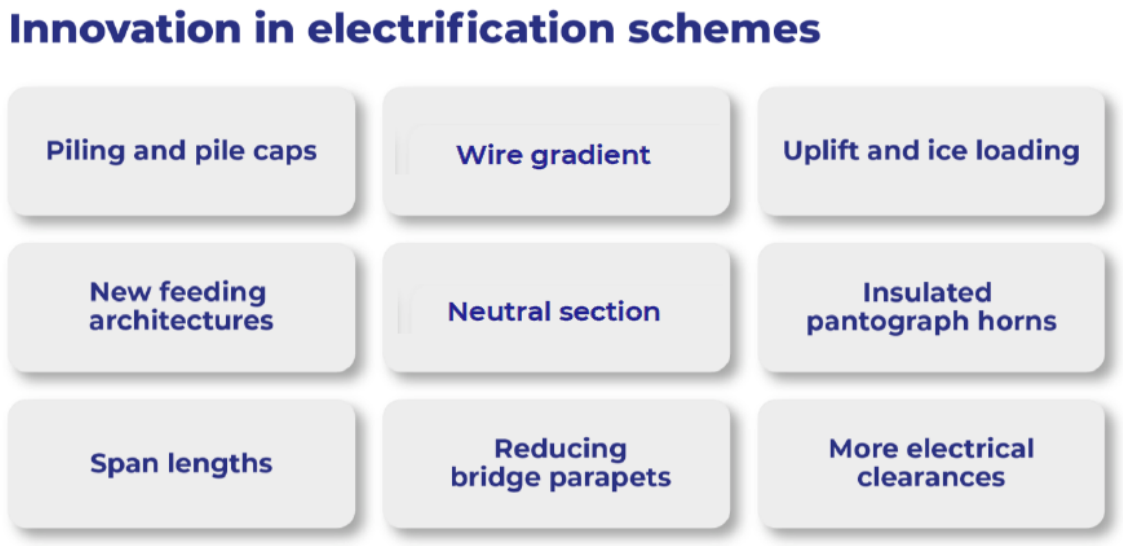


Diagram showing innovation in electrification schemes

A deep-dive into innovation

- **span lengths**: Network Rail's current electrification designs use shorter lengths between masts than previous British Rail designs or comparable practice in Europe. Costs, programme length and disruption to passengers and freight customers during construction are driven by the number of masts. Therefore it is necessary to give consideration to overhead equipment type, tension, how straight the track is and wind loading to increase the span length between overhead structures, minimising overall structure numbers in order to save on costs

- **parapet heights**: 1.8 metre bridge parapet height is now a Network Rail standard requirement for new electrification projects, but protection to people may be provided by more cost effective means. This will be a key consideration when assessing a particular bridge and its relationship with overhead line equipment (proximity to public interface) to determine if the parapet height requires to be increased. The fewer structural interventions required will drive efficiencies in both cost and programme

- **insulated pantograph horns**: this initiative may enable the clearance requirement at stations and lineside equipment to be reduced without impacting safety requirements – with overall savings to cost and programmes

Additionally, to ensure efficient delivery we have had early engagement with power suppliers and the National Grid. We will continue to work with power suppliers, and other third parties to focus on maximising the use of renewable energy sources as part of our decarbonisation objectives.

Disruptive access

Whilst service disruption will be minimised whenever possible there can be considerable financial costs associated where work on the rail network requires closure of the line and the resulting payments made to compensate operators. Further details and costs will be considered throughout subsequent development stages (known as GRIP[26] stages). As well as disruption to operators there will be impacts for passengers, freight customers and residents close to the railway line.

Alternative traction models

Alternative traction fleets, using for instance hydrogen fuel cells, will require supporting infrastructure to maintain, clean and fuel/recharge trains to ensure robust daily operations can be delivered to help with availability, performance and reliability across the ScotRail operation. This will align with work on depots and stabling and we will focus on using existing facilities whenever possible. We will engage with rolling stock manufacturers and owners to assess whether they can support or lead on the delivery of new and/or adapted facilities to enable fleets introductions. We will aim to do this in an efficient manner to minimise the impact of service disruption on passengers and staff.

Benefits

The key benefits identified through the use of electrification and alternative traction technologies are:

- global climate change benefits, lower emissions through the decarbonisation of passenger traction away from diesel – the rationale for this plan
- local environmental benefits – such as local air quality and noise (aerodynamics, rolling contact and engine noise)
- direct railway and rail user benefits – improved connectivity and faster journeys
- net operating cost benefits – lower power and maintenance costs

[26] GRIP – Governance for Rail Investment Projects

Edinburgh to Glasgow Improvement Programme

A recent comprehensive programme of improvements to Scotland's railway infrastructure. The introduction of modern efficient electric rolling stock on the newly electrified route has enabled a cleaner, greener and quieter railway with lower carbon emissions. Scotland's commuters, business users, tourists and leisure travellers have benefitted from improvements in service choice and faster journey times on modern, attractive, more energy efficient trains as well as new and redeveloped stations.

Since the introduction of the new class 385 trains, which are able to run in formations up to 8-cars, the capacity on the Edinburgh to Glasgow via Falkirk High route has increased by 44%, with a fastest journey time on the route of 42 minutes.

Comparing the previous diesel units (class 170) against the new electric rolling stock (class 385), there has been **a reduction of CO_2 emissions of 9,972 tonnes in 2019 - a 69% reduction in CO_2 emissions**.

Removing diesel trains

Work on the Glasgow to East Kilbride services/route is already being taken forward as a potential early electrification scheme in this rail control period (2019-2024). Currently diesel trains (class 156s) run on this very busy commuter route.

Based on average current diesel fuel consumption the electrification of this line or use of alternative traction trains would **save at least 1,086 tonnes of CO_2 annually**. An even bigger impact will be secured by running more, longer electric trains and integration of this improved service with bus and active travel networks and expanded park and ride facilities. The growth in passengers attracted from private cars will help further decarbonise the wider transport network.

Freight benefits

Electrification is currently the only viable option for rail freight to decarbonise over long distances and on mixed use lines. There is known latent demand for rail freight and the rail freight industry is working with Scottish businesses to develop new rail freight services as environmental concerns are beginning to change the logistics choices of Scottish producers. We have recently identified that there is demand for an additional four trains a day (in each direction) to both Aberdeenshire and Inverness-shire. As each freight train can remove up to 76 HGVs from the road,[27] these additional services could provide a potential maximum reduction in road transport of 1216 lorries. On an increasingly busy, mixed use, rail network the opportunity to expand rail freight is becoming challenging, especially north of the

[27] https://www.raildeliverygroup.com/files/Publications/2019-05_rail_freight_delivering_for_britain.pdf

central belt of Scotland, and electrification is a key component to unlocking environmentally sustainable rail freight growth.

Over and above the environmental benefits of electrically hauled or bi-mode rail freight, electrification would offer other significant advantages including:

- faster acceleration which both reduces journey times - crucial for rail freight to be competitive with road freight, and it would support improved capacity for all rail users
- increased modal shift to rail - prevents lorry miles and reduces road congestion
- efficiency – electric haulage removes the unpredictability and expense of diesel costs and the increased payload potential also reduces overall industry costs
- productivity gains (more freight carried per path) - would not come at the expense of performance or capacity
- benefits to those who live close to the railway - as electric freight locomotives can be quieter than diesel locomotives

Network efficiency/performance impacts

Recognising the impact on the overall performance of the rail network is a crucial factor in establishing a rolling programme. Continuation of the programme is necessary to capture all of the potential benefits of decarbonisation interventions and to avoid potential inefficiencies. As we recognise the economic and social value of cross-border passenger and freight services we are coordinating with Network Rail's strategy development work which is underway on GB-wide traction decarbonisation, which aligns with the Department for Transport's overall strategy for decarbonising transport.[28] Following our recent electrification to the freight terminal at Grangemouth, we also commit to work with the UK Government seeking alignment with respective electrification plans as key freight routes from England to Scotland need to have fully electrified lines especially to/from key English ports.

Timescales and actions

Our early, focussed first-stage assessment, and action plan milestones are shown in the indicative programmes in the maps at section 5. Currently three of Scotland's seven cities are already connected by a modern electrified network: Glasgow, Edinburgh and Stirling with all routes between Glasgow and Edinburgh now electrified.

[28] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878642/decarbonising-transport-setting-the-challenge.pdf

Network Rail has already started design development work on a number of electrification schemes to connect and consolidate the electrification of lines in central Scotland which in some instances will enable the relocation of rolling stock to assist with pressure points elsewhere on the network. These schemes have been agreed across the industry as being the most appropriate for initial activity:

Passenger lines:

- Glasgow Anniesland (via Maryhill)
- the Borders line
- Levenmouth and other discrete sections in Fife
- South from Glasgow to East Kilbride, Barrhead and Kilmarnock

Fife and mid Scotland

Network Rail is undertaking development and design work in 2020 for routes in Fife (from Edinburgh Haymarket to Fife/Dundee) reviewing the constraints and opportunities in this area. Our aim is for a continuous electrified line of route from Edinburgh through Fife to Dundee and Aberdeen to the benefit of passenger and freight services. Some (early) discontinuous electrification may be appropriate for the wider Fife lines. At all times we will seek to secure early passenger improvements through longer trains. Design and development work will also be progressed in 2020 for the route from Dunblane to Perth.

Scotland's rural network

Based on fleet expiry dates, and rolling stock interworking, the Far North Line, West Highland Lines and Kyle Line are considered appropriate for the early introduction of an alternative traction technology as a permanent solution. This workstream will be expedited and routes considered together as a package whilst taking account of the distinct requirements of each of the lines.

North-East Scotland

At this stage we envisage that additional diesel trains (made available by electrification) and then alternative traction technologies could be used as a transitional solution in the North East of Scotland until electrification works can be fully developed, funded and efficiently delivered on the appropriate routes. We are focussed on train service patterns over distinct route sections with flows such as Perth to Arbroath and Arbroath to Inverurie, crossing the respective cities of Dundee and Aberdeen.

Connecting Aberdeen and Inverness to the Central Belt

By 2035 we plan to have fully electrified routes from the central belt to both Aberdeen and Inverness east. The length of these routes, potential planning constraints, complexity of programme and power requirements, and the need to coordinate workbanks means that early development work on these routes will start significantly in advance of when we expect passenger trains to enter into service. Alternative traction may be used during the transition from the central belt to Aberdeen if it aligns with Aberdeen to Inverness rolling stock requirements, and subject to sufficient advancement of alternative traction technologies.

Inverness to Aberdeen

Though our plans are to electrify the entire route, the current programme, predicated on our average annual implementation rate of single track kilometres, indicates that we may only be able to electrify the section from Aberdeen to Inverurie by 2035. That will facilitate local cross-Aberdeen electric services. However, as new, innovative approaches develop, the pace of implementation and the industry's capability to deliver may increase further and thus allow us to achieve full electrification of the route by 2035. As that increased pace is currently unknown our planning assumption is that alternative bi-mode traction, capable of achieving the speeds necessary to deliver our improved journey time aspirations, will be required to operate on the route as an interim measure with an expectation that the route, with an extension to Tain, will be fully electrified in the years shortly after 2035.

South-West Scotland

By 2035 we aim to have an electrified route between Glasgow via Gretna to Carlisle benefitting commuter flows from New Cumnock to Glasgow and Dumfries to Carlisle. Additionally, by electrifying the line we envisage an enhanced strategic capability for rail freight, and a valuable diversionary route for freight and passenger services during closure of the West Coast Main Line. We will use alternative traction as a transition in the South-West of Scotland until full electrification and also on the line from Ayr to Girvan. At this stage we are planning to run alternative traction permanently from Girvan to Stranraer.

Plan more broadly

Our action plan is strategic and sets out our commitment and an indicative programme for the next 25 years. It is clear that there will be a range of issues, constraints, risks and opportunities which will need to be managed given the scope, scale and significance of this work, the funding and resources required, and the implications for the supply chain. The publication of the report during the COVID-19 health pandemic means there is added unavoidable uncertainty, so such flexibility will be vital going forward.

However, we aim to electrify, on average, 130 single track kilometres per year in order to achieve our 2035 target. Whilst this rate may seem challenging it should be noted that in recent years we have delivered considerable electrification projects in

conjunction with major infrastructure enhancements on routes between Edinburgh and Glasgow via Falkirk High and Shotts as well as extensions northwards to Dunblane and Alloa.

We are confident that in having a commitment to a long-term programme, rather than an intermittent schedule with its inherent peaks and troughs, we can create the opportunity for our rail supply industry to rise to the occasion and implement more appropriate techniques and equipment utilising knowledge and experience gained from our earlier projects in order to deliver and secure greater efficiencies (including through plant based in Scotland). Additionally, there will be significant prospects for the creation of more skilled, sustainable jobs in Scotland and, accordingly, a significant additional contribution to the economy. These jobs will be in the direct provision of electrification as well as in the supply of rolling stock and advanced technologies in the design of alternative traction methods to complement our electrification of the network.

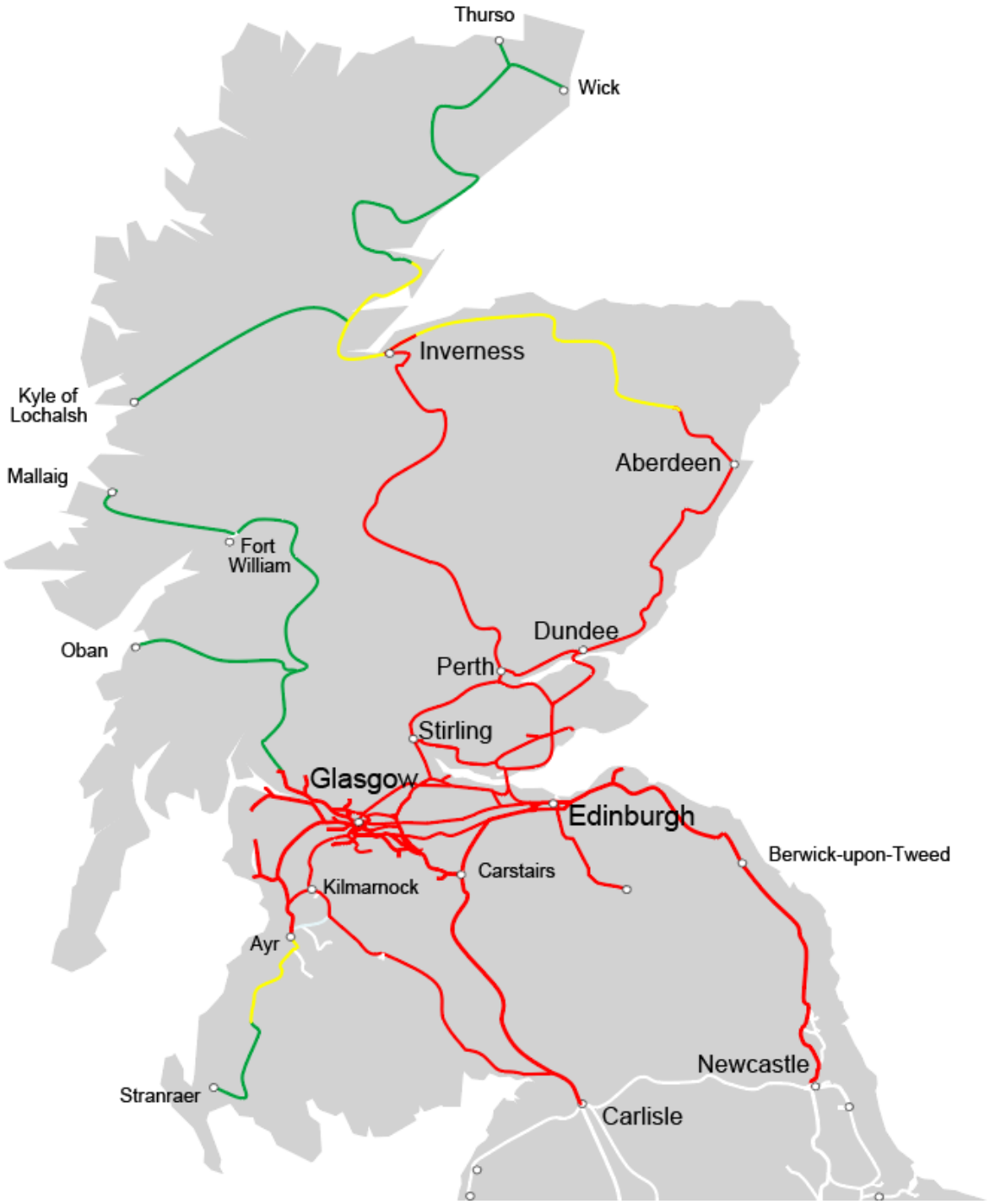
The maps on the following pages illustrate the rail network in Scotland in 2020, 2035 and 2045 and show the extent of work to be completed. We have used 2045 in order to co-ordinate with the Scottish Government's net-zero carbon target of that year.

5. Maps: showing rolling indicative action programme

Railway electrification in Scotland, 2020

Map showing railway electrification in Scotland, 2020

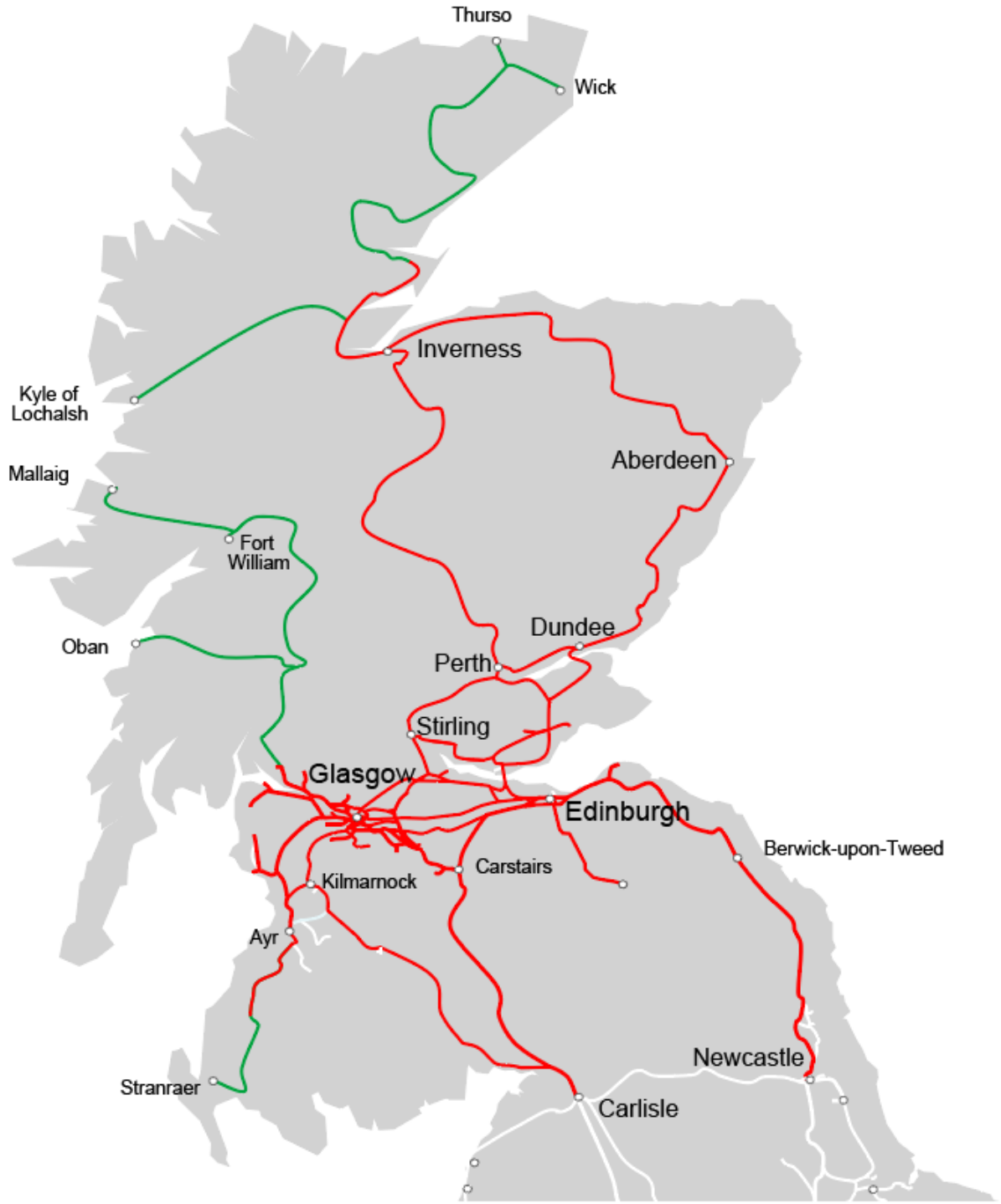
Railway - decarbonised network in Scotland, 2035



Map showing decarbonised rail network in Scotland, 2035

- Electrified network (sections of route may include discontinuous – or intermittent – electrification and the use of battery/electric bi-modes) and the electrification of some freight only lines may be subject to review
- Alternative traction - transition solution
- Alternative traction - permanent solution

Railway - decarbonised network in Scotland, 2045



Map showing decarbonised rail network in Scotland, 2045

Electrified network, the electrification of some freight only lines may be subject to review

Alternative traction - permanent solution

6. Continuous improvement

Benefits realisation

We will accurately measure the reduction in carbon emissions and improvement in air quality – where possible - to report progress against our plan and wider Scottish Government targets. To do so we are pooling industry resources to establish a single carbon measurement methodology for rail to calculate our carbon impact.

Our approach will build on reliable and publicly available data-sets, such as the traction energy reporting systems, and official datasets collected by government for national and international greenhouse gas reporting purposes. We commit to providing clear publicly available information on these measurement methodologies, and our progress, once robust frameworks are established. We envisage an annual statement on progress.

Whilst we will at all times seek to secure early benefits from phases of decarbonisation, for example through the use of bi-mode rolling stock, instead of diesel-only, there may be instances when fuller/full benefits cannot be achieved until a rail corridor has been completely decarbonised.

A dynamic action plan

This plan aims to provide certainty where possible but recognises the need to remain flexible. We will consolidate, review, refine and provide publicly available updates to this plan. Future updates will capture:

- further development of alternative traction technologies, an area where developments are happening at an unprecedented rate
- emerging electrification costs and delivery rate improvements
- the outputs from the future Infrastructure Investment Plan and Strategic Transport Projects Review
- innovation, research and development
- additional service/route requirements
- supply chain capability and sustainability
- funding availability
- prevailing government policies, particularly in light of the green recovery following the coronavirus pandemic
- appraisal and evaluation of work undertaken to date

We will also monitor progress. At all times we will seek to accelerate work and secure steady workbanks for the supply chain and stand ready to engage as part of the update cycle.

7. Rail industry more widely

Wider implications for rail

Whilst the scope of this action plan is the decarbonisation of domestic passenger rail traction, we expect and encourage all constituent parts of the rail industry, including Network Rail, train and freight operating companies and rolling stock providers, to produce long-term plans to achieve both interim and long-term targets towards broader industry-wide decarbonisation.

Whilst we are committed to working with the rail industry to ensure that wider Government policies can facilitate and support decarbonisation, we also understand that there will be services such as the Caledonian Sleeper and heritage railway services, which bring substantial value to the Scottish economy, that are unable to electrify their traction by 2035. These services constitute less than 0.2% of total rail services in Scotland.

Research and development

The RSSB, Network Rail, the Rail Delivery Group and the RIA have agreed to set out clear, five-year research plans to align with broader rail industry work. Of specific interest are the intentions to:

- increase the capabilities of battery and hydrogen technology and the supporting infrastructure required
- reduce the cost of whole-system electrification – this option will include the use of discontinuous/intermittent electrification particularly for less busy routes
- increase the efficiency of both current and future rolling stock

Our action plan updates will reflect the progress of this work.

8. Glossary

Bio-diesel is diesel fuel made from vegetable oils, animal fats, or recycled restaurant greases. It is safe and biodegradable and produces less air pollutants than petroleum-based diesel.

Bi-mode: a bi-mode train is capable of using two different types of energy source.

Circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

Climate change: a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide (CO_2), and other greenhouse gases produced through the combustion of fossil fuels.

Climate Change Plan: this plan sets out the Scottish Government's path to a low carbon economy while helping to deliver sustainable economic growth and secure the wider benefits to a greener, fairer and healthier Scotland.

CO_2 is carbon dioxide, a colourless gas. It is the most significant long-lived greenhouse gas in the Earth's atmosphere.

CO_2e is CO_2 equivalent. We report emissions for a range of greenhouse gases in accordance with international agreements. Each gas has a different global warming potential (GWP). CO_2e is used to report these GWP in a single number. Some gases break down much more quickly or slowly than CO_2 or have very much greater warming impacts. A given amount of methane, for example, has about 25 times the warming potential as CO_2 even though it breaks down faster in the atmosphere. Other gases have very much greater GWP than this. CO_2e is calculated as the equivalent amount of warming each gas produces when compared with the impact of the same quantity of CO_2 over 100 years. Where the data is available, the CO_2e factor is reported in this action plan.

Decarbonisation is the process by which the average amount of carbon in primary energy reduces over a period, for rail this relates to traction power.

Discontinuous electrification occurs when there is not continuous electrification such as at an earthed section through an overbridge. This is most likely to occur in places such as older bridges, tunnels and other obstacles. Discontinuous electrification is likely to have much more frequent, much shorter breaks on particularly constrained sections of track when compared with discrete electrification. A train running on electric power only may be able reliably to bridge gaps through momentum alone, although this is an operational risk, or through some limited energy storage, such as a flywheel.

Electrification in a rail context - is the process of providing the infrastructure required to enable electrically powered trains to operate on the rail network.

Infrastructure will generally include a power supply, and a means of conveying this power to train (e.g. through overhead wires and a pantograph mounted to a train).

Greenhouse gas emissions is the emission into the earth's atmosphere of any of the various gases, (e.g. carbon dioxide) that contribute to the greenhouse effect.

Governance for Rail Investment Projects (GRIP): Network Rail's project development planning stages.

Hydrogen fuel cell is a device that generates electrical power through a chemical reaction by combining hydrogen with oxygen to make electricity.

Hybrid trains use a combination of more than one traction type – this can be stored and rechargeable energy sources to power the train which provide a set of characteristics neither energy source can deliver on its own. Hybrid trains may use the energy sources separately or together. A typical hybrid in use now is a combination of diesel and battery.

Infrastructure Commission for Scotland provides independent informed advice to the Scottish Government on a 30 year infrastructure strategy.

National Grid is the system operator of Great Britain's electricity and gas supply. It is the company that manages the network and distribution of electricity and gas that powers all our homes and businesses.

National Infrastructure Commission is the executive agency responsible for providing expert advice to the UK Government on infrastructure challenges facing the UK.

National Performance Framework provides a clear vision for Scotland with broad measures of national wellbeing covering a range of economic, health, social and environmental indicators and targets.

National Transport Strategy: this Strategy sets out an ambitious and compelling vision for Scotland's transport system for the next 20 years, one that protects our climate and improves lives.

Network Rail (NR) is the owner and infrastructure manager of most of the railway network in Great Britain.

Net-zero carbon: carbon neutrality, or having a net zero carbon footprint, refers to achieving net zero carbon dioxide emissions by balancing carbon emissions with carbon removal (often through carbon offsetting) or simply eliminating carbon emissions altogether.

NOx is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO_2). These gases contribute to the formation of smog and acid rain, as well as affecting the tropospheric ozone.

Office of Rail & Road: the rail economic and safety regulator, also known as the ORR.

Particulate emissions are characterised by the presence of small particles of solids and liquids. These common by-products of combustion are a major health and environmental concern. PM_{10} refers to atmospheric particulate matter (PM) that have a diameter of less than 10 micrometres.

Programme for Government is published every year at the beginning of September and sets out the actions the Scottish Government will take in the coming year and beyond. It includes the legislative programme for the next parliamentary year.

Rail Delivery Group (RDG) is the British rail industry membership body that brings together passenger and freight rail companies, Network Rail and High Speed 2.

Railway Industry Association (RIA) is the main industry trade group for railway equipment manufacturers in the United Kingdom.

Rail Industry Decarbonisation Taskforce is the taskforce set up by the industry in 2018 to answer the challenge set by then UK Minister for Rail for the rail industry to remove all diesel-only trains from the GB network by 2040 and to provide a vision for how rail will decarbonise.

Rail Safety and Standards Board (RSSB) is an independent not-for-profit company which was established in 2003. The RSSB's principal objective is to lead and facilitate the rail industry's work to achieve continuous improvement in the health and safety performance of the railways in Great Britain.

Rolling stock refers to any vehicles that move on a railway. It usually includes both powered and unpowered vehicles, for example locomotives, coaches, and wagons.

ScotRail is the brand name used for all Scottish regional and commuter rail services.

Strategic Transport Projects Review sets out the Scottish Government's transport investment priorities.

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Transport Scotland
Buchanan House
58 Port Dundas Road
Glasgow
G4 0HF

0141 272 7100

info@transport.gov.scot

ISBN: 978-1-911582-92-2

Further copies of this document are available, on request, in audio and visual formats and in community languages. Any enquiries regarding this document / publication should be sent to us at info@transport.gov.scot

This document is also available on the Transport Scotland website: www.transport.gov.scot

Published by Transport Scotland, July 2020

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