



RAIL INDUSTRY DECARBONISATION TASKFORCE

FINAL REPORT TO THE MINISTER FOR RAIL

JULY 2019 | WITH THE SUPPORT OF RSSB







Foreword

I am pleased to present, on behalf of the Rail Industry Decarbonisation Taskforce and RSSB, the final report responding to the UK Minister for Rail's challenge to the industry to remove "all diesel only trains off the track by 2040" and "produce a vision for how the rail industry will decarbonise."

The initial report, published in January 2019, set out credible technical options to achieve this goal and was widely welcomed by stakeholders.

RIA has published its report on the Electrification Cost Challenge. This final report confirms that the rail industry can lead the way in Europe on the drive to decarbonise. It sets out the key building blocks required to achieve the vision that the rail industry can be a major contributor to the UK government's¹ target of net zero carbon^{2,3} by 2050, provided that we start now.

The GB rail system continues to be one of the lowest carbon modes of transport. It has made material progress in the short time since the publication of the initial report.

- The industry has continued to develop technologies toward lower carbon.
- RSSB has completed its technical report into decarbonisation, T1145.
- The investigation into alternatives for freight, T1160, is well underway.
- The Network Rail System Operator is conducting a strategic review to develop the lowest cost pathway for rail to decarbonise to contribute to the national net zero carbon target.

The Taskforce is very cognisant of the government review of the rail industry ongoing under the independent chairmanship of Keith Williams and we have provided evidence accordingly. Throughout this report we have endeavoured to use the current structures and bodies, rather than cutting across the Williams review and/or suggesting the need to create new bodies and interfaces. We looked at the improvements in safety achieved within the industry and have sought to adopt similar principles; action plans at a 'local' level contributing to an overall strategy, named individuals responsible and overall monitoring body.

It remains our view that the removal of diesel only passenger trains from the national rail network by 2040 and the whole industry contributing to the government's net zero carbon target by 2050, is achievable. We note that the most cost-effective way to achieve net zero carbon may be to net off some residual rail emissions within the wider UK carbon reduction effort. However, a number of key decisions have to be taken from this point on, with the clear target of net zero carbon by 2050 or before.

¹ The Scottish Government is considering complementary initiatives to decarbonise rail, supported by engagement with stakeholders, in line with the outline strategy presented by the RSSB. The Scottish Government has acted on the advice from the Committee on Climate Change by lodging in September 2019 amendments to the Climate Change (Scotland) Bill to set a legally binding target of net-zero greenhouse gas emissions by 2045 at the latest.

² Net zero carbon is defined in Annex A: Definitions and explanatory notes. Where this report refers to 'net zero carbon' and the scope is not defined in the context, 'net zero carbon' should be read as applying to the UK economy and not specifically to the rail industry.

³ The overwhelming majority, approximately 99%, of greenhouse gas (GHGs) emissions in the rail industry are in the form of CO₂, as per the final 2016 emissions data tables published by BEIS in 2018. In this report, 'carbon', 'GHGs' and 'emissions' may be regarded as synonymous unless the context explicitly makes a distinction.



“GB RAIL CAN BE A MAJOR CONTRIBUTOR TOWARD NET ZERO CARBON BY 2050.”

Building on the initial report, this final report makes five strategic recommendations for all involved in GB rail to achieve this objective.

- **Targets** – the rail industry, including government, should support the target of net zero carbon by 2050 as proposed by the Committee on Climate Change (CCC).
- **Policy** – the whole rail industry has responsibility to contribute to net zero carbon in a cost-effective manner. To facilitate this, the government should set out clear, consistent and enabling policies.
- **Industry structure** – from the Williams Review we should have an industry structure which effectively enables, incentivises, monitors and regulates the route to support delivery of net zero carbon.
- **Delivery plan** – each key constituent of the industry eg Network Rail, TOC, FOC, ROSCO etc, should publish a long-term plan to achieve interim and long-term targets towards rail decarbonisation in support of net zero carbon by 2050. These will be reviewed, monitored and regulated by a central body.
- **Research and Development** – the industry should set out clear 5-year periodic research plans to reduce technical and implementation uncertainties.

These recommendations are further expanded in this report.

GB Rail can be a major contributor toward net zero carbon by 2050. The Taskforce has considered a number of pathways toward reducing carbon, which are detailed in the report, what is clear is that a significant decarbonisation by 2050 can only be achieved with a balanced and judicious mix of cost effective electrification, coupled with the deployment of targeted battery and hydrogen technology where these are the best solution.

There are examples throughout where the industry is already adopting low carbon initiatives. A simple way to view carbon reduction is to view it as waste reduction, and to treat carbon in the rail industry as a form of waste which comes with a cost. Therefore, carbon reduction should not just be viewed as an end in itself, but also good business practice. Thus, our recommendations are rooted in making business decisions based on customer, cost and carbon.

In conclusion we are encouraged by the steps already taken by the whole industry, however we need to accelerate our activity. We make our five recommendations to take GB rail forward and to be a major contributor toward net zero carbon by 2050 and enable our industry to become a world leader in delivering low carbon solutions.

*Malcolm Brown,
Taskforce Chairman*



Key recommendations

We have identified five strategic recommendations to provide a clear goal, robust and consistent leadership and a framework for innovation.

1. Targets

Government should commit the railway to playing a major role in contributing to the national net zero carbon target by 2050. This means that rail will need to move well beyond 'business as usual' in decarbonising its operations, to deliver a step change in planning, investment and delivery. A process should be put in place to develop interim targets consistent with this. This process should be the responsibility of a named technical body that is consistent with the results of the Williams Review. In the interim this should sit with RSSB. The details of the targets will be subject to confirmation of the lowest whole system cost, to be developed in the Traction Decarbonisation Network Strategy, which will report back in October 2020.

The target for rail freight should be contingent on the approach taken across modes. It should recognise the National Infrastructure Commission's (NIC) recommendation for a detailed cross modal analysis of the long-term options for rail freight's transition to zero emissions.


2. Policy

Government should set out a clear policy position that defines the expectation of rail in delivering net zero carbon. This should lay down that a suitable mix of zero-carbon traction technologies – currently battery, hydrogen and electrification – should be developed. It should include a long-term target and outline how this will be delivered through public procurement and specifications. The policy should be enabling, not prescriptive. It should allow the industry to maximise its ability to innovate and deliver against the agreed target in the most cost-effective manner.

The policy for rail freight should be contingent on the analysis recommended by the NIC (above) and align to the NIC's recommendation for government to publish 'by the end of 2021, a full strategy for rail freight to reach zero emissions by 2050, specifying the investments and/or subsidies that it will provide to get there'.

3. Industry structure

The Williams Review should ensure that any future industry structure enables and incentivises the move to net zero carbon. Fundamental to this is aligning incentives, risk and reward to maximise opportunities for successful, cost-effective decarbonisation. The structure should give clarity over where the responsibilities lie for target setting, research and development, monitoring, and regulation.



“GOVERNMENT SHOULD SET OUT
A CLEAR POLICY POSITION THAT
DEFINES THE EXPECTATION OF RAIL
IN DELIVERING NET ZERO CARBON.”

4. Delivery plan

The key industry elements, including Network Rail, TOCs, FOCs and ROSCOs⁴ should set out plans to deliver against the agreed target and published policy. These should identify levels of investment, timescales and key decision points. As a first step in this, the Taskforce has noted and supports the System Operator’s Traction Decarbonisation Network Strategy.

Network Rail and its regions, passenger and freight operators and ROSCOs should embed carbon management in their management systems and standards. Named executives should be responsible for the delivery of carbon emissions reductions.

5. Research and development

The industry, through RSSB, Network Rail, RDG and RIA⁵, should set out a clear periodic 5-year research plan to reduce the uncertainties identified in this report. This should align with the work of the cross-industry Technical Leadership Group and be reflected in the planned refresh of the Rail Technical Strategy. Key areas for this include:

- freight and yellow plant decarbonisation, building on the current RSSB-led research project
- increasing the capabilities of battery and hydrogen, including through developing appropriate infrastructure and reducing whole system costs
- reducing the whole system cost of electrification, including through various forms of intermittent electrification
- increasing efficiency of both current and future rolling stock as well as infrastructure
- increasing the ability to model and measure system wide carbon emissions, arising from both operational and capital works.

⁴ Train operating companies, freight operating companies, rolling stock leasing companies

⁵ Rail Safety and Standards Board, Railway Industry Association and Rail Delivery Group



Executive summary and detailed recommendations

The remit we accepted as a Taskforce was to propose how to remove diesel-only trains from the network by 2040 and to develop a vision as to how the rail industry might decarbonise across traction, property and infrastructure. We published our initial report, which focused on credible technical options, on 31 January 2019. The Rail Minister then asked us to consider in our final report what decarbonisation targets should be recommended for the industry.

As we finalised our report and recommendations, the government, on 27 June 2019, committed to a legally binding net zero carbon target for the UK as a whole. The Taskforce fully supports this clear and longer-term intention. It has allowed us to state, with greater confidence, that our recommendations fit squarely within the wider national context.

Two recent major reports have influenced the government's position, and also the Taskforce. Firstly, the National Infrastructure Commission (NIC) published its national freight transport study⁶ on 17 April 2019, then the Committee on Climate Change (CCC) published its recommendations to the government on a revised national carbon target⁷ on 2 May 2019.

The CCC recommended that the 'UK should set and vigorously pursue an ambitious target to reduce greenhouse gas emissions (GHGs)⁸ to 'net-zero' by 2050, ending the UK's contribution to global warming within 30 years.⁹ Although it was published first, the NIC study recommendations were set in the context of that expectation: 'Delivering the UK's climate targets will require decarbonisation of transport. It is therefore a question of how to decarbonise the railway for both freight and passengers, rather than whether it should be done.'¹⁰

Rail is a naturally low-carbon transport mode, comprising less than 2.5% of total transport emissions and only about 0.6% of the UK's total emissions. The industry has been focussed on reducing those emissions. It has considered trainsets that might operate in lower-carbon modes, such as diesel/electric hybrids. However, these are incremental improvements. At the rate they are being adopted in the current policy, financial, and operational environment, they will not deliver change anywhere near fast enough.

6 National Infrastructure Commission (17 April 2019), Better Delivery: The Challenge For Freight – Freight Study final report, <https://www.nic.org.uk/publications/better-delivery-the-challenge-for-freight/> viewed 17 April 2019

7 Committee on Climate Change (2 May 2019), Net Zero – The UK's contribution to stopping global warming, p.11, <https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/> viewed 2 May 2019

8 Definitions and explanatory notes of key terms are at Annex A

9 Committee on Climate Change, *ibid*, p.119

10 National Infrastructure Commission (April 2019), p.10



“WE HAVE CONFIRMED THAT THE
RAILWAY REMAINS A VERY LOW
CARBON FORM OF TRANSPORT FOR
BOTH PASSENGERS AND FREIGHT.”

The transport market is operationally and commercially challenging. But the rail industry recognises that decarbonisation is possible and is willing to accept this challenge if rail is allowed to compete on a level playing field with other transport modes. The recommendations we make below assume that the same net zero carbon target is applied in a balanced manner to the wider UK economy. In particular, to other transport modes that are or will be in direct competition with rail for the same passengers and freight.

The urgency in the wider national context emphasises the immediacy of the actions needed to deliver the 2050 target. It is clear that key decisions on the purchase and, by extension, the refurbishment of rolling stock must be taken very soon. A significant proportion of this rolling stock will have a serviceable life well beyond the 2040 date for removing diesel-only trains and probably beyond the 2050 date for net zero carbon. To minimise the loss of economic value of replacing rolling stock early, it will be necessary to manage transitional arrangements such as the need to convert or re-engine vehicles. Some of these decisions will need to be made within the next one or two years.

The Williams Rail Review¹¹ will report later in 2019. Keith Williams has stated the need for the railway to work as a total operating system. He has highlighted its inability, in its current format, to bring through system-wide responses to strategic issues such as CO₂ reduction.¹² The Taskforce is pleased that the Williams Review team has identified the need to consider decarbonisation in their work.

Traction is the single biggest source of carbon; and the part of the industry where the greatest change is possible within the 2040 target date. We have established that, alongside electrification, the two technologies that are likely to be sufficiently mature to make a significant decarbonisation impact by 2040 are hydrogen and battery power.

¹¹ The Williams Rail Review. See <https://www.gov.uk/government/collections/the-williams-rail-review>, viewed 8 May 2019

¹² Keith Williams speech at Accelerate Rail, 19 March 2019. See https://www.gov.uk/government/speeches/keith-williams-at-accelerate-rail-2019?utm_source=8e7f09a7-a975-48a5-95a9-d67a2fb80c2c&utm_medium=email&utm_campaign=govuk-notifications&utm_content=daily

We developed a ‘top down, bottom up’ approach that we believe will result in the most cost-effective way to achieve net zero carbon. This is illustrated in the figure below. This approach seeks to balance the benefits of electrification on intensively-used lines with the benefits of emerging new technologies in areas where electrification is clearly not the right answer.

Likelihood of electrification	Most likely long term traction mode	Key decision issue(s)	
Existing electrified network	Always run electric	None	Top down case for electrification
Case for infill electrification	Transition to always run electric	Timing, transition arrangement	
Limited access to electrified network	Uncertain solution; not pure electric	Final traction option(s); transitional arrangements	Squeeze sub-optimal solutions in geography and time may depend on policy rather than cost and other factors
Will never run on the electrified network	Best non-electric option	Least cost, lowest carbon	
			Bottom up case for other traction modes

This involves a combination of:

- additional, progressive electrification of more intensively used routes in line with an agreed, practicable cost of electrification as both the lowest whole life carbon solution and the lowest practicable whole life cost option
- beginning to implement alternative zero or low carbon solutions, where we know electrification will never be the lowest whole life carbon and cost option (primarily battery and hydrogen, where their performance capabilities meet journey requirements)
- driving significant carbon reduction where diesel cannot be replaced by anything other than electrification due to its very high energy density (the case for most types of freight and yellow plant)
- using diesel and diesel bi-modes on a transitional basis until electrification works are complete, even if there is agreement to electrify key lines which carry high speed, long distance traffic.

We estimate that there are, or shortly will be, about 3,000-3,300 diesel passenger vehicles that will need to be replaced, re-engined or converted, to decarbonise the railway. It should be possible to replace in excess of 2,400 vehicles with alternative low-carbon traction options such as hydrogen and battery trains. This will leave about 500-900 high speed vehicles where the most cost-effective option is likely to be to electrify the routes on which they run.

In developing this strategic approach, we saw that electrification options should be addressed in two steps:

1. initially a purely economic assessment in line with previous business cases.
2. on a strict comparative basis with other zero or very low carbon traction options to develop scenarios that produce the most cost-effective routes to achieving agreed carbon targets and deadlines.

When considered in the context of scenarios, our research shows that:

- it is possible to remove diesel-only passenger trains from the network by 2040
- there is the potential for diesel and diesel bi-modes to be part of a permanent solution to reduce rail carbon by 80% by 2050
- diesels and diesel bi-modes have only a limited role on a transitional basis as part of any route map to contribute to net zero carbon by 2050
- diesels and diesel bi-modes will have to be replaced, re-engined or converted (and no new ones brought into service) as part of any route map to reach net zero carbon by 2040.

So, we conclude that the best target to aim for now is net zero carbon by 2050. The earlier we provide certainty for the rail industry, the more time it has to plan the most cost-effective, least disruptive and most robust decarbonisation pathway. It is possible, under the implementation of national net decarbonisation plans, that some residual rail emissions may be netted off against other sectors. Under those circumstances, there may be a case to retain some diesel and diesel bi-modes (or some other very efficient form of thermal combustion) for specific purposes, most likely in freight and yellow plant. This would only be where there is no justification, on whole system carbon grounds, to remove them. Any decision on any level of residual rail carbon to be offset in this respect should be part of a wider debate on how to deliver an integrated low carbon transport sector and meet national net zero carbon targets in the most cost-effective manner. The specifics of how this may be done are not discussed further in this report.

There are already credible options to decarbonise property in rail, namely stations and depots. There are examples of the use of renewable energy generation, battery storage, draught exclusion, LED lighting, energy control systems and other emerging technologies. We recommend that, where these options exist, they should be mandated. We recommend also that carbon should be factored into major refurbishments and new stations and depots. The use of carbon assessment methodologies such as PAS2080 and in-use monitoring of carbon emissions, should be mandated.

Network Rail, including the road fleet will become part of the Greening Government initiative, which sets targets for road fleet emissions reductions. We support this as it will drive the decarbonisation of Network Rail's road fleet at a pace consistent with what is being demanded of the wider road transport sector.

Infrastructure on the railway tends to be long-lasting. Where major maintenance and improvement works are planned, we again recommend that effective carbon assessment methodologies such as CEEQUAL¹³ be mandated in the project design process. And that, where relevant, carbon emissions in use are monitored.

We have been mindful that all options will affect, to a greater or lesser extent, local communities when any infrastructure and engineering works are carried out. This has been raised as an issue for electrification projects in particular. While these acute impacts may be highly disruptive to those affected, we have, in the light of our remit, focused our considerations on the long-term carbon benefits of the various options.

¹³ CEEQUAL is an evidence-based sustainability assessment, rating and awards scheme for civil engineering, infrastructure, landscaping and public realm projects, which is now part of the BREEAM family. See <https://www.ceequal.com/>

It will be necessary to make sure that the disruption caused to local communities is minimised. The implementation of any decarbonisation schemes shall be in accordance with good construction practices, particularly with agreed electrification programmes.

Decarbonisation is a long-term programme, particularly in the rail industry. We know that decisions that need to be made in the next five years or so will lock the industry into certain pathways for decades. One of the reasons why we have encountered so many challenges in looking for innovative solutions in our work as a taskforce is that we must recognise that parts of the network are of Victorian vintage and not likely to be renewed in the foreseeable future. We recommend that government, as with the visionary Climate Change Act, takes the long-term view and works with the industry to agree a stable, consistent, goal-oriented policy framework that allows the industry to make the right long-term decisions now.

We make five key recommendations. These are underpinned by a wider range of detailed recommendations.

Recommendations

Recommendation	Lead	By when
1. Targets		
<p>Government should commit the railway to playing a major role in contributing to the national net zero carbon target by 2050. This means that rail will need to move well beyond 'business as usual' in decarbonising its operations, to deliver a step change in planning, investment and delivery. A process should be put in place to develop interim targets consistent with this. This process should be the responsibility of a named technical body that is consistent with the results of the Williams Review. In the interim this should sit with RSSB. The details of the targets will be subject to confirmation of the lowest whole system cost, to be developed in the Traction Decarbonisation Network Strategy, which will report back in October 2020.</p> <p>The freight target should be contingent on the approach taken across modes, recognising the National Infrastructure Commission's recommendation for a detailed cross modal analysis of the long-term options for rail freight's transition to zero emissions.</p>	DfT	Within 12 months
<p>A single, industry-wide carbon measurement methodology should be defined and established. This should build wherever possible on reliable, publicly available datasets such as the EC4T traction energy reporting system and official datasets collected by the government for national and international greenhouse gas (GHG) reporting purposes.</p>	RSSB	Within 18 months

Recommendation	Lead	By when
1. Targets (cont.)		
A systematic methodology should be established and applied, to set pathways to decarbonise the rail industry on an integrated, system-wide basis, such as Science-Based Targets.	RSSB	Within 18 months
All industry operators, including passenger and freight operating companies and Network Rail, should be required to provide carbon emissions data at the earliest practicable opportunity. Data should be disaggregated to traction, property and infrastructure.	DfT/ORR via agreement, licence conditions or regulation	Within 1 year
A central body for carbon management in the industry should be remitted to set and endorse interim targets, monitor and regulate performance.	ORR or other body under remit from DfT dependent on outcome of Williams Review	Remit within 12 months Operational within 2 years
2. Policy		
Government should set out a clear policy that defines the expectation of rail in supporting the delivery of national carbon targets. The policy should be enabling, not prescriptive, to allow the industry to maximise its ability to innovate and deliver against the agreed target in the most cost-effective manner. The freight policy should be contingent on the analysis recommended by the NIC being done, as noted above, and align to the NIC's recommendation for government to publish 'by the end of 2021, a full strategy for rail freight to reach zero emissions by 2050, specifying the investments and/or subsidies that it will provide to get there.'	DfT	Within 12 months
The policy position should specifically address the need for planning and investment to extend beyond the short timeframes inherent in existing franchises and funding agreements. Robust residual value transfer agreements or other mechanisms should be set up, which will, where necessary, encumber future contracting parties.	DfT	Within 12 months
The policy should address requirements around industry structure and governance of carbon performance. It should give clarity on how industry targets will be embedded in contracts and other enforceable requirements.	DfT	Within 12 months

Recommendation	Lead	By when
3. Industry structure		
<p>The Williams Review should ensure that any future industry structure enables and incentivises the move to zero carbon. Fundamental to this is aligning incentives, risk and reward to maximise opportunities for successful, cost-effective decarbonisation. The structure should give clarity over where the target setting, research and development, monitoring and regulation sit.</p>	Williams Review	Autumn 2019
<p>The government should indicate its support for the Williams Review recommendation and the timeline for implementation, identifying interim solutions to ensure continued progress.</p>	DfT	Within 6 months of the publication of the Williams Review
4. Delivery plan		
<p>The key industry elements, including Network Rail, TOCs, FOCs and ROSCOs should develop strategic plans to deliver against the agreed target and published policy. These should detail levels of investment, timescales and key decision points. As a first step in this, the Taskforce has noted and supports the System Operator's Traction Decarbonisation Network Strategy.</p> <p>Network Rail and its regions, passenger and freight operators and ROSCOs should embed carbon management in their management systems and standards. Named executives should be explicitly responsible for the delivery of carbon emissions reductions as necessary.</p>	TOCs, FOCs, Network Rail, Network Rail Regions, ROSCOs	Within 2 years
<p>The Traction Decarbonisation Network Strategy now being developed should identify preferred combinations of electrification, hydrogen and battery traction options to achieve the most cost-effective low carbon outcome. This should consider not only the preferred long-term solution but also the most effective transitional arrangements.</p>	System Operator, Network Rail	Within 18 months
<p>Following the Network Strategy, Network Rail Regions, through the strategic business planning for CP7, should develop a progressive and judicious decarbonisation programme in line with the agreed network strategy.</p>	Network Rail Regions	2022-2024 subject to confirmation of the planning timetable for CP7 preparations

Recommendation	Lead	By when
4. Delivery plan (cont.)		
There should be a detailed review of ways to incentivise a transition to lower carbon forms of traction, capital and major refurbishment works. Ideas such as variable track access charges, some form of carbon tax, incentives to generate additional renewable energy, and increased R&D aimed towards adapting low carbon forms of tractive power should all be considered as part of such a review.	Independent, commissioned by industry potentially through cross-industry research fund	Within 18 months
All major construction and refurbishment projects, whether repair, renewal or new build, above a minimum project value threshold, should mandate an effective carbon assessment (such as PAS2080 ¹⁴ or suitably modified BREEAM ¹⁵ assessment) to minimise lifecycle carbon impacts.	Network Rail	Within 18 months
The recommendations of the 'Zero Carbon Stations' report ¹⁶ should be implemented on all stations across the rail network where this is cost-effective to do so. The aim is to achieve zero carbon energy use for all heating and lighting in, at least, common station areas. Any exceptions should be considered through a defined process.	Network Rail for directly managed stations. DfT for stations that are managed under franchise	
<p>To the extent possible, yellow machines – both dedicated on-track and road/rail – should seek to replace diesel engines with electric motors at the earliest economic opportunity. These are to be powered from appropriate energy storage and pantographs or other acceptable power sources.</p> <p>Where it is not feasible to replace diesel engines on yellow machines with electric motors, they should be inventoried on a regular basis. This would be to establish, from evolving technology and technical improvements in the automotive sector, what potential there is to remove diesel power from the system in a cost-effective manner.</p>	Network Rail and supply chain	Review process to be determined within 18 months

14 Publicly Available Specification, PAS 2080:2016 Carbon management in infrastructure. See <https://shop.bsigroup.com/ProductDetail?pid=000000000030323493>

15 Building Research Establishment Environmental Assessment Method. See <https://www.breeam.com/>

16 Ricardo report for RSSB (6 November 2017), Zero Carbon Stations Feasibility Study for Category C, E and F stations. Unpublished

Recommendation	Lead	By when
4. Delivery plan (cont.)		
<p>There should be a survey of all static sources of power, such as diesel generators on the railway. These should be removed where no longer needed or where an alternative, such as possession lighting, exists. They should otherwise be replaced by renewable energy generation and storage options. Where feasible, this should be on a progressive cycle, either on natural renewal dates, or where inspections show that the existing generators no longer work economically.</p> <p>Where renewable energy generation and storage systems are not feasible, such power sources should be replaced, where possible, with power sources that meet minimum carbon efficiency and emissions standards, such as fuel cells.</p>	Asset Managers, Network Rail	Survey completed within 12 months
<p>The Network Rail road fleet should comply fully with all applicable low carbon initiatives mandated for government vehicle fleets. It should meet the government's ambition for all new cars and vans to be effectively zero emission by 2040. Where targets have to be set for zero- and low-emission vehicles to aid procurement decisions, or where investment decisions are made by the routes and not by NR fleet management, a process should be developed and implemented to ensure that this is done in a cost-effective and risk-managed manner.</p>	Road Fleet Manager, Network Rail	Process and implementation plan developed within 12 months
<p>On completion of the RSSB study, <i>Decarbonisation and air quality improvement of the freight rail industry</i>, at the end of 2019 recommendations on freight (and yellow plant) should be updated in the light of its findings.</p>	All relevant recommendation owners	Within 12 months

Recommendation	Lead	By when
5. Research and Development		
<p>The industry, through RSSB, Network Rail, RDG and RIA, and aligning with the Technical Leadership Group, should set out regular 5-year research plans, initially to cover the 2020-21 to 2024-25 planning periods, to reduce the technical uncertainties identified. Key areas for this include –</p> <ul style="list-style-type: none"> • freight (and yellow plant) decarbonisation, building on the current RSSB led research project • increasing the capabilities of battery and hydrogen, including through developing appropriate infrastructure • reducing the whole system cost of electrification, including through discontinuous electrification • increasing efficiency of both current and future rolling stock and infrastructure • increasing the ability to model and measure system wide carbon impacts. 	RSSB, Network Rail, RDG, RIA	By end of 2019/20
<p>Network Rail should continue its work in understanding the drivers of cost and variation in programmes of electrification, including continued analysis of the previous portfolio. The Traction Decarbonisation Network Strategy will be informed by a better understanding of efficient electrification costs, driven both by this analysis and the RIA Electrification Cost Challenge. Differences between the analyses should be understood. These costs will inform business case analysis to support the strategy.</p>	Network Rail	18 months
<p>Network Rail should review the ongoing findings of Project Levatus¹⁷ in the light of the recommendations of the Williams Review in conjunction with the designated oversight body. This is to ensure that carbon management of both directly managed property assets and Network Rail-owned but separately managed property assets are coordinated in a consistent and integrated manner.</p>	Network Rail	As results are generated

17 A work programme consolidating a range of energy and carbon reductions initiatives. See paragraph 85



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The challenge and remit

1. On 12 February 2018, Jo Johnson MP, then UK Minister for Rail, called for the rail industry to take ‘all diesel-only trains off the track by 2040’ and to propose ‘a clear, long-term strategy with consistent objectives and incentives’ with ‘ambitious and bold plans on decarbonizing the whole rail sector.’
2. In response, the rail industry set up the Decarbonisation Taskforce (the Taskforce) under the Chair of Malcolm Brown, then CEO of Angel Trains. This comprised representatives from the major parts of the rail industry including Network Rail, the Rail Delivery Group, the Rail Freight Group, the Railway Industry Association and RSSB, which also provided the secretariat and technical authorship. The purpose of the Taskforce was to draft a collective response to the challenge, including a route map to delivering the mission, which will embed delivery in business as usual. The agreed Vision and Mission of the Taskforce were:


Vision

For the UK to have the world’s leading low-carbon railway by 2040.

Mission

To move UK rail to the lowest practicable carbon energy base by 2040, enabling the industry to be world leaders in developing and delivering low carbon transport solutions for rail.

3. The full remit and membership of the Taskforce are set out in Annex B.
4. The Taskforce split the task into three sections, in line with the remit, to consider the key elements that will need to be decarbonised:
 - **Traction:** trains and how they are powered. There are over 14,000 passenger vehicles and around 850 freight locomotives available for service. This is by far the largest part of rail’s footprint and the primary focus of this report.
 - **Property:** buildings such as stations and depots. There are around 2,500 stations and over 500 depots on the network, as well as various office buildings and commercial properties.
 - **Infrastructure:** all other elements of the railway necessary for trains to operate, including the rail lines themselves, points, signalling, power supplies, control systems, telecommunications, maintenance and renewal capability, and associated road fleets. These will have significant dependencies on traction types, the operation and management of trains on the network, and the maintenance and renewal of the network. There are over 15,000 route km on the GB network.



“A CLEAR, LONG-TERM STRATEGY WITH CONSISTENT OBJECTIVES AND INCENTIVES”

5. In the Taskforce’s initial report, published on 31 January 2019, we noted that:
 - a. the GB rail system is one of the lowest carbon forms of transport
 - b. significant levels of collaborative thinking already under way to develop innovative solutions should be supported with a strong industry-led research and development programme
 - c. the removal of diesel-only passenger trains from the network by 2040 could be done with a balanced mix of electrification, efficiency improvements and the introduction of new traction options
 - d. the picture for freight and yellow plant is a lot less clear and further work would be necessary in these areas to find solutions
 - e. significant progress would require the industry and government to work together to develop long-term policies to drive decarbonisation and avoid unintended consequences, such as an imbalance between the costs of rail freight and road haulage.¹⁸

6. In preparing this final report we have spoken to several hundred individuals, from industry, academia and government. The report builds on this engagement and the findings from the initial report to produce a series of clear and robust recommendations and sets out the evidence and thinking which underpins these. Our analysis has been supported by a research project, *Options for traction energy decarbonisation in rail (T1145)*¹⁹ commissioned by RSSB. A further study, *Decarbonisation and air quality improvement of the freight rail industry*, has been commissioned to consider freight in more detail. This project is due to report at the end of 2019 and we recommend that our recommendations on freight be updated in the light of its findings.

¹⁸ Rail Industry Decarbonisation Taskforce (2019), Initial Report to the Minister for Rail, pp4-5, <https://www.rssb.co.uk/Library/improving-industry-performance/Rail-Industry-Decarbonisation-Task-Force-Initial-Report-to-the-Rail-Minister-January%202019.pdf?web=1>, viewed 24 March 2019

¹⁹ The full content of this project is available on SPARK, www.sparkrail.org, a free, interactive web tool for the rail industry to share and find key information and help drive innovation. It may be necessary to register to access materials. See, for example, <https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=25995> for the T1145 interim report, viewed 24 March 2019




The climate context

7. On 27 June 2019, the UK government committed to set a legally binding target to achieve 'net zero' greenhouse gas emissions by 2050. This follows from the recommendation by the Committee on Climate Change. It is a world leading legal commitment for an advanced economy. It is intended to ensure that the UK plays its part in limiting the global rise in temperature to 1.5°C. The Taskforce fully supports this commitment.
8. Since the last ice age, which ended about 11,000 years ago, Earth's climate has been relatively stable. That is no longer the case. Global temperatures have risen significantly over the 20th and 21st centuries, driven primarily by the rise in atmospheric carbon dioxide (CO₂) and other greenhouse gases. Since the Industrial Revolution, atmospheric CO₂ has increased by over 40% to levels that are unprecedented in at least 800,000 years. This has caused warming throughout the climate system.
9. This warming is having effects on the global climate which include predicted temperature rises of between 1.5°C and 5°C this century above the prevailing pre-industrial climate. This will lead to a significant loss of ice cover and rising sea levels, more severe weather such as stronger storms and more prolonged droughts, and significant shifts in rainfall patterns. In northern Europe, we are already seeing wetter weather, more severe winter floods and heat waves. Many plant and animal species are increasingly struggling to cope with the pace of change. The economic costs of floods, wildfires and other storm damage is increasing and the stress on infrastructure becoming more severe.²⁰
10. The international response is framed by the United Nations Framework Convention on Climate Change (UNFCCC). It was launched in 1992 as a framework for international cooperation to combat climate change. This led to the 1997 Kyoto Protocol which binds developed countries to emission reduction targets. It was in this global context that the UK introduced the world's first statutory climate change targets with the introduction of the Climate Change Act in 2008. The Act requires that emissions of carbon dioxide and other greenhouse gases (GHGs) are reduced and that climate change risks are prepared for. It established the Committee on Climate Change (CCC) to ensure that emissions targets are evidence-based and independently assessed. The first target set in 2008 was for a cut of 80% in six greenhouse gases by 2050, on a 1990 baseline.²¹

²⁰ Adapted from https://ec.europa.eu/clima/change/consequences_en, <https://climate.nasa.gov/effects> and <https://www.wf.org.uk/effectsclimatechange>

²¹ These are, in accordance with the Kyoto Protocol, carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride



“THE CCC CONCLUDED THAT, AS PART
OF A NET ZERO CARBON SOCIETY
IN THE UK IN 2050, PASSENGER RAIL
SHOULD BE NET ZERO.”

11. In December 2015, 195 countries adopted the first universal, legally binding global climate deal, the Paris Agreement. The central aim of the agreement is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. The Paris Agreement is a bridge between today’s policies and climate neutrality before the end of the century.²²
12. On 18 November 2016, the UK government announced that it had ratified the Paris Agreement. Two years later it asked the CCC to advise on the date by which the UK should achieve net zero GHGs and carbon emissions. And what range of GHG emissions should be targeted by 2050 to deliver the UK’s contribution to global commitments to limit warming to both 2°C and 1.5°C above pre-industrial levels.^{23, 24}
13. The CCC published its recommendations on 2 May 2019, concluding that:

‘net-zero is necessary, feasible and cost-effective. Necessary – to respond to the overwhelming evidence of the role of greenhouse gases in driving global climate change, and to meet the UK’s commitments as a signatory of the 2015 Paris Agreement. Feasible – because the technologies and approaches that will deliver net-zero are now understood and can be implemented with strong leadership from government. Cost effective – because falls in the cost of key technologies permit net-zero within the very same costs that were accepted as the likely costs by Parliament in 2008 when it legislated the present 2050 target.’

The Committee also noted that:

‘Our advice is offered with the proviso that net-zero is only credible if policies are introduced to match.’²⁵

14. The CCC concluded that, as part of a net zero carbon society in the UK in 2050, passenger rail should be net zero but implicitly expected some remaining emissions in rail freight.²⁶

22 This section is adapted from pages dealing with the UNFCCC and the Paris Agreement at <https://unfccc.int/process>, and https://ec.europa.eu/clima/policies/international/negotiations/paris_en, viewed 24 May 2019

23 <https://www.gov.uk/government/news/uk-ratifies-the-paris-agreement> viewed 24 May 2019

24 <https://www.gov.uk/government/news/climate-experts-asked-for-advice-on-net-zero-target>

25 CCC (2019), pp8-9

26 CCC (2019), p.145

15. Overlapping the production of the CCC report, the government in 2017 asked the National Infrastructure Commission (NIC) to advise on the move to a low carbon national freight system. In its report published on 17 April 2019, the NIC reached a more optimistic conclusion that, 'through the adoption of new technologies and the recognition of freight's needs in the planning system, it is possible to decarbonise road and rail freight by 2050, and that this would require 'government to outline clear, firm objectives.'²⁷ The Commission also recommend that:

'Road and rail freight should have a common, single target to decarbonise fully by 2050. No part of the freight system should be indirectly subsidised by being allowed to emit carbon when other parts are decarbonising.'

Industry structure

16. The railway in GB has a notoriously complicated structure. The extensive contractual interfaces, with differing time horizons and funding arrangements, inevitably lead to situations where incentives are not aligned to deliver the most effective long-term, system-wide investment.
17. In September 2018, the government announced that Keith Williams would lead a review of the industry structure. This will report in Autumn of 2019. The terms of reference for the Rail Review are to recommend the most appropriate organisational and commercial frameworks to deliver the government's vision of:
- rail industry structures that promote clear accountability and effective joint-working for both passengers and the freight sector
 - a system that is financially sustainable and able to address long-term cost pressures
 - a railway that is able to offer good value fares for passengers, while keeping costs down for taxpayers
 - improved industrial relations, to reduce disruption and improve reliability for passengers
 - a rail sector with the agility to respond to future challenges and opportunities.²⁸
18. It is clear that the current industry structure has not incentivised the innovation and long-term investment needed for ambitious decarbonisation. Keith Williams has highlighted this, stating that the rail industry:

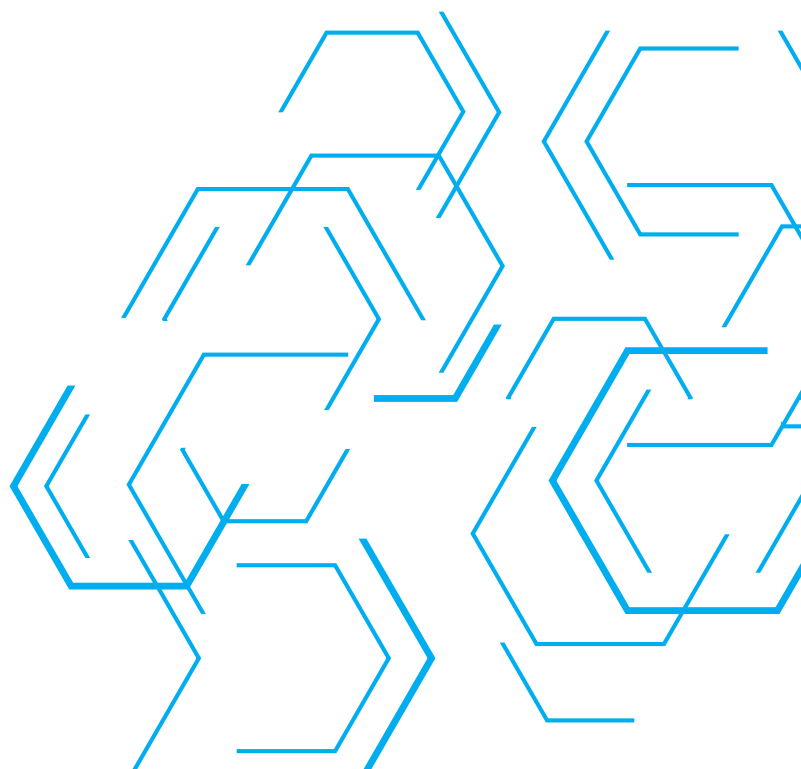
'struggles to deliver major projects and is unable to bring through system-wide responses to ... strategic issues, like CO₂ reduction...'²⁹

²⁷ NIC (2019), p.6

²⁸ Adapted from <https://www.gov.uk/government/collections/the-williams-rail-review> and the terms of reference of the Williams Review

²⁹ Keith Williams (19 March 2019), speech at Accelerate Rail. https://www.gov.uk/government/speeches/keith-williams-at-accelerate-rail-2019?utm_source=8e7f09a7-a975-48a5-95a9-d67a2fb80c2c&utm_medium=email&utm_campaign=govuk-notifications&utm_content=daily

19. The opportunity to establish a structure which is fit for purpose to deliver necessary carbon reductions will be influenced by the recommendations arising from the Williams Rail Review. Proper management of the carbon agenda demands accountability, as well as both the opportunity and the incentives to work closely among the various parts of the industry to deliver a common objective (see following page). A realistic decarbonisation programme has to support the value for money and reliability objectives expected of the industry as a whole. It must also be sufficiently flexible and robust to respond to the inevitable challenges and opportunities. A key recommendation of the Taskforce is that the Williams Rail Review fully considers the decarbonisation imperative in its work and provides a clear steer on how future industry structure and governance will support decarbonisation. Key requirements within the carbon governance system are:
- a. Setting effective and progressive interim targets to deliver the long-term policy outcome and embedding these in contracts and requirements.
 - b. Monitoring and enforcing performance against targets.
 - c. Ensuring robust, accurate and consistent data against which performance may be assessed.
20. Accepting the need for policy to support net zero carbon is a necessary but not sufficient condition to provide the best opportunity for cost-effective change. We therefore recommend that the government accept, within six months of publication, the recommendations of the Williams Review that are relevant to establishing a suitable structure and governance mechanisms for decarbonisation. This is consistent with the wider government intention to make timely progress towards net zero carbon by 2050. And is reflected in the tabling of legislation on 27 June 2019 for the UK to eradicate its net contribution to climate change by 2050.



Rail carbon footprint calculation, reporting and management

To assess the whole life implications of different traction options, a comprehensive understanding of the carbon impacts of the railway is needed, not only in operation but also in ‘capital carbon’ incurred in the construction of property and infrastructure.

The various officially reported industry emissions figures and the industry’s own estimates are sufficiently different to suggest that they are not using the same methodologies. This lack of consistency gives enough concern that we have recommended the need to produce a single, consistent methodology for collecting, collating and reporting GHG data. This will need coordination between the industry, DfT, ORR and other agencies involved in determining the UK’s overall GHG emissions reporting. Network Rail, some train operators and others in the industry have been looking at one methodology, Science Based Targets (SBT),³⁰ as a possible way to collect data and develop a single industry carbon footprint.

A recent study³¹ highlighted a number of factors that would need to be addressed to develop a cross-industry carbon assessment system. These issues, such as approach to data collection, policy, availability of resources, regulatory issues and governance mechanism, mirror those identified by the Taskforce.

Figure 1³² illustrates the complexity inherent in any comprehensive carbon footprinting process. Any process must clearly identify all carbon emission sources across the industry and assign responsibility for managing each one. To the greatest extent possible, the responsible agency should have the authority, the resources and the incentive to drive carbon emissions reductions. This means that in each case, the responsible agency should be the beneficiary of any savings, additional income or other incentives that may be available.

The encouraging collective efforts of several rail organisations to develop a common carbon data collection, management and reporting system should continue and be supported. We recommend that this should be coordinated across the industry, including NR, the train operators, contractors, DfT, ORR and other relevant policy and regulatory arms of government. It is essential to ensure the industry’s carbon footprint, both operational and capital, is:

- properly understood and accepted by all key organisations in the rail industry
- managed in a way that attributes responsibility and delivery within a consistent, transparent, properly resourced and reasonable framework.

RSSB has developed industry-specific carbon management tools and is familiar with the types of challenges that an integrated, industry-wide system might present. They are well placed to lead on coordinating this work and we recommend that they be instructed to do so.

³⁰ ‘Science-based targets provide companies with a clearly defined pathway to future-proof growth by specifying how much and how quickly they need to reduce their greenhouse gas emissions.’ ‘Targets adopted by companies to reduce greenhouse gas (GHG) emissions are considered ‘science-based’ if they are in line with the level of decarbonization required to keep global temperature increase below 2°C compared to pre-industrial temperatures.’ See <https://sciencebasedtargets.org/what-is-a-science-based-target/> and <https://sciencebasedtargets.org/faq/>. The target should now be aimed to meet levels of decarbonisation needed to keep global temperatures below 1.5°C. Viewed 12 April 2019

³¹ *ibid*, p.25

³² Arup and University of Leeds, (13 November 2018), *Outlining a robust approach to the development of science-based targets for GB rail*, p.25. RSSB, unpublished

High level map of industry context and main carbon targets and plans

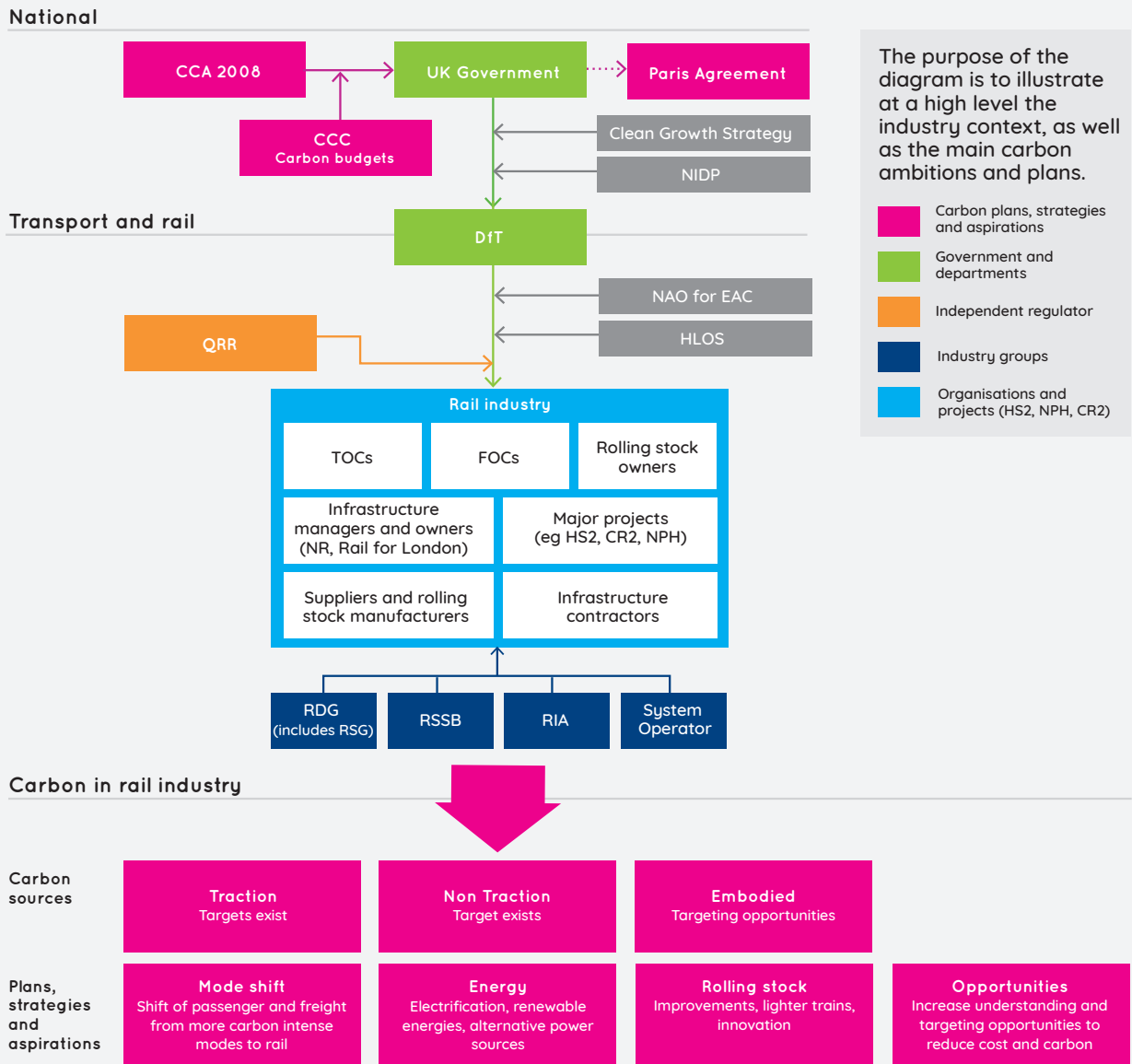
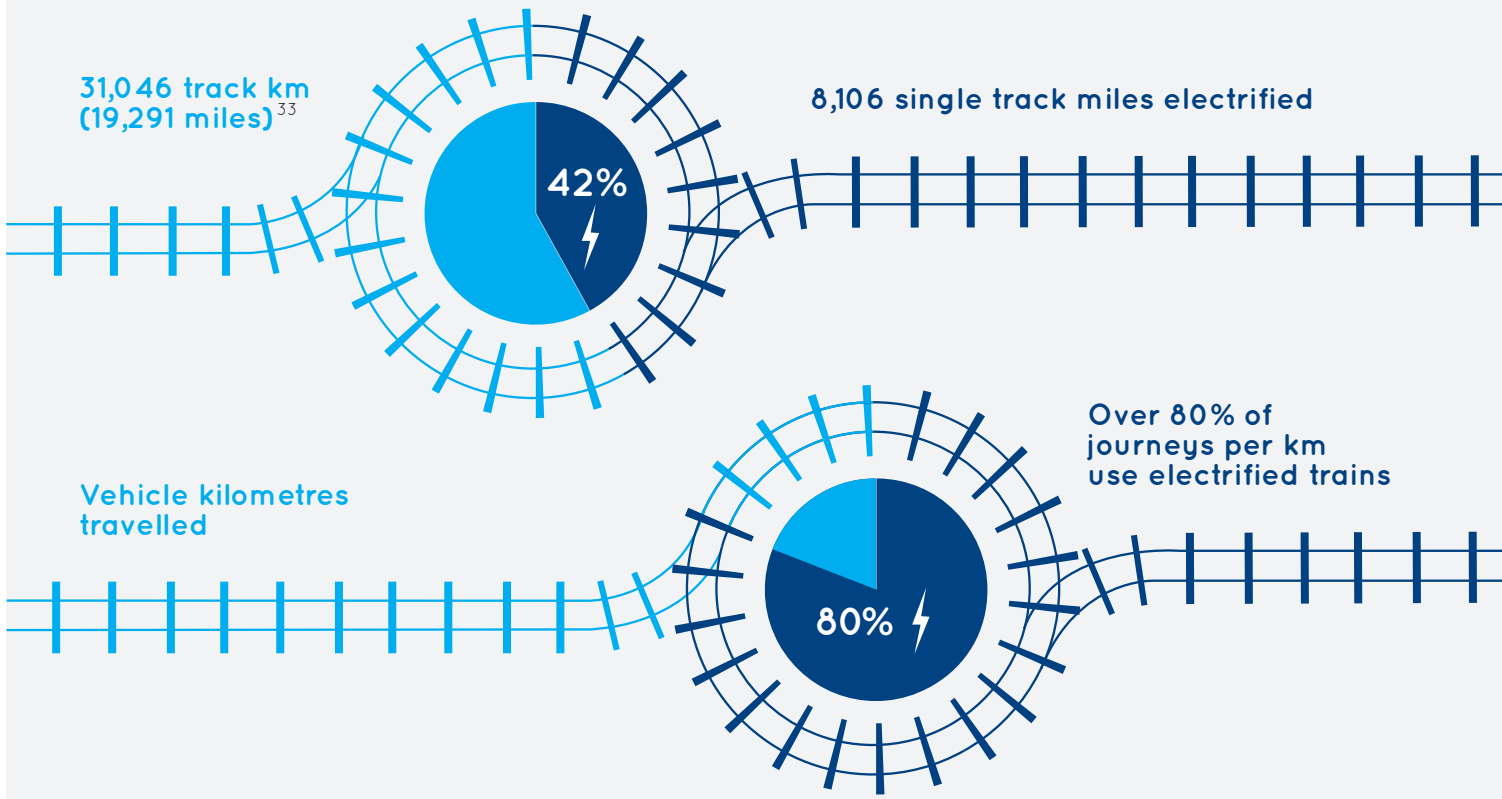


Figure 1: High level map of the rail industry from a carbon management perspective

The rail industry

How much of Britain's railway is electrified?



Rail share of total transport CO₂ emissions, 1990-2017, %

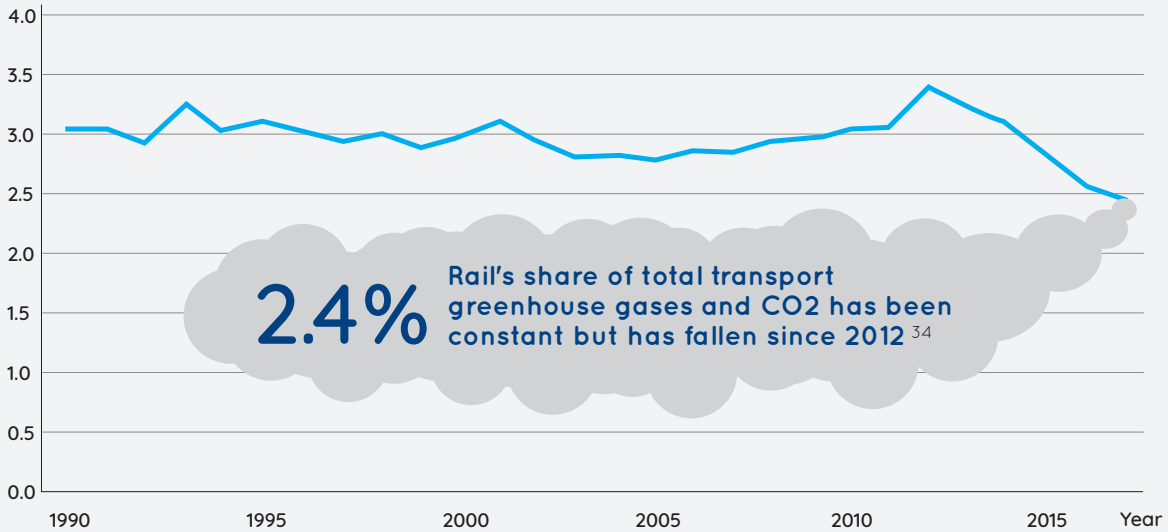


Figure 2: rail's share of total CO₂ emissions, 1990-2017

Rail's GHG emissions have reduced from 4.6 MtCO₂e in 1990, including stationary combustion, to approximately 3.5 MtCO₂e in 2017, while the transport sector's total GHGs have reduced slightly, from 146.6 MtCO₂e to 140.9 MtCO₂e.

³³ Figures drawn from ORR (October 2018): Rail infrastructure, assets and environmental statistical release 2017-18 at <https://dataportal.orr.gov.uk/media/1114/rail-infrastructure-assets-environmental-2017-18.pdf> and Rolling Stock Strategy Steering Group, (March 2018), Long Term Passenger Rolling Stock Strategy for the Rail Industry Sixth Edition, p.15. See https://www.raildeliverygroup.com/files/Publications/2018-03_long_term_passenger_rolling_stock_strategy_6th_ed.pdf, viewed 25 August 2018

³⁴ Adapted from BEIS (2019) Final UK greenhouse gas emissions national statistics 1990-2017, Table 3, at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/780395/Final_greenhouse_gas_emissions_2017_tables.xlsx, viewed 12 April 2019

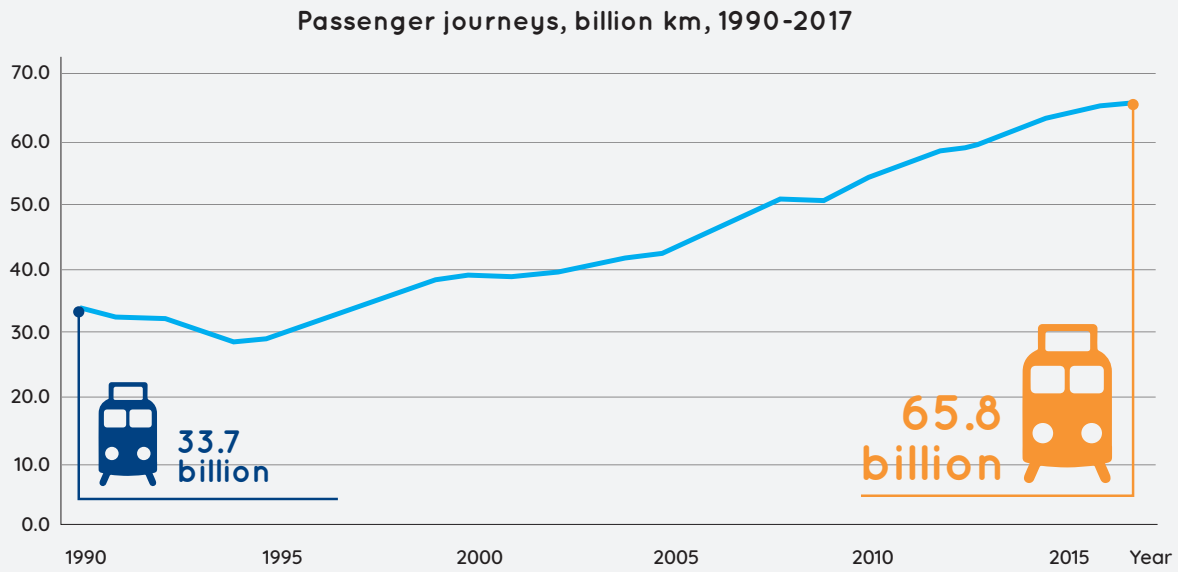


Figure 3: passenger kilometres by year, 1990-2017 ³⁵

Over 10 years

50% ▼ emissions per passenger km in the last decade

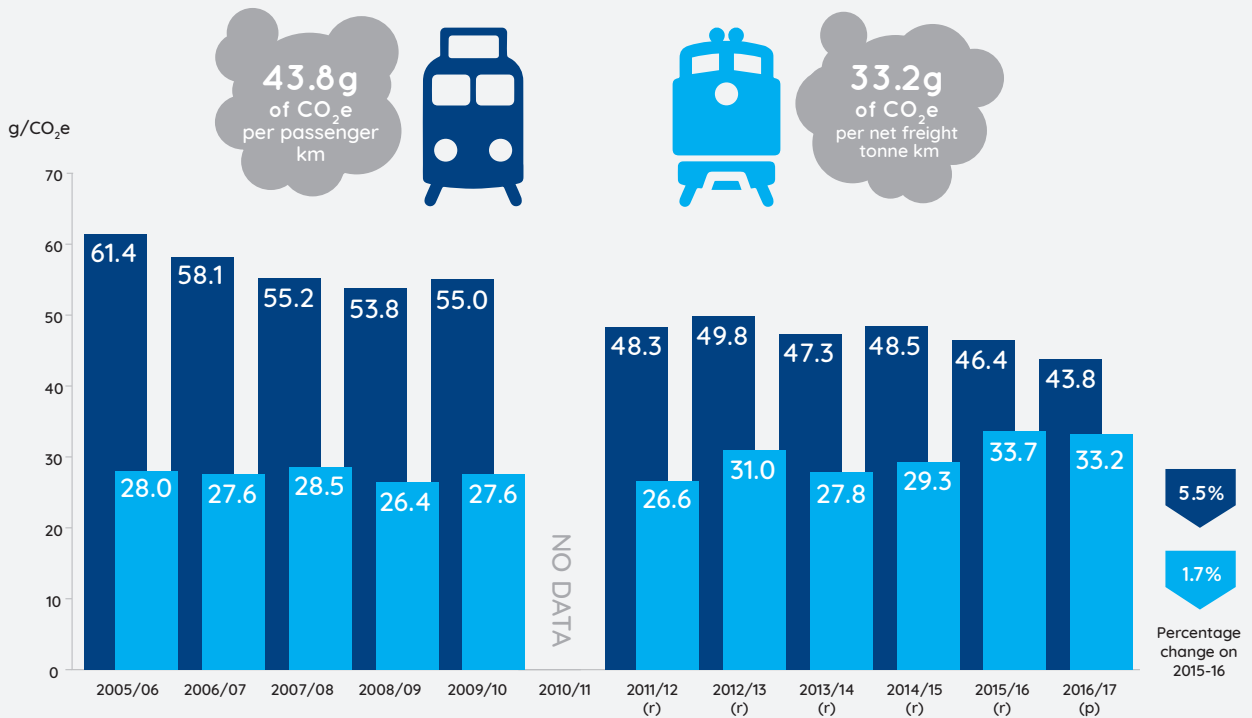
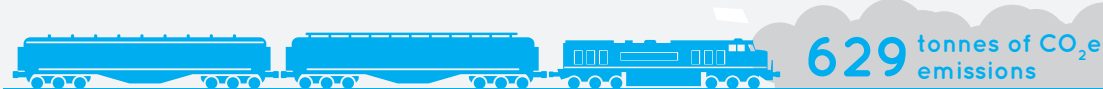


Figure 4: CO₂e impacts for passengers and freight, 2005-2017

³⁵ <https://dataportal.orr.gov.uk/displayreport/report/html/21c19868-5153-4d1c-8157-c1606b0e50>, viewed 24 March 2019

Emissions ^{36, 37, 38}

2016-17



Per tonne kilometre



25%³⁹
CO₂e

Rail emits 25% of the CO₂e of road freight

³⁶ ORR (24 October 2017) Rail infrastructure, assets and environmental 2016-17 Annual Statistical Release, p. 2-3. See http://orr.gov.uk/__data/assets/pdf_file/0008/25838/rail-infrastructure-assets-environmental-2016-17.pdf, viewed on 9 August 2018 p.11

³⁷ Ibid, p.12

³⁸ This totals almost 3.6Mt. In the previous section on overall emissions, we reported total emissions of 3.5Mt. These two figures are reporting at slightly different times, hence the difference, but are consistent

³⁹ National Infrastructure Commission (December 2018), Future of Freight Interim Report, p.13. <https://www.nic.org.uk/publications/3730/>, viewed 14 April 2019.



850 freight locomotives
in regular service

In 2017 rail freight removed:

8.2 million
equivalent road journeys



1.7 billion
road miles from the roads



Freight baseline growth



2016-17
86 million tonnes
19 billion tonne kilometres

Network Rail estimates that freight growth from a baseline of 86m tonnes and 19 billion tonne kilometres in 2016-17 to 2023-24 will range from about minus 7.7% to 50%.⁴²

40 Rail Industry Decarbonisation Taskforce (January 2019), Initial report to the Minister for Rail, p.22. <https://www.rssb.co.uk/riskcontent/rail-industry-decarbonisation-task-force-initial-report-to-the-rail-minister-january%202019.pdf> viewed 12 May 2019

41 DfT (December 2018), Number of freight train movements, impacts on road haulage and Freight Performance Measure, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/762195/rai0403 ods, viewed 14 April 2019

42 MDS Transmodal (November 2017), Rail freight forecasts: Scenarios for 2023/24.

Final Report, pp1-2. <https://cdn.networkrail.co.uk/wp-content/uploads/2018/10/Rail-freight-forecasts-final-report.pdf> viewed 14 April 2019

Our strategic approach

21. In considering decarbonisation, we have aligned our analysis to consider targets and outcomes for the 2040 date by which the industry was challenged to remove diesel only trains. We have also considered the implications of 2050 targets to align to the national carbon reduction target date. Considering both these dates has been informative in understanding how different decarbonisation targets might be delivered, both in the mix of options that could be employed, and how transitional arrangements might be delivered.
22. What is clear is that there are likely to be two distinct technology pathways, depending on the choice of targets (see Figure 5):
 - a. Removing diesel-only trains by 2040 and reaching 80% reduction on 1990 GHG emissions by 2050, in line with previous national targets, can be delivered with the continued long-term use of diesel in passenger bi-modes and in freight applications.
 - b. To deliver net zero carbon, whether by 2040 or 2050, requires a different pathway. There is no long-term role for diesel, in diesel-only or bi-mode forms, that will allow the railway to achieve net zero carbon. The mix of technologies, of electrification, battery and hydrogen, will be the same regardless of target date. The questions will be more of timing and management of transitional arrangements.

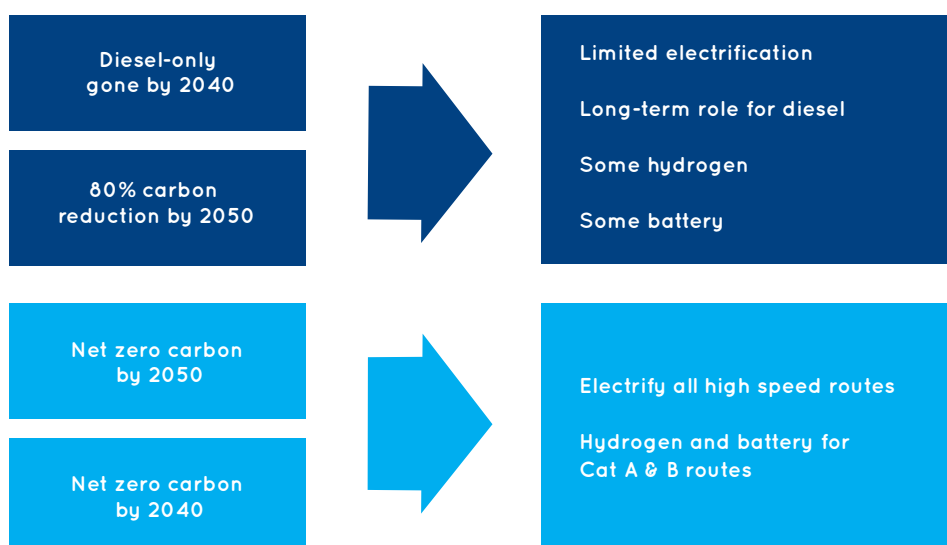


Figure 5: Two different decarbonisation pathways



“DELAYS NOW HAVE A VERY HIGH PROBABILITY OF AFFECTING CARBON OUTCOMES IN 2040 AND 2050.”

23. Our analysis shows that decisions which need to be made imminently on targets and policies, and in the next 2-5 years on vehicle procurement, will define the mix of technologies that will be in place by 2040 and 2050. Figure 6 illustrates the key milestones and vehicle replacement opportunities based on the approximate times when a significant number of vehicles in key vehicle classes reach 40 years of age. Rolling stock investments, and the necessary associated infrastructure, have long lifecycles and economic return periods. Delays now have a very high probability of affecting carbon outcomes in 2040 and 2050. If the decision now is to adopt the softer targets of removing diesel-only trains and aiming for 80% carbon reduction by 2050, then the costs of switching to a net zero trajectory later will be significantly more expensive, time-constrained and disruptive. The later any such decision to switch pathways is made, the more expensive it is likely to be. This analysis is in line with the conclusions of the CCC in regard to the mix of solutions necessary to decarbonise the wider economy.

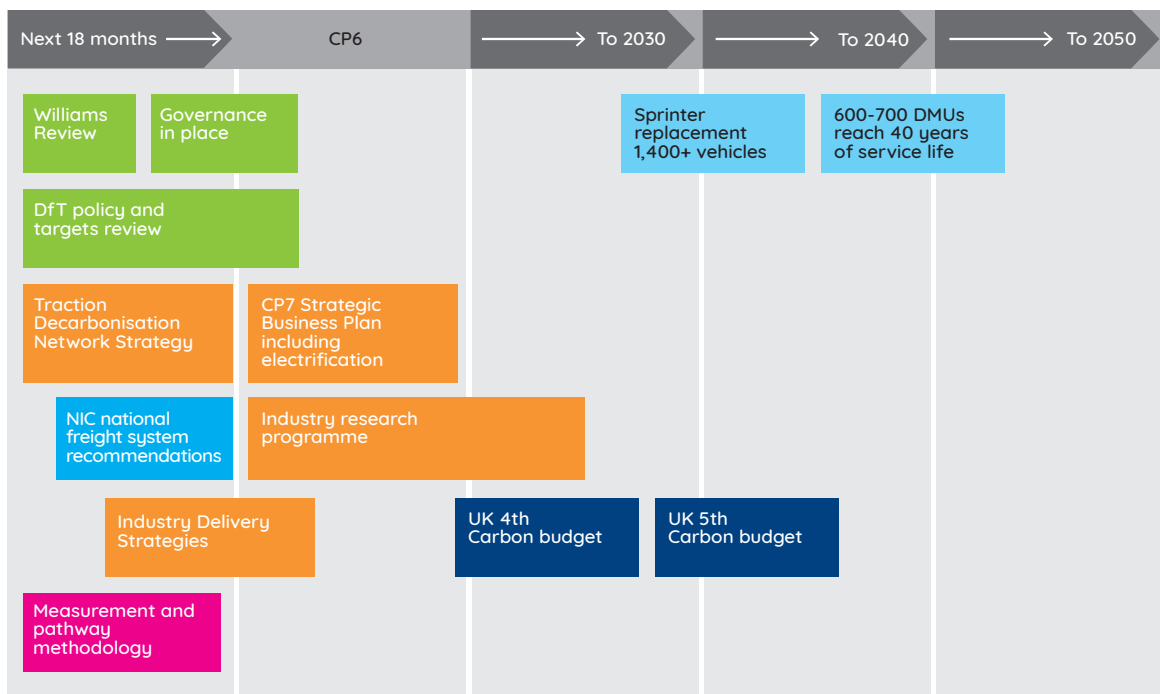


Figure 6: key milestones and vehicle replacement opportunities up to 2050

24. The economic modelling work that has been undertaken as part of the T1145 suggests that, to remove diesel-only passenger trains from the railway by 2040 and to achieve 80% carbon reduction on 1990 levels by 2050, it may be necessary to electrify about an additional 4,000 route km. By comparison, the modelling suggests that, to achieve net zero carbon, is likely to be only about 250 route km more than that. If the outputs of this high-level modelling are proved correct in more detailed analysis, the marginal additional electrification is so limited that it almost makes sense on this basis alone to decide now on a net zero carbon target by 2050. The implication would be that diesel should be used on a transitional basis only to the extent necessary to facilitate the smoothest possible rollout of the target. It should be noted that this economic model provides high level guidance only. The actual numbers will have to be assessed fully in the Traction Decarbonisation Network Strategy. This is being undertaken by the System Operator within Network Rail, and will deliver outputs in late 2020. It is discussed in more detail in paragraph 35.

Technology

25. The simplest way to eliminate carbon emissions is to reduce waste in all its forms. Measures such as removing unnecessary weight from trains, streamlining, improving timetabling to smooth journeys, even considering whether any journeys may be better serviced by other transport modes. All these ideas should be looked at in every case before looking at more complex and capital-intensive options. Simple measures such as these are almost certainly going to be cheaper ways to remove carbon from the railway than further electrification or introducing new low carbon traction options. However, these have impacts on factors both within and outside the railway other than carbon reduction. These will have to be considered to achieve the best balance between possibly conflicting priorities. The Taskforce supports the proposal by RSSB for a decarbonisation research programme which should, among other things, consider what can be achieved by these and similar initiatives.
26. Electric traction, where the line is sufficiently intensively used, provides the lowest whole life carbon impact, and delivers services that are faster, more reliable, quieter and less polluting than diesel. On less intensively used lines, the long-term benefits of electrification may not justify the investment cost and disruption caused by engineering works. Our focus throughout this report has been to challenge whether electrification is the best solution to achieve a net zero carbon railway in a manner consistent with delivering passenger benefits.
27. As outlined in our initial report, where electrification is not appropriate, battery and hydrogen are the only technologies which are likely to be readily available in the time period under consideration. Indeed, they are already in use, in single- and in multi-mode vehicles in the UK and elsewhere.
28. While there is potential for diesel bi-modes to reduce emissions, they are not able to eliminate emissions sufficiently to make a long-term contribution to a net zero carbon railway. The only occasion when we see that there is a case on a net zero carbon railway for the continued use of diesel in the long-term is where there is no other option for the delivery of a service. We consider that this is only likely to be the case for rail freight and yellow plant, where diesel provides an energy density unmatched by any fuel or power source other than electrification. In these cases, residual emissions may have to be 'netted off' either within or beyond rail. In such cases, the potential for internal combustion engines to become more efficient and, in some circumstances, to be able to combine fuels (co-firing) or to use lower-carbon fuels, will need to be considered.

Strategy

29. Taking these technology considerations into account the approach to decarbonisation must be optimised on cost, carbon and customer benefit grounds.
30. A decarbonisation strategy should minimise the lifecycle impact of introducing new traction options to the greatest extent feasible, such as through using the infrastructure already in place. Beyond this, we must minimise the need for overlapping infrastructure needs. The principles of minimising the variety of traction modes on single segments of track is a key driver of our thinking.
31. Therefore the Taskforce concludes that:
 - where trains are running on the electrified network they should be required always to use electric traction where practicable
 - further electrification should be considered where the economic and carbon case is clear, this is likely to be on intensively used and higher speed routes
 - on less intensively used routes where electrification may not be the best option, viable self-powered net zero carbon alternatives, currently most likely to be hydrogen but also possibly battery, should be put in place as rolling stock is replaced
 - where there is limited or partial access to the electrified network, hybrid options including battery/electric hybrids are likely to play a role.
32. This top-down : bottom-up approach, as illustrated in Figure 7, should focus on squeezing, over time and geography, the uncertain area in the middle where we will need to manage options which may be sub-optimal in the long term. Throughout, there may need to be transitional options as we wait for technologies to mature or infrastructure to be built. Transitional arrangements may include continued use of existing diesels and diesel bi-modes.

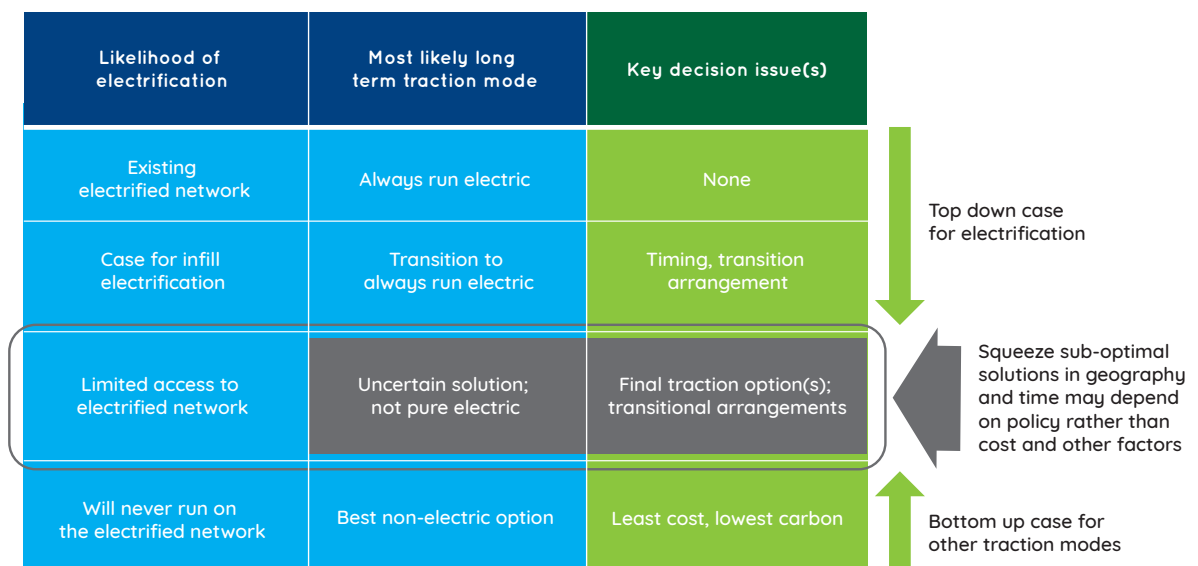


Figure 7: the approach towards optimising the traction mix

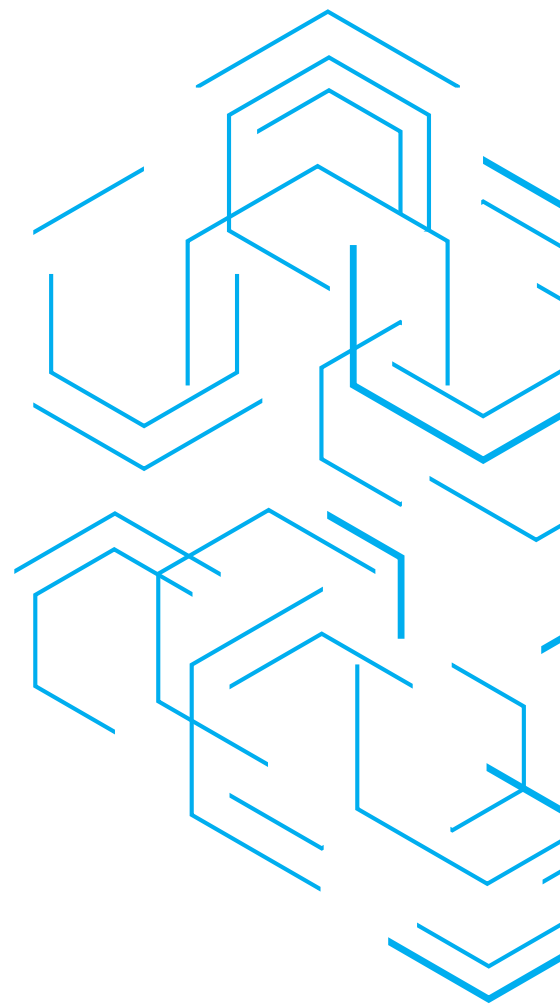
33. To demonstrate that any decarbonisation pathway is cost-effective, we need to be able to justify any decision not only on its carbon reduction potential (its strategic fit) but also on economic grounds, in accordance with the Treasury's established Green Book economic appraisal tests.⁴³ The first assessment step should be to identify where the intensity of use of the line is such that electrification is, in its own right, the sound economic decision. The second step, where the economic case in itself may not be conclusive, should be to compare the possible whole life costs and impacts against other options, to determine whether it may still be the lowest-cost option to deliver the necessary carbon reduction.
34. To support these decisions we have sought to understand, from a technical perspective, when:
- electrification is likely to be the best option
 - electrification is never likely to be the best option
 - journey demands off the electrified network will be suitable for battery or similar range extending options that are able to take advantage of access to the electrified network for charging purposes, now or at some reasonable time in the future
 - journey demands off the electrified network are not likely to be suitable for battery or similar range extending options within any reasonable timeframe
 - when the best option is likely to be one of:
 - » battery/electric self-power, charged both from the electrified network and from lineside charging points
 - » hydrogen or equivalent self-power.
35. The System Operator within Network Rail is leading a Traction Decarbonisation Network Strategy. This will develop a more detailed understanding of potential options on a geographical basis and explore in more detail the economic rationale as well as other areas of focus which make up the Treasury-approved five-case business case model. This will report back in late 2020. The Taskforce fully supports this process.
36. We also see merit in looking at other innovative financial and policy measures to incentivise the industry to innovate and implement lower carbon measures for traction, capital works and major refurbishment works. Various ideas are suggested throughout this report, and other ideas should also be considered. These may include variable track access charges, some form of carbon tax, incentives to generate additional renewable energy, and increased R&D aimed at adapting low carbon forms of traction power. We see this review as being best delivered by an independent agency, perhaps funded through cross-industry research funds. The outcomes of such a review would need to align with the outcomes proposed by the Traction Decarbonisation Network Strategy so would need to complete at around the same time.

⁴³ See <https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government> for the Green Book and associated materials. Viewed 11 April 2019

37. In developing traction route maps to illustrate credible pathways to deliver the target scenarios, the Taskforce has considered the capabilities, carbon and cost impacts of each option.

Capabilities

38. In addition to electric and diesel traction, the two options that will be sufficiently mature to contribute by the 2040 and 2050 target dates are hydrogen and battery. The research study that supported the Taskforce reviewed the potential of each option to identify their operational capabilities and constraints. This included consideration of mass, volume and gauge constraints. This has been mapped to a train type categorisation, based on and expanded from the categorisation used in the Long-Term Rolling Stock Strategy, to incorporate potential hybrid and bi-mode options. Table 1 shows which options will be technically viable for each rolling stock category.⁴⁴



⁴⁴ This is, at this point, simply a statement of which traction options are likely to be technically viable. It does not indicate which is most cost and carbon-effective.

FUTURE ROLLING STOCK CATEGORY	DESCRIPTION	TOTAL SELF-POWERED RANGE REQUIRED (MILES)	TOTAL MAX POWER PER VEHICLE (KW)	APPROX. ENGINE ENERGY OUTPUT PER VEHICLE PER DAY (KWH)	ELECTRIC		AUTONOMOUS POWER			
					AC ELECTRIC (OLE)	DC ELECTRIC (THIRD RAIL)	DIESEL	HYDROGEN	BATTERY	BIODIESEL
A	Shorter distance self-powered with 75mph maximum speed	500	275	1,200	✓	✓	✓	✓	✗	✓
B	Middle distance self-powered with 100 mph capability	800	400	2,400	✓	✓	✓	✗	✗	✓
C	Long distance self-powered with 125 mph capability	1,100	550	4,620	✓	✗	✓	✗	✗	✓
E-A	Electric to 100mph, self-powered to 75mph	250	300	600	✓	✓	✓	✓	✗	✓
E-B	Electric to 100mph, self-powered to 100mph	400	400	1,200	✓	✓	✓	✗	✗	✓
E-SH	Electric to 100mph with ability to do short hops 'off wire'	50	400	150	✓	✓	✓	✓	✓	✓
F-A	Electric to 125mph, self-powered to 75mph	250	300	600	✓	✗	✓	✓	✗	✓
F-B	Electric to 125mph, self-powered to 100mph	400	400	1,200	✓	✗	✓	✗	✗	✓
F-C	Electric to 125mph, self-powered to 125mph	550	550	2,310	✓	✗	?	✗	✗	?
F-SH	Electric to 125mpg with ability to do short hops 'off wire'	50	550	210	✓	✗	✓	✓	✓	✓
Freight	Freight loco capable of hauling 2,500 tonne trailing load	750	2,400	18,000	✓	✓	✓	✗	✗	✓

Table 1: suitability of different traction options to rolling stock categories

Green: suitable/ potentially suitable traction option for train category within 2040 timeframe

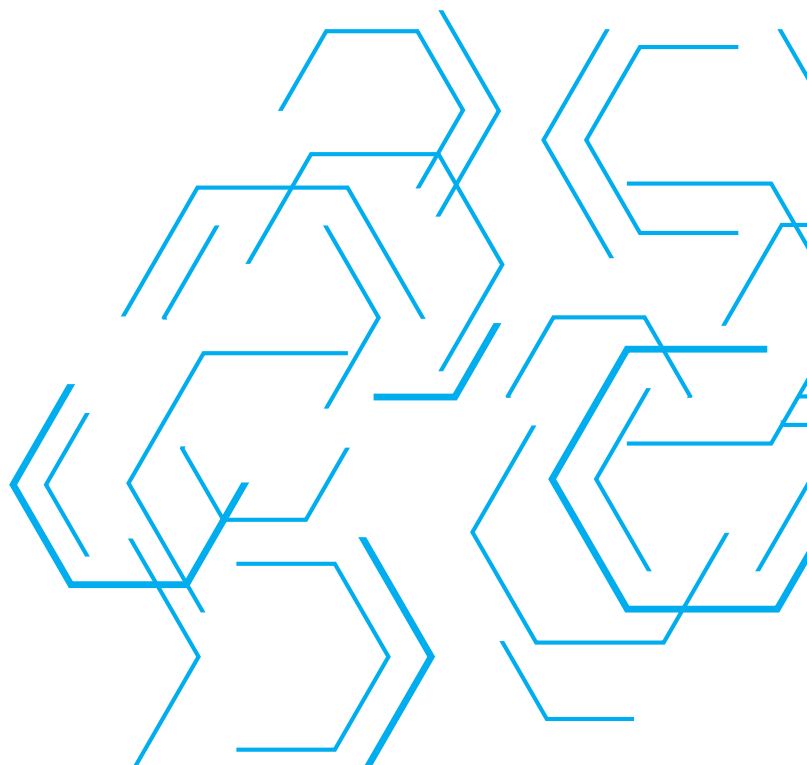
Red: not suitable

Amber: could be suitable if sufficient feedstocks could be obtained

39. We conclude that:

- For self-powered vehicles, hydrogen offers an alternative for Category A trains. It may not be viable for all Category B journeys without compromising passenger capacity. It will not be viable for Category C or freight, where electrification is currently the only viable 'net zero' option.
- The only clear widely-applicable use for battery technology as it is now on a single mode train is to power frequent stop, short hop journeys. It is likely to be much more widely used, at least in the short term, as part of a hybrid drive to boost the performance of the primary energy source and/or to bridge short gaps when needed. In short-hop applications, batteries have a notable advantage over diesel or hydrogen fuel cells, in that they can recharge 'on the go' from the overhead wires on electrified sections.
- Other than electrification there are no obvious technical alternatives to diesel for freight, assuming that both engine and fuel are to be accommodated within the same vehicle. Were it possible to tow a fuel car adjacent to the locomotive in an operationally acceptable configuration and length, hydrogen might be useable. However, in a length-constrained train the additional fuel car(s) would reduce the amount of freight hauled, increase the costs of ownership, maintenance and track access charges, and thereby often eliminate the marginal profitability of the train.

40. Technology in these areas is developing quickly and traction capabilities are now likely to exceed what was stated in published literature available for review during the research phase of T1145. The Taskforce has received credible evidence of one battery train that has an effective range of 60 miles, is capable of running at 60mph and is able to recharge sufficiently in 2 minutes to provide a range of 25 miles. Similarly, there is credible information that hydrogen trains under development will be capable of meeting all the requirements for a Category B train operating up to 100 mph.



Carbon

41. The current and future CO₂e impacts of different energy sources are fundamental to which traction options will be able to contribute effectively to meeting each target. Figure 8⁴⁵ shows that electrification is the lowest current operational carbon option of the possible energy sources. In addition to grid electricity being a relatively low carbon source of energy, its advantage is in part due to the relatively low losses in the energy cycle compared to other fuels. The forecast ongoing reduction in carbon emissions in the grid electricity mix means that it will become an even lower carbon option in the future. Green hydrogen, and green biodiesel, if produced from genuinely zero carbon processes, would be zero operational carbon. This would also be the case for electricity, if the grid completely decarbonises or if the rail network is able to use its own, certifiably additional electricity from renewable sources.

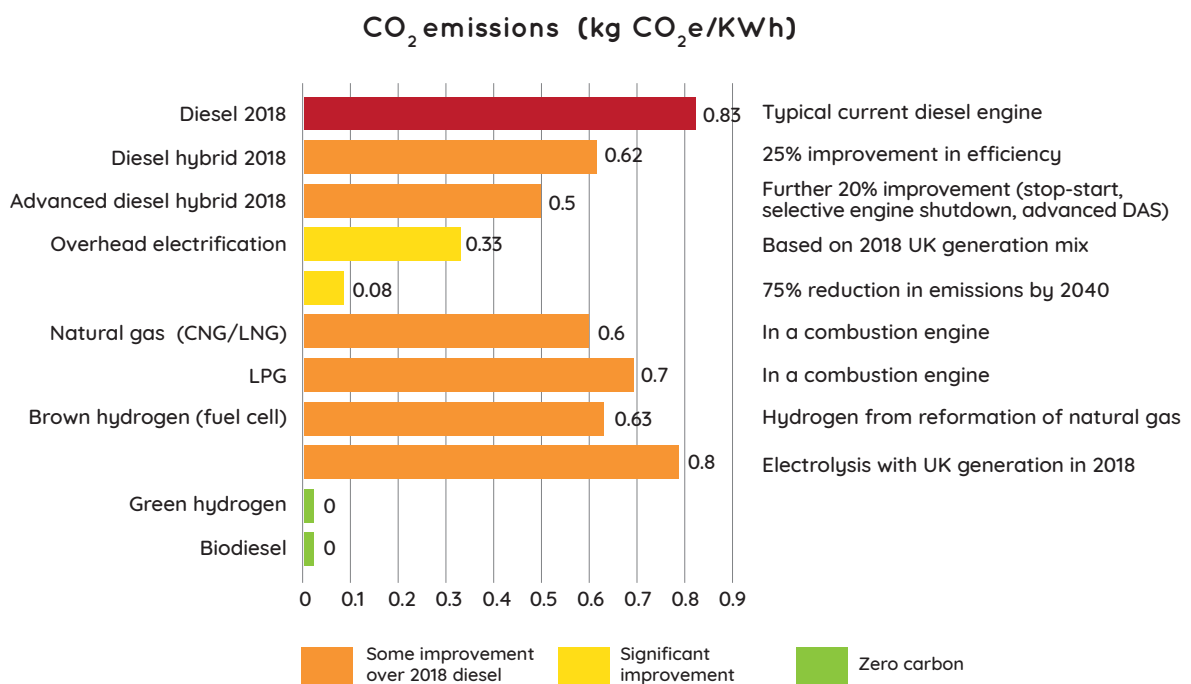


Figure 8: current and predicted CO₂ emissions produced per unit of energy consumed by a train

42. Other potential fuel sources such as liquid petroleum gas (LPG) and compressed natural gas (CNG) have limited carbon advantages over diesel and have a significant energy density disadvantage. They do not have the same capabilities as diesel at moving heavy trains or very fast trains on the UK network, and do not make meaningful inroads into the carbon reduction challenge. The CCC has stated that best uses of biomass, including biodiesel, are those which permanently remove and store carbon; and that use of biofuels in surface transport should be phased out during the 2030s.⁴⁶ This is consistent with the information the Taskforce has received from DfT that biodiesel will not be available in sufficient quantities to rail to have anything other than a marginal impact. The Taskforce acknowledges that biofuels, if available, may be useful as part of transitional arrangements in reducing the carbon impact of combustion engines.

⁴⁵ Adapted from RSSB (April 2019), T1145 – Options for Traction Energy Decarbonisation in Rail Final Report, p.ii and Table 4

⁴⁶ CCC (2019) technical report, p.140

- 43. There is an important point in any near-term decisions the industry makes on long-term decarbonisation options, given the long asset lifecycles of trains. The availability of green hydrogen of sufficient purity, however produced, at scale may have major impacts on costs. This may lie outside the control of the industry. We have been advised that, for example, decisions on a national hydrogen infrastructure are at least five years off. The rail industry will have to make purchasing decisions well within this timeframe on rolling stock that would certainly, under normal usage, be in active use in 2040 and quite probably 2050. This may mean that the most economic decarbonisation strategy is to re-power vehicles, perhaps on a transitional basis with more efficient diesel, to realise their full economic value and minimise the total cost of decarbonisation. This further supports the notion that the route maps below are simply a 'best informed' view of possibilities rather than definitive statements, and that costs, capabilities and availability of fuel stocks for different options need to be kept under review.
- 44. There is significant uncertainty on the costs of all the main decarbonisation technologies, which are outlined below. Beyond this, finding the most cost-efficient and practical way to decarbonise depends on a wide range of factors. Some are largely within the control of the rail industry, others outside (see Table 2).

Examples of factors affecting decarbonisation decisions for rail	
Endogenous	Exogenous
Industry structure	National climate change targets: extent and pace of change
Policy framework for carbon reduction	Policy framework for carbon reduction
Franchise requirements	Funding for rail decarbonisation improvements
On-site renewable energy generation	National freight strategy
Economic appraisals of traction options	Decisions on regional and national hydrogen generation, storage and distribution
Costs of electrification of segments of varying technical difficulty	Availability of batteries of suitable technical specifications
Cooperation and collaboration with road and other transport sectors	Carbon grid mix
Incentivisation for procurement of zero / lower lifecycle carbon traction vehicles	Availability of sustainable biofuels for rail
	Decarbonisation of road passenger and freight traffic
	Cost of diesel fuel for the rail industry

Table 2: example of endogenous and exogenous factors affecting decarbonisation decisions for the rail industry

45. These affect the costs of decarbonisation through:
- costs of electrification and other infrastructure to support various traction options
 - costs and availability of fuel stocks or energy, including the cost of grid-supplied and locally-generated renewable electricity
 - economic impact of possible decarbonisation trajectories
 - access to technology
 - policy and implementation of wider transport strategy for passengers and freight.
46. In March 2019, RIA published the Electrification Cost Challenge report.⁴⁷ The origins of this report were in the curtailment of the Great Western Electrification Programme (GWEP) following cost increases which fundamentally changed the cost-benefit of electrifying the line. The report uses examples from the UK and internationally to show that the high costs seen on some recent projects, including GWEP, can be avoided in the future. It suggests that significant increases in cost on some past projects have been caused by:
- an unrealistic programme of work
 - unpreparedness in using novel technologies resulting in poor productivity
 - a ‘feast and famine’ electrification policy.
47. Using data from Network Rail as well as its own sources, RIA found that there is a significant spread in the costs of electrification projects in the UK and elsewhere. These depend on the complexity of the geotechnical and engineering requirements. RIA concluded that it is possible to deliver electrification programmes at a typical cost of £1m-£1.5m per single track kilometre (stk) and, for simpler sections, at between £0.75 and £1m/stk.
48. If these costs can be achieved consistently, the economic case for electrification will become more attractive. Efficient costs will inform the Traction Decarbonisation Network Strategy. Network Rail has carried out analysis on electrification costs based on the previous portfolio. As part of the strategy work, the relationship between these costs, which will be used to inform the strategy, and the Electrification Cost Challenge will be understood. The Taskforce supports this and would, based on the needs we have identified in our work, agree that this should inform the industry; both on lessons learned, and how the industry should support Network Rail to enable it to control costs better, within agreed limits, in future electrification programmes. This review should feed into the Traction Decarbonisation Network Strategy to report back in late 2020. So that the strategy may take these revised costs of electrification into account in making its recommendations about which sections of track should and should not be electrified.

⁴⁷ Railway Industry Association (March 2019), RIA Electrification Cost Challenge. https://www.riagb.org.uk/RIA/Newsroom/Stories/Electrification_Cost_Challenge_Report.aspx, viewed 14 March 2019

49. For batteries, existing technologies all have limitations. While intensive improvement efforts will continue with existing technologies, there is a realistic possibility that they will be superseded by other technologies by 2050. So, it is difficult to state with any certainty what the availability and cost of traction power batteries, in either single mode or in multi-mode, will be in 2050, let alone 2040.
50. The T1145 traction options research project has concluded that battery vehicles may now be built at a cost comparable to, or little greater than, the diesel vehicles that they may replace, although the speed and range of the battery vehicle will be lower. When used as part of a multi-modal or hybrid arrangement, the Taskforce notes the experience of the bus industry that a hydrogen ‘battery charger’ has enabled an overall cost reduction by reducing the size of battery required. Our discussions within the industry, particularly with manufacturers, indicates that this is a reasonable assumption. The critical factors in battery costs in the future are likely to be the price of electricity, and the cost of the batteries themselves. This will depend on the availability of necessary raw materials and the demand for batteries of a type that will be suitable for use on rail vehicles. The key technical gaps are illustrated in Figure 9.⁴⁸ While it is clear that the cost of batteries is falling significantly, at the same time as capacity is rising, the level of uncertainty and the relatively small size of the UK rail market means that we have not made specific assumptions around future capabilities, we recommend that this is an area for future continued research and development.

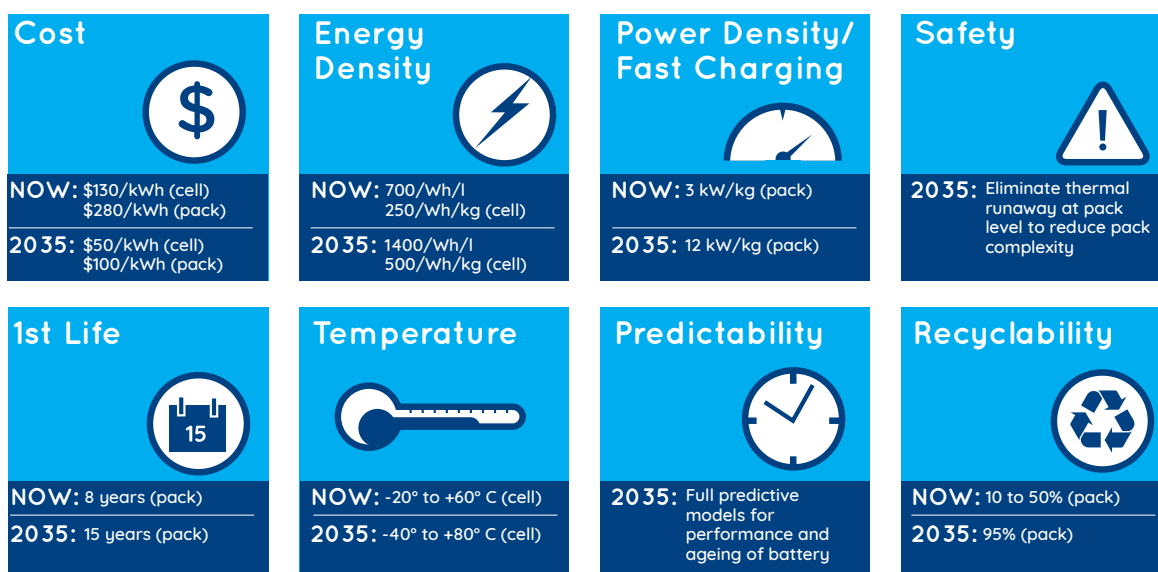


Figure 9: technical gaps for battery development

51. For hydrogen, it is likely that electrolysis (from renewable energy sources) will become the preferred means of production of hydrogen for fuel cell applications. The alternative, steam methane reformation, is not sufficiently pure. Of the various electrolysis production technologies, the view is that the most promising technology is proton exchange membrane (PEM) electrolysis. CCC research suggests that, by 2040, the production cost of hydrogen by PEM electrolysis will be about £73/MWh, with a range of estimates from £48-80/MWh.⁴⁹

48 Graphic from UK Research and Innovation

49 Committee on Climate Change (November 2018), Hydrogen in a low carbon economy, p.66. <https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf> viewed 12 May 2019

52. The future cost of hydrogen is unpredictable, especially given the lack of certainty on means of production. As with batteries, there remain significant uncertainties over the costs, including infrastructure, for hydrogen for rail. We recommend this as an area for further research and development.
53. With the limited working examples available, there is uncertainty on levels of orders, and consequently the unit cost of vehicles, as well as the uncertainty of the ability of the market to meet demand. These make it difficult to state definitive prices for battery and hydrogen vehicles at scale. The economic analysis developed for the Taskforce in the T1145 study assumes, based on best available information from its research, that the cost of a hydrogen passenger train is likely to be of the order of 20% more than a diesel equivalent. This is consistent with the informal feedback that the Taskforce has received from knowledgeable sources. Other T1145 economic model working assumptions are that the lifetime cost of a hydrogen passenger train⁵⁰ is already likely to be 10% lower than a diesel train. This is largely due to lower maintenance costs, notwithstanding the likely need to make more frequent trips to refuelling facilities. Similarly, there is evidence that an electric/diesel/battery tri-mode, while having a higher purchase cost than an electric-diesel bi-mode, has a lower whole life cost. There is insufficient experience with battery trains to be certain as to their lifetime costs. Nevertheless, some manufacturers believe that they are likely to be significantly lower than the whole life costs of a diesel train that it may replace.
54. The uncertainty over these costs increases when needed infrastructure and future fuel costs are taken into account. As such the Taskforce does not think it is credible to provide cost estimates over the thirty or so years of each scenario. Rather the Taskforce recommends that a clear outcome carbon target is established in the long-term. This should be implemented through shorter-term targets (similar to existing national carbon budgets), clear outcome-based specifications in all franchises, and rolling stock specifications. As we state elsewhere in this report, one way to reduce uncertainties is to give a clear and robust statement of intent for a net zero carbon target by 2050 for rail. This should be done through a clear policy statement to the rail industry, as soon as is practicable; and providing this is consistent with obligations on other parts of the UK economy generally, other transport modes in particular. In addition, it should be clearly stated where it is identified that it would be more cost effective to net off residual rail industry emissions elsewhere in the UK economy rather than seek to eliminate them.

⁵⁰ The cost, possible configuration and operational capability of a hydrogen locomotive suitable for freight operations in the UK will be significantly different to a passenger train. The research project T1160 is looking at traction options and issues specific to the freight industry and will report its conclusions at the end of 2019.

Economic model baseline

55. The Taskforce economic model was first tested on a ‘do nothing’ baseline. Figure 10 shows that there will be a 32% reduction in emissions by 2040 (37% by 2050) simply from decarbonisation of grid electricity.

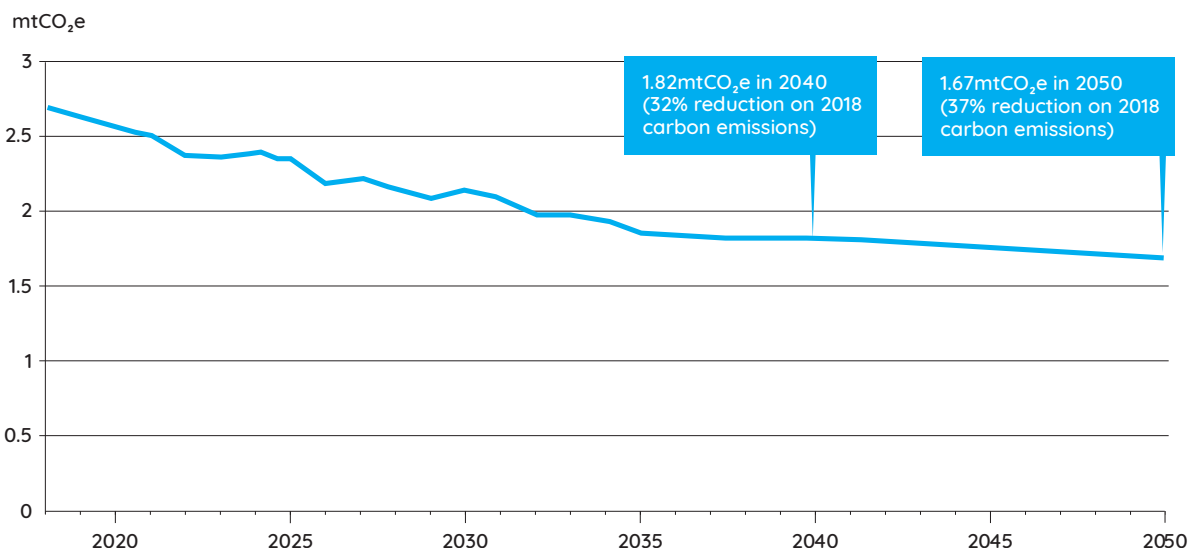


Figure 10: baseline network emissions, based on forecasted national grid mix

Options to remove diesel only passenger trains and achieve 80% carbon reduction

56. Various pathways with no or limited electrification (up to 1,000 route km) were tested, using bi-modes to a greater or lesser extent. Table 4 summarises the four pathways.

	No additional electrification	1,000 route km additional electrification
Favour bi-mode	P1: Bi-mode heavy	P3: Bi-mode heavy plus
Favour alternative fuels	P2: Bi-mode light	P4: Bi-mode light plus
Bi-mode heavy: use diesel/electric bi-modes on all routes which are mostly (>50%) or partially (<50%) electrified for all self-powered journeys		
Bi-mode light: use diesel bi-modes only on mostly electrified routes for self-powered journeys. Use hydrogen and biofuels for journeys on routes which are only partially electrified		

Table 4: bi-mode test scenarios

57. The carbon reductions for these four pathways were compared with the baseline. All of them showed significant improvements over the baseline, ranging from 56% reduction (pathway 2) to 69% reduction (pathway 4) in 2040 as shown in Table 5.

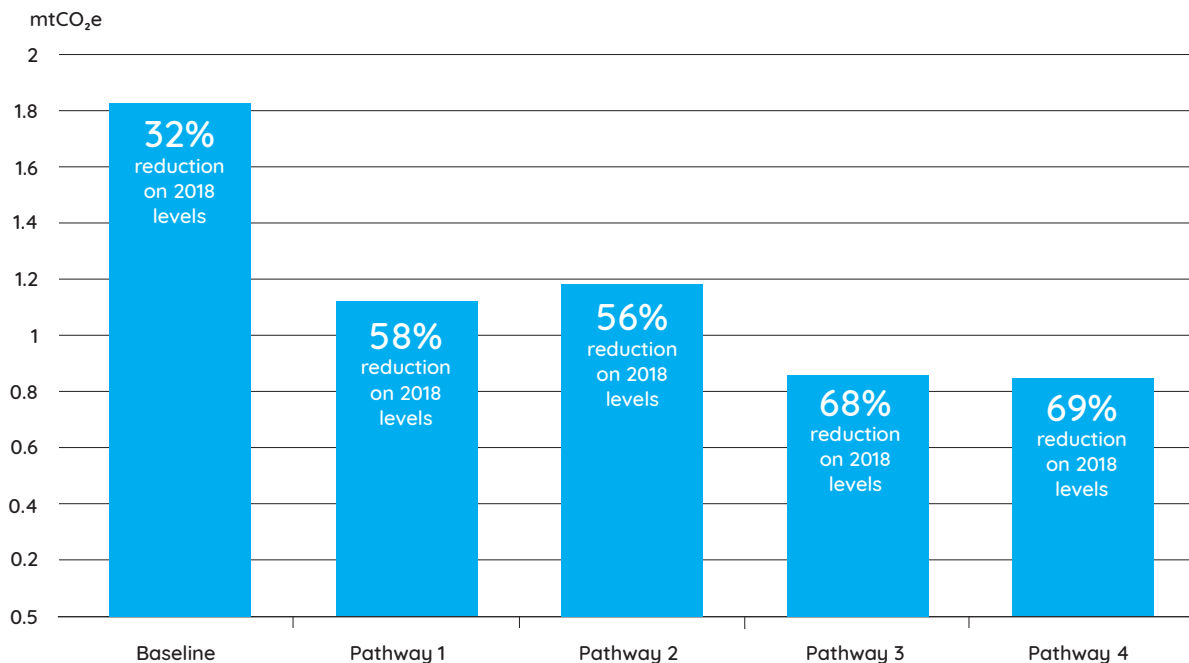


Table 5: baseline and bi-mode scenarios carbon emission reductions

58. Continuing the projection to 2050, both bi-mode heavy and bi-mode light pathways get close to, and may achieve, the existing 80% carbon reduction target on 1990 levels.

Net zero decarbonisation by 2050 and 2040

59. The final two targets the Taskforce tested were net zero carbon by 2050 and 2040. With the assumptions used in the model, which references the official government projected carbon grid mix, none of the traction options will be net zero carbon by 2050. This is due to the residual carbon arising from grid electricity supply. If grid electricity were to decarbonise fully, these would then be net zero carbon.

60. The road maps generated in the T1145 project, in accordance with the technical basis of the work, indicated when technologies would realistically be available to support decarbonisation efforts, rather than make any judgement on whether they would be deployed. So, they incorporated the use of biodiesel in bi-modes, for example, and tested some assumptions to understand their carbon impacts for comparative purposes. The extreme limit of electrification, to cover 90% of all route km, was modelled to see what carbon outcome this would produce.⁵¹ This would result in total emissions of 0.4mt CO₂e by 2040, an 85% reduction on 2018 values. By 2050, the grid is predicted to have decarbonised further to produce 0.2mt CO₂e, or a 95% reduction on 2018 values. If the industry were to be able to produce its own electricity from verifiably additional renewable energy sources, this would reduce the carbon mix of electricity used on the railway below the carbon grid mix.

⁵¹ At a constant rate of electrification, this would require the electrification of 685 route km every year for 20 years. The purpose of this scenario is to assess what carbon emissions would result in 2040.

Route maps

61. Figure 11 illustrates a possible pathway to achieve both the removal of diesel-only passenger trains from the network by 2040 and the decarbonisation of the railway by 80% on 1990 levels by 2050. This shows clearly that these two scenarios may be considered stages on the same pathway, and also that there is a continuing role for more efficient diesel on a long-term basis.

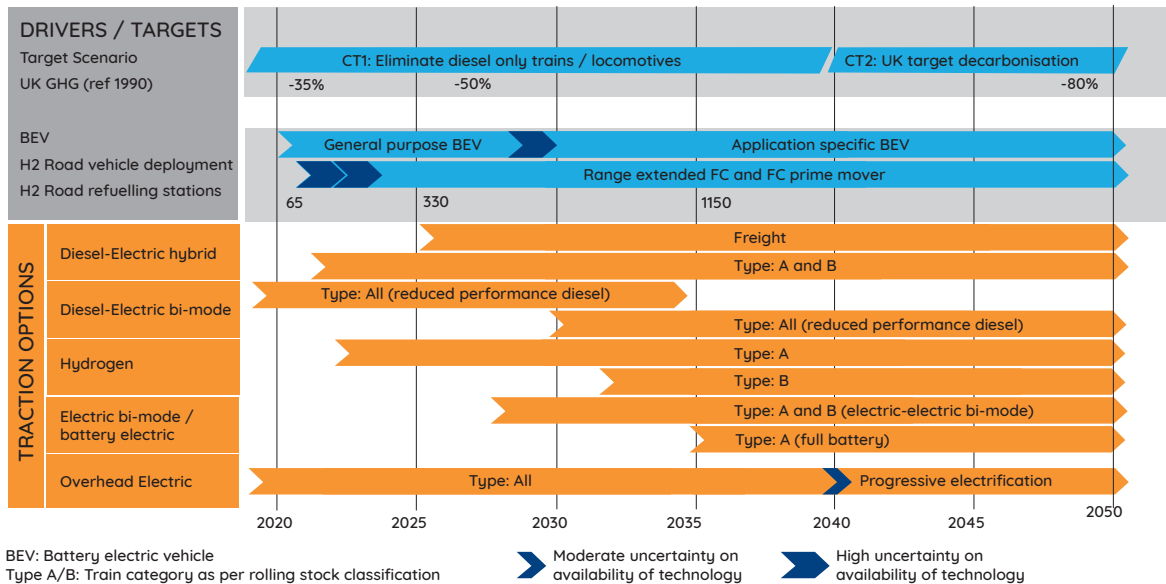


Figure 11: indicative route map to remove diesel-only passenger trains by 2040 and reach 80% carbon reduction by 2050

62. The Taskforce has adapted the pathway for net zero decarbonisation by 2050 to reflect information received, as noted earlier, about the availability of biofuels and the practicalities of being able to undertake such extensive electrification. An indicative pathway on this basis is shown in Figure 12. Again, we caution that these are indicative pathways to illustrate credible possible solutions. They would need to be subject to rigorous analysis, as the Traction Decarbonisation Network Strategy is doing.

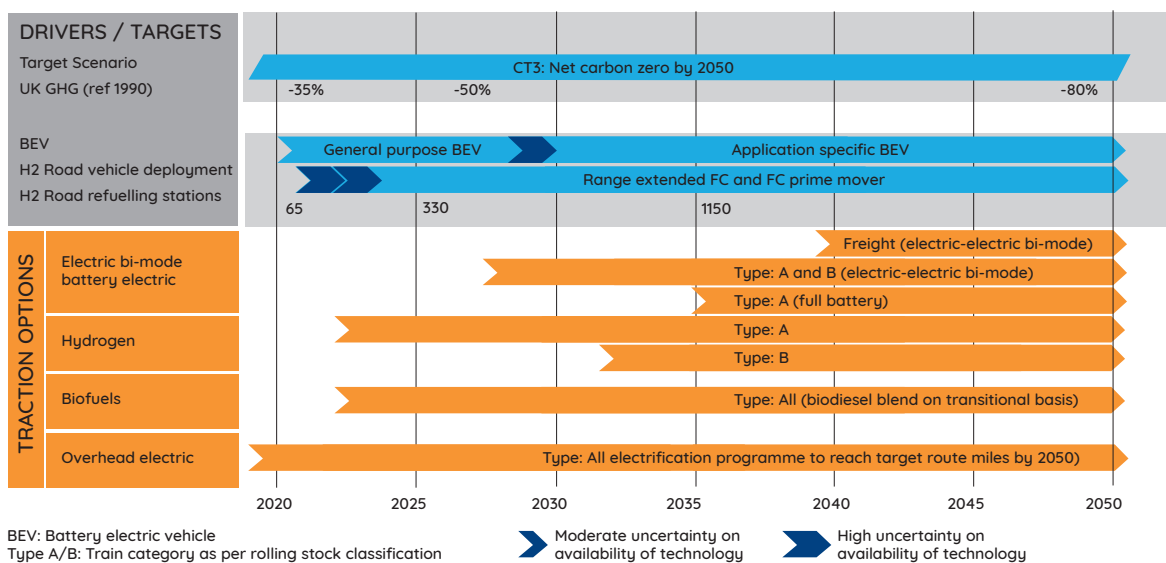


Figure 12: indicative route map to achieve net zero carbon by 2050

63. Similar to the explanation given regarding a net zero decarbonisation by 2050, in Figure 13, the Taskforce has adapted the T1145 net zero carbon by 2040 pathway to produce the indicative pathway.

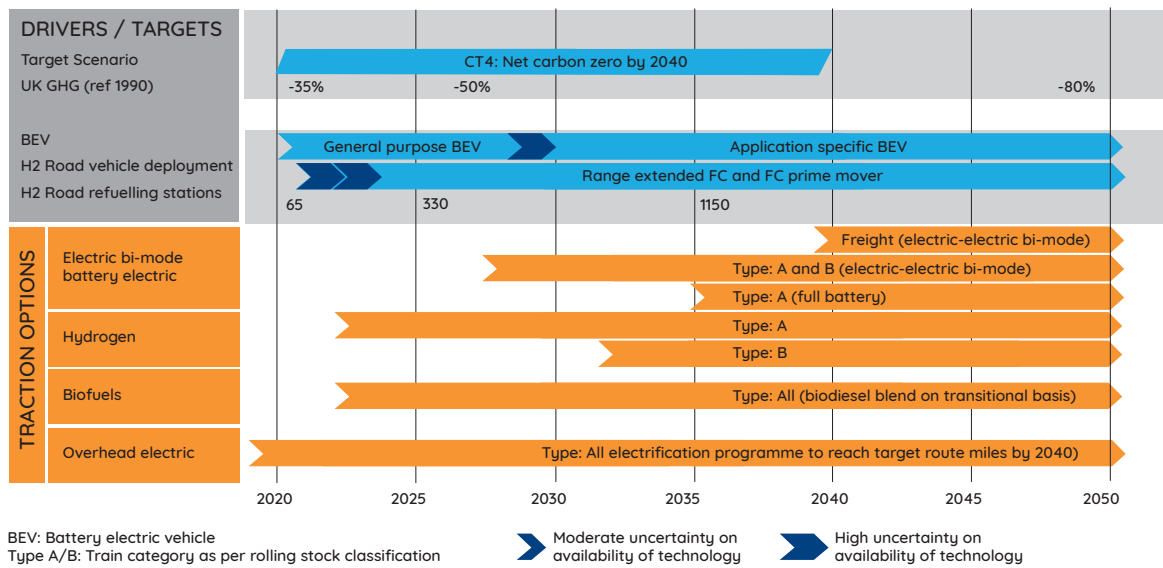


Figure 13: indicative pathway to achieve net zero carbon by 2040

64. The route maps to net zero carbon in 2050 and 2040 raise a number of points worth noting:

- a. Biodiesel blends are included on a transitional basis to 2050 notwithstanding CCC's view that they should not continue to be used for surface transport beyond the 2030s. This illustrates the need to consider the long asset lifecycles and high replacement costs for rolling stock when considering options. This will need to be considered in full detail in the context of wider, national decisions on fuel options, which are outside the direct control of the rail industry.
- b. The preferred combination of options needed to achieve net zero carbon by 2040 could be similar to that for net zero by 2050. This means that, if there is a need in the future to accelerate the decarbonisation target, it should be possible to do this without having to make a major change of direction in technological terms.
- c. There is almost certainly a role for diesel-powered vehicles, in single and multi-mode, on a transitional basis, but not in the long term. This will allow the industry to plan the phased refurbishment and/or retirement of diesel-powered vehicles in the most cost-effective manner, within clear and predictable timeframes.

65. What is clear from these analyses is that a net zero carbon railway can only be achieved with additional electrification as part of a balanced programme of low-carbon traction options. While there is increasing confidence that battery and hydrogen traction will be able to replace self-powered journeys running up to 100mph, the only realistic low carbon solution to replace diesel self-powered vehicles running up to 125mph is electric traction.

66. In the following section, we set out what we see to be the key decision points in the development of a robust route map.

Way forward

Traction

Passenger fleet

67. The March 2018 Long Term Rolling Stock Strategy, which was finalised before the industry appointed the Taskforce and began to consider what a low carbon railway with no diesel vehicles might look like, estimated that there would be between 2,750 and 4,800 self-powered vehicles by 2047. Of these, between 2,600 and 3,500 were anticipated to be operating routes at less than 100mph.⁵² As highlighted above, it is these Category A and B vehicles, with relatively limited range, power and energy demands, that are most suitable for replacement by alternative forms of low carbon traction. As at May 2019, there were 2,346 Category A and B vehicles in the passenger fleet.
68. The purchasing and displacement of vehicles is a commercial process. We assume, conservatively, that a typical train life is of the order of 30-35 years. This means that the last DMU⁵³ that could expect to have a full economic life would be bought in 2015-2020. The last diesel bi-mode, designed on a platform that cannot be easily re-powered, should be bought no later than 2020 if we are to achieve net zero carbon on the railway by 2050 while limiting lost vehicle economic value. With newer designs, there is the possibility of conducting a mid-life re-power or energy source conversion. For example, the new Stadler bi-mode multiple units have a diesel power unit which could be swapped out for an alternative energy source power unit without the need to replace the entire multiple unit. Vivarail is designing its vehicles specifically to allow for the quick swapping of diesel engines, hydrogen fuel cells and batteries. Costs for powering and re-powering such vehicles are likely to be significantly lower than was previously the case with vehicles not designed with this in mind. One major source of cost reduction in use extensively in Europe and also in the UK will be the use of suitably adapted truck engines. These are inherently cheaper, due to their much larger production runs, than dedicated engines for rail vehicles and so could be replaced at the end of their economic life.
69. A particular opportunity is in the replacement of the Sprinter fleet (Class 150-159). 1,000 vehicles will reach 40 years of age between 2026 and 2031. Decisions on these will need to be taken in the next 3-5 years. The Taskforce considers this as a key opportunity to make a step change in alternative traction on the network and a key stepping stone to a net zero carbon railway. We recommend that further research and development is undertaken to understand system requirements, expand potential capabilities, and take full advantage of this opportunity.
70. Conversely, trains with maximum speeds of up to 125 mph are much harder to replace with low carbon alternatives outside of electrification. Over the period to 2040, best projections are that approximately 500-800 such diesel-only vehicles with a maximum speed of 125 mph may continue in service in a 'do nothing' scenario. As at May 2019, there were 756 such vehicles in the fleet. In any net zero carbon scenario the only realistic option for these is to electrify the routes on which they run at full speed. Greater decision-making flexibility will come from: improvements in the design and deployment of bi- or multi-modal and hybrid

⁵² Long Term Rolling Stock Strategy, p.17

⁵³ Diesel multiple unit train

traction options, allied to our improving understanding of what might be possible with the various forms of intermittent electrification. It is now possible to assess electrification across a range of options rather than just a binary yes/no decision. This will certainly open up options for better transitional pathways and may well lead to innovative long-term intermittent electrification solutions.

71. Previous electrification studies have only considered journeys which took place wholly on the electrified network. These led to a binary choice of running an electric train or not running an electric train. There is now an increasing confidence in the range of possible traction options in electric hybrid or multi-mode configurations, such as diesel/electric bi-mode, hydrogen/electric and battery/electric, on a transitional or a long-term basis. In effect, these are all options which allow an electric train to range-extend beyond the electrified network or to bridge across electrified sections of the network. However, the much higher volume needed to store the equivalent energy in hydrogen or battery form, compared to diesel, becomes a significant factor in determining practical solutions.
72. Figure 14 shows the range of options that may now be considered in any economic appraisal of whole life traction options. This illustrates the possible basic electrification and power supply options to a stretch of non-electrified line, when considering the most cost-effective whole system traction options. These could be either permanent solutions or low-cost ways to implement transitional arrangements.

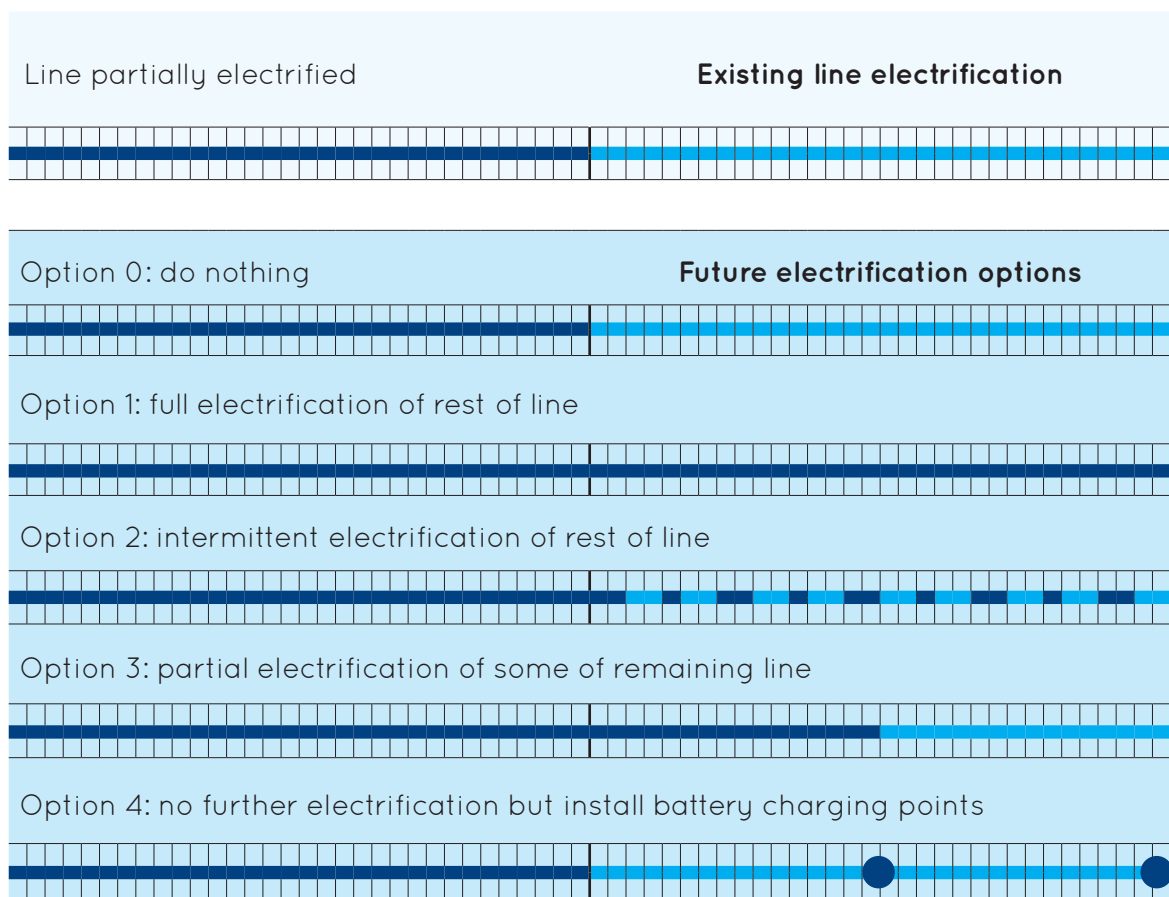


Figure 14: options for electrification assessment

73. In these options, trains that run on non-electrified sections could be hydrogen, battery or diesel, in single mode or bi-mode, depending on the performance needed for the journeys being undertaken on that stretch of line.
- **Option 0:** an active decision to do nothing. The whole life cost and carbon benefit of not electrifying an additional stretch of line outweighs the benefit of any form of electrification.
 - **Option 1:** the whole life cost and carbon benefit of electrifying the whole line is justified and the trains would be electric.
 - **Option 2:** the whole life cost of electrifying the whole line cannot be justified, but there is a case for intermittent electrification. This may be in short runs which avoid the need to electrify the costliest sections when no innovative technical solution is available, such as was done for the Cardiff Intersection Bridge.⁵⁴ These might include bridges, tunnels and other constrained sections which disproportionately increase the cost of electrifying the line. It may be in much longer sections, likely to be measured in kilometres, bridging two electrified sections.
 - **Option 3:** the whole life cost of electrifying the whole line cannot be justified. There may be a cost and carbon case to electrify part of the line and to operate a range-extending train to complete the journey.
 - **Option 4:** the whole life cost of electrifying the whole line cannot be justified. The journey types on the route are such that there is a case to install charging points along the line which would allow a short-hop battery train to operate with top-up charging.
74. Based on this, the Traction Decarbonisation Network Strategy will, for the first time, be able to assess the most suitable options for electrification for the network against this extended range of options and performance requirements. The aim will be to develop a prioritised map of preferred long-term traction options across the network; to achieve the lowest whole life, whole system cost for decarbonisation. The Taskforce fully supports the Network Strategy approach.
75. Once the extent of electrification has been agreed, Network Rail Routes should develop a progressive electrification programme. This would be part of a balanced mix of solutions to achieve the lowest whole system cost pathway to achieve net zero carbon, through the strategic business planning for CP7.

54 RIA, *ibid.* p.48

Freight fleet

76. There are about 850 freight locomotives in regular service⁵⁵ moving 19 billion tonne kilometres in 2016-17.⁵⁶ As highlighted by the NIC, per tonne kilometre, rail emits only about a quarter of the CO₂ of road freight.⁵⁷
77. Rail freight is a commercial market, competing with other modes, with tight margins and high capital costs. These limit the ability to invest directly in developing new lower carbon traction solutions. Freight operators have expressed concern that manufacturers may have neither the appetite nor the capacity to design and build a new hybrid or other form of low carbon emissions heavy haul locomotive that could achieve significant carbon savings over the options now available. The UK would place small orders (the replacement rate averages about 30 locomotives each year) and has a bespoke gauge not compatible with the European market. Additionally, the much bigger market in Europe for solutions to the last mile haulage off the electric network is more attractive to manufacturers. This concern is shared by the NIC, which states, 'Delivering carbon free rail freight using either electrification or alternative fuels is likely to entail very significant costs for infrastructure or new locomotives. But without these costs being paid, most likely from public expenditure, the only other way for rail freight to be carbon free would be for it to transfer to other modes, such as zero emission HGVs.'⁵⁸
78. The NIC's analysis is largely consistent with the Taskforce findings. However, due to the volume of energy storage required for battery or hydrogen power (details are in Annex C), we do not believe these are suitable for main line freight locomotives with the railway's existing timetabling and operational constraints. Nor does our review support the assumption that biodiesel will be available in sufficient quantity. From a technical perspective electric traction is the only available viable solution for most freight services to fully decarbonise. The Taskforce acknowledges that this is the most challenging area for rail to decarbonise and supports the NIC recommendation for a government led analysis and strategy for rail decarbonisation, including 'the investments and/or subsidies that it will provide to get there.'

Efficiency improvements

79. This report sets out how the industry might decarbonise in accordance with our remit. There is no place for diesel in a net zero carbon railway. As the CCC notes, where it is difficult or expensive to replace carbon emissions these might be offset within a net zero carbon UK. For rail this is most likely to be the case for rail freight and for 'yellow machines', the on-track plant and machines that carry out critical maintenance and renewals work, often where there is no access to electrification or other sources of external power. There would need to be a detailed analysis of how offsets would be funded, should it be necessary, as seems likely, to offset such residual emissions from the rail industry elsewhere in the UK economy.

55 Rail Industry Decarbonisation Taskforce (January 2019), Initial report to the Minister for Rail, p.22. <https://www.rssb.co.uk/riskcontent/rail-industry-decarbonisation-task-force-initial-report-to-the-rail-minister-january%202019.pdf> viewed 12 May 2019

56 MDS Transmodal (November 2017), Rail freight forecasts: Scenarios for 2023/24. Final Report, pp1-2. <https://cdn.networkrail.co.uk/wp-content/uploads/2018/10/Rail-freight-forecasts-final-report.pdf> viewed 14 April 2019

57 National Infrastructure Commission (December 2018), Future of Freight Interim Report, p.13. <https://www.nic.org.uk/publications/3730/>, viewed 14 April 2019.

58 Ibid, p.8 and p.10

80. Further, to minimise the lifecycle economic and carbon impacts, the industry needs to be able to make transitional arrangements. These may involve re-powering or implementing other carbon reduction measures on existing trains. Some existing diesel traction still has considerable economic life left, and in the case of 125 mph routes there is currently no alternative to electrification. If electrification, where it is the most effective whole system decarbonisation option, is rolled out in a progressive programme, it will take a significant number of years to reach a point where diesel-powered vehicles could be completely removed. In these cases, increasing the efficiency of diesel traction will be important.
81. The Taskforce therefore recommends that research and development continue into the potential for increased diesel efficiency. The opportunity for collaboration with the Advanced Propulsion Centre (APC)⁵⁹, should be explored through a programme of research into power options for heavier duty cycle requirements. This should link rail and sections of the automotive sector such as HGVs (Figure 15). Accordingly, the Taskforce recommends that rail should be able to access APC and similar funding sources for research and innovation into efficiency improvements in heavy duty cycle engine applications.

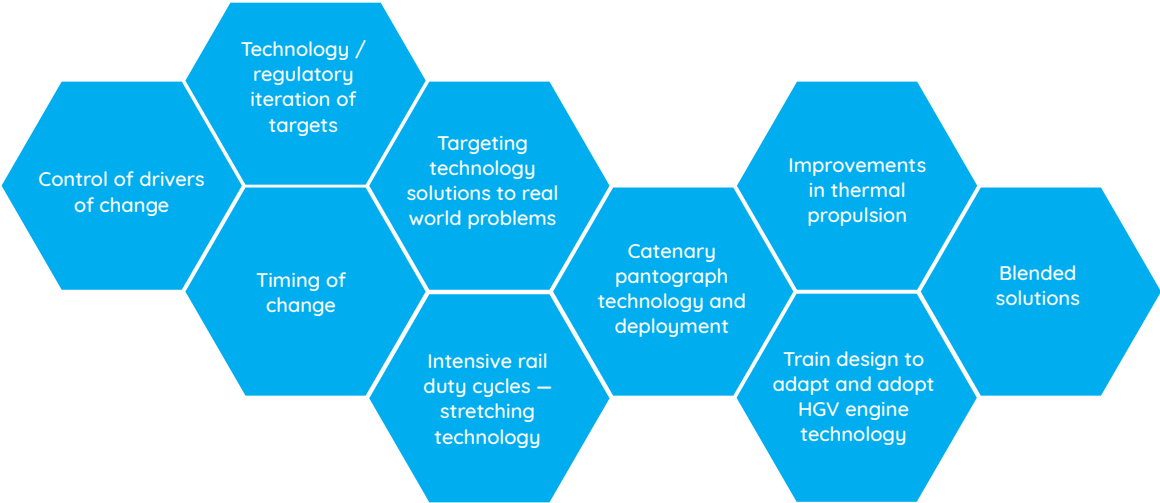


Figure 15: areas of common interest between the rail industry and the APC

RSSB and InnovateUK have jointly funded and sponsored an ‘Intelligent Power Solutions’ research programme. Part of the remit of this programme is to support first of a kind feasibility research into efficiency improvements in existing diesel engines. Examples include: co-firing with diesel and alternative fuels, better engine management systems and improved design. The Taskforce welcomes this research programme and recommends that funding support in this key area should continue.

59 See www.apcuk.co.uk for further information

Property

82. As at 2016-17, there were 2,560 mainline stations in operation. In 2011, when there were slightly fewer stations, DfT categorised them into six classes as illustrated in Table 6. The smaller stations tend to use only energy from electricity supplies, primarily for lighting. Larger stations may also use gas, and the direct energy use (excluding offices, retail space and any other uses not controlled by the station operator) will be for more diverse purposes, such as vending machines, ticket machines, ticket offices and other non-lighting uses. One increasingly significant use of energy in stations is for necessary IT equipment.⁶⁰

Description	No. Stations	%	Av Daily Passengers (per station)	% of Customers	Criteria (per annum)
A. National Hub	25	1	90,000	42	Over 2m trips: over £20m
B. National Interchange	66	3	13,000	15	Over 2m trips: over £20m
C. Important Feeder	275	10	5,000	20	0.5-2m trips: £2-20m
D. Medium Staffed	302	12	2,500	13	0.25-0.5m trips: £1-2m
E. Small Staffed	675	27	700	8	Under 0.25m trips: under £1m
F. Small Unstaffed	1,192	47	100	2	Under 0.25m trips: under £1m
Totals	2,535	100	111,300	100	

Table 6: station types and numbers on the national rail network as at 2011

83. A recent study on station decarbonisation indicates that the extent of possible carbon savings depends on the size and usage of the station. This study considered the Type C, E and F stations described above. It found that about 60% of the electricity consumption in a Type C station is relatively difficult to impact through direct energy efficiency measures by the station operator. The electricity consumption is primarily for operational activities such as vending and ticket machines, tenants and retailers. By comparison, over 95% of the energy used in a typical Type F station is for lighting.⁶¹ The measures explored included draught proofing, LED lighting, heating controls, solar PV, air source heat pumps and battery storage. The marginal cost of full decarbonisation, beyond about 30% decarbonisation, is nearly zero. These findings have been used to inform requirements for recent franchise bids.

⁶⁰ The sections in this report on Property and Infrastructure draw heavily on the work done for and by the Taskforce for the initial report published in January 2019. For more detail on related research and projects, please refer to that report.

⁶¹ Ricardo AEA for RSSB (6 November 2017), Zero Carbon Stations Feasibility Study for Category C, E and F stations, p.26 (in PDF: pages not numbered). See <https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=26099>, viewed 3 June 2019

84. Franchise agreements now require an average 2.5% per year reduction in non-traction energy. These requirements are still relatively new.⁶² Our consultations suggest that one of the main challenges to train operators that install energy efficient technologies on the stations they lease from Network Rail is that the payback period can extend beyond the life of the franchise. As a result, there is limited commercial incentive for train operators to invest unless energy efficiency requirements are hardwired into the franchise specification. Nevertheless, the recommendations of the 'Zero Carbon Stations' report,⁶³ that were discussed in detail in our initial report, should be implemented on all stations across the rail network where this is cost-effective to do so. The aim would be to achieve zero carbon energy use for all heating and lighting in at least common station areas. Any exceptions should be considered through a defined process.
85. In part driven by this independent research, and in part by its own ongoing work activities, Network Rail has identified significant opportunities for decarbonisation of the property estate. These are through the application of energy reduction measures, low-carbon design, and the application of renewable, decentralised energy generation and storage. Network Rail has consolidated these into a single work programme, Project Levatus. This is designed to accelerate the application of these technologies across their estate and includes softer measures such as capability building and cultural change.
86. Network Rail has set stretching targets for energy and carbon reduction in CP6. It is developing a set of long-term, stepped Science-Based Targets towards near-complete decarbonisation. The minor gap is expected to be delivered by technologies which have not yet emerged. These targets will be supported by clear strategies detailing how to get there. Some TOCs are also considering developing similar target structures. While this is encouraging, what is needed is a mandate that all parties within the rail sector should follow this example. They should not work independently to develop strategies for their organisations, but collaborate and establish a consolidated view. Aligned industry data and associated metrics should be reported to track progress and incentivise accelerated decarbonisation of the non-traction estate.
87. Policy and governance will play a key part in the property portfolio. Targets and regulatory review drive activity and these are needed to make change happen. It will be necessary to consider how the outputs of Project Levatus can be extended most effectively to stations and other property now managed by franchise operators. This will depend on the outcomes of the Williams Review on the future structure of the railway, taking into consideration our earlier recommendations on responsibilities for industry-wide carbon footprinting, target setting, management, reporting and auditing of carbon reduction measures. The Taskforce recommends that Network Rail reviews the ongoing findings of Project Levatus in the light of the recommendations of the Williams Review, in conjunction with the designated oversight body. This should aim to ensure that carbon management of both directly managed property assets and Network Rail-owned but separately managed property assets are coordinated in a consistent and integrated manner.

⁶² For example, see the ITT for the West Midlands Franchise, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/553594/wmf-itt-attachment-b-franchise-agreement.pdf, p.627, viewed 26 September 2018

⁶³ Ricardo report for RSSB (6 November 2017), Zero Carbon Stations Feasibility Study for Category C, E and F stations. Unpublished

88. Focus needs to be not only on the swift decarbonisation of the existing property portfolio, but also on the low-carbon design of new property assets. Assessment methods such as BREEAM⁶⁴ and PAS2080⁶⁵ should be embedded into planning processes as ways to design out carbon at early project stages. During our research and consultation, we met with BRE⁶⁶ and BSRIA⁶⁷ to consider how existing, well-established and recognised standards and methodologies may be adapted, where necessary, and applied to rail property and infrastructure. They have indicated that they are agreeable to working with the rail industry to develop suitable assessment methodologies, tools and standards. The Taskforce recommends that this engagement with BRE and BSRIA be taken forward by Network Rail and, pending determination of a long-term oversight body which will be able to work with organisations other than Network Rail that may manage stations and other property assets, RSSB.
89. Depots are key to the successful operation of the railway. Although they serve a nominally common core purpose, to service rolling stock, they are highly diverse in design and function. As noted in our initial report, RSSB has recently updated and published industry guidance on depot design.⁶⁸ This recommends but does not mandate the use of BREEAM assessment methodologies in the design of new depots. The Taskforce believes that it should be possible to apply a similar approach to depots as for other property assets on the railway. RSSB should look at how this guidance may be moved to a mandatory basis. This would make good environmental design generally, and low carbon considerations specifically, an integral part of depot design, refurbishment and operation.

Infrastructure

90. As stated in our initial report, the Taskforce found that there is limited scope for in-life impact reductions for infrastructure, due to its long lifecycle. Where infrastructure is renewed, all other things being equal, it is reasonable to expect that incremental improvements will enable a 10% reduction in impacts.
91. As for property, designing out carbon during early stages of infrastructure enhancements is necessary. Assessment models should be considered to see which, if any, suit the needs of the rail industry when planning infrastructure enhancements. The most suitable should be adopted quickly and embedded into early planning processes. Where a suitable assessment model does not exist, the industry should work with BRE and BSRIA to develop a workable methodology for the rail industry.
92. Innovation in this area is increasing, and new research and development opportunities are beginning to come forward which will enable greater carbon reduction. The rail industry should embrace these and develop new ways of working as they become available, removing the legacy practice of like-for-like replacement.

64 Building Research Establishment Environmental Assessment Method. See <https://www.breeam.com/>

65 Publicly Available Specification, PAS 2080:2016 Carbon management in infrastructure. See <https://shop.bsigroup.com/ProductDetail?pid=000000000030323493>

66 BRE generates independent research which is used to create products, standards and qualifications that help to ensure buildings, homes and communities are safe, efficient, productive, sustainable and enjoyable places to be. It is part of the BRE Trust, an independent charity dedicated to improving the built environment for the benefit of all. See www.bregroup.com

67 BSRIA is a non-profit making, member-based association providing specialist test, instruments, research and consultancy services in construction and building services. Any profits are invested in their research programme, producing industry recognised best practice guidance. See www.bsria.co.uk

68 <https://www.rssb.co.uk/rgs/standards/GIGN7621%20Iss%201.pdf>, viewed 27 October 2018

93. Network Rail has a mixed fleet of over 2,600 vehicles comprising locomotives, coaches, self-propelled plant and wagons; this includes vehicles inherited from Railtrack and British Rail. Of these, 130 vehicles have diesel engines and are capable of self-powered movement on the railway, while 375 have some form of generator on board for working purposes but are not self-powered. In addition, it regularly hires in around 80 other specialist vehicles and spot hire assets to undertake various tasks. These machines are used to undertake key maintenance, monitoring and renewal services without which the network would not be able to function or to operate safely.
94. Most of these machines operate across the whole network, both on and off electrified sections. They need to be able to work continuously for extended periods, often away from refuelling facilities and on electrified sections when the power has been turned off. Accordingly, those that have their own traction need to be self-powered for most of their operating time. For the work they do, they typically need hydraulic drives which can be configured to deliver slow speed, high power delivery. These drives are not compatible with electricity as the energy source. They may have limited electrical supplies to support the electrical control systems and supply for the staff amenities. For safety reasons, the working environment, particularly in confined spaces, cannot include low flash point, high combustibility fuels or spark risks. This will limit the availability of suitable fuels other than diesel and similar biofuels.
95. There are cases where we cannot see an alternative to the continued use of diesel or other thermal combustion as a power source. In these situations, as we recommended earlier in regard to passenger and freight traction, we see merit in collaborating with the APC to maximise the efficiency and minimise the carbon emissions of such engines. We see that the same applies here, especially to on-track machines (OTM) and on-track plant (OTP), which share similar power and duty cycle requirements to HGVs and off-road vehicles. We recommend accordingly that future collaboration with APC extend to include OTM and OTP where appropriate.
96. We said in our initial report that we would report back on opportunities for replacing lineside diesel generators in a manner that invites private investment through load balancing opportunities. It is not possible to do this in the absence of a better inventory of the numbers, locations, uses and operational status of generators and other static power sources. We therefore recommend that Network Rail undertakes a comprehensive survey of all diesel generators and static power sources. Where they are no longer needed, they should be removed. Otherwise they should be replaced by renewable energy generation and storage options, where feasible. This could be on a progressive cycle, either on natural renewal dates, or where inspections show that the existing generators no longer work economically. In addition, we now believe that this recommendation should extend to generators which may not be static: that are used for possession lighting and similar works. Network Rail recently announced that it had saved 97% of the typical diesel use for lighting and heating on one possession through the use of renewable power generation. It is aiming for complete elimination of diesel for these purposes in suitable future possessions.⁶⁹
97. Where renewable energy generation and storage systems are not feasible, such power sources should be replaced, where possible, with those that meet minimum carbon efficiency and emissions standards, such as fuel cells.

⁶⁹ <https://www.networkrail.co.uk/feeds/network-rail-and-colas-rail-ltd-achieve-a-97-diesel-free-site-of-the-future/>

98. When the initial survey is complete and before any replacements are made, Network Rail should revisit the feasibility of configuring the replacement devices, to provide load balancing opportunities.
99. Network Rail has a road fleet of over 8,000 vehicles categorised into cars, light goods vehicles and heavy goods vehicles. The company started moving away from an owned fleet to a leasing arrangement during 2017. One of the considerations for this ongoing and future fleet renewal is to consider the implications of the decarbonisation challenge. Network Rail signed the Clean Van Commitment in 2018 and is now developing a strategy to transition its road vehicle fleet to electric, working in collaboration with the Transport Systems Catapult. A new vehicle leasing contract recently signed with Hitachi will provide opportunities for replacing higher emission vehicles in the short term. This is an interim measure while investigation continues to understand, and ultimately overcome, some of the more complex issues surrounding a transition to electric vehicles.
100. We shortly expect decisions on the scope of application of the Greening Government commitments for road fleets from 2020. We understand that these may be extended to include the Network Rail road fleet. Should this be the case, the Taskforce would support doing so on the basis that this is done in a manner that is consistent with expectations for other road fleets and which allows Network Rail to meet its road fleet service delivery commitments to its client regional network management teams.

Research programme

101. The railway has been seen as a low carbon mode of transport. Until recently, very little was done to understand just where it gained its carbon advantage over other transport modes. The ability to move large numbers of passengers and freight tonnages very efficiently when running at high load factors was a given. Consequently, the industry has been poorly structured to drive carbon reductions across its main impact areas. We have earlier made recommendations on the need for appropriate structures and governance mechanisms to ensure accountability for carbon management and reduction. We also see the need to encourage research and innovation, to identify where significant carbon reduction opportunities lie, and how they may be implemented in a cost-effective and socially responsible manner.
102. Therefore, the industry, through RSSB, Network Rail, RDG and RIA, and aligning with the Technical Leadership Group, should set out regular 5-year research plans. The initial plan, to cover 2020-21 to 2024-25, should aim to reduce the technical uncertainties identified. Key areas for this include:
 - freight and yellow plant decarbonisation, building on the current RSSB led research project
 - increasing the capabilities of battery and hydrogen, including through developing appropriate infrastructure
 - reducing the whole system cost of electrification, including through discontinuous electrification
 - increasing efficiency of both current and future rolling stock
 - finding other ways to remove carbon from the railway in a cost-effective manner; through improved design, materials, operation, maintenance and other interventions.

Annex A:

Definitions and explanatory notes

For the purposes of this report, we use the following definitions:

Trains

Bi-mode

Bi-mode trains operate either on the electrified network or by some other form of traction power, such as a diesel engine or a battery. They use the energy sources separately so, for example, would run 'under the wire' (see explanatory note below) or using diesel, but not both at the same time.

Hybrid

Hybrid trains are self-powered and do not take power from the electrified network. They use a combination of stored and rechargeable energy sources to power the trainset which provide a set of characteristics neither energy source can deliver on its own. They may use the energy sources separately or together. A typical hybrid in use now is a combination of diesel and battery, although a hybrid train may use a combination of other stored energy sources such as capacitors, flywheels, hydraulic accumulators, hydrogen or LPG.

Tri mode or multi-mode

Tri-mode or multi-mode trains are a combination of bi-mode and hybrid in one trainset.

Types of electrification

Continuous electrification

Continuous electrification refers to those sections of line where the electrified network is continuous. An electric train can run, stop and start at any section of the line under electric power only.

Discrete electrification

Discrete electrification is where certain sections of the line are electrified, and others are not electrified at all. The gaps between electrified sections are often likely to be significant, typically measured in kilometres. With discrete electrification, the number of gaps between electrified sections are likely to be limited. A train running on electric power will not reliably be able to bridge gaps between sections of the electrified network. If it stops on a non-electrified section, it will not be able to restart.

Discontinuous electrification

Discontinuous electrification is electrically discontinuous over short sections, such as at an earthed section through an overbridge. Trains are likely to keep pantographs up when operating on discontinuous sections. 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. If an electric-only train stops on a non-electrified discontinuous section, it will not be able to restart.

Last mile journeys

By comparison, last mile journeys run on sections of line beyond any electrified stretches. The train will have to run self-powered there and back. It may be able to recharge or refuel at the end point and/or intermediate points of the journey if facilities are available. The 'last mile' is a loose term and is often much longer than the short stretch the term implies: on a journey from London to Aberdeen, for example, the 'last mile' stretch from Edinburgh to Aberdeen is about 127 miles. In considering traction options, the last mile stretch, as with the length of gaps in discrete electrification, is a significant factor in determining the most suitable existing and possible future traction options.

Under the wire

Electrification may be via overhead wire or via a third/fourth rail. In the text, unless otherwise stated, references to running 'under the wire' refer to any form of electrified network.

Other power sources

Internal and thermal combustion

Internal and thermal combustion are synonymous in this report. They refer broadly to any engine or power source that burns fuel. Diesel trains are a means of thermal combustion. Other fuels may include compressed and liquid natural gas, hydrogen, biofuels and other types of synthetic fuel.

(Hydrogen) fuel cell

A fuel cell converts the chemical energy of a fuel such as hydrogen through chemical reaction with oxygen to generate electricity which may power the train directly or charge a battery. While it has similarities to batteries, it is not self-contained and usually draws the oxygen directly from the atmosphere. A hydrogen train is, in effect, a generator that works in tandem with a battery to provide tractive power.

Power pack

Any form of power supply, such as a diesel motor, fuel cell or battery system that provides the energy to drive a train. In trains, the output is normally an electric current supply of, say, 750V which uses a standardised connection arrangement into the drivetrain motors to power the wheels. In these cases, the power pack may be removed quickly and an alternative power pack swapped in readily. Some new trains are now 'future-proofed' to do this, as it is cheaper and less disruptive to do than replacing the whole vehicle as low carbon traction technologies improve and supersede legacy power options.

Range extenders

Any form of power supply that allows the train to run off the wire in a low carbon mode. Options under development include battery trains that can hold and/or receive sufficient charge to do short hop, frequent stop journeys, battery/electric trains that can charge up under the wire and hydrogen/electric trains that.

Carbon emissions measures

CO₂

The actual emissions of CO₂.

CO₂e

CO₂ equivalent. The UK reports emissions for a basket of greenhouse gases in accordance with international agreements. These have different global warming potentials (GWP). CO₂e is used to report these GWP in a single number. Some gases break down much more quickly or slowly than CO₂ or have very much greater warming impacts. A given amount of methane, for example, has about 25 times the warming potential as CO₂ even though it breaks down faster in the atmosphere.⁷⁰ Other gases have very much greater GWP than this. CO₂e is calculated as the equivalent amount of warming each gas produces when compared with the impact of the same quantity of CO₂ over 100 years. We have made every effort in this report to state figures as CO₂e as this is the more inclusive statistic. In some cases, data sources report only CO₂ and this is shown accordingly.

CO₂e/seat km

A measure of efficiency of engineering design. The number of seats on a given train is constant so this statistic depends on the carbon emissions of the energy source driving the train. It is a measure of the inherent carbon efficiency of the vehicle. This will be constant for any vehicle under any given standard operating conditions.

CO₂e/passenger km

A measure of utilisation rates. We note, where appropriate and where the source material states, the assumptions used to calculate CO₂e/passenger km. For rush hour commuter journeys, the number of passengers on a train may exceed the number of seats available and will therefore have relatively low emissions per passenger. For overall rail carbon emissions calculations, assumed utilisation rates are generally in the order of 30-40%. Generally, the greater the number of passengers on a train, the lower the CO₂e/passenger km.

70 The Greenhouse Gas Protocol organisation cites a GWP for methane at around 25-28 (it has been revised upward in more recent studies) based on reports from the Intergovernmental Panel on Climate Change. See, for example, https://ghgprotocol.org/sites/default/files/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

CO₂e/ seat km and CO₂e/ passenger km are complementary. Both should be considered in identifying the best technical outcomes as illustrated in Figure 16.

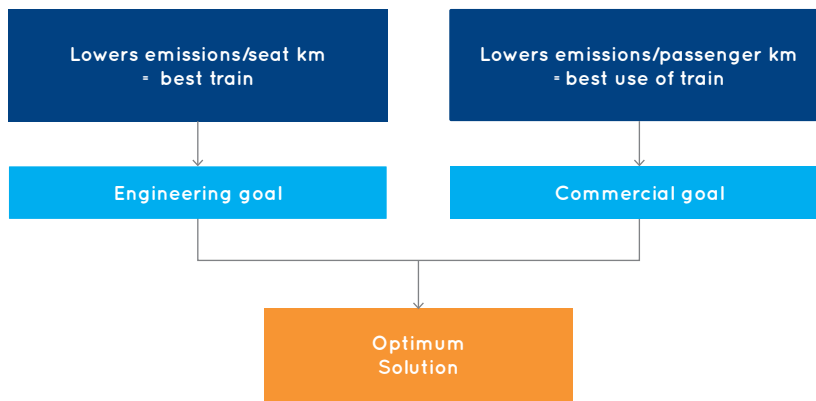


Figure 16: optimising rail carbon performance

There are very few reliable comparative studies of passenger carbon emissions across transport modes. We quote figures from a 2007 source for simple comparison purposes in the absence of any more recent reliable studies, while recognising that transport has become more carbon efficient since then and is likely to have become so at different rates for different transport modes.

Net zero carbon

The CCC defines a net-zero target as one which “requires deep reductions in emissions, with any remaining sources offset by removals of CO₂ from the atmosphere (e.g. by afforestation). Net emissions, after accounting for removals, must be reduced by 100%, to zero.” This can be legislated as “a 100% reduction in greenhouse gases (GHGs) from 1990.”

In addition, the CCC notes that “the transition, including for workers and energy bill payers, must be fair, and perceived to be fair. Government should develop the necessary frameworks to ensure this. An early priority must be to review the plan for funding and the distribution of costs for businesses, households and the Exchequer.” In the case of rail, this means that it may be more cost effective, as part of the transition, for some residual carbon emissions on the railway to be offset elsewhere in the UK economy.

Annex B:

Decarbonisation Taskforce remit

1. Vision
 - 1.1. For the UK to have the world's leading low-carbon railway by 2040.
2. Mission
 - 2.1. To move UK rail to the lowest practicable carbon energy base by 2040, enabling the industry to be world leaders in developing and delivering low carbon transport solutions for rail.
3. Purpose of Taskforce
 - 3.1. To draft the rail industry's response to the Minister's vision, including a route map to delivering the mission, which will embed delivery in business as usual.
4. Scope
 - 4.1. Identify relevant current work being delivered or planned by the industry, identify gaps in knowledge or understanding and propose solutions to these.
 - 4.2. Identify current technology developments and any potential upgrades to infrastructure which could be delivered more cheaply [at lower whole life cost] and more efficiently. For developments which can support the vision, outline the potential appropriateness and current understanding of costs, and the benefits in each. It is envisaged that there will not be 'one answer for all' and solutions should fit the challenge.
 - 4.3. Identify priority areas for resolution and options for addressing these.
 - 4.4. Identify key opportunities for achieving the vision, and options for taking advantage of these.
 - 4.5. Identify a timeline of key milestones.
 - 4.6. Propose a governance and monitoring framework for achieving the vision.
 - 4.7. The strategy shall cover freight, franchised passenger services and non-franchised passenger services, non-traction energy including stations and fleet on the mainline network. It shall not cover heritage rail services (the strategy does not cover the UK electric grid mix).
 - 4.8. The strategy shall cover England, Wales and Scotland.
5. Operation and management
 - 5.1. The Taskforce shall include members from relevant industry parties including ROSCOs, Network Rail, RDG, RSSB, RIA, RFG and RDG Freight Group and may co-opt other expertise and establish working groups as needed.
 - 5.2. RSSB shall provide the secretariat.

5.3. Meetings shall be quorate when at least three representative groups (including the Chairman) or authorised alternatives are present.

5.4. Malcolm Brown, Angel Trains, shall chair the taskforce.

5.5. Meetings shall be as needed.

6. Timescales

6.1. Initial response by September 2018.

Taskforce members and secretariat		
Malcolm Brown, Chair	Head of Asset Management Europe	AMP Capital
Maggie Simpson	Executive Director	Rail Freight Group
Wendi Wheeler	Energy & Carbon Strategy Manager	Network Rail
Helen McAllister ⁷¹	Head of Strategic Planning (FNPO), System Operator	Network Rail
Gary Cooper ⁷²	Director, Planning, Engineering, Operations	Rail Delivery Group
Mark Gaynor ⁷³	Interim Director, Planning, Engineering, Operations	Rail Delivery Group
Paul Smart	COO, Freightliner	RDG Freight Group
David Clarke	Technical Director	Railway Industry Association
Tom Lee	Director of Standards	RSSB
Shamit Gaiger ⁷⁴	Programme Director Sector Policy	RSSB
Secretariat		
Anthony Perret	Head of Sustainable Development Programme	RSSB
Andrew Kluth Technical author	Lead Carbon Specialist	RSSB

RSSB has made an invaluable contribution in the research and drafting of this report. The Taskforce wishes to acknowledge this support, which exemplifies the wider contribution the RSSB makes to the rail industry.

71 First Taskforce meeting: 20 February 2019

72 Resigned, 15 February 2019

73 With effect from 15 February 2019

74 Resigned 31 March 2019

Annex C:

Mass and volume of different traction energy sources

1. There are practical limitations to what types of trains different traction options can drive. These are defined by the mass and volumes of the different energy sources in terms of on-train storage needed as well as the drive train. These are shown in Table 7⁷⁵ and Table 8⁷⁶.
2. Table 7 shows that, in almost all cases, the mass of batteries needed to meet the performance requirements of each train type will be significantly heavier than the equivalent diesel it might replace.

Train type	Mass of Diesel Engine + Fuel (kg)	Mass of Hydrogen 'Engine + Fuel' (kg)*	Mass of Battery 'Engine + Fuel' (kg)*
A	3,826	2,845	16,885
B	5,805	4,767	33,620
C	8,466	7,821	64,499
E-A	3,914	2,424	8,605
E-B	5,365	3,615	17,010
E-SH	4,980	2,608	2,476
F-A	3,914	2,424	8,605
F-B	5,365	3,615	17,010
F-C	7,619	5,604	35,525
F-SH	6,848	3,589	3,457
Freight	36,150	32,054	251,553

Green: lighter than diesel Amber: slightly heavier Red: substantially heavier

Table 7: mass estimates for different engines and fuels

3. Table 8 shows where, in volume terms, hydrogen and battery options may fit on a typical multiple unit.

Train type	Diesel Storage Volume (m ³)	Hydrogen Storage Volume (m ³)	Battery Storage Volume (m ³)
A	0.43	4.26	10.04
B	0.87	8.51	20.07
C	1.67	16.39	38.64
E-A	0.22	2.13	5.02
E-B	0.43	4.26	10.04
E-SH	0.05	0.53	1.25
F-A	0.22	2.13	5.02
F-B	0.43	4.26	10.04
F-C	0.83	8.19	19.32
F-SH	0.08	0.74	1.76
Freight	6.49	63.85	150.54

Green: likely to fit on a typical unit Amber: marginal fit Red: will not fit

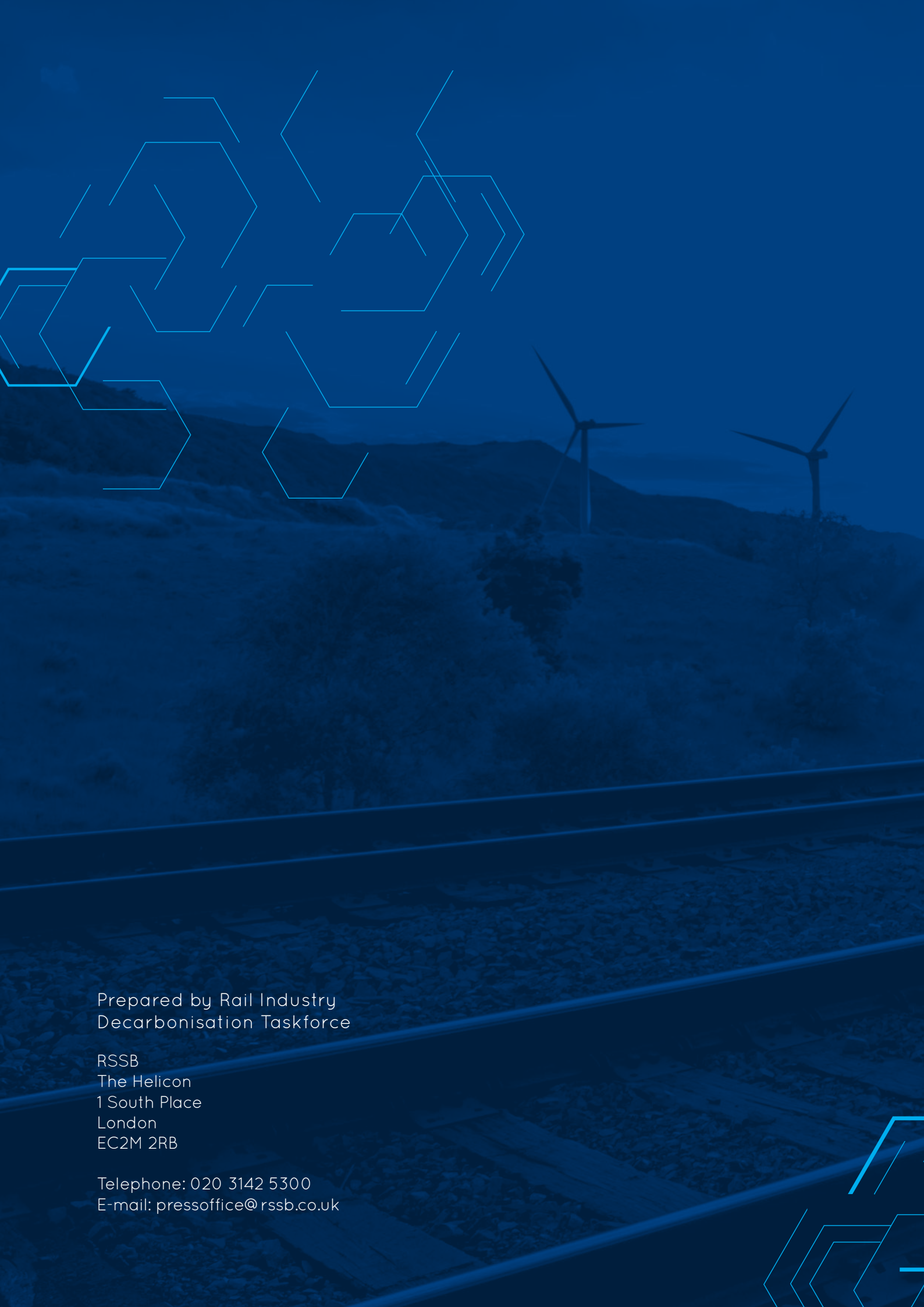
Table 8: volume estimates for different engines and fuels

75 T1145 (ibid), Table 5

76 T1145 (ibid) Table 6







Prepared by Rail Industry
Decarbonisation Taskforce

RSSB
The Helicon
1 South Place
London
EC2M 2RB

Telephone: 020 3142 5300
E-mail: pressoffice@rssb.co.uk