March 2021

Transition to Zero-Emission Transport – A Pathway for Long-Haul Heavy Goods Vehicles

Catapult Connected Places

Executive Summary

The Need to Decarbonise HGVs

In June 2019, the UK became the first major economy in the world to pass laws to end its contribution to global warming by 2050. This Net Zero commitment means that every part of every industry must be decarbonised as far as possible.

Heavy Goods Vehicles (HGVs) are vital to industry and represent the backbone of trade and commerce across the world. They are responsible for ensuring we have access to food, medicines, and goods of all kinds. In the UK, HGVs produced 16% of domestic transport greenhouse gas emissions in 2019, and this will need to be reduced to zero by 2050 as set out in the Department for Transport's 'Decarbonising Transport: Setting the Challenge,' which is preparing for the Transport Decarbonisation Plan.

The Challenge

Large, long-haul HGVs are particularly challenging to decarbonise. Vehicles are in use for long periods of the day and require high levels of power and energy for their operations. Larger articulated vehicles are driven significantly further than rigid vehicles. The average articulated HGV travels more than 400km per day, mostly at high speed[1].

The HGV market is heavily fragmented, with a wide range of vehicles serving many different sectors. Different operations require different vehicles and duty cycles, and any solution must enable hauliers to maintain customer-focussed, efficient and cost-effective movement of goods.

The Options

The key near-term options for fully decarbonising HGVs are hydrogen and Electric Road Systems (ERS). Hydrogen fuel cell HGVs are fitted with an electric powertrain. Energy is stored within the on-board hydrogen and is converted to electricity in fuel cells. ERS involve installing infrastructure that enables electrical energy to be delivered directly into a vehicle while it is in motion. The most developed and HGV-compatible ERS is a conductive overhead catenary system, which involves wires suspended above the carriageway and a pantograph mounted on top of the vehicle, designed to extend to meet the catenary and draw power when the vehicle is in position. This technology has been deployed in trials on public highways across Europe, including in Germany and Sweden, and is proven to provide sufficient power for large HGVs at highway speeds.

Both technologies provide promising options for the future of zero-emission HGVs. Due to their relatively low technology readiness levels and other uncertainties, more information is needed to confirm which technology or combination of technologies will best suit the future UK market.

The potential of a pure battery electric HGV solution was investigated alongside ERS and hydrogen fuel cells. Based on analysis of battery technology and industry engagement, it is considered that battery electric HGVs are unlikely to be able to meet the necessary requirements for the majority of long-haul operations in the short term. However, battery technology underpins both hydrogen fuel cell and ERS vehicle systems and is vital for the zero-emission transition of smaller vehicles. Investment in battery technologies, and monitoring of their potential for long-haul HGVs, should continue.

[1] https://www.eti.co.uk/search?false&query=Report+on+telematics+data+analysis+and+truck+performance+algorithms

The Pathway to 2050

To achieve full decarbonisation of HGVs by 2050, a significant coordinated national effort will be required. If all vehicles on the road need to be zero-emission by 2050, sales of non-compliant HGVs will need to cease at least ten years earlier, so by 2040. It could take at least ten years to develop a fully competitive vehicle marketplace and build supporting refuelling / recharging infrastructure across the country, so key decisions on which mix of technologies to deploy at scale must be taken by around 2027. The most effective way to gather evidence and mature the technology is to run large-scale demonstrations of the candidate technologies, operating in real-world conditions, and they will need to start by 2025 at the latest.

We have developed a proposed outline for these demonstrations, designed to:

- Demonstrate the potential technologies at scale
- Learn lessons that will support planning a rapid roll out
- Collate evidence to support decision-making and the business case for further investment

Based on current uncertainties regarding performance, costs, and practicalities of both hydrogen and ERS HGVs in the UK context, it is proposed that both technologies are demonstrated in parallel. For hydrogen, approximately 40 vehicles and 6 refuelling stations would begin to remove barriers to adoption of zero-emission HGVs, and 100 vehicles and 15 refuelling stations would do so to an even greater extent.

Previous work on ERS at the Connected Places Catapult considered 60-100 vehicles, and 20-40km of catenary in each direction on a stretch of highway. Demonstrations would be expected to last 4-5 years, and would provide independent evidence on costs, performance, reliability and suitability of the technologies. They should also stimulate development and production of zero-emission HGVs for the UK, help to establish supply chains, enable UK-based expertise to flourish, and improve trust in the technology.

While demonstrations will perform this vital role in the transition to zero-emission HGVs, a much wider programme of activities will also be required. We have engaged with stakeholders across the private and public sector to understand the challenges associated with the transition, and the key elements for success, which include:

- Setting a clear vision
- Funding and de-risking the transition
- Developing trust in the technology
- Infrastructure deployment
- Regulations and standards
- Building the UK supply chain
- Enabling a sustainable market

These activities, as well as detailed planning for the demonstrations, need to start as soon as possible. In November 2020, the Government confirmed £20m of funding to pioneer zero emission HGV technology on UK roads.

For access to further evidence and analysis compiled by Connected Places Catapult, please email
ZeroEmissionRoadFreight@cp.catapult.org.uk

Next Steps

The next steps required within the coming year are:

- Design and assess feasibility of large-scale hydrogen and ERS demonstrations, including confirmed locations, cost estimates, communication plans, and business case
- Update technology analysis based on latest data, and review suitability of regulations
- Establish open principles of operation to support the drafting of open standards
- Clarify and communicate plans for activities beyond the first year

At the Connected Places Catapult, we look forward to working closely with stakeholders over the coming year and beyond to ensure the UK sets out on the best pathway to 2050.

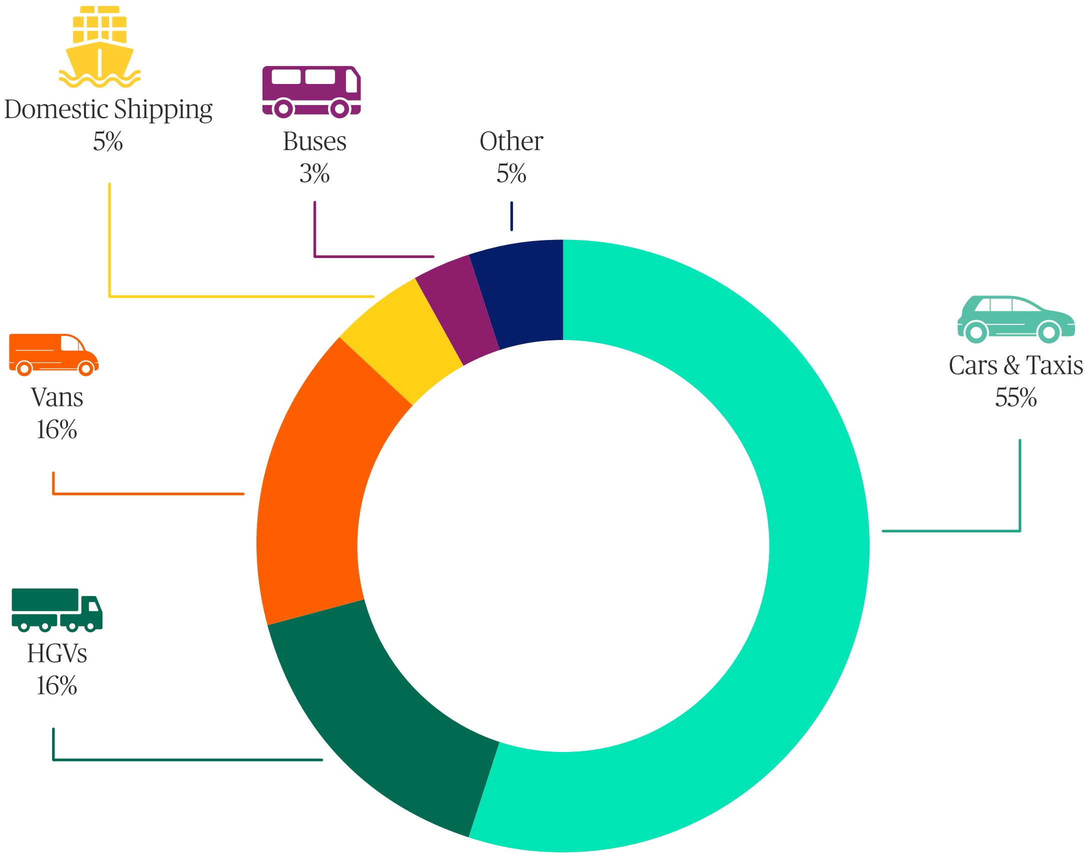
Introduction

In June 2019, the UK became the first major economy in the world to pass laws to end its contribution to global warming by 2050[2]. This Net Zero commitment means that every part of every industry must be decarbonised as far as possible. In the transport sector, the Department for Transport's 'Decarbonising Transport: Setting the Challenge'[3] document confirms that the aim is

'net zero emissions across every single mode of transport by 2050'.

While battery electric vehicles are expected to gradually take over the car and van market, a different plan is required for the majority of Heavy Goods Vehicles (HGVs). HGVs are vital to our economy and represent the backbone of trade and commerce across the world. They are responsible for ensuring we have access to food, medicines, and goods of all kind and play a part in the supply chain of almost every industry.

In the UK, articulated HGVs, which tend to be longer and heavier, do the bulk of this work. In 2019, of all domestic freight moved by HGV, articulated vehicles lifted 62% (897 million tonnes), compared to 38% by rigid vehicles. Of all domestic freight, 79% was moved by road, compared to 13% by water and 8% by rail. Despite comprising a relatively small proportion of vehicle mileage, HGVs produced 16% of domestic transport greenhouse gas emissions in 2019.



Domestic UK Greenhouse Gas Emissions by Mode, 2019

Source: BEIS, Final UK greenhouse gas emissions national statistics 1990-2019, Table 3.2. Excludes international aviation and international shipping.

The largest, long-haul HGVs, however, are probably the most challenging of road vehicles to decarbonise. Vehicles are in use for long periods of the day and require high levels of power and energy for their operations. Larger articulated vehicles are driven significantly further than rigid vehicles. One study[1] found that the average articulated HGV travels more than 400km per day, mostly at high speed.

The HGV market is heavily fragmented, with a wide range of vehicle sizes and body types serving many different sectors. Different operations require different vehicles and duty cycles, and any solution must enable hauliers to maintain customer-focussed, efficient and cost-effective movement of goods.

At the Connected Places Catapult, we have been investigating the zero-emission options for large long-haul HGVs over the past three years. We have compiled a body of evidence to help inform government and industry decision-making. This report summarises the analysis carried out to date, and sets out the key considerations and activities required to enable the UK to transition to zero-emissions HGVs by 2050.

[2] House of Commons Library Briefing Paper, "Net zero in the UK", 2019, https://commonslibrary.parliament.uk/research-briefings/cbp-8590/

[3] https://www.gov.uk/government/publications/creating-the-transport-decarbonisation-plan

Zero-emission Options for HGVs

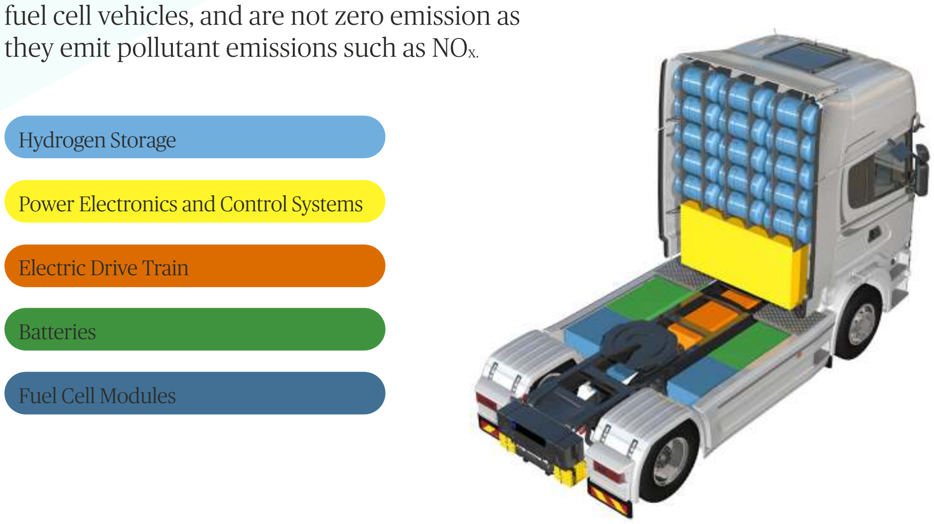
Hydrogen

Hydrogen fuel cell HGVs are fitted with an electric powertrain. Energy is stored on board the vehicles as hydrogen, which is converted to electricity in fuel cells. There are no tail pipe emissions - the only by-products are warm air and water vapour. The vehicle will also have a battery to produce additional power when needed, and to recuperate electrical energy from braking. Vehicles will need to refuel at hydrogen refuelling stations.

Conventional internal combustion engine powertrains can also be converted (or specifically developed) to operate with hydrogen as a fuel. However, these vehicles are generally less efficient than the equivalent fuel cell vehicles, and are not zero emission as they emit pollutant emissions such as NO_x.

Hydrogen fuel can be made using electricity to electrolyse water, or through reforming methane, sourced either from natural gas or biomass. Following methane reforming, the resulting carbon dioxide can be sequestered so that it is not released into the atmosphere, though this technology is in the early stages of implementation in the UK.

Long-haul hydrogen fuel cell HGVs have been trialled internationally, but are not yet being mass-produced, and there have not yet been any trucks built to UK specifications. However, fuel cell cars and buses have already been introduced in the UK, so the basic technology is well understood.



Hydrogen Fuel Cell HGV Components (indicative only)

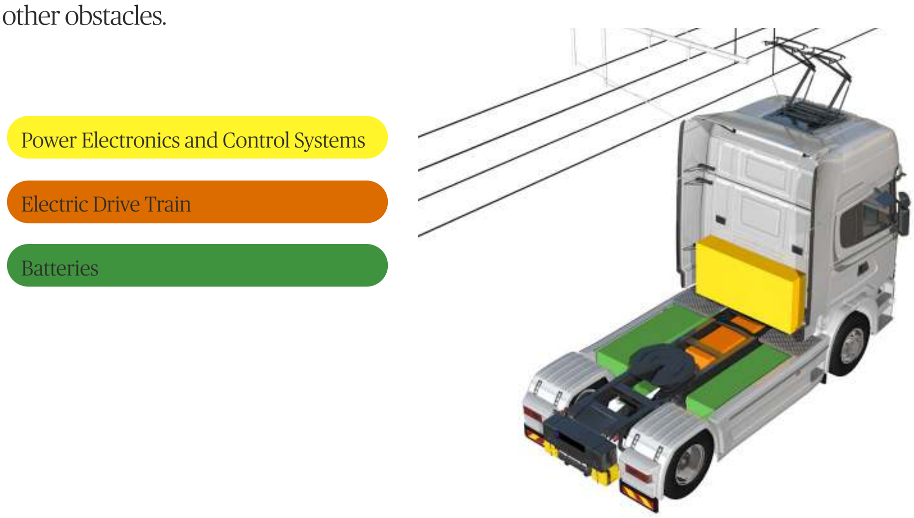
Electric Road Systems

Catenary infrastructure on A5 in Germany (Image source: Hessen Mobil)

Electric Road Systems (ERS) involve installing infrastructure that enables electrical energy to be delivered directly into a vehicle while it is in motion. The most developed and HGV-compatible ERS technology is conductive overhead catenaries. In this system, a catenary wire is suspended above the carriageway. A pantograph is mounted on top of the vehicle, designed to extend to meet the catenary when the vehicle is in position, enabling power to flow from the overhead wires into the vehicle powertrain. Vehicles feature a full electric drive and a pantograph system, similar to overhead rail electrification. ERS-enabled vehicles also need a backup system such as battery energy storage to travel between ERS-enabled roads, and for interruptions such as bridges/tunnels and other obstacles.

Electricity to power the vehicles would come via the electricity network, though additional capacity and new connections would be required.

ERS-enabled articulated HGVs have been trialled in Germany, Sweden and the USA, but they are not yet being mass-produced, and they have not yet been trialled in the UK. Much can be learnt from international deployments, as well as similar technology applications for other modes such as rail electrification, trams and trolley buses.



ERS HGV Components (indicative only)

Battery Electric HGV Components (indicative only)

- Power Electronics and Control Systems
- Electric Drive Train
- Batteries

Battery Electric Vehicles

The basic vehicle architecture of a pure battery electric HGV is similar to the other options, but the vehicle must store all of its energy in batteries. Battery technology is a fundamental part of both hydrogen fuel cell and ERS solutions, and can be suitable for lighter vehicles with shorter routes. However, as a standalone solution for the largest long-haul HGVs, we do not think it is ready for a large-scale demonstration in the near future due to range limitations, the weight of batteries which reduces efficiency and carrying capacity, and technical and operational concerns regarding charging.

Comparing the Options

Hydrogen and ERS articulated HGVs are both credible options for decarbonising long-haul road freight. Each technology has some compelling advantages, while also having potentially significant disadvantages and risks. These are summarised in the table to the right.

	Hydrogen	Electric Road Systems
Advantages / Opportunities	Short refuelling time. Long vehicle range between refuelling. Can be operationally similar to conventional vehicles. Hydrogen availability is likely to increase as it becomes useful in other sectors (e.g. heating, aviation, maritime, industry). Hydrogen can be a useful storage vector for surplus renewable energy.	High 'windmill to wheel' efficiency (>80% reported), enabling low operating costs, and benefitting the overall energy system. Reduces operating time spent on refuelling, potentially to zero for certain operations. Technology well developed for railways, trams, trolleybuses, etc, with UK-based expertise and supply chains available.
Disadvantages / Risks	'Windmill to wheel' efficiency is relatively low compared to other zero-emission options. A vehicle may need over twice as much primary energy to cover the same distance as an electric equivalent. Requires an extensive network of HGV hydrogen refuelling stations, which may be costly and/or delayed by land constraints and planning regulations. Fuel cost may remain high for zero-emission hydrogen from electrolysis. High specification materials are required for fuel cells and onboard hydrogen storage, making these components significant drivers of cost.	Requires major upfront infrastructure investment, and uncertainty over installation costs including electricity network connections and reinforcements. Achieving high utilisation could be challenging without an extensive network of ERS routes. Potential objections to visual impact of catenaries. Safety, operational and disruption risk in case of overhead line equipment failure. Risk of delays or restrictions to infrastructure deployment due to planning regulations.

As shown in the table, many of the potential disadvantages and risks for both technologies relate to cost. We have developed a cost model to enable comparison of the expected future cost of ownership for each option, including vehicle capital costs, maintenance costs, and fuel/infrastructure costs. The model draws on best-available cost data and has been benchmarked against a range of other models. The conclusion of this analysis to date is that there is no clear winner on a cost basis, with any differences well within the bounds of uncertainties in future costs.

Considering cost and all the other factors above, both hydrogen and ERS technologies appear to provide promising options for the future of zero-emission HGVs in the UK. Due to their relatively low technology readiness levels and other uncertainties, more information is needed to confirm which technology or combination of technologies will best suit the future UK market.

The Pathway to 2050

The target of full decarbonisation of HGVs by 2050 may appear to be a long time in the future, but working backwards from that date shows the importance of acting quickly.

2050 — All HGVs on the road net zero compliant

2040 — End of sale of fossil-fuelled HGVs

Commercial, competitive market for zero emission HGV technologies established

Nationwide deployment

2030

Scale infrastructure and vehicle numbers

Demonstrations

Large-scale commercial demonstrations of vehicle technology and infrastructure

Now

Preparing for demonstrations

If vehicles on the road need to all be zero-emission by 2050, sales of non-compliant HGVs will need to cease at least ten years earlier, so by 2040. It could take at least ten years to develop a fully competitive vehicle marketplace and build all the required infrastructure, so key decisions on which routes to follow must be taken by around 2027.

To enable key decisions to be made about which technology or technologies to deploy, significant evidence gathering will be required during the 2020s. The most effective way to gather the required evidence, and mature the technology to the required level, is to run large-scale demonstrations of the candidate technologies, operating in real-world conditions. Demonstrations will need to run over a significant period, and all relevant data should be recorded to provide the evidence required. Demonstrations would therefore need to start by 2025 at the latest, and as they will require detailed planning, this needs to start as soon as possible. In November 2020, the Government confirmed £20m of funding to pioneer zero emission HGV technology on UK roads.[4].

[4] HM Government, "The Ten Point Plan for a Green Industrial Revolution", 2020, https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title

Enabling the Transition

Setting a Clear Vision

The transition to zero-emission HGVs will not be driven by market forces alone, due to the large infrastructure investments and coordination required. This means that government must work with industry to set out a clear vision and commitment to support the transition, including a long-term commitment to trialling, demonstrating, and ultimately deploying the most promising technologies.

The vision will need to be clearly communicated to all stakeholders, and the public, to enable the required investments and decisions to be made. It can be updated as the technologies mature through trials and demonstrations, providing improved clarity and confidence to investors. The forthcoming Transport Decarbonisation Plan from the Department for Transport will be the first step in setting a clear vision for decarbonisation across the whole transport sector.

Funding and De-risking the Transition

An important part of the vision and planning for the transition to zero-emission HGVs is how it will be funded. The two largest cost elements will be the purchase of the vehicles, and the cost of the infrastructure. Most fleet operators will require significant support to be able to trial or buy zero-emission vehicles without incurring additional costs, including consideration of any reduced productivity due to challenges arising with new technology.

For the infrastructure, a variety of business models are possible to ensure investors can expect to recoup costs. Government must work in partnership with industry to ensure the appropriate roll out of infrastructure is funded. Hydrogen refuelling stations are likely to be easier for the private sector to finance than ERS infrastructure, since return on investment depends on utilisation, and this can be achieved with local demand for hydrogen, whereas ERS needs wider roll out before high utilisation will be achieved.

Developing Trust in the Technology

Many stakeholders, such as fleet operators, are understandably cautious about the unknown. They wonder whether zero-emission technologies will be able to fulfil current operational requirements, and whether new equipment will have reliability or safety issues. The best way to alleviate these concerns is to demonstrate the technology options working in a wide range of real-world conditions. Before this, early tests and small trials should be carried out to confirm sufficient performance and reliability, since it is important that demonstration participants have a positive experience to improve their trust levels. Demonstrations must also be well-supported, and potentially include some redundancy, so that any issues arising can be addressed with minimal disruption to operations.

Public trust in the technology is also crucial and must be considered from the earliest stages of activity, with clear communication ahead of trials and demonstrations, especially to those living or working nearby. Safety analysis should take place as part of planning for and running demonstrations and deployments. This will reduce the likelihood of any incidents occurring during operations, and also provide assurance to all that risks are being appropriately addressed.

Data will need to be collected throughout all trials and demonstrations to provide the evidence required to confirm the suitability and reliability of new technology, which will also support investment decisions and development of the overall vision.

Infrastructure Deployment

For all zero-emission vehicle technologies, there tends to be a 'chicken and egg' problem between deployment of vehicles and deployment of the required refuelling/recharging infrastructure. Vehicle owners do not want to invest in zero-emission vehicles until they are sure they can access the required infrastructure to power them, but infrastructure providers do not want to invest in equipment until they are sure there is sufficient demand to provide a return on their investment. This challenge can be overcome through coordinating deployments of vehicles and infrastructure, as well as the setting of the clear vision, and providing funding support for both elements during the early stages. Data collection will be critical to understanding real world refuelling and recharging behaviour, and infrastructure reliability, to enable deployment of vehicles and infrastructure to stay in step throughout the transition.

How the hydrogen or electricity is produced and distributed to the point of use will need to be considered in all infrastructure decisions, and will depend on how other sectors transition to their Net Zero targets. The energy sector should therefore be engaged throughout the transition.

Regulations and Standards

Development of technologies and deployment of infrastructure must take place within a supportive regulatory environment to enable the required progress to be made. HGV regulations may need to be revised, as well as infrastructure and planning regulations, to facilitate this and other elements of the national transition to Net Zero.

New standards will also be required to ensure systems are safe, reliable, and interoperable. Draft standards should be derived ahead of the large-scale demonstrations, and then verified during them. These standards should be open, to support generation of a competitive market for both vehicles and infrastructure. To enable cross-border freight movement, they must also be compatible with emerging European standards.

Building the UK Supply Chain

Developing UK supply chains for zero-emission technologies will provide jobs and growth for the economy, as well as improving security of supply and ongoing technical support for UK vehicles and infrastructure. To achieve this, early procurement activities should be structured to maximise UK supply chain opportunities, and industry incentivised to share knowledge and form meaningful collaborations. Demonstrations will create initial supply chains, and the outputs of demonstrator activities, including open standards, should lead to an open playing field for new entrants. This will ensure the ongoing cost competitiveness of systems and maximise supply chain opportunity and resilience.

Enabling a Sustainable Market

An important part of the vision for zero-emission HGVs is that they operate as part of a commercially sustainable market as soon as possible. Government will have a key role to play in shaping the market conditions, through taxes and incentives related to zero-emission and other technologies. The costs of vehicles, infrastructure, hydrogen, and electricity in future will depend on many factors, making it challenging to predict exactly what will be needed. Government departments, such as the Department for Transport and the Department for Business, Energy & Industry Strategy, will need to work together to support the market as it develops.

Demonstrations

A key step along the pathway to zero-emission HGVs is to gather evidence and mature technologies through large-scale demonstrations operating in real-world conditions. We have developed a proposed outline for these demonstrations, designed to:

- Demonstrate the potential technologies at scale
- Learn lessons that will support planning a rapid roll out
- Collate evidence to support decision-making and the business case for further investment

Based on current uncertainties regarding performance, costs, and practicalities of both hydrogen and ERS HGVs in the UK context, it is proposed that both technologies are demonstrated in parallel. These demonstrations may be substantially independent from each other, and may be in different locations, though data gathering processes must be aligned to ensure a robust evidence base is developed.

Our focus has been on articulated HGVs over 40 tonne gross weight, since these are the hardest to decarbonise, and are crucial to the freight industry. 83% of articulated HGVs are over 40 tonne, and in 2019, GB-registered articulated HGVs moved 122 billion tonne kilometres of goods, compared to 32 billion tonne kilometres by rigid vehicle[5]. Other vehicles and even other types of transport could be included in a demonstration, but these should not detract from the core purpose.

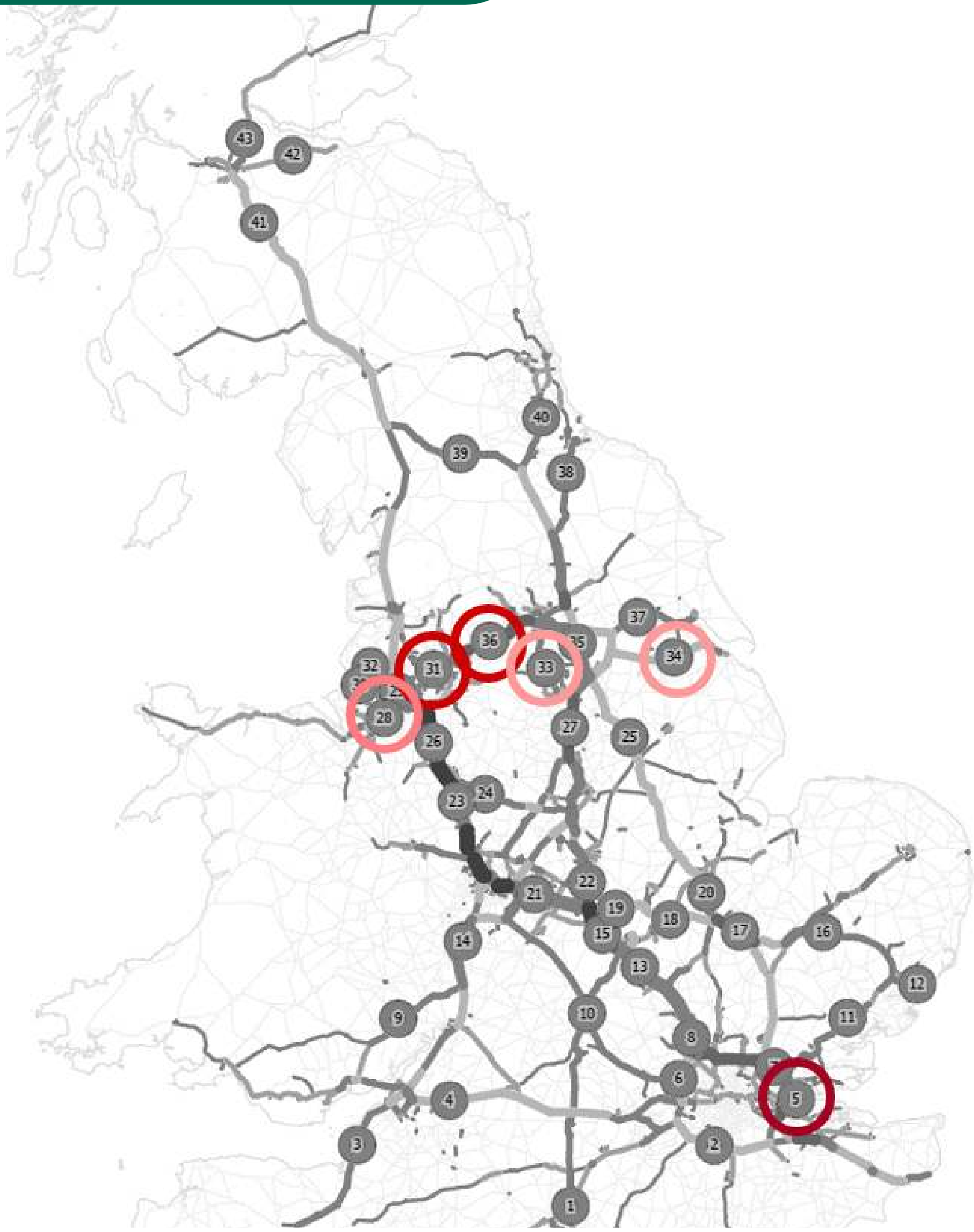
Scale

The optimal scale for the demonstrations is hard to define. Through analysis and stakeholder feedback, we have ascertained that for hydrogen, 40 vehicles and 6 refuelling stations would begin to remove barriers to adoption of zero-emission HGVs, and 100 vehicles and 15 refuelling stations would do so to an even greater extent. For ERS, the range explored was 60-100 vehicles, and 20-40km of catenary in each direction on a stretch of highway. Again, the higher the ambition, the greater the benefits of the demonstrations are expected to be. In fact, if demonstrations are hoped to stimulate the supply chain for UK zero-emission HGVs, many more vehicles would be needed. The Climate Change Committee has called for 'large commercial-scale demonstrations, involving hundreds of vehicles...' which would kick-start the transition in the UK[6].

Demonstrations would be expected to last 4-5 years, with the number of vehicles built up over that period, and initial results to be shared approximately two years after first deployment.

[5]DfT Road Freight Statistics, Table RF20109. Goods moved is a measure of the weight of goods carried multiplied by the distance hauled, measured in tonne kilometres

[6]Climate Change Committee, "The Sixth Carbon Budget - Surface Transport", 2020 https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Surface-transport.pdf



Links with high number of HGVs travelling less than 100km
Source: MDS Transmodal

Locations

In terms of location, a first ERS deployment would be well suited to corridors with high HGV flows and where a high proportion of this traffic is undertaking 'back and forth' movements, with limited distances to be covered 'off the wires' between origin and destination. It would also be beneficial to pick a location that can be expanded over time, so the initial deployment is the starting point of a longer-term network.

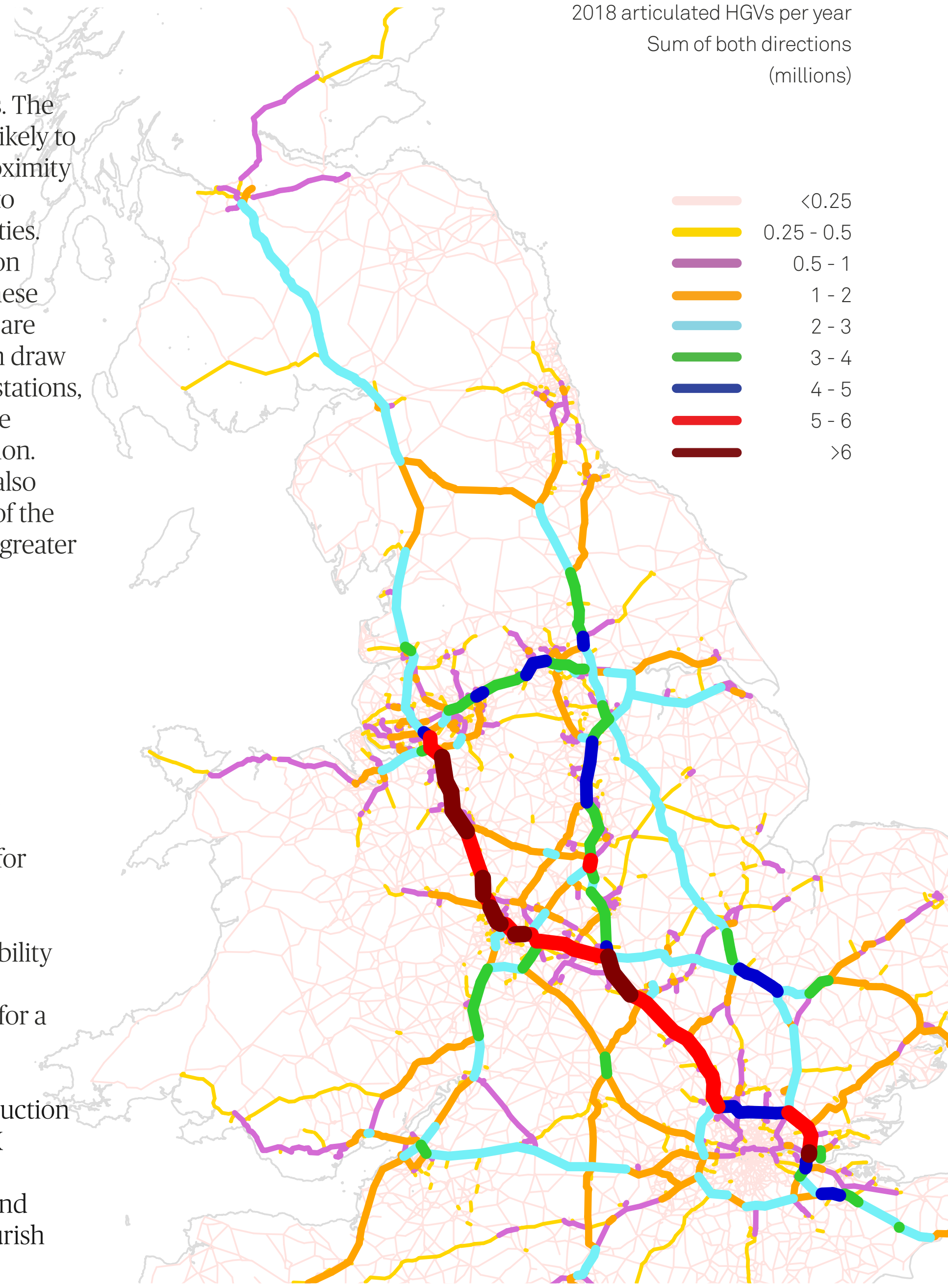
The exact location will depend on the locations of fleet operators prepared to take part in initial demonstration activities, as well as practical issues, such as how the ERS can be safely deployed within the constraints of the highway, power requirements associated with topography and ease of connection to the electricity network. There may be opportunities to combine efforts with planned electricity capacity upgrades at motorway service areas. Planning aspects should be considered, which may include the potential for objections in sensitive parts of the landscape, and the level of support from the relevant authorities.

For hydrogen, there is more flexibility regarding location of refuelling stations. The general location of a demonstration is likely to be determined by factors including proximity to fleet operators prepared to commit to take part in initial demonstration activities. Refuelling requirements will be based on optimal operational convenience for these fleets. If much of the vehicles' activities are daily 'back to base' operations, they can draw most of their fuel from local refuelling stations, providing the potential for a predictable demand and high utilisation of the station. Some 'satellite' refuelling stations may also be required outside the main location of the demonstration, to allow HGVs to travel greater distances with confidence.

Outcomes

A successful demonstration will:

- Gather independent evidence on
    - Costs, and key drivers of cost, for each technology
    - System performance and reliability
    - Suitability of each technology for a range of use cases
- Stimulate development and production of zero-emission HGVs for the UK
- Help to establish supply chains, and enable UK-based expertise to flourish
- Improve trust in technology by demonstrating real world operations
- Enable verification of open standards



HGV flows from Great Britain Freight Modal. Source: MDS Transmodal

Next Steps

The vision for how to transition the heaviest HGVs to zero-emissions by 2050 is becoming clear. It will involve trialling, demonstrating, and ultimately deploying hydrogen and ERS technologies (whichever one, or combination, proves most advantageous), and it needs to start now. In November of 2020 the Government confirmed funding of £20 million for freight trials to pioneer hydrogen and other zero emission lorries, to support industry to develop cost-effective, zero-emission HGVs in the UK.

The next steps required within the coming year are:

- Design and assess feasibility of large-scale hydrogen and ERS demonstrations
- Confirm locations for demonstrations
- Develop cost estimates for demonstrations
- Develop business case for demonstrations
- Develop safety plans for demonstrations
- Update technology maturity analysis based on latest data
- Review suitability of applicable regulations
- Develop communication plan for trials and demonstrations
- Establish open principles of operation to support drafting of open standards
- Clarify and communicate plan for activities beyond first year

At the Connected Places Catapult, we look forward to working closely with the Department for Transport, Innovate UK, and stakeholders over the coming year, and beyond, to ensure the UK sets out on the best pathway to a net-zero transport 2050.

For further information please contact us:

ZeroEmissionRoadFreight@cp.catapult.org.uk

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