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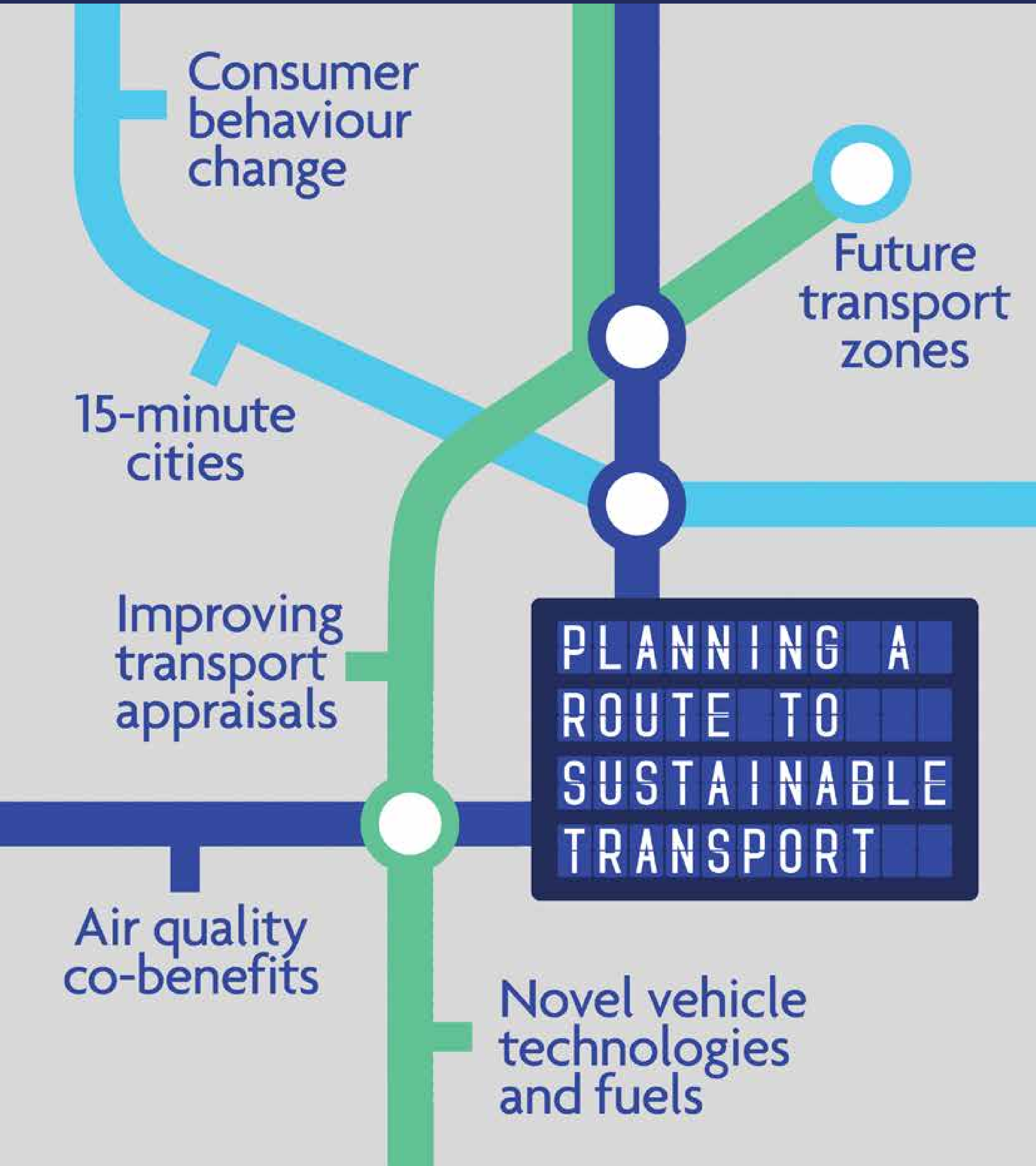

EDITORIAL

Delivering a different transport future today

What strikes me most about the subject of transport today is its complexity, in part demonstrated by the range of articles in this edition. The scale of the task in front of us is enormous and multifaceted: an intricate, complex jigsaw where every piece is essential. But, as we do not have the final picture, the challenge is even greater. What is clear is the importance of every piece; the wide range and number of experts who are or need to be involved; and the need to work closely together. There is also no single solution. The right one will vary across the country and the world and identifying it requires multisector expertise. Many of these experts are represented in this journal edition, but not all.

The combination of the major current societal issues has put a spotlight on transport: health concerns, be it obesity, asthma or other conditions; climate change in all its characteristics; the quality of places for people to live and work; and evolving technology, to name but some. The interactions between transport and health are complex, affected by many factors such as demographics, travel behaviour and planning approaches. Climate change, similarly, is being driven not only by transport decisions and options but by technology, energy supplies and other factors. Technological change can provide numerous benefits for transport, but it is not the panacea some believe it to be. To try to resolve the problems, at the speed required, will take courage, determination, strategic thinking and a holistic, coherent approach that engages and balances all the collaborating disciplines. Working in silos will not work. Nor will any single-aspect focus.

The relationship between planning and transport is one of the key partnerships required. The need for access to homes, work, services and social networks drives transport, so the location of these activities and their relationship are at the heart of both travel demand and mode of travel. Over the last 40 years the planning system and transport planning have failed to deliver development which accords with the need to minimise essential journey numbers and distances.[1] A radically different approach is now needed.

This may be about to change. The Department for Transport is following up on its recent decarbonisation of transport strategy[2] with the establishment of a new planning division. This, together with the forthcoming revisions to planning legislation and the National Planning Policy Framework,[3] provides a critical opportunity to redress some of the current barriers to minimising the need to travel and increasing active and sustainable travel activity.

As well as expertise and collaboration across skills, a key aspect is behaviour change from politicians, professionals and all local communities. To achieve such change within a very limited timeframe will challenge everyone. Given the steep trajectory of climatic change, urgent action is needed by all the relevant disciplines in unison to develop a coherent action plan for us to transition to living and travelling differently. The Government established multidisciplinary task teams to tackle Covid-19. We now need the equivalent to develop and deliver a transition action plan for transport to tackle climate change and health together.

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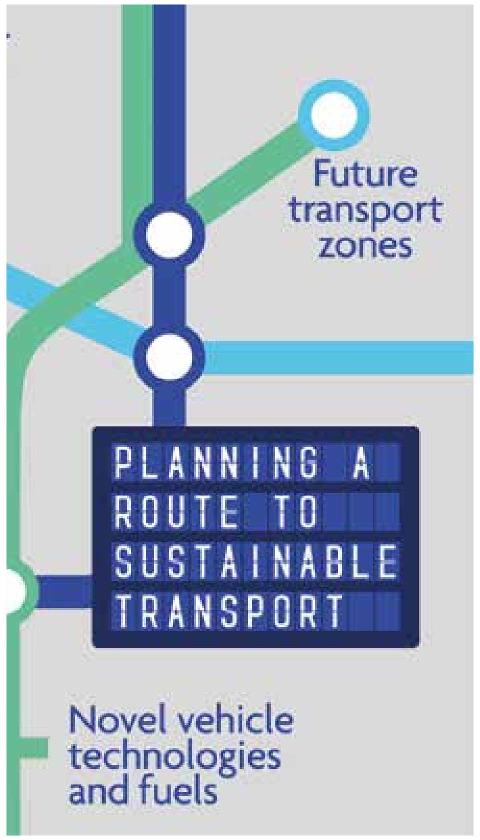

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INTRODUCTION

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The route to a better transport future

Justin Bishop reviews the need for and pathways to a sustainable decarbonised transport future.

In the UK, transport became the largest sectoral emitter of greenhouse gases (GHG) in 2016, growing to account for 27 per cent of national emissions by 2019. In the decade to 2019, national domestic transport emissions fell by only 3 per cent, with decreases from cars, buses and heavy goods vehicles being offset by increases in emissions from vans.[1] Therefore, our current trajectory will be insufficient to achieve net zero by 2050. A step change in the scale and pace of both consumer behaviour and novel vehicle technology is necessary in the next three decades.

DRIVERS FOR CHANGE

There is a spectrum of interventions for delivering a future with decarbonised transport. At one end is the technology-led pathway, where the fleet of vehicles used to deliver transport for people and goods switches completely to electric and hydrogen power across all modes. The UK Government's recent announcement on ending the sale of new petrol and diesel cars, vans[2] and heavy goods vehicles[3] by 2040 suggests a technology-driven path to decarbonisation.

At the other end is a mobility-led pathway, where we meet our needs using active and sustainable modes, accomplished through mixed-use land and transport planning that deliver places for people. In July 2021, the Government concluded consultations on its National Planning Policy Framework and National Model Design Code. These documents focus on promoting safe and healthy communities and sustainable transport.[4]

The reality will lie between these two pathways and should draw on the positive characteristics of each; moreover, we can expect geographical variety across the UK, with some places closer to the technology-led and others closer to the mobility-led ends of the spectrum. The opportunity lies in those interventions which can deliver broader sustainable outcomes by identifying and capturing the value of co-benefits. Well-rehearsed examples of the positive impacts around a mobility-led approach include improved placemaking, accessibility and inclusion for citizens across the range of ages and abilities. Some co-benefits of the technology-led approach can be viewed as avoided costs to society, such as reduced emissions of local air pollutants arising from fuel combustion. For example, nitrogen oxide emissions from cars fell 19 per cent in the decade to 2019, despite an overall increase in car use.

As it does today, a future decarbonised and sustainable transport system will depend on infrastructure, much of which is already in place. For example, there were almost 400,000 km of roads[5] and over 31,000 km of rail track[6] in Great Britain in 2020. Building adaption and resilience to climate change into current and new infrastructure is critical to ensuring its longevity and fitness for purpose.

The spectrum of technology-led and mobility-led interventions (and supporting infrastructure) will reduce but not eliminate emissions from transport. The Climate Change Committee expects around 1 million tonnes of residual GHG emissions from surface transport by 2050.[7] Therefore, achieving net zero will require additional efforts to remove these residual emissions.

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THE PATHWAYS TO CHANGE

This special issue illustrates some of the components of a sustainable and decarbonised transport future and how they may work together.

Anthony Velazquez discusses vehicle and fuel options, focusing on road transport. Some of the wider ecological impacts of switching vehicle technologies are highlighted for both batteries and the electric traction drives to which they are paired. Greg Archer reviews the fuel options for road, marine and air transport. He presents an energy hierarchy, where electricity should be the preferred fuel, followed by hydrogen, then other derived fuels. Anthony discusses some of the advantages of transitionary biofuels, while Greg observes there is no role for these and that policy should focus on deployment of the fuels we need in 2050.

On the one hand, the technology-led path can be achieved as the end of sales of new petrol, diesel and hybrid road vehicles locks in uptake of electric and hydrogen vehicles. On the other hand, the mobility-led path requires integrated action by decision-makers across all levels of government as well as public acceptance.

The article on 15-minute cities by Mark Philpotts and Chris Fallen highlights the local authority-led efforts underway in London, Birmingham and Ayrshire, recognising that strong leadership is necessary to deliver this vision. Part of this leadership requires the introduction of policies and infrastructure to support consumer behaviour change. Natalie Rees investigates the role of restricting private car use while simultaneously boosting the attractiveness of public transport to support modal shift.

Andy Cope reviews the role of transport appraisal and how traditional transport economics do not appropriately value active and sustainable modes of transport, including the placemaking benefits of such infrastructure. Andy suggests that pilot schemes are essential to test the effectiveness of proposed traffic-reduction measures. This real-world evidence can support both the business case and stakeholder engagement and is key to project success.

Sam Pollard's article on air quality illustrates the importance of modal shift to achieving the co-benefit of clean air. Sam asserts the role of planning in delivering developments that facilitate the use of active and sustainable transport modes over the private car. Richard Pemberton introduces the Solent Future Transport Zone as a good example of how a group of local authorities are working together to integrate active, personal and sustainable transport modes through mobility as a service. This is relevant since most people in the UK do not live in an area covered by a combined or integrated transport authority.

The technology-led and mobility-led examples described will reduce GHG emissions. Craig Love discusses the use of woodlands to support climate change adaptation and resilience of transport infrastructure. Such nature-based solutions provide the co-benefits of habitat creation and emissions removal, which are necessary to achieve net zero.

LOOKING INTO THE FUTURE

It was hoped the extent of travel disruption during 2020 due to the Covid-19 pandemic could be an opportunity to shift to the new trajectory required to deliver net zero. Globally, carbon dioxide emissions fell 5.8 per cent in 2020, of which almost half were attributed to a decrease in surface transport activity. This decrease did not arise due to a structural change in the global economy, energy or transport systems. Therefore, some scientists believed the social changes associated with the pandemic would be insufficient to preserve the decreases observed.[8] They were right; global emissions rebounded by 5 per cent to almost pre-pandemic levels by 2021.[9] In the UK, domestic transport emissions returned to within 7 per cent of pre-pandemic levels by the end of 2020.[10]

Globally, governments have committed to various 'build back better' plans. Although the objective is to boost economic activity, the imperative should be to build back sustainably. Designing new, large-scale infrastructure to deliver such outcomes can be the catalyst to shift to the required net zero trajectory. Unfortunately, less than 0.2 per cent of the US$12 trillion pledged by the world's 50 largest economies was earmarked for climate-related policies.[11] If most of the remaining money is deployed on conventional design approaches, it could lock us into the existing business-as-usual (or even a regressive) trajectory for decades and lock us out of achieving net zero by 2050. ES

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Walking and wheeling: the best route to true 15-minute living?

Mark Philpotts and **Chris Fallen**
look at ways to overcome the barriers to active travel.

The potential of bicycle and pedestrian travel in cities has long been underestimated, resulting in a deterioration of facilities and infrastructure over time. Encouragingly though, we are now seeing a revival of active modes of transportation as more people recognise the associated health, social and environmental benefits, which could and should open the door to 15-minute city living.

While the concept is valid and more salient than ever, the term 'active travel' itself has increasingly been diluted into somewhat limiting shorthand that tends to generalise movement as only being for exercise purposes rather than crediting it with the wider societal benefits that can be unlocked when people move under their own steam.

Community fitness might indeed be of importance for some policymakers, but most people are more interested in simply travelling by whichever mode happens to suit their purpose at a given time.

MOVING TOWARDS THE 15-MINUTE CITY

Where we think about the 15-minute city concept specifically, walking and wheeling lie at the heart of the far-reaching opportunities open to us. However, the actual distance covered in 15 minutes can vary wildly depending on infrastructure conditions. For instance, a journey's progress may be halted by how a cyclist or pedestrian is treated when crossing the road – large junctions with multiple waits can significantly impact the quarter-hour travel budget.

Currently, many of the features on the roads are geared towards a motoring infrastructure, which other modes must work around. In reality, truly walkable and cyclable streets are in fact just streets that rarely require any controls. Once motors are introduced, we see traffic signals, parking controls, one-way streets and other measures aimed at the mechanical and not the human. We must therefore aim to remove the motors to subsequently eliminate the controls and break down the barriers to free-flowing travel that forms the basis of any bona fide 15-minute city.

MOVING FROM ACTIVE TRAVEL TO SOCIAL TRAVEL

Our daily conversations explore all sorts of benefits accruing from active travel in 15-minute living, but the most interesting effects centre around community cohesion. In a world where the furthest people might realistically walk is from their front door to their car (and at a time more recently defined by social separation), there is little neighbourhood interaction other than through a windscreen. When people are on the street, there is immediately a greater chance of 'seeing, stopping and socialising' as they meet friends and neighbours. This creates relationships and bonds that simply do not exist when we are constrained by our cars.


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With that in mind, it is worth noting that from a logistical standpoint achieving 15-minute cities is not just about the infrastructure to get people from A to B. It is the distance between two points and whether people can also do other things along the way. This requires a change in spatial planning, where mixed-use development, employment and local retail are enabled in and around where people live.

Gradually, car-based planning has left us with retail parks, drive-throughs, and edge-of-town hospitals and business parks. In contrast, 15-minute cities are enabled by active travel and, as a by-product, would thrive because of it – with shopping parades, corner shops, small supermarkets, community health facilities and local business hubs returning to prominence.

MOVING BEYOND THE THEORY

To understand how we can achieve 15-minute city transformation, we must first look at the roadblocks in our way. They include:

- Siloed service planning;
- A planning system that facilitates the loss of small retail and business premises to residential conversion;
- Minimal parking provision;
- A political unwillingness to push ahead with street retrofit schemes that prioritise active travel because of a pro-driving minority;[1] and
- A reluctance to densify suburbs.

Local authorities are best placed to overcome most if not all of these obstacles, especially unitary authorities in control of local planning and highways since the two are closely interlinked. On that basis, it is probably no surprise that some of the most interesting work in terms of putting words and plans into action comes from London boroughs such as Hackney and Waltham Forest. There, we see investment in streets being rebalanced towards enabling active travel and developing community facilities (including local shopping parades). This means that the facilities people want to use are within local travelling distance.

Away from London, there are interesting things happening in Birmingham. Again, the city council is in control of planning and highways and so schemes such as the City Centre Segments[2] to prioritise walking, cycling and public transport over people driving through will create conditions where denser and more people-focused development becomes more attractive.

On the west coast of Scotland, in Ayrshire, bold and ambitious plans are being developed to reallocate existing carriageway space to create direct and cohesive active travel links that never previously existed. These core networks are not simply looking to connect one place to another, but also to bring sustainability, green infrastructure and vibrancy throughout – thereby making walking and cycling the attractive choice.

Fostering (and maintaining) political will is key. The local authorities working with planners and other professionals to make 15-minute cities happen are those with knowledgeable and empowered senior councillors who are leading the charge from the front, including challenging those who support the status quo. While unitary authorities may be best placed to deliver 15-minute cities, since they are responsible for planning and local transportation, combined and regional authorities are also creating the conditions within their area to align planning and transportation at different levels, with the most successful having political leadership at the front and centre.

Local politics are also important in building bridges with the community so that hyperlocal issues are understood, local cultural nuances are recognised, and change is truly inclusive. It is crucial that we collectively engage and bring people along on the journey rather than have it imposed from the top. This extends to how grassroots and community-based organisations can be empowered to develop plans and ideas that can be enabled by local government, including trialling alternative street layouts and uses. The key measure of success here is whether people are genuinely being offered realistic alternatives to travel and live their lives locally. The 15-minute city concept is scalable, even within large cities. For example, London has many metropolitan, major and district centres which can (and do) serve local catchments. Perhaps the challenge is to ensure that services are planned and provided where people live rather than pursue centralisation.


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Acceptance of one another as people travelling from origin to destination, as opposed to the 'them and us' culture of private vehicle driver versus pedestrians or cyclists, is a sensitive but critical issue in the successful delivery of new active travel infrastructure. The voices of the opposing few are often very loud, while the numerous quiet, positive voices can be drowned out, influencing design considerations. This can result in the withdrawal of local political support to continued delivery.

Creating empathy for all users is the key measure to effectively communicate how active travel infrastructure can be a hugely positive intervention. It is the creation of choice, allowing people to travel more sustainably that is often seen as detrimental to another person or user; for example, where carriageway space is seen as being removed, when often it is being repurposed to provide safe and attractive choices for cycling and walking. This may result in drivers re-evaluating the decision to drive and leaving the car at home next time.

CONCLUSIONS AND RECOMMENDATIONS

As 2022 unfolds and the threat from Covid-19 subsides, we need to take stock of some of the lessons from the past couple of years. We have seen a real interest from people who want to be able to walk and wheel where they live as well as use local shops and services. We have seen the rapid introduction of low-traffic neighbourhoods and protected cycle lanes, which have seen levels of walking and cycling increase and the use of motor vehicles decrease, even where there were fears of greater congestion on main roads. There are potential unintended consequences of the 15-minute cities concept. If the pace of change happens quickly, there is a risk that parts of the community are left behind – an issue brought home by Transport for All in its Pave the Way review, which highlighted issues with disabled people being left out of the conversation around the rapid introduction of low-traffic neighbourhoods.[3] There are also risks around equity, where services are not provided across all areas, depriving some citizens access to the range of services that others might enjoy elsewhere.

We have also seen the role of regional walking and cycling commissioners become more important in raising both the quality of interventions and awareness of active travel as being a proper mode of transport. We have also seen improved design guidance for cycling across the UK that challenges previous advice of combining it with walking or driving when it should be treated as a distinct mode.

As planners, designers, engineers, policymakers – and citizens – we need to come together to work towards:

Increasing cycle ability. All cities should investigate different strategies and measures to increase bicycle availability. For instance, more employers can provide office pool cycles and programmes to buy (e)bikes for their employees, although this facility is not available to self-employed people. Access to cycles is a barrier for people who cannot afford the initial cost; projects such as Birmingham City Council's Big Birmingham Bikes try to address this.[4] Disabled people sometimes require non-standard or adapted cycles, and this is often a cost barrier as highlighted by the charity Wheels for Wellbeing.[5]

Improving the status of cyclists and pedestrians. The status of pedestrians and cyclists in many cities needs significant improvement. Developing a method of urban planning that prioritises cyclists and pedestrians from the outset, in all phases of the planning process and for all types of urban spaces, will create the best starting point to better position these travel modes.

Developing safe infrastructure. Although active mode travellers may be great in number and may even dominate a city's traffic, they are still a vulnerable group. Considering the positive impact of active travel modes on a city and its inhabitants, walking and cycling should have the best available infrastructure. Cities with low numbers of cyclists and pedestrians should formulate goals to accelerate infrastructure development, convert car lanes into space for cycles and pedestrians, create dedicated cycle paths and redesign crossings for safer active mode travel.

Changing behaviours. Influencing the behaviour of all travellers through promotions, cycle-sharing programmes and cycle use reward schemes is key to achieving the goal of reducing the carbon footprint of tomorrow's resilient cities. Cities should clearly connect higher goals for society, such as improved health and sustainable development, with mobility and traffic. This provides arguments in the political arena to address motorists' objections.

Maximising funding. Public funding for sustainable transport infrastructure has never been as widely available or as extensive. There are various current funding sources across the UK, including:

- Sustrans – Places for Everyone and Spaces for People programmes;
- UK Government – Levelling Up Fund;
- Paths for All – Active Travel Grants Scheme;
- Department for Transport – Transforming Cities Fund;
- Scottish Government – Cycling, Walking and Safer Routes;
- Welsh Government – Active Travel Fund;
- Various local area partnership funds across the UK; and
- City Region Sustainable Transport Settlements for English mayoral authorities.

Through promoting active modes of transport we can create cities that are more environmentally friendly, healthier and better connected socially. Whether we label it active travel, walking and wheeling or something else yet to be determined, making cities more pedestrian- and cycle-friendly will remain a top priority for urban planners in the coming years.

Developing plans at a neighbourhood level will be key to developing 15-minute cities, and this includes putting community facilities and services at the centre of those plans to maximise utility trips by foot and cycle. It also requires a recognition that when only provided for commuters, the potential market for local utility trips, especially those that can be linked together (trip chaining), is largely ignored. Having the ability for carers to do the school run, pick up shopping and work locally will be the kind of thing that helps reduce the number of short car journeys we are trying to target. ES

Mark Philpotts has over 25 years' general civil engineering and highways experience in the public and private sectors. His main area of professional interest is designing streets to enable people to walk and cycle, with a strong emphasis on inclusivity, accessibility and sustainable safety principles, something he has had the opportunity to specialise in through his role with Sweco UK. Mark leads Sweco's active travel team, which sees the role of 15-minute cities as an important feature of future urban places and has experts based across the UK in London, Manchester and Edinburgh.

Chris Fallen is the Active Travel Team Manager within Sweco's Transport Planning sector in Scotland. He has wide-ranging experience in delivering policy advice, feasibility and concept design as well as detailed design and construction supervision.

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TECHNICAL

State of the art in decarbonising transport: technologies and fuels

Anthony Velazquez assesses the routes to decarbonising transport.

INTRODUCTION

The air quality and decarbonisation agendas have driven change faster in the transport sector over the past five years than anything else in the last three decades. Policymakers are pushing for implementation of a new Euro standard that is so stringent that it will be very difficult for vehicle manufacturers for comply with unless they shift towards electromobility. With the exception of active travel, no transport mode is truly clean; the use of rare earths and other critical materials, the non-exhaust emissions from tyres and brake pads and the embodied carbon emissions make it virtually impossible. It is, however, possible to achieve zero pollutant and greenhouse gas (GHG) tailpipe emissions by selecting the right technologies and energy pathways.

POWERTRAIN TECHNOLOGIES

The most effective way of decarbonising transport is to use human propulsion (walking and cycling) or natural forces (sailing, gliding, etc.). For all other motorised vehicles (excluding spaceships), the two main powertrains are internal combustion engines and electric motors.

The path to zero emissions (zero tailpipe pollutant and GHG emissions) in transport is difficult due to the broad range of modes found within the existing transport system. The choice of low-carbon technology and energy pathway depends on multiple internal and external factors, such as vehicle range requirements, payload capacity, operational needs, auxiliary loads, weather conditions, the characteristics of each national energy system, availability of refuelling and recharging infrastructure, the existence of reliable supply chains and a favourable total cost of ownership. Fossil fuels deliver in all these dimensions but at a very high environmental cost. The thermal efficiency of an internal combustion engine (ICE) is relatively low (45 per cent) compared to electric motors (90 per cent). However, the low cost of fossil fuels, their high energy intensity, and the poor economies of scale of alternative powertrains makes them a very cost-efficient solution for all transport modes, slowing down the transition towards electromobility.

Internal combustion engines. ICEs are versatile and can be powered by several types of fuel, including those that

Table 1. Characteristics of zero-emission road transport systems

Type	Electric road system (wireless induction)		Electric road system (conduction)			Battery only	Fuel cell
Well-to-wheel efficiency for heavy goods vehicles	69% (62% if electric road system charges battery)*		77% (69% if electric road system charges battery)[1]			69%[1]	28%*
Energy transfer	Overhead	In-road	Overhead	In-road	Side-rail	Plug-in	Hydrogen pump
Infrastructure	Recharging point	Under-ground	Catenary	On the ground	Monorail	Recharging points	Refuelling stations
Feasibility for buses	No dynamically (only static) recharging points	Yes (expensive)	Yes**	Yes***	Yes***	Yes	Yes
Feasibility for large heavy goods vehicles			Yes**	Yes***	Yes***	Yes****	Yes
Feasibility for cars & light-duty vehicles			No	Yes**	Yes**	Yes	Yes

* Data derived from author's analysis.
** When installed in the strategic road network, the configuration is compatible with all modes simultaneously.
*** Safety risk assessments pending.
**** Very limited range/payload.

are hydrocarbon based (with fossil or biological origins) and less well-known ones such as hydrogen or ammonia. Hydrocarbon combustion in ICEs releases a range of pollutants, such as particulate matter, nitrogen oxides, ground-level ozone, carbon monoxide, volatile organic compounds and GHG emissions. Hydrogen ICE vehicles only release water, but they are less efficient than fuel cell electric vehicles. Tailpipe emissions are difficult to eliminate completely even with exhaust gas treatment technologies, which are expensive since catalysts use precious metals. Euro VI and the upcoming Euro VII vehicles will emit very small amounts of pollutants; however, when these are aggregated across the millions of vehicles on the road, they become significant. Furthermore, Euro Emission Standards do not apply to all transport modes (rail, shipping, aviation, non-road mobile machinery), which worsens air quality around railway stations, ports, airports and construction sites.

Electric motors. Electric motors efficiently convert electric into mechanical energy, and for this reason the well-to-wheel GHG emissions for electric vehicles tend to be lower, although this depends on the carbon intensity of the energy pathway. Since electricity as a fuel source

Table 2. Environmental impact of the production of 1 kg of permanent magnets (neodymium)[2]

Name	Impact result	Unit
Environmental impact (ozone depletion)	3.74951E-6	kg CFC[a] - 11 - eq[b]
Environmental impact (photochemical oxidation)	0.00234	kg NOx[c] - eq[b]
Environmental impact (global warming)	0.45572	kg CO_2[d] - eq[b]
Human health (non-carcinogenic)	0.072892	kg toluene - eq[b]
Environmental impact (ecotoxicity)	1.43199	kg 2,3-D[e] - eq[b]
Environmental impact (acidification)	27.70012	moles of H+[f] - eq[b]
Environmental impact (eutrophication)	0.00143	kg N[g]
Human health (respiratory effects)	0.13675	kg $PM_{2.5}$ - eq[b]
Human health (carcinogenic)	0.23562	KG benzene - eq[b]

[a] CFC = chlorofluorocarbons
[b] eq = equivalent
[c] NOx = nitrogen oxides
[d] CO_2 = carbon dioxide
[e] 2,4-D = dichlorophenoxyacetic acid
[f] H+ = hydrogen ions
[g] N = nitrogen
[h] $PM_{2.5}$ = particulate matter with a diameter of 2.5 μm

does not contain carbon, no tailpipe GHG emissions are released (this is not the case if the electricity is produced by a solid oxide fuel cell fed by hydrocarbon fuels). The well-to-wheel efficiency of a vehicle dynamically recharged via a conductive electric road system (ERS) is considerably higher than for hydrogen fuel cell vehicles; however, hydrogen presents significant operational advantages (see **Table 1**).

Electric powertrains tend to be much simpler than ICE because they have fewer mechanical parts. However, they often use rare earths to improve motor efficiency (e.g. permanent magnets use neodymium and dysprosium) and as components for batteries and fuel cell catalysts. Rare earths are elements with very attractive electronic and magnetic properties whose mining and conversion processes are highly polluting,[2] affecting human health, the natural environment and natural resources (see **Table 2**). Around 88 per cent of rare earth element reserves are located in four countries: China (36 per cent), Vietnam (18 per cent), Brazil (17 per cent) and Russia (17 per cent).[3]

Electric road systems. The range of battery electric vehicles is limited and requires behavioural changes

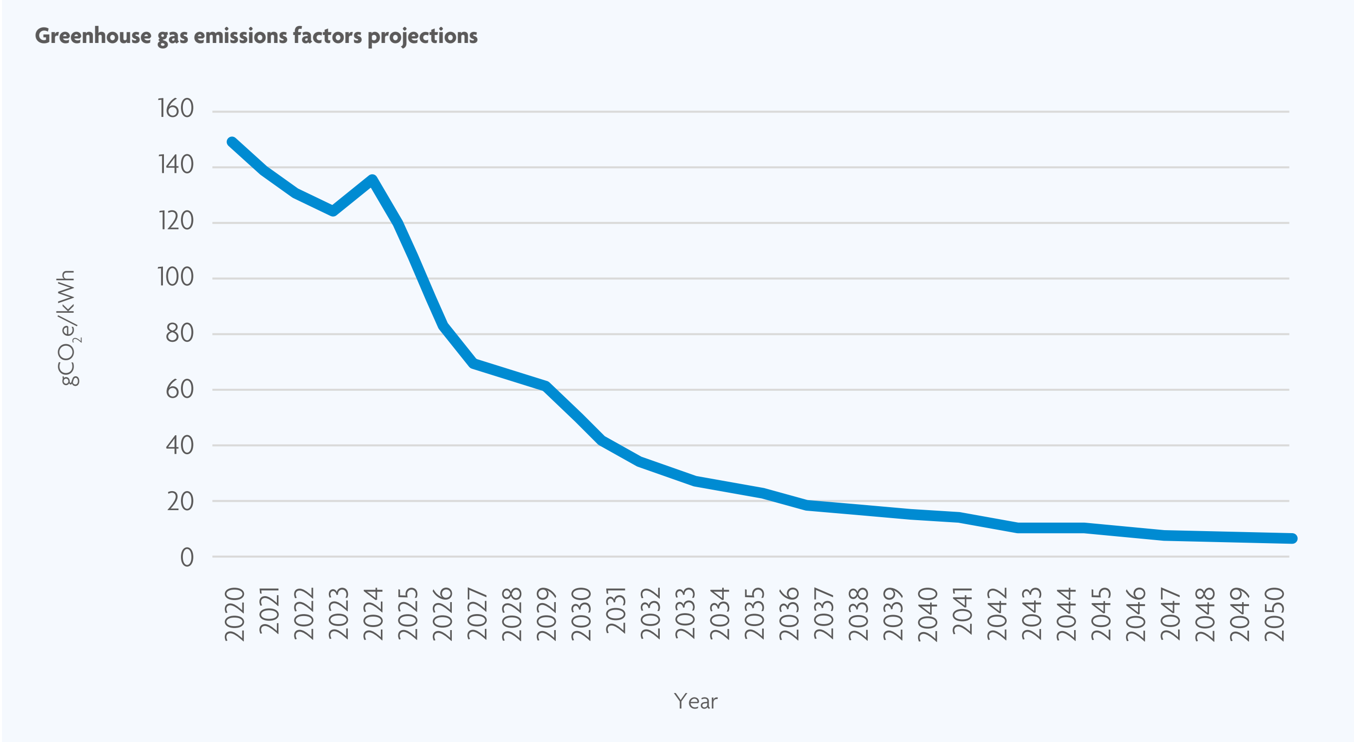
TECHNICAL

▼ **Table 3. Greenhouse gas savings for different biofuel pathways using waste as feedstock compared to conventional mineral diesel[12]**

Pathway code	Waste feedstock	Fuel	Chain carbon intensity				WTW GHG[o] savings versus fossil fuel pathway
			WTT[j] fuel	WTT[j]	TTW[l]	WTW[m]	
			(kg CO_2eq./t[k] biofuel)	(g CO_2eq./MJ[n])			
WOFA[a]	UCO[g]	FAME[h] biodiesel	499	13.4	0.2	13.6	84.7% vs COD[p]
TOFA[b]	Burger fat	FAME[h] biodiesel	493	13.3	0.1	13.4	84.9% vs COD[p]
WOHY[c]	UCO[g]	HVO[i] biodiesel	666	15.1	-4.9	10.2	88.5% vs COD[p]
TOHY[d]	Burger fat	HVO[i] biodiesel	654	14.9	-5.2	9.7	85.1% vs COD[p]
FFCG[e]	Food waste	Biomethane	1,030	22.9	3.5	26.4	61.9% vs CMCG[q]
WWET[f]	Wood waste	Bioethanol	714	35.8	0.2	36	58.7% vs COG[r]

[a] WOFA = used cooking oil to fatty acid methyl ester
[b] TOFA = tallow oil to fatty acid methyl ester
[c] WOHY = used cooking oil to hydrotreated vegetable oil
[d] TOHY = tallow oil to hydrotreated vegetable oil
[e] FFCG = food waste to compressed biomethane gas
[f] WWET = wood waste to bioethanol
[g] UCO = used cooking oil
[h] FAME = fatty acid methyl ester
[i] HVO = hydrotreated vegetable oil
[j] WTT = well to tank
[k] CO_2eq./t = carbon dioxide equivalent per tonne
[l] TTW = tank to wheel
[m] WTW = well to wheel
[n] MJ = megajoules
[o] GHG = greenhouse gases
[p] COD = conventional diesel
[q] CMCG = conventional natural gas
[r] COG = conventional petrol

for the public to accept long recharging times. This is even more relevant for heavy-duty fleets or trains. Electrification of the rail network in the UK is currently below 50 per cent, and it is not commercially feasible to electrify routes with low utilisation rates. ERS is a technology that allows vehicles to recharge dynamically (while driving along the strategic road network), enabling the downsizing of batteries or extending vehicle ranges, and making recharging times shorter and enabling higher vehicle payloads. In 2021, Innovate UK funded three ERS feasibility studies that concluded in March 2022. These studies will demonstrate the business case for ERS and the environmental impacts that deploying this technology may have. Such impacts include the embodied emissions of the infrastructure itself and the storage requirements necessary to provide the large amounts of energy needed to dynamically recharge a significant number of vehicles simultaneously.



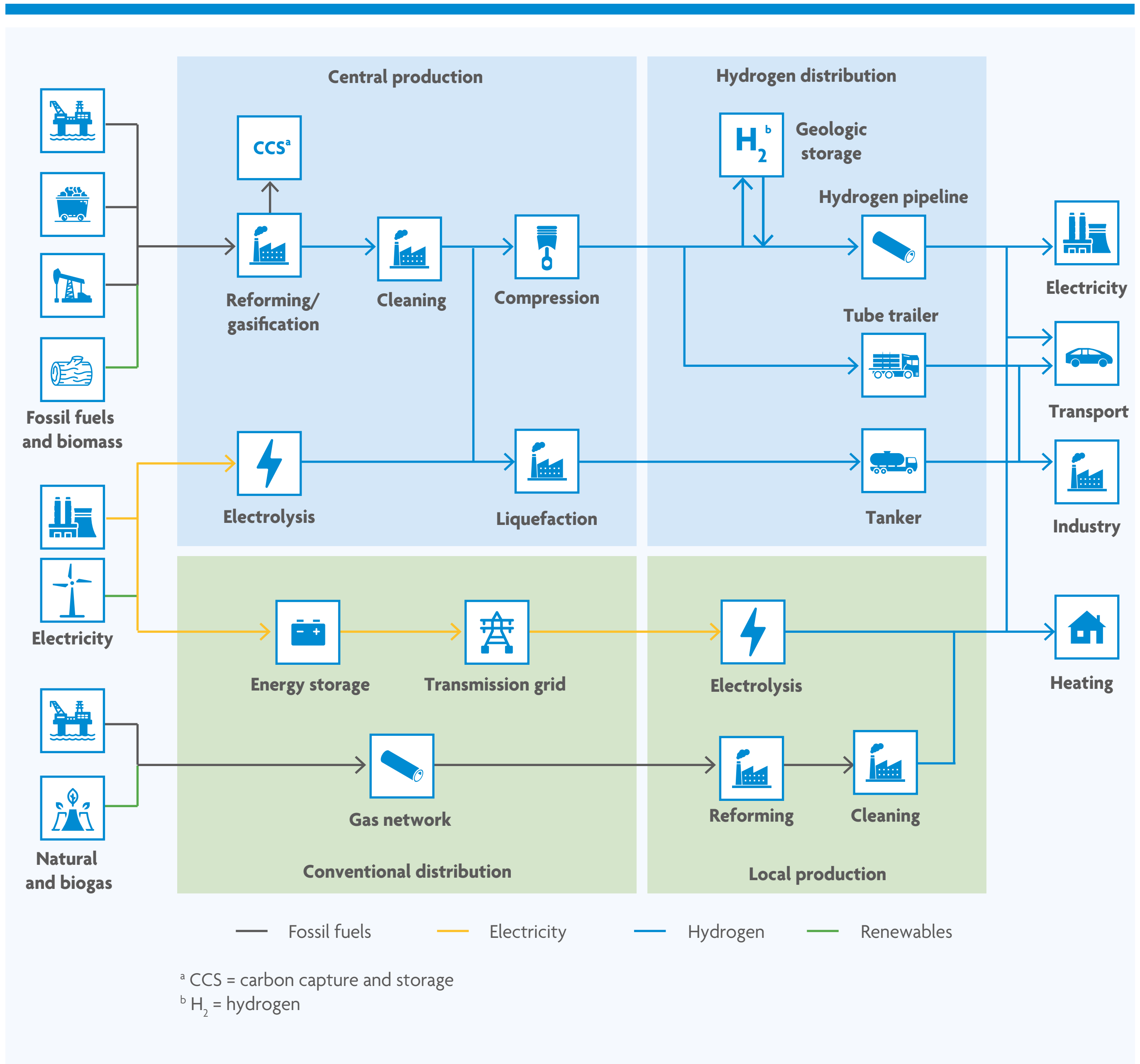
▲ **Figure 1. Projected greenhouse gas emissions factors per unit of electricity generated in the UK. (Adapted from the Department for Business, Energy and Industrial Strategy[13])**

Batteries. The constraints of current battery electric vehicles are well documented and include reduced vehicle payload due to the weight of the batteries. Furthermore, reducing the battery pack to decrease vehicle costs or maintaining similar payloads leads to shorter ranges. The range can be dramatically reduced even further through auxiliary loads (e.g. cabin heating and cooling) and the use of transport refrigeration units. A lack of fast and high-power recharging infrastructure is therefore just one of the challenges.

Current battery compositions can have significant socio-environmental impacts due to the nature of the critical materials used in manufacturing. For example, cobalt is used to produce battery cathodes and is mined in the Democratic Republic of Congo, where almost half of worldwide reserves are located.[4] This is a country with identified human rights violations (including forced labour of adults and children in artisanal mining) and low environmental standards.[5] More than half of the world's lithium reserves are located in the Atacama Desert, between Chile and Argentina.[6] Further research is needed to ensure that lithium mining does not exacerbate the impact of droughts in the region through deposit build-up in fresh groundwater. Other issues with lithium batteries include safety concerns (e.g. leakage, temperature-related damage), relatively high embodied carbon emissions associated with their long supply chains (mining, refining, production, assembly and installation in vehicles often occurs in different countries) and poor recyclability after a second-life reuse. This is something that the European Commission proposal on batteries and waste batteries is trying to resolve, by mandating targets for battery recycling and materials recovery before 2026.[7] Lithium-ion battery packs are not recycled because it is not cost-efficient: manipulating high voltages requires training, reverse logistics are expensive, and they are not designed with circularity in mind.

Solid-state batteries can solve some of the problems with existing battery technology by improving battery capacity, safety and recharging times, and they also have a longer life. However, research indicates that these are not likely to reach a significant manufacturing scale until 2040, with a projected market share in transportation of under 30 per cent.[8] Furthermore, not all batteries pollute the same, with some life cycle analysis studies estimating that nickel–metal hydride batteries pollute more than lithium ones.[9]

Fuel cells. Fuel cells convert chemical energy into electric energy and this, in turn, into mechanical energy to propel vehicles. There are two main fuel cell types used for traction in vehicles. Proton exchange membrane fuel cells (PEMFC) use pure hydrogen stored in compressed or cryogenic tanks to generate electricity, producing water as the only byproduct. As hydrogen does not contain carbon, tank-to-wheel emissions are clean.



▲ **Figure 2. Hydrogen production pathways and feedstocks. (Adapted from: Staffell, *et al.* [2019].[14])**

Solid oxide fuel cells, in contrast, can reform fossil fuels (or biofuels) into hydrogen, which is converted into electricity. In this case, small amounts of GHG and other pollutants are generated.

Fuel cell electric vehicles operate in a similar way to conventional vehicles. Hydrogen can be transferred quickly from the pump to the engine, offering equivalent range and refuelling times to fossil fuels. In 2021, Innovate UK funded a range of hydrogen-fuelled transport trials, including proton exchange membrane fuel cell cars, fork-lift trucks, buses, heavy goods vehicles and one hydrogen ICE ship. The well-to-wheel emissions of fuel cell vehicles depend mainly on the energy pathway followed to generate hydrogen. Fuel cell catalysts contain small amounts of platinum (also used in vehicle catalytic converters), a critical material that is widely recycled as it is very expensive.

ENERGY

The reduction of carbon emissions in transport is as simple as replacing fossil fuels with biofuels (or synthetic fuels) in current (compatible) ICEs. However, electrification is the only alternative to eliminating tailpipe emissions. Switching to biofuels and biogas can yield GHG reductions in the order of 88.5 per cent when using waste feedstocks (see **Table 3**). GHG footprints of biofuels made from crops vary considerably, with

GHG[a]	Renewable energy pathway	Non-renewable energy pathway
High carbon $>36.4\ gCO_2e/MJ\ H_2$[d]	Grey hydrogen (steam methane reforming)	
	Brown/black hydrogen (coal gasification and other fossil fuel processes)	
Low carbon $<36.4\ gCO_2e/MJ\ H_2$	Green hydrogen (electrolysis/biomass gasification/steam biomethane reforming/ biochemical processes)	Blue hydrogen (SMR[b] + CCS[c])
		Pink hydrogen (nuclear)

[a] GHG = greenhouse gases
[b] SMR = steam methane reforming
[c] CCS = carbon capture and storage
[d] $gCO_2e/MJ\ H_2$ = grams of carbon dioxide equivalent per megajoule of hydrogen

▲ **Figure 3. The colours of hydrogen. (Based on the definitions of Velazquez Abad and Dodds[15])**

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estimates that bioethanol produced in the US from corn crops can increase GHG emissions by 24 per cent compared to conventional petrol when indirect land use changes are taken into consideration.[10] In contrast, the Department for Business, Energy and Industrial Strategy reports 80 per cent reductions for UK bioethanol and 92 per cent for second-generation biodiesel compared to the average UK diesel (biofuel blend).[11]

Electricity. As a result of the UK's commitment to the 2015 Paris Agreement, the carbon intensity of the UK's electric power system is expected to decrease from 129 gCO_2e/kWh today to 6 gCO_2e/kWh by 2050 thanks to higher integration of renewables in the grid (see **Figure 1**). The decarbonisation of electric vehicles very much depends on the characteristics of the energy system. The same electric vehicle will produce a much smaller well-to-wheel carbon footprint in France, where the energy system relies heavily on nuclear power, than in Poland, where most of the electricity is generated using coal as a feedstock.

Hydrogen. Hydrogen can play an important role in improving the flexibility of the entire energy system by providing ancillary services to the grid and supporting the deployment of renewables. Hydrogen can be used as a short- and long-term energy storage medium when there is a surplus of renewables and improve the business case for renewable power generation. Hydrogen is an energy carrier that can contribute to the provision of energy security to any country due to the range of energy pathways and feedstocks (see **Figure 2**). Hydrogen generation is highly energy intensive (around 91 gCO_2e/MJ hydrogen for grey hydrogen). The efficiency, energy and carbon intensity of hydrogen production varies broadly from green or low-carbon hydrogen on one side of the spectrum (produced via electrolysis from renewables, biomass gasification or nuclear energy) to blue or grey hydrogen on the other (produced via steam methane reforming or coal gasification with or without carbon capture, storage, sequestration and utilisation). When the carbon intensity is 60 per cent lower than for grey hydrogen and the energy pathway is renewable, hydrogen is labelled as green (see **Figure 3**).

Gaseous hydrogen is easier to handle than cryogenic hydrogen. However, cryogenic liquid hydrogen needs less storage space because it is denser. For certain uses (e.g. shipping), hydrogen carriers – such as ammonia, liquid organic hydrogen carriers or methanol that are used to transport hydrogen molecules – may be easier to transport and store. However, these molecules can have detrimental environmental impacts if there is a spillage.

SUMMARY

It is possible today to reduce GHG emissions from transport by simply replacing fossil fuels with biofuels or biogas. Well-to-wheel GHG emissions depend on the efficiency of the powertrain and the carbon intensity of the energy pathway. Zero-emission transport requires a transition towards electric powertrain technologies. However, the full decarbonisation of all transport modes seems unlikely if we consider the embodied production-related emissions, and carbon removal solutions will be necessary to deliver net zero emissions.

The suitability of a particular zero-emission technology and energy pathway combination depends to large extent on the specific use. Most smaller cars, light-duty fleets, buses and small trucks will be suitable for battery electric powertrains. Fuel cells seem a good alternative for larger heavy goods vehicles operating over longer distances and some buses running for long periods of time – particularly those with recharging infrastructure or space constraints. Investment in electrification cannot be justified for railways operating at lower utilisation rates in areas with low population densities, and hydrogen and batteries could provide realistic alternatives. Hydrogen in rail will be better suited for freight locomotives as well as for longer and faster passenger trains. Hydrogen, liquid organic hydrogen carriers, and other hydrogen vectors (e.g. methanol, ammonia) are likely to power the ships of the future, although the choice of fuel will depend on the distance, port infrastructure, and the type of vessel and payload constraints. Ammonia and methanol, two of the main hydrogen carriers, present a much higher environmental risk to the maritime ecosystem in case of spillage. For a while, it seemed that the future of aviation fuels was bio-kerosene; however, recent roadmaps from the main aircraft manufacturers suggest that by 2035 planes may be powered by liquid hydrogen turbines, although smaller aircraft and drones around urban areas could be powered by batteries.

No one knows what future technological breakthroughs will bring, but for the moment, the future of transport decarbonisation depends on so many factors that there is no single solution for each transport mode or use case. The technologies that can deliver decarbonisation are already here, but they require scalability to become affordable. Without scalability, the transition towards clean transport will stall. **ES**

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OPINION


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Green electrons: ending transport's fossil fuel addiction

Greg Archer looks at the future of green energy transport.

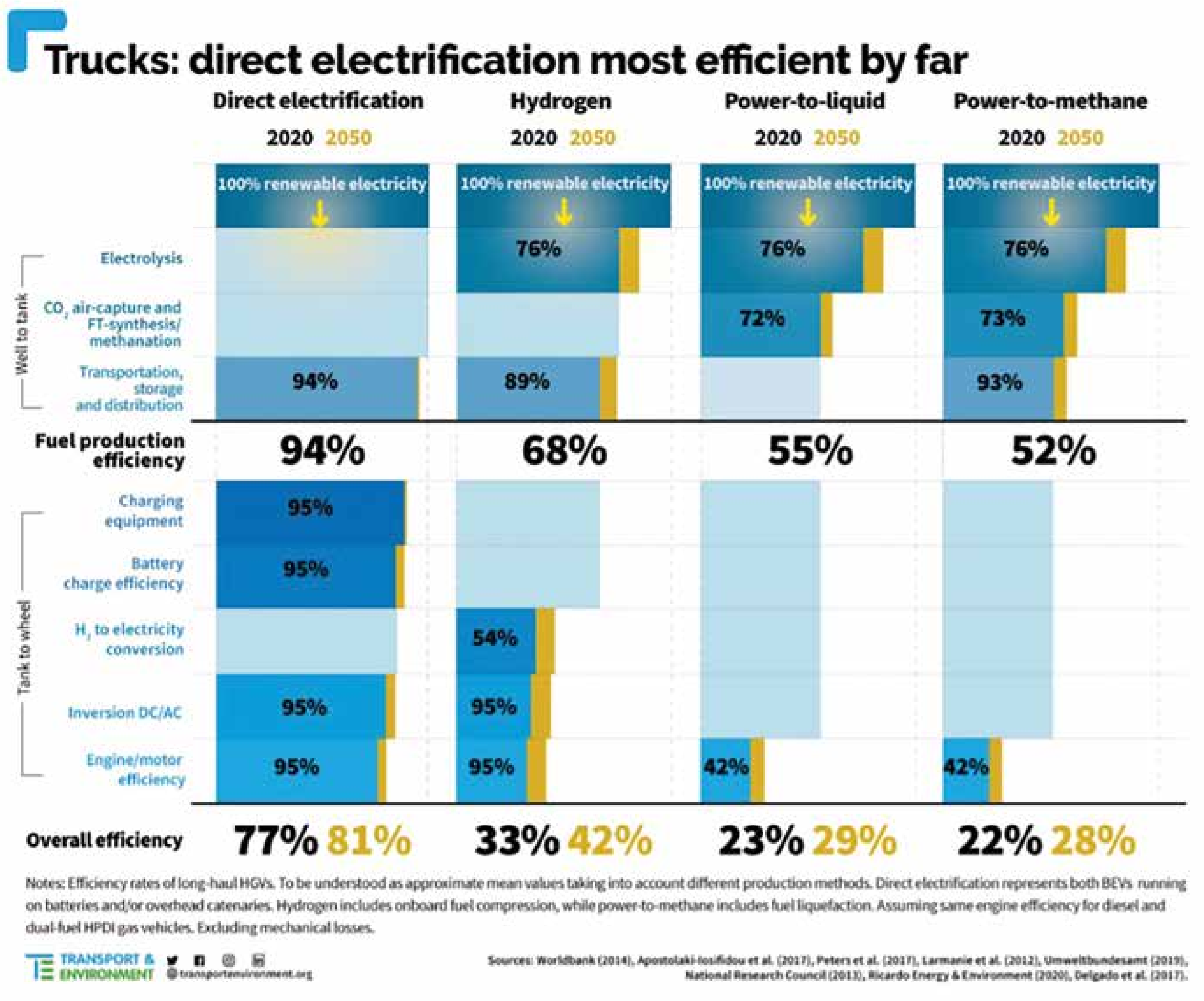
A GREEN ENERGY REVOLUTION IN TRANSPORT

The bare facts do not lie: petroleum continues to dominate energy use in transport as it has done since engines replaced horse power a century ago. In 2018, less than 3 per cent of energy used in transport was supplied from renewable sources.[1] Transport is now the biggest source of carbon dioxide (CO_2) emissions in Europe, accounting for over a quarter of all greenhouse gas emissions. Around 8 per cent of UK oil and 18 per cent of diesel also originate in Russia, bankrolling its hostilities. But a revolution is underway that should eliminate the use of fossil fuels in transport within a quarter of a century – and in the process render most of the oil industry's assets worthless. The change is driven by the dramatic fall of almost 90 per cent in the price of renewable energy[2] and lithium-ion batteries[3] over the last decade – trends that are forecast to continue.

EFFICIENCY FIRST

For all classes of road vehicles, batteries storing renewably sourced electricity are forecast to become the dominant technology within a decade.[4] But for applications that require a higher energy density fuel, like long-haul aviation or intercontinental shipping, liquid fuels will still be needed. Here, renewable electricity will remain the key enabler, generating green hydrogen through electrolysis that will be used both as a fuel and reagent. By combining green hydrogen with a carbon or nitrogen source (ideally captured directly from the air) synthetic fuels can be produced: e-kerosene for use in aircraft and ammonia for ships.[5,6]

But the production of synthetic fuels and hydrogen comes with a significant energy efficiency penalty requiring two to three times more primary energy than a battery electric vehicle (see **Figure 1**). So synthetic fuels can only be used in the sectors for which there is no viable alternative. If the UK selects the most efficient options for using renewable energy in transport (including batteries for all road vehicles), it will require 369 TWh of renewable energy by 2050 – slightly more than the total amount of electricity generated in the UK today.[7] Generating this power would require 92 GW of offshore wind capacity, equivalent to over 13,000 offshore turbines – a significant



▲ **Figure 1. Conversion efficiencies of different fuels and powertrains on a well-to-wheel basis for trucks.[8]**

challenge. However, choosing less-efficient pathways, including unnecessary use of hydrogen and synthetic fuels in vehicles, could result in over 50 per cent more renewable electricity demand.

CLEAN TECHNOLOGY *AND* MODAL SHIFT

The need for energy – and materials – efficiency creates a hierarchy of green solutions in transport, which prioritises the direct use of electricity and batteries over hydrogen, and hydrogen over synthetic fuels. It also requires that the shift to clean technologies is accompanied by increased car sharing and use of public and active transport (walking and cycling) to reduce both the total energy and raw materials needed by the transport system. These measures are especially important in the s hort term to maximise the impacts of the planned Russian oil embargo.

Most countries have also left it too late to only rely on electric cars to meet their intermediate climate goals. For example, achieving climate targets for 2033–2037 (sixth carbon budget) in the UK requires selling only new battery electric cars by 2030.[9] If sales only reach 50 per cent by then, an accompanying 27 per cent cut in car mileage is needed to offset the higher emissions and meet climate budgets.

There is no choice between clean technology and modal shift – *both* are needed. This requires policies that raise the driving costs of all vehicle types, including electric cars, while avoiding taxes that disincentivise the shift to battery electric vehicles. Reductions in car use will not be achieved without providing attractive active travel and public transport alternatives. In urban areas, road space must be reallocated from car to bus, tram and cycle lanes. Public transport must also be improved, such as by using on-demand buses in rural areas.

Local solutions are also needed to reduce the need to drive to work or school and for leisure, health and retail purposes. By reducing vehicle use, ownership should also fall; this can be encouraged by an expansion of shared vehicle schemes.[10] By reducing car ownership, raw material and energy use in vehicle production will also decline. It is a virtual cycle supporting the shift to a net zero economy.

BATTERY ELECTRIC SOLUTIONS WILL DOMINATE

The green electricity revolution in transport is beginning for cars. Last year, sales of electric cars reached 3.5 million globally, a leap of over 60 per cent from 2020. The market is particularly strong in China and Europe where regulations require carmakers to sell an increasing share of low- and zero-emission electric cars. By the mid-2020s, electric cars are anticipated to reach purchase price parity,[11] and they are already substantially cheaper to run.

Battery electric vans and rigid trucks for urban and regional deliveries are also anticipated to become the dominant technology. These will be overwhelmingly charged at depots overnight and at selected drop-off points during the day. There is no chicken and egg dilemma for the future of these urban and regional deliveries; the switch to electric trucks will be possible before the public infrastructure has been established.

For long-haul articulated trucks and coaches, battery electric vehicles are also expected to dominate new vehicle sales within 10–15 years and to largely replace diesel trucks by 2050. However, charging infrastructure at rest stops must be established in parallel with the growth in vehicle numbers. Transport & Environment analysis shows electric trucks are cheaper than other options when charged from gigachargers or catenary systems (overhead wires).[12] Batteries are also feasible for light aircraft making short hops from islands to the mainland, and they are already deployed on some ferries such as those found in in Oslo, Norway.[13]

IMPLICATIONS OF INCREASED DEMAND FOR BATTERIES

There is no geological shortage of the key metals, such as lithium, cobalt or nickel, required to manufacture the cells needed to power the transport sector.[14] However, surging consumer demand is causing short-term spikes in metal spot prices that will inflate prices and may delay the date when price parity is reached between electric and conventional cars. These short-term effects are unlikely to become structural as new mining projects open.[15] However, access to raw materials could also become an issue. Former Chinese premier Deng Xiaoping presciently remarked: 'The Middle East has oil, but we have rare earths.' It illustrates the importance of both reuse and recycling of metals, and that Europe – including the UK – secures a reliable and fair share of the materials needed to deliver the transport system of tomorrow.[16]

The environmental damage created by extracting minerals for batteries or fuel cells can be minimised but not eliminated. Producing batteries is an energy-intensive process which must also be decarbonised; this can be achieved by using renewable electricity in the manufacturing process and by switching to synthetic fuels in mining vehicles. Improving working practices and conditions is possible if car companies universally demand high standards from their supply chains, and robust, industry-wide sustainability assurance schemes are implemented that follow best practices to progressively raise standards.[17]

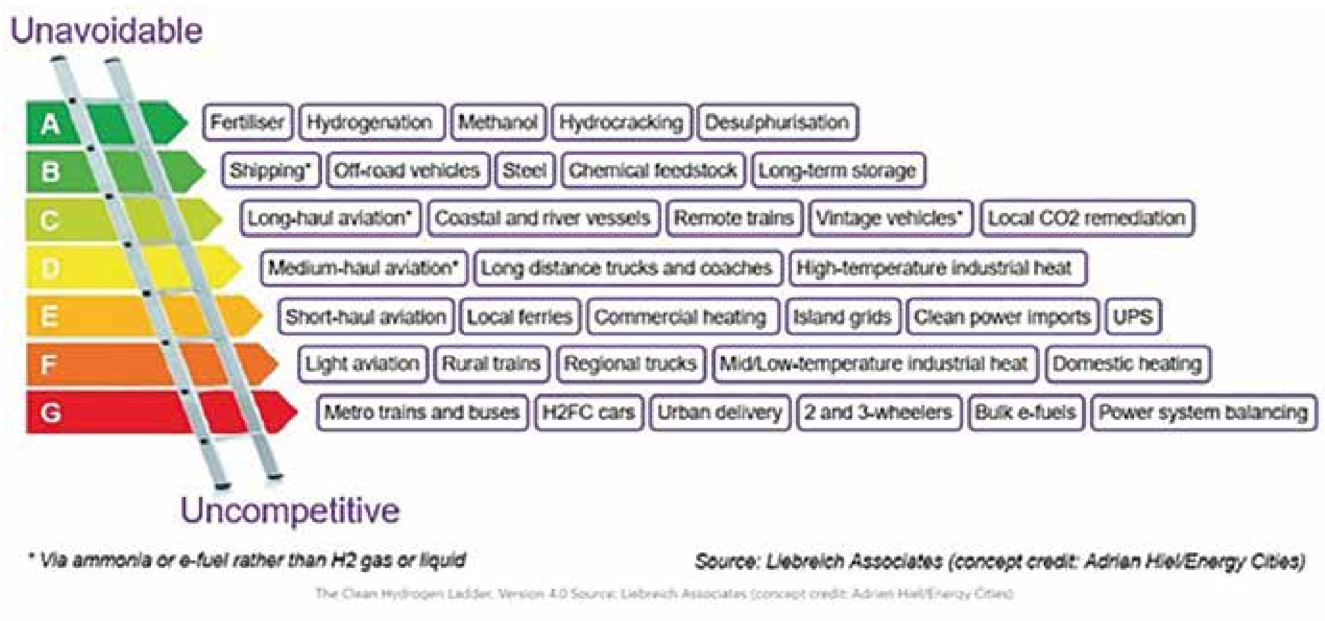
Reducing the demand for primary raw materials is also important. The European Union's (EU) Battery Directive does this by setting targets for collection and recycling activities, labelling, and removability from equipment.[18] The UK needs to match or ideally improve upon the EU's proposals, and the EU needs to speed up implementation of the directive.[19]

Fortunately, the lifetime of batteries in electric vehicles will be considerably longer than their seven- or eight-year warranty. Typically, vehicles only lose range at a rate of about 2.3 per cent per year[20] – about a 14 per cent loss of range over seven years, so the battery will maintain a practical range and in many cases last at least as long as the average 17-year car lifespan. Crucially, once the battery is no longer usable in the car it remains valuable and will be removed and reused for grid energy storage or recycled.

With longer battery lifetimes and cells increasingly made in Europe with green electricity, the carbon footprint of electric cars is also falling. Experts estimate an electric car 'pays off' the additional emissions caused during its production within about 16,000 miles.[21] Over its lifetime, a European electric car emits about two-thirds less CO_2 compared to an average combustion vehicle[22] – and this figure will fall as electricity grids are decarbonised and cell production transfers to Europe. Misinformation about the real environmental impacts of electric cars is widespread. The reality is that they deliver substantial reductions in emissions.

HYDROGEN: A KEY FUEL FOR AVIATION AND SHIPPING

The dominance of battery electric cars makes the role for hydrogen in road vehicles niche. By 2030, just 0.28 per cent of cars produced in the EU are forecast to have hydrogen fuel cells compared to the 50 per cent of battery electric models.[23] Given the high cost of hydrogen as a fuel it also seems unlikely it will emerge



▲ **Figure 2. The hydrogen ladder**[24]

as a competitive solution in the cost-conscious freight sector. It will not be a hydrogen economy, but rather a renewable electricity one which replaces the use of fossil fuels in road vehicles. There are, nevertheless, important applications for hydrogen including off-road vehicles, long-haul aviation, coastal and river vessels, and intercontinental shipping (see **Figure 2**).

Except for the shortest commercial flights carrying a small number of passengers, batteries will not have the required energy density for use in aircraft. On longer regional flights, hydrogen is an option, with Airbus aspiring to produce a plane with a range of over 2,000 miles for more than 200 passengers that burns green hydrogen.[25] For long-haul flights, green hydrogen will be used to make e-kerosene.[26]

Only green hydrogen, produced by electrolysis and using renewable electricity, delivers zero-emission transport. Blue hydrogen, made by steam reforming using natural gas with carbon capture, has high fugitive methane emissions during extraction and transmission of the gas that appreciably raises the real-world life cycle emissions. It is also twice the price of grey hydrogen (made without the carbon capture).[27]

BIOFUELS: A NICHE ROLE IN LONG-HAUL AVIATION

Biofuels are currently the most widely used renewable fuel in transport, with low blends of ethanol and biodiesel in petrol and diesel, respectively. But competing demands on available land and wastes that would act as biofuel sources severely limit their potential role. With the shift to electric cars and the increasing demand for land for rewilding and carbon sequestration, crop-based biofuels will need to be phased out and the land put to better uses.

Used cooking oil is the principal feedstock for UK biofuels and appears to be a no-regrets option. But 85 per cent of used cooking oil in the UK is imported, much of it from China and Southeast Asia where it has existing uses, and its import indirectly drives deforestation (see **Figure 3**). Like so much use of bioenergy, biofuels are better in theory than in practice. Some waste-based fuels will be used in aviation, but Transport & Environment analysis for European jet fuel demand concludes they are likely to meet just over 10 per cent of total demand in 2050.[28]

Similarly, biomethane, which is made from the anaerobic digestion of green wastes and animal slurry, is a sustainable feedstock. But over four-fifths of biomethane used in the UK are imported, and shortages of feedstock require energy crops to be planted and also divert food from food banks to be used as a fuel source.[30] Biomethane is not a mass-market solution for powering trucks.

NO ROLE FOR TRANSITIONAL SOLUTIONS

There is also no role for so-called 'transitional fuels' in transport, including using natural gas in trucks and shipping. Gas trucks have no climate or air pollution benefits and are not part of the climate solution.[31] Liquid natural gas shipping runs the risk of locking out superior zero-emission technologies like ammonia. The focus of policy and investment should now be on developing the solutions that will deliver the ultimate zero-emission transport solutions.

DELIVERING THE CHANGE

The pathways to decarbonising transport are increasingly clear: renewable electricity will drive the change and be stored in batteries in most vehicles. Renewables will also make green hydrogen, which will mainly be used as a

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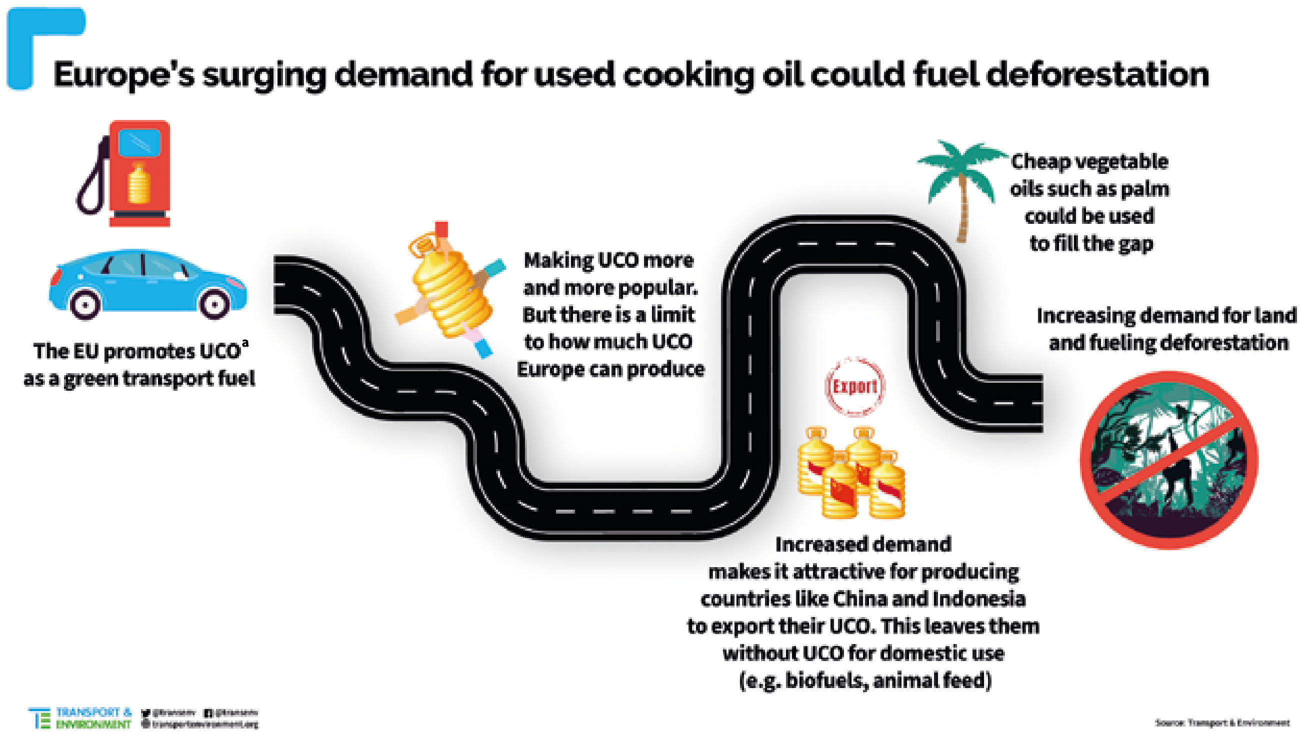
OPINION



▲ **Figure 3. Deforestation impacts of Europe's surging demand for used cooking oil[29]**

[a]UCO = used cooking oil

reagent to make synthetic liquid fuels for aviation and shipping. Driving the transition will require effective policies to enable solutions to scale up. There are three key stages to the transition to:

1. Support innovation. Government incentives for technology developers in the form of research, development, demonstration and early adoption funding (for example, research support or Contracts for Difference, or electric vehicle grants).

2. Enable regulation to phase in green solutions. Stipulating that an increasing share of the renewable fuel or technology must be supplied – such as the proposed mandates on zero-emission vehicles or sustainable aviation fuels. Targets can initially be very low but rise through interim objectives. Regulation can be complemented by tax breaks.

3. Set an end date. Setting a stated year after which conventional technology cannot be sold (like 2030 for cars) or used (usually 2050). Such targets are important to persuade businesses that change is inevitable and to stimulate private sector investment.

By following these steps, fossil fuel use in transport can be eliminated by 2050, which is essential if the world is to avoid the worst extremes of climate change. There are now clear technology pathways and scalable solutions to meet this goal. In cars, good progress is being made but in commercial vehicles, shipping and aviation progress remains glacial. To drive change across the transport sector, government policies that set end dates for fossil fuel use and regulations to phase in sustainable solutions are needed. Complemented by policies to reduce car dependency and encourage active travel, public transport use and vehicle sharing, rapid cuts in emissions will be delivered.

It is not the technology or lack of human ingenuity that is holding back progress, only misguided short-term political priorities. ES

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Best practice in mitigating shifting environmental problems

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CASE STUDY

Craig Love considers how engineering and natural solutions can work together to combat climate change.

NATURE-BASED SOLUTIONS AND CLIMATE CHANGE

Addressing anthropogenic contributions to climate change is a major challenge for the whole planet. This challenge has led to a significant legislative shift for the UK Government and Devolved Administrations, with each now having established net zero targets.

In the midst of this climate crisis, the transport sector will play an important role in reducing carbon dioxide equivalent (CO_2e) emissions across the UK, particularly as emissions associated with this sector are main contributors to CO_2e levels. Transport is the largest carbon-emitting sector in Scotland.[1] In response, the Scottish Government has unveiled a world-leading commitment to reduce car kilometres by 20 per cent by 2030,[2] underpinned by various actions currently under consultation by Transport Scotland.

Although the importance of addressing emissions cannot be overstated, the reality is that we will still face challenges in terms of alleviating the weather-related effects of our changing climate, even if we reach net zero emissions across the globe. Progress towards meeting these challenges is occasionally hampered by a lack of understanding of the subject, whereby some may confuse or blur the lines between each of the possible interventions. This does not mean that everyone needs to be an expert; having even a simple understanding of each key intervention can help identify the best course of action.

TYPES OF INTERVENTION

There are three key interventional approaches to tackling the effects of climate change. While they target different aspects, they are intrinsically linked:

- **Mitigation** is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases;
- **Adaptation** is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities; and
- **Resilience** is 'the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity,

▲ Figure 1. Glen Croe. (© Forestry and Land Scotland)

and structure, while also maintaining the capacity for adaptation, learning, and transformation'.[3]

In short, mitigation relates to reducing and preventing the release of greenhouse gas (GHG) emissions, adaptation is preparing for the current and future challenges of climate change, and resilience is the ability to respond to the weather-related effects of climate change.

NATURE-BASED SOLUTIONS

Nature-based adaptation measures or solutions can demonstrate these links by enhancing natural ecosystems to improve adaptation, strengthen resilience and sequester carbon, particularly within the transport sector. Such solutions are founded on the understanding of natural processes and the impact these can have in meeting the challenges of global climate change imposed by human activities. At the same time, this approach also provides benefits for both human wellbeing and biodiversity. Such solutions focus on the protection, improved management and restoration of natural and semi-natural ecosystems.

On the A83 through Glen Croe (see **Figure 1**), below Rest and Be Thankful, there has been a longstanding issue with landslides from the hillside causing road closures. Due to the anticipated effects of climate change leading to increased rainfall events, it is expected that the frequency and impact of such landslides will increase over time. The A83 is a vital lifeline route to Argyll and Bute and its many settlements, and it is estimated to cost the local economy between £50,000 and £60,000 per day for every landslide-related road closure.[4] The importance of finding a suitable solution to the issue cannot be overestimated.

Comprehensive analysis of the local conditions and research from other areas around the world experiencing similar problems led to the proposal of a series of hard-engineering interventions aimed at physically protecting the road and its users from future landslides. In addition to these more traditional approaches, Transport Scotland, working in partnership with Forestry and Land Scotland, identified an opportunity to establish a native mixed-species woodland on the slopes above the road to complement the engineering works (see **Figure 2**). This nature-based solution is intended to help stabilise the slope by anchoring the soil to the underlying rock substrate via the plants' variable root structure.

Working in tandem, the engineering and nature-based approaches will help alleviate the challenges presented by this notoriously unstable slope.

CASE STUDY

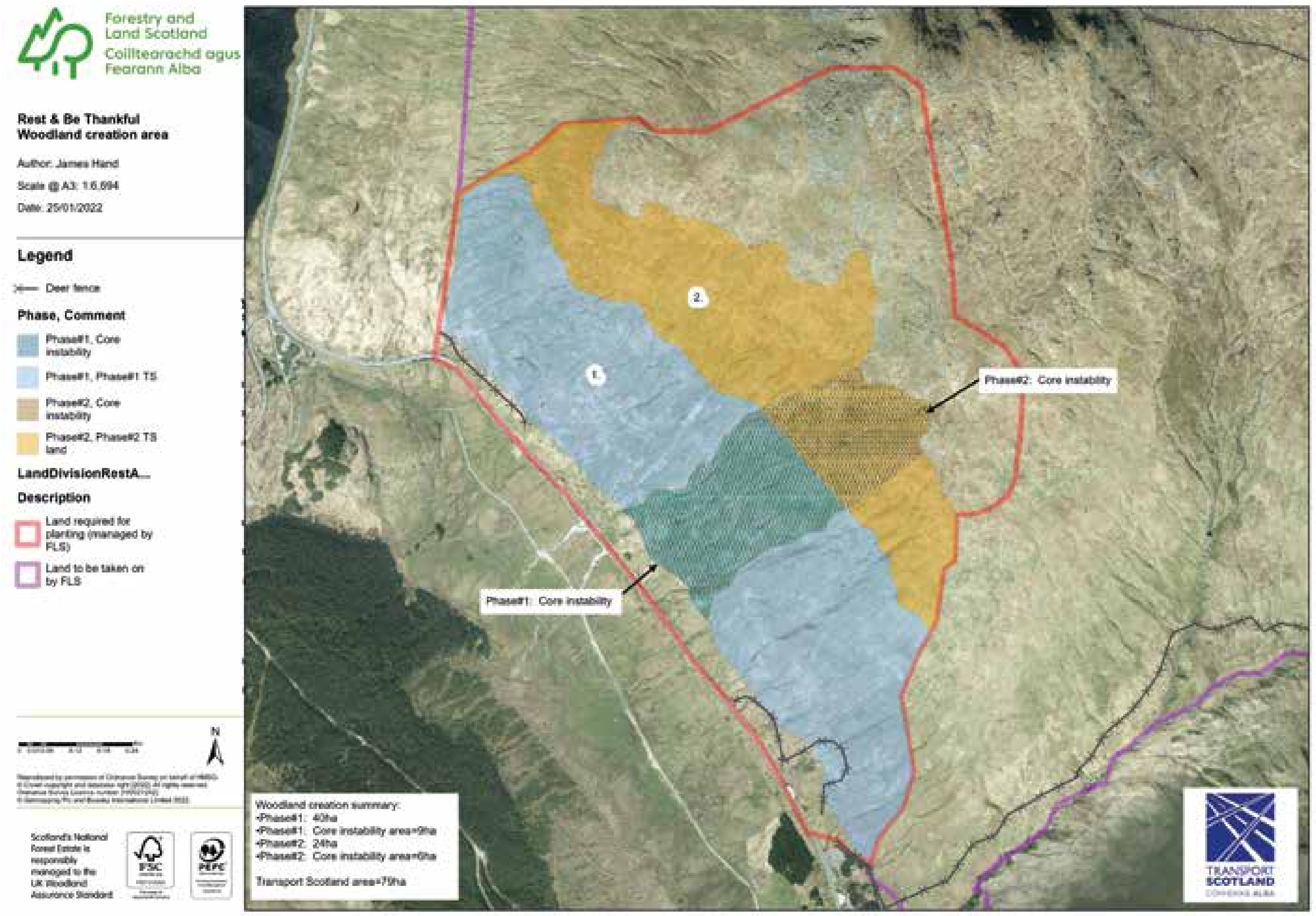
While the new woodland will take time to become established (see **Figure 3**) it will ultimately have additional benefits beyond the intended resilience effect of slope stabilisation. The planting proposal also represents a natural adaptation measure, helping to address the local impact of the increased rainfall forecast across Scotland in the years to come. The planting will reduce the quantity of water infiltrating into the soil through increased root water uptake and subsequent transpiration via the leaf cover.

At the same time, this proposal will restore a significant area of the woodland cover once prevalent in this area, helping to re-establish a rich and varied local ecology and enhance habitat connectivity between Glen Croe and the Ardgartan Forest on the shores of Loch Long. This will deliver significant benefits for local and regional biodiversity. The proposal includes the planting of more than 250,000 native trees, with species such as birch, oak, aspen and blackthorn planted across around 400 acres of previously grazed moorland above the A83. It is also intended to encourage mixed scrub planting within the many gullies and minor watercourses that traverse the steep slopes and to establish low-growing montane planting towards the upper reaches of the hillside (above 400 m). The cost of planting suitable native trees is estimated to be approximately £200,000.[5]

CARBON SEQUESTRATION

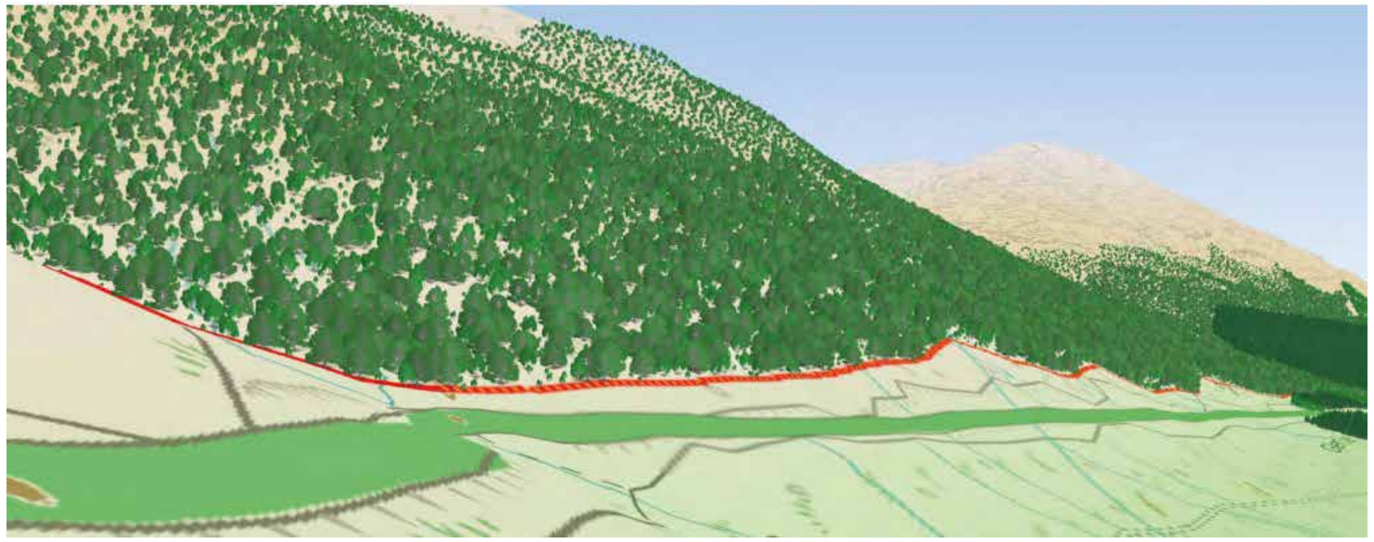
The planting element of the proposed combined solution also represents a demonstrable example of climate change mitigation, as tree planting provides a natural means of removing carbon from the atmosphere via carbon sequestration.

Carbon sequestration is the provision of long-term storage of carbon in the terrestrial biosphere helping to slow down or reduce the build-up of CO_2 in the atmosphere.[6] This is a natural process that has been occurring over millennia, where CO_2 is regulated and kept in balance to provide the optimum conditions for life on earth. This balance is gravely threatened by the effects of a changing climate and there is widespread understanding that we need to work towards redressing the equilibrium by preserving, restoring and enhancing natural ecosystems.[7] Although there are several available processes for sequestering carbon, this project seeks to do so by removing CO_2 from the atmosphere through an increased vegetation mass.



▲ Figure 2. Rest and Be Thankful slopes proposed planting area. (© Forestry and Land Scotland)

CASE STUDY



▲ **Figure 3. Current image of the Rest and Be Thankful slopes and visualisation of established planting. (© Forestry and Land Scotland)**

Assessing the sequestration potential can be challenging. However, the suite of tools developed by the Woodland Carbon Code (WCC) – a voluntary standard for the creation of woodland – provides a recognised and verified route. The WCC is currently managed by Scottish Forestry and defines project carbon sequestration as the 'variations in carbon stocks due to woodland creation over the project duration as a direct result of the project'.

To account for project carbon sequestration, the WCC has developed guidance with associated carbon calculation tools in the form of Excel spreadsheets to assist in project development. The tool is split into two project carbon calculator types:

- Standard – for projects greater than 5 hectares; and
- Small – for projects smaller than 5 hectares.[8]

Calculations in the WCC tools are based on the WCC Carbon Lookup Table V2.0, which estimates changes in carbon stocks in forestry projects and makes certain assumptions in the calculations and multipliers used.[9]

The tools provide sequestration rates at intervals of five years for a range of woodland types. To predict the success of any project, the WCC assigns a pending issuance unit (PIU). The PIU is a commitment to deliver a woodland carbon unit (WCU) over a period of time, calculated on predicted growth.[10] Each WCU is fundamentally a tonne of CO_2 that has been sequestered and verified through the WCC post planting. A PIU is not a guarantee that a project will deliver the predicted amount of sequestration, but the tool is designed to help organisations plan to compensate for future emissions and WCU can only be reported against UK emissions if verified.

Seeking to sequester carbon while providing adaptation and resilience solutions to address climate change cannot be achieved in every instance. However, it may change the way we view or decide on the interventions that we can make. Research by University College London has estimated that the cost of purchasing corporate carbon offsets is likely to increase over the next decade and by as much as US$20 to $50 per tonne of CO_2e by 2030, as demand grows. A bespoke planting scheme offers the potential to apply for a verified offset without purchasing credits.[11]

It is essential that any project seeking to be established as an offsetting carbon-sequestration scheme must be verified and validated to the highest standard by an appropriate institution, with continual verification to ensure environmental credibility. Offsetting in this manner cannot be viewed as a replacement for emissions reduction and should always align with national targets, particularly as there are timescales applied to the amount of carbon sequestered over time. A planting project established to offset could therefore be aligned to aid a corporate pathway to net zero, predominantly applicable to residual emissions that cannot be reduced due to a lack of technology or capacity.

CONCLUSION

By adopting this type of nature-based solution it is possible to limit the impacts of climate change on the planet (mitigation) while also addressing current climate-related pressures on existing infrastructure (resilience) and preparing for the changes we know will happen in the future due to the climate crisis (adaptation). ES

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FEATURE

Enabling behaviour change towards sustainable transport choices

Natalie Rees examines how behaviours and habits are formed and what it takes to change them.

TRAVEL PATTERNS AND HABITS

Travel patterns are dominated by habit, and our habits and routines are embedded within our everyday lives. Behaviours like driving to work tend to be ingrained habits that are difficult to change, with people questioning their frequent behaviours less as it is these routine ones that we tend not to think about.

So, what does change our habits? Usually, we do. While external factors, such as policy changes or encouragement by celebrities like David Attenborough, can persuade us to alter our behaviour, we tend to modify it in response to changes in our environment and through changes in perception resulting from better education. New behaviours – rather than changed behaviours – can result from increased costs and the benefits of potential savings made. For example, higher energy costs can lead to implementation of energy-saving initiatives. Alternatively, changes could come about because of several interconnected factors such as perception, attitude and the prevalence of behaviours in society. A recent example is the move towards plastic-free living.

The 'fresh start effect', a term coined by Dr Katherine Milkman, PhD Professor of Operations, Information and Decisions at the University of Pennsylvania's Wharton School, describes how disruptive routines can lead to changed behaviours,[1] and we have certainly seen disruption over the past two years. Our routines and habits have been changed to the point where we are now forming new ones, such as regularly working from home.

PERCEPTION AND BEHAVIOUR PATTERNS

Over 90 per cent of changes in car use are associated with a change in circumstances. Transport for London's Car Ownership and Use Exploratory Study examined the reasons behind current trends in car ownership and use and explored whether these trends could be expected to continue. The study found that significant change is necessary for people to think about their travel and identified the following key trigger factors:

- Changing job;
- Moving to a new house;
- A change in health (especially among older people);
- A change in family circumstances (especially among younger people);
- Changes to the transport network and cost of travel;
- A desire to improve fitness; and
- A desire to reduce one's carbon footprint.[2]

There are of course other key influences on behaviour, which include attitude, perception, cost and capability. For example, the perception that it is unsafe deters people from cycling. In 2020, the national travel attitudes study (NTAS) showed that 66 per cent of adults aged over 18 said that they felt it was too dangerous to cycle on the road, with a higher percentage of women agreeing than men. In contrast to perception, the NTAS showed that a cycling fatality occurred once in every 9 million bike rides, and that there was a 5 per cent risk of injury for every 1,000 hours of cycling. In fact, statistically, cyclists are less likely to be injured or killed than car drivers.[3] Changing people's attitudes through this evidence should create a better perception of the safety of cycling and inspire behaviour change, particularly if people's attitude is that they would like to give cycling a go.

A report from Sustrans found that 55 per cent of people from ethnic minority groups would like to start cycling. This is not the only group of potential users that were identified in the report: 38 per cent of people at risk of deprivation, 36 per cent of women and 31 per cent of disabled people who do not cycle would like to.[4]

The OVO bike scheme (formerly nextbike) in Cardiff saw bicycles placed throughout the city and take-up by a range of community users. Therefore, it is reasonable to conclude that bike-share schemes would form a valuable element of any integrated transport network. In Cardiff there were a total of 89,496 members in July 2020 with nearly 115,000 rentals for its 1,000 bikes.

The charity Living Streets believes that it is for those journeys that people could walk where the biggest impact could be made. One such journey is the school run. Just one generation ago, 70 per cent of British children walked to school; now fewer than half do, despite studies showing that children who walk or bike to school tend to be more focused and less likely to be overweight.[5]

In 2020, 25 per cent of trips were for distances under 1 mile and 80 per cent of these trips were done on foot. However, as distance increases to 5 miles, the number of people walking decreases to 25 per cent, the number of people cycling is around 5 per cent and the number of car users is now 65 per cent.[6] How we choose to travel to the office, or even pop to the shops, is becoming one of the biggest day-to-day climate decisions we face. The Transport and Environment Statistics Annual Report states that in the UK 55 per cent of transport emissions come from cars[7] and that as well as releasing a lot of carbon into the atmosphere, pollution from cars dramatically decreases the quality of the air we breathe.

LEARNING FROM OTHERS

For the last 100 years, city transport strategies have prioritised cars.[8] Today, the cities creating successful transport strategies are prioritising the movement of people, giving residents and visitors a wider variety of attractive transport options.

A 2013 survey by the European Commission found that Europeans believe the two best measures for improving urban transport are lower prices and better public transport.[9] In March 2020, Luxembourg made all public transport free, and Paris, France, has free travel for under-18s. Surprisingly, where free public transport has been introduced, only a small number of car users make the switch; those making use of free public transport are the active travellers.[10]

There is also evidence from studies undertaken in Tallinn, Estonia, where free public transport resulted in a 10 per cent modal shift from cars. However, this was accompanied by a change from walking to public transport, with a 40 per cent decrease in walking trips.[11]

Nevertheless, free public transport should not be overlooked. It could considerably reduce the number of private vehicle journeys if the under-18s can access public transport, and free public transport could improve access to jobs, education and other services for ethnic minority and low-income groups.

Free transport alone, however, may need to be used in conjunction with deterrents against car use to be most effective. In Oslo, Norway, and Seville, Spain, measures have been introduced to make parking more difficult by turning parking spaces into cycle lanes or pedestrian areas, or by increasing parking fees. As well as making car use less attractive, a move away from private cars will require convenient and affordable alternatives that are easy to access for travellers.

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THE ROLE OF PLACEMAKING

Just as important as providing suitable transport options is the creation of place. Placemaking refers to the strengthening of connections between people and places. It requires people-centric planning and participation by communities to create places that meet their aspirations. Where placemaking principles are used, well-designed and safe walking, cycling and public transport routes are prioritised, and a good variety of modes lessen people's dependence on cars. The local community is involved in the development process, and proposals are shaped to meet their needs. This helps to create pride in the community.

With a pledge to become carbon neutral by 2025 and with awards for the Most Sustainable City in the World and the Greenest City in Europe, Copenhagen, Denmark, leads the world in sustainability. It is not only its exceptional transport networks that have won it these accolades, but also access to urban farming and moveable housing. Off the designated cycle lanes, Copenhagen's residential streets are home to traffic-calming measures including narrow lanes and textured road surfaces, so cyclists and motorists can share the space.[12]

Similarly, the 20-minute neighbourhood (also referred to as the 15-minute city), where communities can conveniently access the facilities and services they need could reduce car dependency. A 1-mile journey on foot takes about 20 minutes. Yet, as we have moved away from traditional town centres to out-of-town shopping centres and superschools and as housing has been built without suitable travel routes, the journey from home to the services, green spaces and jobs we need has become longer and more difficult. Poor planning has meant that some communities are so isolated that access to even small local shops requires a car journey.

Some journeys will remain difficult to undertake via public transport, by bike or on foot. For those who live in very rural areas and for carers of elderly people or people with disabilities, a car may be essential.

By creating better communities, we can make it easier for people to travel sustainably. Research undertaken by Sustrans shows that people are generally happy to walk for 20 minutes to get to and from the places they need to go.[13] Habitual behaviour can take a long time to change, and without the right support and reinforcement it is easy to slip back into old habits. The key to enabling transformation is to catch people at that moment of change – when they buy a new house or start a new job – and the balance and measures needs to be right. Otherwise, this can push behaviour down the opposite path, making change difficult.

TRANSPORT PLANNING FOR THE FUTURE

Reaching the 2050 net zero target would involve change at a pace and scale that requires new systems that make it easy to access more sustainable travel options and enable earlier formation of new habits. Subtle nudges may change attitudes and lead to new behaviours,[14] but more robust policies and actions aimed at directly changing habits are required, such as increasing vehicle tax, raising fuel prices or introducing road pricing – tolls, congestion charging or charging for peak time travel, which is utilised in Singapore to manage road congestion, are some examples.

Co-benefits are also important. Reducing the number of short trips made by car cannot only reduce carbon emissions but can also improve air quality, help people improve their fitness, and reduce levels of obesity. It can also inspire young people to continue good habits into adult life. Travelling more actively could also improve prosperity and equality: active travel is a low or no cost option, and money saved could be invested in local communities or improve conditions for people living in poverty. To enable this behaviour, safe active travel routes and accessible, reliable public transport need to exist.

Creating an integrated transport system and increasing the availability of services – so that people can easily change from bus or train to cycling or walking or utilise multiple modes of travel with one app – will be key to enabling effective behaviour change. Ultimately, it is about making it as easy as getting your keys and getting in the car. Mobility as a service (MaaS) is a term used to describe digital transport service platforms that enable users to access, pay for and get real-time information on a range of public and private transport options. MaaS envisages users buying transport services as packages based on their needs instead of buying the means of transport. The emergence and implementation of MaaS will be exciting to watch and be a part of for those who work in and use public transport and active travel. ES

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The challenge of making the case for innovative transport schemes

Andy Cope, **Robert Beauchamp** and **Stephen Cragg** examine the limitations of our current transport appraisal mechanism.

THE ROLE AND CHALLENGES OF TRANSPORT APPRAISALS

Transport appraisal is an important component of how we prioritise investment in transport. Appraisal mechanisms used by UK governments include qualitative assessments of alignment to policy areas and quantitative estimation of socio-economic impacts. In this way, we can make an informed assessment of whether the outcomes we would expect to see from a change to the transport network – such as a new public transport or road link, or improvements to a walking and cycling network – align with the outcomes that policies prioritise. We can then estimate the extent to which a transport scheme might affect these outcomes by modelling the consequences of a proposed scheme.

The approaches used to measure socio-economic impacts are complex. We can put values on changes in travel time, variations in pollutant emissions, the differing extent of access to opportunity and various other factors. If factors can be forecast, they can be compared against a scheme's capital and operating costs.

In theory, any adjustment to the transport system can be considered in terms of the changes in value of the factors considered. However, modelling the consequences of transport interventions is complex. In particular, there are two major shortcomings in the ways in which we forecast changes from schemes that reduce traffic or affect traffic flow. Firstly, most transport models are weak at forecasting walking and cycling trips; the focus is on private motor vehicle and public transport demand. This is partly a legacy of policy priorities that predate the recognition of climate crisis and the significance of wellbeing, and partly because it is easier to model car and public transport use than it is to model walking and cycling. If the aim of a scheme is to encourage modal shift away from the private car towards walking and cycling, these models will not pick up this effect. Secondly, transport economic appraisal tends to emphasise the cost of journeys between places (in time and money, for instance) and pays little regard to the effects on utility of place for those living or working there – either at the origin and destination, or the places in between. This is again partly a reflection of historical policy priorities and the ways in which these priorities have shaped industry practice over time.

The twin challenges of the global climate crisis and Covid-19 pandemic bring the limitations of the traditional transport appraisal paradigm into stark relief. Policymakers may see the benefit of schemes that reduce private car traffic, either as a way to cut carbon emissions

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or to improve the utility of residential or commercial locations. However, making the socio-economic case for such schemes using the traditional paradigm is difficult.

Recent, as yet unpublished, work by the Centre for Economics and Business Research, Transport Scotland and Sustrans considers approaches that can enable a more complete assessment of the impacts of schemes that do not simply enable more traffic to travel further faster.[1]

TRANSPORT POLICY IN SCOTLAND

Transport Scotland is the national transport agency for Scotland, responsible for delivering the Scottish Government's vision for transport. Transport Scotland is responsible for policy and investment decisions in respect of an extensive trunk road network, a multimodal public transport network, and complex air and sea connections to islands and other remote communities. Transport Scotland is also responsible for supporting local authorities to manage local networks – local roads, public transport, and walking and cycling provision.

This responsibility includes traffic-reduction measures in some contexts. The goals of traffic-reduction schemes are reflected in the Scottish Government's policy agenda:

- The Programme for Government[2] (the annual legislative and policy programme) is based around the National Performance Framework, which covers a wide range of outcomes.[3] This includes the creation of vibrant, healthy and safe places and communities, promotion of physical and mental health, and environmental sustainability.
- The National Transport Strategy priorities for the transport system include reduction of inequalities, taking climate action, inclusive economic growth and improved health and wellbeing – all of which can be supported by traffic reduction.[4]
- The Climate Change Plan targets a 20 per cent decrease in car kilometres across Scotland by 2030 compared to 2019 levels.[5]
- The Active Travel Framework aspires to make walking and cycling the most popular choices for short, everyday journeys by 2030.[6] This will be supported by high-quality active travel infrastructure and improved safety.

These policies lay a high-level foundation for schemes such as low-traffic neighbourhoods and pedestrianisation that reduce the capacity for motorised vehicles. But conventional appraisals based on typical transport modelling may conclude that projects would not benefit either the economy or local residents. Increased journey times for motorised vehicles are an easily quantifiable cost of traffic-reduction schemes; the benefits to quality of place or of active travel journeys are harder to capture.

Therefore, these policies and their implications for the sort of transport schemes that are needed in Scotland have necessitated some refinement of the Scottish Transport Appraisal Guidance (STAG).

IMPROVING APPROACHES TO APPRAISAL

As well as developing the toolkit to better enable the inclusion of factors that express the value of utility of place and capture modal shift towards active transport, there are numerous other areas where development of appraisal and decision-making processes in STAG are already improving approaches to transport appraisal and allow net zero ambitions to be reflected sooner in the real world.

Decision-makers and scheme promoters should continue to be bold in their approach to making and assessing business cases for traffic-reducing schemes. Articulation of the impacts on a wider-than-usual range of factors as part of the narrative that expresses the advantages a scheme offers is key to making a good case. In the absence of quantified evidence, the use of qualitative or quasi-quantitative approaches is acceptable; such assessments must accord with the principle that the appraisal being conducted is proportionate to the transport problem at hand.

Traffic-reduction schemes sometimes lend themselves to partial or interim implementation, providing low-cost, low-risk ways of determining what effect they will have. Practically, this may mean putting in temporary traffic-reduction measures to test effectiveness and help build the business case, for example. This could also support the stakeholder consultation process, which feeds into the appraisal. An all-or-nothing approach (a scenario where decision-making is on a discrete 'proceed' or 'do not proceed' basis) risks creating situations in which schemes do not happen at all because they cannot attain a sufficient level or standard of ex ante evidence.

It follows that monitoring and evaluation of schemes should be prioritised. This applies in the context of interim implementation – collecting data to make a case for full or permanent implementation. It also applies in a context of collecting data from other similar, innovative schemes. Learning from scheme effectiveness can be transferable between geographical contexts and can often support improved scheme design.

Scrutiny and accountability are essential parts of how policy alignment is supported and decision-making assured. The developments in the Scottish Transport Analysis Guide are a welcome move towards an approach that better supports a more equitable footing for transport schemes that reflect the demands posed by the climate crisis and post-pandemic living. ES

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How can sustainable transport benefit air quality and health?

Sam Pollard analyses the links between sustainable transport, air quality and health.

INTRODUCTION

Elevated concentrations of air pollutants are known to adversely affect people's health. In urban areas, elevated pollutant concentrations tend to stem from road traffic emissions of nitrogen oxides (NOx) and particulate matter (PM) with diameters of less than 10 µm and 2.5 µm (known as PM_{10} and $PM_{2.5}$, respectively) in combination with emissions from other sources. These adverse health effects were starkly highlighted by the coroner's verdict into the 2013 death of Ella Roberta Adoo Kissi-Debrah, aged nine, who lived near the South Circular Road in south-east London. The coroner concluded that Ella 'died of asthma contributed to by exposure to excessive air pollution'.[1]

THE CHANGING LEVELS OF POLLUTANT CONCENTRATIONS

While emissions of NOx from UK road transport are estimated to have decreased by 31 per cent between 2009 and 2019,[2] largely as a result of tighter emissions standards being introduced for petrol and diesel vehicles, annual mean concentrations of nitrogen dioxide (NO_2) were still in excess of the health-based air quality threshold for this pollutant in many urban areas of the UK in 2019 (i.e. before the Covid-19 pandemic). Furthermore, road transport remains a significant source of $PM_{2.5}$ emissions in the UK (12 per cent in 2019), and while exhaust emissions have decreased by 85 per cent since 1996 due to stricter emissions standards, this decrease has been partially offset by an increase in 'non-exhaust' emissions – emissions from brakes, tyres and road wear – as traffic activity has increased.[2] These non-exhaust emissions are estimated to represent an increasing proportion of total road traffic-derived $PM_{2.5}$ emissions (approximately 66 per cent in 2019) and may even grow in the future due to the increase in road traffic flows and weight of passenger vehicles – resulting from the trend for larger vehicles and the weight of batteries in hybrid and electric vehicles. Emissions of $PM_{2.5}$ are particularly important with regard to human health; although air quality thresholds and guideline values have been set, there is no 'safe level' for this pollutant.

Achieving modal shift from private cars to sustainable transport modes, such as public transport, walking and cycling, therefore has the potential to result in a reduction in both road traffic-derived NOx (exhaust) and $PM_{2.5}$ (exhaust and non-exhaust) emissions in urban areas, thereby improving air quality and public health. The potential level of improvement was starkly illustrated during 2020. The Covid-19 pandemic restrictions led to reduced traffic levels, resulting in a decrease in concentrations of NO_2 of 20–30 per cent in UK urban areas.[3] Should reductions in NO_2 concentrations of this

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magnitude be maintained, it would be possible to achieve the current air quality objective and limit value for NO_2 (40 μg/m³) in most urban areas of the UK (concentrations of which rarely exceed 60 μg/m³).

Between 2007 and 2019, annual mean NO_2 concentrations at roadside sites in the UK decreased by an average of 1.8 μg/m³ each year, as newer vehicles subject to stricter emissions standards entered the transport fleet.[4] Road traffic exhaust emissions are expected to continue to decrease over time, as older vehicles are gradually replaced by newer ones with lower emissions, especially electric vehicles. This transition may not, however, be achieved as quickly as expected, due in part to economic factors and supply shortages. While electric vehicles have zero exhaust emissions, they still generate non-exhaust $PM_{2.5}$ emissions, and perhaps more so than conventionally fuelled vehicles due to their increased weight. It is also recognised by the Royal College of Physicians, among others, that a continued focus on improving urban air quality by reducing vehicle exhaust emissions is less beneficial for public health than an emphasis on measures that increase active travel (walking and cycling) and public transport (where active travel is often part of the journey).[5] Reductions in traffic flows in urban areas will also have other tangible benefits, such as reduced noise levels, greenhouse gas emissions and road traffic accidents. Such changes may make urban areas more attractive places to visit, which in turn may benefit local businesses.

Due to the impact of the Covid-19 pandemic on travel patterns, largely the result of increased home working, car usage is currently at approximately 90 per cent of pre-pandemic levels, while rail and bus usage is only at 65 per cent and 75 per cent, respectively.[6] As we begin to emerge from the pandemic-imposed restrictions, it is important to avoid a car-led recovery, which could occur should public transport users choose to switch to private cars due to Covid-19 transmission concerns or as a result of reduced public transport provision caused by funding shortfalls. People may also travel differently post-pandemic: they may make fewer commuting journeys by public transport but more leisure journeys by private car. Such behavioural changes could result in an increase in road traffic flows and emissions in the short term and a potential worsening of air quality in urban areas. These effects could be reduced or counteracted by an increase in sustainable transport.

HOW COULD BETTER ACCESS EQUAL BETTER AIR QUALITY?

In order to achieve sizeable reductions in road traffic emissions, and consequently measurable improvements in air quality from modal shift, it is important that:

- A substantial reduction is achieved in the number of vehicle movements within a particular area or along a certain route;
- Modal shift primarily occurs from private cars to more sustainable transport modes. Switching from public transport to cycling or walking, for example, would have a negligible effect on emissions; and
- The modal shift achieved is consistent (e.g. it occurs five days a week) and long lasting.

This type of modal shift is most likely to be achieved through targeted interventions developed from a detailed understanding of the journeys people make in a particular area. For example, people making longer journeys with school-age children are less likely to shift to cycling or walking than those making shorter journeys. Such information can be gathered in several ways, including surveys undertaken at key locations such as schools and using automatic number plate recognition data, modelled traffic data or anonymised mobile phone data to understand journey origins, destinations and routing. It is also important that new developments are appropriately sited and designed in ways that facilitate the use of sustainable transport.

While providing sustainable transport infrastructure – cycle lanes and junction improvements – and increasing public transport provision are essential to driving changes in travel behaviour, such measures alone may not result in a substantial modal shift. Additional interventions may therefore be required to encourage or incentivise changes in behaviour. These could include reducing the availability and increasing the price of council-operated car parks within town centres or introducing workplace parking levies. Nottingham City Council, for example, observed an 8 per cent reduction in annual average daily traffic flows across the city between 2000 and 2016 as a result of the introduction of a workplace parking levy and measures to encourage the use of sustainable transport. In doing so, Nottingham City Council was able to demonstrate that compliance with the NO_2 air quality limit value would be achieved more quickly in the city than what the national-scale modelling projections showed,[7] thus avoiding the need to introduce a charging clean air zone (CAZ).

Vehicle access restrictions such as congestion charging or charging CAZs, school streets[8] or low emission streets and neighbourhoods[9] could also be used to improve air quality and change travel behaviours. London's expanded Ultra Low Emission Zone, for example, is estimated to have resulted in 11,000 fewer vehicles on an average weekday within the zone (a 1 per cent reduction),[10] while a study into the air quality effects of school streets found that closing the roads around schools to traffic at pick-up and drop-off times reduced NO_2 concentrations by up to 23 per cent.[11] Some form of road user charging could also be used, something currently under consideration by the Mayor of London.[12]

However, those interventions that seek to force behavioural change, such as financial penalties for travelling by private car, must be supported by measures to enable modal shift, and the financial consequences to non-compliant individuals should be limited as far as possible.

The cumulative effect of multiple interventions – for example, targeting different types of journeys – with a variety of modes, such as cycling and public transport, is also likely to be substantially greater than that of a single intervention for one specific travel mode. Ideally, a coordinated strategy of interventions would be developed and implemented in a particular area instead of modifications being implemented in a piecemeal fashion as opportunities are identified or funding arises. A good example of such strategic thinking is Essex County Council's Sustainable Transport School Travel Design Guide,[13] which sets out how a new-build school in a new community should be designed to prioritise sustainable travel by using a zonal approach to encourage travel by different modes.

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OTHER FACTORS TO CONSIDER

As with all interventions, it is important to consider how different members of society would be affected, particularly those who may be financially impacted or who may have reduced accessibility options – such as disabled or elderly people. It is noted, however, that research suggests that those areas with households least able to access a vehicle are also exposed to the highest pollution concentrations, and therefore will likely benefit most from improvements in air quality.[14]

It is also important to recognise that there may be adverse effects associated with sustainable transport interventions that could require assessment and potentially mitigation. For example, the implementation of cycling infrastructure and junction improvements along a particular route could introduce additional delays for car users, and consequently make that route less attractive. While this may result in additional benefits along the affected route – through a further reduction in traffic flows, for example – these vehicles could then seek alternative routes resulting in adverse effects elsewhere. These effects may counteract or even outweigh the modal shift benefits achieved along the affected route and would require careful consideration.

MONITORING AND EVALUATING EFFECTS

As noted by Defra's Air Quality Expert Group, assessing the effectiveness of specific interventions on air quality can be challenging for several reasons, including the fact that they rarely occur in isolation from other changes that affect air quality, and that it is difficult to detect and quantify changes if the interventions are relatively minor.[15] For example, Newcastle City Council concluded that there had been little, if any, reduction in NO_2 concentrations between 2012 and 2016 within the city centre's air quality management area as a result of the implementation of Air Quality Action Plan measures.[16] Indeed, the impact of a specific intervention may not be detectable in terms of a change in pollutant concentrations even with sophisticated analysis techniques.

To better understand the impact of an intervention and develop evidence on the effectiveness of sustainable transport measures in improving air quality, it is essential that appropriate data are collected for those activities that would be expected to change. In terms of sustainable transport approaches, this is likely to involve collecting mode-based traffic data. A more recent technical development that is particularly useful for this purpose is traffic sensors that use machine learning to identify motorised road users, pedestrians and cyclists from video imagery, thereby allowing trends in different modes to be observed.

The availability of well-sited ambient air quality measurement data also increases the potential for data analysis and the application of statistical methods to quantify changes in pollutant concentrations. Air quality sensors are one way in which large amounts of high time-resolution data (e.g. every 15 minutes) could be obtained in urban areas, which may be useful for this purpose. It should also be noted that when interventions are assessed based on changes in pollutant concentrations, it is important to take account of meteorological influences, which can easily hide or overemphasise changes in concentrations resulting from changes in emissions. Methods do exist, however, to account for such weather-related influences.

CONCLUSION

A greater use of sustainable transport has the potential to result in a beneficial effect on air quality and human health. However, careful consideration must be given to the design of interventions aimed at achieving modal shift in order to maximise their effectiveness. Such interventions also likely need to be complemented by behavioural change incentives in order to achieve substantial and sustainable reductions in traffic flows and improvements in air quality.

Going forward, a key challenge to achieving the UK's net zero target will be fully decarbonising road transport by 2050, as set out within the UK Government's Transport Decarbonisation Plan.[17] While there will be significant reductions in ambient NO_2 concentrations in urban areas as a result of increasing vehicle electrification, a consequence of the elimination of the primary source of urban nitrogen monoxide (NO) from vehicle exhaust will be localised roadside increases in ozone (O_3). The overall air quality benefits of reducing urban NO_2 are, however, likely to be much larger than the effects of roadside incremental increases in O_3.[18] Particulate matter emissions will, however, remain an undesirable consequence of road transport even in 2050 under a fully decarbonised scenario. It is therefore critical that the other policy actions that support modal shift to options such as walking, cycling and public transport are delivered to maximise air quality and health benefits as well as reduce greenhouse gas emissions. ES

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CASE STUDY

The Solent future transport zone programme: an overview

Richard Pemberton outlines the new mobility schemes underway around the Solent area.

TECHNOLOGY IN THE TRANSPORT SECTOR

Like many aspects of the world we live in, the methods by which people and goods are transported change and evolve over time, driven by changes in society, the economy, and perhaps most frequently by developments in technology.

Transport professionals believe that the sector is currently in the midst of a technological disruption and transformation that may be as profound as the changes following development of the internal combustion engine at the turn of the twentieth century. The twin driving forces behind this transformation are the transition from fossil fuels to electricity and hydrogen as a source of motive power and, perhaps more critically, the transport sector leveraging the full potential of digital technology and wireless data connectivity through smartphones and technology embedded in vehicles.

The adoption of disruptive technologies often occurs in an S-curve. The early adoption stages take place slowly, but once the barriers are overcome – cost, ease of use or societal acceptance – rapid increases in adoption and usage occur, with mass market usage in developed economies taking place in as little as a decade.

Such rapid development of technologies may outstrip the ability of governments and regulators to respond to changes, limiting their ability to steer fast-moving trends towards better outcomes for society, the environment and the economy.

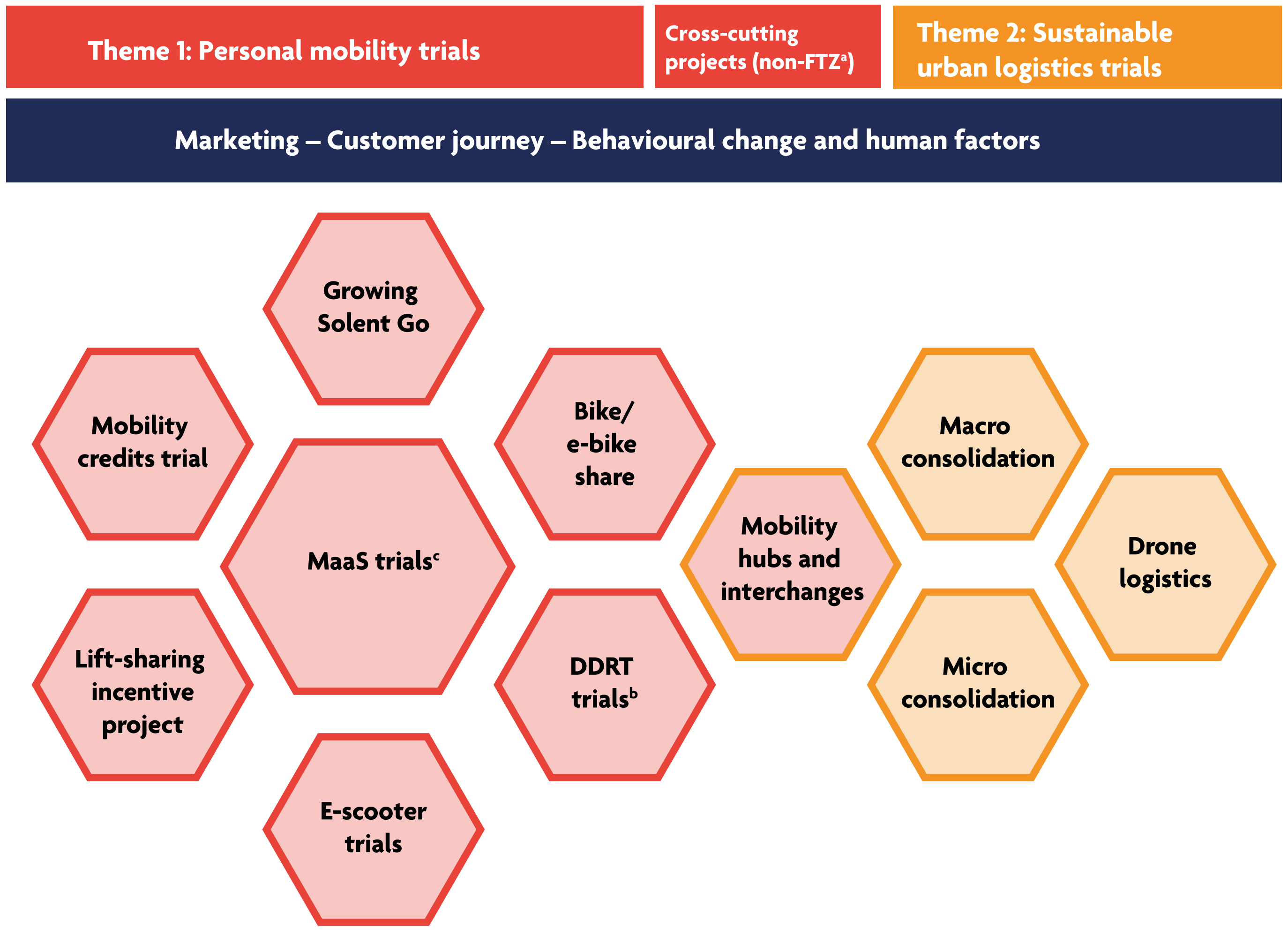
In 2017, the UK's Department for Transport (DfT) commissioned a major policy study, the Future of Mobility,[1] aiming to proactively position the UK to respond to and take best advantage of anticipated changes. The final report, published in 2019, provides an expansive review of the subject and is still highly relevant today.[2] The subsequent Future of Mobility: Urban Strategy[3] set out the government's approach to maximising the benefits and managing the risks of new transport technologies in urban areas.

FUTURE TRANSPORT ZONES AND THE SOLENT PROGRAMME

A significant component of the future of mobility strategy was the allocation of £90 million to support the creation of future transport zones (FTZ). FTZs are used to test new mobility technologies and services and understand how users respond to them in a concentrated area. This information will help prove the commercial case for investors, identify and respond to regulatory or other challenges and enable the introduction of successful projects on a larger scale. Additionally, there are objectives to significantly improve mobility for consumers (particularly via emerging shared modes of transport and through use of technology to create digital 'marketplaces for mobility') and to provide an exportable template to allow successful initiatives to be replicated more easily elsewhere.

Therefore, FTZs need to monitor, evaluate and disseminate the findings of their trials to the wider transport community more actively than many transport projects currently do.

The Solent area was one of four areas awarded FTZ funding in spring 2020 following a competitive bidding process. A £28.8 million programme is led by Solent Transport, a partnership of the local authorities around the Solent comprising the Isle of Wight Council, Hampshire County Council, Portsmouth City Council and Southampton City Council.Much of the Solent area is urbanised and densely populated, with the cities of Portsmouth and Southampton and the towns and suburbs between them forming the UK's seventh largest built-up area (population 855,000 in 2011).[4] However, there are also parts of the Solent FTZ area – especially on the Isle of Wight – that are rural and isolated.



▲ **Figure 1. Overview of individual projects within the Solent FTZ programme. (Source: Solent Transport)**

[a] FTZ = future transport zone
[b] DDRT = dynamic demand-responsive transit
[c] MaaS = mobility as a service

The Solent area contains the largest urban area in the UK not covered by a combined authority (CA) or integrated transport authority (ITA). Transport governance in CA and ITA areas differs to that in the rest of the UK, with a higher degree of devolved powers and funding and more direct control or influence over urban metro, rail and bus networks. However, 59 per cent of the UK's population lives outside of CA and ITA areas. Therefore, the Solent FTZ programme is well placed to undertake trials of future mobility in an administrative environment representative of those parts of the UK. Around the Solent, partnership working with transport providers is essential to developing the transport offer for those modes (e.g. public transport) over which local government has few statutory powers and limited dedicated funding.

Like many other local authorities, Solent Transport's member authorities have all declared climate emergencies and are seeking to achieve net zero carbon dioxide (CO_2) emissions by 2050 or before and reducing emissions from transport is a critical element of these plans. The Solent FTZ programme is designed to support this policy by trialling initiatives that may become permanent.

While partnerships with transport operators and technology providers are crucial for many of the programme's trials, collaboration with universities is also a key feature. The University of Portsmouth and University of Southampton are extensively engaged in leading some areas of work and delivering parts of other projects, and contribute capabilities around data collection, analysis, evaluation and dissemination that the local authorities involved do not possess.

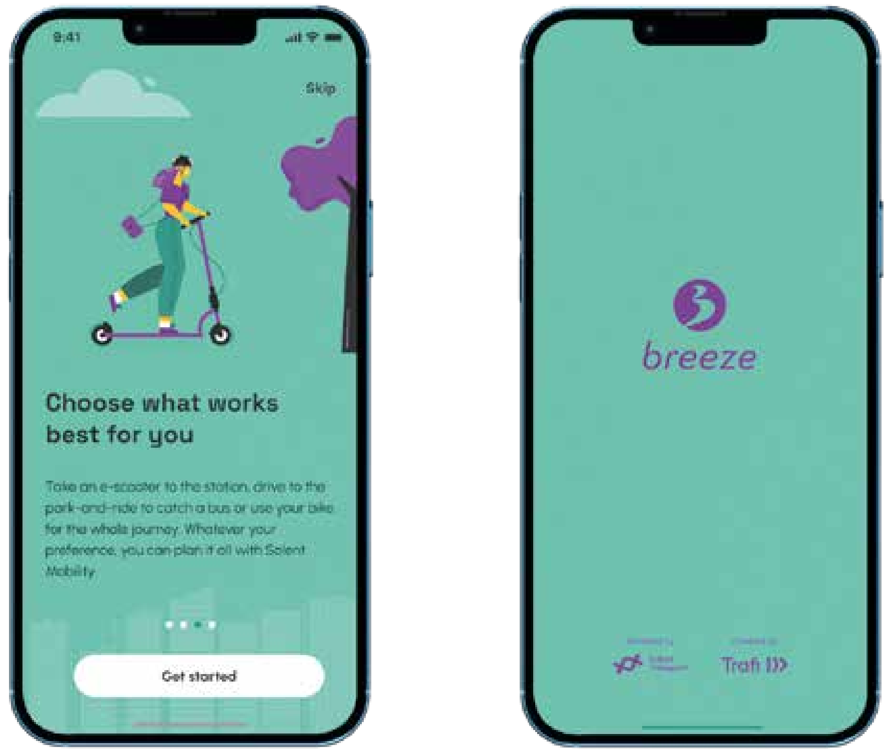
ELEMENTS OF THE SOLENT FTZ PROGRAMME

The Solent FTZ programme comprises 11 individual trial projects across two thematic areas: personal mobility and sustainable urban logistics (see **Figure 1** and **Table 1** for an overview).

As well as supporting DfT requirements to conduct real-world testing of future mobility projects, the Solent FTZ programme supports a range of local priorities, including:

- Developing and supporting adoption of zero-emission transport modes;
- Supporting mode shift away from private cars;
- Improving the transport offer and access to opportunities for people in the trial area; and
- Enhancing the benefits of other projects implemented by member authorities, such as bus rapid transit, walking and cycling network improvements, and car clubs.

The programme is designed to play to the strengths of its partners and the needs and opportunities in the Solent area. It does not involve testing autonomous road vehicles or similar technologies because other parts of the UK, such as the Midlands, have greater capabilities in this area.



▲ **Figure 2. Breeze, the Solent mobility as a service app that is a core part of the Solent future transport zone programme. (Source: Solent Transport)**

▼ **Table 1. Summary of projects within the Solent future transport zone programme**

Theme 1: Personal mobility trials	
Mobility as a service (MaaS) trial	Mobility as a service (MaaS) is a single mobility service accessed through a smartphone app that provides access to multiple forms of mobility via a single planning, payment and ticketing channel (instead of multiple options for different operators and modes).[5] There has been significant industry attention on MaaS for several years in the hope it can deliver a seamless, integrated and customer-friendly non-car travel experience. There are many examples of MaaS apps in mainland Europe, enabled by greater local control of public transport services, but few examples of MaaS exist in the UK outside of London to date. The Solent MaaS app, due to launch in March 2022 and branded as 'Breeze' (see **Figure 2**) will allow users to travel around the Solent region with just a smartphone. The app will automatically find the best travel options based on users' needs and preferences; allow users to buy and scan tickets for trains, buses or ferries; unlock e-scooters and e-bikes for rent; and even enable car rental from car clubs. The MaaS trial will integrate other projects in Theme 1, creating a marketplace for all forms of mobility in one place. Extensive research and testing are being undertaken by the universities, including experimentation with and testing of various algorithms within the app; testing of gamification to encourage particular behaviour and offer rewards; and testing of the impact of changes to user interfaces. The Solent MaaS system will also be exportable to cover other areas at a relatively low capital cost.
Growing Solent Go	This project expands the range of multi-operator public transport tickets offered via the MaaS app, including new carnet and 1-hour tickets, thus creating new options for seamless and integrated journeys across multiple providers.
Mobility credits trial	Launching in late 2022, this will trial distribution of free travel credit via the MaaS app. The direct and wider impacts of the credit on the trial group will be monitored and analysed via in-app surveys and app usage analysis and compared against a control group of individuals who do not receive mobility credits.
Dynamic demand-responsive transit (DDRT) trial	This project will procure a digital back-office system enabling dynamic demand-responsive transit (demand-responsive 'street corner to street corner' minibuses and shared taxis) to plug into MaaS. This system will be applied to the operations of several community transport and Dial a Ride services in the FTZ area. These services are often manually planned and operate with significant spare capacity which, better utilised, could improve financial viability and provide extra mobility options.
Bike/e-bike share	Currently no bike-share schemes operate in Portsmouth, Southampton or the Isle of Wight, despite high forecast potential, particularly in Portsmouth and Southampton.[6] This project introduces shared bikes and e-bikes to help expand the MaaS app mobility marketplace, as well as provide an additional travel option for residents and visitors.

CASE STUDY

Theme 1: Personal mobility trials	
E-scooter trials	As part of wider national trials of shared e-scooters, trials on the Isle of Wight and Portsmouth and Southampton city centres were launched in 2021. At present, a total of 1,840 scooters are available across the three trial areas. Monitoring to date shows low levels of incidents and indicates that four in ten riders have switched modes to use rental e-scooters when they would have previously used a car, replacing an estimated 200,000 short car journeys and saving an estimated 120 tonnes of CO_2 in the first year of the trial.
Theme 2: Sustainable urban logistics trials	
Drones for medical logistics	Using drones for medical deliveries has the potential to significantly reduce the time it takes to get crucial medical test results to hospital patients or deliver lifesaving medicines to remote parts of the country. This project will develop the systems required to manage drone flight paths and test the best drones for deliveries beyond the pilot's visual range. Trials commenced in May 2020 between the mainland and the Isle of Wight. Solent Transport and the University of Southampton are working with the Isle of Wight National Health Service (NHS) Trust[7] and other partners, including Apian, to examine the issues of using a vertical takeoff and landing drone (VTOL) to deliver chemotherapy drugs to patients on the island. Trials took place in late 2021 (see **Figure 3**) and early 2022; additional flights are scheduled for later in 2022 with the aim of making the world's first drone delivery of live chemotherapy drugs to a hospital using a VTOL unmanned aerial vehicle (UAV). The knowledge gained in these trials will be used to develop options for testing several drones in the same airspace and to examine how the supply chains' logistics systems could work together to enable ongoing medical deliveries to the island. The world's first testing of the impact of drone flight (e.g. vibration and temperature) on medicines is also being carried out to research how UAVs can integrate with ground-based medical logistics supply chains.
Macro consolidation	Macro consolidation is where numerous small deliveries to a large business, location or area are combined at a regional distribution centre into one load, significantly reducing the number of freight vehicle movements. Model studies forecast that consolidated deliveries to locations such as hospitals could cut delivery and service vehicle movements by over 90 per cent. This project will assess methods and incentives to maximise the potential of the existing Southampton sustainable distribution centre[8] to enable opportunities for macro consolidation in the Solent region.
Micro consolidation	Micro consolidation is where numerous individual deliveries to residents and small businesses are combined at a local logistics hub for last mile delivery using lower-emission transport modes – for example, electric vans or cargo bikes. Micro consolidation is rare outside the densest parts of large cities but offers potential to mitigate the impacts of rapid growth in van traffic driven by online shopping. The project will evaluate how micro hubs and different vehicle types for the first and last miles affect cost, speed and ease of delivery. It will also explore repurposing of land in high-density areas – for example, disused town and city centre land – into locations for local consolidation hubs, often in conjunction with changes to land for public transport interchanges and mobility hubs.

▲ **Figure 3. Testing of an Apian electric vertical takeoff and landing drone at Thorney Island, 22 November 2021. (© Chris Fletcher, Ministry of Defence)**

COVID-19 AND PROGRAMME-LEVEL LEARNING TO DATE

The Solent FTZ programme received funding in March 2020, just as the Covid-19 pandemic began. After early optimism that long-term travel mode shift might occur due to short-term travel behaviour changes, road traffic has now rebounded to 2019 levels, but use of public transport has only returned to around two-thirds of previous levels. As a result, the key programme objectives – the creation of a wider non-car travel digital marketplace to support modal shift and measures to reduce the impacts of logistics – remain relevant and the programme is largely unchanged. However, details of several projects have been amended in response to changes in transport user behaviours and commercial challenges for public transport:

- The DDRT trial has been updated to focus on community transport services because the impacts of the pandemic on the bus industry made the planned approach to the trial unviable due to commercial risks and reduced demand.
- The lift-share incentives project has been deprioritised due to difficulties of promoting car sharing during the pandemic.
- Elements of certain projects have only had soft launches due to government advice at the time to avoid promoting public transport use.
- Supply chain and resourcing and recruitment issues have slowed progress on some projects.

Launching the FTZ programme in the early days of the pandemic brought challenges, the greatest being that decision-making resources were diverted to urgent public health and pandemic response activities, which consumed significant amounts of organisational capacity in the early days of the programme. Similar issues have affected key partners, particularly the NHS, university partners and the logistics sector (whose focus was diverted to meeting the short-term surge in demand for home deliveries). As a semblance of business as usual returned, progress to launch various trials has accelerated, and in 2022 key parts of the programme will be launched, enabling data collection and analysis to begin.

Many of our learnings to date relate to project management and delivery, including:

- The complexity of procuring services and products in emerging markets and sectors – and the benefits of having dedicated support and use of methods such as dynamic purchasing systems to accelerate procurement.
- Developing projects that are deliverable using only capital funding – and which have a good chance of developing into sustainable commercial models rather than requiring ongoing subsidy – that also deliver revenue share or other returns to the funder.
- Delivering trials that come with some risks in risk-averse environments – and how to overcome these concerns. ES

Richard Pemberton is a Principal Transport Planner at Solent Transport. He has 14 years' experience in private and public sector transport planning roles, including working for several local authorities in the Solent area. Richard has expertise in sustainable transport and public transport modes, and in technical subjects such as transport modelling and geographic information systems. Richard led the development of the Solent FTZ proposal in 2019.

FURTHER READING

Find out more as the programme progresses through the following channels:

- Solent Transport FTZ website: https://www.solent-transport.com/solent-future-transport-zone
- Social media: https://twitter.com/SolentTransport www.linkedin.com/company/solent-transport
- For queries or to sign up to our newsletter: https://www.solent-transport.com/contact-us
- Job opportunities: www.solent-transport.com/vacancies

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