Appendix 1
Road Freight decarbonization options: briefing note for DePoLARiZE

Summary
Decarbonization of road freight is challenging, but possible over a period of decades. The deployment of zero-emission vehicles will likely be complemented by some shift of traffic to other modes (rail/water), optimised vehicle use, and greater vehicle efficiency. It may possibly also be reinforced by broader structural economic trends to reduce growth in demand for freight; for example, stimulated by policies to promote more circular economies. The key obstacles are uncertainty regarding infrastructures and technology choices, near-term costs, long asset lifespans, and weak policy drivers.

Developing effective policy with wide stakeholder buy-in will require attention to critical contextual issues: interests of communities and workers, scales of authority, and locational factors. There are clear opportunities to use the Port and freeport developments in combination with the needs of the local community as a driver for wider systemic change.

Background
Road freight accounts for almost 10% of global emissions. The sector is arguably 'hard to abate' because of high energy intensity, long asset life and challenges to electrification.[1] The reliance of freight vehicles on a refuelling network increases the challenge as any significant change in technology requires a commensurate roll-out of refuelling infrastructure. Volumes of road freight continue to grow, not only in the global South, as economic trends continue towards globally fragmented manufacturing, global procurement but combined with increasingly re-localized and 'just-in-case' (not 'just-in-time') supply chains, and rapid delivery (not least to end consumers).

Nonetheless there are multiple strategies for reducing emissions, and a growing consensus that the sector can reach or approach decarbonization by 2050, underpinned by a roll-out of battery and fuel-cell electric vehicles. The academic literature highlights **five broad strategies for reducing emissions**[2] each of which is considered in this briefing. Achieving full decarbonization likely implies a combination of these strategies, not only the deployment of zero-emissions drive-power technologies.

There are several reasons why multiple other approaches are needed as well as cleaner vehicles. There are significant levels of embodied carbon in vehicles and infrastructures, many competing demands for carbon-free electricity, and other undesirable impacts of road-freight such as congestion, severance, noise, road damage, and other pollution from engines, tyres and brakes. For example, road freight currently generates around 60% of health-threatening particulate and nitrogen dioxide pollution from vehicles, despite only accounting for around 10% of road vehicles.[3] All of these imply that more efficient systems and even reduced overall volumes may be necessary alongside cleaner vehicles to achieve decarbonization in economic and socially acceptable ways.

Our research and stakeholder deliberations highlighted the importance of social issues in any efforts to decarbonize road freight. The desire for a just transition which respects both workers in the industry, and the communities it both serves and impacts, come through clearly.

Contributions to decarbonization

This section summarizes each of the five broad strategies for decarbonization. As already noted, none of them can be expected to achieve full decarbonization alone.

(1) Reducing demand for freight

Measures to reduce demand include both deliberate efforts to restructure economies towards wellbeing and service delivery, with lowered material consumption (sometimes described as ***'degrowth'***), and measures to reduce the input of raw materials and energy into the economy, particularly through reuse and recycling (typically called ***'circular economy'*** but also including concepts of industrial ecology and economic localisation, and often making use of new technologies such as additive manufacturing, 3-D printing, digitisation and virtualisation).

Such tools are reliant on national (or even international) policy measures, and will likely appear nebulous from the perspective of haulage operators or local communities. They are very large scale, relatively long-term, and dependent on decisions outside of any one locality or 'node' (such as a single port). Nonetheless they are gaining traction in some polities. For instance, both the EU and China have established growing bodies of policy to promote circular economies[4] which could have profound impacts on the flow of resources, and the location of manufacturing, with more localised manufacturing based on recovered, recycled and reprocessed materials.

Circular economies might mean less bulk transport of raw materials, but also more shorter distance transport of recovered materials (which may imply a shift from rail to road transport). Lower demands for raw materials may reduce freight flows through ports, but for some products, such as steel, scrap for recycling already flows relatively long distances between nations (in the case of Liverpool, around 3 million tonnes per year of scrap steel is exported to Turkey, and a similar amount of finished steel products - coil, plate and rebar - imported).

Current structural trends towards globalisation may seem set in stone, and are assumed in most projections of freight growth. However, they arguably reflect 'underpricing' of transport (i.e. the low cost of carbon emissions) as much as they follow the possibility of off-shoring of production in low-wage, low-standard economies. If transport costs were to reflect more of the external costs of climate impacts as a result of carbon taxes, for example, this may help reverse some of these trends. However, in the UK at present there seems limited political will to increase transport costs (for example, road freight remains outside the emissions trading scheme and proposals for its extension in the coming decade) and, indeed, there is significant concern about the potential negative social and economic impacts of higher fuel costs arising from external impacts.

Nonetheless, if the 2022 Russian war in Ukraine is followed by further shocks to globalised economic systems, some localisation and circularity measures may well be pursued in the name of enhanced national (economic and/or energy) security, with a more general reduction in international material flows. Even in the absence of strategic policies for circularity or degrowth for climate reasons, nations may well consider structural reorientation of production and supply chains (slowing, or possibly even reversing trends towards just-in-time production, centralization of inventory, spatially fragmented production, and global trade and procurement) in an effort to reduce dependence on potential enemies. Indeed, there are already clear moves within supply chains to just-in-case production/warehousing and re-regionalization, though it remains unclear how profoundly this will challenge established and dominant globalized flows.

Conventional wisdom anticipates growth in demand for freight (driven by economic growth, e-commerce and expectations of rapid delivery speed).[1] In industry forecasts growth outweighs potential for modal shift, logistics optimisation and benefits of autonomous vehicles. Continued pressures for 'on-demand' delivery at the consumer end do not necessarily mean higher speeds, frequency etc… in port deliveries/dispatches – but it would seem challenging to disentangle.

It is therefore difficult to quantify the potential contribution of demand reduction measures. One study for France suggested a circular economy strategy might reduce freight volumes by 20% (although with less impact on emissions because of less carbon efficient modes for non-bulk transport of materials).[5] It is reasonable, however, to conclude not only that demand reduction could assist with decarbonization, but that twin pressures for economic security and decarbonization might shape a policy context that reduces freight demand, especially for imports; and that this in turn might cast doubt on forecasts for rapid future growth in freight volumes.

(2) Optimizing vehicle use and loading

At the other end of the scale, there are a range of tools that are largely under the control of the freight operator, or even the vehicle driver. Even when all taken together these fall far short of full decarbonization, but they could support meaningful reductions in average emissions per tonne mile of freight transport. These measures include:

- *More fuel-efficient operation*, involving driver training for lowered fuel consumption, reduced speeds, supportive digital assistance and increased vehicle automation (such as predictive cruise control). Estimates of the potential efficiency benefits vary widely; for example, from 1-10% from predictive cruise control and automated eco-driving.[1]

- *Improved logistics* with better route planning, enhanced load optimisation and reduced empty running. The potential here is large, as up to 30-50% of journeys are empty, though much of this would be very difficult to eliminate. 1-25% efficiency improvements may be possible through route and load optimisation, although customer demands for reduced delivery delays are currently *increasing* empty or part-load running.[1]

- *Regulatory and public sector interventions* could also support improved logistics. For example, the provision of sites and services for *urban consolidation centres* could help to minimise journeys into busy urban centres and help avoid congestion.[6] Logistic benefits might also be realised by greater coordination (rather than competition) between ports, to maximise the potential for rail, waterway, or even pipeline distribution of appropriate commodities.

Delivering substantial improvements through logistics and operation requires the willing cooperation of drivers. For example, reducing empty running would likely significantly increase the need for overnight absences from home or a wholesale shift to autonomous vehicles. It is unclear whether such major shifts in working conditions are possible, in the face of driver concerns about increasing digital oversight (or 'surveillance') of drivers, and the poor quality of provision of services for drivers. Although imposition of logistic and operational measures might also be stimulated by a change in the relative costs of transport, realising significant potentials would inevitably require cultural change too.

(3) Increasing the efficiency of conventional freight vehicles

Most of recent progress in the sector has been a result of improved efficiency of conventional ICE engines and vehicles. Continued improvements can be expected, but, as with past gains, much of the benefit is expected to be offset against increasing freight mileage and volumes.[7] Here we focus on vehicle efficiency gains that might be combined with a transition to electric drivetrains. These include:

- *Improved vehicle* design, especially to enhance aerodynamics. Fuel efficiency improvements of 7-15% might be achievable on new vehicles with existing technology (under new UK design rules), with lesser improvements from alterations that could be retrofitted to existing vehicles.[8] Technological improvements in aerodynamics, transmission and tyres together are variously forecast to offer between 8% and 29% emissions savings over 10-30 years.[9]

- *Autonomous (or semi-autonomous) vehicles* are anticipated to also achieve fuel efficiency savings (partly through changed driving practices, and improved informatics to reduce congestion), but particularly through *platooning on motorways*, where vehicles are digitally linked in a close driving formation, delivering efficiency improvements ranging from 8-50% for those parts of journeys where platooning is possible, according to different estimates.[10] Autonomous vehicles are also anticipated to reduce empty running necessitated by a need to get the driver to a particular location.

- *Increasing capacity* of vehicles with larger or longer trailers is estimated to offer savings of around 5% of freight miles, with significant increases in average capacity utilisation.[11] However, bridge clearances limit trailer heights on many routes.

Increasing weight limits could allow further savings (or compensate for the increased weight of battery electric vehicles), at the cost of more road damage, and greater safety risk, especially in urban areas.

Such efficiency measures could be significant and cost effective in the face of high fuel prices, but tend to involve trade-offs with other concerns such as safety or road wear; and they risk rebound effects in the absence of measures to control increasing demand.

(4) Reducing the carbon content of fuel/power

This area is attracting most current attention and investment. Currently through biofuels or other 'drop-in' fuels that can be used in existing diesel engines, but increasingly in terms of development of battery or fuel-cell electric goods vehicles.

Drop-in fuels promise an easier transition, using or modifying existing vehicles and engines (and fuel distribution services) to use biofuels, compressed or liquid natural gas (CNG, LNG) or even synfuels (potentially synthesized from CO_2 captured from the air). Increasing the proportion of biofuel blended into diesel from 8 to 20% might deliver an 8-10% decarbonisation.[12] The Port of Seattle has several demonstration trucks converted to CNG, used in container hauling service.[13] Such options, however, tend to involve at least residual emissions of CO_2 and other pollutants, or require high renewable energy or land inputs.[14]

Electrification offers much more substantial carbon gains (though carbon intensity depends on carbon intensity of electricity grid), and substantial reduction in local air pollutants, but faces multiple systemic obstacles. Vehicles and fuel distribution methods both need to change. Heavy batteries reduce vehicle load capacities, and battery vehicles at present lack the power and range for some HGV routes. Manufacturers of HGVs are heavily invested in diesel, and differentiate largely through drive-train and gearbox design configuration (which would be removed in EV drive-trains) – thus they not only fear loss from existing investments, but also fear risk to competitive differentiation.[1]

Electrification covers a variety of options, with the frontrunners being fuel-cell electric (FCEV)[15] and battery electric (BEV), with route electrification on long distance routes.[16] Freight electrification would substantially increase demand for zero-carbon electricity.[17] BEVs are beginning to penetrate markets for light and medium vehicles used in urban delivery cycles. Electric HGVs are on the market, with ranges growing, though still most suitable for more localised use (100-200 miles per day),[18] and at a capital cost three times that of diesel trucks. EVs are, however, significantly cheaper to run and maintain (especially as diesel fuel costs rise).

EVs for intensive, long-distance drive cycles with little idle time are in early development. Refuelling, recharging, and electrified road infrastructures are also very limited at present, and for vehicle operators or purchasers the competing visions of FCEV and BEV make delay a sensible choice. Real issues remain about network and complementary effects: uncertainty about viable future technologies is hampering adoption. Many anticipate competition between FCEV and BEV markets, though in practice there are likely overlapping niches for both technologies, with perhaps some degree of geographical specialization. Uptake can be expected to accelerate once complementary infrastructures are available[19] and costs low enough to meet the short payback expectations of operators (1-4 years),[20] and eventual decarbonisation is feasible, but most projections expect this transition to take decades.[21]

Fleet turnover is anticipated to take 10-30 years, in part slowed by the fear that early BEV and FCEVs will hold capital value less well than diesel trucks. Whether regulatory measures will change this equation is unknown: the UK's proposed ban on new diesel vehicles (at 2035 for MDTs under 26 tonne, and 2040 for HGVs up to 44 tonne) would not directly affect resale markets, and might even extend use of second hand vehicles, whereas enhanced carbon taxes on fuel might help curtail such use and reduce the values of older diesel vehicles, and scrappage measures could be used to directly incentivise diesel vehicle retirement. The UK Climate Change Committee recommends that vehicle and fuel taxation from the 2020s onwards should be designed to incentivise commercial operators to purchase and operate zero-emission HGVs.[22] A rebate or feebate model to incentivise zero-emission vehicles (ZEVs) purchase might be effective.

The overwhelming majority of port transfers involve heavy (or medium) duty trucks, where battery electrification implies challenges in operations, range, and infrastructures. A large-scale shift to BEV for such vehicles seems unlikely in absence of electrification of major routes, even though many journeys are within BEV ranges. In the Mersey region, BEVs would perhaps be more feasible for shorter range Freeport transfers. The Freeport plans include trialling FCEVs rather than BEVs, and an ongoing trial at Port of Los Angeles also uses FCEVs, despite the current low efficiency and high emissions associated with conventional hydrogen production.[23]

(5) Shifting freight to low carbon-intensity modes

Even with existing technology carrying freight by rail or inland waterway is less carbon intensive than by road, and can be expected to remain so until all these modes are fully decarbonized. At a European scale, potential modal shift is estimated to offer 20% carbon savings by 2030, although some scholars suggest that possibilities here are typically underestimated by policy makers.[24] Opportunities for modal shift tend to require substantial investments to improve, or establish, appropriate infrastructures for transport and transhipment. As well as rail or canal improvements and extensions, pipelines might be constructed for some commodities, and schemes for magnetic freight distribution tunnels in cities have been proposed.[25]

The key operational and cost issue with modal shift is the trade-off between additional transhipments and distance. Most destinations are no longer on railways or waterways, so using these modes from a port implies an additional transhipment to road for the final delivery.[26] This can be justified in cost terms if the overall distance is long enough (which is more often the case on continental Europe or US than in the UK). However, the rising costs of road fuel is changing this equation; for example, making container shipments to the Midlands by rail viable from PoL as well as shipments to Scotland's central belt. Despite recent dualling of the rail-track access to the Port, the direct rail link to PoL Sefton remains constrained (physically and in terms of scheduling), making additional modal shift more challenging.

On the other hand, Mersey Maritime estimates that 'only 5%' of the freight capacity of the Estuary (and its links to the Manchester Ship canal) is currently utilised. But use of the ship canal by larger vessels is constrained by the need to open road bridges to allow ship passage. Moreover, most of the shipping into the Port of Liverpool is deep water vessels that can't even reach the Garston freight terminal and railhead. So transhipment at the port into low-profile vessels (perhaps (semi)autonomous electric barges) would be needed to utilise this capacity, and further transhipment facilities in Manchester or at some interim exchange point.

A note on offsetting
Net-Zero presumes some residual emissions 'offset' by removals. The description of heavy freight as 'hard-to-abate' is (in effect) a political claim for access to removal offsets to counterbalance residual emissions in 2050. However, the UK Committee on Climate Change figures suggest very little residual for heavy freight (perhaps 2MtCO2e in 2050 – for HGVs and rail combined, implying at least 90% reduction in HGV emissions through adoption of battery or fuel cell technologies). We do not, therefore, consider offsetting as relevant to policy choices today.

Policy and action in context

In this section we briefly examine issues arising in considering freight decarbonisation both in the specific context of Sefton and the region, and in the context of wider concerns regarding the industry.

Environmental justice
Complete decarbonization through a mix of reduced freight volumes, modal shift and electric vehicles could deliver major local environmental benefits also by 2050, but during the gradual process, environmental injustice in the form of severe socially mal-distributed impacts on health and wellbeing from pollution, disruption and severance would persist in places like Sefton. Heavy and medium goods vehicles make a disproportionate contribution to particulate and NOx pollution, with particularly elevated impacts on populations around warehouses and other transhipment facilities such as ports.[27] In most cases these effects add to the already disproportionate pollution load, and effects of noise and community severance borne by poorer communities. These burdens might be ameliorated through use of clean-air zone regulations, graduated vehicle charging, and time-limits to access. Communities would likely also welcome some form of compensatory or reparatory measures (from double-glazing against noise, to community facilities, perhaps paid for by HGV tolls or road charging). Of course, such measures would not legitimate continued pollution and disruption.

Fleet standards, new vehicle standards and future-dated bans on diesel vehicles all can help drive decarbonization, but none will transform the on-road fleet swiftly. Current mandates would ban new diesel HGVs in the UK from 2040; EU rules require the average new vehicle to be 15% lower emitting by 2025 (which does *not* mean that 15% of new vehicles will be ZEVs once other efficiency gains or fuel-switching is taken into account). By contrast, California's Advanced Clean Trucks rule, mandates that by 2025, 7% of HDTs sold must be zero-emission, rising to 40% by 2035. Even at best, such rules imply that most vehicles on the road will likely remain polluting until after 2040.[28] With optimistic assumptions of 20% vehicle turnover,[29] no fleet growth, and all the required improvement met by ZEVs, even by 2040, only 45% of the fleet would be ZEVs.

Location, location

Focusing interventions on a particular area or corridor can accelerate the improvements, and have wider synergies for the overall transition. Many operators seek to meet the highest standards or requirements within the territory they cover. City scale or regional initiatives such as clean air mandates requiring lower emission vehicles can therefore have snowball effects. For example, the Californian approach typically has wide leverage across all US markets, currently favouring BEVs.[30] Even localised rules can have multiplier effects: in southern California warehouses are now subject to low emissions standards that incentivise wider uptake of ZEVs. The North-West regional 'distribution economy' involves lots of warehousing and distribution centres well within range for BEVs from the Port of Liverpool. In addition, regionally targeted interventions could aim to also improve logistics efficiency and load optimisation on these routes.

A concentrated source / flow of HGVs offers particular scope for measures targeting a corridor or a hub. Along a corridor there may be potential for more ambitious measures, such as road electrification, variable vehicle charging or even replacement with a local transfer system – such as a container gondola (or aerial ropeway) to a motorway-based hub.[31] Hubs and clusters offer possibilities for accelerating ZEV uptake through localised roll-out of refuelling or charging infrastructures (ideally linked to good driver facilities). The Freeport plans to trial FCEVs could be a foundation for a regional cluster (although it is not clear what the Freeport will mean for levels of local traffic). The Freeport mode of operation could mean that less freight heads out of the region (lowering flows), or more movements between the different locations within the Freeport (increasing flows).

'Just transition'

It is important to take into account the potentially negative consequences for workers and communities from the rapid transformation to net-zero and the fairness of the distribution of its costs; concerns that are sometimes labelled as issues of 'just transition'. [32] Decarbonization is less of an existential threat to the freight industry and its jobs than it is to oil and gas production, although as previously noted, reduced freight volumes through localization and greater circularity may be an essential part of the transition. However, current working conditions are often challenging, facilities for drivers are poor quality and scarce, and vehicle automation threatens both the amount and quality of work available. And in the UK the industry and workers face severe pressures from Brexit, Covid, and the effects of the war in Ukraine on costs and supply chains. There are good reasons, therefore, for considering employment conditions and worker welfare as part of the goal, as envisaged by ideas of 'just transition' for economic changes driven by climate goals. Strategic interventions must therefore consider cross-cutting issues around both driver and freight operator interests as well as communities.[33]

Decision-making authority
Clearly many of the interventions foreseen here are outwith control of the locality, and the whole 'package' of measures likely needed is not in the gift of any one specific actor or role. Our stakeholder group focused on short- and medium-term measures such as modal shift and logistics /vehicle use optimisation which might be influenced regionally/locally, even largely through agreement with port operators. In the existing local circumstances of a constrained corridor, port aspirations to increase throughput, existence of ship canal, and threat of loss of green space to new road, measures such as degrowth/circularity, and even vehicle technologies are likely to require interventions at a different (national/ international) scale. Nonetheless this review has identified ways in which local interventions could reinforce and synergise with larger decarbonization goals. A critical opportunity might be to establish a new intermodal hub where the ship canal and/or motorway network intersect with other modes (and potentially also providing an urban consolidation centre serving (parts of) the Liverpool City Region), with attractive facilities for ZEVs (e.g. charging infrastructures) and drivers.

Conclusions: Implications for policy makers

There's no silver bullet: delivering decarbonization with community benefits will take a mix of interventions, evolving over time. However, it would be wise to *anticipate an earlier tipping point* than typically suggested in the wider literature (published before the Russian invasion of Ukraine).[34]

We would also suggest that *presumptions of ever-increasing freight volumes are implausible* in a decarbonizing (and post-Ukraine crisis) world. Interventions that maximize environmental, social and economic benefits of reducing vehicle and freight volumes will be an essential part of the policy toolbox.

Policy choices are likely to have bigger impact than technology choices on overall speed of transition, and infrastructures and policy support for both battery and fuel cell vehicles will likely be needed. *Regional measures can lead or even drive national change*. How regional actors exploit *key opportunities to use hubs and corridors* to lead or drive decarbonization change will likely significantly affect future regional success.

The market alone *(consumer demand) will not drive necessary change*, even with rising fuel prices and as 'scope 3 emissions' reporting increasingly spreads pressure to decarbonize across supply chains. The road freight market is cost sensitive, and little impacted by greener consumer demand – so we can expect only limited voluntary uptake of more expensive, lower emission vehicles. By contrast *the market is heavily driven by regulatory standards*, which are critical to driving finance markets to support new technology procurement.[35] Regional policy tools to drive uptake such as low emissions zones or variable charging will impact on how vehicles are deployed, and thus the relative vehicle mix in any given location. *Nor will carbon prices alone drive adequate change*[36] and particularly will not be able to deliver socially equitable outcomes.

Aiming for decarbonization need not preclude interim measures to reduce carbon intensity – but with care to *address issues of asset life and complementary infrastructures* in ways that avoid risk of lock-in. *Targeted measures to reduce traffic and speed decarbonization will be essential to overcome environmental injustices* of geographically concentrated harms faced by specific (and generally disadvantaged) communities. *New road capacity should be considered a last resort* after measures to address logistics optimisation, modal shift and demand reduction.

Method

This brief outline is based on a rapid review of the academic literature using Google Scholar and Google search for professional and grey literature sources.

Jargon and acronyms

HGV = heavy goods vehicle, also HDT Heavy Duty Truck, gross weight over 15 tonnes
MDT = medium duty truck (gross weight 3.5-15 tonnes)
LCV = light commercial vehicle (under 3.5 tonnes) – not generally relevant to this study.
BEV = Battery Electric Vehicle
FCEV = Fuel Cell Electric Vehicle
(P)HEV = (Plug-in) Hybrid Electric Vehicle
EV = Electric Vehicle
ZEV = zero-emissions vehicle
CCS = carbon capture and storage
Duty cycle = pattern of usage of a vehicle (how much it is used per day)
Drive cycle = how a vehicle is used (speed/power loading vs time)
LNG = Liquid Natural Gas
CNG = Compressed Natural Gas
ICE = Internal combustion engine

Notes and References

[1] Shell and Deloitte (2021) *Decarbonising Road Freight: Getting into Gear*. Available at https://www.shell.com/energy-and-innovation/the-energy-future/decarbonising-road-freight.html

[2] Lynn H Kaack *et al* 2018 *Environ. Res. Lett.* 13 083001 Decarbonizing intraregional freight systems with a focus on modal shift. Alan McKinnon, 2016. https://www.the-klu.org/fileadmin/the-klu.org/media/klu_experience/article/170223_McKinnon_Freight_in_a_Low_Carbon_World.pdf

[3] Particulates from brakes and tyres are increasingly dominant as exhausts become cleaner. Such emissions would be reduced from EVs with regenerative braking (because of no or less use of brake pads), but increased by increased vehicle (although weight may not increase in FCEVs vs BEVs) See: Leach et al 2020 The scope for improving the efficiency and environmental impact of internal combustion engines https://www.sciencedirect.com/science/article/pii/S2666691X20300063.

[4] EU Circular Economy Action Plan at https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en; China's Development Plan for the Circular Economy outlined at https://www.china-briefing.com/news/chinas-circular-economy-understanding-the-new-five-year-plan/

[5] Dente and Tavasszy 2018. Impacts of trade related sustainability strategies on freight transportation. https://www.sciencedirect.com/science/article/abs/pii/S1361920917303061

[6] Climate Change Committee, https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

[7] Shell & Deloitte (ref 1); and US 21st Century Truck Partnership https://www.energy.gov/sites/default/files/2019/02/f59/21CTPResearchBlueprint2019_FINAL.pdf

[8] Shell & Deloitte (ref 1) suggest a similar range 6-14% for aerodynamics, plus a further 1-9% for improved tyres and wheels.

[9] US analysis suggests potential (over 30 years) for 5% savings from transmission improvements, 8% from aerodynamics, 8% from tyres and wheels. Shell & Deloitte (ref 1) cite nearer-term figures for aerodynamics (6-14%) tyres (1-9%) and drivetrain (1-4%). Ecofys estimate a further 10-12% average efficiency improvement to be possible by 2030 (https://www.farm-europe.eu/wp-content/uploads/2019/06/Ecofys2019_Transport-decarbonisation-2030-CEE.pdf).

[10] Diverse figures cited for gains – eg 4-17% according to Shell & Deloitte (ref 1); 8-16% reduced emissions according to the European Automobile Manufacturers Association (https://www.acea.auto/files/Platooning_roadmap.pdf); 33-50% energy reductions (Hu and Bauer, 2021 -

https://www.mdpi.com/2032-6653/12/4/180); platooning possible on 65% of mileage, saving just 4% of total fuel (US DoE: https://www.energy.gov/eere/articles/platooning-trucks-cut-cost-and-improve-efficiency).

[11] Based on trials of longer semi-trailers (up to 15.6 m, within the 44 tonne gross limit). See https://tigertrailers.co.uk/road-transport-hub/longer-semi-lst-trials/.

[12] EU estimates from Ecofys report (ref 8). But land availability makes this an unlikely route in practice.

[13] See Khanna, N. *et al.* Near and long-term perspectives on strategies to decarbonize China's heavy-duty trucks through 2050. *Sci Rep* **11**, 20414 (2021). https://doi.org/10.1038/s41598-021-99715-w and for the Seattle demonstration: https://pscleanair.gov/Blog.aspx?IID=17

[14] Natural (fossil) gas based fuels appear particularly problematic, with well to wheel GHG emissions potentially exceeding those from diesel (See Gupta et al 2020: Well-to-wheels total energy and GHG emissions of HCNG heavy-duty vehicles in China. https://www.sciencedirect.com/science/article/abs/pii/S0360319920300896?via%3Dihub; Langshaw et al Environmental and economic analysis of liquefied natural gas (LNG) for heavy goods vehicles in the UK https://www.sciencedirect.com/science/article/abs/pii/S0301421519307475?via%3Dihub).

[15] Assuming 'green' hydrogen, FCEV require up to twice the energy of BEV because of conversion losses, but offer range and refuelling time benefits. Neither BEV or FCEV would be emissions free until electricity production is zero-emissions, and hydrogen provided entirely from 'green' sources. 'Green' hydrogen is produced through electrolysis, using zero-carbon generating capacity; most hydrogen today ('grey') is produced from natural gas, with substantial emissions, and while some see potential for 'blue' hydrogen where 'carbon capture and storage' technology is applied to reduce emissions in hydrogen production, this would still not reach zero-emissions across the fuel cycle (https://www.weforum.org/agenda/2021/07/clean-energy-green-hydrogen/).

[16] Centre for Sustainable Road Freight: "Building a network of overhead catenary cables along 7,500 km of the UK's major road network would electrify approximately 65% of HGV kms, at an estimated cost of £19.3b. It is technically viable, economically attractive and could be achieved by the late 2030s." (https://www.csrf.ac.uk/2020/07/white-paper-long-haul-freight-electrification/) Overhead power is unlikely to be provided beyond motorways and major routes, but, as part of such a system, zero emissions could be maintained to and from the port as this model is not intended to enable hybrid vehicles, but to extend range of BEVs and/or reduce battery sizes/weight.

[17] Electricity needs estimated at around equal to 2017 global renewable production for BEV option, or almost twice global renewable production for FCEV routes (respectively taking 22 exajoules (EJ) and 44EJ electricity to replace the current 38EJ of diesel used) (see ref 1).

[18] Though one US company is experimenting with a 'pony express model' in which longer distances can be achieved without recharging delays by switching the loaded trailer (and its driver) to a waiting charged tractor unit at the charging station (although this inevitably implies higher capital costs, and the tractor unit is the expensive part, not the trailer)). https://www.canarymedia.com/articles/electric-vehicles/electric-heavy-duty-trucks-are-hitting-the-roads-in-california-and-beyond)

[19] According to the CCC (ref 5), for HGVs in the UK, a hydrogen-based switchover would require 800 refuelling stations and electrification would need 90,000 depot-based chargers for overnight charging.

[20] Lifespan fuel cost savings in CCC scenarios (ref 5) more than cover the increased capital costs (for HGVs they estimate a net benefit of £35 per t-CO2 saved). But operators seek rapid payback for capital costs. Based on US data, operators of 20 trucks or fewer only consider technologies with paybacks ranging from six to 36 months (averaging a year), while those operating fleets of 500 trucks or more still only consider a payback periods of 18-48 months (averaging two years) (Gross 2020 The challenge of decarbonizing heavy transport https://www.brookings.edu/wp-content/uploads/2020/09/FP_20201001_challenge_of_decarbonizing_heavy_transport.pdf)

[21] E.g. US 21st Century truck partnership (ref 6) project up to 50% fuel efficiency improvement by 2050 (through EVs and gas use).

[22] CCC (ref 5)

[23] However, current hydrogen production ('grey' hydrogen) is more carbon intensive than diesel. Lower carbon 'blue' H_2 requires speculative carbon capture and storage facilities (some of which are proposed in the NW regional HyNet scheme). Decarbonised 'green' hydrogen relies on expansion of renewable electricity generation, and while this may utilise otherwise curtailed wind power, it will likely also require dedicated electricity supplies to be economic. Reducing emissions in hydrogen production would be supported by further improvements in hydrolysis efficiency: currently conversion of electricity to hydrogen (and back) is 50-75% efficient, although cutting edge innovative methods claim up to 95% efficiency.

[24] Ecofys (ref 8); Kaack et al (ref 2).

[25] See eg https://www.theengineer.co.uk/magnetic-freight-delivery-system/ - oriented to consumer/retail scale crates / pallets / totes (90cm diameter pipes) https://www.bbc.com/future/article/20120601-high-speed-pipedreams and https://www.lowtechmagazine.com/2011/01/aerial-ropeways-automatic-cargo-transport.html.

[26] A notable exception for the Port of Liverpool is the rail link to Drax power station, which enables shipment of large volumes of imported wood chips by rail.

[27] In the US, EPA figures show these 10% of vehicles generate 60% of particulate and NOx pollution. New rules in Southern California impose duties on warehouse operators to reduce trucking emissions https://www.aqmd.gov/docs/default-source/news-archive/2021/board-adopts-waisr-may7-2021.pdf.

[28] If we assume a 10-20% annual stock turnover, in the first year max 1.5-3% of the vehicles will be zero emission. By 2030 max 9-18% would be (assuming the 2030 target for 30% emissions reduction were also met by increasing ZEV penetration). Even the ban on diesel HGV sales anticipated for 2040 would then only slowly transform the remainder of the fleet for the 2050 target year. This does mean that past improvements, in diesel efficiency for example, are still working their way through the existing fleet, and will contribute to reducing emissions intensity – but also to meeting of future targets based on emissions intensity – potentially slowing penetration of more expensive zero-emissions options.

[29] Turnover rates may actually fall: Shell & Deloitte (ref 1) suggest that regulatory pressures might lead to asset sweating, as resale values of older trucks fall (slowing the transition, but possibly also slowing growth in the overall fleet size).

[30] There is a risk of 'environmental dumping' in areas with poor standards, but this is less acute for vehicles which move across the region (and should meet standards at all points in their journeys) than with point-source polluting facilities.

[31] See: https://www.lowtechmagazine.com/2011/01/aerial-ropeways-automatic-cargo-transport.html

[32] See for example P. Newell and D. Mulvaney, The political economy of the 'just transition' *The Geographical Journal* 2013 Vol. 179(2).

[33] Especially regarding small operator challenges: Gross (ref 19): "In the United States, a strong majority of trucks are owned by companies that operate 20 trucks or fewer. In Asia, nearly 90% of trucks are owned by individual drivers. Smaller companies are less able to take risks on new technology or provide dedicated refuelling infrastructure, and they have less access to capital to cover up-front costs of trucks and changing technology. Smaller companies are also less likely to face public pressure to take the lead in new technology, since they are not household names and are often privately owned, and thus do not face pressure from shareholders or investors. Smaller companies operate in a competitive market with thin margins."

[34] Even before that, Shell & Deloitte suggested that "Road freight decarbonisation is close to an inflection point due to increasing regulatory and market pressure, and will evolve faster than many expect." (ref 1).

[35] Current standards fall far short of decarbonisation (Shell & Deloitte, ref 1). Where there is end-use consumer demand for greener shipping, it may well be diverted unproductively into carbon offsetting (as seen in coach and air travel).

[36] Econometric modelling finds transport remains dominated by liquid fuels even in 2050, despite high carbon and fuel prices Pietzcker et al 2014. Long-Term Transport Energy Demand and Climate Policy: Alternative Visions on Transport Decarbonization in Energy Economy Models. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2214812