Hydrogen technology is unlikely to play a major role in sustainable road transport

Standfirst: Technical and economic developments in battery and fast charging technologies could soon make fuel cell electric vehicles, which run on hydrogen, superfluous in road transport.

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Road transport remains dominated by fossil fuels. Transport is responsible for about one quarter of all energy-related greenhouse gas emissions and about 72% of this is due to road transport[1]. However, the emissions budgets implied by the Paris Agreement mean that transport should be climate neutral — that is, it should have net zero greenhouse gas emissions — within just a few decades[2-4]. Urgent action is thus needed, and stock turnover in road transport is slow[2].

Non-technological changes, including a reduction in travel (due to, for example, working from home) and a shift to more sustainable modes of transport (such as rail and bikes), can and — should — contribute to greenhouse gas emission reduction in road transport. However, their role will be limited as behavioural change at the massive scale required is slow[2,4] and almost all advanced economies are trapped in car-dependent systems[5].

Luckily, technologies that offer low carbon road transport are under development or are already commercially available. These technologies include battery electric vehicles (which use electricity directly), plug-in hybrid vehicles (which combine a battery and electric motor with a fuel tank and a combustion engine), and fuel cell electric vehicles (which use a fuel cell to convert hydrogen to electricity), as well as vehicles that use biofuels and synthetic renewable fuels. The various options are at different stages of commercialisation and the role of each in a future sustainable road transport system is a matter of debate[6]. However, the urgency of the climate crisis forces us to choose between these technologies now, despite the uncertainty. Electricity and hydrogen are the two key energy carriers for a low-carbon future, and hydrogen will play a vital role in industry, shipping, and synthetic aviation fuels. But for road transport, we cannot, I believe, wait for hydrogen technology to catch-up and our focus now should be on battery electric vehicles in both passenger and freight transport.

Cars

At the beginning of 2021, there were about 25,000 hydrogen fuel cell cars in stock globally, and more than 90 % of such vehicles are located in only four countries: Korea, the US, China, and Japan[7]. Currently, only two passenger fuel cell car models are available from global manufacturers. Fuel cell electric vehicles also cannot be fuelled at home and need hydrogen refuelling stations; about 540 hydrogen stations are in operation globally.

In contrast, by the beginning of 2022, there are likely to be about fifteen million battery electric and plug-in hybrid vehicles on the road across the world[7]. Almost all manufacturers now sell such vehicles, with more than 350 models available globally. Battery electric vehicles get their electricity from charging via the grid. For users without a home charging option, and for long-distance travel, charging at publicly accessible chargers is essential. In 2020, about 1.3 million public chargers were in operation globally, with about one quarter fast chargers (at least 22 kW power)[7]. More recently, charge point operators have started to construct high power fast chargers with more than 150 kW, typically up to 300 kW (with more than 800 charge points at 300 kW in operation in Europe already)[8].

When battery electric vehicles had limited range of under 150 km, and charging took a few hours, there was an important and large market segment for fuel cell vehicles: long-distance travel. The higher energy density of compressed hydrogen, compared with battery electric vehicles, and the ability to refuel within only a few minutes, made fuel cell vehicles potentially ideal for frequent long-distance trips. But battery electric vehicles now offer about 400 km real world range and the newest generation use 800 V batteries, which can be charged for a range of 200 km in about 15 min.

Many of the ongoing investments in hydrogen cars appear to follow the sunk cost fallacy: we have already spent so much on this technology, let's not give up now. But with economies of scale in full effect for batteries, and with further cost reductions and performance improvement of electric vehicles and charging infrastructure coming, fuel cell cars are highly unlikely to be able to compete.

Trucks

Zero emission trucks are in a much earlier market phase than zero emission passenger cars, lagging about ten years behind. There are around 30,000 battery electric trucks in stock globally[7], and more than 90 % of these are in China. There is also currently no dedicated infrastructure for zero emission trucks. Compared to passenger cars, the large batteries of trucks require higher charging power for a full recharge, though existing fast chargers can be used for battery electric trucks if the size of the parking is sufficient to fit the vehicle. Fuel cell electric trucks, on the other hand, have only been operated in test trials (from two manufacturers) to date and are not yet commercially available.

Stimulated by ambitious carbon dioxide reduction targets for heavy-duty vehicles[2], many manufacturers have announced new electric truck models: over 100 models have been announced for medium freight trucks (3.5–12 tonnes gross vehicle weight) and over 50 models for heavy freight trucks (more than 12 tonnes gross vehicle weight)[7]. These trucks will essentially be the first generation of battery electric trucks, and have proposed ranges of 250 km in medium freight and 300–350 km range in heavy freight trucks[7,9].

This first generation of battery electric trucks can be used for urban delivery with limited vehicle weight and load, as well as annual distances of up to 50,000 km (Fig. 1). The current challenge for battery electric vehicles is long-haul logistic operation (with an average of 100,000 km per year) and transport of very heavy goods (which implies high energy consumption per km). This is the use case often discussed for hydrogen trucks. Several truck manufacturers, as well as fuel cell and infrastructure providers, have joined forces and announced a target of 100,000 fuel cell trucks on European roads by 2030[10], but this appears very unlikely when contrasted with announcements from the companies about the earliest start date for production of commercial series fuel cell electric trucks being in 2027. By that time, the second generation battery electric vehicles will already be commercially available and in operation.

Despite the potential for future reductions in battery costs and increases in energy density, long-haul operation, which could mean more than 500 km per day, poses a challenge for heavy battery electric trucks. However, driving regulations in Europe allow only 4.5 hours of driving followed by a compulsory resting time of at least 45 min. Within 4.5 hours, a heavy truck could travel up to around 400 km and thus practical ranges of about 450 km would suffice, if high power fast charging for battery electric vehicles was widely available.

Charging 400 km in 45 min for a heavy truck means about 800 kW average charging power. The current fast charging standard (the combined charging system) allows up to 350 kW. But a new megawatt charging system standard is under development, which should allow over 2 MW charging; specifications are expected for the end of 2022, with a final standard in 2023. Truck manufacturers are pushing for the construction of a megawatt charger network in Europe and potential locations for fast chargers have been proposed[11]. A draft infrastructure proposal in Europe has suggested that high power chargers every 50 km along the main highway network are required (Fig. 2)[12,13]. Electric road systems — in which trucks are charged via overhead lines or in-road power while driving along the highway — are also being tested on public roads in Europe and could support long-distance battery electric truck operation on major highways, with no need to charge during rest times[14].

Costs

Wider discussions about future energy technologies often focus on questions of what is technically possible[15,16], rather than the costs associated with a technology. This is often misleading, as in many historical cases costs were key, not the technical properties. And technological development and cost reduction potentials are frequently underestimated. For example, there are currently no technical issues that stop a battery electric vehicle with a 1000 km range being built: just put numerous battery cells into the vehicle. But current battery costs would make it an expensive vehicle to purchase. In the long term, costs are decisive.

Studies have suggested that the total costs of ownership for fuel cell electric trucks would be higher than for battery electric trucks with megawatt charging[17-19]. The logistics sector is highly cost driven, and thus battery vehicles are likely to dominate even if fuel cell vehicles became widely available. In regard to infrastructure, it is not clear yet whether hydrogen or megawatt charging will have total lower costs.

There are applications with very high energy demands or low cost sensitivities, such as really heavy transport in remote areas or the transport of oversized and extremely heavy goods. Here, the transport task must be completed almost irrespective of the operating cost. But the question remains: are such niche areas large enough to sustain the commercialisation and economies of scale required to produce fuel cell electric trucks and their infrastructure? Depending on the specific size of the niche, biofuels or renewable synthetic fuels might be sufficient after 2030 to operate the application with carbon neutrally.

Outlook

The energy transition needs hydrogen and there are many relevant applications beyond road transport, including aviation, shipping, and steel making. But the window of opportunity to establish a relevant market share for hydrogen cars is as good as closed. For trucks, operating costs are more important than for cars, making the use case for fuel cell electric trucks even smaller. If truck manufacturers do not start mass production of fuel cell trucks soon to reduce costs, such vehicles will never succeed in low carbon road transport. Policy makers and industry need to decide quickly whether the fuel cell electric truck niche is large enough to sustain further hydrogen technology development, or whether it is time to cut their losses and focus efforts elsewhere.

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Competing interests

The author declares no competing interests.

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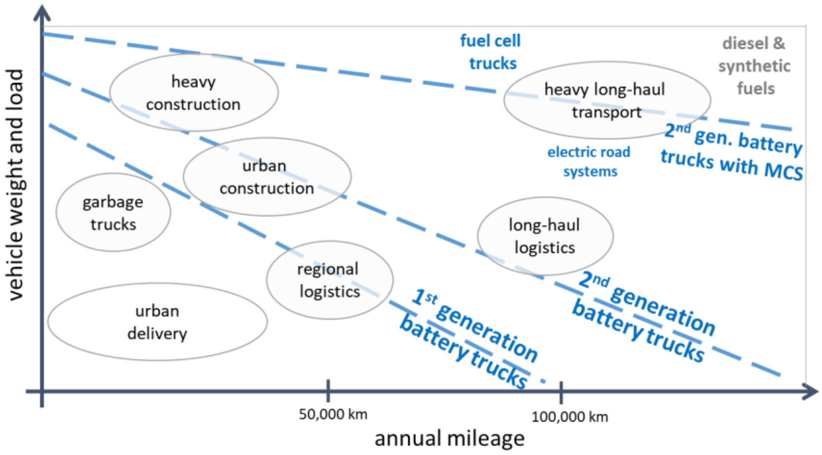

Figure 1. Freight segments and potential applications for zero emission trucks. The different applications of trucks are arranged according to annual mileage and vehicle weight and load. The centre of the ovals indicates the typical annual mileage and weight for each given heavy-duty vehicle application. The dashed lines indicate the mileage and weight combinations that are feasible with different truck technologies (first generation battery trucks, second generation battery trucks and second generation battery trucks with megawatt charging systems; MCS). The maximal capabilities of trucks powered by hydrogen fuel cells, and diesel or synthetic fuels are also indicated, as well as electric road systems. Figure based on information in ref. 9 and 20.

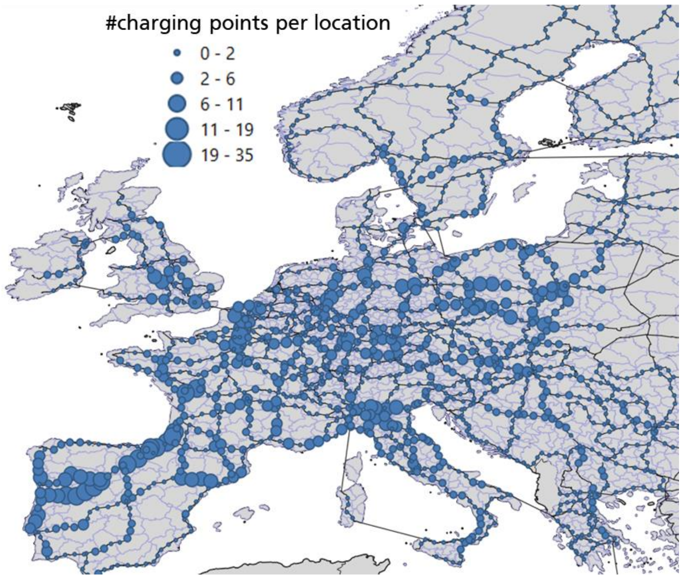

Figure 2. Proposed megawatt charging station locations for trucks in Europe. The map shows a potential public megawatt charging station network with stations located along the main European motorways at 50 km intervals. The size of the circles indicates the number of megawatt chargers that might be required at each location by 2030 or shortly after — depending on the future share of battery electric trucks. Figure taken from ref 21.