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# INTERN REPORT: How does the type of vehicle impact on whether hydrogen fuel cell EVs are better than battery EVs?

## Author:

OPMCSA - Intern - Odile Smits


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# How does the type of vehicle impact on whether hydrogen fuel cell EVs are better than battery EVs?

Odile Smits

Intern with the Office of the Prime Minister's Chief Science Advisor

Transport is a major contributor to greenhouse gas emissions. In 2017, road transport was responsible for 14.5 kT $CO_2$-e, or 17.5% of New Zealand's total emissions, up from 7.5kT in 1990.

One of the key ways to reduce these emissions is to replace the internal combustion engine fleet with more sustainable alternatives. Battery electric (BEV) or hydrogen fuel cell electric vehicles (FCEV) (Figure 1) both offer significant opportunities reduce $CO_2$ emissions from New Zealand's road transport network.

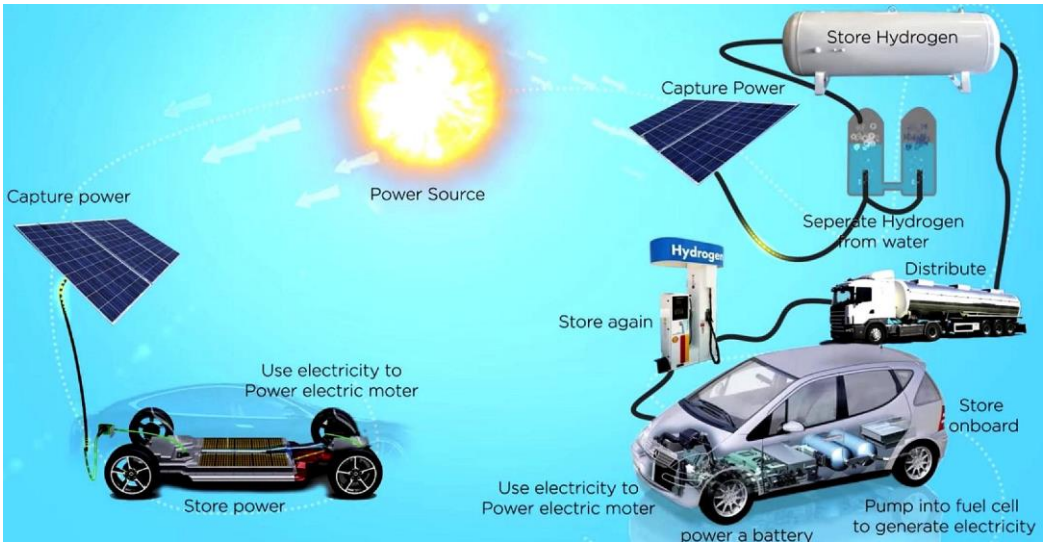


***Figure 1:*** *Left, power mechanism of battery electric vehicle. Right, power mechanism of hydrogen fuel-cell electric vehicle (Image: [www.aveq.ca](http://www.aveq.ca)).*

The different characteristics of the two types of electric vehicles makes them suitable for use in different parts of the vehicle fleet.

Hydrogen vehicles are limited by the current lack of fuelling stations and higher fuel cost. The disadvantages of battery electric vehicles are the long refuelling times, relatively short travel distance per fill, and weight of the battery.

Although battery electric vehicles have a low carbon emission during use, the energy required to produce the vehicle, especially the battery, makes a significant contribution to the carbon intensity.

This report examines the advantages and disadvantages of battery electric vehicles and fuel cell vehicles for different parts of New Zealand's fleet and does some high-level modelling on their impact on fuel use and carbon emissions at different levels of adoption.

## Passenger Vehicles

Worldwide both battery electric passenger vehicles (BEPV) and fuel-cell electric passenger vehicles (FCEPV) are gaining popularity.

The number of electric and plug-in hybrid cars on the world's roads exceeded 3 million in 2017. In New Zealand, electric vehicles have increased in popularity over the last few years; there are around 20,000 currently in use.[1]

*Table 1. Advantages and Disadvantages of battery electric and fuel cell vehicles as light passenger transport.*

| **Passenger Vehicles** | | |
|---|---|---|
| | Battery Electric | Fuel-cell Electric |
| Vehicle - cost | | **Vehicle is expensive**: Also a HEPV itself is still considerably more expensive than a non-luxury BEPV. (Nissan Leaf: $30,000 – $45,000 USD, Toyota Mirai: $60,000 USD.) |
| Vehicle - availability | | |
| Fuel - cost | **Low cost of driving:** BEV's are, with current electricity and approximate hydrogen prices, cheaper to run than hydrogen electric vehicles. (See the WTW analysis in the second part of this report.) | **Hydrogen is expensive**: Hydrogen fuel is currently expensive, making it more costly to drive a HEV than a BEV. (This is calculated in the next section) |
| Fuel - refuel time | **Charging time**: Recharging with a domestic plug into a regular household socket takes 8-to-10 hours. It is possible to have a charging station for domestic electric vehicles installed at your home, for which recharging takes 4-to-6 hours. | |
| Infrastructure | **Rapid charging stations**: Most BEPVs are limited to driving a short distance range. However, as of Jan 2020 there are already over 200 DC rapid charging stations in New Zealand for passenger vehicles.[2] DC fast charging can charge some EVs to 80 percent in 20-30 minutes. | **Lack of infrastructure**: The lack of infrastructure makes it currently impossible to own a hydrogen passenger vehicle. If hydrogen passenger vehicles were to be introduced, hydrogen refueling stations would need to be built over the entire country. |
| Range | **Driving range**: Nissan Leaf BEV's have a relative short range, approximately 350 km.[3] If fast charging stations would be installed, this disadvantage would be less problematic. Longer range electric cars are also available, but are costly relative to the Nissan Leaf.[4] For example, the Tesla Model S has a driving range up to 600 km.[5] | **Driving range**: FCEPVs have a driving range similar to passenger vehicles with a combustion engine. For example, the Toyota Mirai has a range of 500 km. |
| Other | **Limited battery lifetime**: The battery expects to last for 10 years and a new battery is expensive. The battery of the Nissan Leaf is $5,500 USD plus installation. | |

[1] https://www.transport.govt.nz/mot-resources/vehicle-fleet-statistics/monthly-electric-and-hybrid-light-vehicle-registrations/

[2] https://www.leadingthecharge.org.nz/charging-sites

[3] https://www.nissanusa.com/vehicles/electric-cars/leaf/features/range-charging-battery.html

[4] https://www.edfenergy.com/electric-cars/longest-range

[5] https://www.tesla.com/blog/longest-range-electric-vehicle-now-goes-even-farther

## Trains

Currently all trains obtain their power from diesel or drive on electricity, which is directly supplied by overhead powerlines, with the exception of a few hydrogen fuel-cell (HF) trains;

- Germany has had two commuter trains in active service since 2018, with another 14 to be delivered in 2021.[6]
- Britain plans to become one of the next countries to start running them, their first hydrogen train is being tested by HydroFlex with the goal to carrying passengers in two to three years.[7]
- Recently (December 2019) it was announced that hydrogen trains will be developed in Poland.[8]

The national rail service in New Zealand, KiwiRail, is wholly owned by the Crown. KiwiRail owns 198 mainline locomotives and 4,585 freight wagons and carries approximately 15 percent of freight moved in New Zealand.[9] The commuter trains operate on electricity and the intercity freight trains run on diesel. Considering the advantages of HF trains as laid out in the table, hydrogen shows to be a strong candidate as an alternative for the diesel trains in New Zealand.

*Table 2. Advantages and disadvantages of overhead electric supply and fuel cell electric trains.*

| **Trains** | | |
|---|---|---|
| | Overhead electricity supply | Hydrogen fueled[10] |
| Train - cost | ? | ? |
| Train - availability | | |
| Fuel - cost | **Power supply by electricity cheaper**: Since the production of hydrogen costs more energy than producing electricity, trains that operate on electricity are environmentally more friendly to operate then hydrogen trains if the infrastructure is already present. | |
| Fuel - refuel time | | **Fast refueling:** HF trains enable operation with very short downtimes of less than 20 minutes (due to fast refueling) and are also able to withstand long operating hours of more than 18 hours without refueling. |
| Infrastructure | **No rural infrastructure**: In New Zealand, for the trains that operate outside Auckland there is no infrastructure. Therefore in order to decide if diesel powered trains should be substituted with electric or hydrogen powered trains, additional cost and building time of necessary infrastructure for electric trains also needs to be considered. | **Economical solution for New Zealand**: HF trains make economic sense above all when they are used on longer non-electrified routes of over 100 km and on routes that have very low utilisation (up to 10 trains per day). |

[6] https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train
[7] https://www.railway-technology.com/projects/hydroflex-hydrogen-train/
[8] https://www.railwaygazette.com/traction-and-rolling-stock/pesa-and-pkn-orlen-to-develop-hydrogen-fuel-cell-trains/55352.article
[9] https://transport.cwp.govt.nz/rail/rail-in-new-zealand/
[10] Shift2Rail gives a detailed discussion of the advantages of HF trains in https://shift2rail.org/publications/study-on-the-use-of-fuel-cells-and-hydrogen-in-the-railway-environment/

| | Overhead electricity supply | Hydrogen fueled[11] |
|---|---|---|
| Infrastructure - contd | | **No wayside infrastructure needed**: Since FCH trains do not rely on continuous wayside infrastructure for power supply, this fuel type is most likely economically favorable over overhead electric change in New Zealand because otherwise the entire infrastructure would still need to be built for the overhead powered electric trains. |
| Range | | |
| Other | **Battery powered trains should also be considered:** In some cases, battery-powered trains may appear as a more cost-effective option but come with operational constraints resulting from their highly route-specific tailored battery configurations. | |

## Forklifts

*Table 3. Advantages and disadvantages of battery electric and fuel cell electric forklifts.*

| **Forklifts** | | |
|---|---|---|
| | Battery Electric | Fuel Cell Electric |
| Forklift - cost | ? | **Higher initial costs:** Hydrogen forklifts are more expensive then battery-powered forklifts.[12] |
| Forklift-availability | **Availability:** Battery electric forklifts are already well developed, widely available on the market and there exists a wide range of forklifts to choose from.[13] | |
| Fuel - cost | | **Higher fuel costs:** The price of hydrogen is higher than charging a battery for the same amount of productivity.[14] |
| Fuel - refuel time | **Battery charging**: The largest disadvantage of electric forklift operating on a lead-acid battery is the battery charging. These batteries provide enough power for 5 to 6 hours of constant use but needs to be charged for 8 hours, during which time it heats up, so it must then be allowed to cool for another 8 hours. Therefore, an operation that runs 24/7 requires three batteries for each forklift. | |
| Infrastructure | **Charging stations**: Battery charging stations must be installed and these charging operations must be separated from other operations, because of the above mentioned possible acid spills. Furthermore they need a dry, ventilated, and temperature-controlled location, since batteries release oxygen and hydrogen during charging. | **Fueling stations:** One or multiple fuel stations will need to be installed, which may be distributed around the site from a central tank. There exists a possibility of hydrogen production on site. |

[11] Shift2Rail gives a detailed discussion of the advantages of HF trains in https://shift2rail.org/publications/study-on-the-use-of-fuel-cells-and-hydrogen-in-the-railway-environment/

[12] WTW hydrogen using GREET model. 15 kWh electricity use at the wheels for electric forklifts is equivalent to 1 kg H2 use for FC forklifts, https://www.energy.gov/sites/prod/files/2014/03/f9/fuel_cycle_comparison_forklifts_presentation.pdf

[13] https://hyundaiforklifts.co.nz/product.php?id=3

[14] WTW hydrogen using GREET model. 15 kWh electricity use at the wheels for electric forklifts is equivalent to 1 kg H2 use for FC forklifts, https://www.energy.gov/sites/prod/files/2014/03/f9/fuel_cycle_comparison_forklifts_presentation.pdf

| | Battery Electric | Fuel Cell Electric |
|---|---|---|
| Infrastructure - contd | **No fuel storage:** Electric forklifts charge at a charging station, hence there is no need for fuel storage. | **Fuel storage required** |
| Range | | **Uninterrupted use**: For hydrogen forklifts the time needed for battery changing is eliminated and thus allow for uninterrupted use. |
| | | **Constant voltage:** Hydrogen fuel cells deliver constant voltage until fuel tanks are depleted, in contrast to lead acid battery-powered forklifts that suffer performance degradation over the last half of the battery charge or in cold locations. |
| Other | **Acid spills**: Testing and overcharging of the battery can result in acid spills. Acid must be washed off the batteries regularly to prevent development of conductive paths that would reduce battery efficiency. | **Flammability**: Although there are no environmental concerns from acid runoff or lead, or from tailpipe emissions, the handling and storage of hydrogen on-site also has safety concerns since it is highly flammable. |
| | **Battery weight:** Heavy batteries require a special lift for changing the battery. | **Little space required:** The space required for fueling is much smaller than the space required for battery charging and storage. |
| | **Limited lifting weight**: The forklifts are limited to lifting 5,500 kg. | |

## Large vehicles: Heavy trucks and buses

Large vehicles cover a wide range of usage types. Although the weight and size for these vehicles are similar, their covered range and usage type can be very different. For example:

- Cargo trucks are primarily used over extensive periods on the highway and must be capable of carrying an additional heavy load.
- Waste collecting trucks are used locally and stop often.
- Intercity buses cover long distances on the highway
- Similar to waste collecting trucks, local buses have a continuous use on short distances and stop often.

Besides the difference in weight between passenger vehicles and heavy vehicles, the expected travel distance over a lifetime is also different. A passenger car is expected to last 240,000-320,000 km whereas a Class 8 truck is expected to travel 1,600,000 km over its lifetime.

### Current state of hydrogen heavy vehicles

Hyundai has equipped its trucks with two hydrogen fuel-cell stacks driving electric motors. The motors are 190 kW system with a range of around 400 km, depending on the load. There are eight large hydrogen tanks, mainly between the cabin and the rigid body. The first of Hyundai's hydrogen fuel cell-powered, heavy duty trucks will be put to work in 2020 on the roads of Switzerland which is part of an order for 1,600 trucks that will be delivered between January 2020 and 2025.[15] The vehicles will be leased out through Hyundai Hydrogen Mobility, which is a combination of refueling stations, logistics and transport companies.[16]

[15] https://www.hyundai.co.nz/hyundai-motor-and-h2-energy-to-bring-the-world-s-first-fleet-of-fuel-cell-electric-trucks-into-commercial-operation-

[16] https://hyundai-hm.com/en/

Nikola Motors, the start-up Arizona-based American manufacturer**,** produces a Class 8 rig, which is expected to retail for USD $375,000 when it goes into production in 2022.[17] (Compared with $180,000 for the all-electric Tesla Semi with a 500-mile range and a comparable diesel truck sells for about $120,000).

## Current state of battery electric heavy vehicles

The BYD T8 truck, a truck meant for waste collection, is equipped with 2 packs of batteries with a capacity of 175 kWh each. The BYD T8 has a maximum speed of 85 km/h, and a range of 300 km with a charging time of 4 hours.[18]

*Table 4: Advantages and disadvantages of battery electric and fuel cell electric heavy vehicles.*

| **Electric Heavy Vehicles** | | |
|---|---|---|
| | **Battery Electric** | **Fuel Cell Electric** |
| Heavy vehicle - cost | | |
| Heavy vehicle - availability | | |
| Fuel - cost | | |
| Fuel - refuel time | **Long charging time:** The BYD truck needs around 4 hours of charging. | **Fast refueling:** Fast refueling of the hydrogen is a great advantage for heavy vehicles that are continuously used. |
| Infrastructure | | **Few stations needed on specified routes:** The problem that remains the lack of refueling stations. However this might be less problematic for these type of vehicles. For example, buses that start from the same place, or travel through the same location or are parked at the same location when not in use (i.e. most of Auckland public transport buses have the city center as one of their destinations), a few stations could serve a large amount of buses. Ports of Auckland has recently applied for consent to build Auckland's first hydrogen production and refueling facility at its Waitemata port which can facilitate the fueling of trucks that travel in close vicinity to the port. |

[17] https://nikolamotor.com/motor

[18] http://www.byd.com/en/news/2019-09-29/BYD-Delivers-to-Rio-de-Janeiro-the-Largest-Fleet-of-Electric-Waste-Trucks-Outside-of-China

| | Battery Electric | Fuel Cell Electric |
|---|---|---|
| Range | **Short range**: The range of BET is limited to 400 km with current battery technologies and weight limits (however, claims have been made that batteries have been developed with technology that could double the range).[19] BET are therefore not suitable for heavy duty trucks that cover large distances. | **Energy density of hydrogen**: Hydrogen has a more than 200 times greater energy per kilogram than Lithium-ion batteries. Therefore hydrogen fuel cell electric trucks have a significant weight and space saving as increasing the range does not require a large increase in the energy storage size and or mass. |
| | **Large battery needed:** A fully electric long-haul truck would require a large and heavy battery that would be needed for supplying enough power. Such a battery takes over a large part of the cargo space and cargo total weight. | |
| Other | **Waste collection trucks may be conveniently powered by batteries:** Around 10 waste collection trucks, provided by BYD, a Chinese automotive company, are operational in Rio de Janeiro, Brazil. These trucks are equipped with regenerative brakes that generate power when traveling downhill. The battery is capable of powering an e-truck for up to 200-300 km on a single charge, a range that is approximately equivalent to eight hours of operation under normal traffic conditions. Besides, these trucks are only operational during certain hours of the day and therefore not necessarily need to be charged rapidly. | **Combustion engine HEHV:** Instead of building new hydrogen vehicles, existing diesel engines may be adapted to run on hydrogen-diesel dual fuel. Unlike other hydrogen-fueled vehicles, the MLE truck will use hydrogen to power the vehicle with a combustion engine rather than fuel cells and an electric motor.[20] Using conventional engines and existing truck designs, rather than the full transformation needed for electrification, the time-frame to the target of zero carbon emissions can be shortened significantly, at the same time it reduces the cost for customers. |

## Other Resources (updated April 2021)

Australia

- An article by Alan Finkel '145 years after Jules Verne dreamed up a hydrogen future, it has arrived' in The Conversation https://theconversation.com/145-years-after-jules-verne-dreamed-up-a-hydrogen-future-it-has-arrived-127701
- Australia's National Hydrogen Strategy 2019 - https://www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf
- National Hydrogen Strategy Issues Papers - https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-issues-papers/
  - Hydrogen at scale
  - Attracting hydrogen investment
  - Developing a hydrogen export industry
  - Guarantees of origin
  - Understanding community concerns for safety and the environment
  - Hydrogen in the gas network
  - Hydrogen to support electricity systems

[19] Possible breakthrough in battery technology: https://www.trucks.com/2019/11/19/nikola-motor-historic-battery-technology-breakthrough/

[20] Hydrogen vehicle converter ULEMCo have achieved thermal efficiencies of 45%, which was demonstrated for the Mega Low Emissions (MLE) Volvo FH16 truck demonstrator.

    - Hydrogen for transport
    - Hydrogen for industrial users
- Future Fuels Strategy: Discussion Paper – consultation closed 2 April 2021
    - https://consult.industry.gov.au/climate-change/future-fuels-strategy/supporting_documents/Future%20Fuels%20Strategy%20%20Discussion%20Paper.pdf

Canada

- Zero Emission Vehicle Infrastructure Program
    - https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/zero-emission-vehicle-infrastructure-program/21876
- Hydrogen Strategy for Canada – Seizing the opportunities for hydrogen – Dec 2020
    - https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

UK

- 2021: UK has signaled it will publish its Hydrogen Strategy and begin consultation on the Government's preferred business models for hydrogen.
- UK Policy paper -The ten point plan for a green industrial revolution – 18 Nov 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf
- Hydrogen and Fuel Cell Resources, UK Hydrogen and Fuel Cell Association
    - http://www.ukhfca.co.uk/resources/external-hydrogen-and-fuel-cell-resources/
        - The case for green hydrogen - 3 March 2021 http://www.ukhfca.co.uk/wp-content/uploads/Green-Hydrogen-final-21-02-21-1.pdf