# Hydrogen and Battery Technologies are Mutually Beneficial for Transport Applications

## Introduction

Over the past few decades there has been a long running argument over whether hydrogen or battery vehicles are the best technology for low carbon transport systems. This has led to the two technologies competing with each other rather than competing with the incumbent fossil fuel transport technologies.

This is a mis-directed effort and it is the hypothesis of this paper that the technologies share a symbiotic relationship and are therefore mutually beneficial, rather than competing technologies. Hence, they should be developed in parallel with a focus on hybrid systems.

⇒ Hydrogen and battery transport are potentially applicable to different areas of the transport sector.
⇒ Hydrogen and battery technologies can be combined in hybrid systems to overcome the limitations of each technology on its own.

## Hybrid Systems Solve the Disadvantages and Use the Advantages of Each Technology

**Benefits of hydrogen as a storage medium, with a variety of sources.**

The energy density of hydrogen storage(including the mass of the fuel cell system) is much greater than battery storage.
⇒ An estimate of the volumetric energy density of a hydrogen system is around 1.5 times the energy density of a lithium ion battery (e.g. 440Wh/L to 300Wh/L).
⇒ An estimate of the gravimetric energy density of a hydrogen system is around 6 times greater than a lithium ion battery (e.g. 770Wh/L to 130Wh/L).

**Hydrogen can come from a number of sources**, green renewable electricity, biomethane, biodiesel or fossil fuels (without conversion to electricity), nuclear or any raw energy feed stock available to society. In the Hebrides, Scotland, Royal Mail is trialling two hydrogen powered vans that will be running off reformed biomethane from food waste.

In comparing efficiencies, the source of energy and whether it must be converted to electricity before hydrogen should be taken into account. Direct conversion to hydrogen improves efficiency.

**Refuelling times for hydrogen** cars is typically around **3-5 minutes** in a manner similar to when refuelling petrol (with which the public is familiar).

In contrast **electric vehicles** normally take a **few hours to fully charge** (see Table 1). At home over night this is not a problem, but impractical if a car must be recharged part way through a journey. If faster charging is achieved, it may require extra infrastructure that will cost more.

**Electric vehicles are more efficient in 'city-driving' conditions**
Where there are numerous stops and starts and slow driving conditions **battery vehicles perform better than fuel cells**.

An example of the worse performance of fuel cell system without batteries was illustrated by the European CUTE Bus trials in which the vehicles needed to accelerate or decelerate frequently.

⇒ At an average speed of 15-20km/h, the fuel efficiency of the buses was reduced by 66%, compared to that of 40-42km/h. This was because the vehicle was idling or travelling very slowly in congested traffic 50% of the time. Further optimisation of the fuel cell is possible.

⇒ As a result, newer models use a hybrid battery and fuel cell system, which allows re-generative braking and a smoother loading of the fuel cell.

⇒ For example, this technique is being adopted for new buses in London. TriHybus launched in the Czech Republic has lithium batteries and ultracapacitors as secondary energy sources.

**Hydrogen can extend range and speed, batteries improve acceleration**
Generally the maximum range of electric vehicles is only around 100 miles maximum and maximum speed are typically 80-96kmph (Table 1). **Hydrogen offers additional power and range** (Table 2). **Batteries improve acceleration** and facilitate **regenerative braking.**

**Table 1 Capabilities of battery vehicles.**

| Name | Top speed (kmph) | Charge time (hours) | Car type | Range (km) | Battery type |
|---|---|---|---|---|---|
| **Nissan Leaf** | 145 | 0.5 | compact | 160 | Lithium-ion |
| **Aixam Mega City** | 90 | 8 | compact | 80 | Lead-acid |
| **Think City** | 100 | 9-13 | compact | 170 | Sodium |
| **Quiet Car 1** | 70 | 5 | compact | 96 | Lithium -ion |
| **ZECar** | 90 | n/a | Small van | 90 | Lead acid or Lithium ion |
| **Citroen C1** | 96 | 6-7 | compact | 60-70 | Lithium ion |
| **Fiat e500** | 96 | n/a | compact | 75 | Lithium ion |

**Table 2 Capabilities of hydrogen power vehicles.**

| Name | Top speed (kmph) | Car type | Range (km) | Battery type |
|---|---|---|---|---|
| **Daimler F-cell** | 145 | Compact | 270-400 | Battery present |
| **Honda Clarity** | 160 | Mid-Size | 430 | Lithium-ion |
| **Mazda Premacy RE** | 200 | Multiple people | 200 | Lithium-ion |
| **GM Equinox** | 145 | SUV | 320 | Nickel-metal |
| **GM HydroGen 4** | 160 | SUV | 320 | Nickel-metal |
| **Toyota FCVH** | 155 | SUV | 580 | Nickel-metal |

## How Hydrogen and Battery Technologies can Work Together

Table 2 shows that hydrogen powered cars also use **batteries** for **regenerative braking** and to **improve traction and acceleration**.

The future could be that **small electric vehicles** are **used around town** and **larger hydrogen or hydrogen-battery cars** are used for **longer journeys**. Table 1 and Table 2 show that the initial target market for:

⇒ hydrogen power cars is larger, longer range (extra-urban) models.
⇒ battery power cars is smaller, short range (urban) vehicles.

Alternatively some hydrogen vehicles can run for a few 10s of kilometres on their battery. This could be used for short journeys. Hydrogen-battery hybrid systems could still have a ‘plug-in’ facility.

This **may need a user paradigm shift** whereby drivers have the use of 2 vehicles: **small all-electric vehicle** for **use in town** and a **larger hydrogen powered vehicle** for **longer journeys**.

**Larger vehicles**, such as lorries and ships may need to **use hydrogen** as batteries alone would simply be inadequate for the **energy they require**. **Fast refuelling times for hydrogen** make it appropriate for campus **vehicles used 24 hours a day**.

Whilst some hydrogen-battery hybrid vehicles use different types of batteries to battery-only vehicles (Table 1 and Table 2), the development of batteries and battery management systems will be beneficial to both.

Down stream of the battery or fuel cell, the vehicle technology will be the same. Likewise the down stream technology of different hybrid vehicles will be the same. Increasing the deployment of battery, fuel cell or hybrid systems will help justify mass production and improvement of the down stream technologies.

**ICE Engines**

Replacing diesel with hydrogen in diesel-electric hybrid vehicles will substantially reduce the emissions. These use internal combustion engines (ICEs) combined with batteries.

⇒ To date, fuel cell vehicles are more efficient than ICEs, hydrogen fuelled ICEs may be a useful stepping stone in the development of low carbon transport.

⇒ As well as reducing emissions, hydrogen fuelled ICEs will help to expand hydrogen refuelling infrastructure whilst the cost of fuel cells reduces.

⇒ Hybrid technology will improve the efficiency of ICEs and facilitate the development of battery technology and control systems. Hybrid ICE-battery systems designed for hydrogen could compete with fuel cell hybrids.

## Recommendations

**Hydrogen and batteries** should be considered as symbiotic**, not competing, technologies**. It would be helpful if government **policies** aim to **encourage the coordinated and mutually beneficial development of both technologies**.

Recommend support for **ICEs designed to use hydrogen, especially when hybridised with batteries** whilst ensuring the development of fuel cells. This could be a **stepping stone** towards **fuel cell-battery-hybrid** powered transport. Hydrogen-methane mixes may also be used in this transition.

Investigate how the different **sources of hydrogen and electricity** can be used for the **greatest benefit for transport and a low carbon energy system.**

## Sources

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