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# Solving the Conundrum of Battery Electric Cars Versus Hydrogen-Electric Vehicles

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**ABSTRACT**

The hydrogen powered vehicle was invented long before the battery electric car but both were beaten by the petrol/diesel combustion engine that is now being chopped as the zero-emission transition of many nations is aiming for net zero in 2050. The conundrum is that present designs of vehicles might be pure battery or could instead be hydrogen-fuel-cell-battery drive train, allowing much more onboard energy storage. The success of the lithium battery that started near 2008 has been extended in many countries, giving exponential rise in pure battery designs, but there are several snags that still need to be solved. In contrast, the hydrogen-fuel-cell-battery-electric-vehicle only became economically viable near 2018, giving a decade lag, but with numerous advantages such as low price, less weight, long range and rapid refuelling. The purpose of this paper is to outline key difficulties, mainly of infrastructure, before attempting to predict the future advances of both technologies.

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## Introduction

It is surprising to reflect that hydrogen was available in bulk well before electricity became widely usable after Volta's creation of the battery in 1800 [1]. Robert Boyle had observed hydrogen gas bubbling up as acid reacted with iron filings in 1671. Then Francois Isaac de Rivaz originally created the first hydrogen internal combustion engine, patenting it in 1807, installing it in a flimsy vehicle one year later. The hydrogen was stored in a small balloon that limited volume and energy. Combustion was controlled by hand, so the driver had to fill the cylinder with an explosive $H_2/O_2$ mixture which he then sparked off using a Voltaic pile. It must have been exhilarating and dangerous at the time, thus no-one was interested in building nor riding such a machine until the Hippomobile was constructed near 1860. In contrast, the first battery electric vehicle was assembled around 1832, put together by Robert Anderson, but it took until the 1870s or later for battery electric cars to be practical [2]. Then combustion cars became universal after 1912 when the electric starter was invented.

Two electric zero emission technologies, BEV (Battery Electric Vehicle) and HFCBEV (Hydrogen Fuel Cell Battery Electric Vehicle), are now being built in rapidly expanding numbers as nations replace dirty and toxic fossil fuel designs with electric drives [3]. Figure 1 shows how sales of battery electric vehicles (BEVs) have increased in several countries, with Norway racing ahead, followed by Iceland, China and the world, with Britain lagging slightly. The leading countries have a common reason for the BEV success: Both Norway and Iceland are almost 100% green already because of hydro power and other large renewable resources, while China is doubling its renewables every 3 years. Paradoxically, Norway is one of the world's biggest exporters of fossil fuel, so you might expect they would stick to combustion, as USA and Saudi Arabia have. Typically, the rest of the world is near 20% green and has a long way to go in both renewables and electric cars. This applies to UK, as Britain's new BEV sales are 20% in May 2025, but they are heading for 100% by 2035 according to government policy [4].

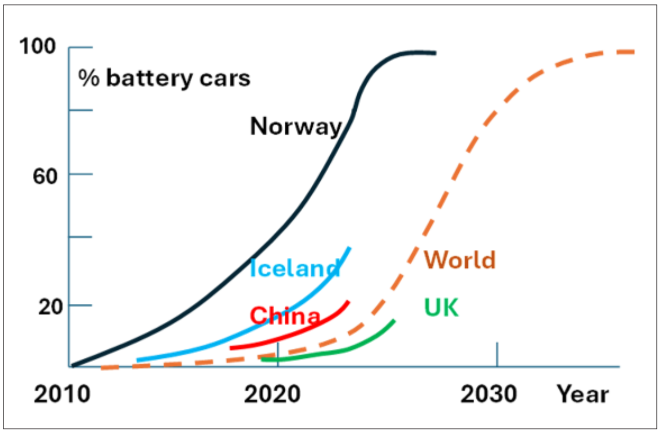


**Figure 1:** Battery Electric Vehicles (BEVs) as Share of New Car Sales by Country

The main difference between BEVs and HFCBEVs (Hydrogen Fuel Cell Battery Electric Vehicles) is the fuel cell that took longer to reach maturity around 2018, when lithium battery drives were well ahead in the marketplace, causing hydrogen to fall more than ten years behind [5-7]. The task now is to compare and contrast these two competing designs, in an attempt to understand how the markets may shake out over the coming decades. First consider the benefits of electric vehicles, then move on to distinguish the snags that arrest the markets, followed by the infrastructure problems and the rapid acceleration of technologies in both battery and hydrogen fields, making predictions difficult as both batteries and fuel cells improve rapidly.

**Electric Benefits**

The main benefit of electric vehicles is that they do not directly emit $CO_2$ which causes global warming. However, when the electricity sources are not green, as in UK at 50%, $CO_2$ is still produced in the supply chain, in addition to toxic $CO_x$, $SO_X$, $NO_X$, VOCS and nanoparticles that cause significant deaths due to emissions from fossil fuel power stations. This problem has urged China to introduce electric vehicles in Beijing because the air pollution was killing citizens. Norway, Iceland and others are further forward because they have near 100% green hydro-electricity, making electric vehicles zero emission already.

Several other issues pushed China towards both BEVs and HFCBEV:

- Imported oil was too big
- Rebuilding the economy after the 2008 world-wide financial crash was tricky
- China was too far behind the hybrid electric-combustion vehicles where Toyota was leading since 1997

The sensible conclusion the communist government reached was that China could win on pure electric vehicles (BEVs), thus focussing their 2016 MOST document on New Energy Vehicles, both BEVs and HFCBEV [8,9]. Remember, the hydrogen car typically has a lithium battery. But China had started early in 2001, after ten years' experience making battery bikes, by putting BEVs in the 5-year plan as a primary science. Figure 2 illustrates the acceleration of China making more BEVs than USA, causing BYD to beat Tesla in 2024 [10].

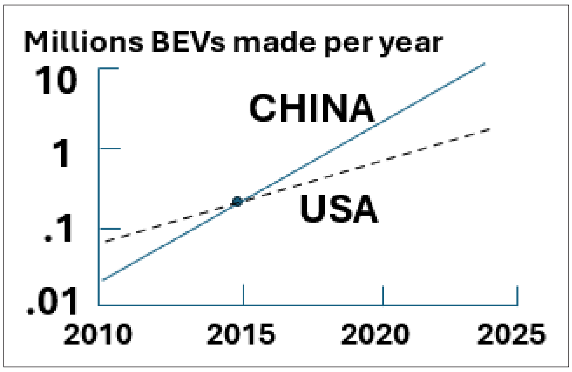


**Figure 2:** China was behind USA making EVs up to 2015 but overtook, reaching 11Million in 2024, an order of magnitude better. Log scale shows exponential rise for both countries but USA is far slower than China. Data from Statista

Then in 2007, Wan Gang was promoted to Minister of Science and Technology, and he had worked for Audi, then tested Tesla's first prototype the Roadster in 2008, when it was just released. He recognised the Tesla advantages and made the national decision to focus China 100% on electric vehicles. It worked and has been prioritised in subsequent National Economic Planning. Wan Gang also supported hydrogen for more energy storage in electric vehicles, so China is now also world number one in hydrogen-fuel-cell-battery-electric vehicles. Every hydrogen fuel cell (HFC) vehicle has a lithium battery. So, it is always hybrid.

A second benefit of electric vehicles is that they all obey the electrochemical rules that Faraday defined in the 19th century, with each cell producing about 1Volt of energy. Thus, the battery in the BEV behaves like the Fuel Cell in the HFCBEV because the ideal battery characteristic shown in Figure 3 applies approximately to both. In practice, the battery internal resistance is not linear, which means that Figure 3 will be slightly more complex, but the basic idea remains the same [11].

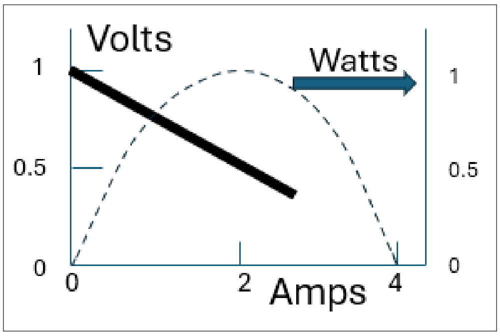


**Figure 3:** Ideal Volts-Amps-Watts Characteristic for a Battery or Fuel cell with Ohmic Resistance

Elon Musk said fuel cells were 'Fool Cells' and described hydrogen cars as 'mind bogglingly stupid'. Somehow, the idea that a battery drive train is 90% efficient was propagated, to suggest that the Tesla design could travel much further than the Toyota Mirai hydrogen electric car on the same stored energy. This is not true as the voltage efficiency of any battery (or fuel cell) is 100% at zero current but only 50% at maximum power, as shown in the ideal volts vs amps line in Figure 3. In other words when you push your accelerator pedal to the floor, the efficiency of both BEV and HFCBEV is near 50% as electrochemistry theory predicts. The cells then get hot and that is why effective cooling is necessary to prevent fires, which can arise on both BEVs and HFCBEVs. The message is that the concept of efficiency for the competing BEV and HFCBEV drives must be clarified using standard drive cycles if a proper comparison is to be revealed. The main problem with BEVs is that the range given on the dashboard and on sales adverts is often over optimistic, with a TeslaX mileage 'up to 333 miles' whereas the Mirai dial range is realistic at 300 miles, but achieves 400 if the driver uses eco-drive.

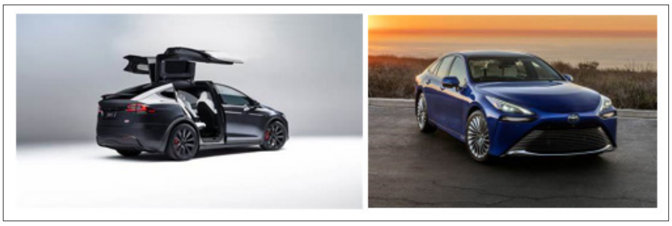

**Figure 4:** Comparing the Tesla X with Toyota Mirai in 2021

The comparison of the Tesla X and Toyota Mirai in 2021 is valid because each car weighs almost 2 tons. Comparing vehicles at equal weight is important since range drops per kWh energy storage as weight rises. Both are electrochemical drive and so follow the Volts-Amps curves shown in Figure 3. Therefore, claiming the pure battery car (BEV) is more efficient than the HFCBEV is a false argument.

The fully charged Tesla X carries 100 kWh of energy while the Mirai has180kWh, almost double, which is why the hydrogen car has much bigger range: 400 miles versus 'up to 333 miles'. Also, the Mirai fully refuels in 5 minutes while the Tesla takes 30 minutes to reach 80% charged. Most important, the Mirai in UK costs £50,000 whereas the Tesla X is £93,000. The conclusion is that the hydrogen car beats the Tesla. The main question that arises is 'Where are the refuelling stations?'.

**Problem Areas**

The key problem confusing the status of BEVs and HFCBEVs is that the BEV is at least a decade more mature and still improving as battery costs decline and stored energy density in kWh/kg rises. Yet the progress of HFCBEVs is in its infancy, since the first effective vehicle was the Ballard bus in 1993 that took 20 years to attain a good performance [12]. The upshot is that the influx of hydrogen vehicles lags behind battery cars by ten to 15 years as shown later by the results in Figure 8.

This gap has been recognised in China which authorised the New Energy Vehicle policy in 2016, summarised for hydrogen vehicles in Figure 5. At the starting point, the China Government wished to spend $1billion to provide 100 hydrogen vehicles with 4 refuelling stations. This ambition was well behind the UK which had about 15 stations and several hundred cars/buses. California, EU and Japan were also far ahead. The impressive idea was that China would expand rapidly to $24bn/a investment in 2050, powering 10 million hydrogen vehicles with more than a thousand refuelling stations connected by a hydrogen grid. Very large subsidies were gifted to hundreds of companies building New Energy Vehicles, such that the 2020 target was reached and the 2025 target almost achieved at 50,000 hydrogen vehicles and nearly 500 hydrogen stations.

| | 2016 | 2020 | 2030 | 2050 |
|---|---|---|---|---|
| | 4 | 100 | 1000 | H grid |
| FUNDS | 1bn$ | 2bn$ | 6bn$ | 24bn$ |
| CARS | 100 | 10000 | 2M | 10M |

**Figure 5:** The 34-year China plan for Hydrogen Vehicles in the 2016 report [8].

The main innovation allowing HFCBEVs to compete with BEVs was introduced by Toyota around the year 2000, the Type4 composite cylinder for storing hydrogen on the vehicle at 700bar with a low volume [13]. This was banned in China until recently but has now spread globally, though the high pressure requires more compressor equipment. This invention allowed the hydrogen vehicle to compete with the battery designs, because 3 small gas storage cylinders could be fitted easily in the Toyota Mirai cabin, where previously the boot had been taken over by low pressure-high volume gas containers.

But the main difficulty for both battery and hydrogen vehicles is the increasing energy storage demands as cars get bigger, doubling in size every 50 years [14]. The Tesla X hit the benchmark of 100kWh energy storage in 2015 but now bigger cars reach 250 kWh while trucks and buses can hit 3MWh to 10MWh and higher. Whereas we could recharge the smaller BEVs in 2009 at UK home on a 4kW plug, it is now not possible with larger vehicles. Hence, high powered fast chargers are being introduced across nations at great expense. The problem in UK is that this works for 4% penetration of car populations in 2025 but will fail because the UK electric Grid cannot handle 40 million battery cars, plus many buses and trucks. Figure 6 shows the rapid increase in BEVs worldwide.

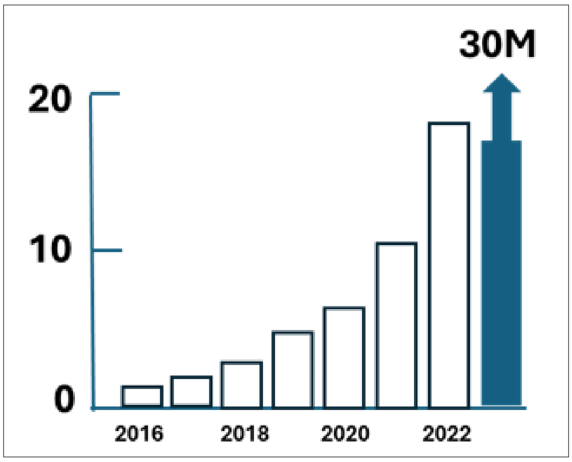


**Figure 6:** World Population of BEVs Rising Exponentially Almost 30% Every Year

**Infrastructure of Green Energy**

It follows that the rise in both BEVs and HFCBEVs must be limited by the availability of green energy across nations. In 2024, seventeen million battery electric vehicles (BEVs) were manufactured globally, contrasting with about 15,000 hydrogen electric vehicles (HEVs). Although both continue to rise in China, other countries have limits on their green electricity and green hydrogen production. At present, BEVs have an advantage because they are allowed to charge with electricity that is not green, for example only 50% green in UK, whereas hydrogen vehicles must use green hydrogen.

First, high power electric chargers are needed for fast charging of bigger vehicles, but small BEVs are good for home charging.

Second, green hydrogen is not available in many regions, so it is limited in supply at present.Third, both BEVs and $HFCBEV_s$ need more refuelling infrastructures on highways, not yet available.

Hydrogen is especially limited because it is not generally known nor available to the public whereas electricity is accessible in almost every home. However, electric infrastructure is not available to charge bigger batteries that are now being installed in electric cars up to 250kWh energy storage. The conclusion is that small electric cars with batteries below 100kWh will be satisfactory but larger designs will shift to hydrogen electric vehicles as new refuelling infrastructure is built by government leverage as is happening in China. The key issues are the recent announcements of Hydrogen Fuel Cell improvements, the cost-cutting of lithium batteries, improving fuel cells, the growing installations of economic high-power chargers/Hydrogen refuelers and the market responses to these developments.

**Rapid Advances of Batteries and Fuel Cells**

Figure 7 shows how fast the costs of US lithium batteries have fallen since 2013, illustrating how both the cells and the packs have been made more economically [15]. This is continuing in 2025 and lithium batteries are now competing on price with the lead acid products per kWh stored, yet the lithium packs are very much lighter in weight [16].

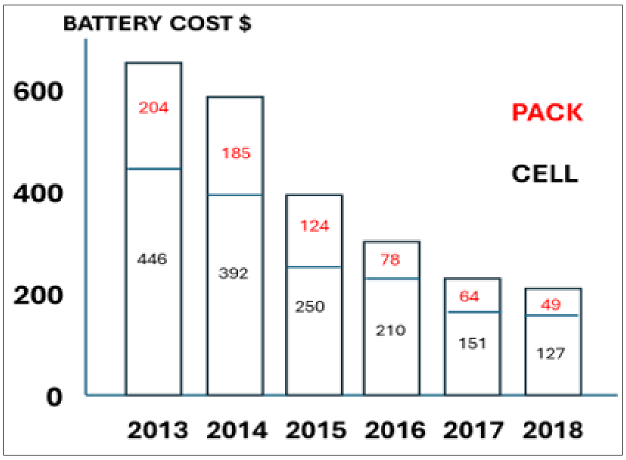


**Figure 7:** Fall in US Battery Costs with Time in the USA as Zero Emission Vehicles were Encouraged

Costs of hydrogen fuel cells read have fallen as power performance and density have increased. Durability has been rising substantially such that present HFCBEVs can compete with both combustion and battery cars [17]. Consequently, the race to dominate the markets is continuing.

At the February 2025 Tokyo Exhibition, Toyota announced the improved Hydrogen Fuel Cell that is more compact, more efficient, and longer lived than the 2020 Mirai version. Application of the new design in trucks, to replace present diesel engines, has been predicted [18]. Double power output of 240kW was claimed with 20% greater efficiency and compaction competing with a contemporary diesel motor. Lifetime was claimed to equal a current diesel. Although the Mirai was meant for cars rather than trucks, new applications have been discovered in buses, trucks, diggers and other transport systems. Whereas the Mirai introduction in 2014 has led to car sales of 28,000 across 30 countries, the 2019 move by Toyota to heavier vehicles has already made 2700 Fuel Cell installations in buses, trucks, railroads and stationary power generators operated by over 100 clients.

**Prediction of Green Hydrogen Expansion**

Since Green Hydrogen is not much available in 2025, only about 1 million tons/a globally around 1% of fossil hydrogen that is used in oil/gas refineries and ammonia/methanol production plants, it needs to expand by two orders of magnitude by 2035. This will be a major development if hydrogen cars, taxis, buses and trucks are applied to compete with battery electric vehicles (BEVs). It is anticipated that 2billion vehicles of all kinds will be running globally by 2040. If every such vehicle was based on hydrogen-battery-electric drive train (HFCBEV) using 1 kg per day, then the green hydrogen demand would be 1460 Mtons/a, more than ten times the current tonnage of fossil hydrogen made worldwide. Of course, the competition from pure battery cars is dominating at present because the HFCBEV is a decade behind the BEV in development and sales. Even if the hydrogen vehicle market is only 10% of BEVs, the 2025 green hydrogen market will be bigger than the present global tonnage of hydrogen at 100Mt/a. In summary, the transport market for hydrogen could be very large, but prediction is unreliable at present.

Consider China as the most advanced country in the world building both BEVs and HFCBEVs to compare the market trends in the two competing technologies. The data need to be plotted on log-log scales because exponential growth is being observed over the past decade. The China plan for 'New Energy Vehicles' established in 2016 was ambitious in recognising that both electric and hydrogen-electric drive trains were important. The problems of hydrogen infrastructure were not fully known and the 2025 results fall slightly behind the predicted curve. Figure 8 shows the contrasting registration numbers for BEVs (above) and Hydrogen-electric below. This shows that hydrogen drive is 100 times lower in registrations than pure battery. However, the slopes of the two exponential lines are similar, suggesting that demand for hydrogen is substantial and could rise to read many millions of vehicles by 2035. China is unique. Across the planet, HFCBEVs are only 0.1% of BEVs because matching vehicle demand with hydrogen delivery is difficult and has only properly been achieved in Asia.

A recent paper noted the drop in UK Hydrogen refuelling infrastructure during 2020 to 2024 in UK, as 15 small prototype stations were closed, leaving only the three large hydrogen refuellers in Aberdeen, Birmingham and Heathrow [19]. This up-sizing is now moving on, with one new large station opening soon in Teesside near the airport. In 2025, a significant announcement of £6.5 billion investment by key UK hydrogen transport companies HydraB Power (chaired by Jo Bamford), Centrica, JCB, Johnson Matthey, ITM Power, Heidelberg Materials, ITM Power and National Gas has been published [20]. The UK Secretary of State for Science, Innovation and Technology said, 'We cannot compete on cost in the production of Batteries. That ship has sailed. But on hydrogen, what we are doing in Britain is Market Leading. Pulling together 2000 electrolysers, 155 compressors, 600 Hydrogen refuelling stations, 5000 buses, 490 coaches, 1000 fuel cells and 1640 Green Chemicals to create 24000 jobs is an ambitious target'.

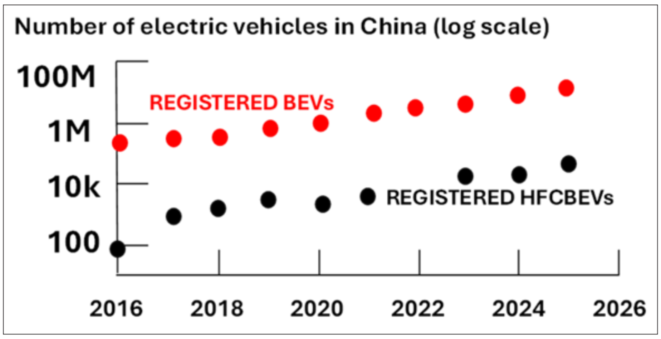


**Figure 8:** Comparing Rise of Battery Vehicles with Hydrogen Electric Vehicle Increases in China

**Conclusions**

Both Battery Electric Vehicles (BEVs) and Hydrogen Fuel Cell BEVs (HFCBEVs) are being manufactured to replace combustion cars, taxis, buses and trucks as the Net Zero transition takes place. As BEVs are now being made in many millions across the globe, HFCBEVs are also increasing in numbers, especially for heavier vehicles like 40-ton trucks that need to travel long distances.

The two final products are similar in zero emissions, energy usage, good acceleration, and low noise. But the HFCBEV beats the BEV when comparing the 2021Toyota Mirai with the TeslaX:

- Price is lower
- Range is almost twice as high
- Refuelling time is 5 minutes for hydrogen filling versus 10 times longer for TeslaX.

Yet, the Tesla is well ahead in manufactured numbers because it matured 10 to 15 years before the Mirai. Progress on both technologies is advancing rapidly as costs drop and equipment improves.

The key problem for both is the availability of infrastructure, first for high power electric chargers, second for green hydrogen delivery to refuelling stations.

Predicting the future for these two innovations is difficult, but both are on exponential paths in China, with HFCBEVs lagging by10-15 years. Countries differ in their targets. For example, Norway is approaching 100% battery cars with a much small number of longer-range hydrogen taxis, trucks and buses. China is mass manufacturing BEVs but still subsidising numerous HFCBEV companies as the 2040 target of 10 million hydrogen vehicles is retained. UK has just reached 1.5 million battery vehicles (3.8% penetration) in May 2025 with no sensible plan to attain electric charging infrastructure, while ignoring HFCBEVs which now number about 500 [21]. But new hydrogen refuelling stations are being planned by private companies with hope to create 24,000 new jobs, while allowing many thousands of new hydrogen vehicles to run across the country.

There is no doubt that electric vehicles of several types are moving forward rapidly, especially in China, where 2025 saw 36M BEVs on the road, way ahead of EU and USA. Of course, hybrid combustion/battery cars confuse the numbers, and are likely to continue for another decade. Half of new cars sold in China are now electric, largely BEVs [22].

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