# Fuel Cell and Battery Electric Vehicles Compared

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This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 6: Stationary Applications / Transportation Applications
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-6
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-656-9

# Fuel Cell and Battery Electric Vehicles Compared

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Detailed computer simulations comparing various alternative vehicles illustrate that society must move toward all-electric vehicles to achieve our goals of an 80% reduction in greenhouse gas emissions, substantial reductions in petroleum consumption and near-zero urban air pollution. Biofuels, hybrid electric vehicles and plug-in hybrids that still rely on the internal combustion engine for some motive power will help to reduce environmental and energy security burdens, but we must eventually eliminate most internal combustion engines to fully achieve our societal goals.

We have two primary choices to power all-electric vehicles: hydrogen-powered fuel cells and batteries or other energy storage devices such as ultra-capacitors. This paper compares the major attributes of fuel cells and batteries for full function passenger vehicles, including on-board vehicle mass (Figure 1); on-board energy storage volume (Figure 2); greenhouse gas emissions; electric vehicle mass production incremental costs compared to conventional cars; fuel costs per kilometer; life-cycle costs; well-to-wheels energy efficiency using natural gas, biomass and wind turbines as the energy source; fueling times and infrastructure costs to support these two options. We conclude that the hydrogen-powered fuel cell electric vehicle is superior to the battery electric vehicle for most of these major attributes if consumers demand vehicles with more than 150 to 200 km range.

Consider the weight of an electric vehicle. As shown in Figure 1, the weight of a battery EV (BEV) grows rapidly with increased vehicle range. For each additional km of range required, more batteries must be added. But each kg of battery weight also requires extra vehicle structure to support that weight. In addition, each kg added requires a slightly larger motor to provide adequate vehicle acceleration. And the braking system must be larger to stop the vehicle. This non-linear feedback process is called „Weight-compounding," or „mass-compounding."... the vehicle mass grows more than linearly to achieve greater range. For example, to achieve the 480 km range demanded by most US drivers, a FCEV would have a mass of approximately 1280 kg, while a BEV would have 1.72 times more mass at 2196 kg, assuming an advanced lithium-ion battery with a useful specific energy of 150 Wh/kg. But achieving 150 Wh/kg will require significant improvements over current Li-ion technology. For example, the new Chevy Volt PHEV with 40 miles all-electric range reportdly has a 181-kg battery with a nameplate energy of 16 kWh. But only half of this energy can actually be used, so the useful specific energy is 0.44 Wh/kg which is 3,400 times lower than the specific energy used in our models. Similarly, according to the literature, the Audi „e-tron" 471-kg battery pack has a nameplate energy rating of 53 kWh, of which 80% can be used to propel the car, resulting in a useful specific energy of 0.0899 kWh/kg, or 1,700 less than that used in our computer model. Finally, the US Department of Energy estimates that the current useful specific energy of Li-ion batteriy systems is approximately 0.025 kWh/kg, which requires a 3.5 times improvement to reach the 150 Wh/kg used in our model. Therefore our model assumes significant future improvements in Li-ion battery system performance.

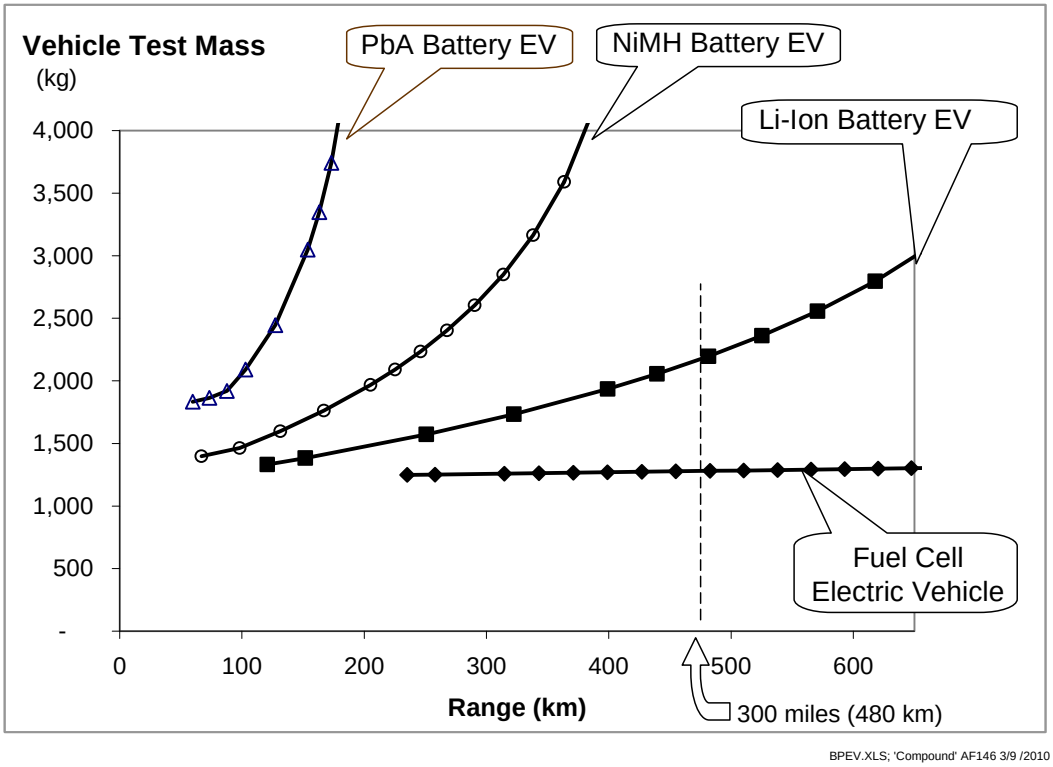


**Figure 1: Estimated vehicle test mass for battery EVs with three different battery technologies compared to a hydrogen-powered fuel cell electric vehicle as a function of vehicle range.**

Everyone knows that batteries are heavy. Many do not realize that batteries also take up lots of space. Commentators criticize the space required to store hydrogen in high pressure tanks. But advanced Li-ion batteries have approximately the same energy density (200 Wh/liter) as a 300-bar (35 Mpa) compressed hydrogen tank plus fuel cell system. However, since the BEV weighs more than a FCEV for a given range greater than 60 km, it will need more stored energy to meet the vehicle range and acceleration specifications (we require a zero to 37.3 km/hour (60 mph) acceleration in 10 seconds for all vehicles in this study.) Thus the space occupied by the battery bank is larger than the space required for the 300-bar compressed hydrogen tank and fuel cell system for Evs with more than 200 km range as shown in Figure 2.

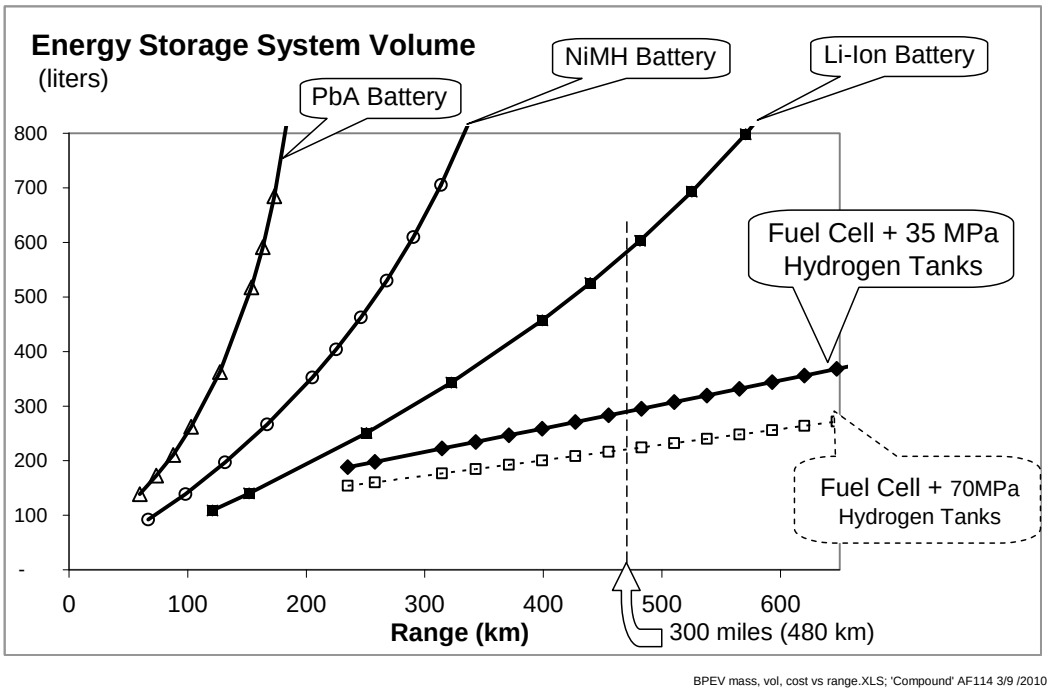


**Figure 2: Estimated storage volume required for batteries and for hydrogen tanks plus the fuel cell system as a function of vehicle range**