

BATTERY ELECTRIC VEHICLES IN THE FAST TRACK

A COMPARISON OF BATTERY AND
FUEL CELL ELECTRIC VEHICLES



Article description

For the past few years, battery electric vehicles (BEVs) have dominated the headlines, but what about fuel cell electric vehicles (FCEVs)? The number of FCEVs on today's streets is negligibly small relative to the fast-increasing number of BEVs, and the production of FCEVs and hydrogen is often still seen as prohibitively expensive. This might seem surprising, given that many players assign high potential to fuel cell technology.

To explain the current prevalence of BEVs over FCEVs, this Point of View article summarizes the relative strengths and weaknesses of BEVs and FCEVs with special reference to German OEMs' passenger cars. We compare the two types of electric vehicles (EVs) in terms of product readiness, infrastructure, and technology, to explain the current state of play. Our analysis focuses on the next 10 years to match OEMs' planning timeframe, but we acknowledge that technology advances over the next decade may change the picture for the longer term.

THE INDUSTRY EXPECTS BEVS TO DOMINATE FOR THE NEXT FEW YEARS

The CEO of the Volkswagen Group, Dr. Herbert Diess, has clearly stated that there is no alternative to battery electric drive for the foreseeable future, explaining that BEVs are an essential part of the Group's CO2 strategy because they are the most efficient way to decarbonize the automotive industry. In contrast to this strong statement of commitment to BEVs, BMW CEO Oliver Zipse has stated that the company will continue to provide customers with all relevant drive systems:

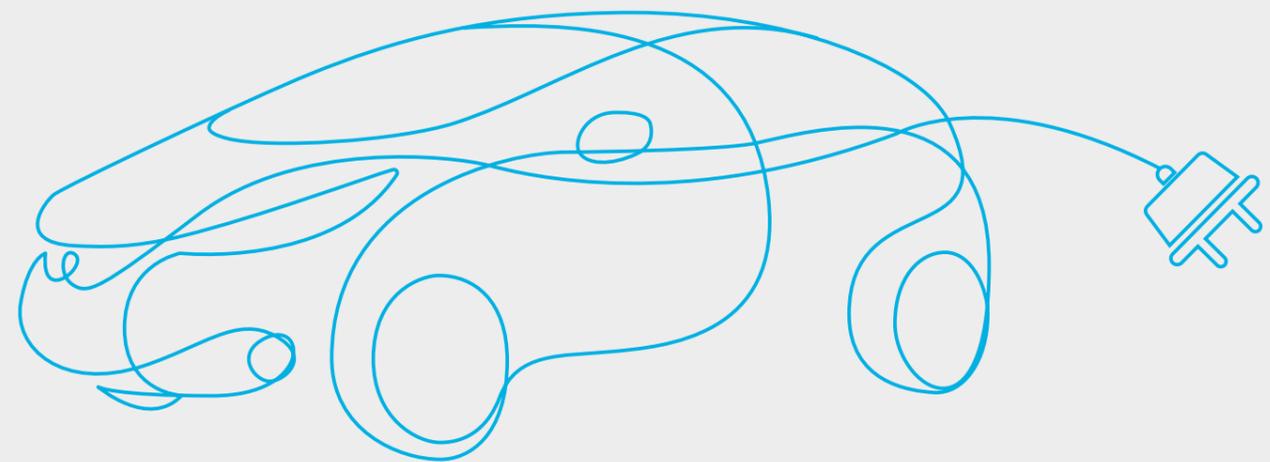
increasingly efficient conventional engines, battery electric drives, and in the future, hydrogen fuel cells. But, like VW, BMW is betting on battery-powered vehicles for the near future.

What are the reasons for the current focus on BEVs? Let's consider some of the pros and cons, starting with product readiness.

INTERNATIONAL COMPETITION AND EUROPEAN EMISSIONS REGULATIONS ARE FORCING A RETHINK OF OEMS' PRODUCT PORTFOLIO

The automotive industry is in the middle of a radical and disruptive change. Pressure from governments and the public to decrease carbon emissions, together with the success of new competitors such as Tesla, have forced established OEMs to reshape their portfolios. The focus has shifted towards EVs which will complement, and in the long run completely replace, the current product range.

A change like this brings many challenges for OEMs, and is requiring major investments in new technologies. In order to meet the European regulations for fleet emissions and avoid carbon emission penalties, these investments have had to be targeted at a technology with immediate impact. The technology chosen was battery electric drive.





OEMs RESEARCHED BOTH BEVs AND FCEVs, BUT BEVs WON OUT, WITH ADVANCED MASS PRODUCTION READINESS AS A PRIMARY REASON

A closer look at the history of German OEMs' R&D spending reveals that after 1990 these companies intensified their EV research in order to become oil independent, but were initially investigating both BEVs and FCEVs. For example, Mercedes-Benz presented its first fuel cell prototype, the NECAR 1, as early as 1994. Furthermore, around the turn of the millennium focus was set on FCEVs. But even though several prototypes and small series were unveiled, no German OEM has yet decided to put FCEVs into mass production.

A major reason why BEVs won out is that they were ready for advanced mass production sooner. Following the **2009 announcement of tighter fleet emission limits (95g CO2/km), which came into force in 2020**, OEMs resumed their R&D efforts in both technologies in parallel. However, in the past five years, BEVs have increasingly hogged the limelight. This technology has been seen as more suitable for the mass market, resulting in accelerated rollout that ensured faster and easier compliance with CO2 regulations. This is the main reason why all German OEMs have established series production of BEVs – a strategy that has paid off, since today the market for BEVs and related vehicle mass production is increasing rapidly, enabling OEMs to reduce their fleet emissions successfully.

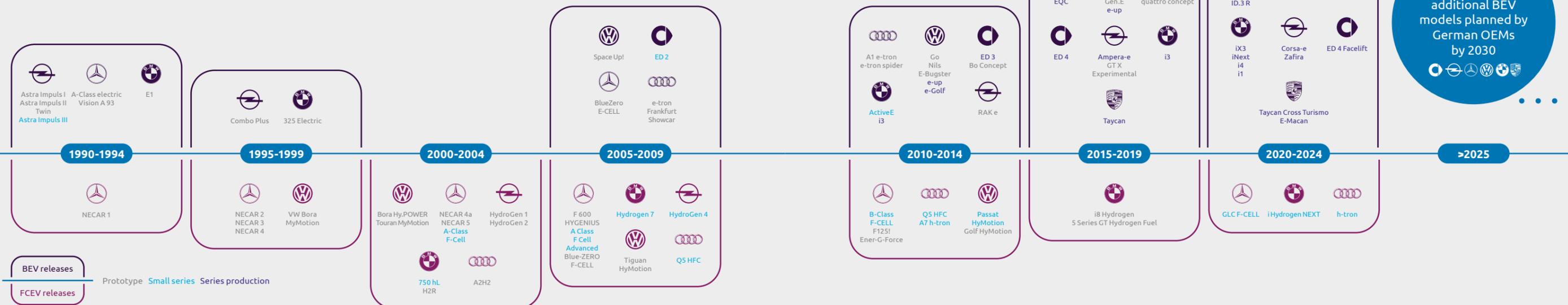
But why did BEVs become market ready sooner? Factors include their lower production costs enabling greater profitability, which led the OEMs to prioritize battery R&D. For FCEVs, there was also a problem of missing infrastructure: both hydrogen supply mechanisms and fueling stations. This raises a chicken-and-egg dilemma: Without sufficient infrastructure, FCEVs are not suitable for mass market adoption, but until they begin to be used in significant numbers there is no motivation to provide the infrastructure. We'll discuss the infrastructure issues in more detail shortly.

OEMs ARE FOCUSING ON BEVs WHILE SLASHING FCEV R&D SPEND – BUT FCEVs REMAIN ON THE RADAR

BEVs' market share will likely increase fast in the next few years. For example, **VW wants to bring 75 new BEV models to the market by 2029.**¹ To achieve such an ambition, other areas have had to be restricted. Therefore, VW has stopped funding its fuel cell research, based on the assumption that fuel cells will not be a relevant factor in the next 10 years. That makes a rapid strategy change by the brand unlikely in the foreseeable future, one reason being that production facilities take time to build. Meanwhile, Audi, BMW, and Daimler continue to produce small series or prototype FCEVs, but like VW, spend most of their resources on battery-driven electrification of their fleets.

Overall, German OEMs still have FCEVs on their radar, but their public statements suggest their future strategies focus on BEV technology. Worldwide sales figures for BEVs and FCEVs in recent years show that this trend is observable not just among German OEMs, but also internationally. While in 2015 only around 335,000 BEVs were sold, this number jumped to **over 1,700,000 BEVs sold in 2019**: an average yearly growth rate of around 50%. In comparison, **between 2015 and 2019 only around 18,500 FCEVs were sold** in total.

Figure 1: BEV and FCEV models launched or planned by German OEMs between 1990 and 2025



¹ <https://www.volkswagen-newsroom.com/de/e-mobilitaet-3921>

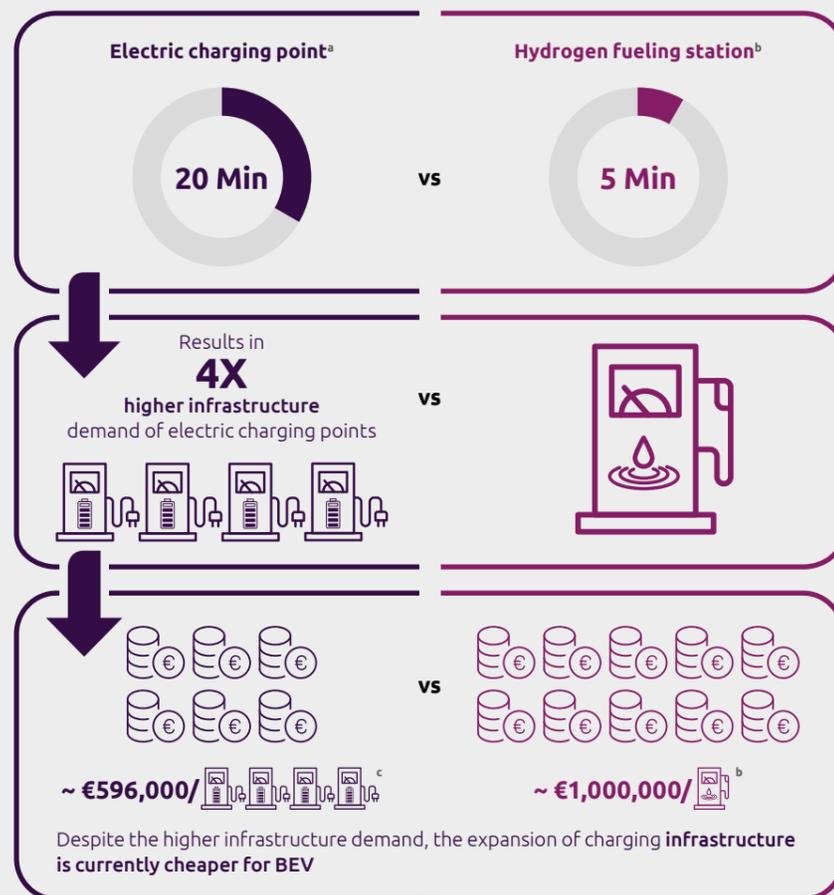
NO ELECTRIC VEHICLE CAN SUCCEED WITHOUT A COMPREHENSIVE INFRASTRUCTURE – AND FOR FCEVs THAT'S HARDER

As discussed earlier, infrastructure is a key reason why BEVs have surged ahead of FCEVs. But why is infrastructure so much harder for FCEVs?

To deliver the highest value to customers, it is important to provide not only a car that exceeds expectations, but also an ecosystem that enables the full potential of the product. The most important part of this ecosystem is a functional infrastructure to guarantee that

customers can use their cars whenever they like. Bearing in mind that range and charging anxiety are two of customers' biggest concerns regarding EVs, let's now compare the charging and hydrogen fueling processes and their respective infrastructure.

Figure 2: Comparison of charging points and hydrogen stations with respect to refueling time, number needed, and overall cost



Charging/fueling duration for 400km
Electric charging from 20 to 80% SoC (state of charge) at a charging point requires 20 minutes (150 KW supercharger). A hydrogen fueling process is comparable to petrol fueling and takes only about five minutes. Therefore, a hydrogen fueling station can process four times more EVs than an electric charging point in the same time period.

Infrastructure demand
To meet a given level of demand, four times more charging points than hydrogen stations are needed. However, introducing higher-power charging points can speed up charging and so decrease the number of charging points needed, whereas the scope for speeding up hydrogen fueling is limited.

Cost of infrastructure expansion
Although more charging points are needed than hydrogen stations, the charging points currently cost less. At today's prices, building a single hydrogen station at €1,000,000 per station is more expensive than installing four 150KW charging points for a total of €596,000.

^aSoC 20-80%, 150 KW Charging point
^bComparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles
^cBased on Reducing EV charging infrastructure costs

While infrastructure expansion is at present more expensive for FCEVs than for BEVs, there are various hypotheses about how possible economies of scale could change that picture.

If and when the number of FCEVs in Germany exceeds 20 million, RWTH Aachen University expects infrastructure expansion for hydrogen to become more cost-efficient than that for electricity charging.

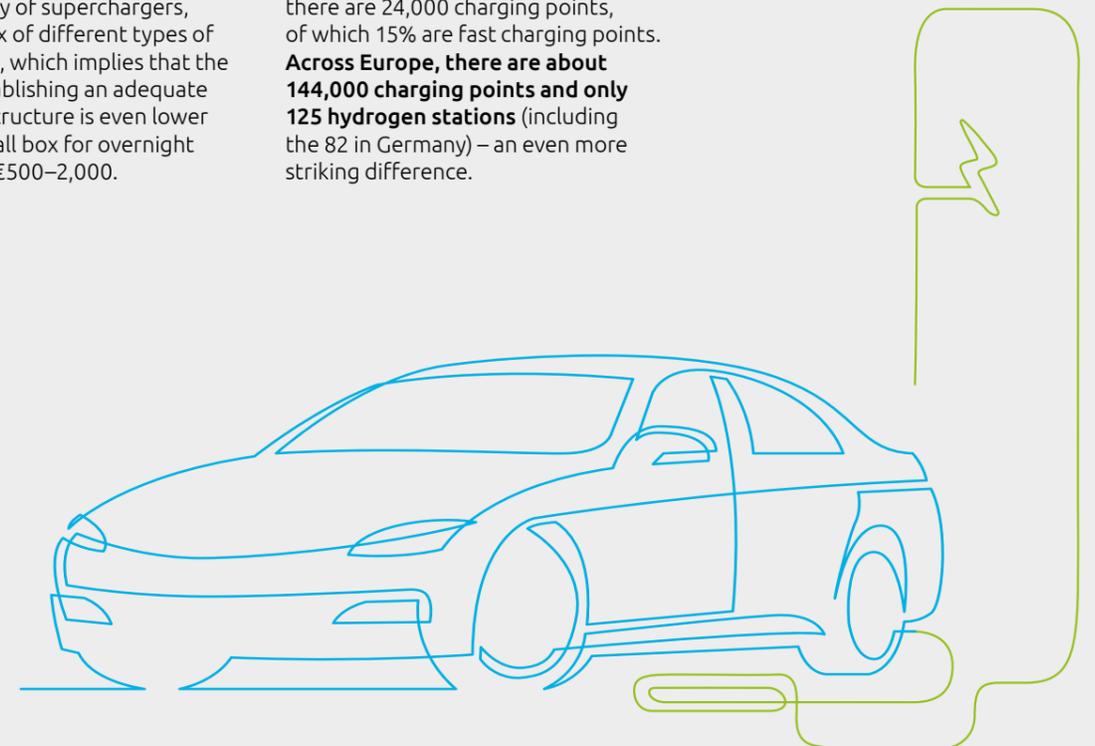
Until then, the investment for charging infrastructure is lower and achieves more impact for less money.² On the other hand, due to OEMs' current intense R&D activity, technical breakthroughs for charging points are also possible.

ELECTRICITY IS MORE READILY AVAILABLE THAN HYDROGEN, AND CHARGING SOLUTIONS CAN BE CUSTOMIZED

An advantage of BEVs is that electricity can be delivered through a variety of charging points, including existing domestic electricity supplies. Superchargers are relatively expensive, but their main use case is long-distance travel. For normal day-to-day use, batteries can simply be recharged at night or during working hours, when charging speed isn't crucial. Thus, an efficient charging infrastructure consists not only of superchargers, but also of a mix of different types of charging points, which implies that the real cost of establishing an adequate charging infrastructure is even lower in practice. A wall box for overnight charging costs €500–2,000.

A further advantage of BEVs arises from the fact that cars can be charged at home using an existing electricity supply, so early adopters didn't face the problem of finding a charging point. FCEV owners, by contrast, need access to a hydrogen station, which isn't usually easily obtained. Even Germany, the leading hydrogen nation in Europe, has only 82 operative hydrogen stations. In comparison there are 24,000 charging points, of which 15% are fast charging points. **Across Europe, there are about 144,000 charging points and only 125 hydrogen stations** (including the 82 in Germany) – an even more striking difference.

These considerations, together with the fact that charging networks can be deployed relatively cheaply in the early stages of rollout, are additional reasons why BEVs were and are more market ready than FCEVs, and why it was logical for OEMs to focus on the BEV market.



²Comparative analysis of Infrastructures: Hydrogen fueling and electric charging of vehicles

DELIVERY OF HYDROGEN FOR USE BY FCEVS POSES TECHNICAL CHALLENGES THOUGH TRANSPORTATION OF ELECTRICITY ALSO NEEDS IMPROVEMENT

Building charging points and hydrogen stations is essential, but they need to be embedded into a supporting energy grid. Aside from a sufficient supply of electricity, which both technologies need, one of the most significant infrastructure challenges relates to energy transportation from the source to the charging points/hydrogen stations. While there is already a power grid that can be used for BEVs, **there are as yet no hydrogen distribution networks that could support a large number of FCEVs.**

For smaller demand (<10,000 hydrogen refuels per day), various methods of transportation are being discussed. For example, trucks with modified

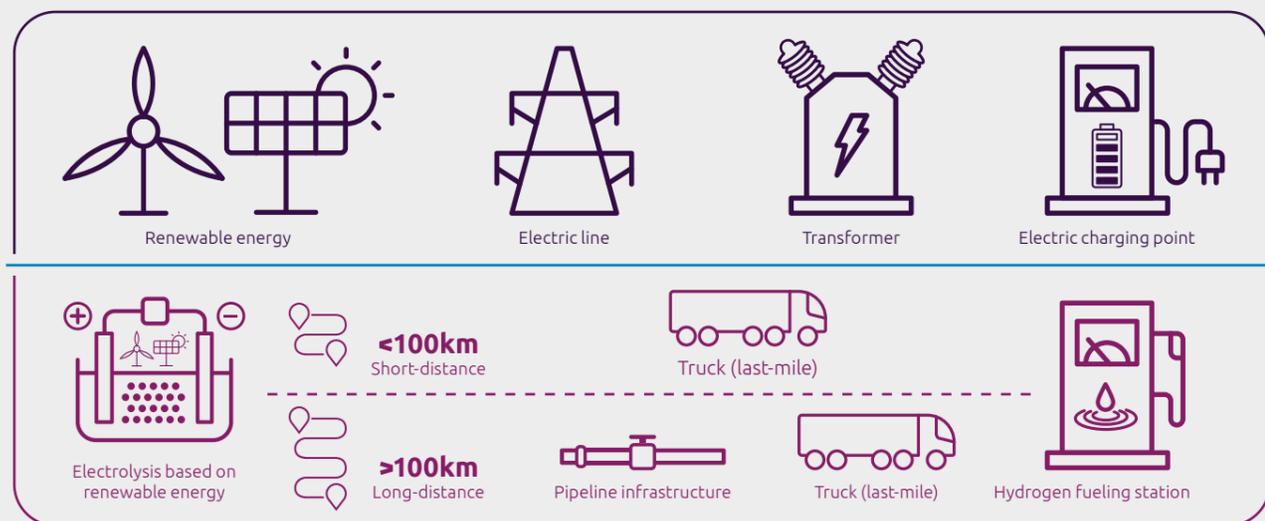
trailers can be used to transport hydrogen, either under high pressure in its gaseous state or at extremely low temperatures in liquid form. Alternatively, an additional substance can be used as a carrier, and then separated from the hydrogen at the target location.³ If demand for hydrogen increased drastically (>10,000 hydrogen refuels per day) and distribution over longer distances (>100km) became necessary, pipelines would need to be built to transport sufficient amounts of hydrogen.⁴

The idea of using natural gas pipelines for transportation is widespread, but because hydrogen molecules diffuse more easily than natural gas, there are different transportation requirements

that might necessitate retrofits to existing gas pipelines. Building a new hydrogen pipeline infrastructure from scratch would take time and require major investments. A further option is to produce hydrogen on-site, but the expense of the necessary electrolyzers makes this economically inefficient at present.

The power grid, too, needs improvements to support BEVs, however. The transmission network requires expansion to transport renewable energy to distribution networks, and the distribution networks need to be strengthened to cope with higher demands.

Figure 3: Transportation of hydrogen and electricity from the source to the charging point/hydrogen station



³ It must be tested if the purity of the hydrogen is high enough after the separation to be used for FCEVs and if this method is economical efficient

⁴ <https://www.energy.gov/eere/fuelcells/hydrogen-delivery>

For well-to-wheel efficiency, BEVs outperform FCEVs by more than 40%

Even though hydrogen is the most common element in the world, it is usually found combined with other substances (for example in natural gas or water), and hence it has to be manufactured before it can be used. There are several ways to do so, but only “green” and (potentially) “blue” hydrogen are desirable from the point of view of CO2 emissions. Green hydrogen is produced using renewable energy, while blue hydrogen is produced from natural gas with the resulting CO2 stored or used industrially to limit CO2 emissions. In the long term, the focus needs to be on green hydrogen.

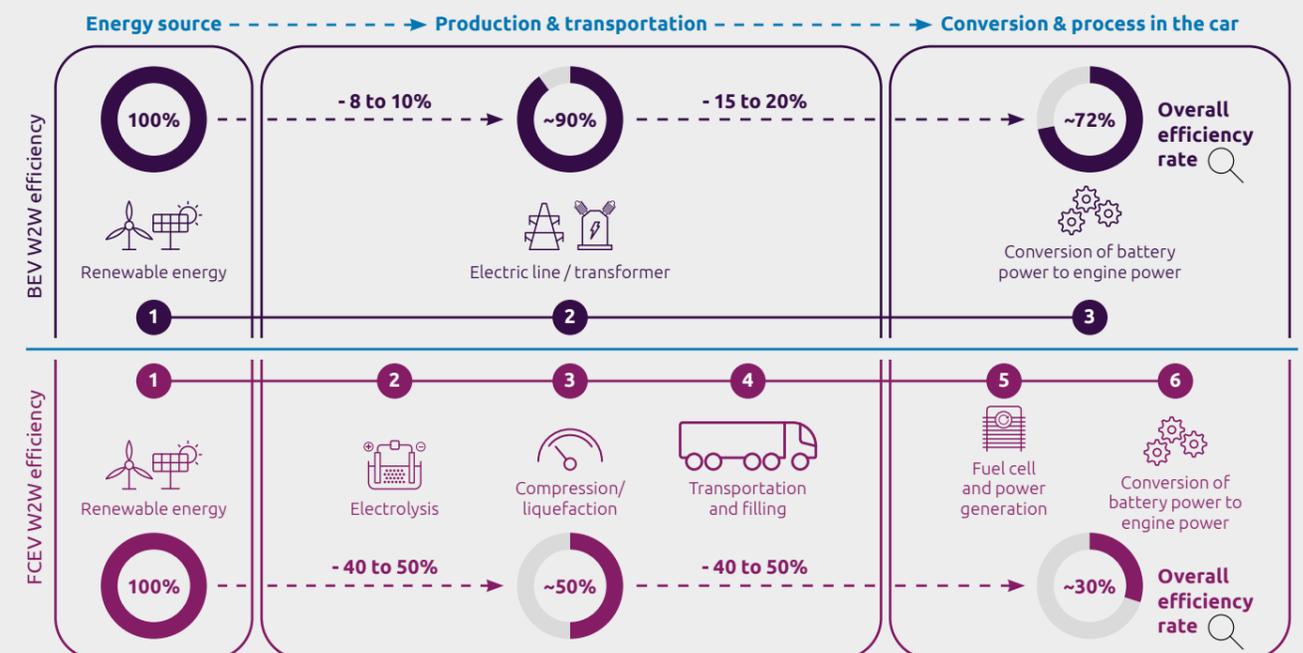
A key technology for green hydrogen is electrolysis, already tested for large-scale applications by several projects. During electrolysis, electricity is used to separate water into hydrogen and oxygen. In contrast, BEVs can directly use electricity for charging. This casts doubt on the efficiency of the well-to-wheel (W2W) process for FCEVs. (W2W analysis describes the efficiency of the complete process chain from production of the primary energy through to conversion into kinetic energy by a vehicle.)

Looking at the W2W of BEVs, even for long-distance transportation (about 700km) of electricity only, between 8–10% is lost before it is stored in the BEV’s battery.⁵ Depending on the vehicle’s technical characteristics, another 15–20% is lost in the electric motor during conversion to kinetic energy. Combining these numbers results in a BEV W2W efficiency level of roughly 70–80%.

The overall efficiency rate of FCEVs is significantly lower. Around 40–50% of primary energy is already lost during production of hydrogen by electrolysis and transportation to the hydrogen station. Of the energy that is left, 40–50% is again lost during the conversion by the fuel cell and the electric motor. This leads to an W2W efficiency level of only 25–35% for hydrogen cars.⁶

Based on the lower overall W2W efficiency of hydrogen cars, adoption of FCEVs instead of BEVs would increase the **demand for renewable energy by a factor of around 2.4.** A possible solution is to establish energy partnerships, because it is cheaper to produce renewable energy in some countries whereas others have only limited renewable energy resources.

Figure 4: Comparison of well-to-wheel (W2W) efficiency of BEVs and FCEVs



Because the W2W efficiency of FCEVs is less than half that of BEVs, **2.4 times as much renewable energy would be required**

⁵ https://www.destatis.de/DE/Themen/Querschnitt/Jahrbuch/jb-energie.pdf?__blob=publicationFile

⁶ <https://www.volkswagenag.com/en/news/stories/2019/08/hydrogen-or-battery--that-is-the-question.html>



FUEL CELLS COULD BE A GOOD SOLUTION FOR TRUCKS

The automotive industry will focus on BEVs in the upcoming years to meet European CO2 targets and avoid fines, and to counter competition from abroad. However, fuel cell technology has potential for the future, particularly where long distances and heavy loads are involved – so the truck business is very interested. **Cost parity between battery-powered trucks and fuel cell trucks is reached at a range slightly above 100km, and the fuel cell trucks can carry a higher payload.** Startups such as the Nikola Motor Company partner with manufacturers such as

Bosch, Mahle, and Iveco to produce hydrogen-driven trucks with a focus on these use cases.

There are still obstacles to overcome, but the automotive industry won't necessarily have to solve them alone. For example, hydrogen can be used as a synthetic fuel for internal combustion engines, trains, or airplanes, and the chemical and steel industries use hydrogen for many of their processes. It's possible that these other industries and use cases will push forward and establish green hydrogen as a CO2-free

alternative energy source. This would make it possible for the development of fuel cell technology to proceed, and probably its efficiency would then improve to the point where it is suitable for mass market production.

However, it remains an open question whether the automotive industry would then adapt its product portfolio to include FCEVs, or whether the lock-in effect of BEVs would already be too high creating an unassailable technical lead.

In the longer term, fuel cell technology may cross the finishing line, at least for specialist use cases such as trucks. For at least the next decade, though, battery-driven technology will likely retain its place on the victor's podium.

BEVS ARE THE WINNERS FOR NOW, BUT FOR THE LONGER TERM, FCEVS ARE WORTH WATCHING TOO

As we have seen, BEVs have forged ahead of FCEVs to dominate the worldwide market for passenger cars, but there is of course room for improvement even with regard to BEVs.



Product:

- ✓ OEMs are focusing on expanding their BEV offering and are reducing R&D in fuel cell technology
- ✓ Even though many German OEMs have built FCEV prototypes and small series, not one has a FCEV model in mass production
- ✓ In 2019, more than 1,700,000 BEVs were sold compared to only 7,500 FCEVs.



Infrastructure:

- ✓ A hydrogen fueling process is four times quicker than charging at a 150 KW fast charging point (~5min vs 20min)
- ✓ Because of the lack of economies of scale, building a hydrogen station infrastructure exceeds the costs of building a comparable charging infrastructure (at least when FCEV penetration is lower than about 30%)⁷
- ✓ Functional charging infrastructure is already in place compared to a sparsely developed hydrogen infrastructure.



Technology:

- ✓ Renewable energy needs to be the base of both technologies to reduce CO2 emissions and enable sustainable mobility
- ✓ A 2.4x higher demand for renewable energy results from the poorer well-to-wheel efficiency of FCEVs: 30% compared with 72% for BEVs.

However, for heavy-duty applications such as long-haul trucks, fuel cell technology might become a valid solution and make its way to the mass market in the next decade. This depends on whether it becomes possible to produce green hydrogen for industrial applications with sufficient economies of scale to be leveraged for mobile use. We will return to this topic in a future article.

Based on the analysis described here, we expect BEVs will continue to predominate over FCEVs, at least for the next 10 years, thanks to advantages that can be summarized as:

- ✓ Better well-to-wheel efficiency
- ✓ Higher infrastructure availability
- ✓ Market-ready technology.

Battery Electric Vehicles is part of Capgemini's Smart Mobility Connect offering. It empowers OEMs to create the mobility ecosystem of the future designed with people at heart. We bring the mobility ecosystem of the future to life through a host of products and services within three core pillars: Connected Customer, Connected Services and Products as well as Connected Ecosystem.

The technological framework that helps us deliver on our approach, the Customer Engine, connects these pillars and integrates intelligence into different stages of the journey.

Find out more: www.capgemini.com/invent/smart-mobility-connect

⁷ Based on RWTH Aachen: Comparative analysis of Infrastructures: Hydrogen fueling and electric charging of vehicles.

About Capgemini Invent

As the digital innovation, consulting and transformation brand of the Capgemini Group, Capgemini Invent helps CxOs envision and build what's next for their organizations. Located in more than 30 offices and 22 creative studios around the world, its 6,000+ strong team combines strategy, technology, data science and creative design with deep industry expertise and insights, to develop new digital solutions and business models of the future.

Capgemini Invent is an integral part of Capgemini, a global leader in consulting, technology services and digital transformation. The Group is at the forefront of innovation to address the entire breadth of clients' opportunities in the evolving world of cloud, digital and platforms. Building on its strong 50-year heritage and deep industry-specific expertise, Capgemini enables organizations to realize their business ambitions through an array of services from strategy to operations. Capgemini is driven by the conviction that the business value of technology comes from and through people. It is a multicultural company of almost 220,000 team members in more than 40 countries. The Group reported 2019 global revenues of EUR 14.1 billion.

Visit us at

www.capgemini.com/invent

The information contained in this document is proprietary.
©2020 Capgemini Invent. All rights reserved.



Christian Hummel

Vice President Head of Automotive
DACH

christian.hummel@capgemini.com



Dr. Philipp Martin Haaf

Head of Electric Mobility

philipp.haaf@capgemini.com

Other authors

Daniel Buchmann

Daniela Niemann

Jan Huppertz

Stefan Kolbeck