ARE FUEL CELL ELECTRIC CARS BETTER THAN BATTERY ELECTRIC CARS?

Insights from battery systems expert, Bostjan Hari, PhD

PRESCOUTER

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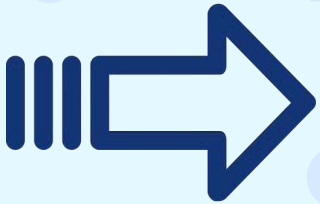
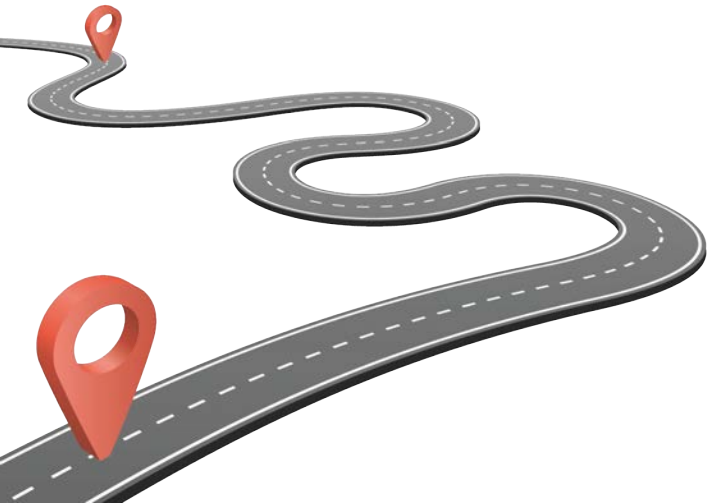
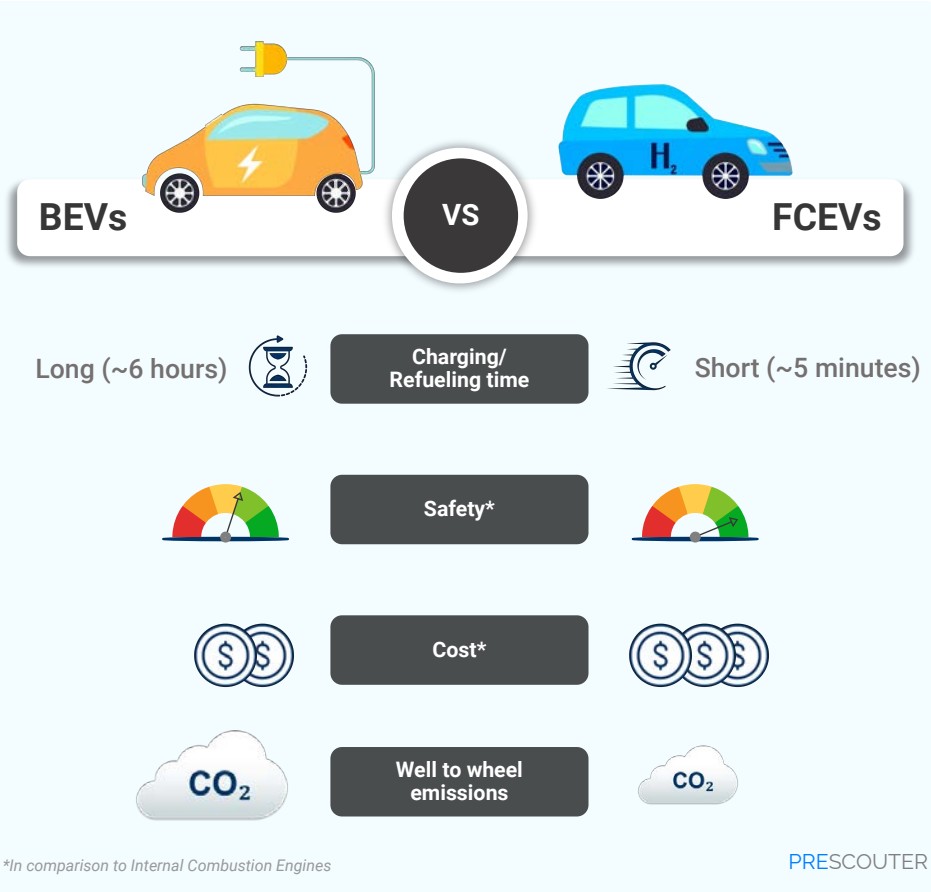


In the absence of an infrastructure to support Fuel Cell Electric Vehicles (FCEVs), Battery Electric Vehicles (BEVs) are the more favorable option *today*.

This could change within the next 5 to 10 years as investments in hydrogen production and infrastructure surge, pushing FCEVs to potentially surpass the BEV market and become the more sustainable option.

BEVs vs FCEVs: How do they compare?





Expert insights:

“There will be another potential bottleneck in the near future for BEVs, as we have recently witnessed shortages of automotive electronic chips, which could last until 2023. Since all major automotive companies have started ramping up production of batteries (and competing to secure raw materials) for their upcoming BEVs, there might be a problem with mining and supply chain of battery materials (cobalt, graphite, lithium, nickel), or even copper for many wires needed in BEVs. If that indeed happens (and is very likely), companies that also manufacture FCEVs, such as Hyundai and Toyota (and BMW and JLR in the near future), would be in a much better position, because they could sell more FCEVs due to BEVs shortages. And that could change the minds of customers to switch to FCEVs. The future looks exciting and uncertain at the same time.”

- Bostjan Hari, PhD, Battery Systems Engineer

Cutting well to wheel emissions is the biggest driving factor of the EV market in particular and the automotive sector as a whole. Contrary to common belief, BEVs might not be the only answer to do so. FCEVs could also become the renewable energy solution for the automotive sector.

With an estimated one billion passenger vehicles on the roads today, the commercial vehicle market potentially emits 4.6 billion metric tons of carbon dioxide (CO_2).

Several auto manufacturers have been manufacturing and marketing low-emission and/or zero-emission vehicles for years; namely, these have been BEVs and plug-in hybrid-electric vehicles (PHEVs). Despite achieving the perceived goal of reduced carbon emissions, the lithium-ion batteries (LIBs) used in these types of vehicles are projected to pose a grave environmental crisis as LIBs from BEVs reach their end of life and in the absence of efficient recycling processes.

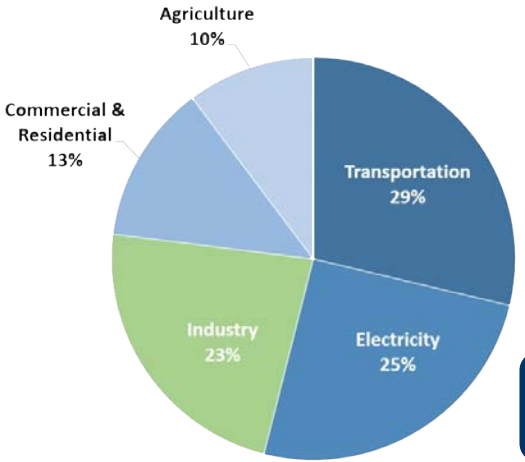
In this Intelligence Brief, we cover some of the technological advancements in the FCEV space by profiling innovations from 11 companies. We also discuss some of the emerging technologies and market opportunities for future FCEVs.

Automakers need to cut emissions to comply with new regulations.

FCEVs and BEVs (more commonly referred to as EVs) are similar in that they use an electric motor instead of an internal combustion engine to power the vehicle. While EVs run on LIBs that must be plugged in to recharge, FCEVs generate their electricity from on-board hydrogen tanks or cylinders connected to fuel cells. Both technologies offer zero tailpipe emissions, presenting a sustainable and environmentally friendly solution.

However, regulatory bodies have moved beyond looking at just tailpipe emissions to the overall carbon footprint of a vehicle, from materials used to the fate of end-of-life car components such as batteries. LIBs from EVs are on track to generate a multimillion metric ton of waste with the growing popularity of EVs. Economically speaking, mining raw materials is easier than recycling batteries for metal recovery. This, paired with difficulties in current battery recycling processes, is why less than 5% of batteries are recycled globally. The European commission has proposed strict battery-recycling requirements, which could come into place by 2024.

According to the U.S. Environmental Protection Agency (EPA), a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year. And the Center for Climate and Energy Solutions (C2ES) estimates that 29% of U.S. greenhouse gas emissions come from the transportation sector, making it the largest source of total U.S. greenhouse gas emissions.



Total U.S. Greenhouse Gas Emissions by Economic sector in 2019

Total emissions in 2019 was 6,558 million metric tons of CO_2 equivalent.
Source: C2ES.

1. https://www.edfenergy.com/electric-cars/batteries
2. https://theicct.org/sites/default/files/publications/Zero%20Emission%20Vehicle%20Mandate%20Briefing%20v2.pdf
3. https://www.epa.gov/greenvehicles/hydrogen-fuel-cell-vehicles
4. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle
5. https://www.c2es.org/content/regulating-transportation-sector-carbon-emissions/
6. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

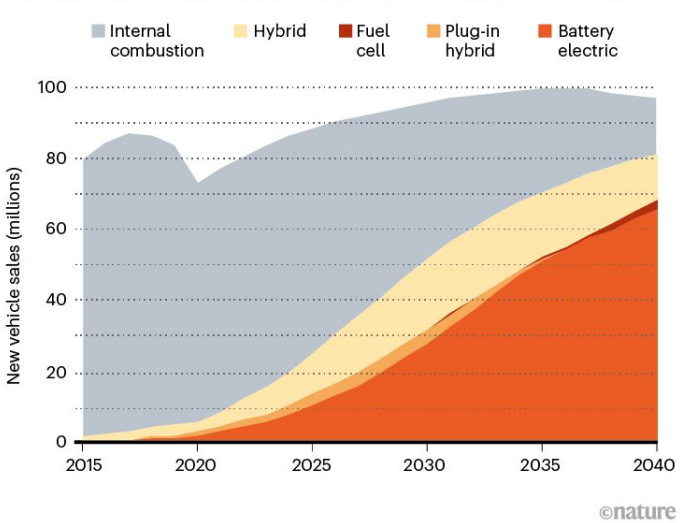
BEVs might not be the answer and, at present, are not a viable solution.

Although there are many debates on the efficiency and effectiveness of BEVs, Volkswagen and some other supporters argue that BEVs are the technology that should be used in passenger cars, claiming BEVs are a more energy-efficient alternative than FCEVs. They said in other applications, such as heavy-duty transport, aviation, and shipping, FCEVs might be an option in the long run. The most defended and mentioned point by the supporters of BEVs are maturity of the technology and readiness for the mass market. It is understandable, since huge amounts of investment decisions were made by some of the global players already. They do not want to lose their positions.

In a scenario where world might be dominated by BEVs, materials scientists will have some big challenges, such as battery recycling, as previously mentioned. It is still less expensive, in most instances, to mine metals than to recycle batteries. Moreover, whether recycling or not, batteries pose harsh environmental and social costs. Another challenge for researchers is to reduce the amounts of metals that need to be mined for BEV batteries.

Despite these challenges, it is not anticipated to move away from lithium-ion batteries any time soon due to their cost reduction and performance improvement over the years since the early 1990s, when they first entered to the market.

Requirement of longer charging time and presence of shorter range of BEVs also prevent them to be a long-term choice in transportation.



A forecast suggests that by 2035, more than half of new passenger vehicles sold worldwide will be electric, even without further policies to promote switching. Source: Nature.

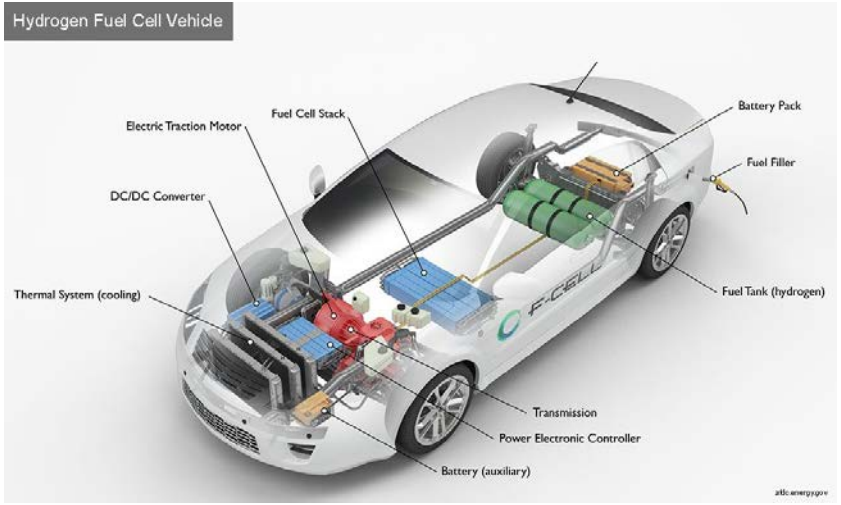
1. https://www.nature.com/articles/d41586-021-02222-1
2. https://www.caranddriver.com/research/a32758614/electric-cars-pros-and-cons/
3. https://www.energysage.com/electric-vehicles/101/pros-and-cons-electric-cars/
4. https://www.volkswagenag.com/en/news/stories/2020/03/battery-or-fuel-cell--that-is-the-question.html
5. https://www.greencarreports.com/news/1127660_battery-electric-or-hydrogen-fuel-cell-vw-lays-out-why-one-is-the-winner

Fuel cells can be a 100% renewable and environmentally friendly energy system.

FCEVs are zero-emission vehicles. While hydrogen is abundant in the universe, it is required to apply some chemical processes to dissociate hydrogen from other compounds to be used as fuel. Hydrogen sourcing and production methods are diverse. Current methods often come from natural gas. But hydrogen fuel can also be made from water, oil, coal, plant material, and even from trash. Electricity generated from renewable sources such as wind, solar, geothermal, or biomass is also another source in the production of hydrogen.

Since today's FCEVs are mainly composed of a fuel cell and battery combination, they are called hybrid electric vehicles. The fuel cell EV has advantages over the advanced lithium-ion battery EV on six major counts listed on the right.

- ✔ Weighs less
- ✔ Appropriate for travelling longer distances
- ✔ Generates less greenhouse gases
- ✔ When mass produced, will potentially cost less
- ✔ Requires less well to wheels energy
- ✔ Takes less time to refuel



Key Components of a Hydrogen Fuel Cell Electric Car. Source: AFDC.

1. https://www.energy.gov/eere/fuelcells/hydrogen-resources
2. https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work
3. https://www.sciencedirect.com/science/article/abs/pii/S1364032117303647
4. https://www.energy.gov/sites/default/files/2014/03/f9/thomas_fcev_vs_battery_evs.pdf

BEVs vs FCEVs: Which is safer?

Hydrogen fuel cell energy storage systems are safer than batteries alone. Lithium is the lightest metal on earth, reacts violently with oxygen, and is toxic. Lithium is highly flammable by nature. Despite this factor, we still use it in batteries due to many other advantages.

> ***A fully charged battery pack can lead to an explosion if only one cell explodes inside the battery pack due to a chain reaction of cell failures (Tesla Model S has around 7000 cells in a battery pack). It is also difficult to extinguish such battery pack explosions.***

Hydrogen is a combustible, explosive, non-toxic, colorless, odorless, and tasteless gas. Hydrogen sensors are needed to detect if hydrogen escapes from the tank (cylinder). BUT, in combination with air, hydrogen can only cause fires or explode if it comes in contact with a spark or flame.

KEY TAKEAWAY: In an FCEV “fireless” crash, hydrogen tanks (cylinders) may simply just crack, although unlikely. In a BEV “fireless” crash, damaged batteries may catch fire or cause an explosion. Hence, accidents are not a major concern with FCEVs.

A look at the FCEV market segments today

FCEVs today: A summary of the profiled technologies

Name	Type of automobile	Technology maturity	Range	Refueling time	Hydrogen storage capacity
Honda – Clarity Fuel Cell	Sedan	Commercially available	Up to 750 km	3-5 min	5.46 kg
Hopium - Machina	Sedan	Prototype	1000 km	3 min	6.0 kg
KPIT & CSIR	Sedan	Prototype	250 km	Unspecified	1.75 kg
Toyota – Mirai	Sedan	Commercially available	More than 700 km	Less than 5 min	5.6 kg
BMW - i Hydrogen NEXT X5	SUV	In trials / Pilot	Several hundred kilometers	3-4 min	6.0 kg
Great Wall Motor Co. (GWM)	SUV	In trials / Pilot	Up to 900 km	3 min	Unspecified
Hyundai – NEXO	SUV	Commercially available	666 km	5 min	6.3 kg
Land Rover – Defender	SUV	Prototype	Unspecified	Unspecified	Unspecified
Hyperion - XP1	Supercar	Prototype	1635 km	3-5 min	Unspecified
Viritech – Apricale	Supercar	Prototype	805 km	Unspecified	More than 5.0 kg
Stellantis	Van	In trials / Pilot	400 km	3 min	4.5 kg

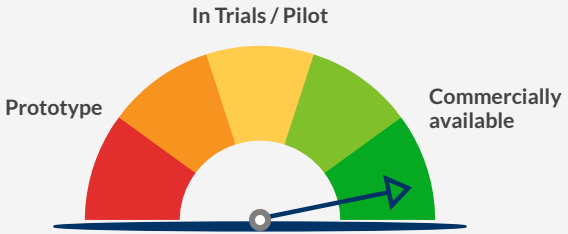
Hydrogen Fuel Cell Electric Sedan

Honda - Clarity Fuel Cell

Type of automobile

- Sedan ✓
- SUV
- Supercar
- Van

Technology maturity



Technical specs

Range	Up to 750 km
Hydrogen storage capacity:	5.46 kg
Refueling time:	3-5 minutes
Source of fuel cell components:	Honda

Hydrogen Fuel Cell Electric Sedan

Honda - Clarity Fuel Cell

Technology Overview:

The idea of the Honda Clarity Fuel Cell is based on some 20 years of Honda research and development efforts. One of the distinguishing properties of the model is having the entire fuel cell powertrain fit under Clarity's hood. The vehicle has a 579 km range and 750 km in new designs. Refueling can be performed in 3 to 5 minutes at a hydrogen refuelling station, with a fuel tank capacity of 5.46 kg. Top speed is reported to be 165 km/h.

2021 Honda Clarity Fuel Cell. Source: Honda.

Hydrogen Fuel Cell Electric Sedan

Honda - Clarity Fuel Cell

Technology Details:

A smaller fuel cell stack was developed by improving a PEM fuel cell performance and cell structure design. The Clarity Fuel Cell powertrain is composed of a fuel cell stack, hydrogen and air supply system, air compressor, fuel cell voltage converter unit, and drive motor. The propulsion system includes lithium-ion battery cells for energy storage, apart from hydrogen tanks. A higher torque and higher output were achieved by increasing the motor's maximum drive voltage. A new Clarity Fuel Cell design offers a range of up to 750 km, 3 minutes refueling time, and 4 times more impact-resistant fuel cell stacks.

The Honda Clarity fuel cell engine. Source: Caricos.

1. *https://automobiles.honda.com/clarity-fuel-cell#how-much-cost*
2. *https://hondanews.com/en-US/honda-automobiles/releases/release-4f88c507e72a4e7630685979cb04f2cb-2021-clarity-fuel-cell-specifications-features*
3. *https://h2.live/en/fuelcell-cars/honda-clarity-fuel-cell/*

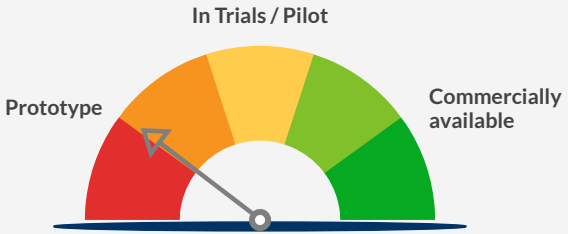
Hydrogen Fuel Cell Electric Sedan

Hopium - Machina

Type of automobile

- Sedan ✓
- SUV
- Supercar
- Van

Technology maturity



Technical specs

Range	1000 km
Hydrogen storage capacity:	6.0 kg
Refueling time:	3 minutes
Source of fuel cell components:	Plastic Omnium

Hopium - Machina

Technology Overview:

Hopium's Machina is a Type IV prototype that will produce around 500 hp with hydrogen fuel cells and batteries, where hydrogen is stored in hydrogen tanks under 700 bar. The technology is characterized as ergonomic, convenient, durable, and sustainable. A shorter refueling time, lighter fuel cell and hydrogen storage system compared to battery-based electric vehicles (EVs), and longer driving range make the hydrogen fuel cell technology of the Machina attractive for the market, especially for racing. Hopium aims to develop hydrogen FCEVs by balancing efficiency and performance at the highest level.

Hopium Machina platform concept. Source: Hopium.

Hydrogen Fuel Cell Electric Sedan

Hopium - Machina

Technology Details:

Hopium is a French startup that focuses on hydrogen fuel cell automotive manufacturing. The Hopium Machina is designed to deliver performance, with more than 500 hp, 230 km/h, and 1,000 km of range, along with a refueling time of 3 minutes. The capacity of the hydrogen tank is reported as more than 6 kg. The prototype Alpha 0 model of Hopium Machina is estimated to enter the market in 2026. The fuel cell has a compact design that is supplied by three hydrogen tanks, where two are in the middle and one is in the back of the car.

Hopium Machina sedan. Source: Hopium.

1. *https://www.hopium.com/#intro_platform*
2. *https://www.finyear.com/Hopium-Machina-Alpha-0-Hits-the-Road_a44792.html*
3. *https://www.euronews.com/next/2021/06/23/could-hopium-s-hydrogen-sports-car-be-europe-s-answer-to-tesla*
4. *https://fuelcellsworks.com/news/hopium-unveils-its-concept-hydrogen-technological-platform/*

Hydrogen Fuel Cell Electric Prototype Sedan

CSIR and KPIT

Type of automobile

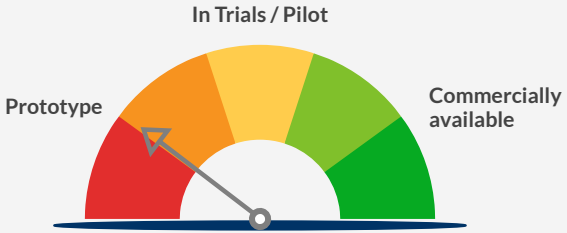
Sedan

SUV

Supercar

Van

Technology maturity



Technical specs

Range	250 km
Hydrogen storage capacity:	1.75 kg
Refueling time:	Unspecified
Source of fuel cell components:	CSIR-National Chemical Laboratory

CSIR and KPIT

Technology Overview:

At the CSIR-National Chemical Laboratory in Pune, India, the Council of Scientific and Industrial Research (CSIR) and KPIT Technologies Limited successfully tested India's first hydrogen fuel cell prototype car powered by an indigenously produced fuel cell stack. KPIT contributed their stack engineering experience, which included the design of lightweight metal bipolar plates and gaskets, the creation of the balance of plant (BoP), system integration, control software, and the electric powertrain that enabled the fuel cell vehicle to run. The fuel cell is a PEM type that operates between 65 °C and 75 °C. The tests were conducted on a battery-electric passenger car platform that had the fuel cell stack retrofitted. The prototype car was fitted with a Type III commercial hydrogen tank and is estimated to have a range of roughly 250 km when driven on Indian roads.

CSIR and KPIT prototype sedan. Source: PIB.

CSIR and KPIT

Technology Details:

The heart of the system is a 10 kWh automotive-grade low-temperature PEM fuel cell stack developed in-house. The fuel cell stack is made up of very thin metal bipolar plates, which cut the stack's weight by two-thirds. The technology is best suited for battery-electric commercial vehicles with large batteries to obtain the needed operational range. The hydrogen fuel cell technology requires a much smaller battery for a very large operating range and offers more flexibility for the commercial vehicle segment. With approximately 250 km range, this technology promises to significantly reduce pollution and fossil fuel consumption.

"The successful trial of the technology is a proud moment for all of us. The technology has a great future and owing to its indigenous development, is expected to be more commercially viable than ever before. This is our contribution to the country's technological growth and vision. It is an important technology that will help India significantly reduce pollution and reduce our fossil fuel imports".

Ravi Pandit, Chairman, KPIT

1. *Autocar India*

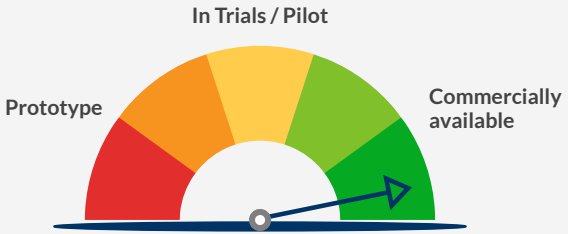
Hydrogen Fuel Cell Electric Sedan Vehicle

Toyota - Mirai

Type of automobile

- Sedan ✓
- SUV
- Supercar
- Van

Technology maturity



Technical specs

Range	More than 700 km
Hydrogen storage capacity:	5.6 kg
Refueling time:	Less than 5 minutes
Source of fuel cell components:	Toyota

Toyota - Mirai

Technology Overview:

The Mirai is the most commercially successful hydrogen fuel cell vehicle from Toyota. The 2021 Mirai offers a driving range of more than 750 km under normal driving conditions, with less than 5 minutes refueling time at a 700 bar refueling station. Thanks to the hydrogen fuel cell system, Mirai is highly efficient and has no exhaust or carbon emission problems (the only exhaust is water or water vapor). The system operates quietly, and the modular setup allows it to be adapted to different usage scenarios.

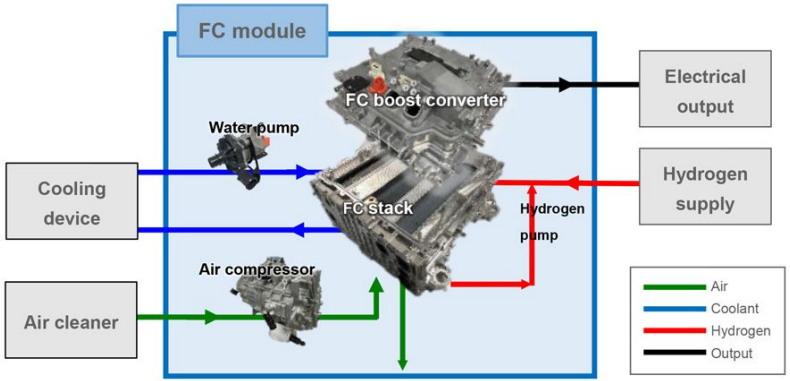
X-ray Mirai image shows powertrain, hydrogen storage tanks.
Source: Wards Auto.

Hydrogen Fuel Cell Electric Sedan Vehicle

Toyota - Mirai

Technology Details:

Toyota's Mirai uses a hydrogen fuel cell system combined with a lithium-ion battery pack to emit zero CO_2 emissions. The hydrogen fuel cell system developed by Toyota allows a 750 km driving range under normal conditions (the Executive Package delivers up to 850 km), with a 5.6 kg hydrogen storage capacity. The PEM-based fuel cell stack offers a maximum power output of 128 kW and a power output density of 5.4 kW/l. The compressed hydrogen can be refilled within 3 to 5 minutes using a 700 bar filling pressure.



Schematic example of connecting the fuel cell module to an external device. Source: Toyota.

1. https://global.toyota/pages/news/images/2020/12/09/1200/20201209_01_02_en.pdf
2. https://electricvehicleweb.com/photos-production-second-gen-toyota-mirai-fcev/
3. https://www.toyota.com/content/ebrochure/2021/mirai_fueling_V11.pdf
4. https://global.toyota/en/newsroom/corporate/35209996.html

Hydrogen Fuel Cell Electric Sport Utility Vehicle

BMW - i Hydrogen NEXT X5

Type of automobile

Sedan

SUV

Supercar

Van

Technology maturity

Technical specs

Range	Several hundred kilometers*
Hydrogen storage capacity:	6.0 kg
Refueling time:	3-4 minutes
Source of fuel cell components:	Toyota and BMW

** Exact range unspecified*

Hydrogen Fuel Cell Electric Sport Utility Vehicle

BMW - i Hydrogen NEXT X5

Technology Overview:

BMW Group carried out research and development for the production of the BMW i Hydrogen NEXT series, a 100% pure electric vehicle that uses hydrogen as fuel and converts it into electricity, with water vapor as the only byproduct. The prototypes of the new series will be tested on European roads to explore how efficiently the CO_2-free drivetrain, model-specific chassis technology, and vehicle electronics systems work together under real-life conditions. BMW is already testing the small series model BMW X5 utilizing this drive technology. From 2022, they plan to pilot the BMW i Hydrogen NEXT series. BMW has also collaborated with Toyota Motor Corporation. The individual cells are made by Toyota Motor Corporation, and the fuel cell stack and complete drive system are developed by BMW Group.

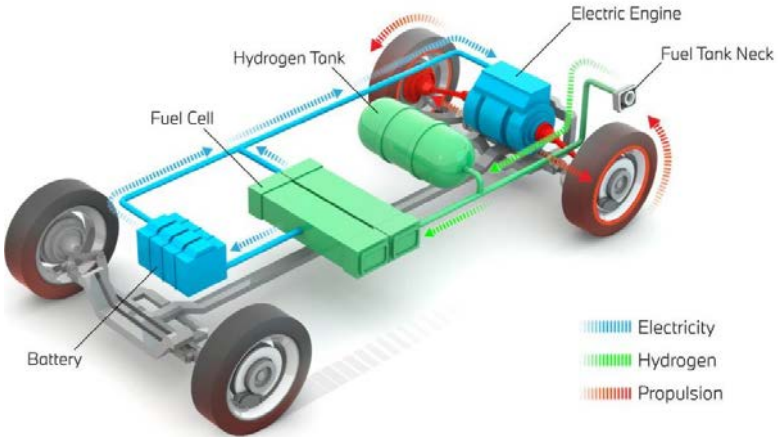
The BMW i Hydrogen NEXT X5. Source: BMW Blog.

Hydrogen Fuel Cell Electric Sport Utility Vehicle

BMW - i Hydrogen NEXT X5

Technology Details:

The BMW i Hydrogen NEXT series vehicle design involves two 700 bar tanks made of carbon-fiber reinforced plastic (CFRP) holding 6 kg of hydrogen. The hydrogen fuel tanks (cylinders) can be filled within 3 to 4 minutes. Hydrogen from the tanks is fed to the fuel cell that generates up to 125 kW, or 170 hp of electrical power. Additionally, energy stored in the buffer battery is used for short bursts of speed for overtaking. The system delivers a total output of 275 kW, or 374 hp.



Overview of an FCEV hydrogen fuel cell technology. Source: BMW.

1. *https://www.press.bmwgroup.com/global/article/detail/T0334225EN/everyday-testing-of-bmw-i-hydrogen-next-with-hydrogen-fuel-cell-drive-train-begins?language=en*

Expert insights:

“Supercapacitors could potentially replace batteries in hybrid propulsion systems with fuel cells. This would be a good application in high-performance cars.”

- Bostjan Hari, PhD, Battery Systems Engineer

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Great Wall Motor Co. (GWM)

Great Wall

Type of automobile

Sedan		SUV	
Supercar		Van	

Technical specs

Range	Up to 900 km
Hydrogen storage capacity:	Unspecified
Refueling time:	3 minutes
Source of fuel cell components:	GWM

Technology maturity

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Great Wall Motor Co. (GWM)

Technology Overview:

Great Wall Motor Co. (GWM) is a well-known pickup truck maker in China. They cooperate with BMW to build electric vehicles and have strong manufacturing capacity in China. Also, Chinese automakers are now moving forward in developing alternative energy technologies with government funding, supportive supply chains, and encouraging policies. GWM is planning to expand quickly, within 5 years, and compete with Toyota and Volkswagen in the future. GWM will mass-produce its first hydrogen fuel cell sport utility vehicles in 2021, targeting the high-end market in China. The company also plans to launch a fleet of 100 49-ton hydrogen-powered trucks.

GWM's FCEV SUV. Source: GWM Global.

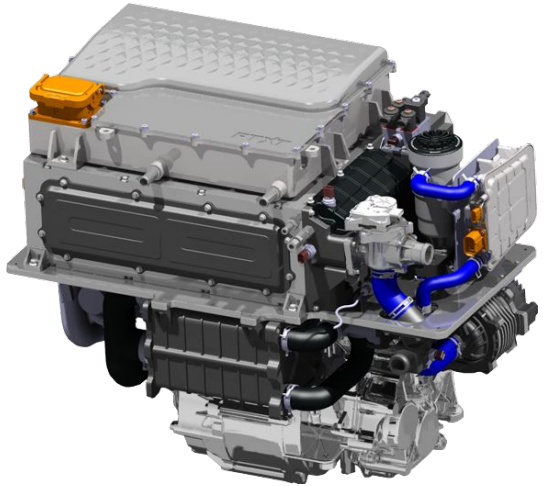
Hydrogen Fuel Cell Electric Sport Utility Vehicle

Great Wall Motor Co. (GWM)

Great Wall

Technology Details:

GWM's Hydrogen Lemon Technology (氢柠技术) includes a hydrogen PEM fuel cell system, hydrogen storage system, and core components. This technology allows for an over 200 kW hydrogen fuel cell system running at higher than 100 °C for over 20,000 hours. The power efficiency of membrane electrode is over 1.3 W/cm^2. The rated power of the first-generation fuel cell stack is 150 kW, and its power density can reach 4.2 kW/l. It can be used with a 95 kW fuel cell system for passenger cars and a 110 kW fuel cell system for commercial vehicles. GWM develops its own Type IV 700 bar high-pressure hydrogen storage system.



The 95 kW fuel cell system. Source: GWM Global.

Expert insights:

"Smaller BEVs, such as Model Y and Model 3 or Volkswagen ID.3 and ID.4, will be the future of cars for daily commute to work and travelling short distances, where charging is possible at home overnight or at work. This is a potential application for the vehicle-to-grid (V2G) system."

- Bostjan Hari, PhD, Battery Systems Engineer

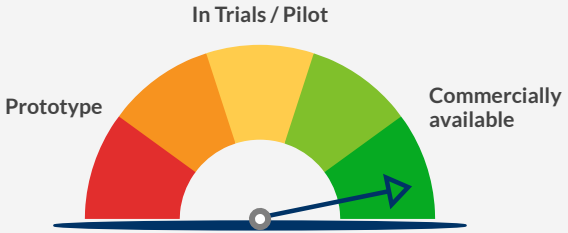
Hydrogen Fuel Cell Electric Sport Utility Vehicle

Hyundai - NEXO

Type of automobile

Sedan		SUV	
Supercar		Van	

Technology maturity



Technical specs

Range	666 km
Hydrogen storage capacity:	6.3 kg
Refueling time:	5 minutes
Source of fuel cell components:	Hyundai

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Hyundai - NEXO

Technology Overview:

The NEXO FCEV from Hyundai is the world's only fuel cell sport utility vehicle (SUV) in mass production, which began in 2013. The powertrain is a combination of fuel cells and battery for powering and energy storage. The hydrogen is supplied to the fuel cells from three hydrogen tanks. Following the hydrogen and oxygen reactions, only electricity and water are generated. Water is emitted through the tailpipe and electricity powers the electric motor. The vehicle was designed to cold start at temperatures as low as -30 °C.

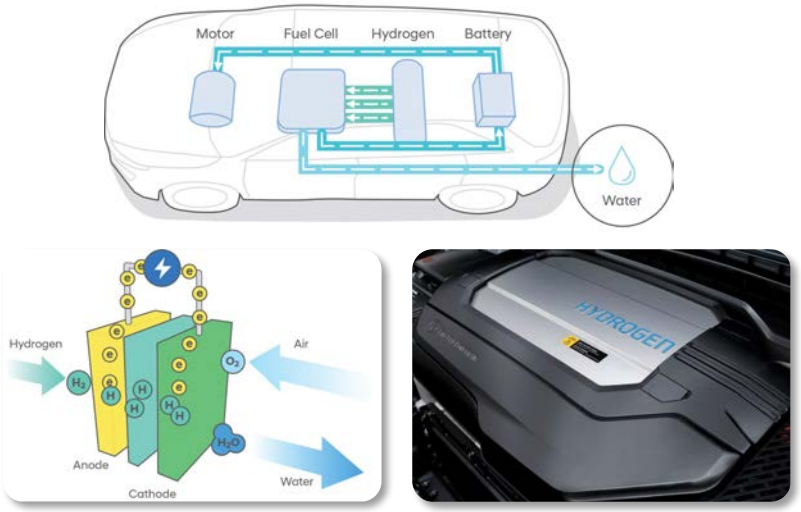
Hyundai NEXO SUV. Source: Hyundai.

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Hyundai - NEXO

Technology Details:

The Hyundai NEXO is the first dedicated hydrogen-powered SUV. Its fuel cell system powers the electric drive motor and charges the 1.56 kWh high-voltage battery. The vehicle has 5 minutes refueling time, up to 756 km range with one refueling, and 179 km/h top speed. It has three equal sized carbon-based hydrogen tanks with a total capacity of 6.33 kg of hydrogen.



Nexo hydrogen fuel technology basic visualization and real appearance.
Source: Hyundai.

1. https://www.hyundai.co.uk/new-cars/nexo
2. https://h2.live/en/fuelcell-cars/hyundai-nexo/

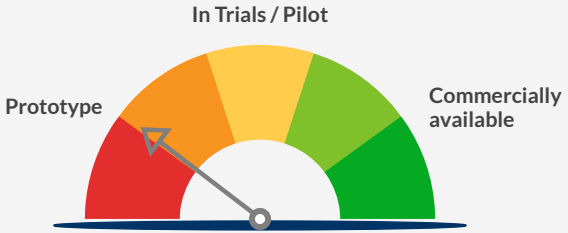
Hydrogen Fuel Cell Electric Sport Utility Vehicle

Land Rover - Defender

Type of automobile

Sedan		SUV	
Supercar		Van	

Technology maturity



Technical specs

Range	Unspecified
Hydrogen storage capacity:	Unspecified
Refueling time:	Unspecified
Source of fuel cell components:	Zeus Project partners

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Land Rover - Defender

Technology Overview:

The fuel cell electric vehicle (FCEV) prototype developed by Jaguar Land Rover is based on the Land Rover Defender. The testing stage is expected to be completed by the end of 2021 in the UK. This hydrogen-powered FCEV has been developed as part of the Zeus project, partially funded by the UK government-backed Advanced Propulsion Centre (APC) along with partners Delta Motorsport, AVL, Marelli Automotive Systems, and the UK Battery Industrialisation Centre (UKBIC).

"We know hydrogen has a role to play in the future powertrain mix across the whole transport industry, and alongside battery electric vehicles (...) The work done alongside our partners in Project Zeus will help us on our journey to become a net zero carbon business by 2039".

JLR Head of Hydrogen and Fuel Cells, Ralph Clague

Hydrogen Fuel Cell Electric Sport Utility Vehicle

Land Rover - Defender

Technology Details:

The FCEV Land Rover Defender prototype has onboard hydrogen storage tanks that deliver hydrogen to the PEM fuel cell supported by a battery pack. The energy from the hydrogen reaction with oxygen is converted into electrical energy, with only pure water as a byproduct.

Hydrogen-powered FCEVs show almost negligible range loss under low temperatures and provide high energy density alongside zero carbon emissions.

Defender on the road. Source: Jaguar Land Rover.

1. *https://media.jaguarlandrover.com/news/2021/06/jaguar-land-rover-develop-hydrogen-powered-defender-fuel-cell-prototype*

Hydrogen Fuel Cell Electric High-Performance Vehicle

Hyperion - XP1

HYPERION

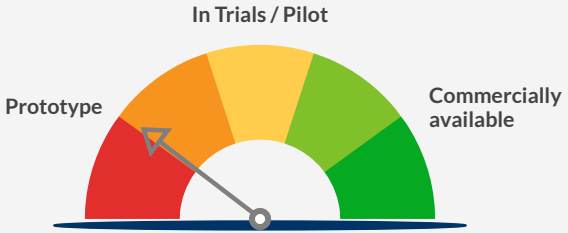
Type of automobile

Sedan		SUV	
Supercar ✓		Van	

Technical specs

Range	1635 km
Hydrogen storage capacity:	Unspecified
Refueling time:	3-5 minutes
Source of fuel cell components:	Unspecified

Technology maturity



Hyperion - XP1

HYPERION

Technology Overview:

Hyperion is a technology company that was founded in 2011 and is active in three sectors: energy, motors, and aerospace. Hyperion has a mission to contribute to the transportation industry by offering expedient, quality, and cost-efficient hydrogen fuel across North America. They use a space flight technology developed by NASA engineers to store more hydrogen in less volume. The company also paid attention to the exterior design of the vehicle by using a full glass canopy and titanium-reinforced carbon fiber composite construction to build a lightweight and durable chassis. Hyperion's high-performance hydrogen-powered electric supercar has a 1016 mile (1635 km) range and can refuel in 5 minutes. Deliveries are expected to begin in early 2022.

Hyperion's XP-1 Hypercar. Source: Tekdeeps.

Hyperion uses a combination of fuel cells and supercapacitors unlike other FCEVs profiled here that use a hybrid fuel cell and battery system.

Hyperion - XP1

HYPERION

Technology Details:

The Hyperion XP-1 goes from zero to 60 miles per hour in under 2.2 seconds and has a top speed of over 221 mph. The XP-1 has an estimated range of 1016 miles (1635 km) with its PEM fuel cell and supercapacitor power system. Former NASA scientists and energy specialists developed technology for Hyperion XP-1 based on many years of experience and the latest technological innovations. The basic principle behind hydrogen fuel cell technology is the electrochemical reaction between hydrogen and oxygen molecules that can release electrical power and emit water as a byproduct. Energy is stored in hydrogen tanks, where its chemical energy is converted into electricity in fuel cells instead of being stored in lithium-ion batteries. This significantly improves refueling times compared to the long charging times of batteries.

Hyperion Hydrogen Propulsion System. Source: Hyperion.

1. *https://www.hyperion.inc/xp1*
2. *https://tekdeeps.com/introduced-hyperion-xp-1-hydrogen-supercar-driving-1600-km-on-one-tank/*
3. *https://www.enginetechnologyinternational.com/news/fuel-cells-technologies/hyperion-unveils-supercar-prototype-with-hydrogen-fuel-cell.html*

Viritech - Apricale

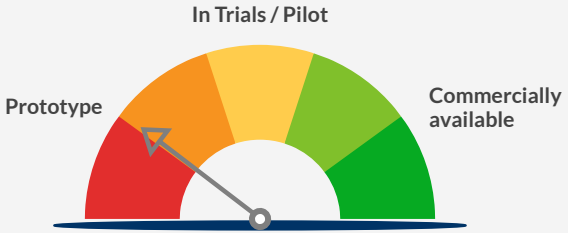
Type of automobile

Sedan		SUV	
Supercar ✓		Van	

Technical specs

Range	805 km
Hydrogen storage capacity:	More than 5.0 kg
Refueling time:	Unspecified
Source of fuel cell components:	Unspecified

Technology maturity



Viritech - Apricale

Technology Overview:

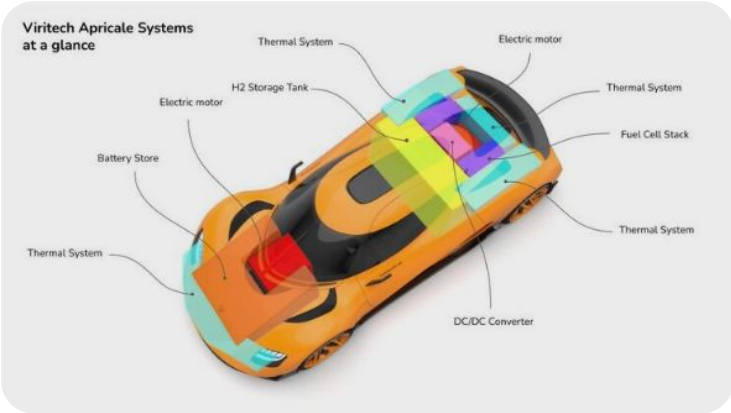
While Viritech is keen to present solutions to the heavy goods vehicle transport, aerospace, and marine industries, Viritech's starting point is the development of the Apricale hypercar for piloting hydrogen fuel cell powertrains. Its hydrogen fuel cell powertrain technology includes vehicle control systems and structural graphene pressure vessels in addition to high-performance energy storage capabilities. The Apricale hypercar is a platform to develop a hybrid hydrogen fuel cell and battery powertrain and related technologies by scaling hydrogen power solutions that are applicable to heavy transport, aircraft, and marine vehicles.

Viritech's hypercar Apricale. Source: Green Car Reports.

Viritech - Apricale

Technology Details:

Viritech Apricale uses a hybrid hydrogen PEM fuel cell and a battery powertrain for efficient energy storage and power generation. The fuel cell generates electricity, while the battery stores electricity generated elsewhere. Apricale has half the weight of its battery competitors. It is targeted to have a range of 805 km and a top speed of 200 mph. Hydrogen storage capacity is anticipated to be more than 5 kg. Viritech has a business model to license its advanced technologies, including Apricale, to global original equipment manufacturers (OEMs) and Tier 1 suppliers.



Schematic view of Viritech Apricale model with hydrogen fuel cell system. Source: Viritech.

1. *https://www.viritech.co.uk/*
2. *https://www.autocar.co.uk/car-news/new-cars/viritech-developing-1100bhp-hydrogen-hypercar-mira-uk*
3. *https://robbreport.com/motors/cars/viritech-apricale-hypercar-powered-hydrogen-1234610539/*
4. *https://www.viritech.co.uk/faqs*

Stellantis

Type of automobile

Sedan

SUV

Supercar

Van

Technology maturity

Technical specs

Range	400 km
Hydrogen storage capacity:	4.5 kg
Refueling time:	3 minutes
Source of fuel cell components:	Faurecia and Symbio

Stellantis

Technology Overview:

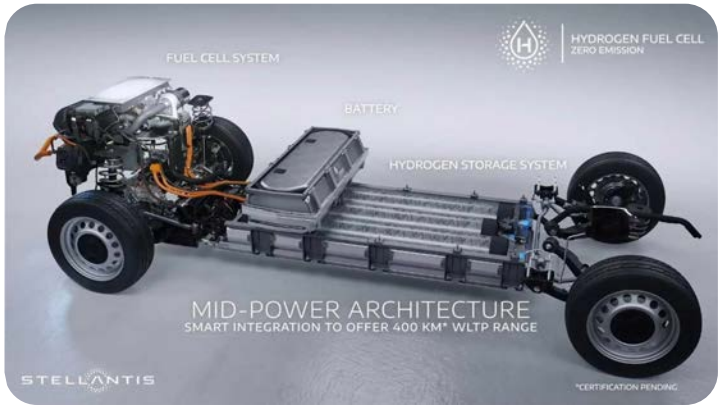
Stellantis is a recently formed multinational automotive corporation by merger of PSA and Fiat Chrysler that is planning to launch hydrogen fuel cell electric vans under the Peugeot, Citroen, and Opel brands. The company introduced itself as a global mobility player with the ambition of presenting attractive, distinctive, and affordable solutions. They claim their vans will have a range of around 400 km (249 miles) and will refuel with hydrogen in just 3 minutes. The company plans to begin deliveries of the first medium-size vans powered by hydrogen fuel cells in Europe by the end of 2021. Packaging, performance, durability, and cost are some of the advantages offered by Stellantis with their mid-power architecture concept.

Stellantis fuel cell van. Source: Inside Evs.

Stellantis

Technology Details:

By partnering with Faurecia and Symbio, Stellantis has developed a fuel cell electric powertrain consisting of a 45 kW hydrogen PEM fuel cell stack and 4.4 kg hydrogen tank compressed under 700 bar integrated under the floor. The hybrid propulsion system includes a relatively small 10.5 kWh lithium-ion battery as a buffer. While the battery pack will control acceleration and deceleration with regenerative braking, fuel cells will be used to generate flat power output with the option to charge from the grid. The company wants to achieve zero emissions, long-range driving, fast refueling, and the same loading capacity as in their combustion engine versions at a reasonable cost. The setup of the combined fuel cell and battery system is designed to mix power sources, where the battery provides power from a standstill, at low speeds, and under acceleration, while the fuel cell is active at cruising speeds, when less energy is needed.



Stellantis mid-power hydrogen fuel cell system. Source: Inside Evs.

1. https://www.reuters.com/article/uk-stellantis-hydrogen-idUKKBN2BN28J
2. https://www.stellantis.com/en/group/about-us
3. https://insideevs.com/news/498495/stellantis-hydrogen-fuel-cell-system/

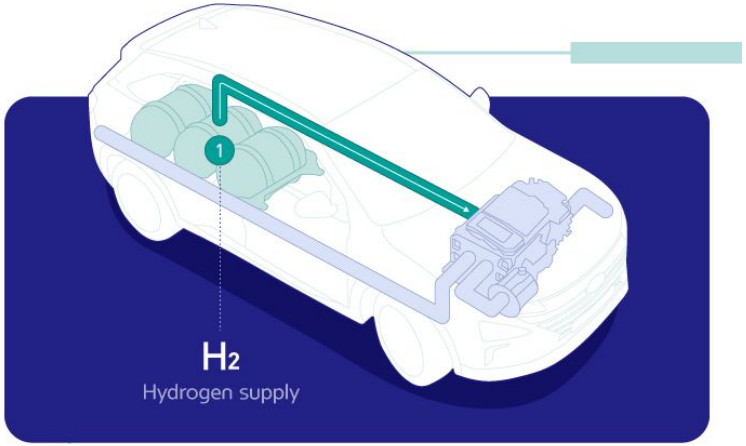
Emerging technologies & market opportunities

What the next generations of FCEVs will look like

The next generation of FCEVs are expected to have improved power densities, reduced costs, and increased durabilities. This will be achieved by a number of advances in green hydrogen production, hydrogen refueling infrastructure, hydrogen storage, fuel cell, and battery technologies.

Compressed hydrogen tanks in passenger FCEVs are bulky and take up a lot of valuable space. This is one drawback currently present in today's hydrogen fuel cell electric cars. One possible solution in the future is to replace bulky hydrogen tanks with lightweight hydrogen metal or non-metal hydrides. But such developments are still in infancy.

Metal hydrides, on the other hand, can absorb hydrogen like a sponge. Upcoming FCEVs that could use metal or non-metal hydrides to store hydrogen will not necessarily need cylindrical shaped storage tanks. Any shape will be possible, providing better weight management and stability. They could be stored between wheels, similar to how batteries are stored in BEVs.



Schematic view of where hydrogen tanks are located in an FCEV. Source: Hyundai.

Emerging market opportunities

In the commercial vehicle market segment, FCEVs show the most value over BEVs in sedan, off-road, sport utility vehicles, and high-performance vehicles (supercars).

An emerging opportunity to maximize this value is by replacing batteries with supercapacitors.

- In off-road vehicles, charging stations are not always available, and driving on rough terrain with ups and downs on the road causes a battery to discharge relatively quickly. Supercapacitors, in combination with fuel cells, could take advantage of this and replace batteries with fast-discharging and fast-charging fuel cells and hence provide a longer driving range.
- In high-performance vehicles, weight reduction is key. Supercapacitors can help achieve that. They last longer compared to batteries, do not need a thermal management (cooling) system, do not need an equivalent to a battery management system (BMS), and can be discharged at higher C-rates.

In public transportation systems, fuel cell buses can benefit from their size to store larger hydrogen tanks under lower pressure compared to fuel cell passenger cars, making them a safer option.

About the Expert

Bostjan Hari, PhD

Battery Systems Engineer

Bostjan Hari holds a BSc degree in Mechanical Engineering focusing on energy and process systems, and an MSc degree in numerical modelling of combustion processes inside internal combustion engines, both from the University of Maribor in Slovenia.

After some years of experience in industry, Bostjan decided to pursue his interests in research and innovation. He graduated with a PhD degree in Chemical Engineering and Analytical Science from The University of Manchester in the United Kingdom working on catalytic microreactors. After completing his PhD project, Bostjan worked at the University of Birmingham in the United Kingdom on collaborative research projects with industry, from biochemical reactors that mimic human duodenum to solid oxide fuel cell propulsion systems for unmanned aerial vehicles. He joined WMG, a special department of the University of Warwick in the United Kingdom, working on industrial lead projects related to design and modelling of lithium-based battery cells and modules with different cooling systems for battery electric vehicles. One of his many interests is also teaching about hybrid hydrogen-based fuel cell and battery electric propulsion systems for applications in air, land, and water transport sectors.

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