Development of the Honda FCX Fuel Cell Vehicle

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ABSTRACT

Honda has developed the ultimate clean power fuel cell vehicle, the FCX, to respond to environmental and energy issues. Honda simultaneously marketed the FCX in the U.S. and Japan in December 2002. This vehicle is provided with a compressed pure hydrogen type fuel cell and an Ultra capacitor as a combined power source, and is driven by a high-performance drive motor. Honda's original packaging technologies enable these units to be fitted in a compact body. The FCX has a practical driving range, high maximum speed, and excellent power performance. The vehicle also ensures crash safety from all directions and comfortably seat four adults.

1. Introduction

In order to make a significant response to various environmental and energy issues, including air pollution, global warming, and the depletion of petroleum resources, the ideal is to have an energy source that does not depend on fossil fuels, in addition to having no toxic substances or CO_2 emissions. Prior to the FCX, Honda had been developing and marketing the electric vehicle Honda EV PLUS, and hybrid vehicles. The focus is now on hydrogen, as the next generation of ideal fuels. Honda has been developing a power train that gives high vehicle energy efficiency, based on a fuel cell that makes possible the ultimate environmental performance. Electricity is generated from a chemical reaction between hydrogen and oxygen, with water discharged as the only by-product. The aim has been to actualize a fuel cell vehicle giving advanced passenger vehicle performance, habitability, and safety.

The FCX series began with simultaneous announcements, in September 1999, of the prototypes V1 and V2, followed in 2000 by V3 and by V4 in 2001. In 2002 the FCX was announced, with further research and refinements made through drive tests using in-house test vehicles, collision safety, hydrogen safety, and electrical safety tests. In addition, tests were carried out on public roads – by participation in the CaFCP (California Fuel Cell Partnership) in the US, and by the Japanese Ministry of Land, Infrastructure and Transport's certification program in Japan.

As a result, on December 2, 2002, Honda announced the world's first fuel cell vehicle, with vehicles delivered to both the Japanese Cabinet Office in Japan, and to the city of Los Angeles in the USA on the same day.

2. Development History

A history of the major specifications for the FCX is provided in Table 1 by showing the transition of specifications from V1, V2, V3, and V4 to the current FCX. The FCX-V1 announced in 1999 was a pure hydrogen fuel cell vehicle, with a hydrogen tank of metal hydride. The V2 was a methanol reformer type fuel cell vehicle.

In September 2000, the FCX-V3 was introduced for participation in the CaFCP. Performance of the power plant system was confirmed by adopting a pure hydrogen gas type fuel cell vehicle which stores the hydrogen fuel in high-pressure hydrogen gas tanks. Furthermore, public road testing was implemented in California with V3 vehicles having a fuel cell stack built by either Canada's Ballard Power Systems or Honda's own in-house developed stack. In July of 2001, Japanese certification was obtained, and public road testing began. The testing continued for approximately one year.

In September of 2001, the basic structure and layout were reviewed, and the announcement of the FCX-V4, which became the foundation for the completed FCX vehicle, was made. The results of the major collision testing items were

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Table 1 History of major specifications

	FCX V1	FCX V2	FCX V3 / V3 with Honda FC Stack	FCX V4	FCX
Exterior					
Hydrogen supply system	Metal hydride	Methanol reformer	High-pressure hydrogen tank (25MPa)	High-pressure hydrogen tank (35MPa)	High-pressure hydrogen tank (35MPa)
Hydrogen storage volume	—	—	100L	137L	156.6L
Fuel cell stack	PEMFC (Proton-exchange membrane fuel cell)	PEMFC (Proton-exchange membrane fuel cell)	PEMFC (Proton-exchange membrane fuel cell)	PEMFC (Proton-exchange membrane fuel cell)	PEMFC (Proton-exchange membrane fuel cell)
Power assist	Battery	Battery	Ultra capacitor	Ultra capacitor	Ultra capacitor
Maximum motor output	49kW[67PS]	49kW[67PS]	60kW[82PS]	60kW[82PS]	60kW[82PS]
Maximum motor torque	—	—	238N·m[24.3kg·m]	238N·m[24.3kg·m]	272N·m[27.7kg·m]
Maximum speed	—	—	130 km/h	140 km/h	150km/h
Range (With LA4 mode)	—	—	180 km	315 km	355 km
Passenger	2	2	4	4	4
Cargo space volume	—	—	—	98 L	102 L

favorable, and it was possible to establish the layout of the major structural elements for the vehicle. V4 also received Japanese certification, and while repeating public road testing, it formed the basis for the production vehicle, the FCX. With these series of modifications, the FCX was manufactured in 2002.

3. Overview of the Vehicle

3.1. Vehicle Appearance

Figure 1 is a photograph of the FCX, and Fig. 2 shows the interior design. The exterior design is based on the body of Honda's electric vehicle, the EV PLUS[(1), (2)]. The design, with the fuel cell power unit fitted in the bottom half of the body, gives a feeling of firmness and steadiness. In addition, the two-tone color with undertones of blue gives an image of hydrogen and water. The interior, too, uses trim colors with blue undertones, giving an integrated design.

Fig. 1 Exterior view of FCX

Fig. 2 Interior design

3.2. Package Concept and Major Specifications

To create a new power train fuel cell system structure that could be mass-produced, a new platform unique to fuel cell vehicles was developed for the FCX. The package concept was as follows.

- Fuel cell system layout concentrated under the floor.
- A compact body, based on the EV PLUS.
- Sufficient cabin and luggage space for four adults.
- A specially designed chassis with original hydrogen tanks giving advanced cruise performance.
- High reliability and safety measures for the hydrogen systems and the high-voltage electrical system.
- All-directional collision safety, protecting both the occupants and the power train.

We succeeded in fitting the fuel cell system within the same dimensions as the EV PLUS and keeping the weight increase to a minimum. Table 2 gives the FCX major specifications.

Table 2 FCX major specifications

Length / Width / Height (mm)	4 165 / 1 760 / 1 645
Wheel base (mm)	2 530
Vehicle weight (kg)	1 680
Number of passengers	4

3.3. Component Layout

In order to achieve a high level of fundamental functions and performance requirements of a vehicle, such as a generous body size, spacious cabin, collision safety performance, etc., a unique platform was developed for the FCX. Figure 3 shows the placement of major components.

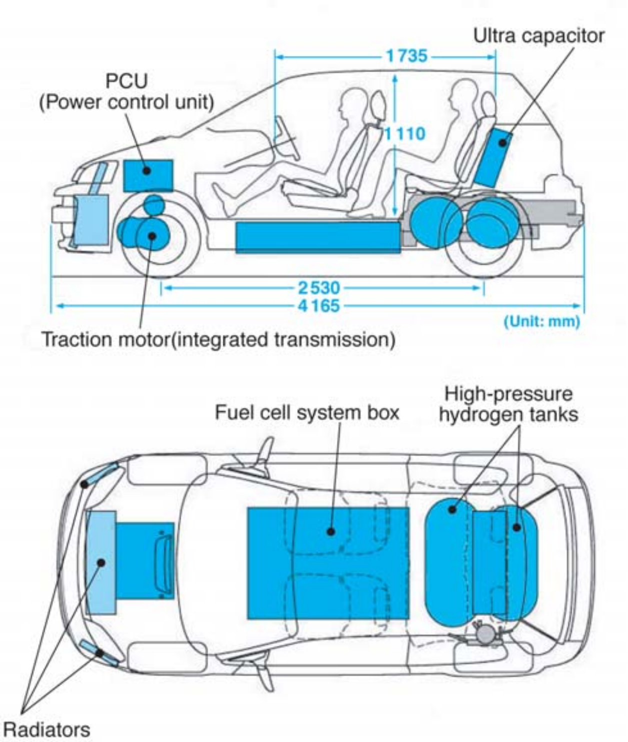

Fig. 3 Placement of major components in FCX

Taking advantage of the freedom allowed by the fuel cell system layout, the high-pressure hydrogen tanks were placed below the rear seats. The fuel cell system placement was concentrated below the cabin floor by giving full considerations to the weight and size. This layout made it possible to maintain a spacious interior while giving advanced collision safety. The Ultra capacitor was placed at an angle behind the rear seat backs, securing sufficient luggage space. In addition, adopted rear suspension uses space efficiently and gives advanced cruise performance. In addition to these innovations, an easy to drive body size was achieved through the use of a compact PCU and a compact transmission. A large fuel cell system radiator was placed in the center, and sub-radiators for the drive train were placed on both sides, giving improved cooling performance. Although it is a fuel cell vehicle with many structural elements, optimal layout enables the vehicle to accomplish a front/rear weight distribution of 55:45, which is an ideal weight ratio for a FF vehicle.

3.4. Major Unit Configuration and Layout

Figure 4 shows the positioning of the major components, and Fig. 5 shows the configuration. All of the major components have a compact layout.

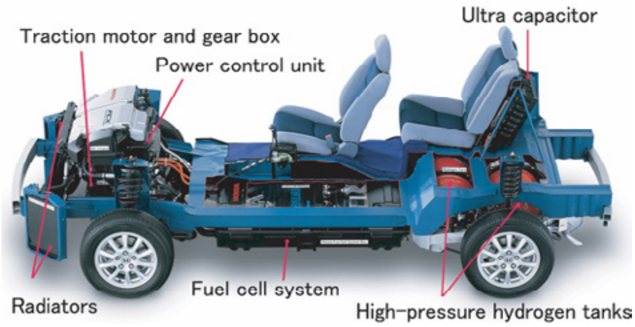

Fig. 4 Positioning of power train

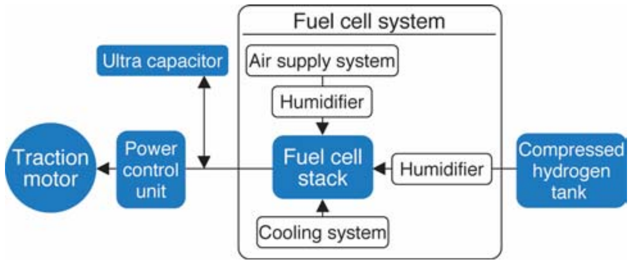

Fig. 5 Simplified diagram of power train system

4. Installed Technologies

4.1. Hydrogen Tank and Installation Structures

In order to improve the vehicle's cruising range, it is necessary that the hydrogen tanks have a large capacity and lightweight structural characteristics. On the FCX, the high-pressure hydrogen tanks have three layers – an aluminum liner, carbon fiber, and glass fiber – giving them strength and corrosion resistance and making it possible to fill at 34.4 MPa. The structure of the hydrogen tank is shown in Fig. 6. Two of these tanks are fitted to the vehicle, yielding a tank capacity of 156.6 L. Together with improvements to fuel consumption, this has resulted in a cruising range of 355 km. In addition, the refueling time using high-pressure charging equipment is approximately 3 minutes, roughly equivalent to that for filling a gasoline vehicle.

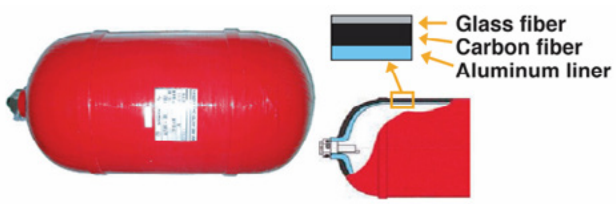

Fig. 6 High-pressure hydrogen tank

As shown in Fig. 7, the two hydrogen tanks are fitted to a sub-frame composed of extruded aluminum members that surround them. A five-link double-wishbone type rear suspension is also fitted to the sub-frame. This configuration makes integrated installation possible, and contributes to efficient use of space.

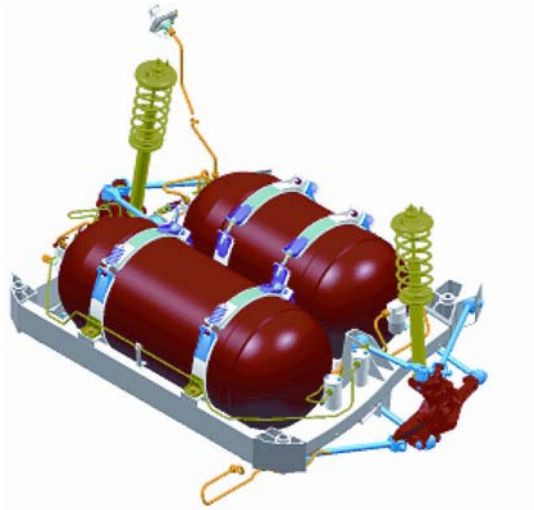

Fig. 7 Rear suspension module

4.2. Hydrogen and High-voltage Safety Measures

As aforementioned, by placing the fuel cell system box under the floor, the structure completely isolates the occupant space from the hydrogen and high-voltage system. In addition, hydrogen sensors were placed in various locations, considering unforeseen hydrogen leaks, and a forced ventilation system is also provided. If a hydrogen leak occurs within the fuel cell system box, the ventilation system will be activated to keep the hydrogen concentration at a safe level. Also provided is a system that automatically shuts off the hydrogen, using the in-tank main valves and shut off valves placed in the hydrogen supply path.

Figure 8 shows the safety system for hydrogen and locations of hydrogen sensors, both important in hydrogen safety. If a hydrogen sensor detects a hydrogen leak with a concentration higher than the specified level, a warning light comes on in the instrument panel, and at an appropriate time, the supply of fuel is cut off.

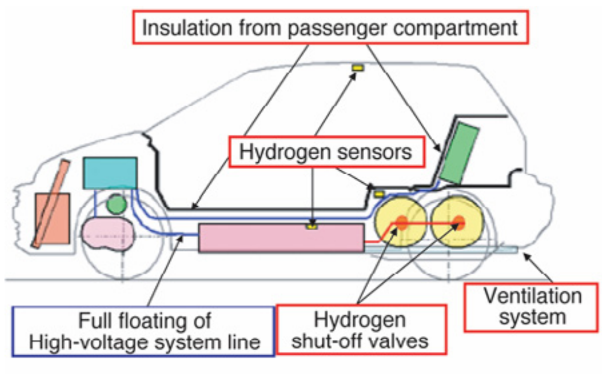

Fig. 8 Hydrogen and high-voltage safety structure and location of the hydrogen sensors

In addition, the high-voltage system is insulated from the body structure. If a ground fault occurs in the electrical systems and the vehicle body, a sensor will give the warning to the occupant, and if a collision occurs, the main power source would be shut off by a circuit breaker. These systems were proven to be safe and highly reliable by repeated floodwater testing, tank fire testing, and others.

Figure 9 shows one example of reliability testing – flood water test in which the vehicle drives through a pool of water.

Fig. 9 Flood water test

4.3. Safety Measures while Charging Hydrogen

The hydrogen charging inlet receptacle provides a good contact with the nozzle, has a highly reliable filter, and has a check valve integrated structure that provides secure sealing of hydrogen. The nozzle geometry prevents the introduction of the wrong type of gas to the vehicle or connection with a nozzle that charges at a higher pressure.

In addition, a grounding system has been adopted that eliminates static electricity from vehicle body prior to hydrogen charging. As shown in Fig. 10, the hydrogen charging inlet lid opener is inside the grounding lid. This safety design feature allows the charging inlet lid opener to be operated only when the grounding lid is open.

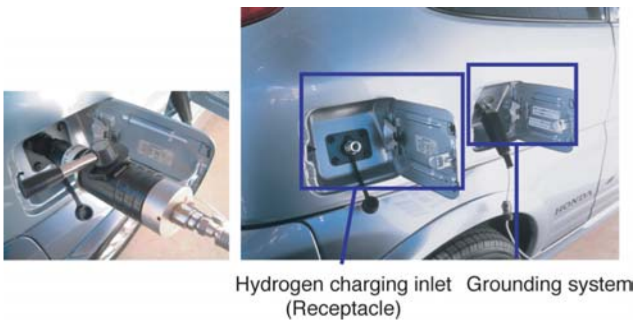

Fig. 10 Hydrogen charging inlet and grounding system

4.4. Body Structure and Collision Safety

4.4.1. Principles of fuel cell system collision safety

In addition to occupant protection, development was carried out to achieve a sufficient safety performance of the fuel cell system and hydrogen tank system against impact and body deformation that may be caused by collisions. The body structure is composed of a shock-absorbing frame, as shown in Fig. 11. The fuel cell's major devices are placed so that they are protected by body frame structures against collision deformation from all sides of the body.

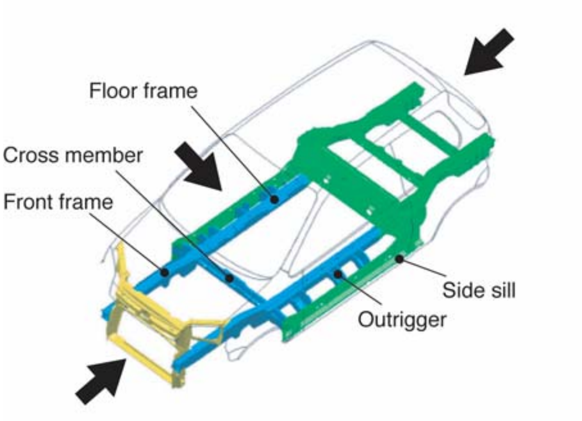

Fig. 11 Basic framework

In the vehicle's longitudinal direction, a sectional straight frame is formed from the front frame to the floor frame, and in the lateral direction, there is a cross member from the floor frame to the side sill and outriggers. The front frame has an impact-absorbing structure, minimizing protrusion into the cabin in a front impact collision. The outriggers effectively absorb the shock of side impact, and minimize the effect of side impact on the cabin and the fuel cell system.

The structure of the box under the body floor storing the fuel cell stacks is a highly secure structure which protects the system against deformation during a collision. Figure 12 shows the rear sub-frame mounting structure and the body structure. The aluminum sub-frame is connected to the rear frame and these two frames above and below form a protective structure for the hydrogen tanks. The Ultra capacitor is placed in the cabin above the hydrogen tanks, and so the body structure forms a firm, protective structure for both the hydrogen and the electrical system.

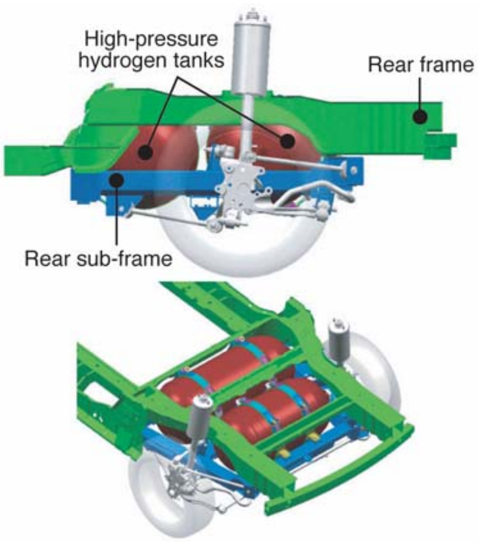

Fig. 12 Rear suspension module & rear sub-frame

4.4.2. Collision test results

In order to verify fuel cell system layout and body structure, collision tests were conducted. Full frontal, front offset, side, and rear impact tests, as shown in Fig. 13, resulted in controlled deceleration acceleration rate and degree of body crush confirming good safety performance for both the hydrogen and electrical systems.

In the collision tests, helium was used as the test gas substitute for hydrogen, because its characteristics are similar. The tests were carried out after charging the hydrogen tanks and piping to approximately 35 MPa.

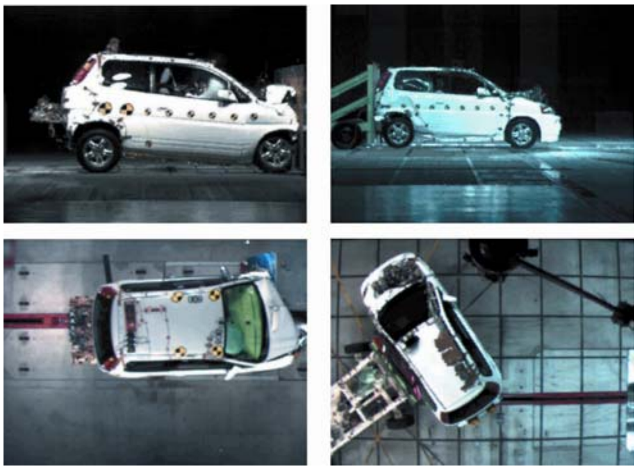

Fig. 13 Crash test images

4.4.3. Shutt off system for electricity and hydrogen during collision

The previous sections explained body structures that provide protection against the collision impact, but to further improve safety, a system is provided to shut off the main power source and the hydrogen supply system during a collision. As in the airbag system that protects occupants from impact acceleration applied to the vehicle body, acceleration sensors are fitted to detect front, side, and rear impact phenomena. This makes it possible to safely stop and isolate the system by shutting off the power source and hydrogen. In order to have collision diagnosis function capable of detecting FR off-set impact as well as local impacts on the side, multiple auxiliary sensors are equipped for improved ability in detecting body deformation.

4.5. Chassis (Suspension, EPS, Brakes)

In addition to a smooth and powerful drive feeling provided by the fuel cell power train, Honda has pursued ride comfort, stability, operating comfort, and etc., with focus on the chassis. From city streets to highways, ease of driving and a comfortable ride have been accomplished.

A McPherson strut was adopted for the front suspension, and for the rear, Honda's five-link double-wishbone type used in the Accord was adopted. They give advanced handling and stability as well as ride comfort.

The steering system is a unique rack assist type electronic power steering system, giving both a natural and smooth steering feel when driving at low speeds, and a feeling of firm stability when driving at high speeds.

The braking force is appropriately assisted by an electric vacuum pump and a master power. In addition, ABS with EBD (electronically controlled brake distribution system) is provided as a standard feature.

4.6. Gauges

An advanced-design original meter cluster for FCV is installed in the FCX to allow the driver to truly experience the system operation when driving the vehicle. The cluster display has the speedometer in the center with the power gauge and hydrogen fuel system indicators on each side. It is a highly effective 3-gauge meter system. Figure 14 shows the display when all the gauges are lit.

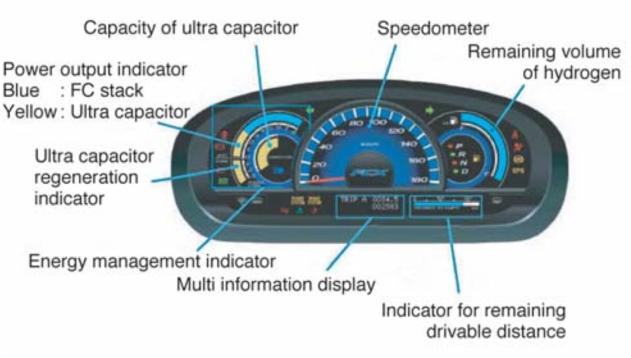

Fig. 14 Cluster design

The output indicator shows various information such as, fuel cell stack output, charged volume of the Ultra capacitor, and the energy management status which changes moment to moment depending on driving conditions. This information is displayed in an easy-to-understand format. Figure 15 is an operation diagram of the output gauges. There is also a remaining drivable distance gauge, which shows the distance the vehicle could travel with remaining hydrogen. Furthermore, in the middle of the bottom there is a multi-information display that can switch between an odometer, trip meter and vehicle status change message display.

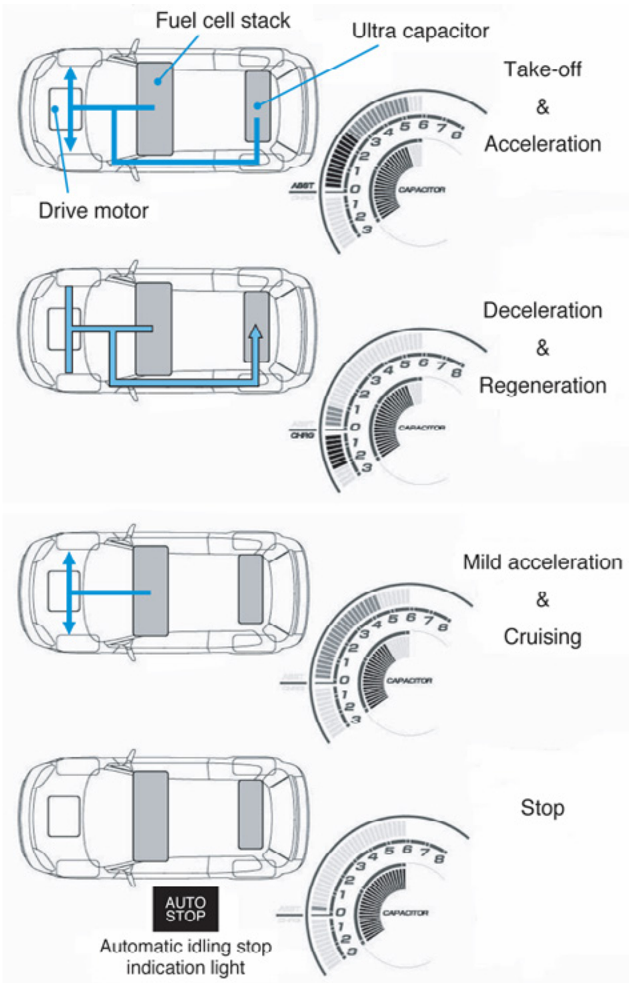

Fig. 15 Graphic images of meter functions

5. Summary

The Honda FCX is the world's first marketed fuel cell passenger vehicle. However, the current version is no more than the beginning of the spread of fuel cell vehicles. Many issues remain, such as low temperature start up, cost reduction, and hydrogen charging infrastructure. These issues must be resolved if there is to be a real popularization of fuel cell vehicles in the near future. Honda will continue to tackle these issues enthusiastically. The more people come to see the wonders of fuel cell vehicles and support their use, the more they will be advanced as the vehicles that are a true response to the environmental issues.

Making the world's first marketing and delivery of a fuel cell passenger vehicle as a milestone, Honda will proceed with even further technological development.

6. Acknowledgments

Finally, the authors would like to express their sincere appreciation to many people who generously gave their cooperation in the sales and delivery of the FCX, including those at each research facility, at the manufacturing plants, and those in the relevant departments in cooperating suppliers.

7. References

(1) Imai, H., Suzuki, S., Hasegawa, O., Matsumoto, K.: Introduction of Electric Vehicle "Clean Urban Vehicle-4", HONDA R&D Technical Review Vol. 7, p. 1-8 (1995)

(2) Ogura, M., Suzuki, S., Matsumoto, K.: Introduction of Electric Vehicle "EV PLUS", HONDA R&D Technical Review, Vol. 9, p. 1-10 (1997)

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