

Development of New Honda FCX with Next-generation Fuel Cell Stack

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ABSTRACT

In December 2002, Honda produced the first practical fuel cell vehicle, delivering models to the Japanese government and to the City of Los Angeles in the United States. To encourage greater public acceptance of fuel cell vehicles, Honda announced a new stack with enhanced performance in low temperatures in October 2003 and installed it in the New Honda FCX. This is the first fuel cell vehicle that can be used below freezing temperature. Vehicles were delivered to New York state in November 2004 and to Hokkaido in January 2005. This paper introduces Honda's fuel cell vehicle, the first to be used in both temperate and cold regions in major cities worldwide.

1. Introduction

Honda developed the Honda FCX fuel cell vehicle (FCV) as an ultra environment-adaptable vehicle and in December 2002 became the first to supply a fuel cell vehicle to the Japanese government and the City of Los Angeles, in the United States. Since then this vehicle has demonstrated that the fuel cell vehicle is an achievable technology, and a large part of society is now aware of this technology^{(1), (2)}.

The next step is to develop the technical elements that will help society to fully embrace hydrogen vehicles. One of the most important issues here has been driving performance at temperatures below freezing, a weak point for earlier fuel cells. In October 2003, Honda announced a stack capable of starting at below freezing temperatures. In February 2004, Honda conducted vehicle starting and driving tests at below freezing temperatures in Hokkaido, and

announced the results. This report introduces the new Honda FCX technology.

2. Development Details

The Development of the new Honda FCX began by using the frame of the 2002 model. The principle technical issue was ensuring the ability of the vehicle to start and drive at below freezing temperatures.

Other goals included enhancing driving performance, including power, fuel efficiency, and range. The vehicle's overall weight and dimension specifications were unchanged from the construction shown in Table 1. However, the fuel cell system was redesigned, with the goals of ensuring that the vehicle could start and drive at -20°C , achieving vehicle energy efficiency of at least 50%,

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Table 1 Major specifications

Model	2005 Model FCX	2003 Model FCX
Length/Width/Height	4165 × 1760 × 1645mm	4165 × 1760 × 1645mm
Wheel base	2530mm	2530mm
Vehicle weight	1670kg	1680kg
Number of passengers	4	4
Maximum speed	150 km/h	150km/h
Range (in LA4 mode)	430 km	355 km
Maximum motor output	80kW [109PS]	60kW [82PS]
Maximum motor torque	272 N·m [27.7kg·m]	272 N·m [27.7kg·m]
Fuel cell stack	PEMFC	PEMFC
Power assist	Ultra-capacitor 9.2F	Ultra-capacitor 8F
Hydrogen supply system	High-pressure hydrogen tank	High-pressure hydrogen tank
Hydrogen pressure	34.4 MPa	34.4 MPa
Hydrogen storage volume	156.6L	156.6L

increasing acceleration by 10%, and providing a vehicle range of at least 400 km. Development proceeded with the goal of winning the first type certification as an FCV in Japan to prove this technology for full-scale mass production.

3. Summary of Vehicle and Its Technology

3.1. Appearance and Basic Specifications

The exterior and interior design of the 2005 FCX are the same as in the previous model, but the body was covered with a bright and transparent-seeming blue base tone to project an image of newness and progressiveness, as seen in Fig. 1. The mascot logo, which is new to this vehicle, projects the image of electricity being produced from hydrogen and oxygen, thus contributing to the global environment. The vehicle is newly equipped with navigation and traction control systems, as well as a standard ABS brake system. The vehicle also has front McPherson struts, rear five-link multi-link suspension and an electronically controlled power steering system.



Fig. 1 Exterior design and mascot mark

3.2. Major Vehicle Equipment

3.2.1. Navigation system

The Honda FCX is equipped with the first navigation system to display hydrogen fueling stations. Such facilities are shown just as gasoline stations are, but with a unique “H2” emblem, and drivers can search for routes and get verbal driving instructions as well (Fig. 2). The NAVI system release coincided with the announcement of the California Hydrogen Highway network, and it earned praise for furthering the arrival of a hydrogen-based society.

The vehicle also has an HVAC system that performs well at below freezing temperature. This system warms the refrigerant directly using an electric heater, for quick and comfortable heating.

3.2.2. Traction control system

To ensure that the vehicle can drive safely on snow, the New Honda FCX is equipped with a traction control system, which is part of its package as an FCV capable of driving at below freezing temperatures. Maximum torque in an electric motor occurs directly after the motor begins to turn, and when taking off on slippery road surfaces, the tires are liable to spin. When driving on snow, the vehicle's new traction control system interprets the driver's intent precisely to ensure smooth takeoff.



Fig. 2 Navigation system

The drive system of the Honda FCX consists of a motor and deceleration gears. Without a clutch, gearshift, or reverse gear, the structure has fewer elements and is much simpler than that of a gasoline vehicle. The characteristics of the drive mechanism, which include minimal transmission loss and a motor that provides higher torque at low rotational speeds than gasoline engines, enable this vehicle to deliver torque to the tires quickly at takeoff and provide extremely agile power performance. By taking advantage of these excellent basic characteristics, the new traction control system can directly control motor torque without using the brakes in situations when the tires spin right after takeoff. As a result, the tires recover their grip quickly after starting to slip and show excellent responsiveness to subsequent demands for speed (Fig. 3).

The quiet, smooth acceleration of the Honda FCX on snow makes the driver keenly aware of its new power performance—quite unlike that of a vehicle with a conventional engine.

3.3. Power Plant System

The development objective of the power plant system was to further enhance the acceleration performance to achieve a sporty feeling, and achieve -20°C startup capability, while also improving fuel economy. Figure 4 shows the layout of the new FCX's power plant system.

3.3.1. Fuel cell stack

The new FCX fuel cell stack uses strong metal separators that are only 50% of the thickness of conventional carbon separators. Moreover, because of the use of integrated molded seals, the cell units are thinner. By using the springiness of stamped metal separators, construction has been simplified by merely encasing the stacked cells with panels, thereby reducing the number of

parts in the entire stack to nearly half. In this way, the fuel cell stack has been made lighter and more compact, and the output density has been increased to more than two times that of the conventional carbon separators stack (Fig. 5)⁽³⁾⁻⁽⁶⁾. The amount of ion exchange substrate that governs ion conductivity was increased significantly compared with that of the conventional fluorine electrolyte membrane. The result was that membrane resistance was halved, excellent proton conductivity was attained even below the freezing point, and a fuel cell stack that could start generating power at -20°C was achieved. Due to the newly developed aromatic electrolyte membrane, which does not soften or deform at high temperatures due to the high strength and high thermal resistance of the main chains, the fuel cell stack can be used at temperatures as high as 95°C .

3.3.2. Fuel cell system

To enhance the space efficiency of the fuel cell system box, the fuel cell stack was divided into two units. By utilizing features of the smaller units, the humidifier modules were integrated (Fig. 6). By efficiently laying out the entire system after integrating/discarding auxiliaries, a compact fuel cell system box was obtained, leading to better energy efficiency by reducing air and fuel pressure losses.

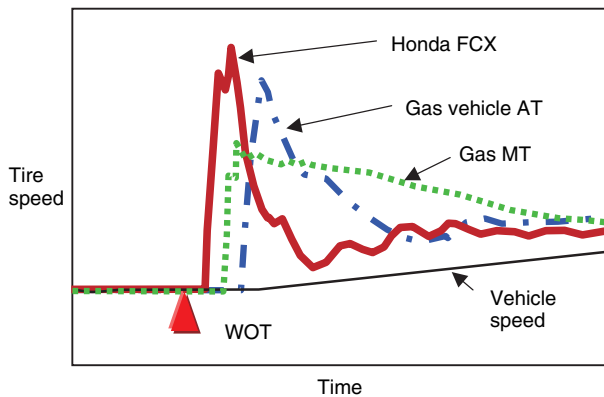


Fig. 3 Response of tire rotation on WOT

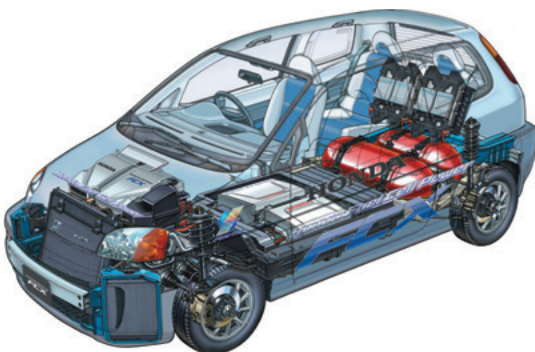


Fig. 4 Perspective view of Honda FCX

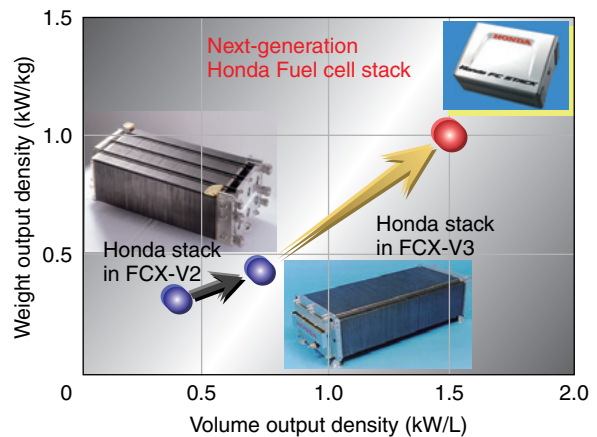


Fig. 5 Evolution of Honda stacks

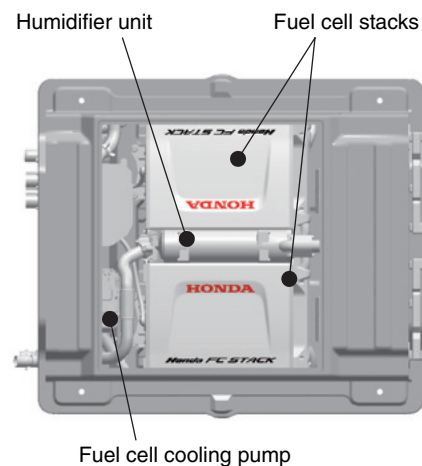


Fig. 6 Fuel cell system box configuration

3.3.3. Drive motor

In addition to raising the fuel cell's output as explained above, Honda also adjusted the output of the drive motor. Eddy current generation was controlled by magnetic partitioning to counter the increase in rotor magnetic flux fluctuation resulting from the combined use with a reluctance system. Furthermore, the use of heat-tolerant magnets and a magnetic circuit configuration designed for high output helped to achieve highly effective demagnetization suppression. As a result, maximum output was increased from the previous 60 kW to 80 kW while maintaining high efficiency over a wide range, meaning that driving potential was increased (Table 2, Fig. 7).

3.3.4. Ultra-capacitor

An ultra-capacitor is used as the auxiliary power source to provide a powerful drive. Conventional high-performance activated charcoal electrodes were used previously. The electrode wrapped-element construction has been reexamined, and the number of turns of the electrode was increased without increasing the size of the cell. This enabled a significant increase in the stored energy capacity. As a result, energy and power were enhanced by more than 10% compared to those of the previous capacitor (Fig. 8). The increased performance of the capacitor allows for increased fuel economy through more efficient energy management.

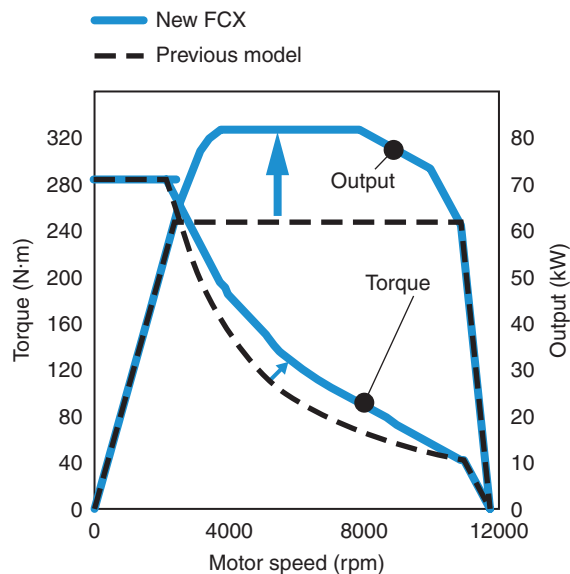


Fig. 7 Output torque characteristic

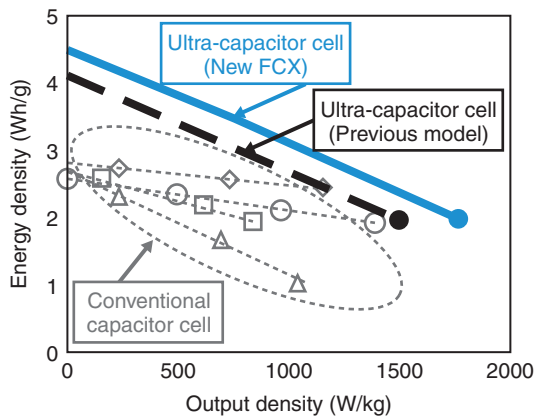


Fig. 8 Capacitor charging and discharge performance (cell unit)

Table 2 Comparison of drive motor performance

	New FCX	Previous model	EV-Plus
Max. output	80kW	60kW	49kW
Max. torque	272N·m	272N·m	275N·m
Max. rpms	11000rpm	11000rpm	8750rpm
Max. efficiency	97%	97%	96%
Avg. efficiency (LA-4 mode)	93% or greater	93% or greater	90%

4. Achieved Performance

4.1. Efficiency

As shown in Fig. 9, drive energy efficiency was enhanced by 22% compared to that of the previous model by increasing the power generating efficiency of the newly developed Honda FC Stack and by increasing the efficiency of the air supply system to the stack and the hydrogen circulation system. Better power efficiency and lower fuel consumption were realized by combining conventional high-efficiency energy management with other techniques, such as regeneration of the deceleration energy in the ultra-capacitor, and using a fuel cell auto idling stop system. Tank to Wheel energy efficiency of 55% was achieved, which is about three times higher than that of a gasoline-engine vehicle and about two times that of a hybrid vehicle.

4.2. Fuel Economy and Driving Range

Because the energy from 1 kg of hydrogen and 1 gallon of gasoline are approximately equivalent, the fuel consumption in CITY mode of equal-sized ICEV, HEV and CNG vehicles can be compared. Figure 10 shows the results. The fuel consumption performance of the FCX was twice that of the gasoline-engine and CNG vehicles, and 1.3 times that of the hybrid vehicle. The fuel

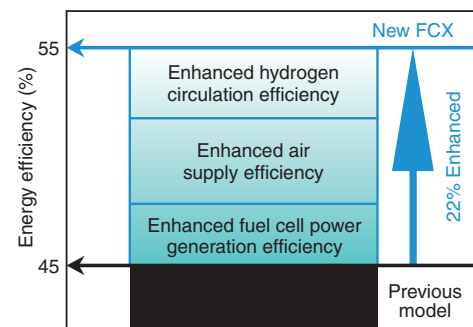


Fig. 9 Energy efficiency, LA-4 Mode

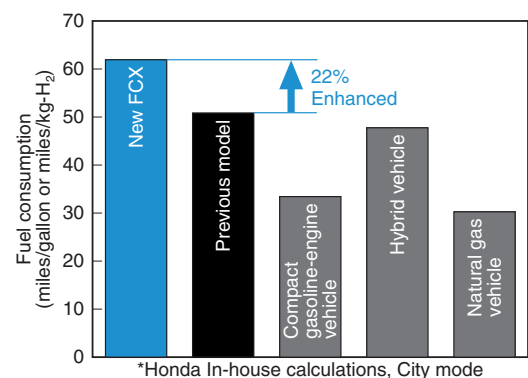


Fig. 10 Fuel consumption

consumption performance was enhanced by 22% compared to that of the previous model, while the driving range increased from 355 km to 430 km.

4.3. Acceleration

Figures 11 and 12 illustrate the output responsiveness at takeoff and the vehicle's takeoff acceleration characteristics. The expanded capacity provided by the ultra-capacitor and the increased output of the fuel cells allow the vehicle to take advantage of a drive motor that delivers maximum torque from low rotational speeds. This results in a shorter response time during acceleration as compared to a hybrid electric vehicle (HEV). Further, there is no transmission and no gear changing, so acceleration is exceptionally smooth. As a result, takeoff acceleration time has been reduced 13% and passing acceleration time 20% compared to the previous model (Fig. 13).

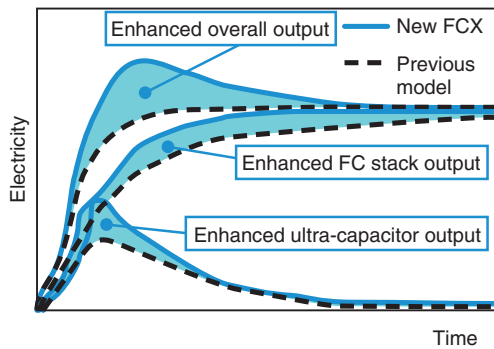


Fig. 11 Electricity at takeoff

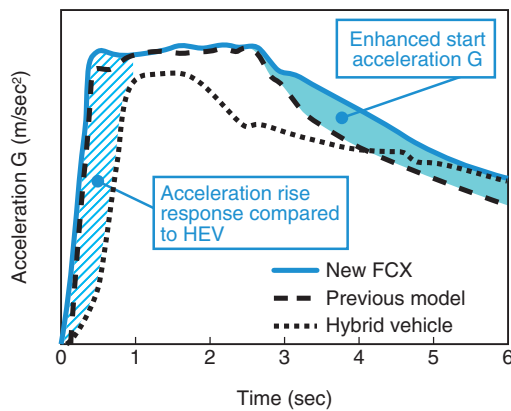


Fig. 12 Takeoff acceleration

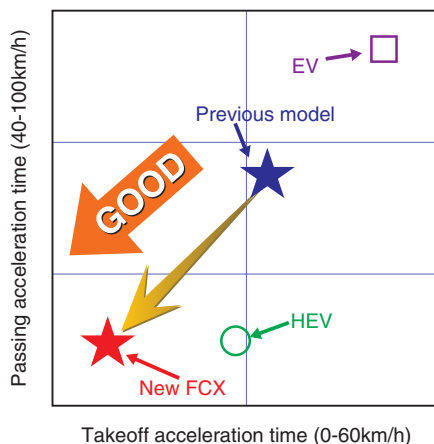


Fig. 13 Acceleration performance

4.4. Noise Countermeasures

The new model's air pump rotor has a solid construction, rather than the hollow construction of the previous FCX. This change suppresses air column resonance and reduces intake noise. In the interior, the noise of the air pump is reduced by 10 dB over the previous model. In addition, the part of the traction motor stator where the coil is wound is now made of molded resin, which increases the rigidity of the stator overall and cuts motor resonance vibration. In the interior, the noise of the motor is reduced by 6 dB over the previous model (Fig. 14).

4.5. Performance at below Freezing Temperatures

With conventional fuel cells, power cannot be generated below 0 °C. There are three basic reasons for this:

- The hydrogen ion conductivity of ion exchange membranes declines as the temperature decreases below 0 °C.
- The contact resistance of carbon separators increases significantly as the temperature decreases below 0 °C.
- Carbon separators have a low thermal conductivity and take a long time to warm up.

Below freezing, the next generation HONDA FC STACK has excellent ion conductivity and 25% lower intracellular contact resistance than previous stacks. The superior warming characteristics, due to the reduced heat capacity of the fuel cell and the fuel cell system, reduced the stack warm-up time by 80%. As well, with optimal water management of the generated water, start-up at -20 °C has become possible. The use of the FCX in low temperature environments, such as on snowy roads, is comparable to that of gasoline-engine vehicles, and the low temperature operation goal has been achieved (Fig. 15).

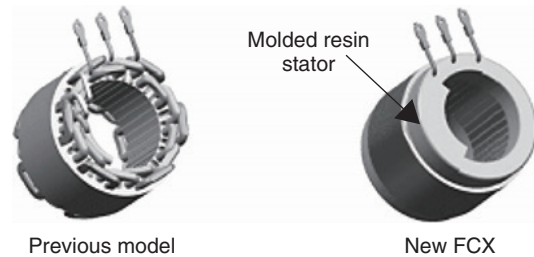


Fig. 14 Motor structure



Fig. 15 Test driving in snowy area

5. Certification

5.1. United States

In July 2004, the new model received sales authorization (as did the previous model before it) from the U.S. Environmental Protection Agency (EPA) and the California Air Resources Board (CARB). It has been recognized as the first fuel cell vehicle usable in cold areas. The Honda FCX has been registered as a zero-emissions vehicle (ZEV), meaning that it has no pollutant gas emissions at all (Fig. 16).

5.2. Japan

On March 31, 2005, the Ministry of Land, Infrastructure and Transport established technical guidelines establishing the world's first fuel cell vehicle safety standards, making it possible to apply for type certification. With officials from the Ministry of Land, Infrastructure and Transport observing, Honda conducted the nation's first fuel cell vehicle crash tests to ensure that the vehicle met crash safety standards. Figure 17 shows the tests in progress. These crash tests demonstrated that the Honda FCX fulfills the technical standards, and in June 2005, it received the first type certification for a fuel cell vehicle in Japan.



Fig. 16 ZEV label



Fig. 17 Crash tests

6. Conclusion

With the FCX, Honda has achieved extremely environmentally adaptable automotive technology. The result of these technical developments is that, for the first time, such a fuel cell vehicle is being sold in areas where temperatures fall below freezing in the winter. In November 2004, a new vehicle was delivered to the government of New York State, in the northeastern part of North America. Subsequently, a vehicle was delivered to the government of Hokkaido in January 2005. The FCX has proven that FCVs can be widely used in the major cities of the world.

However, there are still many issues with fuel cell vehicles and problems that need to be overcome, so R&D remains ongoing. Another important issue is the creation of an environmental society, and part of this issue is supplying the hydrogen. Yakushima Island in Kagoshima Prefecture has been the site of a proving test for the "recirculating hydrogen energy society" since April 2004. Honda is taking part in this project, which seeks to run fuel cell vehicles on hydrogen produced from hydroelectric power (Fig. 18).



Fig. 18 Test driving on Yakushima Island

Honda has become the first company to market a fuel cell vehicle, and will continue to innovate as a leader in environmental technology.

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