Development of New Fuel Cell Vehicle CLARITY FUEL CELL

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ABSTRACT

The newly developed fuel cell vehicle, the CLARITY FUEL CELL, has evolved to provide new era appeal together with the same usability as a vehicle with an internal combustion engine. The fuel cell powertrain is mounted under the front hood, realizing the world's first fuel cell vehicle to be commercially available in a five-passenger sedan package. The key technologies in this achievement are the greater compactness and shock-resistant construction of the fuel cell stack, the adoption of an electric turbo air compressor and fuel cell voltage control unit, and the compact drive unit. Optimal placement of the hydrogen tank and increased pressure capacity extend the driving range (reference value) to approximately 750 km, and achieve a hydrogen refueling time of about three minutes. Driving performance is also heightened by pursuing reductions in vehicle body weight and enhancement in its aerodynamic performance, through increased power of the motor, and so on. These efforts have realized a level of usability on a par with vehicles running on internal combustion engines. In further innovation, this model features external power supply functionality, a new linking technology that gives a foretaste of the vehicle of tomorrow.

1. Introduction

Hydrogen is receiving attention as a technology that addresses both the issue of global warming caused by CO_2 and the depletion of resources, which are energy issues faced by motor vehicles today. It can be manufactured from a variety of energy sources, and it can be transported and stored. Hydrogen is therefore a promising energy carrier for the next generation.

With its aim to realize the joy of free mobility and a prosperous sustainable society, Honda started basic research on fuel cells in the 1980s. In 1999, Honda unveiled the FCX V1 and V2 test vehicles(1) and has engaged in development for the popularization of fuel cell vehicles (FCV). The FCX developed in 2002 was the first such vehicle in the world to receive certification in the United States, and Honda began lease sales in Japan and the United States(1). In 2003, the world's first fuel cell stack capable of starting in temperatures below freezing (Honda FC Stack) was developed in-house(2), (3). In 2008, the FCX CLARITY(4) was launched on the market as the world's first FCV to have an innovative sedan-type package and a whole new dimension of driving feel. Honda has led the field of other manufacturers in presenting vehicles with the new value and appeal that are distinctive attributes of the FCV.

In developing new vehicle models that serve to expand the popularization of the FCV, it was necessary to further evolve the FCV to provide both usability on a par with internal combustion engine vehicles and the appeal of a new era that is not present in conventional vehicles. This involved providing the data acquired to that point and the views of customers as feedback to the process.

2. Development Concept and Goals

The CLARITY FUEL CELL (Fig. 1) development concept was formulated as "Red Carpet to the New Era." The meaning of this concept is that, in order to replace internal combustion engine vehicles for the purpose of widely popularizing the FCV, such universal values as performance and usability would be left unchanged while adding new appeal that never previously existed. In this way, development would yield a vehicle that becomes a special one-of-a-kind vehicle for those customers who take the step forward into the new era.

Based on this concept, the development goals for the

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CLARITY FUEL CELL were defined as follows:

(1) Realize the world's first five-passenger FCV sedan package
Downsizing the fuel cell powertrain and installing it under the front hood realized a five-passenger cabin with a spacious feeling.

(2) Reduce the weight of the vehicle body and make comprehensive reductions in running resistance
High-strength materials were used to reduce the vehicle body weight while also seeking a body shape for aerodynamic performance together with reduction in running resistance by the configuration of aerodynamic parts.

(3) Achieve a balance of environmental performance and vehicle performance
Realize vehicle performance equal to or better than that of an internal combustion engine vehicle while providing the ultimate environmental performance of zero emissions.

(4) Linking technology that gives a foretaste of the vehicle of tomorrow
Provide external power supply functionality as standard equipment, and aim to make vehicles and society connect.

Fig. 1 Honda CLARITY FUEL CELL

3. Achieve the World's First Five-Passenger FCV Sedan Package

3.1. Fuel Cell Powertrain Installation Under the Front Hood

Following the "man maximum, machine minimum" philosophy, the CLARITY FUEL CELL was intended to provide the comfortable occupancy space of a sedan. Measures were therefore taken to downsize the fuel cell powertrain, and it was successfully installed for the first time in the world under the front hood of a commercially available sedan. This increased the space efficiency of the vehicle and realized an FCV sedan package that comfortably seats five adults. At the same time, this opened the way to future deployment in multiple vehicle types when the time comes for expanded popularization of the FCV.

This compact fuel cell powertrain was realized by the following four key technologies, which are shown in Fig. 2.

(1) Fuel cell (FC) stack downsized and made more shock-resistant
(2) Electric turbo air compressor adopted
(3) Fuel cell voltage control unit (FCVCU) adopted
(4) Drive unit downsized

3.1.1. FC stack downsized and shock resistance enhanced

As shown in Fig. 3, the current density of the new model FC stack was increased by a factor of 1.5, reducing the number of cells by approximately 30%, in order to downsize the stack. The cell structure, as shown in Fig. 4, inherits the unique Honda wave flow channel and cooling construction for every two cells while achieving a 1-mm thickness for each cell. The gas diffusion performance of the membrane electrode assemblies (MEA) was also enhanced and the height and width of the gas flow channels in the separators were reduced. As shown in Fig. 5, the FC stack realized the world's highest level of power output density at 3.1 kW/L and achieved a 33% reduction in size compared to former stacks.

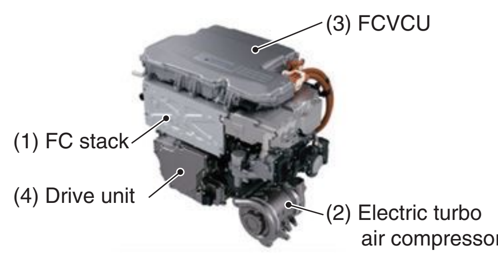

Fig. 2 Downsized fuel cell powertrain

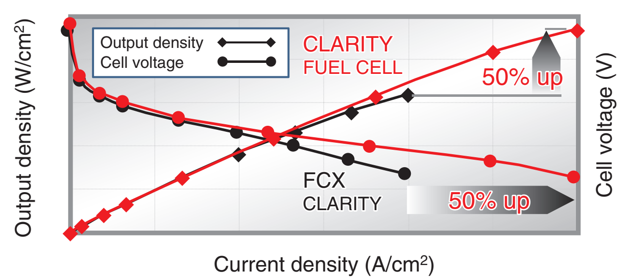

Fig. 3 Enhancement of FC current density

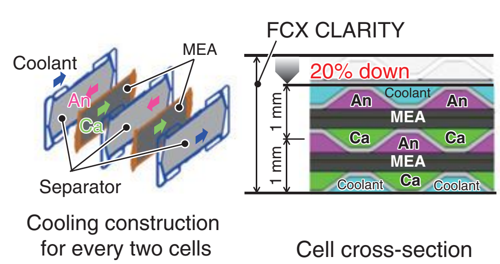

Fig. 4 FC structure

Figure 6 shows a cross-section of the stack to illustrate how its shock resistance has been increased by a factor of four by refining the cell retaining structure. This was done in order to assure safety in the event of a frontal collision.

Figure 7 shows the MEA construction with a resin frame around the outer periphery to which it is joined. The use of the resin frame reduces the amount of material in the MEA, while squaring off the MEA shape enabled continuous coating of catalyst and related material. This had the effect of reducing the amount of remnant material that is wasted. In combination, these measures reduced by approximately 40% the amount of expensive materials used, while contributing to the increased productivity of the fuel cell stacks and reducing their cost.

3.1.2. Electric turbo air compressor adopted

Figure 8 shows an external view of the newly developed air compressor that supplies air to the fuel cell stack.

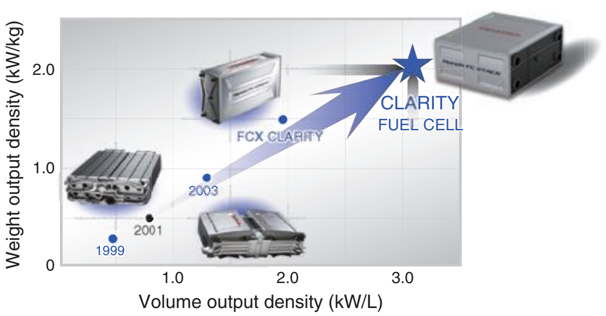

Fig. 5 Evolution of power density of FC stack

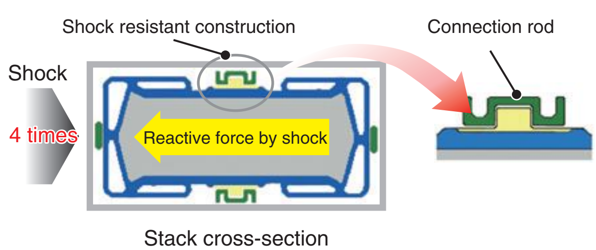

Fig. 6 Shock resistant construction of FC stack

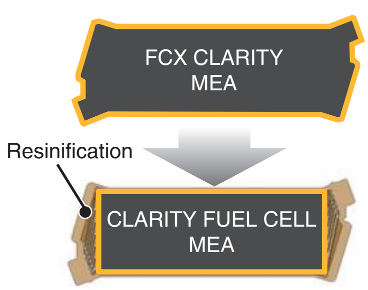

Fig. 7 Resin frame around MEA

An electric turbo air compressor with excellent flow rate characteristics, capacity, and cost was adopted. It is also very quiet, which contributes to cabin comfort even when the vehicle is accelerating or cruising at high speed. It is a coaxial two-stage motorized turbo-type compressor, which increased the pressure of the air supply by a factor of 1.7 over the conventional type and contributed to the downsizing of the fuel cell stack.

3.1.3. Fuel cell voltage control unit (FCVCU) adopted

The FCVCU was adopted because it is necessary to raise the voltage of the power supplied to the traction motor in order to reduce the number of cells stacked in a fuel cell and to increase the power output from the traction motor. A full-SiC Intelligent Power Module, the first such in the world to be used in a mass-production vehicle, was applied in the FCVCU, and its high-frequency switching at approximately 30 kHz was a step toward the downsizing of capacitor, inductor, and other such components. The adoption of a coupled inductor and the optimal layout of component parts also achieved approximately 40% downsizing of volume relative to previous types.

3.1.4. Drive unit downsized

In previous models, the power control unit (PCU) was mounted on top of the traction motor. In order to install the fuel cell stack under the front hood, the PCU was placed at the front of the traction motor and integrated with it. As shown in Fig. 9, this reduced its height relative to the FCX CLARITY by approximately 34%, thereby ensuring the space for mounting the fuel cell stack.

By means of these key technologies, the fuel cell

Fig. 8 Electric turbo air compressor

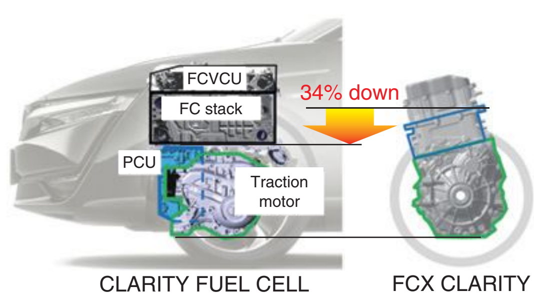

Fig. 9 PCU integrated with traction motor

powertrain was successfully reduced to the size of a conventional V6 engine, as shown in Fig. 10.

3.2. Optimal Placement of the Hydrogen Tanks

Figure 11 shows the vehicle package with the hydrogen tanks installed. The hydrogen tanks are installed below the floor under the rear seat and above the rear axle (between the back of the rear seat and the forward side of the trunk). This layout realized a sedan package that provides seating for five occupants and trunk space (capable of holding three golf bags) appropriate to the vehicle class. Table 1 shows a comparison with the basic dimensions of the 2013 model Accord and the 2015 model LEGEND.

Figure 12 shows the hydrogen tank as installed. It is a Type 3[5] tank with an aluminum liner. It complies with global technical regulation GTR No. 13 and is capable of storing approximately 5 kg[*1] of highly compressed hydrogen gas at 70 MPa.

Table 1 Basic dimension

Specification \ Model	CLARITY FUEL CELL	2013 model year Accord PHEV	2015 model year LEGEND
Weight (kg)	1890	1740	1980
Length (mm)	4915	4915	4995
Width (mm)	1875	1850	1890
Height (mm)	1480	1465	1480
Wheel base (mm)	2750	2775	2850
Seating capacity	5	5	5

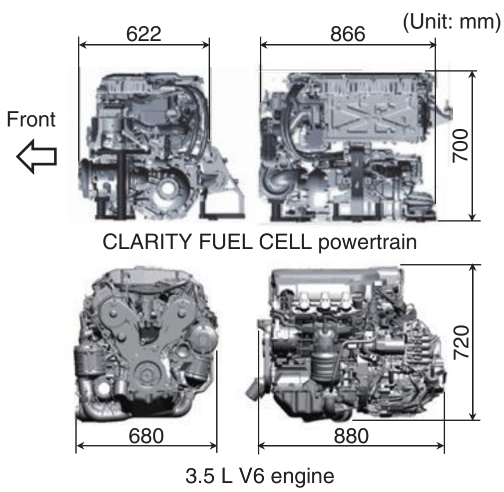

Fig. 10 FC powertrain equivalent to V6 engine in size

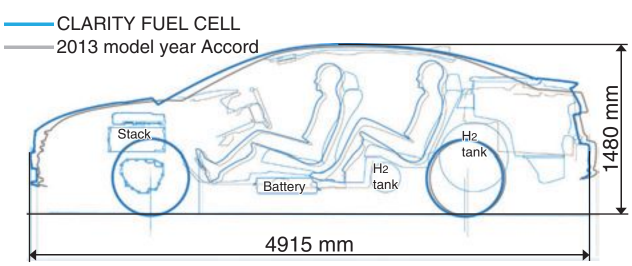

Fig. 11 Package (Japan model)

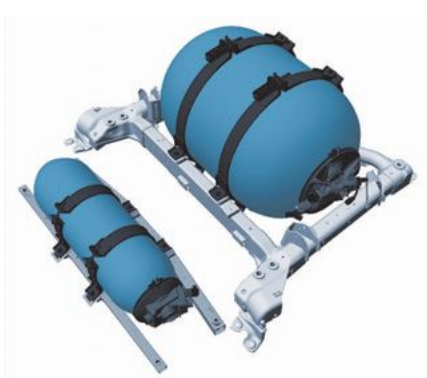

Fig. 12 Image of H_2 tank installation

4. Reduction of Vehicle Body Weight and Comprehensive Reduction of Running Resistance

4.1. Reduction of Vehicle Body Weight by Use of High-Strength Materials

Figure 13 shows the technology used to reduce the weight of parts making up the vehicle body. Figure 14 shows the usage rate of reduced-weight materials. Parts in which the material was replaced by aluminum alloy

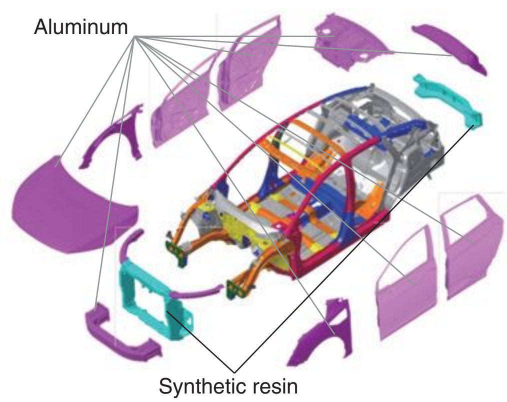

Fig. 13 Weight saving parts

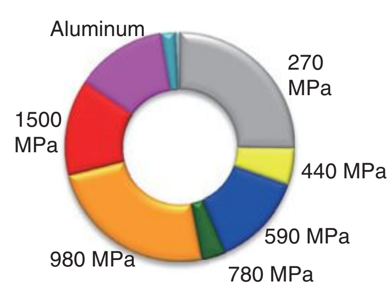

Fig. 14 Usage rate of lightweight materials

include the front bumper beam, front hood (skin and frame), fenders, front and rear door components (sash, skin, panels), trunk components (skin and frame), and rear parcel shelf. Parts in which the material was replaced by resin include the front bulkhead and rear bumper beam. The usage rate for ultra-high tensile strength steel sheet was also raised, and this realized approximately 15% of the weight reduction relative to former vehicles. Figure 15 shows a comparison by body weight.

4.2. Seeking Body Shape Informed by Awareness of Aerodynamic Performance

Figure 16 shows a conceptual image of the air flow along the top and sides of the vehicle body. This flow of air along the top of the vehicle body and the flow along the side converge at the rear of the vehicle body. Figure 17 shows the appearance of the air flow where it lifts up and toward the rear of the vehicle body. In the figure on the right in Fig. 17, the induced drag generated by the longitudinal vortex is reduced when the difference between the flow velocity at the upper surface and the side surfaces has been reduced by comparison with the figure on the left. In order to realize this body shape, a cabin silhouette that is advantageous in terms of aerodynamic performance was adopted, and in order to achieve a balance with cabin space, a distinctive sedan structure with the trunk lid placed at a higher level (a high-deck sedan structure) was adopted. The body shape was decided through the use of a wind tunnel with a rolling road[6] from the initial stage of development, and repeated wind tunnel tests were conducted.

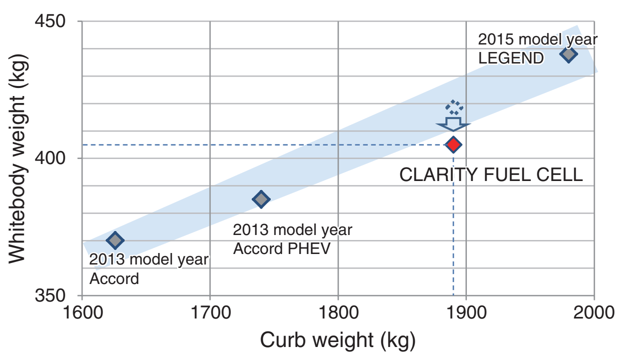

Fig. 15 Whitebody weight Ration

Fig. 16 Image of aerodynamic body shape image

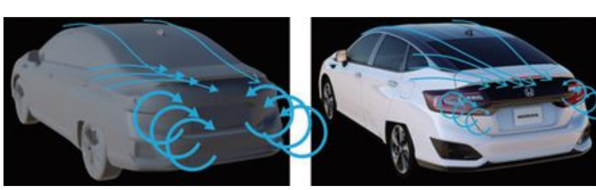

Fig. 17 Induced drag generated by longitudinal vortex

Table 2 Aerodynamic parts effect

Parts	⊿CD (%)
Rear spoiler	-1.0
Rear under cover	-1.0
Rear air curtain	-0.5
Rear combi washboard	-1.0
Tire cover	-1.0
Tank under cover	-1.5
Main floor under cover	-2.5
Front air curtain	-1.5
Motor under cover	-3.0
Total	-13.0

4.3. Device Configuration for Heightened Aerodynamic Performance

As shown in Fig. 18, all types of aerodynamic device were configured in order to reduce the aerodynamic drag. Air curtains on the sides of the front and rear tires for streamlining, tire covers over the tops of the rear tires, and flat covers under the floor to promote smooth air flow under the vehicle body yielded the effect of reducing the coefficient of drag by approximately 13%. Table 2

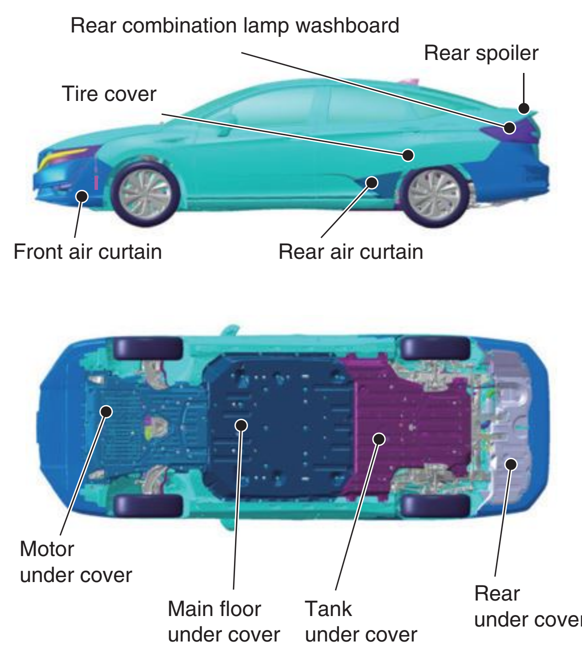

Fig. 18 Aerodynamic parts

shows the effects of individual devices on reduction of the coefficient of drag.

5. Achieving a Balance of Environmental Performance and Vehicle Performance

The CLARITY FUEL CELL was developed to have the ultimate environmental performance, known as zero emissions, while also aiming for vehicle performance equal to or greater than that of an internal combustion engine vehicle.

5.1. Achieved Driving Range (Reference Value) of Approximately 750 km[*2]

Equipped with a hydrogen tank with a pressure rating increased to 70 MPa, together with increased powertrain efficiency and reduced running energy, achieved a driving range (reference value) of approximately 750 km[*2] (when driving in JC08 mode, measured by Honda). This places it at the highest level in the world for a zero emissions vehicle.[*4] When refilled at a hydrogen station on the new standard expected to enter operation in fiscal year 2016 or later, the increased amount of hydrogen filling the tank is expected to give the vehicle a range of approximately 800 km.[*3] Moreover, the hydrogen refueling time taken to fill the tank once is expected to be about three minutes,[*5] which in combination with other factors means that the FCV achieves usability equal to that of an internal combustion engine vehicle.

5.2. Increased Motor Power and Driving Mode Switchable Between Normal and Sport Driving Yield Attractive Performance

By means of optimal voltage control by the FCVCU, the traction motor achieves power output of 130 kW. This is a 30% increase over former models, and it is gained while maintaining the same size as before. A switch that allows switching between normal and sport driving modes was also adopted. When sport mode is selected, more agile and direct acceleration is produced by the faster power response time for torque versus accelerator pedal opening during acceleration, as shown in Fig. 19. The responsiveness of power regeneration by the motor has also been enhanced, so that releasing the accelerator pedal will produce an effect corresponding to the engine brake in an internal combustion engine vehicle. These settings provide still more of the attraction of agile driving.

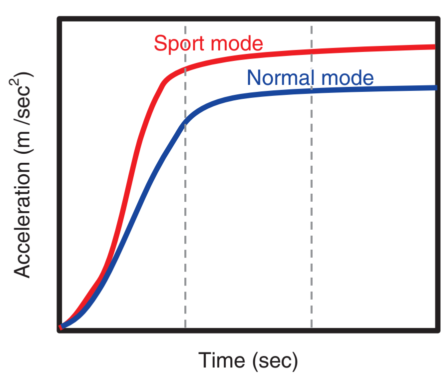

Fig. 19 Acceleration performance

5.3. Adoption of Dedicated Chassis Yields Driving with Quality Feeling

Figure 20 shows the front and rear suspension and the subframe construction. A strut-type front suspension and five-link rear suspension were adopted. For the front subframe, a hollow aluminum die cast process was used in a world first that achieved high rigidity with a weight reduction of approximately 46% relative to conventional manufacturing methods. All aluminum materials were also used in the rear subframe, yielding a weight reduction of approximately 27% while including frames for installing the hydrogen tanks.

Installation of a hydrogen tank below the rear seat lowered the vehicle's center of gravity by approximately 10 mm and reduced the static stability factor (SSF) by 5% relative to the Accord PHEV. As a result, rolling is less likely to occur due to steering while driving and the flat ride feeling is enhanced. Sensitive frequency response dampers (SFRD)[(7)] were adopted for the suspension, realizing smoother ride comfort. Dual pinion-assist electric power steering (EPS) was adopted for the steering gearbox (Fig. 21), and aluminum alloy was used for the tie rod ends, reducing the weight by 20% relative to conventional configurations. Electric servo brakes (ESB)[(8)] and an electric parking brake (EPB) were adopted for the brake system. Active noise control (ANC)[(9)] was also adopted to reduce road noise and increase cabin comfort.

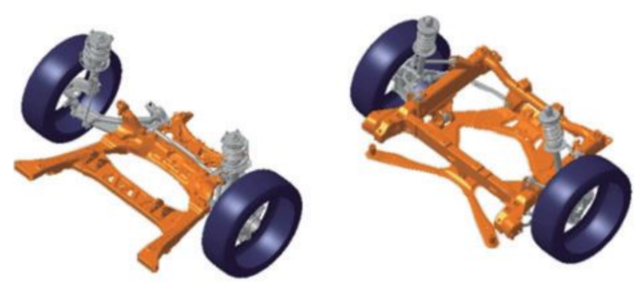

Fig. 20 Front suspension (left) and rear suspension (right)

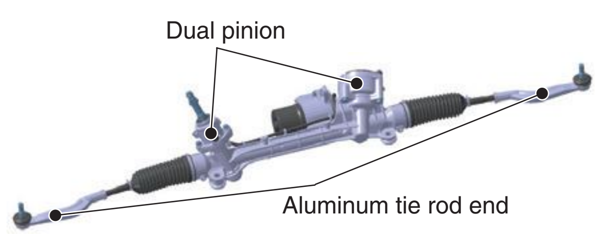

Fig. 21 Dual pinion assist EPS

6. Linking Technology that Gives a Foretaste of the Vehicle of Tomorrow

6.1. Honda's Vision for a Hydrogen Energy Society

Looking ahead to the coming hydrogen society, Honda has also engaged in hydrogen-related development other than the FCV. This effort is based on the three concepts of "generate hydrogen, use hydrogen, get connected with hydrogen" (Fig. 22).

From the perspective of generating hydrogen, Honda has developed the Smart Hydrogen Station (SHS) and is conducting proving tests. The SHS is intended to supply hydrogen energy in a distributed manner using renewable energy from such sources as photovoltaic energy and wind power to manufacture the hydrogen.

In terms of connecting with hydrogen, the FCV serves as a moving electric power source. The aim is to connect the vehicle with the local community by using it to supply electricity for use outdoors or in emergencies. The POWER EXPORTER 9000 is an external electric power source that features the high reliability cultivated through Honda's development of electric generators together with high-quality AC power output. It can provide an external supply of a maximum of 9 kVA from the CLARITY FUEL CELL. Figure 23 shows an external view of the unit connected to a vehicle. A dedicated socket with lid for supplying electricity has been provided out of consideration for usability.

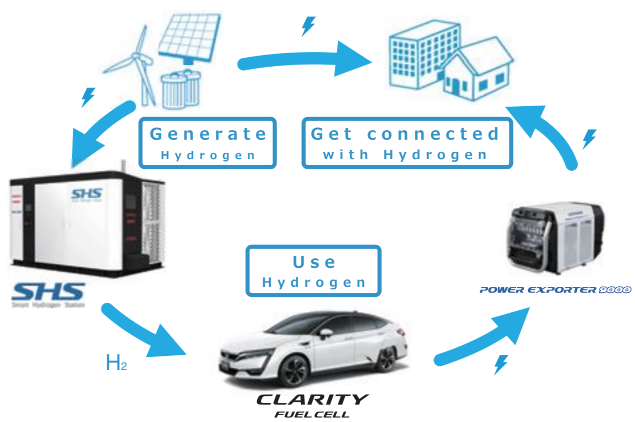

Fig. 22 Honda's vision of a hydrogen-powered future society

Fig. 23 POWER EXPORTER 9000

7. Conclusion

The CLARITY FUEL CELL was developed for the purpose of becoming a special vehicle for those customers who are taking a step forward into a new era. It is a vehicle for a new age, and it possesses both usability on a par with internal combustion engine vehicles and a new appeal that cannot be found in conventional vehicles.

The market for the FCV is still developing, and it will be important to continue with ongoing initiatives to expand the market in coordination with hydrogen infrastructure. Honda will strive to enhance the performance, reduce the cost, and take other such measures to further heighten the appeal of the FCV. Honda aims to realize the joy of free mobility and a prosperous sustainable society, and, as in the CLARITY's name, Honda's initiatives are bright and clear.

*1 Value measured by Honda in filling operations at a station supplying hydrogen under 70-MPa pressure in accordance with the criteria in SAE standard J2601.

*2 Value measured by Honda while driving in JC08 mode. This is a value measured by Honda based on filling operations at a station supplying hydrogen under 70-MPa pressure in accordance with the criteria in SAE standard J2601. If the vehicle is refilled at a hydrogen station with different specifications, the amount of hydrogen filling the hydrogen tank will differ, as will the range. Range can also vary greatly according to the environment of use (air temperature, congestion, etc.) and how the vehicle is driven (sudden starts, using air conditioner, etc.).

*3 Value measured by Honda under the same conditions as in *2, when the vehicle is filled at a hydrogen station on the new standard expected to enter operation in fiscal year 2016 or later.

*4 As of March 2016, according to a Honda study.

*5 Value measured by Honda in filling operations at a station supplying hydrogen under 70-MPa pressure in accordance with the criteria in SAE standard J2601. (Filling time may vary with the filling pressure and outside air temperature.)

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