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# Development of 70MPa Hydrogen System Light-duty Truck Powered by Fuel Cell (Public Road Demonstration in 2018)

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**Summary**

To lead the world in realizing CO2 reduction in motor traffic utilizing hydrogen energy, we must urgently implement FC vehicles in the field of commercial application following FC automobiles. Commissioned by the Ministry of the Environment*1, Tokyo R&D has developed a fuel cell light-duty truck targeting a fuel efficiency that is 1.75 times more in CO2 emission conversion than that of existing diesel vehicles, validated the vehicle's basic performances and serviceability as a commercial vehicle and is engaged in realizing a basic form of fuel cell light-duty truck.

*1: Low Carbon Technology Research, Development and Demonstration Program, Ministry of the Environment, Government of Japan

*Keywords: fuel cell, fuel cell vehicle, hydrogen, BEV*

## 1 Development and Layout of the Fuel Cell Light-duty Truck

### 1.1 Outline of Vehicle

We examined specification by setting delivery truck as the target of use of the fuel cell light-duty truck. Vehicle specification was decided considering performance and equipment required in light delivery truck that is generally used in services such as home delivery and studied the basic packaging. Table.1 shows the vehicle's targeted specification and Figure1 shows the vehicle appearance.

Table1: Vehicle specification

| Items | Descriptions |
|---|---|
| Base vehicle manufacturer and vehicle name | Isuzu Motors Limited, Elf |
| Type | TRG－NMR85AN(mod) |
| Dimensions (L×W×H) | 6,345mm×1,915mm×3,040 mm |
| Riding capacity | 3 |
| Load capacity | 2,000kg |
| High pressure hydrogen vessel | Filling pressure 70MPa ×3 |
| | Capacity 36L/vessel |
| Fuel cell battery power module | 30kW output ×2 units |
| Secondary battery, type and capacity | Li-ion battery, 14kWh |
| Motor type | Brushless DC |
| Max output / max torque | 110 kW/305Nm |
| Duration | 150 km (assuming JC08 mode) |
| Equipment | 100VAC outlet for external power supply |

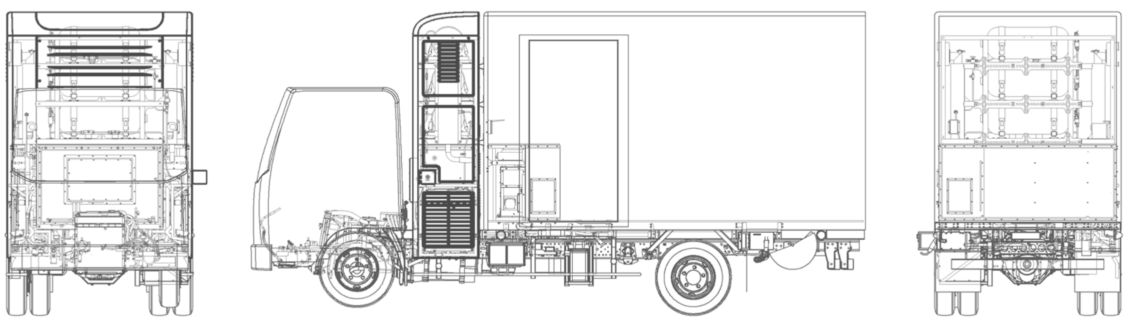


Figure1: Appearance of the fuel cell light-duty truck

### 1.2 Vehicle Characteristics

The vehicle system configuration features a power system that accommodates both the optimum efficiency operation of the fuel cell (FC) and the state optimization of the secondary cell by adopting a general-purpose FC stack and high-pressure hydrogen vessel which, by completing, shall contribute to early dissemination of the light-duty trucks powered by fuel cell and to thereby improve development of low-carbon society.

By applying 60kW high output performance by adopting 2 units of 30kW FC, the vehicle can correspond to various operating patterns thus offering a high versatility over wide range of vehicle types and applications.

The high pressure hydrogen vessels that correspond to 70MPa filling pressure available at the hydrogen station in Fukuoka City Chubu Water Processing Centre consists of 3 high pressure hydrogen vessels each sporting 36L inner volume which makes a total of 108L allow 150km plus mileage, longer than general BEVs (Battery Electric Vehicles).

## 2 Performance Test of the Fuel Cell Light-duty Truck

### 2.1 Chassis Dynamometer Test

We test drove the completed fuel cell light-duty truck on a chassis dynamometer and verified its vehicle performance and fuel efficiency. To check the consumed hydrogen amount, we supplied hydrogen fuel from a detachable external hydrogen vessel to the vehicle, and a gravimetric method was adopted to calculate the consumed hydrogen mass by measuring the weight of hydrogen vessels with a precision balance before and after the test.

Test items were; electric power consumption, climbing hill and continuous running. Table 2 shows the results of the electric power consumption test.

Table2: Results of the electric power consumption test

| Mode | Date | Frequency | Hydrogen consumption | | Electric power consumption | Average electric power consumption |
|---|---|---|---|---|---|---|
| | | | g | L | km/kWh | km/kWh |
| JC08 (w/o strong regenerative braking) | 6/20 | 1 | 275.92 | 3,067.82 | 1.750 | 1.754 |
| | 6/20 | 2 | 268.59 | 2,986.46 | 1.786 | |
| | 6/20 | 3 | 276.63 | 3,075.80 | 1.727 | |
| JC08 (w/ strong regenerative braking) | 6/20 | 1 | 257.40 | 2,861.82 | 1.880 | 1.891 |
| | 6/20 | 2 | 254.65 | 2,831.51 | 1.904 | |
| | 6/21 | 3 | 255.43 | 2,840.00 | 1.888 | |

From the results in JC08 mode, we verified the electric power consumption rate improves by approx. 7.8% by using strong regenerative braking.

## 2.2 Hydrogen filling test

We conducted a hydrogen filling test at the Japan Automobile Research Institute on its Hydrogen and Fuel Cell Vehicle Safety Evaluation Facility (Hy-SEF).

- Pressure test and validation of hydrogen leak from hydrogen piping
- 70MPa hydrogen fuel filling and validation of hydrogen leak from hydrogen vessel
- Functional verification of hydrogen safety and acquisition of adaptability test certification prescribed in the Announcement that Prescribes Details of Safety Regulations for Road Vehicles, attachment 100.

## 2.3 Running Test

We validated running performance of the fuel cell light-duty truck and collected data necessary for obtaining an automobile inspection certificate. Various test items included; braking, noise, coasting, continuous running, etc. The results of the continuous running test aimed to verify our target duration of 150km is explained here.

The test was carried out at the Japan Automobile Research Institute on its peripheral oval road in two times by driving the vehicle from full hydrogen vessels to empty. Although the driving condition differed from that of the JC08 mode, the duration reached approx. 165km and we validated our target duration of 150 plus km.

## 2.4 Low Temperature Starting Test

There is a concern with fuel cell battery that inner moisture would freeze at low temperature, and the fuel cell battery module (FCPM) by Hydrogenics does not start generation when the coolant temperature is below 2℃.

We therefore integrated a heater into the fuel cell cooling system on the fuel cell light-duty truck to secure low temperature starting and validated its effectiveness in the low temperature starting test. Figure 2 shows the test results.

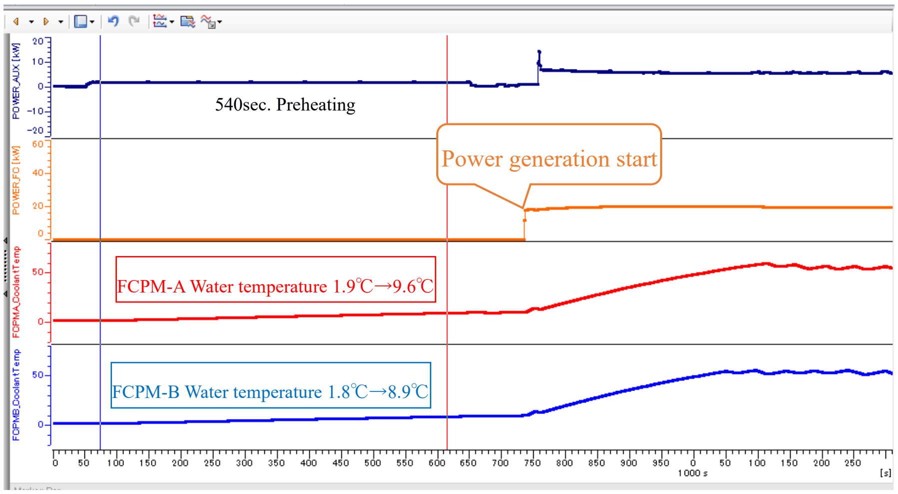



Figure 2: Low temperature starting test

We checked;

- the Hydrogenics FCPM does not operate when the cooling water temperature is below 2℃
- the heater integrated into the fuel cell cooling system has heating capacity of approx. 0.8℃/min
- the cooling water temperature rapidly rises due to FCPM's own heat generation as the power generation starts

### 2.5 Test Summary

- By chassis dynamometer test, we validated the basic function and performance of the vehicle system as well as the FC system and collected basic data of the fuel efficiency.
- By hydrogen filling test, we validated the safety of the hydrogen vessels as well as pipings, and the function of the hydrogen gas leak detector.
- By running test, we measured the vehicle performance and validated a performance equivalent to that of commercially available BEV trucks. Simultaneously, we collected data necessary for obtaining an automobile inspection certificate. We also adjusted the vehicle control parameters and collected electric power consumption correction data.
- By pre-demonstration public road driving, we inspected the user-friendliness of the vehicle on public roads and validated the appropriateness of the control parameters.
- By low temperature starting test, we validated the practicability at cold time.
- As the results of our fuel efficiency simulation based on the performance test data, the electric power consumption of this vehicle in an ideal condition worked out at 2.19km/kWh in JC08 mode.

## 3 Public Road Demonstration of the Fuel Cell Light-duty Truck

The developed vehicle went on a public road demonstration in Fukuoka City operated by the Tenjin-district Co-operative Transportation Co., Ltd. to validate its practical use as a fuel cell light-duty truck for a delivery application. The public road demonstration program utilized the sewage biohydrogen station owned by the City of Fukuoka who provided the hydrogen fuel, and the Tenjin-district Co-operative Transportation Co., Ltd. who jointly works with the city on urban environmental load reduction and congestion reduction operated the delivery services.

### 3.1 Demonstration Schedule

The program was carried out approx. 3 months, from 10th of October to 27th of December 2018.

### 3.2 Traveling Course

Figure 3 shows the traveling course. The demonstration was programmed to operate 2 roundtrips a day between the Tenjin-district Co-operative Transportation Co., Ltd. and its main delivery area covering a mileage of approx. 30km. When filling hydrogen, the vehicle would run directly to the Tenjin-district Co-operative Transportation Co., Ltd. from the hydrogen station. Positional relations of each transit points are shown in Figure 3.


① The Tenjin-district Co-operative Transportation Co., Ltd.

② Main delivery area (Tenjin district, Fukuoka City)

③ Hydrogen station (Fukuoka City Chubu Water Processing Centre)

Figure3: Traveling course

### 3.3 Traveling Pattern

We scheduled 2 traveling patterns for the demonstration as follows:

Regular pattern: 2 roundtrips a day between the Tenjin-district Co-operative Transportation Co., Ltd. and its main delivery area

Filling pattern: IN addition to above, to route via the hydrogen station for hydrogen filling

### 3.4 Results of the Public Road Demonstration and Analysis

From the start to completion of the demonstration; between 10th of October and 27th of December 2018, the vehicle covered a total mileage of 1,460km over 54 days of operation. Also, a total of 59.6kg hydrogen has been refilled in 26 times of refilling.

### 3.4.1 Traveling Pattern and Electric Power Consumption

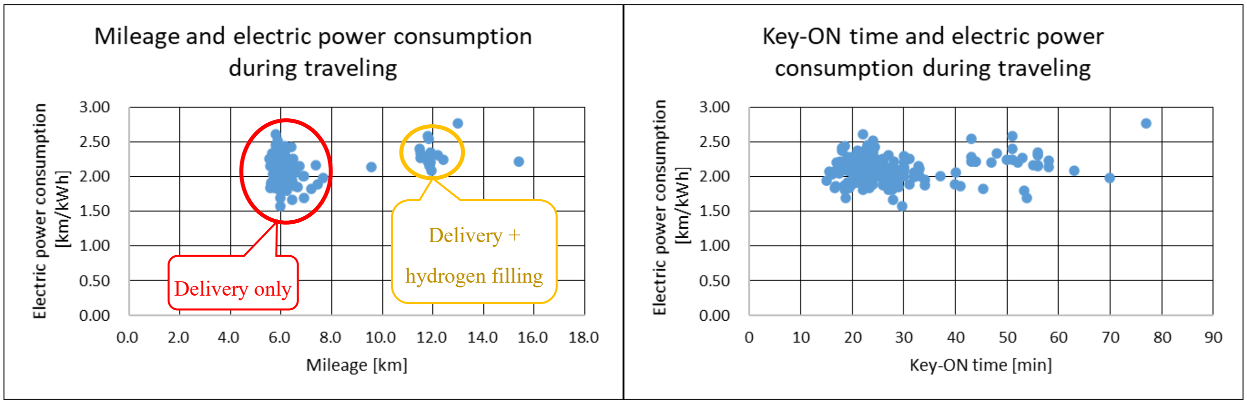



Figure 4: Mileage, key-ON time and electric power consumption

As shown in Figure4, mileages on two traveling patterns differed in twofold; 6km on the regular pattern (delivery only) and 12km on filling pattern (delivery + hydrogen filling). However, no significant difference existed in the electric power consumption and there was no relation between the mileage and electric power consumption. Similarly, there was no relation between the key-ON time and electric power consumption.

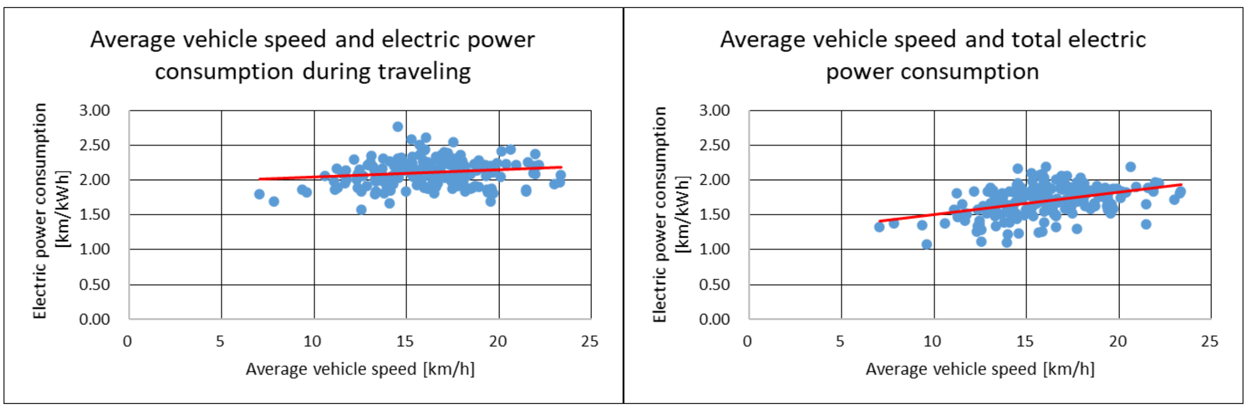



Figure 5: Average vehicle speed and electric power consumption

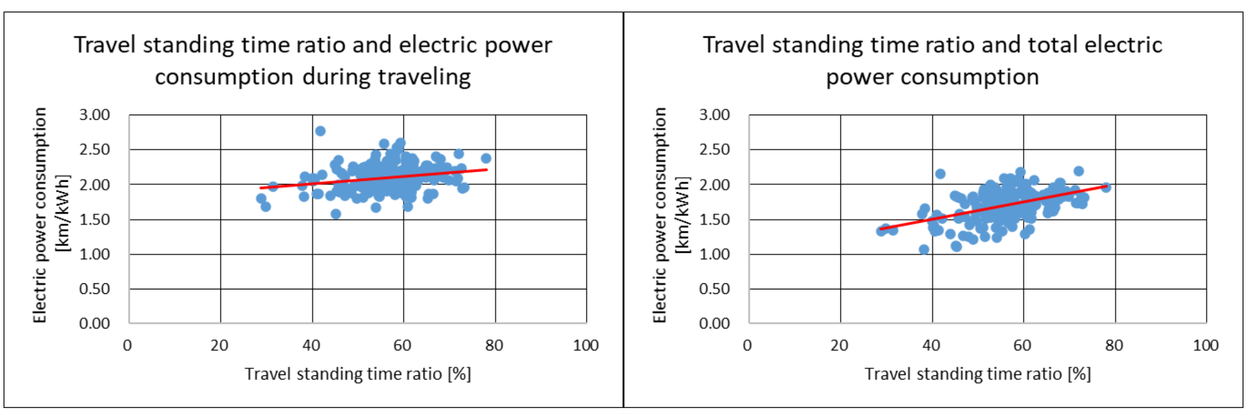



Figure 6: Travel standing time ratio and electric power consumption

The average vehicle speed shown in Figure 5 and the travel standing time ratio (the ratio of the time the vehicle is actually traveling during the operating hours) is related to traffic conditions which is; "greater travel standing time ratio" = "less congestion" = "higher average vehicle speed".

Which means, from Figure 5, we can say; the higher the average vehicle speed, the better the electric power consumption, but the congestion rather than the average vehicle speed affects the electric power consumption.

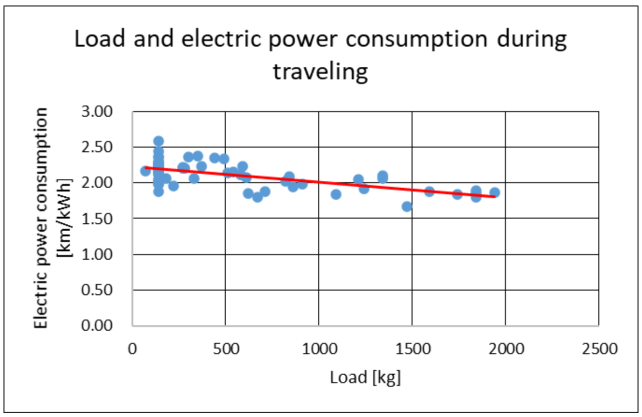
Similarly, the total electric power consumption is deteriorated as compared to electric power consumption during traveling, but this is caused by the greater auxiliary machinery power consumption during the longer standing time, which tells that the total electric power consumption is affected more by the congestion.

### 3.4.2 Improvement in Electric Power Consumption by Regenerative Brake

We examined the improvement in electric power consumption by utilizing a regenerative brake.

Regenerative brake is a device that collects the electric energy generated by the driving motor and utilizes as a brake. It operates in the same way as the exhaust brake. A strong regenerative braking or a normal regenerative braking is available by switching the exhaust brake switch ON/OFF.

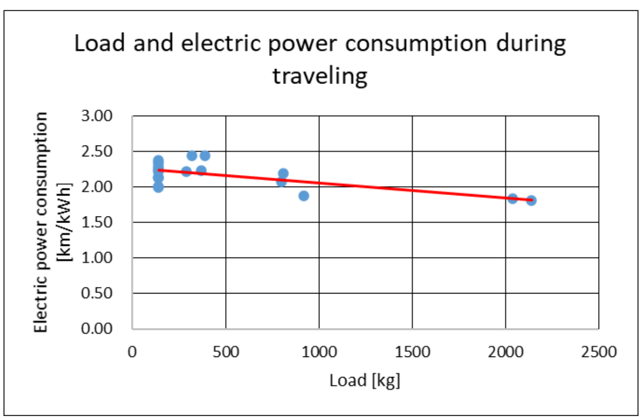
We analysed how strengthening the normal regenerative brake, or, a regular use of strong regenerative brake worked on the electric power consumption.




Trial period: 22nd of October to 14th of November

2.21km/kWh electric power consumption w/ 0kg load

Figure 7: Load and electric power consumption (using normal regenerative brake)



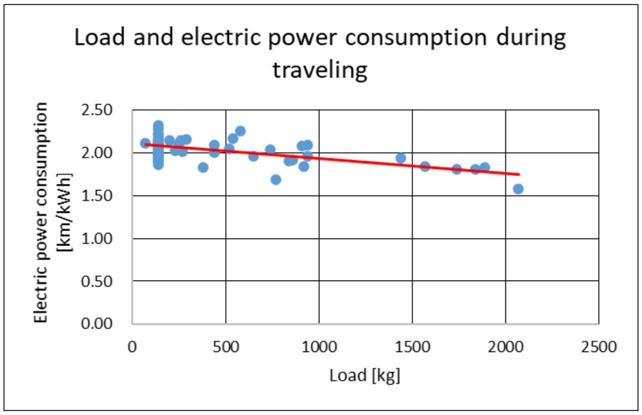

Trial period: 15th to 21st of November

Used strong regenerative brake

Strong regenerative brake force is quadruple of that of the normal regenerative brake

2.26km/kWh electric power consumption w/ 0kg load

Figure 8: Load and electric power consumption (regularly using strong regenerative brake)




Trial period: 7th to 27th of December

Doubled the normal regenerative braking force

2.09km/kWh electric power consumption w/ 0kg load

Figure 9: Load and electric power consumption (doubled normal regenerative braking force)

In contrast with the use of normal regenerative brake, although only slightly, a regular use of the strong regenerative brake helped to improve the electric power consumption. Aiming for a further improvement in the electric power consumption, we tried to alter the normal regenerative braking force. However, despite our expectation, no improvement was observed because of the significant impact from the public traffic conditions as well as the vehicle operation.

### 3.4.3 Load and Electric Power Consumption

We examined how the increased load affects the electric power consumption.

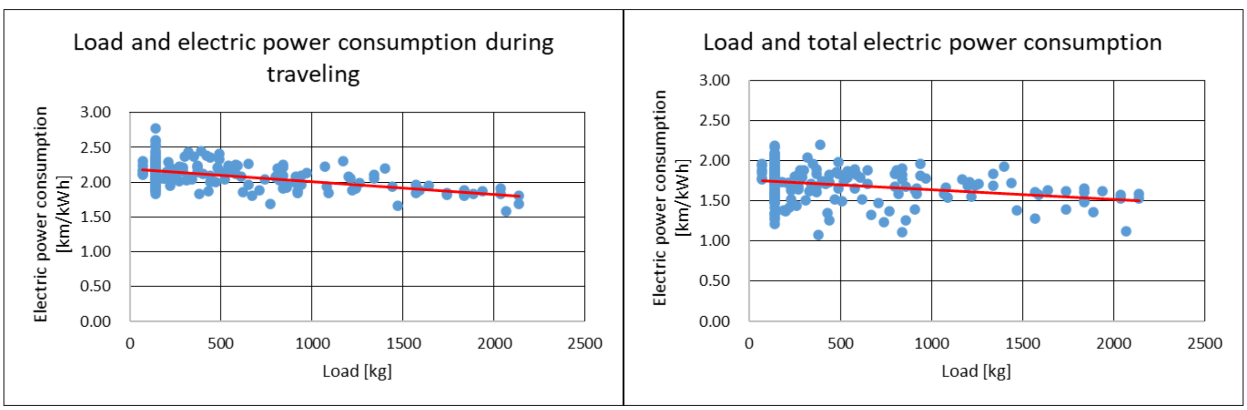



Figure 10: Load and electric power consumption

The electric power consumption during traveling (calculated based on the driving motor power consumption alone) was 2.2km/kWh when the load was 0kg, and it deteriorated by approx. 9% per 1,000kg load.

The total electric power consumption (calculated based on the driving motor + auxiliary machinery power consumption) also showed similar trend. It was 1.75km/kWh when the load was 0kg, and it deteriorated by approx. 9% per 1,000kg load.

### 3.4.4 Comparison between Actual and Simulated Electric Power Consumption

Based on the traveling patterns collected through the public road demonstration, we simulated the electric power consumption during traveling and compared the value with the electric power consumed. Exact value of the hydrogen consumption during demonstration was unidentified, therefore, we carried out a comparison of power consumption in the simulation.

Table3: Simulation results

| | Actual traveling data | Corrected simulation | Deviation [%] |
|---|---|---|---|
| Driving power consumption [kWh] | 5.896 | 5.707 | 3.3 |
| Auxiliary machinery power consumption [kWh] | 2.384 | 1.763 | 35.2 |
| Total power consumption[kWh] | 8.280 | 7.470 | 10.8 |

As shown above, the simulated driving power consumption approximated the actual traveling data.

Deviation regarding the auxiliary machinery power consumption is considered to result from factors such as; the consumption caused by a frequent use of brake during congestion or use of lighting units.

We found that a measurable accuracy can be obtained in the simulation of electric power consumption regarding the actual public road traveling. Further accuracy improvement can well be expected by considering additional simulation elements such as; traffic conditions as well as drivers' specific characteristics.

## 3.5 Demonstration Summary

- The electric power consumption in the public road demonstration in the City of Fukuoka was 1.75km/kWh with 0kg load. This figure deteriorated by 9% as the load increased every 1,000kg.
- The electric power consumption deteriorated by approx. 5% when the ambient temperature was below 14℃ (effect of the use of the heater).
- Similarly, the electric power consumption deteriorated by approx. 3% when the ambient temperature was beyond 23℃ (effect of the use of the air conditioner).
- Mileage or uptime are not interrelated with the electric power consumption.
- Although only slightly, a regular use of the strong regenerative brake helped to improve the electric power consumption.
- Generation of creep torque during standing time was considered for convenience, however, it worked against in terms of the electric power consumption.
- Through a simulation using the public road traveling data, a measurable accuracy can be obtained in the simulation of electric power consumption.


Figure 11: Running on public roads

# 4 Capacity Distribution between Fuel Cell and Secondary Battery

Capacity distribution between fuel cell and secondary battery of the developed vehicle was determined placing importance in versatility and expandability, and we examined the fitness of the capacity distribution with the traveling pattern by changing the ratio.

## 4.1 Traveling Pattern Classification

We classified the use and traveling pattern applicable to standard light-duty trucks powered by diesel engine into 3; highway, inter-city delivery and in-city delivery.

Based on the records of the demonstration, we segmented data approximate to each traveling pattern and examined speed / frequency, and drive-motor power consumption / frequency to determine the ideal capacity distribution.

## 4.2 Traveling Pattern and Fuel Cell / Secondary Battery Capacity

We examined the fitness of fuel cell capacity and secondary battery capacity with traveling patterns.

Utilizing the demonstration vehicle, we examined various cases increasing and decreasing the number of FCPM (Fuel Cell Power Module) and the capacity of secondary battery. Evaluation solely considered the fuel efficiency and not the cost.

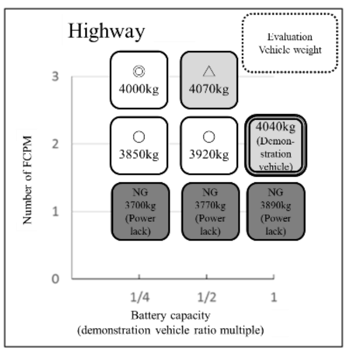



Figure 12: Highway

Electric power consumption during traveling outstands on highways.

After using the secondary battery power up, the vehicle speed can no longer be maintained because the electric power balance turns to negative with one FCPM unit.

The electric power balance remains positive with two FCPM units, but the generation load is high, and the efficiency is low.

Generation becomes is efficient on highways with three FCPM units, but the vehicle weight becomes excessive thus deteriorates the power consumption in city area where the vehicle frequently stops and goes.

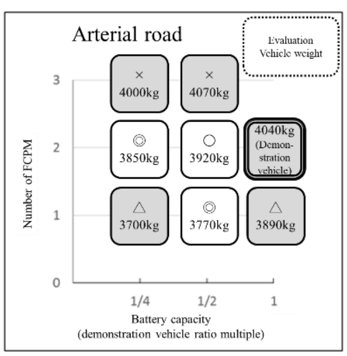



Figure 13: Arterial road

Efficiency becomes most favourable with two FCPM units on arterial roads, meaning, the best efficiency generated power well balances with the traveling power consumption.

With one FCPM unit, the generation load is high, and the efficiency is low, but enough secondary battery capacity will help to balance the electric power and improve the efficiency.

With three units, excessive generation capacity and weight just deteriorates the power consumption.

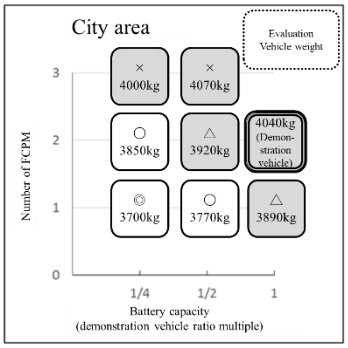



Figure 14: City area

One FCPM unit sufficiently caters power.

Power consumption can be improved by mounting less FCPM and secondary batteries.

However, one FCPM will limit the traveling on highways hence it will be necessary to give a clear solution to the vehicle operation.

### 4.3 Summary of Capacity Distribution between Fuel Cell and Secondary Battery

- Weight of the FCPM and the secondary battery has a significant impact on the fuel efficiency.
- Traveling power consumption is greater on highways, and the energy management shall fail if a greater fuel cell power is not secured. (the secondary battery power runs down thereby fails to maintain the speed).
- On local streets, a total power of fuel cell and secondary battery should be secured supposing a constant traveling pattern, hence the total capacity is in a trade-off relationship.
- Apart from the cost of the FCPM, the vehicle shall be available for various traveling patterns and vehicle type development by increasing the fuel cell output. This is because, increase of the secondary battery capacity still limits the highway traveling.
- Traveling power will only be covered by the secondary battery when the FC generation is stopped hence if the secondary battery capacity is to be reduced, a high output type secondary battery needs to be selected.

## 5 Summary

Through the 3-year development and demonstration program of a fuel cell light-duty truck that commenced in 2016, we developed a fuel cell vehicle technology, built a light-duty truck and evaluated its performance. Also, we carried out a delivery demonstration on public roads in the City of Fukuoka, examined the vehicle's basic performance, validated its practicability as a service vehicle, sorted through the future issues and completed the development of system assuming the production of the basic fuel cell light-duty truck that contributes to the dissemination.
Hereafter, infrastructure development should advance due to promotion of the hydrogen energy lead by the government, and changes in the environment to introduce light-duty trucks powered by fuel cell is well conceivable.

We will continue our activities in the technology development and public relations activities to promote the light-duty trucks powered by fuel cell that are effective in reducing CO2 emissions.

## 6 Acknowledgement

At last but not least, we would like to express our gratitude to those who supported us in the program namely; the City of Fukuoka and the Tenjin-district Co-operative Transportation Co., Ltd. who jointly worked with us as the joint practitioner of the program including the Ministry of the Environment.

# References


[1] Kazuya Maita and Akihiro Yamamoto et al., Development of 70MPa Hydrogen System Fuel cell light-duty truck, 2018



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(Detailed descriptions are not applicable due to confidentiality obligations.)