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Optimization of Fuel Cell Output for a Small Fuel Cell Bus

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Executive Summary

Tokyo R&D has extensive experience in the research and development of Zero Emission Vehicles but has also recently been involved in the development of FCEVs. For this project, Tokyo R&D was commissioned by Niigata Prefecture to develop a small fuel cell bus ("small FCEV bus") and empirical data from the demonstration of the bus was used to optimize the fuel cell output of the small FCEV bus considering future possible expansion to other applications.

Keywords: bus, fuel cell, fuel cell vehicle, heavy-duty, medium-duty

1 Small Fuel Cell Bus Design and Development

1.1 Vehicle Overview

The specifications of the small FCEV bus were studied based on the assumption that the bus would be operated mainly on the flat urban roads of Niigata city, which will be the main driving environment used for this demonstration. The study was conducted based on the premise that the vehicle should have the same power performance and maximum passenger capacity as the base diesel vehicle. Table 1 provides an overview of the studied vehicle specifications.

Table 1: Vehicle Specifications

Base vehicle	Hino Motors, Poncho
Length x Width x Height	6,990mm x 2,080mm x 3,200mm
Vehicle weight	6,900kg (calculated)
Passenger capacity	26 persons (13 seated + 12 standing + 1 driver)
Gross vehicle weight	8,330kg (calculated)
High-pressure hydrogen vessel	51L x 3 tanks (nominal working pressure 70MPa, UN-R134 certified)

FC stack	45kW maximum output
Rechargeable battery type and capacity	Lithium-ion battery (traction battery), 35kWh (UN-R100.02 certified)
Maximum output and torque	200kW, 1200Nm
Maximum speed	Over 80km/h
Hill-climbing performance	Above 15%
Equipment	Normal AC200/100V charger (charges traction battery directly) External power supply AC100V outlet

1.2 Vehicle System Configuration

The vehicle system configuration is largely divided into three main categories: the high-pressure hydrogen system, the FC system, and the EV system. As shown in Fig. 1 below, each system is comprised of a high-pressure hydrogen vessel, a fuel cell stack, a traction battery and a drive motor and inverter.

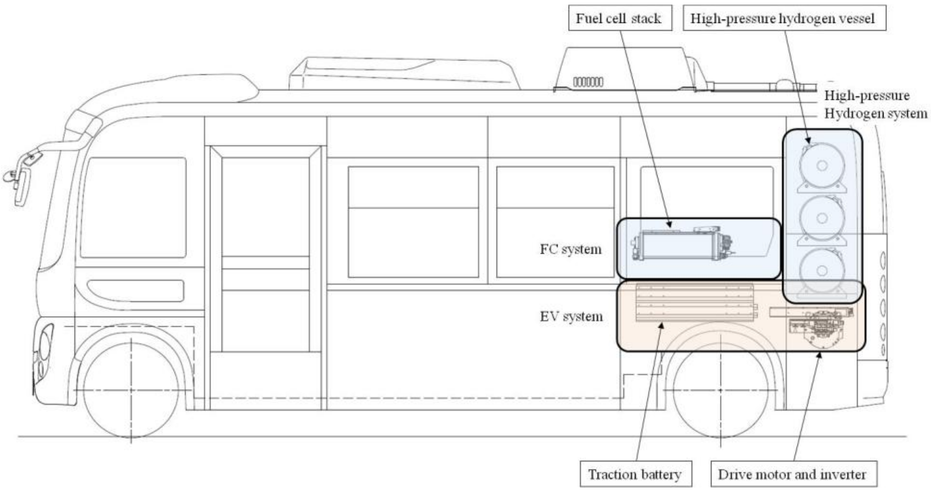

Figure 1: Overview of mounted key components

The basic configuration of this system replaces the generators usually found in range extenders of EVs with a fuel cell stack. As a result of this configuration, the FC system supplies the electricity generated from hydrogen to the EV system, and the EV system then stores the supplied electricity to the traction battery which in turn is used to drive the vehicle with the drive motor.

The advantage of this configuration is that the FC system is electrically independent, allowing it to be used with multiple EV platforms without being limited by the EV system it is currently connected to. Fig. 2 shows a schematic diagram of the system configuration.

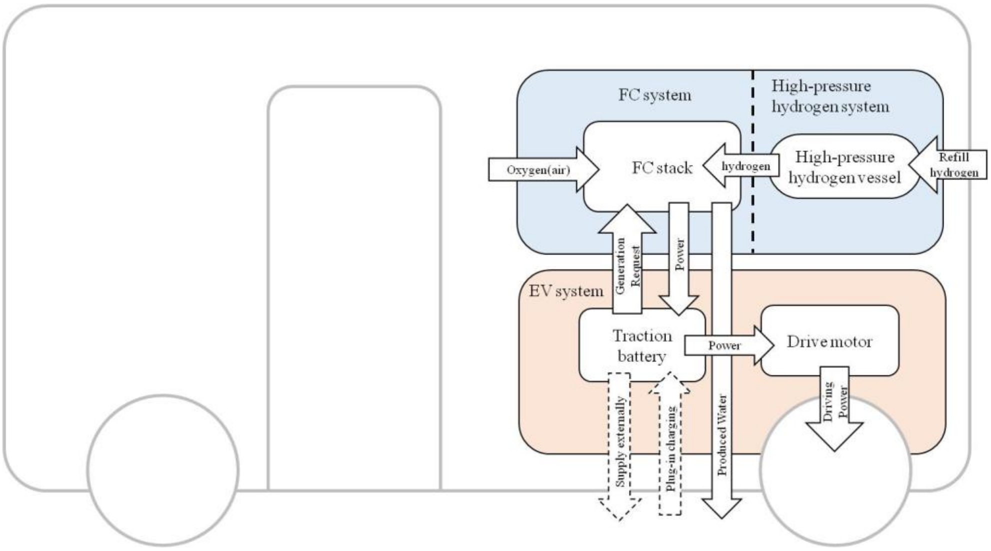

Figure 2: Vehicle system configuration schematic design

1.3 Chassis Dynamometer Testing of Completed Vehicle

A chassis dynamometer test was conducted using the completed vehicle to measure the vehicle's JE05 mode fuel consumption. The measurement result was at approximately 21.7km/kg. Fig. 3 shows a picture of the completed vehicle and Fig. 4 shows a picture of the vehicle during the chassis dynamometer testing.

Figure 3: Exterior of completed vehicle

Figure 4: Vehicle during chassis dynamometer testing

2 Small Fuel Cell Bus Demonstration

Data regarding the fuel cell's power generation status, power consumption of auxiliary equipment etc. are collected throughout the vehicle demonstration runs in Niigata city. The demonstration runs are still ongoing but the fuel consumption data acquired so far are as shown below.

2.1 Demonstration Run Results

The demonstration run results obtained so far are as summarized below.

Table 2: Demonstration Run Results

Demonstration run period	November, December 2022
Running days tallied	26 days
Refilled hydrogen amount	approx. 100kg
No. of times refilled	40 times
Cumulative run distance	approx. 1,850km

Representative routes of a typical demonstration run are as shown below.

Both routes are on flat and paved roads with 5km travel distance for the A route and 14km for the B route.

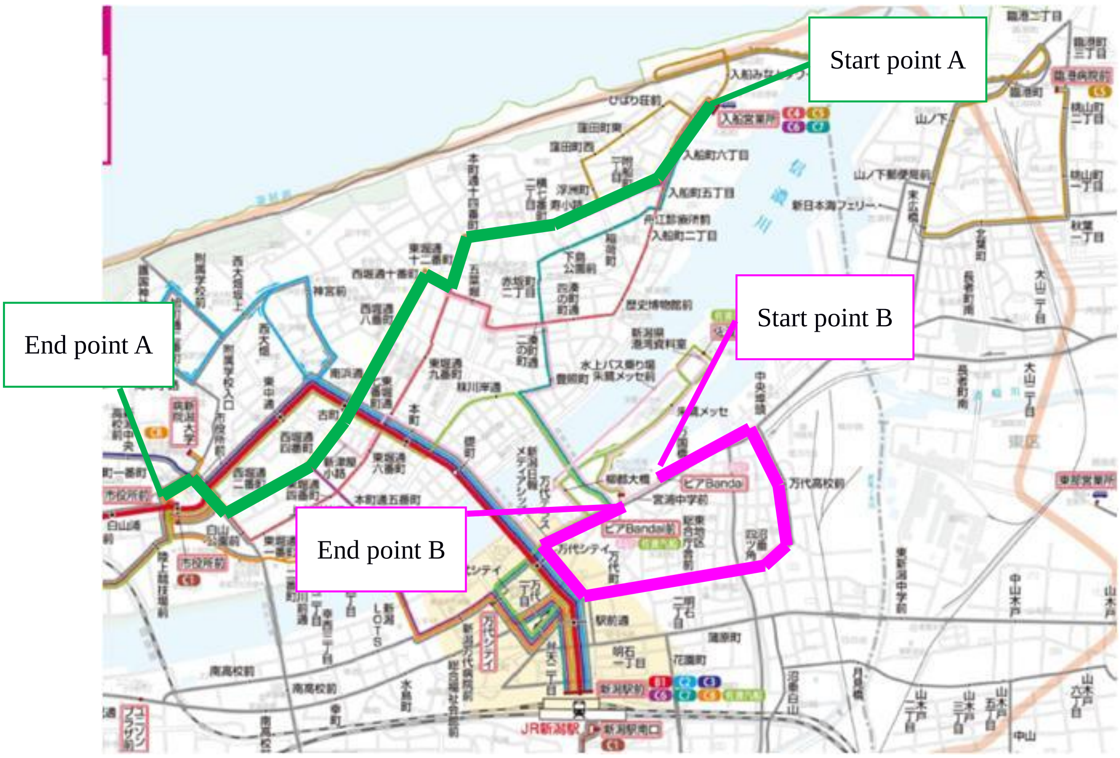

Figure 5: Demonstration run routes (typical run routes)

2.2 Demonstration Run Fuel Consumption

The driving fuel consumption data obtained from the demonstration runs are shown in Fig. 6. The graph shows the cumulative results of one run plotted as dots. The overall average fuel consumption is at approximately 19.6km/kg. When fuel efficiency was calculated separetely based on whether vehicle heating, a driving condition that significantly impacts fuel efficiency, was used, the fuel efficiency results were 15.1km/kg with heating and 21.8km/kg without heating. Heating was not used in the aforementioned fuel efficiency measurement during the chassis dynamometer testing and the measured values were close to the demonstration run fuel efficiency results without vehicle heating.

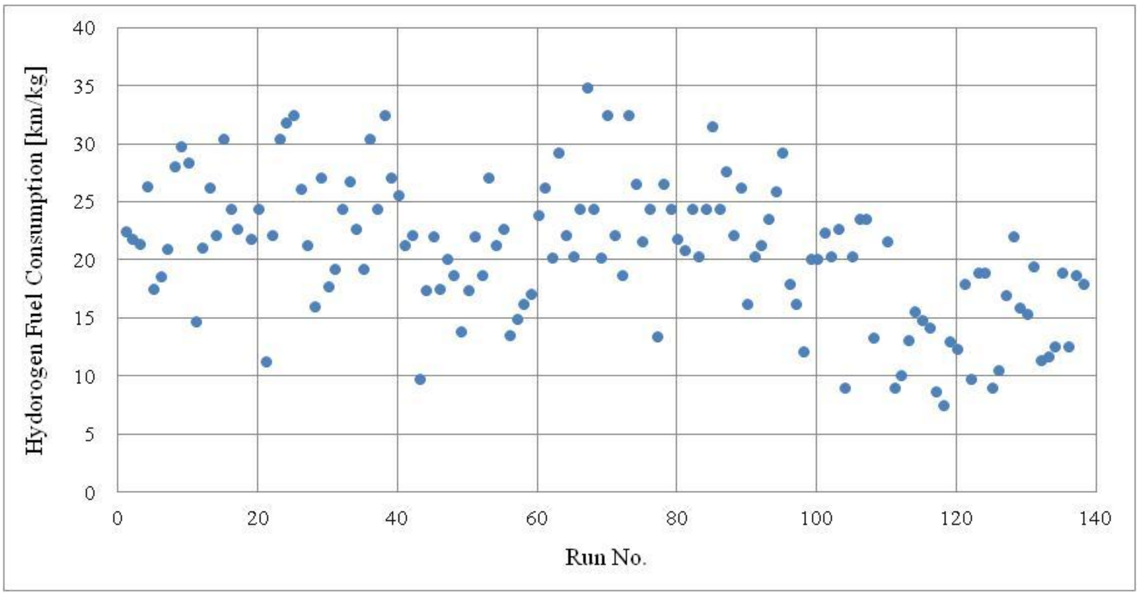

Figure 6: Demonstration Run Fuel Consumption Data (entire dataset)

3 Optimization of Fuel Cell Output at High Speeds

The fuel cell installed in the vehicle has a maximum output of 45kW, but in order to examine the possibility for further expansion to other use-cases for small FCEV buses in the future, five types of fuel cells (30, 45, 60, 80, and 90kW) were considered for the study.

The study considers the maximum output of each fuel cell along with the fuel efficiency and power consumption data obtained during the demonstration runs to evaluate the system from the perspectives of fuel consumption and initial cost.

3.1 Maximum Speed Relative to Fuel Cell Output

The five fuel cell variants described above were installed in the vehicle and their maximum output was used till a point where the vehicle runs at a constant speed without the traction battery SOC constantly increasing or decreasing. The maximum speed and fuel consumption values at this point were then recorded and evaluated for the study.

However, the entirety of the fuel cell output is not used solely for driving power as the vehicle's auxiliary equipment will certainly use a certain amount of power when the vehicle is running. Based on the results of the demonstration runs, the power consumption of the auxiliary equipment was at approx. 6kW. As the power consumption of the auxiliary equipment has little correlation to the vehicle running speed, the maximum output of the fuel cell minus the power consumption of the auxiliary equipment was considered the driving power data for this study.

In addition to the above, the drive motor was used within the range of its rated continuous output.

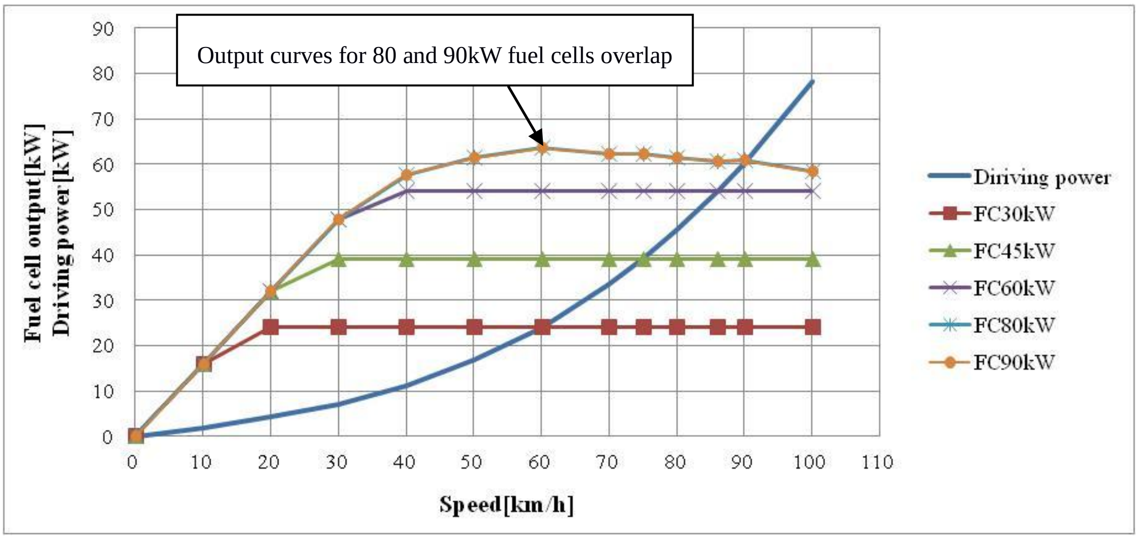

Figure 7: Vehicle running speed relative to fuel cell output

Fig.7 shows the vehicle running speed relative to the fuel cell output and the driving power displayed in the graph shows the energy consumed by the running resistance for each speed level. Thus in the above data, the range where the fuel cell output exceeds the driving power can be construed as the range where the target speed can be achieved.

The 80 and 90kW graph data overlap as the rated output of the drive motor is lower than the upper limit of the fuel cell output.

Assuming stable highway driving requires a speed of 80km/h (calculated based on Japanese highway conditions), the graph shows that a fuel cell output of 60kW or more is necessary for stable operations.

The maximum recorded constant speeds for each fuel cell output type are as shown below.

Table 3: Maximum Speed for Each Fuel Cell Output Type

Fuel cell maximum output [kW]	30	45	60	80	90
Maximum speed recorded [km/h]	60	75	86	90	90

Fuel cells that recorded maximum speeds exceeding 80km/h were those with a fuel cell output of 60kW or more.

As 30 and 45kW output fuel cells do not have sufficient output for the requirement, output assistance by a drive battery will be necessary.

Based on the above, it can be said that continuous driving on highways is possible by installing fuel cells with an output of 60kW or more. In addition, the above results are not influenced by vehicle battery capacity as the output assistance of the drive battery were set to zero for this study.

In this section, we further examined which output is optimal among fuel cells with an output of 60kW or more deemed suitable for highway driving by examining them from a fuel consumption and initial cost perspective.

Table 4: Fuel Consumption at Maximum Speed and Fuel Cell Initial Cost

Fuel Cell Maximum Output [kW]	60	80	90
Power generation efficiency[%]	43	43	43
Fuel consumption [km/kg]	19.8	18.8	18.8
Initial cost*	1.3	—	2.0

*Ratio of fuel cell cost with 45[kW] output fuel cell cost set to 1.0

Assuming a constant power generation efficiency, fuel consumption naturally decreases with higher speed as running resistance also increases with higher speeds. Recorded fuel cell consumption for 80 and 90kW output fuel cells in Table 4 have the same values as the rated output of the drive motor was already reached for the above hence the recorded maximum speeds are also the same.

No significant difference in fuel efficiency was found between the 60kW, 80kW and 90kW fuel cells.

With regards to the initial cost of the fuel cells within the 30 to 90kW range examined in this study, the cost per unit of output tended to be less expensive for the fuel cell with higher outputs, although the cost per unit of the fuel cell with the highest output ultimately was still higher.

In line with the above, it is therefore necessary to consider whether to use the minimum fuel cell output required by the planned application or to select a higher fuel cell output to take into account possible use-case expansion of the system in the future.

For this vehicle, a 45kW fuel cell was selected based on the assumption during the planning stages that the vehicle will be running on flat roads and that the above was sufficient to meet required performance levels. However, upon further consideration of factors such as highway driving and hill climbing, a fuel cell with an output of 60kW or more but not too far from this value is deemed to be optimal for the studied application.

4 Conclusion

In recent years, various manufacturers have developed affordable fuel cells with higher power compared to those previously available or readily available integrated fuel cell systems. As the number of available fuel cells in the market increases, the importance of optimization studies to determine the best suited fuel cell for the application in the study also increases.

Although this study only focuses on optimizing the fuel cell output relative to highway driving applications, further optimization studies of fuel cell output for different driving conditions, such as steep hill climbing conditions and with varying battery capacities will also be conducted.

Acknowledgments

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References

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Presenter Biography

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Graduated from the National Institute of Technology, Hachinohe College.

Took charge of various E-bus, E-truck, and fuel cell vehicle developments.

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