Economics of Hydrogen Production from Electrolyzer-Battery Hybrid System Using Surplus Electricity

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The production of hydrogen from electrolyzers using surplus electricity faces the challenge of high cost due mainly to the low capacity factor of electrolyzers. Smoothing the input power to electrolyzers by using a battery may be one way to elevate the capacity factor. This study developed an hourly simulation model for hydrogen production by an electrolyzer-battery hybrid system, and evaluated the impact on the hydrogen production cost, using the surplus electricity profile in the Hokkaido region determined by the power generation mix optimization model. The results showed that introducing the battery had no effect on reducing the cost of hydrogen production. This is because the cost of the battery far exceeded the reduction in hydrogen production cost gained by improving the capacity factor of the electrolyzer. In order to identify the positive contribution of the battery, further analyses are required based on a larger scale of surplus electricity or direct input of variable renewable energy to the hybrid system.

Keywords: Hydrogen, Electrolyzer, Battery, Surplus electricity, Power to gas

1. Introduction

Batteries and electrolysis are currently both attracting strong interest as a means to ease the output fluctuations of power from variable renewable energy (VRE). Many studies have been published on easing output fluctuations for both batteries and electrolysis. In recent years, studies have also been conducted to assess the combination of these technologies, which have distinctly different technical characteristics, for their potential to increase grid flexibility and reduce hydrogen production cost. For instance, one research[1)] analyzed the coordinated operation of batteries and electrolysis by retailers for the purpose of compensating the VRE imbalance.

Meanwhile, from the perspective of hydrogen production cost, another research[2)] indicated that the cost can be reduced by using batteries to level the solar PV power input into electrolyzers and thereby improving their capacity factor. As well as the direct supply of VRE described above, hydrogen can also be produced using surplus electricity.[3)] However, as surplus electricity is assumed to be generated less frequently and on a smaller scale than by solar PV generation, it is not clear whether the reduction in hydrogen production cost achieved by using batteries to level the supply of surplus electricity to electrolyzers would exceed the additional costs of installing batteries.

Accordingly, this study assesses the economics of hydrogen production of the electrolyzer-battery hybrid system using surplus electricity by identifying a surplus electricity profile that is expected to occur in real life using the power generation mix optimization model[4)]. The profile was identified for the Hokkaido region, where relatively large amounts of surplus electricity can be expected.

2. Analytical framework

First, we began by establishing multiple VRE capacity scenarios and identifying the full-year surplus electricity profile for each scenario using the power generation mix optimization model. Several combinations of electrolyzer and battery capacities were prepared for the surplus electricity capacity for each scenario. Then, a simplified simulation was conducted for each combination to determine the amount of surplus electricity supplied directly into the electrolyzers and via batteries (Figure 1), and based on these results, the capacity factor of the electrolyzers and hydrogen production costs were analyzed.

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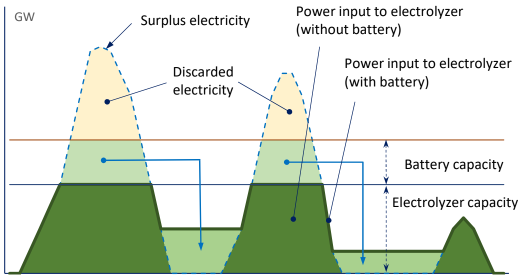

Figure 1 Operation Pattern of Electrolyzer-Battery Hybrid System for Hydrogen Production Using Surplus Electricity

3. Surplus Electricity Profile

In this study, we used the power generation mix optimization model developed through joint research by the Institute of Energy Economics, Japan and the Fujii-Komiyama Laboratory of the University of Tokyo. The model employed the linear programming method to simulate an economically-rational electricity supply-demand operation with the minimum total cost. Xpress was used as the optimization software. Refer to Reference[4] for details.

3.1 Assumptions

The target region of this study was Hokkaido. However, as the surplus electricity generated in this region is affected by other regions through inter-regional transmission lines, we conducted an analysis of the entire country using the power generation mix optimization model, and determined the surplus electricity profile for Hokkaido based on the result of the nationwide analysis. The following assumptions were adopted.

- Electricity demand: We referred to the user-end demand data for each area published by the Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) (up to 2030). For 2031 and beyond, the figures for 2030 were used.
- Cross-regional operation: The thermal capacity limit of OCCTO's forecasts was adopted as the upper limit for the amount of electricity carried through HVDC Hokkaido-Honshu and other inter-regional transmission lines.
- Thermal power: Both existing plants and planned ones were taken into account.
- Nuclear power: For the Hokkaido region, we assumed that Tomari Units 1-3 had restarted. For the capacity factor, we referred to the data from the Electricity Systems Working Group (hereafter, "the Systems WG") under METI's Advisory Committee for Natural Resources and Energy[5].
- Large-scale hydropower: The increase in capacity anticipated under the Sixth Strategic Energy Plan[6] (hereafter, "the new Strategic Plan") was included in the assumption in accordance with the Systems WG. We referred to the capacity factor indicated by the Systems WG (around 30%).
- Biomass: We assumed that the FIT-licensed capacity in the new Strategic Plan would be reached in 2030, considering the rate of implementation.
- Geothermal: We assumed that capacity would increase toward the 2030 new Strategic Plan target, considering the projects being planned. The capacity was allocated proportionally to all regions.
- Pumped storage hydropower: We adopted the same assumption as the Systems WG.
- Solar PV: For 2030, the nationwide target capacity in the new Strategic Plan was allocated proportionally to all regions based on the FIT licensing information, considering the rate of implementation. For 2030 through 2040, we referred to the rate of increase in the IEA's Stated Policies Scenario (STEPS) cases.
- Wind power: For 2030, the nationwide target capacity in the new Strategic Plan was allocated proportionally to all regions, considering the rate of implementation based on environment assessment data information[8]. For 2040, we referred to the figures for the 45 GW offshore wind power scenario of OCCTO's *Master Plan Study Committee*[9].
- For batteries, no additional capacities other than the already installed battery substations were considered.

The VRE capacity assumption for Hokkaido is given in Table 1. Scenario 1, which represents our estimate for 2030, anticipates 2.5 GW of solar PV and 5.4 GW of wind power. Scenario 2, which represents a longer-term estimate for 2040, anticipates 3.19 GW of solar PV and 16.1 GW of wind power.

Table 1 VRE Deployment Scenarios

	Solar PV	On-shore Wind	Off-shore Wind
Scenario 1	2.5GW	5.4GW	
Scenario 2	3.19GW	1.48GW	14.65GW

Note: Scenario 1 represents our estimate for 2030 and Scenario 2 for 2040.

3.2 Results

Figure 2 indicates the duration curve for the surplus electricity in each scenario. For Scenario 1, the VRE surplus rate (i.e. surplus electricity divided by the possible generation output) is 15% and the load rate of surplus electricity (i.e. average surplus electricity output divided by the maximum surplus electricity output) is 5%. Meanwhile, for Scenario 2, which has a larger VRE capacity, the surplus rate of VRE is higher with 46% and the load rate of surplus electricity with 14%.

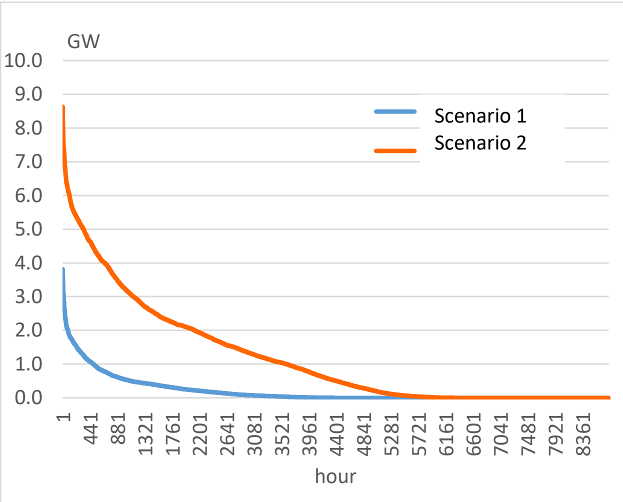

Figure 2 Duration Curve of Surplus Electricity

4. Economics of Hydrogen Production from Electrolyzer-Battery Hybrid System

4.1 Assumptions

The specific electricity input of hydrogen production from electrolysis was set to 4.72 kWh/Nm^3-H_2 (i.e. 52.9 kWh/kg-H_2), assuming the use of pressurized hydrogen production and including the motor required for pressurizing. The charging/discharging efficiency of the battery was set to 90% × 90% and the self-discharge rate to 0.02%/h. Facility costs of 50,000 yen/kW for electrolysis, 20,000 yen/kWh for battery cell stacks, and 40,000 yen/kW for power conditioner systems (PCS) were also factored in. The capacity storage time of the batteries was set to 5 hours. The product life of all facilities was set to 20 years, with a discount rate of 5%.

4.2 Analysis results

The analysis results for the economics of hydrogen production are shown in Figure 3 for Scenario 1 and in Figure 4 for Scenario 2. As the purpose of this study is to assess the reduction in the hydrogen production cost when batteries are installed to improve the capacity factor of electrolyzers, among the levelized costs of hydrogen (LCOH), only the levelized cost related to facilities (LCOH_CAPEX) was considered as the economic efficiency indicator.

When installing batteries, it is necessary to take into account the roundtrip efficiency of batteries and additional electricity cost arising from self-discharge losses. However, for simplification these factors are disregarded in the following discussions.

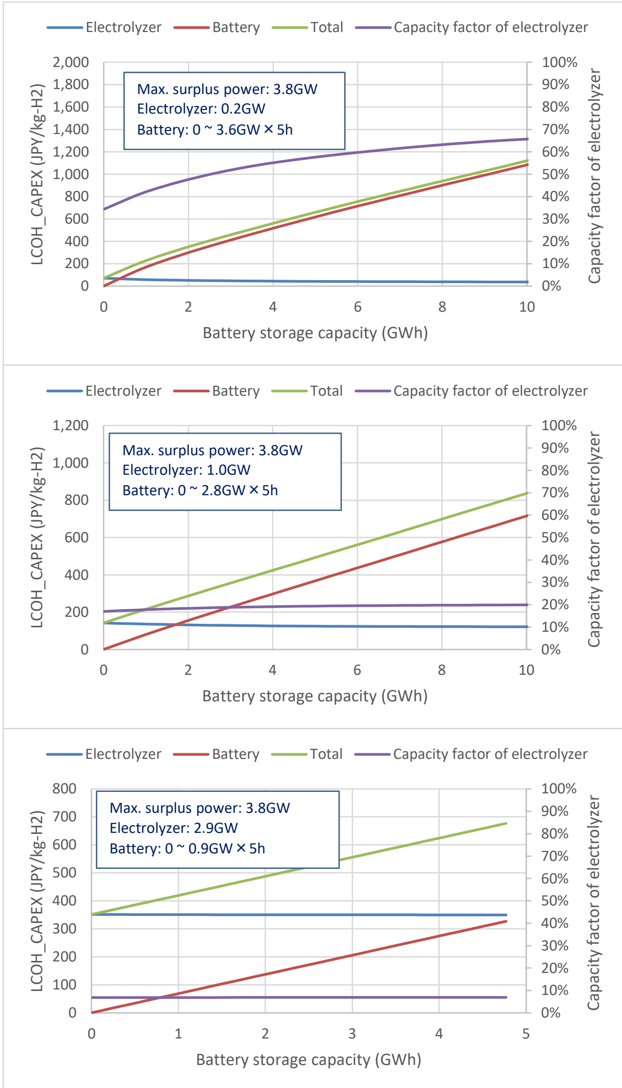

Figure 3 CAPEX in LCOH: Scenario 1

For Scenario 1, which has maximum surplus electricity of 3.8 GW, the results are indicated for three cases, namely with an electrolyzer capacity of 0.2 GW, 1.0 GW, and 2.9 GW, respectively (Figure 3). For each of these cases, the difference between the maximum surplus electricity and the electrolyzer capacity represents the maximum battery capacity that can be introduced (in GW), and analyses were conducted for a battery capacity ranging from 0 GW to the maximum battery capacity. The battery capacity (GW) multiplied by 5 hours (described earlier) is the battery capacity and is plotted on the horizontal axis. For the case where the electrolyzer capacity is 0.2 GW (top row in Figure 3), we can see that the electrolyzer capacity factor improves as more battery capacity is installed: the electrolyzer capacity factor is 34% when the battery capacity is 0, but it goes up to nearly 70% when 10 GWh (i.e., 2 GW x 5 hours) of battery capacity is introduced. However, the additional cost associated with introducing battery capacity is far greater than the decrease in hydrogen production cost resulting from an improved electrolyzer efficiency, and as a whole, there is no reduction in hydrogen production costs resulting from introducing batteries. As the electrolysis capacity increases (from the top row to the middle, and then to the bottom in Figure 3), the capacity factor improvement effect of introducing batteries decreases.

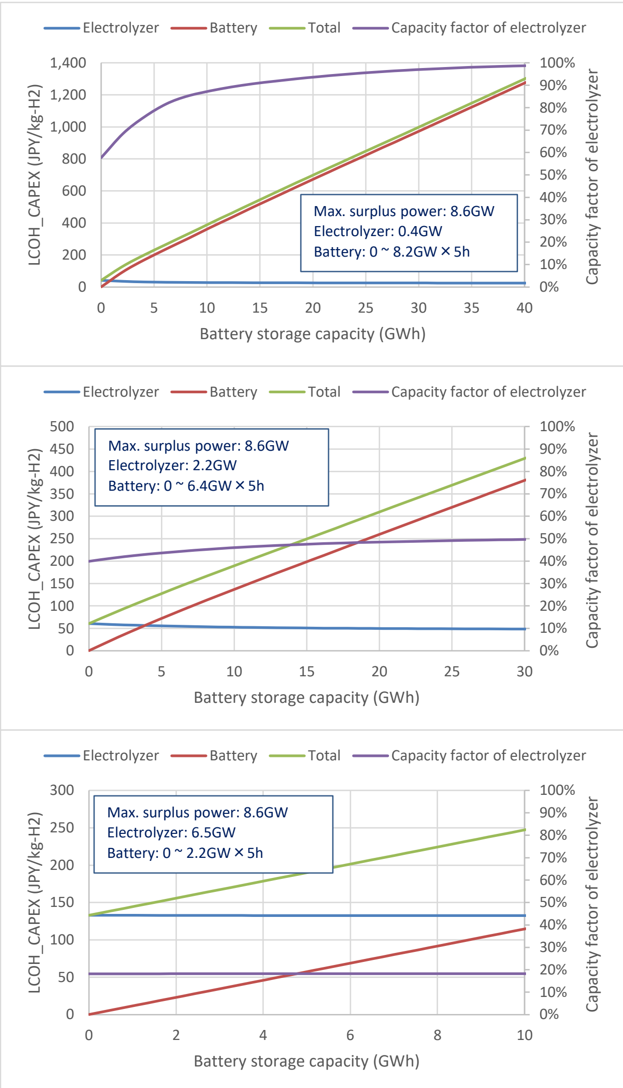

Figure 4 CAPEX in LCOH: Scenario 1: Scenario 2

This occurs because as the electrolyzer capacity increases, so does the amount of surplus electricity supplied directly into the electrolyzer, and thus the electricity to be supplied via the batteries becomes less in amount and frequency. The same trend can be observed in Scenario 2 (Figure 4) which has a larger amount of surplus electricity.

As mentioned earlier, since battery costs would increase even more when the roundtrip efficiency and self-discharge losses of batteries are taken into account, it is not worth installing batteries to improve the electrolyzer capacity factor in terms of reducing hydrogen production costs.

Needless to say, the effect of battery installation also depends on the relative relationship between the costs of electrolyzers and batteries. When the anticipated facility cost for electrolyzers was set at a fixed level and that for batteries was gradually lowered to find the conditions at which LCOH_CAPEX becomes the smallest, the lowest point was found to be one-twentieth of what we expected (Figure 5).

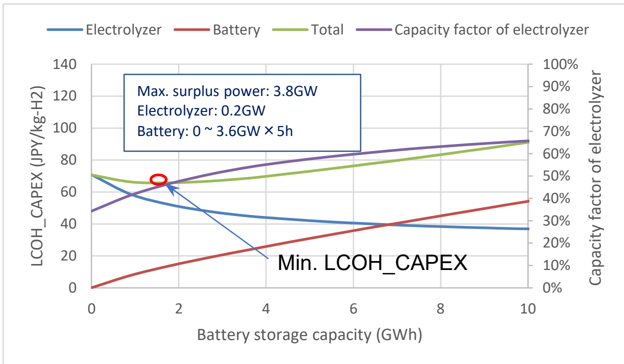

Figure 5 CAPEX in LCOH: Scenario 1 & Battery cost reduction

Note: CAPEX of battery is assumed to be 1/20.

5. Conclusion

This study assessed the economics of hydrogen production of the electrolyzer-battery hybrid system using surplus electricity. Installing batteries would level the supply of surplus electricity into electrolyzers and thereby improve their capacity factor. However, the study found that the additional facility cost associated with introducing batteries is far greater than the reduction in the hydrogen production cost resulting from an improved electrolyzer efficiency, and therefore it is not realistic to produce hydrogen with an electrolyzer-battery hybrid system using surplus electricity.

This means that with the VRE capacity adopted in this study, neither the frequency of occurrence nor the amount of surplus electricity is adequate and the amount of surplus electricity remaining after it is supplied directly into the electrolyzers is small, and therefore the process of storing such small quantity of surplus electricity in batteries and supplying it into electrolyzers is not economically rational.

Although the effect of battery installation also depends on the relative relationship between the costs of electrolyzers and batteries, if battery costs were one-twentieth of the levels we assumed, there could be a combination in which hydrogen production with an electrolyzer-battery hybrid system could become the least expensive. However, it is unrealistic to assume that battery costs will decrease to such levels.

Meanwhile, when solar PV or wind power, rather than surplus electricity, is supplied directly to electrolyzers, there could be cases in which the electrolyzer-battery hybrid system would be effective, though it depends on the capacity factor of these power sources. Furthermore, while this study did not closely examine the volume of hydrogen production, it may be possible to identify the optimal combination of electrolyzer and battery capacities by taking the hydrogen production volume as the constraint function and the hydrogen production cost as the objective function. These different cases remain to be verified in the future.

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