Hydrogen Production using Solid Oxide Electrolyzer Cell (SOEC) and Small Modular Reactors (SMR)

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1. Introduction

To achieve 2050 carbon neutrality, the importance of reducing carbon dioxide emissions is getting noticed. As a method to produce hydrogen fuel more cleanly, high-temperature steam electrolysis is one of the possible alternatives.

Solid Oxide Electrolyzer Cell (SOEC) is one of the high-temperature steam electrolysis methods, which operates above 700℃. The high operating temperature of SOEC decreases the amount of electricity consumed by replacing the electricity used with heat. It can be an effective method considering that the electricity price has a big impact on hydrogen production cost.

However, using grid electricity on steam electrolysis is insufficient to achieve zero-carbon emission. Although the energy mix ratio varies by country, high-temperature steam electrolysis using grid electricity can lead to opposite results to our goal since fossil fuels account for a high percentage of power generation. In this context, SOEC coupled with small modular reactor (SMR) can be a more attractive option to produce hydrogen.

Therefore, the costs for hydrogen production using SOEC coupled with SMR are investigated in this study.

2. Methods and Results

In this section, some of the boundary conditions used to model and cost evaluation methods are described.

2.1. Solid oxide electrolyzer cell (SOEC) model

Solid oxide electrolyzer cell (SOEC) consists of anode, membrane, and cathode. The total reaction in a SOEC is as follows:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2 \quad (1)$$

The SOEC model is built by using commercial simulation software, ASPEN PLUS V11 (Fig. 1). The boundary conditions used in the model are summarized in Table I.

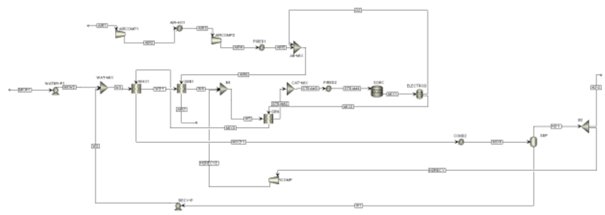

Fig. 1. Process flowsheet diagram of SOEC plants

Table I: Boundary conditions of SOEC [1], [2]

Parameter	Value
Temperature	800℃
Pressure	10 bar
Conversion	0.7
Inlet H_2 mole fraction	0.1
Outlet O_2 mole fraction	0.5
Product conditions	
Temperature	25℃
Pressure	9.4 bar
Purity	97.5 wt%

2.2. Very high temperature reactor (VHTR) model

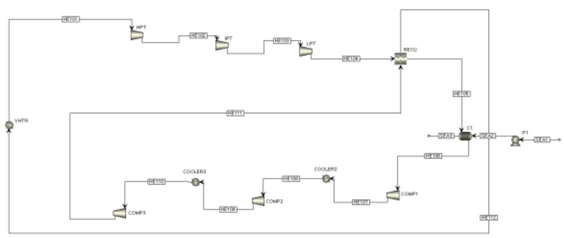

Fig. 2. Process flowsheet diagram of VHTR plants

To utilize the heat of SMR to steam electrolysis, a small nuclear power plant (NPP) that operates at 800-900℃ or higher should be selected rather than the conventional 300℃ NPPs. A very high-temperature reactor (VHTR) is one of the Generation IV-nuclear power plants which utilizes helium gas as a coolant and operates at 950℃, 9 MPa[3]. The Brayton cycle is used to generate electricity by three gas turbines and compressors. Depending on the amount of electrical power required by SOEC, the generated electricity of VHTR is coupled with it by optimized thermal efficiency using MATLAB. The VHTR model is also built by using commercial simulation software, ASPEN PLUS V11 (Fig. 2).

2.3. Cost evaluation method

The base year of cost evaluation is 2019, so the values are corrected using CEPCI if the year is different from the base. For the conservative approach, the cost of heat is added by multiplying thermal efficiency on electricity cost. Cost frameworks of SOEC and VHTR models are listed in Table II and III, respectively.

Table II: Cost framework of SOEC model [4]

Direct Costs	
	Fraction of TEC
Total Equipment Cost (installed) (TEC)	1
Instrument and Control	0.09
Piping	0.23
Electrical equipment and material	0.07
Site development	0.1
Buildings	0.05
Site development	0.1
Land	0.06
Total Direct Costs (TDC)	TEC*(1+0.7)
Indirect Costs	
	Fraction of TDC
Engineering and Supervision	0.1
Construction expenses	0.13
Project contingency	0.1
Total Indirect Costs (TIC)	0.33
Fixed Capital Investment (FCI)	TDC+TIC
	Fraction of FCI
Working Capital	0.15

Table III: Cost framework of VHTR model ($2019, WACC=5.2%) [5]

	Value	Units
Total Overnight cost	3,333	$ M
Total Overnight Cost per kW	11,110	$/kW
Interest During Construction Factor	8.69	%
All-in Capital Costs	3,548	$ M
Levelized Capital Cost+D&D Cost	92.87	$/MWh
Levelized O&M Costs	26.43	$/MWh
Levelized Fuel Cost	8.84	$/MWh
Levelized Cost	128.13	$/MWh

Also, carbon dioxide emissions from NPP are converted to operating costs by SimaPro Ecoinvent Database and carbon credit price. Since there is no database analyzing the effect of the VHTR, it is replaced with the database of the pressurized water reactor (PWR) in Korea. Carbon credit price is also calculated based on 2019, which is 28,440 won per ton CO_2. The results are presented in Fig. 3.

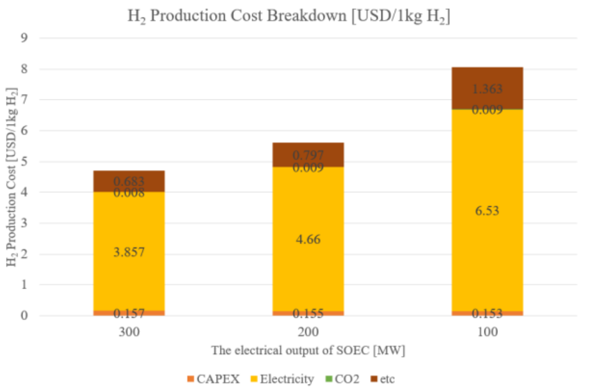

Fig. 3. Hydrogen production cost breakdown [$/kg]

3. Conclusions

In this study, hydrogen production costs using SOEC and SMR are estimated. As a result, the range of hydrogen production costs is 4.705-8.055 $/kg along with the electrical output of SOEC.

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