Preliminary Hydrogen Production Cost Estimation based on the HEEP

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1. Introduction

The International Atomic Energy Agency (IAEA) has just released the newly developed Hydrogen Economic Evaluation Program (HEEP) software, which can be used to perform economic analysis related to large scale hydrogen production. The HEEP software is appropriate to perform economic analysis for comparative studies not only hydrogen production using nuclear or fossil fuel but also only hydrogen production or cogeneration with electricity. The HEEP software requires basic input data to calculate hydrogen production cost such as chronological data, finance data, and technical data related to nuclear power plant and hydrogen generation plant.

2. Input and assumptions

As a preliminary study of cost estimates for nuclear hydrogen systems, the hydrogen production costs of the nuclear energy sources are estimated in the necessary input data on a Korean specific basis. The HEEP was used to calculate the cost for hydrogen production of SI process with VHTR (Very High Temperature Reactor) as a thermal energy source. The general ground rules and assumptions follow the HEEP internal program logic. The formula used for calculation of levelized cost of hydrogen generation is : [2]

$$C_{H2} = \frac{E_{NPP}(t_0) + E_{H2GP}(t_0) + E_{H2T}(t_0)}{GH_2(t_0)} \quad (1)$$

Where, C_{H2} = levelized cost of hydrogen generation; ENPP(t_0) = Present value of expenditure of nuclear power plant at time t_0; $E_{H2T}(t_0)$ = Present value of expenditures of hydrogen transportation facility at time t0; GH2(t_0) = Present value of gross hydrogen generation at time t_0; t_0 = Base year of comparison.

The present value of expenditures is calculated using following fundamental formula:

$$E(t_0) = \sum_{t=tSTART}^{tEND} \frac{CIt}{(1+r)^{t-t_0}} + \sum_{t=tSTART}^{tEND} \frac{Rt}{(1+r)^{t-t_0}} + \sum_{t=tSTART}^{tEND} \frac{DCt}{(1+r)^{t-t_0}} \quad (2)$$

Where, CI_t = Capital Investment expenditures at year t; R_t = Expenditures towards running the facility in the year t; DC_t = Decommissioning expenditures at year t; r = Real discount rate.

The economic assessments were performed for PMR (4 * 600MWth) coupled to a SI chemical plant as a hydrogen production process. The capital costs for PMR were mainly referred to the GT-MHR related paper, Korea energy economics institute (KEEI) report and Idaho National laboratory (INL) report for some account items, corrected to the input data on a Korean specific basis. Typical input data of the HEEP are summarized in Table 1.

1) Account items in the reactor indirect costs were partially considered in this calculation due to the insufficient data.
2) Due to insufficient data, unapparent values or detail items for the account were set to the HEEP's default value.
3) The instantaneous hydrogen production rate for four, 600MWth prismatic modular reactor is assumed to 7.61 kg/s, which corresponds to a plant hydrogen production rate of 216,000 tones per year at a plant capacity factor of 0.9 and the others were appropriately scaled up.

Table 1. Summary of input data of the HEEP

Items	Sub-Items	Values
Finance Details	Discount rate	5%
	Inflation rate	1
	Equity/Debt	70%/30%
	Borrowing interest	10%
	Tax rate	10%
Time Period	Construction (year)	5
	Operating (year)	60
Nuclear Power Plant Details	Thermal rating (MWth/Unit)	600
	Number of units	4
	Initial fuel load (kg/unit)	4515
	Annual fuel feed (kg/unit)	1644
	Capital cost (USD/unit)	1.83E+9
	Capital cost fraction for electricity generating infrastructure (%)	0
	Fuel cost /ore (USD/kg)	122
	O&M cost (% of capital cost)	2.07
	Decommissioning cost (% of capital cost)	10
Hydrogen generation plant details	H2 generating per unit (kg/yr)	5.40E+7
	Heat consumption (MWth/unit)	540
	Number of units	4
	Capital cost (USD/kg of H2)	1.41E+9
	Energy usage cost (USD)	6.25E+7
	Other O&M cost (% of capital cost)	5.46
	Decommissioning cost (% of capital cost)	10 %

3. Results of the HEEP calculation

The costs for hydrogen production are summarized on a annual basis in Table 2. Real discount rate for interest during construction and amortization was assumed to be 5%. The preliminary hydrogen production costs for PMR were estimated to be 5.36$/kg. Comparing the preliminary study with past study result[4], the preliminary production cost value is relatively higher than that of the past study about 1$/kg. We think different baseline year, HEEP's internal program logic and detailed item input values make these cost difference.

Since hydrogen transportation and hydrogen storage were not considered in this study, sum of cost indicated in third and fourth column is set to zero.

Table 2. Summary of output result of the HEEP

Items	Capital Cost (Debt)	Capital Cost (Equity)	O&M and Refurbishment	Decommissioning Cost	Fuel Cost	Total of the facility
Nuclear Power Plant	0.9	1.17	0.63.	0.11	0.01	2.82
Hydrogen Generation Plant	0.77	1.01	0.69	0.08	-	2.54
Hydrogen storage	0	0	0	0	-	0
Hydrogen Transportation	0	0	0	0	-	0
Total of all facilities	1.67	2.18	1.32	0.19	0.01	5.36

4. Conclusions

In this paper, we present preliminary hydrogen production cost estimation based on the HEEP. In order to get more concrete and accurate cost calculations, we need to consider many parameters and input values in details including hydrogen storage cost and hydrogen transportation cost.

The estimated costs presented in this paper show that hydrogen production by VHTR coupled to SI plant system could be competitive with current techniques of hydrogen production from fossil fuels if CO_2 capture and sequestration is required. This favorable situation is expected to further improve as the cost of natural gas rises. Nuclear hydrogen production would allow large-scale production of hydrogen at economic prices while avoiding the release of CO_2. Nuclear production of hydrogen could thus become the enabling technology for the hydrogen economy.

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