Preliminary Cost Estimates for Nuclear Hydrogen Production: HTSE System

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1. Introduction

KAERI is now focusing on the research and development of the key technologies required for the design and realization of a nuclear hydrogen production system. As a preliminary study of cost estimates for nuclear hydrogen systems, the hydrogen production costs of the nuclear energy sources benchmarking GT-MHR and PBMR are estimated in the necessary input data on a Korean specific basis. G4-ECONS was appropriately modified to calculate the cost for hydrogen production of HTSE (High Temperature Steam Electrolysis) process with VHTR (Very High Temperature nuclear Reactor) as a thermal energy source. The estimated costs presented in this paper show that hydrogen production by the VHTR could be competitive with current techniques of hydrogen production from fossil fuels if CO_2 capture and sequestration is required. Nuclear production of hydrogen would allow large-scale production of hydrogen at economic prices while avoiding the release of CO_2 [1]. Nuclear production of hydrogen could thus become the enabling technology for the hydrogen economy. The major factors that would affect the cost of hydrogen were also discussed.

2. Cost Estimates

G4-ECONS Version 1.0 was appropriately modified to calculate the cost for hydrogen production of HTSE process with VHTR as a thermal energy source rather than the LUEC (Levelized Unit Electricity Cost) [2, 3]. Through a preliminary study of cost estimates, we wished to evaluate the economic potential for hydrogen produced from nuclear energy, and, in addition, to promptly estimate the hydrogen production costs for an updated input data for capital costs. Although some input data were modified on the Korean specific basis, most of capital costs for the GT-MHR and E4-ECONS baseline data were available and served as the basis of our estimate. It is well known that the four or more reactor cluster makes sense from an availability basis because fueling can be staggered and the plant can be kept at high percentage of capacity at all times. On this basis, the preliminary cost estimates were performed to the multi-reactor cluster.

The economic assessments were performed for two types of cores of the nuclear reactors, PMR (4 x 600MWth and 4 x 200MWth) and PBR (10 x 250 and 4 x 200 MWth), respectively, coupled to a HTSE chemical plant as a hydrogen production process. The capital costs for PMR and PBR were referred to the GT-MHR and PBMR, respectively, and, for some account items, corrected to the input data on a Korean specific basis [4-6]. The capital costs for HTSE chemical plant were referred to the H2-MHR based on HTSE plant [4]. The input data of the capital costs were based on scaling the previous reactors and HTSE plant, and increasing costs of some equipment to account for the use of higher-temperature materials. Capital costs were also escalated to 2005 dollars. We estimated the hydrogen production costs for four types of modular reactors coupled to HTSE plant, whose items and relevant specifications are described in Table 1.

Table 1. Plant specifications of calculation models

Items		Specifications			
Analysis Models	Reactor Type	Prismatic Core		Pebble Bed Core	
		PMR1	PMR2	PBR1	PBR2
	Reference Plant	H2-MHR: HTSE-Based Plant			
Thermal Output (MWth)		4 x 600	4 x 200	10 x 250	4 x 200
Operational Period (yr)		60	60	40	40
Outlet Temperature (℃)		950	950	950	950
Plant Efficiency (%)		55.8	55.8	55.8	55.8
Capacity Factor (%)		90	90	90	90
Fuel Cycle		Open	Open	Open	Open

The base line estimate was based on the following assumptions:

- Real discount rate for interest during construction and amortization: 5%
- PMR and PBR plant indirect costs: considered in the partial 2-digit items such as field indirect cost and design service offsite costs
- HTSE plant indirect costs: 20% of direct costs
- Site size: n/a
- No electric generation

The reactor and HTSE plant systems were subdivided into 58 and 17 items in the cost estimates, respectively, i.e., costs shown in Table 2 were rolled-up at the level of major subsystems.

Table 2. Capital cost for PMR1 calculation model

Account Description		Costs, $M
MHR Plant	Structure and Improvements	142.1
	Reactor Plant Equipment	517.9
	PCS Equipment	111.1
	Electrical Equipment	44.7
	Water intake and heat rejection plant	38.5
	Miscellaneous plant equipme nt	30.1
HTE Plant	SOE	584.0
	Etc	206.2

3. Results and Discussion

The costs for hydrogen production are summarized on an annual basis in Table 3. Real discount rate for interest during construction and amortization was assumed to be 5%. The baseline hydrogen production costs for PMR1, PMR2, PBR1 and PBR2 were estimated to be 2.47 $/kg, 3.19 $/kg, 3.12$/kg and 3.70 $/kg, respectively. Comparing the PMR with the PMR with similar thermal output coupled to the same HTSE plant, the costs for PBR types requires higher costs for hydrogen production than the ones for PMR. Those were mainly due to the assumed operational life of the systems.

Parameter studies were performed to determine the sensitivity of the hydrogen production costs and efficiency to construction time, fixed charge rate and SOE costs which are key components in HTSE plant system. As shown in Table 4, the fixed charge rate and electricity costs have a significant influence on hydrogen production cost. It should be noted that the shaded cells in Table 4 indicate results for the baseline cost estimate. It is well known that increasing the construction time results in higher interest charges, but the increase in hydrogen production cost is only 0.05 $/kg ~ 0.23 $/kg as shown in Table 4.

Table 3. Annual costs for hydrogen production

Reactor Type		**Cost ($/kg$H_2$)**
Prismatic Type	PMR1 (4 x 600 MWth)	2.47
	PMR2 (4 x 200 MWth)	3.19
Pebble-Bed Type	PBR1 (10 x 250 MWth)	3.12
	PBR2 (4 x 200 MWth)	3.70

Table 4. Results for parametric studies of hydrogen production costs

Parameters	Capital Cost ($M)	Hydrogen Production Cost ($/kg$H_2$)
SOE Costs	500	2.42
	750	2.57
	1000	2.71
Construction Ti me, Months	36	2.47
	48	2.58
	60	2.70
Fixed Charge R ate, %	12.6	2.47
	16.6	3.11
Reactor Plant	500	2.46
	750	2.61
	1000	2.77

VHTR as well as HTSE plant system is one of highly innovative nuclear energy systems just in Korea. Cost modules, using cost/size scaling equations, as well as system design sufficient to precisely calculate hydrogen production cost are thus no doubt about being in its early stages comparing with an advanced country for VHTR. The decision maker, nonetheless, needs more than just the overall costs on R&D phases, whose particular interest are the cost per kilogram of hydrogen of installed capacity from hydrogen production systems. For several reasons mentioned above, more conventional systems such as GT-MHR and PBMR were to be utilized for cost estimates. Although the conventional scaling method for sizing and increase of design temperature was used in these calculations, it was no doubt that difference in design specifications between VHTR and GT-MHR and PBMR gave rise to excessive assumptions in these calculations.

The estimated costs presented in this paper show that hydrogen production by VHTR coupled to HTSE plant system could be competitive with current techniques of hydrogen production from fossil fuels if CO_2 capture and sequestration is required [7]. 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.

4. Reference

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