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Study on Competitive Exporting Price-forecast of the SMART in the U.S

In-Su Kim*, Tae-Ryong Kim,
KEPCO International Nuclear Graduate School, 1456-1 Shinam-Ri, Seosaeng-Mueon, Ulju-Gun, Ulsan
**Corresponding author: mister@kepco.co.kr*

1. Introduction

Even though nuclear power is considered clean energy for global warming, there has been some controversy due to its safety issues and high capital cost as well as public acceptance. However, despite the disadvantages, many countries cannot but consider nuclear power as a sustainable energy source for energy security and climate change mitigation. Furthermore, in a future energy mix where a small grid capacity and intermittent production from Renewable Energy Systems will become more common, SMRs (Small Modular Reactor) could play an important role in supporting reliable electricity market [1]. In line with this, the U.S. has a renewed interest in SMRs rather than large reactors. Nothing, however, has been implemented yet. The only SMRs under construction are in Russia: the first floating nuclear plants. For the most part, the primary candidates to be the first land-based counterparts of Russia's are the SMART (System integrated Modular Advanced Reactor) reactors [2].

The Korean SMART has been developed and licensed for standard design. In addition, the SMART reactor may be suited to countries, which have a small grid capacity, low population density, and decentralization power system such as the U.S.

Therefore, the purpose of this paper is to develop a target price for the SMR market opportunities in the U.S., competing against the CCGT (Combined Cycle Gas Turbine) which is currently a very attractive option for generating due to the shale innovation.

2. The main body

2.1 Potential market demand for the SMART

In this section the methodology of market research is described. First, this paper did research on small-sized coal plants to be replaced from 2015 to 2035 shown in the table 1. Because SMRs are considered to present an alternative for coal replacement in the U.S. [3] [4], and then forecasted the net growth of the nuclear market in the table 2.

Table 1. Predicted SMR Market Scale I [5]

Unit: GW

Coal Retirement	Small-sized Coal Retirement*			SMR** Market Scale
	Announced	Potential	Sum	
87	8.3 (64 units)	11.1 (96 units)	19.4 (160 units)	**1.75**

* assumes that 30MW ≦ Small-Sized coal retirement ≦ 300MW.

** In the U.S., NPP Market scale is 9% in 2035 according to WEO 2012 (New), which can be applied to the small-sized coal retirement.

Table 2: Predicted SMRs Market Scale II [6]

Unit: GW

Source	NPP Capacity 2015 (a)	NPP Capacity 2035 (b)	NPP* Decommission (c)	NPP Net Growth (b – a + c)
WEO 2012 (New)**	**108**	**119**	**65**	**76**
WEO 2012 (450***)	108	140	65	97
WEO 2011 (New)	112	124	65	77
WEO 2011 (450)	112	156	65	109
IEO 2013	104	109	65	70
IEO 2011	106	111	65	70

* Decommission: NPPs whose license will expire from 2015 to 2035 are considered potential decommission plants.
**New scenario: basic scenario in International Energy Agency.
***450 scenario: sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2℃.

Secondly, the market scale of SMRs was predicted on the ratio of SMRs within outcomes of the first phase [7] [8]. In this paper, the market scale of SMR was assumed to be 3% in the reference case. Finally, the SMART market demand was predicted on the anticipated ratio of market share in the U.S. Korea is considered one of the leading countries that have SMR technology including Russia, China, and U.S. Moreover, there are 12 current leading SMR designs [8]. This paper, therefore, assumed that its market share would be 10% in the U.S. As a result, the predicted market demand of the SMART is 4 units as shown in table 3.

Table 3: SMART Market Demand in the U.S, 2015~2035

Unit: GW

No.	SMRs Market Scale			SMART Market Demand	
	A*	B**	Total	Capacity	Unit(EA)***
1(3%)	**1.75**	**2.3**	**4**	**0.4**	**4**
2(5%)	1.75	3.8	6	0.6	6
3(1%)	1.75	0.8	3	0.3	3

* obtain from the table 1.
** came from multiplying 76GW in table 2 by 3%, 5%, and 1%, respectively, according to the assumed market scale of SMR.
*** SMART with 100MWe capacity is only addressed in this study.

2.2 Economics Analysis

For the comparison with target price, this paper additionally estimated LCOE (Levelized Cost Of Energy) which is a standard method to compare energy cost produced by difference sources. Table 4 shows their basic parameters.

To compare them with the same capacity, the overnight cost and O&M cost for the CCGT were adjusted from the CCGT with a capacity of 400MWe using scaling factor. Also, the SMART added technology risk, 3%, to discount rate.

Table 4: Input Data ($ in 2015) [7][9*][10**]

Components	SMART	CCGT
Capacity(MWe)	100	100
Overnight Cost($/kW)	3,000 ~ 5,000*	2,294**
O&M Cost($/MWh)	6.81*	7.97**
Fuel Cost	15.43($/MWh)*	7.544($/Mbtu)
Economic Plant Life	60*	30
Discount Rate (%)	8	5
Scaling Factor	-	0.5
Capacity Factor (%)	90	85
Carbon Tax ($/t-$CO_2$)	-	16.24

According to fig 1, LCOE of the SMART varies from 52.99 to 73.48$/MWh depending on overnight cost, while the CCGT has 59.44$/MWh including carbon tax.

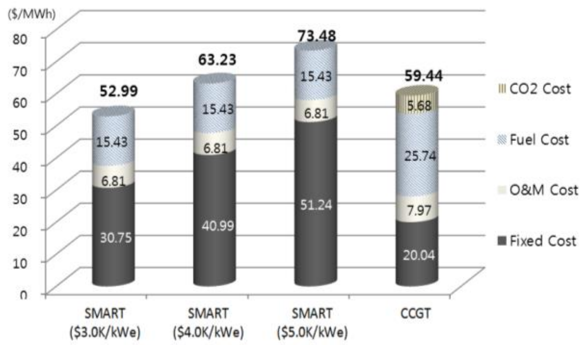


Fig. 1. The LCOEs for alternatives

If the construction cost of the SMART is around 3,000$/KWe, it has already competitive edge regardless of carbon tax. On the other hand, provided that construction cost is higher than 4,000$/KWe, fig 1 indicates that it is hard to have price competitiveness against CCGT, even considering carbon tax. Since fixed costs account for more than half of the LCOE of the SMART, it is highly recommended to reduce the construction cost to gain its competitive edge. On the other hand, fuel cost is the most critical element in economic assessment of CCGT.

2.3 Estimated a Target Price

This paper attempted to estimate the target price from the general method of determining the market price, assuming that $LCOE_{SMART}$ should be lower than the sum of $LCOE_{CCGT}$ and carbon tax so that the SMART could have an opportunity to build in the U.S.

Moreover, this study focuses on an estimation of the construction cost for the SMART because it is a decisive factor in the case of exporting, which makes the LCOE of alternatives have identical value [11]. The description above can be transformed into the following equation (1).

$$LCOE_{smart} = \frac{I_{smart} \times FCR(r,n) + O\&M_{smart} + Fuel_{smart}}{P.G.} \le LCOE_{CCGT} + Carbon_{tax} \quad (1)$$

Here, I_{smart} is overnight cost, $Fuel_{smart}$ is the fuel cost, $O\&M_{smart}$ is operating expense, FCR is Fixed Charged Rate with discount rate (r) and life time of plant (n), $Carbon_{tax}$ is CO_2 cost ($/MWh), and P.G is annual power generation. Equation (1) can be rearranged to equation (2), and all cost factors in equation (2) are Levelized values.

$$I_{smart} \le \frac{(LCOE_{CCGT} + Carbon_{tax} - O\&M_{smart} - Fuel_{smart}) \times P.G}{FCR(r,n)} \quad (2)$$

I_{smart} is a target price of the SMART, which could be interpreted as the construction cost for the SMART as well.

Table 5: Inputs & Outputs of the Target Price ($ in 2015)

Components	Unit	Min	Reference	Max
LCOE (CCGT)*	$/MWh	50.13	53.76	55.77
Carbon Tax	$/MWh	3.79	5.68	7.58
O&M (Smart)	$/MWh	6.81	6.81	6.81
Fuel (Smart)	$/MWh	15.43	15.43	15.43
P.G. (Smart)	GWh	788.4	788.4	788.4
FCR(r,n)	%	8.0798	8.0798	8.0798
Target Price(I_{smart})	$/KWe	3,091	3,630	4,011

* The range of scaling factors: 0.45(max) ~ 0.6(min) [12].

Assuming gas price is 7.544$/Mbtu and discount rates (r), capacity factors, and economic plant life (n) for the SMART and CCGT follow the data in table 4, the target price varies from 3,091 to 4,011$/KWe depending on scaling factors and carbon tax. It is clear, from comparing the range of target prices with those of overnight costs in table 4, that it is essential to strive to reduce construction cost of the SMART to gain price competitiveness in the U.S market.

2.4 Sensitivity Analysis

The sensitivity analysis was performed to understand the impacts on the target price from the price of natural gas, carbon tax, and discount rate. Fig 2 indicates that the target price goes up in proportion to the natural gas price.

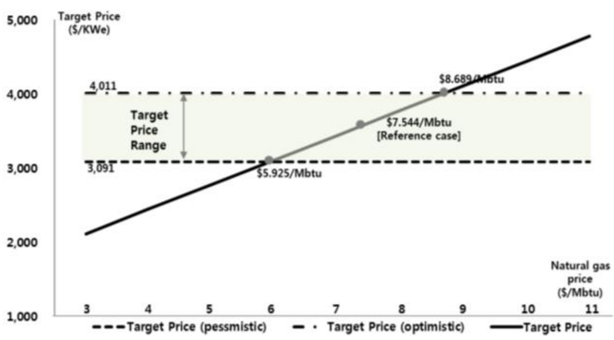


Fig. 2. Sensitivity analysis with the price of natural gas

For examples, if the gas price is higher than 8.689Mbtu, the target price will rise higher. The higher natural gas price rises, the more chances the SMART can be exported. In other words, obtaining higher target price is more feasible alternative to export the SMART than having lower one.

To gain the SMART's competitive edge, the price of gas should be higher than 8.689$/Mbtu in the optimistic case where target price is 4,011$/kWe as seen in Fig. 2. On the other hand, in the pessimistic case, it should be higher than 5.925$/Mbtu.

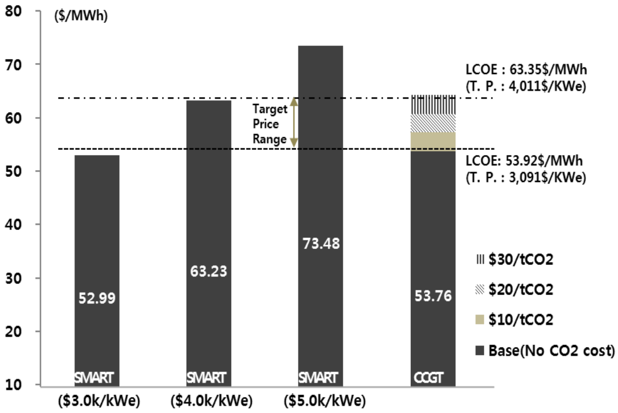


Fig. 3. Sensitivity analysis with Carbon Tax I

Fig 3 shows that if CO_2 cost is 30$/t- CO_2 and the SMART's construction cost is 4,000$/KWe, it has price competitiveness against CCGT.

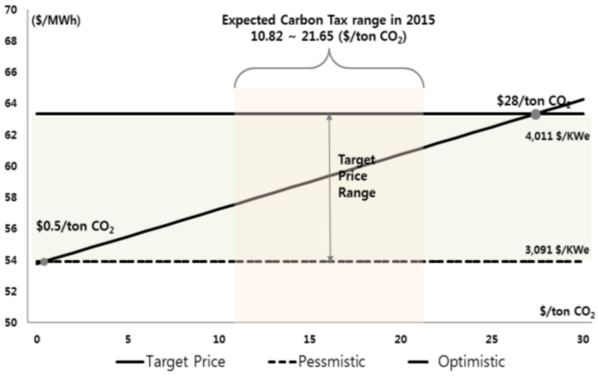


Fig. 4. Sensitivity analysis with Carbon Tax II

Fig 4 indicates that carbon tax should be higher than $0.5 to have price competitiveness in case that the SMART's target price is 3,091$/kWe. On the other hand, carbon tax should be higher than $28 in case of 4,011$/kWe. The imposition of carbon tax on the CCGT would help the SMART become more competitive and make it more possible for the SMART to implement export to the U.S

This paper also evaluated the impact of the discount rate on the target price of the SMART in the reference case, while the discount rate for the CCGT was fixed at 5% for analysis with a conservative view.

Fig 5 reveals that the discount rates in the reference case should lie within the range of 7.2 % and 9.446%. In other words, considering added technology risk in the SMART, 3%, discount rates should lie within the range of the 4.2% and 6.446% to have its price competitiveness.

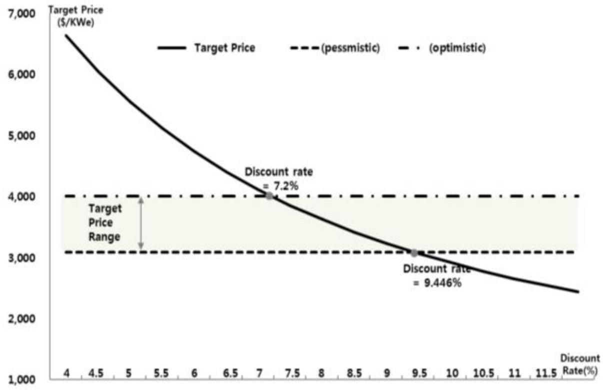
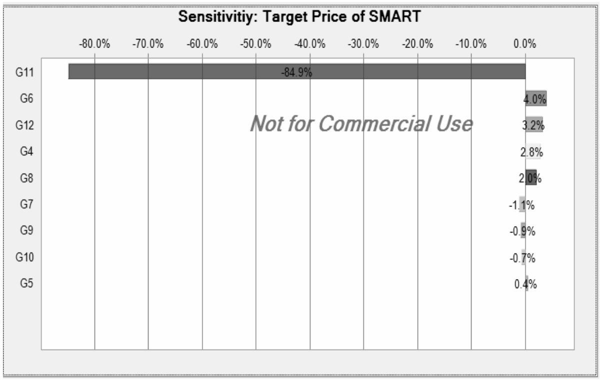


Fig. 5. Sensitivity analysis with discount rate

Target price was influence by several factors; however, it had distinctive changes in the effect of the input parameters. Therefore, a number of sensitivity analyses were performed with Crystal Ball software to evaluate the impact of parameters on the target price of the SMART [13].



G11: Discount Rate, G6: Gas price, G12: Capacity Factor (SMART)
G4: Construction cost, G8: Carbon Tax, G7: Capacity Factor (CCGT)

Fig. 6. Order of Sensitive factors

Fig 6, the output of software, shows that the discount rate was identified as the most sensitive parameter on developing a target price. This paper, therefore, suggests that favorable financing terms are essential to implement the SMART and export it to the U.S.

3. Conclusions

Even though detailed cost estimates are not available, target price can be derived based on generally determining market price. This paper demonstrates the target exporting price of the SMART in the U.S. ranging from 3,091~ 4,011$/kWe depending on the scaling factor and carbon tax, assuming that discount rates are fixed. This value could be a target cost of construction, developing the U.S market whose demand of the SMART is potentially 4 units 2015~2035.

Sensitivity analysis shows that the price goes up in proportion to the gas price, the capacity factor of the SMART, the overnight cost of CCGT, etc. More than anything else, this study reveals that carbon tax does not have much influence on the target price compared with those listed above. On the other hand, the price goes up in inverse proportion to the interest of the SMART, the capacity factor of CCGT, O&M costs of the SMART, and so on.

For the price competitiveness, construction cost should first be reduced because construction cost is the largest component of LCOE as well as the effect of interest rate is the most sensitive for target price. Therefore, design simplification, shorter construction period, serial production and factory fabrication will be necessary. In addition, the company in charge of business should have enough financial resources as well as marketing. Aside from the result of sensitivity analysis of interest rate, this is because the IDC (Interest During Construction) generally accounts for about 10～20% of total construction cost in nuclear plant project.

If the SMART are successfully exported to the U.S. where most technologies and regulations of nuclear energy are being made, it may lead to new nuclear renaissance in Korea as well as to prove the excellence of the SMART, along with a lot of intangible effects.

4. Limitation of this study

Since the SMRs haven't been built yet, this paper was not able to estimate the economics of the SMART with real data. Also, this paper restricted the capacity of CCGT in 100MWe. Accordingly, it is necessary to consider 200MWe and 300MWe of capacity in order to conform to market demand forecast. In addition, a review on co-generation of the SMART remains for a further study.

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