An Exploratory Study on a Target Capital Cost and Cost Reduction Methodologies of Innovative SMR in Korea

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1. Introduction

Korea has achieved technological independence of nuclear power plants and exported four 1400 MWe nuclear power units to the UAE in 2009. However, since then no follow-up nuclear export contracts have been made. Therefore, the Korean government has recently been working on ways to push ahead small modular reactor(SMR) project which will be the axis of the new export industry.

Under these circumstances, this study particularly focused on the global market potential and technology development prospects for SMR. And through the meta-analysis method, we evaluated the First-of-a-kind(FOAK) and Nth-of-a-kind(NOAK) target capital costs for SMR to be developed by Korean government. Finally, we looked over the domestic and overseas examples of ways to reduce the capital costs.

2. SMR Market Size & Its Technology Development

Based on the assessments of various foreign agencies, SMR's global market size is expected to be between 21 and 85GWe by 2035, with a huge market up to $1 trillion expecting to be formed. Meanwhile, Korean government expects a market of 8.8GWe with $35 billion, to be formed by 2030. These are summarized in table 1.

Table 1: Estimation of SMR market size by Agency

Evaluation Agency	Market Size
OECD's Nuclear Energy Agency	21GWe by 2035
Small Modular Reactor Research and Education Consortium	(USA) $34~250 billion or more
UK National Nuclear Laboratory, SMR Smart consortium	(World) 65 to 85GWe by 2035, 250~400 billion pounds (USA) 1/3 of the world market
Power Engineering magazine	(World) $1 trillion by 2035
MOTIE(Ministry of Trade Industry and Energy(Korea)	(World) 8.8GWe by 2030, $35 billion

2.2 Technology Development[4]

In the short-term, the IAEA predicts that the light-water reactor types of SMR will gain a competitive advantage in the SMR market of 300MWe or less based on technology.

On the other hand, in the mid- and long-term, non-light-water types of SMR are also expected to be improved to the level of commercialization, so light-water reactor and non-light-water reactor types of SMRs are expected to compete.

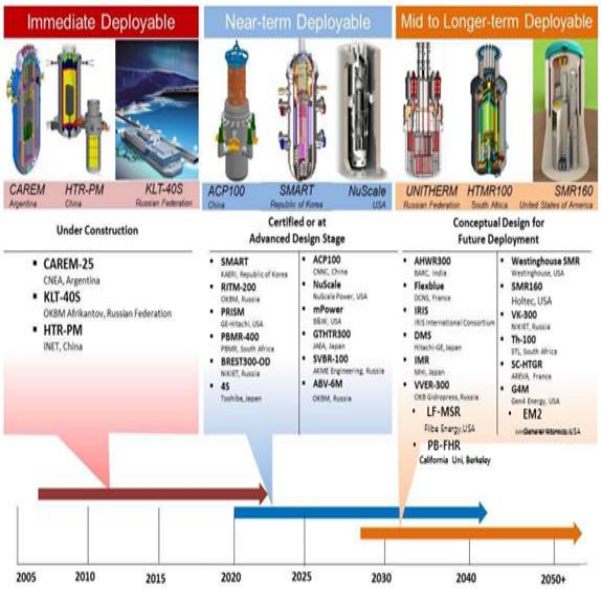

Fig. 1 Estimated timeline of SMR deployment

3. Target capital costs of innovative SMR in Korea

This study firstly applied the literature research to set the target capital costs of innovative SMR in Korea. Through the above survey the target capital costs were evaluated for First-of-a-kind(FOAK) plant and Nth-of-a-kind(NOAK) plant in Korea.

3.1 Target cost of FOAK SMR[1] [7]

The average target capital costs of the FOAK SMRs under development in the world are evaluated as about $7,333/kWe. NuScale is the nearest reactor to commercialization among these SMRs, and its target cost is estimated as about $4,386/kWe as shown in Fig. 2.

Fig. 2 shows that the capital cost of large nuclear power plant(NPP), which is supplied by Korea to UAE, is valued at $3,652/kWe. And its capital cost is 62% of the world average of $5,864.

Therefore, the SMR to be developed in Korea should be more competitive than NuScale and enter the stage of competing with current large NPPs.

When judging these results comprehensively, the target capital cost of the innovative SMR FOAK plant in Korea should be set at around $4,000/kWe, at least 10 percent less than the NuScale's targeting.

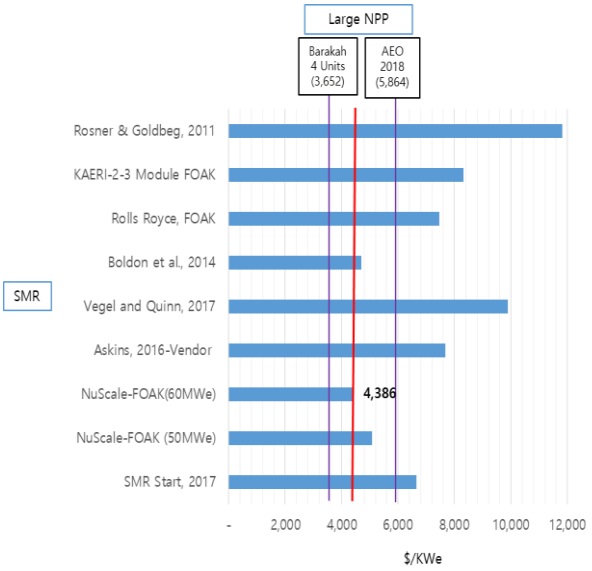

Fig. 2 Range of Capital Costs for the competitive FOAK SMR

3.2 Target of NOAK Plant[1][7]

The average capital cost of the SMR NOAK plants currently under development in the world is valued at $5,130/kWe, which is estimated to be 30% less than FOAK. The target capital cost of NuScale's NOAK plant is valued at $3,509/kWe, which is more expensive than BWRX-300 as shown in Fig. 3.

In order to secure export competitiveness, SMR must not only be competitive with the large NPP but also be more competitive than NuScale's estimated target. Therefore, in this study, it is reasonable to set the target capital cost for the innovative SMR NOAK plant, which is planned to be developed in Korea, at around $3,000/kWe, 15% less than the estimated NuScale's NOAK plant targeting

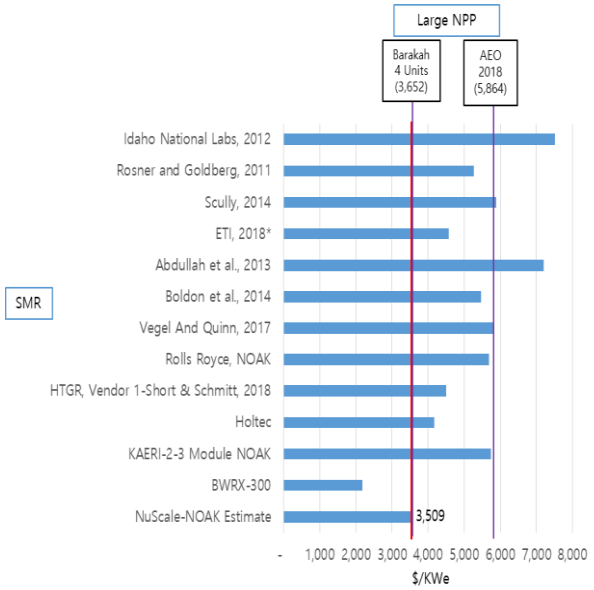

Fig. 3 Range of Capital Costs for the competitive NOAK SMR

4. Methodologies for Capital Cost Reduction of Innovative SMR in Korea

4.1 Korean experience

There is no significant difference between the unit price per unit, especially after Shin-Kori #1/#2, which are recently constructed or under construction, indicating that maturity of the technology and project management capabilities have reached their highest levels and that the cost-cutting factor is not significant.

While the NSSS, T/G, and BOP/Supplementary equipment sectors, which correspond to direct costs, have been stabilized by period, the indirect costs such as civil engineering cost and project cost are assessed to be a little more variable.

Therefore, it can be seen that innovative savings in construction costs cannot be achieved without an innovative concept in the equipment to direct costs. Also, it is necessary to achieve downward stabilization of construction cost and project cost among overhead costs.

NuScale has taken into account the system to achieve significant savings(reference 3) in the overhead cost rather than in the direct costs when comparing to the large nuclear power plants, suggests much to domestic innovative SMRs.

Therefore, it can be seen that innovative savings in construction costs cannot be achieved without an innovative concept in the equipment to direct costs. Also, it is necessary to achieve downward stabilization of civil engineering cost and project management cost among overhead costs.

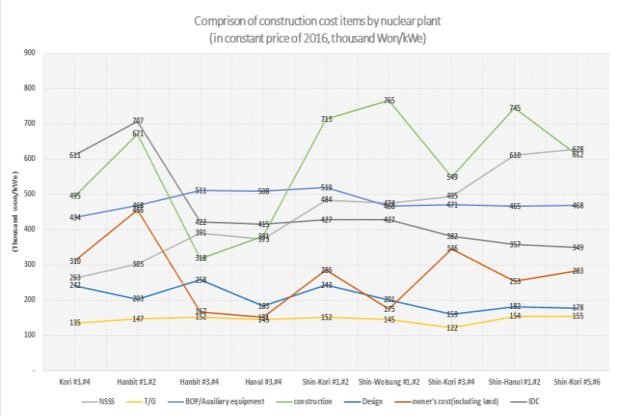

Fig. 4 Comparison of construction cost items by NPPs in Korea

4.2 Foreign experiences

4.2.1. United States [3]

NuScale's 'Reactor Plant Equipment(Cost Account 22) cost was estimated to be more than twice as much as PWR-12, due to the integrated design characteristics of the reactor vessel. But these costs are offset by greatly improving safety features, shortening construction period, reducing associated financing costs, and simplifying the design to fully utilize the benefits of modularity, such as factory construction, simplified supply chain and learning effects as shown in Table 2.

Table 2: Cost per kWe comparison for NuScale SMR and PWR-12

COA	General Description	NuScale SMR Cost	PWR-12 Cost	Cost Difference
20	**Capitalized Direct Costs(21-26)**	**73.1%**	**47.3%**	**-25.8%**
21	Structures and Improvements	24.8%	18.5%	-6.2%
22	Reactor Plant Equipment	35.2%	10.3%	-24.9%
23	Turbine Plant Equipment	7.9%	8.8%	0.8%
24	Electric Plant Equipment	1.4%	4.8%	3.4%
25	Heat Rejection Systems	2.5%	2.1%	-0.5%
26	Miscellaneous Plant Equipment	1.2%	2.9%	1.6%
30	**Capitalized Indirect Costs(31-36)**	**26.9%**	**52.7%**	**25.8%**
31	Design Services at Home Office	5.3%	18.8%	13.5%
34	Field Construction Management	2.5%	1.3%	-1.2%
35	Field Construction Supervision	10.0%	15.2%	5.2%
36	Field Indirect Costs	9.1%	17.4%	8.3%
	Base Construction Costs(20+30)	**100.0%**	**100.0%**	**0.0%**

4.2.2. United Kingdom [2]

For SMRs, a theoretical capital cost reduction is estimated up to 32% in aggregate, a saving of up to 20% is considered a more appropriate, conservative estimate for application of five areas of opportunity (Advanced manufacturing, Digital engineering, Modularisation factory build, Advanced construction method, Co-siting of multiple reactors) as shown in Fig. 5.

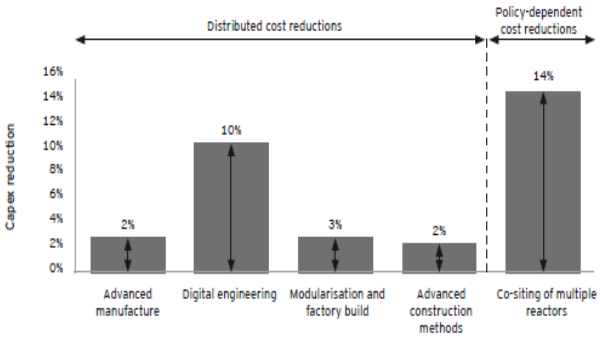

Fig. 5 The potential capital cost reduction through applying different techniques to SMR

4.2.3. Other study [7]

The economic potential and readiness of a cross-cutting technologies has been analyzed. These include capital cost reducing technologies such as accident tolerant fuels, additive manufacturing, advanced concrete, seismic isolation, and modular construction.

To sum up the results, cross-cutting technologies could reduce the capital cost of new builds by up to 22%~30% by 2030.

5 Conclusions

We focused on setting the target capital cost of SMR in Korea through the results of the literature survey as well as the actual experiences in nuclear field. The target capital costs for innovative SMRs in Korea to be competitive in the global market are evaluated as around $4,000/kWe for FOAK unit and around $3,000/kWe for NOAK unit.

Also we judge that innovative savings in construction costs which include equipment, building, and owner's costs will be absolutely needed to achieve the above proposed target costs

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