# Effect of Reactor Technology on Economics of SMR Projects

I.ZHURAVLEV

Center for Analytical Research and Developments (CARD), Private Enterprise “Science and Innovation”, SC ROSATOM, Russian Federation

Email contact of corresponding author: IBoZhuravlev@rosatom.ru

**Abstract**

Using regression analysis of the LCOE values published by vendors of SMR projects and own calculations, effects of the scale, “learning” and reactor technology on the economics of SMR were identified. The competiveness of SMR projects versus another power sources was considered in relation to two markets - "Off-Grid" market (the power supply of remote communities) and "Grid" market (basic generation in medium and large grids), differing by the upper limit of the LCOE. It is shown that SMR based on LWR (both PWR and BWR) can be competitive on the “Off-Grid” market starting from module power 50 MW. At the same time, the competiveness of PWR SMRs on “Grid” market is weak within the whole range of SMR module power (until 300 MW). BWR SMRs have a potential to be competitive on the “Grid” market starting from module power about 150 MW, but there may be safety concern arising from the Fukushima accident. Maximal potential of LCOE reduction have FBR SMRs, but their fuel cycle still needs commercialization, and at near time the non-proliferation issues may be addressed. The competitiveness of SMRs based on advanced reactor technologies beyond 2030 depends on the future severity of nonproliferation issues for potential customers. Depending on this, either HTGRs with a thermal spectrum (the most proliferation-resistant due to the use of TRISO fuel) or reactors with a fast neutron spectrum can receive priority.

Keywords: Small Modular Reactors, Fast Neutron Reactors, Liquid Metal Coolants, Levelized Cost of Electricity, Economical Analysis.

## INTRODUCTION

Objectives of this study were: 1) to analyze the requirements of potential Small Modular Reactors (SMR) markets – “Grid” market and “Off Grid” market (energy supply for remote communities) and 2) to identify effects of scale, learning and reactor technology on the economic characteristics of SMRs.

There is an increased interest worldwide in projects of SMR, which is associated with a number of advantages of low-power reactors, including modular ones, in comparison with large power reactors:

* SMR modules allow manufacturing on a factory away from the construction site;
* shorter payback period of the investment due to the modular design, shorter construction time and a serial commissioning of modules at one site;
* stronger motivation for financial institutes to lending for nuclear projects;
* guaranteed safety (elimination of large radioactive releases), possibility to reduce the radius of the emergency planning zone (EPZ) around the nuclear power plant (up to 300 meters);
* possibility of realistic nuclear insurance due to the lower potential losses caused by potential accidents on SMR [1];
* higher ability of SMRs to vary their output (load following);
* high mobility of SMR modules including an option of factory fuel loading (for some projects);
* рossibility of underground and underwater location of SMR;
* easier and less costly decommissioning;
* smaller water consumption;
* co-generation of the electricity and heat and/or water desalination is a possible option.

The Center for Analytical Researches and Developments (CARD) of Private enterprise “Science and Innovations” issued in 2019 an analytical study “Technical and Economic Aspects of SMR Projects” [2]. A statistical analysis of 54 foreign and 38 domestic SMR projects by their power, reactor technology, the readiness level and the vendor has been performed in the study.

## SMR Analytical study

Then, the competiveness of SMR projects versus another power sources has been analyzed in relation to two markets - "Off-Grid" market (the power supply of remote communities) and "Grid" market (basic generation in medium and large grids). The requirements of potential SMR markets were analyzed in terms of the upper limit of the Levelized Cost of Electricity (LCOE) which is restricted by competitive power sources for “Grid” and “Off Grid” markets, as shown in Table 1.

TABLE 1. ANTICIPATED REQUIREMENTS TO SMR PROJECTS ON “GRID” AND “OFF-GRID” MARKETS

|  |  |  |
| --- | --- | --- |
| Parameter | *“Off-Grid” market*: remote communities | *“Grid” market*: generation in medium and large grids |
| LCOE (at discount rate 7% $/MWh | ≤ 100.Competition with:Diesel generation ~ 400-700\*;Renewables ~150-200\* at strong weather conditions;LNG ~ 90 – 150\* (including transportation).  | ≤ 50.Competition with:Coal with CCS ~90-125\*\*;Gas combined cycle ~40-55 (75 with CCS)\*\*;Combustion turbine ~70-100\*\*; Large power nuclear ~75-80\*\*; Wind, onshore ~40-70\*\*;Solar: ~40-110\*\*.  |
| Power of SMR module | ~ 30-50 MW.Up to 4-5 modules on site. | ~ 100-200 MW. Up to 10-12 modules on site for the replacement of coal and large power nuclear generation. |
| Applications | 1. Communal heat
2. Electric power
3. Water desalination
 | 1. Electric power
2. Water desalination
3. Communal heat
4. Industrial heat
 |
| Fuel cycle | Refueling once in 5 years (or more) on site with centralized service by the vendor.  | Refueling once in 12-24 months by the operator.  |
| Load following | 100-30-100% within 24 hours, otherwise a support by diesel or energy storage system will be required that increases LCOE. | 100-50-100% in grids having a power reserve. |

\* Calculated LCOE values.
\*\* LCOE values taken from [3].

The scale effect has been analyzed from the point of view that the share of fixed (independent of a module’s power) costs in the total electricity generation costs (i.e. LCOE) of the module decreases with an increase in the power of the module. Separate regression dependences of LCOE on the electrical power of the module were derived for different reactor technologies based on the data published by SMR projects’ vendors and verified by own calculations.

The approximation of the dependence of the LCOE estimates on the installed electric power *P* was expressed by the dependence described, in particular, in [4]:

*LCOE* (*P*) = *A* + *B* / *P* (1),

where *A* and *B* are coefficients.

The following approximation of LCOE has been found for projects of SMR with Pressurized Water Reactors (PWR):

*LCOEPWR = 83.5 + 966/P* (2)

with coefficient of determination *R*2 = 84.6% and the standard error $ 24/MWh (Fig. 1).



*Fig. 1. Approximation of LCOE Values for SMR projects with PWR*

There are fewer SMR projects with Boiling Water Reactors (BWR) than with PWRs. That why the dependence of the LCOE for BWR based SMRs is splitting into to approximations – for First Of A Kind (FOAK) and for Nth Of A Kind (NOAK) SMR modules:

*LCOEBWRFOAK = 49 + 1595/P* (3)

with coefficient of determination *R*2 = 79% and the standard error $ 9/MWh;

*LCOEBWRNOAK = 40 + 1832/P* (4)

with coefficient of determination *R*2 = 98% and the standard error $ 3/MWh.

Both LCOE approximations for BWR based SMRs are shown on Fig. 2.



*Fig. 2. Approximation of LCOE Values for SMR projects with BWR*

The LCOE for PWR technology with increasing power tends to a range of about $ 56–117 / MWh (which corresponds to an 80 percent confidence interval of the LCOE). The upper limit of the range corresponds to a greater extent either to the FOAK stage, or to SMR layouts that do not provide for multi-modularity, and the lower one – for NOAK multi-module SMRs.

The BWR technology at high module power allows achieving a very low LCOE of about $ 40 / MWh. Thus, the LCOE estimate for SMR projects based on BWRs can be 25-40% lower than the LCOE estimate for PWR-based projects.

SMR projects based on both PWRs and BWRs can be competitive on the “Off-Grid” market starting from module power 50 MW.

It follows from the analysis that a LCOE value of less than $ 50 / MWh is in principle unattainable for PWR-based SMRs (this is the lower limit of the 90% confidence interval for the LCOE limit at the upper edge of the SMR power). Therefore, SMRs based on PWR technology are unlikely to be competitive at all against gas generation and renewable energy sources on the "Grid" market. On the contrary, BWR-based SMRs have the potential to achieve LCOE of about $ 45-60 / MWh at a 200-300 MW module power at the NOAK stage and can pretend on the "Grid" market starting from the module power about 150 MW, but there may be safety concern arising from the Fukushima accident.

According to a 2018 study of Energy Technology Institute (ETI) [5] the dependence of LCOE on reactor technology is significant (Fig. 3.). It can be seen that all advanced reactor technologies have a potential to reduce LCOE due to the low pressure inside the reactor vessel and due to the simplification of safety systems.



*Fig 3. LCOE Estimates for SMR Based on Different Reactor Technologies in USA [5]*

Transition from water to more efficient coolants: gas (helium), metal (sodium, lead, lead-bismuth eutectic) or molten salts predetermines the achievement of improved technical and economic characteristics: an increase in thermodynamic efficiency, the increased safety based on physics laws instead of expensive emergency cooling systems, and leads to CAPEX reduction. A less expensive Brayton cycle with the gas turbine (HTGR, GFR) will be possible in some cases.

Results of the analysis of published LCOE estimates for SMR projects with different reactor technologies verified by LCOE calculations [2] are shown of Fig. 4 and are similar to ETI estimates (except the LCOE for Fast Breeder Reactors (FBR) which estimate by ETI seems to be too high because of very high fuel cost ($ 19/MWh) assumed for FBR).



*Fig. 4. Comparison of LCOE approximations for different reactor technology [2]*

The analysis has shown that FBR SMRs have the maximum potential for reducing the LCOE, but their fuel cycle still needs commercialization, and at near time the non-proliferation issues may be addressed. HTGR with Brayton cycle have certain potential to reduce LCOE, but their deployment requires a deep R&D.

## CONCLUSION

Thus, the competitiveness of SMR projects based on advanced reactor technologies beyond 2030 depends on the future severity of nonproliferation issues for potential customers. Depending on this, either HTGRs with a thermal spectrum (the most proliferation-resistant due to the use of TRISO fuel) or reactors with a fast neutron spectrum can receive priority.

It should be mentioned that estimates of technology readiness level (TRL) for all advanced reactor technologies are lower than TRL of PWR technology. Thus, the question for further studies is: how strong the economical characteristics (CAPEX and LCOE) of SMR based on advanced reactor technologies are correlated with their readiness levels, and how much the economics of SMR projects can change with increase of TRL.

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