

“Need of Analytical Study on Significant Research Causes and Construction Small Modular Reactor”

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Abstract

The Nuclear Industry Association believes there is potential for SMRs as a complementary technology to larger reactors, and a viable proposition for future deployment. Small Modular Reactor (SMR) is an emerging energy technology that meets the demand of safety, efficiency and sustainability. This paper reviews the representative SMR designs, develop and test materials working in harsh environment; study the integrated components manufacturing techniques; develop advanced instrumentation and controls; to complete the verification and validation through single effect tests and integrated tests. These efforts require a lot of investment. Based on empirical analysis, this paper suggests an approximate ten-year effort be needed for the leading light water reactor (LWR) based SMR to solidify the final form and operate under the full range of commissioning conditions. SMRs have important implications for its energy planning as well as for the emerging energy technology for SMRs. Many of them were linked with the religious belief system of SMRs. The discovery of SMRs Modern Scientific Findings and Validations Science, Technology indicates existence.

Keywords: *Embedded Multicore/Many-core Systems-on-Chip; Network-on-chip; Low-power design*

I. INTRODUCTION

SMR provides an energy option with low carbon emission, enhanced safety conviction, convenient construction and operation, which is becoming more and more evident. The term “small” generally refers to the reactors with an equivalent electric power less than 300 MW, while “modular” means a single reactor that can be grouped with other modules to form a larger nuclear power plant. SMR can repower aging fossil plants, be coupled with other energy sources, including renewable and fossil energy, to produce multiple energy end-products. Tens of SMRs at various development stages can be categorized as light water reactors (LWR), gas cooled reactors, liquid metal cooled reactors, and molten salt reactors.

The diversity of the SMR concepts provides a good flexibility of selection, but the investors may be dazzled to decide which SMR design has the best maturity and prospect for commercial deployment. The technicians may be dedicated to resolve the problems SMRs suffered from decreased thermodynamic efficiencies and neutron economy compared to large reactors.

Among the characteristics of SMRs that make it specially attractive to developing countries are the suitability of the lower power levels to electrical grids with smaller capacity and the expectation that these would be more affordable even in the face of financial limitations.

2. SMRS STATUS

Currently ten countries are pursuing the development of 31 different SMR concepts, including Argentina, China, France, India, Italy, Japan, Korea, Russia, South Africa and USA. There are two main technologies being pursued: of the 31 designs 22 are light water reactors, 20 being pressurized power reactors (PWRs), 1 being a boiling water reactor (BWR) and 1 being a heavy water reactor (HWR), and the remaining 9 concepts are high temperature gas cooled reactors.

Currently, there are four SMRs under construction (Table 1). These include three PWRs and one HTGR, and all of them are scheduled to start operation by 2017.

Table 1 SMR under construction

Named reactor	Reactor type	Designer, country	Capacity MWe	Planned operation
CAREM-25	Integral pressurized water reactor	CNEA, Argentina	27	2017
KLT-40S	Pressurized power reactor	OKBM Afrikanov, Russian Federation	35 × 2 modules	2017
RITM-200	Integral pressurized power reactor	OKBM Afrikanov, Russian Federation	50	2017
HTR-PM	Pebble Bed HTGR	Tsinghua University, China	211	2017

Table 2 SMRs design status progress

Named reactor	Reactor type	Designer, country	Capacity MWe
Licensing/certified SMART	Integral pressurized water reactor	KAERI, Republic of Korea	100
Detailed design ACP-100	Integral pressurized water reactor	CNN (NPIC/CNPE), China	100
ABV-6M	Pressurized water reactor	OKBM Afrikanov, Russian Federation	8.6 per module 6 × 2 modules
VK-300	Simplified boiling water reactor	RDIP, Research and Development Institute of Power Engineering, Russian Federation	250
Basic design AHWR300-LEU	Pressure tube type heavy water moderated reactor	BARC, India	304
IRIS	Integral pressurized reactor	IRIS, International consortium	335
DMS	Boiling water reactor	Hitachi-GE Nuclear Energy, Japan	300
m-Power	Integral pressurized reactor	B&W Generation mPower, USA	180 × 2 modules
NuScale	Integral pressurized reactor	NuScale Power LLC, USA	45 × 12 modules
GT-HTR300	Prismatic Block HTGR	Japan Atomic Energy Agency, Japan	100–300
Xe-100	Pebble Bed Reactor	USA	50 × 4 modules

Table 2 shows the SMR designs that have already been licensed or are ready to start the process of design certification and licensing. In addition, there are 15 designs that are still in the conceptual stage.

3. SMR KEY FEATURES

SMRs are designed with flexibility and reduced cost in mind. Below are some key features that may reduce the life-cycle GHG emissions:

- Longer refueling cycles. Generation II NPPs are typically refueled every 12-18 months, whereas it is expected that SMRs will need to be refueled at a minimum of every 24 months. There are some SMR designs that never have to be refueled during their lifetime. Within this design after the fuel is depleted, the core is removed for decommissioning.
- Increased thermal efficiency. Generation II and III+ NPPs

typically have a thermal efficiency of 30%-33%. While this is also true for most SMR designs, the EM2 SMR is claimed to achieve a thermal efficiency of around 48%. This higher efficiency increases the amount of energy you receive per unit of fuel.

- Improved construction efficiency through modularity. Generation II NPPs are typically built on site. Generation III+ plants such as the Westinghouse AP1000 have introduced modularity into the design; as a result several structural and mechanical components are built in a factory and shipped to site where it is assembled. SMRs are designed to be totally modular in their design.
- Shorter, more efficient supply chain. SMRs are a fraction of the size of Generation II and III+ plants. Typically Generation II and III+ plant components are large leaving only a few vendors with the resources available to manufacture these components. SMRs will utilize smaller components meaning additional vendors can be included in the supply chain.
- Lower operation and maintenance cost. The simpler design of SMRs will employ fewer materials as well as have a majority if not all of their components fabricated in a factory. The benefits of having a simpler design will allow for fewer pumps, valves, and components. This will increase the quality and therefore reduce the amount of maintenance required during the lifetime of the plant.
- Reduction in construction time and mass production. Typically 7 years were needed to construct a Generation II NPPs. Generation III+ plants reduced this time to 5 years. SMRs have the ability to be mass produced reducing overall construction time. It is expected that some SMRs can be fully constructed in 18 months.
- Simpler decommissioning. Simpler methods of disassembly that will involve disconnection of

transportable modules that can be reused.

4. APPROACHES TO SAFETY

The basic consideration is to prevent accident imitators.

1) Integral pressurized water reactor design.

The NuScale, mPower, and W-SMR designs use an integral pressurized water reactor (iPWR) design in which most of the primary system components are contained within a single vessel. The integral design reduces the number and size of penetrations and welding links through the reactor pressure vessel, eliminating the high-consequence accident scenario of a large pipe-break LOCA. In an iPWR the maximum size pipe penetrating the reactor vessel is 5e7 cm in diameter, while in a large PWR pipes that connect the reactor vessel to the external steam generator vessels are 80e90 cm diameter. SMR focus its safety functions on proper cooling of reactor core in case of accidents through following methods.

2) Increased relative coolant inventory. An enlarged vessel yields a larger inventory of water per unit of power than in the loop type plant, which increases the relative thermal inertia within the reactor vessel. This result

in a reduction in the rate at which the system temperature increases during a loss of forced flow transient, providing the operators with more time to respond to an upset condition.

3) Increased relative heat transfer area. A simple calculation could reveal that relative surface area of the iPWR vessel per unit power is increased. Roughly speaking, if a diameter of a SMR reactor core is 1/n of a large reactor, then the relative surface area of reactor vessel per unit power could be n times of a large reactor.

4) Increased passive cooling capability. The vessel height-to-diameter ratio of a SMR is 2-3 times larger than that of a large reactor since more equipments are incorporated vertically inside the vessel. This increases gravity-driven natural convection circulation capability. In the NuScale design, the natural circulation driving force is designed to be sufficiently strong to be used as a core cooling mechanism for full power operation, thus eliminating the need for pumps entirely.

5. ECONOMIC COMPETITIVENESS OF SMRS V/S COAL AND COMBINED CYCLE PLANTS

Table 3 Power plant characteristics

	Coal	Combined cycle	SMR
Overnight cost (US\$/kW)	2200	1053	4500
Fuel cost	80 US\$/ton 120 US\$/ton	4.74 US\$/GJ (5 US\$/mmBTU) 9.48 US\$/GJ (10 US\$/mmBTU) 14.22 US\$/GJ (15 US\$/mmBTU) 18.96 US\$/GJ (20 US\$/mmBTU)	9.60 US\$/MWh
Operation and maintenance US\$/MWh	9.03	7.17	14.54
Gross power MW (internal use)	350 (4.10%)	115.60 (2.80%)	112.20 (10.87%)
Thermal efficiency	40.61%	46.54%	34%
Construction time years (investment program)	5 (0.10%, 4.10%, 52.30%, 36.40%, 7.10%)	3 (0.10%, 82.20%, 17.70%)	3 (60%, 20%, 20%)
Capacity factor %	80	75	90
Lifetime years	40	30	60
CO ₂ emissions	0.940 ton/MWh	0.442 ton/MWh	

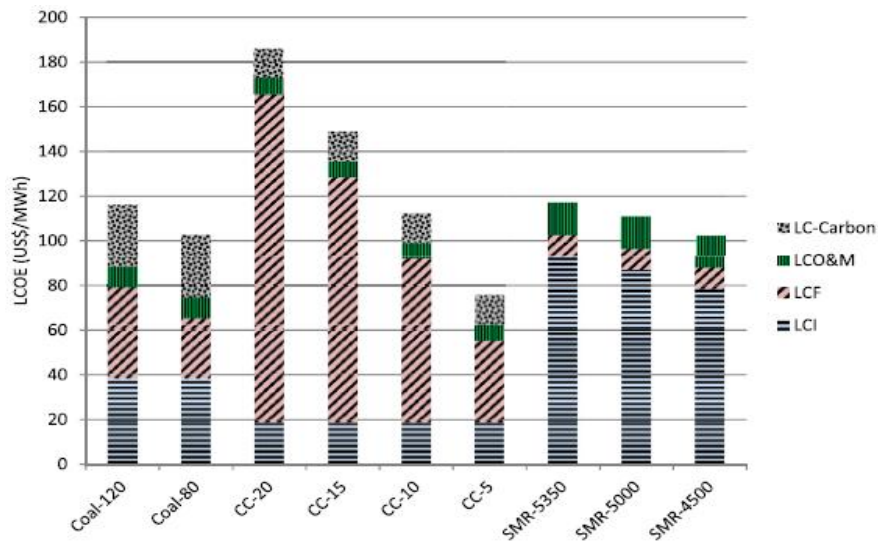


Fig.2 Levelized cost at 10% discount rate under different power plant conditions.

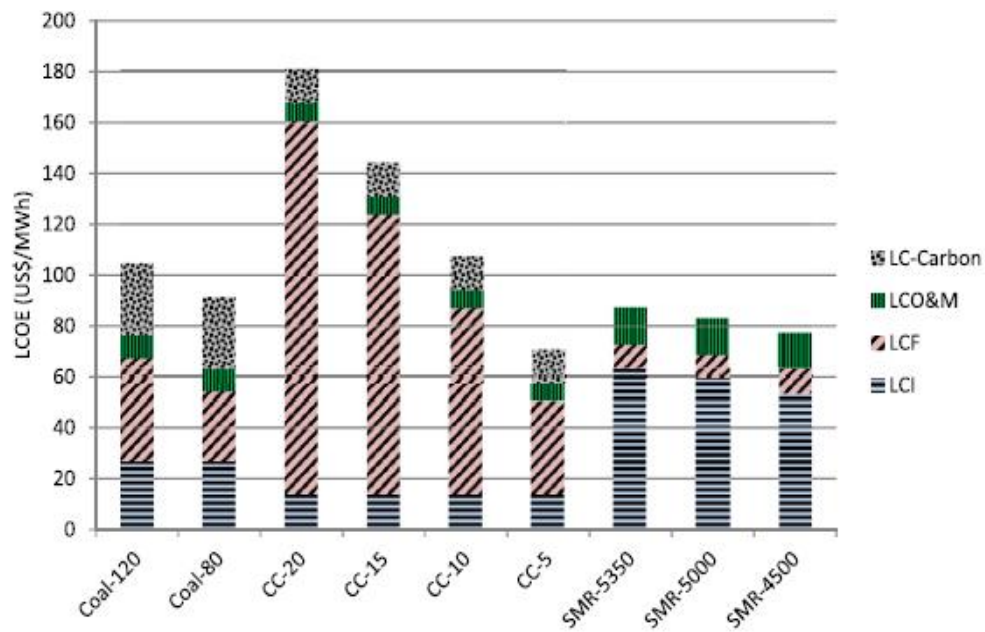


Fig.3 Levelized cost at 7% discount rate under different power plant conditions.

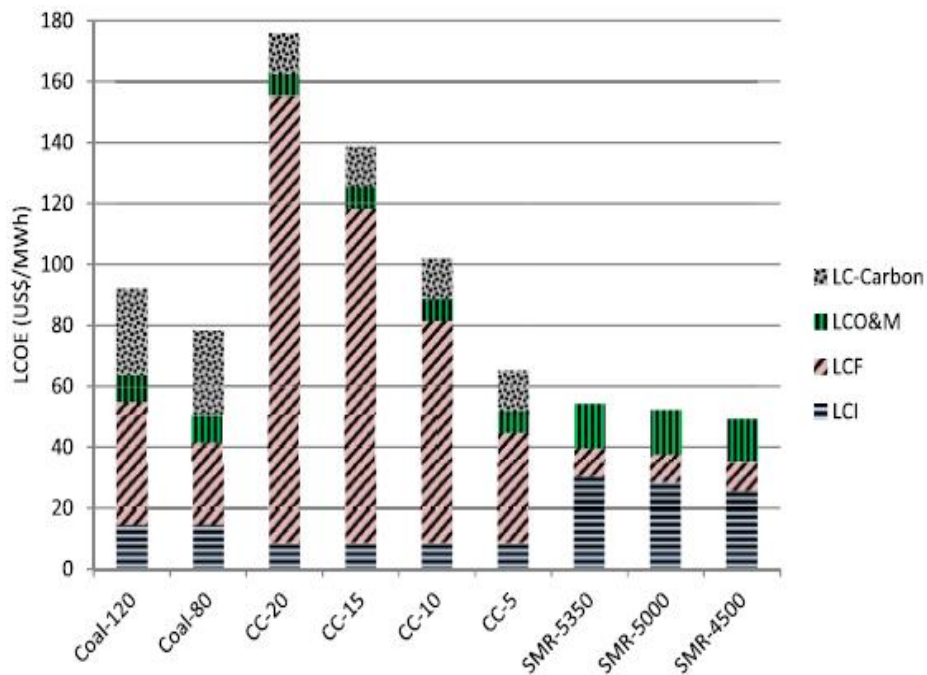


Fig.4 Levelized cost at 3% discount rate under different power plant conditions.

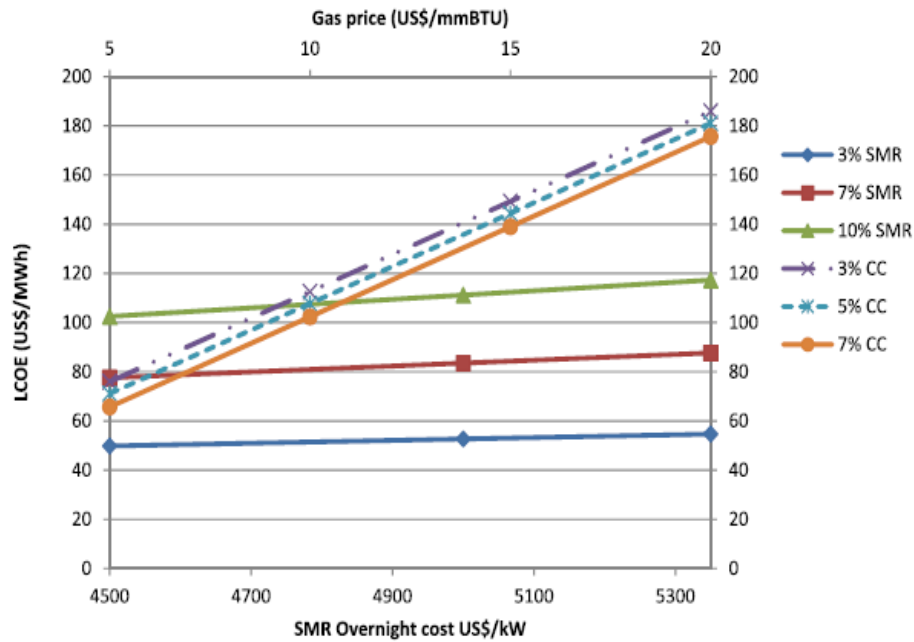


Fig.5 Levelized cost of electricity behavior for SMRs and combined cycle plants.

6. THE ENVIRONMENTAL COMPETITIVENESS OF SMRS

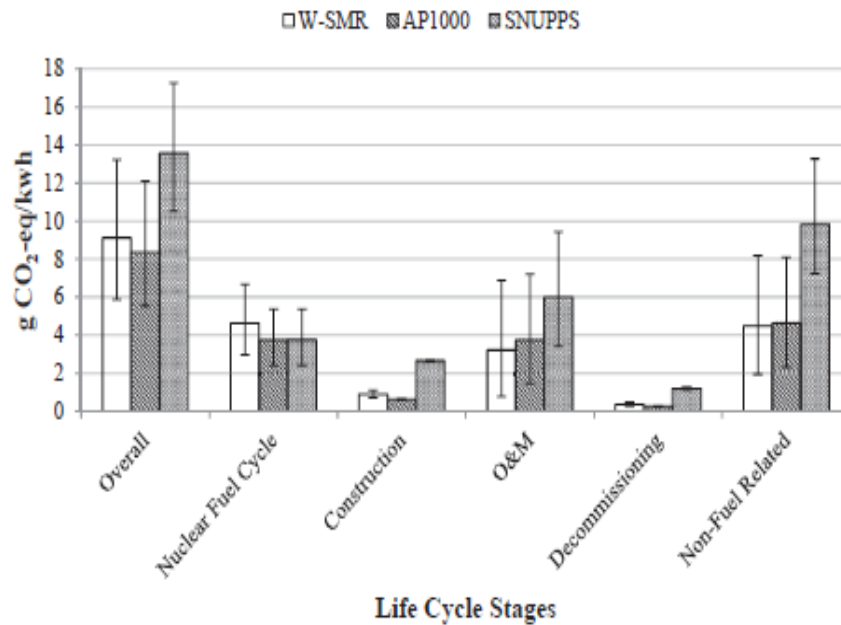


Fig.6 Mean and 90% confidence interval CO₂-eq emissions for W-SMR, AP1000, and SNUPPS from Monte Carlo sampling.

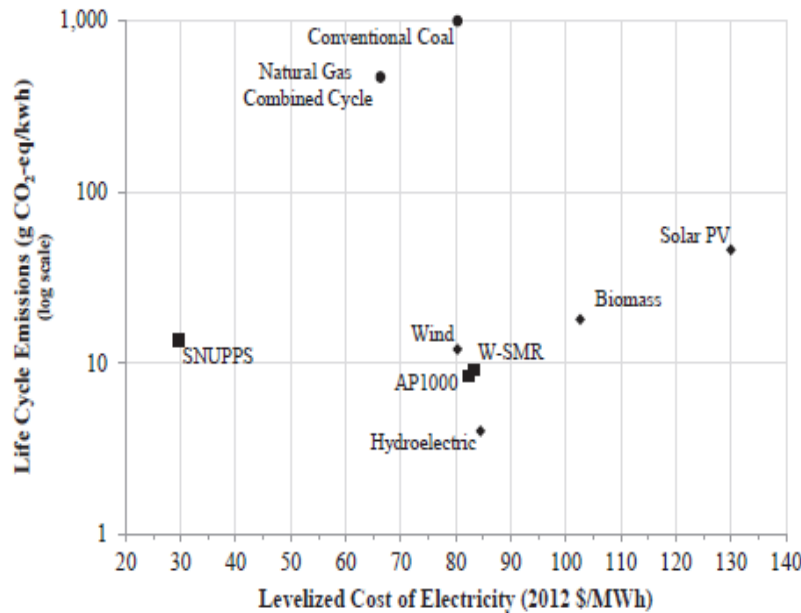


Fig.7 Electricity generation life cycle GHG emissions and LOCE comparison.

CONCLUSIONS

The biggest challenge in the development of SMR is the higher integration of the primary system. Efforts will be needed on the following aspects: 1) to develop and test materials working in harsh environment; 2) to study the integrated components manufacturing techniques; 3) to develop advanced instrumentation and controls; 4) to complete the verification and validation through single effect tests and integrated tests. These efforts require a lot of investment.

SMR technology could be economically competitive with fossil fuel technologies (i.e., Generation III+ plants and SMRs can be

viewed as a suitable middle option for climate-mitigation strategies). Though this study does not include a long-term solution for final storage of spent nuclear fuel. As expected when discount rates decrease, SMRs are more economically attractive because they are capital intensive projects, at 3% discount rate SMRs are more economically attractive than CC and coal plants even if gas prices are as low as 4.74 US\$/GJ.

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