THE GE HITACHI BWRX-300 SMR: THE FUTURE OF NUCLEAR TECHNOLOGY

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INTRODUCTION

The Massachusetts Institute of Technology (MIT) published a study in 2018, titled "The Future of Nuclear Energy in a Carbon-Constrained World" which warns of the enormous challenge that will be posed throughout the 21st century by the need to drastically reduce greenhouse gas emissions while extending access to energy to billions of people. This prestigious institution proposes the contribution of nuclear energy as one of the keys to achieving the objectives of decarbonisation.

Nevertheless, the study notes the prospects for the expansion of nuclear energy remain weak in many parts of the world because, while other generation technologies have reduced their costs, large new nuclear plants are becoming more and more costly. This trend undermines their potential contribution, while at the same time increasing the cost of decarbonisation.

The fundamental question we are therefore facing is whether nuclear energy can become economically competitive with other sources of generation.

The answer is implicit in EPRI's report, "Exploring the Role of Advanced Nuclear in Future Energy Markets" EPRI, Palo Alto, CA: 2018, 3002011803. This report assumes a series of global electricity generation needs with a 2050 horizon and analyses the variation of the energy mix with progressively decreasing investment costs in a nuclear plant from the current estimated cost of $5,000/kW. The results from the study predict that, if such investment can be reduced to $2,000/kW, new nuclear energy technologies would become a predominant source in the generation mix (Figure 1).

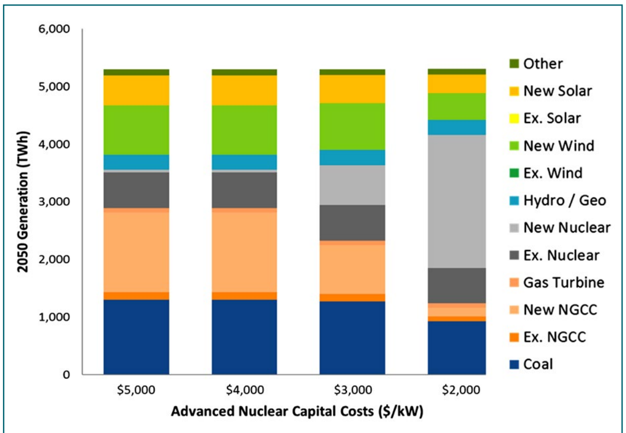

Figure 1. *Source*: Figure 3.2, "Exploring the Role of Advanced Nuclear in Future Energy Markets", EPRI, Palo Alto, CA: 2018, 3002011803.

The MIT study points out some of the factors that need to be addressed in order to achieve the cost-reduction goals. For example:

- An increased focus on using proven project and construction management practices to increase the probability of success in the execution and delivery of new nuclear power plants.

  However, the recent experience of nuclear construction projects in the United States and Europe has demonstrated repeated failures of construction management practices in terms of their ability to deliver products on time and within budget. Several corrective actions are urgently needed: (a) completing greater portions of the detailed design prior to construction; (b) using a proven supply chain and skilled workforce; (c) incorporating manufacturers and builders into design teams in the early stages of the design process to assure that plant systems, structures, and components are designed for efficient construction and manufacturing to relevant standards; (d) appointing a single primary contract manager with proven expertise in managing multiple independent subcontractors; (e) establishing a contracting structure that ensures all contractors have a vested interest in the success of the project; and (f) enabling a flexible regulatory environment that can accommodate small, unanticipated changes in design and construction in a timely fashion.

- A shift away from primarily field construction of cumbersome, highly site-dependent plants to more serial manufacturing of standardized plants

  Opportunities exist to significantly reduce the capital cost and shorten the construction schedule for new nuclear power plants. First, the deployment of multiple, standardized units, especially at a single site, affords considerable learning from the construction of each unit. In the United States and Europe, where productivity at construction sites has been low, we also recommend expanded use of factory production to take advantage of the manufacturing sector's higher productivity when it comes to turning out complex systems, structures, and components. The use of an array of cross-cutting technologies, including modular construction in factories and shipyards, advanced concrete solutions (e.g., steel-plate composites, high-strength reinforcement steel, ultra-high performance concrete), seismic isolation technology, and advanced plant layouts (e.g., embedment, offshore siting), could have positive impacts on the cost and schedule of new nuclear power plant construction. For less complex systems, structures, and components, or at sites where construction productivity is high (as in Asia), conventional approaches may be the lowest- cost option.

In addition to its high cost, the growth of nuclear energy has been hindered by public concerns about the consequences of severe accidents in traditional Generation-II nuclear power plant designs. These concerns have led some countries to renounce nuclear power entirely. To address safety concerns, MIT recommends:

- A shift toward reactor designs that incorporate inherent and passive safety features.

  Core materials that have high stability, high heat capacity, negative reactivity feedbacks, and high retention of fission products, together with engineered safety systems that require limited or no emergency AC power and minimal external intervention, will likely make operations simpler and more tolerable to human errors. Passive safety designs can reduce the probability that a severe accident occurs, while also mitigating the offsite consequences in the event an accident does occur. Such designs can also ease the licensing of new plants and accelerate their deployment in developed and developing countries. Further, our assessment of the U.S. and international regulatory environments suggests that the current regulatory system is flexible enough to accommodate licensing of these advanced reactor designs. Certain modifications to the current regulatory framework could improve the efficiency and efficacy of licensing reviews.

Beyond those considerations purely technical, some other series of recommendations in the report related to key actions by policy makers, are also launched to capture the benefits of nuclear benefit. They would include:

- Decarbonization policies that allows all low-carbon generation technologies to compete in their merits,
- Establishing reactor sites where companies can deploy prototype reactors for testing and operation oriented to regulatory licensing or
- Establishing funding programs around prototype testing and commercial deployment of advanced reactor designs.

Due to their political nature, they are not considered in the following, although their value for the future of nuclear energy are out of question.

THE BWRX-300 DESIGN

Evolution of previous BWR designs

GE has designed nine generations of boiling water reactors (BWRs) prior to the BWRX-300. From the first reactor in Vallecitos, California in the 1950s to the ESBWR, which was certified by the U.S. NRC in 2014, designers have progressively incorporated different concepts to promote the evolution of the design in order to improve efficiency and safety.

In Spain, the Santa Maria de Garoña BWR/3 design has been in operation for more than 40 years with high capacity factors, among the best of the reactors in service worldwide. The Cofrentes BWR/6 design has recently achieved 11 years of operation with zero unplanned stoppages.

The K6 and K7 units of Japan's Kashiwazaki-Kariwa nuclear complex, the largest in the world, were the first Advanced

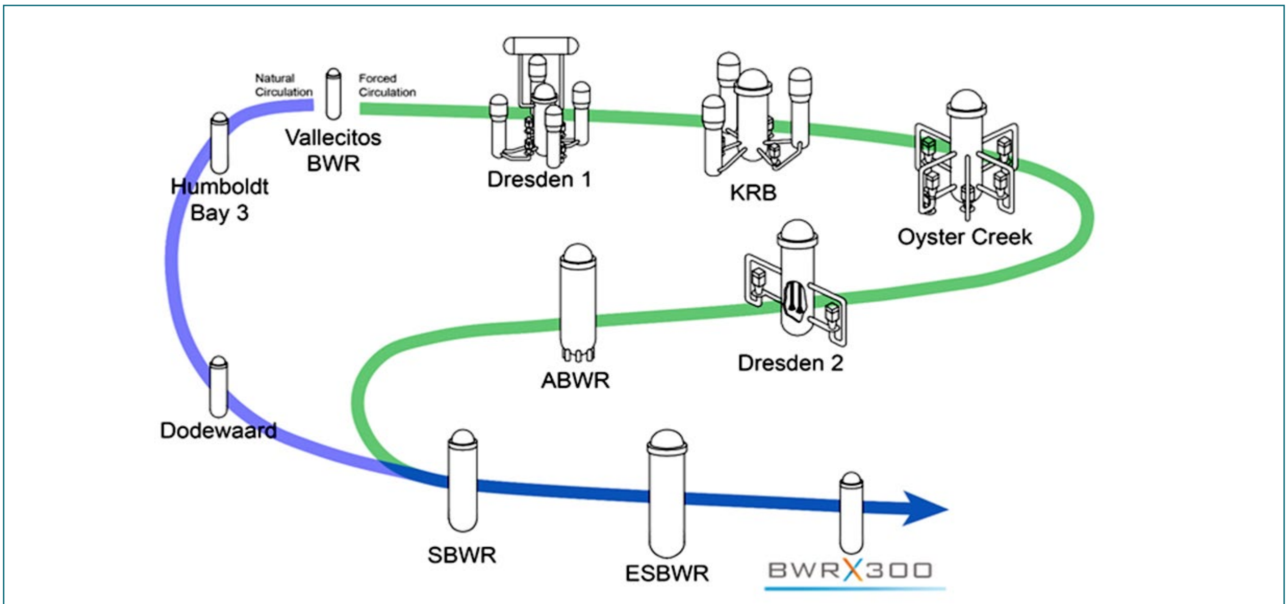

Figure 2. Evolution of the BWR.

BWR (ABWR) designs to go into operation, with a net electrical output of 1,315 MWe each, the largest of any BWR reactor built. Both units began operating in the mid-1990s (Figure 2).

BWRX-300 Small Modular Reactor

The GE Hitachi BWRX-300, the 10th generation BWR, has been designed with an electrical power capacity of around 300 MWe, it is a water-cooled, natural circulation Small Modular Reactor (SMR) with passive safety systems. While, it is based in large part on the US NRC licensed, 1520 MWe ESBWR design, its goal is to provide clean and flexible baseload electricity generation that is competitively priced with the lifecycle costs of typical natural gas combined-cycle plants, targeting $2000/kW for NOAK (nth of a kind) implementations, following the recommendations of the MIT study above.

The simplicity is one of its primary objectives. It incorporates safety measures approved worldwide and incorporates design features to eliminate the need to design and analyses for a Loss of Coolant Accident (LOCA). This innovation enables simpler passive safety systems and a more compact reactor building compared to prior Light Water Reactor (LWR) designs.

A strong focus on design-to-cost has resulted in an innovative solution that limits plant volume, concrete and steel, while it utilizes the ESBWR's design and licensing basis to the fullest extent. Traditional support system designs are simplified and scaled from the ESBWR.

The BWRX-300 utilizes natural circulation and passive cooling isolation condenser systems from the licensed ESBWR. The steam condensation and gravity allow to passively cool itself for 7 days without power or operator action during abnormal events, which includes station blackout. An indefinite cooling can be achieved by the simple action of water addition to the isolation condenser pools.

The design also takes advantage of components with a mature supply chain, including fuel, that have been successfully tested in previous designs.

This allows for rapid rollout of the design, with an estimated commercial operation date prior to 2029 with a total projected investment costs of less than $1 billion, equivalent to a levelized cost of energy (LCOE) of less than $35/MWh.

Some of the most significant aspects of the design include:

- Maximize use of design and licensing basis of ESBWR, which received U.S. NRC design certification in 2014
- Underground containment for increased safety
- Natural circulation
- Isolation Condenser System (ICS) as a cooling system
- Simplified control systems

In addition, seeking to simplify construction, building volumes have been reduced by more than 50 percent compared to the ESBWR design. Concrete requirements are also reduced by approximately the same amount.

The BWRX-300 is designed to operate with a permanent staff of just 75 people (Figure 3).

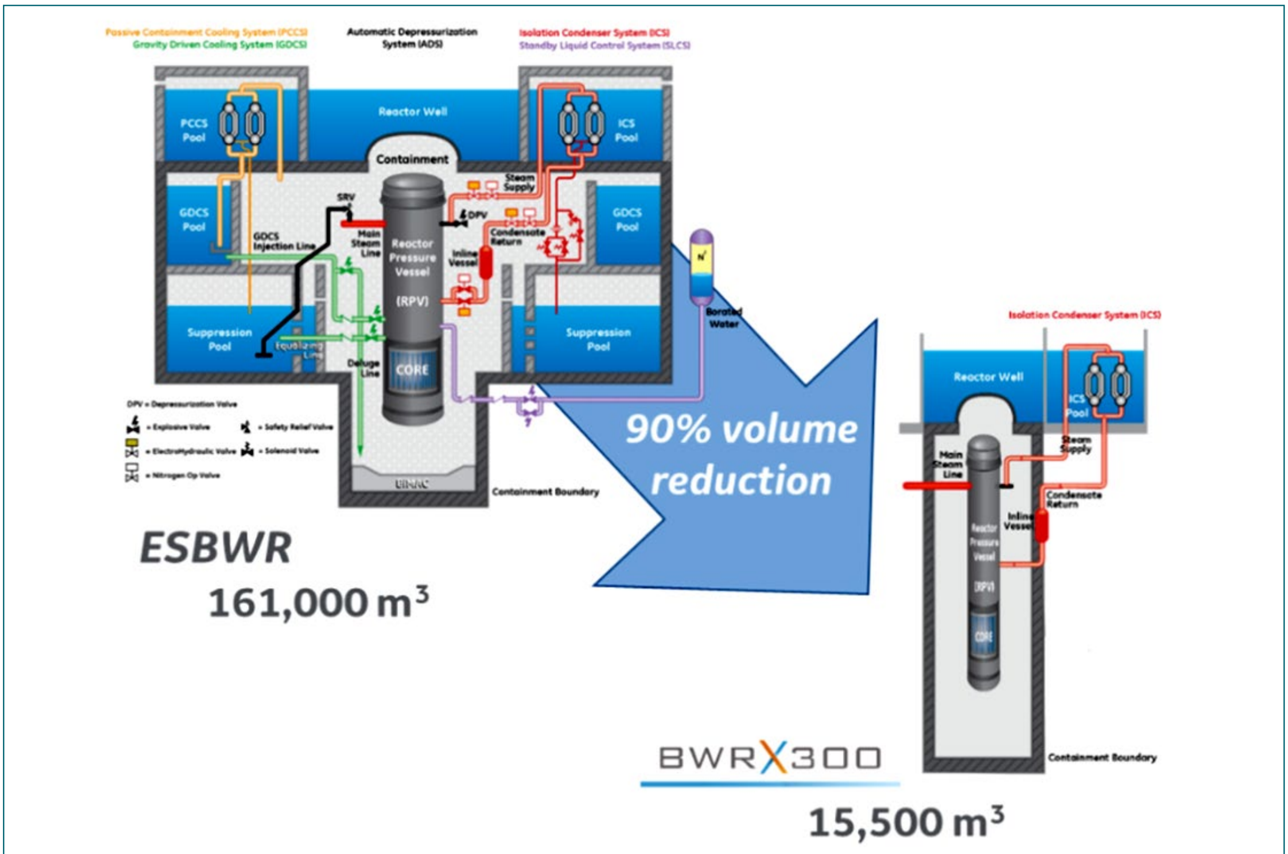

Figure 3. ESBWR 90% volume reduction.

Tested components

With the aim of reducing costs and taking advantage of the vast accumulated experience, the same components and equipment that have already been tested in previous designs will be used as much as possible in the BWRX-300 design. For example:

- The **Reactor Vessel** is designed using the same material and manufacturing processes as those used in the ABWR (which has more than 22 years of operational experience) and many others in the BWR fleet. The diameter is similar to that of the Kernkraftwerk Mühleberg (KKM) reactor, which has been in operation since 1972.
- The **Steam Dryer** has the same characteristics as those in the ABWR and ESBWR, with the improvements and upgrades introduced during power uprates in several reactors of the BWR fleet currently in operation. It is similar in size to the steam dryer in the KKM reactor.
- The **Steam Separator** design is identical to those in the ABWR and ESBWR and similar to others in the BWR fleet.
- It will use **GNF2 fuel**, used by approximately 70 percent of the BWR fleet, with more than 18,500 elements delivered to date.
- The **Control Rod** design is the same as the design used in the ABWR, longer than those of the ESBWR and almost identical to the latest designs used in the rest of the BWR fleet.
- The **Control Rod Actuators** use fine-motion control rod drives (FMCRDs) identical to those used in the ABWR and ESBWR design.
- The concept of the **Chimney** located between the Fuel and Steam Separators is based on the ESBWR design and the Dodewaard reactor, a natural-circulation BWR that was in service in the Netherlands from 1969 to 1997.

The reactor pressure vessel and other components can be manufactured in various countries. Components and piping are skid-mounted equipment and straight forward to install. The reactor building is modular and simple to construct. Turbine Building and Balance of Plant equipment is also skid-mounted and utilizes "off-the-shelf" combined cycle equipment (Figure 4).

INDUSTRY COLLABORATION

The BWRX-300 design has sparked great interest in the nuclear industry.

U.S. utility Dominion Energy has provided funding to further work that could lead to commercialisation of the reactor. In a 2018 GEH news release, Dominion stated the innovations being pursued have the potential to make the BWRX-300 a strong competitor in the marketplace.

GE Hitachi continues to make significant progress in advancing this technology. In January, the company announced that it had officially begun the U.S. regulatory licensing process for the reactor with the submittal of the first licensing topical report to the Nuclear Regulatory Commission. And in February, the company announced that it had made its first submittal to the nuclear regulator in Canada. In addition, several other countries including Poland, the Czech Republic and Estonia have expressed interest in the BWRX-300 as a part of their future energy mix.

CONCLUSIONS

Small modular reactors are ideal for power generation needed in remote consumption centres, as well as for a variety of industrial applications such as seawater desalination. They typically require low water consumption because they are largely air-cooled.

In any case, the development of this technology will have to demonstrate its economic competitiveness in comparison with other generation sources, including renewables.

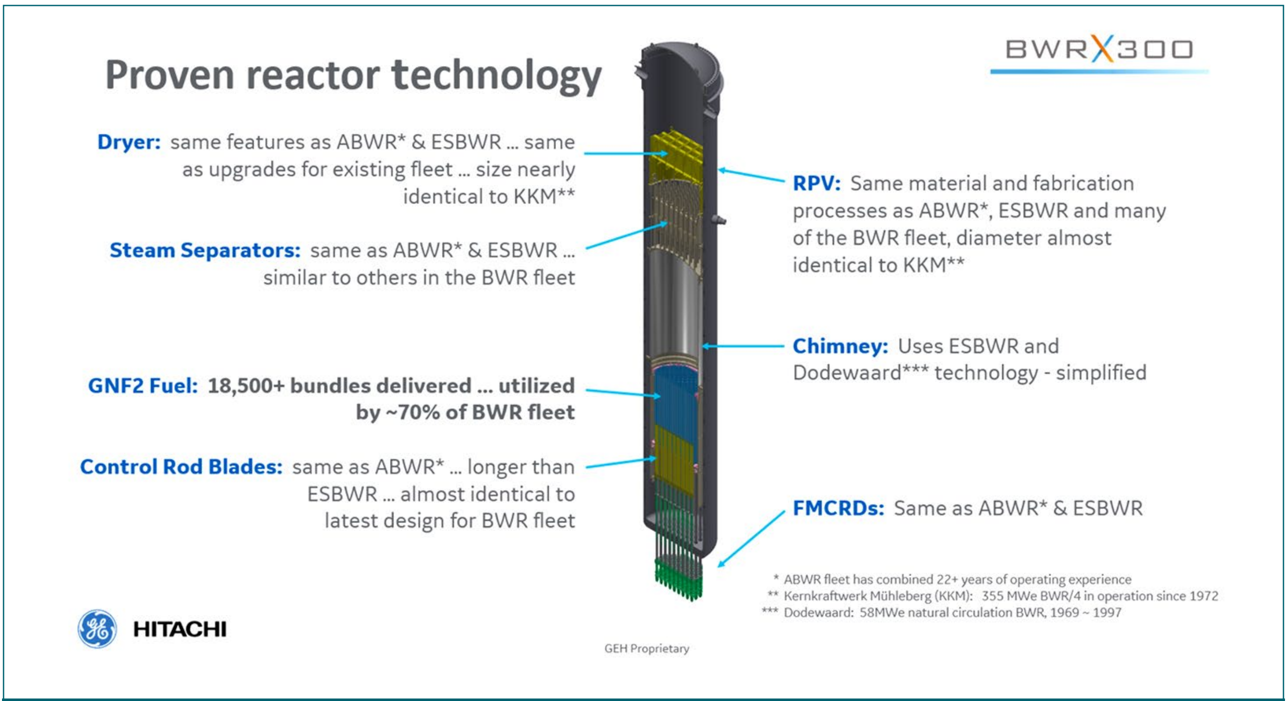

Figura 4. Proven reactor technology.

Prestigious institutions, such as MIT and EPRI, have made public their recommendations on the aspects to be considered to simplify the designs and construction methods and, consequently, reduce investment costs. On that basis, the BWRX-300 design represents an evolution from previous licensed and operational designs, so that development and licensing costs can be minimised, and the experience gained in BWR technology can be leveraged.

This tenth evolution of the Boiling Water Reactor technology represents the simplest, yet most innovative design since GE began developing nuclear reactors in 1955. The result is a dramatic reduction on scale and complexity compared to large reactors, as well as other SMR designs. It is projected to have up to 60% less capital cost per MW when compared with other typical water-cooled SMR and large nuclear designs in the market. In addition, it is designed for significant reductions in operating staff, maintenance cost and security requirements.

Regarding timing, the BWRX-300 can be commercially deployed as early as 2030, utilizing modular and open-top construction techniques proven in Japan. The power plant is approximately 10% of the size and complexity of a large nuclear project, thereby, substantially reducing project risk and total capital cost requirements.

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