Denmark’s Seaborg Technologies CMSR Power Barge Concept

Peter Lobner, 15 May 2021

1. Introduction

Seaborg Technologies (https://www.seaborg.co) was founded in 2014 in Copenhagen, Denmark, where they have focused on developing inherently safe 4th-generation small, modular, molten salt reactors. Since 2017, their focus has been on developing a 250 MWt /100 MWe Compact Molten Salt Reactor (CMSR) with a liquid moderator for use in modular floating nuclear “power barges” that they intend to market worldwide.

2. Power barge vessel design

The Seaborg power barge is a flat bottom, unpropelled barge comprised of at least three modular sections: a bow, a power module housing two CMSRs, and an accommodation / control section.

General arrangement of a basic power barge with a single two-reactor power module. Source: Seaborg Technologies

The first power barges will have a single power module and be capable of delivering a total of 200 MWe. By inserting additional power modules, the power barges also will be available with four, six or eight 100 MWe reactors, delivering a total of 400 MWe, 600 MWe or 800 MWe, respectively.

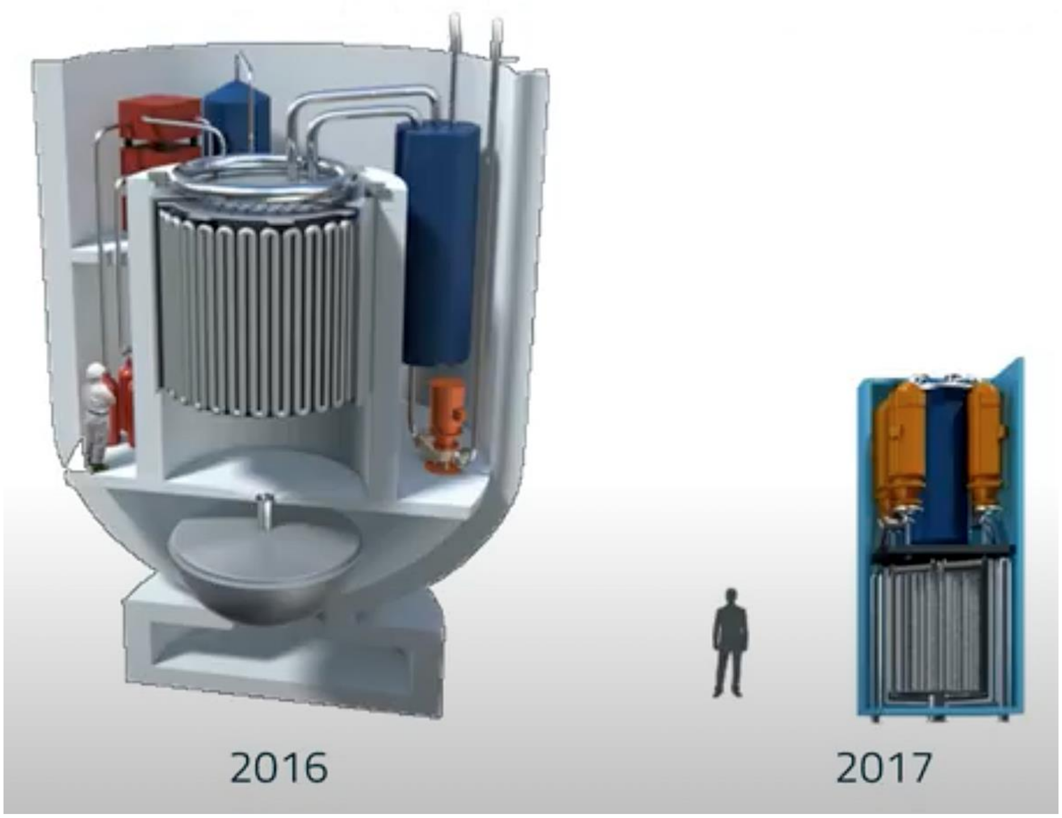
Family of Seaborg power barge with one, two and three power modules. Source: Seaborg Technologies

3. Reactor design

Seaborg Technologies' first reactor design effort was the Molten Salt Thermal Wasteburner (MSTW). This was a conceptual design, circa 2016, for a terrestrial 270 MWt / 115 MWe thermal fission, molten fluoride salt reactor with a graphite moderator. The basic MSTW design was functionally similar to the Molten Salt Reactor Experiment (MSRE) that successfully operated for more than 13,000 hours at Oak Ridge National Laboratory (ORNL) in the early 1960s. Both were high-temperature, molten fluoride salt, thermal fission reactors with graphite moderators.

In these reactors, the molten salt is both the liquid nuclear fuel and the coolant that continuously circulates in a closed-loop primary system operating at or near atmospheric pressure. The reactor core is formed by an array of fuel / coolant pipes that pass through the moderator inside the reactor vessel. Heat from nuclear fission is transported by the circulating molten fuel / coolant and transferred via heat exchangers to a secondary coolant / power conversion system.

By 2017, Seaborg refocused its efforts on the 250 MWt /100 MWe Compact Molten Salt Reactor (CMSR), which uses a proprietary liquid moderator that enables the reactor core to be about 1/8 the size of a graphite-moderated core with a comparable power rating, such as the MSTW. The importance of the liquid moderator to the scale of the reactor is shown in the following graphic.

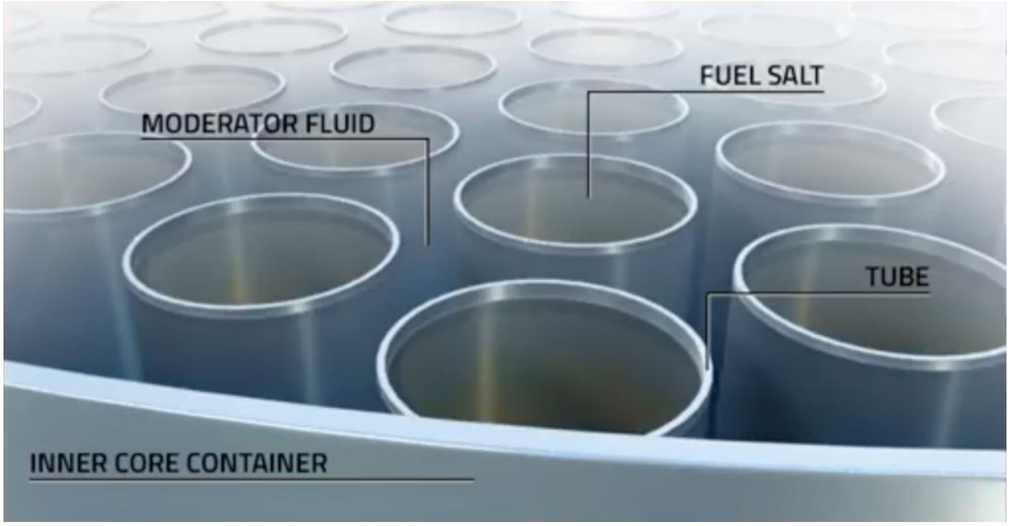


Relative scale of the Seaborg Technologies MSTW with a solid graphite moderator (left) and the CMSR with a proprietary liquid moderator (right). Source: Seaborg Technologies.

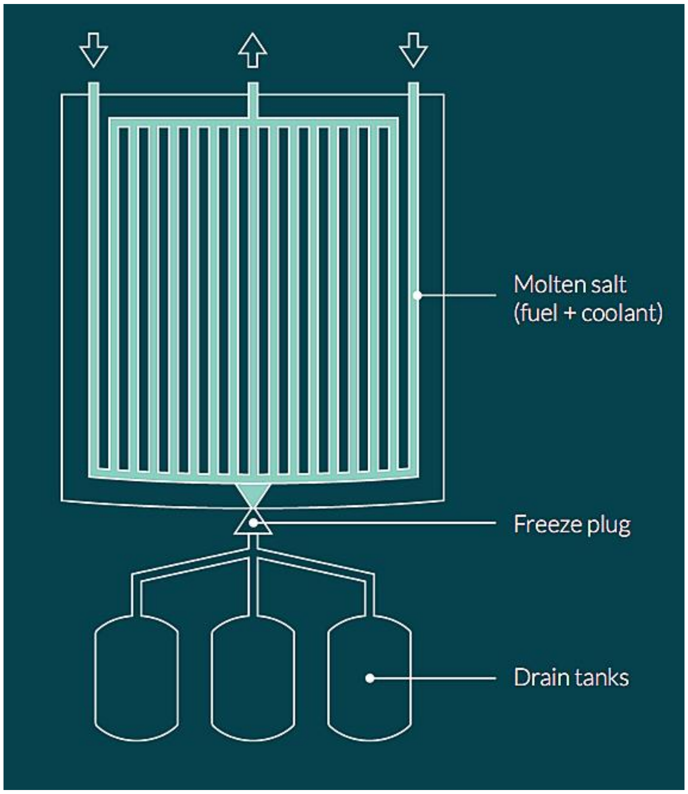
Like MSRE, the MSTW and CMSR are designed to continuously remove volatile fission products from the molten fuel / coolant during operation, thereby greatly reducing the amount of radioactive material that could be released from the reactor during an accident. In contrast, all fission products are retained within the solid fuel of a marine pressurized water reactor (PWR) and volatile fission products can be released from fuel that is damaged or melts during an accident. Note however, that the volatile fission product inventory removed from the fuel / coolant remains aboard the power barge in a separate radioactive waste system.

Molten salt reactors are designed to be refueled online by periodically adjusting the amount of enriched uranium fluoride salt in the molten fuel / coolant to sustain near-term power operations. In an emergency, the entire inventory of molten fuel / coolant can be discharged from the primary system into criticality-safe drain tanks under the reactor. In contrast, civilian marine PWRs contain enough enriched uranium to sustain operating cycles lasting from several years to a decade between refuelings. Marine PWRs severe accident phenomena may include hydrogen generation in the reactor core (from hot zirconium-water reaction) and core melt. These accident phenomena cannot occur in the CMSR.

General arrangement of one Seaborg CMSR module showing the heat exchangers (orange) above the reactor, and the drain tanks (silver) under the reactor, design circa 2017. Source: Seaborg Technologies



Inside the reactor core, the molten fluoride salt fuel / coolant flows up through the tubes, which establish a critical array within the proprietary liquid moderator inside the reactor vessel. Source: Seaborg Technologies



If reactor temperature gets too high, the freeze plug melts and all of the molten salt fuel / coolant is passively discharged into criticality-safe drain tanks. Source: Seaborg Technologies

4. CMSR power barge development plans

The modular power barges are designed to be serially produced in shipyards at low cost. Seaborg and its South Korean partners aim to bring their CMSR power barges to market by 2025. They are specifically targeting developing countries in global regions where renewables have a weak market share, such as in Southeast Asia. It seems unlikely that there is a domestic market for this FNPP in Denmark or in much of the European Union.

Seaborg's business timeline is summarized in the following chart.

Source: Seaborg Technologies

This timeline seems to be very optimistic, particularly given the short time allocated for CMSR reactor design, demonstration and licensing by an appropriate nuclear regulatory agency. I think a big issue will be the lack of mature regulations that adequately address nuclear safety issues for this novel marine reactor design.

After a power barge has been constructed in the shipyard, and then fitted out, fueled and tested, it will be towed to a coastal or offshore site where it will be moored and operated for the service life of barge, which currently is 24 years. This service life is short in comparison to Russia's *Akademik Lomonosov* FNPP, which originally was designed with a 40-year service life. Russia's recently announced (2021) Optimized Nuclear Power Unit (OPEB) 2^{nd}-generation FNPP is being designed with a 60-year service life

Seaborg has not specified a scheduled shipyard maintenance cycle for the power barge vessel. Such periodic maintenance should be necessary to maintain the marine vessel and associated systems in good condition. Russia's *Akademik Lomonosov* FNPP is designed for a 12-year "factory repairs" shipyard cycle and the new OPEB is expected to have a 20-year "factory repairs" shipyard cycle.

Applying the ABS NTQ process to CMSR power barge development

In late 2020, the American Bureau of Shipping (ABS) issued a Feasibility Statement for the CMSR modular power barge. The Feasibility Statement is the first milestone in the five-stage New Technology Qualification (NTQ) process, which ABS describes as follows:

> "The guidance notes introduce a systems engineering approach to qualification that allows for systematic and consistent evaluation of new technologies as they mature, all the way from a concept through to the intended application in operations. A five-stage process is followed that aligns with the typical product development phases of a new technology:
>
> - Feasibility stage
> - Concept verification stage
> - Prototype validation stage
> - System integration stage
> - Operational stage
>
> The qualification activities within each stage revolve around risk assessments and engineering evaluations that build upon each other in order to determine if the new technology provides acceptable levels of safety in line with current offshore and marine industry practice. The qualification efforts by all stakeholders such as the vendor, system integrator and end-user at each stage are recognized and captured within a new technology qualification plan."

Nuclear licensing by an appropriate agency (not ABS) will be separate from the NTQ process.

<u>CMSR funding</u>

Seaborg's first external funding was secured in January 2018, when it received the first ever public grant for a nuclear project in Denmark. In November 2020, Seaborg secured about $24 million in funding, mostly from private investors.

In March 2021, the Danish state made a profit when it sold its shares in Seaborg as part of major reforms in how the state provides subsidies for startups and innovation.

While Seaborg has secured significant funding that will enable it to expand its development team and advance its CMSR program into the NTQ concept verification stage, much more funding is needed in the near term (next few years) to build and operate demonstration reactor hardware and prepare for construction of a full-scale prototype starting in 2025.

A two-reactor basic power barge. Source: Seaborg Technologies

5. For more information

- Video: "Making Nuclear Sustainable with CMSR (Compact Molten Salt Reactor) - Troels Schönfeldt @ ThEC2018," 27 May 2019: https://www.youtube.com/watch?v=ps8oi_HY35E&t=3s

- Brian Wang, “Seaborg Molten Salt Reactor Will Fit on A Truck and Cost Less Than Coal Power,” NextBigFuture, 29 May 2019: https://www.nextbigfuture.com/2019/05/seaborg-molten-salt-reactor-will-fit-on-a-truck-and-cost-less-than-coal-power.html
- Kamen Kraev, “New Technologies / Denmark’s Seaborg Attracts Private Funding For Molten Salt Reactor Project,” Nucnet, 27 November 2020: https://www.nucnet.org/news/denmark-s-seaborg-attracts-private-funding-for-molten-salt-reactor-project-11-5-2020
- Jillian Ambrose, “Floating 'mini-nukes' could power countries by 2025, says startup,” The Guardian, 17 December 2020: https://www.theguardian.com/environment/2020/dec/17/floating-mini-nukes-could-power-countries-by-2025-says-startup
- “Seaborg Technologies Clears First Classification Milestone for Maritime Deployment of Nuclear Power Barges with ABS Statement,” Press Release, Seaborg Technologies, 17 December 2020: https://www.seaborg.co/press-release-dec-2020
- “IN THE SPOTLIGHT: ABS completes feasibility study on Molten Salt Reactor Technology,” American Bureau of Shipping, 17 December 2020: https://news.cision.com/american-bureau-of-shipping/r/in-the-spotlight--abs-completes-feasibility-study-on-molten-salt-reactor-technology,c3257392
- “Status Report – MSTW,” Advanced Reactors Information System (ARIS), International Atomic Energy Agency, 28 July 2016: https://aris.iaea.org/PDF/MSTW.pdf