Unlimited Fusion-Energy Station Based on Lithium Recovery from Seawater for a Net-Zero Carbon World

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This article presents the concept of unlimited fusion-energy station (U-FESTA), comprising a fusion power plant and a lithium (Li) recovery facility to recover Li from seawater, for example the Li-separation method by ionic conductor (LiSMIC). To realize the U-FESTA, we discuss the relationship among the seawater-based Li-recovery efficiency, blanket technology on ^{6}Li enrichment, intake cooling seawater in a power plant, and the blanket-replacement period.

Keywords: unlimited fusion energy, lithium recovery, LiSMIC, electricity, hydrogen, ancillary service

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The fusion energy produced by the reaction between deuterium (D) and tritium (T) is considered a source of unlimited energy, as both D and T-breeder, lithium (Li), are abundantly found in seawater (158 ppm of D [1] and 0.18 ppm of Li [2]). While the recovery method for D has already been established [1], the method for Li recovery from seawater, such as LiSMIC (Li Separation Method by Ionic Conductor) [3, 4], is currently in its development stages. In this study, we discuss the conditions required for recovering Li from seawater for unlimited fusion energy and propose the concept of an Unlimited Fusion Energy Station (U-FESTA), which combines a fusion power plant (FPP) with a Li-recovery facility from seawater.

To emphasize that fusion energy is available in unlimited supply on the earth, the use of the seawater-based Li-recovery facility by such as LiSMIC is essential. In addition, the outlook on Li supply from mines must be sensibly considered [5]. For the U-FESTA concept, to consider the requirement of recovering Li from seawater, JApan's fusion DEMOnstration power plant (JA DEMO) was assumed as the model plant [6]. Other fusion-energy systems, such as the helical/stellarator system and the inertial confinement one including various blanket concepts, are also applicable for the development of U-FESTA.

The essential issue for the U-FESTA is enough Li supply from seawater to maintain the T self-sufficiency in FPP. In other words, the T-breeding material (Li) must be recovered from seawater and installed periodically into the FPP as a blanket system. In the present model plant of JA DEMO, the total breeding material (Li_2TiO_3 and 90% enriched ^{6}Li is assumed) for one set of the blanket system is evaluated at 389 ton, and the required natural Li from seawater for the breeding material is 518 ton. The ^{6}Li-enrichment using LiSMIC has also been proposed by Ref. [7].

Figure 1 shows the relationship between the seawater-based Li-recovery efficiency and the required period for one set of blanket breeding material of JA DEMO. Here, the Li-recovery efficiency, η_r^{Li}, is defined as the Li concentration of seawater before (C_{Li}^B) and after the Li-recovery process (C_{Li}^A): $\eta_r^{Li} = (1 - C_{Li}^A/C_{Li}^B) \times 100$ (%). In case of the similar seawater intake of 45 ton/s as cooling water to a pressurized water reactor (PWR), η_r^{Li}~50% is required for the design target of the blanket-replacement period (4 years) for JA DEMO [8]. In case of 180 ton/s, the required η_r^{Li} decreases to approximately 15%. Furthermore, advancement of the blanket concept with natural Li (without ^{6}Li enrichment) will drastically relax the requirement of η_r^{Li} to approximately 1%. Consequently, the required η_r^{Li} strongly depends on the advancement of the blanket technology in maintaining the T self-sufficiency. In addition, the reuse and recycle of the breeding material of a used

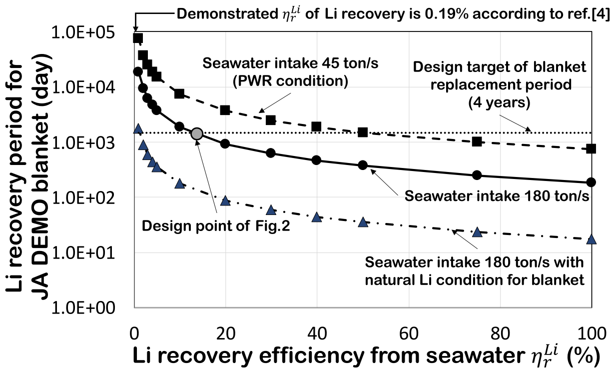

Fig. 1 Relationship between Li recovery efficiency η_r^{Li} from seawater and Li recovery period for one set of JA DEMO blanket.

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blanket could relax the requirement of η_r^{Li}. According to the recent advancements in LiSMIC, a mixed alkaline solution greatly improves the Li-recovery rate up to 94%, while that of the electrolytic solution of the used Li-ion battery and brine water is 8.3% and 0.19%, respectively [4]. The Li recovery rate from brine water is low as shown in Fig. 1, and thus the similar advancement to mixed alkaline solution is required for Li recovery rate by using seawater in the future.

Next, Fig. 2 presents the U-FESTA concept and describes its power/material flow. U-FESTA comprises a FPP and a Li-recovery facility. In Japan, a power plant usually requires huge amounts of cooling seawater, which can then be available for use by the Li-recovery facility. This is the basic motivation for combining the FPP and the Li-recovery facility. A gross output power of 640 MWe is summed up by a net output power of 204 MWe, an input power of 50 MWe for Li recovery, and an internal power of 386 MWe of the FPP. The net output power can be controlled by changing the input power for Li recovery. The seawater intake for steam condensation from the turbine is 180 ton/s, which is approximately four times larger than that of the usual PWR. This design point is shown in Fig. 1. After condensation of steam from the turbine system, the natural Li is recovered from seawater at 0.018 ton/h, where η_r^{Li} is assumed to approximately 15% as shown in Fig. 1. In the case of JA DEMO, 90% enriched ^{6}Li was applied and, the recovered ^{6}Li is used as the T-breeding material. Most of ^{7}Li from seawater was left over and can be afforded in the Li market. According to LiSMIC [4], 5 V of voltage was applied to recover Li from seawater, and the electric current produced H_2 at the cathode. Assuming H_2 electrolysis efficiency of 100%, 50 MWe of power input (Fig. 2) could theoretically produce hydrogen of 0.37 ton/h.

Finally, we propose an ancillary service by the U-FESTA in the grid. The net output power of the U-FESTA can be controlled from −386 to 254 MWe by changing the input power of the Li-recovery facility. Recently, a large amount of solar power plant installation in the grid has resulted in the overgeneration risk during mid-day and the steep ramping up during the evening, that is, duck curve [9]. The proposed U-FESTA concept can manage such grid issues caused by large amounts of variable renewable energy (VRE). When the solar power over-generates electricity during mid-day, U-FESTA receives electricity of up to 386 MWe and produces Li and hydrogen. When the solar power decreases during evenings, U-FESTA can increase the net output power up to 254 MWe. Such a contribution of flatting the load curve in the grid by U-FESTA, could support the installation of VRE in large numbers, which is compatible with the concept of future net-zero carbon world.

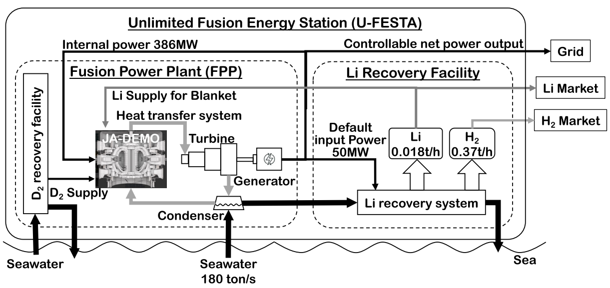

Fig. 2 A concept of U-FESTA, and its power and material flow.

The primary technological issues to realize this U-FESTA concept are considered as follows: (1) realization of a steady state power output by FPP, (2) sufficient Li-recovery efficiency η_r^{Li} from seawater, (3) blanket technology to reduce ^{6}Li enrichment for T self-sufficiency, and (4) reuse and recycle technology for the breeding material of the blanket.

This paper clarified the key trade-off relationship among Li-recovery technology, blanket technology (especially ^{6}Li-enrichment issue), cooling seawater intake in a power plant and blanket-replacement period for unlimited fusion energy. Second, we propose the concept of U-FESTA, which can provide electricity, hydrogen, Li and ancillary service in the grid. Third, we showed how U-FESTA can be used to flatten the duck curve caused by VRE. Realization of such a concept would surely contribute to the future net-zero carbon world.

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