Conceptual Design of Fusion Power Complex with Hydrogen Storage Function in Superconducting Magnet System

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(Received 22 October 2022 / Accepted 15 November 2022)

This paper is the first to define a conceptual design of a fusion power complex with hydrogen storage capability in a superconducting magnet system using cryogenic hydrogen. The fusion power complex realizes a carbon-neutral society by combining a large-capacity power source of renewable energy with the flexibility of energy output. Therefore, the proposed design is positioned as one of the most important next-generation power sources.

Keywords: hydrogen production, superconducting magnet, fusion power plant, energy storage

DOI: 10.1585/pfr.18.1205001

In a traditional electric power plant design, heated water is used to drive turbine generators. Deuterium-tritium fusion reactions produce high-energy neutron of 14 MeV that is injected to the facing wall. The wall materials with coolant are heated up. Nevertheless, fusion plants are associated with heat wastage at different ranges of temperature. Thus, fusion plants should consider using a waste heat recovery system that is economical and carbon-neutral. Different studies have examined the use of waste heat recovery systems from fusion output in forms other than electricity. For example, S. Yamada *et al*. proposed a fusion plant for hydrogen production that utilized the heat generated from fusion reactions [1]. In fusion plasma experimental devices, cryogenic helium is used to cool superconducting coils, which use cryogenic helium for magnetic field coils necessary for plasma confinement [2]. However, there is great concern about the depletion of helium resources [2]. Therefore, cryogenic hydrogen should be considered as a refrigerant for cooling superconducting coils since many plants with large-scale superconducting coils will be built in the future, the adoption of cooling using cryogenic hydrogen as a refrigerant for superconducting coils should be considered.

Table 1 shows the helium inventories of superconducting magnets and peripheral equipment in major fusion experimental devices currently in operation or under construction. The numbers in parentheses indicate the facility capacity of gas tanks in helium facilities [3–6] Currently, 27 tons of helium are used in ITER. Based on the volume of the device, the amount of helium required is estimated to be more than double for JA DEMO [7] and the fusion reactors that will be built after ITER. This amount is equivalent to about 0.15% of the global production of 33,000 tons of helium in 2019, as evaluated from the amount and share of helium supplied by the U.S. Bureau of Land Management [2]. Thus, given the concerns about the depletion of helium resources in the future, it will be difficult to construct and operate a large number of facilities that utilize helium.

Table 1 Helium inventory [tons] of fusion experimental devices. The values without notes are taken from Ref. [3].

ITER	JT-60SA	KSTAR
27	1.1 (3.6[1))	1.4
SST-1	W-7X	LHD
0.6	3.6[2)	(7.9[3))

Note: Values in parentheses are the facility capacity of the helium gas tanks. [1) value is taken from [4], [2) value is estimeted from [5], [3) value is estimated from [6] table 7.

In recent years, much research has been conducted on high-current superconducting conductors that use high-temperature superconducting (HTS) wires. It is expected that cryogenic hydrogen will be used to cool HTS coils in superconducting magnets for fusion plants in the future. In addition, when compared to helium cooling, HTS coils can increase the operating temperature and reduce the cost of facilities and operation, thus improving the efficiency of cooling system.

Given this background, we propose a fusion plant that combines a fusion plant for hydrogen production and temporary storage of hydrogen for cooling large superconducting coils. The proposed plant is illustrated in Fig. 1. As shown in the figure, the area elongated by the dashed line shows Fusion Power Complex, which combines power generation and hydrogen production. The fusion reactions

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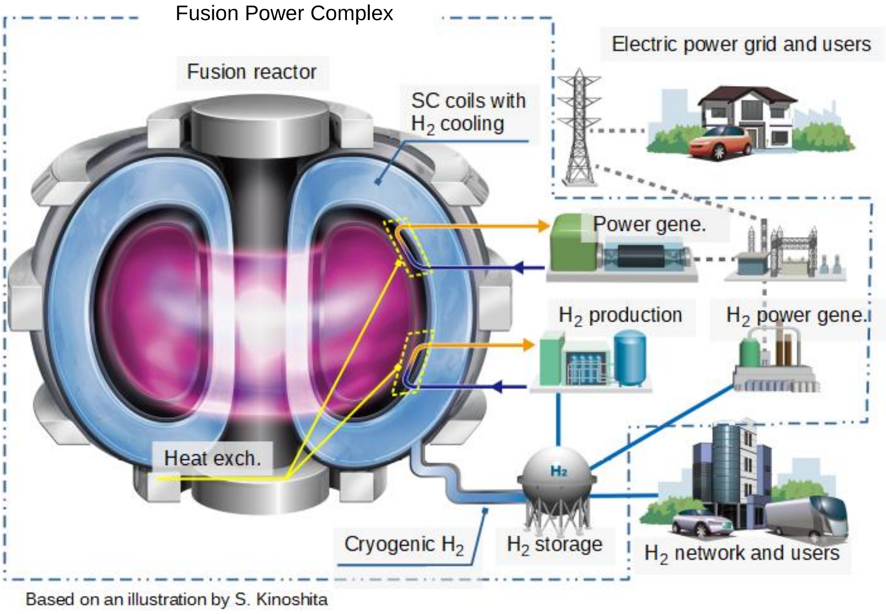

Fig. 1 Diagram of the proposed fusion power complex.

in the fusion reactor produce primary energy. In a conventional design, the heat of coolants in the blanket systems is used to generate electricity, which is supplied to the electric power grid. In a complex design, waste heat from fusion reactions is used to produce hydrogen, which is released in the current fusion reactor design. In addition, the combined system of power generation and hydrogen production enables the stored hydrogen to produce electric power through hydrogen power generation. The produced hydrogen is used as a refrigerant for cooling the superconducting coils and supplied to the hydrogen network via pipelines. Hydrogen storage facilities can absorb the difference between hydrogen production and consumption, and can also be used as cryogenic hydrogen for cooling superconducting coils in the complex. Additional costs can be minimized by sharing the necessary hydrogen handling facilities with facilities for cooling superconducting coils. This complex plant configuration can adjust the amount of electricity supplied to the electric grid by controlling the amount of hydrogen production and hydrogen power generation.

Based on previous estimations, the superconducting coils and their peripheral equipment in a fusion plant will hold about 50 tons of hydrogen. This inventory is considered as an emergency energy source and as a part of hydrogen storage. Conversion of hydrogen to combustion energy yields 7.12×10^{12} [J], which is equivalent to 186,000 liters of diesel oil. Assuming that this energy is converted to electricity by fuel cells at 60% efficiency, a total of 1.19 million kWh will be generated, which is equivalent to supplying 30,000 kW for 40 hours. Thus, even if electric power connections to power grids in a commercial setting are lost due to accidents, such as large-scale earthquakes, there will still be several options that can use the energy possessed by the fusion power complex. For example, electrical energy can be used to maintain the fusion power complex control functions to maintain safety.

This paper proposes the fusion power complex with hydrogen storage capability in a superconducting magnet system. This complex combines both renewable energy and a large-capacity power source with the flexibility of energy output to realize a carbon-neutral society. Therefore, the proposed fusion power complex is considered as one of the most important next-generation power sources. Finally, this paper is just an initial proposal, and further quantitative analysis must be taken in future.

This work is supported by NIFS budget UFFF028-2 and JSPS-CAS Bilateral Joint Research Projects, “Control of wall recycling on metallic plasma facing materials in fusion reactor,” 2019 - 2022 (GJHZ201984 and JPJSBP120197202). Authors are grateful to Prof. H. Yamada from the University of Tokyo for his useful suggestions regarding fusion power complex, discussions in unit groups, safety science for nuclear fusion, and applied superconductivity and cryogenics in NIFS.

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