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# Experimental study of hydrogen storage with reaction heat recovery using metal hydride in a totalized hydrogen energy utilization system

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ABSTRACT

Experimental results for hydrogen storage tanks with metal hydrides used for load leveling of electricity in commercial buildings are described. Variability in electricity demand due to air conditioning of commercial buildings necessitates installation of on-site energy storage. Here, we propose a totalized hydrogen energy utilization system (THEUS) as an on-site energy storage system, present feasibility test results for this system with a metal hydride tank, and discuss the energy efficiency of the system. This system uses a water electrolyzer to store electricity energy via hydrogen at night and uses fuel cells to generate power during the day. The system also utilizes the cold heat of reaction heat during the hydrogen desorption process for air conditioning. The storage tank has a shell-like structure and tube heat exchangers and contains 50 kg of metal hydride. Experimental conditions were specifically designed to regulate the pressure and temperature range. Absorption and desorption of 5,400 NL of hydrogen was successfully attained when the absorption rate was 10 NL/min and desorption rate was 6.9 NL/min. A 24-h cycle experiment emulating hydrogen generation at night and power generation during the day revealed that the system achieved a ratio of recovered thermal energy to the entire reaction heat of the hydrogen storage system of 43.2% without heat loss.


## 1. Introduction

### 1.1. Background

Air conditioning in commercial buildings in Japan not only increases electrical power demand but also increases the demand gap between daytime and nighttime. Load leveling of electrical power demands saves energy cost and reduces the environmental impact by "leveling" these demand variations and by depending more on base-load power plants because such plants generally produce less $CO_2$. Energy demand for air conditioning, especially in commercial buildings, must be stored during off-peak hours.

Hydrogen is a promising candidate as an energy storage medium due to its storability and portability [1]. Water electrolyzers produce hydrogen from water during off-peak hours

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and fuel cells supply electric power during peak hours to level out the daily variations in power demand. Compared with compressed hydrogen or liquid hydrogen in vessels, hydrogen storage with metal hydrides is suitable for stationary on-site storage due to its relatively low operating pressure and moderate operating temperature. These advantages plus a high volumetric storage density compensate for disadvantages of using metal hydrides, such as its heaviness. Bossi et al. used a metal hydride tank to examine power generation with a fuel cell during fluctuating demands [2].

Because the hydrogen absorption/desorption process of metal hydrides is an exothermic/endothermic process, thermal management of metal hydrides is essential for achieving a continuous process. Metal hydride in a reaction vessel is granular and its effective thermal conductivity is small, ≈1 W/(mK). The equilibrium pressure of metal hydrides depends on temperature, and an efficient heat exchanger is required to maintain a continuous reaction and stable hydrogen flow. Heat and mass transfer in a metal hydride tank have been investigated experimentally and numerically. Tubular-type heat exchangers have been applied to hydrogen storage systems with metal hydride reactors [3–13]. Mellouli et al. studied a spiral tube in a reactor to enhance its heat exchange ability [13]. Botzung et al. validated the concept of a combined heat and power system and used a metal hydride tank to store excess hydrogen and to deliver it during high consumption periods [14]. Metal foam is also employed to smooth the distribution of the reaction heat during the absorption and desorption [15–17]. To evaluate reaction heat of metal hydride and heat exchange between the metal hydride and the heat transfer media such as coolant or air, various mathematical models and numerical simulation of heat and mass transfer in metal hydride beds have been proposed [18–23].

As reviewed by Muthukkumar and Groll [24], metal hydride has also been used in a heat pump system to store thermal energy [25–27]. These heat pump systems use two or more types of metal hydrides with different physical properties, and transport hydrogen between these metal hydrides to achieve reaction heat of absorption or desorption without continuous hydrogen production or consumption. Koseki et al. designed large-scale metal hydrogen tanks for a heat pump system to examine the pressure profile during heat pump operation [27].

Studies on applications of metal hydrides can be categorized into two groups: 1) hydrogen storage for other system, such as water electrolyzer and fuel cell, and 2) heat pumps using reaction heat generated by transferring hydrogen between two or more metal hydride tanks. There has been relatively little attempt to utilize both hydrogen storage and reaction heat. In our original study, first we introduce the concept of our totalized hydrogen energy utilization system (THEUS), in which a metal hydride tank absorb and desorbs hydrogen for the storage and simultaneously utilize reaction heat for cold energy demand. Then, we present experimental results from a feasibility study on a metal hydride tank to store both hydrogen itself and thermal energy as an important component of THEUS. Finally, we evaluate the efficiency of energy storage of the metal hydride tank and its potential for load leveling.

### 1.2. *Totalized hydrogen energy utilization system*

An energy storage system that uses hydrogen has been previously proposed and is called the “Totalized Hydrogen Energy Utilization System (THEUS).” [28] The system involves water electrolyzers, metal hydride tanks, and fuel cells. The water electrolyzers and fuel cells can be replaced by a unitized reversible fuel cell proposed by Kato et al. [29] THEUS has a potential to be installed on-site at commercial buildings in Japan.

Fig. 1 illustrates a conceptual overview of THEUS. This system stores the electricity energy at night by using a water electrolyzer and generates power during the day by using fuel cells. The system also utilizes the cold heat of reaction heat for air conditioning. At night, THEUS produces hydrogen by using a water electrolyzer powered by inexpensive nighttime electrical power and then stores hydrogen by a metal hydride tank. During the day, THEUS generates electrical power by using fuel cells with the stored hydrogen to meet power demands in the respective building. A local system such as THEUS takes advantage of a simultaneously generated cold source and heat source to improve total energy efficiency. The metal hydride tank of THEUS does not store hydrogen only for the fuel cells of THEUS. Stored hydrogen can be used for fuel cell vehicles. THEUS can (1) optimizes the integration of energy storage and poly-generation of electric power, cold source, heat source and hydrogen to meet energy demand, (2) balances the load leveling, and (3) store renewable energy such as solar energy and wind energy. THEUS can bridge the gap between renewable energy and energy demand. Use of renewable energy sources becomes easier when THEUS is installed because fluctuations in electrical power loads can be managed. In this study, we focus on the metal hydride tank in THEUS to experimentally examine efficient operating conditions.

### 1.3. *Operation principles of metal hydride tanks in THEUS*

To ensure absorption/desorption ability of metal hydride for load leveling and to maximize the thermal efficiency of the total system, the operating conditions must be designed carefully. Table 1 shows the system requirements for the tank

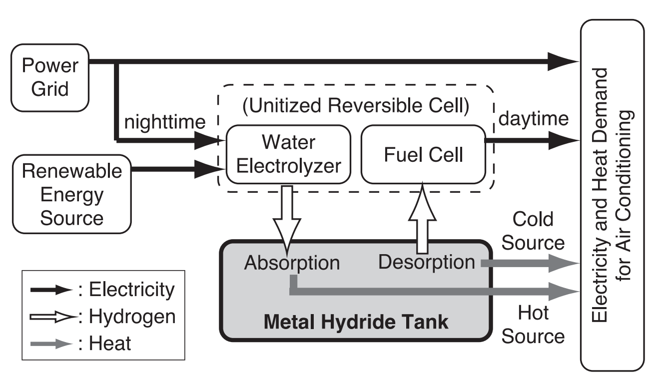


**Fig. 1 – Concept of Totalized Hydrogen Energy Utilization System (THEUS) showing flow of electricity, hydrogen, and heat.**