INTERNATIONAL JOUNAL OF: ENGINEERING RESEARCH AND TECHNOLOGY

TIMBOU-AFRICA ACADEMIC PUBLICATIONS
INTERNATIONAL JOURNAL, NOVEMBER, 2022 EDITIONS
VOL. 11 NO. 5 ISSN: 2707-5654

CASE STUDY ON RENEWABLE ENERGY STORAGE TECHNOLOGY

BOYA S. N.; YUNUSA M. A.; C. S. ONATE; & ABDULKADIR A.

Department of Electrical Electronics, Department Federal Polytechnic Bauchi, Bauchi State, Nigeria

ABSTRACT

Energy storage will be a critical aspect in the future of renewable energy (RE) systems, according to a widely acknowledged concern. The most recent research on the utilization of energy storage for high RE penetration has gotten a lot of press. We shall look at several energy storage methods, types, categorizations, and comparisons in this paper.

Introduction

Energy systems are critical in the production and transformation of energy from diverse sources to the uses that require it, such as industry, building, and transportation. Fossil fuels can be easily stored while not in use, but other sources of energy, such as solar and wind, must be collected and stored as soon as feasible.

Other previous evaluations have focused mainly on forms of energy storage for a single use, such as utility applications, thus it's critical to perform more comprehensive reviews that encompass all types of energy storage to gain a better understanding of their differences. Furthermore, the area of energy storage is extremely broad, and several publications from both scientific and

> Electrochemical and battery energy, thermal, thermochemical, flywheel, compressed air, pumped energy storage, magnetic, and chemical and hydrogen energy are some of the options. There is also research on new types of energy storage and key technological advancements in energy storage.

economic perspectives are published on it every year. The present page seeks to cover a broader assessment of different forms of energy storage and compare their qualities, whereas the previous article provided a bigger and more recent summary of each storage classification category.

Types of energy storage

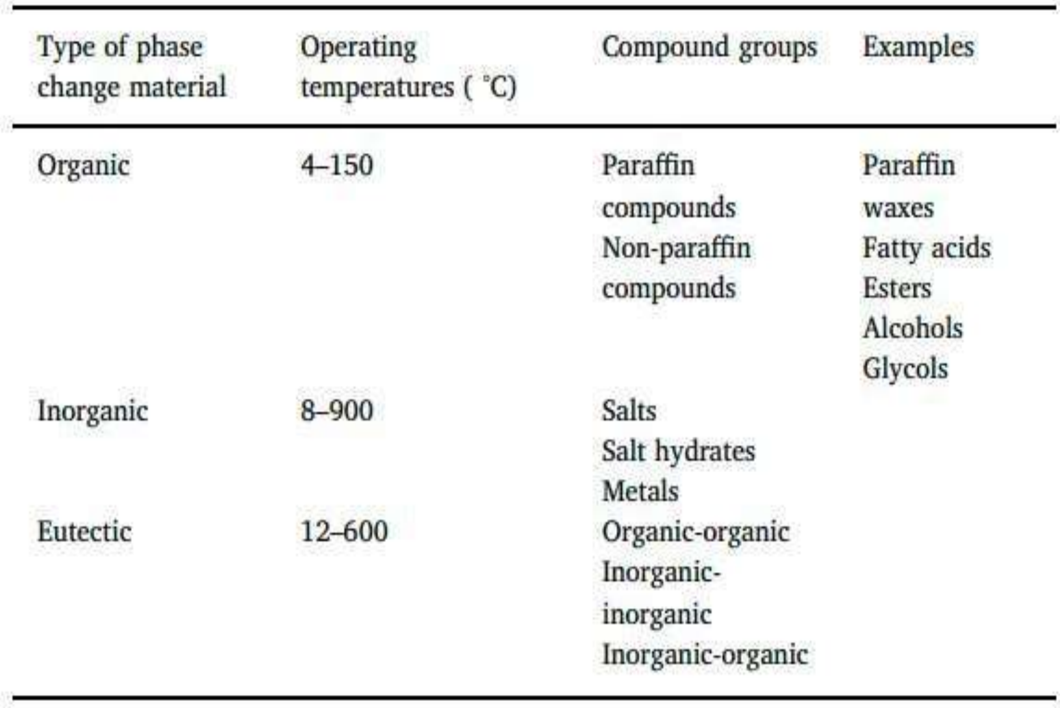
We divided it into electrochemical and battery energy storage, thermal, thermochemical, and flywheel energy storage, compressed air, pumped energy storage, magnetic, chemical, and hydrogen energy storage from many types and categories.

THERMAL ENERGY STORAGE

The term "thermal energy storage" refers to storing heat or "cold" in a storage medium. There are three main types of thermal energy conservation: sensible, latent, and thermochemical. Such energy storage includes hot water storage, subsurface thermal energy storage [1], and rock-filled storage. The most common phase change materials (PCMs) employed as storage media include paraffin waxes, esters, fatty acids and salt hydrates, eutectic salts, and water [2]. PCMs are classified in Table 1.

When a thermal energy source does not provide energy at a constant rate and/or at a fixed cost, thermal energy is stored. Seasonal energy storage necessitates a larger energy storage system capable of retaining heat for usage after several months. An analogous concept could be implemented by storing solar thermal energy in the summer for use in the winter. These systems can also be used to store solar thermal energy throughout the day for use during the cooler hours when heating is required. The study of thermal energy storage systems is extensive, and numerous detailed assessments of various features of these technologies are available [3].

Table 1, solid- liquid phase classification modify materials



Type of phase change material	Operating temperatures (°C)	Compound groups	Examples
Organic	4–150	Paraffin compounds Non-paraffin compounds	Paraffin waxes Fatty acids Esters Alcohols Glycols
Inorganic	8–900	Salts Salt hydrates Metals	
Eutectic	12–600	Organic-organic Inorganic-inorganic Inorganic-organic	

PCM is a new method for analyzing fatty acids in vegetable and animal oils [4]. They describe the employment of PCMs in smart thermal grid systems with intermittent renewable energy sources as "interesting." Ground thermal storage is an increasingly widespread type of sensible thermal energy storage, in which a circulating medium extracts heat from a structure in the summer and stores it in the ground for use in the winter. [5] discusses ground heat exchanger models and their applications.

Water tanks are indicated as the most suitable solution from a thermodynamic standpoint [6] due to the high specific heat of water and their high-capacity values for energy charge and discharge. Aquifer thermal energy recovery (ATES) devices.

Electrochemical and battery energy storage

Electrical energy can be stored electrochemically in batteries and capacitors. Many types of electrode materials and electrolytes have been evaluated and suggested to enhance the cost, power density, energy density, cycle life, and safety of batteries with high energy densities and high voltages. [7] discusses lithium-ion batteries, flow batteries, sodium–sulphur and similar zebra batteries, nickel–cadmium and related nickel-metal hydride batteries, lead acid batteries, and super capacitors, as well as other electrochemical energy storage systems. Because of its high specific energy (energy per unit weight) and energy density, lithium batteries are becoming increasingly essential in electrical energy storage among the numerous battery types (energy per unit volume).

Capacitors are classified as electrolytic, electrostatic, or electrochemical because they store and deliver electricity electrochemically. Electrochemical capacitors, sometimes known as super capacitors, have the highest capacitance per unit length. [8] provides performance data for super condensers and lithium-ion batteries. Sharma and Bhatti [9] discuss the history of electrochemical double-layer capacitor technology, as well as classification, construction, design, research, and voltage balancing. Electrochemical capacitors have a high storage efficiency (>95%), making them possible to cycle hundreds of thousands of times without losing any energy.

In terms of useful energy density, a charged Li-air battery provides an energy source for electric vehicles that rivals that of gasoline (Fig.)

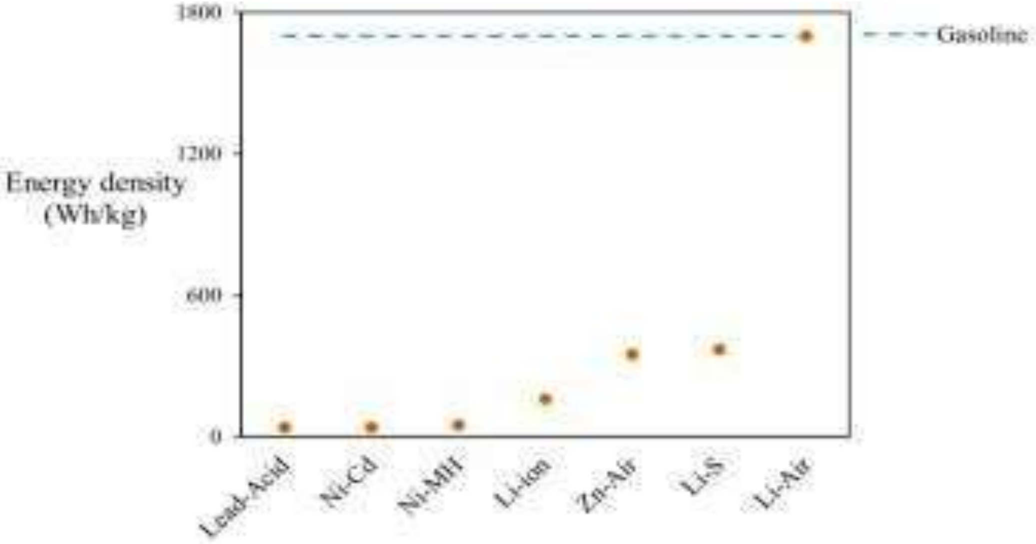


Fig. 1 . Rechargeable batteries and there energy densities, comparison to gasoline

Na-ion batteries have the potential to be the low-cost batteries of the future. Because sodium is widely available and inexpensive, it is ideal for smart electric networks that incorporate renewable energy sources.

Energy storage flywheel

Kinetic energy storage, often known as mechanical energy storage, is a type of mechanical energy storage. Depending on the charge/discharge mode, kinetic energy is transmitted in and out of the flywheel via an electric motor operating as a motor or generator. The flywheels drive generators to generate power. The flywheel system operates in the high vacuum environment. Because of their great efficiency, high power densities, and low rotor losses, magnetic devices are extensively utilized in flywheels [10]. Induction, bearing-less, and variable-reluctance machines are all different in terms of application speed limits, idle losses, vibration, noise, and cost. Magnetic bearings that function in a vacuum keep the rotating mass in place to reduce friction losses and safety concerns during long-term storage [11].

The magnetic bearing does not require lubrication because it has no frictional failure. The flywheel rotor and its housing are made of steel, alloys (such as titanium or aluminium alloys), and, more recently, heavier materials such as composites. Rotor components account for most of the production, and design and speeds of up to 10,000 rpms are currently possible. Flywheel energy storage systems are known for their high capacity and power efficiency, as well as their extended cycle life (tens of thousands of cycles), long operating life, high round-trip efficiency, and low environmental impact . When compared to batteries and super capacitors, flywheel energy storage systems have lower power density, cost, noise, maintenance effort, and safety concerns.

An innovative hybrid system design in which super capacitors are installed inside the flywheel spinning disc to maximize their power density. This allows for the exchange of pulsed power as well as the storage of large amounts of energy.

Storage of Thermochemical

Chemical reactions that require or release thermal energy are used in thermochemical energy storage systems. Endothermic dissociation, storage of reaction products, and exothermic reaction of dissociated products are the three operational phases of thermochemical energy storage: (See Figure 2).

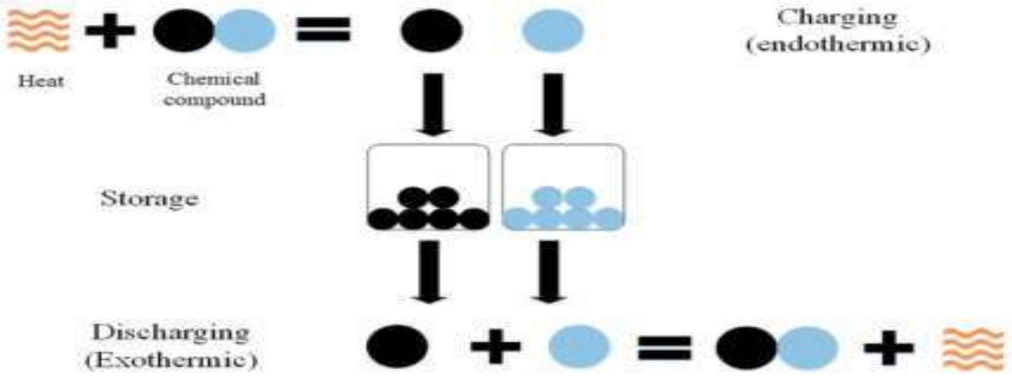


Fig. 2. Processes of thermochemical energy storage cycle

Thermochemical energy storage techniques can be described in a variety of ways, one of which is depicted in Fig. 3.

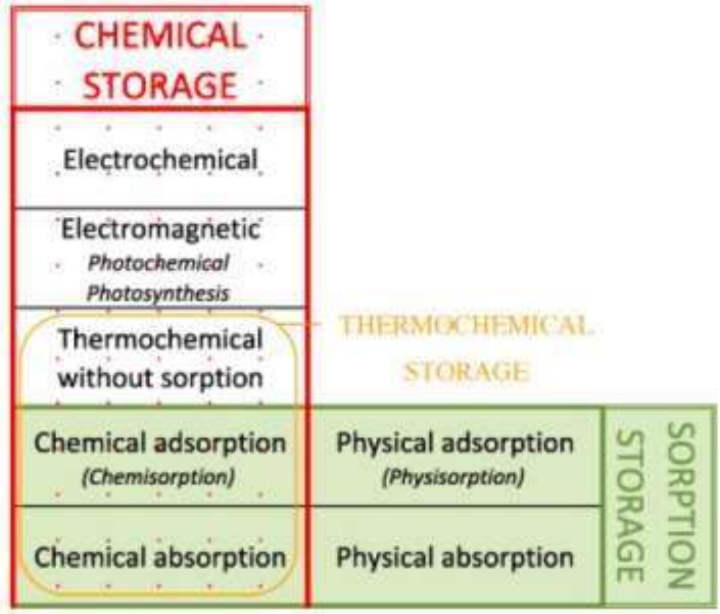


Fig. 3. Chemical storage classification

Because energy losses during storage are fewer for thermochemical energy storage than for sensible or latent TESC composite materials, it has a lot of potential for long-term storage applications [12]. suggests that salt-impregnated materials are suitable for application in thermochemical storage systems. According to them, one area that requires more research is ensuring the consistency of salt addition to the adsorbent material for repeated stable long-term applications.

A study on thermochemical energy storage principles and recent improvements is published in , and thermochemical storage systems are compared to other TES systems. A new energy storage technology based on microwave-induced CO2 gasification of carbon compounds. Various carbon compounds are evaluated to determine the quantity of energy used. The device has achieved energy efficiency of 45 % in the laboratory and appears to be improvable to compete with existing energy storage devices.

Energy storage for compressed air

When additional energy is available, compressed air will be stored in an underground cavern in such a system. When energy is required, this pressured air can be released into a turbine to generate electricity. Commercially, compressed air energy storage systems are appealing because of their ability to shift energy consumption periods and, more recently, because of the need to mitigate the impact of renewable energy grid development that is irregular [13].

Liquid air has lower losses than compressed air because it may be kept at moderate pressures. As a result, it may be a safer option for long-term storage than compressed air. Liquid air is also denser, allowing it to fit into smaller containers. Liquefied air energy storage technologies outperform compressed air energy storage systems. Liquid air is the simplest approach, which is based on the Linde-Hampson cycle. To supply high-pressure air, liquid air is injected under high pressure at the discharge, evaporated, and heated. The basic work performance and quality of the system improves as the air temperature rises, making it like other energy storage systems. We can also raise the temperature by using combustion. The air or gas from a liquefied container can be expanded in generators to generate electricity. Any suggestions for reducing liquefaction waste and external energy requirements for liquefied air regasification have been made.

Hydro Pumped energy storage

Pumped hydro energy storage stores hydraulic potential energy by transferring water from a water body through a conduit to a higher water reservoir at a low level using an electric pump (Fig. 4).

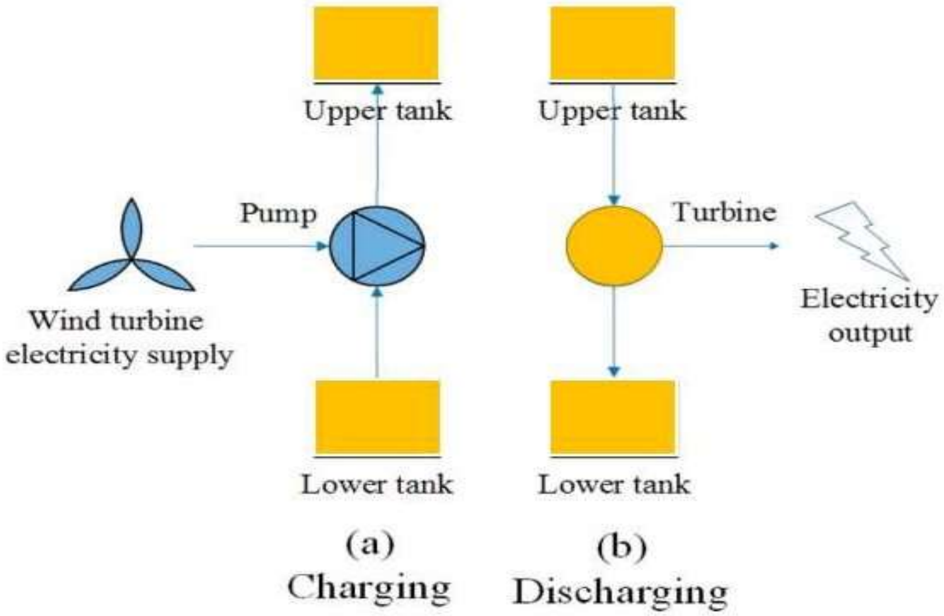


Fig. 4. Hydro storage with the pumping energy, provided by wind turbines as seen in (a) off-peak hours, (b) peak hours.

The energy can be released by allowing the water to flow from a high to a low height into the turbine. The turbine is coupled to a generator that can generate power as energy is discharged from the turbine. To allow for variable power output, the incoming flow of water to the turbine can be adjusted using gates. When charging, variable-speed drives can also be employed to get power. Pumped hydro energy storage systems must meet a few conditions, including the availability of elevation gap sites and access to water. If the prerequisites are met, it is an appropriate solution for both renewable energy storage and the grid. [15] The efficiency of these systems ranges from 70 to 80 %, and they are commonly scaled at (1000-1500 MW) . Long asset life, i.e., 50 to 100 years, and low operating and maintenance expenses are also features of these systems.

The functional height difference between reservoirs and environmental ones, as well as large unit sizes, high maintenance costs, and topographical limits, are some of the scheme's downsides. Work on techniques and tools like is needed to assess locations and proposed timelines for the construction of new PHES, as well as to review patterns in development in depth. Also examine existing and potential PHES facilities, as well as the technological and economic aspects that influence them. With restricted capacity, PHES systems will vary the design pumping capacity from 60% to 100% and the generation capacity from 20% to 100% . Vasil-Be-Hagh et al. introduce a new form that does not require large water tank towers or long pipelines and can operate at a wide range of capacities depending on electrical surpluses. The design allows for steady pressure and speedier discharge, allowing for quick response to demand changes.

Storing magnetic energy

It is superconducting with a big coil, has no electrical resistance at near zero temperature, and can store electrical energy in liquid helium or nitrogen vessels.

The temperature of the superconducting coil is kept at a cryogenic level. Although energy losses in the coil are nearly insignificant due to superconductors' low resistance to electron flow, the cryogenic temperature preserving cooling system is associated with certain energy losses. SMES coils can quickly discharge large amounts of electricity and can perform an endless number of high efficiency (70 to 75%) charging and discharge cycles[16]. Some of the major characteristics in the SMES design that determine storage performance are coil configuration, energy capability, composition, and operating temperature. They propose that the cost of SMES technologies be divided into two categories: the cost of energy storage capacity (i.e., the cost of conductors, coil structure components, cryogenic vessels, refrigeration, protection, and control equipment) and the cost of energy storage capacity (i.e. the cost of conductors, coil structure components, refrigeration, protection, and control equipment).

In contrast to other research conducted through computer simulation or in laboratories, emphasizes the necessity of creating practical applications of SMES for power systems. They also advise that effective control strategies be developed to integrate tiny ratings of SMES systems at various places to increase their power capacity.

Energy storage Applications

The significance of creating realistic SMES applications for the power sector Energy storage is a key enabler for a variety of applications. This section focuses on various energy storage applications, such as utilities, renewable energy, buildings and communities, and transportation. Table 2 lists some of the characteristics of energy storage systems that are now in use or being developed, as well as some of the attributes of such storage systems[17].

Utilities

The significance of creating realistic SMES applications for the power sector the usage of energy storage technology in power networks has become increasingly critical and a priority as more storage alternatives become accessible. Renewable energy penetration can be increased by combining renewable energy systems with energy storage technology. While grid management and maintenance stability are provided, total system efficiency improves. Implementations of any of the energy storage technologies include

- Congestion reduction in the transmission system,
- Energy storage during times of low demand for use during high demand period,
- Under standard operating ranges, maintaining voltage and frequency,
- Compensating for unforeseen situations, such as a generating unit breakdown,
- A real-time equilibrium between generation and load is maintained.

Renewable energy utilization

The significance of creating realistic SMES applications for the power sector • The use of renewable energy is fast rising, helping to meet global demand for electricity while reducing environmental impacts, particularly those related to the electrical industry. Storage permits excess energy created by renewable energy sources to be stored and dispatched later when needed, resulting in a higher penetration of renewable energy generation. As a result of the inconstancy of clean energy sources, space is likewise spread.

Buildings, and communities

The significance of creating realistic SMES applications for the power sector • Because energy storage is a typical approach for buildings and communities, there is a lot of literature on storage categories and materials, as well as new advancements, thermal storage standards and performance, restrictions, and possibilities.

The significance of establishing realistic SMES applications for power enhancements. Buildings and neighborhood's may benefit from long-term and short-term storage. Thermal energy storage, for example, can move electrical loads from peak to off-peak hours, making it a powerful tool in demand-side control programmes. This system is a relatively mature energy storage process, and research and development are ongoing to address technical issues such as sub-cooling, segregation, and material compliance, PCMs used to improve the thermal ability of storage when working at a constant temperature, underground thermal energy storage, and storage tanks to develop more effective and cost-effective TES facilities in buildings, such as building thermal mass consumption.

Transportation

The significance of developing SMES-based power applications •

Batteries are the most common kind of energy storage in electric cars. Electrochemical capacitors, which offer a better power density than batteries, can be used in electric and fuel cell vehicles. In these applications, the electrochemical capacitor may store regenerative braking energy and functions as a high-power, short-term energy storage. For a long time, flywheels have been employed in public transit systems. Hybrid solutions combining flywheels and batteries, where flywheels can cope well with fluctuating power demand due to their high-power densities and batteries are the primary source of propulsion energy due to their high energy densities [18], can also be appealing options for improving energy storage energy density. As a result, for a global research effort focused on the development of physical and chemical hydrogen storage methods, new materials with increased efficiency, or novel approaches to hydrogen storage,

Comparisons and categorizations of energy storages

Many types of energy storage are defined and/or contrasted from technological and economic viewpoints in this section, rather than their categories and values. Similar research and comparisons have been published in the past and have been judged to be significant. The analysis in this section will be included in a revised comparison.

Economics point comparisons

There are multiple economic benefits and obstacles associated with the usage of energy storage technologies for various purposes. An energy storage facility's cost is also determined by the programme. Furthermore, the cost of an energy storage device for a particular application varies by geography, building method, and size, and the cost-effectiveness is determined by the price of the energy supply, such as natural gas. Economic studies, in comparison to a wide range of energy technologies, have a degree of uncertainty that must be considered. Nonetheless, Table

4 shows the approximate cost of capital for various energy storage technologies. It should be noted that the expenses shown below are collected from publications from various years.

In a few articles, the possible costs of energy storage systems were examined to determine the viability of a specific system in the future, as well as the necessary expenditures to become competitive. Due to a paucity of information on technology developments, future breakthroughs, knowledge spillovers, and changes in commodity pricing, such analyses are ambiguous

Conclusions and future directions

A summary and critical examination of the existing energy storage systems is provided. Storage classifications, comparisons, implementations, current trends, and research avenues are all explored. Batteries are expected to be the most cost-effective energy storage option for applications with a relatively modest number of cycles. While pricing and the manufacture of electrolytes remain issues, batteries appear to be the best option for large-scale electrical energy storage (e.g., energy from renewable energy sources). Other types of electrical energy storage, such as flywheel energy storage, which is utilized for very short storage times and daily use, and magnetic energy storage, have received less attention. The major criteria for flywheels are reductions in electronic, electrical, and power-conversion losses. Hydro and compressed air pumped energy storage systems are modern, cost-effective, and reliable technologies that are employed on a regular basis.

Adsorption technologies are currently not commercially viable for storing thermal energy. Hydrogen energy storage systems are one of the many forms of energy storage systems that can help to improve the current energy structure significantly. Many scientific, economic, social, and political barriers must be overcome before hydrogen technology may be deployed in large-scale installations. If more renewable energy solutions are integrated with energy storage systems, the use of hydrogen and electricity as energy carriers is projected to rise in the future.

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