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Short Communication

The role of hydrogen and fuel cells to store renewable energy in the future energy network – potentials and challenges

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HIGHLIGHTS

- Energy storage technologies provide the balance in modern energy networks.
- Storing renewable energy in the form of hydrogen via the electrolysis process is concluded to be the most promising option.
- Hydrogen energy provides high energy density, low capital cost and easy integration with the existing energy network.
- Hydrogen and fuel cell contribute to a more sustainable future.

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ABSTRACT

The penetration of renewable energy sources is expected to rapidly increase from 15% to 50% in 2050 due to their vital contribution to the global energy requirements, sustainability and quality of life in economical, environmental and health aspects. This huge rise highlights the necessity of development of energy storage systems, especially for intermittency renewable energies such as solar photovoltaic and wind turbine, in order to balance the energy network. In this study, renewable energy options including pumped hydro, pressurized air, flywheels, Li ion batteries, hydrogen and super-capacitors are compared based on a specific set of criteria. The criteria considered are energy/power density, ease of integration with the existing energy network, cost effectiveness, durability, efficiency and safety. Our study showed that storing renewable energy sources in the form of hydrogen through the electrolysis process is ranked as the most promising option considering the mentioned criteria. It brings about several benefits suggesting that hydrogen and fuel cells are promising contributors towards a more sustainable future, both in energy demand and environmental sustainability.

1. Introduction

Providing safe, environmentally friendly, and reliable energy supplies is essential for having a sustainable and high quality life, but they are subjected to social, political, environmental and economical challenges. It is generally agreed that no single energy source will dominate the energy market and hence energy-mix model is the way to go, depending on the availability of usable resources in each region/country or the options of importing these resources. The future energy network would include a combination of different technologies (Whitesides and Crabtree, 2007). To generate sufficient energy or power for surging energy demand, not only the technologies but also their potential social, political, environmental and economical impacts must be taken into account carefully. Improving energy efficiency and increasing the contribution of carbon-free fuels in energy supply will be effective in developing an efficient and a more sustainable future. To achieve this objective, fundamental understanding on different aspects of these technologies should not be neglected (Gao et al., 2013; Tozzini and Pellegrini, 2013; Whitesides and Crabtree, 2007; Zhang et al., 2013).

Renewable energy resources are playing and will play a vital role in meeting current and future energy needs. They are also a key component in the sustainable development. The origin of renewable energies is associated with the energy from the sun. They are more environmentally friendly compared to the conventional fossil energy sources and will not be depleted within the foreseeable future. Above all, they make the decentralization of electricity networks a possibility. Therefore, they improve the flexibility of the energy system and provide economical advantages for off-the-grid applications due to the nature of distributed generation. However, existing issues including high cost, intermittency of energy supply, grid connection and storage challenges (Aghaei and Alizadeh, 2013; Devabhaktuni et al., 2013; Gahleitner, 2013; Jebaselvi and Paramasivam, 2013; Tan et al., 2013) should be

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addressed before the penetration of renewable energy in the energy market would be significant.

Small output renewable energy sources could easily be balanced within the energy network, but the large incrementing percentage of global renewable power highlights a substantial need for energy storage. The prediction of market penetration of renewable energy resources is controversial as different organizations might predict the growth according to their interests. For instance, an oil company would downplay the growth; a renewable energy instrumentation company would project the biggest renewable energy penetration, while a conservative organization would predict some moderate penetration. Fig. 1 presents the range of projections made by the three groups representing three different types of companies mentioned.

Fig. 2 presents the REN21 report on the electricity shares from renewable energy sources by different countries. The presented scenarios are modeled assuming different political choices, and therefore they are very diverse. For example, the Greenpeace scenario assumes a huge development for the deployment of renewable sources. Taking a close look at the diverse range of projections, the REN21 report comes to the conclusion that a 40–50% electricity share is likely to be achieved by 2030 if national policies remain the same as now. In addition, it should be noted that connecting the renewable electricity generated to the grid directly causes serious grid instability. To manage the energy in an effective way, a strategy is required to balance the power demand.

2. Material and methods

The energy produced from any source should be converted and stored for off-the-grid applications such as automotive, air

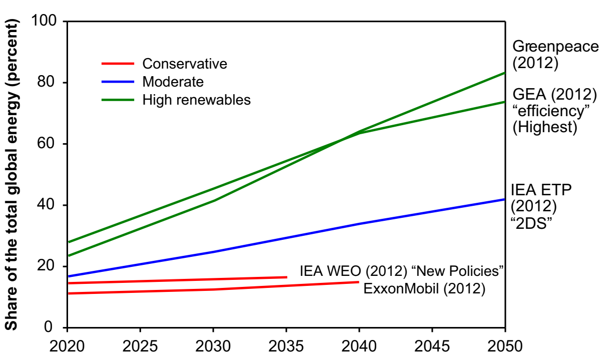

Fig. 1. Moderate, conservative and high-renewable energy sources scenarios to 2050. (REN21 Renewables Global Futures Report (GFR)).

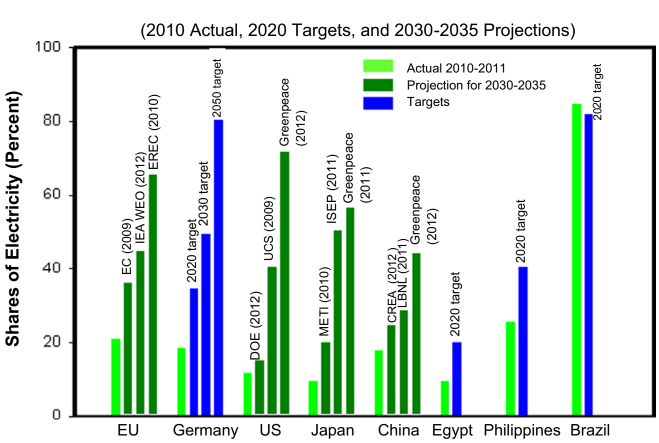

Fig. 2. National and EU electricity shares from renewables, 2010–2030 (REN21 Renewables Global Futures Report (GFR)).

Table 1
General comparison of different energy storage technologies (Ferreira et al., 2013).

Technology	Capital cost ($/kWh)	Durability (Year)	Power density ($W\,kg^{-1}$)	Gravimetric energy density ($Wh\,kg^{-1}$)	Efficiency (%)
Li ion battery	600–2500	5–20	100–5000	75–250	85–90
Super-capacitor	300–2000	20+	500–5000	0.05–30	97
Pumped-hydro	5–100	40–100	–	0.5–1.5	70–87
Hydrogen	2–20	30	–	400–1000	–
Flywheel	1000–5000	15–20	400–1600	5–130	80–99
Pressurized air	2–50	20–100	–	30–60	40–80

transportation and ships propulsion. To select the most practical method of energy storage for a certain energy consumer system, the available options and their advantages and disadvantages must be taken into consideration. The options of energy storage include batteries, capacitors, pressurized air, pumped hydropower, flywheels, and hydrogen are among the most popular available options to be considered as energy storage systems (Chatzivasileiadi et al., 2013; Ferreira et al., 2013; Hall and Bain, 2008).

A suitable energy storage system should have a number of properties: (a) High gravimetric and volumetric energy and power densities; (b) easy deployment and integration with the renewable energy sources and the existing energy network; (c) high efficiency; (d) economical viability in storing large amount of energy; (e) extended lifespan and reliability of the systems and components; and (f) safe in operation (Chatzivasileiadi et al., 2013; Ferreira et al., 2013). To provide comprehensive guidelines for selecting the most reasonable option for transportation applications, the energy storage options are discussed based on the above-mentioned criteria. Table 1 presents a general comparison of different technology options. In this study, energy storage options including pumped hydro, pressurized air, flywheels, Li ion batteries, hydrogen and super-capacitors are compared based on a specific set of criteria. A brief description of the energy storage options is presented in Table 2.

3. Results and discussion

Fig. 3 presents the comparison of the volumetric versus gravimetric energy density of a group of materials and technologies (Dial, 2008). It can be seen that hydrogen has an extremely high gravimetric energy density compared to other materials and technologies. Application of pressurized hydrogen tanks and hydrogen in chemical hydride such as lithium borohydride and carbon-hydrides might address the issue of low volumetric energy density of hydrogen.

Fig. 4 shows the comparison of power density versus energy density of the energy storage options. As presented in Fig. 4, none of the available options possess both high energy density and power density required for transportation and other industrial applications. Therefore, there is a significant need for fundamental research to develop new materials and devices which possess both high energy and power densities.

Integration of the energy storage with the renewable energy source and the existing energy network is very important since it would affect the performance and the reliability of the system (Jiang et al., 2013; Neuhoff et al., 2013; Samaniego et al., 2008). The components used and the matching strategies to effectively connect these components influence the energy efficiency and service life of the system. In addition, determining the optimum size of the components is