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# Prospects of applying ionic liquids and deep eutectic solvents for renewable energy storage by means of redox flow batteries

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ABSTRACT

Ionic liquids (ILs) and deep eutectic solvents (DESs) have been applied in various fields such as electrolytes for lithium ion batteries, electrodeposition, electropolishing and even in fuel cells. ILs and molten salts have found some applications in redox flow batteries (RFBs) in the past and recently some metal ion based ILs have been proposed and used by Sandia National Laboratories. In addition, only two papers have very recently reported on the application of DESs for the same. This review gives an overview on DESs and discusses the possibility of employing them in RFBs for renewable energy storage and utility-scale load leveling applications. Commencing with a discussion on energy storage technologies and the RFB, this paper goes on to provide an account on ILs and DESs as well as their applications in electrochemistry and energy conversion. A succinct discussion on the results of Sandia National Laboratories on using ILs as electrolytes for RFBs is provided building onto the feasibility of replacing ILs with DESs in the near future (based upon recent publications on the topic).


**Contents**



## 1. Introduction

Efficient renewable energy storage needs to accumulate energy during times when demand is low (peak shaving) and to supply it

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when demand is high in order to ensure efficient energy handling (load leveling) [1]. A number of technologies based on electrical, chemical, electrochemical and mechanical processes have been proposed to address the energy storage needs of electrical grids [1–6]. Electrochemical storage systems are found to be robust due to their relative ease of siting as well as fast response times [1].

Electrochemical energy storage systems provide direct conversion between chemical and electrical energy and are therefore particularly suited to the storage of the latter [1]. Electrochemical storage technologies also offer additional advantages compared with other types of energy storage systems, including [7]:

- Modularity whereby they can be used in applications ranging from a few kWh to several MWh.
- Simultaneous application for both power quality and energy management.
- Low environmental impact, which means they can be sited near residential areas.

Redox flow batteries (RFBs) are rechargeable electrochemical systems that rely on the redox states of various soluble species for the purposes of storing and releasing energy via highly efficient charge/discharge processes [8–10]. The redox flow cell concept can be traced back to the zinc/chlorine system that was developed in 1884 by Charles Renard and Arthur Krebs to power their army airship "La France" (a historical timeline for the development of RFBs is shown in Fig. 1) [11,12]. The concept was then re-visited by Posner in the mid-1950s [12] prior to an independent investigation that was conducted in Japan around 1968 [2,13]. The modern iron/chromium RFB was invented by Lawrence Thaller at the National Aeronautics and Space Administration (NASA) in the USA [13–15]. Since then, the technology has been developed significantly leading to many small to medium-scale field tests and demonstrations in the last two decades [16]. As fully soluble redox couples and inert electrodes are used (Fig. 2) [1,7,9,13,17], undesirable electrode processes are eliminated (especially structural changes of the electrode) in comparison to secondary battery systems [1,18]. The system energy storage capacity is determined by the concentrations of the reactants and the size of the storage tanks, while the system power is determined by the number of individual cells within a battery stack and their electrode area [19]. As a result it is possible to independently optimize the flow cell's storage capacity and power output [1]. This feature makes RFBs unique in their ability to provide the specific power and energy requirement for each application. Storage capacity can be increased by adding more electrolytes, so the incremental cost of each additional energy storage capacity unit is lower than that of other types of batteries [7]. The cost per kWh of the system therefore decreases substantially with increasing storage capacity, making the RFB particularly attractive for applications requiring storage times in excess of 4–6 h [1].

One of the key factors limiting the widespread commercialization of RFBs appears to be their low energy density. One means of overcoming this drawback has been the employment of non-aqueous electrolyte solvents that can offer a wide potential window of operation and increase the energy capacity of the system [20–25]. Nonetheless, the organic systems used so far have limited availability (thereby affecting their cost) and are also not environmentally friendly [1,22]. Therefore a new class of non-aqueous electrolytes has been considered for energy storage applications and is popularly known as ionic liquids (ILs) [26–30]. This also has limitations due to its high cost and its electrochemistry can be severely affected in the presence of water [31]. This can be avoided if deep eutectic solvents (DES) are employed in the place of ILs [32].

The aim of this paper is to stimulate interest within the scientific community to explore the application of ILs and DESs in various RFB configurations. Recently, Sandia National Laboratories [4] and Tianjin

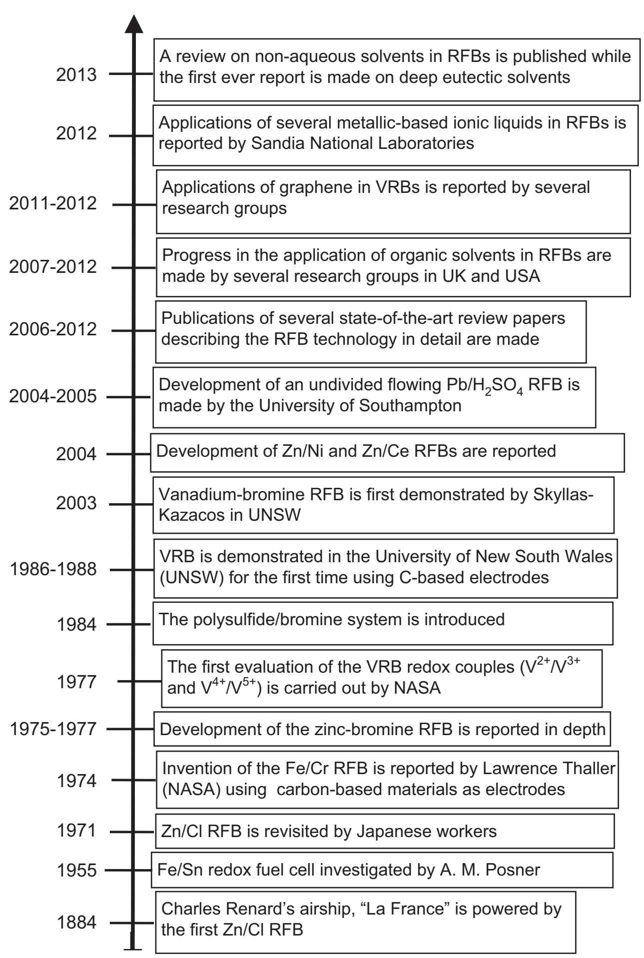


**Fig. 1.** Timeline for the development of RFBs.
Adapted from Walsh and co-workers [7].

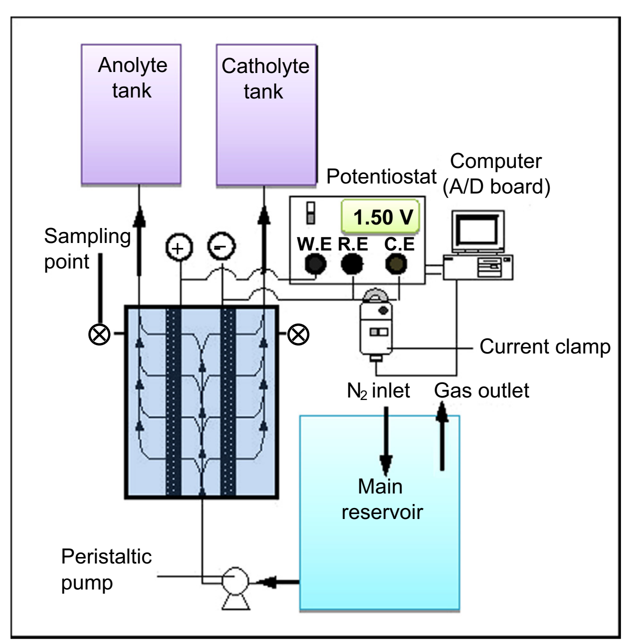


**Fig. 2.** Schematic diagram of a redox flow battery reactor.
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