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Future cost and performance of water electrolysis: An expert elicitation study

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ABSTRACT

The need for energy storage to balance intermittent and inflexible electricity supply with demand is driving interest in conversion of renewable electricity via electrolysis into a storable gas. But, high capital cost and uncertainty regarding future cost and performance improvements are barriers to investment in water electrolysis. Expert elicitations can support decision-making when data are sparse and their future development uncertain. Therefore, this study presents expert views on future capital cost, lifetime and efficiency for three electrolysis technologies: alkaline (AEC), proton exchange membrane (PEMEC) and solid oxide electrolysis cell (SOEC). Experts estimate that increased R&D funding can reduce capital costs by 0–24%, while production scale-up alone has an impact of 17–30%. System lifetimes may converge at around 60,000–90,000 h and efficiency improvements will be negligible. In addition to innovations on the cell-level, experts highlight improved production methods to automate manufacturing and produce higher quality components. Research into SOECs with lower electrode polarisation resistance or zero-gap AECs could undermine the projected dominance of PEMEC systems. This study thereby reduces barriers to investment in water electrolysis and shows how expert elicitations can help guide near-term investment, policy and research efforts to support the development of electrolysis for low-carbon energy systems.

Introduction

Energy storage could play a pivotal role in future low-carbon energy systems, balancing inflexible or intermittent supply with demand. Storage of renewable energy in chemical bonds, in particular hydrogen, is attractive due to high energy density, elemental abundance, long-term storability, potentially low costs and the ability to transfer renewable electricity into other energy sectors [1–6]. Recent years have seen rising interest in this idea of converting intermittent renewable electricity via electrolysis into a storable gas, also termed *Power-to-Gas* [7–10]. The concept was first formulated as *Renewable Power Methane* in a patent filed in 2009 [11] and is

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regarded as the most cost-efficient solution for inter-seasonal energy storage [12]. It also allows linking electricity and gas networks and diffusing renewable energy to the heat and transport sector, and the chemical industry [13–15]. Water electrolysis is the key enabling technology. However, significant barriers to commercialisation remain; notably high capital costs of electrolysers and uncertainty about their future development [16,17].

Expert elicitations use structured discussions with experts to obtain estimates for uncertain parameters. They are a valuable tool to support investment and policy decision-making in conditions of uncertainty and limited data availability [18,19]. Accordingly, both the US National Research Council and the 2010 Inter Academy Council review of the IPCC climate change assessment recommend the use of expert elicitations to inform funding decisions in the energy field [20,21]. As a result, this method has been used to investigate the impact of research, development and deployment (RD&D) funding on cost reductions for low-carbon generation technologies [22–28] and electric vehicle batteries [29,30]. These studies also compare the impact of additional funding between technologies [23,24,30] or funding type [28], and identify the underlying technical innovations [22,28] or possible deployment scenarios [25,26].

This article explores cost and performance improvement potentials for water electrolysis through expert elicitations and therefore adds to this growing body of research in two dimensions: at the content level, a stationary energy storage technology is investigated; at the methodology level, cost as well as performance parameters are analysed, under extreme research and development (R&D) funding scenarios, while separating the impact of R&D funding alone and R&D funding combined with production scale-up.

The following section describes the three electrolysis technologies considered. Section Elicitation process then outlines the elicitation process and Section Results and Discussion presents and discusses the results. Section Conclusion concludes.

Water electrolysis

Three water electrolysis technologies are investigated: Alkaline Electrolysis Cells (AEC), Proton Exchange Membrane Electrolysis Cells (PEMEC) and Solid Oxide Electrolysis Cells (SOEC). Fig. 1 depicts the technology set-up and Table 1 summarises component materials as well as performance and cost parameters.

AEC is the incumbent water electrolysis technology and widely used for large-scale industrial applications since 1920 [31]. AEC systems are readily available, durable and exhibit relatively low capital cost due to the avoidance of noble metals and relatively mature stack components [32–34]. However, low current density and operating pressure negatively impact system size and hydrogen production costs. Also, dynamic operation (frequent start-ups and varying power input) is limited and can negatively affect system efficiency and gas purity [33]. Therefore, development is focussed on increasing current density and operating pressure, as well as system design for dynamic operation [32,34], to allow operation with intermittent renewable sources, for example. Previous analyses suggest that future cost reductions are most likely driven by economies of scale [9,16,33].

PEMEC systems are based on the solid polymer electrolyte (SPE) concept for water electrolysis that was first introduced in the 1960s by General Electric to overcome the drawbacks of AECs [31]. The technology is therefore less mature than AEC and mostly used for small-scale applications [33]. Key advantages are high power density and cell efficiency, provision of highly compressed and pure hydrogen, and flexible operation [33–35]. Disadvantages include expensive platinum catalyst and fluorinated membrane materials, high system complexity due to high pressure operation and water purity requirements, and shorter lifetime than AEC at present. Current development efforts are therefore targeted at reducing system complexity to enable system scale-up and reducing capital costs through less expensive materials and more sophisticated stack manufacturing processes [9,33,34].

SOEC is the least developed electrolysis technology. It is not yet widely commercialised, but systems have been developed and demonstrated on laboratory scale [31] and individual companies are currently aiming to bring this technology to market [36]. SOECs use solid ion-conducting ceramics as the electrolyte, enabling operation at significantly higher temperatures. Potential advantages include high electrical efficiency, low material cost and the options to operate in reverse mode as a fuel cell or in co-electrolysis mode producing syngas (CO + H_2) from water steam (H_2O)

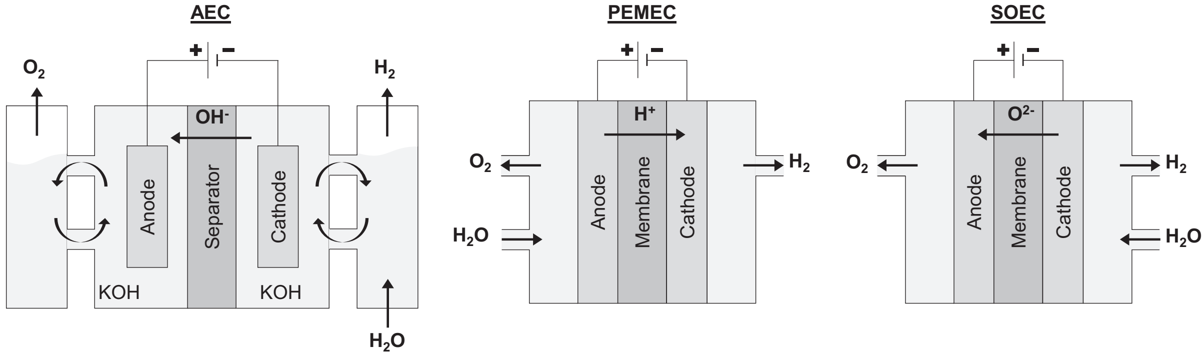

Fig. 1 – Conceptual set-up of three electrolysis cell technologies [9].