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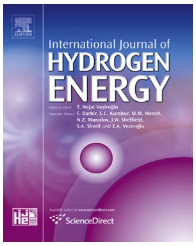

Life cycle assessment of the manufacture and operation of solid oxide electrolyser components and stacks

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ABSTRACT

Solid oxide electrolysis cells (SOEC) can be used for high-temperature electrolysis to efficiently transform electrical energy into hydrogen. To evaluate the environmental impacts of manufacturing 1 kW stack consisting of SOEC and interconnects, we performed a life cycle assessment for an early development stage of the SOEC. Cells differed in air electrode materials. Cell and interconnect production is generally responsible for most of the impacts on the environment and human health, while differences between stacks due to differing air electrode materials are low. Reducing interconnect material use was identified as most promising improvement potential regarding manufacturing. If the electrolysis process is included, most impacts per MJ hydrogen produced come from the electrolysis itself (>80%). Reducing degradation rate and increasing current density and lifetime could e.g. reduce climate change impacts by up to 20%. From an environmental perspective, emphasis should be on reducing degradation and expanding cell lifetime.

Introduction

Use of renewable electricity sources like wind and solar power has been promoted to reduce carbon intensity of electricity generation. However, they are less reliable than electricity from fossil sources due to their intermittent nature. One of the challenges of the integration of renewable energies into an existing energy system is the storage of electricity: lows in wind and solar power availability must be compensated for and electricity production during highs should not be wasted. A promising medium for this storage is hydrogen. Solid oxide electrolysis cells (SOEC) can convert electricity into hydrogen via high-temperature electrolysis (HTE) [1]. SOEC share design and materials with solid oxide fuel cells which means that SOEC can be reversely run as fuel cells to produce electricity [2,3]. A study by Petipas et al. [4] showed that SOEC can be operated at transient conditions without increasing degradation rate, which would make it suitable for integration into renewable energy systems.

HTE is generally operated at ~800 °C. The dissociation of steam into hydrogen and oxygen needs less energy than electrolysis of liquid water, usually operated at ambient temperature [5]. However, high temperatures can accelerate material degradation in components and lead to lower efficiency. The resulting decrease of hydrogen production over lifetime makes

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a use unprofitable at that stage. To achieve commercialization of HTE in the future, the main research challenge lies in the extension of lifetime of cells and on the optimisation of performances, i.e. hydrogen production rate over the entire lifetime [5,6]. The air electrode substantially affects cell polarization resistance and the higher the resistance, the lower the cell performance. The improvement of air electrode material could therefore add significantly to an increase in cell efficiency [1]. Developing and testing cells with new air electrode materials was one of the main objectives of the publicly funded FidelHyo project [7], the framework of this study.

To assess the environmental performance of a technology or product, its whole life cycle should be taken into account to prevent shifting of environmental or health burdens to other locations or periods in time. For example, Caduff et al. [8] showed that although there are no CO_2 emissions from wind electricity during generation, emissions from production of the windmills are non-negligible. Additionally, technologies that cause fewer greenhouse gases than equivalent counterparts could show a larger toxicity to humans or the environment [9]. Life cycle assessment (LCA) can identify environmental hotspots in a technology's life cycle and thereby aid guiding further technological optimisation. It is important to systematically take into account environmental aspects as early as possible in the technology development, i.e. already in the laboratory stage (e.g. Refs. [10,11]).

Several LCAs have been published dealing with fuel cell systems, their stationary or mobile application and also with electrolysers using solid oxide cells [12–16]. Karakoussis et al. [12] showed that production and supply of materials for fuel cell manufacturing account for a significant share of the emissions of air pollutants like NO_x, particulates and CO_2. They did not, however, use these emissions to calculate a life cycle impacts assessment. Furthermore, they highlight the importance of recycling and material recovery at the end-of-life. Patyk et al. [15] showed that the largest environmental impacts of hydrogen production using SOEC resulted from electricity demand during HTE, while Giraldi et al. [16] found that manufacturing of the cells had a similar climate change impact as energy needed during the HTE process. So far, an early-stage assessment of innovative cell materials based on measured laboratory data and covering aspects of cell lifetime and degradation is currently not available and thus this study focused on comparison of innovative cell materials and addressed these issues in more detail to guide current and future development of HTE cells.

This study complements SOEC and HTE research by providing valuable insights into the importance of cell degradation and lifetime on environmental impacts of SOEC manufacturing and electrolysis. The objective was to assess and compare the environmental performance of SOEC stack production in the laboratory for cells with different air electrode material. The assessment focused on environmental performances of stacks, which differ in their cell air electrode material: lanthanum strontium cobalt ferrite (LSCF), lanthanum strontium cobalt oxide (LSCo) and praseodymium nickel (PrNi). LSCF is conventionally used in SOECs and SOFCs [17]. The LSCo and PrNi air electrodes were used within FidelHyo's project to improve degradation stability, performance and overall efficiency. Additional scenarios were defined to estimate environmental impacts of the hydrogen production phase. The electrolysis stage was modelled as scenarios with two different durations and estimated current density and degradation rate. This analysis provides insight into how these parameters influence environmental impacts.

Methods

Stack composition

A stack consisted of five cells, two interconnects (IC, 3 kg each) at the outside and four internal interconnects (145 g each) between the cells. At the H_2 electrode side, a nickel mesh was put between cell and IC to ensure good electrical contact. A glass sealant was used to make the cells gastight. Fig. 1 provides a scheme of cell and stack structure.

The air electrodes of the LSCo and PrNi cells were made of $La_{0.6}Sr_{0.4}CoO_{3-\delta}$ and $Pr_{1.97}NiO_{4+\delta}$, respectively. The LSCF cell had an air electrode of $La_{0.6}Sr_{0.4}Co_{0.8}Fe_{0.3}O_{3-\delta}$. For all cells, the same materials were used for the blocking layer (yttria-doped ceria ($(CeO_2)_{0.8}(YO_{1.5})_{0.2}$; YDC)), the electrolyte (yttria-stabilized zirconium; YSZ) and H_2 electrode (YSZ-NiO). The interconnect sheets were made of chromium-alloyed steel. All interconnects had a thin cover of lanthanum strontium manganese ($La_{0.8}Sr_{0.2}MnO_{3-\delta}$; LSM) at the air electrode side. The production of the balance of plant components such as pipes, casing, heat exchangers, etc. is not included in the LCA, since the laboratory equipment used for this study was also used in other experiments and the relative contribution of these components to overall impacts could not be identified. The stack analysed here had a nominal capacity of 0.32 kW: For the purpose of comparability, results are given on a 1 kW basis.

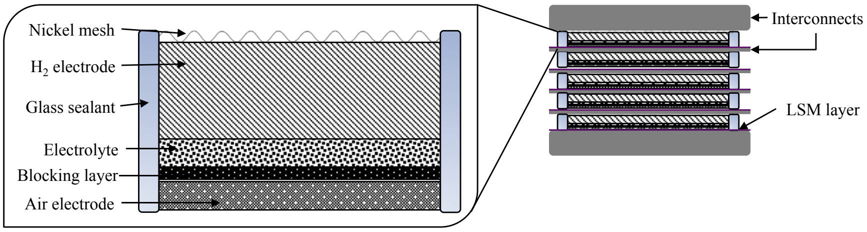

Fig. 1 – Schematic representation of SOEC and stack structure. LSM: lanthanum strontium manganese.