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Life cycle assessment of gas atomised sponge nickel for use in alkaline hydrogen fuel cell applications

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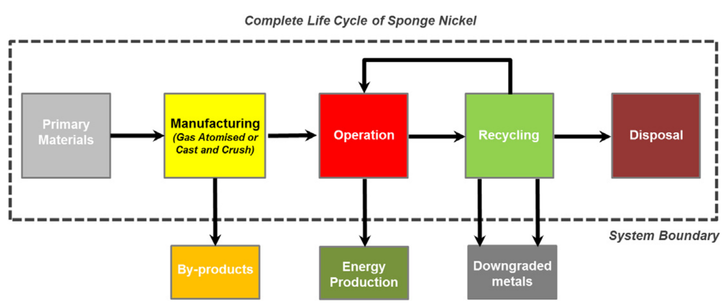
HIGHLIGHTS

- Emissions during catalyst use greatly outweigh those of manufacture and recycling.
- Gas Atomised spongy nickel catalysts can have a markedly lower environmental impact.
- Doped Gas Atomised sponge nickel shows behaviour similar to a normal AFC Pt electrode.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents a cradle-to-grave comparative Life Cycle Assessment (LCA) of new gas atomised (GA) sponge nickel catalysts and evaluates their performance against the both cast and crush (CC) sponge nickel and platinum standards currently used in commercial alkaline fuel cells (AFC). The LCA takes into account the energy used and emissions throughout the entire life cycle of sponge nickel catalysts – ranging from the upstream production of materials (mainly aluminium and nickel), to the manufacturing, to the operation and finally to the recycling and disposal. Through this assessment it was found that the energy and emissions during the operational phase associated with a given catalyst considerably outweigh the primary production, manufacturing and recycling. Primary production of the nickel (and to a lesser extent dopant materials) also has a significant environmental impact but this is offset by operational energy savings over the electrode's estimated lifetime and end of life recyclability.

List of abbreviations: AD, abiotic depletion; AFC, alkaline fuel cell; AP, Acidification Potential (kg SO_2 eq.); APU, auxiliary power units; CC, cast and crush; CHP, combined heat and power system; CML 2001, Institute of Environmental Sciences, Lieden; EDIP97, Environmental Design of Industrial Products; GA, gas atomisation; GABI, Software by PE international for lifecycle assessment; GER, Gross Energy Requirement (MJ); GHG, green house gas; GWP, Global Warming Potential (kg CO_2 eq.); LCA, life cycle assessment; PEM, polymer electrolyte membrane; PSD, powder size distribution; SOFC, Solid Oxide Fuel Cell.

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Alkaline fuel cell (AFC)
Cast and crush (CC)
Life cycle assessment (LCA)

From the results it can be concluded that higher activity spongy nickel catalysts produced by gas atomisation could have a significantly lower environmental impact than either CC nickel or platinum. Doped GA sponge nickel in particular showed comparable performance to that of the standard platinum electrode used in AFCs.

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1. Introduction

Over the past twenty years fuel cell technologies have come to be regarded as one of the most promising alternative power sources due to their potential for high efficiency electricity generation and low environmental impact [1–4]. However, more recently with increasing legislation and enhanced environmental awareness efforts have been made to subject various fuel cell systems and applications to life cycle assessment (LCA). These assessments have embraced a wide range of aspects including the systematic development of the necessary tools for life cycle assessment of fuel cell powered vehicles as demonstrated by Contadini et al. [5] who combined the Fuel Upstream Energy and Emission Model (FUEEM) with academic/manufacturer literature and the work of Pehnt [6,7], which addressed both methodological and environmental aspects with regard to Solid Oxide Fuel Cells (SOFC). In addition, such investigations have also concerned themselves with the fundamental question of fuel sources for the next generation of automotive propulsion [8,9] including various biofuels [10] as part of this holistic approach towards the environmental impact of fuel cell technologies.

In contrast other researchers have focussed more on specific fuel cell types or applications including SOFC [11,12], polymer electrolyte membrane, (PEM) [13] microbial [14] and fuel-cell based auxiliary power units (APUs) [12]. Alkaline Fuel Cell (AFC) type fuel cells have themselves been the subject of a comprehensive LCA by Staffell and Ingram [15] who assessed the impact of including an AFC fuel cell as part of a domestic combined heat and power (CHP) system. Their results showed that production of the AFC stack is relatively insignificant when compared to the other components of the CHP system, but that the biggest environmental impact was from the sulphur dioxide (and other generated respiratory inorganics like particulates) from the mining/refining of nickel and silver for the electrodes. Overall, it was concluded that improvements to the nickel catalysts used – in terms of increased activity and longevity – and better design to ease of disassembly and recycling are key to improving environmental performance of AFC and fuel cells in general.

The use of Raney or Sponge nickel [16,17] has been investigated in a number of fuel cell applications including as a basis for the electrodes in both AFC [18–20] and SOFC [21] and low temperature AFCs are attracting renewed interest [22] due to the potential of low material costs coupled with high system efficiencies. One of the driving factors is an economic benefit based on the potential to replace platinum and palladium by nickel-based electrodes. This has related environmental benefits, due to the scarcity of the noble metals in the Earth's crust the energy requirements and emissions associated with their mining and concentration are orders of magnitude greater than those for nickel [23–25].

A major drawback to the use of Raney nickel in alkaline fuel cell assemblies is its pyrophoric nature [26], which can lead to spontaneous ignition in oxygen containing atmospheres and to allow their use as an electrode material the Raney nickel catalyst is commonly stored in distilled water where its pyrophoric nature is controlled. Nevertheless, in order to locate the catalyst onto the supporting electrode structure a passivation process is carried out that typically entails the use of hydrogen peroxide leaching resulting in a thin layer modification of the surface. This process creates thin oxide layers which trap entrained hydrogen in the surface pores. Once the catalyst is in place on the anode, the passivation step is reversed and the material is reactivated by heating the electrode in a hydrogen atmosphere [27].

Another disadvantage that has prevented the more widespread use of Raney sponge nickel in fuel cells applications has been the unsatisfactory performance, particularly at higher electrical currents, and stabilities far below the 4000 h which could typically be obtained from a platinum electrode [23]. However, as can be seen in Fig. 1, electrodes manufactured by a gas atomisation process demonstrate operational fuel cell voltages (OCV) that are comparable to that of a platinum electrode, for example, 440 mA cm^{-2} (Doped-Gas Atomised, Doped-GA) *cf.* 500 mA cm^{-2} (Pt) at a cell voltage of 750 mV. It is also worth noting that sponge nickel produced by gas atomisation but without doping also offers increased levels of activity when compared to the more traditional methods of manufacture: 310 mA cm^{-2} (Gas Atomised, GA) *cf.* 190 mA cm^{-2} (Cast and Crush, CC) also at 750 mV.

Approximately 2.5% of primary nickel metal (a majority of which is in the form of sponge nickel) is used for catalytic purposes, which in 2001 – according to Larsen and Tyle [28] – was equivalent to ~2144 tonnes in Europe. Traditionally sponge nickel has been produced by the Cast and Crush (CC) method, which involves the casting of a mixed nickel–aluminium ingot (normally 50:50 wt.%). This ingot is then subject to a crushing process that produces a 50–100 μm powder with the characteristic appearance shown in Fig. 2a.

An alternative method for the production of Ni–Al powder is to use the Gas Atomisation (GA) method. GA has a number of advantages when compared to the Cast and Crush (CC) method, in particular the ability to produce smooth and spherical particles with extremely fine metallurgical microstructures that are much more refined than those produced by CC (Fig. 2b) with diameters ranging from >5 μm to ~45 μm. The fine and spherical nature of the powder results from GA process where a high velocity gas flow is used to break up a stream of molten Ni–Al alloy emerging from a nozzle into

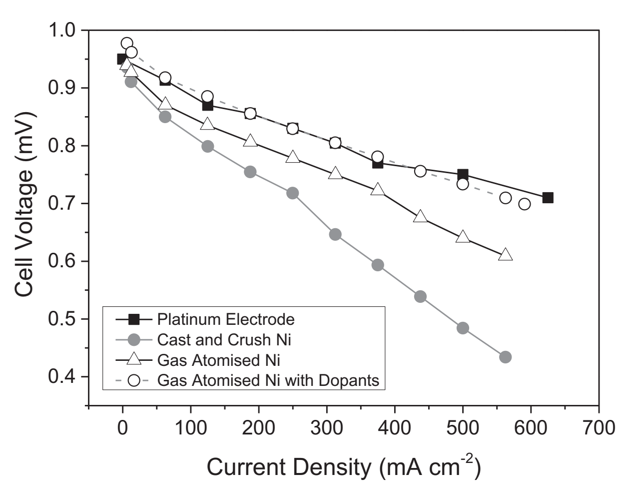

Fig. 1. Comparison of the Operation Fuel Cell Voltages (OCV) achievable for the different types of alkaline fuel cell (AFC) electrodes.

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