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Nanomaterials for solid oxide fuel cells: A review

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ABSTRACT

Nanotechnology is utilized well in the development and improvement of the performance in Solid Oxide Fuel Cells (SOFCs). The high operating temperature of SOFCs (700–900 °C) has resulted in serious demerits regarding their overall performance and durability. Therefore, the operating temperature has been reduced to an intermediate temperature range of approximately 400–700 °C which improved performance and, subsequently, commercialized SOFCs as portable power sources. However, at reduced temperature, challenges such as an increase in internal resistance of the fuel cell components arise. Although, this may not be as serious as problems encountered at high temperature, it still significantly affects the performance of SOFCs. This review paper addresses the work of researchers in the application of nanotechnology in fabricating SOFCs through distinct methods. These methods have successfully omitted or at least reduced the internal resistance and showed considerable improvement in power density of the SOFCs at reduced temperatures.

1. Introduction

Fuel cells have advantages over other systems because of their high electrical efficiency and fuel flexibility. The electrochemical reactions are efficient and occur through the supply of H_2 and O_2 (usually air). As a result, the electrochemical oxidation of H_2 fuel can be achieved with high performance. The most important factor influencing fuel cell performance is the material used as a catalyst. Catalysts speed up the reactions at both anode and cathode. There are several types of fuel cells. They are categorised depending on the nature of the electrolyte. Each type of fuel cell requires specific materials and fuels for different applications. Fuel cell types include: Proton Exchange Membrane Fuel Cells (PEMFCs), Direct Methanol Fuel Cells (DMFCs), Phosphoric Acid Fuel Cells (PAFCs), Alkaline Fuel Cells (AFCs), Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs). Nowadays, researchers focus on SOFCs. SOFCs have many advantages for a wide range of applications because of their electrical efficiency, potential to use natural gas, biogas or CH_4 as a fuel and high performance [1,2]. Many researchers mentioned that fuel cells are important for their modularity and distributed nature with lack of noise and pollution [1–4].

SOFC is an important type of fuel cell and it is consists of two porous components (anode and cathode) separated by a highly dense component (electrolyte, such as Yttria-Stabilised Zirconia (YSZ)) or Gadolium doped Ceria (GDC). Although many electrode materials for SOFCs have been developed over the past three decades,challenges of cost and limited durability still exists [5]. Therefore, great effort is being made to overcome these challenges through synthesis and design of new materials, at a nano-scale level, which may lead to improved SOFC performance in different applications at reduced temperatures. Furthermore, many attempts were made to develop electrode materials for SOFCs over the last 30 years. Some materials, especially Ni/YSZ, are favored as SOFC anodes because of their high electrochemical activity for H_2 oxidation and high stability under SOFC operating conditions. The use of $La_{0.75}Sr_{0.25}MnO_3$ (LSM) cathode material has been proven to have a high performance for application in SOFCs [2]. Current research on SOFC development has focused on temperatures below 1000 °C (usually 400–700 °C) with the aim of decreasing material cost and improving stability [1,4,6–8].

The consideration of fossil fuels (oil, coal, and natural gas) as a long term energy source is becoming difficult to justify. Specifically, carbon dioxide, nitrous oxides and green houses emissions are considered the major contributors to global warming. In addition to the rapid increases of the world population makes the need of energy an essential source.

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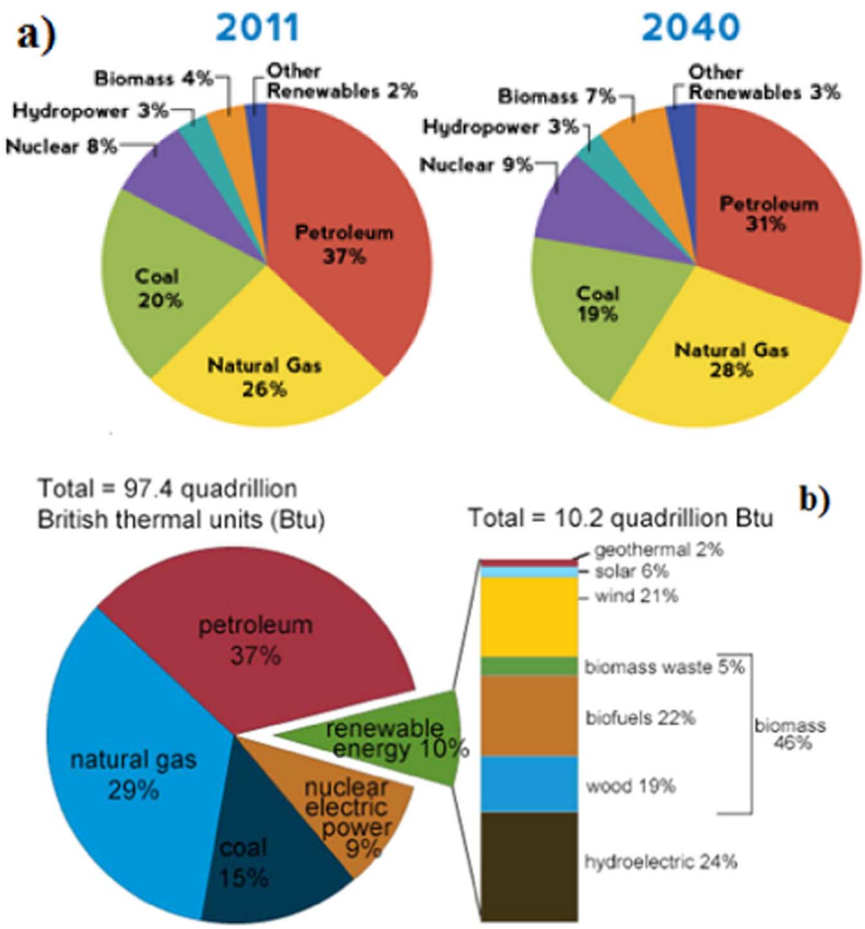

Fig. 1. Multiple sources of energy consumption in (a) Worldwide by 2040 and in (b) USA in 2017. Data are in units of Quads per year [1,12].

The estimation of energy powers almost two-thirds of our electricity and virtually all of our transportation [9–12]. Moreover, Moreover; these kinds of resources are not sustainable and will finish someday.

The total consumption of energy worldwide and in USA are shown in Fig. 1. For the total world consumption, the total amount of 600 Quads is dominated by oil (37%), with all fossil fuels accounting for83% of the total until 2011 and will be 78% by 2040 because of more usage of renewable energy resources. On the other hand, for the USA, the total of 97.4 Quads is dominated by oil and natural gasses, with fossil fuels accounting for 81% of the total by 2016. Basically renewable energy, mainly from wind, solar,biomass, geothermal and nuclear amounted in 2016 to only 17% of the total in the world and 19% in the USA. According to the past three decades, we can see that the world's annual consumption of renewable energy is rapidly increases and Fig. 2 below is showing the average rate of increase from 1990 to date and the expectations until 2040 [11,12].

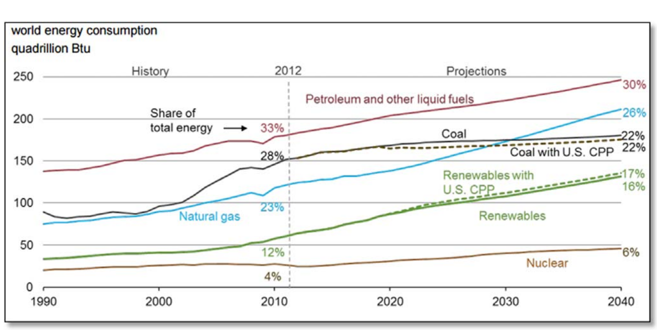

Fig. 2. Previous three decade's history trend to the world's annual consumption of total energy and the expected quads amounts by 2040 from various sources including fossil fuels and renewable energy [13].

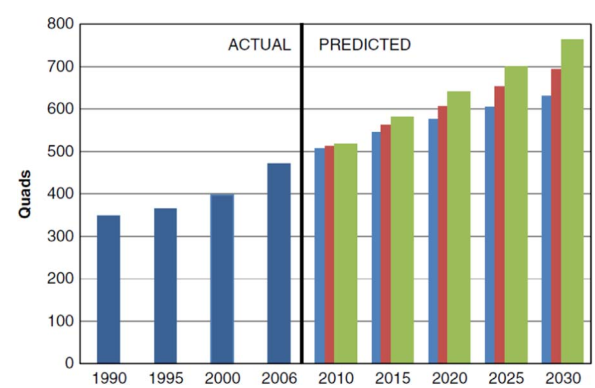

Fig. 3. Bar charts of the actual world's annual energy demands from 1990 to date. The triple bars show the prediction of minimum average and maximum values in the world by 2030 [10].

The needs of energy in future in the world makes it very essential to estimate and expect the consumptions of the used energy (see Fig. 3). By considering the minimum and maximum values this is guaranteed that these kinds of expectations can reduce the risks which might be happened in the future.

It is very crucial to consider the usage of alternatives sources renewable and sustainable ones. And it can be able to stand with the human needs and the most obvious way that small sustainable farms can help in reducing the nation's dependence on fossil fuels(oil, coal and natural gas) can be done by widespread this technology in different scales. Therefore, working with fuel cell types [1–8] presents a promising future for this source of energy, because of its durability, clean