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Submission title: Design of Pd based electrocatalysts for Oxygen reduction re...  
File name: of\_Pd\_based\_electrocatalysts\_for\_Oxygen\_reduction\_reaction...  
File size: 124.21K  
Page count: 58  
Word count: 26,035  
Character count: 140,033  
Submission date: 10-Sep-2024 10:55AM (UTC+0530)  
Submission ID: 2449850726

### 1. General Introduction

This introductory section delineates a preview of the fuel cells (FCs), various types and the reactions involved, focusing mainly on oxygen reduction reaction (ORR). Recent trends in the development of Pt-free electrocatalysts over a period of time will also be discussed in this chapter. This chapter will also provide a comprehensive explanation of numerous reports on considerable attempts to explore Pd-based nanocatalysts with advanced stability that can be utilized as substitutes for Pt. Special emphasis has been given to the Pd electrocatalysis, including bimetallic and trimetallic nanoparticles for ORR. This chapter also includes the extensive literature survey, scopes, objectives, and research plan for the present investigation.

#### 1.1. Overview

The most vital resource for a nation's development is energy, and the amount of energy used per person is rising dramatically. Any nation's energy policy is driven by three factors: economic growth, environmental protection, and energy security, or the "three E's". The world of today is dependent particularly on fossil fuels. Fossil fuels are mainly used to generate power and heat. Since 1950, the global population has been growing, and rising living standards have resulted in a rapidly growing need for energy, which will reach its maximum in 2035, as seen in Figure 1.1a [1-9]. Furthermore, governments worldwide are considering energy security because fossil fuels like coal, oil, and natural gas are non-renewable throughout human history. Fossil fuels will eventually run out, though it might not happen in the next two decades because substantial supplies of coal and natural gas are still accessible. However, existing reserves of coal and natural gas should endure for about 200 years and 70 years, respectively, at the current pace of usage; oil is predicted to run out much sooner [3-7]. When the remaining fossil fuels run out, an alternative fuel will be required to meet the world's energy needs. This is especially true for the transportation sector, which accounts for about 60% of global energy use. The need to conserve energy and use alternative energy sources, especially renewable energy, has grown due to concerns regarding greenhouse gas emissions (Figure 1.1b), environmental degradation, and serious health problems. Therefore, new energy resources must be developed immediately to meet our energy needs more securely and sustainably. Fuel cells (FCs) and Metal-air batteries (MABs) with high efficiency and environmentally benign characteristics have attracted much attention owing to their irreplaceable roles in the construction of the future sustainable energy system [7-13]. These technologies help lower greenhouse gas emissions, decrease pollution, and encourage sustainability for a carbon-neutral world.

#### 1.2 Fuel Cells

FCs are electrochemical conversion devices that convert chemical energy into electrical energy without the combustion of fuels [5-9]. Instead of several steps required by combustion-based heat engines, FCs directly convert chemical energy to electrical energy [11, 12]. Nevertheless, external reserves continually supply the reactants to the fuel cell, unlike batteries, which store their reactants inside a cell. FCs are considered one of the most potential technologies that have significantly impacted renewable energy advancement. The

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