# Cost-effective Green Hydrogen Production: Single-step Synthesis of Nickel Cobaltite Nanostructures Electrode


## Abstract

Green hydrogen is a continuously rising way of storing clean energy, wherein electricity from renewable sources is used to split water into oxygen and hydrogen. Unfortunately, current materials used in this process are extremely expensive and unstable, which prevents hydrogen from being a viable clean energy storage method. The aim of this study is to find the most optimized conditions for the synthesis of Nickel Cobaltite ($NiCo_2O_4$) water splitting electrodes using electrodeposition as a synthesis method. 50 different electrodes were synthesized at different time frames, substrates, and electrical currents. The electrodes morphology and performance were then tested and the electrode that showed the most potential was chosen for this study. The morphology and purity of the electrode were then tested by XRD, SEM, and EDS mapping. The electrochemical catalysis performance was tested using linear sweep voltammetry, impedance test, and a chronoamperometry stability test. The results showed the formation of a defect-free thin film on the electrode, high stability, and a current density of 10 $mA/cm^2$ at 1.56 eV. The solution kinetics were also improved greatly, showing a resistance as low as 10 Ω. Finally, the electrode fabrication costs were reduced by 99.89%; which will lower the cost of hydrogen production immensely. This electrode has the potential to produce cost-effective hydrogen in industrial-based electrolysers in the near future, which will push the industry one step closer to a carbon-emission free future.


**Color Legend for Required Abstract Components:**

Problem Statement
Project Purpose
Experimental Procedures
Experimental Results
Project Implications

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# Research Plan

## 1. Introduction

In 2017, fossil fuel supplied around 80% of the energy consumed in the United States. This percentage is still very high even though it is the lowest percentage in the past century. Fossil fuel consumption decreased due to the rise of new renewable energy harvesting methods [1]. One of the potential candidates for clean energy generation is hydrogen fuel cells. Having water as its only by-product and only using Hydrogen and Oxygen to function, a hydrogen fuel cell is one of the most environmentally friendly ways of producing energy. [2]. Producing Hydrogen cleanly and cost-effectively will help reduce the usage of fossil fuels [3-7].

In 2020, Air Products, one of the largest hydrogen production companies globally, signed a deal for a green hydrogen facility in Neom, Saudi Arabia [8]. This facility is planned to produce one hundred times more hydrogen daily than any current hydrogen facility [9]. All the hydrogen production will the world is moving into a hydrogen-based economy, and the kingdom is in the center of it all.

In this project, and for the first time, we will investigate the effect of depositing Nickel thin films on carbon cloth electrodes at very low time frames. By doing so, the electrode will be both cost-effective and efficient compared to other systems that use efficient but expensive catalysts such as $RuO_2$ and Pt. Nickel cobaltite was chosen as an electrocatalyst due to its availability, reported high efficiency, and, most importantly, low cost [10-13]. Carbon cloth was selected as a substrate due to its low cost, flexibility, and double-sided conductivity [14-16].

## 2. Hypothesis

If Nickel Cobaltite is electrodeposited to a carbon cloth electrode, the water-splitting efficiency will increase.

## 3. Objectives

This project aims to develop a catalytically efficient, in terms of consuming solar cells energy, and cost-effective electrode and investigate its operating conditions in the water oxidation reaction. And also assess the feasibility of applying the aforementioned electrode in an industrial size electrolyzer in Saudi Arabia.

## 4. Materials

| | |
|---|---|
| Nickel Nitrate [$Ni(NO_3)_2 \cdot 6H_2O$] | Ethanol |
| Cobalt Nitrate [$Co(NO_3)_2 \cdot 6H_2O$] | Carbon cloth without MPL and FTO |
| Sodium Hydroxide [NaOH] | 2x2 cm Pt electrode |
| DI water | Ag/AgCl electrode |

# 5. Experimental Methodology

## *5.1 Electrodeposition Conditions optimization*

### *5.1.1 Electrodes synthesis*

50 electrodes will be synthesized via the electrodepostion of [$Ni(NO_3)_2 \cdot 6H_2O$] and [$Co(NO_3)_2 \cdot 6H_2O$] by changing:

a) Current density of the electrodepostion current (-1.2,-1.1,-1,-0.9,-0.8 will be used)

b) change of depostion time (15 sec, 2 minutes, 5 minutes, 15 minutes, 30 minutes, 45 minutes will be used)

c) changing the deposited on substrate (FTO and carbon cloth will be used)

### *5.1.2 Electrodes characterization*

*The 50 electrodes will be charcterized via Scaning Electron Microcopy (SEM) and Linear Sweep Voltmettry (LSV). The electorde that shows the best results will be analyzed even further (STEP 5.2 & 5.3)*

## *5.2 Morphological characterization*

*5.2.1 X-Ray Diffraction (XRD).*

*5.2.2 Energy-dispersive X-ray spectroscopy (EDS).*

*5.2.3 Energy-dispersive X-ray spectroscopy Mapping  (EDSM).*

*5.2.4 Scanning Electron Microscopy.*

***5.3 Solar and Electrochemical Charcterization***

*5.3.1 Linear Sweep Voltmmetry (repeated 13 times to ensure reproducibility).*

*5.3.2 Solar Cell Simulator Stability Test (repeated 13 times to ensure reproducibility).*

*5.3.3 Nyquist plots (electrode-to-electrolyte ressistance). (repeated 13 times to ensure reproducibility).*

*5.3.4 Tafel Plot.*

## 6. Error Analysis

All possible measures were taken into action to ensure the validity and accuracy of results: Potentiostat was properly calibrated before testing. Solutions prepared freshly. Platinum electrode rinsed with DI water between electrochemical tests and cleaned with $H_2SO_4$ and water between electrodeposition trials. All the experiments were repeated, and the difference in results was less than %3 at all times.

## 7. Future work

***7.1 Short term future work (March -July. 2021)***

*7.1.1 Density Functional Theory calculation using the KAUST Shaheen II supercomputer.*

*7.1.2 Testing the electrode with real solar radiation.*

*7.1.3 testing the electrode in an industrial-sized electrolyzer (which is present in KACST).*

*7.1.4 Submission to the International Journal of Hydrogen Energy.*

### *7.2 Long term future work*

Due to its low cost, short synthesis time, and impressive electrocatalytic activity, the $NiCo_2O_4$/CC electrode can be used soon to produce green hydrogen in large-scale water electrolysis plants.

## 8. Risk Assessment

The Materials Safety datasheet of each of the chemicals will be read and discussed before the experiments with the research mentor. No toxic or hazardous materials will be used thus, this project has a low risk on the environment. Lab coats, gloves, and masks will be used at all times during the experiments. All the experiments will be conducted by me while experiments that use concentrated $H_2SO_4$ will be conducted by the research mentor while I stand from a safe distance to observe.

## 9. References

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**<u>Color Coded Research Plan Legend and Components:</u>**

Project Introduction - Includes problem statement, background information and project purpose with novelty, research hypothesis and research objectives.

Experimental Setup - Includes all pertinent materials (equipment and supplies) and step by step experimental procedures.

Data Analysis – Includes number of related trials and what tools will be used to determine the significance of the data.

Future Work – Includes short term and long-term procedures that cannot be done in the time frame of the original project.

Risk Assessment – Includes short term and long-term procedures that cannot be done in the time frame of the original project.

References – Includes all relevant publications that were part of the project literature review in MLA or APA format.