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Turkey's Green Economy Initiative: An Experimental Evaluation of Hydrogen Energy

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Abstract

Green economy is a concept that aims to achieve sustainable economic growth without harming the environment. Reducing carbon footprint is an important tool for the green economy. The contribution of reducing carbon footprint to the green economy is to measure the impact of economic activities on the environment and guide the development of green economy practices. Through green economy practices, carbon footprint can be reduced, environmentally friendly production and consumption habits can be promoted, and natural resources can be used more efficiently. Turkey is in a moderate position in terms of carbon footprint worldwide. As of 2019, Turkey's carbon footprint was calculated as 370 million tons of carbon dioxide (CO_2) equivalent. The energy sector, industrial activities, transportation and agriculture sectors are among the largest sources of carbon footprint in Turkey. In this study, the evaluation of hydrogen gas production for reducing carbon footprint during Turkey's transition to the green economy is discussed. The production and evaluation of the cathode electrode used in hydrogen gas production with the alkaline electrolysis system were conducted. For this purpose, a novel, cheap and accessible cathode material containing transition metal was used for the first time in the literature, which was produced by a triple coating of nickel (Ni), iron (Fe), and molybdenum (Mo) on a nickel foam electrode surface at different potentials (2.1 V - 3 V) and different times (5-30 minutes) with two electrode techniques to produce hydrogen gas. According to the results, the amount of hydrogen gas produced per unit surface area (m^2) of the electrode during a 30-minute period was approximately 516 L, and the energy value determined by the Lower Heating Value (LHV) was 5533.2 kJ/kg H_2.

Keywords: Green economy, Alkaline electrolysis, Hydrogen, Carbon footprint

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Türkiye'nin Yeşil Ekonomi Girişimi: Hidrojen Enerjisinin Deneysel Bir Değerlendirmesi

Öz

Yeşil ekonomi, çevreye zarar vermeyen, sürdürülebilir ekonomik büyümeyi hedefleyen bir kavramdır. Karbon ayak izi azaltılması yeşil ekonomi için önemli bir araçtır. Karbon ayak izi azaltılmasının yeşil ekonomiye katkısı, ekonomik faaliyetlerin çevreye olan etkisini ölçerek, yeşil ekonomi uygulamalarının geliştirilmesine yol göstermesidir. Yeşil ekonomi uygulamaları sayesinde, karbon ayak izi azaltılabilir, çevre dostu üretim ve tüketim alışkanlıkları yaygınlaştırılabilir ve doğal kaynakların daha verimli kullanılması sağlanabilir. Türkiye, karbon ayak izi açısından dünya genelinde orta düzeyde bir konumda yer almaktadır. 2019 yılı itibariyle Türkiye'nin karbon ayak izi, 370 milyon ton karbondioksit (CO_2) eşdeğeri olarak hesaplanmıştır. Türkiye'nin en büyük karbon ayak izi kaynakları arasında enerji sektörü, endüstriyel faaliyetler, ulaşım ve tarım sektörleri yer almaktadır. Bu çalışmada, Türkiye'nin yeşil ekonomiye geçiş sürecinde karbon ayak izinin azaltılması için hidrojen gazı üretimin değerlendirilmesi ele alınmıştır. Alkali elektroliz sistemiyle hidrojen gazı üretiminde kullanılan katot elektrot üretimi ve değerlendirilmesi yapılmıştır. Çalışmada literatürde ilk kez üretilen, geçiş metali ihtiva eden, ucuz ve ulaşılabilir katot malzemesi kullanılmıştır. Bu amaçla nikel köpük elektrot yüzeyinden nikel (Ni); demir (Fe) ve molibden (Mo) üçlü kaplama oluşturulmuştur ve farklı potansiyellerde (2,1 V – 3 V), farklı sürelerde (5-30 dak) iki elektrot tekniğiyle hidrojen gazı üretimi sağlanmıştır. Elde edilen sonuçlara göre üretilen elektrotun birim yüzeyi (m^2) başına 30 dakika süresince oluşturulan hidrojen gazı yaklaşık 516 L iken alt ısıl değerine (LHV) göre belirlenen enerji değeri ise 5533,2 kJ/kg H_2'dir.

Anahtar Kelimeler: Yeşil ekonomi, Alkali elektroliz, Hidrojen, Karbon ayakizi

1. INTRODUCTION

Energy transformation based on renewable energy sources, waste management, resource efficiency, and the use of environmentally friendly production technology are only a few examples of sustainable practices that are part of the green economy [1-8]. The implementation of these practices helps reduce carbon footprint and promote more efficient use of natural resources. Carbon footprint and green economy are closely related topics because carbon footprint measures the environmental impact of economic activities and evaluates sustainability. The carbon footprint is a measure of the damage that an individual, a business, or a country causes to the environment [9-12]. The carbon footprint measures the amount of greenhouse gases, directly or indirectly released into the atmosphere. The carbon footprint is calculated by evaluating many factors together. These factors include activities such as transportation, household energy use, food production and consumption, and production and consumption of goods. Carbon footprint calculations help individuals and businesses understand their impact on the environment and help them adopt a more sustainable lifestyle. Many steps can be taken to reduce the carbon footprint. The first step is to increase energy efficiency. Individuals and businesses can reduce their carbon footprints by using devices that consume less energy and adopting habits that save energy. Additionally, the use of renewable energy sources also plays an important role in reducing the carbon footprint. Turkey can reduce its carbon footprint by taking advantage of renewable energy sources such as solar energy, wind energy, and hydroelectric energy. In summary, carbon footprint and green economy are complementary topics [13-15]. Carbon footprint estimates are a crucial instrument in the development of green economy practices since they assist minimize carbon emissions and promote sustainable economic growth [16-18]. Hydrogen energy is a sustainable energy source that can help reduce greenhouse gas emissions by replacing fossil fuels. Hydrogen fuel cells combine hydrogen with oxygen to produce electrical energy, with only water vapor being released as a byproduct. Therefore, hydrogen energy can reduce carbon footprint by preventing greenhouse gas emissions associated with fossil fuel use. One way to obtain hydrogen is through the electrolysis of water. This process can be carried out using renewable energy sources such as solar or wind energy, making the energy source used in hydrogen energy production also environmentally friendly [19-21]. Hydrogen can be obtained by splitting water through electrolysis. Electrolysis is a chemical reaction that uses electrical current. In electrolysis, water is converted into hydrogen and oxygen gases by the use of an electric current. During this process, hydrogen gas is stored in hydrogen tanks, while oxygen gas is released into the atmosphere. Hydrogen production through electrolysis does not directly reduce carbon footprint because the electrolysis process requires energy, and greenhouse gas emissions depend on the source of energy used to produce the electricity. However, producing hydrogen through electrolysis using renewable energy sources is a key step towards reducing carbon footprint [22,23].

The carbon footprint of the hydrogen produced depends on the source of electricity used in its production and the efficiency of the electrolysis process. It's crucial to consider the source of electricity, whether it comes from renewable sources or those that emit greenhouse gases, such fossil fuels. Additionally, the efficiency of the electrolysis process also affects the carbon footprint of hydrogen. Efficient electrolysis processes can produce more hydrogen with less energy, resulting in a lower carbon footprint. Renewable energy sources such as solar, wind, or hydroelectric power can also be used as the energy source for hydrogen production instead of fossil fuels. This contributes to reducing the carbon footprint through hydrogen production using electrolysis [24-26]. The calculation of carbon footprint for electrolysis can vary depending on various factors such as; energy source (the energy source used for electrolysis will determine the carbon emissions generated during the process); efficiency of the electrolysis process (the efficiency of the electrolysis process will determine the amount of energy used. A more efficient electrolysis process will use less energy and, therefore, result in fewer carbon emissions); production of materials (the production of materials used in the electrolysis process can also affect the carbon footprint) [27-29].

In this study we aimed to produce electrodes which have higher catalytic performance and lower production investments for reducing carbon footprint. For this purpose, nickel, molybdenum and ferrous were determined as deposition metals. Due to the spiderweb-like morphological advantage of Ni foam electrode, it was used as a substrate and NiMoFe was deposited on it. We calculated the carbon footprint of the produced system. As the carbon footprints insights in the fabrication of the electrode are a challenging and complex process to calculate, inaccurate calculations can be generated. Therefore, in this study, we used the data which was obtained from literature. The creation of hydrogen utilizing a renewable energy source has been shown to significantly reduce its carbon footprint, according to the results obtained at various voltage values.

2. MATERIAL AND METHOD

A Ni foam roll (NF - Sigma GF28024657-1EA) was cut to dimensions of 1x1x0.16 cm (0.036 g) for the production of an electrocatalyst. The surface was galvanostatically coated with a Ni:Fe:Mo ratio of 0.9:0.05:0.05 mol to achieve a surface density of 100 μg/cm^2. An Ivium electrochemical analyzer was used as the electrochemical workstation for this process. The study was performed using the three-electrode technique, with an Ag/AgCl (3 M KCl) reference electrode and a 2x2x0.1 cm Ni plate counter electrode. A 1x1x0.1 cm Pt plate counter electrode was used for hydrogen gas production in the two-electrode system. The bath compositions used are given below.

Nickel plating bath: 30% $NiSO_4.6H_2O$, 1% $NiCl_2.6H_2O$, 1.25% H_3BO_3

Iron plating bath: 9.69% $FeSO_4·7H_2O$, 0.84% $FeCl_2·4H_2O$, 1.25% H_3BO_3

Molybdenum plating bath: 30% $MoNa_2O_4$, 2% NaCl, 1.25% H_3BO_3

During the electrochemical deposition, a constant current density of 5 mA/cm^2 was applied, and the Ni foam surface was coated with Ni:Fe:Mo at a ratio of 0.9:0.05:0.05 mol to achieve a surface density of 100 μg/cm^2. The deposition time was calculated using Faraday's laws. For the amount of hydrogen gas produced in a 1 M KOH solution, a burette filled with 1 M KOH was inverted onto the cathode and various fixed potential values (10 different values between 2.1 V and 3.0 V) were applied to the system for 30 minutes.

3. RESULTS AND DISCUSSION

3.1. Carbon Footprint of Electrocatalyst Production

In this study, the high electrocatalytic activity Ni foam electrode surface was modified with Ni, Fe, and Mo. The carbon footprint of metal catalysts can vary depending on the energy sources, processing methods, and supply chain stages used during their production. Therefore, there may be differences in carbon footprints among different producers. However, in this study, observations were made based on approximate values. Norilsk Nickel, a Finland-based nickel producer, announced that it emits less than 10.4 tons of CO_2 equivalent greenhouse gas emissions per ton of nickel produced as of 2019. The Nornickel Group, as confirmed by Ernst & Young (EY), a global auditing company, reduced its carbon dioxide emissions in 2019-2020. With the help of a leading independent international consultant, Nornickel calculated the carbon footprint of nickel produced according to the ISO 14040 and 14044 international standards, which corresponds to 8.1 tons of CO_2 per ton of finished product [30].

In the steel industry, it has been reported that 2.6 gigatons of carbon dioxide (Gt CO_2) emissions will be released for approximately 1878.5 million tons of production worldwide in 2022 [31]. According to these reports, more than 1.8 tons of CO_2 equivalent emissions are released per ton of iron production on average worldwide [31]. Freeport-McMoRan, a mining company operating in the United States, stated that it emitted approximately 9.9 tons of CO_2 per ton of molybdenum production in 2020 [32].

Based on the information provided, it can be calculated that the production of one kilogram of catalyst for the electrochemical deposition method results in approximately 8.5 kg of CO_2 emissions, including emissions from raw material production and energy consumption during production. Additionally, the production of one kilogram of hydrogen gas through electrolysis requires approximately 50 kWh of electricity. It is important to note that the actual emissions from the production of hydrogen gas depend on the source of electricity used. If renewable sources of electricity are used, the emissions would be significantly lower. Sources used for calculations include the United States Environmental Protection Agency (EPA), the International Energy Agency (IEA), and the European Environment Agency (EEA).

3.2. Hydrogen Production and Its Contribution to The Green Economy

It is observed that a lot of scientific studies have been conducted on the production of hydrogen gas through literature review [33-38]. Mert and her colleagues [39] designed different cathodes and produced hydrogen gas in an alkaline electrolysis system using electricity from a real hybrid system based on solar and wind energy, which was necessary for each cathode.

Although the production of hydrogen gas by electrolysis is an environmentally friendly approach, it still relies on the use of fossil fuels when produced using traditional electricity generation methods [40-43]. However, electricity produced using renewable sources such as solar and wind power offers a more environmentally friendly option for hydrogen gas production and has many advantages. One of the most important is that when renewable sources such as solar and wind power are used in hydrogen gas production, the carbon footprint is minimal. Therefore, hydrogen gas production is more environmentally friendly compared to other energy production methods that use fossil fuels. Another principal issue is sustainability. By acting as an energy carrier, hydrogen gas ensures sustainability with solar and wind hybrid systems. In addition, the high energy density of hydrogen gas makes it a suitable energy carrier. Hydrogen gas can carry more energy per unit volume than oil or natural gas. Therefore, hydrogen is seen as an environmentally friendly and renewable option for energy storage and transportation. The volumes of hydrogen gas produced at different durations and fixed potentials in a 1M KOH solution using the NiF/NiFeMo cathode, which was first produced in the literature, are given in Table 1 in this study.

As seen in Table 1, the volume of hydrogen gas produced increases with increasing electrolysis potential. For example, during the 15-minute electrolysis process, the volumes of accumulated hydrogen gas in the cathode range from 19 mL to 52.23 mL as the potential increases from 2.1V to 3V. Similarly, for a 30-minute electrolysis process at the same potential range, the minimum and maximum hydrogen gas volumes obtained were determined to be 35.5 mL and 103.2 mL, respectively. Figure 1 shows the hydrogen gas volumes produced on the NiF/NiFeMo surface with a 3V potential applied for 30 minutes. Figure 2 presents the hydrogen gas volumes produced at all potential values and durations applied. When compared to various cathode materials used in the literature, it can be said that the NiF/NiFeMo cathode used in the experimental production shows effective catalytic performance.

Table 1. Experimentally produced hydrogen gas volumes in the electrolyzer cell consisting of NiF/NiFeMo cathode and Pt anode

Electrolysis time/min	Volumes of hydrogen gas produced at different constant potentials /mL									
	2.1V	2.2V	2.3V	2.4V	2.5V	2.6V	2.7V	2.8V	2.9V	3V
5	6.44	6.89	8.95	12.6	13.3	14.35	14.83	15.46	17.34	17.44
10	12.7	13.6	17.4	25.14	26.46	28.62	29.6	30.78	34.61	34.89
15	19	20.4	26	37.6	39.59	42.83	44.29	45.75	51.81	52.23
20	25.1	27.2	34.5	49.86	52.65	56.96	58.5	60.58	68.80	69.36
25	30.5	33.8	43	61.8	65.28	71.03	72.77	75.21	85.48	86.35
30	35.5	40.3	51.2	72.7	77.3	85.03	87.12	89.83	101.9	103.2

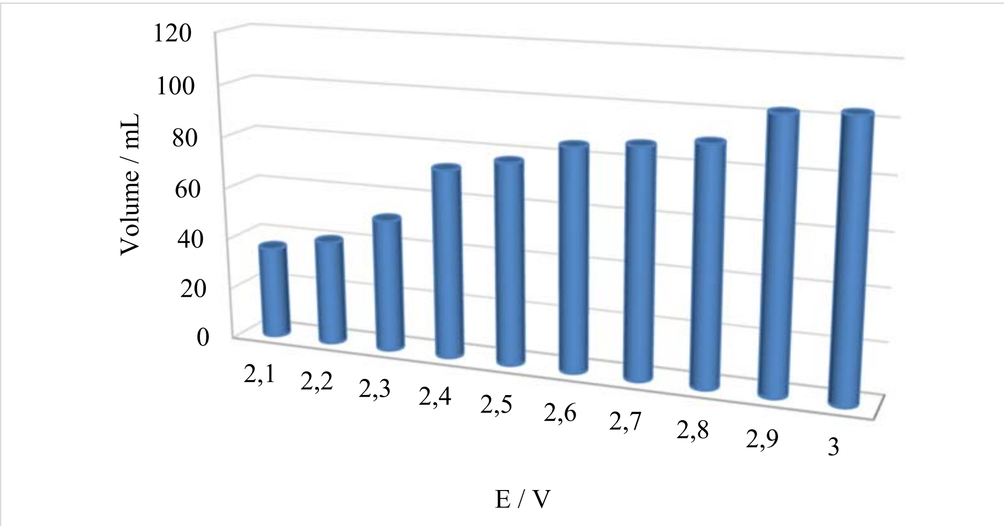

Figure 1. Volumes of hydrogen gas produced after 30 minutes of electrolysis in the electrolyzer cell consisting of NiF/NiFeMo cathode and Pt anode

As seen in Table 2, the hydrogen gas production at 3V for 30 minutes per unit surface area (m^2) of C/NiGa [42] and NiF/NiFeMo cathode materials, compared under similar conditions using alkaline electrolysis, are 68.75 L and 516 L, respectively. The energy values determined based on the LHV corresponding to these gas quantities are 737.2 and 5533.2 kJ/kg H_2, respectively.

Table 2. Comparison of the amount of hydrogen gas produced by the electrolysis method for 30 minutes according to the literature

Cathode	Time /min	Surface area / cm^2	The amount of hydrogen gas obtained	Consumed Energy / kWh	Energy to be produced per m^2* /kJ	Refs
NiF/NiFeMo	30	2	77.3 $mL_{@2.5V}$		5533.2	Present study
NiF/NiFeMo	30	2	103.2 $mL_{@3V}$			Present study
C/Ni/Co	30	0.36	42 $mL_{@3V}$			[39]
NiF/NiCu	30	2	79.2 $mL_{@2.7V}$			[40]
NiF/NiCu	30	2	106.2 $mL_{@3V}$			[40]
G/NiCoAg	30	0.36	54 $mL_{@2.5V}$	$1.3x10^{-3}$		[41]
C/NiGa	30	4	27.5 $mL_{@3V}$		737.2	[42]
Ni/CoBGd	30		16 $mL_{@3V}$			[43]

** The amount of energy released when 1 kg of hydrogen is completely burned with 100% efficiency has been calculated. The conversion of volume to mass was determined according to ideal gas laws. The LHV of hydrogen, which is 120.1 MJ/kg, was used.*

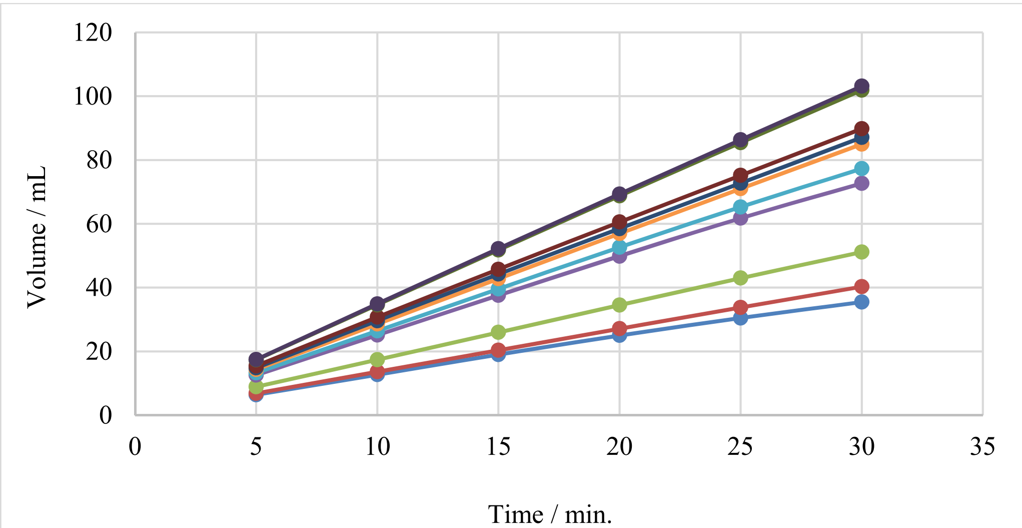

Figure 2. Hydrogen gas volumes produced at different electrolysis times and different potentials in the electrolyzer cell consisting of NiF/NiFeMo cathode and Pt anode

4. CONCLUSION

The consequence of this study, the production of hydrogen gas through electrolysis using renewable energy sources is an important step in reducing carbon footprint. Hydrogen fuel cells can also help reduce greenhouse gas emissions by replacing fossil fuels. Therefore, hydrogen energy is considered an important solution for reducing carbon footprint. When the data obtained in this study is evaluated, it can be seen that the use of cathodes containing transition metals such as Ni, Fe, and Mo in alkaline electrolysis systems provides highly efficient hydrogen gas production. For constant potential values of 2.5V and 3V, the amount of hydrogen gas produced per unit electrode surface area (m^2) after 30 minutes is 386.5 and 516 L, respectively. The results showed that energy to be produced per m^2 was almost 5533.2 kJ.

Such studies should be expanded and supported in order to promote the development of new electrode types and hydrogen gas production using renewable energy sources.

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