International Journal of Scientific Engineering and Science
Volume 6, Issue 2, pp. 72-77, 2022. ISSN (Online): 2456-7361

Design and Build of Hydrogen Production Prototype Using Water Electrolysis Method Using Solar Panels

Choirul Saleh[1], Bima Romadhon[2]
[1, 2]Electrical Engineering, National Institute of Technology, Malang, Indonesia, 65153

***Abstract*— *The production of renewable H_2 through NRE resources can be done by 2 methods of Biomass Process and Water Splitting (thermolysis, Photolysis, and Electrolysis). Separation of water using the electrolysis method in the law of thermodynamics states that "the reaction of water separation is a non-spontaneous transformation". However, it can be driven externally by providing energy to the system, for example, electricity. This reaction is called an endergonic transformation and the device used is an electrolyzer. An electrolyzer contains at least one electrolyzing cell. Electrolysis has two electrodes placed opposite each other and separated by a thin layer of ionic conductors (electrolytes). In the water electrolysis cell, electrical work is applied to the cell to break water molecules into H_2 and O_2 gases. However, the low efficiency of the electrolyzer causes high energy consumption in the H2 production process. Hydrogen produced from renewable energy sources (solar energy) electrolytically, can be considered as renewable hydrogen, is environmentally friendly, and does not cause greenhouse gas emissions. From the results of the tests that have been carried out, the volume of hydrogen production is influenced by the amount of current applied to the cell, the concentration of KOH also affects the production efficiency, where the concentration of 8% KOH with a current of 1 ampere has the best efficiency in electrolytic hydrogen production.*

***Keywords*— *Buck Converter, Electrolysis, Hydrogen, Solar Panel*.

I. INTRODUCTION

The 2015 Paris Agreement in history became the first climate agreement and one of the agreements related to environmental issues [1]. Since the attention of international agencies and the climate movement has made policies towards the use of renewable energy with the gradual elimination of fossil fuels, which has an impact on the elimination of fossil fuel subsidies so that the price of fossil fuels becomes high [2]. The high price of fossil fuels makes biomass use in developing countries, because it is considered a safe and sustainable fuel, with relatively low investment in procurement and risk of use [3][4]. The use of biomass is generally carried out with open fire which is an inefficient combustion, producing greenhouse gas emissions and soot [5]. One of the main challenges to reducing greenhouse gas emissions and addressing the ever-increasing demand for energy, is with environmentally friendly and sustainable energy solutions [6].

Hydrogen (H_2) is recognized as a potential fuel because it can be used as an energy carrier, storage medium, fuel cell raw material and also as a carbon emission-free fuel with a high calorific value compared to fossil fuels [6]. H_2 can be produced from a variety of resources, different raw materials, and technologies used, including fossil fuels and new and renewable energy resources (RE) [7]. With increasing attention being paid to reducing emissions of greenhouse gases (CO_2, nitrogen dioxide (N_2O), CH_4, and freon (SF_6, HFC and PFC), RE resources are rapidly gaining potential as a clean source for producing renewable H_2 [2].

The production of renewable H_2 through RE resources can be carried out using 2 methods of Biomass Process and Water Splitting (Thermolysis [8][9], Photolysis [10][11], and Electrolysis [12][13][14]). Separation of water using electrolysis method in the law of thermodynamics states that "water separation reaction is a non-spontaneous transformation". However, it can be driven externally by providing energy to the system, for example, electricity. This reaction is called an endergonic transformation and the device used is an electrolyzer. An electrolyzer contains at least one electrolyzing cell. Electrolysis has two electrodes placed opposite each other and separated by a thin layer of ionic conductors (electrolytes). In the water electrolysis cell, electrical work is applied to the cell to break water molecules into H_2 and O_2 gases [15] However, the low efficiency of the electrolyzer [16] causes high energy consumption in the H_2 production process [17].

II. LITERATURE REVIEW AND RESEARCH HYPOTHESIS

A. Hydrogen (H)

The first element, hydrogen ($H_{(g)}$) is located above the alkali metals in the first column of the periodic table, but $H_{(g)}$ is not included in the alkali metals group. This gas element has the simplest atom with one electron and one proton so that the physical properties of $H_{(g)}$ are very light. Chemical properties $H_{(g)}$ is highly flammable, reactive and forms compounds with metals and non-metals. The most common $H_{(g)}$ compound is water [21]. H_2 can be produced from a variety of resources, raw materials, and technologies used, including fossil fuels and NRE [7]. There are various methods for converting available sources to H_2. Reforming/Combustion and Pyrolysis methods for fossil resources, then Biomass Process and Water Splitting methods for NRE sources [22]. Among the processes mentioned above, natural gas catalytic steam methane reforming (SMR) (sub-method of Reforming/Combustion) is the most widely used method for the production of H_2 with a contribution of 80-85% of the total world production capacity [23][24]. The production of H_2 by the SMR method consists of three steps. Methane (CH_4) is reformed by steam at high temperature and pressure conditions to obtain a mixture of H_2, carbon monoxide (CO), carbon dioxide (CO_2), and water. The water gas shift (WGS) catalytic reaction was then carried out to convert CO and water into CO_2 and H_2. The H_2-rich gas mixture is then purified by various purification processes such as pressure swing adsorption (PSA) [22]. Processes involving combustion in SMR have high CO_2 emissions, up to 7 kg CO_2/kg H_2, and are responsible for about 3% of global industrial sector CO_2 emissions [25]. With increasing attention being paid to reducing emissions of greenhouse gases (CO_2, nitrogen dioxide (N_2O), CH_4, and freon (SF_6, HFC and PFC), Electrolysis Water Splitting consists of two half-reaction processes, the reaction Hydrogen Evolution Reaction (HER) and Oxygen Evolution Reaction (OER) HER is a two-electron transfer reaction involving two processes: adsorption of H_2O in alkaline or acidic solution at the cathode (Volmer step) and desorption of H_2 from the cathode. through a chemical reaction (Tafel step) or an electrochemical process (Heyrovsky step) [26].

Water electrolysis technology can be classified according to the electrolyte used, which separates water by two half-reaction processes at the anode (Oxygen Evolution Reaction) and cathode (Hydrogen Evolution Reaction) from the electrolyzer. Separation of water using the electrolysis method in the law of thermodynamics states that "the reaction of water separation is a non-spontaneous transformation". However, it can be driven externally by providing energy to the system, for example, electricity. This reaction is called an endergonic transformation and the device used is an electrolyzer. In a water electrolysis cell, electricity is supplied to the cell to break water molecules into H_2 and O_2 gases [15]. Based on Faraday's Law, the amount of H_2 and O_2 gas produced by the electrode is proportional to the amount of electric current given to the electrolysis cell [13].

Renewable energy or renewable power plants generally require energy storage to support the system. Research on electrolysis cells can be an efficient way to convert excess electricity into gaseous fuels [27]. Water electrolysis has the potential to be a key element in combining the electricity, mobility, heating, and chemical sectors through Power-to-Liquids (PtL) or Power-to-Gas (PtG) [28]. In a water electrolysis cell, electrical work is applied to the cell to break water molecules into H_2 and O_2 gases.

B. Electrolyzing Cell Components

The electrolysis cell consists of an electrolyte solution and two electrodes connected to a power supply [29]. Figure 1 shows the simplest water electrolysis unit, consisting of an anode and a cathode immersed in an electrolyte solution and connected to an external DC power supply. In the general process of electrolysis of water, H^+ ions move towards the cathode, while hydroxide ions move towards the anode. The gas collector is used to collect H_2 and O_2 gases, which are formed at the cathode and anode, respectively [30]. In a water electrolysis cell, electricity is supplied to the cell to break water molecules into H_2 and O_2 gases [15]. However, the low efficiency of the electrolyzer [16] causes high energy consumption in the H_2 production process [17]. Physico-chemical parameters (voltage, current, cell temperature, electrolyte type and electrolyte concentration) affect the efficiency of H_2 production. The electrolyte used is basic (KOH, NaOH). The process of the water electrolysis reaction that occurs at the electrode surface in an acidic or neutral electrolyte, is described by (1,2):

Chatode

$$2H^{+}_{(aq)} + 2^{e-} \rightarrow H_{2(g)} \tag{1}$$

Anode

$$H_2O_{(l)} \rightarrow \frac{1}{2}O_{2\,(g)} + 2H^{+}_{(aq)} + 2^{e-} \tag{2}$$

The sum of these two s leads to the overall reaction of electrolysis of water, as given in (3):

All Reactions

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2 \tag{3}$$

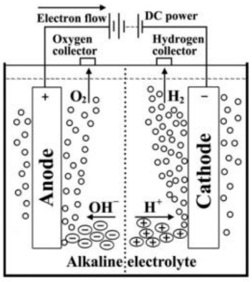

Fig. 1. Basic Schematic of Water Electrolysis [10]

However, for the case of electrolysis of alkaline water, where a strong base is used as the electrolyte, hydroxide anions are transferred through the electrolyte to the anode surface, where they lose electrons which then return to the positive terminal. To increase conductivity, potassium hydroxide (KOH) is commonly used in the electrolysis of alkaline water, although used electrolyte solutions have a higher conductivity. Therefore, for the case of electrolysis of water in an alkaline solution, the process occurring at the electrode surface is described by (4,5), respectively:

Chatode

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \tag{4}$$

Anode

$$2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^- \tag{5}$$

[31]

C. Physico-Chemical Parameters

Electrolyzer performance models are generally developed using basic electrochemical empirical relationships. The basic relationships are used to calculate various important parameters in the electrochemical cell electrolysis process. The reversible voltage is the minimum voltage that must be supplied to initiate an electrochemical reaction. The reversible stress can be determined in (6,7), Gibb's free energy (ΔG).

$$\Delta G = \Delta H - T\Delta S \tag{6}$$

$$\Delta G = n.F.V_{rev} \tag{7}$$

So if (7) is used to find the value of the Reversible Voltage (V_{rev}), it is shown in (8).

$$V_{rev} = \frac{\Delta G}{nF} \tag{8}$$

The minimum cell voltage required for the electrolysis of water is related to the enthalpy of the reaction and is called the enthalpy voltage or thermo-neutral cell voltage (V_{enth}), as (9).

$$V_{enth} = \frac{\Delta H}{nF} \qquad (9)$$

[32].

Neither the reversible voltage (V_{rev}) nor the thermo-neutral voltage (V_{enth}), is sufficient to initiate a chemical reaction, an additional potential is supplied which is known as the activation voltage (V_{act}). The activation voltage is a function of the electrode coefficient and temperature. The activation voltage for a given temperature can be calculated using (10) at a constant temperature of 273° K.

$$V_{act} = A + B \,.\log{(I)} \qquad (10)$$

A and B are the anode and cathode constants, where the constant values from the literature reveal that stainless steel 316 (316SS) exhibits a current density of 10 mA.cm^{-2} with a voltage = 370 mV (0.37 V) in a 1.0 mol solution. L^{-1} KOH [33]. Voltage loss occurs due to resistance of electrolytes, electrodes and electrical wires, etc. Collectively represented as Ohmic voltages (V_{ohms}), can be calculated using (11).

$$V_{ohm} = \frac{r}{A} \qquad (11)$$

The cell voltage or cell overvoltage potential is the total amount of potential applied in the electrolyzer and it is the sum of the enthalpy, activation and Ohmic voltages. The cell voltage can be calculated by (12) [34].

$$V_{cell} = V_{enth} + V_{act} + V_{ohm} \qquad (12)$$

The efficiency of hydrogen production during the electrolysis process can be calculated using (13), where Eff (%) in percent is the ratio between the measured volume of gas (VH_{2real}) and the ideal volume of H_2 (VH_{2ideal}):

$$Eff(\%) = \frac{VH_{2real}}{VH_{2ideal}}.100\% \qquad (13)$$

Using Faraday's law of electrolysis, the ideal volume of H_2 (VH_{2ideal}) is calculated as follows (14):

$$VH_{2ideal} = \frac{I.V_m.t}{n.F} \qquad (14)$$

where I is the current (in Ampere) passing through the cell during the period t (in second), V_M is the molar volume of the ideal gas (liters/mol) under standard conditions (where T = 298° K and P = 1 atm) as shown in (15) and F is Faraday's number (96485C/mol).

$$V_m = \frac{n.R.T}{P} \qquad (15)$$

To simplify the calculation, H_2 gas is considered a perfect gas, then the temperature must be applied to the standard T conditions (273° K), the real volume (VH_{2real}) will be as described in (16):

$$VH_{2real} = VH_{2(measured)}\frac{T_{standart}}{T_{measured}} \qquad (16)$$

Where $VH_{2(measured)}$ is the volume obtained by displacement of alkaline water, T measured is room temperature (in ° Kelvin) [29].

III. METHOD

For the case of electrolysis of water in an acidic or neutral aqueous electrolyte, the process occurring at the electrode surface is described by (1,2):

Cathode

$E_0 = 0.00$ V

Anode

$E_0 = 1.23$ V

The sum of these two s (1, 2) leads to the overall reaction of electrolysis of water, as given in (3):

All Reactions

$E_0 = -1.23$ V

However, for the case of electrolysis of water in an alkaline solution, the process occurring at the electrode surface is described by Eq. (4, 5), respectively:

Chatode

$E_0 = -0.83$ V

Anode

$E_0 = 0{,}40$ V

Of course the number of Eqs. 4 and 5 will cause the same overall reaction as described in 3, with the same value (−1.23 V) for the theoretical cell voltage. The reversible stress can be determined in (6,7) Gibb's free energy (ΔG). Where H is the standard change in enthalpy (ΔH = 286 k J/mol) and S is the entropy of the electrolysis process at a temperature (T) where standard conditions (T = 298o Kelvin and 1 atm) Gibbs free energy (ΔG = 237.2 kJ/mol) for water separation [42], the value of Faraday's constant (F = 96485 C/mol) and the number of electrons (n = 2). So if (7) is used to find the value of the Reversible Voltage (V_{rev}), it is shown in (8).

$$V_{rev} = \frac{237.2\ k\ J/mol}{2\ .96{,}485}$$

$$V_{rev} = 1.229\ V$$

The minimum cell voltage required for the electrolysis of water is related to the enthalpy of the reaction and is called the enthalpy voltage or thermo-neutral cell voltage (V_{enth}), as (9).

$$V_{enth} = \frac{286\ k\ J/mol}{2\ .96{,}485}$$

$$V_{enth} = 1.482\ V$$

The activation voltage is a function of the electrode coefficient and temperature. The activation voltage for a given temperature can be calculated using (10) at a constant temperature of 273 °K. A and B are the anode and cathode constants, where the constant values from the literature reveal that stainless steel 316 (316SS) exhibits a current density of 10 mA.cm^{-2} with voltage = 370 mV (0.37 V) in a 1.0 mol solution. L^{-1} KOH [43]. So that the activation voltage is obtained using (10) as follows if the desired current (I) is 20A.

$$V_{act} = 0.37 + 0.37\,.\log{(20)}$$

$$V_{act} = 0.8513\ Volt$$

In the design, the molarity of the solution is neglected, the electrode is designed with an area of (A) 1.2 m^2, and the resistance value (r) 0.21/m^2 at an electrode distance of 0.006 m. Using (11) the value of Ohmic voltage is obtained.

$$V_{ohm} = \frac{0.21\Omega/\mathrm{m}^2}{1.2m^2}20A$$

$$V_{ohm} = 3.5\ Volt$$

$$V_{cell} = V_{enth} + V_{act} + V_{ohm}$$

$$V_{cell} = 1.482 + 0.8513 + 3.5$$

$$V_{cell} = 5.8333\ Volt$$

The cell voltage or cell overvoltage potential is the total amount of potential applied in the electrolyzer and it is the sum of the enthalpy, activation and Ohmic voltages. The cell voltage can be calculated by (12). At STP the thermodynamic decomposition voltage of water under theoretical conditions is 1.229 V (1.23 V) and the current efficiency is 100%. Therefore, the theoretical energy consumption (Etheo) to produce 1m^3 H_2

is 2.94 kWh/m^3 H_2. However, for the decomposition of water, the voltage requires 1.65–1.7 V. Therefore in industry a voltage of about 1.8-2.6 V is used. Hence the practical energy consumption is almost 1.5 to 2.2 times more than the theoretical energy consumption. Therefore the actual efficiency is between 48% to 70%[44]. While in this study used cell voltage (V_{cell}) of 5.8333 Volts. The efficiency of hydrogen production during the electrolysis process can be calculated using (13), where Eff (%) in percent is the ratio between the measured gas volume (VH_{2real}) and the ideal volume of hydrogen (VH_{2ideal}):

$$Eff(\%) = \frac{VH_{2real}}{VH_{2ideal}}.100\%$$

V_M is the molar volume of an ideal gas (liters/mol) under standard conditions (where T = 273° K and P = 1 atm) as shown in (15) and F is Faraday's number (96485C/mol).

$$V_m = \frac{1\,.0.082\,L\frac{atm}{mol}K\;273\;Kelvin}{1\;atm}$$

$$V_m = 22.4\;Liter/mol$$

Using Faraday's law of electrolysis, the ideal volume of hydrogen (VH_{2ideal}) is calculated as follows (14):

$$VH_{2ideal} = \frac{20\;A\,.22.4\,\frac{Liter}{mol}\,.3600\;S}{1\,.96485\;C/mol}$$

$$VH_{2ideal} = \;16{,}7155516\;liter$$

Where I is the current (in Ampere) that passes through the cell during the period t (in second), To simplify calculations, hydrogen gas is considered a perfect gas, consequently under standard conditions, the real volume (VH_{2real}) will be as described in the following (16):

$$VH_{2real} = VH_{2(measured)}\frac{T_{standart}}{T_{measured}}$$

Where $VH_{2(measured)}$ is the volume obtained by displacement of alkaline water (l), $T_{standard}$ is standard temperature (273° Kelvin) and $T_{measured}$ is room temperature (in ° Kelvin) [45]. So from s (13,14,15,16) a table of estimates of the theoretical amount of H_2 gas can be made based on the strong electric current flowing in the cell, shown in Table I.

TABLE I. Theoretical H_2 gas volume based on current strength in 3600 seconds.

V_{cell} (Volt)	**I_{cell} (Ampere)**	**Power (Watt)**	**Theoretical H_2 gas volume (Liter)**	**Watt/Liter H_2**
5.8	20	116.7	16.7	7.0
5.7	19	107.5	15.9	6.8
5.5	18	98.7	15.0	6.6
5.3	17	90.2	14.2	6.4
5.1	16	82.1	13.4	6.1
5.0	15	74.4	12.5	5.9
4.8	14	67.0	11.7	5.7
4.6	13	59.9	10.9	5.5
4.4	12	53.2	10.0	5.3
4.3	11	46.8	9.2	5.1
4.1	10	40.8	8.4	4.9
3.9	9	35.2	7.5	4.7
3.7	8	29.9	6.7	4.5
3.6	7	24.9	5.9	4.3
3.4	6	20.3	5.0	4.0
3.2	5	16.0	4.2	3.8
3.0	4	12.1	3.3	3.6
2.9	3	8.6	2.5	3.4
2.7	2	5.4	1.7	3.2
2.5	1	2.5	0.8	3.0
2.3	0	0.0	0.0	-

IV. RESULT AND DISCUSSION

The data collection process was carried out in the laboratory of the Malang National Institute of Technology. The test was carried out in an air-conditioned laboratory with an ambient air temperature of 23o Celsius. The data tested in the form of current flowing in the electrolysis cell based on the percentage of KOH solution and the electric voltage applied to the electrolysis cell shown in Fig 2.

Fig. 2. Prototype Hydrogen Reactor Water Electrolysis

The test results data can be seen in Tables II to VI which present the results of the H2 reactor testing based on the electric current and the concentration of KOH used by the reactor.

TABLE II. The volume of H_2 gas was measured based on the current within 1 hour at a concentration of 0% KOH.

V_{cell} (Volt)	**I_{cell} (Ampere)**	**Power (Watt)**	**Measurement H_2 gas volume (Liter)**	**Watt/Liter H_2**
11.2	10	112.4	8.06	13.9
10.3	9	93.1	6.83	13.6
9.5	8	75.6	6.03	12.5
8.9	7	62.4	6.25	10.0
7.7	6	46.0	5.30	8.7
6.8	5	33.9	3.91	8.7
5.9	4	23.5	2.97	7.9
5.3	3	15.8	2.50	6.3
4.3	2	8.6	1.63	5.3
3.3	1	3.3	0.74	4.5
2.3	0	0.0	0.00	0.0

TABLE III. The volume of H_2 gas was measured based on the current within 1 hour at a concentration of 4% KOH.

V_{cell} (Volt)	**I_{cell} (Ampere)**	**Power (Watt)**	**Measurement H_2 gas volume (Liter)**	**Watt/Liter H_2**
7.0	10	70.1	8.48	8.3
6.5	9	58.9	7.73	7.6
6.1	8	48.5	6.16	7.9
5.8	7	40.5	6.37	6.3
5.1	6	30.8	5.45	5.6
4.7	5	23.3	4.37	5.3
4.2	4	16.7	3.20	5.2
3.9	3	11.6	2.73	4.3
3.3	2	6.7	1.82	3.7
2.8	1	2.8	0.78	3.6
2.3	0	0.0	0.00	0.0

TABLE IV. The volume of H_2 gas was measured based on the current within 1 hour at a concentration of 8% KOH.

V_{cell} (Volt)	I_{cell} (Ampere)	Power (Watt)	Measurement H_2 gas volume (Liter)	Watt/Liter H_2
4.8	10	47.8	8.48	5.6
4.5	9	40.8	7.20	5.7
4.3	8	34.3	6.90	5.0
4.1	7	28.9	5.96	4.9
3.8	6	22.7	5.50	4.1
3.5	5	17.7	4.62	3.8
3.3	4	13.2	2.97	4.4
3.1	3	9.4	2.60	3.6
2.9	2	5.7	1.82	3.1
2.6	1	2.6	0.87	3.0
2.3	0	0.0	0.00	0.0

TABLE V. The volume of H_2 gas was measured based on the current within 1 hour at a concentration of 12% KOH.

V_{cell} (Volt)	I_{cell} (Ampere)	Power (Watt)	Measurement H_2 gas volume (Liter)	Watt/Liter H_2
3.9	10	38.8	7.56	5.1
3.7	9	33.5	7.50	4.5
3.6	8	28.5	7.30	3.9
3.5	7	24.3	6.20	3.9
3.3	6	19.5	5.25	3.7
3.1	5	15.5	4.28	3.6
2.9	4	11.7	3.50	3.4
2.8	3	8.5	2.73	3.1
2.7	2	5.3	1.55	3.4
2.5	1	2.5	0.78	3.2
2.3	0	0.0	0.00	0.0

TABLE VI. The volume of H_2 gas was measured based on the current within 1 hour at a concentration of 16% KOH.

V_{cell} (Volt)	I_{cell} (Ampere)	Power (Watt)	Measurement H_2 gas volume (Liter)	Watt/Liter H_2
3.5	10	35.3	8.23	4.3
3.4	9	30.6	7.20	4.3
3.3	8	26.3	6.16	4.3
3.2	7	22.4	5.37	4.2
3.0	6	18.2	5.30	3.4
2.9	5	14.6	4.41	3.3
2.8	4	11.2	3.27	3.4
2.7	3	8.1	2.25	3.6
2.6	2	5.1	1.58	3.3
2.4	1	2.4	0.77	3.2
2.3	0	0.0	0.00	0.0

V. CONCLUSION

Hydrogen produced from renewable energy sources (solar energy) electrolytically, can be considered as renewable hydrogen, is environmentally friendly, and does not cause greenhouse gas emissions. From the results of the tests that have been carried out, the volume of hydrogen production is influenced by the amount of current applied to the cell, the concentration of KOH also affects the production efficiency, where the concentration of 8% KOH with a current of 1 ampere has the best efficiency in electrolytic hydrogen production.

REFERENCES

[1] Julia Dehm. (2017). Post Paris reflections : fossil fuels, human rights and the need to excavate new ideas for climate justice. Journal of Human Rights and the Environment, Vol. 8 No. 2, September 2017. Pages : 280–300
[2] Keston K. Perry. (2020). For politics, people, or the planet? The political economy of fosil fuel reform, energi dependence and climate policy in Haiti. Elsevier. Energi Research & Social Science 63 (2020) 101397
[3] Soo Min Lee, Yeon-Su Kim, Wanggi Jaung, Sitti Latifah, Mansur Afifi, Larry A. Fisher. (2015). Forests, fuelwood and livelihoods—energi transition patterns in eastern Indonesia. Elsevier. Energi Policy 85 (2015). Pages : 61-70
[4] Boqiang Lin, Jiamin Ge. (2020). How does institutional freedom affect global forest carbon sinks? The analysis of transfer paths. Elsevier. Resources, Conservation & Recycling 161 (2020) 104982. Pages : 1-11
[5] H Y S H Nugroho, M Saad, W Isnan, A Suryaman. (2020). Performance assessment of KOMBI, energi-saving biomass stove : a gender friendly technology for rural and semi urban communities. IOP Conference Series : Earth and Environmental Science. Pages : 1-10
[6] H. Ishaq, I. Dincer. (2021). Comparative assessment of renewable energi-based hidrogen production methods. Elsevier. Renewable and Sustainable Energi Reviews 135 (2021) 110192. Pages : 1-13
[7] Furat Dawood, Martin peneliti, G.M. Shafiullah. (2019). Hydrogen production for energy : An overview. Elsevier. International Journal of Hydrogen Energy 45· Pages : 3847-3869
[8] Amit Singhania, Ashok N. Bhaskarwar. (2018). TiO2 as a catalyst for hydrogen production from hydrogen-iodide in thermochemical water-splitting sulfur-iodine cycle. Elsevier. Fuel Vol. 221. Pages : 393-398
[9] Amit Singhania, Ashok N. Bhaskarwar. (2017). Development of catalysts for hydrogen production from hydrogen iodide decomposition in thermochemical water-splitting sulfur-iodine cycle : A review. Catalysis Reviews Science and Engineering. Pages : 1-44
[10] Ishaq, Tehmeena & Yousaf, Maryam & Ahmad, Ijaz & Ahmad, Muhammad & Ikram, Mujtaba & Khan, Muhammad & Qayyum, Ayesha. (2020). Photo-assisted splitting of water into hydrogen using visible-light activated silver doped g-C3N4 & CNTs hybrids. International Journal of Hydrogen Energy. 45. 10.1016/j.ijhydene.2020.08.191
[11] Peharz, Gerhard & Frank, Dimroth & Wittstadt, Ursula. (2007). Solar hydrogen production by water splitting with a conversion efficiency of 18%. International Journal of Hydrogen Energy. 32. 3248-3252. 10.1016/j.ijhydene.2007.04.036
[12] F. E. Chakik, M. Kaddami and M. Mikou, "Optimization of physico-chemical parameters of hydrogen production by electrolysis of water," 2018 Renewable Energies, Power Systems & Green Inclusive Economy (REPS-GIE), 2018, Pages : 1-6
[13] Rusdianasari, Yohandri Bow, Tresna Dewi. (2018). HHO Gas Generation in Hydrogen Generator using Electrolysis. (ICoSITeR) 2018. IOP Conf. Series : Earth and Environmental Science 258 (2019) 012007. Pages : 1-9
[14] A. Nicita, G. Maggio, A.P.F. penelitiloro, G. Squadrito. (2020). Green hydrogen as feedstock : Financial analysis of a photovoltaic-powered electrolysis plant. Elsevier. International Journal of Hydrogen Energy Volume 45, Issue 20, 14 April 2020. Pages : 11395-11408
[15] Agata Godula-Jopek. (2015). Hydrogen production : by electrolysis. Weinheim, Germany : Wiley-VCH, 2015. Pages : 36
[16] N.A. Burton, R.V. Padilla, A. Rose, H. Habibullah. (2021). Increasing the efficiency of hydrogen production from solar powered water electrolysis. Elsevier. Renewable and Sustainable Energy Reviews 135 (2021) 110255. Pages : 1-16
[17] Du H, Gu S, Liu R, Li C. (2016). Highly active and inexpensive iron phosphide nanorods electrocatalyst towards hydrogen evolution reaction. Int J Hydrogen Energy 2016;41 : 14272e8
[18] Wilberforce Awotwe, Tabbi & El-Hassan, Zaki & Nisar, Fawwad & Al Makky, Ahmed & Baroutaji, Ahmad & Carton, James & Olabi, Abdul Ghani. (2017). Developments of electric cars and fuel cell hydrogen electric cars. International Journal of Hydrogen Energy. 10.1016/j.ijhydene.2017.07.054
[19] David Jure Jovan, Gregor Dolanc. (2020). Can Green Hydrogen Production Be Economically Viable under Current Market Conditions. Energies 2020, 13, 6599; doi : 10.3390/en13246599. Pages 1-16

[20] Dobó, Zsolt & Palotas, Arpad. (2016). Impact of the current fluctuation on the efficiency of Alkaline Water Electrolysis. International Journal of Hydrogen Energy. Pages : 1-8
[21] Tom Jackson, Jack Challoner. (2017). The Periodic Table Book : A Visual Encyclopedia of the Elements. Dorling Kindersley. Pages : 18-21
[22] Bakhtyari, Ali & Makarem, Mohammad Amin & Rahimpour, M. R.. (2017). Hydrogen Production Through Pyrolysis. R. A. Meyers (ed.), Encyclopedia of Sustainability Science and Technology
[23] Farniaei M, Abbasi M, Rahnama H, Rahimpour MR, Shariati A. (2014). Syngas production in a novel methane dry reformer by utilizing of tri-reforming process for energy supplying : modeling and simulation. J Nat Gas Sci Eng 20. Pages : : 132–146
[24] Rahimpour MR, Hesami M, Saidi M, Jahanmiri A, Farniaei M, Abbasi M. (2013). Methane steam reforming thermally coupled with fuel combustion : application of chemical looping concept as a novel technology. Energy Fuel 27. Pages : : 2351–2362
[25] Soltani, Reza & Rosen, Marc & Dincer, Ibrahim. (2014). Assessment of CO2 capture options from various points in steam methane reforming for hydrogen production. International Journal of Hydrogen Energy. 39. 10.1016/j.ijhydene.2014.09.161
[26] Zhijie Chen, Wei Wei and Bing-Jie Ni. (2021). Cost-effective catalysts for renewable hydrogen production via electrochemical water splitting : Recent advances. Elsevier. Current Opinion in Green and Sustainable Chemistry 2021, 27 : 100398. Pages 1-8
[27] Yu Luoa, Xiao-yu Wu, Yixiang Shi, Ahmed F. Ghoniem, Ningsheng Cai. (2018). Exergy analysis of an integrated solid oxide electrolysis cell-methanation reactor for renewable energy storage. Elsevier. Applied Energy 215 (2018). Pages 371–383
[28] Buttler, Alexander & Hartmut, Spliethoff. (2017). Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids : A review. Renewable and Sustainable Energy Reviews
[29] Fatima ezzahra Chakik, Mohammed Kaddami a, Mohammed Mikou. (2017). Effect of operating parameters on hidrogen production by electrolysis of water. Elsevier. International Journal of Hidrogen Energi (2017). Pages : 1-8
[30] Diogo M. F. Santos, César A. C. Sequeira, José L. Figueiredo. (2013). Hidrogen production by alkaline water electrolysis. Quim. Nova, Vol. 36, No. 8. Pages : 1176-1193
[31] Xuefeng Guo, Shanyong Chen, Yu Zhang, Mingjiang Xie, Jian Chen. (2020). Electrochemical Water Electrolysis Fundamentals and Technologies. Alkaline Liquid Electrolyte for Water Electrolysis. CRC Press Taylor and Francis Group. Pages 27-68
[32] Md Mamoon Rashid, Mohammed K. Al Mesfer, Hamid Naseem, Mohd Danish. (2015). Hidrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis. International Journal of Engineering and Advanced Technology (IJEAT) ISSN : 2249 – 8958, Volume-4 Issue-3, February 2015. Pages : 80-93
[33] Eric M. Garcia, and Hosane A. Taroco. (2018). Water Electrolysis Anode Based on 430 Stainless Steel Coated with Cobalt Recycled from Li-Ion Batteries. MDPI. Recycling 2018, 3, 42. Received : 4 August 2018; Accepted : 4 September 2018; Published : 6 September 2018. Pages : 1-10.
[34] Balaji Subramanian, Venugopal Thangavel. (2020). Analysis of onsite HHO gas generation sistem. Elsevier. International Journal of Hidrogen Energi, https :// doi.org/10.1016/j.ijhydene.2020.03.159. Pages : 1-14
[35] Joseph Burdick And Philip Schmidt. Install Your Own Solar Panel : Designing And Installing A Photovoltaic System To Power Your Home. Storey Publishing. Pages 21-22.
[36] Neha Adhikari. (2018). Design of solar photovoltaic energy generation system for off-grid applications. Int. J. Renewable Energy Technology, Vol. 9, Nos. 1/2, 2018. Pages 198-207
[37] Demirdelen, Tuğçe & Ekinci, fırat & Doğru Mert, Başak & Karasu, İlyas & Tümay, Mehmet. (2020). Green touch for hydrogen production via alkaline electrolysis : The semi-flexible PV panels mounted wind turbine design, production and performance analysis. International Journal of Hydrogen Energy. 45. 10.1016/j.ijhydene.2020.02.007
[38] Kovač, Ankica & Marciuš, Doria & Budin, Luka. (2018). Solar hydrogen production via alkaline water electrolysis. International Journal of Hydrogen Energy. 44. 10.1016/j.ijhydene.2018.11.007
[39] Akhmad Hidayatno, Andri D. Setiawan, I Made Wikanpeneliti Supartha, Armand O. Moeis, Irvanu Rahman, Eddie Widiono. (2020). Investigating policies on improving household rooftop photovoltaics adoption in Indonesia. Journal Pre Prof. Pages 1-25
[40] Dinita Setyawati. (2020). Analysis of perceptions towards the rooftop photovoltaic solar system policy in Indonesia. Elsevier. Energy Policy 144 (2020) 111569. Pages 1-10
[41] Ranjit Kumar. (2011). Research Methodology a step-by-step guide for beginners 3rd edition. SAGE Publications India Pvt Ltd. Pages : 18-19
[42] Yun Zheng, Jianchen Wang, Bo Yu, Wenqiang Zhang, Jing Chen, Jinli Qiao, and Jiujun Zhang. (2016). A review of high temperature co-electrolysis of H2O and CO2 to produce sustainable fuels using solid oxide electrolysis cells (SOECs): advanced materials and technology. The Royal Society of Chemistry 2017.
[43] Eric M. Garcia, and Hosane A. Taroco. (2018). Water Electrolysis Anode Based on 430 Stainless Steel Coated with Cobalt Recycled from Li-Ion Batteries. MDPI. Recycling 2018, 3, 42. Received: 4 August 2018; Accepted: 4 September 2018; Published: 6 September 2018. Page 1-10.
[44] Md Mamoon Rashid, Mohammed K. Al Mesfer, Hamid Naseem, Mohd Danish. (2015). Hidrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis. International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-4 Issue-3, February 2015. Page 80-93.
[45] Fatima ezzahra Chakik, Mohammed Kaddami a, Mohammed Mikou. (2017). Effect of operating parameters on hidrogen production by electrolysis of water. Elsevier. International Journal of Hidrogen Energi (2017), http:// dx.doi.org/10.1016/j.ijhydene.2017.07.015. Page 1-8..