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Feasibility Study of Green Hydrogen Production from Geothermal Power Plant

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***Abstract* - Fossil energy such as coal, gas, and oil are nonrenewable energy, and the use of fossil energy has negative effects in the environment. Global warming as one of the effects of the use of fossil energy encourages many countries to start using renewable energy. Geothermal energy and green hydrogen are an alternative energy to reduce the use of fossil energy. This study is to aim feasibility of using geothermal energy to produce green hydrogen. Simulation of the geothermal power plant system was carried out to evaluate the levelized cost of geothermal energy (LCOE) from Geothermal Power Plant (GPP). The results of the technical evaluation of the GPP, the LCOE are USD 7.52 c/kWh. Proton Exchange Membrane (PEM) technology is used to evaluate the price of green hydrogen production from geothermal power plants. The results of the technical and economic evaluation of GPP and PEM obtained a green hydrogen production price of USD 6.59 /KgH$_2$. LCOH sensitivity evaluation obtained a value range of USD 4.96 /KgH$_2$ to USD 8.23 /KgH$_2$. The feasibility price of Green Hydrogen with IRR values of 12%, 14%, and 16%, are USD 8.14 /KgH$_2$, USD 9.18 /KgH$_2$, and USD 10.3 /KgH$_2$. The NPV values of the 3 IRR scenarios are positive and PB for 9-11 years.**

Keywords: Green Hydrogen, Geothermal, PEM, LCOE, LCOH.

I. INTRODUCTION

High population growth and boost of industrialization of most of developing countries resulted the significant increase in fossil energy demand (Sui et al., 2019). Fossil energy such as coal, gas and petroleum will run out in time and the burning of fossil energy has caused negative effects such as weather change, clean water availability, land availability and impacts on human life (Phuoc-Anh et al., 2023). Diminishing fossil energy and accelerating global warming due to increasing greenhouse gas (GHG) emissions that produce carbon dioxide have prompted countries to make policies related to the environment and new renewable energy (Rahmouni et al., 2014).

Indonesia is one of the world's largest greenhouse gas emitters, and it has committed to achieving a 29%-41% reduction in carbon emissions by 2030 (Gunawan, 2020). Renewable electricity can be produced from wind, solar, hydropower, and geothermal energy (Phoumin et al, 2020).Geothermal energy is a highly reliable and sustainable renewable energy source that is independent of climate conditions (Bina et al., 2016).Geothermal energy can be used in three main ways: electricity generation, direct use of heat, and geothermal heat pumps (Lund and Boyd, 2015).

Indonesia's total geothermal energy potential is 23,965 Mwe consisting of resources of 9,339 Mwe and reserves of 14,626 Mwe (DEN, 2023). The Indonesian government targets to achieve 23% of renewable electricity generation by 2025, which as of 2021 has only reached 11.5% (PT. PLN, 2021). Indonesia's geothermal potential is spread across 356 Geothermal Working Areas (WKP). Sumatra Island has 101 WKP with a total geothermal potential of 9,460 Mwe with an installed capacity to date of 949 Mwe or 10% of its total potential (PT. PLN, 2021). Sumatra Island is the island with the largest potential in Indonesia. Therefore, geothermal power plants are one of the most potential energy sources to be developed in Indonesia.

Hydrogen as an environmentally friendly energy and industrial raw material that can be used for various applications that is shown in Figure 1. (Gunawan, 2022). Hydrogen in Indonesia is currently mostly produced from natural gas and is used for the industrial sector, especially as a raw material for fertilizers. The current demand for hydrogen in Indonesia is 1.75 million tons per year (IEA 2022), dominated by urea at 88%, ammonia at 4%, and oil refineries at 2%. Indonesia is gradually expected to develop and produce low-carbon hydrogen to replace hydrogen that is currently mostly produced from fossil energy (ESDM, 2024).

Various methods have been developed to produce hydrogen gas. These methods are steam methane reforming, electrolysis, coal gasification. (Yilmaz et al., 2015). Hydrogen production from water electrolysis is one of the most widely used methods in the world (Hadjiat et al., 2020).

This research will focus on looking at geothermal potential along with economic analysis of the cost of electricity generation from geothermal in Indonesia. The price of electricity generation is important in producing green hydrogen energy from electrolysis because the largest cost component of the electrolysis process is the cost of electricity apart from the cost of the hydrogen electrolyzer itself. This study assumes that the electrical energy generated from Geothermal Power Plant will be used 100% to produce green hydrogen. Thus, it is expected to get an idea for the price of green hydrogen production from geothermal.

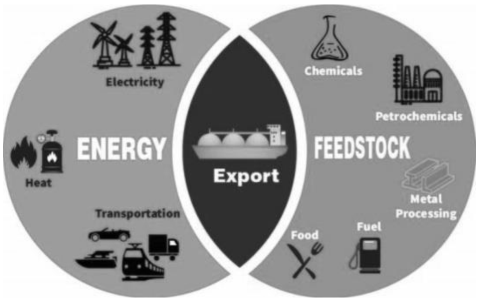


Figure 1: Hydrogen Application (Bruce, et al., 2018)

II. LITERATURE REVIEW

Geothermal is one of the clean and renewable energies that can be one of the cornerstones to achieve the NZE target of 2050 and help the process of decarbonizing the energy sector in the world in addition to other renewable energies such as solar power, hydropower, biomass, seawater power, and wind power. Geothermal development is highly dependent on the temperature of the geothermal source (IRENA, 2023).Geothermal temperatures are classified into three groups: high temperature (more than 150°C), medium temperature (90 - 150°C) and low temperature (below 90°C).High and medium temperature geothermal resources suitable for development as Geothermal Power Plants (GPP) are generally located in the Ring of Fire area as shown in Figure 2.

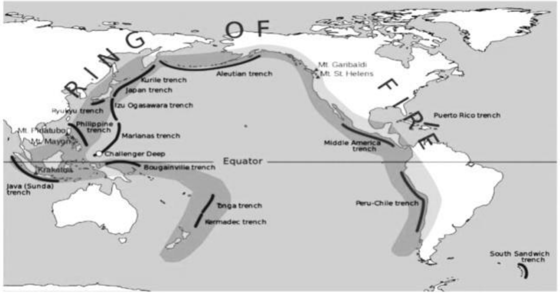


Figure 2: Ring of Fire (R. Archer, 2020)

Technically, the worldwide geothermal potential is 200 GW and of the 200 GW, the potential to be developed into geothermal power plants ranges from 70-80 GW spread across more than 20 countries (Pambudi, et al., 2023).

2.1 Geothermal Technology

Geothermal power plant technology currently consists of four commonly developed technology options, namely Dry Steam geothermal power plant, Flash geothermal power plant, Binary geothermal power plant, and Combined-cycle geothermal power plant (DiPippo, 2007).Geothermal in Indonesia is dominated by a two-phase system which is either a vapor dominated system, or a water dominated system. Vapor dominated systems are rare (Nisa, 2010).

Flash steam technology is the most widely used technology in the world today. Most types of geothermal fluids in the world and Indonesia in particular are two-phase fluids that are a mixture of steam and water (brine). There are two types of flash steam geothermal plants, namely Single-flash geothermal plants and Double-flash geothermal plants (DiPippo, 2007).

In the Double-flash GPP system, there are two separations of steam and water, namely the high pressure separation in the first separator and the brine coming out of the first separator will be separated again from the steam and brine in the low pressure separator. The main difference between single-flash GPP and double-flash GPP is that there is an additional low-pressure separator in double-flash GPP and also a low-pressure steam input to the steam. The scheme of Double-flash GPP can be seen in Figure 3.

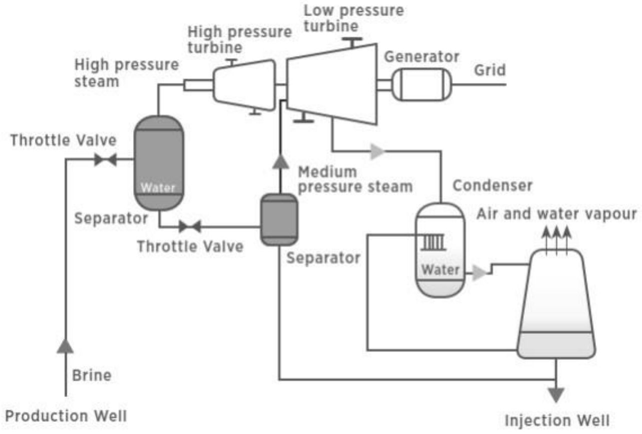


Figure 3: Double-flash GPP (IRENA, 2017)

Some geothermal plants in the world use Combined-cycle geothermal plants where flash geothermal systems or dry steam geothermal plants are combined with Binary geothermal plants (Yilmaz, et al., 2015). In principle, the separation of steam and brine fluid is carried out like a flash system, the steam will be used to rotate the steam turbine to generate electricity, and the existing brine will be used for the system in Binary GPP. The combination of these two geothermal technologies is used to increase the efficiency of geothermal plants. The schematic of Combined-cycle geothermal power plant can be seen in Figure 4

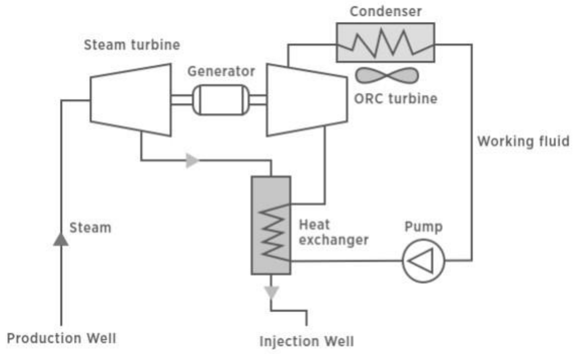
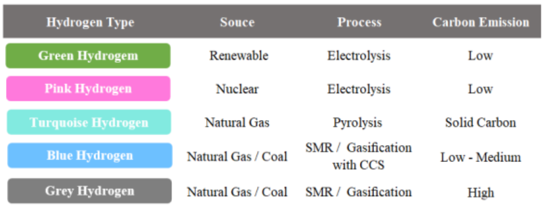


Figure 4: Combined-cycle GPP (IRENA, 2017)

2.2 Hydrogen

Green hydrogen is being developed by several countries to achieve the Net Zero Emission (NZE) target by 2050-2060. Hydrogen plays an important role in limiting global warming to 1.5ºC by 2050 (Hydrogen Council, 2021).The change in energy use from fossil energy to new and renewable energy is a response to the challenges of climate change and environmental impacts. From many studies, hydrogen is considered a major component in sustainable energy development plans that can significantly reduce air pollution, climate change and global warming (Yue, et al., 2021).

Some differences in hydrogen production methods depend on its origin such as water, natural gas, petroleum, and coal. Until now, the world's hydrogen production is still dominated by fossil feedstocks through steam methane reforming (SMR) and coal gasification processes (Gunawan, 2022).Hydrogen is a colorless gas, but there are several colors used to identify types of hydrogen. These colors indicate where the hydrogen energy source comes from, the production process and the resulting carbon emissions. There are five types of hydrogen colors identified in this paper. The colors of hydrogen can be seen in Figure 5.



Hydrogen Type	Souce	Process	Carbon Emission
Green Hydrogem	Renewable	Electrolysis	Low
Pink Hydrogen	Nuclear	Electrolysis	Low
Turquoise Hydrogen	Natural Gas	Pyrolysis	Solid Carbon
Blue Hydrogen	Natural Gas / Coal	SMR / Gasification with CCS	Low - Medium
Grey Hydrogen	Natural Gas / Coal	SMR / Gasification	High

Figure 5: Hydrogen Colour (IRENA, 2023)

2.3 Water Electrolysis

Water electrolysis is currently a mature technology applied in several industrial applications. The main advantage of this method is that the electricity used can come from new and renewable energy so that low-carbon or carbon-free results can be obtained (Zhou et al., 2022). Currently, there are four existing electrolyzer technologies: alkaline water electrolysis (AWE), proton-exchange membrane (PEM) electrolysis, the solid oxide electrolysis cell (SOEC), and anion-exchange membrane (AEM) electrolysis. AWE and PEM technologies are already in the commercial stage while SOEC and AEM are still in the laboratory experimental stage, but are promising in the future (IRENA, 2020).

PEM technology is easy to integrate and has a high conversion efficiency but requires a high initial cost. PEM technology is currently being developed to scale to several MW of electricity (Reksten, et al., 2022). The small size of the electrolysis cell makes PEM very flexible to be paired with renewable energy sources, which makes it very potential as a future electrolyzer option. PEM technology is highly efficient compared to other electrolyzers (Han, et al., 2020).

The cost of green hydrogen from electrolysis depends on several factors such as project location (access challenges to renewable electricity), electrolysis technology (AWE, PEM, SOEC, AEM, photocatalysis), electrolysis capacity and lifetime of the production facility. Currently the production cost of green hydrogen from electrolysis ranges from USD 2.28 - USD 7.39/kgH_2 (Yu, M., et al., 2021). Low electricity prices from renewable energy are key to obtaining competitive prices for green hydrogen (IRENA, 2020). Up to now, there is no electrolysis project of more than 100MW. The land requirement for electrolysis relies more on engineering estimation. The price table of hydrogen produced from renewable energy can be seen in table 1.

Table 1: Hydrogen Price from Renewable Energy

Electrolisys	Energy Source	Electricity Price ($/kWh)	H_2 Price ($/kg)	Source
PEM	Wind	-	9.37	Olateju et al. (2016)
PEM	*Solar Thermal - Natural Gas*	-	6.35	Boudries (2018)
PEM	*Solar PV*	0.02	12.6	Shaner et al. (2016)
PEM	Geothermal	0.02	2.39	Kanoglu et al. (2011)
AEM	Wind	0.06	8.01	Bertuccioli et al. (2014)
SOEC	Geothermal	0.017	2.13	Kanoglu et al. (2011)
PEM	Geothermal	0.1253	5.51	Awaleh et al. (2021)
SOEC	Geothermal	0.1253	4.56	Awaleh et al (2021)

III. METHODOLOGY

3.1 Geothermal Selection

The selection of geothermal technology for the development of geothermal power plants will determine the amount of electrical energy that can be generated. Geothermal sources with high temperature and high enthalpy have a positive effect on the energy produced. Geothermal resources with water dominance and medium enthalpy are used for the calculation of three geothermal technology scenarios, namely, 2x55MW Single Flash, 1x110MW Double Flash, 110MW Combined-Cycle PLTP.

Geothermal technology is influenced by the characteristics of the production wells (pressure and enthalpy) and other factor. The technical parameters used in this study are in table 2.

Table 2: Geothermal Parameter

Parameter	Value			Unit
	Low	Medium	High	
Process				
Installed Capacity		110		MW
Capacity Factor		95		%
Enthalphy	1,100	1,300	1,500	Kj/Kg
Wellhead Pressure	10	11	12	Bara
Flow rate		100		Kg/s
Temperature		> 225		°C
NCG (Low)	0	1	2	%
Pressure Drop at Separator		1		barg
Pressure drop Separator to plant interface		1		barg
Drilling				
Exploration Drilling		50		%
Production Confirmation Drilling		75		%
Injection Confirmation Drilling		90		%
Production Development Drilling		90		%
Injection Development Drilling		90		%
Exponential Decline Rate		2.5		%
Drilling Cost	2,733	3,432	4,549	USD/m
Drilling Depth	1,600	2,200	2,800	m

Above geothermal parameters used to calculate the net electricity output from three geothermal technology scenarios, namely, 2x55MW Single Flash, 1x110MW Double Flash, 110MW Combined-Cycle PLTP.

3.2 PEM Electrolyzer

The installed capacity of Proton Exchange Membrane (PEM) Electrolyzer technology until 2023 is 30%, and the largest is Alkaline Water Electrolyzer (AWE) and with future predictions PEM technology will be greater than AWE (IEA, 2023). PEM technology is currently being developed because, (1) PEM manufacturing costs have decreased significantly in recent years, (2) PEM technology has a higher current density than AWE (~5x), (3) the efficiency of PEM can be 6% higher than AWE (Mayyas, et al., 2019).

From an economic point of view, PEM technology can provide greater advantages than AWE technology even though it requires more capital because PEM technology has a higher efficiency than AWE (McDonagh, et al., 2020). The technical and economic parameters used for PEM calculations in this study are shown in Table 3.

Table 3: PEM Parameter

Parameter	Value	Unit
Stack power	1000 100000	kW
Parasitic Load	100 10000	kW
Gross system power	1100 110000	kW
	1.1 110	MW
Operating Pressure	<70	Bar
Operating Temperature	50–80	◦C
Electrical efficiency (system)	50–83	kWh/kg H_2
Lifetime (stack)	50 000–80 000	h
Capital costs minimum 10 MW	750-1300	USD/kW
PEM Capacity	110	MW
Electrical efficiency (system)	66.5	kWh/kg H_2
Lifetime (stack)	7.4	years
CAPEX	1025	USD/kW
OPEX	3%	/Annum
Hydrogen storage	6240	USD/MW per hour
Discount Rate	8.75%	%

The PEM Parameters used to calculate the levelized cost of hydrogen (LCOH) and the economic analysis for this study.

All electricity from Geothermal Power Plant will be used for electrolysis process using PEM Technology. This study will using maximum capacity of 110MW electricity for 110MW Electrolizer Plant. Geothermal energy analysis and hydrogen production analysis on this study are calculated by using Microsoft Excel.

3.3 Economic Analysis

Economic analysis is required to assess the feasibility of a project. Each project has different characteristics from one another. Engineering and the characteristics of a production system have a significant influence on the economic value of a project (Sanyal, 2009). The economic analysis of a project requires parameters to measure the feasibility of a project. The parameters used to measure the feasibility of green hydrogen energy development projects from geothermal power plants in this paper include: Levelized cost of geothermal electricity (LCOE), Levelized cost of hydrogen (LCOH), Net Present Value (NPV), Internal rate of return (IRR) and Payback Period (PB).

LCOE and LCOH are standard methods for estimating energy costs over the life of a project and are used to look at the cost of energy such as coal, solar, wind, geothermal and hydrogen (Gareth T. Cooper, et al., 2010). The LCOE and LCOH equations are as follows:

$$LCOE = \frac{\sum_{t=1}^{n}\frac{CAPEX\ GPP+OPEX\ GPP}{(1+r)^t}}{\sum_{t=1}^{n}\frac{Et}{(1+r)^t}} \tag{1}$$

$$LCOH = \frac{\sum_{t=1}^{n}\frac{CAPEX\ Hydrogen+OPEX\ Hydrogen}{(1+r)^t}}{\sum_{t=1}^{n}\frac{H_2}{(1+r)^t}} \tag{2}$$

Net Present Value (NPV) is the sum of all present values (PV) of a series of cash flows over time. The NPV method is one of the methods to assess the feasibility of a project. A project is said to be feasible if its NPV value is greater than zero and vice versa, if the NPV value is less than zero, then the project can be said to be economically unfeasible. The NPV method is not commonly used in estimating geothermal feasibility due to the uncertainty of geothermal costs and the lack of historical data (Gareth T. Cooper, et al., 2010). However, by using the NPV method, the economic analysis of geothermal feasibility is still feasible with the caveat that an NPV of less than zero may not mean that a geothermal project is not feasible. The NPV equation is as follows:

$$NPV = \sum_{t=1}^{n} \frac{Revenue_t - OPEX}{(1+r)^t} - CAPEX \qquad (3)$$

Internal rate of return (IRR) is the interest rate that will cause the NPV value to equal zero. If the IRR value is higher than the interest rate, the project value is said to be feasible. The IRR equation is as follows:

$$NPV = \sum_{t=0}^{n} \frac{Cash\ flow_t}{(1+IRR)^t} = 0 \qquad (4)$$

Payback Period (PB) is the time required to earn revenue to recover the capital cost or CAPEX. Assuming that the net revenue from year to year during the operating period is fixed, the PB equation is as follows:

$$PB = \frac{CAPEX}{Annual\ Revenue} \qquad (5)$$

IV. RESULTS AND DISCUSSIONS

4.1 GPP Technology

The table 4 showing the result of geothermal electricity generated from three geothermal technology selection. The analysis result of Single Flash GPP with a capacity of 2x55 MW (gross), the internal load required for generation is 2.6 MW for each unit. For 2 units a total of 5.6 MW is required so that the total electrical energy generated for Single Flash PLTP is 103.6 MW (Net).The analysis result of Double Flash GPP with a capacity of 1x110 MW (gross), the internal load required for generation is 5.6 MW for 1 unit. The total electrical energy generated for Double Flash GPP is 104.4 MW (Net).From the analysis of GPP technology, the Double Flash GPP can produce greater net electrical energy compared to the other 2 types of GPP.

Table 4: GPP Technology Analysis

Parameter	Technology *Single Flash*	 *Double Flash*	 *Combined-Cycle*
GPP Capacity (*Gross*) (MW)		110	
Separator Pressure (bara)	10	HP 10 - LP 6	10
Turbine Pressure (bara)	8.8	HP 8.8 - LP 3.3	8.8
Total Drilled Wells	22	19	20
Total Production Wells	10	9	9
Total Injection Wells	7	6	8
Total Failed Wells	5	4	3
MW per Well	13.4	15.7	15.7
In-plant loads (MW)	6.4	5.6	7.6
GPP Capacity (*Net*) (MW)	**103.6**	**104.4**	**102.4**

4.2 Levelized Cost of Geothermal Electricity (LCOE)

The results of the LCOE analysis of the three scenarios 2x55MW Single Flash, 1x110MW Double Flash, and 110MW Combined-Cycle GPP, the LCOE price is USD 8.45 c/kWh, USD 7.52 c/kWh, and 7.66 c/kWhrespectively. The total cost required for the construction of GPP for each scenario is USD 530 Million, USD 470 Million, and USD 470 Million.

4.3 Levelized Cost of Hydrogen (LCOH)

With net electricity of GPP 104.4 MW and PEM Electrical efficiency (system) of 66.5 kWh/kg H_2, and 95% capacity, the PEM Electrolizer Plant in this study can produce 13,076,444 Kg H_2/year or 13,078 Ton H_2/year.

The results of the LCOH analysis using the reference electricity price of USD 7.52 c/kWh or USD 75.2 /MWh the price of green hydrogen production from Geothermal Power Plants in this study of USD 6.59 /KgH_2. The LCOH price determined from this study is still above the LCOH price of fossil power with CCUS of USD 3.6 /KgH_2 but still within the LCOH price range of new renewable energy. The largest component for hydrogen production is from the electricity price, followed by the price of the electrolyzer and hydrogen storage at 77%, 20%, and 3% of the total CAPEX required to produce Green Hydrogen from Geothermal Energy.

4.4 Sensitivity analysis

Sensitivity analysis was conducted to determine the effect of the parameters used in the calculation of LCOH. The parameters that are significant to LCOH are electricity costs, electrical efficiency of the electrolyzer, and discount rate.

The analysis of the three parameters shows that the cost of hydrogen production or LCOH can decrease to USD 4.96 /KgH_2 if the efficiency value of the electrolyzer system used is high. For the parameters of discount rate and electricity cost, the LCOH value is USD 6.25 /KgH_2 and USD 6.05 /KgH_2 respectively. Details of the LCOH value with sensitivity parameters can be seen in table 5.

Table 5: LCOH Sensitivity Analysis

Parameter	Electrical Efficiency (system)	Discount Rate	LCOE
Low	\$8.23	\$6.05	\$6.25
Medium	\$6.59	\$6.59	\$6.59
High	\$4.96	\$7.16	\$7.14

4.5 Economic analysis

IRR is a key parameter often used by geothermal power plant developers to assess investment feasibility. The higher the IRR value of a project, the better profit it will generate, while conversely, the lower the value of the project, the less profit it will earn. The IRR target for this study is assumed to be 12% to 16%. IRR can also be interpreted as the discount rate value that will make the NPV equal to zero. The discount rate used in this study is 7.5% to 10%, so the IRR value must be greater than the discount rate.

From the analysis, it is found that to achieve the IRR target of 14%, the selling price of hydrogen produced is USD 9.18 /KgH_2 with a positive NPV value of 264.1 million USD and PB for 9 years. For a lower IRR target of 12%, the selling price of hydrogen is USD 8.14 /KgH_2 with a positive NPV of 157.5 million USD and a PB of 11 years. For a higher IRR target of 16%, the hydrogen selling price is USD 10.3 /KgH_2 with a positive NPV value of 378.2 million USD and a PB for 9 years.

V. CONCLUSION

The study's main findings are summarized below:

1. The most optimum Geothermal Power Plant (PLTP) technology to develop is Double Flash technology with the development of 1 unit of 110 MW capacity. The GPP can produce 104.4 MW of clean electrical energy with an electrical energy generation price or LCOE of USD 7.52 c/kWh.
2. Green Hydrogen production price from GPP with PEM Electrolyzer technology was determined to be USD 6.59 /KgH_2. Sensitivity analysis of the LCOH get the price of USD 4.96 /KgH_2 and the highest price of USD 8.23 /KgH_2. The LCOH value from this study is still above the LCOH price of fossil power with CCUS of USD 3.6 /KgH_2.
3. To have economic feasibility, the selling price of Green Hydrogen from Geothermal Power Plant with IRR values of 12%, 14%, and 16%, the price of H_2 is USD 8.14 /KgH_2, USD 9.18 /KgH_2, and USD 10.3 /KgH_2 respectively. NPV value of 3 IRR scenarios get positive value and PB for 9-11 years.

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