

TECHNO-ECONOMIC OF HYDROGEN PRODUCTION WITH BRINE UTILIZATION TECHNOLOGY AT ULUBELU GEOTHERMAL POWER PLANT

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Received: 22/04/2026 | Revised : 01/05/2026 | Accepted: 15/05/2026 | Published :16/06/2026

Abstract

Indonesia's substantial geothermal potential, particularly at the Ulubelu Geothermal Working Area, offers a strategic opportunity for green hydrogen production by utilizing brine energy that is currently reinjected into wells. This study aims to analyze the techno-economic feasibility of an integrated hydrogen production system at Ulubelu Geothermal Power Plant Units 3 and 4, utilizing Thermolectric Generator (TEG), Organic Rankine Cycle (ORC), and a combined TEG+ORC configuration to convert brine thermal energy into electricity for powering a Proton Exchange Membrane Electrolyzer (PEME) with a capacity of 1000 kg/day. The methodology includes thermodynamic modeling based on mass, energy, and exergy balance under steady-state conditions, as well as economic investment analysis encompassing Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), and Levelized Cost of Hydrogen (LCoH) under two electricity price scenarios (0.075 USD/kWh and 0.126 USD/kWh). The results show that cooling tower and PACWP modifications successfully provide 102.94 kg/s of cooling water per unit with an additional power consumption of 88 kW, reducing cooling water temperature from 38.8°C to 28°C and increasing cooling tower exergy efficiency from 94.92% to 98.22%. The PEM electrolyzer system achieves an energy efficiency of 86.6% and an exergy efficiency of 3.4%, producing 1079 kg H₂/day and 8628 kg O₂/day. Economically, the ORC configuration consistently delivers the best performance, with the lowest LCoH of 4.16 USD/kg (at 0.126 USD/kWh) and 5.06 USD/kg (at 0.075 USD/kWh), the highest IRR of 15.51% – 20.31%, and the fastest payback period of 6 – 7 years. In contrast, the TEG+ORC combination yields the highest LCoH (6.9 – 7.73 USD/kg) and the longest payback period (9 – 11 years). It is concluded that the ORC-based brine-to-hydrogen system is the most techno-economically viable option for hydrogen production at the Ulubelu Geothermal Power Plant.

Keywords: Green Hydrogen, Geothermal, Hydrogen Production, Techno economic

INTRODUCTION

Indonesia possesses substantial geothermal potential, estimated at approximately 28 – 29 GW across 312 fields, positioning geothermal power as a strategic backbone for low-emission energy supply and enabling synergies with hydrogen production workflows (Gutiérrez-Negrín, 2024). Beyond capacity, advances in exploration technologies and the deployment of Geothermal Power Plants (GPPs) create opportunities to integrate geothermal heat and electricity into hydrogen pathways. These include supplying electricity for electrolysis and utilizing low-grade geothermal heat to improve overall plant efficiency and cost-effectiveness (Montesdeoca-Martínez & Velázquez, 2023; Hadjiat et al., 2021). The Ulubelu Geothermal Working Area in Indonesia exemplifies brine-dominated resources containing high-temperature fluids suitable for energy conversion and potential hydrogen-related applications, reinforcing the link between local geothermal fluids and hydrogen production opportunities (Hadjiat et al., 2021). These assessments align with global energy transition trajectories that frame green hydrogen as a key vector for decarbonization, where abundant renewable energy and baseload renewable electricity can power electrolysis at scale (Yakubson, 2022; Vartiainen et al., 2021). Global hydrogen demand had already reached substantial levels by 2020 (approximately 90 Mt/year), with historical production dominated by fossil-based routes (brown hydrogen) and associated CO₂ emissions concentrated in the chemical sector (Panah et al., 2022; . Forward-looking analyses consistently indicate meaningful cost declines for green hydrogen produced via water electrolysis powered by renewables, driven by technology maturation, economies of scale, and favorable electricity costs;

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CAPEX is projected to fall markedly (on the order of 50–60% by 2030) while the Levelized Cost of Hydrogen (LCOH) continues to decline as technologies mature and deployment scales up (Panah et al., 2022; Li et al., 2024; Gómez & Castro, 2024). Electrolysis technologies—Alkaline Water Electrolysis (AWE), Polymer Electrolyte Membrane (PEM) electrolysis, and Solid Oxide Electrolysis Cells (SOEC)—offer distinct performance and material profiles, with PEM facing material constraints (notably iridium supply) that may limit deployment unless mitigated by higher current densities, reduced catalyst loading, or recycling strategies (Panah et al., 2022; Chung et al., 2024; Huang et al., 2023). In geothermal contexts, coupling electrolysis with consistently available low-cost electricity or heat-assisted cycles (e.g., ORC/TEG) can further reduce the effective cost of hydrogen, reinforcing the strategic rationale for geothermal-based hydrogen hubs (Panah et al., 2022; Dock et al., 2022; Bristowe & Smallbone, 2021). Most geothermal brines are characterized by low to medium enthalpy, which makes Organic Rankine Cycle (ORC) technology particularly suitable for converting geothermal heat into electricity or enabling heat integration for hydrogen production. Globally, ORC capacity installed for geothermal brines accounts for a substantial majority of installed ORC capacity, reported at 74.8% of all ORC capacity worldwide (Ghazvini et al., 2019). Thermoelectric Generators (TEGs), which generate electricity from temperature differences via the Seebeck effect, are presented as a modular, low-maintenance alternative to ORCs, though they typically entail higher upfront costs and deliver smaller power outputs (Azizi et al., 2022).

The literature consistently emphasizes converting geothermal heat—from low- to medium-enthalpy brines—into electricity via ORC or into heat/electricity integration for hydrogen production through electrolysis, with several studies highlighting the role of ORC and TEG in supporting baseload power at geothermal sites and enabling hydrogen production pathways (e.g., ORC-driven electricity to power PEM electrolysis or heat recovery for high-temperature electrolysis) Panah et al. (2022)(Dock et al., 2022)(Bristowe & Smallbone, 2021)(Hekim & Cetin, 2021)(Seiidhoseiny et al., 2022)(Ghaebi & Abbaspour, 2025). In field cases such as Ulubelu and analogous geothermal fields, exergy analyses indicate substantial brine energy potential that can supply ORC/TEG-based power to electrolysis systems, underscoring waste-to-energy opportunities that address electrolyzer baseload demand and improve overall system viability (Hekim & Cetin, 2021)(Seiidhoseiny et al., 2022)(Ghaebi & Abbaspour, 2025). Divergences among studies largely reflect site-specific conditions, technology maturity, and cost trajectories, but converge on the conclusion that integrating ORC/TEG with geothermal-powered electrolysis can materially enhance hydrogen production viability at appropriately designed sites Panah et al. (2022)(Dock et al., 2022)(Bristowe & Smallbone, 2021)(Hekim & Cetin, 2021)(Seiidhoseiny et al., 2022)(Ghaebi & Abbaspour, 2025).

Indonesia's abundant geothermal resources can underpin a viable green hydrogen economy, particularly when paired with ORC/TEG technologies that convert brine heat into reliable base-load electricity or heat for electrolysis, reducing intermittency concerns and potentially lowering the LCOH for hydrogen (Ghazvini et al., 2019; Zhou et al., 2022; Loni et al., 2021). Cost trajectories for electrolyzers and renewable electricity, along with ongoing improvements in materials and supply chains, suggest plausible pathways for green hydrogen to reach cost-competitiveness with fossil-derived hydrogen under policy support and scale-up (Panah et al., 2022; Li et al., 2024; Gómez & Castro, 2024; Zhou et al., 2022; Loni et al., 2021). However, achieving this vision requires overcoming regulatory fragmentation, ensuring sustainable land-use practices, and securing local social licenses, especially in regions where geothermal development intersects with protected forests or vulnerable communities (Kurnia et al., 2021; Faraldo & Byrne, 2024).

Future research should prioritize site-specific techno-economic assessments that quantify exergy, heat-to-power integration, and hydrogen production costs at Indonesian sites (e.g., Ulubelu), alongside policy design experiments and stakeholder engagement analyses to chart concrete deployment roadmaps and timelines for geothermal-based green hydrogen hubs (Zhou et al., 2022; Loni et al., 2021; Ghaebi & Abbaspour, 2025; Eyvazi, 2025). The Ulubelu GPP has an exergy potential of 48,025 kW in the form of brine (mud or liquid), which is currently reinjected into the well (Alimuddin et al., 2018). Adopting a waste-to-energy concept, geothermal brine should be able to generate electricity for the electrolysis process using ORC or TEG. Current national green hydrogen strategies have a gap in providing reliable, low-cost, baseload renewable electricity for electrolysis. Research into TEG-ORC integration at geothermal sites like Ulubelu is urgent to address this supply chain gap and establish a viable geothermal-based green hydrogen hub (Ghazvini et al., 2019; Zhou et al., 2022; Ghaebi & Abbaspour, 2025; Eyvazi, 2025).

Methods

In this study, the system modeling process was carried out by simulating the flash cycle system from the mass and energy balance data at the Ulubelu GPP Units 3 and 4. Modeling of the Ulubelu GPP system Units 3 and 4 by increasing the performance of the cooling tower fans in both units by increasing the mass rate of air that is sucked in to increase the mass of cooling water coming out of the cooling tower. The increasing demand for cooling water

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makes the performance of the PACWP (Packing Auxiliary Cooling Water Pump) also increase from previously only flowing cooling water to the intercondenser and Liquid Ring Vacuum Pump (LRVP), but also for cooling fluid to the TEG. Mass, energy and exergy balances for any control volume at steady state with negligible kinetic and potential energy changes can be expressed, respectively, by (Cengel, 2019)

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

$$\sum \dot{m}_{in} \cdot h_{in} = \sum \dot{m}_{out} \cdot h_{out} \tag{2}$$

$$\dot{E}_{x,heat} + \dot{W} = \sum \dot{E}_{x,out} - \sum \dot{E}_{x,in} + \dot{E}_{x,dest} \tag{3}$$

The integration system of the hydrogen production system at Ulubelu GPP schematically Figure 1 and working fluid data property state shown Table 1.

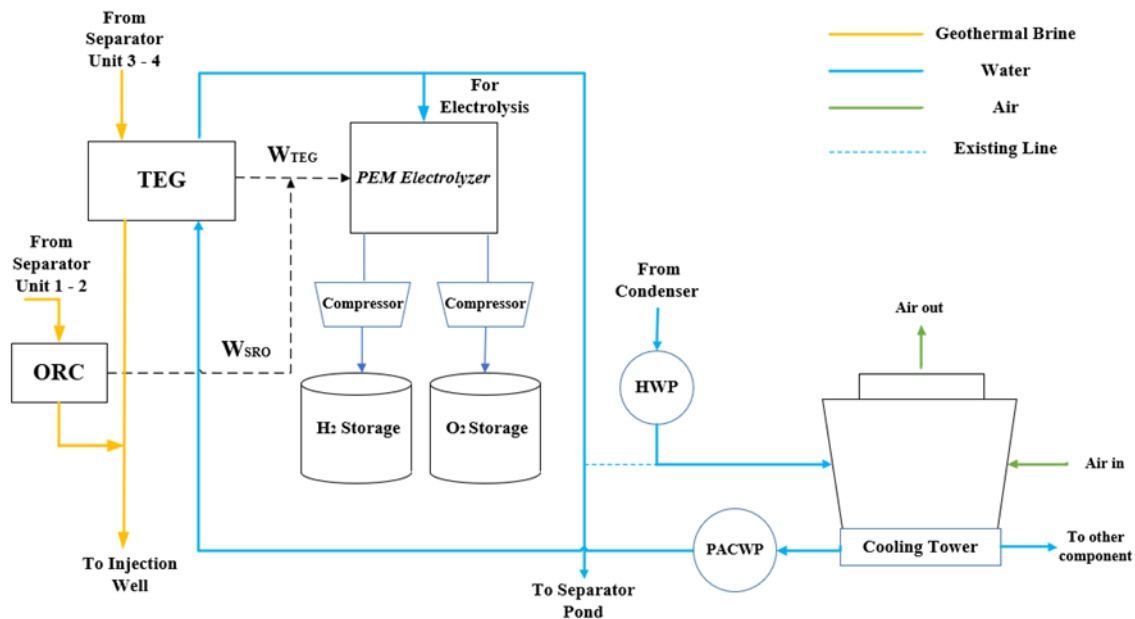


Figure 1. Hydrogen Production System Integrated Ulubelu GPP

Table 1. Working Fluid Data Property

Parameter	Separator Unit 1-2	Separator Unit 3-4	Water from PACWP	Air in	Air out
Mass (kg/s)	763.73	61.88	205.88	4811.87	4811.87
Pressure(MPa)	0.869	0.9	0.275	0.092	0.097
Temperature(°C)	174.02	175.4	28	26.7	38
Enthalpy(kJ/kg)	736.8	742.85	116.99	130	230

The results of the thermodynamic analysis of the Ulubelu Unit 3 and 4 GPP systems have energy and exergy efficiency of 9.6 % and 21%. The following are the results of the overall analysis of the system Specific Steam Consumption (SSC) of 6,823 kg/kWh and net power 55 Mwe. Analysis of increased fan power of cooling towers is expressed as Break Horse Power (BHP), respectively (Hensley, 2006)

$$BHP = \frac{Q \cdot p_t \cdot \rho}{33000.12} \tag{4}$$

Hydraulic power from PACWP can be expressed by.

$$P_{PACWP} = \rho \cdot g \cdot Q \cdot H \tag{5}$$

Head pump calculate only pressure head respectively by.

$$H = \frac{P_{out} - P_{in}}{\rho \cdot g} \tag{6}$$

2.1. Hydrogen Production System

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Hydrogen production modeling using water electrolysis method with PEME technology. The electrochemical process in the PEM Electrolyzer operates at constant pressure and temperature, where the maximum work equals the change in Gibbs energy. This study used PEM Electrolyzer with three models in a hybrid manner from three resources, namely TEG, ORC, and a combination of TEG and ORC were analyzed on a hydrogen production system with a capacity of 1078 kg/day. This study using PEM Electrolyzer with the brand Hydrogenics type Cummins HyLYZER Series with hydrogen capacity of 1000 kg/day. The total power requirement of the system is 2500 kW, including a water treatment system and hydrogen outlet pressure of 30 Bar. The modeling scheme is shown in figure 2.

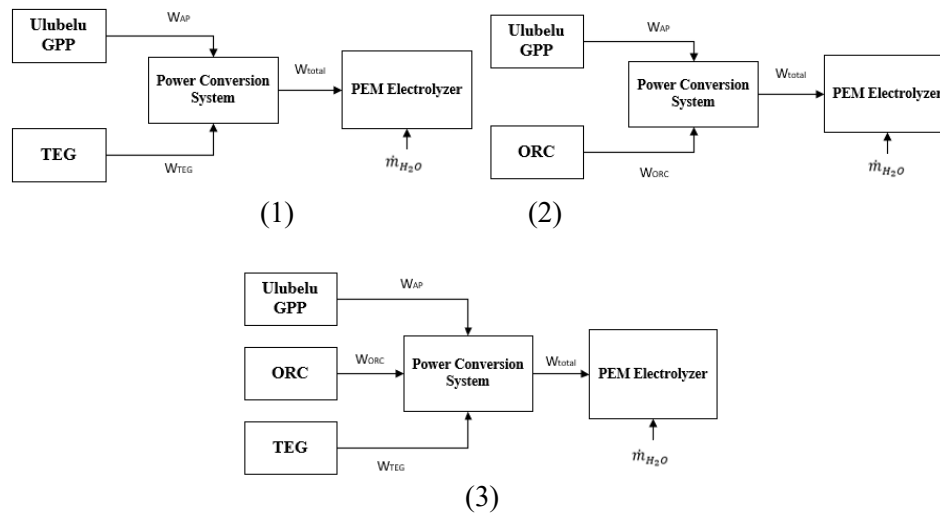


Figure 2. Schematic design of hydrogen production system (1) TEG (2) ORC (3) TEG+ORC

In the PEM electrolyzing system, the electrical power is needed in addition to the heat source for the electrochemical reactions in order to decompose the water into the hydrogen and oxygen. Electrical energy and exergy that occurs in the electrolysis process computed by (Ni et al., 2006):

$$\dot{W}_{PEM} = \dot{E}_{electric} = J \cdot V \quad (7)$$

So, the potential of the electrolyzer is computed by:

$$V = V_0 + V_{act,cat} + V_{act,an} + V_{ohm} \quad (8)$$

Where, V_0 is the reversible voltage, and is computed using the Nernst relation in the following form:

$$V_0 = 1,229 - 8,5 \times 10^{-4} (T_{PEM} - 298) \quad (9)$$

In addition, $V_{act;a}$ and $V_{act;c}$ are the activation losses of the anode and cathode, respectively. Also, V_{ohm} denotes the ohmic voltage loss, which is computed by:

$$V_{ohm} = J \times R_{PEM} \quad (10)$$

where R_{PEM} is the total ohmic resistance and J denotes the current density, and it is presented as:

$$R_{PEM} = \int_0^L \frac{dx}{\sigma(\lambda(x))} \quad (11)$$

In which, $\sigma(\lambda(x))$ is the local ionic conductivity that is presented as follows:

$$\sigma(\lambda(x)) = (0,5139\lambda(x) - 0,326) \cdot \exp\left(1268 \left(\frac{1}{303} - \frac{1}{T_{PEM}}\right)\right) \quad (12)$$

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here, $\lambda(x)$ indicates the water content of interface of the cathode-membrane. As well, $V_{act;a}$ and $V_{act;c}$ are the metrics of the activity of the electrodes and are presented in the following form the membrane in x location that is computed as:

$$\lambda(x) = \frac{(\lambda_{an} - \lambda_{cat})}{L} x + \lambda_{cat} \quad (13)$$

In this relation, L is the thickness of the membrane; λ_a denotes the water contents of the anode-membrane; λ_c is the interface of cathode membrane.

$$V_{act,i} = \frac{\bar{R}T}{F} \sinh^{-1} \left(\frac{J}{2J_{0,i}} \right) = \frac{\bar{R}T_{PEM}}{F} \ln \left(\frac{J}{2J_{0,i}} + \sqrt{\left(\frac{J}{2J_{0,i}} \right)^2 + 1} \right) \quad (14)$$

In which, $J_{0,i}$ indicates the exchange current density that determines the electrode's ability in electrochemical reactions, \bar{R} as an ideal gas constant of 8.314 J/(K mol) and it's computed by

$$J_{0,i} = J_i^{ref} \exp \left(- \frac{E_{act,i}}{\bar{R}T_{PEM}} \right) \quad (15)$$

Furthermore, the molar mass flow rates of the generated hydrogen and oxygen in the positive and negative electrodes are presented respectively as follows:

$$\dot{m}_{H_2} = \frac{J}{2F} M_{H_2} \quad (16)$$

$$\dot{m}_{O_2} = \frac{J}{4F} M_{O_2} \quad (17)$$

Hydrogen Low Heating Value (LHV) is 119,960 kJ/kg (Linstrom, 2025). The energetic and exergetic efficiencis in the thermal plants are often described by:

$$\eta_{en.PEM} = \frac{LHV \cdot \dot{m}_{H_2}}{W_{PEM} + E_{nH_2O}} \quad (18)$$

$$\eta_{ex.PEM} = \frac{\dot{E}_{xH_2}}{\dot{E}_{PEM} + \dot{E}_{x,H_2O}} \quad (19)$$

2.2. Economic Analysis

Investment feasibility analyses commonly employ Net Present Value (NPV) to evaluate profitability, defined as the present value of cash inflows minus cash outflows over the project lifetime; this approach is discussed across techno-economic analyses of hydrogen and renewable projects (Munther et al., 2024; Tijani, 2022; Majumdar et al., 2023).

$$NPV = \sum_{t=1}^N \frac{C_t}{(1+i)^t} - C_{inv} \quad (20)$$

Internal Rate Return (IRR), the value of the interest rate that generates the NPV is equal to the rate of return on the total current investment (Syazili et al., 2021).

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} (i_2 - i_1) \quad (21)$$

Payback Period, method of valuation against the calculated timeframe by accumulating net cash flow for return on investment (Dai et al., 2022).

$$PP = \sum_{t=1}^N (C_i - C_{inv})_t = 0 \quad (22)$$

Hydrogen selling price (LCoH). This research uses two different electricity price variations in the levelized Cost of Electricity (LCoE) for electricity cost (C_E).

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$$LCoH = \frac{C_E + CAPEX_{Total} + OPEX_{Total}}{\dot{m}_{H_2} \cdot L_f \cdot C_f \cdot \eta_{electrolyzer}} \quad (23)$$

Electrolyzer lifetime is 80.000 hours, electrolyzer efficiency 82%, and capacity factor 98%. Tax and interested rate assumed of 5% (Glenk et al., 2021). The selling price of electricity from the Ulubelu GPP is 0.075 \$/kWh and oxygen selling cost is 0.07 \$/kg (Adhikari et al., 2021). The cost of electricity required by the system (C_E) is calculated based on the loss of the selling value of electricity from the Ulubelu GPP to grid for one year to compensation power shortage of PEM Electrolyzer for 8000 annual hours of and it's computed by:

$$C_E = (W_{net} \cdot LCoE \cdot 8760) - ((W_{net} - W_{AP}) \cdot LCoE \cdot 8000) \quad (24)$$

The economic analysis calculates the CAPEX parameter as investment capital that must be spent to realize this project and OPEX as capital to carry out its functions within a certain period of time. Some of the component CAPEX costs in the design of this system are shown in Table 5 as follows.

Table 5. Systems CAPEX Value

Component	Price	Unit	Reference
PEM Electrolyzer ($CAPEX_{EI}$)	2,068	\$/kW	(Christensen, 2020)
TEG ($CAPEX_{TEG}$)	13,900	\$/kW	(Li et al., 2021)
Hydrogen and Oxygen Storage ($CAPEX_{str}$)	0,6	\$/kg	(Christensen, 2020)
Organic Rankine Cycle ($CAPEX_{SRO}$)	3,535,131	\$	(Widiana, 2017)
Balance of System ($CAPEX_{BOS}$)	50	\$/kW	(Christensen, 2020)
Hydrogen Compressor ($CAPEX_{comp.H2}$)	272,808	\$	(Christensen, 2020)
Oxygen Compressor ($CAPEX_{comp.O2}$)	186,932	\$	(Dincer, 2021)

In this study, a compressor is needed to drain hydrogen and oxygen into a storage tank. The storage tank is designed to hold hydrogen and oxygen with a total production capacity of 10 days. The compressor CAPEX is calculated based on the shaft power required to compress hydrogen from an electrolyzer outlet pressure of 30 bar to a pipeline inlet pressure of 700 bar. The idealized gas relationship is used to calculate the power requirement (Christensen, 2020). Analysis from literature results compressor CAPEX for hydrogen and oxygen is \$272808 and \$186932. OPEX costs in the design of this system are shown in Table 6 as follows.

Table 6. Systems OPEX Value

Component	Price	Unit	Reference
PEM Electrolyzer System ($OPEX_{EI}$)	40	\$/kW	(Christensen, 2020)
TEG System ($OPEX_{TEG}$)	4	% CAPEX	(Aromada et al., 2020)
Compressor ($OPEX_{comp}$)	4	% CAPEX	(Dincer et al., 2021)
ORC System ($OPEX_{ORC}$)	0.02	\$/kW	(Widiana, 2017)
Hydrogen dan Oxygen Storage ($OPEX_{str}$)	1	% CAPEX	(Gorre et al., 2020)
Balance of System ($OPEX_{BOS}$)	25	\$/kW	(Zakeri & Syri, 2015)

3. Results and Discussion

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Improved cooling tower performance is needed as a supplier of cooling water needs for TEG. Modifications are made by closing the water line to the cooling pond so that all of the water goes to the cooling tower. The water source for the TEG cold fluid comes from the cooling tower units 3 and 4. This causes additional air requirements to be sucked in by the cooling tower by increasing the fan's performance and PACWP to flow cooling water to the TEG. Assumption of total pressure (pt) before and after modification is same. Modifying the injection waterway and adding a line from PACWP for water distribution to TEG increases the power of PACWP and cooling tower fans due to the increased amount of air required. The simulation is carried out by taking the reinjected water and increasing the air capacity in the cooling tower to decrease cooling water temperature from 38,8°C to 28°C. The TEG design is designed to utilize a brine of 763.73 kg/s with cooling water of 205.88 kg/s resulting in a maximum TEG power of 538.25 kW (Resha.M et al, 2025). The exergy efficiency of the cooling tower increased from 94,92% to 98,22% for produce 102.94 kg/s of cooling water to the TEG per unit. Total exergo-economic loss of the Ulubelu GPP Unit 3 and 4 system was 8497 \$/day, decrease 6% from before it was modified. Hydrogen production modeling with a capacity of 1000 kg/day required 0.168 kg/s water from cooling fluid Thermoelectric generator for reverse osmosis process before used in PEM Electrolyzer. Specification PEM Electrolyzer can produce 1079 kg hydrogen per day or 500 Nm³/day with a power of 2500 kW (Hydrogenics, 2021)The electrochemistry analysis system have an electrolyzer power is 1700 kW and then produce 1079 kg H₂/day and 8628 kg O₂/day. Hydrogen and Oxygen compressor power is 58.7 kW and 31.5 kW. The capacity of hydrogen and oxygen tank is 10,000 kg and 80,000 kg for 10 days of a storage system. PEM Electrolyzer has energy efficiency and exergy efficiency of 86.6% and 3.4%, respectively. Losses power in the power conversion system is neglected and auxiliary power (WAP) is required from the hydrogen production modeling system shown in Figure 3.

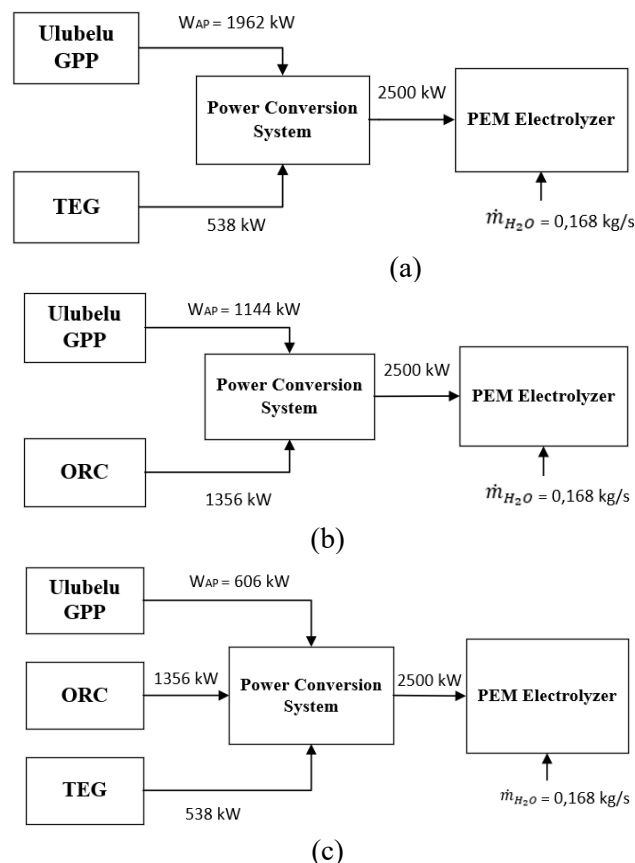


Figure 3. Power requirements each modeling system (a) TEG (b) ORC (c) TEG+ORC

Economic analysis uses a CAPEX (Capital Expenditure) parameter which serves as the capital expenditure needed for various purposes such as goods, factories, and parameter equipment for project economic calculations (Griner & Gordon, 1995). OPEX (Operating Expenses) parameters a reused to meet operational needs such as operator payroll, operations, and maintenance, energy costs, annual capital costs (raw materials, marketing, administration), and (Mytilinou & Kolios, 2019). CAPEX and OPEX component system shown in Table 7.

Table 7. CAPEX and OPEX

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Component	CAPEX (\$)	OPEX (\$/Year)
Thermoelectric Generator	7912254	316490
PEM Electrolyzer	3694574	68059
Compressor & Storage	543878	19001
Balance of System	31232	19963
Organic Rankine Cycle	3535131	216956

The financing components of CAPEX and OPEX each modeling have similar characteristics, with some facts such as is the ORC modeling has a CAPEX ORC equivalent CAPEX PEM Electrolyzer and then CAPEX TEG half of the CAPEX system at combination modeling (TEG+ORC). The investment feasibility analysis uses the purchase price of electricity from the Ulubelu GPP of 0.075 \$/kWh and 0.125 \$/kWh by finding

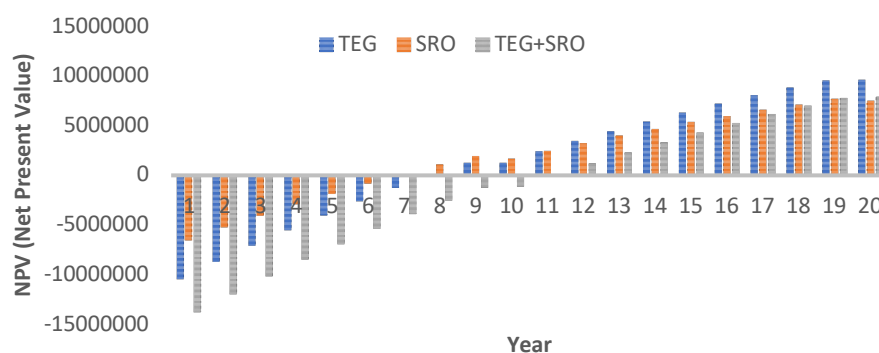


Figure 4. Net cash flow analysis at electricity price 0,075 \$/kWh

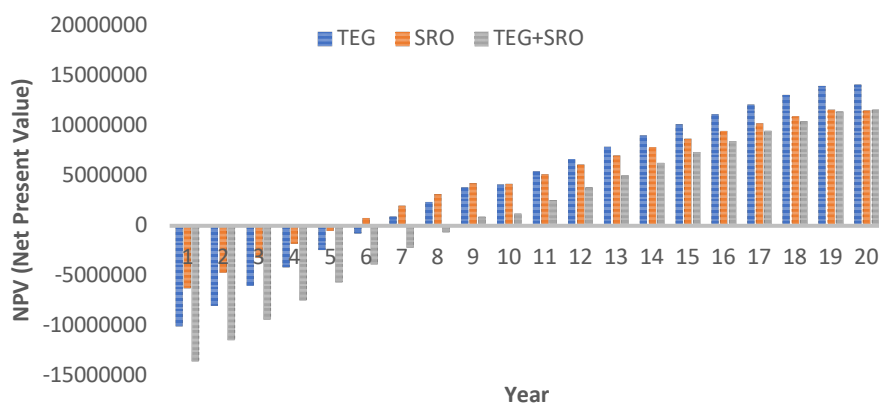


Figure 5. Net cash flow analysis at electricity price 0,126 \$/kWh

Based on Figure 4 and Figure 5, the best cash flow analysis schemes are ORC, TEG, and the combination of the two different electricity price values. Comparison result economic analysis shown on Table 8.

Table 8. Comparison of LCoH with Electricity Price

Schematic	TEG	ORC	TEG + ORC	TEG	ORC	TEG + ORC
Electricity Price (\$/kWh)		0.126			0.075	
NPV (\$)	9553059	7464287	7866152	14145138	11514893	11514893
IRR (%)	13.56	15.51	10.63	17.11	20.31	13.01
PP (Year)	8	7	11	7	6	9
LCoH (\$/kg)	5.88	4.16	6.9	6.91	5.06	7.73

Table 8 presents a comparison between the Levelized Cost of Hydrogen (LCoH) and electricity prices across different system configurations, namely TEG, ORC, and the combination of TEG + ORC, under two distinct electricity price scenarios (\$0.126/kWh and \$0.075/kWh). At the higher electricity price (\$0.126/kWh), the lowest LCoH value is achieved by the ORC system at \$4.16/kg, followed by TEG (\$5.88/kg) and TEG+ORC (\$6.90/kg). This outcome correlates with the highest IRR observed in the ORC system (15.51%) and its fastest payback period (7 years). Meanwhile, at the lower electricity price (\$0.075/kWh), all configurations show higher LCoH values, with ORC remaining the lowest (\$5.06/kg), followed by TEG (\$6.91/kg) and TEG+ORC (\$7.73/kg). Interestingly, despite the increase in LCoH, the NPV values for all configurations are significantly higher at the lower electricity price compared to the higher electricity price. This indicates that even though the production cost per kilogram of hydrogen is higher, the overall net profit may be greater due to other factors such as production scale or operational costs. Therefore, the selection of a system configuration should not rely solely on LCoH but also consider other economic indicators such as NPV, IRR, and payback period. The ORC system consistently demonstrates the best economic performance, both in terms of LCoH and IRR, making it the most efficient choice under both electricity price scenarios.

CONCLUSIONS

This study provides significant closure to the techno-economic dilemma of geothermal brine utilization by establishing the standalone Organic Rankine Cycle (ORC) configuration as the most viable foundational pathway for green hydrogen production at the Ulubelu plant, thereby offering a concrete strategic direction for Indonesia's geothermal hydrogen hub development. The research's primary contribution lies in demonstrating that technological simplicity and optimized auxiliary cooling integration outweigh the theoretical benefits of hybrid power generation systems in achieving economic feasibility under constrained geothermal power supply conditions. While this work successfully resolves the immediate question of configuration selection, it simultaneously exposes critical knowledge gaps that necessitate further investigation. Future research must address the comprehensive life cycle environmental impacts of ORC module deployment, explore dynamic electrolyzer load management in response to long-term brine thermodynamic fluctuations, and most critically investigate specific fiscal policy mechanisms required to bridge the remaining cost differential with fossil-derived hydrogen, thereby transitioning this system from a technically proven concept to a fully market-competitive reality.

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