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Cost Optimization Strategies for Geothermal Power Construction in Indonesia: Insights and Lesson Learned from the U.S. and Turkiye

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ABSTRACT

Indonesia possesses significant geothermal potential, historically concentrated in high-temperature fields. However, with these resources nearing saturation, future development is shifting towards the nation's abundant but underdeveloped low- and medium-temperature geothermal resources. This transition presents challenges in technology adoption and cost optimization, areas where Indonesia has limited experience. This paper conducts a comparative analysis of geothermal power plant construction practices and costs in Indonesia, the United States, and Turkiye—countries with extensive experience in utilizing low-to-medium temperature resources, particularly through binary cycle technology. By examining development cost trends, market competitiveness among power plant manufacturers, and contracting strategies, this study identifies key lessons for Indonesia. Findings indicate that Indonesia's development costs are notably higher than in the U.S. and Turkiye. The analysis suggests that adopting binary technology, fostering greater competition among turbine providers, developing local manufacturing capabilities, and optimizing EPC contracting strategies are critical pathways to reducing costs. These strategies, drawn from successful practices in the U.S. and Turkiye, offer a framework for Indonesia to enhance the economic viability and accelerate the development of its low-to-medium temperature

1 RESEARCH BACKGROUND

Indonesia has significant geothermal potential, but its development has been concentrated in high-temperature fields, especially with the successful operation of plants like Kamojang since 1983 (see Figure 1 for the brief history and updated target). However, as the high-temperature fields near saturation and face socio-political challenges in places like Lawu and Bedugul, attention is shifting towards low- and medium-temperature geothermal resources. These resources, while abundant, present unique challenges in technology adoption and cost optimization, which are key to accelerating their development.

Countries like the United States and Turkiye have leveraged advancements in geothermal technology, particularly in binary cycle plants suited for medium and low-temperature resources. These technologies have not only helped optimize the development costs but also improved the efficiency of power generation from geothermal fields. Given Indonesia's more limited experience with low-temperature geothermal development, this report will analyze power plant construction practices in the US and Turkiye for comparison with those in Indonesia. By examining cost trends and market competitiveness among power plant providers in these countries, the report identifies practices from the US and Turkiye that could be considered for adoption in Indonesia to help optimize development costs.

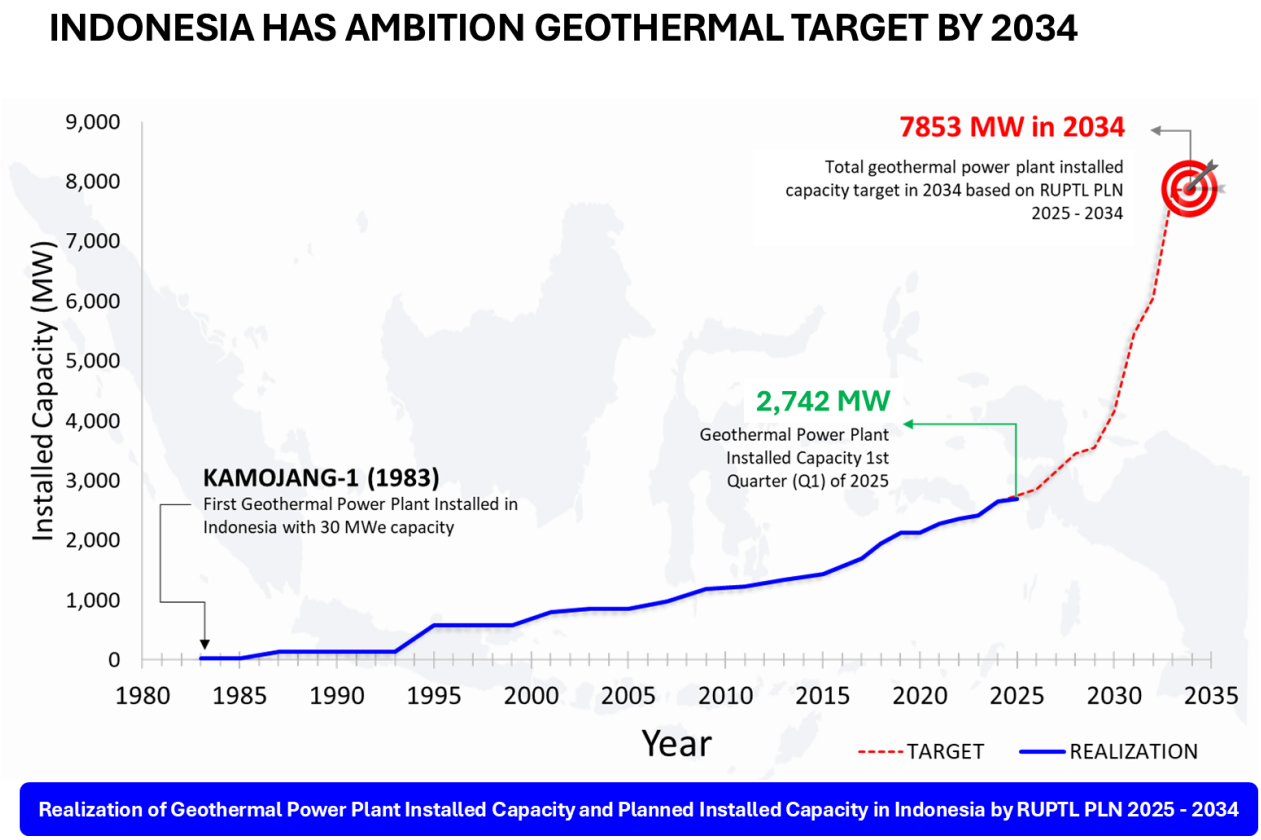


Figure 1. Realization of Geothermal Power Plant Installed Capacity and Planned Installed Capacity in Indonesia by RUPTL PLN 2025 - 2034

2 GEOTHERMAL DEVELOPMENT HISTORY IN INDONESIA

Since the first geothermal power plant (GPP) at Kamojang began operations in 1983, Indonesia has predominantly focused on high-temperature resources. As of December 2023, these resources account for a significant 2,375 MW, making up 99.5% of the country's total installed geothermal capacity (Figure 2). In contrast, development of low to medium temperature resources has been minimal, with only 10.79 MW installed across three units—merely 0.1% of the potential of these resources. The first medium-temperature GPP, commissioned in 2013 at Mataloko, has a capacity of 2.5 MW. The Sokoria field in Eastern Nusa Tenggara added two units in 2022 and 2023, contributing an additional 8.29 MW. This underscores that despite considerable potential, low to medium temperature geothermal resources remain underdeveloped in Indonesia.

The evolution of GPP technology in Indonesia has seen significant milestones and shifts in technology over the years. Starting with dry steam and single-flash technologies at the Kamojang plant, it took over three decades to embrace more advanced technologies. The first double-flash unit began operations in 2021 at Rantau Dedap, and the first combined flash-binary cycle was implemented at Sarulla Unit 1 in North Sumatra in 2017. The binary GPP technology, initially integrated into combined systems at Sarulla and Sokoria, saw standalone commercial use in 2022 at Lahendong in North Sulawesi. This gradual integration of advanced technologies demonstrates a shift towards more efficient geothermal exploitation.

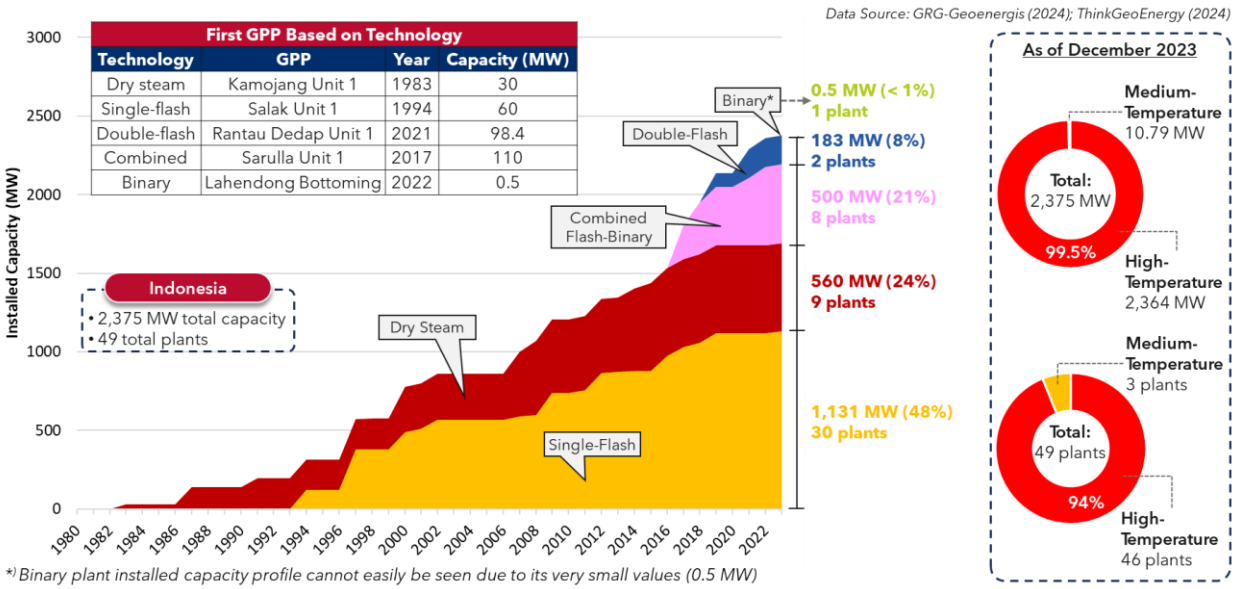


Figure 2. Evolution and distribution of geothermal power plant technologies in Indonesia from 1983 to 2023 (Brilian, et al., 2025)

2.1 Future Geothermal Project Pipeline in Indonesia

The Indonesian government, under the National Electricity Supply Business Plan (RUPTL) for 2021-2030, has outlined a strategic pipeline for future geothermal development, categorized into three distinct ranks based on their readiness and strategic importance:

1. **Rank 1**: Projects classified as National Strategic Projects (PSN) are integrated into the power grid (Neraca Daya) and are prioritized for development. This category includes 22 fields expected to contribute approximately 1.5 GW of power, with specified commissioning dates within the RUPTL 2021-2030 period.
2. **Rank 2**: Comprises projects also integrated into the power grid but without designated specific fields, expected to supply around 710 MW.
3. **Rank 3**: Encompasses potential projects not yet included in the power grid, with no expected commissioning dates stated, covering 80 fields with a total capacity of approximately 4.3 GW.

Figure 3 presents a detailed breakdown of Indonesia's future geothermal project pipeline based on temperature classification and regional distribution, aligned with the RUPTL 2021-2030. From this figure, it is evident that nearly two-thirds of the upcoming geothermal projects are in fields with medium and low temperatures. This is significant as Indonesia has limited experience in developing medium and low temperature fields, highlighting the need for focused attention and strategies to enhance capabilities in these areas.

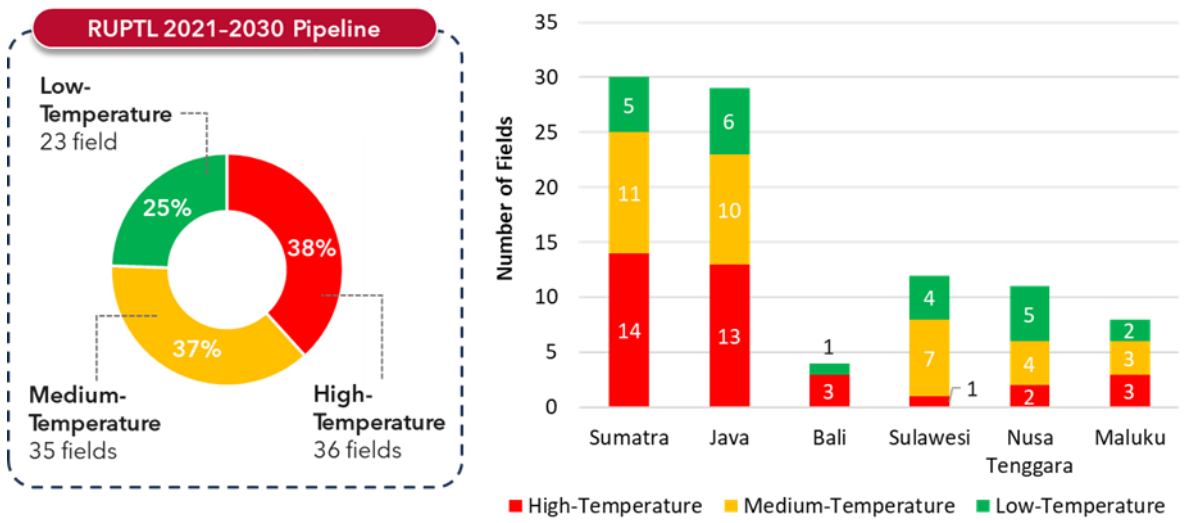


Figure 3. Resource temperature classification of future geothermal project pipeline based on RUPTL 2021-2030 (Brilian, et al., 2025).

For Rank 1 projects, the main focus is still on the high-temperature fields (Figure 4) but start the shift toward exploring low to medium temperature fields, reflecting a diversification in geothermal resource development strategies. This trend is evident across various regions, with Java focusing significantly on medium-temperature explorations and Sumatra and Nusa Tenggara both emphasizing high and medium-temperature projects.

Furthermore, a nuanced analysis of Rank 1 projects reveals a primary focus on high-temperature fields, yet a notable shift

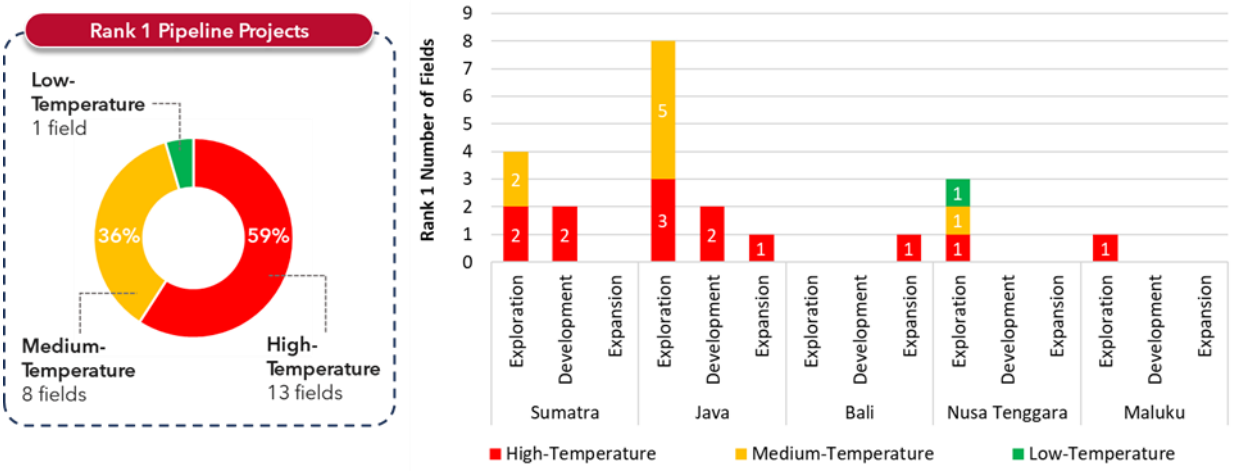


Figure 4. Temperature distribution of Rank-1 geothermal project pipeline based on RUPTL 2021-2030 (Brilian, et al., 2025).

The majority of the pipeline projects, particularly those in Rank 3, focus on low to medium temperature resources, constituting 62% of the total (Figure 5). Sumatra is particularly prominent, with the highest number of future pipeline fields for low and medium-temperature resources, underscoring its significant role in Indonesia's geothermal expansion efforts.

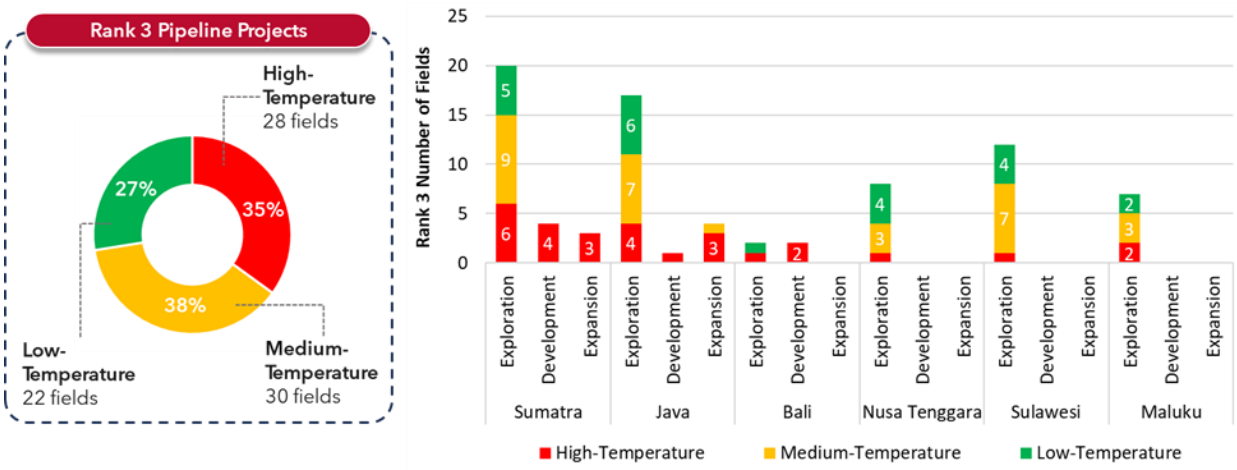


Figure 5. Temperature distribution of Rank-1 geothermal project pipeline based on RUPTL 2021-2030 (Brilian, et al., 2025).

3 GEOTHERMAL DEVELOPMENT IN USA

As Indonesia seeks to advance its geothermal development, particularly in medium and low-temperature fields, it is practical to consider the experiences of countries with established practices in these areas. The United States, with considerable experience in utilizing medium to low-temperature geothermal resources through various technologies, provides a relevant example. Given Indonesia's limited experience with these specific temperature ranges and technologies like the Organic Rankine Cycle (ORC) systems, examining the U.S. approach offers practical insights. This comparison can help identify straightforward strategies, technological innovations, and cost-effective practices that could be adapted to enhance Indonesia's geothermal development. By understanding the approaches and challenges encountered by the U.S. in exploiting geothermal resources, Indonesia can better plan and execute a strategy for a more diversified and efficient geothermal energy infrastructure.

3.1 Geothermal Development History in USA

The historical and contemporary landscape of geothermal development in the United States presents a comprehensive narrative of both technological evolution and the strategic deployment of geothermal power plants (GPP). With an installed capacity of 3,615 MW as of 2023, the U.S. geothermal sector is predominantly driven by high-temperature resources, which collectively contribute 2,408 MW across 45 plants. This capacity represents the foundational role of high-temperature geothermal resources in the U.S. energy mix, historically initiated by the commissioning of the Geysers 1 plant in California in 1960.

Over recent decades, there has been a notable shift towards harnessing lower temperature geothermal resources, reflecting advancements in technology and changes in resource exploitation strategies (Figure 6). The first medium-temperature GPP commenced operations in 1985 with the Beowawe plant in Nevada, followed closely by the initiation of the low-temperature Wabuska 1 plant in Nevada in 1984. These developments mark the beginning of a broader utilization spectrum, with medium and low-temperature resources now contributing 341 MW and 866 MW, respectively.

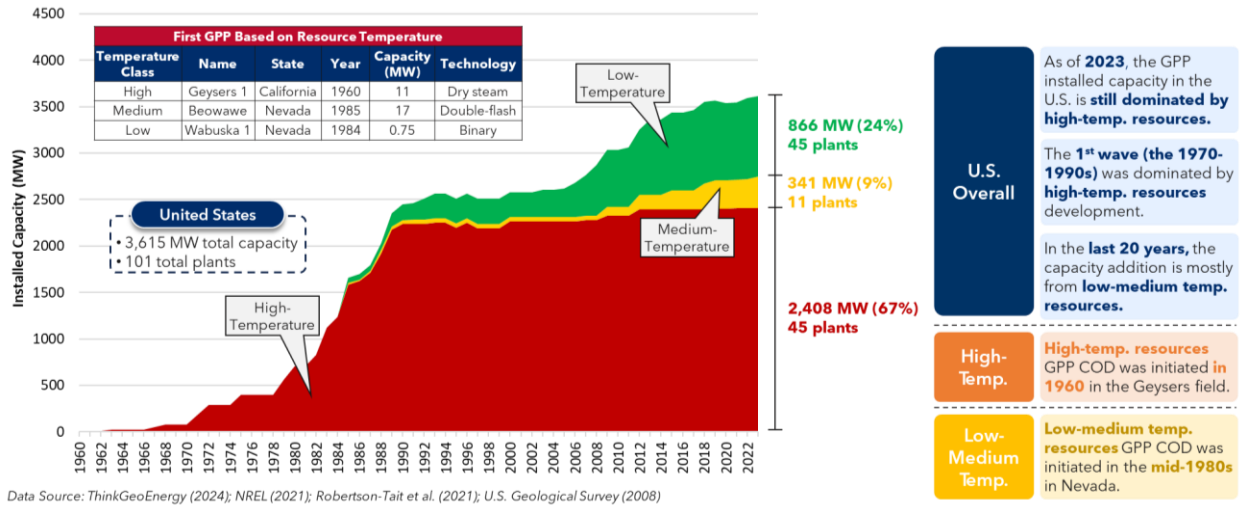


Figure 6. Evolution and distribution of geothermal power technologies in the United States (1960-2023).

Technologically, the U.S. has seen a significant pivot from the traditional dry steam systems that once dominated the landscape. Dry steam technology still plays a critical role, especially in high-temperature applications, accounting for 1,477 MW of total capacity. However, the last two decades have witnessed a significant increase in the adoption of binary technology, particularly effective for low to medium-temperature fields, as shown in Figure 7. As of 2023, binary GPPs account for 1,298 MW, spread across 58 plants, highlighting their growing prevalence due to its efficiency and lower temperature versatility.

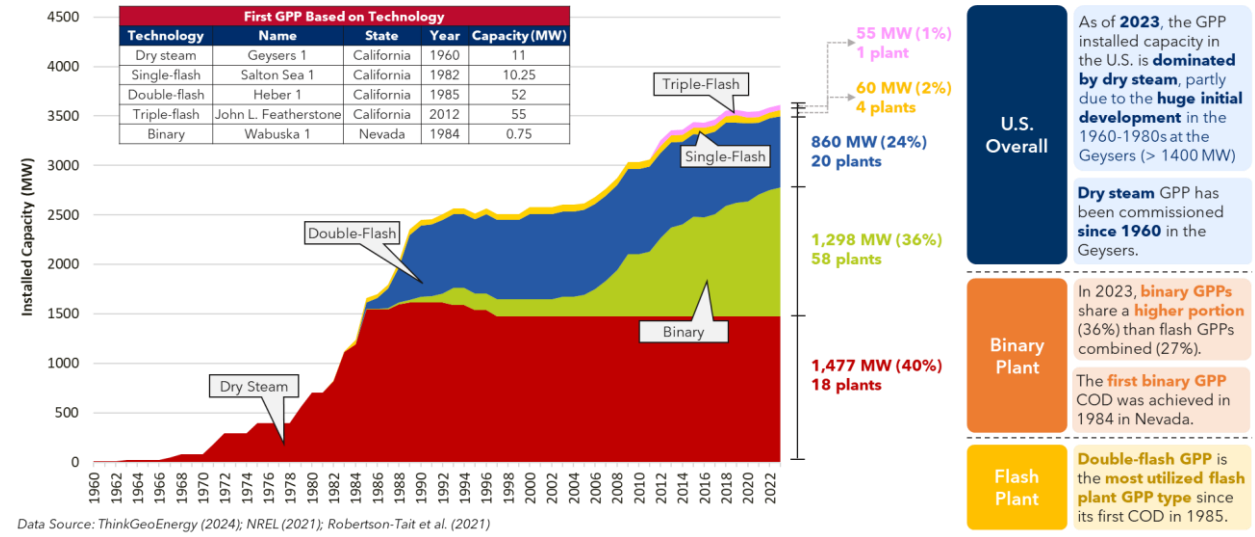


Figure 7. Evolution and distribution of geothermal power plant technology used in United States (1960-2023)

3.2 Distribution of Medium-Low Temperature Geothermal Power Plant in United States

As of December 2023, the distribution of low-medium temperature binary GPP in the U.S. shown in Figure 8 reveals Nevada as the leader in installed capacity. Nevada holds the majority share, with a total installed capacity of 753 MW across 29 plants, accounting for 67% of the nation's total capacity. This dominance correlates with Nevada's abundant low-medium temperature geothermal resources compared to other states. California is the second-largest contributor, with 246 MW of geothermal capacity from 14 plants, representing 22% of the U.S. total for low-medium temperature binary plants.

This significant contribution underscores California's role in the country's geothermal energy landscape. Other states also contribute to the overall geothermal capacity, albeit on a smaller scale. Utah has 45.3 MW from 2 plants, making up 4% of the total, while Oregon contributes 38.1 MW from 4 plants, accounting for 3%. Idaho adds 18 MW from 1 plant (2%), New Mexico provides 15 MW from 1 plant (1%), and Alaska has 1.1 MW from 2

plants, representing 0.01% of the national total. Overall, the total installed capacity for low-medium temperature binary GPPs in the U.S. is 1,116 MW, distributed across 53 plants. This figure highlights the varied contributions of different states, with Nevada and California playing the most significant roles.

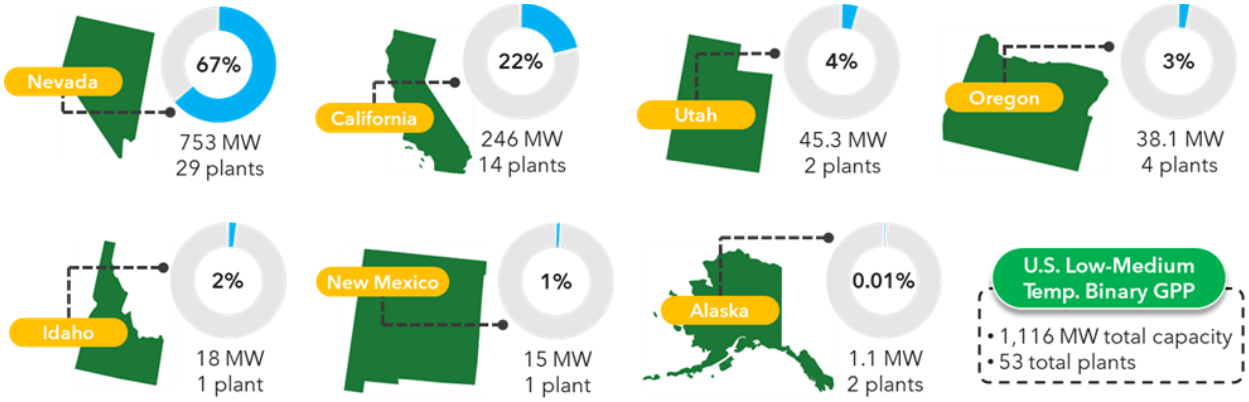


Figure 8: Low-Medium Temperature Binary GPPs' Installed Capacity Distribution in the U.S. as of December 2023 (NREL, 2021; ThinkGeoEnergy, 2024). The Percentage Values Represent Each State's Portion to the Entire U.S (Brilian, et al., 2025).

4 POWER PLANT TECHNOLOGY SUITABILITY FOR VARIOUS RESOURCE TEMPERATURE

Geothermal power plants are tailored to the specific conditions of geothermal resources, primarily distinguished by their temperature levels—high, medium, and low. The choice of technology—single flash, double flash, or binary—is crucial to maximizing efficiency and output based on these temperature conditions. The simplified illustration for technology suitability across various temperatures is shown in Figure 9.

- **High-Temperature Resources**: Traditionally, high-temperature resources have been utilized using dry steam and flashed steam technologies. Single flash systems are suited for resources where the reservoir fluid can be flashed directly to drive a turbine. This technology has been effective in exploiting high enthalpy steam at temperatures typically above 200°C. Double flash systems are more advantageous for higher efficiency. This technology allows for a second flashing of steam at a lower pressure, which extracts additional energy and increases efficiency.

- **Medium-to-Low Temperature Resources**: Binary cycle power plants are ideal for low to medium-temperature resources, typically ranging from 100°C to 200°C. In these systems, geothermal heat is used to vaporize a secondary (binary) fluid with a lower boiling point than water, which then drives the turbines. Binary plants are highly effective for resources that cannot efficiently vaporize water to produce steam.

The adoption of binary technology has increased due to its versatility and ability to operate efficiently across a broad range of lower temperatures, which are more common but less utilized in traditional steam-based systems. This technology also tends to have lower environmental impacts and can be integrated into areas with geothermal resources that were previously considered non-viable.

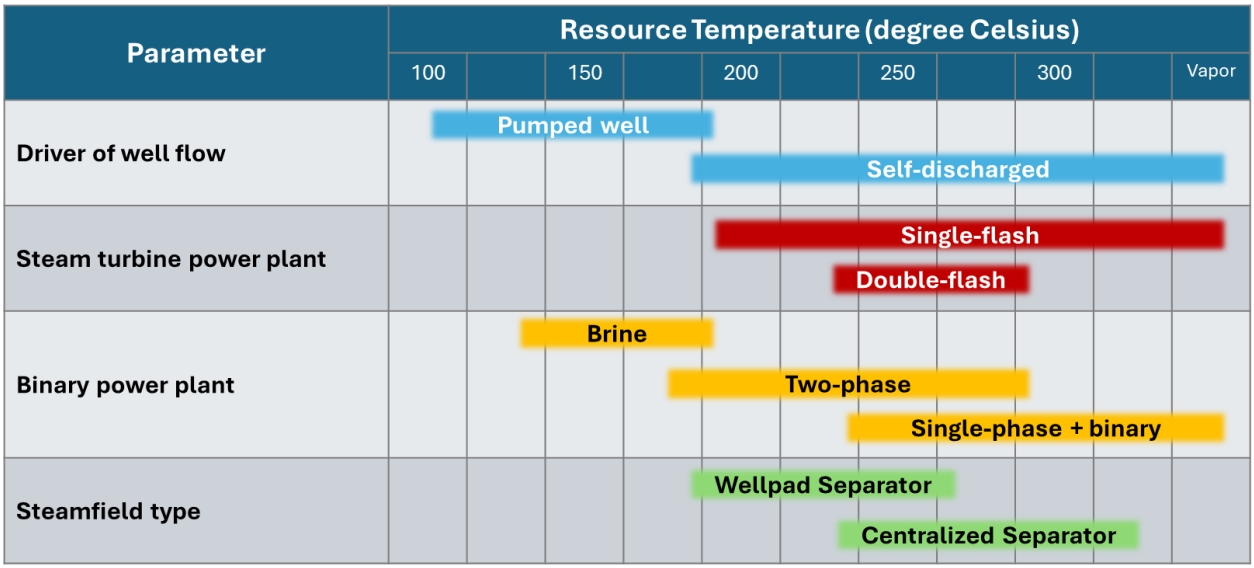


Figure 9. Simplified diagram of suitable technologies for geothermal power plants across various temperatures (modified from Jacobs, 2021).

Efficiency assessments of different GPP technologies underscore the suitability of binary systems across a wide temperature range, as illustrated in Figure 10. Binary technology maintains competitive efficiency, starting at around 3% at 100°C and peaking at nearly 8% at 230°C, making it a versatile choice for a wide spectrum of geothermal resources. In contrast, double-flash technology, while efficient, is typically reserved for higher temperature brackets, demonstrating efficiencies between 5% and 7% from 190°C to 230°C. The distribution of geothermal power plant technology used in the USA is shown in Figure 11. AS shown in Figure 11, the medium and low temperature resources in USA power plant is dominated by binary power plant.

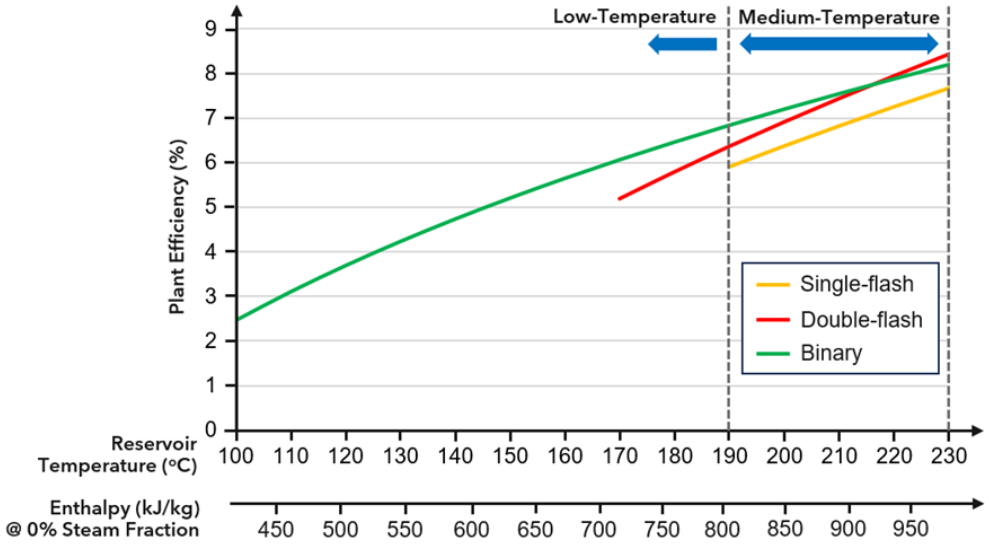


Figure 10. GPP Efficiency Based on Reservoir Temperature/Enthalpy for Different GPP Technologies (Zarrouk & Moon, 2014; Sanyal, 2005).

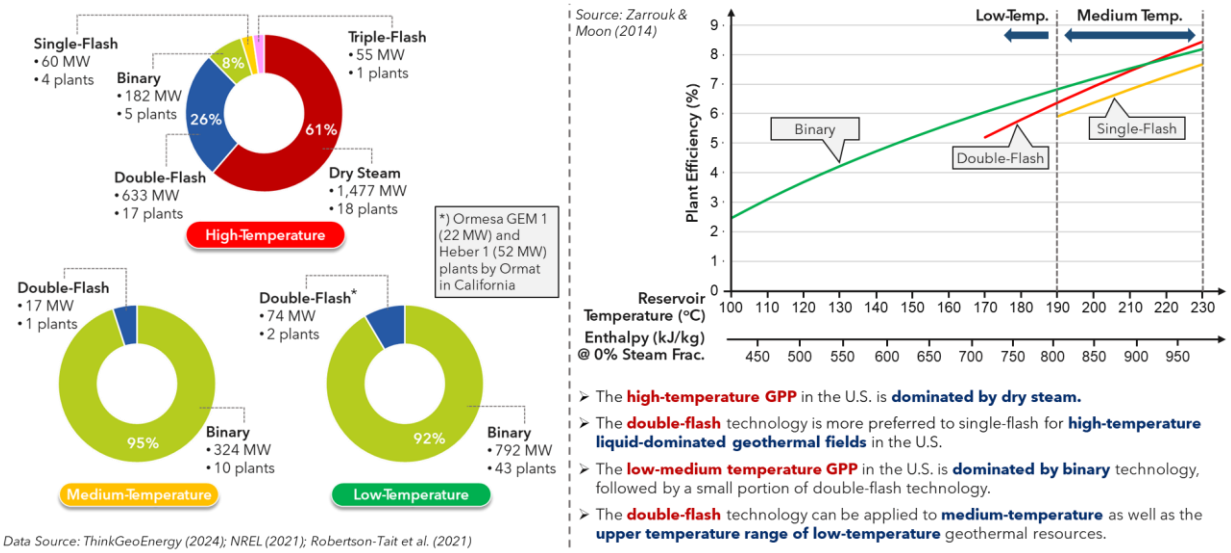


Figure 11. Geothermal power plant technology distribution in each resource temperature class.

5 GEOTHERMAL DEVELOPMENT COST TREND IN INDONESIA, USA, AND TURKIYE

Geothermal energy, a vital component of the renewable energy mix, has varying development costs depending on geographic and technological factors. This section examines the development costs associated with geothermal power plants in the United States, Turkiye, and Indonesia, utilizing data from multiple sources including GETEM (Mines, 2016) and NREL Annual Technology Baseline (2021), with costs escalated to 2023 using the US Producer Price Index (PPI).

It is important to note that while drilling costs are a major component of geothermal development costs, they vary widely between regions due to geological conditions, depth of wells, and local market conditions. In Indonesia, drilling costs are higher due to challenging geological conditions that require more advanced and thus expensive drilling techniques. This contrasts with regions like the US and Turkiye, where more established local industries or more favorable geology may reduce these costs. However, this report centers on the costs beyond drilling, providing more focus on power plant cost.

5.1 Geothermal Development Costs in the United States

In the United States, the construction of geothermal power facilities, particularly the Engineering, Procurement, and Construction (EPC) of power plants and Steam Above Ground Systems (SAGS), constitutes a major portion of development expenditures. Notably, the cost metrics for these components reveal an interesting scale of economy; smaller 15 MW plants incur costs of approximately $9.1 million per MW for reservoir temperatures at 170 degrees Celsius. In contrast, larger 120 MW facilities benefit from significantly reduced costs of around $2.7 million per MW for reservoirs at 225 degrees Celsius. This disparity underscores the impact of scale on geothermal development economics, suggesting larger projects may offer more cost-effective solutions per unit of energy capacity. The geothermal development cost trend obtained from NREL and GETEM model is summarized in Figure 12 and Figure 13.

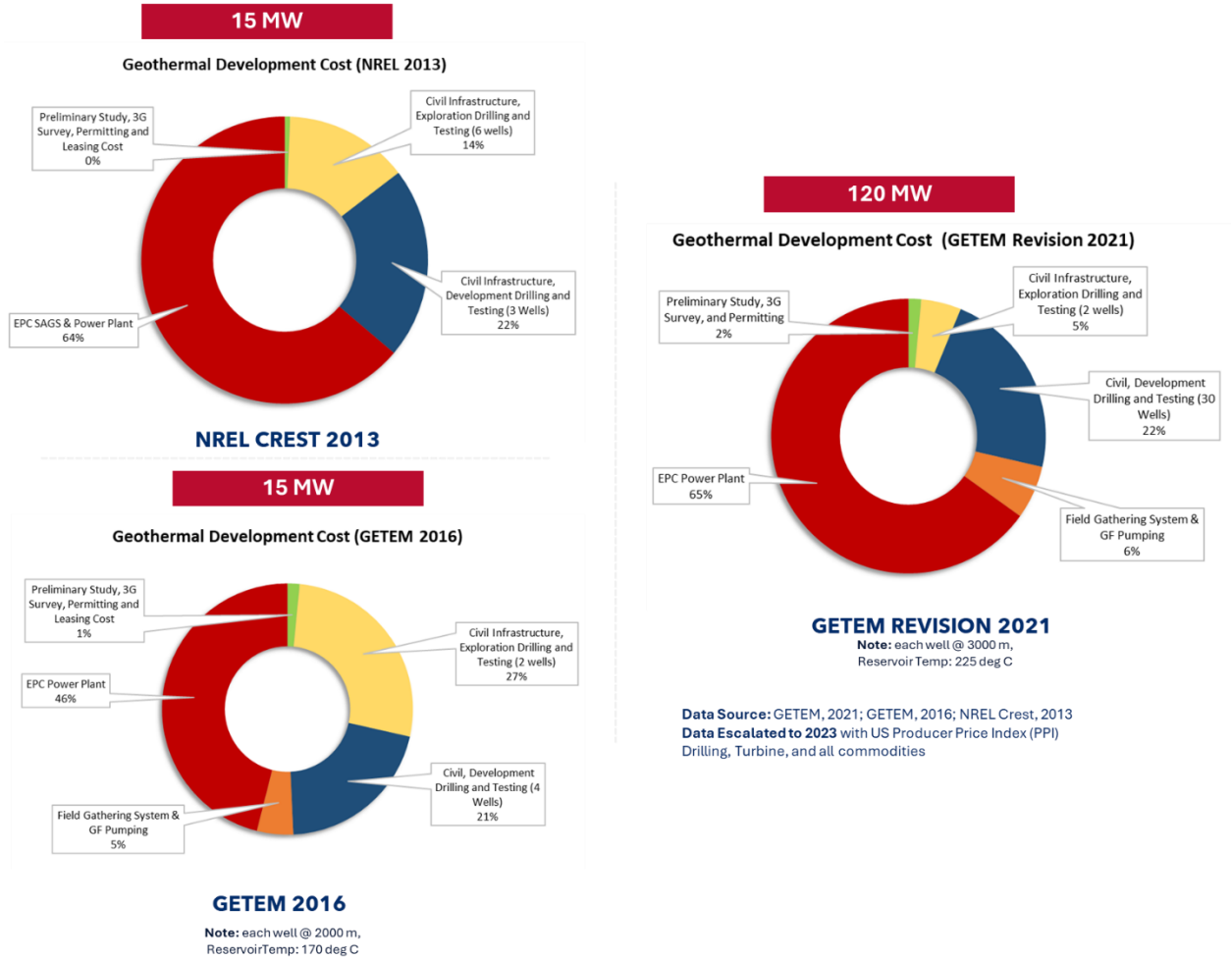


Figure 12. Geothermal development cost in USA according to the model from NREL and GETEM.

Geothermal Development Cost in United States

Data Escalated to 2023 with US Producer Price Index (PPI) Drilling, Turbine, and all commodities

15 MW

Cost Component	Cost (USD)
Preliminary Study, 3G Survey, Permitting and Leasing Cost	$750.000
Civil Infrastructure, Exploration Drilling and Testing (6 wells)	$17.500.000
Civil Infrastructure, Development Drilling and Testing (3 Wells)	$27.012.243
EPC SAGS & Power Plant	$91.279.535
Total	**$136.541.778**

9.1 MUSD/MW

NREL CREST 2013

15 MW

Cost Component	Cost (USD)
Preliminary Study, 3G Survey, Permitting and Leasing Cost	$1.213.131
Civil Infrastructure, Exploration Drilling and Testing (2 wells)	$22.647.857
Civil, Development Drilling and Testing (4 Wells)	$17.384.801
Field Gathering System & GF Pumping	$4.744.106
EPC Power Plant	$46.686.202
Total	**$92.676.097**

6.1 MUSD/MW

GETEM 2016

Note: each well @ 2000 m, ReservoirTemp: 170 deg C

120MW

Cost Component	Cost (USD)
Preliminary Study, 3G Survey, and Permitting	$4.616.261
Civil Infrastructure, Exploration Drilling and Testing (2 wells)	$13.195.722
Civil, Development Drilling and Testing (30 Wells)	$62.402.164
Field Gathering System & GF Pumping	$21.549.528
EPC Power Plant	$223.198.017
Total	**$324.961.692**

2.7 MUSD/MW

GETEM REVISION 2021

Note: each well @ 3000 m, Reservoir Temp: 225 deg C

Figure 13. Breakdown of geothermal development cost in USA according to NREL and GETEM model

.

5.2 Geothermal Development Costs in Turkiye

The cost structure of geothermal development in Turkiye, dominated by Engineering, Procurement, and Construction (EPC) and Steam Above Ground Systems (SAGS), exhibits variability according to project size. Specifically, a modest 10 MW project incurs costs of about $3.8 million per MW, while a medium-sized 35 MW project reduces the cost to $2.5 million per MW. However, for larger projects such as those at 120 MW, costs escalate to approximately $4.4 million per MW. This pattern suggests that while economies of scale can reduce costs, other factors like site-specific conditions and regulatory environments also play crucial roles in influencing overall expenses. Additionally, with 60 out of 66 geothermal power plants in Turkiye being binary due to the prevalence of medium-low temperature resources, there is an opportunity to extract valuable lessons from the predominance of binary power plants. These lessons could potentially inform cost-effective practices and technological applications beneficial not only to Turkiye but also to other regions developing similar geothermal resources. The breakdown of these costs is detailed in Figure 14.

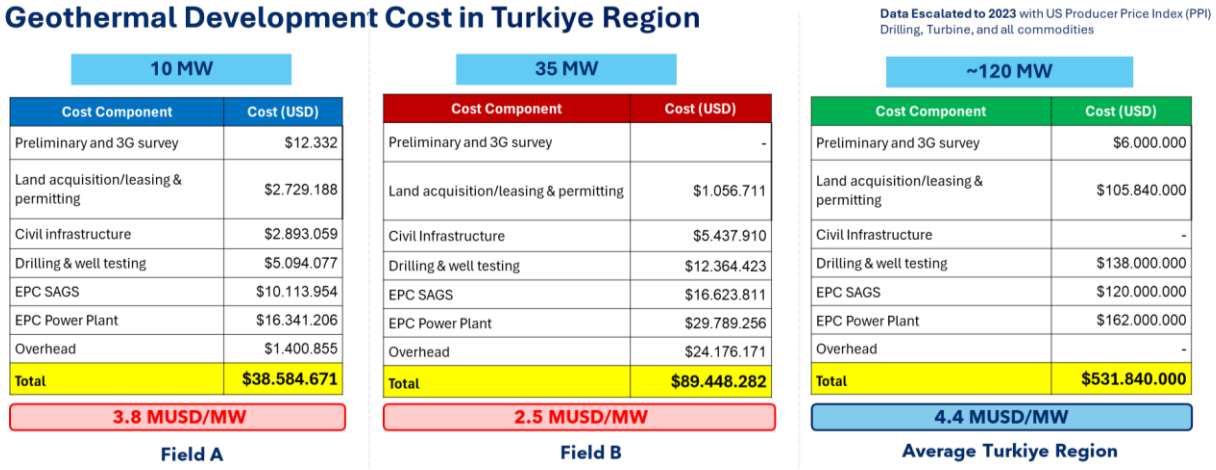


Figure 14. Geothermal development costs breakdown in Turkiye.

5.3 Geothermal Development Costs in Indonesia

Turning to Indonesia, the development costs are notably higher compared to the US and Turkiye. For example, a 30 MW project in Indonesia is estimated to cost $7.4 million per MW. Medium-scale 45 MW projects see a slight decrease in cost per MW to $5.4 million, whereas the largest 90 MW projects align closely with the smallest, costing $7.5 million per MW. These figures highlight Indonesia's unique challenges in geothermal development, potentially driven by geological complexities or less mature local supply chains for geothermal equipment and services. The example of geothermal cost breakdown in Indonesia is shown in Figure 15.

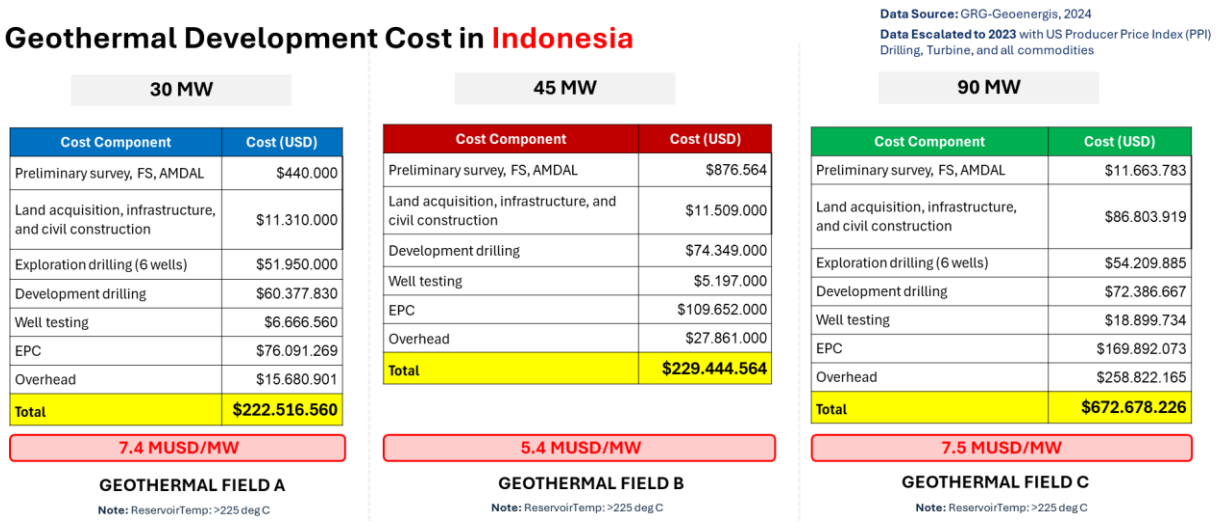


Figure 15. Geothermal development cost breakdown in Indonesia.

5.4 Comparative Analysis of Geothermal Power Plant Cost in Indonesia, USA, and Turkiye

A comparison of the three countries shows that Indonesia's geothermal development costs tend to be higher than those in the US and Turkiye (see Figure 16), with the average cost per MW in Indonesia being slightly above $2.49 million compared to $2.08 million in the US and $2.2 million in Turkiye respectively.



Figure 16. A Stark Global Discrepancy in Development Cost

To address these higher costs, it is essential for Indonesian stakeholders to focus on optimizing project designs and embracing advanced technologies that can reduce both operational and capital expenditures, especially considering the upcoming geothermal projects in Indonesia will be dominated by medium to low temperature geothermal fields.

6 GEOTHERMAL POWER PLANT MANUFACTURERS IN INDONESIA, USA, AND TURKIYE

The geothermal energy sector relies heavily on the capabilities of power plant manufacturers to provide efficient and technologically advanced solutions. This report delves into the current state of geothermal power plant manufacturing in the United States, Turkiye, and Indonesia, highlighting key players and their market dominance, as well as the technological preferences that shape their offerings.

6.1 Geothermal Power Plant Manufacturers in the United States

In the United States, the geothermal power plant manufacturing landscape is characterized by a diversity of players, with ORMAT standing out as a major supplier. ORMAT has installed a total of 48 units, holding a substantial 44% market share. This prominent position underscores ORMAT's pivotal role in shaping the U.S. geothermal market, particularly through its adoption of binary technology tailored for low and medium temperature geothermal fields.

ORMAT's dominance for binary technology is significant as it aligns with the broader industry trend towards utilizing lower temperature resources more efficiently. This approach not only maximizes resource utilization but also enhances the economic feasibility of geothermal projects. Other notable manufacturers like Fuji and Toshiba have traditionally focused on high-temperature resources, employing flash technology since the early 1970s. This technology dichotomy highlights the varied strategies manufacturers deploy based on available geothermal resources and market demands. The breakdown of turbine manufacturers based on the number of units installed and capacity is illustrated in Figure 17 and Figure 18.

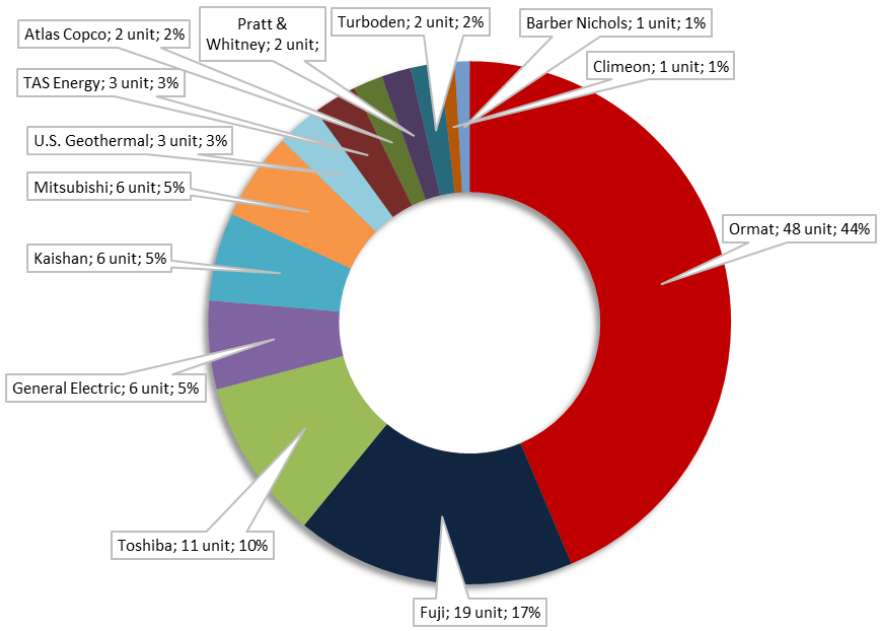


Figure 17. Number of Geothermal Turbine Units Installed in the USA by manufacturers.

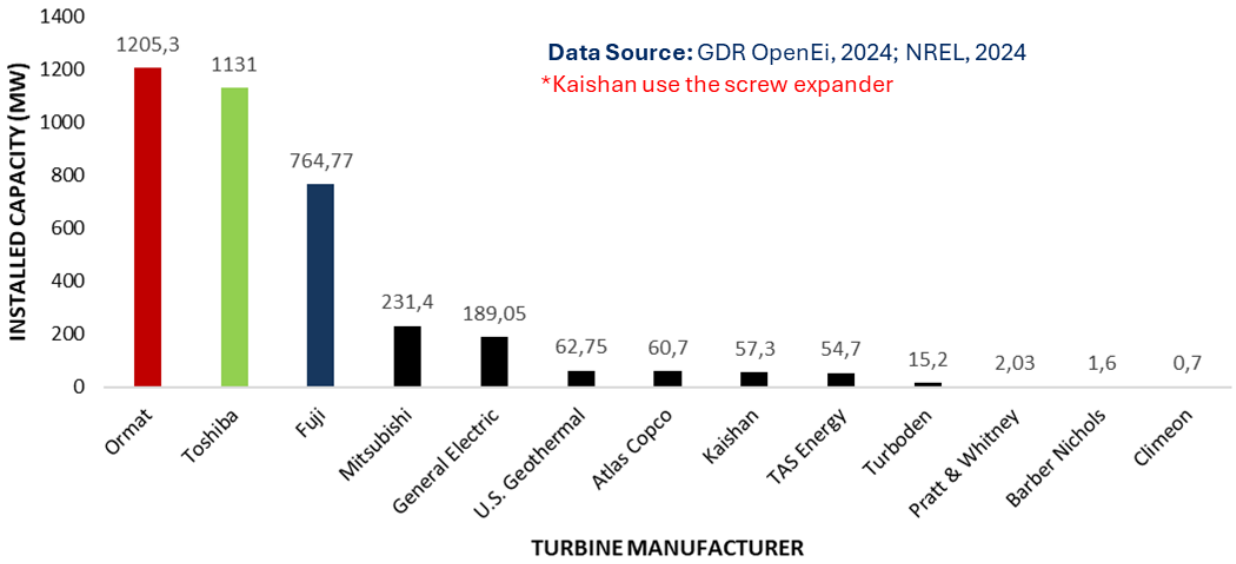


Figure 18. Distribution of turbine manufacturer based on installed capacity in USA.

6.2 Geothermal Power Plant Manufacturers in Turkiye

To date, seven power plant providers operate in Turkiye. The market is dominated by ORMAT, which holds a 62% market share with 43 installed units. ORMAT's dominance in Turkiye reflects its strong global presence and effective deployment of technology, particularly in regions with medium-low temperature geothermal resources that are well-suited for binary geothermal power plants

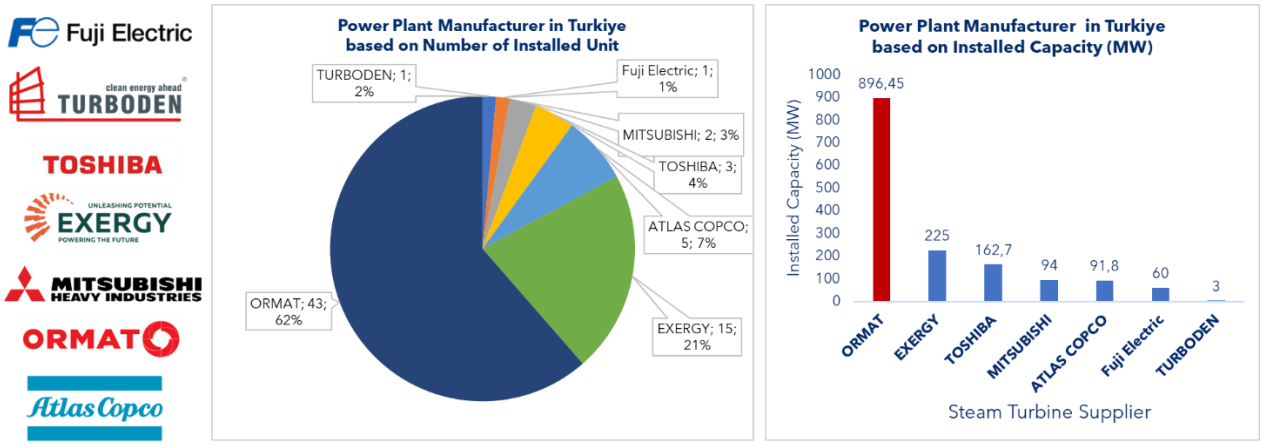


Figure 19. Power Plant Manufacturer in Turkiye.

6.3 Geothermal Power Plant Manufacturers in Indonesia

In Indonesia, Fuji Electric is the market leader, having installed 19 units and secured a 40% market share. Other major Japanese companies, Mitsubishi Heavy Industries (MHI) and Toshiba, hold the second and third positions, respectively, in terms of installed capacity.

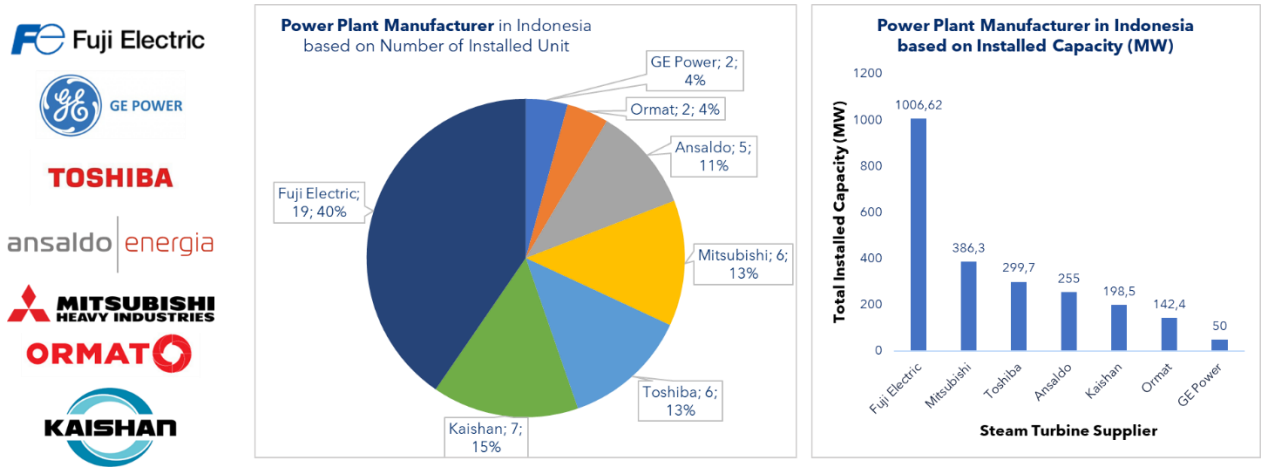


Figure 20. Geothermal power plant manufacturer in Indonesia.

Historically, the market for steam turbine providers in Indonesia, especially for high-temperature fields, has been dominated by these Japanese companies, resulting in a less competitive environment. However, in recent years, new entrants such as Kaishan, which provides screw expanders for flashed steam and Organic Rankine Cycle (ORC) systems, and Ormat, known for their ORC units, have started to gain market share, signaling a shift towards a more competitive market landscape (see Figure 21).

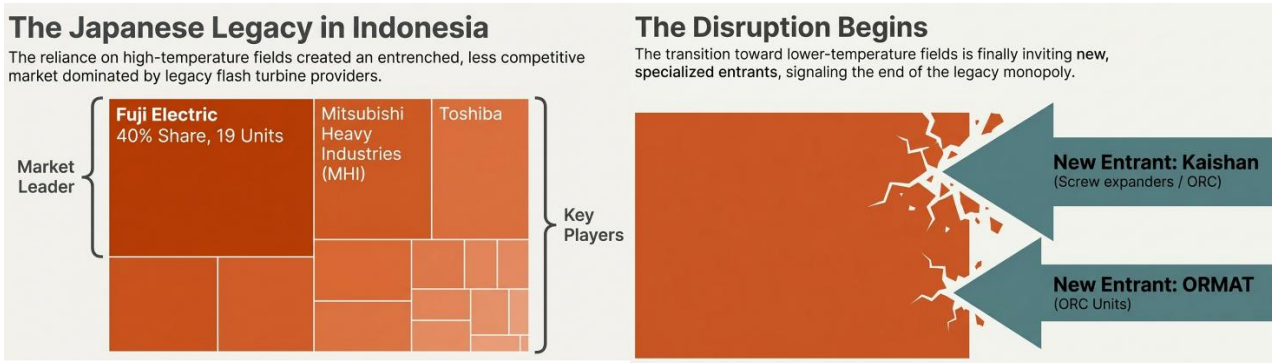


Figure 21. State of geothermal power plant manufacturer in Indonesia in 2023-2024.

7 LESSON LEARNED FROM US AND TURKIYE FOR OPTIMIZING GEOTHERMAL POWER PLANT COST

By studying the experiences of the United States and Turkiye, we can identify several effective strategies for lowering geothermal power plant costs. These include using advanced technologies, increasing competition, and developing local manufacturing capabilities. These methods show how changes in the market and technology can lead to significant cost savings.

It is crucial to assess these options in detail for each case. This will ensure the chosen strategies are practical and well-suited to local needs. A careful assessment will help in applying the most affordable and efficient solutions for building geothermal power plants.

7.1 Adoption of Binary Technology

The research highlights that increased competition among power plant providers can significantly influence market dynamics by driving down costs and enhancing overall market competitiveness. This is particularly evident in regions like the United States and Turkiye, where a competitive environment has led to more economically efficient solutions and innovations in the energy sector. As noted in various studies, when multiple providers compete for market share, it typically results in lower prices and improved service offerings, as each provider strives to offer more value to attract customers.

In the context of geothermal power plant providers, this principle suggests that enhancing competition among turbine manufacturers could potentially reduce costs in markets like Indonesia, where the market is currently less competitive and dominated by a few major players. By encouraging a more competitive environment, possibly through regulatory changes or incentives for new entrants, Indonesia could see a decrease in the costs associated with geothermal power development.

Such a strategy could be particularly effective given the current dominance of companies like Toshiba and Mitsubishi in the Indonesian market, which contrasts with the more diverse manufacturer landscape in the US and Turkiye. Encouraging more manufacturers to enter the market could lead to a broader selection of technologies and more competitive pricing, ultimately benefiting the geothermal industry in Indonesia.

7.2 Manufacturing Proximity

In Turkiye, the development of local manufacturing has been a key factor in reducing the costs and improving the efficiency of geothermal power projects. The country has a strong network of suppliers and manufacturers that specialize in geothermal system components, which not only supports the local economy but also speeds up the implementation of projects.

In the USA, local manufacturing has played a crucial role in the geothermal industry, especially in states like California and Nevada, where geothermal resources are abundant. American manufacturers such as Ormat Technologies are leaders in both the production of geothermal power plants and the development of new geothermal resources. This proximity has facilitated rapid deployment and maintenance of geothermal facilities, contributing to the USA's position as a leader in geothermal energy.

Establishing local manufacturing facilities for geothermal power plant components in Indonesia presents a strategic opportunity to reduce logistical costs and bolster the domestic industry (see Figure 22). Currently, the Indonesian geothermal sector relies heavily on imported equipment, leading to increased expenses and extended project timelines. By developing local manufacturing capabilities, Indonesia can mitigate these challenges and enhance its energy infrastructure.

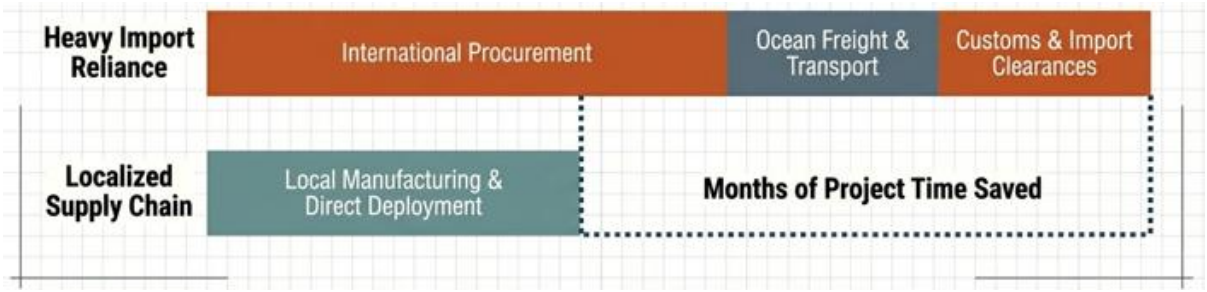


Figure 22. Illustration of establish manufacturing proximity to cut logistical overhead

The Indonesian government has recognized the importance of local content in energy projects. Policies have been implemented to encourage the use of domestically produced materials and services in renewable energy developments, including geothermal power plants. These initiatives aim to stimulate local industries, create employment opportunities, and reduce dependency on foreign suppliers (Assegaf Hamzah & Partners, 2025).

However, the enforcement of stringent local content requirements has sometimes posed challenges in securing international funding for renewable energy projects. To address this, Indonesia has recently relaxed certain regulations to attract foreign investment and access international concessional loans. This adjustment aims to balance the promotion of local manufacturing with the need for financial support to advance renewable energy initiatives.

Collaborations between local companies and international partners have been instrumental in advancing geothermal technology in Indonesia. For instance, PT Pertamina Geothermal Energy (PGE) has engaged in joint studies with international entities to develop binary cycle power plants, which are suitable for lower-temperature geothermal resources. Such partnerships facilitate technology transfer and can lay the groundwork for establishing local manufacturing capabilities (PGE, 2024).

By investing in local manufacturing facilities, Indonesia can reduce the costs associated with importing equipment, shorten project development timelines, and enhance the competitiveness of its geothermal industry. This approach aligns with the country's broader goals of energy security, economic development, and environmental sustainability.

7.3 Competition Among Turbine Providers

The Indonesian geothermal energy sector has traditionally been dominated by a few Japanese companies, such as Fuji Electric, Mitsubishi Heavy Industries (MHI), and Toshiba, which have been the primary suppliers of steam turbines for high-temperature geothermal fields. This limited competition has contributed to higher costs and slower innovation within the industry.

However, recent developments indicate a shift towards a more competitive market landscape. New entrants like Kaishan, which provides screw expanders for flashed steam and Organic Rankine Cycle (ORC) systems, and Ormat, known for their ORC units, have started to gain market share in Indonesia. These companies offer alternative technologies and solutions that can cater to different geothermal resource conditions, potentially leading to more cost-effective and efficient power generation.

The introduction of these new players is expected to enhance competition among turbine providers, which could result in several benefits for the Indonesian geothermal sector:

a. Cost Reduction: Increased competition can lead to more competitive pricing, reducing the capital expenditure required for geothermal power plant development.
b. Technological Innovation: A diverse range of providers encourages the development and adoption of new technologies, improving the efficiency and reliability of geothermal power plants.
c. Supply Chain Resilience: A broader supplier base can mitigate risks associated with supply chain disruptions, ensuring more consistent project timelines and outcomes.

To further stimulate competition, Indonesia could consider implementing policies that encourage the entry of new turbine manufacturers and support local manufacturing capabilities. Such measures would not only enhance the competitiveness of the geothermal sector but also contribute to the overall growth of the renewable energy industry in the country.

7.4 Splitting EPC Contract

Splitting the Engineering, Procurement, and Construction (EPC) scope into separate contracts can offer potential cost savings and tax benefits in geothermal projects, a practice that is increasingly common in international energy projects (see Figure 23). This approach involves dividing a traditional EPC contract into two parts: an onshore contract that handles local construction and installation, and an offshore contract responsible for the design, engineering, and procurement of equipment from abroad. This division is primarily driven by the aim to reduce exposure to local taxes on imported equipment and services, which can be significant depending on the host country's tax laws.

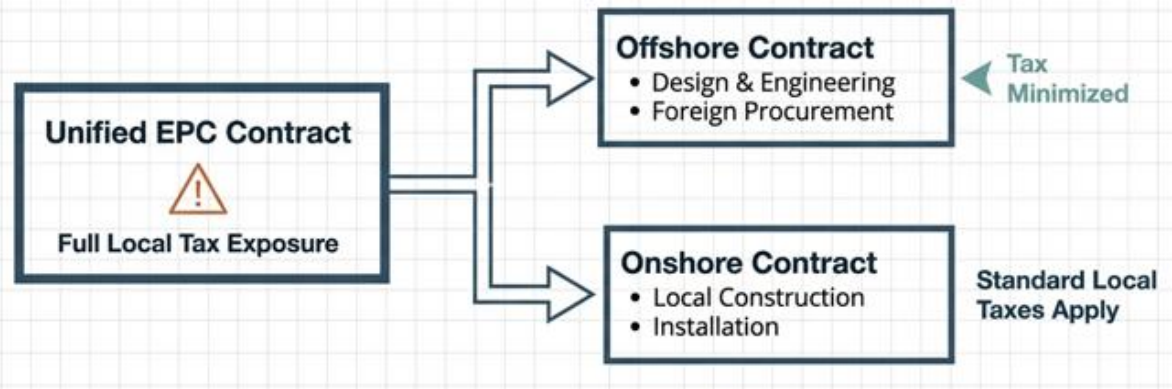


Figure 23. Illustration of Splitting the EPC contract to reduce heavy import taxes

In Turkiye and the USA, similar practices have been observed, especially in large infrastructure and energy projects where the cost and complexity of the projects justify the additional coordination required between multiple contracts. For example, in Turkiye, where local content requirements and import taxes can significantly affect project costs, splitting EPC contracts allows for minimizing these financial burdens. In the USA, such strategies are often utilized to optimize tax structures and streamline project execution by aligning specific project components with specialized contractors, thus enhancing overall efficiency and reducing costs.

However, there are considerations and risks associated with this approach. Splitting contracts can increase the complexity of project management and may lead to coordination challenges. Ensuring that all contractual parts are seamlessly integrated and that responsibilities are clearly defined is crucial to avoid gaps in project execution. Legal and tax advice is essential to navigate these complexities and to ensure that the split contracts deliver the intended benefits without unintended consequences.

7.5 Integrating Pilot Plants with Well Testing for Enhanced Technology Selection and Risk Mitigation in Geothermal Development

In the process of selecting technology for geothermal projects, incorporating pilot plants alongside well testing can significantly reduce development costs and associated risks. This integrated approach allows for real-time evaluation of geothermal resources and the direct application of technology under actual field conditions.

- **Real-Time Data Acquisition**

  Conducting pilot plant operations concurrently with well testing provides immediate feedback on how the technology performs with the specific geothermal fluid characteristics and reservoir conditions. This real-time data is invaluable for making quick adjustments to the technology or operation parameters, enhancing the overall efficiency and effectiveness of the geothermal extraction process.

- **Risk Mitigation**

  The primary benefit of this approach is the significant reduction in development risks. By testing the technology in the field at the pilot scale, developers can identify potential issues and challenges early in the project lifecycle. This early detection allows for mitigations to be implemented before full-scale deployment, reducing the likelihood of costly failures or inefficient operations.

- **Cost Reduction**

  Early risk identification and mitigation ultimately lead to lower development costs. Problems identified during pilot testing can be addressed without the extensive costs associated with scaling up potentially faulty or suboptimal technology. Additionally, integrating these tests can minimize the need for separate testing phases, further reducing project timelines and associated costs.

- **Optimized Technology Selection**

  This approach aids in selecting the most suitable technology for a given geothermal resource. Different technologies might perform better or worse depending on the reservoir's characteristics; pilot plants can reveal this in a controlled, manageable environment. This ensures that the selected technology is well-suited to the site's specific geothermal characteristics, improving the project's overall viability and efficiency.

- **Application and Case Studies**

  Several geothermal projects globally have adopted this approach, demonstrating its effectiveness. For instance, in projects where non-condensable gases, scaling issues, or varying pressure and temperature conditions are concerns, pilot plants have provided essential insights that guided the final technology selection and configuration. This practice is becoming more common as the geothermal industry continues to innovate and as project developers seek more reliable and cost-effective methods to harness geothermal energy. In Indonesia, PT Geo Dipa Energi has been using the pilot plant result for finalizing the design of its Dieng-2 geothermal power plant (see Figure 24).

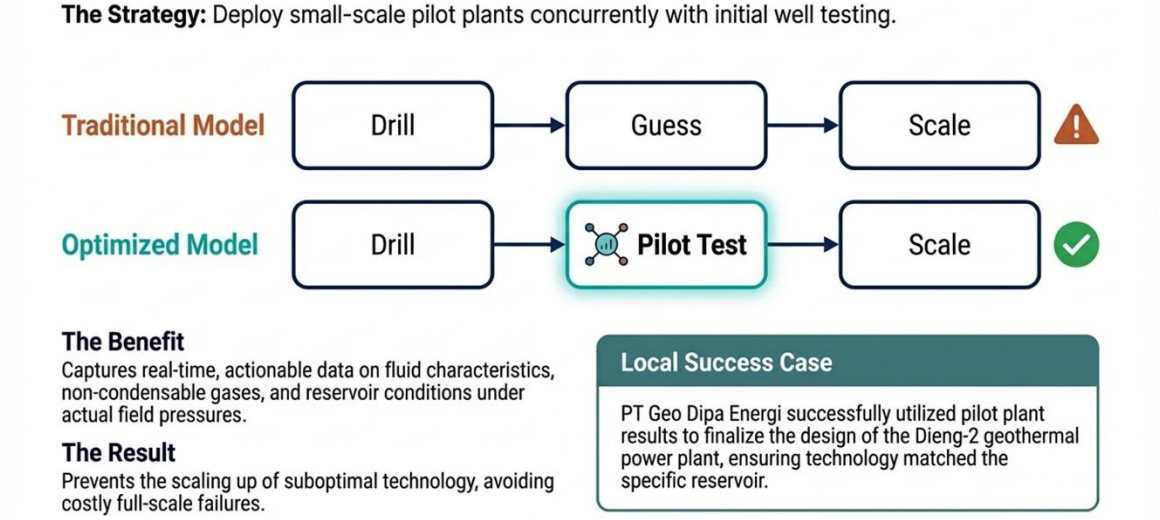


Figure 24. De-risk execution through real-time pilot testing

7.6 Optimizing EPC Contracting through Detailed Front-End Engineering Design (FEED) and Providing Comprehensive Data to the Contractors

In the geothermal energy sector, the pricing determined by Engineering, Procurement, and Construction (EPC) contractors is influenced by a variety of factors. These include project-related risks, market trends, and industry best practices within the local context. EPC contractors often face constraints in terms of resources and time, which can hinder their ability to develop comprehensive proposals and thus includes large safety margin in their bid (see Figure 25).

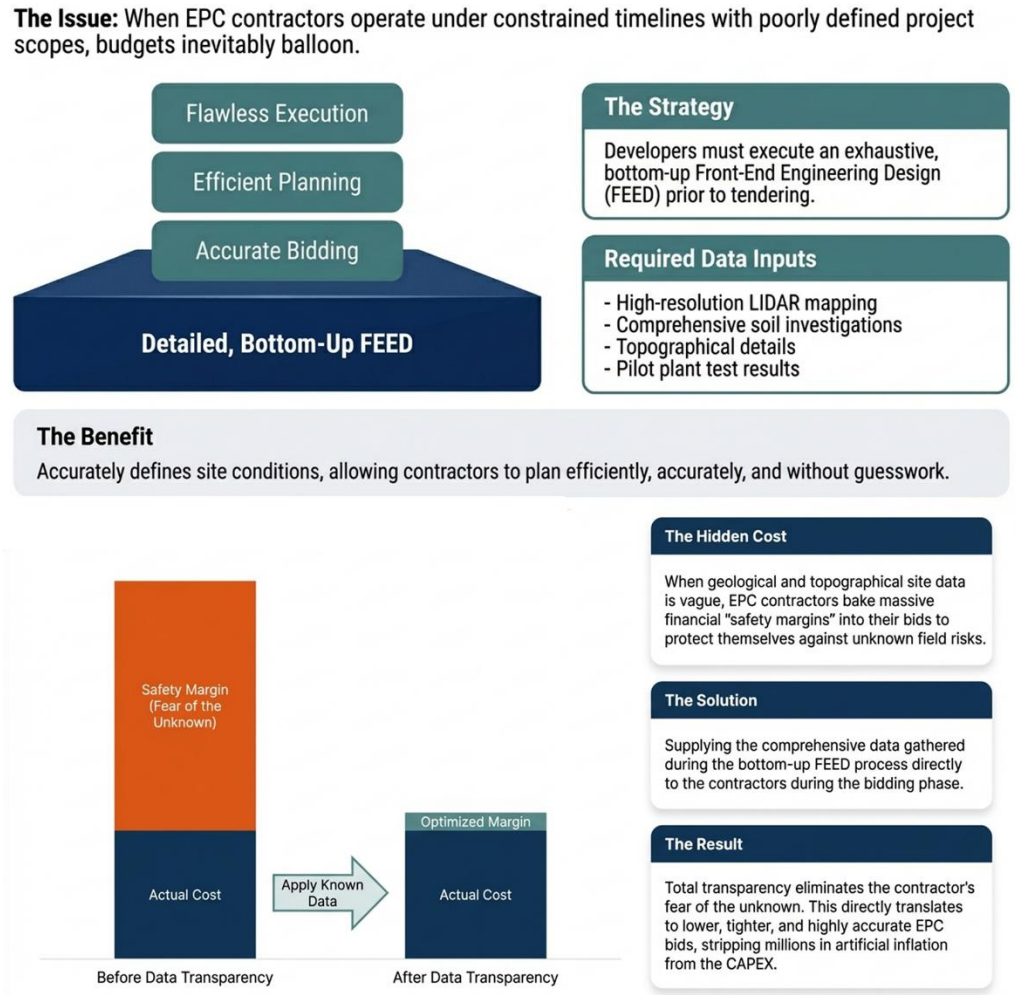


Figure 25. Illustration of Eliminatig EPC safety margins through detailed FEED and data transparency

To address these challenges, geothermal developers should consider implementing a detailed Front-End Engineering Design (FEED) using a bottom-up approach. This method involves compiling extensive data such as LIDAR information, soil investigations, topographical details, and results from pilot plant tests. Providing a detailed FEED allows EPC contractors to have a clear and thorough understanding of the project requirements and site conditions. This level of detail helps contractors to estimate costs more accurately and plan the project more efficiently.

By supplying comprehensive data, developers can significantly reduce the need for EPC contractors to include large safety margins in their bids, which often inflate project costs. Detailed FEED thus not only facilitates more accurate budgeting but also enhances the overall execution plan, ensuring that the geothermal project is developed optimally with minimized financial and technical risks.

8 CONCLUSIONS

As Indonesia's historically utilized high-temperature geothermal fields approach saturation, the nation is undergoing a critical transition toward its abundant, yet underutilized, low-to-medium temperature resources. This shift is highly visible in the national pipeline, where low- and medium-temperature resources now constitute 62% of future Rank 3 projects. However, this transition is currently bottlenecked by severe economic disparities. Indonesia faces significantly higher geothermal development costs—ranging from $5.4 million to $7.5 million per MW—compared to established global leaders like the United States (averaging 2.2 million per MW).

To ensure the economic viability of these upcoming projects, Indonesian stakeholders cannot rely on traditional development frameworks. The comparative analysis with the U.S. and Turkiye demonstrates that lowering capital and operational expenditures requires a multi-faceted approach, moving away from a monopolized market and embracing advanced technologies, optimized procurement, and modernized project execution.

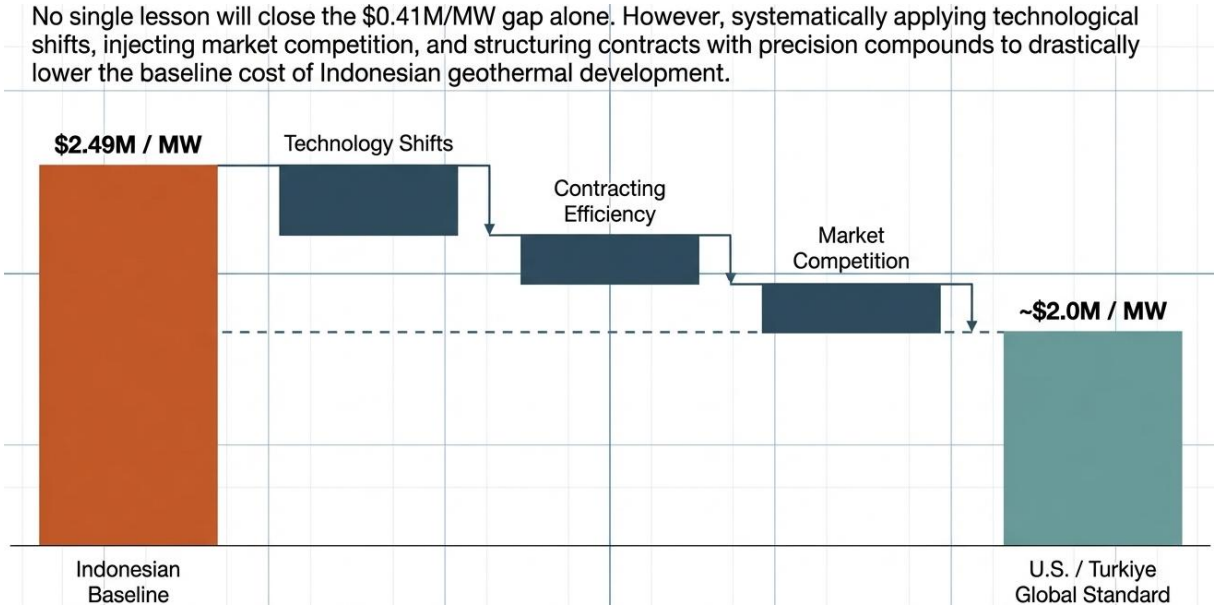


Figure 26. Illustration of the compounding effect of applying various best practices in optimizing geothermal power plant cost

The Path Forward: Strategic Recommendations for Indonesia

To bridge the cost gap and accelerate its renewable energy transition, Indonesia should adopt the following actionable strategies derived from successful international practices:

- **Accelerate the Adoption of Binary Technology**
  Indonesia must pivot toward binary cycle technologies (such as Organic Rankine Cycle systems), which maintain competitive efficiencies of 3% to 8% across temperatures ranging from 100°C to 230°C. As demonstrated by the U.S. and Turkiye—where binary systems dominate low-to-medium temperature applications—this technology is highly versatile, environmentally friendly, and essential for making lower-temperature fields economically feasible.

- **Stimulate Market Competition Among Turbine Providers**
  The Indonesian market has historically been dominated by a few Japanese manufacturers (e.g., Fuji, MHI, Toshiba) focused on high-temperature steam turbines. To drive down capital expenditures and foster technological innovation, Indonesia must implement policies that encourage new entrants offering alternative technologies, such as Ormat and Kaishan, to create a more competitive pricing environment.

- **Develop Local Manufacturing Capabilities**
  Mirroring the supply chain resilience seen in the U.S. (e.g., Nevada and California) and Turkiye, Indonesia must invest in local manufacturing facilities. Building domestic capacity for geothermal components will drastically reduce logistical expenses, shorten project timelines, minimize reliance on costly imports, and align with the government's goals for local content and economic development.

- **Optimize EPC Contracting Strategies.**

  - **Splitting EPC Contracts**
    Developers should divide traditional Engineering, Procurement, and Construction (EPC) scopes into separate onshore (local construction) and offshore (design/equipment procurement) contracts. This legally minimizes exposure to local taxes on imported equipment, a strategy successfully utilized in both the U.S. and Turkiye.

  - **Implement Detailed FEED**
    To prevent EPC contractors from inflating bids with large safety margins due to resource or time constraints, developers should provide a comprehensive, bottom-up Front-End Engineering Design (FEED). Supplying detailed LIDAR, topographical, and soil data allows for precise budgeting and minimized technical risks.

- **Integrate Pilot Plants with Well Testing.**
  Conducting pilot plant operations concurrently with well testing provides immediate, real-time data on reservoir fluid characteristics. This proactive approach, already being tested at Indonesia's Dieng-2 project, prevents costly scale-up errors, ensures the finalized technology perfectly matches site conditions, and significantly reduces early-stage development risks

ACKNOWLEDGMENT

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Please note that the data and analysis for this study were researched during the 2024 period. As a result, the projections and pipeline analysis for Indonesia's future geothermal projects are based on the National Electricity Supply Business Plan (RUPTL) 2021-2030. The newest RUPTL PLN 2025-2034 is not considered in this report.

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