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Geothermal Captive Use to Support Industrial Activities: Applicable Industry Sectors, Worldwide Experience, and Its Potential and Challenges in Indonesia

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ABSTRACT

In the conventional geothermal power generation, the electricity is sold by the geothermal power plant operators to the offtakers that distribute the electricity to the buyers, such as the industries. However, some industries are located too far away for an economically viable connection to the existing grid so that they have to generate power independently to support their industrial activities. Geothermal captive use offers a new approach on how geothermal energy can provide clean and cheap electricity for the local industries yet no electricity grid is accessible and the costs of diesel and natural gas are high. Examples of geothermal captive use can be seen in Lihir (Papua New Guinea) and Florida Canyon (United States). Although geothermal captive use is yet to be implemented in Indonesia, several mining sites have the potential to implement geothermal captive use. This paper aims to identify the potential of geothermal captive use to support industrial activities, with an emphasis on the mining industry. A literature review is conducted to review the captive use mechanisms from the worldwide experience and extract the lessons learned that may be applicable in Indonesia. Additionally, the mining sites near to or intersecting geothermal prospect areas are identified. This study also reviews the challenges and pathforward to accelerate the industrial geothermal captive use in Indonesia.

1. INTRODUCTION

By the end of 2022, there are 46 geothermal power plant (GPP) units in Indonesia across 17 geothermal working areas with the total installed capacity of 2.3 GW (Pambudi, et al., 2023). The electricity generated from these GPPs are sold by the operator to the sole offtaker in Indonesia, which is PT Perusahaan Listrik Negara (Persero) (abbreviated as PLN). The electricity is then transmitted and distributed by PLN to the consumers from various sectors, including industries, offices, and households. The energy-intensive industries, such as steel factories, cement factories, and mining, require a significant amount yet stable electricity supply to support their primary equipment for continuous production, including electric-arc steel furnace, concrete grinding machine, and mining smelters (Su, et al., 2021). Meanwhile, the characteristics of geothermal energy are renewable, available around the clock, low CO_2 emissions, and negligible fuel requirements (Yao, et al., 2021). Therefore, these industries could benefit from geothermal captive use to fulfill their power needs independently without relying on the existing electrical grids, especially if the grid is not economically reachable from their locations. Moreover, in such cases, geothermal electricity is cost-competitive compared to other alternative options, such as diesel generators or liquefied natural gas (LNG) engines or turbines (IESR, 2023).In the geothermal captive use business model, the industries develop GPP to power their primary industrial activities located near to the geothermal area instead of selling the electricity to the grid, such as PLN for the case of Indonesia. Therefore, such industries usually hold multiple permits that covers both the geothermal development and the main industrial activities. Figure 1 illustrates the differences between the conventional geothermal power generation and the geothermal captive use business models for the industrial sector. Two prominent examples of existing industrial geothermal captive use are the ones in Lihir (Papua New Guinea) and Cerro Prieto (Mexico). However, geothermal captive use has not been implemented in Indonesia despite the potential being present.

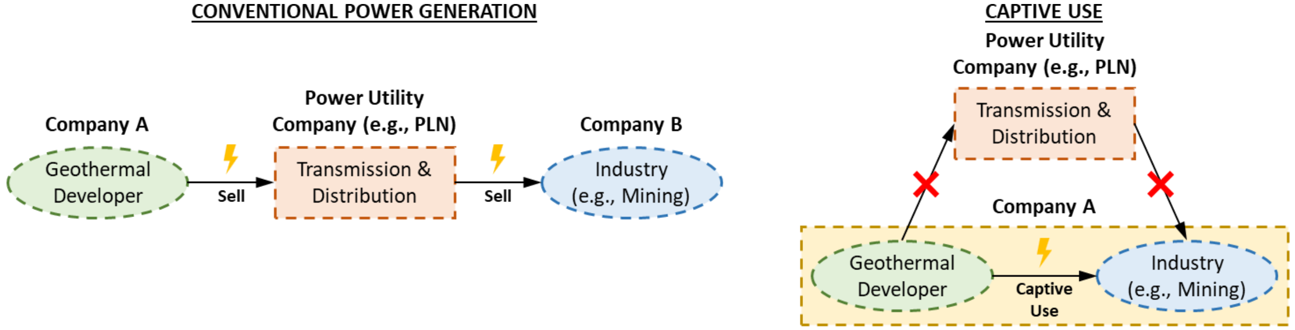

Figure 1: The differences between conventional geothermal power generation and geothermal captive use business models for the industrial sector.

2. WORLDWIDE EXPERIENCE

2.1 Lihir (Papua New Guinea)

Lihir Island is located 800 km northeast of the Papua New Guinea's capital, Port Moresby. On the island, gold bearing ore has been mined by Newcrest Mining Ltd. since 1997 in an open-pit mining. The mining site's northern and western parts are located within an active geothermal system. The Lihir geothermal development was driven by the need of pit dewatering as well as cooling and depressurizing the rock formation to enable safe and efficient deep open-pit mining. Initially, the mining site was reliant on heavy fuel oil (HFO)-fired power plants to provide electricity for the mining activities. As the geothermal drillings were performed and the geothermal resource was better understood, the role of geothermal development in Lihir evolved from merely mine dewatering and depressurization to providing cheaper and cleaner electricity than HFO for the mining activities (Melaku, 2005).

The Lihir geothermal development started when eight deep (1260-1790 mMD) standard-hole directional geothermal wells were drilled in 1999 (Melaku, 2005). Three wells that were drilled northwards encountered high permeability and production capacity. Meanwhile, three wells that were drilled southwards produce smaller capacity. The produced fluid has high pH (around 9), high chloride content (30,000 ppm), and high sulphate content (40,000 ppm) with a low non-condensable gas content (0.6 %wt). Due to its high mineral content, calcite deposition in the wellbore and silica scaling in the pipelines caused some of the wells being clogged after sustaining the discharge for only several months. Afterwards, around 20 shallow (400-800 mMD) geothermal wells were drilled to accelerate the pit dewatering and depressurization. Most of the deep and shallow wells encounter steam or high temperature fluids that can be used for power generation. The output of the deep wells are tabulated in Table 1.

Table 1: The output of Lihir deep geothermal wells drilled in 1999 (Melaku, 2005).

Well	Mass Flow Rate (t/h)	Enthalpy (kJ/kg)	Gas Content (%wt)
GW1	320	1100	n/a
GW2	65	2000	n/a
GW4	95	2750	n/a
GW5	150	2700	2
GW6	180	2700	0.6
GW7	100	2400	0.6
GW8	400	1200	0.7

A 6 MW backpressure GPP was commissioned in 2003 just north of the pit boundary to utilize the steam from four of the 28 geothermal wells. The performance of the GPP was excellent in the first two years of operation, in which its availability factor was higher than 95% (Melaku, 2005). Subsequently, a 30 MW flash GPP was commissioned in 2005, which was expanded to 50 MW in 2007 (Huttrer, 2021). As a result, Lihir GPP once had an installed capacity of 56 MW, which could supply 50% of the gold mine's electricitiy demand. However, due to the failure to reinject the utilized geothermal fluid and the decommissioning of the backpressure GPP in 2009, today's Lihir GPP only generates 15-18 MW. The site layout consisting of the Lihir gold mine pit, the geothermal wells, and the geothermal power plants is shown in Figure 2.

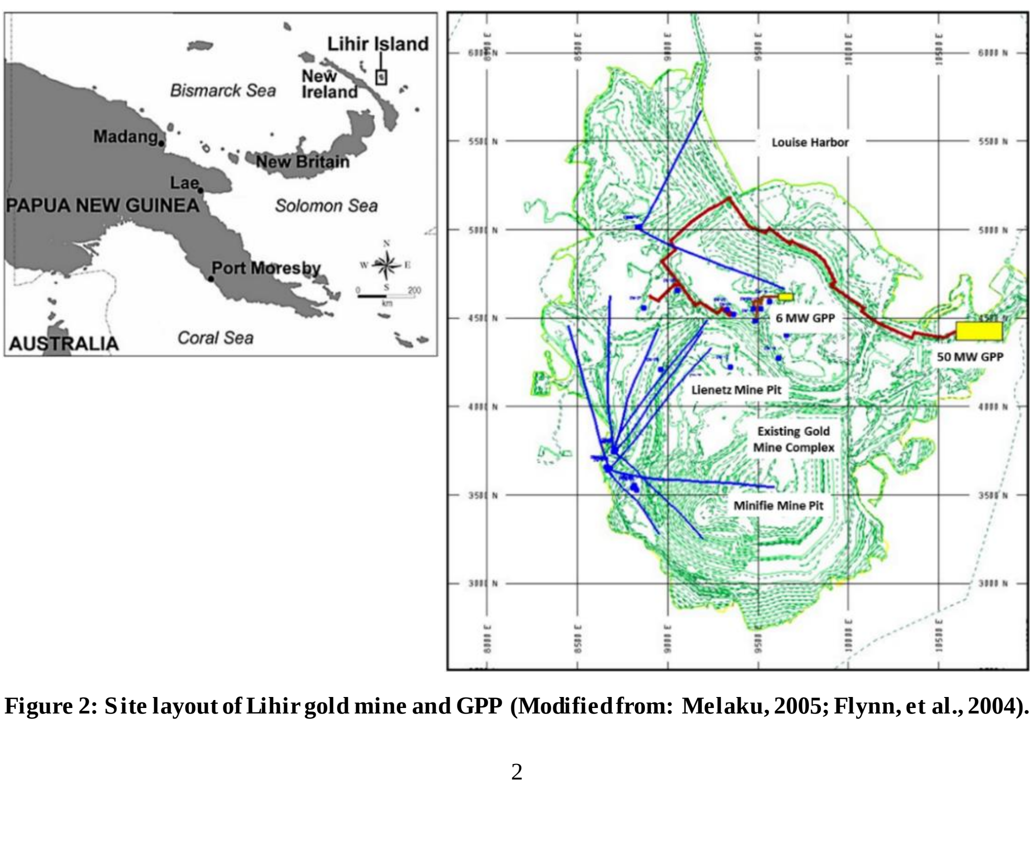

Figure 2: Site layout of Lihir gold mine and GPP (Modified from: Melaku, 2005; Flynn, et al., 2004).

The lessons learned from the geothermal captive use in Lihir are as follows:

- Geothermal utilization in mining areas could improve mining safety as well as reducing reliance on fossil fuel.
- The availability factor of the GPP is high (> 95%) and it could provide up to 50% of the mine's electricity needs.
- Proper geothermal reservoir management strategy is vital to maintain production level.
- Proper mineral scaling mitigation strategy is needed in geothermal fields located within mineral mining areas.

2.2 Florida Canyon (United States)

Florida Canyon is a gold mining site located in Nevada, United States, which was initially owned by Alio Gold Inc. The site has been producing gold through an open-pit mining for more than 30 years. Apparently, the mining site is adjacent to an active geothermal system, which leads to the belief that Florida Canyon is a hot spring-type epithermal gold deposit (MDO Data Online Inc., 2023). The mine wells at the Florida Canyon discharge 36 t/h of fluids at 100°C from the depth of 175 m. Initially, in 1980, the fluids were utilized as the heat source for heap leaching (NBMG, 2014). Afterwards, 2x50 kW binary GPP units were commissioned in 2010 and 2013, respectively, to convert the discharge fluid heat into electricity, which could provide 5% of the mining's electricity needs. Unfortunately, the GPPs have been decommissioned due to the mineral scaling in the piping and the acquisition of Alio Gold Inc. by Argonaut Mine Inc. in 2020 (NREL, 2022). Figure 3 shows the location of the pilot GPP within the Florida Canyon mining site.

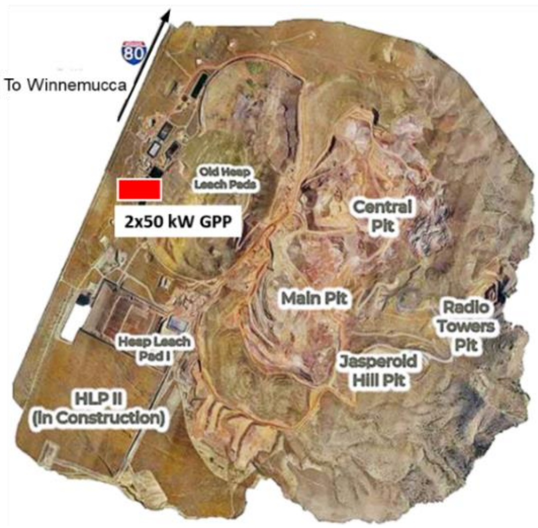

Figure 3: Site layout of Florida Canyon gold mine and GPP (Modified from: Harding, 2020).

The lessons learned from the geothermal captive use in Florida Canyon are as follows:

- Proper mineral scaling mitigation strategy is needed in geothermal fields located within mineral mining areas.
- Commitment from the mine owner is required to sustain the geothermal captive use.

3. POTENTIAL OF GEOTHERMAL CAPTIVE USE IN INDONESIA

3.1 Comparison of Electricity Generation Costs Between Various Energy Sources

In the absence of nearby electrical grids, the typical preferred energy source for industrial captive use is either gas turbines or diesel generators due to their low upfront cost, compact equipment, quick installation, and short ramp-up period (IRENA, 2019). However, these energy sources bring the operational challenges, such as expensive fuel requirements and insecure fuel supply chain, especially if the industrial location is in the rural areas or remote islands. Additionally, the use of fossil fuels creates high greenhouse gas (GHG) emissions. The presence of geothermal potential near to the industry could be a promising option of relatively cheap and clean captive use energy source, as shown in Table 2 and Figure 4. The levelized cost of electricity (LCOE) of geothermal is way lower than diesel generators and is equivalent to gas turbines. Additionally, the GHG emissions from geothermal is negligible compared to diesel and natural gas. Moreover, the LCOE shown in Table 2 and Figure 4 also has not considered the externalities, such as carbon tax for fossil fuel power generation. If it is considered, the GPP LCOE might be more favorable.

Table 2: Comparison between diesel generator, natural gas turbine, and geothermal power plant.

Parameter	Units	Diesel Generator	Gas Turbine	Geothermal	References
Capital expenditure	MUSD/MW	0.5-0.8	0.8-0.9	4-6 million	(Statista, 2023)
Land area	m^2/MW	900	800	5,000-20,000	(Strata Policy, 2017)
Installation duration	year	< 1	2-4	5-7	(ESMAP, 2012)
Ramp-up	minute	< 1	10-20	10-20	(Abudu, et al., 2020)
Capacity factor	-	10-30%	50-60%	80-95%	(U.S. DOE, 2020)
LCOE	USD¢/kWh	12.5-37.1	9.1-13.5	3.6-13.4	(IESR, 2023)
Fuel requirement	-	Yes	Yes	No	(IMF, 2019)
GHG emission	kg CO_2e/kWh	0.51-1.18	0.32-0.99	0.02-0.24	(NREL, 2021)
Subject to carbon tax	-	Yes	Yes	No	(IMF, 2019)

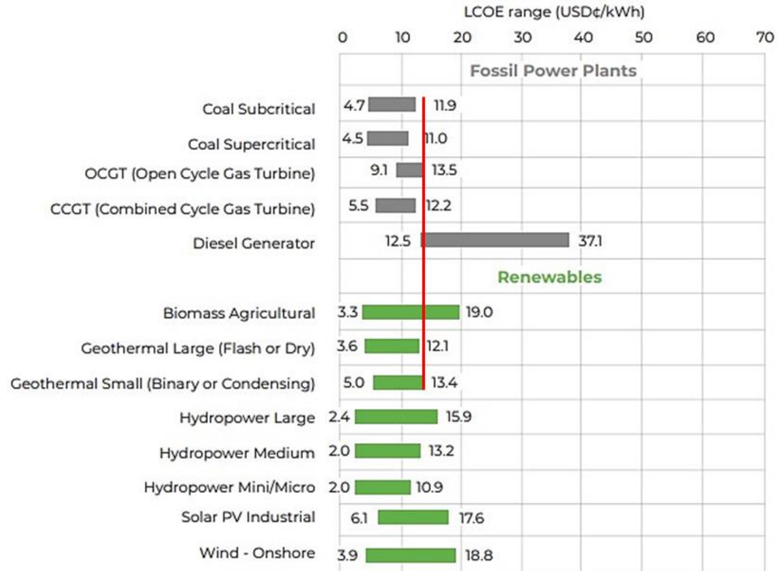

Figure 4: LCOE comparison between geothermal energy and other energy sources (Modified from: IESR, 2023).

3.2 Geothermal Prospect Areas Near to Mining Areas Without PLN's Grid Nearby

Currently, there are no commercially operational geothermal captive use by any industry in Indonesia, including mining. However, Hu'u Daha in West Nusa Tenggara is the only mining site that has made a notable progress on geothermal captive use development. Hu'u Daha is a copper-gold deposit, which is currently being explored by PT Sumbawa Timur Mining (abbreviated as "STM"). Apparently, the deposit is located within an active geothermal system. STM is interested in developing the geothermal potential in Hu'u Daha to provide electricity for their own mining activities, especially the smelter operation, since the mining site is located up to 30 km away from the nearest existing substation (Dompu 150 kV). In 2018, the Indonesian Ministry of Energy and Mineral Resources (MEMR) announced that STM was awarded the Hu'u Daha geothermal Preliminary Survey and Exploration Assignment or *Penugasan Survei Pendahuluan dan Eksplorasi* (PSPE), which was completed by STM in mid-2023. As a result of the PSPE award, STM currently holds two permits consisting of both the mining and geothermal permits. During the PSPE activities, STM discovered a temperature of more than 150^{o}C (SuaraNTB.com, 2023) despite the presence of geothermal fluid is yet to be proven.

In this study, the mining sites in Indonesia that have the potential of implementing geothermal captive use are mapped and tabulated in Table 3 based on the following criteria:

- The geothermal prospect area has not been auctioned by MEMR (except for Hu'u Daha) so that there is still a potential for the mining permit holders to obtain the geothermal permit for their captive use.
- The distance between the mining site and the nearest existing or planned substation according to PLN's Electricity Supply Business Plan or *Rencana Usaha Penyediaan Tenaga Listrik* (RUPTL) Year 2021 – 2023 is larger than 30 km so that the connection to the substation is unlikely to be economical.
- The distance between the mining site and the nearest geothermal potential is less than 10 km so that the geothermal captive use is likely to be more economically attractive than the connection to the existing or planned substation with the distance of more than 30 km.

The information about the mining site and the nearby geothermal potential are gathered from MEMR's Renewable Energy Map, Electric Utility Map, and Minerba One Map Indonesia (MOMI), which are available online. Meanwhile, the distances from the mining site to the nearest substation and to the geothermal potential are measured approximately using the online Google Earth. As shown in Table 3, there are up to 425 MW potential of geothermal captive use by the mining industry across 10 mining sites in Indonesia. Most of the prospective mining sites are located on remote islands in eastern Indonesia without existing or planned electricity grid according to RUPTL 2021 – 2023. Therefore, this condition should prompt the mining industries in this region to seriously consider implementing geothermal captive use to achieve clean and cheap independent power generation.

Table 3: Prospective mining sites for geothermal captive use in Indonesia.

Mining Site Location	Mining Permit Holder	Distance to Nearest Substation	Commodity	Mining Status	Mining License Validity	Nearby Geothermal Potential	Geothermal Potential Size
Sarolangun and Merangin Regencies, Jambi	PT Aneka Tambang Tbk.	57 km (Tess 150 kV)	Gold	Exploration	2020 – 2024	Sungai Tenang (2 km)	74 MW (hypothetical resource)
Bima and Dompu Regencies, West Nusa Tenggara	PT Sumbawa Timur Mining	37 km (Dompu 150 kV)	Gold	Exploration	2022 – 2023	Hu'u Daha (inside the mining site boundary)	69 MW (probable reserve)

East Manggarai Regency, East Nusa Tenggara	PT Istindo Mitra Perdana	34 km (Ruteng 70 kV)	Manganese	Production	2016 – 2026	Wai Pesi (9 km)	54 MW (probable reserve)
East Flores Regency, East Nusa Tenggara	PT Adisti Indah	Remote island	Natural gravel sand	Backup (*Pencadangan*)	n/a	Oyang Barang (1 km)	37 MW (probable reserve)
Lembata Regency, East Nusa Tenggara	PT Trans Lembata	Remote island	Excavated gravel	Backup (*Pencadangan*)	n/a	Adum (9 km)	36 MW (probable reserve)
South West Maluku Regency, Maluku	PT Batutua Kharisma Permai	Remote island	Copper	Production	2018 – 2031	Lurang (2 km)	20 MW (speculative resource)
Sula Island Regency, North Maluku	PT Bintani Karya Bumi Persada	Remote island	Iron ore	Production	2018 – 2034	Kramat (1 km)	10 MW (speculative resource)
Sula Island Regency, North Maluku	PT Patria Sekarjaya	Remote island	Iron ore	Production	2018 – 2034	Losseng (inside the mining site boundary)	30 MW (speculative resource)
Sula Island Regency, North Maluku	PT Indotama Mineral Indonesia	Remote island	Iron ore	Production	2018 – 2034	Auponia (inside the mining site boundary)	20 MW (speculative resource)
Sula Island Regency, North Maluku	PT Wirabahana Perkasa	Remote island	Iron ore	Production	2018 – 2034	Bruokol (inside the mining boundary)	5 MW (speculative resource)
						Total	**425 MW**

Out of the 10 prospective mining sites that have been identified, 2 sites are still under exploration, while 6 sites are already in the production phase, as shown in Figure 5(a). The example of parallel mining and geothermal captive use explorations could be seen in Hu'u Daha. Meanwhile, the example of performing geothermal captive use exploration after the mine has been operational could be seen in Lihir. Furthermore, four prospective mining sites have the geothermal potential inside their mining boundaries, the other four have the geothermal potential 1-5 km away, and the remaining two have the geothermal potential 6-10 km away, as shown in Figure 5(b). In order to make geothermal captive use more economically attractive than diesel and natural gas, the geothermal's higher upfront cost should be counterbalanced by the short distance between the mining site and the geothermal potential. Should the geothermal potential is more than 10 km away from the mining site, geothermal captive use is deemed to be less economically attractive than diesel and natural gas since it would require extensive electrical grid connecting the GPP to the mining site.

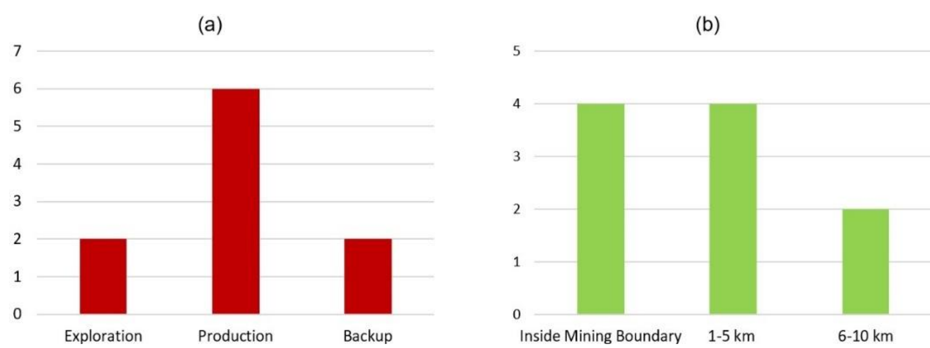

Figure 5: (a) prospective mine status; (b) distance between the mining site and geothermal potential.

The strategy of developing geothermal captive use either in the mining exploration phase or in the mining production phase has its own advantages and disadvantages, as shown in Table 4. Consequently, the mining permit holders should implement distinctive action plans to develop geothermal captive use using either strategy.

Table 4: Comparison between conducting geothermal captive use development during mining exploration and production.

During Mining Exploration		During Mining Production	
Advantages	Disadvantages	Advantages	Disadvantages
✓ Mining and geothermal site plans could be integrated	× High upfront cost × Uncertainty of mining discovery × No existing infrastructure × Limited subsurface data from mining wells	✓ Existing infrastructure ✓ Mining revenue could be allocated for geothermal captive use development ✓ More available subsurface data from mining wells	× Geothermal site plan should adjust to the existing mining site × Challenging geothermal equipment mobilization due to existing mining activities

Action Plan	Action Plan
➢ Gather subsurface data as much as possible through both the mining and geothermal exploration wells ➢ Create an integrated mining and geothermal site plans to ease infrastructure preparation and later operation ➢ Allocate more financial resources to enable parallel mining and geothermal exploration activities	➢ Gather and evaluate the existing subsurface data from past mining exploration wells ➢ Conduct geothermal exploration drilling to gather subsurface data regarding the geothermal system ➢ Evaluate the existing infrastructure's readiness to support geothermal development activitiy ➢ Adjust the geothermal site plan to the existing mine site plan

3.3 Challenges of Geothermal Captive Use in Indonesia

The limited geothermal captive use by the industries in Indonesia and globally is likely related to the technical, economic, and regulatory challenges facing its development. The challenges of developing geothermal captive use with an emphasis on the mining industry are listed as follows:

- Geothermal system within mineral deposits is likely to cause mineral scaling in the geothermal facilities within or near to mining sites (NBMG, 2014).
- Challenging geothermal equipment mobilization and installation within an operational mining site.
- Knowledge gap between geothermal and the company's preexisting core business, such as mining.
- Permits are required for both the mining and geothermal activities.
- Financially strong enterprises are required to develop both geothermal and their preexisting core business activities.
- Since natural gas turbines could provide similar LCOE and faster installation compared to geothermal power plants, strong commitments from the enterprise to provide clean source of electricity from geothermal captive use is mandatory.

As the consequences of these challenges, the industry should implement the necessary action plans as follows:

- Create mineral scaling mitigation strategy in the geothermal facilities within or near to mining sites.
- Assess whether the existing infrastructure is capable of supporting geothermal equipment mobilization and installation.
- Hire geothermal experts and conduct capacity building to fill the knowledge gap between geothermal and the company's preexisting core business, such as mining.
- Coordinate with MEMR for the possibility of acquiring geothermal permit to explore nearby geothermal prospect areas.
- Gather internal and external financial aid to support the geothermal captive use development.
- Build strong commitment to provide clean source of electricity from geothermal captive use despite natural gas turbines could provide similar LCOE and faster installation.

3. CONCLUSION

In the conventional geothermal power generation business model, the electricity is sold by the GPP operators to the offtakers that distribute the electricity to the buyers, including the industries. However, some industries are located too far away for an economically viable connection to the existing grid so that they have to generate power independently for their industrial activities. Geothermal captive use offers a new approach on how geothermal energy can provide clean and cheap electricity for the local industries yet no electricity grid is accessible and the costs of diesel and natural gas are high. Examples of geothermal captive use can be seen in Lihir (Papua New Guinea) and Florida Canyon (United States). Although geothermal captive use is yet to be implemented in Indonesia, up to 10 mining sites are identified as having the potential of geothermal captive use up to 425 MW in total. While the geothermal captive use development during either the mining exploration or production phase present its unique advantages and disadvantages, the mining permit holders should conduct necessary action plans to initiate the geothermal captive use development. Additionally, the technical, economic, and regulatory challenges should be addressed by the industry with the support from the government to accelerate geothermal captive use development in Indonesia.

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