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Harnessing Geothermal Energy Amid Volcanic Challenges: Insights from Ormat's Puna Geothermal Venture

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ABSTRACT

The Puna Geothermal Venture (PGV) initiated commercial operations in 1993 to provide renewable geothermal power to the Big Island of Hawaii. Operation of the facility was taken over by Ormat in 2004 and can provide an estimated 38 MW of geothermal energy to the island, and providing up to 31% of the islands energy as of 2017, In early May 2018, the eruption in the Lower East Rift Zone of the Kilauea Volcano changed the landscape of the southeast portion of the island, covering large areas of the land around PGV with an estimated one billion cubic yards of lava, inundating several hundred homes, and surrounding the plant with multiple lava flows. Specifically, lava blocked the main access road to the power plant, covered two geothermal wells, and burned the electrical substation and other plant infrastructure. Through activation of an Emergency Response Plan, PGV was able to safely navigate the eruption.

The PGV plant came back online in November 2020 through careful planning with government agencies, increased community outreach, technical solutions related to understanding changes in the post-eruption resource, and re-drilling of geothermal wells to support the plant as just a few examples. The technical experts and leadership team at Ormat and PGV joined together to navigate all the risks, mitigation, and management to respond and rebuild following the eruption. The plant is now preparing for a repower approved through an Environmental Review completed in 2023 that is designed, engineered, and permitted to clear a new path to the future of the facility utilizing new technologies, updated reservoir and well management practices, and industry leading groundwater and environmental monitoring programs.

This case study shares a few perspectives of bringing together the technical science, environmental management, and alignment in permitting of a geothermal project. PGV is a great example of tenacity and the perseverance to overcome the complications of a major volcanic eruption to come back even stronger with an exciting state of the art of repower that will ensure reliable, safe, and clean geothermal energy to the people of Hawaii.

1 INTRODUCTION

Puna Geothermal Venture (PGV), a subsidiary of Ormat Technologies, Inc., has operated a geothermal facility on the Big Island of Hawai'i for over three decades starting in 1993. Ormat took the helm in 2004 to bring the power plant to roughly 38 MW of geothermal power. This amount of power has been provided since 2017 amounting to approximately one third or 31% of the island's energy.

A major disruption occurred in early May 2018 that would challenge the Big Island including PGV with the eruption of the Lower East Rift Zone (LERZ) of the Kilauea Volcano that flowed almost one billion cubic yards of lava. The lava flow covered major areas of access roads, homes, and infrastructure. For PGV, the lava flows created challenges blocking the main access to the power plant, covered two wells, and buried the electrical substation and operational infrastructure. With enough time and planning in place, PGV activated its Emergency Response Plan to get staff and operations secured. The situation was constantly monitored with the help of emergency repose teams.

While the surface was inundated with flow lava and debris from the erupting rift zone, the subsurface environment was also undergoing incredible changes. The summit lava lake in Kilauea drained, resulting in a caldera collapse, followed by a magnitude 6.9 earthquake that was accompanied by over 40 magnitude 3 (or

higher) earthquakes daily. A total of 24 fissures opened along the LERZ, allowing volatile gases such as CO_2, H_2S, and SO_2 to be released into the shallow groundwaters and atmosphere (USGS 2020). The eruption itself involved multiple phases of different lavas, suggested multiple sources for each, with more chemically- evolved magmas representing residual magma from the LERZ, while less evolved, hotter fluids were like those seen in recent crater eruptions at Kilauea (Gansecki, et al., 2019).

The groundwater system within Kīlauea's Lower East Rift Zone (LERZ) is highly compartmentalized by intrusive dike complexes, creating perched and dike-impounded aquifers above a basal freshwater lens, with permeability decreasing sharply with depth due to hydrothermal alteration and dense intrusions. Shallow thermal wells and springs in the LERZ show elevated temperatures, but almost no direct chemical signature of deep geothermal fluids, indicating that heat transfer to the surface occurs primarily by conduction through low-permeability rock rather than advective flow of reservoir fluids (USGS 2021; Janek, 1994; Evans, 2015). Groundwater chemistry reflects a complex interplay of meteoric recharge, seawater mixing, and magmatic volatile input (Hurwitz, 2003), the degree of all of which were likely drastically altered by the 2018 eruption and the proximity of these reservoirs to the shallow magma centers and lava flows.

2 THE PUNA GEOTHERMAL SYSTEM

The Puna Geothermal Venture (PGV) taps a high-temperature, two-phase, liquid-dominated geothermal resource, and derives its heat from active magma migration and elevated heat flow associated with the rift zone. The PGV reservoir lies at depths exceeding 1,200 meters and is hosted in fractured submarine basalts and diabase dikes. Permeability is fracture-dominated, primarily controlled by rift-parallel structures aligned with the LERZ trend (approximately N63ºE), with additional contributions from rift-perpendicular fractures formed near a prominent left-step in the rift zone. These structural complexities create zones of enhanced permeability that sustain convective hydrothermal circulation within the area.

The reservoir is overlain by a clay-rich caprock formed through hydrothermal alteration of hyaloclastite and basaltic flows, which limits vertical fluid migration and suppresses surface manifestations. Despite this seal, minor leakage is suspected to occur through tectonic fractures, but the system remains largely confined. Geophysical surveys, including airborne magnetics and magnetotellurics, reveal structural features consistent with the conceptual model, while geochemical analyses indicate that reservoir fluids are Na-Cl brines derived from thermally altered meteoric and seawater mixtures, with most recent chemistry suggesting a full transition to a modified seawater endmember like that seen in the geothermal fields of Reykjanes, Iceland.

2.1 Hydrologic Monitoring at PGV

Hydrologic monitoring at PGV is intrinsic to understand what is happening below the surface. Historically, the hydrologic monitoring program (HMP) for PGV focused on utilizing three groundwater monitoring wells (MW-1, MW-2, and MW-3) to characterize the shallow basal aquifer chemistry, which regionally within the LERZ is deemed non-potable water by the County of Hawaii. Previous studies (Evans, 2015) showed little to no impact from geothermal production on the basal aquifer chemistry. However, because of the eruption, the three historic monitoring wells were destroyed by flowing lava, necessitating a transition to three new monitoring locations in 2019 and 2020: MW-4, MW-5, and MW-6. The wells MW-4 and MW-5 are basically twins of each other located within the power plant and work to provide operational support to ongoing drilling programs and plant recommissioning but were deemed suitable for monitoring wells starting in 2019. The last well, MW-6, is a private residential well that was used for agricultural use prior to the eruption, but post eruption the pH, temperature, and dissolved solids of the water increased to a point where it could no longer be used.

Geochemical changes associated with the 2018 eruption were evident when the facility returned to operation in late 2020; the resource produced higher enthalpy fluids with elevated concentrations of carbon dioxide and hydrogen sulfide, and temporal changes in chloride and major cations (sodium, calcium, potassium) and conservative species (chloride, boron, bromide) were indicative of increasing amounts of a hydrothermally altered seawater into the geothermal reservoir. Similar trends were seen in the shallow groundwaters in the vicinity of the LERZ, with elevated chlorides, lower pH, and higher temperatures that were indicative of additional heat input to the system; however, distinct geochemical ratios between the two aquifers confirmed the lack of hydrologic communication between the geothermal reservoir and the overlying aquifers and were consistent with previous reports (Janek, 1994; Evans, 2015; USGS 2021).

During plant recommissioning and permitting of an additional injection well to the Underground Injection Control (UIC) permit, ongoing discussions with various agencies, including the Hawaii Department of Health (HDOH), raised concerns on whether the current HMP utilizing MW-4, MW-5, and MW-6 and frequency of sampling were suitable for monitoring potential influences of geothermal injection on the basal aquifer. This sparked a multi-

year effort between HDOH and Ormat, along with third party contractors to provide an updated conceptual site model (CSM), HMP, new monitoring well installations, and a reservoir tracer test. This work is on-going and many of these requirements are living documents to support the understanding of the PGV geothermal system.

3 ENVIRONMENTAL MANAGEMENT

In the years following the eruption, PGV went to work on options to bring PGV back online and balance environmental management needs. The first major piece took place on March 16, 2022, when the Hawai'i Public Utilities Commission (HPUC) approved an Amended and Restated Power Purchase Agreement (ARPPA) between PGV and Hawaiian Electric to provide an additional eight megawatts (MW) of geothermal energy with the PGV Repower Project (Project). The ARPPA would allow for an increase of up to 46 MW. The Project includes the commissioning of new efficient generating units and the decommissioning of the old generating units, allowing for an increase in generation.

As part of the approval of the ARPPA, the HPUC required an environmental review under the Hawaii Environmental Policy Act (HEPA) (Chapter 343, Hawaii Revised Statues, and Title 11, Chapter 200.1, Hawaii Administrative Rules) to be completed before the commencement of construction for the Project. The HPUC, the Department of Land and Natural Resources and the Department of Health Clean Air Branch all declined to be the authorizing agency for the environmental review; therefore, a request was made to the Office of Planning and Sustainable Development (OPSD) to determine the approving agency. OPSD determined that the County of Hawaii Planning Department be designated as the accepting authority for the environmental review because they are responsible for supervising the project through compliance with county permits that govern the Project. At Ormat's request and after much discussion with agency staff, PGV, and the county, it was determined that an Environmental Impact Statement (EIS) would be the appropriate level of environmental review and would provide the most opportunity for public input.

PGV requires authorization from several federal, state, and county governments to operate. There are six main permits for development. At the county level, construction authorizations for grading and building are required from the Department of Public Works. To comply with the Hawaii ambient air quality standards, amendments to the Noncovered Source Permit from the State of Hawaii Department of Health (DOH) must be submitted. The Geothermal Resource Permit (GRP) from the Hawaii County Planning Department is the primary permit, focusing on local land use requirements. In addition, a Plan of Operations for geothermal well drilling with the State of Hawaii, Department of Land and Natural Resources (DLNR) is also required. Wellfield operations include permits authorized under the Underground Injection Control Permit from the U.S. Environmental Protection Agency and DOH.

The EIS analyzed the potential impacts of the Project, which included the replacement of the current 12 operating power-generating units with only four much more efficient power-generating units. The project would increase renewable energy production at the existing facility (within the current site fence line) using new, more efficient Ormat Energy Convertor (OEC) units on a co-located smaller land footprint compared to the existing units. The Project would increase power production from 38 to 46 MW in Phase 1 and may further increase production to 60 megawatts in Phase 2. The overall property size would remain the same, and most of the existing infrastructure and buildings would remain for the Project, including administration buildings, the control room, maintenance areas, well pads, and the gathering system. The proposed new units would continue safely supplying reliable power from renewable geothermal resources with more efficient and quieter equipment.

In coordination with the county, Ormat contracted Stantec Consulting Services Inc. (Stantec) to be the third-party consultant preparing the EIS. During the entire EIS process, PGV made all documents available on the project's website (https://punageothermalproject.com/eis/) to keep the public informed of upcoming meetings and the status of the EIS.

The Project's EIS Prep Notice (EISPN) was published on July 23, 2022, which began a 30-day public scoping period. The EIS analyzed the ARPPA-approved Project, which increased power production up to 46 MW (Phase 1). The EIS also analyzed a potential increase from 46 to 60 MW (Phase 2). During the scoping period, the public could submit written comments anytime. As a Hawaii Environmental Review Program requirement, PGV hosted a community meeting during the scoping period. The community meeting was held on August 17, 2022, at the Pahoa Neighborhood Center in Pahoa, HI, with a link for virtual attendance. A one-hour informational open house was held during this meeting, followed by a two-hour period for oral comments. During the scoping period, 29 letters or oral comments were received regarding the Project.

Once the scoping period was over, Stantec began preparing the Draft EIS document. The public scoping comments were reviewed, with substantial comments received during the scoping period being addressed in the Draft EIS. The Draft EIS analyzed potential impacts to the following resources: geology, hydrology, air quality and climate change, noise, biological resources, socioeconomics and environmental justice, historic resources, cultural practices, aesthetics, hazardous materials and solid waste, public health and safety, transportation and access, and cumulative effects. The Draft EIS was published on May 8, 2023, beginning a 45-day public comment period. While not required by statute, PGV hosted an open house and public comment meeting on June 1, 2023, where information on the DEIS was presented, and the public could provide written and oral comments. The meeting was again held at the Pahoa Neighborhood Facility Center in Pahoa, HI. During the public comment period, 90 comments (letter or oral) were received, with more than 1000 individual comments. Comments mainly related to the following issues (not an all-inclusive list): existing operations, hydrology, air quality, cultural impacts, hazardous materials and waste, noise, emergency response, and geologic hazards.

During the preparation of the Final EIS, each comment received during the public comment period was reviewed and responded to, and any necessary changes were made to the final document. The Planning Department accepted the Final EIS on January 22, 2024 and submitted to the HPUC on February 8, 2024.

4 ALIGNMENT IN PERMITTING

4.1 Federal, State, and County Level

With the completion of the EIS, the timeframe to construct the Repower Project was established by the HPUC, which was 36 months. This timeframe includes completing the required operational permits and updates. The environmental permits necessary for the operation of PGV are managed at the federal, state, and county levels. Several types of permits are currently needed for operation from these agencies. The Project will require an update to the County Geothermal Resource Permit, the DLNR Plan of Operations, and the State and Federal Underground Injection programs. An amended permit will be sought for air quality under the Noncovered-Source Permit program, and then new building and grading permits will be requested. The following are the detailed types of permits and lead agencies required for the operation of a geothermal facility in Hawai'i.

4.2 Required Environmental Permits

Ormat has operated PGV for over 20 years and is committed to providing safe, reliable renewable energy to the grid by operating our plants safely and sustainably. This includes protecting our employees, our environment, and our neighboring communities. PGV recognizes the need to maintain and comply with environmental regulations, and from its inception, the facility has maintained the appropriate environmental permit approvals for operation.

4.2.1 Geothermal Resource Permit (GRP

The GRP is managed by the County of Hawai'i Planning Department, with permit approval authority with the East Hawaii Planning Commission. This permit focuses on local land use requirements maintaining home rule. The GRP allows PGV to increase the power output up to 60 MW. The GRP was initially approved in 1989 and was amended in 2001. Informational updates have been provided accordingly with changes to the operation. The Repowering Project will require grading, grubbing, and building permits from the County Department of Public Works.

4.2.2 Plan of Operations (PoO)

PGV operates a geothermal wellfield comprised of production and injection wells. The DLNR regulates all new geothermal wells. PGV's living document that oversees geothermal well development is referred to as the Plan Of Operations (POO). The Plan of Operations with DLNR allows PGV to drill up to 30 wells and generate up to 60 MW. The geothermal well program is an iterative process that is fit-for-purpose based on geology, resource constraints, land holdings, and regulatory requirements. New wells that are eventually designated as injection wells are regulated by the HDOH & EPA UIC programs.

4.2.3 Underground Injection Control (UIC)

The underground injection control program at PGV is regulated by two agencies, the EPA and HDOH. Both agencies have their respective UIC permits for the PGV facility. Well operations are continuous and include testing for integrity and reservoir monitoring programs. The UIC permits under EPA and HDOH include injection pressure limits that are based on formation testing to reduce the potential for the creation of fractures and well construction requirements so that injected fluids do not intersect the potential underground sources of drinking

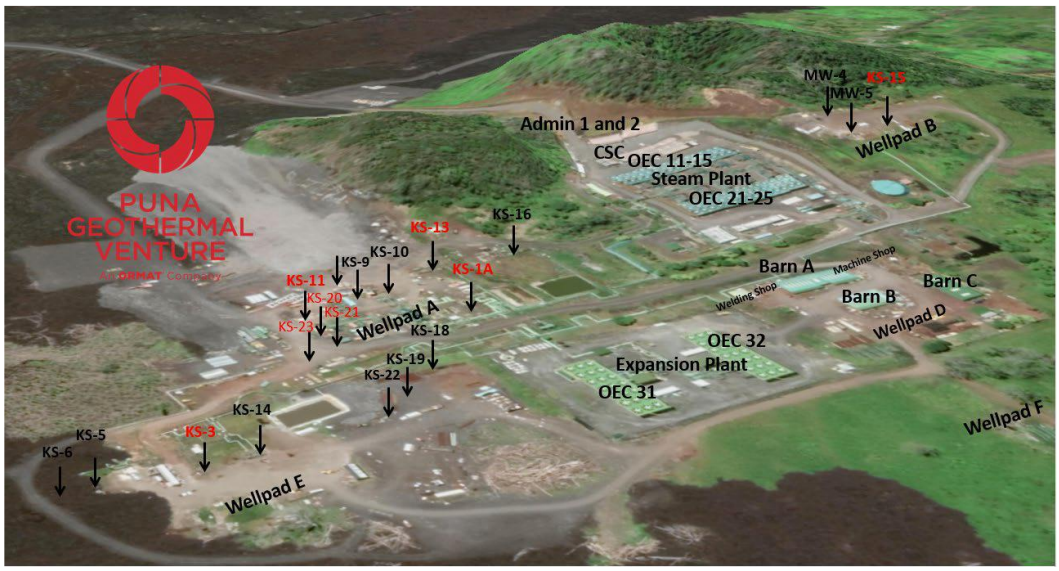
water. Continuous monitoring and systematic testing requirements are in place for each injection well, including mechanical integrity tests. Groundwater is monitored, as described above with the HMP, to ensure no impacts to groundwater quality occurs from the geothermal operations. The State UIC permit is renewed every five years, and the Federal UIC permit is renewed every ten years.

4.2.4 Noncovered Source Permit (NSP)

The State of Hawai'i Clean Air Branch manages air quality regulations for PGV by issuance of Noncovered Source Permits (NSP) for the operation of the wells and geothermal facility. The NSP allows PGV to generate up to 41 MW nominal. The geothermal facility permit will be amended to add the repower OEC units. The advanced OECs will use geothermal fluid from existing geothermal wells.

Fugitive H_2S emissions are controlled by capture and treatment with a series of two reactors for chemical abatement. The combustion emissions for current and future drilling are covered in the Project's existing NSP. No greenhouse gas emissions are emitted from PGV plant operations. The State NSP is renewed every five years.

Figure 1. PGV Facility and Wellfield



Conclusion

Currently, all the necessary environmental and government permits to operate the PGV facility are active without any interruptions, ensuring the production of 38 MW of renewable power and including an updated hydrological monitoring program to ensure the continued quality of potential future sources of drinking water in the LERZ. Everyone is facing complex regulatory challenges involving local, state, and federal authorities as PGV progresses toward the 46 MW Repower Project, and as the State of Hawaii's renewable energy mandate is to be at 100% by 2045. For example, the Public Utilities Commission's requirement for an Environmental Review of the proposed 46 MW Repower Project BEFORE any construction can commence added an unprecedented layer of complexity that is unique in its nature. The 46 MW Repower Project in the form of the Amended and Restated Power Purchase Agreement (AARP) was negotiated and approved between Ormat and Hawaii Electric Light Company (HELCO) in 2019. On December 31, 2019, HELCO submitted the ARPPA to the PUC for review and approval. The PUC opened a docket, which from January 2020 through March 2021, followed the PUC procedural schedule for information requests and responses by all parties. On March 31, 2021 the PUC suspended the docket, pending the completion of an environmental review. The suspension by the PUC was ordered, AFTER the Department of Health and the Department of Land and Natural resources both informed the PUC that an environmental review was not required. With the docket for the 46 MW Repower Project in limbo, PGV reached out to the Office of Environmental Quality Control (OEQC) for guidance. The result was that PGV was able to designate Hawaii County to be the Accepting Authority for the environmental review. The County's position was that an environmental review was not required, but, to assist with completing the PUC review and approval of the ARPPA, the County accepted the designation. The EIS took over two years to complete, but PGV submitted the Final EIS on December 27, 2023. On February 8, 2024, HELCO filed a copy of the EIS with the PUC. This filing concluded the conditional approval of the ARPPA, and now allows construction to begin on the 46 MW

Repower Project. In the end, it took over four years to get an approval from the PUC for an additional 8 MWs to an existing 38 MW facility.

PGV's Repower Project is not just about expansion—it symbolizes a commitment. A commitment to responsibly harness geothermal energy, provide reliable and sustainable power, and honor the people and traditions of Hawai'i. By aligning our operations with the regulatory expectations from county, state, and federal agencies as detailed in this report, PGV is positioned to enhance its capacity while preserving the delicate balance between progress and conservation.

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