GEOTHERMAL RESOURCES COUNCIL

Bulletin

Vol. 48, No. 6
November/December 2019

Re-powering Geothermal Around the World

The Repowering of the Lightning Dock Geothermal Plant in New Mexico

Joseph Bonafin[1] and Halley K. Dickey[2]
[1]Turboden, Italy
[2]Industrial Builders, USA

1. Introduction

The Lightning Dock Geothermal (LDG) resource area is located on the east side of Animas Valley in Hidalgo County, in the southwest corner of New Mexico. For over 30 years, starting in 1977, LDG was home to a greenhouse complex that became one of the largest in the U.S. In 2013, a 4 MW plant was installed by Cyrq Energy, Inc. (Cyrq Energy), with plans to further enhance it to 10 MW. However, the second phase of the development with the original equipment supplier was never completed.

In 2017, Cyrq Energy selected Turboden and Industrial Builders to perform a complete repower of the power plant at Lightning Dock. The contractor offered to provide a new power plant producing 11.0 MW net (14 MW gross) electric power with a single Organic Rankine Cycle (ORC) turbine.

The new plant began commercial operation in December 2018 and outputs over 10 MW of electricity onto the grid. The plant provides power for over 10,000 homes in New Mexico with 100% renewable energy, through a *Power Purchase Agreement* (PPA) with PNM, the state's largest utility.

The project was completed ahead of schedule and on budget due to the team effort by the owner, Cyrq Energy, the plant supplier, Turboden, and the engineering procurement and Construction (EPC) contractor, Industrial Builders. Thus, this project is a useful lesson on how an improved design and technology can be utilized for repowering an older plant to create a positive business case, due to the expected higher plant availability and greatly increased efficiency.

2. Lightning Dock Geothermal Field

The Lightning Dock Geothermal (LDG) project is in the Animas Valley of Hidalgo County, New Mexico, approximately 12 miles east of the New Mexico/Arizona border and 55 miles north of the US/Mexico border. LDG is at 4236 ft above mean sea level, with an average ambient temperature of 60 °F.

Figure 1: From left to right, inactive direct use heating greenhouses, Pyramid Mountains, and injection well 76-7

The Animas Valley is within the Mexican Highland part of the Basin and Range physiographic province, a large region characterized by steep, well dissected mountains separated by flat-floored desert valleys. North-South trending, range-bounding faults define the Animas Valley on the west and east; thus, the valley is both a topographic low and a structural graben, bounded on the west by the Peloncillo Mountains and on the east by the Pyramid Mountains (Figure 1).

The LDG geothermal system is a "blind" geothermal resource (without any surface manifestations) discovered during drilling for crop irrigation in 1948 (Elston et al., 1983). The thermal anomaly in the Animas Valley is likely the result high regional heat flow and the intersection of several geologic structural features, including the margin of a Tertiary age volcanic caldera (the Muir Cauldron) that is a potential source of geothermal heat, and one or more large offset Basin and Range normal faults that likely serve as conduits for heated water to rise to shallow depths, resulting in a natural geothermal outflow plume at the site (Crowell & Crowell, 2014).

In 1974, the resource was designated by the Federal government as a Known Geothermal Resource Area (KGRA) encompassing 23,552 acres. Exploration and development of the resource was undertaken by several entities over the years, including Amax Exploration, Inc., who were the first geothermal lease holders from 1979 to ~1984; Steam Reserve Corporation, who drilled well 55-7 and operated the lease from ~1984 to 1987; Lightning Dock Geothermal, Inc. (not related to Cyrq) run by Roy Cuniff and Roger Bowers, who operated the lease from 1987 to 2008; and Lightning Dock Geothermal HI 01, LLC, current operator of the field since 2008 (owned first by Raser Technologies and now by its successor Cyrq Energy).

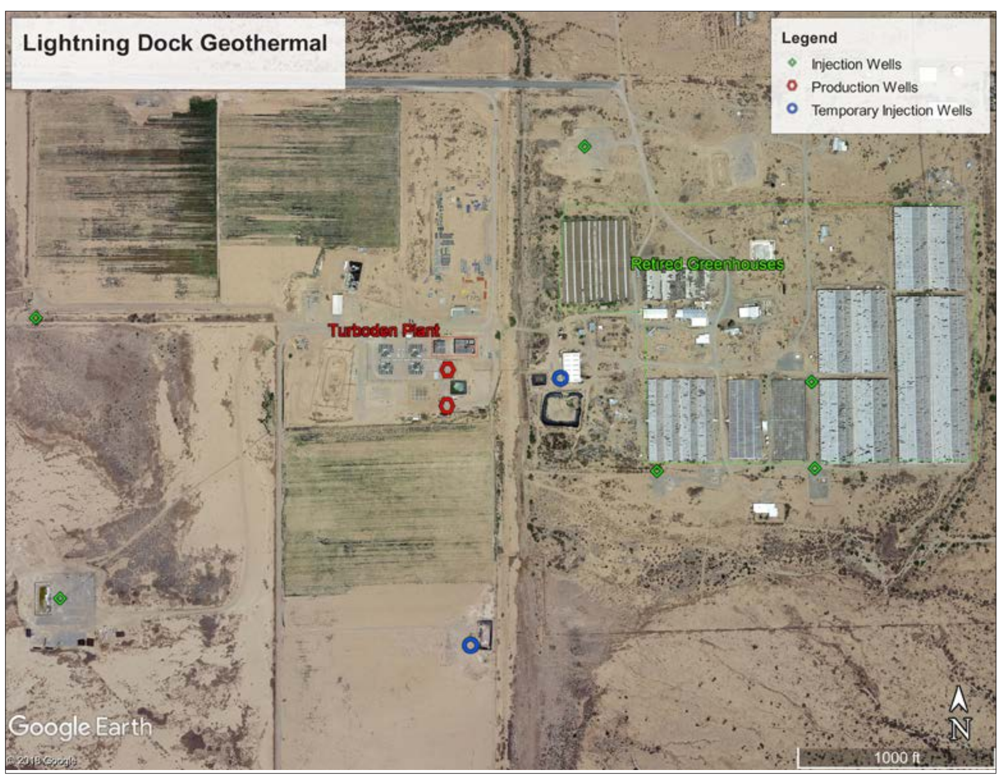

Figure 2: Well field and plant map of Lightning Dock Geothermal Field, New Mexico

Two production wells, 45-7 drilled by Cyrq in 2011 and its nearby twin, 45A-7, completed by Cyrq in February 2018, provide about 5000 gpm of 310 °F water to the plant. After cooling in the plant heat exchangers, the brine is returned to the reinjection wells at about 170 °F. The reinjection field potentially includes up to eight wells with depths between 550 and 6200 ft, including 55-7, drilled by AMAX in 1984. The operators are currently optimizing the injection strategy to maximize pressure support and minimize thermal breakthrough.

Faults identified on seismic profiles act as both barriers and conduits, resulting in surprising reservoir compartmentalization for a relatively small geothermal field and unpredictable permeability distribution.

3. The Repower Team

Cyrq Energy is a leader in renewable energy with geothermal energy generation in New Mexico, Utah, and Nevada, and more than a decade of experience in utility scale power plants and renewable energy production.

In 2017, Cyrq Energy selected Turboden and Industrial Builders to construct the new power plant for LDG. Turboden offered to provide a power plant producing 11.0 MW net (14 MW gross) electric power with a single ORC turbine, compared to four ORC expanders in the old plant.

Turboden (MHI) is a world leading ORC Technology provider. Turboden has engineered, manufactured, and delivered 389 plants in 45 countries and 649 MWs of high efficiency ORC power generation.

Industrial Builders (IB) is an EPC constructor of eight (8) modular ORC power plants over the past 12 years, along with numerous industrial power and process plants.

4. The Turboden Plant Design

Turboden and Cyrq designed the plant to utilize geothermal brine from two geothermal wells. After careful study and testing, isobutane was selected as the most efficient working fluid for the produced geothermal fluid temperature, ambient temperatures, and air-cooling. This choice of the working fluid was made after other alternatives were carefully studied. For example, pentane was also considered and tested but failed to produce as efficiently as isobutane.

The plant has been configured to utilize a single turbine. The power plant is composed of heat exchangers, a single turbine directly coupled with a generator, a recuperator, a condenser, and feed pumps (Figure 3).

Based on the low corrosivity potential of the geothermal water observed during five years of operations in the previous installation, carbon steel was adopted as the material for the parts in contact with geothermal water (e.g. tube sheet, distributor channel, partition plate and heat exchanger tubes). Likewise, on the ORC working fluid side, carbon steel was employed. Cyrq suggested the minimum reinjection temperature to be considered in the plant design, in order to avoid any risk of deposition of silica or other solids.

The single turbine designed and manufactured by Turboden is axial, multistage and operates at 1800 rpm. The Turbine is directly coupled to the electric generator. The turbine design inlet pressure is about 400 psi. The expected turbine isentropic efficiency is about 90% (total to static, including all the stage losses). The axial geometry is the most suitable to achieve high efficiency in the widest range of operation. The expected efficiency derate is only -1% during summer operation, and -4% during winter operation. The turbine is designed to maximize the energy production according to the ambient conditions at the LDG site.

The air-cooled condenser, a Turboden design, is composed of many tube bundles interconnected to each other in parallel. To limit the influences of different condensing pressure of the bundles and to mitigate potential upsets such as one bay of cooling fans out of order, the pipeline collecting the liquid phase includes routing with a syphon and vapor trap. The favorable properties of isobutane ensure that it will never be under vacuum, and the condenser is expected to operate at constant volumetric flow (on the air-side) to maximize energy production. This factored into the decision to eliminate variable speed drives for the cooling fans. This simplification also removes additional maintenance and complexity of the control system.

The ORC working fluid feed pumps are centrifugal multi-stage, driven by 3-phase motors connected to a variable frequency drive in order to achieve optimal control and to minimize the power consumption. This solution is required particularly considering the operating pressure of the working fluid; in fact, the traditional solution of pump regulation by means of valves would significantly decrease the net energy production.

The operation of the ORC turbogenerator is automatic: continuous monitoring by personnel during operation, will not be required. The ORC turbogenerator can operate at partial load, the process and the generated electric power self-adapt to the available thermal power.

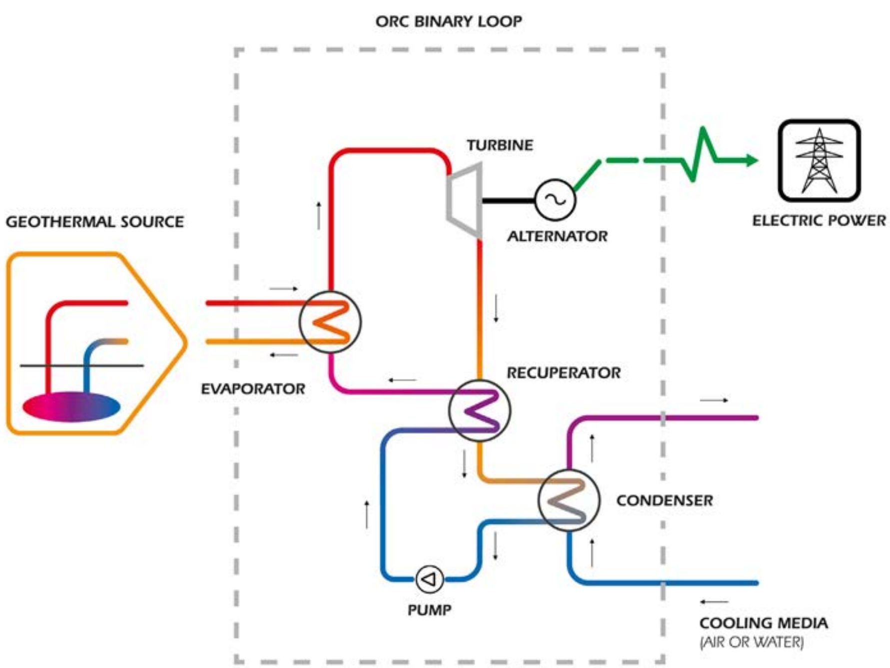

Figure 3: Turboden Plant Diagram

5. Plant Construction Activities

The procurement and construction duration, from order release to commercial operating date (COD) for geothermal power plants normally ranges from 20 to 24 months. The LDG repower project was completed 6 months faster than normal, due to a unique partnership between all parties. The partnership succeeded due to superior project communication and planning, parallel path schedule management, advanced collaborative development of all project facets, and close vendor coordination. Each team member's previous geothermal experience and incorporation of lessons-learned was also invaluable to the success.

Cyrq, Turboden and IB adopted a TEAM strategy for moving forward and constructing this project. The TEAM together finalized a "value engineered design", specific to; the LDG site, project parameters, specific equipment, integrating and fabricating as much of the equipment as possible in the shop for rapid deployment and smooth installation and execution.

This TEAM effort facilitated a project that capitalized on all of our previous geothermal ORC and plant experience in design and manufacture, modularization and prefabrication. As much of the plant as possible was packaged, pulling man hours out of the field and into a controlled shop fabrication environment. This allowed the team to mitigate virtually all risk, greatly improving project simplicity and speed to COD, minimizing costs to the Owner and meeting all financing requirements. The roles and responsibilities of each team member are enumerated below:

- IB, the EPC, installed the power plant equipment. Turboden, the power plant manufacturer, guaranteed and backstopped equipment delivery, with a 100% Performance and Payment Bond
- IB guaranteed/backstopped construction schedule and cost – Turboden, the technology provider, guaranteed and backstopped overall ORC performance, schedule, and cost.
- IB performed all necessary site layouts and other engineering for permitting, including preliminary engineering, purchase specifications necessary to maintain schedule, installation of ORC power plant equipment, as well as obtain all construction-related permits, including; logistics and transportation, building, etc.
- ALL TEAM members collaborated on the schedule. Schedule collaboration included long lead procurements needed to maintain schedule, including expedited completion schedule and continuous review, and preparation for construction of necessary electric and heat exchange interconnections, providing and performing EPC; testing and

- startup, including utility interconnection and permitting, achieving COD on or before the scheduled completion date.
- ALL TEAM members cooperated together in prosecuting any guarantee or warranty claims.

With the proper TEAM coordination with Turboden, IB completed site work with all foundations, underground Electrical, Sub-station and completed Fire Water System, before any ORC equipment arrived at site. When the ORC equipment arrived, it was off-loaded, set into place quickly and in a single pick as often as possible to avoid doubling of crane lifts, and all prefabricated piping and electrical connections could then immediately take place.

While waiting for long lead items from Turboden, IB built the prefabricated modules for the Power Distribution Center, Equipment Center (housing all Variable Frequency Drives), Control Room and Office, and the Compressor Module for the plant air system. All Equipment Modules were delivered, set-in-place, installed and field connected, before any long lead items arrived from Turboden, saving significant time and costs, minimizing lifts and downtime.

Equipment deliveries from Turboden were staged, so that the work could be completed in an optimized and orderly manner, without the crew stacking, adding labor inefficiencies and costs.

All Structural Steel was set-in-place, and the air-cooled condensers were erected before the large heat exchanger vessels; pre-heaters and evaporator, and turbine and generator - arrived at site. Large equipment piece delivery was well -coordinated and set-as-they arrived. Piping and electrical crews could start without interference with the erection crews.

With IB as EPC, designing and coordinating the balance of plant work and the Owner furnished production well system, along with the coordination with the local Utility for interconnection and power distribution, all potential problems and schedule interruptions were mitigated during construction and start up. The project struck first power nearly two weeks ahead of schedule, and IB began to demobilize early.

The project was completed ahead of time and on budget by performing all work and services as smoothly as possible, relative to; design, permitting support, engineering, procurement, quality assurance, inspection, construction, start-up, performance testing, and system optimization.

6. Plant start-up

The plant commenced delivery of electricity to the grid in December 2018 and passed initial performance testing in January 2019.

The start-up activities for the plant were performed very timely and effectively. The installation and commissioning processes were completed in five and two months respectively. The first start-up was performed on December 21, 2018 with a net power of 4 MW limited by the grid. On January 7, 2019, with grid limits lifted, the power provided to the grid increased to 11.0 MW.

During the performance test (with internal load bank) on January 24, 2019, a production of gross 15.29 MW and net 13.09 MW was achieved. Later on, a capacity test, a reliability test and a capability demonstration test customized according to the client's requests, were performed. The duration of the reliability test was 14 days. The start-up activities were finalized with success with the effort and collaboration of all parties involved.

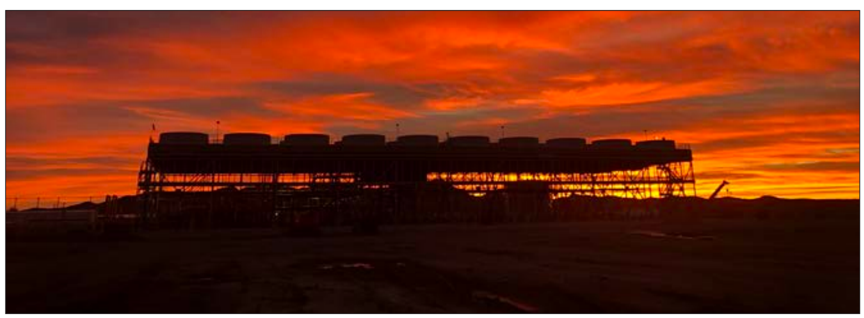
Figure 4: Lightning Dock geothermal power plant Christmas Morning, four days after startup

7. Repower Celebration and Renaming

Cyrq held a celebration of the repowering at the plant in October 2019. The event was attended by New Mexico Governor Michelle Lujan Grisham and Ron Darnell, Senior Vice President of PNM Resources. At that time, Cyrq named the new plant after geothermal pioneer Bruce Levy, whose accomplishments included work on the

New Mexico site. Levy concluded his career in geothermal energy of over 30 years with Cyrq Energy, where his years of experience in the industry proved invaluable to Cyrq's development and engineering efforts. Levy, who died last year, loved the Animas Valley and will be sorely missed by all in the industry that had the pleasure of working with him.

Bruce Levy was a true champion of geothermal energy and naming this plant after him is a tribute to his pioneering vision and brilliant work in development of resources.

In 2019, The Geothermal Resources Council awarded a posthumous Geothermal Special Achievement Award to Bruce Levy "For his lifelong passion for power generation, the development of new power plants, and his love of all the wonderful, diverse personalities in the geothermal industry." Nick Goodman, Chairman/CEO at Cyrq Energy, received the award at the GRC Annual Meeting & Expo in Palm Springs, California, in September 2019.

Figure 5: GRC Annual Meeting Honors & Awards Committee - Chair, Marcelo DeCamargo (left) presents a Geothermal Special Achievement Award in memory of Bruce Levy to Nick Goodman (right).

8. Conclusion

The Lightning Dock Geothermal repower was a very successful project because Cyrq, Turboden, and Industrial Builders, worked together from the initial stage, through design and final installation, as a TEAM. The result was that Cyrq received a quality project exactly as envisioned, planned, and contracted, ahead of schedule and on budget, in a smooth well executed project.

The repowering of the Lightning Dock geothermal project has been a resounding success, and the plant is well poised to deliver geothermal energy to the grid for the next 25 years. All of the required components, including a confirmed geothermal resource, transmission access for delivery of the electricity, and a long term PPA with a solid off-taker are in place, allowing the development team to execute in the design, installation and operation of this binary plant. The commitment and teamwork demonstrated by Turboden, Industrial Builders and Cyrq Energy has proven binary projects can be installed on schedule and generate efficiently, even in the remote region of the desert Southwest of the US.

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