400kW Geothermal Power Plant at Chena Hot Springs, Alaska

Final Report Prepared for: Alaska Energy Authority

Chena Power, LLC

FINAL PROJECT REPORT

PREPARED FOR THE ALASKA ENERGY AUTHORITY
BY
CHENA POWER COMPANY

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EXECUTIVE SUMMARY

This document represents the final report for Chena Hot Springs Geothermal Power Plant Project. The objective of this project has been to install two 200kW Organic Rankine Cycle (ORC) geothermal power plants at Chena Hot Springs, Alaska, for a total generating capacity of 400kW. The Chena plant is the first geothermal power plant installed in the State of Alaska, and serves as a demonstration of the technology for rural Alaska. The geothermal power plant has been operating with 95% availability since the installation of the first 200kW unit in July, 2006, and has relegated diesel generation to a supplemental and backup role in power generation for the site. The power plant operated for over 3000 hours in 2006, generating 578,550kWhrs and displacing 44,500 gallons in diesel fuel. In 2007, the project is expected to generate 3 million kWhrs of clean geothermal power and displace 224,000 gallons of diesel for an estimated savings of $550,000.

The geothermal power plant installed at Chena Hot Springs has reduced the cost of power from 30¢ per kWhr to 5¢ per kWhr, with further reductions expected once loans to fund project infrastructure are repaid. Maintenance cost for the power plant is expected to be 1¢ per kWhr. This dramatic decrease in the cost of power has led to new development at Chena Hot Springs. A 5,000ft^2 year-round geothermally heated greenhouse was installed in 2006 to supplement existing greenhouse production onsite. This greenhouse represents a 60kW additional electric load 18 hours per day, and was cost prohibitive prior to installation of the new power plant. To operate the new production greenhouse facility, an additional 1.5 fulltime positions were added. The number of guests using the Chena Hot Springs Resort facilities increased 8.8% during 2006, which can at least in part be attributed to publicity surrounding the renewable energy projects and geothermal power plant. An extensive expansion of the pool building is planned for 2007 to accommodate expected future increases.

1. BACKGROUND – CHENA HOT SPRINGS

Chena Hot Springs is located approximately 60 miles east-northeast of Fairbanks, Alaska at an elevation of 1205 feet. It has been used extensively for recreational bathing since its discovery in 1905 by miners from Fairbanks who noticed steam rising over the hills in the upper reaches of the Chena River. It was privatized as a patented homestead in 1920, and cabins and a small lodge quickly sprung up to serve the local population.

Today, Chena Hot Springs Resort has grown to become the premier hot springs recreational and resort facility in Alaska, and serves a small community of private residents in addition to the employees and guests of the resort.

Figure 1: Oblique Air Photo of Chena H.S. looking southwest. Photo by R. Jones.

The Chena Hot Springs community is semi-remote. It is served by a paved road from Fairbanks, but is 33 miles distant from the closest power grid. For this reason, Chena is confronted with many of the same infrastructure challenges facing numerous remote Alaskan villages, including maintenance of power generation facilities, phone and internet systems, sewage and municipal waste disposal, road maintenance, and emergency medical and fire equipment.

The cost of electric power in rural Alaska is among the highest in the United States, and frequently approaches $1 per kW. The cost of power is currently 86¢ per kW at Manley Hot Springs[2], and 56¢ per kW at Central (near Circle Hot Springs). At Chena, power has been generated in the past using diesel gensets – as in most Alaskan villages – at a cost of 30¢ per kW. In 2005, $365,000 was spent on fuel alone, at an average price of $2.46 per

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[2] Manley Hot Springs is a community of approximately 75 year-round residents located 90 miles northwest of Fairbanks on the Elliot Highway.

gallon delivered. The high cost of power generation has motivated Chena to seek alternatives. Beginning in 2004, a plan to increase the energy independence of the site using the available local resources, including geothermal, was adopted and implemented.

Today, Chena heats 44 buildings on site, some as large as 20,000 ft^2, via an extensive district heating system. This resulted in a savings of $183,000 in 2005. Additionally, Chena uses its geothermal resource for absorption chilling, proving 15 tons of refrigeration to the Aurora Ice Museum[3]. Chena operates two greenhouses totaling approximately 6000 ft^2 to grow produce year-round to supply the restaurant. This is the only commercial scale year-round greenhouse operating in interior or northern Alaska.

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[3] The Aurora Ice Museum, constructed in 2004, is the largest year-round predominately ice structure in the world, consisting of hundreds of tons of snow and ice. It houses extensive ice carvings and architecture created by 13 time World Ice Art Champion Steve Brice and his team.

2. BACKGROUND – POWER GENERATION PROJECT

Because the largest operational expense for the site is power generation, Chena has long been interested in tapping the available geothermal resource for generating electric power. However, an exploration program conducted in the late 1970's and early 80's (Wescott and Turner, 1981) discounted the site for power generation with technology available at that time. As a result, Chena decided to take a two-tiered approach to re-evaluating the site for power generation. Simultaneous projects were undertaken with the first involving the short-term installation of a small geothermal power plant designed to operate off the existing, proven resource. At the same time, a more extensive exploration and assessment program was conducted to define the deeper resource potential, and ensure the long-term sustainability of the resource. This second exploration program became the DOE funded Chena Hot Springs GRED III project.

Finding a manufacturer willing to work on a small generation project at a marginal resource proved to be challenging. Initial project quotes were obtained from Ormat and Barber-Nichols, both companies experienced in geothermal development. Eventually Barber-Nichols was selected to manufacture a single 400kW power plant for Chena. This power plant would have closely resembled existing Barber-Nichols installations at Wendel Hot Springs in California. The initial AEA Grant Application was submitted with Barber-Nichols as the manufacturer.

In October, 2004, Chena Hot Springs was approached by the United Technologies Research Center (a division of United Technologies Corporation) on the recommendation of the Department of Energy Geothermal Technologies Program. United Technologies Corporation had developed a modular ORC power generation system designed to use waste heat from industrial applications. The product was called the PureCycle 200, and United Technologies was interested in installing a unit to operate on heat from a geothermal resource as another application of their technology. Chena was an excellent candidate for the project, and after discussion with Barber-Nichols, it was decided to proceed with a project through United Technologies Corporation.

The primary reason for making the switch in manufacturer was that United Technologies (UTC) represented an opportunity to further the geothermal industry as a whole. UTC had developed a unique approach to reducing costs through the use of inexpensive, mass produced, U.S. manufactured air conditioning and refrigeration equipment from Carrier Refrigeration[4]. In fact, UTC's stated goal was to reduce the cost of geothermal power generation equipment from $3000/kWhr installed to $1300/kWhr installed. In contrast, Barber-Nichols had last manufactured a geothermal power plant in the mid 1980's and did not intend to build additional units in any significant quantity. Therefore, the opportunity for the Chena project to impact future development in Alaska and elsewhere would be limited.

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[4] Carrier Refrigeration is a division of United Technologies Corporation

3. RESOURCE EVALUATION

The Chena hot springs are located on the floor of Monument Creek Valley at an elevation of approximately 1170ft. Chena is one of approximately 30 low to moderate temperature geothermal systems located in interior Alaska, between the Alaska and Brooks Mountain Ranges (Figure 2). This belt of thermal springs extends approximately 2000 miles from the Seward Peninsula on the west into the Yukon Territory in Canada on the east. Most of these thermal springs in this belt are found within or near the margins of granitic plutons, which can have anomalously high concentrations of radioactive elements. It has been postulated that the hot springs exist due to a combination of high local heat gradients from radiogenic decay in the granitic rock combined with vertical fracturing which allows for deep hydrothermal circulation.

Two geologic and geophysical studies of Chena Hot Springs were conducted in the 1970’s and 80’s, both through the University of Alaska, Fairbanks. The first was a Master’s thesis by Norma Biggar et al, and the second was a more comprehensive study in 1981 conducted by the Geophysical Institute under the direction of Gene Wescott and Don Turner. Both of these reports, along with additional historic publications cataloging Alaskan hot springs resources were used as baselines for the 2005-06 Chena GRED III resource evaluation[5].

Unlike previous resource evaluations of Chena Hot Springs, the GRED III project was specifically designed to assess the resource for power generation. The stated goal of the project was to determine if the Chena resource was large enough to sustainably generate 10MW of power, which was the amount of generating capacity required to justify the costs of a 33 mile transmission line extension to bring the power to markets in Fairbanks.

Under the GRED III project, extensive geologic and geophysical surveys were conducted using both airborne and ground based techniques. Additionally, a series of temperature gradient holes were drilled to directly access the shallow reservoir and determine its relationship to the deeper geothermal system. These holes, drilled to depths of up to 1020ft, permitted extensive logging and testing of the shallow geothermal resource. This information was extremely useful in siting a production well for the power plant, and subsequently in developing an injection strategy. A sample of static temperature logs from most wells at Chena Hot Springs is included as Figure 3.

Based on heat flow estimates and history of geothermal development at other sites, it was determined that Chena Hot Springs could likely sustain 5MW of electric generation (Figure 4). This is well above the 400kW installed under the scope of this project. However, initial flow testing did indicate the necessity to reinject produced water to maintain shallow reservoir pressures and minimize impact to the natural thermal springs.

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[5] The Chena GRED III Project was funded by the Department of Energy and Chena Hot Springs Resort and titled ‘Integrated Geoscience Investigation and Geothermal Exploration at Chena Hot Springs, Alaska.’

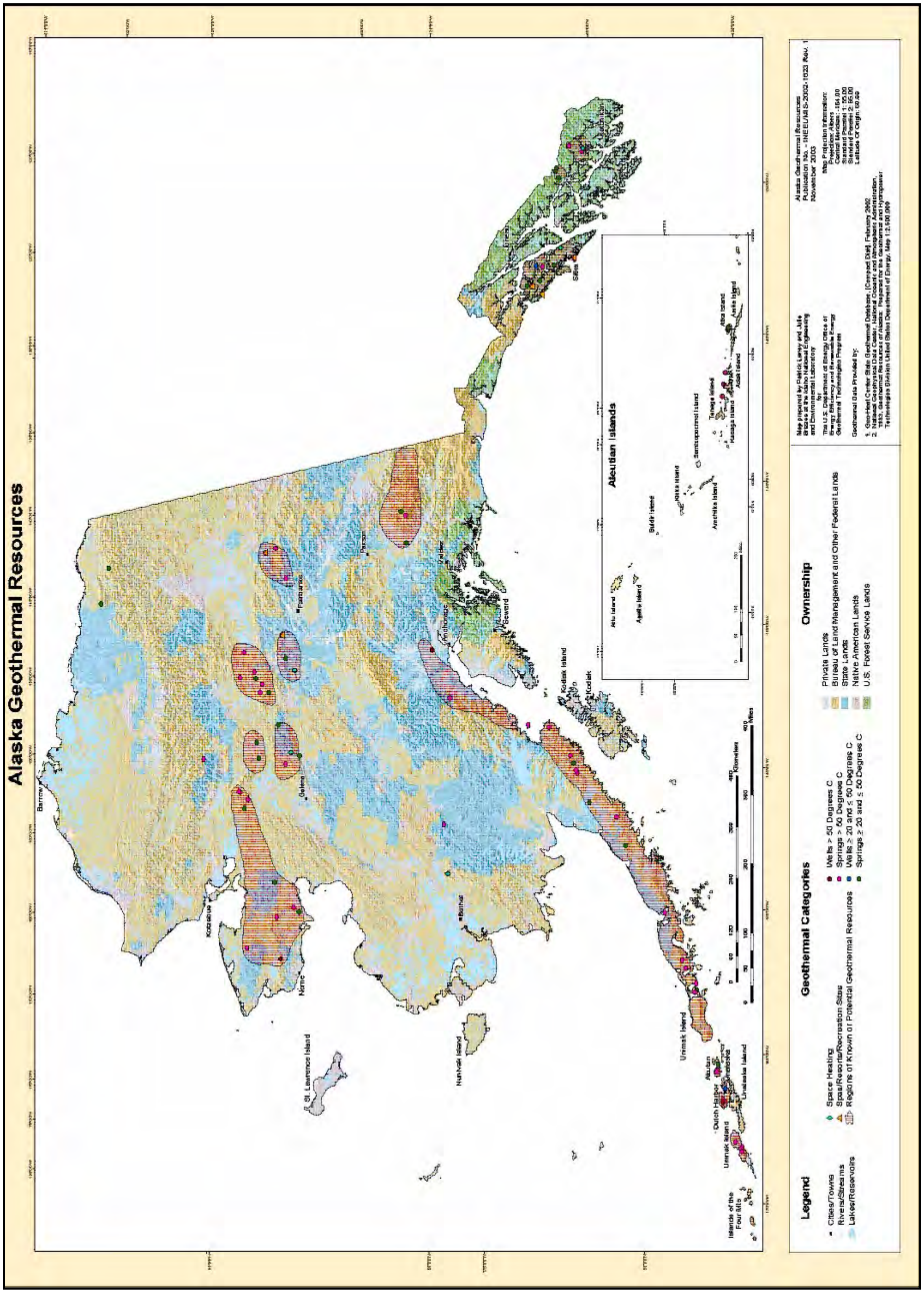


Figure 2. Alaska Geothermal Resources Map (from DOE)

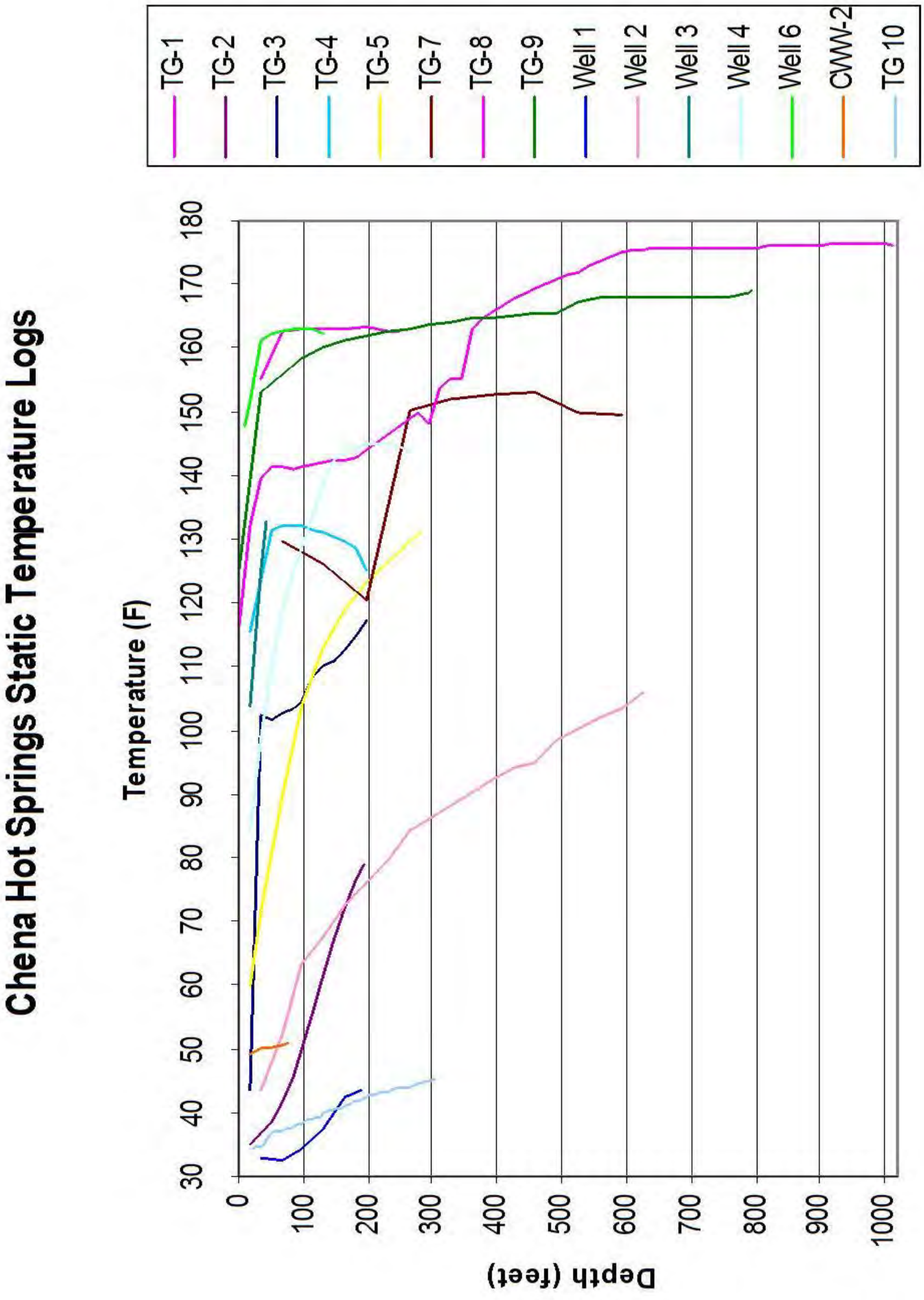


Figure 3. Static Temperature Gradient Profiles of Chena Wells, June 2006

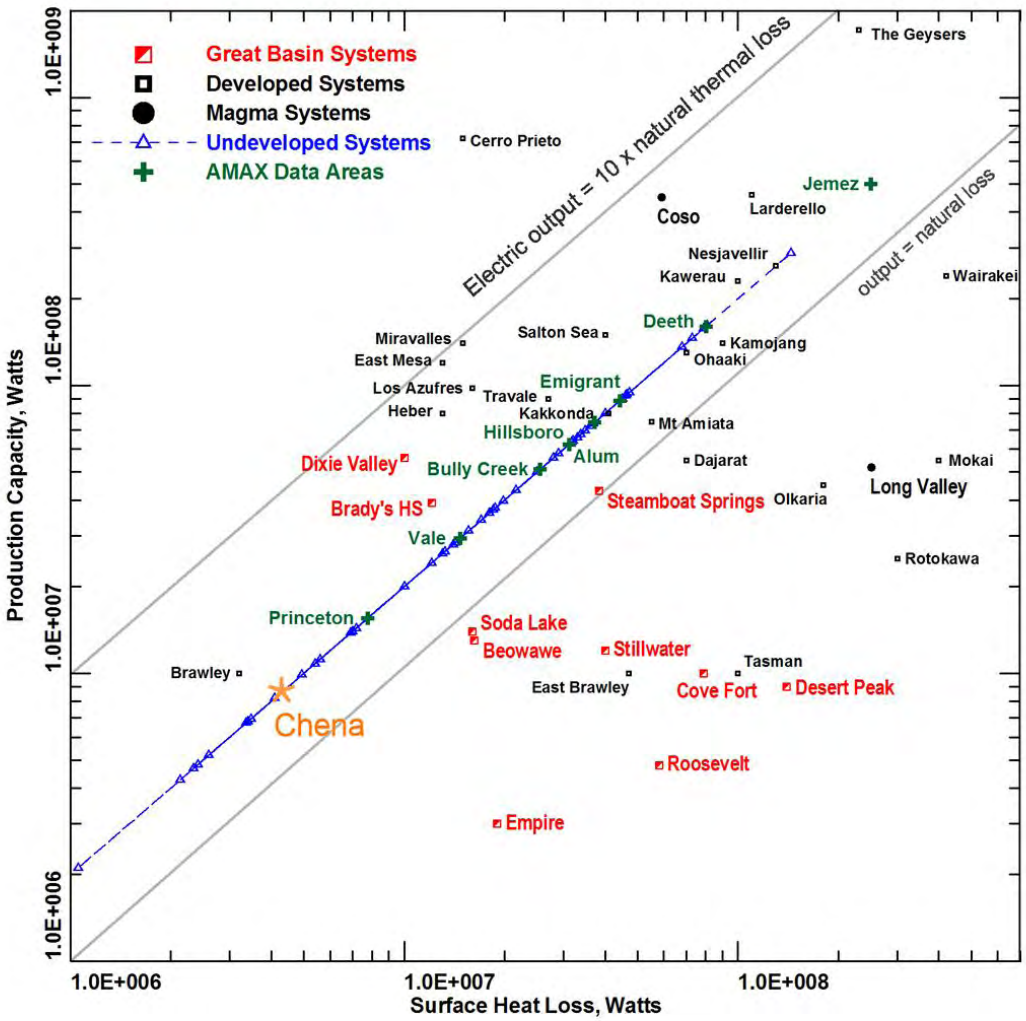


Figure 4: Natural Heat Loss versus electric power generation for geothermal systems

A flow test of Well 5, located adjacent to the main hot springs area, was conducted on August 6th, 2005. Production rates as high as 1185 gpm were measured, which is slightly higher than the 1000 gpm production rate required for the power plant. During this test, the flowing temperature of Well 5 increased by 5 °F during the first hour of high flow and then stabilized at 167 °F. Kuster temperature and pressure gauges installed in three nearby shallow holes (TG-1, TG-3, and TG-4) showed responses varying from no appreciable response to the flowing of Well 5 (TG-3), to a decline of 30 °F in TG-1, to a temperature increase of 4 °F in TG-4. This test demonstrated the serious risk of rapid cooling in shallow production wells at Chena without proper pressure support, and that there is no barrier or separation between cooler and hotter waters in the shallow wells.

To mitigate these potential problems, both production and injection wells were cased and cemented to well below the local ground water table. Additionally, production and injection zones were spaced at opposite ends of the field, 3000 ft apart. Wells throughout the field are monitored continually and the injection strategy will be reassessed in early 2007. To date, no cooling of the production well has been observed.

4. POWER PLANT DESIGN

The Chena geothermal power plant is designed based on the technology and hardware from the commercially available Air-Air PureCycle® power plant from UTC Power. The PureCycle® is designed to produce 200kW of electric power from waste hot gas sources between 500 and 1000°F. The design achieves unusually low cost through the innovative application of mass-produced Carrier chiller components. The most critical components include a single-stage centrifugal compressor which runs in reverse as a radial inflow turbine to produce 200kW of power, and heat exchangers originally designed for large chiller applications. Additionally, local and remote monitoring was applied for both operation and data collection.

United Technologies Corporation (UTC), through their Research Center, partnered with Chena Hot Springs in early 2005 with the goal of adapting the PureCycle® product to a moderate temperature geothermal resource. The specific objective for UTC was to demonstrate the feasibility of producing electricity at a cost of less than 5¢/kWh from a 165°F geothermal resource with 98% availability. The geothermal application for the PureCycle® platform would involve some additional innovation and opportunities for cost reduction beyond that of the original PureCycle® 200 platform, includung:

- Changing the working fluid used in the PureCycle® ORC plant from R245fa to R134a. This fluid is a better match for low temperature geothermal applications and enables a significant cost reduction, both directly because R134a is a low cost fluid widely used in HVAC equipment and indirectly by allowing lower cost commercially available components to be used in the power plant.
- Developing low cost heat exchangers specific to geothermal applications based on designs and production capability in place for Carrier's large commercial and marine water-cooled chillers.
- Reducing the plant cost relative to the PureCycle® ORC plant by incorporating and qualifying more commercially available components made feasible by the lower operating temperature in geothermal applications.
- Develop control algorithms and methods for operation with tube and shell heat exchangers rather than the fin-tube technology applied in the PureCycle® plant.

The geothermal plant modules were designed and qualified at the United Technologies Research Center before installation at Chena Hot Springs. Cycle analysis shows that with the 164°F temperature geothermal liquid as the heat source and 40ºF river water as heat sink, two geothermal power plants can be developed with HFC134a as the working fluid. The first power plant has been operating at the following conditions:

4.1 Water Design Points

Heat source: Tin = 164 °F Tout = 130 °F Flow rate: 530 gpm

Heat sink: Tin = 40 °F Tout = 50 °F Flow rate: 1614 gpm

4.2 Refrigerant Design Points

Mass flow rate:	26.8 lbm/s
Evaporator/turbine inlet pressure:	232 psia
Condenser/turbine exit pressure:	63.6 psia
Turbine gross power:	250 kW
Pump power:	40 kW
System output power (net):	210 kW
Thermal efficiency:	8.2 %

This efficiency is quite a challenge given the limited thermodynamic availability of the low temperature geothermal heat source. A completely reversible thermodynamic cycle working with the same heat source and heat sink temperature glides would have a thermal efficiency just under 18%. Fortunately, efficiency improvements are far less critical in power generation when the fuel is essentially free.

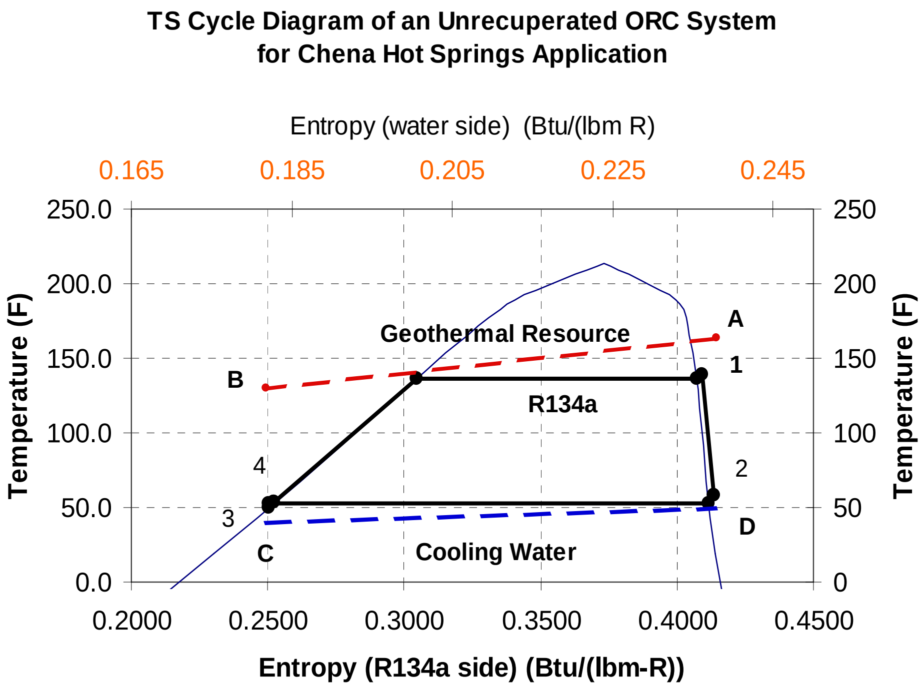


Figure 5: TS Cycle Diagram for the Chena Hot Springs Power Plant

A TS Cycle Diagram for the power plant is included in Figure 5. On the preheater/evaporator side of the ORC system, 530 gpm of 164 °F hot water (point A in Figure 5) enters the unit and is cooled to 130 °F (point B) transferring 2.58 MW of thermal energy to the refrigerant. This energy preheats the 26.8 lbm/s refrigerant mass flow rate from 54 °F (state point 4) to 136 °F and subsequently boils the working fluid at this temperature before slightly superheating it (state point 1). The high-pressure refrigerant vapor is expanded in the turbine that extracts 270 kW of mechanical power from the refrigerant flow at 80% aerodynamic efficiency. After accounting for mechanical and electrical losses 250 kW of electrical power is delivered by the generator. The refrigerant vapor leaving the turbine (state point 2) is de-superheated, condensed at 53 °F and then slightly subcooled to state point 3 in the 2.36 MWth water-cooled condenser. The condenser heat is transferred to 1615 gpm of 40 °F cold water (point C) that is heated to 50 °F (point D). The refrigerant loop is closed by a pump, which elevates the refrigerant pressure from 65 psia (state point 3) to 245 psia (state point 4). The pump requires 40 kW of electrical power. Accounting for all losses, the net power produced by each power plant module is 210 kW. This can be increased when using the air cooled condenser during the winter months.

Major components of the ORC system were sized based on the cycle analysis elaborated above and are described in the following sections:

4.3 Turbogenerator

The turbogenerator component combines a radial inflow turbine with an internal gearbox and an induction generator in a single hermetically sealed unit as shown in Figure 6. Generator cooling is provided by the working fluid. This hermetic design reduces maintenance and eliminates issues with shaft seal leakage typical of existing geothermal plants. The single-stage radial inflow turbine is the most cost effective turbine design possible. The turbine is internally lubricated with a high temperature lubricant that is compatible with the working fluid and has been qualified for use up to 350 °F in the PureCycle® 200 test program. The turbine can be specified with a rotor and multi-port conical nozzles chosen from a range of standard options to provide the optimal performance for specific design points. The Bill of Materials (BOM) of the PureCycle® turbogenerator has a total of 171 line items. Relative to the corresponding chiller compressor assembly, the PureCycle turbogenerator has only 13 unique manufactured parts. There are no significant changes in processes, patterns or tooling. This allows for the turbine to be manufactured with the same consistent quality as commercial chiller plants.

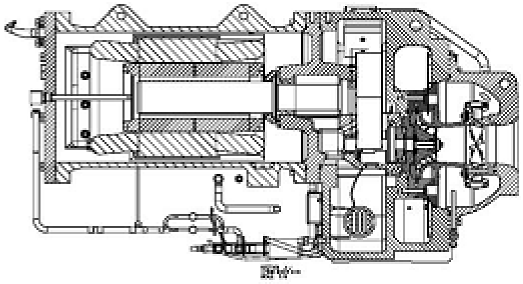


Figure 6: Internal view of the 19XR2 turbogenerator

Several modifications were made to the turbine design, which included installing a particle filter over nozzle to prevent impeller erosion, redesigning the turbine wheel and cap to lower thrust load, removing inlet-guide-vanes and reshaping the suction housing to recover static pressure, opening nozzles to a diameter of 0.457”, and resizing the impeller to achieve desired mass flow rate for this application.

Previous installations of the PureCycle® power systems have been deployed on a "stiff" grid. The induction generator is connected to the grid by either a wye-delta or soft-starter. Grid protection is provided by the non-islanding properties of the induction generator and, if required, a utility protection relay. Chena Hot Springs Resort provides its own grid via 3 large (750 kVA) UPS systems, which can be powered by multiple sources (diesel genset, geothermal power plant). The ORC induction generator may be started from the inverter output, and be used to reduce the load seen by the UPS systems. When the total facility load is less than the ORC output, the ORCs charge the UPS batteries.

4.4 Heat Exchangers

Most commercial geothermal power plants use separate heat exchangers to preheat and vaporize the working fluids. Using two separate heat exchangers can increase manufacturing costs and installation complexity compared with using a single heat exchanger. The UTC Research Center designed an integrated evaporator with preheater such that the preheater section is integrated into the bottom of a shell-and-tube heat exchanger while the boiling section occupies the top portion of the heat exchanger. In this case, the hot geothermal liquid flows in the tubes while the working fluid absorbs heat on the shell side. There is a partition panel dividing the two heat exchange sections and a distributor nozzle to guide the working fluid flow into the evaporator section from the baffled preheater section. This integrated evaporator design provides the required heat transfer capacity to preheat and vaporize the working fluid within just one heat exchanger shell that can be produced on existing production lines, reducing both component cost and system complexity.

A separate water analysis has been performed prior to the heat exchanger design finalization in order to assure the correct selection of materials. It should be noted that Chena water analysis shows that the both the geothermal water quality and that of the surface water is "drinkable", meaning it is soft and has low ammonium. Based on the water analysis and Carrier's water quality guidelines for heat exchanger, the tube materials for the heat exchangers were then finalized.

The evaporator size to provide the required heat capacity is:

2-pass on geothermal resource side,
    including 1-pass in boiler region, 260 tubes
    1 pass in preheater region, 90 tubes
    ¾" OD, 0.035" tube thickness, Cupro-Nickel 90-10 TurboChill
32" OD shell, 10" flanges

The condenser is a standard tube-and-shell heat exchanger used in Carrier's commercial chiller line. Based on the cycle analysis, the condenser size to provide the required heat rejection capacity is:

Carrier 19XR Frame 5, size 57, 2-pass, 602 tubes

Copper Spike Fin II tubes, tube wall thickness 0.025”, 0.635” ID

4.5 Refrigerant Pump

Based on the cycle analysis, the pump was chosen to be a regenerative pump from Roth Pump.

4.6 Control Electronics

The Carrier CC6400 programmable controllers are used. One Carrier NetLink module was used for remote access and alarm relaying.

4.7 Power Electronics

A compact Benshaw starter was used in the power plant design to provide less current inrush in order to enable startups on weak grid such as generators. An ABB inverter was employed for the pump.

4.8 System Qualification Testing

During qualification testing at the United Technologies Research Center (UTRC) in Hartford, Connecticut, the system was operated for more that 1000 hours. The testing was conducted at the CHP lab of UTRC, where hot water was generated using plant steam, and cold water is supplied via a cooling tower. The table below summarizes the tests that were performed on the first unit.

Test	**Status**
Envelope testing	**Complete:** Peak power 245 kW gross due to cooling tower limitations, Low power at stable 83 kW gross (~60 net).
Turbine Thrust.	**Complete:** Thrust less than 600 Lbf, lower at Chena condition.
Closed-loop control implementation	State Machine: **Complete** Continuous Control: see last slide. Monitoring: All current monitoring tasks tested with PC-6400 setup. Still need leak detection and purge operation.
Sensor failures	**Complete:** All alarms tested with a PC-6400 setup. Real unit: Level indicator forced to zero, Pump exit pressure unplugged.
Vibration/noise testing	**Complete:** Noise measured with and without lagging**.** Muffler design on hold.
Oil reclaim	**Complete with scavenger.**
Loss of relay trips	**Complete:** Done from low and mid-power levels. Turbine has minimum overspeed; pump does back-spin.
Pump Cavitation	**Complete:** Does not cavitate with large increase in

	flow rate.
Power trips	**Over 40 grid outages were done.**
Startup current, Beckwith	**Complete.**
Endurance	**Complete, as of 5/15:** 1000 hours

Table 1. Scope and status of the qualification test at UTRC

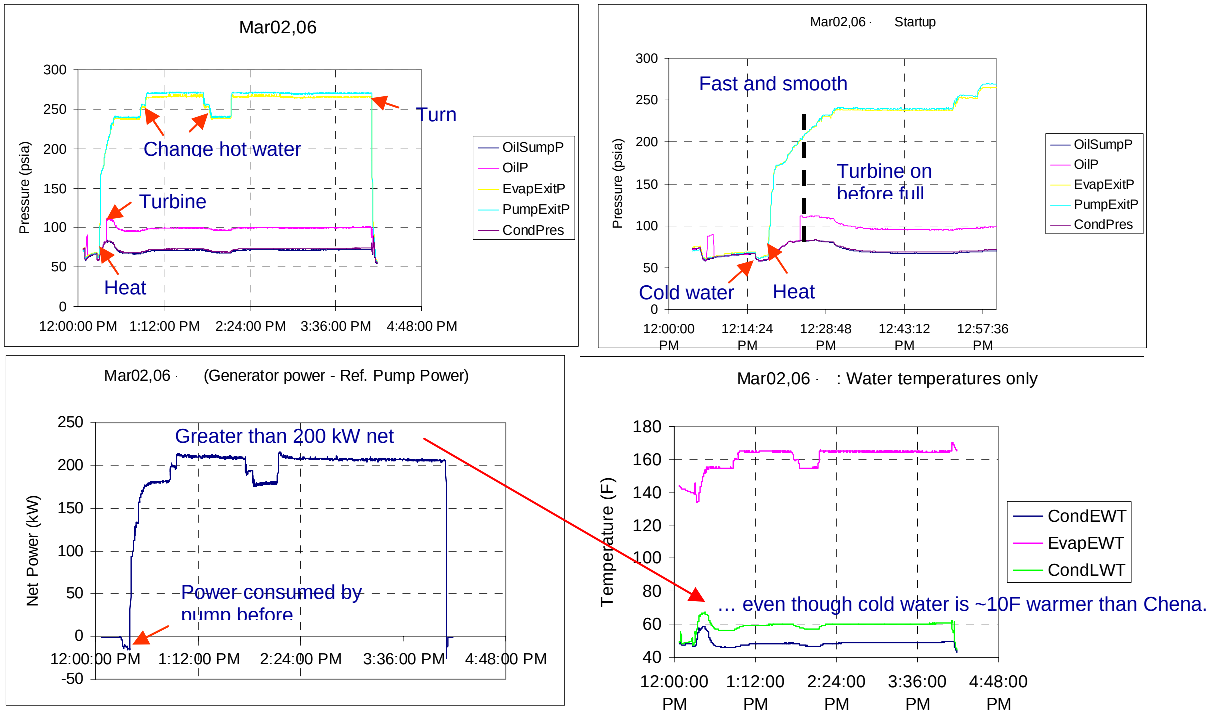


Figure 7: Typical operating data from test at UTRC

During testing, inspection of the turbine impeller found erosion, shown in Figure 8. Additionally, the turbine nozzle filter failed with penetration holes. Further investigation determined that the turbine was run backwards, i.e. as a compressor, during the early stage of commissioning the unit in the lab. In addition, further study of start-up procedure found that following the refrigerant charging process, turbine was immediately flooded with manufacturing debris left in the condenser once the service valve is open.

Figure 8. Turbine Impeller Erosion after qualification test in April

Thereafter, a new turbine nozzle filter was assembled and new start-up procedure was defined and implemented. A test of 50 hours of dirt injection was conducted, which is enough to indicate any early turbine impeller erosion damage. Subsequent inspection of turbine impeller showed no erosion damage at all.

After the qualification test, a validation review was held to analyze the test results and it was concluded that the design of the system was satisfactory. Subsequently the unit was decommissioned from UTRC CHP lab and shipped to Chena at end of June, 2006.

Figure 9: First geothermal plant is ready for shipping to Alaska

5. POWER PLANT BUILDING

A new power plant building was constructed to house the geothermal power plant. The building is a pre-manufactured 60ft x 150ft steel building which has been insulated with spray foam and painted. The power plant also contains a separate control room, which was recycled from the Healy Clean Coal Project. The new building is adjacent to an existing maintenance equipment hanger and in close proximity to the current power plant, to permit relatively easy tie in to existing electric infrastructure. The building is heated geothermally using water leaving the power plant.

Figure 10. ORC unit delivered to Power Plant building

6. COOLING SUPPLY FOR CONDENSERS (WATER AND AIR)

To maximize system performance and take advantage of the excellent cold water resources available locally, the first ORC module was designed to be water cooled at 40ºF. In order to maximize net power production, a water supply system was designed which would require no pumping load. This was accomplished by employing a low tech siphon to ‘pull’ water out of a shallow, large diameter well located 2700ft to the east of the power plant. The elevation difference of +33ft between the cold water well and the power plant allows 1500gpm to flow through each condenser at 5psi without a pump. To minimize pressure loss due to friction in the pipeline, the pipeline was oversized with 2400ft of 18in and 300ft of 16in steel pipe.

The cold water gains 10ºF in the condenser before being discharged to Monument Creek via an existing drainage ditch which runs under the runway through a 24in culvert. Chena Power has obtained a permit (2006DB0040) to discharge this water from DEC, along with a water use permit from DNR. Both permits are on file at Chena Hot Springs Resort. An automated shutdown procedure is in place to avoid the potential for refrigerant discharge into Monument Creek if a leak in the condenser is detected.

Figure 11. Installation of 16in Cold Water Pipeline, July 2006

Due to time constraints, only portions of the pipeline were insulated and buried prior to freezeup in October, 2006. The remaining sections will be completed in 2007. To compensate for freezing temperatures, a supplemental 3in hot water line was installed piggyback on the cold water line along the entire length. Additionally, the second ORC unit, installed in December 2006, was designed to be cooled either with air or water.

This was accomplished through the installation of a separate air cooled condenser which sits next to the power plant building. The air condenser fans draw an additional load of 24kW, however they allow for an increase in net generating capacity at sub zero temperatures, which are common at Chena during the winter months. During the summer, the unit will be switched to use a water cooled condenser identical to the one installed in ORC #1. In fact, the air cooled system has worked so effectively, a second air cooled condenser has been ordered and will be installed on the first ORC unit for next winter.

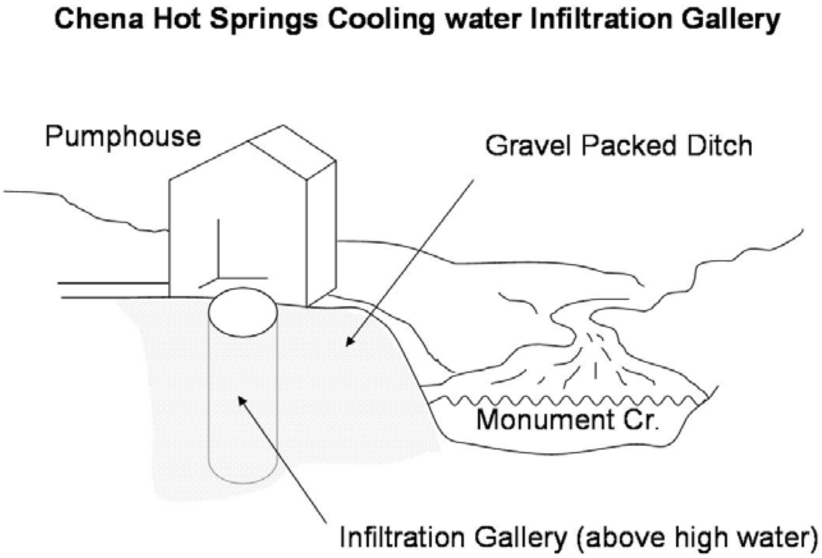


Figure 12. Cooling Water Well for Geothermal Power Plant

Figure 13. Air Cooled Condenser for ORC#2

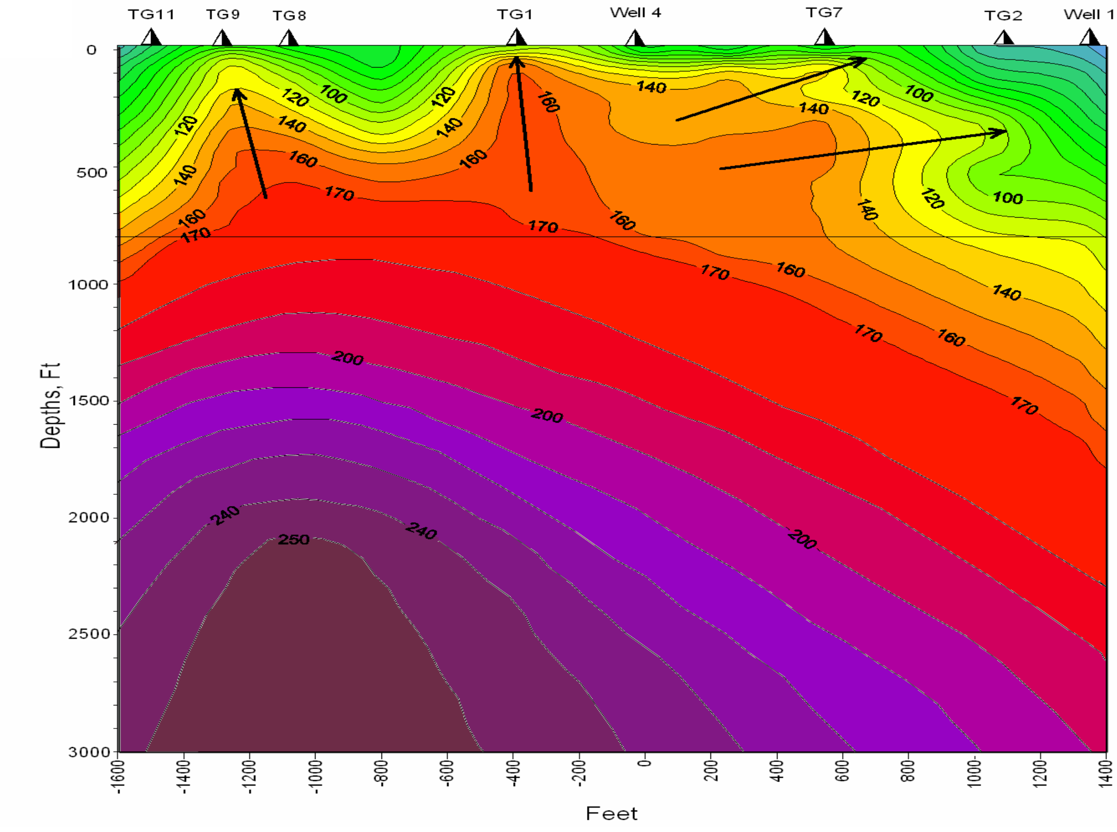
7. HOT WATER SUPPLY AND REINJECTION SYSTEM

7.1 Chena Geothermal Resource

All available geothermal waters in the vicinity of Chena Hot Springs have been sampled and analyzed for their basic brine chemistry, stable isotopes, total organic carbon and dissolved inorganic carbon as part of the DOE funded GRED III project. The basic chemistry of waters near Chena Hot Springs falls into two distinct end members connected by a mixing trend. The end members are very dilute cold surface or near-surface water and more saline thermal water, with a few samples being variable mixtures of the two end members.

The Chena thermal spring waters are quite dilute for thermal waters, having a total dissolved content of only 300 to 388 mg/l, with a pH near 9. This has made selecting materials for the power plant heat exchangers somewhat easier than usual for a geothermal fluid, however there are still concerns about the sulfur content and reactions with the copper alloy in the evaporator units. This may cause some minor scaling and ultimately it may be necessary to inject a surfactant into the hot water supply, as is common in many other geothermal installations. This issue is still being researched.

Quartz and Na-K-Ca geothermometers predict temperatures as high as 278 and 263 ^{o}F respectively as the base temperature of a deeper resource at Chena. These temperatures are expected to be accessed at depths of 1500 to 2500ft, according to the model developed through the Chena GRED III project (Figure 11 below).



Development as part of the current power generation project has focused on the shallow geothermal system, and extensive testing of the resource has determined the upflow zones lies approximately 1500ft to the west of the natural hot springs area. Test wells with the highest artesian pressures and temperatures (168.9ºF) were drilled in this area during 2006. Prior to 2006, drilling had focused on the area immediately surrounding the hot springs, and to the east of the springs. It has now been established from clear rollovers in the temperature depths curves that this is part of the outflow plume, and not the source of the upflow.

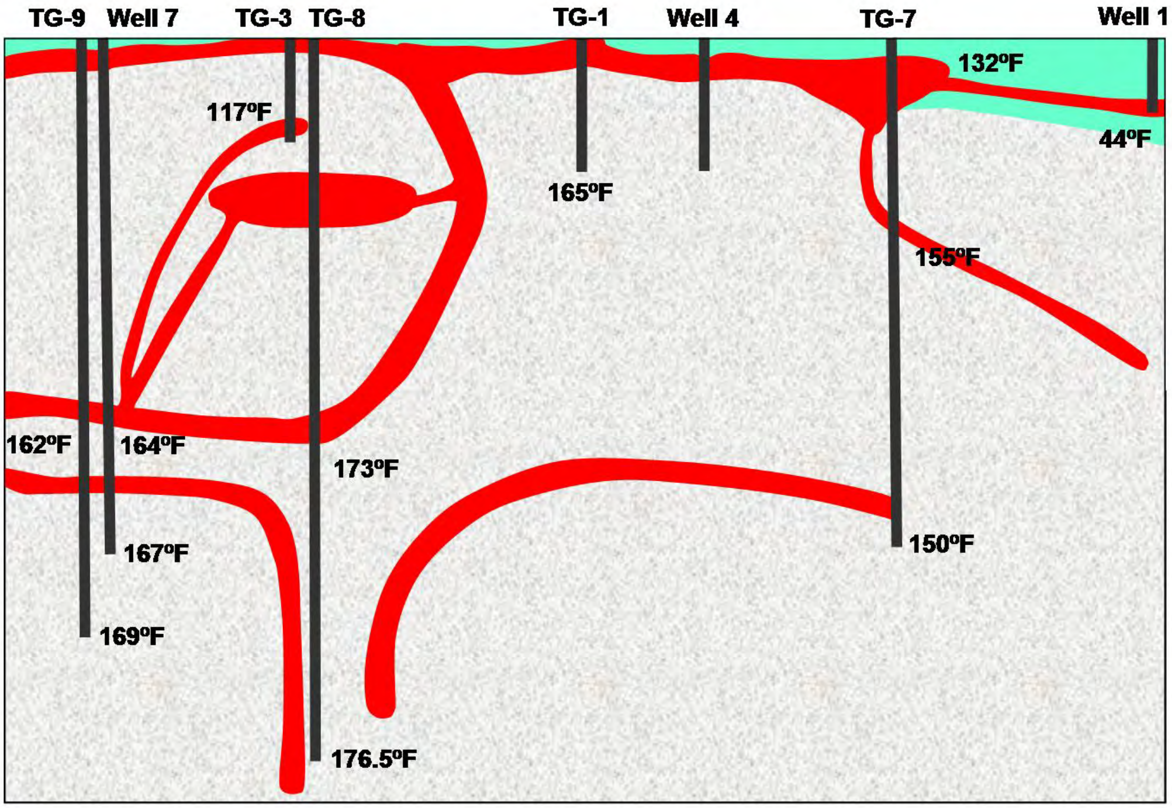


Figure 15. Shallow Geothermal Map of the Chena Hot Springs System

7.2 Geothermal Production Well Completion and Testing

The first production well for the power plant, Well #6, was drilled adjacent to the hot springs area at a depth of 130ft. However, this well was abandoned once a clearer model of the shallow reservoir (see Figure 12 above) was established. A second production well was drilled in May and June 2006, to a depth of 713ft.

After completion, Well 7 was flowed on July 8th, 2006 for 7 hours and 55 minutes at rates of 240, 186, and 87 gpm. The total production was 91,000 gallons. A detailed static log Kuster log was run with stops every 2 meters in Well 7 before flow commenced. After the well was flowing, the downhole pressure changes associated with start of flow, flow rate changes, and shut in were monitored with the Kuster tool. Additionally, two traversing logs were run in the lower part of the well during flow to document in detail the locations of the fluid-entry points with differing temperatures. This was useful in planning final cementing of the casing to exclude shallow (and cooler) fluid entry zones and isolate the producing geothermal fractures.

Because the well was flowed at three different rates during the July 8th test (Table 1), three productivity values can be calculated. The downhole productivity data are linear, and the overall productivity of the well between zero flow and 240 gpm is 15.6gpm/psi.

Date	Flow Rate(gpm)	Downhole Pressure (psi)	Change in Pressure (psi)	Productivity Index (gpm/psi)
July 5, 2006	220		16.2	13.58
July 8, 2006	0	321.3	0	0
July 8, 2006	87	316.8	4.5	19.33
July 8, 2006	186	309.6	11.7	15.90
July 8, 2006	240	305.9	15.4	15.58

Table 2: Well 7 July 2006 Productivity Data

From this test, we were able to estimate a drawdown of 148ft in the well at the production rate of 1000gpm, which is required for power plant operation. This allowed us to select a pump and determine what depth the pump should be set at to prevent cavitation. A 40hp submersible Franklin Electric motor with a Flowserve Model 10EHL single stage submersible turbine pump was selected, with a VFD controller. A backup pump, capable of supplying 400gpm, will also be installed in nearby TG-8 in case of primary pump failure. Actual drawdown in the production well was measured to be 90ft after the pump was installed.

7.3 Geothermal Supply Pipeline

Installation of 3000ft of 8in insulated HDPE was completed at the end of July. The line was laid in a shallow ditch along 90% of the route, and will eventually be buried. The pipeline follows an existing unimproved road along the south boundary of the Chena Hot Springs Resort Property. 1.8ºF is lost in the pipeline between the production well and the power plant.

Figure 16. Geothermal well pump tested prior to hookup to pipeline

Figure 17. Installation of Hot Water Supply Pipeline

7.4 Geothermal Injection System

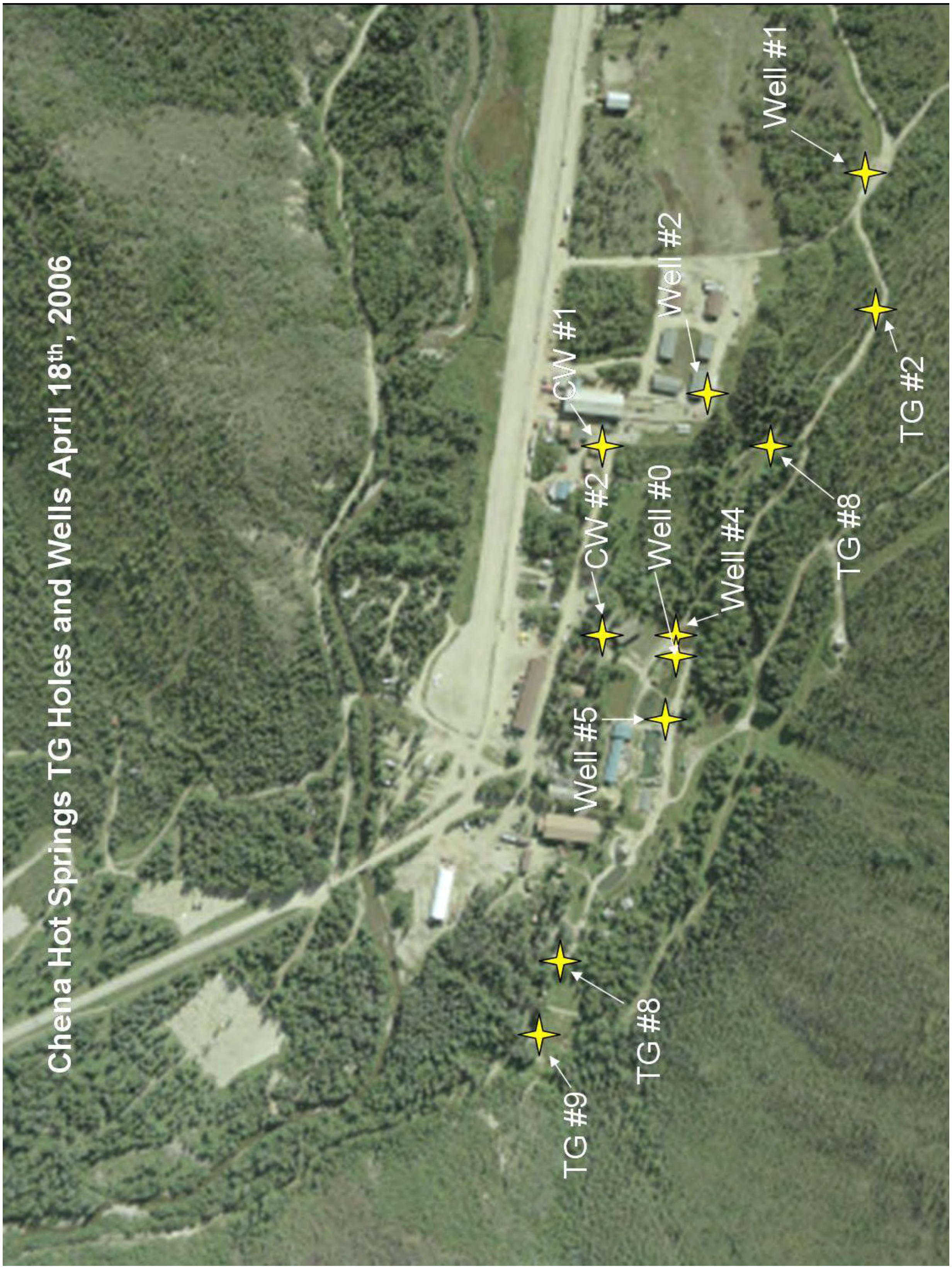
Developing a successful injection strategy is integral to the success of any large scale geothermal project. Chena has been working on characterizing its wells for nearly 2-1/2 years, largely in anticipation of minimizing the stresses placed on the reservoir due to this power generation project (see Section 3)

Initial injection candidates Well#1 and Well#2 were chosen primarily due to their distance from the proposed production area. However, additional testing during this Quarter has shown that while these wells are both unequivocally linked to the geothermal system/ reservoir, both have low injectivity indexes which make them poor candidates for injection of any substantial volume of fluid under the low wellhead pressures planned. In fact, further testing of Well#1 showed it was capable of drinking only 20-30gpm, and so it was eliminated as an injection site.

Well #2, cased to 300ft and open hole to 820ft is being used for injection, but is capable of drinking less than 100gpm. This well has been well characterized in terms of fracture zones.

TG#7 has replaced Well#1 as the primary injection well. This well was drilled to 702ft, and injection testing conducted in December 2005 indicated a very high injectivity index which has subsequently been verified through actual injection of spent fluid. The well was cemented in July, 2006 and has been used successfully for injection ever since the first unit began operating.

The geothermal field is still being monitored, and changes to the injection strategy over the long term is expected to minimize cooling of the resource. A map showing the locations of all the existing wells and TG (temperature gradient) holes at Chena is included on the following page.


Chena Hot Springs TG Holes and Wells April 18th, 2006
Well #1
Well #2
TG #2
CW #1
TG #8
CW #2
Well #0
Well #4
Well #5
TG #8
TG #9

8. COMMUNICATIONS AND CONTROL SYSTEMS

8.1 Communications and Remote Monitoring

Chena Power installed a dedicated dsl satellite system to allow remote monitoring of the power plant from any location around the world. There is also a phone line installed in the control room. The communication and data collection system is designed to accomplish several tasks:

1) Allow for alarms and alerts to be sent out in the case of potential problems with the unit. Because a constant grid is provided to the site via a UPS/battery bank, a power outage is not immediately apparent. The com system is designed to notify a monitoring system at UTRC, and send out automated calls to relevant individuals, including the front desk of Chena Hot Springs Resort, which is staffed 24 hours a day.
2) Allow continual data logging of system components, including pressures and temperatures throughout the system, power output, flow rates for refrigerant and water, etc. This is automatically transmitted back to UTRC where it is analyzed to trouble shoot any potential problems and note any changes in performance.
3) Permit remote real-time system logon capability so UTRC operators can control and monitor the system in Hartford Connecticut as easily as if they were onsite.

8.2 System Controls and Monitoring

Carrier CC6400 programmable controllers are used for the system, with a Carrier NetLink module used for remote access and alarm relaying. Additional instrumentation has been installed for supplementary data collection and is monitored using Labview software. The power plant is monitored by both on-site Chena personnel and UTC engineers remotely. At design condition, the power plant produced 205kW net (see Figures 16 and 17 on the following page).

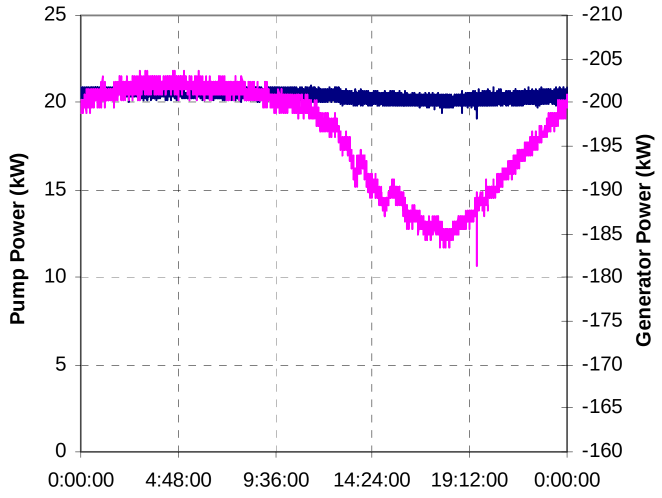


Figure 19. Power Plant Net Generation

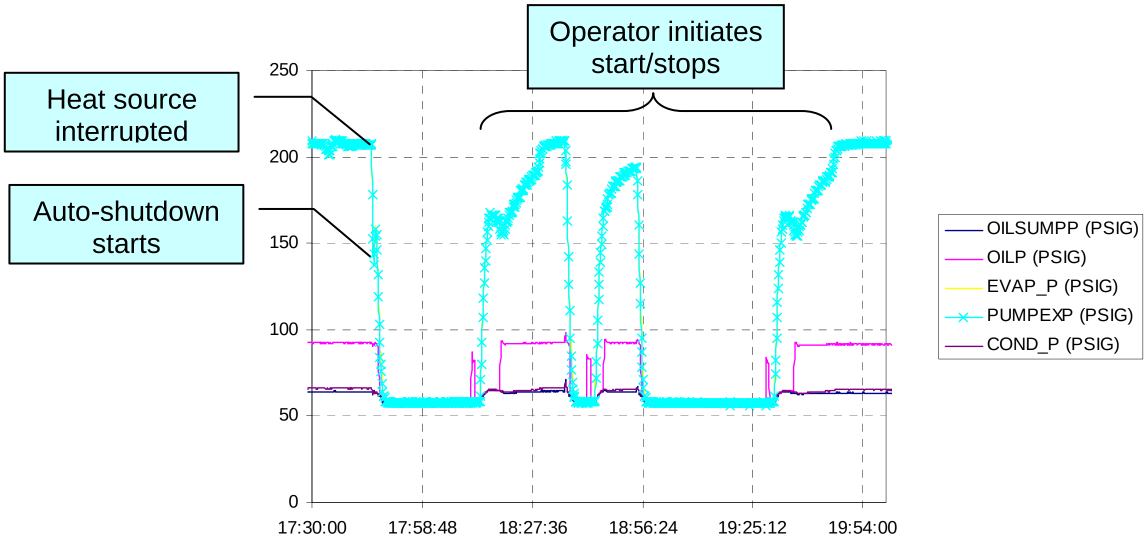


Figure 20. Plant Startup/Shutdown Sequence

9. INSTALLATION AND STARTUP OF ORC #2

The second ORC power plant module was installed in November and December, 2006 as scheduled. It was brought online on December 16th, 2006. The installation of the second unit was completed almost entirely by the crew of Chena Power, with UTRC and UTC Power representatives onsite for only a few days for final hookup of control wiring, systems check, and initial startup. The second unit is essentially identical to the first one, however a muffler was fabricated by Chena Power and installed at the turbine outlet to reduce the noise level. This has been very effective and ORC#1 may be retrofitted with a similar muffler in the future.

Figure 21. Moving ORC #2 into the Power Plant Building

As discussed in Section 5, the second ORC unit is a dual air and water cooled system. This allows maximization of system performance by taking advantage of the cold ambient air in winter, and the cool groundwater in the summer months. The second unit has been operating consistently since installation, however due to problems with the cold water supply ORC #1 has been shut down temporarily. Both units are expected to be running in tandem in early 2007.

Figure 22. ORC #1 (background) and ORC #2 installed in the power plant building

10. MODIFICATION TO EXISTING ELECTRIC INFRASTRUCTURE AND HOOKUP TO UPS SYSTEM

One of the major project challenges has been upgrading an aging diesel generator plant and marginal power distribution infrastructure to permit installation of the geothermal power plant modules. Modifications to the exiting electric infrastructure began almost a year prior to the installation of the first ORC module.

10.1 Battery Bank and UPS System

One specific challenge was how to allow the geothermal modules, which generate power via induction generators and thus requires grid support to provide a stable input voltage and frequency for startup, to operate as stand alone generation. This was accomplished through the installation of a 3MW UPS system. The 480V inverter which is part of the UPS system can provide voltage and frequency to the induction generator as it extracts current. This type of system, with batteries for startup and load balancing, allows for the grid-independent operation required by Chena Power.

An additional benefit of the UPS system was that it allows seamless power production from multiple sources (primarily the ORC units and the paralleled diesel generators) to smoothly and continually provide power to the site, via the inverters which are part of the UPS system.

The battery bank and UPS system were purchased and moved onsite in June, 2005. The manufacturer of the system is MGE, and the model is the EPS 6000 UPS Module. The system has been installed in four Conex units and was hooked to the Chena Power grid as scheduled in November 2005 under the supervision of an MGE representative.

10.2 Diesel Generator Upgrades

In preparation for the installation of the ORC geothermal power plant, the three existing generators for Chena Power were paralleled. Originally, the generators were configured in series with only one of the three Caterpillar 3306 200kW providing grid power at any one time. Paralleling the existing generators was necessary for a number of reasons. The ORC geothermal power plant will have some parasitic load associated with it, due primarily to pumps for the hot water supply and reinjection system. Internal system loads are accounted for and the net output of each unit will be 200kW, however the grid requirement will almost certainly average over 200kWhr once the geothermal plant is on line. Therefore, parallel operation will be required during high load time periods. When the ORC units are online, they will take the place of the paralleled generators. The existing diesel generators will remain in place and paralleled with the ORC units through the UPS system to provide emergency backup.

In late December, 2005, Chena Power purchased a new 3456 Caterpillar Generator (455EKW, 480V) to supplement the existing 200kW 3306 Caterpillar Gensets. While this is not directly related to the geothermal power plant project, it was necessary to increase fuel efficiency for the diesel power generation and replace the aging 3306 Gensets.

10.3 Chena Power Grid Upgrades

Because the ORC Geothermal Power Plant is designed to produce an output voltage of 480VAC, it was also necessary to switch the entire primary grid for Chena Power to 480VAC output. This was completed in November, 2005 in conjunction with bringing the UPS system online.

It was also determined that there was inadequate power at the eastern end of the property to supply the production well pumps. A new 4160V buried power main was installed along the geothermal production pipeline to supply power to the pumps and other infrastructure.

11. GRAND OPENING OF THE POWER PLANT

The official ribbon cutting ceremony for the power plant was held on August 20th, in conjunction with the First Annual Chena Renewable Energy Fair. 1400 people attended the Fair, with approximately 900 taking advantage of a free shuttle service from town provided by Chena Hot Springs Resort. 50 vendors and 35 workshops were held, attracting participants from around the country. Almost all Fair attendees toured the power plant during the event.

A number of individuals representing the Denali Commission, Alaska Energy Authority, Department of Energy, and United Technologies Corporation attended the celebration. Senator Ted Stevens and Governor Frank Murkowski were also in attendance and addressed the crowd.

Figure 23. Grand Opening of the Geothermal Power Plant, August 20th, 2006

12. BUDGET AND TIMELINE

The project has been completed on schedule and close to the original budget of $1,899,065. At the end of 2006, project expenses totaled $2,007,770, or 5% above the original estimate. The project was funded in part through a $246,288 grant from the Alaska Energy Authority. An additional loan was obtained through the AIDEA Power Project Loan Fund in the amount of $650,000. The rest of the project included cash and in-kind contributions from Chena Power and its sister corporations Chena Hot Springs Resort and K&K Recycling.

The original timeline planned to have both units installed by the end of 2006, and this was accomplished when the second ORC unit began generating power on December 16th, 2006.

13. CONCLUSION

The installation of the Chena Geothermal Power Plant has been highly successful. The project was completed on schedule and very close to the initial budget projection. The power plant logged over 3000 hours with 95% availability in 2006, generating 578,550kWhrs and displacing 44,500 gallons in diesel fuel. In 2007, the project is expected to generate 3 million kWhrs of clean geothermal power and displace 224,000 gallons of diesel for an estimated savings of $550,000.

The power plant has received international recognition, and was awarded the Project of the Year Award by Power Engineering Magazine in the renewable energy category. It has also been nominated for a prestigious R&D 100 Award by the Department of Energy. Chena Hot Springs Resort also received a Green Power Leadership Award from EPA and DOE, in large part due the onsite geothermal power generation.

It is hoped that the Chena geothermal plant will encourage installations at other sites in Alaska. The project has demonstrated the cost of power production, even in semi-remote locations such as Chena, can be reduced to as low as 5¢ per kWhr. This makes geothermal power generation highly competitive with existing diesel generation in rural Alaska, particularly since fuel costs are virtually eliminated once the plant is installed. Even in locations with no geothermal resources, the same power generation technology, using an Organic Rankine Cycle (ORC), can operate off other industrial waste heat sources to reduce power generation costs, and a demonstration biomass power plant using the same UTC platform is planned for installation in Fairbanks in 2007.

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