Kawerau and Nga Awa Purua Geothermal Power Station Projects, New Zealand

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1. Summary

Mighty River Power's nominal 90 MW Kawerau Geothermal Power Station has been the largest geothermal project in New Zealand for more than 20 years. Fuji Electric has played a major role in this project for which Sumitomo Corporation was the turnkey EPC Contractor. Fuji Electric has engineered and manufactured principal equipment such as the steam turbine, generator, condenser, MV & LV electrical switchgear, etc., procured balance of plant equipment and materials, supervised construction and commissioned the project. The project has successfully satisfied its contractual performance criteria, construction work and commissioning have achieved the required quality standards, and the plant was put into commercial operation on August 30, 2008, more than one month ahead of contractual time limit. Success of the Kawerau project has led Fuji Electric to work on a next project, the 132 MW Nga Awa Purua Geothermal Power Station at Rotokawa, New Zealand, where construction is underway and commercial operation is expected to start in 2010. The Nga Awa Purua Geothermal Power Station is a joint venture between Mighty River Power and the Tanhara North No.2 Trust.

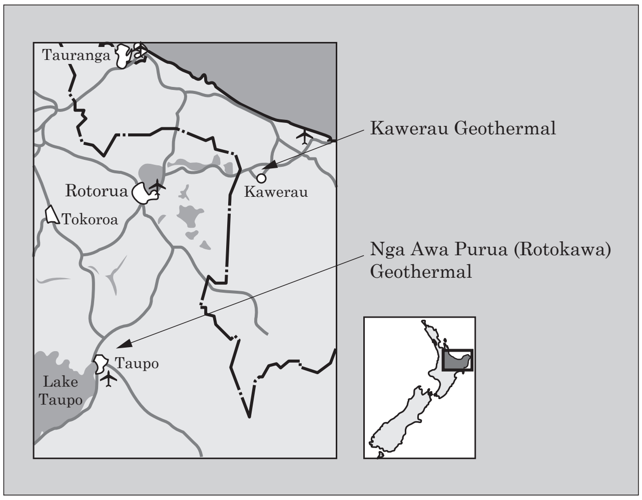
This paper introduces and presents an overview of the Kawerau and Nga Awa Purua geothermal projects, technical features of the plant systems and components, and our experiences in supervising the construction and commissioning the projects. Technical features of the plant systems are divided into the Steam Separation System (SSS) which separates and produces purified steam from geothermal two-phase fluid, and the Power Generation Facility (PGF) which converts steam energy to electricity, as in boiler-based steam power plants.

2. Project Overview

2.1 Project location

The Kawerau project is located approximately 3 km east of Kawerau Township near the east coast of the North Island of New Zealand. The Nga Awa Purua site is located 10 km north of Taupo, close to the Waikato River downstream of the Aratiatia Hydro Power Station and on the Tauhara North No. 2 Trust land adjacent to the existing Rotokawa Geothermal Power Station. These plants are located at the southern and northern ends of the Taupo volcanic zone of New Zealand (Fig. 1), where significant potential exists for further geothermal development.

Fig.1 Location map of Kawerau and Nga Awa Purua projects



The Steam Separation System as well as the Power Generation Facility is situated within the power station boundary. The equipment, buildings and ponds are suitably arranged in the available space to provide easy access for operation and maintenance, as shown in Fig. 2 for Kawerau and in Fig. 3 for Nga Awa Purua.

2.2 Project scope and major parties involved

For both projects, the scope of work and services to be supplied within the context of the EPC contract comprise the planning, design, manufacture, procurement, transportation, construction, installation and commissioning of all facilities within the boundary of the power station. Fuji Electric was responsible for the conceptual and detail engineering, overall project management, installation supervision and commissioning & start-up of the power station including both SSS

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Fig.2 Kawerau plot plan

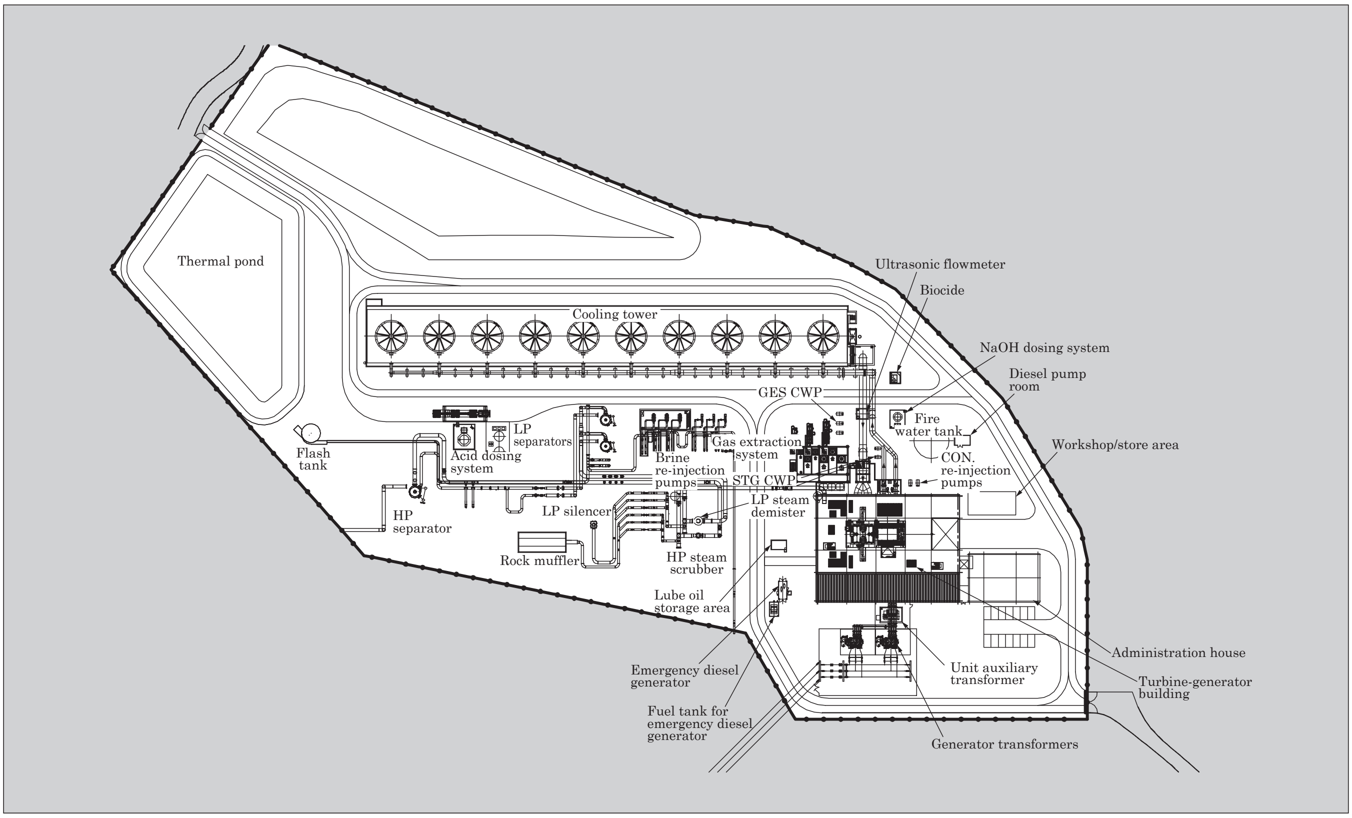
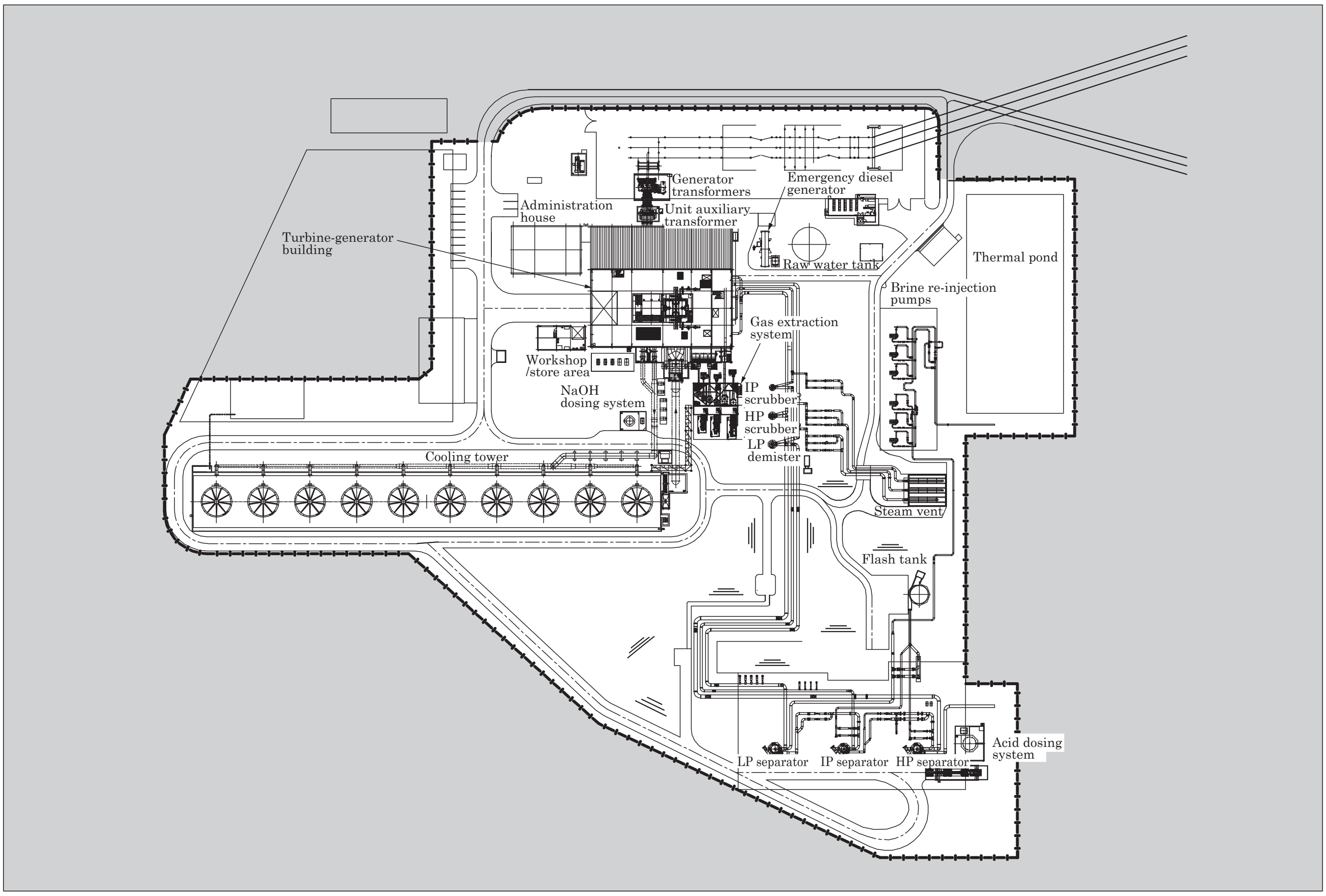


Fig.3 Nga Awa Purua plot plan



and PGF. Fuji Electric has also signed an agreement with a major NZ civil construction company, Hawkins Construction Limited, who assumed a partnership role in civil, structural, architectural and building services works. The agreement between Fuji Electric and Hawkins aimed to maintain a close and collaborative working relationship in order to complete this fast-track project within the targeted program without jeopardizing the quality of the work.

There were following three major process interfaces in the scope boundary of the EPC contract;

(a) TP-01: Two-Phase Geothermal Fluid Supply
(b) TP-02: Geothermal Brine Reinjection
(c) TP-03: Geothermal Condensate Reinjection

3. Overall Project Program

The overall programs for both projects are summarized as shown in Table 1.

For Kawerau, the power station commenced commercial operational more than one month ahead of schedule in compliance with the contractual performance guarantees. This outcome is the result of the high technical performances and great contributions from all related parties, i.e., the owner, civil partner, regulatory agencies, construction contractors, manufacturers, and designers and their staff.

4. Description of Technical Features

4.1 Power station

The process interface between the steam field and the power station is incoming geothermal two-phase fluid and the return of brine and condensate for re-injection, each at the power station perimeter fence. The Kawerau plant is designed for a rated two-phase fluid flow of 45,000 tons per day and a maximum of 55,000 tons per day. The Nga Awa Purua plant is designed for a rated two-phase fluid flow of 45,000 tons per day and a maximum of 48,000 tons per day. For Kawerau, six production wells ranging from 1,900 to 2,100 m depth, supply two-phase fluid with an enthalpy of approx. 1,300 kJ/kg, and for Nga Awa Purua, nine production wells will supply two-phase fluid with an enthalpy of approx. 1,560 kJ/kg. To provide flexibility to changing reservoir conditions, the plant is designed to cover a range of enthalpy, non-condensable gas (NCG) content and chemistry.

The Kawerau and Nga Awa Purua Power Stations are typical dual and triple flash plants respectively, so as to maximize electricity generation from the geothermal fluid. Kawerau is the largest dual flash geothermal single unit in the world when it started operation, and Nga Awa Purua will be the largest triple flash geothermal single unit in the world.

Table 1 The overall programs of Kawerau and Nga Awa Purua projects

Milestone Event	Kawerau (Completed)	Nga Awa Purua (Under Construction)
Resource consent granted	August 2006	January 2008
EPC project commencement	November 2006	May 2008
Delivery of generation equipment	October 2007	April 2009
First geothermal fluid admission	April 2008	November 2009 (Planned)
Power station operational	August 2008	May 2010 (Planned)

4.2 Steam Separation System (SSS)

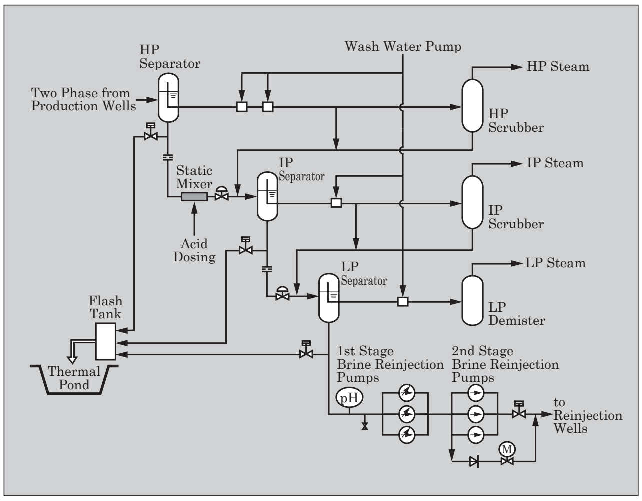
SSS receives the two-phase fluid from the production wells, separates the steam and brine, removes impurities in the steam and then delivers the purified steam to the steam turbine.

Figure 4 shows an overview of the Steam Separation System of the Nga Awa Purua project. Other than the fact that Kawerau has HP and LP systems only, there are no basic differences in the SSS between Kawerau and Nga Awa Purua.

At first, a high pressure (HP) separator receives the geothermal fluid from the production wells and separates it at approximately 12 bar abs (24.5 bar abs for Nga Awa Purua). The separator is a vertical, Webretype cyclone with a spiral two-phase inlet, internal steam pipe with side outlet and a tangential brine outlet from the steam drum. Brine flows from the steam drum to the brine drum through a loop seal.

The separated steam may carry minor quantity of impurities such as brine and volatile silica. The operating regime envisages that the steam turbine will be able to achieve four years operation between major outage, when the turbine will be opened up for internal inspection and cleaning. This resulted in a strong focus to achieve high steam purity at the steam turbine inlet. Particular attention was paid to the design of three key elements, namely: separa-

Fig.4 Nga Awa Purua Steam Separation System overview



tor, purifier and steam-line scrubbing system. The two-phase fluid gathering system results in relatively short steam piping compared to plants using well-head separators. That is whole separators are located near production wells some distance from the power station, and natural condensation can be used to facilitate steam scrubbing. Therefore, to capture impurities carried over from the separator, steam wash water is injected downstream of the HP separator. The wash water spray provides nucleation sites for condensation of steam and agglomeration of the droplets which have been carried over from the separator. Impurities fall down to the bottom of the pipe and are collected at condensate pots. To enhance the scrubbing effect, the steam scrubbing piping is designed so as the length is at least 100 m for Kawerau and 200 m for Nga Awa Purua, and the steam velocity is no more than 20 m/s. The remaining liquid in the steam is removed at the recycling type HP steam scrubber. The drains from the HP condensate pots and the scrubber are directed to the low pressure (LP) separators (IP separator for Nga Awa Purua) to utilize the available energy and minimize the discharge to the surface drains.

The brine from the HP separator flashes at the level control valves and it becomes two-phase LP (IP for Nga Awa Purua) fluid at approx. 1.8 bar abs (IP fluid at approx. 8.9 bar abs for Nga Awa Purua).

High purity (IP and) LP steam is achieved in a similar manner to the HP steam, with Webre-type cyclone separators, water washer steam-line scrubbing and a vane-type LP steam demister.

The LP separator levels are usually controlled by variable speed brine reinjection pumps. The separated LP brine is pumped-up and returned to the steam field for reinjection. The brine reinjection pumps are tandem configuration; the first stage utilizes the variable speed pump and the second stage pumps utilize the fixed speed pumps. The second stage pumps provide flexibility to address changes of the reinjectivity of the wells during start-up and long-term operation. The second stage pumps also provide sufficient pressure to enable the plant to operate with one well out-of-service. In normal operation, with all reinjection wells in service, the first stage pumps are sufficient and the second stage pumps are stand-by.

After removing the steam and reducing the temperature by flashing to approx. 1.8 bar abs (2.6 bar abs for Nga Awa Purua), the silica in the residual LP brine becomes supersaturated. To prevent the consequent polymerization and deposition of silica in the brine system, the pH of the brine is controlled by dosing the HP brine with sulfuric acid. The acid injection rate is precisely adjusted by the variable speed dosing pump to maintain the LP brine to the reinjection system at a target value of pH 5.0. The acid titration curve is quite steep which makes the control loop very sensitive to changes in acid dosing rate. The pH control logic is designed with the acid dosing rate being proportional to the HP brine flow rate. The set point for this control loop is trimmed with the measured LP brine pH. The acid dosing rate depends on the brine composition, which changes when the production well flows are adjusted.

The HP (IP) and LP brine systems have 2 x 100% emergency dump valves downstream of the separators. Excess brine is discharged to the thermal pond, which has a design capacity of 3 hour discharging brine.

4.3 Power Generation Facility (PGF)

Figure 5 shows an overview of the PGF system overview at Nga Awa Purua.

HP (IP) and LP steam from SSS are brought to the steam turbine, which produce electricity at the generator.

The steam turbine for Kawerau is of dual pressure inlet, single-casing, single-shaft, single-flow HP section and double-flow LP section, bottom exhaust and its nominal output is 95 MW. The steam turbine for Nga Awa Purua is of triple pressure inlet, single-casing, single-shaft, double-flow HP, IP and LP sections, bottom exhaust, and its nominal output is 139 MW. Both steam turbines utilize 31.4-inch-long last-stage blades, which are the largest in any geothermal application. This makes it feasible to build the largest singlecasing geothermal power station utilizing multi-flash cycle technology.

The generator is totally enclosed water to air-cooled (TEWAC) type with brushless exciter. Design features to mitigate the risk of corrosion from H_2S gas include: global vacuum pressurized impregnated stator coil, tin-plated rotor coil and slot wedges, and catalytic filters for circulating and make-up air.

Table 2 shows the major design parameters of the steam turbine and generator of each project and Fig. 6 shows a view of the steam turbine and the generator for Kawerau.

Turbine exhaust steam is condensed at approximately 0.08 bar abs in a direct-contact, spray-type condenser with cooling water from the forced draft cooling tower. The NCG is removed from the condenser with a hybrid gas extraction system (GES).

For both projects, the GES comprises of three in-

Fig.5 Nga Awa Purua Power Generation Facility overview

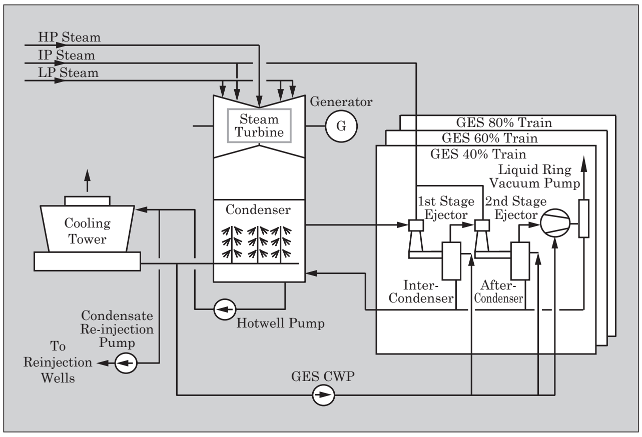


Table 2 Design parameters of steam turbine and generator for Kawerau and Nga Awa Purua

Steam Turbine	Kawerau	Nga Awa Purua
Type	Single cylinder, Double flow, Reaction, Condensing	
Output	Rated 95 MW Max 113 MW	Rated 139 MW Max 147 MW
Inlet steam pressure	HP 11.3 bar abs LP 1.8 bar abs	HP 23.5 bar abs IP 8.4 bar abs LP 2.3 bar abs
Inlet steam temperature	HP 185 °C LP 118 °C	HP 221 °C IP 172 °C LP 125 °C
Exhaust pressure	0.08 bar abs	0.085 bar abs
Steam flow	HP 465 t/h (including 2.3wt% NCG) LP 180 t/h	HP 617 t/h (including 2.3wt% NCG) IP 113 t/h LP 103 t/h
Rotation speed	3,000 r/min	3,000 r/min

Generator	Kawerau	Nga Awa Purua
Type	Totally Enclosed Water-to-Air Cooled (TEWAC)	
Capacity	130 MVA	173 MVA
Rated power factor	0.85	0.85
Voltage	11 kV	11 kV

Fig.6 Photo of steam turbine and generator at Kawerau

dependent trains sized for 40%, 60% and 80% of the design NCG flow. Each train is designed as a hybrid system, with two stages of ejectors followed by a liquid ring vacuum pump. (See Fig. 7.)

This configuration produces the seven combinations of GES trains, which handle 40 to 180% of NCG flow rate. This configuration provides flexibility to allow for uncertainty of NCG content. It should be noted that the GES is procured before all production wells are drilled and tested. During the commissioning period of Kawerau, all three trains were operated but after six months, of operation, only 40% and 80% trains are required in normal operation.

Fig.7 Photo of gas extraction system at Kawerau

For both projects, the cooling tower is a counterflow, mechanical draft-type and made of FRP. It consists of ten cells, arranged in a single line. Two cells are equipped with dual speed fans. Switching fans on or off and selection of half/full speed provides flexibility to adjust the operating configuration to the atmospheric conditions and save the auxiliary power consumption.

The steam flow into the system exceeds the cooling tower evaporation loss, which results in an excess of condensate. Condensate is reinjected to the well to maintain a constant level in the cooling tower basin.

4.4 Plant control

The plant control system provides overall control and supervision not only for SSS and PGF, but also for steamfield and switchyard. The control system matches the steamfield supply to the power demand and maintains safe operation of the plant under transients or equipment faults. The turbine governor controls the entire plant steam pressure and the production well control valves open or close in accordance with the required generator output. In the event of a fault or transient, when the steam vent valves open or a rupture disc burst, the production well control valve position is automatically locked to prevent the further discharge. For a turbine trip the fluid supply from the steamfield is reduced and shutdown automatically without operator intervention.

5. Engineering and Design

Mighty River Power had a dedicated contract management and design review team within their organization. During the detail design stage, periodical design review meetings were held between Mighty River Power and project engineering team members. At the freezing point of key engineering deliverables such as P&IDs, single line diagrams, functional descriptions, etc., a full project HAZOP review was conducted.

The review was facilitated by an external specialist and was attended by Mighty River Power design review staff, operating staff, external plant specialists and Fuji Electric engineering team members. After HAZOP, a detailed 3D-model review meeting was also conducted to review buildability, operability, maintainability, etc.

In the HAZOP review for Nga Awa Purua, systems and areas different from those of Kawerau were intensively reviewed.

6. Construction and Commissioning at Kawerau

Following the ground breaking ceremony of November 29, 2006, site establishment and temporary work commenced, and bulk earthwork started in January 2007. The erection of steel structures for the turbine building started in July 2007 and the final pour for the turbine generator pedestal was completed in September. From late October, major pieces of equipment started to arrive, at which time mechanical and electrical contractors began to mobilize onsite, and piping work for the steam separation system commenced in November. The load rejection, runback, houseload operation test etc. work was implemented by three subcontractors, i.e., mechanical works, electrical works, and cooling tower works. Despite its fast-track program and interference challenges, the overall site construction was generally well coordinated among the relevant parties. There were also ETF and Steam field Contractors, having been separately engaged by Mighty River Power. The work in some areas of the power station overlapped among the contractors, but work interface coordination was also well managed among the parties. For the mechanical work, the outdoor construction work was prioritized because commissioning of the SSS area had started earlier than for the PGF, and also in anticipation of being affected by rain, but the construction period fell during the summer season in NZ so such affect was minimal.

In early 2008, pre-commissioning began in February and the first commissioning milestone of power backfeed from the 110 kV grid was achieved on March 14th, followed by another milestone of the commencement of steam blowout, or in other words, the admission of two-phase geothermal fluid into the power station which was achieved on April 19th.

Commissioning works were planned and executed by Fuji Electric's commissioning managers and supervisors, with involvement of Mighty River Power operators.

Overall commissioning works were managed and executed in the following stages and work sequences.

a) Site acceptance test and commissioning of DCS
b) Electrical system commissioning to achieve power backfeed from 110 kV grid
c) Stationary commissioning of a Steam Separation System to bring geothermal fluid
d) Commissioning of a Steam Separation System, including HP/LP steam pressure control and steam venting, HP/LP separator level control and brine dumping, pH modification control for LP brine, steam scrubbing system to achieve targeted steam purity
e) Commissioning of circulating water system, including hotwell pumps, cooling towers, condenser level control, and other auxiliary cooling water circuits
f) Commissioning of Gas Extraction System including vacuuming of condenser
g) Steam admission to turbine and load testing
h) 30-day reliability run
i) Plant efficiency testing

During commissioning, it was revealed that the actual NCG content was greater than 100%, so all three trains of the GES system were run most of the time during commissioning and the reliability run. Also, to maintain the LP brine at a pH of 5.0, a higher than expected sulfuric acid dosing rate was required and the variable-speed drive for the acid dosing pump was readjusted to match the actual demand. At the condensate reinjection system, originally the condensate was flashed before reaching the plant outlet interface point, so an adjustment was made to maintain positive interface pressure by using the wellhead valve instead of the power station side.

On the other hand, than those, the steam purity rate for the originally targeted condition was achieved without major adjustment or modification of the original design, and commissioning was advanced in the fast-track mode. Before and after the 30 day reliability run, the plant was shut down for inspection and cleaning of vessels, drains, condensate drain pots, etc. and no particular erosion, corrosion or scaling was revealed. Cleanup of the system took some time, but that was not substantially different from other geothermal projects. During the reliability running test, the plant was operated not only at its rated condition but also at a maximum condition most of the time, without any trips, upsets or difficulties.

7. Construction at Nga Awa Purua

Our experience at Kawerau was reviewed by project participants, and in order to improve constructability but to maintain accessibility, several design changes have been implemented into the Nga Awa Purua project.

a) The Kawerau electrical annex has two stories. For Nga Awa Purua, the building was changed to a flat single-story building to improve construction and operational access.
b) At Kawerau, the project land site was flat so brine pumps were located in a 4 meter deep pit to retain suction head from the LP Separator. The Nga Awa Purua site natural terrain is hilly

compared to that of Kawerau, so separators were located at higher elevation and this brine pump pit was deleted.

c) At Kawerau, all the 1st and 2nd stage steam jet ejectors were arranged vertically to minimize the footprint area. For Nga Awa Purua, they are rearranged horizontally.

Photo of Nga Awa Purua construction site as of September 2009 is shown in Fig. 9a, as well as 3D model of the same view in Fig. 9b.

8. Postscript

The construction of the Kawerau and Nga Awa Purua geothermal power stations has taken advantage of the latest technologies. The design has maximized the power output for a given geothermal energy input and minimized the parasitic loads, under consideration of economic factors. Appropriate design margins have been included for the plant and equipment to provide operation flexibility and ensure that the plant can respond to foreseeable changes in the geothermal reservoir. These plants are aligned with the New Zealand government strategy and contributes to a reduction of NZ's carbon footprint from a global perspective.

Fig.8 Photo of Kawerau Geothermal Power Station

Fig.9a Photo of Nga Awa Purua construction site (As of September 2009)

Fig.9b 3D model of Nga Awa Purua (same view as Fig. 9a)