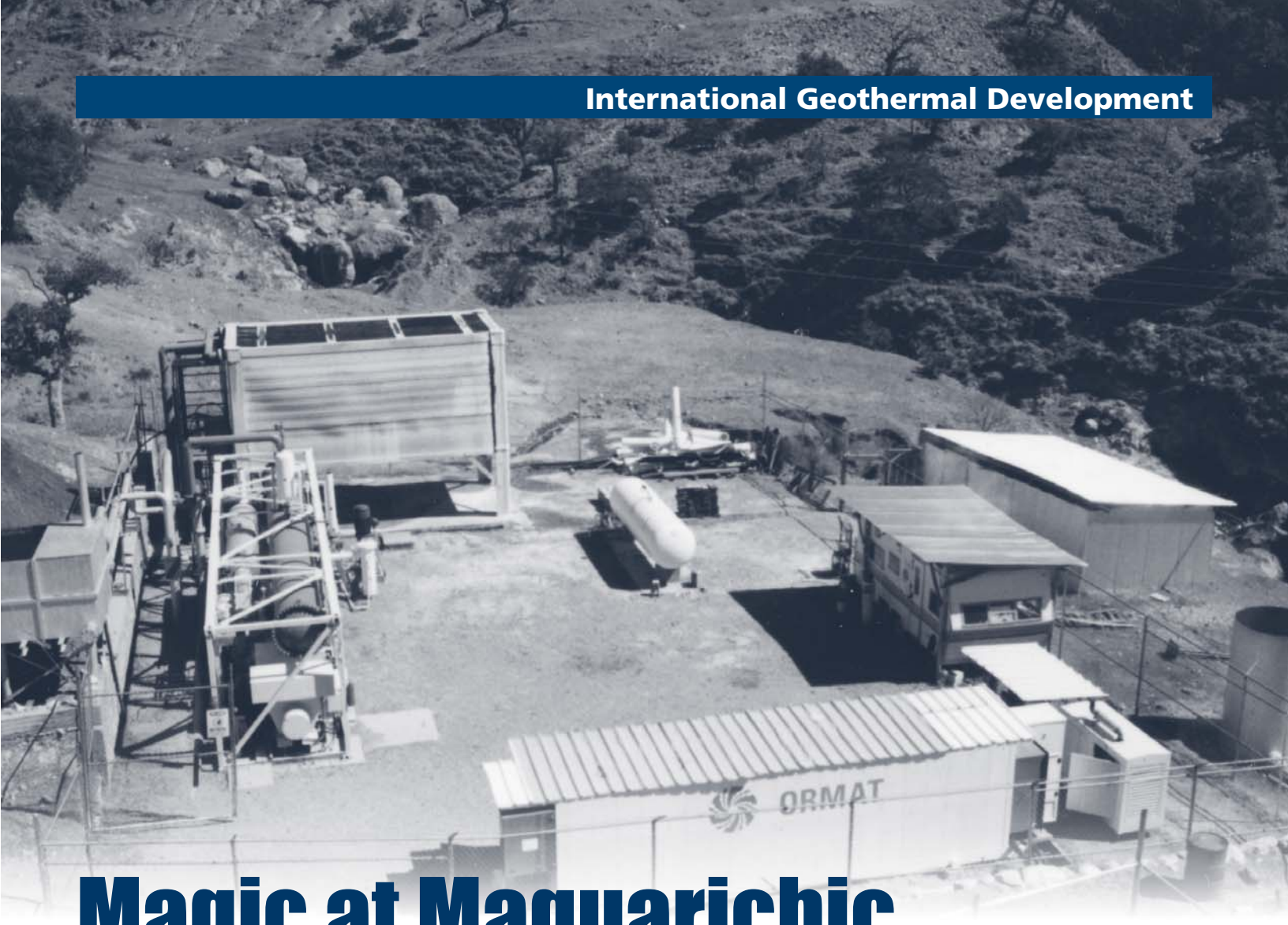

Magic at Maguarichic

New CFE Geothermal Village Power Plant in Mexico Bestows Local Residents with Prosperity—and Children With Ice Cream

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In Mexico, 96 percent of the population has access to electric service. The remaining 4 percent live in small hamlets and villages with less than 100 inhabitants, located far away from electrical transmission lines. Rural electrification with off-grid, small-scale projects using geothermal energy can be an important option to provide electric service to Mexican citizens who have not yet enjoyed the prosperity it offers. The concept was recently proven at Maguarichic, Chihuahua with a small binary geothermal power plant that is revolutionizing life in the village.

Mexico's state-run utility, Comisión Federal de Electricidad (CFE - Morelia, Michoacán), has identified more than 30 low- and moderate-temperature geothermal prospects in Mexico. The prospects are located mainly on the Baja California Peninsula, in Chihuahua and Sonora

Until April 2001, the 600 residents of Maguarichic in northern Mexico relied on electricity for only a few hours per day from a diesel generator. With installation of an ORMAT 300-kW binary power plant at a nearby geothermal reservoir, the remote village has found new prosperity.

states, and in the Mexican Volcanic Belt where the states of Michoacán, Colima and Nayarit present several excellent prospects. There are important technical and economic challenges to solve, however, before entering into a long-term program to develop those resources. Problems include:

Site Access. Most rural roads in Mexico are narrow, cutting across often steep terrain. Heavy truck and equipment access to areas served by these roads is very difficult.

Casing Size. Geothermal well casing design depends on if a downhole pump will be installed. The decision must take into account not only self-discharge, but the thermodynamic characteristics of the geothermal fluid and possible evolution of the reservoir.

Power Plant Capacity. The capacity of the geothermal power plant depends mainly on reservoir temperature.

Reliability. This is probably the most important challenge, because operation of a geothermal power plant and auxiliary equipment without extensive maintenance is the technical and economic key to project success.

CFE began a pilot project to produce electricity from shallow (no deeper than 500 m), low-temperature geothermal brines. In 1997, four 300-kilowatt (kW) binary units were acquired from ORMAT. One of these units was installed in 2000-2001 in the Piedras de Lumbre Geothermal Zone, near the village of Maguarichic, Chihuahua. This article describes various development steps to the success of the project, and how problems were solved.

The Maguarichic Project

Maguarichic is located in southwest Chihuahua State, in the high Tarahumara Sierra, 350 km from Chihuahua City. The area is one of beautiful landscapes, with dense pine forest and impressive rock formations that make it a favorite tourist destination. To reach this remote hamlet of 600 inhabitants, travelers must brave 6 hours on a rough, unpaved road. And because the village is located 75 km from the nearest transmission lines, providing electricity to Maguarichic from the power grid is not economically possible. Until 2001, power for the village was provided for only a few hours each evening (7:00 p.m. - 10:00 p.m.) by a polluting diesel generator, at an elevated price per kilowatt-hour (kWh).

Natural manifestations of hot geothermal fluids at Piedras de Lumbre (fire stones) Geothermal Zone near Miguarichic prompted the Comisión Federal Electricidad to investigate the resource for its potential to provide small-scale power to the village.

Six kilometers from Maguarichic lies the Piedras de Lumbre (fire stones) Geothermal Zone, with fumaroles and hot springs related to the Basin and Ranges Province in the United States. Water from the springs has a sodium-chloride composition, at a temperature calculated with geothermometers of 130 °C. After geological, geochemical and geophysical surveys, CFE decided to drill a slim hole into the geothermal reservoir. Well PL-1 was drilled using a self-contained rig, finishing a 3.5" diameter hole to a depth of 49 m. The well produced water at 120 °C.

With this information and temperature and pressure logs, CFE decided to drill a second well, with a 9 5/8" casing to 35 m and slotted liner to 300 m. Well PL-2's target was to gain even higher temperature and more production. Well PL-2 did not offer higher temperature than measured in the PL-1 well, but produced 35 tons per hour (t/h) of hot water. With this positive result, CFE decided to install one of its small ORMAT geothermal power plants near the village of Maguarichic, at a total cost of approximately $1.3 million (US). Federal, state and municipal funds financed the project, and the community provided in-kind services.

Power Plant Characteristics

The power plant installed at Piedras de Lumbre is an ORMAT binary-cycle unit with 300 kW net capacity. The turbine employs isopentane as working fluid, and requires a water supply of 55 t/h at 150 ° C. The condenser is shell-and-tube type, with 400 t/h of cooling capacity at 21 ° C. CFE decided to install a modular cooling tower with an integrated basin to reduce the civil works on the power plant site. Cooling is accomplished by eight fans, powered by electric motors (4-kW each) located in the bottom of the tower.

The 480-volt generator is synchronous, with fully automatic unattended control and

redundancy of critical parts. The turbine, generator, heat exchanger, condenser and control room were assembled and tested on a skid in the ORMAT factory. Auxiliary equipment comprises an air compressor and diesel generator for the start-up process. Characteristics of the electrical system are:

Substation: 480/13,800 V
Transmission line: 6 km in straight line from Piedras de Lumbre to Maguarichic.
Distribution grid: 75 KVA
Transformers: Five 13800/125-220 V
Project costs: See Table 1.

Table 1. Costs of the Maguarichic Village Power Geothermal Project

Activity/Part	Cost (US$)
Power plant	900,000
Cooling tower	60,000
Electric substation	10,000
Access conditioning	50,000
PL-1 (slim hole 49 m depth)	50,000
PL-2 (production well)	100,000
Pumping system	40,000
Construction works	50,000
Isopentane	10,000
Transmission distribution lines	75,000
Total	**1,345,000**

Project Challenges

The main problems encountered in developing the Maguarichic project and their solutions are presented below, with brief descriptions of technical aspects.

Access. The original 78-km road to the village was narrow, cutting through steep terrain with many difficult curves. From Maguarichic to the Piedras de Lumbre the road (another 6 km) was unsuitable for heavy traffic. It was necessary to broaden the curves and improve the surface with gravel.

Traffic with Heavy Equipment. The power plant turbine, generator, heat exchanger and condenser were skid mounted, with a total weight of ~28 tons. It was necessary to disassemble the condenser and the heat exchanger for separate transport because in some places the road grade was greater than 15 percent. During some segments of power plant transport, it was necessary to help the truck overcome the steep road by pulling it with a tractor.

Drilling Activities. Drilling took place with a self-contained rig. Since the truck base was not high enough for installation of blowout prevention equipment, the truck was mounted on a platform.

Decreasing Temperature. Reservoir pressure was 5 bar, with a fluid temperature of 120 °C. Well PL-2 produced as single-liquid phase, flashing at 15 m depth. From this depth to the surface, temperature dropped to 105 °C. To solve this problem two solutions were tested, including injecting a small amount of air below the flashing point, and installing an electric pump. Both solutions were evaluated and technically acceptable. The electric pump was selected because operation and maintenance would be much easier than the airlift.

Qualified Workers. During various stages of the project, qualified workers were needed to disassemble and assemble the main equipment of the rig, and install different systems for the power plant. CFE contracted people from Maguarichic and trained them with the supervision of its engineers. The Maguarichic power plant is now being successfully operated by people from the village.

Photos: CFE

Since gaining access to continuous geothermal power, Maguarichic has attracted new business, including a small clothing factory that employs several electric sewing machines.

Operation of the Unit

The Maguarichic geothermal power plant was commissioned on April 30, 2001. Since CFE technicians are headquartered in Morelia, about 1,000 km from the village, local residents were trained on basic operation of the unit, including start-up, resetting of alarms, checking main readings, and re-starting. If a major problem occurs, CFE engineers go to the site. During two years of operation, the local operators have solved problems like condensation in the air-compressor filters, and vacuum-leakage of compressor pressure. CFE personnel assisted with problems encountered with automatic start up of the air compressor; trouble with the brine stop-valve; salt deposits in the cooling tower; and troubles with downhole pump bushings.

Social Impacts of the Project

This is probably the most important issue surrounding the Maguarichic project. Before operation of the geothermal-electric plant began, the village had little public lighting, and households were connected directly to a diesel generator without breakers, which produced electric leakage. Total electric consumption from the diesel generator was around 90 kW.

With no refrigerators, village residents rarely consumed meat, cheese and milk, and local children had never seen ice cream. Because of voltage variations, there were no TVs, disconnecting the people of Maraguichic from the march of domestic and national and international events. But electrification brought almost immediate change.

Local authorities soon installed a public lighting system, with sidewalks and paved streets. The community formed a committee that is responsible for operation and maintenance of the power plant, as well as the distribution of electricity. They installed meters at households, where residents were required to install breakers. With the new distribution system and improved home installations, power consumption at Maraguichic decreased from 90 kW with the diesel generator to 35 kW.

Present power consumption at Maraguichic is around 75 kW, the result of residents buying refrigerators and a few TVs. The village is also the new home of a *tortillería*, where tortillas are made with electric equipment, and a small clothing factory with electric sewing machines. The village is growing, as people who want the benefits of electricity and the work and business opportunities it provides move to Maraguichic from nearby villages.

Conclusions

With experience gained at Maguarichic, CFE has learned a number of answers to technical and economic questions that will be taken into account for similar, future projects in Mexico.

Regarding the geothermal reservoir:

- The aquifer to be exploited should be located preferably at depths of 500 m or less, so wells can be drilled with a small rig.
- To acquire reservoir information, it is better to drill a production well instead of a slim hole. Costs are almost the same, but a slim hole probably cannot exploit a reservoir because of its inability to accept a downhole pump.
- Minimal reservoir temperature should be 115°-120° C. Lower temperatures increase water needs, demanding more than one well to supply the required flow. In addition, the size of the heat exchanger must be greater. Optimum flow rate for a 300-kW binary unit is 150 t/h.

Regarding the power plant:

- Binary equipment should be designed with different working fluid. Handling isopentane at an isolated rural area is very difficult because it is considered dangerous material. To replace leaked fluid (around 7% per year), it is necessary to rent a special transport vehicle that costs more than the fluid ($5,000 [US] for the vehicle compared to $2,500 for the isopentane).
- The plant should be designed to operate within a 120°-135° C range for brine inlet pressure. This range covers several site conditions for operation without problems. The Maguarichic power plant was designed for an inlet temperature of 150° C, but available geothermal fluids are only 120° C. By increasing the flow rate, the plant can produce 200 kW output, but will never reach the equipment's rated 300 kW.
- The generation skid must be designed in a modular fashion, with a maximum weight of 15 tons per module. Heavier modules must be disassembled to transport them on a rough, steep roads.
- The heat exchanger should be designed for a maximum length of 9 meters, to avoid transportation problems.
- The main isopentane pump should be horizontal instead vertical, to reduce civil works.
- The assembly between the turbine and the generator should be direct instead of through a gearbox, which is noisy and demands maintenance.
- Power capacity should be higher than electrical consumption, in order to support a consumption increase. Too large of a difference between power capacity and consumption in the initial stages of a project can make it uneconomical. Too small a difference between capacity and consumption can also constrain desired economic development associated with electricity generation.

Regarding the economy of the project:

- Power plant operation and maintenance activities are handled by three people from Maguarichic. Operational costs were less than $8,000 (US) during the first year. CFE spent a similar amount for supervisory work.
- During the first year of power plant operation, each household paid an average $4 (US) per month for its electric consumption, since the village people cannot afford the electricity's actual cost. Local authorities helped by paying salaries of the three power plant workers.
- In developing countries, this type of rural electrification project must be financed by government agencies, but the community must also be involved and support at least a small share of costs. ■

Editor's Note: CFE will offer a field trip to Maguarichic on Oct. 16, following the GRC 2003 Annual Meeting in Morelia, Michoacan (Oct. 12-15). For more information on this field trip and other Annual Meeting events, visit the GRC web site at: www.geothermal.org.