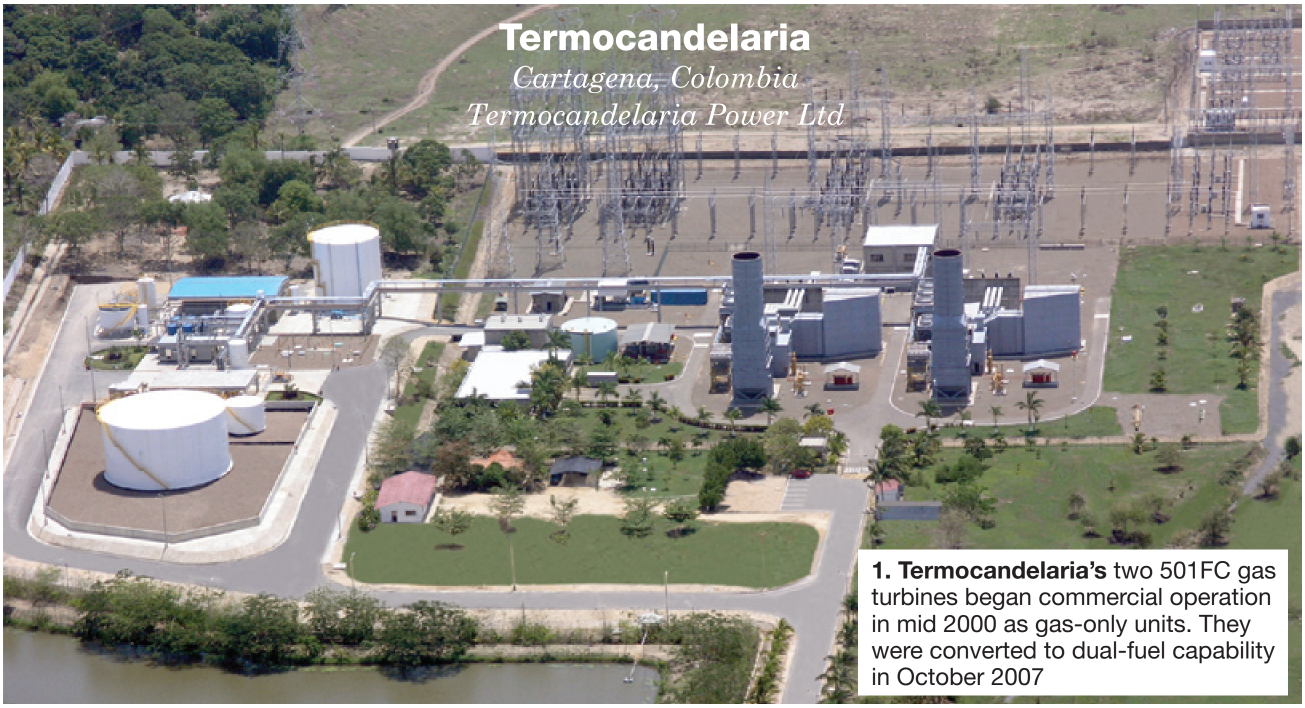
Termocandelaria

Cartagena, Colombia
Termocandelaria Power Ltd



1. Termocandelaria's two 501FC gas turbines began commercial operation in mid 2000 as gas-only units. They were converted to dual-fuel capability in October 2007

Dual-fuel retrofit assures strong balance sheet

Only a few years ago gas-turbine (GT) user group meetings were hosting discussions on converting engines from dual fuel to gas-only. Many owner/operators weren't burning oil except to verify that it was a viable standby fuel. They said oil and water lines at the flame front were a nuisance, adding time and expense to overhauls. Some users simplified their lives by eliminating the capability to burn oil.

Today it seems the industry may be turning back in the other direction, with at least a few plants converting from gas-only to dual fuel. One question grid operators must be asking themselves during exercises to identify system vulnerabilities: "How much generation would we lose if a major gas line were compromised or if gas were not available for some reason?" The number could be large if most plants in the region are powered by GTs. A logical next question if gas-only is considered a vulnerability: "Have we classified gas-only generating facilities as firm capacity and are we paying them on that basis? If the answer is "yes," the next question is "Why?"

Colombia had grid reliability concerns a few years back and promulgated new regulations for powerplants in October 2006. Termocandelaria, a privately held peaking facility located near Cartagena, was impacted by the new rules (Fig 1). It had a contract to supply back-up power to the grid when called upon.

Perez

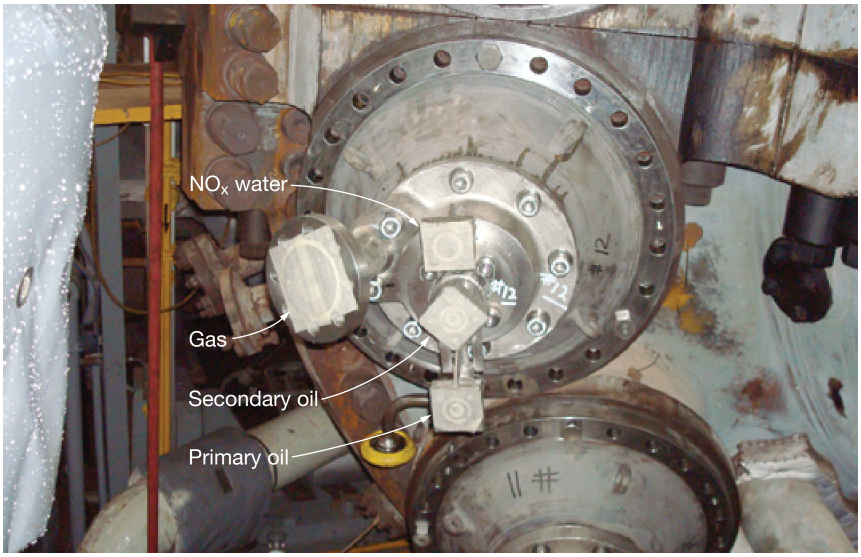
The plant's two 501FC GTs, built by Westinghouse Electric Corp about the time of the company's acquisition by Germany's Siemens AG, were equipped with gas-only dry low-NO_x combustion systems and rated 157 MW each.

Simply put, the Colombian government told Termocandelaria it would have to contract for firm natural gas or add a backup fuel to continue receiving capacity payments; also, the plant's "solution" had to be in place by November 2007. Not much time. Termocandelaria's management found itself between the proverbial "rock and a hard place": The firm-gas option was not viable because of supply and cost considerations.

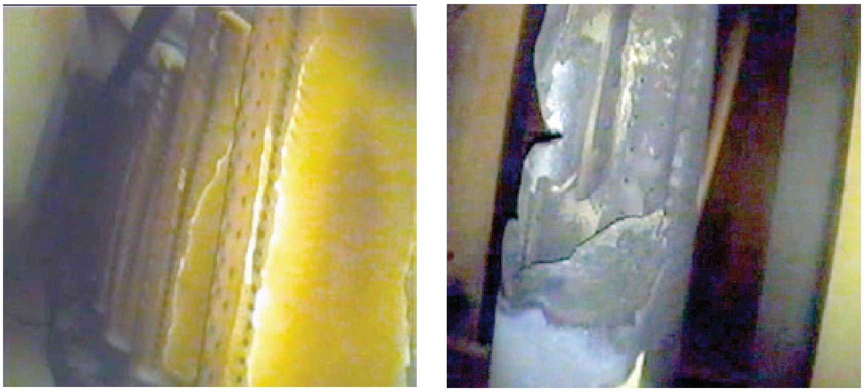
The only permanent solution was conversion to dual-fuel firing, but the odds definitely were against designing, installing, and commissioning, within a year, the infrastructure required to enable that option. On the other hand, the consequences of failing to meet the government's timetable were unacceptable.

What the plant had going for it was a good location for grid support and an experienced and dedicated staff headed by Plant Manager Miguel Perez Ghisays (he goes by Miguel Perez in casual communication). Termocandelaria operates in a highly competitive electricity market dominated by low-cost hydro generation. It usually runs only during droughts and when transmission between the country's interior and north side is interrupted. In a typical year the plant starts about 20 times and operates from 100 to 200 hours.

One of the compelling aspects of



2. DF-42 combustion system does not require flow dividers or atomizing air when burning distillate oil



3. Some hot-gas parts had seen better days. Note oxidation attack on the leading edges of an R1 blade (left) and an R2 vane (right)

the 2006 regulations was that "guaranteed reliability charges" (capacity payments) would be locked in for five years beginning in November 2007. If the deadline were missed, revenues from December 2007 through November 2012 would come into question. Plus, a resolution passed in 2008—as a consequence of the first firm energy auction held by the system operator in compliance with the 2006 regulations—awarded capacity remuneration to new and approved generators beyond 2012.

Termocandelaria quickly issued an RFQ for dual-fuel conversion. Orlando-based Mitsubishi Power Systems (MPS) was awarded the contract, Perez said, because of its technology, high-quality engineering, good warranty, and respect for, and commitment to, the schedule. Work began immediately.

Cloyd

One of the first things Mitsubishi did, recalled Scott Cloyd, technical director of turbine engineering, was to hire WorleyParsons Group Inc's for balance-of-plant (BOP) design and engineering. WP's Chattanooga office had intimate knowledge of Termocandelaria, having been the engineer of record for the original project, which began commercial operation in mid 2000.

Mitsubishi's plan was to convert the turbines to diffusion-flame combustion systems and use water injection for NO_x control. Sounds like a step backward in time, but it actually was a big step forward. Here's why: A requirement of the Colombian regulations is that power producers guarantee the grid operator a firm capacity for remuneration purposes. Conservatism is important; you don't want to overestimate your capability.

The plant's original commitment was 157 MW, which is what it wanted to bid for the dual-fuel configuration. But 501F series GTs normally run with a slightly derated firing temperature on liquid fuels, meaning output would be less on oil than for gas.

The capacity payment for the plant would be based on the expected power output and heat rate on liquid fuel when these numbers were submitted to the regulator in November 2006. Performance would be audited by the system operator before commercial commissioning; if the actual numbers deviated from those declared in November 2006, the plant would not be awarded capacity remuneration.

Water injection, which increases turbine mass flow, can offset this loss. However, had a dual-fuel DLN combustion system been selected, power output still would have been less than 157 MW when burning distillate. Reason, said Cloyd: Water injection is limited on DLN systems to a water-to-fuel ratio of about 0.4.

By contrast, the diffusion-flame system permits a water-injection ratio of 1, possibly higher, thereby assuring 157 MW. In fact, commissioning tests later showed Termocandelaria's engines could achieve 160 MW on oil and 165 MW on gas.

Other benefits of the MPS diffusion-flame combustion system: (1) Liquid-fuel nozzles are unlikey to coke-up, thereby minimizing nozzle repair/replacement costs, and (2) liquid-fuel flow dividers, which can be problematic, are not needed.

Regarding the second point, the MPS DF-42 combustion system features a duplex oil nozzle, which has primary and secondary passages (Fig

2). The primary nozzle is for ignition and unit acceleration, the secondary nozzle for final acceleration and load control. Having two nozzle tips means oil flow for ignition has sufficient pressure drop across the nozzles to preclude the need for flow dividers.

The higher-pressure atomization for startup also eliminates the need for atomizing air and promotes more complete combustion of fuel oil, reducing opacity during the start cycle. To prevent coking, Perez said, the nozzles automatically are drained and purged with air when the unit is shut down.

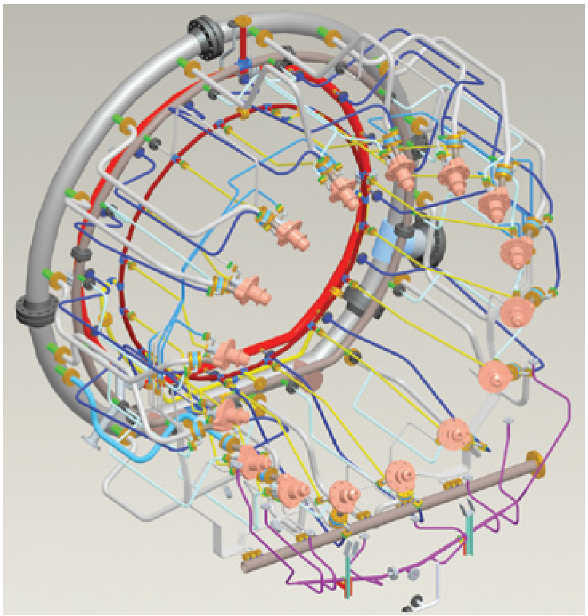
Oil drains by gravity to a collection tank and then an air-purge system blows oil lines clean. The air purge is continued until nozzles are below the coking temperature. Cloyd mentioned that a similar cool-down scheme at another W501F plant that Mitsubishi installed and commissioned with liquid-fuel diffusion-flame combustors had experienced no coking-related issues through more than 100 fuel-oil starts.

Perez added that the water injection line also has a drain valve that opens automatically when the turbine is shut down—this to prevent water from entering the hot machine if the final shutoff valve in the line leaks.

The DF-42 combustion system for

4. More durable transition pieces are visible as millwrights install combustion system

5. New R1 and R2 vanes and blades have an M501F3 pedigree



6. Interferences required changes to standard engine injection-water and fuel piping (left). Engineer responsible for the redesign effort was at the factory during fabrication (right)

the 501F originally was developed by Mitsubishi when the company had an alliance with Westinghouse and Fiat Avio of Italy. The duplex oil nozzle was a subsequent design modification developed solely for Mitsubishi customers.

The company also made its transition pieces more durable, Cloyd said, by increasing the wall thickness about 30%, and by reducing the size and pitch of cooling passages to lower the metal temperature. Also, near-hole masking techniques used during the robotic application of thermal barrier coating reduced panel thinning associated with strip masking techniques used previously.

In addition to retrofit of the DF-42 combustion system, the dual-fuel conversion project included installation of upgraded engine parts produced by Mitsubishi to improve reliability (Fig 3). The new components had a M501F3 pedigree and could be installed in the W501FC with some modified mounting hardware. The new parts were:

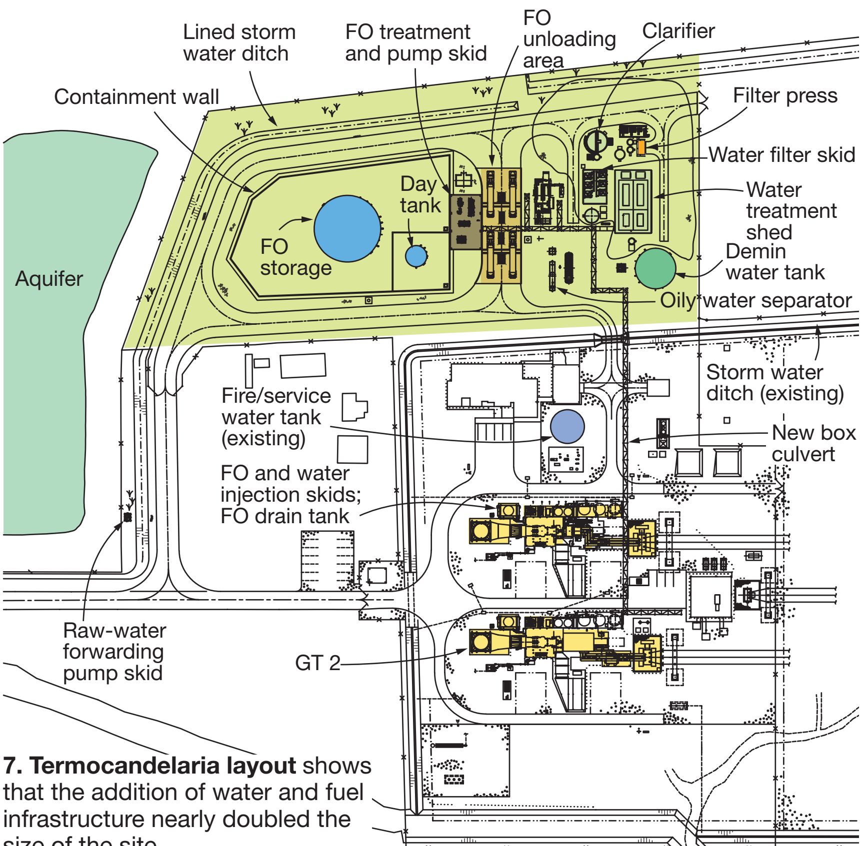
- Combustor baskets, transition pieces, and seals (Fig 4).
- R1 and R2 vanes, blades, and ring segments (Fig 5).
- Ignition system.

Plus, the WDPF (for Westinghouse Digital Processing Family) control system originally installed with the machines was replaced with Emerson Process Management's Ovation®. This system also was selected for balance-of-plant application.

Surprise. Perhaps the biggest challenge related to the engine on this project involved the fuel and water-injection manifolds. Cloyd said that Mitsubishi had planned to supply the standard manifolds it would use on a new dual-fired M501F machine.

But while the W501F engine was jointly developed by Mitsubishi and Westinghouse, design of auxiliary systems and enclosures were unique to the supplier. The differences were such that new manifolds had to be designed. This was learned in March 2007, only seven or eight months before commissioning on dual fuel. Tick tock.

Cloyd immediately assigned Ramy Massoud, a recent graduate with Pro/ENGINEER (Parametric Technology Corp, Needham, Mass) modeling skills, the task of designing new manifolds and piping that would be consistent with the existing turbine cylinder, cooling-air pipes, and enclosure structural steel (Fig 6). The engineer identified interferences on more than 50 of the 84 piping segments for Mitsubishi's standard manifolds. The obvious challenge: Redesign the piping and manifold supports to meet the critical manufacturing schedule. Cloyd said it really was completed "just in time."



7. Termocandelaria layout shows that the addition of water and fuel infrastructure nearly doubled the size of the site

The same engineer stayed with the project through onsite hydrostatic testing. He visited the Elliott Co factory near Pittsburgh to assure top quality and schedule compliance, and then "lived" at the plant to supervise fit-up, welding, and the hydro.

Balance of plant

The W501FC modifications and upgrades to accommodate dual-fuel firing were only a part of the project. The biggest effort in terms of people and materiel was the design, construction, and commissioning of the fuel and water-treatment infrastructure needed to deliver oil and water to the engine, including: fuel unloading station, storage tanks, and treatment system; water treatment and storage; water and fuel forwarding pumps.

Termocandelaria's contract with MPS covered (1) turbine mods/upgrades, including migration from the WDPF control system to Ovation; (2) the GT flow-control systems for the fuels, water injection, purge air, and drains; and (3) balance-of-plant design. WorleyParsons handled the BOP work, which included implementation of Ovation controls and electrical equipment—such as new medium-voltage switchgear for the new liquid-fuel and water treatment systems.

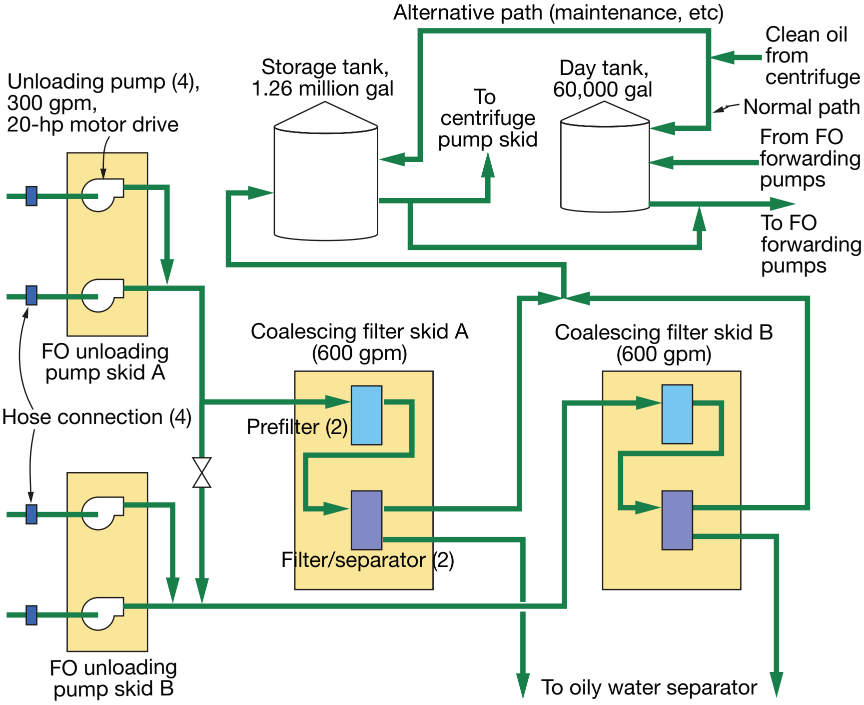
Termo also had contracts with Asesorias y Construcciones (A&C), the general contractor, for all civil, mechanical, and electrical work; Ingetec SA, the owner's engineer; Alfa Laval Mid Europe Gmbh, Glinde, Germany, for the fuel-oil treatment systems; and with a local supplier for raw water treatment and an overseas supplier for the demineralized-water system. Interestingly, A&C and Ingetec, like WP, were key participants in the original project.

Perez was very aware of the need for continual communication and respect among the parties to assure timely completion of a high-quality project. He had been a field engineer for a major GT OEM before coming to Termocandelaria in January 2003. Perez expressed the highest regard for Mitsubishi and WorleyParsons and their ability to work with the plant as an integrated team.

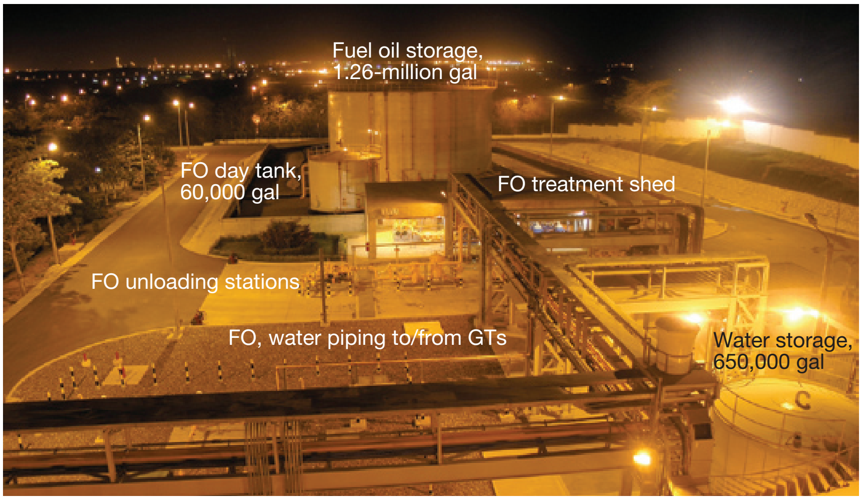
Plant personnel involved, he continued, had a great deal of experience and the ability to review drawings and evaluate alternatives on a timely basis. The first thing the integrated plant/MPS/WP team did, Perez recalled, was to establish minimum design requirements. Next, general specifications were developed so WP could begin detailed engineering. As engineering was completed, documents were sent to the plant for review and comment so any necessary changes could be made quickly. Something was happening all the time.

The WorleyParsons Termocandelaria design group, headed by Project Manager James H Dyer, nearly doubled the plant size by addition of fuel and water infrastructure, as the site layout drawing reflects (Fig 7).

Fuel oil is delivered to the plant by truck; four unloading stations can accommodate 24/7 plant operation on diesel with a suitable factor of safety (Figs 8, 9). Note that when operating base-load, each GT consumes hourly about the same amount of oil delivered by one truck. The unloading skids have coalescing filters to remove entrained particulates and water droplets before the oil is pumped to the 1.26-million-gal storage tank.



8, 9. Fuel system reliability is assured by full redundancy (above). Key components for fuel receiving and storage are shown in photo



Oil is moved from storage to the centrifuge station in the fuel-oil treatment shed for washing to remove any sodium and potassium that may have entered the fuel during ocean transport to the truck filling station (Figs 10, 11). Recall that sodium and potassium can quickly ravage turbine blades and vanes and must be held to Na + K levels below 1 ppm. Washed and treated oil is pumped to the day tank. Forwarding pumps deliver oil from the day tank to the engine FO skids (Fig 12).

FO and injection water are transported from their respective storage tanks to/from the GTs by piping arranged in the overhead rack shown in Fig 9. Power and control wiring for BOP equipment is run the same way. Dyer said that overhead utilities offered advantages over underground lines at Termocandelaria.

Raw water is supplied from a municipal aquifer via a floating suction arrangement to the pretreatment system (Fig 13). Redundant self-priming pumps are installed on the raw-water forwarding skid. Pretreated water flows next to the demin system and after final treatment to the 650,000-gal storage tank shown at the lower right in Fig 9. Demin water is used both for FO washing and the GTs (Fig 14).

Dyer said the water treatment system was challenging despite the apparent simplicity reflected by the drawings here. Interface issues were the result of have a local pretreatment system supplier and an overseas supplier for the demineralizers. The demim forwarding pumps deliver water to the injection pumps at the GTs, which is where WP's scope ended. However, the engineering firm did perform the high-energy stress analyses for the high-pressure injection-water and oil piping serving the GTs.

The various equipment skids were procured by MPS in the US to meet schedule commitments (Fig 15). There was extensive use of Type-316 stainless steel because of the aggressive coastal environment; even Type 304L will rust at Termocandelaria. All carbon steel was coated with an epoxy first, then urethane. Fisher flow-control valves with anti-cavitation trim and Young & Franklin

Some of the Termocandelaria personnel critical to the success of the plant include Shift Supervisor Policarpo Batista, O&M Supervisor Jenner Garcia (bottom row, left to right), Plant Manager Miguel Perez Ghisays, O&M Engineer Jeimy Rodriguez, and Shift Supervisor Sadid Acosta (top row, left to right) hydraulic actuators were standard equipment on all skids.

Constraints, such as the unavailability of Type-316 piping and fittings, control cabling, etc, added to the complexity of the job, Cloyd recalled. He said that the Mitsubishi/Termocandelaria purchasing and transportation team effectively moved from one supply issue to another to keep the project on track. But even they had limitations and at times it took raw ingenuity and the resourcefulness of site personnel to do what had to be done—such as the jury-rigging of fire hoses, scrap piping, and shipping containers lined with plastic to flush sections of fuel oil and water piping.

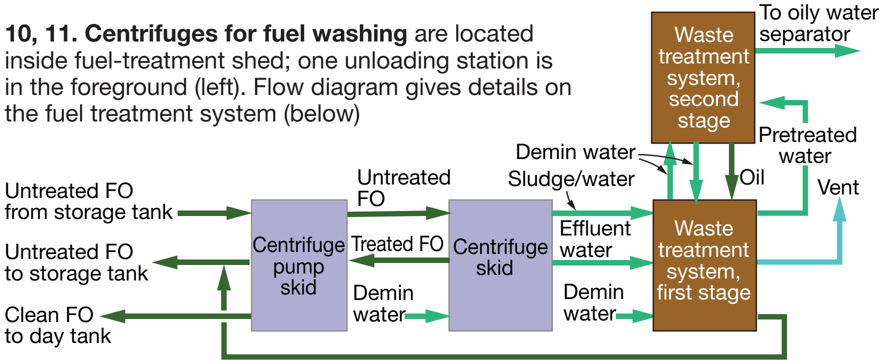
The Ovation integration effort had two components as noted earlier: engine and BOP. For the former, MPS worked with Emerson to define control setting and logic requirements. Emerson supplied the hardware and programmed the controllers. Mitsubishi participated in the factory acceptance tests and Emerson's field personnel supported the turbine startup.

In brief, the WDPF controls were upgraded to Ovation by replacing the processor and work stations with a Windows XP operating platform. Q-Line I/O cards were retained to minimize rewiring and re-termination of existing control devices. New control wiring was run to the gas, oil, water-injection, and purge-air systems.

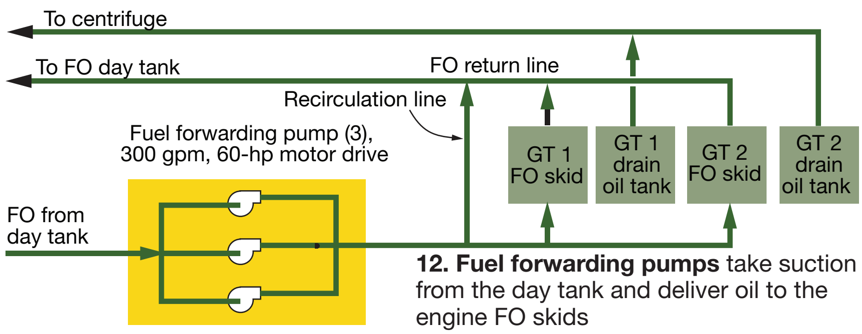
Logic changes were implemented for overall unit control—such as loss of flame. The validity of this logic was demonstrated during unit commissioning because of vibration-induced responses of several water-injection flow meters. Problem was solved by upgrading flow meters to Emerson's Micro Motion Coriolis.

BOP controls integration was not without challenges. Alfa Laval and the vendors for the water treatment systems provided controls for each of their systems and WP brought the outputs back to an OPC (object linking and embedding for process control) controller within Ovation (Fig 16). Integrating programming done in several languages was especially difficult, particularly because verbal communication among some of the parties was challenging.

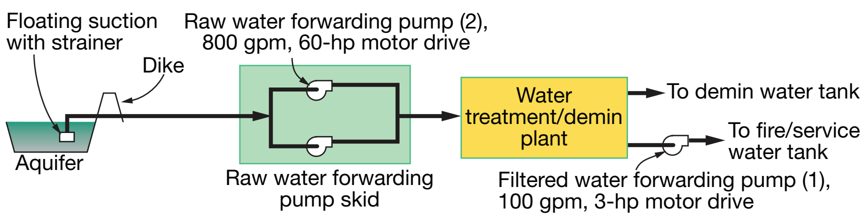
WP engineers said Alfa Laval did a good job of checking-out its system controls prior to delivery so field integration of the fuel washing system into Ovation went smoothly. Two-way communication with the



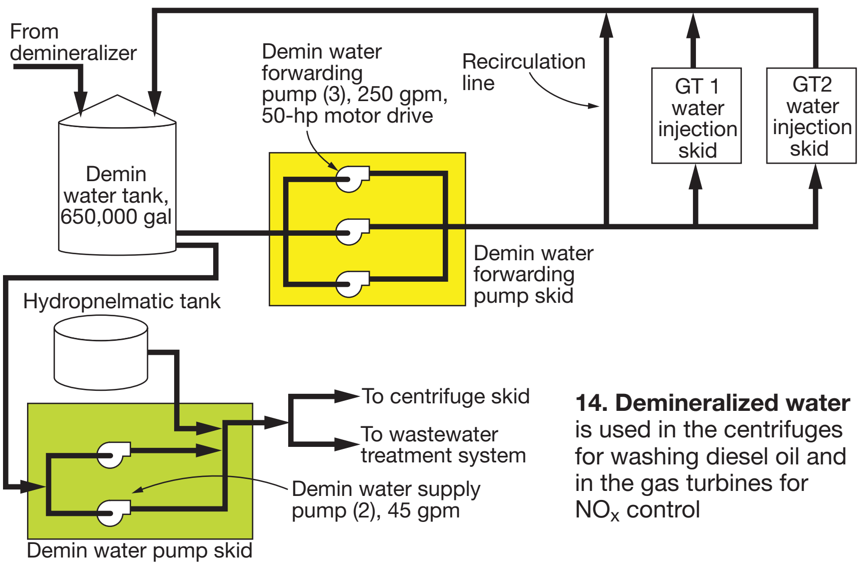
10, 11. Centrifuges for fuel washing are located inside fuel-treatment shed; one unloading station is in the foreground (left). Flow diagram gives details on the fuel treatment system (below)



12. Fuel forwarding pumps take suction from the day tank and deliver oil to the engine FO skids



13. Raw water is pumped from a municipal aquifer to the pretreatment system. Permeate from the RO unit at right in photo is polished by the EDI (electrodeionization) system at left. Staff pride is evident from the level of cleanliness



14. Demineralized water is used in the centrifuges for washing diesel oil and in the gas turbines for NO_x control

plant was excellent, Dyer continued. Weekly net meetings to review drawings, action items, schedule, etc, were especially helpful.

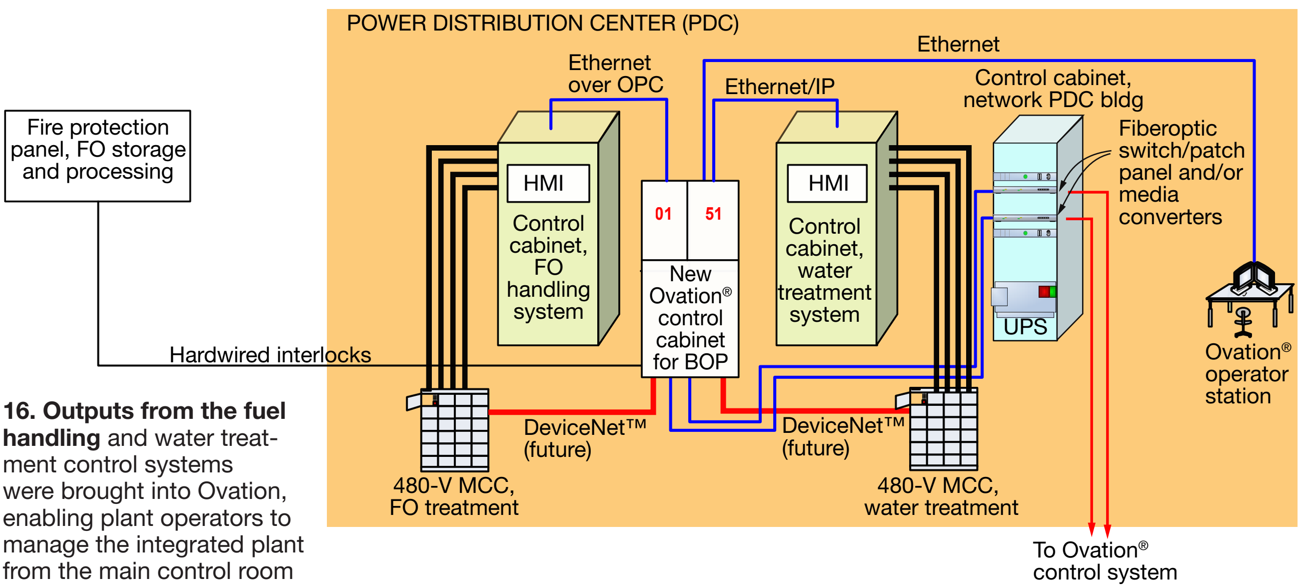
Wrap-up. With the pressures inherent in the Thermocandelaria dual-fuel conversion project you could easily believe that commissioning process would be chaotic. When the editors asked Cloyd about that, he said that chaos was impossible at "Termo" because Perez is a calming influence, a person who won't allow anything to rattle him, "and we were determined not to let him or Termocandelaria down."

Same question later to Perez. "Commissioning? Oh, we pressed the button with oil lined up on Unit 1 and it started, ramped up, and synchronized with the grid. No problems. Then we pushed the button on Unit 2 with oil lined up and it also ramped up and synchronized with the grid without any problems."

Starting reliability, of course, is a big concern for a plant being paid for its standby capability. Perez said that with the old DLN system on gas, there were occasions when two or three start attempts were necessary to get a unit into service. The DF-42 has been virtually perfect on oil. Plus plant availability is above 99.7%.

"Exceeded expectations" was Perez' summary of the project. When asked about lessons learned and what changes he would make were he to do the same project again, Perez responded, "None, except that if I could schedule the project around the two months of rain we had, I certainly would." CCJ

15. Fuel-gas valve skid (left) and water-injection system skid (right) were made in the US to meet schedule commitments



16. Outputs from the fuel handling and water treatment control systems were brought into Ovation, enabling plant operators to manage the integrated plant from the main control room