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Closed-loop, organic Rankine-cycle plants are adding multimegawatts—without additional fuel.

By David Engle

Combined heating and power is a mantra of distributed energy efficiency, but how about capturing the heat to yield more power?

When the waste heat itself isn't directly needed for warmth, using it to boil water for steam-cycle generation does make sense, provided the gain in electricity will be enough—say, 10 MW or more—to justify the capital cost, operational overhead, and maintenance.

But even in this case, suppose the given heat source is in a remote locale, as undoubtedly many thousands are—for example, at compressor stations along North America's natural-gas network? Although lots of potentially valuable heat is roaring up those stacks, harnessing it would not be easy, and making steam wouldn't often make sense. For one thing, abundant water would be needed—not always easy to find in the boondocks. For another, getting wastewater permits might be tough. And what if a mishap occurs in winter?

"When a steam unit goes down," observes Ron Rebenitsch, whose job entails evaluating and developing such out-of-the-way energy projects, "parts begin to freeze up, and this will damage a lot of equipment."

Rebenitsch, of the Basin Electric Power Cooperative (BEPC) in Bismarck, ND, is far more comfortable with four newly arriving power plants being provided by Ormat Technologies' heat recovery generator: the Ormat Energy Converter, or OEC. Since their development in Israel several decades ago

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and entry into the US in 1972, OECs now boast a diverse portfolio of successful geothermal and heat-recovery projects worldwide. About 70 patents are applied in this unique system, which optimizes a closed-loop, organic Rankine cycle. The OEC design offers a range of benefits for a select power niche, covering a surprisingly broad range of applications, as the following discussion shows.

No Steam Needed

At BEPC, for example, each of Rebenitsch's four plants with single-digit megawatt output eliminates the need for steam conversion, thus avoiding attendant water-handling problems.

As a working fluid in lieu of water, several options are available, depending on local conditions and needs. At the BEPC's plants on the frigid northern plains, the choice was pentane. Aside from its desirable thermodynamic properties, pentane eliminates problems associated with boiler turbine plants, such as corrosion, burdensome water-conditioning, potential freezing, excessive pressures, and operator oversight. And in Rebenitsch's case, it means "no wells to dig or maintain, no blowdown, no makeup water, and no chemical pretreatment," he says.

Along with these advantages, the OEC can run, says one Connecticut-based proponent, on "simple waste heat, such as engine exhaust, of much lower temperature than is needed for boilers," notes Carl Nett, an independent consulting engineer who is assisting Ormat in finding and developing new niche applications, mainly in the northeastern US. Even very modest available temperatures of, say, 300°F can be harnessed and transformed into "clean electric power without additional fuel," he adds.

No fuel means, of course, no air emissions and typically minuscule operating costs-"on average about 0.3 to 0.4 cents per kilowatt-hour," he says.

More specifically, in order to operate, the OEC plant requires both a heating and a cooling-cycle source (water or, for the latter, air), with a temperature differential (delta-T) of about 125°F or more. With this minimal requirement, a range of sources is available—as noted, for example, the most obvious perhaps being engine exhaust heat and ambient cooling air. Other good candidates might include heat from industrial processes like cement or lime plants—or even natural hot springs.

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A geothermal version of the OEC taps warm spots in the earth: Worldwide, to date, the installed base of these systems alone comes to about 900 MW, with 350 MW installed in the US.

Rather amazingly, modest heat in sufficient quantity from any of these or other sources can be directly transformed to electricity.

Ormat Vice President Dan Schochet, based at the company's corporate headquarters in Reno, NV, explains that when the OEC unit receives liquid heat flow from any source, "it doesn't know the difference between geothermal and something that's been heated by gaseous waste heat," and so, whatever the input, "it just generates electricity."

Due to a design that minimizes "wear and tear" (for example, turbine speeds of only 1,800 rpm or so), a closed loop, and few moving parts, maintenance costs per kilowatt-hour are only a fraction of comparably powered fueled generators; and the equipment's proven lifespan without major overhauls, notes Schochet, can exceed 20 years.

How it Works, What it Costs, How it Pays

When the OEC is tapping a higher temperature source of, say, gaseous waste heat in a recovered energy generation (REG) application, its remarkable feat begins by first using this heat to warm thermal oil to temperatures ranging (depending on the application) from 400°F to 550°F.

In designs based on lower-temperature, liquid waste heat, this first step can be bypassed.

Next, the hot fluid is pumped through piping to the OEC, where it transfers its heat to an organic working fluid, such as pentane, causing rapid evaporation.

As the pentane flashes to its inherently dry vapor phase, its pressure surges rapidly, driving a turbine.

In this closed loop, the spent vapor is then gathered and condensed back to liquid form, usually by air cooling, in a way that often further contributes heat energy to be captured and added to the turbine output.

Once in liquid phase, the working fluid cycles back to the heat-exchangers, and the process continuously repeats.

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What determines the eventual power output are two things: first, the amount of available heat and its temperature (not surprisingly); and, second, the condenser cooling temperature. As Nett explains, “In an organic Rankine-cycle, the higher the temperature differential and the lower the condensing temperature, the more efficient the cycle gets.”

He illustrates by describing a very early (if uncharacteristically exotic) OEC project built in El Paso, TX, where the delta-T was provided by a salt-gradient solar pond. Nett recounts of this plant, built over two decades ago: “Solar rays heated salt water at the bottom of the pond to 160°F to 200°F—sufficient to flash the motive fluid even at 160°F.”

Then, matched against this was “much cooler, nearly salt-free water at the pond’s surface, with near-ambient air temperature,” he says.

The resulting delta-T averaged around 100°F—“allowing the OEC to successfully generate power,” he notes. “The pond stored energy from day through night and even into colder cloudy periods,” and the system ran for 15 years.

This example also illustrates that, designwise, OECs are customized and site-specific in matching available heat and cooling sources.

Installed costs will thus vary widely, depending on size, of course, and on the available delta-T. Typically, prices will range from $2,000 to $4,000 per kilowatt—much pricier than a reciprocating engine. But Nett stresses that the fuel costs are zero and the maintenance costs minuscule.

Resulting electricity cost per kilowatt-hour “drops to well below that of other generation technologies,” enabling the investment to be recouped, he says.

Cost recovery will, of course, depend on what you would have paid, comparatively, for grid power. One rough rule of thumb here: When your local per-kilowatt-hour generating rates exceed 5 cents or so (considering, of course, that the associated delivery tariffs will typically double this), “the OEC payback” should arrive “within something on the order of three years or so,” suggests energy project developer Kip Waddell, who assisted Rebenitsch and BEPC in the implementation.

As for financing, Nett reports an encouraging trend toward qualifying heat-recovery systems under renewable energy portfolio standards. So far, authorities in Pennsylvania, Ohio, Nevada, South Dakota, North Dakota, New Mexico, and Hawaii have reportedly learned about heat-recovery systems and are taking them into consideration in defining existing and future RPS criteria.

And in mid-2007, the state of Connecticut ruled that Ormat’s OEC specifically does qualify as a Connecticut Class 1 renewable energy source. This, says

Nett, now "paves the way for OEC projects to receive renewable energy credits," trading in late 2007 in the $52-per-megawatt-hour range. Nett is optimistic that five other New England Power Pool states will follow suit as OECs become better known.

Heat-to-Power Along the Alliance Pipeline

Another recent adopter, NRGreen Power in Calgary, AB, is also finding that nearby states "have given [it] the same status that solar, geothermal, and wind power have under renewable energy portfolio standards," notes Jim Goldmann, vice president of transportation services and business development.

NRGreen is installing four 5-MW OEC plants in Saskatchewan to capture heat from compressors pushing gas along the 2,331-mile Alliance Pipeline from British Columbia into Chicago. One OEC was commissioned in December 2006 in Kerrobert, SK; three others in that province will be running in 2007-2008. Once the ties to SaskPower utility are attached, each plant will be capable of yielding 5 MW for NRGreen Power to sell to the provincial grid "on a long-term contract at a scheduled price for up to 20 years," notes Goldmann.

Why the concept of heat recovery and this plant seemed so desirable to NRGreen can be explained for a half-dozen good reasons, which Goldmann enumerates. First, modular construction design allows delivery from abroad "largely complete to the site," he says. Second, reliability has already been proved at numerous sites worldwide. Third, fully automated and nearly unattended operation provides each "robust little plant" with the built-in ability "to synchronize with the grid and even do load-following," he notes. Fourth, environmental friendliness promises to earn green credit vouchers or other incentives and rewards. Fifth, at 5-MW output each, "they will fit into most distribution systems" and typically won't tie up heavy-gauge transmission capacity.

Finally, the pipeline's turbines are running an exceptionally high 99.4% theoretical availability rate, "which is excellent for using their continuous-flow baseload type waste heat," Goldmann notes. This steady rate and quantity "fortifies the grid and provides [much needed] baseload rather than more peaking power."

SaskPower was thus more than happy to contribute materially to making the project go and has also made the usually difficult interconnection challenge a breeze.

Unit number one, online for nearly a year now, is "working quite fine," Goldmann says. "Our compressor-station operators have learned the basics and are successfully managing the power plants without any more labor. We're quite happy."

More Power on the Northern Border Pipeline

South of Saskatchewan and likewise pushing gas southward is the 1,200-mile Northern Border Pipeline, from Montana to Iowa. Thirteen turbine compressor stations are spaced alongside, about 80 miles apart. Each 39,000-horsepower RB 211 turbine yields lots of heat, and they're running most of the time, reports BEPC's Rebenitsch, whose customer base overlaps much of the pipeline territory.

Heat streams out at 800–900°F, which is more than enough for variable heat-recovery conversion to about 5–8 MW, available at each site.

Having no use for the exhaust heat, the Northern Border Pipeline's owners (TC PipeLines LP and ONEOK Partners LP) were venting it to atmosphere. Northern Border didn't need the extra power that could be output either, but BEPC could use it to serve its 4,923 co-op utility members supplying about 2,500,000 customers.

Ormat thus offered to build, own, and operate multiple heat-recovery plants, then sell the power to BEPC on a guaranteed, long-term contract. Per-kilowatt-hour rates are somewhat tied to market fluctuations, says Rebenitsch, but also designed for stability and predictability "for a very long term ... and at a very competitive price ... comparable to the cheapest coal plants." The arrangement has "reduced our risk dramatically" compared with more volatile energy projects like wind power, he says.

Co-op members also are underwriting the cost of 15 miles of interconnection lines. Transformers step the power up to 69 kV for integration into the grid and transmissions system. A four-quadrant meter measures power flow in all directions; and thus, "all of the power will be sold," day or night, he says.

Northern Border's role in the deal is simply to cash the royalty check paying for the engines' exhaust.

In 2006, four OEC plants went into service, each rated at 5.5 MW. Each also yields zero emissions, has no significant environmental impact, and requires minimal maintenance and no additional operator.

Rebenitsch sums up the heat-recovery system admiringly: "This is a very clean design," he says. "Simple and elegant. I'm very pleased with the technology."

For its year of service to date, "It's running very reliably."

As for its future, he sees "tremendous potential." BEPC is looking for new heat-recovery partners anywhere in the region—that is, any facility out there with heat of around 300°F-plus, in quantity.

Processing Gas With Energy Surety

A final profile describes Ormat's first industrial application of heat recovery in the US, commissioned by the Neptune natural-gas processing plant in Centerville, LA, in 2004.

During the first four years of its operation, the plant yielded 2.3-MW of electricity day and night rather effortlessly, "ninety-nine percent of the time," says plant manager David Rogers

Prior to its installation, unscheduled shutdowns at the plant—caused by outages of purchased power—had prevented Neptune from operating at steady peak levels. The site faced "a critical need for reliability," Rogers recalls. Solving this was one of several decisive factors spurring the owners' (Enterprise Products Partners LP) interest in self-generated power; others included the prospect of profiting materially from "exporting power to the grid in certain operating modes," Rogers adds, as well as the ability to use the wasted heat energy productively.

Exhaust from two Solar Mars turbines translates into a total heat rate and electricity output of 4.5 MW for the package.

Says Rogers: "Instead of diverting waste heat to the atmosphere, we capture and convert it—through a heat-medium oil, which is then used to heat a pentane solution," and which, as was noted, "is vaporized to drive the generator package that produces the electricity."

The OEC's modular hardware arrived on skidded sections ready for quick onsite assembly. Positioning of elements was set at a point located about 100 feet and 250 feet, respectively, from the exhaust ports of the two Mars engines.

At each spot, heat-exchangers warm the Therminol 59 oil medium to approximately 500°F; piping delivers it to the OEC unit, where this extremely hot oil vaporizes the pentane, driving generators.

As previously described, the pentane is then cooled, condensed, and pumped back to the vaporizer in a continuous closed-loop recycling.

Installation and commissioning issues were minimal, says Rogers, consisting of a just a couple of modifications: A tandem seal was added to the pentane condensate pumps; venting was redirected to the plant's flare header rather than to atmosphere; and variable frequency drives were installed on feed-pump motors.

So, all in all, the OEC worked reliably right out of the box, says Rogers: "It was very good, and the modifications we implemented made it even better."

Monitoring and control are done via two remote computer stations located onsite. Start and stop sequences are initiated by the operator from one of the two remote computer stations. "Other than surveillance and monitoring of the process, there's very little operator intervention," he notes.

Preventative maintenance consists of oil changes, greasing of equipment, cleaning of condenser coils, and replacement of generator air filters.

No exceptional safety or noise abatement issues are posed where the unit is located; and the learning curve was minimal.

In sum: "It is a great application for our needs, and working with Ormat to get to this point has been a good experience," says Rogers. "The relationship between Enterprise and Ormat has been mutually beneficial and continues to get better as Ormat continues to support us, and we support them by showing the OEC frequently to interested parties looking for solutions to challenges similar to ours."

As for operational benefits, the plant's designers sized the OEC package to supply only the 480-V loads on the plant's two processing trains. This leaves two 2,400-V, 1,500-horsepower motors needing to utilize power from the local purchase power grid. When the motors switch on, the plant shifts to power-import mode.

Thanks to the combination of turbines and heat-recovery self-generation in tandem, the Neptune plant now enjoys, says Rogers, "the ability to disconnect and go on island mode, so we can still process gas, whether the purchase power grid is up or down. All of our 480-V users stay online, and we can ride through purchase power outages." Afterwards, he adds, "whenever power returns, we can re-sync back to the purchase power grid, either to import or export electricity, depending on what operating mode we're in."

Neptune recently won a major gas processing customer—British Petroleum—who were decisively swayed by the plant's exceptional power surety.

In 2005, with Neptune's own energy supply well-assured, its business problems shifted, ironically, to coping with the impact on regional infrastructure ensuing from hurricanes Rita and Katrina. The gas pipeline business declined badly; currently, volumes are only about half of what they once were. Thus, the full 4.5-MW output isn't being used, Rogers notes. Actual gross average generation has been running at approximately 2.3 MW, two-thirds of which is being utilized by the plant. Fortunately, though, the local public power provider, Central Louisiana Electric Co. (CLECO), is required to purchase the remaining 700–800 kW. Rogers comments: "We are not in the power-generating business, but selling power back to CLECO is a nice benefit in that we can actually see income from that."

Neptune's OEC cost $8.6 million, and payback was originally projected in just three years. However, the business setback of two big storms has extended that time frame to six years, based on actual numbers, says Rogers.

Meanwhile, the Gulf region continues its recovery; Neptune foresees offshore gas production ramping up steadily through mid-2008.

Where There's Heat, There's Potential Power

These cases all happen to involve the natural-gas industry, but that should not be construed to suggest that combustion-generated heat is the only viable source for good heat-recovery—or is even the preferred one. On the contrary, as the following examples indicate, the company's project portfolio spans a range of applications and heat-and-cooling delta-T options. A few cases include the following:

- In Austria and Thailand, hot springs are driving OECs to meet the electrical needs of vacation resort spas.
- In Kenya, a flower grower receives 3–4 MW from an onsite geothermal OEC.
- In Martinsburg, WV, Ormat recently signed a $5.7 million agreement for an OEC at a cement plant where hot air from a clinker cooler would otherwise be vented to atmosphere; now an OEC at the back end will put it to work.
- The State of Connecticut is underwriting future clean-power projects to the tune of 150 MW; an as yet undetermined but significant percentage of this will consist of multiple 2.4-MW, high-temperature, molten-carbonate fuel cells. Nett points out that several of these projects have proposed coupling to OEC plants to convert fuel cell exhaust heat to electricity. He comments: "The OEC is a great fit with megawatt-class, high-temperature fuel cells… to cost-effectively convert the [about 700° F] fuel cell waste heat." Doing this "will raise the project's overall electric generating efficiency to well over 50%, and improve the project economic considerably."
- Another innovative application in progress involves super-cooled liquid natural gas (LNG) at –200°F. Often stored at seaport terminals, LNG sits in tanks adjacent to seawater at 45°F and up. With that temperature as the heat input, and with the LNG for condenser cooling, the resulting delta-T of around 250°F, says Nett, is "extremely attractive for OEC implementation." Construction of the first such plant has been contracted with Enagas, SA, of Spain, according to an Ormat press release.

To date, heat recovery projects worldwide total about 50 MW—and demand is growing. Nett sums up: "Rising costs for fuel and power, combined with society's increasing insistence on green solutions, all bode very well for Ormat's future."

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