Recycling waste pressure into electricity

Combined heat and power options in most modern steam plants are an opportunity waiting to happen. Energy conservation at our nation's colleges, mills, and hospitals goes way beyond changing light bulbs and thermostat setpoints. This exclusive report by the CEO of a member of the U.S. Combined Heat & Power Association—one of POWER's business partners—explains why.

By Sean Casten, Turbosteam Corp.

On the island of Anegada in the British Virgin Islands, there is a lovely spot called "cow wreck beach," named for the cow bones that occasionally wash up on the shore. They are the result of an historical and economic anomaly. At the height of their colonial powers, the British used the island to raise cattle not for their meat, but for their bones, which were turned into buttons and bone meal. Thanks to the actions of hurricanes and the presence of a reef offshore, hundreds of years later you can still trip over the odd cow skull as you walk along the coast.

To modern minds, the history of the beach seems to predate classical economic theory, which would never suggest throwing away the most valuable part of the cow and keeping its bones. The obvious analogy can be made with today's steam plants, where modern-day bone farmers are throwing away valuable electric power whenever they generate heat.

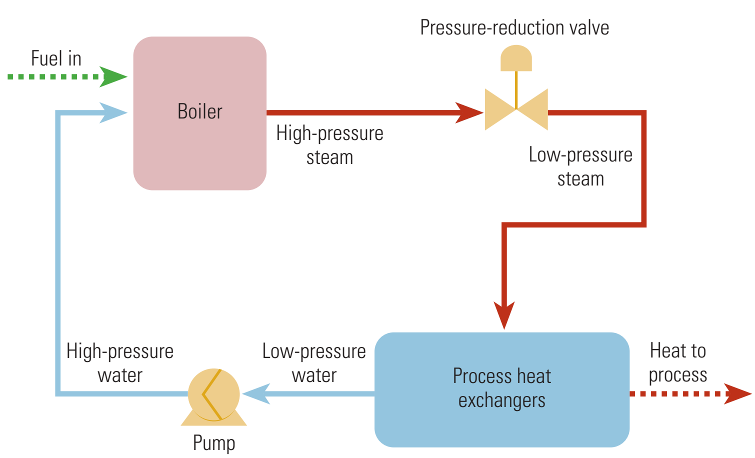
Cover your losses

In virtually all modern steam plants, steam is generated, distributed, and condensed as its heat is sent to local thermal loads. To keep distribution pipes small, the steam is produced at a pressure well in excess of that at which it is used, and a series of pressure-reduction valves (PRVs) throttle this pressure back at one or more spots in the thermal network. But it took fuel energy to raise the pressure of the steam, and that energy is effectively wasted at the PRV.

The simplified schematic of the typical industrial/institutional steam plant shown in Figure 1 hints at the lost opportunity implicit in its design. To those of us in the power industry, these thermal processes look like Rankine power plants, but for the lack of a power island. Water is evaporated, high-pressure steam is reduced, and the heat from low-pressure steam is rejected to a process or radiator that is the thermodynamic equivalent of a cooling tower. Ironically, these designs are often justified for economic reasons: namely, a desire to reduce plant costs. By reducing the specific volume of the steam, these plants save money on distribution pipe.

When considered solely as a steam plant, these design decisions seem to make good economic sense: slight increases in operating cost to over-pressurize steam are traded off against slight reductions in capital cost for smaller pipe. However, when seen for what they could be, these plants represent a long-term energy sink that drains the facility's fuel budget from day one of operation. A facility that makes 600 psig steam and then throttles it to 50 psig for process use is the economic equivalent of extracting 600 psig from a steam turbine, throttling the steam to 50 psig, and then reinjecting it into the turbine's final stages. The potential economic gains from recovering energy from antiquated design practices are significant.

1. Typical thermal plant design. In most steam plants, steam is over-pressurized in a boiler to save on distribution pipe costs and then throttled down to lower pressures prior to use. Throttling, though low in capital cost, is usually not economically attractive. *Source: Turbosteam Corp.*



Opportunities abound

However, like many black clouds, this one has a silver lining. Every steam plant with a PRV is essentially a 75%-complete Rankine power plant.

To illustrate, consider a project recently commissioned at a Kentucky wood products manufacturer. This 750-employee facility produces 45,000 lb/hr of steam at 235 psig in a wood-fired boiler and then reduces the pressure to 30 psig to provide thermal energy for six dry kilns. Prior to 2002 the factory throttled its steam through a PRV. In 2002, Turbosteam Corp. (Turner Falls, Mass.) installed a backpressure steam turbine-generator that recycles the energy that had been wasted in throttling the steam into 1 MW of power generation capacity. Since the backpressure unit was installed, for a capital cost of $500,000 ($500/kW), it has saved the manufacturer $120,000 per year in electricity costs. That this high return was achieved even at Kentucky's low electric rates suggests that energy recycling opportunities are waiting to be discovered.

In truth, most opportunities are more complex (and more interesting) than this simple PRV-replacement example would suggest. Consider:

- Most steam boilers operate at pressures considerably below their design pressure. In some cases, the savings from energy recycling are sufficient to justify increasing boiler pressure to create a pressure drop that did not previously exist.
- Most steam processes (especially those designed for heating applications) are substantially overdesigned to utilize steam pressures well in excess of that required on all but the coldest days. The operating pressure of these processes can often be reduced to create a further pressure drop—and hence a greater opportunity for energy recycling—that would not otherwise exist.
- The recent trend toward replacement of steam heating networks with hot water heating networks creates an opportunity to keep existing steam boilers, use a turbine to lower the steam pressure much more (and thereby extract more power per pound of steam), and then exhaust the resulting steam into a hot water heat exchanger.

In all cases, the new power plant can be piggybacked onto the existing utility infrastructure, thus realizing the maximum return on the minimum capital investment (Figure 2).

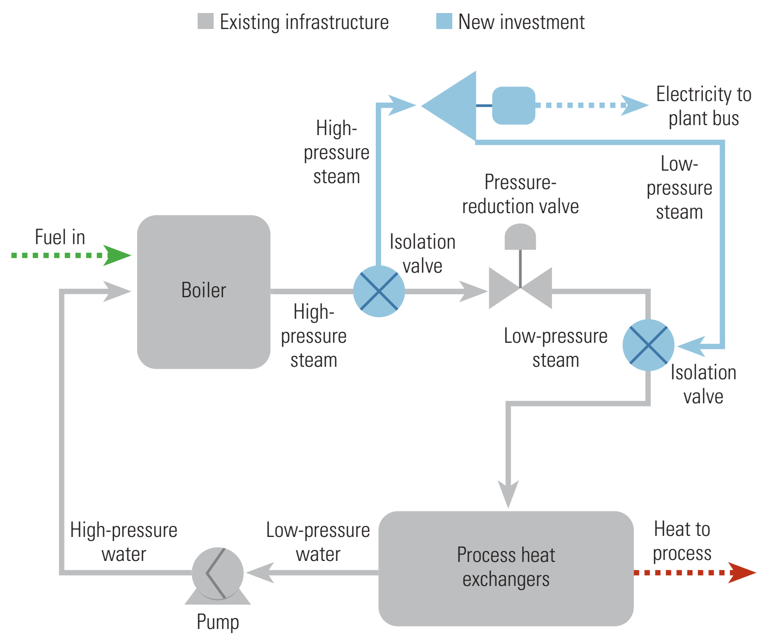
Variable results

The power output from a steam turbine-generator is a function of four variables: steam flow rate, inlet pressure, inlet temperature, and exhaust pressure. Raise any of the first three and the power output will increase. Raise the exhaust pressure and the power output will decrease. Although all designs ultimately involve a complex tradeoff among the variables and site-specific financial requirements, Figure 3 provides an estimate of the power output one can expect from a system designed for 300 psig saturated inlet steam over a range of steam flows and exhaust pressures.

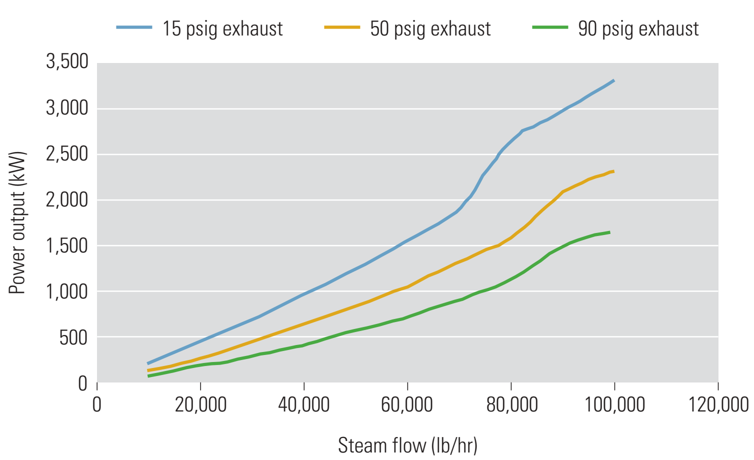
For additional data points, consider the following:

- At Colby College in Waterville, Maine, a turbine-generator designed to enhance power reliability after the 1998 ice storms produces 600 kW from a 30,000 lb/hr steam source by throttling it from 300 psig to 40 psig. The system, which was installed for approximately $360,000, has saved the college an average $186,000 annually since installation.
- At the Franciscan Sisters of Perpetual Adoration hospital/university/convent complex in La Crosse, Wis., two parallel steam turbine-generators reduce a combined 15,000 lb/hr of steam from 135 psig to 30 psig to produce 250 kW, and they resynchronize with existing engines during grid disruptions. The two units, which were installed for a total cost of about $450,000, have reduced the complex's annual energy bill by $55,000. The facility's PRV station and turbine-generators are pictured in Figures 4 and 5, respectively.

2. Conventional thermal plant with power recovery built in. By installing a backpressure steam turbine-generator in parallel with existing thermal plant piping and thermal reduction systems, the value of high-pressure steam can be recovered as electricity without compromising the ability to use low-pressure steam to serve downstream process and thermal loads. *Source: Turbosteam Corp.*



3. Power recovery potential from 300 psig saturated steam. The curves show the recoverable power from 300 psig inlet steam (a common industrial boiler working pressure) as a function of steam flow and exhaust pressure. Flows and exhaust pressures are both dependent on downstream thermal requirements, while inlet pressures depend on upstream boiler capacity. *Source: Turbosteam Corp.*



4. Typical pressure-reduction station. This pressure-reduction station at the Franciscan Sisters of Perpetual Adoration hospital/university/convent complex in La Crosse, Wis., reduces 15,000 lb/hr of steam from 135 psig to 30 psig for local heating loads. *Courtesy: Turbosteam Corp.*

5. Typical backpressure turbine-generator installation. These two systems installed at the La Crosse complex are rated at 100 kW and 150 kW and parallel the previously existing pressure-reduction station shown in Figure 4. *Courtesy: Turbosteam Corp.*

Design challenges

The core technologies described above all have decades of proven, in-field experience. With commercial operation dating back to 1886, backpressure turbine-generators have the lowest technical risk of any distributed generation technology. However, every steam turbine-generator that has ever been built was custom-engineered to local steam pressures, temperatures, and flows. Given this potential for near-infinite design variability, the challenge is thus not the technology but rather the design of the system and its integration into existing steam plants. Even small pressure drops (as little as 100 psi) can often be economically justified by the electric revenue they create.

The steam conditions commonly found in industrial and institutional thermal facilities correspond to power island installations with installed capital costs of $300 to $1,000/kW at sizes as small as a few hundred kW. ■