Cascade waste heat recovery for gas turbine power and efficiency

By Victor de Biasi

Dry bottoming cycle can add up to 50% more power to the shaft output of unmanned gas turbine compressor drive and genset installations without the complexity of a combined cycle HRSG, steam turbine or cooling tower.

Wow Energy, Inc. has introduced a new twist in the design and operation of organic Rankine bottoming cycles to increase the output and efficiency of simple cycle gas turbine plants – without any increase in fuel consumption or emissions.

Basically it extracts more energy by adding a second stage of closed cycle vapor turbine power recovery to operate over a broad spectrum of exhaust temperatures, from around 300°F to over 1000°F, and convert otherwise expended discharge heat into additional electrical power.

It makes power recovery cost effective for gas turbines ranging from 3 MW to over 40 MW unit rating, at both full and part-load operating conditions:

☐ **Range**. Good match for 830°F and 42 lb/sec exhaust of a 3.5 MW Centaur on up to 840°F and 270 lb/sec for 42 MW LM6000 PD.

☐ **Recovery**. Typically will contribute 30 to 45% more power to base load output at up to 50% combined cycle plant efficiency.

☐ **Turnkey Cost**. Unofficially estimated at $1700 to $2200/kW added depending on site specifics and interconnect requirements.

According to Wow Energy project engineers, its Cascading Closed Loop Cycle (CCLC) technology is particularly cost effective for converting exhaust heat of small gas turbines to electrical power at recovery temperatures below 1000°F – a range in which most competing technologies do not function efficiently.

Propane working fluid

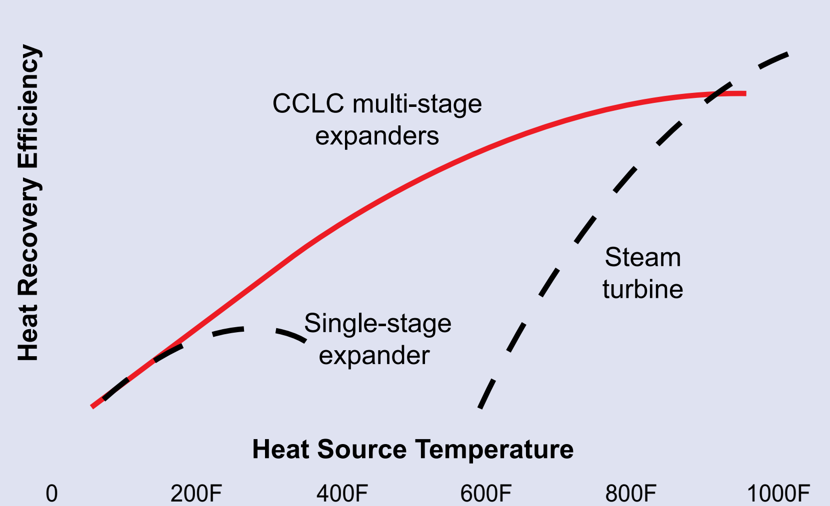
Different type working fluids can be used in an organic Rankine cycle; the patented WowGen system uses propane which vaporizes and condenses at low temperatures. Unlike most other fluid mediums, however, it can also be used at much higher temperatures.

The propane is cycled through a hermetically sealed closed loop system so it is never consumed; simply serves as the heat transfer medium to convert thermal energy into mechanical energy.

As described by Septimus van der Linden, Independent Consultant for Wow Energy, the CCLC system is a unique arrangement of off-the-shelf components designed around commercially available turbo-expanders, heat exchangers and pump, all available from numerous manufacturers.

These components have millions of hours of reliable and nearly maintenance-free service, primarily in refineries, petrochemical and geothermal plants. He stresses that the turbo-expanders in particular have been used for decades in hundreds

Power Recovery. Cascading closed loop cycle technology is more effective than conventional organic Rankine or steam turbine bottoming cycles from around 200 to 900°F heat recovery temperatures.



of applications to drive generators, pumps and compressors in the most demanding of applications.

Turbo-expanders in both radial inflow (centrifugal) and axial configurations are available in sizes ranging from a fraction of a horsepower up to 50,000 hp.

They are essential components in air separation plants; cryogenic processes; LNG plants; natural gas and propane pressure letdown applications; gas plants and pipeline compressor stations.

Multi-stage expanders

For gas turbine power recovery the CCLC system operates simply as a combined cycle turbo-expander system. It differs from a single turbo-expander cycle in that two expanders and two fluid streams are used in series.

This allows the thermal energy (heat) from the discharge of the first expander to be used to vaporize a second propane stream that is expanded in a second turbo-expander and thus increase overall cycle efficiency.

Industrial gas turbine installations are a large market considering the number of aero-derivative gas turbines on various compressor and pump drives sized from 4000 to 40,000 bhp or more.

At the high end are the 40/50MW-class LM 6000/Trent 60 machines that provide peaking service in the mid-range generation sector where 1500 to 2000 hours are the norm and power recovery can make a significant savings in fuel and emissions per MW-hr of generation.

Combined cycle performance

These high power gas turbines, with simple cycle efficiencies of over 40%, will now approach 53% combined cycle performance – while avoiding water usage – and up to 40% power recovery rate, depending upon ambient temperature.

Most of these units would not use water so that power recovery unit cooling (condensing) is air cooled. However, eliminating the water steam cycle reduces operating costs as well as maintenance; it also means that converted installations can be remotely controlled as unmanned facilities.

Considering the wide range of gas turbines operating on existing pipelines, the potential power recovery for oil & gas units alone is enormous, says van der Linden, especially for small gas turbines such as the Centaur and Taurus which can produce 1800 to 2100 kW respectively in the form of power recovery (see table).

Many old pipeline Avon units still in service are prime targets for power recovery – as are the bigger RB211, LM6000 and Trent 60 gensets operating 8 to 10 hours a day. In hot climates, gas turbine inlet cooling can also be provided by the CCLC system to provide 85 percent more power and 30 percent lower heat rates at 100°F ambient temperature.

To do this, high pressure vaporized propane in the CCLC is extracted from the condenser after partial cooling. The vapor is expanded across a turbo-expander, which drops its temperatures to minus 50°F or below, and is then blended to supply a mix of 45 to 50°F vapor for gas turbine inlet cooling.

The turbo-expander is connected to a compressor to re-compresses the propane vapor to its original pressure

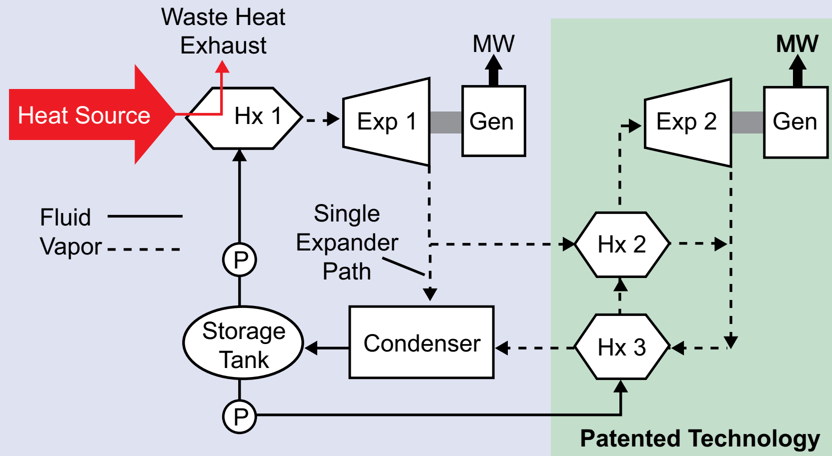
Cascading Closed Loop Cycle

The cascading closed loop cycle is different from a single-stage turbo expander cycle in that two expanders and two fluid streams are used in series.

This allows the heat from the discharge of the first expander to be used to vaporize a second propane stream that is expanded in a second expander to increase power output and overall cycle efficiency.

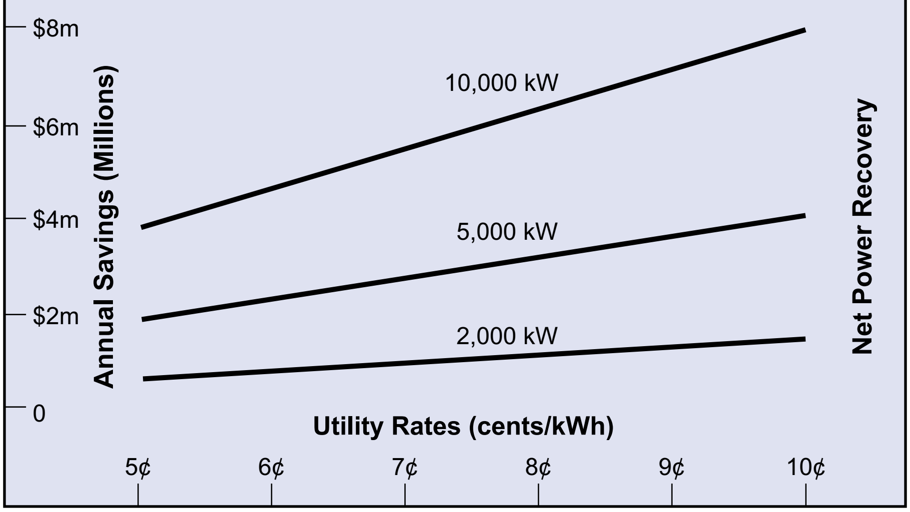
In a single stage design, the discharge from the expander (Exp 1) would go directly to the condenser (as shown by the small dotted arrow entering the condenser) rather than be directed to the Hx 2 heat exchanger.

CCLC Process Flow

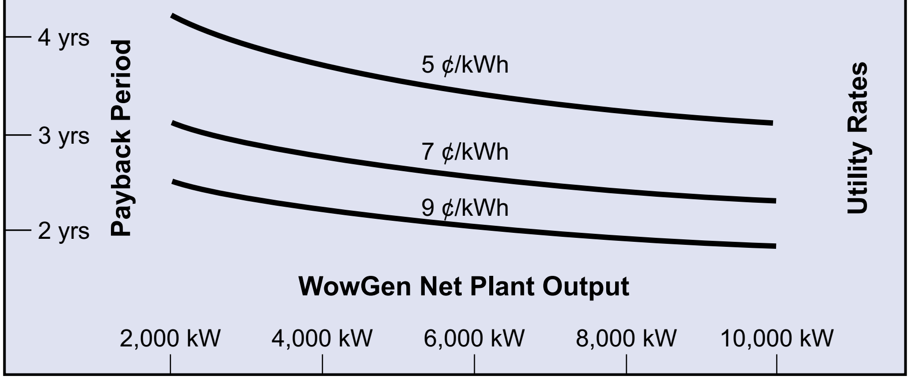


The closed-loop cycle involves five major steps: 1) the working fluid, in this case propane, is pressurized (P) by a pump; 2) vaporized in a heat exchanger (Hx 3) expanded across a turbine (Exp) connected to an electric generator; 4) the discharged vapor is condensed back to a liquid (using a cooling tower or fin-fan heat exchanger) and 5) the condensed liquid then returned to a storage tank from where it is pumped back to pressure to continuously repeat the cycle in a closed loop.

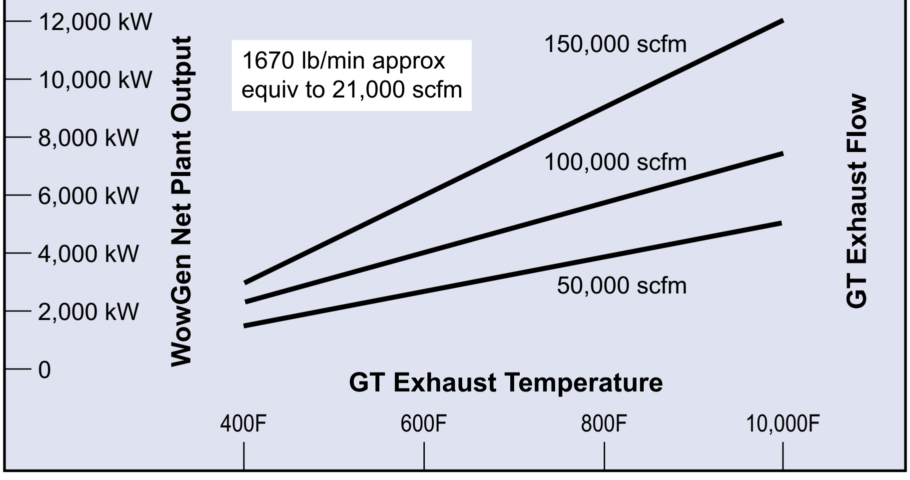
Net Power Savings. Conservative example of annual revenues as a function of utility electricity rates and net power recovery. Actual savings will vary depending on project investment and operating costs.



Simple Payback Period. Actual payback period will be determined by project costs versus revenues as a function of electricity rates (cents/kWh) and amount of net power recovery.



Net Power Recovery. Cascade closed loop cycle power recovery is a function of gas turbine exhaust mass flow (specific cubic feet per minute), exhaust gas temperature, and ambient temperature.



to complete the refrigeration loop.

This is more cost effective than current chilling systems, says van der Linden, and competitive with other inlet cooling systems.

Economics

Typically CCLC power recovery is most effective for small gas turbines and older machines which characteristically have a relatively higher design mass flow per kW and higher exhaust temperatures than new designs.

The cost (and profitability) of converting simple cycle installations to power recovery depend on the cost of fuel, electricity rates and duty cycle versus the turnkey cost of CCLC conversion.

There is also an environmental bonus in the ability to generate zero-emissions electric power for a net decrease in site emissions per kWh generated which may be a factor, he points out, in addition to the potential for CO_2 credits under proposed cap-and-trade legislation.

For example, the RB211 is rated at 39.3% simple cycle efficiency and 32.1 MW output at ISO base load conditions. With CCLC power recovery, plant output can be increased to 42.9 MW and 52.5% efficiency.

Similarly, the LM6000 ISO rated at 42.3 MW and 41.1% efficiency can be up-rated to 54.0 MW and 52.5% efficiency. From these examples it is clear that the emissions are drastically reduced per kW/hr – with zero water discharge.

Installed costs, which vary according to exhaust mass flow volume and temperature as well as site specifics, could range from $1700 to $2200/kW. Typically, simple paybacks can be less than 4.5 years on a recovery system of 5.0 MW with electricity rates of 4.5 cents/kWh.

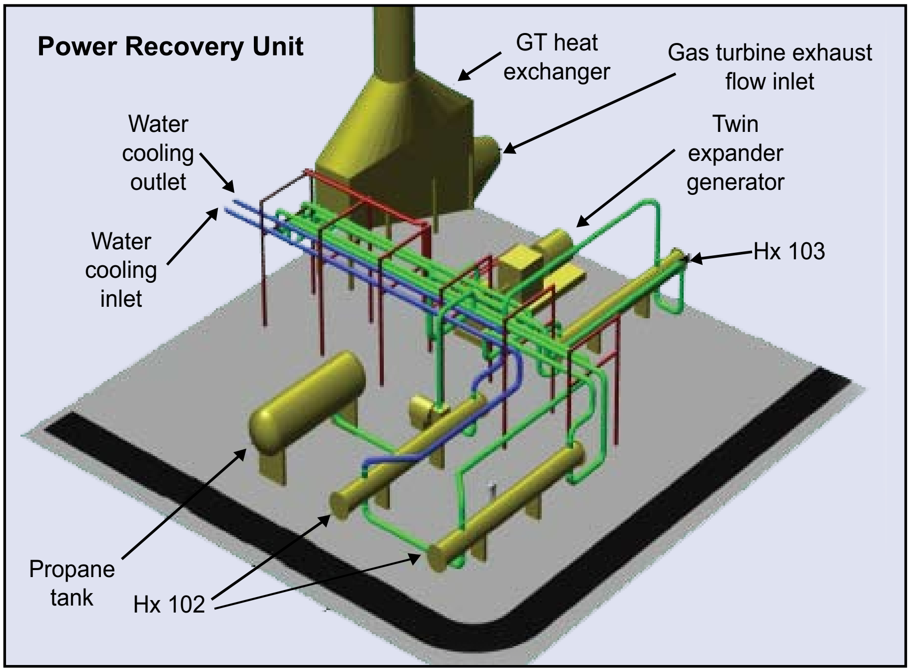
Plant layout

Site specifics will determine the power recovery plant configuration. Ideally, the exhaust heat recovery unit (HRU) should be located close to the exhaust stack where it is easily integrated with a bypass system and induced motorized fan.

The recovery unit and shell and tube heat exchangers can be located somewhat remotely, keeping in mind that an air cooled condensing plant or air/water cooled system requires a fair amount of space (see sketch).

Site work does not have to impact the normal operation of an installed gas turbine unit until the final duct connections are made, says van der Linden. Specialty companies in association with Wow Energy offer complete engineering, procurement and constructions services.

Their scope of supply can include negotiating power purchase agreements and marketing the sale of electricity generated to the grid or local industry. They can also provide online plant monitoring, service and maintenance. ■



Combined cycle performance without steam. Unmanned small gas turbine installations can achieve power recovery combined cycle efficiencies on a par with conventional steam turbine bottoming cycles to generate 30-40% more "green power" for site use or sale under long term power purchase agreements – without requiring water, operators or fuel.

Gas Turbine Model	ISO Base Rating	Open Cycle Efficiency	Exhaust Flow	Exhaust Temp	CCLC Net Power	Percent Recovery	Total Plant Output	GT Fuel Efficiency
Centaur 40	3515 kW	27.90%	42 lb/sec	830F	1850 kW	52.60%	5365 kW	42.60%
Centaur 50	4600 kW	29.30%	42 lb/sec	950F	2180 kW	47.40%	6780 kW	43.20%
Taurus 60	5670 kW	31.50%	48 lb/sec	950F	2560 kW	45.10%	8230 kW	45.70%
Taurus 65	6300 kW	32.90%	46 lb/sec	1020F	2840 kW	45.10%	9140 kW	47.70%
Taurus 70	7520 kW	33.80%	59 lb/sec	905F	3390 kW	45.10%	10,910 kW	49.00%
Mars 90	9450 kW	31.90%	88 lb/sec	870F	3920 kW	41.50%	13,370 kW	45.10%
Mars 100	10,690 kW	32.40%	92 lb/sec	910F	4650 kW	43.50%	15,150 kW	46.50%
Titan 130	15,000 kW	35.20%	110 lb/sec	925F	5640 kW	37.60%	20,640 kW	48.40%
LM2500PE	23,290 kW	36.60%	153 lb/sec	990F	8400 kW	36.10%	31,600 kW	49.80%
PGT25+	30,220 kW	39.60%	186 lb/sec	950F	9200 kW	30.40%	39,420 kW	51.60%
PGT25+G4	32,760 kW	39.70%	196 lb/sec	950F	9900 kW	30.20%	42,660 kW	51.70%
RB211-GT61	32,100 kW	39.30%	208 lb/sec	940F	10,800 kW	33.60%	42,900 kW	52.50%
LM6000 PD	42,335 kW	41.10%	278 lb/sec	840F	11,700 kW	27.64%	54,035 kW	52.45%

Note: All ratings have been rounded off to simplify their tabulation.