

Heat equals power

Several new developments in technologies for iron and steelworks to generate electricity from waste process heat and off-gases emerged during the last quarter of 2011. Richard Barrett summarises the latest advances

Steel producers have long exploited the value of waste process heat and off-gases generated by their plant, but the rising costs of energy and tightening environmental legislation applied to energy-intensive industries has encouraged steelmakers to redouble their efforts to harness these resources.

The overall economics of recovering and using the waste heat and combustible gases that arise from iron and steel production processes – such as coke ovens, blast, oxygen and electric-arc furnaces, or reheat and heat-treatment furnaces – are specific to the size, type and operating characteristics of a particular works, its physical location and local energy prices, and the capital and operating costs of technologies installed to harness them.

Temperature is an obvious parameter. Off-gas and heat availability, essentially continuous or only intermittent, is another. Waste heat and off-gases from one process are often channelled to where they are needed for another elsewhere on site. Steam is often generated to use for on-site processes, or sometimes utilised for local district heating systems off-site.

It is not uncommon for waste heat or combustible gases to be generated with a quality, in a quantity or at a temperature that does not match other process needs on site, or in geographical locations that do not offer convenient direct local uses off-site. Their use to generate electricity is a valuable option.

This Focus section describes three separate technologies. The first uses low-temperature waste heat to generate electricity. The second uses spare process off-gases to generate power. The third generates useful steam from EAF off-gas heat.

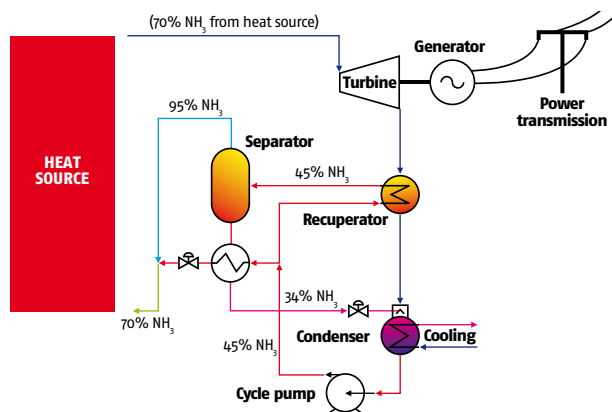
Kalina Cycle feasibility project for ArcelorMittal

International power and technology business Wasabi Energy signed a term sheet with ArcelorMittal South Africa in November to build, wholly own and operate two Kalina Cycle® power plants – with a combined capacity of 30 MW – at the Vanderbijlpark steel plant.

Under those terms, ArcelorMittal will provide the waste heat needed to run the power plants from reheat furnaces running at its hot strip mill for free. The steelmaker would then buy the electricity generated – at a rate discounted to the tariff for electricity bought in from the nation's grid – under a long-term power purchase agreement.

A full feasibility project is now

GENERALISED SCHEMATIC OF THE KALINA CYCLE®*



*At Vanderbijlpark, the electricity produced by the generator will be exported back to the hot strip mill, which consumes up to 50 MW of power during periods of peak production

HOW KALINA WORKS AT KASHIMA

Commissioned in 1999, the Kashima Cycle power plant at Sumitomo's Kashima steelworks in Japan generates electricity from heat recovered from cooling water discharged at 98°C – and a flow rate of 1,300 tph – by the converter gas duct of the gas recovery unit of the works' oxygen steel plant No. 2.

An evaporator uses that heat to generate a wet ammonia-water vapour, which is then divided by a mist separator into high-concentration ammonia vapour and low-concentration ammonia-water.

The ammonia vapour is used at

high pressure (3.16 MPa, 95°C) to drive a turbine to generate electricity. It leaves the turbine at just under a quarter of the pressure to then enter a condenser.

Via a heat exchanger, energy from the low-concentration ammonia-water mixture leaving the mist separator is used to preheat condensed ammonia-water liquid pumped from the condenser back to the evaporator for the next cycle. The low-concentration ammonia mixture enters the sea-water cooled condenser to absorb the high-concentration ammonia leaving the turbine.

under way and is expected to be complete by mid-2012. Engineering, procurement and construction (EPC) support will be provided by South Africa's Group Five and the USA's Power Engineers.

Construction is planned in two stages. First, a 6 MW plant would be built to recover waste heat from the works' one walking beam reheat furnace. It is expected to start up in the second half of 2013. A 24 MW plant would follow in 2014, which would use waste heat arising from the three pusher reheat furnaces at the mill. The steelmaker will also have the option to acquire the power plants on terms to be agreed.

By tailoring a working-fluid mixture of ammonia and water to a waste heat source, the Kalina Cycle can be used to generate electricity from waste heat at much lower temperatures (100–250°C) than most other technologies and, according to Wasabi, more efficiently than other low-temperature systems using organic fluids. Varying the ratio of ammonia to water adjusts the boiling point of the mixture, which is lower than water alone.

Because the increase in temperature of the cooling water for an ammonia-water mixture (see generalised component schematic) can be higher than for condensing steam, the flow rate of the cooling water can be less than is needed for steam. Wasabi notes that this has benefits in requiring smaller cooling towers, pumps, piping and auxiliary power requirements, which lower both capital and operating costs. The company also says that plant availability of over 95% is typical for plants in current operation.

Originally developed in the 1980s, the earliest commercial application for the Kalina Cycle technology was for a 3.5 MW plant built for Sumitomo's Kashima stainless steel works in Japan (see panel). Still in operation after 12 years, the power plant there generates around 29,000 MWh of electricity each year, and is said to have saved 17,000 tonnes a year of carbon dioxide production, or the equivalent of 41,500 barrels (6.6 million litres) of crude oil consumption a year. Estimates for the effects of the use of Kalina Cycle technology planned at the Vanderbijlpark plant suggest that

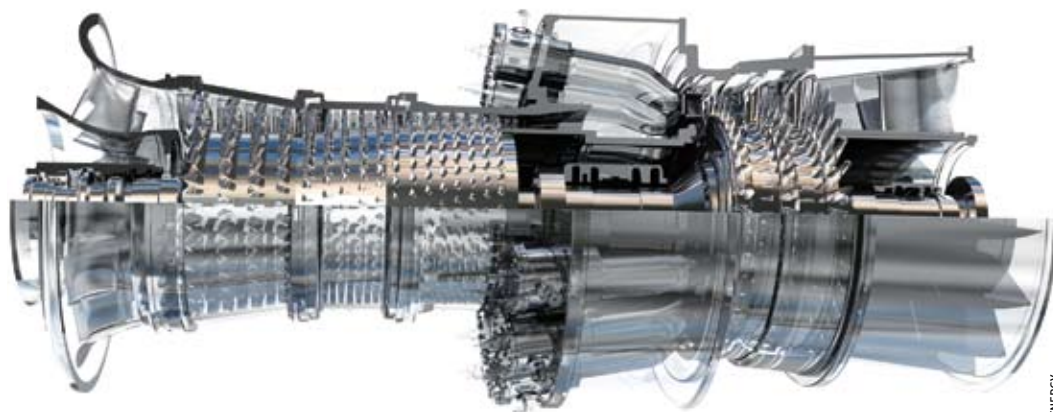
carbon dioxide emissions there could be reduced by 258,000 tpy.

Proprietary rights to Kalina Cycle technology, know-how, engineering- and delivery-capability are owned by Recurrent Engineering, a private US company wholly owned by UK private company Global Geothermal Ltd, which is itself a wholly owned subsidiary of Wasabi Energy.

In addition to converting industrial waste heat into electricity, the system can harness geothermal energy. Two geothermal plants were built in 2011: a 50 kW unit in Japan and a 2 MW unit in Iceland. For another heavy industry, an 8.6 MW plant is under construction to use waste heat generated by a cement plant in Pakistan. As of now, 11 MW of power is generated by the technology and further capacity of 10 MW is currently under construction.

Using purely illustrative estimates for a generic Kalina Cycle plant, Wasabi calculates that the return on capital for a 10 MW power plant with a capital cost of US\$15–20 million could be 39%, based on the generation of 78.8 million kWh a year, a nominal operating cost of 1 cent/kWh and a market price for electricity of 11 cents/kWh. The payback period for that example would be 2.5 years. Some projects may qualify for carbon credit financing.

Nico Bleijendaal, Wasabi's president international (and a former managing director of Hoogovens Technical Services (now Danieli Corus) in the Netherlands), says that the company does not want to be just an equipment supplier, but rather an independent power producer. "The sweet spot for our Kalina Cycle technology is the low-temperature area," he stresses, explaining that the use of an ammonia-water working fluid offers all the advantages of a flexible and controllable boiling point, while avoiding the greenhouse gas effect risks of other media used in heat exchange systems. The only limitation in using ammonia is the need to avoid using copper, or



GE ENERGY

GE 9E gas turbine technology can be used to burn off-gases with low calorific values

copper alloys, in power plant components with which ammonia makes contact, he explains.

Wasabi Energy estimates that the potential market size for installations of Kalina Cycle technology for iron and steel is over 10,000 MW. The plants planned for ArcelorMittal South Africa fit with the steelmaker's target to reduce energy consumption by 12% by 2014 and ArcelorMittal's global target to reduce carbon dioxide emissions by 8% by 2020. Plans declared by Eskom – South Africa's dominant national electricity producer – to continue making sharp increases in tariffs for large power consumers adds weight to the economic argument for building Wasabi Energy's power plants at Vanderbijlpark.

GE gas turbines for off-gas power generation

GE Energy announced in November that it will supply equipment for a 170 MW gas turbine power plant for China's Handan Iron & Steel – a 10 million tpy integrated steelmaker producing plate, as well as hot-rolled, cold-rolled, and coated strip. The electricity generated will be used on site to offset expensive grid power. Handan is investing in the project to help lower its energy costs and to comply with China's twelfth five-year plan emission reduction goals for 2015. Work on the plant is scheduled to begin this year.

Burning gases emitted by blast furnaces and coke ovens in a higher-efficiency gas turbine combined cycle to generate electricity is an established alternative to burning them in a traditional boiler system. For the same amount of fuel, a GE 9E gas turbine plant can increase the electrical output by more than 40% by comparison with a traditional boiler, the company notes. The technology has wide fuel and steam-production flexibilities for steel mill operations in addition to responsiveness to changes in fuel and power demands, says GE.

The gas turbine power train to be used at Handan includes a GE 9A5 generator with modifications to drive a large centrifugal gas compressor, also made by the company. A GE Mark™ V1e controller provides fully automated control and protection of the equipment, including fuel blending, compression, and cleaning. For other steel plants, similar GE 9E technology is already being used to generate power from the export gases of Corex plants and can similarly be applied to Finex and other off-gases.

The turbine at Handan will use a fuel blend predominantly consisting of blast furnace gas with some coke oven gas. This capability to use low calorific value fuel results from a continuing evolution of combustion technology. Fuel conditioning is an integral part of the product and GE will supply

electrostatic precipitators for cleaning, in addition to the manufacture and supply of the two-stage centrifugal fuel gas compressors to boost the fuel's pressure before entering the gas turbine. Large centrifugal compressors were selected due to their robustness and low maintenance requirements when dealing with the low quality of steelmaking off-gases.

"This is the lowest quality fuel we've ever even considered burning, but we saw the potential to redesign the energy landscape in the steel industry," said Keiran Coulton, president, Global Industries, GE Energy, when the order was announced. "Our engineers determined a way to compress the gas, make it more burnable, and add it to the fuel options for what is otherwise a conventional power plant."

Versatile applications

The power a gas turbine combined cycle plant can produce from the process gas emanating from coke-, iron- or steelmaking processes is closely linked to the size of the plant's output. As a rough rule of thumb, a 3 million tpy integrated steelworks produces enough process gas to support operational needs and have enough gas left over to produce 170 MW in combined cycle, explains Ryan Derouin, global account executive at GE Energy. A 5 million tpy steelworks might produce enough extra gas to fuel a 210 MW combined cycle power plant.

Looking at the predominance of integrated steelworks in China, Derouin states that there are many more plants with the potential to generate power using technology similar to that planned for installation at Handan. Handan's plant is essentially a copy of the power plant installed by GE and already in operation at Wuhan Iron & Steel (Wisco), where two 170 MW combined cycle trains are installed.

Steelworks with multiple blast furnaces and coke oven batteries usually generate sufficient gas to keep the gas turbines running even if some of them are off-line. In the event that major maintenance work, for example, substantially reduces supply, richer alternatives, such as natural gas, can be used to continue power generation.

When a plant is interested in reducing a small flare or finding a new purpose for process gas – blast furnace gas, coke oven gas or oxygen furnace gas – a separate system exclusively burning smaller amounts of gas, such as the GE Jenbacher JS620, can be deployed. These systems fit a different profile of plant needs. They operate atmospherically, so no gas compressor is needed for that technology, and a number of them are currently installed in European plants.

At the top end of the power range, some steelmakers have become major electricity producers in their own right, burning natural gas as well as process off-gas to produce power for their own needs and to sell electricity off-site. For example, Ilva in Italy has operated three similar GE 9Es for more than 15 years, producing a total of 520 MW.

Fuel future

GE says that by using its proven multi-nozzle quiet combustor (MNQC) and minor modifications to the overall gas turbine, it can maximise fuel flexibility and performance while retaining the established reliability of the 9E turbine for industrial power generation.

Other innovations are being studied to utilise the gas turbine's flexibility to integrate more closely with the various process flows, such as steam, air and water, into the

ironmaking process to improve overall plant efficiency.

GE's efforts to exploit low-quality off-gases further still continue: "Blast furnace gas is the benchmark – it typically varies in quality by ironmaker from 750 to 900 kcal. We are striving and successfully pushing our technologies into lower limits," says Derouin.

Tenova recovers EAF off-gas heat

Heat recovery is a big source of energy optimisation for an EAF. Around 30% of the energy input to an EAF – electrical, and chemical from natural gas, oil and carbon – is lost through off-gases.

Tenova estimates that the potential power that can be recovered from a 150 tph EAF running with modern operational practice is up to 29 MW. The company's iRecovery technology is a method for converting this energy into steam, but the specific process and equipment configuration used throughout an EAF-based steelworks determine the best ways in which that steam can be used.

Tenova's system recovers energy from the EAF waste gas duct by using a similar tube-tube heat exchanger construction and working principle to a conventional heat recovery system using cold (20–40°C) cooling water. It differs in running at a higher pressure and in using hot (180–250°C) water as the heat transfer medium flowing towards the off-gas duct. This decouples the off-gas energy through evaporation.

Stage 1 of the recovery system uses radiant heat transfer, which is efficient to temperatures as low as around 600°C, but stage 2 (see diagram) uses a waste heat boiler, which is used to recover energy at lower temperatures down to the hot water inlet temperature. The high dust load carried by EAF waste gas requires a special waste heat boiler design like that used at waste incinerators.

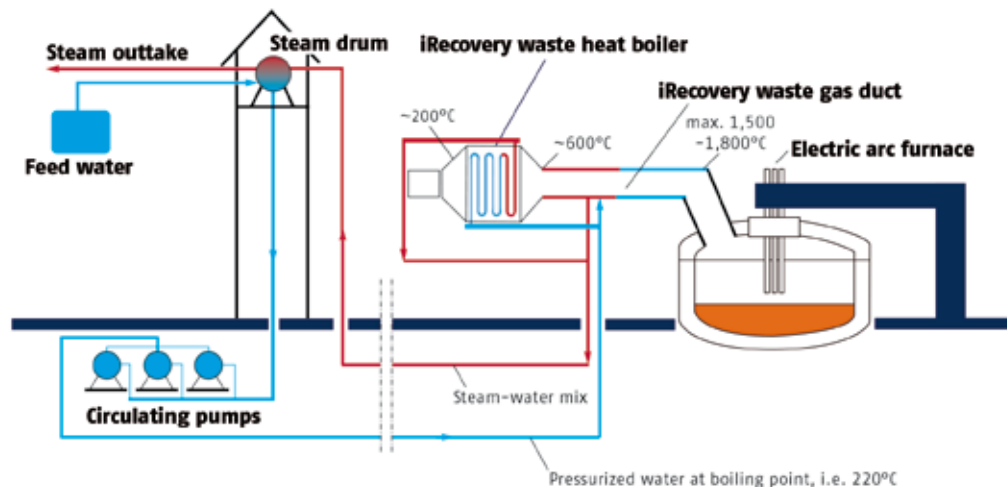
Two important parameters that determine the efficiency of the heat recovery system are: temperature of the waste gas at the iRecovery system outlet; and the control of the input temperature and volume of dilution air that is

mixed with the off-gas before it enters the iRecovery system. Together with the operating scheme of the EAF itself, these factors have a significant impact on the level of energy that can be recovered (see table).

From a theoretical economic viewpoint, Tenova's engineers point out that power generation is not the best choice for using the steam which iRecovery produces – vacuum degassing, pickling, compressors, air conditioning, heating and oxygen production are among some of the other potential uses – but also that when, as in many circumstances, it is the only feasible application, making the right choice of turbine technology then becomes another important decision.

When superheated steam can be continuously generated, a steam turbine offers the best efficiency, but in mills raising steam discontinuously the Organic Rankine Cycle (ORC) turbine is said to be a better choice. The latter can be fed with saturated steam, or even hot water, and automatically stopped or started.

SIMPLIFIED SCHEMATIC OF AN IRECOVERY STAGE 2 SYSTEM



ENERGY RECOVERY POTENTIAL*

Operation scheme	Off-gas energy at fourth hole	Usable without DAC** (600°C)***	Usable without DAC (475°C)	Usable with DAC (430°C)	Usable with DAC (315°C)
Top charged, low chemical energy	25.5	8.9	14.0	19.1	20.7
Top charged, high chemical energy	36.0	12.6	19.8	27.0	29.2
Consteel	19.5	6.8	10.7	14.6	15.8
Top charged, 85% DRI, 15% scrap	39.0	13.7	21.5	29.3	31.6

*For a 150 tonne tapping weight EAF in MWh per melt. **Dilution air control. ***Off-gas temperature.

Source: Tenova