

# ***Waste Heat/Cogen Opportunities in the Cement Industry***

*Paul Cunningham, P.E., President  
Hozea Chambers  
The Altus Group*

## **ABSTRACT**

Significant progress has been made in using the waste process heat in cement plants. But the use of this process heat to generate electricity fell during past years, which saw low and steady power prices. Times are changing. Deregulation is bringing the specter of extremely volatile electricity prices, loss of control over power costs, and the real likelihood that energy prices may increase in the near term in some areas.

As a consequence, it is timely to reconsider the value of using waste process heat to generate electricity. With cogeneration, industries can lower costs and improve the environment.

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## **PAST ENERGY PHILOSOPHY IN THE CEMENT INDUSTRY**

Electrical energy costs in North America have been generally reasonable for the last 50 years. Even though this is typically one of the

largest components of operating costs in cement plants, the prime focus on many plant improvements have centered in reducing other components of the operating costs, namely fuel expense. Planning and designing cement plant upgrades and new facilities have emphasized minimizing first cost and optimizing the use of waste heat in the plant processes.

Watershed changes in the power industry, caused primarily by deregulation, are causing a re-examination of attitudes toward this major expense. Some of the historical beliefs included:

- *Electrical power is a fixed cost; fuels are variable expenses.* Most utility companies' rates were based on standard tariffs, which provided minimum opportunity for cost reduction. However, they provided a degree of stability, which allowed plant personnel to focus their attention elsewhere.
- *Thermal systems should be optimized for minimum fuel use.* Emphasis was placed on reusing the waste heat in various other places in the manufacturing process for maximum fuel efficiency.
- *Cement thermal systems do not favor on-site generation.* The resulting low temperatures of exhausted waste heat were considered of little value for generating electricity, which normally requires a higher initial temperature into the boiler or turbine.

## THE CHALLENGE

Deregulation of the electrical industry, as well as the need for cost effectiveness in the use of all energy, is suggesting that new searches should be made for ways to utilize waste heat from the cement plants. Some of the new realities include:

- *Power is a variable expense that is increasingly volatile.* As with any other commodity, deregulation brings opportunities for cost reductions, increases, and significant price swings.
- *Deregulation shifts power price risks to plants.* Volatility can be a two-edged sword if a plant has not developed some load management capabilities. Load management is a challenge for a plant designed

with no surplus capacities in its components.

- *Greenhouse gases need reducing.* Concerns are increasing about global warming due, in part, to greenhouse gases. Efforts to reduce the amount of this problem are considered very important. This pressure can only increase. Use of waste heat from a cement plant to reduce the need for other fuels consumed elsewhere is considered environmentally beneficial.

## HEAT BALANCES IN CEMENT MANUFACTURING PROCESSES

Waste gas discharged from the kiln exit gases, the clinker cooler system, and where applicable, the kiln preheater system, all contain useful energy that can be converted into power. In addition, there can be considerable heat losses through the shell of a cement kiln, especially in the burning zone, that may be recoverable. Figures 1, 2, 3, and 4 show the four common types of pyroprocessing, namely wet kiln, long dry kiln, preheater kiln, and precalciner kiln.

## POWER GENERATION FROM WASTE HEAT

Recently published papers and presentations indicate that waste heat recovery for power generation in a cement plant can be a viable way to combat rising electricity prices. It should be noted that:

- Waste heat can be effectively recovered from middle and low temperature heat sources such as cement kiln exhaust gases and clinker cooler exhaust gases.
- Waste heat recovery systems are operating reliably with steam boilers and turbines for power generation.
- Heat recovery in the right circumstances can be rather high. In large cement plants, 30 kWh to 35 kWh per ton of clinker can be achieved. This could enable the cement plant to reduce the unit power purchases by some 20-30 percent.

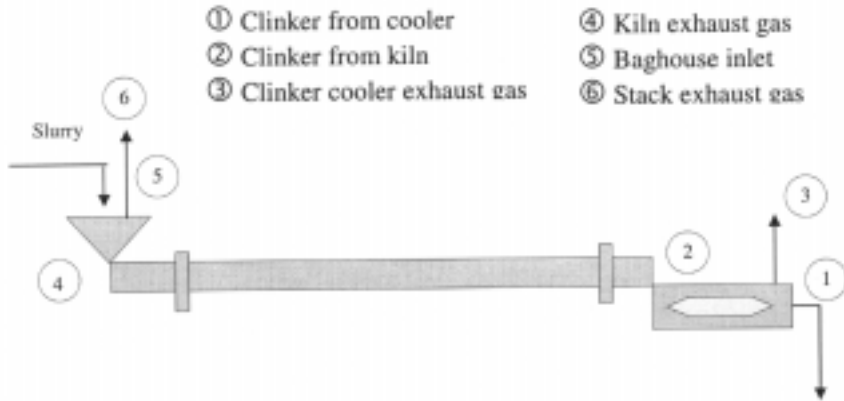


Figure 1. Wet Kiln

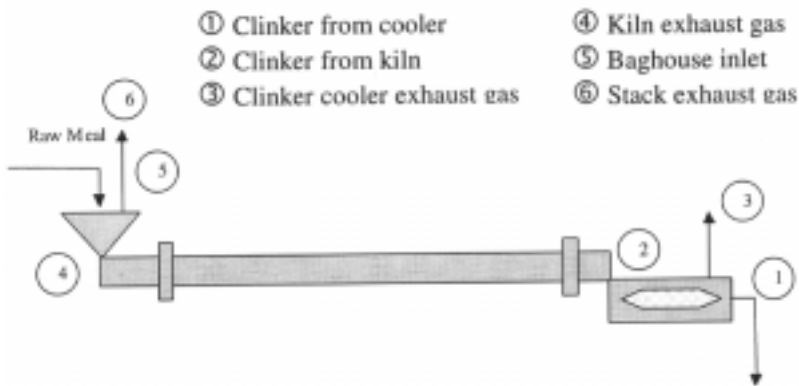
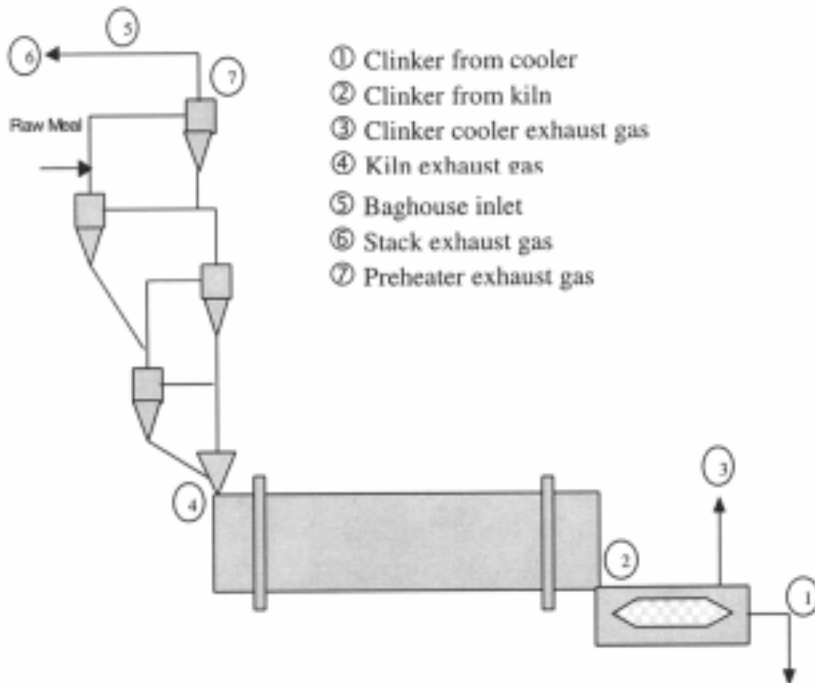


Figure 2. Long Dry Kiln

- The feasibility of the heat recovery system is enhanced with increasing size. Larger production units above 2,700 tons per day are the most likely candidates for heat recovery power generation.
- The technical and economic feasibility has to be calculated carefully for each individual case.
- Further gains in heat recovery efficiencies can be achieved by introducing new power generation technologies described later in this article.



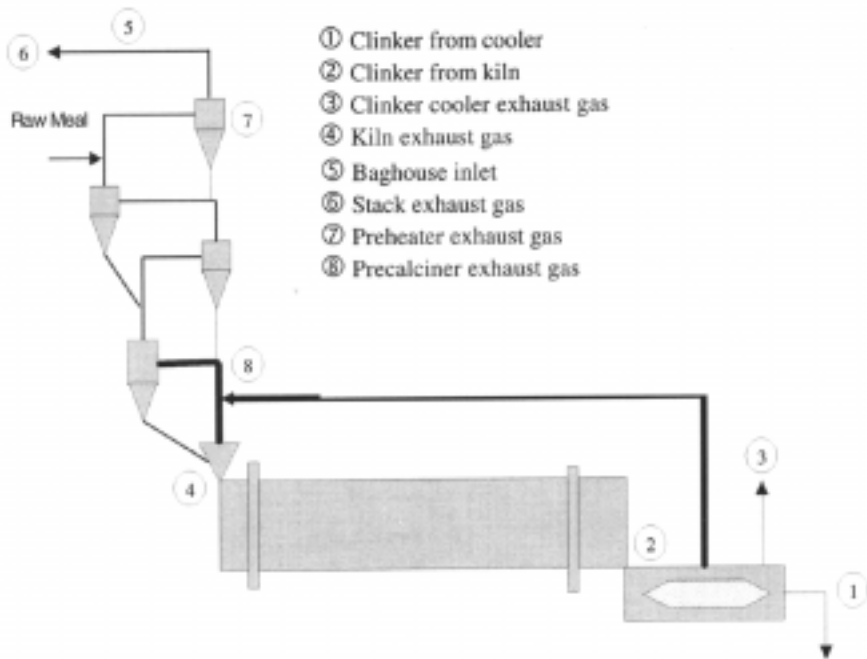
**Figure 3. Preheater Kiln**

### Definition

Waste heat is the energy associated with the waste streams of air, exhaust gases, or liquids that leave the plant envelope or building and enter the environment. These streams eventually mix with the atmosphere, surface water, or groundwater and become unusable as useful energy. The absorption of waste energy by the environment is also referred to as thermal pollution.

### Benefits

The principal reason for recovering waste heat is economic. All waste heat that is successfully recovered directly substitutes for purchased energy and therefore reduces the consumption of and the cost of that energy. A second potential benefit is realized when the utilization of waste heat for the production of electrical power results in smaller capacity requirements for electrical energy equipment, such as line capacities, transformers and switchgear, for interconnection and distribution.



**Figure 4. Preheater-precalfiner Kiln**

Thus the use of waste heat recovery can reduce capital costs of these electrical systems in new installations. The savings in capital expenditures for the primary electrical conversion devices can be great enough to completely offset the cost of the heat recovery system. It should be obvious that the reduction in capital costs cannot be realized in retrofit installations unless the associated primary energy conversion device has reached the end of its useful life and is due for replacement anyway.

A third benefit may accrue in a very special case. As an example, when it is necessary to incinerate by-product gaseous pollutants, the cost of operating the oxidizer may be significantly reduced through waste heat recovery from the exhaust gases.

Using waste heat from a cement plant to generate power has benefits to the environment as well as the economic benefits to the plant. These environmental benefits may not be obvious at first glance. Power from waste heat is generated with no additional emissions to the environment over levels before installing heat recovery generation. The power generated from the waste heat displaces power from the local

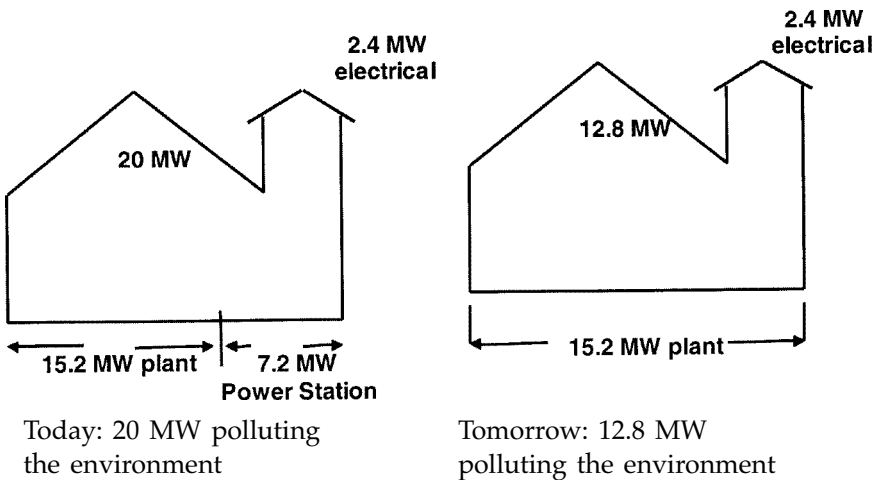
utility company, which lowers the utility power plant emissions.

In fact, the utilization of waste heat for power generation has a multiplier of approximately three. For each kWh generated by waste heat, the utility company will reduce the fuel input, and therefore emissions, by a factor of three, since utility power plants have an efficiency of about 30%. This not-so-obvious benefit to using waste heat for power production may be turned into economic benefits through emission credits or other financial devices. Figure 5 illustrates this environmental benefit from self-generation.

Finally, it can be emphasized that in every case of waste heat recovery, a gratuitous benefit is derived from reducing the thermal pollution of the environment by an amount exactly equal to the energy recovered, at no direct cost to the recoverer beyond that already invested in the waste heat recovery system.

#### Potential for Waste Heat Recovery in Industry

It has been estimated that of the total energy consumed by all sectors of the U. S. economy, fully 50% was discharged as waste heat to the environment. That is not to say that one-half of our national consumption of energy is needlessly wasted. The second law of thermodynamics is a statement of a natural law that prohibits us from achieving 100% efficiency in energy conversions.



**Figure 5. Saving primary energy and reducing thermal pollution of the environment in the cement industry.**

### Quantifying Waste Heat

The technical description of waste heat must necessarily include quantification of the following attributes: (1) quantity, (2) quality, and (3) temporal availability. The quantity of waste heat available is ordinarily expressed in terms of the enthalpy flow of the waste stream. The usefulness of waste heat, however, does not depend as much on the quantity available as it does on whether its quality fits the requirements of the potential load and whether it is available at the times when it is required.

The quality can be roughly expressed in terms of the temperature of the waste stream. The higher the temperature, the more available is the waste heat for substitution for purchased energy. The primary source of energy used in industrial plants is the combustion of fossil fuels. Energy conversion of fossil fuels occurs at high temperatures of the order of 1650°C. Since this is above the melting temperature of common structural materials, it becomes necessary to cool the transfer substances by misting with coolant, or to cool the structural surfaces to preserve them.

### Classifications of Waste Heat

For convenience, the total range of waste heat temperature, 27°C to 1650°C, is broken down into three sub-ranges: high, medium, and low. These classes are designed to match a similar scale that classifies commercial waste heat recovery devices. The two systems of classes allow matches to be made between industrial process waste heat and commercially available recovery equipment. Sub-ranges are defined in terms of temperature range as shown on Table 1.

**Table 1. Waste Heat Sub-range Temperatures**

|              | Temperature range  |
|--------------|--|
| High range   | $600\text{ }^{\circ}\text{C} \leq T \leq 1650\text{ }^{\circ}\text{C}$ |
| Medium range | $200\text{ }^{\circ}\text{C} \leq T < 600\text{ }^{\circ}\text{C}$     |
| Low range    | $20\text{ }^{\circ}\text{C} \leq T < 200^{\circ}\text{C}$              |

Waste heat in the high temperature range is not only the highest quality but is the most useful, and costs less per unit to transfer than lower quality heat. However, the equipment needed in the highest part of the range requires special engineering and special materials and thus requires a higher level of capital investment. Waste heat in the high range is available to do work through the utilization of steam turbines or gas turbines and thus is a good source of energy for cogeneration plants. In cogeneration plants the waste heat generates high-pressure steam in a heat recovery steam generator (HRSG) that is used in a steam turbine generator to generate electricity. The turbine exhaust steam at a lower pressure provides the process heat. Alternatively, the high-temperature gases may directly drive a gas turbine generator with the exhaust generating low-pressure steam in a HRSG for process heating.

Medium range temperatures are still in the temperature range in which work may be economically extracted using gas turbines in the range 100 to 200 kPa or steam turbines at almost any desired pressure. It is an economic range for direct substitution of process heat since requirements for equipment are reduced from those in the high-temperature range.

Use of waste heat in the low-temperature range is more problematic. It is ordinarily not practical to extract work from the waste heat source in this temperature range. To use it at all, heat pumps may be required to raise the source temperature to a suitable load temperature. Practical applications are almost all contained in the category of preheating liquids or gases.

One drawback is that the HRSG has to be shut down whenever the kiln is stopped. This must be taken into consideration in the design and operation of the waste heat recovery boiler. On the other hand, it should be possible to continue operating the kiln in the event of a fault or shut-down of the heat recovery system, without any adverse effects upon the burning process in the kiln.

## COGENERATION

Cogeneration is the sequential production of useful heat and power from the same energy source. The large amounts of waste heat rejected from cement-making operations provide substantial opportunity for bottoming-cycle systems, which recover waste heat to generate

electricity. The two conventional types of cogeneration systems that are applicable are Steam Rankine systems and Organic Rankine systems while a third, the Kalina cycle, has recently appeared.

### **Steam Rankine Cycle**

Steam Rankine systems (standard steam turbines) traditionally have been used with kiln exhausts greater than 500°C. In 1996, four U.S. cement plants were reported to be self-generating electricity with Rankine units. The plants recovered heat from either long dry or preheater kiln exhausts for power production. The steam Rankine system is typically installed between the kiln and the baghouse dust-removal system in the space generally occupied by the kiln exit gas cooler. The exhaust gas is ducted through the waste heat boiler, and heat is transferred to the water to produce superheated steam. The steam is expanded through a turbine to generate shaft power to drive a generator. Steam from the turbine exhaust is then condensed and recycled to the waste heat boiler as boiler feedwater.

There have been a number of innovative attempts in the United States and other countries to implement waste heat recovery and cogeneration in cement plants:

- Nihon Cement Company has operated a steam Rankine system for lower-temperature heat recovery at its Kawara, Japan, plant since 1981. The dual-pressure system recovers 410°C heat from the preheater and 230°C-heat from the clinker cooler. The rated output of the system is 16.200 kW and the payback period on investment was about three years.
- Florida Crushed Stone's 600,000-tpy cement plant at Brooksville, Florida, is designed to function as part of an imaginative cogeneration concept. The plant consists of a dry preheater process cement plant and a bubbling fluidized-bed calciner for lime production. The calciner is combined with a pulverized coal-fired power plant (125 MW capacity). Hot flue gases from the lime calciner, which still contain some limestone, are fed to the pulverized-coal boiler where they give up heat and capture the SO<sub>2</sub> produced by coal combustion. This eliminates the need for expensive scrubbers. An existing and somewhat aging coal-fired utility plant in Indiana was

purchased, dismantled, moved to the Florida site, refurbished, and modified to create the pulverized coal combustion unit. The plant buys power from the local utility to meet its requirements while the cogenerated power is sold to another Florida utility to maximize financial benefits.

- Since May 1985, CalMat Company has been operating a 25 MW cogeneration facility in its Colton, California, cement plant to supply its power requirements. The facility consists of a coal-fired circulating fluidized-bed (CFB) boiler and two heat recovery steam generators (HRSG) supplying steam to two refurbished turbine/generators. Exhaust at 675°C from the long-dry cement kilns flows to the HRSGs after most of the dust is removed in refractory-lined cyclone separators. The advanced CFB boiler technology has been successful in meeting the Southern California environmental regulations, which are among the strictest in the country. Existing coal and limestone sources and handling facilities (used for cement making) are also used for the CFB boiler facility. The boiler's bottom ash and fly ash are recycled into the cement.
- Another major Midwest long dry kiln plant seriously considered a 10 MW Rankine cycle plant not long ago. Extensive analyses showed that the economics were quite favorable, but construction was delayed due to negotiation of an attractive power supply contract.

### **Organic Rankine Cycle (ORC)**

The principal challenge to power generation in many cement plants is the low temperatures that are available, particularly in newer preheater-precalciner plants. The volume of heat flow is adequate for significant generation but the temperature differentials between the steam into the turbine and the condensing temperature is quite narrow. Organic Rankine systems may provide a practical way to recover the low-temperature heat associated with the preheater or precalciner kilns. The ORC is similar to the steam Rankine system discussed above, with the exception that a low-boiling point organic fluid replaces water as the heat transfer medium. ORC systems are potentially up to 50% more efficient than steam Rankine systems at temperatures below 530°C.

Although no ORC systems are currently operating in U.S. cement

plants, they have been used successfully in other industries and in foreign countries. The Heidelberger Zement AG in Germany recently installed an ORMAT © heat recovery system which generates electricity in a 1.5 MW turbine using a thermal oil circulating through a closed loop system collecting heat after the precipitator in the clinker cooler. This oil evaporates the hydrocarbon pentane as the motive force used in the generation process. The pentane vapors are allowed to expand in the turbine and then condensed in a condenser for reuse. Temperatures vary significantly in the clinker cooler exhaust, but the ORC system is generally forgiving of these fluctuations. This same technique could be used to collect heat from preheater gases for additional generation. Plant generating capacity would be correspondingly increased.

Domestic firms have developed ORC systems for a variety of applications, including solar and geothermal applications, bottoming cycles for engines, and industrial waste heat recovery. A large share of the development and demonstration efforts in the United States has been funded by the Department of Energy (DOE), as part of solar, geothermal, or conservation programs. Most of the United States systems are at the prototype stage, with few commercial installations currently operating or under construction.

Several foreign firms have been active in ORC development and manufacture. Japanese government and industry, driven by their dependence on energy imports, have been involved in ORC research and testing for more than 15 years. Sotretes, a French firm, is now producing a limited number of ORC units for water pumping. Onset, an Israeli firm, has been manufacturing smaller ORC units (1 kW) for more than 15 years. The latter two firms market their ORC systems primarily to developing countries for remote application.

The economics of ORC systems currently preclude their adoption for low-temperature waste heat recovery. The major technical barrier to adopting steam Rankine or ORC systems by the cement industry is the scale buildup and metal corrosion problems from the constituents in the kiln off gases. Fouling and corrosion problems result in reduced system efficiency, high maintenance costs, and in some cases, system failure. However, using ORC systems on clinker cooler exhaust air has been suggested and may be a reasonable approach for some cogeneration of electrical power. Adoption of ORC systems is further impeded by the lack of operating history in cement plants.

## Kalina Cycle

There have been few genuinely new ideas in classical thermodynamics put forth since early in this century. One of them is the adjustable proportion fluid mixture (APT) cycle, of which the Kalina cycle is the best-known example. Its creator, Dr. Alex Kalina, started with a question: *Since variable composition is an important aspect of a regenerative ammonia refrigeration cycle, might a similar principle be used to improve the efficiency of the Rankine cycle in the conversion of heat to work?* An analysis of several possible cycles based on this principle shows that the additional degree of freedom provided by variable composition can indeed lead to such an improvement.

Kalina systems have completed the experimental stage and are emerging from demonstration projects. Six are in operation and several more are in various stages of design. To show economic feasibility and resolve operational questions inevitably associated with a new technology, a 3.2 MW demonstration plant was built at the Rocketdyne test facility in Canoga Park, California. The facility was first operated in early December 1991 with encouraging results. A smaller, 1.6 kW, plant has been tested in Japan.

The Kalina Cycle does not change the fireside design of a power plant, which utilizes the waste heat from a cement kiln. The differences are on the fluid or tube side of the boiler. Heat is acquired in a more efficient manner, which improves the plant efficiency and increases the power plant electrical output. For most cement plant waste heat power plants, the Kalina Cycle is said to produce 30 - 60% more electricity in comparison with comparable Rankine Cycle power plants (both steam and ORC).

A two-phase (liquid and vapor) mixture of ammonia and water in equilibrium will tend to have a greater concentration of ammonia in the vapor than in the liquid because ammonia is more volatile. If a mixture of a specified concentration (expressed as mass fraction of ammonia), which is initially all vapor, is gradually reduced in temperature, condensation will begin at the dew point of the mixture. At the other extreme, when an all-liquid mixture is gradually heated, vaporization will start at the bubble point temperature.

During vaporization (still at constant pressure) the temperature of the mixture increases because of the changing liquid composition. If the heat source were, for instance, the exhaust of a gas turbine, the rising vapor temperature of the ammonia-water mixture can be better matched

to recovering the heat from the combustion gas than pure water boiling at constant temperature.

The ability to operate satisfactorily at lower temperatures (Table 5) allows the Kalina cycle unit to be very suitable for both the clinker cooler and preheater exhaust gases. For a typical 2,700 tons per day plant, generation could be in the range of 6 to 9 MW.

**Table 5. Cycle Comparison**

| Comparison Item                   | Rankine   | Organic Rankine | Kalina    |
|-----------------------------------|-----------|-----------------|-----------|
| Waste heat temperature needed (C) | >250      | >200            | >200      |
| Capital cost (TIC) \$/kW          | 1100-1400 | 1500-3500       | 1100-1500 |
| Electric generation (Rankine = 1) | 1         | 1.3-1.7         | 1.3-1.6   |

### Summary of Power Generation Opportunities

Steam Rankine systems are applicable at exhaust gas temperatures commonly associated with long-dry kilns and preheater bypasses. Past evaluations of exhaust heat recovery alternatives for long-dry kilns have indicated that for plants with high electric power costs, cogeneration may be an economically attractive alternative to suspension preheater systems. Preheater exhausts, which are lower in temperature than long-dry kiln exhausts, could more efficiently be recovered with an organic Rankine cycle system. Exhaust gases from efficient, well-maintained wet process kilns are too low in temperature and too high in moisture for practical heat recovery with currently available heat-recovery steam generators. The following energy-savings estimate was made assuming that a steam Rankine bottoming system would be used in conjunction with existing long-dry kilns.

The power that can be recovered from the use of the cycles discussed is summarized in Tables 6, 7, and 8 for the Rankine, ORC and Kalina cycles respectively. The exit gas temperature for the long dry kiln is shown at 500°C and is the temperature after cleanup. Temperatures of 1000°C are available immediately after gas exits the kiln. At this point

the gas has not been cleaned in any manner. Significant additional power generation is possible when heat is recovered at this point instead of after cleanup. Power generation may be as much as double that shown in Tables 6, 7, and 8. Technology to use the hotter, contaminated gas at the kiln exit is similar to that already used in coal fired power boilers used by the electric utilities. Temperatures are similar and both gas streams are laden with dust. However, the dust content before baghouses in cement plants will be much dirtier (4-18 grain/acf vs 1-2 grain/acf).

**Table 6. Energy Recovery—Rankine Cycle**

|                           | Units             | Wet kiln | Long dry kiln | Preheater kiln | Preheater-<br>precal-<br>ciner kiln |
|---------------------------|-------------------|----------|---------------|----------------|-------------------------------------|
| Production                | Tonnes<br>per day | 1,360    | 1,800         | 2,720          | 2,720                               |
| Exit gas                  | kg/kg<br>clinker  | 3.92     | 2.36          | 2.01           | 1.92                                |
|                           | °C                | 224      | 500           | 340            | 340                                 |
| Steam flow                | kg/hr             | 8,200    | 28,800        | 14,200         | 13,500                              |
| Electric generation       | MW                | 0.91     | 4.44          | 2.20           | 2.21                                |
| Cooler vent gas           | Kg/kg<br>clinker  | 0.50     | .98           | 1.32           | 1.32                                |
|                           | °C                | 250      | 250           | 250            | 250                                 |
| Steam flow                | Kg/hr             | 1,300    | 3,500         | 5,700          | 5,700                               |
| Electric generation       | MW                | 0.09     | 0.55          | 0.88           | .88                                 |
| Total electric generation | MW                | 1.00     | 4.99          | 3.08           | 3.09                                |

At least two firms have constructed a number of waste heat boilers for the cement industry. This technology was developed several decades ago and has been operated successfully in at least 30 cement plants. In recent years, however, newer designs in cement plants have emphasized the utilization of waste heat for alternative purposes, such as drying and

**Table 7. Energy Recovery - Organic Rankine**

|                           | Units             | Wet kiln | Long dry kiln | Preheater kiln | Preheater-<br>precal-<br>ciner kiln |
|---------------------------|-------------------|----------|---------------|----------------|-------------------------------------|
| Production                | Tonnes<br>per day | 1,500    | 2,000         | 3,000          | 3,000                               |
| Exit gas                  | kg/kg clinker     | 3.92     | 2.36          | 2.01           | 1.92                                |
|                           | °C                | 224      | 500           | 340            | 340                                 |
| Steam flow                | kg/hr             | 8,200    | 28,800        | 14,200         | 13,500                              |
| Electric generation       | MW                | 1.41     | 6.90          | 3.41           | 3.41                                |
| Cooler vent gas           | Kg/kg<br>clinker  | 0.50     | .98           | 1.32           | 1.32                                |
|                           | °C                | 250      | 250           | 250            | 250                                 |
| Steam flow                | Kg/hr             | 1,300    | 3,500         | 5,700          | 5,700                               |
| Electric generation       | MW                | 0.14     | 0.84          | 1.36           | 1.36                                |
| Total electric generation | MW                | 1.55     | 7.74          | 4.77           | 4.77                                |

**Table 8. Energy Recovery - Kalina Cycle**

|                           | Units             | Wet kiln | Long dry kiln | Preheater kiln | Preheater-<br>precal-<br>ciner kiln |
|---------------------------|-------------------|----------|---------------|----------------|-------------------------------------|
| Production                | Tonnes<br>per day | 1,500    | 2,000         | 3,000          | 3,000                               |
| Exit gas                  | kg/kg clinker     | 3.92     | 2.36          | 2.01           | 1.92                                |
|                           | °C                | 224      | 500           | 340            | 340                                 |
| Steam flow                | kg/hr             | 8,200    | 28,800        | 14,200         | 13,500                              |
| Electric generation       | MW                | 1.32     | 6.45          | 3.19           | 3.20                                |
| Cooler vent gas           | Kg/kg<br>-clinker | 0.50     | .98           | 1.32           | 1.32                                |
|                           | °C                | 250      | 250           | 250            | 250                                 |
| Steam flow                | Kg/hr             | 1,300    | 3,500         | 5,700          | 5,700                               |
| Electric generation       | MW                | 0.13     | 0.78          | 1.26           | 1.26                                |
| Total electric generation | MW                | 1.45     | 7.23          | 4.45           | 4.46                                |

in preheaters and precalciners. As a consequence of this approach and low power costs, the generation of power utilizing waste heat in cement plants has fallen into disuse.

There are three principal techniques used to remove dust from the tubes in dirty airstreams:

- **Steam or Air Blow**—Dust is blown away by high-pressure steam or air injection energy. This is the most efficient method, but requires a lot of energy, which reduces the net amount available for other purposes. Significant additional regular maintenance is required to remove dust buildup.
- **Impact**—Hammers installed outside of the air stream are used to vibrate the piping panels. Dust can be removed almost completely by hammering. Additional regular maintenance would be required to remove dust buildup.
- **Sonic Soot Blowing**—Compressed air is used to generate sonic waves at 250-360 Hz, whose scattered reflections are utilized to remove dust. Energy consumption is between the other two alternatives. Effectiveness varies. High noise levels require soundproofing. Significant additional regular maintenance is required to remove dust buildup.

The need for additional on-site generating capacity, combined with updates of technology developed in the past, may present interesting opportunities to reduce power costs in cement plants.

### **Pyroelectric Conversion**

A Canadian research program has focused on an intriguing concept of pyroelectric conversion of heat into electricity. Still in its bench-scale testing stage, it is said to offer promise of efficiencies of 15% to 28%. Private sector partnerships are being sought to co-finance additional research.

### **Heat Pipe Technology**

Although not a method of generating power directly from waste heat in cement plants, heat pipe technology is an interesting technique of transferring heat and upgrading heat from a high-dust content envi-

ronment to a usable condition. The Energy & Chemical Process Research Team of the Pohang Iron and Steel Company in South Korea has done several years of research work and has successfully developed a IMW generating unit utilizing this technology. No other information is currently available.

## NON-POWER GENERATION USES OF WASTE HEAT

For the waste heat from a cement plant to be of value, it must be moved to the point of use. As electricity, the heat can be moved long distances with little loss after being converted to electricity. As hot water, it can be moved effectively much shorter distances. However, it may be economically feasible in a few instances to move hot water up to several miles. On the other hand, hot air requires much larger duct work and can only be moved very short distances economically. Nevertheless, there are alternatives to power generation that should be considered for utilizing the waste heat from the cement manufacturing process.

### **District Heating**

For cement plants located in metropolitan areas, or near other heat consuming industries, the generation of hot water from waste heat may be a viable alternative to generating power with the waste heat. District heating (and district cooling) systems are gaining in popularity as the cost of fuel rises. Waste heat recovered from the cement process can be used to heat water for use in homes and factories. The key to such beneficial use of the waste heat is that the cement plant must be located near the heat user to cut down on the installation cost of the hot water distribution system. District heating has been used in Europe for many years. In some locations it may be attractive to convert the waste heat into chilled water by using absorption chillers, and then distribute the chilled water in a district cooling system.

### **Process Drying**

The use of waste heat for drying coal and raw meal are familiar to the cement industry. A good use of excess waste heat from the cement plant also includes providing process heat for drying in other manufacturing operations, such as in a wallboard plant. Once again, the neighboring plant must be nearby to reduce the installed cost of piping and ducts.

### **Agriculture and Aquaculture**

Excess waste heat from the cement plant may also be used to heat greenhouses in colder areas. The CO<sub>2</sub>-rich kiln exhaust, when properly cleaned, would also be particularly attractive to farmers. In addition to the heat to keep the greenhouses above freezing, the CO<sub>2</sub> will aid plant growth.

As more and more restrictions are placed on harvesting aquatic life from the open sea, suppliers have turned to aquaculture to provide consumers desire for sea products. Just as hot water can be used in cold climates to enable out-of-season farming in greenhouses, the hot water can also be used to make aquaculture possible in those same cold climates.

### **Chemical Processes**

In addition to supplying neighboring plants with heat for drying and other process uses, the enriched CO<sub>2</sub> in the kiln exhaust might also be used as feedstock for industries that rely on CO<sub>2</sub> for their process. Such symbiotic relationships between the cement industry and other chemical process industries will be even more important in the future.

### **Radiant Heat**

Up to 10% of the fuel heat input to a cement kiln is lost as radiation from the shell. A unique concept is reported from a West German cement plant to recover a part of the kiln shell waste heat through a hinged radiant heat absorber. In this case, the low-grade heat recovered is used for building heating and industrial water heating. The absorber consists of 12 heat exchanging plates which are mounted on two hinged steel constructions so as to form two heptagonal half-shells.

During normal operation, these shells completely enclose the kiln over a length of six meters, with a wall clearance of about one-half meter. The absorber can be swung open. On the side facing the kiln, the absorber plates are painted with black absorber varnish and equipped with weatherproof thermal insulation on the other side. Heat is removed (at about 100°C) from the absorber with a glycol-water mixture. The absorber design results in a kiln shell temperature of 300°C, which corresponds to a shell temperature of 240°C for the non-enclosed kiln.

## WASTE HEAT RECOVERY EQUIPMENT MANUFACTURERS

### **Steam Rankine Cycle**

Turbines for a standard Steam Rankine Cycle are available through a number of manufacturers, including:

- General Electric
- Solar
- Rolls Royce
- Westinghouse

### **Organic Rankine Cycle**

The Organic Rankine Cycle unit is offered by:

- Ormat Industries Ltd

### **Kalina Cycle**

The Kalina Cycle is being offered by:

- Exergy Corporation

## COST BENEFIT ANALYSES

The Cycle Comparison Table (Table 5) compares the capital cost and power generation potential of the Rankine cycle, organic Rankine cycle and the Kalina cycle. Note that both the Organic Rankine cycle and Kalina cycle offer significant improvements in power production over the steam Rankine cycle. The Kalina cycle uses traditional off-the-shelf equipment normally used in the steam Rankine cycle which lowers its capital cost.

Tables 6, 7, and 8 compare the power generation potential of the Steam Rankine cycle, Organic Rankine cycle and Kalina cycle for the four types of pyroprocessing investigated: long dry, wet, preheater and preheater-precalciner. Both the Organic Rankine cycle and Kalina cycle offer significantly enhanced power recovery opportunities over the steam Rankine cycle.

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### ABOUT THE AUTHOR

**Paul R. Cunningham, P.E.**, is president of The Altus Group, Inc., and has 30 years of experience as a consulting engineer and utility ex-



ecutive and has performed over 100 studies of engineering, financial, and managerial, and political feasibility of various projects. He has directed energy management studies of hospitals, office buildings, shopping centers, and industrial facilities, and has also developed innovative analytical techniques for defining energy use in facilities. He was instrumental in establishing a unique joint electrical utility for four cities with a 10-year capital improvement plan of \$1.7 billion, including a 400-MW lignite generating plant, participation in a nuclear plant, and related transmission facilities. In addition, he supervised project financing totaling \$60 million and preliminary work on another project involving \$150 million, coordinating with rating services and bankers. Mr. Cunningham earned his B.A. degree in mathematics from Midwestern University and his B.S. degree in civil engineering from the University of Texas.

The Altus Group, 2407 North Cooper St., Arlington, TX 76006; (t) 817-265-8822; (f) 817-795-8718; [paul@altusgroup.com](mailto:paul@altusgroup.com); [www.altusgroup.com](http://www.altusgroup.com)

**Hosea Chambers** is a senior mechanical engineering consultant with more than 25 years experience in energy management. As the energy administrator for a large industrial plant, he was responsible for a \$30 million annual energy budget. His professional experience includes cogeneration, equipment performance and efficiencies, monitoring and maintenance. Mr. Chambers is also well versed in all aspects of natural gas purchase from calorimeter analysis to flow measurement to piping. His expertise in both the fields of energy conservation and system operation has been achieved while serving industrial complexes as well as all types of commercial and retail facilities.

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