Summary

Process heating is a significant source of energy consumption in the industrial and manufacturing sectors, and it often results in a large amount of waste heat that is discharged into the atmosphere. Industrial process heat recovery effectively recycles this waste heat, which typically contains a substantial amount of thermal energy. The benefits of heat recovery include improving system efficiency, reducing fuel consumption, and reducing facility air emissions. While the type and cost-effectiveness of a heat recovery system are dependent on the process temperature and the facility’s thermal requirements, many heat recovery techniques are available across low, medium, and high temperature ranges.
Introduction

Process heating refers to the application of thermal energy to a product, raising it to a certain temperature to prepare it for additional processing, to change its properties, or for some other purpose. The energy required for process heating accounts for approximately 17% of total industrial energy use in the U.S. [1] As energy costs continue to rise, facilities are constantly in need of ways to improve the performance of their process heating systems and to reduce their energy consumption. In many fuel-fired heating systems the exhaust gas that is emitted through a flue or stack is the single greatest heat loss. Process heat recovery saves energy by reusing this otherwise lost heat for a variety of thermal loads, such as pre-heated combustion air, boiler feedwater, and process loads, as well as for steam generation. This design brief describes the most common and effective methods for recovering waste heat from industrial processes.

What Is Industrial Process Heat Recovery?

Process heat recovery involves intercepting the waste streams before they leave the plant, extracting some of the heat they contain, and recycling that heat.

Applications

Heat recovery can be applied in a wide range of industries. For example, the pulp and paper industry can utilize heat recovery through several processes, from preheating milling water with steam to cooling effluent wastewater before sending it to waste treatment. The chemical industry can apply heat recovery to most processes, including chemical manufacturing, as well as to emissions control devices such as recuperative and regenerative thermal oxidizers. The petroleum industry can use heat recovery from production water and glycol regenerators, as well as using heat exchangers between wet and dry crude, in the natural gas cleaning process, and in waste treatment operations. The food and beverage industry can achieve savings through the installation of heat exchangers for food pasteurizers, blanch water heat recovery, boiler blowdown heat recovery, heating feedstock in the distillation process, and recovery of waste heat from dryers and cookers. In both the commercial and industrial sectors, combined heat and power (CHP) systems can efficiently generate electrical power on-site as well as recovering waste heat to generate hot water or steam for process operations.
Benefits of Waste Heat Recovery

The benefits of heat recovery are multiple: economic, resource (fuel) saving, and environmental. First, recovered heat can directly substitute for purchased energy, thereby reducing the facility’s energy consumption and its associated costs; further, waste heat substitution can lower capacity requirements for energy generating equipment, thus reducing capital costs for new installation projects. Second, for a specific heating process, fuel efficiency can be improved through the use of heat recovery, thus reducing the cost of operation. For example, the use of exhaust gas from a fuel-fired burner to preheat the combustion air can reduce heating energy use by as much as 30%. [1] Third, due to improved equipment efficiency, smaller equipment capacity requirements, and reduced fuel consumption, heat recovery can produce environmental benefits through reductions in emissions of greenhouse gases and atmospheric pollutants.

Sources and Quality of Waste Heat

Waste heat sources can be classified by temperature range, as shown in Table 1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1,100 to 3,000</td>
</tr>
<tr>
<td>Medium</td>
<td>400 to 1,100</td>
</tr>
<tr>
<td>Low</td>
<td>80 to 400</td>
</tr>
</tbody>
</table>

About 92% of process heat energy used by U.S. industry is directly provided by fossil fuels. [7] The waste heat generated from direct-fired processes falls in the high and medium temperature ranges. In the high-temperature range, sources of waste heat include refining furnaces, steel heating furnaces, glass melting furnaces, and solid waste incinerators. High-temperature waste heat is the highest quality and most useful because it provides more heat recovery options and thus greater potential cost-effectiveness than lower temperature waste heat. It can be made available to do work through the utilization of steam turbines or gas turbines to generate energy in a cogeneration plant.
In the medium temperature range, sources of waste heat include exhaust gases from steam boilers, gas turbines, reciprocating engines, water heating boiler furnaces, fuel cells, and drying and baking ovens. Potential heat recovery opportunities include, among others, low pressure steam generation and incoming product preheating.

In the low-temperature range, sources of waste heat include process steam condensate, cooling water from refrigeration condensers, welding machines, boilers, and air compressors. In some applications low-temperature waste heat can be used for preheating through heat exchangers. For example, cooling water from a battery of spot welders can be used to preheat the ventilating air for winter space heating.

Table 2 lists examples of waste heat sources and their potential applications.

**Table 2: Various Waste Heat Sources and Applications**

<table>
<thead>
<tr>
<th>Sources</th>
<th>Temperature Range</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust gas from refining furnaces, steel heating furnaces, glass melting furnaces, solid waste incinerators</td>
<td>High</td>
<td>Hazardous gas reduction</td>
</tr>
<tr>
<td>Steam generation</td>
<td></td>
<td>Water heating</td>
</tr>
<tr>
<td>Water preheating</td>
<td></td>
<td>Combustion air preheating</td>
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<tr>
<td>Power generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exhaust from gas turbines, reciprocating engines, incinerators, furnaces Steam boiler blown down</td>
<td>Medium</td>
<td>Preheating incoming product</td>
</tr>
<tr>
<td>Steam generation</td>
<td></td>
<td>Water heating</td>
</tr>
<tr>
<td>Water preheating</td>
<td></td>
<td>Combustion air preheating</td>
</tr>
<tr>
<td>Exhaust gas from fuel burner Reciprocating engine jacket cooling Waste stream from condensers, boilers, and air compressors</td>
<td>Low</td>
<td>Absorption cooling</td>
</tr>
<tr>
<td>Dehumidification</td>
<td></td>
<td>Feedwater preheating</td>
</tr>
<tr>
<td>Space heating</td>
<td></td>
<td>Evaporation</td>
</tr>
</tbody>
</table>

**Assessing Heat Recovery Projects**

The assessment of potential heat recovery projects requires a systematic study of the sources of waste heat in a given facility and the opportunities for its use. The following steps are needed:
Step 1: Identify all significant heat sources (and their quality) at the facility
As noted above, typical heat sources include exhaust gases from refining furnaces, steel heating furnaces, glass melting furnaces, solid waste incinerators, gas turbines, reciprocating engines, and water heating boilers; waste steam from a steam boiler; and cooling water from compressors. Any chemical components contained in the waste streams, such as carbon monoxide from a furnace or solvent vapors from a drying oven, and any toxic substances, should be noted. The waste heat quality, i.e., the level of contaminations and amount of recoverable heat, and the process heating requirements should also be assessed. For example, typical boiler flue gas may present opportunities for heat recovery but be off limits to food-grade processes.

Step 2: Quantify all heat sources and sinks through heat and material balances
The quantity, quality, and temporal availability of waste energy require that volumetric flow rate, temperature, and flow intervals be measured. When measurements are not possible, it becomes necessary to rely on the best approximations available. Equipment nameplate data, operation and maintenance manuals, production records, fuel and utility invoices, and equipment logs must be collected.

Step 3: Determine the scope of heat recovery and appropriate heat exchanging equipment
The scope of heat recovery can be developed through conceptual designs. If multiple heat sources are available, an integrated analysis approach should be performed to evaluate the optimal system operation for the entire system. Appropriate heat exchanging equipment should be determined.

Step 4: Perform a cost-effectiveness analysis
The cost-effectiveness analysis of a waste heat recovery project requires evaluating the capital costs of the proposed system against the potential energy savings benefits, just as in evaluations of other capital projects. In a waste heat recovery project, the capital cost is often proportional to the peak rate of the heat recovery. The savings depend on several factors, including the availability of waste heat, the availability and efficiency of
heat transfer technology, and utility prices. Economic analyses may be based on simple payback, net present value, or internal rate of return. The method chosen should be appropriate for the corporation’s capital or financial opportunities or in accordance with the specifications provided.

**Heat Recovery Methods**

There are several methods for recovering waste heat. The ten most commonly applied are:

- High-temperature heat recovery through recuperators and regenerators
- Load preheating
- Combustion air preheating
- Steam generation in waste heat boilers
- Feedwater preheating
- Heat recovery in condensing boilers
- Heat recovery from boiler blowdown
- Cascade heating
- Heat recovery using absorption chillers
- Heat recovery using desiccant dehumidifiers

**High Temperature Heat Recovery through Recuperators and Regenerators**

Recuperators and regenerators are two methods of recovering heat from high-temperature processes, such as incineration or thermal oxidation. Recuperators are essentially gas-to-gas heat exchangers, where the gas coming into the process is pre-heated by the high-temperature gas going out of the process. In regenerators, refractory materials are utilized to absorb heat from the high-temperature gas and release it back to the process, thus reducing the combustion energy. Regenerators typically operate in alternate cycles between two chambers.
Recuperators

Recuperators are gas-to-gas heat exchangers that are installed in the stack of the furnace. There are numerous designs, but all rely on tubes or plates to transfer heat from the outgoing exhaust gas to the incoming combustion air, while keeping the two streams from mixing.

A simple configuration and low-cost recuperator is a metallic radiation recuperator, as shown in Figure 1. The inner tube carries the hot exhaust gas while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The assembly is often designed to replace the exhaust stack.

Ceramic-tube recuperators have been developed using materials that permit operation to exhaust temperatures of 2,800°F and on the preheated air side to 2,200°F, although practical designs yield air temperatures of 1,800°F. They are constructed of short silicon carbide tubes with flexible...
seals. However, leakage of up to a few percent between fluid streams is not uncommon.

Another common type of recuperator is a *convective recuperator*. Figure 2 shows a schematic diagram of a combined radiation and convective type recuperator. The hot gases are carried through a number of small-diameter parallel tubes, while the combustion air enters a shell surrounding the tubes and is heated as it passes over the outside of the tubes one or more times in directions normal to the tubes. Convective recuperators are generally more compact and more effective than radiation recuperators, because of the larger effective heat transfer area made possible through the use of multiple tubes and multiple passes of the air. However, convective type recuperators must be protected against overheating damage with high-temperature processes and may not be suitable for some corrosive or dirty exhaust gases. Damage to a convective recuperator by overheating can be costly.

**Figure 2: Combined Radiation and Convective Recuperator**

**Regenerators**

Regenerators are essentially rechargeable storage batteries for heat that utilize an insulated container filled with metal or ceramic shapes capable of absorbing and storing large amounts of thermal energy. Figure 3 shows a plate-type regenerator. A plate-type regenerator is constructed of alternate channels that separate adjacent flows of heated and heating gases by a thin wall of conducting metal. Although their use eliminates cross-contamination, they are bulkier, heavier, and more expensive than recuperators.

**Figure 3: Plate-Type Passive Gas-to-Gas Regenerator**


For the process to operate without interruption, at least two regenerators are required; one provides energy to the combustion air while the other is recharging. Regenerators can operate at temperatures beyond the range of recuperators and at higher efficiency ratings. They are resistant to corrosion and fouling, but because of their back-and-forth switching to maintain continuous operation, they require more complex, more expensive flow control systems than recuperators. These passive air preheaters are used in low- and medium-temperature applications.

**Load Preheating**

In general, there are direct and indirect heat recovery methods. *Direct* heat recovery implies directly preheating incoming product using the process waste heat. If the high-temperature exhaust fluid can be brought into con-
tact with a relatively cool incoming fluid, energy will be transferred to preheat the low-temperature fluid and reduce the energy that finally escapes with the exhaust. Figure 4 presents a schematic of a direct preheating method. Direct heat recovery to the product has the highest potential efficiency because it does not require any “carrier” to return the energy to the product. It does, however, require a furnace or oven configuration that permits routing the stream of exhaust counter-flow to incoming product or materials.

**Figure 4: Direct Preheating of Incoming Product**

![Figure 4](image)


*Indirect* heat recovery implies that the process waste heat is used through a heat exchanger to preheat load, as in a feedwater economizer.

**Combustion Air Preheating**

Two methods of combustion air preheating use the technologies described above under high-temperature heat recovery through recuperators and regenerators. A large amount of energy is required to heat combustion air from atmospheric temperature to combustion temperature. Preheating results in the burners needing less fuel to heat the incoming air to combustion temperature. The most common means of transferring flue gas energy to combustion air is to use a recuperator placed in the exhaust stack or ductwork. This strategy can recover a sizable percentage of the exhaust heat that would otherwise be lost to the atmosphere. Figure 5 shows a recuperator used to preheat combustion air.

Regenerators can be used for applications where cross-contamination cannot be tolerated. During part of the operating cycle, process exhaust gas flows through the regenerator, heating the storage medium. Once the medi-
um becomes fully charged, the exhaust flow is shut off and cold combustion air enters the unit. As it passes through, the supply air extracts heat from the storage medium and rises in temperature before entering the burners. Figure 6 shows a regenerator used to preheat combustion air. The operation cycles between a charge mode (top) and a discharge mode (bottom).

Figure 6: Regenerator System for Storing Energy
Whether air preheating will be cost-effective is usually determined by the process temperature:

- Processes at temperatures above 1,600°F are generally good candidates.
- Processes operating in the range of 1,000°F to 1,600°F may still produce cost-effective savings, but must be evaluated case by case.
- Processes operating below 1,000°F are typically not worth the cost of installing and maintaining the regenerator system. However, low-temperature processes should still be evaluated for heat recovery potential. If the exhaust gas flow rate is high enough, energy savings may still be achievable.

**Thermal Oxidizing/Combustion Emission Control**

Many chemical facilities need to treat hazardous waste gas from their process lines. A thermal oxidizer is used to decompose hazardous gases before releasing them to the atmosphere. In a thermal oxidizer, the hazardous gas is passed through an oxidizing burner (oxidizer) at a controlled and optimal temperature, typically above 1500°F, at which the volatile organic compounds (VOCs) are converted into safe gases such as water vapor and carbon dioxide. Because thermal oxidizers operate at such high temperatures, these systems have significant heat recovery savings potential.

The simplest technique for meeting regulatory VOC reduction requirements would be to heat the gas in an afterburner to more than 1500°F and not recover any heat. Without heat recovery, however, the operation of an afterburner is cost prohibitive unless the gas stream is very rich in VOCs and has a low flow rate. Alternatively, thermal oxidizer efficiency can be optimized by utilizing recuperative or regenerative types of heat recovery methods. A recuperative thermal oxidizer uses a gas-to-gas heat exchanger to recover some of the energy from the high-temperature exhaust gas. Regenerative thermal oxidizers are more energy efficient, reaching thermal efficiencies of up to 95%, while recuperative types typically achieve efficiencies of up to 80%. However, the capital cost for regenerative types is higher than for recuperative types.
When examining the appropriate type of thermal oxidizer, some considerations are the gas stream volume, flow, temperature, and moisture content; the VOC concentrations; and the desired VOC destruction efficiency. Processes with higher gas flow rates and lower VOC concentrations, for example, are more suitably managed with a regenerative thermal oxidizer, illustrated in Figure 7.

**Recuperative Thermal Oxidizer**  
**Jernberg Industries, Inc., in Chicago, Illinois**

As part of a plant-wide assessment, the Jernberg forging facility identified a waste heat recovery opportunity utilizing flue gas from the oxidizer. The facility had an existing recuperator on the oxidizer, but had taken it out of service. As a result, 1,400°F air was exiting the stack during operation. By repairing the recuperator and returning it to service, the stack exit temperature could be reduced to 400°F, and the recovered heat could be used to preheat the incoming flue gas in the oxidizer. This project would save an estimated 1,812 MMBtu/yr. The implementation cost for this project was estimated to be $25,000, assuming that the recuperator would be repaired before it was returned to service. This project would yield an annual cost saving of approximately $9,400, resulting in a simple payback period of 2.7 years. [4]
Non-Combustion Emission Control Technologies

Waste heat recovery for thermal oxidation is an effective measure for minimizing the energy used in thermal oxidation processes. However, there are alternatives to combustion-based emissions controls that do not require fossil fuel burning to reduce or eliminate pollutants from the waste stream.

One alternative is to spray a liquid across the exiting air stream to remove pollutants either by absorbing them or by changing their chemical composition. Examples include chemical scrubbers and some catalytic reduction (CR) systems (although in some cases CR systems do require supplemental heat to reach the optimal reaction temperature). Another alternative is to filter pollutants when the air stream flows through bed media. The pollutants adhere to, or are consumed by, the material making up the beds. Examples include carbon adsorption and bioreactors.

The applicability of these control technologies depends on the characteristics of the waste stream; some require secondary treatments because they do not destroy the pollutant, but rather concentrate it in another stream. The bioreactor, however, does not require secondary treatment. A bioreactor uses microbes in a medium (bed) to consume pollutants from contaminated air streams. The microbes’ diet consists of carbon-based compounds, water, oxygen (for aerobic reactions), and macronutrients. The simplest type of bioreactor is a biofilter. As seen below, contaminated air flows through an air blower to an enclosed plenum with several feet of bed media on top of a support rack above the plenum. Microbes in the bed media consume and decompose organic compounds in the contaminated air. Certain microbes can also consume inorganic compounds such as hydrogen sulfide and nitrogen oxides. After passing through the bed, the decontaminated air is released to the atmosphere.

The major advantages of using biofilters include:

- **Lower installation and operating costs.** According to the EPA’s 2003 report on bioreactors, the initial capital cost of a bioreactor is usually a fraction of the cost of combustion control devices. Additionally, since the treatment process does not involve heating the contaminant.
An alternative type of recuperative or regenerative oxidizer is a catalytic oxidizer, in which a catalyst reduces the temperature required to destroy VOCs from around 1,500°F to around 800°F. Because the catalyst accelerates VOC destruction and lowers the required operating temperature, a catalytic oxidizer can have a 20% to 30% gain in efficiency over thermal oxidizers.

**Steam Generation in Waste Heat Boilers**

While conventional boilers are fired by fossil fuel, waste heat boilers utilize an exhaust gas stream from external sources to heat the water instead of burning fuel in the burners.

Figure 8 shows a waste heat boiler for steam generation. Waste heat boilers may be horizontal or vertical shell boilers, or water tube boilers, where hot exhaust gases are passed over parallel tubes containing water. The water is vaporized and collected in a steam drum. These boilers can be
designed to work with individual applications ranging from gas turbine exhaust to reciprocating engines, incinerators, and furnaces.

Waste heat boilers can be used with most furnace applications, as long as the exhaust gases contain sufficient usable heat to produce steam or hot water at the condition required. For steam generation, the exhaust gas should preferably be above 750°F. For water heating, the exhaust gas should be about 400°F or higher. When the heat source is in the low-temperature range, boilers become bulky. The use of finned tubes extends the heat transfer areas and allows a more compact size.

Waste heat boilers may be an option for facilities looking for additional steam capacity; however, these boilers only generate steam coincident with the process furnace operation. It should be noted too that the phys-
ical size of a waste heat boiler may be larger than that of a conventional boiler because the furnace exhaust gas temperature is lower than the flame temperature used in conventional systems. This may pose a disadvantage in retrofits where space is limited.

Boilers using exhaust gas from engines fired by heavy fuel oil must be carefully designed, because the exhaust gas may contain soot, which can form an insulation layer on the tubes and shells of the boiler. When this happens, heat transfer is impeded and the efficiency of the system can drop dramatically. Therefore, the gas exit temperature must be maintained at a predetermined level to prevent dew point from being reached and soot from accumulating inside the boiler.

The exhaust gas capacities of waste heat boilers can range from less than a thousand to almost a million cubic feet per minute. If the waste heat in the exhaust gas is insufficient to generate the required process steam in an application, it may be necessary to add auxiliary fuel burners to the waste heat boiler, or to add an afterburner. Because waste heat boilers do not use burners, they are less expensive to install and operate than a new combustion boiler. However, for an industrial facility to benefit from a waste heat boiler, the waste heat source must coincide with the steam demand that would otherwise be met with a combustion boiler.
Feedwater Preheating in Feedwater Economizer

Boiler feedwater economizers transfer the waste heat from boiler exhaust gas to the feedwater in a gas-to-liquid heat exchanger in order to recapture some of the heat loss and improve the overall boiler efficiency. Preheating the feedwater is the most common method of recovering waste heat from boiler flue gas. It is typically a very economical investment for industrial and waste heat boilers. Generally, boiler efficiency can be increased by 1% for every 40°F reduction in flue gas temperature. By recovering waste heat, an economizer can often reduce fuel requirements by 5% to 10% and pay for itself in less than two years.

Preheating boiler feedwater offers the following primary advantages:

- Reduced fuel usage and increased boiler efficiency
- Reduced emissions due to less fuel use
- Quicker response to load changes
- Potentially increased steam production
- Potentially longer boiler life

Economizers are available in two types of designs: water-tube and fire-tube. In a fire-tube economizer, flue gas flows inside the tubes heating the surrounding water. This type of economizer has a large water reservoir, which makes it extremely resistant to steaming and eliminates the need for expensive feedwater-proportioning systems. For boilers larger than 400 boiler horsepower or 13.4 MMBtu/hr (1 Boiler HP is about 33.5 MBtu/hr), a water-tube type economizer can be used. In a water-tube economizer like that in Figure 9, feedwater flows through a tube bundle that is heated by the surrounding flue gas. In many cases water-tube economizers can be fit directly into the exhaust stack, allowing cost-effective installation.

When implementing a feedwater economizer, special consideration must be given to ensure that flue gas is not cooled beyond the low-temperature limit. The lowest temperature to which flue gasses can be cooled depends on the type of fuel being used: 250°F for natural gas, 300°F for coal and low sulfur content fuel oils, and 350°F for high sulphur fuel oils. [8]
Cooling below these limits can result in condensation and possible corrosion of the heat exchanger and the exhaust stack.

**Heat Recovery in Condensing Boilers**

Traditional boilers are designed to prevent flue gas condensation because the condensate forms an acidic solution that can damage the boiler and cause maintenance problems. A condensing boiler is designed to resist corrosion and allow the flue gas to be cooled to its condensing temperature, releasing the latent heat contained in the water vapor. Approximately 10% of the energy content of natural gas is used in the latent heat of vaporization. This latent heat content is not released unless the combustion gas is condensed. Under proper operating conditions, condensing boilers can be approximately 10% more efficient than efficient non-condensing boilers.

Inside the condensing boiler exhaust section, heat is transferred from the flue gas through an enlarged heat exchanger surface to preheat the boiler feedwater. In order to effectively extract the latent heat contained in the

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Source: “Heat Recovery for Canadian Food and Beverage Industries,” Agriculture Canada, Ottawa, 1984
Flue gas water vapor, the boiler inlet water temperature must be low enough to cool the flue gas to condensing temperature. Condensing boilers need to be operated at inlet water temperatures below 140°F. Figure 10 shows the change in boiler efficiency relative to inlet water temperature. The efficiency of a condensing boiler also increases when operating at reduced loads. Thus it is often a cost-effective strategy to employ a pair of condensing boilers and operate them at a fraction of their rated outputs.

**Figure 10: Condensing Boiler Efficiency**

Source: [http://www.esmagazine.com](http://www.esmagazine.com) [9]

**Heat Recovery from Boiler Blowdown**

Boiler blowdown involves either periodic or continuous removal of water from a steam boiler in order to remove accumulated dissolved solids and/or sludge, which can have damaging effects on boiler efficiency and maintenance. However, boiler blowdown wastes energy because the liquid blown down is at about the same temperature as the steam produced.

Two methods are typically employed for recovering energy lost from boiler blowdown, and both are often incorporated in one system. In the first method, the saturated liquid high-pressure blowdown is discharged into a relatively low-pressure receiver, or flash vessel. In the receiver, a portion of the liquid flashes to steam, which can be used either in a low-pressure steam system or in the deaerator to preheat the boiler feedwater. Figure 11
shows a flash steam vessel recovering steam from condensate lines. By removing steam from the condensate system, flash steam vessels provide an efficient source of steam to low-pressure end uses. For example, 250°F condensate has a saturation pressure of about 15 psig. It can be used in low-pressure steam applications such as space heating and preheating.

**Figure 11: Flash Vessel Steam Recovery**

![Flash Vessel Steam Recovery Diagram]


The second method of boiler blowdown heat recovery takes advantage of the significant temperature difference that exists between the saturated liquid from the flash vessel and the makeup water. The remaining liquid blowdown is piped through a heat exchanger to preheat the makeup water before entering the deaerator. A combined flash steam and residual blowdown heat recovery system, such as the one shown in Figure 12, can recover up to 90% of heat energy that would otherwise be wasted.

**Boiler Blowdown Heat Recovery**

**Newsprint Mill in Augusta, Georgia**

This Georgia newsprint mill reduced its steam system energy losses by routing the boiler blowdown stream to a flash tank, where the pressure is reduced. The steam created from the pressure reduction is routed to a heat exchanger, preheating the incoming boiler feedwater by 17°F. The project is saving almost $31,000/year in fuel costs. [6]
Any boiler with continuous blowdown exceeding 5% of the steam rate is a good candidate for the introduction of blowdown waste heat recovery. Larger energy savings occur with high-pressure boilers.

**Heat Cascading**

Heat cascading describes a broader application of recycling heat for external uses. Waste heat from a primary process may still contain enough energy to operate a secondary process, as long as its temperature is high enough to drive the energy to its intended destination. Cascading heat from preceding processes can reduce the amount of energy required in subsequent processes. Some examples include: water heating with waste heat boilers, drying or evaporating using exhaust gas from high-temperature furnaces, using multiple-effect evaporators in food processes, and using cooling tower water for space heating. The goal of cascading heat is to use a continuous flow of waste gas through process after process, serving many heat needs in the facility, until no usable heat is left before the gas finally exits.
In a heat cascading process, heat is transferred between sequentially smaller temperature differentials or steps, rather than a single large temperature differential—enabling efficient utilization of thermal energy. In designing heat cascading, it is necessary that the heating load absorbing the waste heat be available during the periods of waste heat generation; otherwise, the waste heat may be useless, regardless of its quantity and

### Three-Effect Evaporators

#### Tomato Processor in California

The purpose of evaporation is to concentrate a non-volatile solute from a solvent by boiling off the solvent, usually water. It is the most common process in the food processing industry. An evaporator consists of a heat exchanger for boiling water and a separator to separate the vapor from the concentrated liquid.

A single evaporator typically requires almost a one-to-one ratio of steam input to the amount of water evaporated. Two or more evaporator units can be run in sequence to perform a multiple-effect evaporator. In a multiple-effect evaporator, water is boiled in a sequence of vessels, each held at a lower pressure than the previous one. Because the boiling point of water decreases as pressure decreases, the vapor boiled off in one vessel can be used to heat the next, and only the first vessel requires an external source of heat.

Multiple-effect evaporators evaporate more water by increasing the area of heat transfer and improving the heat transfer effectiveness due to the viscous effects of the products as they become more concentrated. In a three-effect evaporator, one pound of steam can evaporate approximately three pounds of water from the product through the cascading evaporators.

A tomato processing plant’s operations include the use of evaporators to concentrate tomatoes into tomato paste. New three-effect evaporators use the waste heat produced in the first evaporation chamber to further concentrate the tomato paste without the need for additional steam from the boiler. The project is estimated to reduce the plant’s natural gas usage by 775,000 therms/year. [11]
quality. When source and load cannot be synchronized, either another heat load must be found, or an auxiliary heat source needs to be available to carry the load.

Tying two processes together using cascading heat requires more than just the correct temperatures and heat flows. To make the system operate effectively, the logistics must also be set up correctly. For example, if a chemical plant needs a constant supply of heated water for a specific process, and the water heater is totally dependent on the exhaust from an oven, then the oven must run continuously. If this is not feasible, an auxiliary burner can be installed on the water heater to carry the load when the primary process is not running. On the other hand, as long as the oven is operating there will be a supply of hot water, whether it is needed for the process or not. Another key consideration is the placement of equipment. The closer the proximity of primary and secondary processes, the better. Carrying exhaust gas through long runs of ductwork can create an expensive and difficult-to-maintain infrastructure, and the efficiency of energy recovery will be compromised by the heat losses between the two processes. This is of less concern if the primary energy source is liquid or hot oil because these heat transfer mediums can carry energy over greater distances.

**Heat Recovery Using Absorption Chillers**

Combined heat and power (CHP) plants are being utilized in many facilities. In particular they are becoming more common for facilities with large cooling loads and those with balanced simultaneous demands for electric power and heating. A CHP plant generates electrical power using an internal combustion engine, gas turbine, microturbine, or fuel cell. The waste heat from the power generator can be used for process heating and cooling through a waste heat recovery loop. Applications include space heating, absorption chillers, dehumidifiers, heat pumps, heat wheels, and other devices.

Absorption chillers use heat rather than mechanical energy to provide cooling. A thermal compressor consists of an absorber, generator, pump, and throttling device. In the evaporator, the refrigerant evaporates and extracts heat from the building. The refrigerant vapor then is absorbed by
the absorbent. The combined fluids go to the generator, where heat is provided from a waste steam heat source to separate refrigerant from the absorbent. The refrigerant then goes to the condenser to be cooled back down to a liquid, while the absorbent is pumped back to the absorber. The cooled refrigerant is released through an expansion valve into the evaporator, and the cycle repeats. Low-pressure, steam-driven absorption chillers are available in capacities ranging from 100 to 1,500 tons. Figure 13 illustrates an absorption chiller cycle.

Absorption chillers generally have lower coefficients of performance (chiller load / energy input) than traditional chillers; however, they can substantially reduce operating costs because they are powered by using waste heat. Considering the energy efficiency from the source to the point of use, a waste heat absorption chiller can be comparable to a large water-cooled electric chiller plant. Single-effect absorption chillers have a coef-
efficient of performance of 0.7; double-effect absorption chillers are about 40% more efficient. [12]

In an absorption chiller application in a CHP plant, the waste heat from the electrical generator is captured by a waste heat recovery boiler. The boiler provides steam for processes and also drives an absorption chiller that provides cooling to the facility. Considering the outputs of electricity, heating, and cooling, the fuel efficiency of CHP plants can be as high as 60% to 80%, compared with the 30% to 40% from conventional electrical generators.

**Heat Recovery Using a Desiccant Dehumidifier**

A desiccant dehumidifier uses a drying agent, or sorbent, to remove water from the air used to condition building space. Desiccants can run off the waste heat from distributed generation technologies, with system efficiency approaching 80% in CHP mode. The desiccant process involves exposing the desiccant material, such as silica gel, to a moisture-laden process

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**Figure 13: Absorption Chiller Cycle**

Source: www.trane.com
air stream. Once the moisture is absorbed from this stream, another stream of regenerated air removes the moisture from the desiccant.

A solid desiccant dehumidifier like that shown in Figure 14 is most commonly placed on the surface of a corrugated matrix in a wheel that rotates between the process and regeneration air streams. On the process side, the desiccant removes moisture from the air while releasing heat during the sorption process. As the wheel rotates onto the regeneration side, natural gas, waste heat, or solar energy can be used to regenerate the desiccant material.

**Figure 14: Solid Desiccant System**

Humidification applications are found in the chemical manufacturing industry where control of ambient temperature and moisture content are critical for product quality.

**Cost Considerations**

In general, waste heat recovery methods can improve performance—i.e., increase the overall efficiency of a process heating system—by 5% to 30%. Table 3 provides a summary of the cost-saving potential and expected simple payback periods of waste heat recovery methods and applications described above.
**Table 3: Summary of Waste Heat Recovery Methods**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Waste Sources</th>
<th>Temp Range*</th>
<th>Applications</th>
<th>Savings Potential**</th>
<th>Simple Payback</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-temperature heat recovery through</td>
<td>Exhaust gases from incineration or thermal</td>
<td>H,M</td>
<td>Incoming product pre-heating</td>
<td>20%-40%</td>
<td>24-48 months</td>
</tr>
<tr>
<td>recuperators/regenerators</td>
<td>oxidation processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load preheating</td>
<td>Exhaust gas from fuel-fired burner, afterburner</td>
<td>H,M,L</td>
<td>Incoming product pre-heating</td>
<td>10%-25%</td>
<td>6-24 months</td>
</tr>
<tr>
<td>Combustion air preheating</td>
<td>Exhaust gas from fuel-fired burner, afterburner</td>
<td>H,M</td>
<td>Combustion air preheating</td>
<td>10%-30%</td>
<td></td>
</tr>
<tr>
<td>Waste heat boiler</td>
<td>Exhaust gas from gas turbines, reciprocating</td>
<td>H,M</td>
<td>Steam generation, Water</td>
<td>5%-20%</td>
<td>6-24 months</td>
</tr>
<tr>
<td></td>
<td>engines, incinerators, furnaces</td>
<td></td>
<td>heating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedwater preheating</td>
<td>Exhaust gas from fuel-fired burner</td>
<td>H,M,L</td>
<td>Feedwater, make-up water preheat-</td>
<td>2%-20%</td>
<td>6-24 months</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat recovery through boiler blowdown</td>
<td>Steam boiler blowdown</td>
<td>H,M,L</td>
<td>Steam generation, Feedwater</td>
<td>Up to 90%***</td>
<td>6-12 months</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>preheating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat cascading</td>
<td>Various</td>
<td>H,M,L</td>
<td>Various</td>
<td>5%-20%</td>
<td></td>
</tr>
<tr>
<td>Absorption chiller</td>
<td>Waste steam from gas turbines</td>
<td>L</td>
<td>Absorption cooling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desiccant dehumidifier</td>
<td>Waste steam from gas turbines</td>
<td>L</td>
<td>Air dehumidification and/or</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cooling</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: This summary provides general information. The cost-effectiveness of a particular heat recovery method must be analyzed for the project under consideration.

* High, medium, or low, as defined in Table 1

** Annual energy cost savings compared to the condition without waste heat recovery

*** Annual energy cost savings for boiler blowdown refers to the heat recovery ratio
Facility owners generally use the payback period as a measure of the cost-effectiveness of a project. The payback period is affected by the service life of the equipment installed. Heat exchangers generally have a service life of up to 20 to 25 years, although special applications or harsh environments can shorten that life. Waste heat boilers and turbines have a service life of about 30 years. A longer payback period is generally acceptable for projects having long-life equipment, but a payback period of three to five years is considered reasonable.

The cost of a heat exchanger varies with the temperature range to which it would apply: the higher the temperature range, the higher the cost, due to higher material cost and additional engineering requirements. However, because a high-temperature source provides high-quality waste heat, the cost per unit of energy transferred can be less. Choosing appropriate heat exchange equipment is the key to high cost-effectiveness.
Notes


http://www.esmagazine.com/CDA/Articles/Feature_Article/6fece5d1ab6a9
010VgnVCM100000f932a8c0 (accessed January 2009).

Solutions for Efficiency, Emissions and Cost Controls.
http://www.energysolutionscenter.org/BoilerBurner/Eff_Improve-

11. Confidential. PG&E Non Residential Retrofit – Demand Response pro-
gram. Nexant, Inc.


13. US Department of Energy, Pacific Region CHP Application Center,
“Combined Heat & Power in a Winery: Vineyard 29 120 kW
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