A GUIDE TO
HEAT EXCHANGERS FOR
INDUSTRIAL HEAT RECOVERY

NEW YORK STATE
ENERGY RESEARCH AND
DEVELOPMENT AUTHORITY
CONTENTS

RECOVERY POTENTIAL .................................................. 1
TECHNOLOGY .............................................................. 3
ECONOMICS ............................................................... 15
ENVIRONMENT ........................................................... 17
SYSTEM APPLICATION .................................................. 19
ADDITIONAL INFORMATION .......................................... 20

Recovery Potential

New York State's industrial sector consumes approximately 350 trillion Btu per year. About 110 trillion Btu per year of this annual consumption is dissipated to the atmosphere as boiler or furnace stack gas — the largest, most concentrated form of recoverable waste heat.

Process and cooling water in the 90-200°F range also account for significant quantities of waste heat, about 130 trillion Btu per year, but its low temperature generally precludes direct utilization. Recovery of heat in process and cooling water is a better application for industrial heat pumps rather than heat exchangers alone. A companion brochure describing the use of industrial heat pumps is also available from NYSERDA.

What are the underlying factors limiting the extent of heat recovery?

The amount of heat recovered from stack gas depends on the stack temperature, composition, heat exchanger effectiveness, and quantity of recovered heat that can be utilized. The useful media that accepts the heat from the heat exchanger is called the heat sink. Most often the heat sink limits the extent of heat recovery because the industrial process has no use for the recovered heat at the temperature level of the exiting stack gas.

How much energy can be recovered by different industries?

Stack gas heat recovery systems for different applications and their corresponding recovery potential are listed in Table 1. High-temperature industries (those having minimum processing temperatures between 1500-2800°F) normally have adequate heat sinks to recover 40-70% of their waste heat. Heat exchangers employed to effect this recovery are ceramic and metallic radiation recuperators, ceramic heat wheels, regenerators, waste heat boilers and fluidized beds.

Medium-temperature industries (600-1500°F) can normally recover 35-60% of stack waste heat. Heat exchangers used for these applications are metallic radiation or convective recuperators, metallic heat wheels, air heaters and waste heat boilers.

Heat exchanger technologies available for low-temperature industries (under 600°F) are economizers, air preheaters, condensing heat exchangers, direct-contact heat exchangers and heat wheels. These technologies enable 30-65% of the stack waste heat to be recovered for low-temperature industries.

The energy discharged in boiler stacks (350-700°F) accounts for one-quarter of all stack gas waste heat in New York State. About 30-65% of this heat can be recovered depending on available heat sink through the use of economizers, air preheaters, condensing, and direct-contact heat exchangers and heat wheels.

In summary, 35-65% of the stack waste heat in New York State, 40-70 trillion Btu/year, can be recovered by implementation of commercially available heat exchangers.
TABLE 1. STACK GAS HEAT RECOVERY IN NEW YORK FOR EQUIPMENT APPLICATION

<table>
<thead>
<tr>
<th>Type</th>
<th>Industry</th>
<th>Present Waste Heat Trillion Btu</th>
<th>Potential Waste Heat Recovery %</th>
<th>Commercially Available Heat Exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Temperature (1500-2800°F)</td>
<td>Primary Metals</td>
<td>34</td>
<td>40 - 70%</td>
<td>Recuperator</td>
</tr>
<tr>
<td></td>
<td>Stone</td>
<td>22</td>
<td></td>
<td>— Ceramic</td>
</tr>
<tr>
<td></td>
<td>Chemicals</td>
<td>10</td>
<td></td>
<td>— Metallic radiation</td>
</tr>
<tr>
<td></td>
<td>Fabricated Metals</td>
<td>5</td>
<td></td>
<td>Heat Wheel</td>
</tr>
<tr>
<td></td>
<td>Machinery</td>
<td>3.6</td>
<td></td>
<td>— Ceramic</td>
</tr>
<tr>
<td></td>
<td>Electrical Machinery</td>
<td>2.6</td>
<td></td>
<td>Regenerator</td>
</tr>
<tr>
<td></td>
<td>Motors</td>
<td>1.3</td>
<td></td>
<td>Waste Heat Boiler</td>
</tr>
<tr>
<td>Medium-Temperature (600-1500°F)</td>
<td>Petroleum</td>
<td>1.2</td>
<td>35 - 60%</td>
<td>Recuperator</td>
</tr>
<tr>
<td></td>
<td>Furniture</td>
<td>0.05</td>
<td></td>
<td>— Metallic radiation/conduction</td>
</tr>
<tr>
<td>Low-Temperature (except boiler) (under 600°F)</td>
<td>Food</td>
<td>1.2</td>
<td>30 - 65%</td>
<td>Finned-Tube</td>
</tr>
<tr>
<td></td>
<td>Rubber</td>
<td>0.7</td>
<td></td>
<td>Heat Wheel</td>
</tr>
<tr>
<td></td>
<td>Instrument</td>
<td>0.3</td>
<td></td>
<td>Heat Pipes</td>
</tr>
<tr>
<td></td>
<td>Textile</td>
<td>0.09</td>
<td></td>
<td>Air Preheater</td>
</tr>
<tr>
<td></td>
<td>Lumber</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler Waste Heat (350-700°F)</td>
<td>Chemicals</td>
<td>7.7</td>
<td>30 - 65%</td>
<td>Economizer</td>
</tr>
<tr>
<td></td>
<td>Paper</td>
<td>5.9</td>
<td></td>
<td>Air Preheater</td>
</tr>
<tr>
<td></td>
<td>Instrument</td>
<td>2.8</td>
<td></td>
<td>Condensing Heat</td>
</tr>
<tr>
<td></td>
<td>Fabricated Metals</td>
<td>2.2</td>
<td></td>
<td>Direct-Contact</td>
</tr>
<tr>
<td></td>
<td>Primary Metals</td>
<td>1.1</td>
<td></td>
<td>Heat Wheel</td>
</tr>
<tr>
<td></td>
<td>Printing</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Textile</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Motor Vehicle</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>8.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total for New York State</td>
<td></td>
<td>112</td>
<td>35 - 65%</td>
<td></td>
</tr>
</tbody>
</table>
Why are heat exchangers for stack gas heat recovery worth considering?

Higher fuel prices and recent technology developments enable the cost-effective use of heat exchangers in applications that could not have been considered before. Stack heat recovery has been practiced for over 50 years. However, rejected heat, which was previously considered too expensive to recover, now can have additional value through its recovery. Recent heat exchanger developments allow recovery of heat from high-temperature and dust-laden sources. It is also possible to recover the latent heat from stack gas. All the heat exchangers discussed in this brochure are commercially available.

Heat exchangers can be simply retrofitted to an existing stack at an installed cost and resulting energy saving which yield paybacks between 0.5-4 years. The cost to recover the energy beyond the payback period is well under $0.5/MMBtu.

Stack heat exchangers assist in environmental quality control. For example, condensing heat exchangers reduce particulate emissions, while recuperators lower the volume flow of stack gas by reducing its temperature. The lower volumetric flow rate enables the use of lower capacity cleanup equipment, which can be less costly.

What are the best uses for heat exchangers to recover waste heat?

An oil- or gas-fired operation with a waste heat source of 0.5-15 MMBtu/hr is an excellent candidate for a waste heat recovery system. The lower price of coal makes heat recovery less attractive. Heat recovery from coal-fired operations, however, is still cost-effective in many applications.

How are heat exchangers used for stack gas heat recovery?

Heat exchangers are devices which transfer energy from the waste heat stream to a colder, useful media. The energy gained by this media may be immediately utilized or stored for future use. Heat exchangers are found in almost all waste heat recovery systems: direct utilization, heat augmentation and power generation. In all but direct utilization applications, heat exchangers are components of the total system and do not need to be evaluated separately. Therefore, this brochure focuses only on the use of heat exchangers to directly recover waste heat from stack gas.
In non-contact heat exchangers, which are the most common type, heat transfer occurs through a conductive material separating the cold stream from the hot stream. In direct-contact units, such as spray systems, the two streams are intimately mixed, allowing energy to be directly transferred. In both cases, the maximum amount of energy that can be recovered is the sensible heat of the hot stream over and above the temperature of the entering cold stream. Latent heat can also be captured if the temperature of the heat sink is below the dew point of the stack gas. In reality, this maximum energy can never be achieved because of the need to provide an adequate driving force for the transfer mechanism, and because of external heat losses to the atmosphere. Of these, the driving force limitation is the most important in defining the amount of heat that can be economically recovered.

The effectiveness of the heat exchanger is simply defined as the ratio of the actual amount of heat transferred (to the useful media) to the heat available in the stack gas. The effectiveness can be increased by increasing the heat transfer area or increasing the overall heat transfer coefficient. More area requires greater capital investment and higher heat transfer. Higher heat transfer coefficients generally require higher operating costs. Therefore, the law of diminishing returns applies to heat exchanger design. A heat exchanger which extracts 50% of the available energy would require twice its heat transfer area to recover an additional 30% of the energy in the stack. Heat exchangers for stack heat recovery are normally sized to recover 50-65% of the heat available in the stack.

What types of heat exchangers are available and how much energy can they save?

This brochure includes only equipment which is commercially available or which can be custom-designed in a relatively short time. Heat exchangers are currently available in numerous designs, sizes and configurations for furnaces, boilers, dryers, ovens, kilns, turbines, and engines. This section considers primarily the heat exchanger in the heat recovery system and does not discuss the controls and auxiliary circulation equipment in detail.

In most cases, manufacturers retain flexibility by offering modular heat exchangers that can be custom-engineered for the particular application. Many manufacturers also offer specific models that are designed to meet a variety of needs. This section provides a working description of the generic types of heat exchangers used for flue gas waste heat recovery. These generic categories are useful only for providing working descriptions and some rough economic guidelines. In most instances, the "application factor" is the most significant element in evaluating the technical and economic issues of a technology. An assessment of the real problems associated with installing this equipment for each industry is necessary. This assessment is very application-specific and depends on the industrial application. A discussion of this application factor is presented, by industry, in the next section.

The type of heat exchanger used depends on temperatures of fluid streams, amount of heat to be transferred, contamination characteristics of the exhaust stream, cost and application for recovered heat.

Heat exchangers used in stack gas heat recovery systems can be generally divided into stack gas-to-air heat exchanger and stack gas-to-liquid heat exchanger as shown in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Stack Gas-Liquid Heat Exchanger</th>
<th>Stack Gas-Air Heat Exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economizer/Finned-Tube</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Condensing Heat Exchanger</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Direct Contact</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Air Heater</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Metallic Recuperator</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ceramic Recuperator</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fluidized Bed</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Reversing Regenerator</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Heat Wheel</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Waste Heat Boiler</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Heat Pipes</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Economizers

An economizer is a heat exchanger incorporated into the stack of a boiler to capture exhaust heat. This recovered heat is used to preheat boiler feed, return or makeup water before it enters the boiler. For conventional systems, the heat extraction must not be so great as to lower the exhaust temperature below the sulphur dew point and cause condensation of corrosive acids in the stack.

For applications in which dust or other contaminants collect on the heat exchanger surfaces, soot blowers, spray wash (steam, water, or water plus detergent) systems, shakers or steel shot, methods are periodically used to dislodge the buildup.

The economizers can be designed with some heat storage capacity using the mass of metal and water in the system. This evens out load fluctuations and allows the boiler to operate more steadily and efficiently. Fuel savings for economizers are dependent on the existing flue gas temperature from the boiler. Fuel savings are 9-10% for a boiler with a 600°F flue temperature and drop to 3-4% for boilers with a 400°F flue temperature (see Table 3). The majority of boilers in New York State have flue temperatures near 400°F.

The economizers can be either cylindrical, with a helical coil tube heat exchanger, or rectangular, with tube bundles making single or multiple passes through the unit. The tubes can be bare or finned to provide the greatest possible heat transfer characteristic in the least possible space.

**TABLE 3. FUEL SAVINGS FOR ECONOMIZERS ON OIL- AND GAS-FIRED OPERATIONS**

<table>
<thead>
<tr>
<th>Flue Temperature (°F)</th>
<th>Fuel Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>15-18</td>
</tr>
<tr>
<td>700</td>
<td>12-14</td>
</tr>
<tr>
<td>600</td>
<td>9-10</td>
</tr>
<tr>
<td>500</td>
<td>6-7</td>
</tr>
<tr>
<td>400</td>
<td>3-4</td>
</tr>
</tbody>
</table>

*Assumes economizer exit temperature of 250°F for natural gas, 300°F for fuel oil, and 20% excess air level.
Condensing Heat Exchanger

This heat exchanger type is usually configured as a shell and tube constructed of a corrosion-resistant material which can withstand the acid properties of stack gas condensate. The stack gases are ducted through one side of the heat exchanger. Return water or air flows through the other side and recovers sufficient waste heat to reduce the stack temperature below the dewpoint, thereby recovering a fraction of the content heat of vaporization.

Stainless steel is resistant to corrosion but is not suitable for oil-fired applications. The corrosion problem has been addressed by coating non-corrosion-resistant tubes with materials resistant to corrosion such as Teflon, phenolics or glass. Heat exchanger tubes made of pyrex are now available for stack gas-to-air applications or oil-fired boilers.

Condensing heat exchangers enable sensible energy recovery below the oil-fired dew point (250°F) and a fraction of the latent heat transfer. The extent of latent heat transfer depends on the temperatures and sizes of the heat sink. The best applications for condensing heat exchangers are to direct-fired dryers and boilers. For boiler applications, combustion air alone is not a large enough heat sink. However, for dryers, air preheat can be feasible because of the large excess air levels.

Fuel savings from condensing heat exchangers retrofitted to boilers, dryers, and low-temperature furnaces range between 8-12% depending on the installation.
Direct-Contact Heat Exchanger

The direct-contact heat exchanger places the working fluids in intimate contact, thereby enhancing the area for heat exchange per unit volume. In a direct-spray system, water is sprayed directly into the flue gas and is heated. The water falls to the bottom of the stack and flows to a heat exchanger which transfers the heat to a circulating water or air stream.

If the temperature of the stack gas exiting the heat exchanger is above the water dew point, the extent of heat recovery is severely penalized by evaporation losses of the water spray. Therefore, this system is normally only employed in condensing applications. The spray water loop continuously gains water from the flue gas; therefore, a bleed line is necessary.

Air Heater

Air heaters are constructed of alternate channels so that the stack gas and air are in close contact with one another, separated only by a thin, metallic wall. There is no cross-contamination of gas streams. The unit can operate on cross, counter, or parallel, single- or multiple-pass principles. The flow can be defined by two flat plates or small ducts formed by shaping and welding the plates.

There is no drive mechanism or cross-contamination as with a heat wheel. The disadvantages are that they are more expensive than heat wheels because more surface area is required for the same efficiency, and temperature control is more difficult.

Air heaters installed on boilers have potential fuel savings comparable to economizers. For example, a boiler with a 500°F flue might realize a 6-7% fuel savings when retrofitted with an air heater.
Metallic Recuperators

Since the thermal efficiency of a furnace is determined primarily by the final temperature of the exit gases, recuperators can be employed so that combustion products do not leave the system at excessively high temperatures. Recuperators recover heat in the flue gas to preheat the combustion air. Recuperators are similar to air heaters but are used for higher stack temperatures (above 900°F). The performance of these heat exchangers is limited by the temperature of the materials which separate the air from the hot flue gas. Due to these temperature limitations, the majority of present metallic recuperators are restricted to air preheat temperatures less than 1000°F.

Metallic recuperators are divided into two main groups according to which heat transfer mechanism dominates: radiation or convection. A metallic radiation recuperator usually consists of two concentric lengths of metal tubing. The inner tube contains the flue gas, while the combustion air flows parallel to the flue gas in the annulus. The parallel-flow configuration enables lower recuperator wall temperatures than counterflow designs, thereby extending the lifetime of the wall. The inner tube is usually made of high-nickel-content stainless steel. Methods of supporting the recuperator must allow for significant axial expansion.

The convective recuperator consists of a shell and tube design. The stack gas flows through tubes in parallel, while the combustion air passes over the tubes one or more times. Convective recuperators are generally more compact than radiation recuperators because of the larger heat transfer area due to multiple tubes and passes.

Recuperator installations may require the purchase of high-temperature burners if preheat temperature is above 500-600°F, increased air ducts for higher volume flow, cold-air line for burner cooling, modified controls to ensure constant air/fuel ratio as air temperature changes, and bleed air into flue to protect against over temperature and large fans.

Applications for metallic recuperators are recovering heat from soaking and annealing ovens, melting furnaces, afterburners and gas incinerators.

Fuel savings depend on the extent of air preheat and the baseline furnace efficiency as calculated from the flue temperature and excess air. Fuel savings can range from 40% for preheating air to 1000°F in melting applications (2000°F), to 10% for preheating air to 400°F in a scrap aluminum melting furnace (1260°F) as shown in Table 4.
TABLE 4. FUEL SAVINGS FOR PREHEATERS WITH WASTE STACK GAS

<table>
<thead>
<tr>
<th>Air Preheat Temperature °F</th>
<th>Stack Gas Temperature °F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3000</td>
</tr>
<tr>
<td>400</td>
<td>48-52</td>
</tr>
<tr>
<td>600</td>
<td>58-62</td>
</tr>
<tr>
<td>800</td>
<td>63-67</td>
</tr>
<tr>
<td>1000</td>
<td>68-72</td>
</tr>
<tr>
<td>1500</td>
<td>76-81</td>
</tr>
<tr>
<td>2000</td>
<td>82-86</td>
</tr>
</tbody>
</table>

Ceramic Recuperators

Metallic recuperators cannot be used for heat recovery in the 1700-2800°F range because of their temperature limitations. Ceramic materials are used at these temperatures. Recuperator concepts under development consist of a vertical cylindrical heat exchange column formed from modular sections. Within the column, the modules form two flow passages — one for high-temperature exhaust gases and one for preheating combustion air. The column can be operated in a counterflow or cross flow mode, with the exhaust gas entering at the bottom and the combustion air entering at the top of the column. Many ceramic modules or tubular sections are stacked together to form the recuperator. The number of modules and the length of each module for a given application is a function of the exhaust flow-rate temperature and heat transfer effectiveness.

Ceramic recuperators are made of alumina and mullite, capable of withstanding a flue gas temperature up to 3000°F and preheating air to 2400°F. Recuperators made of cordierite are capable of withstanding a 2400°F flue gas temperature and preheating air to 1800°F.

Although the fuel savings potential is very high for ceramic recuperators, as much as 60% for preheating air to 1500-2000°F, they are complex and require specialized engineering services. Leakage between stack gas and combustion air can upset burner control.

Sketch of Ceramic Recuperator
Fluidized-Bed Heat Exchangers

The single-stage counterflow fluidized-bed heat exchanger consists of a vertical cylindrical vessel filled with particulate solids supported by a distributor plate on the bottom. Hot gas enters the base of the unit and passes through the distributor plate into the fluid bed. The upward moving gas exhausts to the atmosphere after passage through a cycling separator which separates most of the entrained particulate. Feed particles at ambient temperature are charged to the bed on one side of the unit and hot particles are discharged at the opposite side.

An alternative to this design uses an internal heat exchanger through which the coolant fluid flows as it is heated from the fluidized sand.

Substantial work has been done by many organizations in this heat exchange technology. Many applications of fluid-bed heat exchangers are fully developed and commercially available, while others are in various stages of development. The following applications have proven successful:

- Rotary cement kilns
- Electric arc furnaces
- Heat treating of steel

Fluidized-bed heat exchangers have higher heat transfer effectiveness than ceramic recuperators. Fuel savings from a fluidized bed heat recovery device for different conditions are shown in Table 4.

Reversing Regenerators

These devices are for preheating combustion air with flue gas waste heat. Heat is extracted from the flue gas and stored in the regenerator which is then used to heat combustion air.

A reversing regenerator passes flue gas through the heat storage media until it heats up to the maximum allowable operating temperature. The flue gas flow is then reversed with the combustion air flow, and the stored heat is transferred from the absorbing media to the flue gas. The heat absorption materials used are high-conductivity and heat-capacity refractories. Reversing regenerators are simpler in construction than a recuperator and enable high preheat temperatures. However, they are more expensive than recuperators, need reversing gear, and have a continuously changing air preheat temperature.

Achievable fuels savings are dependent on stack temperature and air preheat level as shown in Table 4.
Heat Wheels

A heat wheel has porous heat absorption material mounted on a wheel that rotates between the higher- and lower-temperature gas streams. As a segment of the wheel passes through the hotter gas, it absorbs the heat in its structure which is released when it passes through the cooler stream. Between the clean and dirty sections, there may be a purge section that blows out contaminants.

The heat absorption material can be metal (aluminum, steel, or stainless steel) or other compounds fabricated to provide a large heat transfer surface and sufficient volume to hold the required heat. The heat transfer medium can be coated or compounded with a corrosion-resistant material to resist condensates of the dirty exhaust stream. Cleaning of the wheel can be accomplished by air blowers, steam or water sprays.
Sensible heat can be recovered at temperatures up to 1400°F, depending on the absorption material employed. Latent heat can be captured using desiccant coatings that can also transfer moisture between streams as needed. Heat wheels can be highly effective heat exchangers, capturing 70-90% of the lost heat in the exhaust stream and transferring it to a cooler stream. Low to high air volumes can be effectively handled depending on the size of the device. A variable-speed motor drive, using temperature sensors, can control temperatures of the two streams.

Fuel savings for heat wheels can be determined from Table 4. Heat wheels do not have as high a temperature range as recuperators; therefore, the higher waste flue gas temperature cases in this table do not apply. Fuel savings can range from 12% for 400°F air preheat using 1000°F flue gas to 21% for 600°F air preheat using a 1500°F flue gas.

Waste Heat Boilers

Waste heat boilers are designed to recover heat from exhausts of incinerators, furnaces, ovens, dryers, gas turbines, diesel engines and other equipment having exhaust temperatures of 800°F-2400°F. Steam can be generated or water can be heated for process uses or space heating. These units are normally designed for the special purpose of heat recovery and differ from normal boilers that are converted for heat recovery. The boilers have increased insulation and are designed for low-pressure drop in tubes through which the exhaust flows.

Waste heat boilers range from 2 to 100 MBtu/hour. Fuel savings are 65-70% for a 2500°F flue temperature, 48-53% for a 2000°F flue temperature, and 15-20% for a 1000°F flue temperature.

The units available can provide waste heat input to useful heat output efficiencies of 80% or more.
Heat Pipe Heat Exchangers

A heat pipe is a tube with a capillary wick inside that has been evacuated, filled with a refrigerant and sealed. Heat at one end causes the refrigerant to vaporize and travel to the other end of the tube. The heat is removed, and the vapor condenses and returns to the other end of the tube to complete the cycle. Heat pipe heat exchangers are available on the market for transferring heat between clean or dirty exhaust air or flue gases and clean air streams.

Heat pipes are compact and have high heat transfer effectiveness for gas/gas applications. Applications for currently available heat pipes using organic working fluids such as refrigerants are in the medium temperature range (400°F - 600°F) for flue gas recovery. They can be used in ovens, kilns, dryers and furnaces. Fuel savings are shown in Table 3.

Applications that have 500-600°F stack gas have the potential to achieve 6-10% fuel savings.

What kinds of equipment in addition to the heat exchanger are needed to complete heat recovery systems?

The amount of additional equipment needed to complete the heat recovery system varies depending on the heat exchanger and application. Some air heaters, for example, are totally passive and require no auxiliary equipment, whereas recuperators may require high-temperature limit controls, a high-temperature burner, and increased forced draft. Aside from the heat exchanger, the following equipment may be required:

- Pumps
- Fans or blowers
- Control devices
- Valves, automatic and manual
- Pipes
- Dampers, automatic and manual
- Ducts
- Insulation
- Miscellaneous items (filters, etc.)

The exact equipment required for the application is extremely site-specific.

All of these have capital costs associated with them. Pumps and fans have a utility requirement, generally that of the electrical power to drive them. Some devices require periodic maintenance. Others need periodic replacement. Costs for such action become part of the operation and maintenance cost factor. The equipment must also be installed, the cost of installation being similar to an initial capital cost. The parasitic energy consumption of this additional equipment is usually less than one percent of the total heat recovery.

The cost of the heat recovery systems presented in the Economics section of the brochure includes all the auxiliary equipment required and total installation costs.
How close does the heat sink have to be to the waste heat source?

In most cases, where waste heat is used to preheat combustion air or boiler makeup water, the heat sink is close to the heat source. However, where flue gas is used to heat water or air through a secondary exchanger, the heat sink may be a considerable distance from the waste heat source. Therefore, heat losses from the distribution system and storage tank can substantially reduce the quantity of heat effectively utilized. In these cases, tanks and lines must be insulated to prevent standby heat loss, which adds to the cost of installation. Heat sinks located up to 200-300 feet from the heat source are generally acceptable. However, at greater distances, the distribution and storage energy losses become significant.

How much space is required for a heat recovery system?

Although each application is different, in general very little space is required for waste heat recovery equipment. Most non-direct heat exchangers can be placed directly on the stack, either inside or outside the building; thus, they require little floor space. It is less expensive to place them in the building if space is available, but outdoor installations are not difficult and add only a 10% premium to installation costs. Direct heat exchangers usually require a secondary heat exchanger which adds to floor space requirements.
Economics

Do stack gas heat recovery equipment investments meet my company’s profitability criteria?

If you have an application for stack gas heat recovery based on the previous sections of this brochure, a rough idea of the system economics can be obtained from Table 5. The payback period rated here is the “simple” payback period which ignores everything but first-cost and annual savings. All technologies considered have an extremely wide range of payback periods because the installed costs are very specific to the application. The payback cannot be normalized to a given application for all technologies. For example, a condensing heat exchanger may have a 2-year payback if retrofitted to a boiler with a 78% overall thermal efficiency, or a 6-year payback for a boiler with an 84% efficiency. We have based payback period estimations on actual installations rather than more sophisticated economic measurements. The payback period is an economic criterion most often considered in the initial evaluation of this equipment. The table presents a very rough amount of economic information to help you determine if a heat recovery investment is in the “ballpark” of your company’s profitability criteria. From Table 5, it is evident that the installed cost per unit of recovered energy varies widely. If the investment looks promising, a more accurate economic evaluation enabling a ±20% confidence should be performed.

How can an accurate economic analysis of heat exchangers be performed?

First, you must know your waste heat source and heat sink by characterizing their flow rates, temperature and composition, considering fluctuations during the year. Determine how much heat can be recovered and effectively utilized by load-matching the two fluid streams. Next, based on the heat exchanger selection, develop a conceptual design showing the heat exchanger, auxiliary equipment and material balances. At this point, obtain the names of manufacturers of the heat recovery equipment. Find out what their: (1) recommendations are for specific equipment; (2) rough estimates are for equipment based on the conceptual design; and (3) assessment is of potential energy savings for the given application.

The installation costs can be estimated from the capital equipment costs. Multipliers range from 0.5 to 1.5 for heat recovery installations. For the purpose of this intermediate accuracy assessment, assume a multiplier of 1.0 unless the manufacturer can give a better estimate based on actual installation.

### Table 5: Economics of Heat Recovery Systems

<table>
<thead>
<tr>
<th>Type</th>
<th>Average Energy Savings %</th>
<th>Installed Cost $/MMBtu/hr</th>
<th>Average Payback Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economizer</td>
<td>4- 8</td>
<td>28,000- 60,000</td>
<td>1-2</td>
</tr>
<tr>
<td>Condensing Heat Exchanger</td>
<td>9-12</td>
<td>61,000- 92,000</td>
<td>2-3</td>
</tr>
<tr>
<td>Air Heater</td>
<td>3- 7</td>
<td>31,000- 61,000</td>
<td>1-2</td>
</tr>
<tr>
<td>Metallic Recuperator</td>
<td>20-40</td>
<td>41,000- 70,000</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>Ceramic Recuperator</td>
<td>30-60</td>
<td>55,000- 92,000</td>
<td>2-3</td>
</tr>
<tr>
<td>Heat Wheel</td>
<td>4-20</td>
<td>50,000- 75,000</td>
<td>1.5-3</td>
</tr>
<tr>
<td>Heat Pipes</td>
<td>4-10</td>
<td>57,000- 78,000</td>
<td>2-3</td>
</tr>
<tr>
<td>Direct-Contact</td>
<td>9-13</td>
<td>65,000- 95,000</td>
<td>2-3</td>
</tr>
<tr>
<td>Waste Heat Boiler</td>
<td>30-50</td>
<td>52,000- 95,000</td>
<td>1.5-3</td>
</tr>
<tr>
<td>Fluidized Bed</td>
<td>20-60</td>
<td>60,000-100,000</td>
<td>2-3.5</td>
</tr>
</tbody>
</table>

*Assumes $5/MMBtu for fuel price, typical process efficiencies, and operating times for generic heat exchanger applications.
At this stage, the energy cost savings must be estimated. Each unit of energy recovery actually displaces more than one unit of fuel consumption. To calculate the fuel displacement, the recovered energy must be divided by the baseline efficiency of the devices which convert the fuel to heat. The displaced energy can then be converted to cost savings through factoring by the local fuel price. From this simple analysis, the fuel savings, installed cost and payback period can generally be estimated to within 20%.

If the investment looks promising, the accuracy of the economic analysis should be improved to ±10% by a feasibility study discussed in the System Application section of this brochure. The feasibility study will typically result in a more detailed financial analysis, which will provide all the information necessary to evaluate the proposed project.
Environment

What are the environmental effects associated with the use of stack heat recovery equipment?

The impact of heat recovery on stack emissions must be considered on an individual basis. Lower stack gas temperatures due to heat recovery systems result in a reduction of the volume flow rate of stack gas, thereby allowing downstream cleanup equipment to be smaller in capacity. An added benefit in urban areas is the reduction of thermal pollution. Ground-level pollutant concentrations are effected by the tradeoff between decreased pollutant dispersion and lower emission rates. As stack gas temperatures decrease, reduced buoyancy causes lower emission dispersion rates which results in higher ground level pollutant concentrations. Lower fuel consumption resulting from heat recovery causes lower pollutant emission rates.

Condensing heat exchangers remove 50-80% of the particulates in the flue gas stream. However, flue gas condensate is discharged from the heat exchanger, which in natural gas-fired systems has a pH of 3-5 but in fuel oil-fired systems can be very acidic with a pH of 0-2. This can be diluted with water or neutralized with a base before going to a sewer.

What about safety?

It is important to ensure that the heat recovery equipment does not change pressure and flow in the combustion chamber. Hot duct work should be insulated, and personnel must be aware of and protected against high temperatures. Other hazards include those found in a normal operating environment: mechanical, electrical and general hazards such as tripping, etc.

Are NYS environmental permits required for these systems?

At the local level, building permits may be required for installation of heat recovery equipment. The existing certificate to operate an oil- or solid-fuel-fired furnace or boiler may have to be modified to include heat recovery equipment. Inquiries should be directed to the regional office of the New York State Department of Environmental Conservation. No problems for receiving certificate modifications are anticipated because total emission rates are lower due to reduced fuel consumption.
Stack Emissions from Condensing Heat Exchanger Installed on Fixed-Bed Grain Dryer to Preheat 63,000 ACFM of Inlet Air

Stack Emissions from Three Twin-Radiation Recuperators Fitted to Three Pusher Furnaces, Each of Which Has a Capacity of 325 TONS/HR.
System Application

Is installing a stack gas heat recovery exchanger a simple matter of purchasing the unit?

Yes, it can be. You can purchase a “turnkey” installation. There are many energy service companies that will provide a feasibility study at nominal cost, and upon your approval, will carry out the entire project from conception to system shakedown.

However, you may choose to treat this as any other engineering project and design and install the unit in-house. There are many technologies available; you will want to select the most promising system for your needs.

What are the steps in assembling a complete waste heat recovery system?

Feasibility Study — A careful review of sources of waste heat and of energy needs must be made. This study should include: (a) the identification of heat sources, (b) a characterization of energy needs — i.e., determining quantity of heat, temperature level and heat transfer rate required, and (c) an assessment of the operational effects involved in implementing a waste heat recovery system. Depending upon the complexity of the proposed system, effects may range from reduced fuel consumption rates, if waste heat is used to preheat combustion air to process, or capacity changes resulting from preheated feed streams. A consultant may be required to perform this study if in-house personnel are not experienced in this area.

The financial analysis is the bottom line of the feasibility study. Waste heat utilization should reduce overall energy consumption, but savings must be balanced with installation and operational costs.

Preliminary Design — During the preliminary design phase, different heat recovery systems should be considered as there may be several feasible alternatives for a process. Engineering design firms, consulting firms, and equipment manufacturers should be helpful in selecting the proper unit for the application. Environmental and building permits must be acquired at this stage. Project plans and equipment procurement should be scheduled so that cash flow can be estimated. If engineering or business resources within the firm are limited, consulting with outside firms may be necessary.

Financing — Arranging financing can be similar to financing any investment. Third-party financing is also an option. An energy service company can pay for the cost of installation under a “shared savings contract”; the system’s cost is repaid to the company over a contractually designated period from a portion of the energy savings.

Engineering Design — At this stage, the user will want to ensure that the heat recovery system is properly engineered to fully utilize the energy savings potential in waste heat. A detailed design of the system may be developed in-house or by experienced engineering consulting firms.

Construction — Installation of a stack gas heat recovery system is a straightforward construction project. It should be scheduled to ensure a nominal disruption of plant operations.

Operation — In most cases, operation and maintenance of a system can be carried out by existing plant personnel.
Additional Information

Additional information regarding heat exchangers for waste heat recovery can be obtained from the New York State Energy Research and Development Authority, Two Rockefeller Plaza, Albany, New York 12223, (518) 465-6251. The Authority can provide a more detailed report, “A Guide to Industrial Utilization of Heat Exchangers for Waste Heat Recovery in New York State.” This report elaborates on each technology, presents an example application, and lists the manufacturers of various types of heat recovery equipment.

The 1984 Products and Services section of the Thomas Register is another source of information on manufacturers of waste heat recovery equipment. Equipment manufacturers and their representatives can provide information on details of the application, the approximate cost and installation requirements. They generally offer to demonstrate their equipment installed at other sites with similar applications.

Consulting energy engineers can provide assistance in determining the overall feasibility of a project. If desired, they can also assume the responsibility of implementing the waste heat recovery equipment. Economic and financing advice is available through the New York State Department of Commerce, Division of Industrial and Corporate Development, One Commerce Plaza, Albany, New York 12245, (518) 474-1131.

Information regarding required certificate modifications in your local area can be obtained from your regional office of the Department of Environmental Conservation which issued your original certificate for oil- or solid- fuel-fired systems.
REFERENCES


5. Private communication with heat exchanger manufacturers.
The New York State Energy Research and Development Authority (NYSERDA) is a public-benefit corporation chartered by the New York State Legislature. It is governed by a 13-member Board of Directors appointed by the Governor with the consent of the Senate. State Energy Commissioner William D. Cotter is Chairman of the Board and the Chief Executive Officer. A President manages the Energy Authority's RD&D programs, staff, and facilities.

As expressed in its enabling legislation, the underlying rationale for establishing the NYSERDA is:

... that accelerated development and use within the State of new energy technologies to supplement energy derived from existing sources will promote the State's economic growth, protect its environmental values and be in the best interests of the health and welfare of the State's population. . .

The legislation further outlines the Energy Authority's mission as:

... the development and utilization of safe, dependable, renewable and economic energy sources and the conservation of energy and energy resources.

NYSERDA's RD&D policy and program stress well-designed research, development and demonstration projects based on technologies with potential for near-term commercialization and application in New York State. The Energy Authority seeks to accelerate the introduction of alternative energy sources and energy-efficient technologies and to improve environmental acceptability of existing fuels and energy processes. NYSERDA also seeks to ensure that Federal research programs reflect the needs of the State.

The use of New York contractors and an awareness of energy-related growth opportunities are part of the Energy Authority's effort to support industry in New York. Concentrating on these objectives ensures that NYSERDA's RD&D programs will produce maximum benefits to the citizens and businesses of New York, while attracting the participation of both the private sector and the Federal Government.

NYSERDA derives its research and development revenues from an assessment upon the intrastate sales of the State's investor-owned gas and electric utilities. The Energy Authority also derives income from the investment of retained earnings and leased property, as well as from bond financings of pollution control facilities and special energy projects.