“Steam system energy savings can be just as practical as lowered lighting costs, and it is important for North American industry to grasp this concept and reap the rewards of doing so. In fact, the dollar impact can be far greater.”
EXECUTIVE SUMMARY

Today as much as 90% of all electricity in the U.S. is steam-generated, and virtually half of all fuel consumed by American industry is burned specifically to produce steam. It is used to heat raw materials, treat semi-finished products, provide power to equipment, heat facilities and generate electricity.

Despite steam’s extensive use, modern industrial steam systems often have an overall system thermal efficiency rate as low as 50%, or even less. This paper will identify three guiding principles that will allow steam system operators to address several areas where thermal efficiencies can be enhanced to:

- Lessen energy consumption
- Lower maintenance costs
- Reduce environmentally harmful emissions

THE IMPORTANCE OF STEAM IN HISTORY

Whether it was first noticed arising from natural geysers or when the first water-filled clay pot was placed on a fire, exactly when humankind first became aware of steam is anybody’s guess. What is generally accepted is that the first steam machine, the aeolipile, was invented more than 2,000 years ago in Greece.

Simply put, an aeolipile is a hollow sphere mounted on its axis so that it can spin; featuring two protruding curved nozzles placed perpendicular to the axis. Water placed inside the sphere is boiled, increasing the pressure as water changes to steam. The increased pressure forces the steam through the nozzles, generating thrust and propelling the sphere to spin.

The same principles that were used to power the aeolipile were used to power the Industrial Revolution, which many consider the single most important evolutionary period in humankind’s history. Everything from the way humans travelled, built and warmed their homes, cooked their food, produced goods and transported freight was impacted by steam.

THE IMPORTANCE OF STEAM TODAY

Due to its high heat content, low cost of creation, chemical nontoxicity and ease of management and transportability, steam production is a major force in manufacturing and will undoubtedly continue to be so for quite some time to come. According to the United Nations Energy Statistics database, the U.S. produced 101,308 terrajoules of steam and hot water in 1990. By 2009 that amount increased to 520,524 terrajoules, an increase of more than 413%.

As of May 2005, it was estimated that nearly half of all energy consumed by American industry was done so for the express purpose of generating steam for industrial usage. Key industries for which steam production is a major consumer of fossil fuels include:

- Pulp & paper (81% of total fossil fuel consumption)
- Food processing (57%)
- Chemical processing (42%)
- Petroleum refining (23%)

TYPICAL STEAM SYSTEM OPERATION

Rather than go into a detailed description of the evolution of steam systems, what follows is a description of a typical modern steam system, which features four distinct elements: steam generation; steam distribution; steam usage; and condensate recovery.

Steam generation involves the heating of the water to its boiling point and will typically involve elements that include a fuel supply, combustion burner area, boiler and combustion exhaust stack.

Steam distribution carries the steam to its point of use and involves piping, valves, regulators, steam separators and accumulators, steam traps and flow meters.

Steam usage can involve any number of application-specific functions but some of the more common elements include heat exchangers, condensers, turbines, fractionating columns, chemical reaction vessels, dryers, evaporators and others.

Condensate recovery involves transferring the cooled condensate back to the boiler for re-boiling, and typically includes steam traps, piping, tanks, pumps and condensate treatment equipment.
ENERGY LOSS IN STEAM SYSTEMS

In recent years, there has been a significant move towards increasing the energy efficiency of lighting systems. Sensors that turn lights off in unoccupied rooms and walkways are being installed in commercial buildings throughout the country, which the Department of Energy estimates will provide an average of 60% energy cost savings. Further, incandescent bulbs are being replaced with new, more energy efficient fluorescent and light emitting diode (LED) technologies. In fact, the older technology is actually being legislated out of existence in a growing number of countries throughout the world, and plans are in place to do so in the U.S.

While lighting energy efficiency has become extremely important, preventing energy loss in steam systems has not gained much traction. This is surprising, considering the amount of savings that could be had, and the relative ease with which such savings can be achieved.

As will be addressed below, a typical steam system's overall efficiency rate can be as low as 50%. This means that for every $100,000 of fuel purchased, $50,000 is wasted. Additionally, even though the purchaser of the 100 units of fuel is only getting 50 units of value, all 100 units are being consumed and every unit burned releases harmful emissions to the environment, so not only is money being wasted, but the likelihood of pollution, health issues and other environmental damage is high.

According to U.S. Energy Information Administration estimates, in 2006 (the latest year for which information is available) there were 194,733 commercial establishments in the United States with active steam systems. Of these, only 14,107 or one in thirteen (7.2%) had installed or retrofitted equipment with the primary purpose being to improve their steam system's energy efficiency.

The study further reveals that less than 10% of these establishments perform annual inspection and repair of steam leaks; less than 7% tested their steam traps on an annual basis and an amazing 97.3% did not even maintain a steam trap database.
What steam system owners and operators need to be aware of is the relative ease with which such improvements can be made and the short payback periods over which the initial investments can be recouped. This could result in substantial and near immediate benefits to not just their bottom lines but to the overall society as well.

THREE GUIDING PRINCIPLES OF EFFICIENCY LOSS REDUCTION

There are a number of variables in any steam system, and while many of them are quite similar, they are typically also quite different. Whether it’s the fuel, pressure, components, regulatory environment or any number of other variables, each steam system must be viewed independently.

The following three guiding principles of loss reduction in steam systems will result in enhanced overall system efficiency and provide corresponding financial and environmental benefits:

- Target Life Cycle Cost Reduction
- Run Equipment On-Demand
- Optimize Entire System

Target Life Cycle Cost Reduction

We are all aware of the fact that the lowest cost is not always the least expensive. Is a $1 widget cheaper than a $3 widget? Not if the $3 version lasts four times longer before it needs replacement. Wasting less energy lowers operating costs, which leads to greater profits and better performance.

It would be hard to believe that a steam system manager would not want his system to be as efficient as possible. Yet, as indicated above, for every steam system that has installed or retrofitted equipment with the primary purpose being to improve their steam system’s energy efficiency, there are 13 others that have not.

The problem is that system managers are not looking at the overall lifecycle cost of the system; often they are more concerned with how inexpensively it can be constructed or whether the system is running smoothly at the moment. While those items are important, so is the overall cost of running the system. Most fixes available to steam system operators have payback periods of less than three years, many less than one year resulting in high returns on investment.

Run Equipment On-Demand

For centuries, lighthouses were manned by keepers whose job was to keep the lighthouse fire burning at night, and to put out the fires at daylight, as operating a lighthouse in the day would be a waste of valuable resources. This is a prime example of on-demand operation. So, too, is the installation of occupancy sensors that turn lights on and off in commercial buildings as discussed above. In this manner, energy is consumed only when needed, or on demand.

Such is rarely the case when it comes to steam systems, as they are typically designed and operated only from a supply side perspective—provide the proper PSI of steam necessary to accomplish the task. The switch tends to be always “on” and at the pressure required to perform its task, whether or not the task is being performed.

To be certain, steam systems are not exactly like lighting systems. There are costs and timing issues associated with steam systems that do not exist with typical lighting applications. However, today’s technologies make it much easier to operate systems that better match supply with demand requirements. These component and control options provide important and lasting improvements that quickly pay for themselves, providing a significant return on investment.

It is also important to note that demand is not necessarily a fixed item, particularly when one or both of the other guiding principles of efficiency loss reduction are followed. As an example, consider a system with a total operating pressure of 125 PSI of which 90 PSI does the intended work and 35 PSI is consumed by system losses. As actions are taken to reduce the 35 PSI of system losses to 20 PSI, it creates an opportunity to reduce the overall system operating pressure to 110 PSI. Lowering the system pressure captures further savings by producing to a lower demand, thereby extending the life of the system and reducing the loss associated with leaks.
Optimize Entire System

Often, when thinking of steam system efficiency we speak of boiler combustion efficiency. While it is certainly wise to look for ways to improve on a process that typically only runs between 75 to 85% efficiency, the boiler is not the only source from which energy savings may be had. Steam system managers can operate a significantly more efficient system if they evaluate it as a whole, rather than as individual components. Recall, it is not uncommon to find steam systems that are only 50% efficient. While 100% efficiency may be physically impossible, 95% efficiency can certainly be had, which could effectively reduce fuel consumption to save as much as $45,000 on every $100,000 of fuel purchased.

As we did with supply/demand matching let’s look at energy loss from both the supply and demand sides. Supply side losses include stack, standing and blowdown losses; while demand side losses are caused by steam trap issues, condensate and flash loss, poor pipe insulation and pipe leakage.

Approximately one-fourth of the total system energy consumed can be lost on the supply side of the system, with 18 to 20% coming from stack loss, 3 to 5% from standing loss and 2 to 4% from blowdown loss.

Losses on the demand side can be just as high, with 10 to 12% of energy consumed being lost by steam traps, 5 to 7% from condensate/flash loss, 5 to 7% due to inadequate pipe insulation and 2 to 4% from pipe leakage.

There are specific tactics within each of the seven steam system areas mentioned above that can be applied to improve overall energy efficiency. The following section details how many of these problem areas can be addressed. While this information is presented using a component manner, it is important to note that this is not meant to encourage a component mentality. The system needs to be viewed as a whole in order to achieve maximum gain.

For example, a component mentality encourages people to grab the low-hanging fruit, and first go after the areas where the greatest heat losses are occurring. While this is not a bad idea, a better idea is to go after the system in its entirety. Ultimately such an approach will provide better results. Solving three problems that reduce energy loss by 5% each will provide a greater impact than fixing one issue that accounts for a 10% loss.

![Steam System Optimization Diagram](image-url)
SUPPLY SIDE LOSSES

Stack Loss
The operating principle behind boilers is relatively simple and has really not changed much since the aeolipile; water is placed within a structure, heated to a boil, and the resulting steam is used to accomplish an objective. While simple enough, it is also quite inefficient. With the exception of nuclear power, which has its own unique set of concerns, conventional methods used to heat water involve burning some sort of fuel that requires an exhaust system to remove the combustion by-products. Unfortunately, some of the heat also goes out the exhaust instead of being transferred to the water, resulting in 25% or more of the heat generated going right up the flue.

An exceptionally efficient solution to this concern involves the use of heat recovery systems, where the escaping heat is captured and re-purposed before the exhaust is released—using the heat from the exhaust to pre-heat the water entering the boiler, for example. There are a number of technologies available to do so, including: air-to-air; air-to-water; indirect contact; condensing; and direct contact condensing heat exchangers but the bottom line is every degree warmer the water is before it enters the boiler is one less degree it needs to be heated to boil.

This solution is elegant in its simplicity, yet exceptionally powerful in terms of its results. In one particular application where this technology was applied, a breakfast cereal manufacturer installed a condensing heat recovery system designed to recover up to 5 mmBTU/hour of wasted heat that had previously been exhausted to the atmosphere. In this example, overall thermal efficiency jumped to 96% and the company reduced its fuel consumption by 25%, resulting in $500,000 of cost savings and the elimination of more than 2,000 tons of greenhouse gas emissions, all in just the first year. It is readily apparent how much of an impact 10 years of such savings can have.

Standing Loss
Standing loss pertains to the boiler itself, as heat radiates out of the boiler frame shell. While such losses are typically minimal, especially with today’s high-efficiency boilers, it is virtually always cost-effective to take steps to reduce such loss. One such method refers back to the previous discussion of supply/demand matching and system optimization and is a classic example of leaving money on the table.

As mentioned above, often steam system managers will lower operating costs by changing steam traps, improving pipe insulation and taking other steps. While they enjoy the savings such demand-side steps provide, additional savings can be had by making adjustments to the supply side. After all, if system inefficiencies have been removed, is it really necessary to maintain the same system pressure? Usually not, which means the supply-side pressure can be reduced, simultaneously reducing fuel costs, system strain and standing loss.

Blowdown Loss
As water turns to steam, suspended solids (such as calcium, magnesium, silica, sodium and others) contained within the water are left behind. These solids will accumulate within the boiler, which can cause a number of problems including poor heat transfer, foaming and water carryover into the steam line. To prevent these problems, solids-containing water is removed from the system and replaced with make-up water. While this procedure removes the solids, it also takes heat out of the system, which then must be replaced to bring the make-up water up to boiling temperature.

One solution to this problem involves proper chemistry management. Naturally, the better treated the feed water entering the system, the less trouble suspended solids can cause. Returning condensate back to the boiler, as discussed above, also helps solve this problem, as much of the solids originally contained in the water were lost when it changed to steam previously, although additional solids can be picked from piping within the system as the steam condenses.

Properly executed, both these tactics will reduce the number of blowdowns required, but there will always be need for blowdowns, even if they are less frequent. To help avoid loss at this stage, the use of a heat exchanger from which make-up water can be pre-heated prior to entering the boiler will be beneficial, similar to how stack loss is reduced.
DEMAND SIDE LOSSES

Steam Trap Loss
A major contributor to energy loss involves steam traps, which are a type of valve designed to remove condensate from the steam lines. The less steam they consume to do their job, the more efficient the system.

There are four different types of steam traps: mechanical, which open and close based on the condensate level within the trap; thermostatic, which operate based on the temperature difference between steam and condensate; thermodynamic, which operate based on the velocity of the gas under flow; and venturi (orifice), which are regulated by the flashing effect that occurs when hot condensate is released to a lower-pressure return line. Each of these methods has advantages and disadvantages, but when evaluated with a system-wide perspective, can provide major savings.

For example, a bakery invested $9,300 towards replacing 13 mechanical steam traps with venturi-type traps. Almost immediately, system managers noticed that the typical start-up water-hammer they had grown to expect no longer happened, reducing the physical strain on the overall system—minimizing future risks—while also lowering maintenance costs. Further, make-up water requirements dropped significantly as more condensate was returned to the system, reducing pre-treating costs as well as cutting steam loss and trap bypass. Finally, overall fuel consumption dropped 15%, delivering more than $10,400 in first-year savings and a pay-back period of less than one year.

Condensate Flash Loss
As mentioned, steam traps are designed to remove condensate from the steam line. In the bakery application cited above, it was noted that some of the savings came from increasing the condensate return percentage which reduced make-up water requirements.

Rather than return hot condensate back into the process, many steam systems allow this resource to go to waste, because a condensate-return piping system has been considered to be too costly during the system's construction. In fact, it is more expensive to not install a condensate return piping system, as allowing condensate to leave the system is literally pouring money down the drain.

While condensate is no longer steam, at the point it liquefies it is only slightly below water's boiling point, which means it would only take a minimal amount of energy to convert the condensate back to steam. The amount of energy needed to boil condensate water, which is typically more than 200°F, is significantly less than the energy needed to boil make-up water, which usually is between 50° to 80°F.

An excellent example of the savings offered by returning condensate to the system involves a fertilizer manufacturer. While this particular system was built with condensate return piping, malfunctioning pumps and worn piping had led to a reduced condensate return. Repairing the lines and pumping stations allowed the company to recover 15% more condensate, which resulted in 10,000 mmBTU, reducing energy costs by $83,000 annually, as well as reducing water consumption by more than 3.5 million gallons each year.

Pipe Insulation Loss
Proper pipe insulation is perhaps one of the most obvious and easiest energy-efficient fixes available for a steam system, yet lack of proper insulation continues to be a major source of heat loss. There are a number of reasons why proper pipe insulation is not in place, including system modifications, age and neglect, or damage caused by maintenance, collision or leaks.

The U.S. Department of Energy recommends that any surface that can reach 120°F be insulated. Not only will this protect plant personnel from burns and help keep ambient plant temperature comfortable, it will also reduce associated energy losses by up to 90%.

The important factors to consider when looking at insulation include:

> Durability, which means its ability to avoid damage from being bumped or cut
> Ease of installation, which addresses not just the original application, but also the ability to remove and re-apply it for maintenance and inspection purposes
> Resistance to water absorption
Pipe Leakage

Where there is moisture, temperature changes and high pressure, a leak cannot be far away. Accordingly, rather than hope a leak does not happen, it is better to plan for it.

Pipe leakage can come in one of two ways: as steam or as condensate. In either case, the result of the leak is loss of energy and escape of moisture. The energy loss problem is obvious; heat leaving through a leak needs to be replaced, which requires additional energy consumption. The problems moisture can cause were briefly discussed under pipe loss above. Water absorption can be detrimental to insulation, degrading its ability to prevent heat transfer and increasing its thermal conductivity, allowing even more heat to escape.

More often than not, leaks start out small and imperceptible. Over time, they get larger and larger, and it is not until there is a significant pressure loss, pool of water or even a catastrophic event that a leak’s existence becomes apparent.

The best defense against pipe leakage is a strong offense; a pipe inspection protocol that incorporates regular inspections. Today, thermal imagers (infrared cameras) are a very viable resource as their cost has decreased while their speed, accuracy and ease of use have improved, and the images they provide are a powerful diagnostic tool for thermal systems. Indeed, the fact that heat loss can be readily detected in a pipe 12 feet above without even stepping on a ladder makes one wonder why there are any steam systems out there that are not being regularly inspected. Strangely enough, many plants do not follow a regular pipe inspection program, which if followed by immediate maintenance and repair, is the single best method to protect against pipe leakage.

CONCLUSION

Industrial steam usage is and has been an important part of the development of North America, and there is no reason to think its importance will decrease in the coming decades.

The amount of fuel used to provide industrial steam is substantial, accounting for as much as 50% of the total fuel consumed by American industry. Reductions in fuel consumption will not only save American industry a substantial amount of money every year, it will also lessen the pressure being placed on the environment.

These facts alone should be enough to justify investments to improve efficiency. The fact that many of the steps that can be taken are fairly easy, inexpensive and with quick pay-back periods should only make the decision to do so that much easier. Yet the data indicates companies are moving slowly towards this end, as fewer than one in 13 of all steam systems have installed or retrofitted equipment with the primary purpose being to improve their steam system’s energy efficiency.

Steam system energy savings can be just as practical as lowered lighting costs, and it is important for North American industry to grasp this concept and reap the rewards of doing so. In fact, the dollar impact can be far greater.
CASE STUDIES

Industrial Sector: Beverage Industry, Bunker Oil Preheat

A brewing operation had recently modernized their plant and process control systems and added steam meters throughout the site. To confirm the energy performance of the venturi steam trap, they selected the bunker oil preheat exchanger application which had a meter in place. The evaluation called for a before and after steam measurement for both the mechanical and venturi trap technologies. The meter reflected an improvement of more than 28% for the same operating conditions.

<table>
<thead>
<tr>
<th>Trap Technology Upgrade</th>
<th>Before Mechanical</th>
<th>After Venturi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Steam Usage lbs./hr.</td>
<td>2,636</td>
<td>1,892</td>
</tr>
<tr>
<td>Cost (US$)</td>
<td>$158,136</td>
<td>$113,546</td>
</tr>
<tr>
<td>Steam Savings * Rate lbs./hr.</td>
<td>744</td>
<td></td>
</tr>
<tr>
<td>Annual Steam Savings in Tons</td>
<td>2,897</td>
<td></td>
</tr>
<tr>
<td>Savings Percentage</td>
<td>28.20%</td>
<td></td>
</tr>
<tr>
<td>Value of Savings</td>
<td>$44,590</td>
<td></td>
</tr>
<tr>
<td>Retrofit Cost</td>
<td>$3,530</td>
<td></td>
</tr>
<tr>
<td>Payback Period (Months)</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

* Steam Metered Results

Source: Kaman Industrial Technologies. Based on mechanical trap as found with 6,000 operating hours per year and a steam cost of $20/ton.

Industrial Sector: Rubber Products Industry, Molding Department

A rubber industry project demonstrates the process improvement gains that can be made as system efficiency is improved. The venturi trap technology provides continuous discharge of condensate which avoids pressure and temperature variance associated with mechanical traps. This allows for greater consistency in the temperature and improved heat quality delivered to the machine. Shorter cure time, reduced system pressure and elimination of a process step yielded considerable benefits.

<table>
<thead>
<tr>
<th>Trap Technology Upgrade from Mechanical to Venturi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade Costs</td>
</tr>
<tr>
<td>Annual Energy &amp; Maintenance Savings</td>
</tr>
<tr>
<td>Expected Payback Period (Months)</td>
</tr>
<tr>
<td>Additional Process Benefits (US$)</td>
</tr>
<tr>
<td>Reduced Curing Time Value</td>
</tr>
<tr>
<td>Reduced Boiler Load Value</td>
</tr>
<tr>
<td>Eliminated Process Step Value</td>
</tr>
<tr>
<td>Total Additional Annual Savings</td>
</tr>
<tr>
<td>Total Benefits</td>
</tr>
<tr>
<td>Actual Payback Period (Months)</td>
</tr>
</tbody>
</table>

Source: Kaman Industrial Technologies. Based on mechanical trap as found with 8,000 operating hours per year and a steam cost of $20/ton.
**Industrial Sector: Baking Industry, Waste Heat Recovery**

The baking industry recognizes that the heat from the baking ovens is a lot of energy to just release to the atmosphere as waste. Fortunately, the industry can use much of the energy when recovered and made available as hot water. The recycled energy offsets new demand for gas and thus improves efficiency and lowers costs.

<table>
<thead>
<tr>
<th>Waste Heat Source; Thermal Oxidizer, Oven Exhaust</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Available Waste Heat (Therms)</td>
<td>300,000</td>
</tr>
<tr>
<td>Annual Waste Heat Usage (Therms)</td>
<td></td>
</tr>
<tr>
<td>Building Make-Up Air Heating</td>
<td>35,557</td>
</tr>
<tr>
<td>Process Water Heating</td>
<td>57,707</td>
</tr>
<tr>
<td>Boiler Feed-Water Pre-Heat</td>
<td>17,473</td>
</tr>
<tr>
<td>Domestic Hot Water Heating</td>
<td>10,690</td>
</tr>
<tr>
<td>Total Fuel Consumption Reduction (Therms)*</td>
<td>121,427</td>
</tr>
<tr>
<td>Total Value of Annual Fuel Cost Reduction (US$)</td>
<td>$122,993</td>
</tr>
<tr>
<td>Overall Fuel Consumption Reduction</td>
<td>13%</td>
</tr>
<tr>
<td>Original Project Cost</td>
<td>$342,500</td>
</tr>
<tr>
<td>Utility Rebate/Incentive (50% Project Cost Cap)</td>
<td>$(171,250)</td>
</tr>
<tr>
<td>Actual Cost</td>
<td>$171,250</td>
</tr>
<tr>
<td>Actual Payback – Months</td>
<td>16.7</td>
</tr>
</tbody>
</table>

* Limited by practical waste heat usage

**Source:** Kaman Industrial Technologies. Based on 6,000 operating hours per year and a cost of natural gas of $10.13/Dekatherm.
**Commercial Sector: Hospital, Waste Heat Recovery**

It is the nature of combustion to produce water vapor as a byproduct. Combined with combustion efficiency of 75-85%, a boiler operation can have a good opportunity for waste heat recovery. A hospital will have a large demand for hot water that can frequently be addressed with waste heat recovered from boiler exhaust. Direct contact, condensing economizers can recover 3-5 times more energy than conventional economizers providing boiler plant thermal efficiency as high as 97%.

<table>
<thead>
<tr>
<th>Waste Heat Source; 3 Boiler Exhausts</th>
<th>310,255</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Waste Heat (Therms)</td>
<td>310,255</td>
</tr>
<tr>
<td>Annual Waste Heat Usage (Therms)</td>
<td>40,292</td>
</tr>
<tr>
<td>Make Up Air Heating</td>
<td>60,439</td>
</tr>
<tr>
<td>Heating Hot Water</td>
<td>7,051</td>
</tr>
<tr>
<td>Boiler Makeup Water Pre-Heat</td>
<td>163,187</td>
</tr>
<tr>
<td>Domestic Hot Water Heating</td>
<td>163,187</td>
</tr>
<tr>
<td>Total Fuel Consumption Reduction (Therms)</td>
<td>270,970</td>
</tr>
<tr>
<td>Total Value Of Annual Fuel Cost Reduction (US$)</td>
<td>$153,911</td>
</tr>
<tr>
<td>Overall Fuel Consumption Reduction</td>
<td>19%</td>
</tr>
<tr>
<td>Original Project Cost</td>
<td>$1,152,000</td>
</tr>
<tr>
<td>Public Funding Incentive</td>
<td>$(270,970)</td>
</tr>
<tr>
<td>Actual Cost</td>
<td>$881,030</td>
</tr>
<tr>
<td>Actual Payback – Months</td>
<td>69</td>
</tr>
</tbody>
</table>

Expected payback periods vary based on commercial vs. industrial sector as well as operation and application.

*Source:* Kaman Industrial Technologies. Based on 8,400 operating hours per year and a cost of natural gas of $5.70/Dekatherm.
INFORMATION RESOURCES


Steam Systems in Industry Energy Use and Energy Efficiency Improvement Potentials
Dan Einstein, Ernst Worrell, Marta Khrushch, Lawrence Berkeley National Laboratory


Improving Steam System Performance: A Sourcebook for Industry (DOE)


http://www.eere.energy.gov/

http://mntap.umn.edu/greenbusiness/energy/steam.htm

http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aST%3btrID%3a121