SUSTAINABLE STEAM & WATER SOLUTIONS INC.

Sellers Rapid Response Boiler Case Study

Analysis of the excess energy, cost and emissions which result from maintaining a boiler in a hot back-up state

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Rock R. Kaiser
US DOE Qualified Steam System Energy Expert
Sustainable Steam & Water Solutions Inc.
If it's not Sustainable, it's not a Solution! ®
www.SustainableSteam.com
rkaiser@SustainableSteam.com
(765) 720-1330

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1.0 Executive Summary

Sustainable Steam & Water Solutions Inc. (Sustainable Steam) has reviewed the potential savings which can be realized when using a Sellers Manufacturing Co (Sellers) Rapid-Response Gas-Fired Boiler as a cold standby versus keeping a traditional firetube boiler at, or near, operational temperature. Sellers reports that their single and two-pass fire tube boilers can be brought to operating temperature in under 20 minutes which is not possible for traditional boilers due to the warm-up time required to prevent rapid expansion of the Morrison tube versus the tube sheet and remaining boiler tubes. This uneven firing can result in both short term issues such as leaking tubes as well as significant thermal stresses and ultimately tube failures. These concerns appear to be virtually eliminated by the Sellers design.

Our analysis of two very different firetube boiler systems identified that the respective sites are incurring additional costs of 7.7 and 4.3% of the respective system's annual fuel consumption (as well as the associated greenhouse gas emissions) by a single boiler maintained as a hot standby. These are particularly significant impacts in light of increasing natural gas costs, and exceptionally tight operating margins.

The remainder of this document presents the findings from our analysis of the two boiler systems which are noted as Boiler System 1 and Boiler System 2. Although the respective operators gave permission for data collection on their respective systems, Sustainable Steam agreed not to publish data or photographs which could result in their identification. I will note that both boiler systems are located at healthcare facilities where hot standby boilers are always maintained as these facilities presented boilers which were in a suitable state for analysis. It is important to note that hot standby boilers are also common at food and beverage, pharmaceutical and other manufacturing segments which rely on the production of steam for their operation.

Regards,

Rock R. Kaiser
US DOE Qualified Steam System Energy Expert
Sustainable Steam & Water Solutions, Inc.

2.0 Introduction

Sustainable Steam was contracted by a representative of Sellers in September 2022 to analyze the energy and financial benefits of using a Sellers rapid response fire tube boiler versus a more “conventional” fire tube boiler. This case study will focus more particularly on the savings of using a Sellers boiler as a cold back-up, and the resulting savings from not requiring a boiler in a hot standby condition in the event of loss of a primary boiler. This does not imply that a Sellers boiler should only be considered as a back-up to a boiler or boilers provided by other manufacturers; however, this particular case study focuses on the potential savings which may be experienced by using a Sellers boiler in this capacity.

We used two different boiler systems, of significantly different sizes and ages at two different facilities, as the basis for our analysis. To complete our analysis we looked at all of the ways that a boiler can lose heat, and therefore energy, while waiting in a hot standby state namely; shell losses, end plate losses, blowdown losses (both skimmer and bottom blowdown), and stack losses. These losses will be significantly reduced, if not eliminated, once a cold back-up strategy is implemented. The elimination of the boiler energy losses as listed above also results in a reduced financial impact of maintaining the back-up boiler by reducing natural gas usage as well as a corresponding reduction in greenhouse gas emissions.

It is important to note that this was not a long term study so much of the collected data is assumed for our analysis to be an average, when it was actually collected at a point in time. However, in our experience this data is representative of what we see in boiler rooms regularly, and the reader should see upon review that there are no extreme values in the presented data.

Finally we wish to point out that many of the calculations were done via an Excel workbook. As such the reader may see a slight discrepancy in calculation results when using the numbers incorporated within this document, versus the results as presented (especially with very large numbers). The author has tried to eliminate this issue as much as possible, while still maintaining the integrity of the calculations, so that the reader can reach the same results as those presented here.

3.0 Boiler System 1 Analysis

The first boiler system to be considered is located at a Midwestern critical access hospital. It is a 250 HP (8,625 lb/hr) firetube boiler manufactured in 1977. It operates at a pressure of 60 psig, produces saturated steam at a temperature of 307°F, and has a measured combustion efficiency of 80.6%.

Shell Losses

Using thermal imaging we looked at the shell of the boiler in standby mode and the image is presented in Figure 1. Using this image we estimated that the average shell temperature is 127°F.

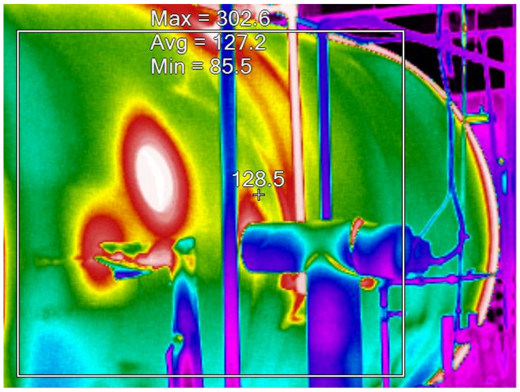


Figure 1 - Boiler 1 Shell Thermal Image

Boiler 1's shell dimensions are 11 ft x 6 ft resulting in a surface area of:

$$\text{Area} = 2\pi rh = 2 \times 3.14 \times 3\text{ft} \times 11\text{ ft} = 207\text{ ft}^2$$

Using *3E Plus,* as developed by the *North American Insulation Manufacturers Association* and supplied by the *U.S. Department of Energy,* we calculate the energy losses to be 96.54 BTU/hr/ft^2 (using an average ambient temperature of 70°F, a horizontal tank shell and no wind). This results in an annual loss of 175,349,773 BTU/yr or 175.4 MMBTU/yr. Using the previously reported combustion efficiency to convert to dekatherms of natural gas gives us:

NG Usage = Loss/Comb. Eff. = (175.4 MMBTU/yr)/(0.806 MMBTU/dekatherm) = 218.56 dekatherms/yr

We will use the average delivered price of natural gas to be $7.85/dekatherm for our analysis (the current natural gas commodities price) resulting in an annual NG cost of $1,708.00 to replace the shell losses while in hot standby.

To determine the greenhouse gas impact we will use the equation provided by the *Environmental Protection Agency* on *EPA.gov* which is:

$$\text{Metric Tons CO}_2 = 0.0053 \times \text{therms}$$

or converting to tons and dekatherms

$$\text{lbs CO}_2 = 0.053 \times 2205 \times \text{dekatherms}$$

$$\textbf{Excess lbs CO}_2\textbf{ = 0.053 x 2205 x 217.56 dekatherms/yr = 25,425 lbs CO}_2\textbf{/year}$$

End Plate Losses

Using thermal imaging we looked at the front and back end plates of the boiler and the images are presented in Figure 2. Using these images we estimated that the average end plate temperature to be 153°F.

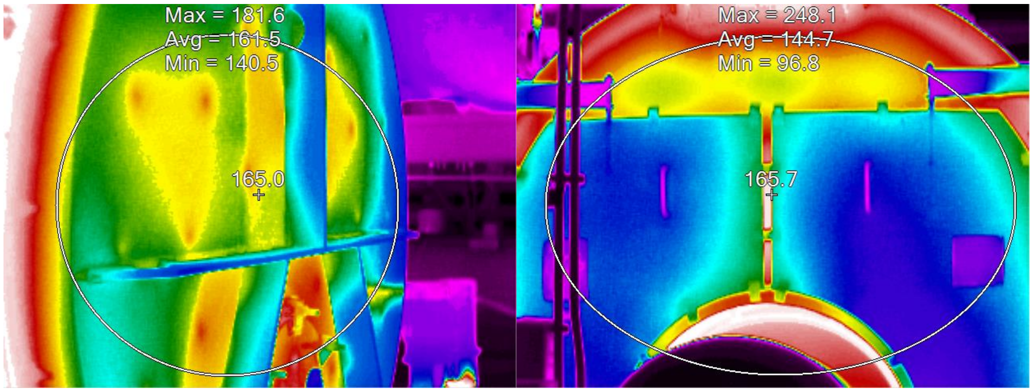


Figure 2 - Boiler 1 End Plate Thermal Images

Boiler 1’s end plate dimensions are 6 ft in diameter resulting in a surface area of:

$$\text{Area} = 2\pi r^2 = 2 \text{ x } 3.14 \text{ x } (3\text{ft})^2 = 56.6 \text{ ft}^2$$

Using *3E Plus* we calculate the energy losses to be 153.3 BTU/hr/ft^2 (using an average ambient temperature of 70°F, a vertical flat surface and no wind). **This results in an annual loss of 75,939,658 BTU/yr or 94.22 dekatherms/yr resulting in an annual cost of $740.00, and excess CO_2 emissions of 11,011 lbs using the previously presented basis and equations.**

Surface Blowdown Losses

Boilers use two different types of blowdown to remove the dissolved and suspended solids; surface (skimmer) and bottom. Boiler System 1’s surface blowdown is activated a total of 4 minutes/day (30 seconds every three hours) resulting in an estimated discharge of 0.95 gallons/minute or 3.8 gallons/day assuming no cycling up of solids while in hot standby mode. Discharge estimates are based on water flow through a nominal ½” blowdown line at a pressure drop of 0.55 psi/100 ft.

At a water temperature of 307°F, and a make-up water temperature of 55°F (23 BTU/lb) we can calculate an annual loss of:

$$\text{Skimmer Loss/Year} = (3.8 \text{ gallons/day})(8.34 \text{ lbs/gal})(277\text{-}23 \text{ BTU/lb})(365 \text{ days/yr})$$

This results in an annual loss of 2,938,165 BTU/yr or 3.65 dekatherms/yr resulting in an annual cost of $29.00, and excess CO_2 emissions of 426 lbs using the previously presented basis and equations.

Bottom Blowdown Losses

Boiler System 1’s bottom blowdown is activated an estimated 1 minute/day resulting in an estimated discharge of 26 gallons/minute or 26 gallons/day. We base our discharge estimates on water flow through a nominal 2” blowdown line at a pressure drop of 0.55 psi/100 ft.

This results in an annual loss of 20,103,236 BTU/yr or 24.94 dekatherms/yr resulting in an annual cost of $196.00, and excess CO_2 emissions of 2,915 lbs using previously presented basis and equations.

Stack Losses

The final losses to be considered on a boiler in a hot standby position are the losses incurred via the boiler’s stack.

To calculate stack losses we measured the draft and used the following equation:

Stack Flow Velocity (ft/min) = √abs(draft(inWC)) x 4005

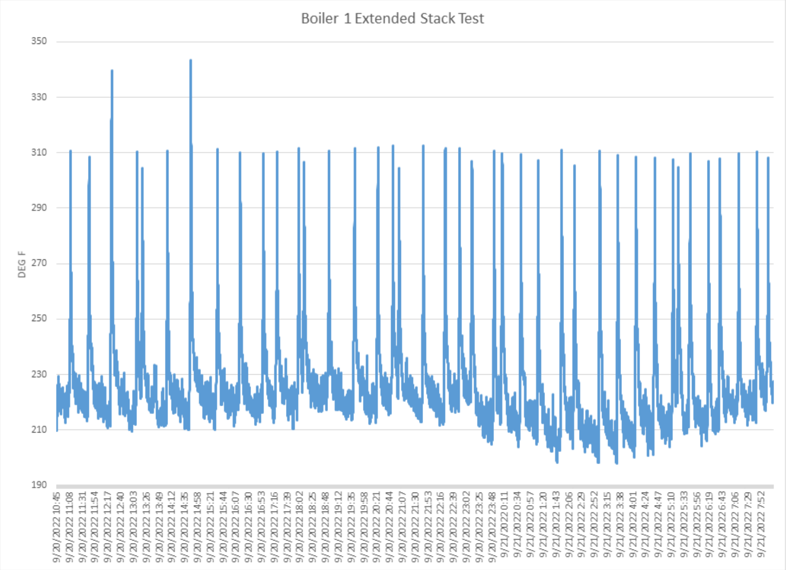
We used a combustion gas analyzer, in draft measurement mode, and determined that the draft for Boiler 1 was - 0.07 inWC (the negative value simply indicates direction which is the reason we take the absolute value of the result) giving us a flow velocity of:

Stack Flow Velocity (ft/min) = √abs(-0.07)) x 4005 = 1,060 ft/min

Boiler 1 has an internal stack diameter of 18” giving us a stack area of 1.77 ft^2 resulting in a volumetric flow rate of:

Volumetric Flowrate = Velocity x Area = 1,060 ft/min x 1.77 ft^2 = 1,873 ft^3/min

For our analysis of Boiler 1 we were able to insert a thermocouple into the stack and gather data over a 21 hour period. A graph presenting the results of this test is shown in Graph 1.



Graph 1 – Boiler 1 Monitoring Results

The stack temperature averaged 226°F during the monitoring period. You will also note from Graph 1 that Boiler 1 fired 41 separate times during the 21 hour period or roughly once every 30 minutes. This firing, and associated energy loss, is the boiler working to maintain the 60 psig pressure setpoint.

Per *engineeringtoolbox.com,* the density of air at this temperature (and atmospheric pressure) is approximately 0.058 lbs/ft^3 which gives us a mass flow rate of:

$$\text{Mass Flow Rate} = \text{Vol. Flow Rate} \times \text{Density} = 1{,}873\ \text{ft}^3/\text{min} \times 0.058\ \text{lbs/ft}^3 = 109\ \text{lbs/min}$$

Using a heat capacity of 0.2433 BTU/lb°F, and an incoming air temperature of 70°F gives us an energy loss of:

$$\text{Energy Loss/Min} = (\text{Stack Temp} - \text{Ambient}) \times \text{Air Mass Flow} \times \text{Air Heat Capacity}$$

$$\text{Energy Loss} = (226°\text{F} - 70°\text{F}) \times 109\ \text{lbs/min} \times 0.2433\ \text{BTU/lb°F} = 4{,}122\ \text{BTU/min}$$

This results in an annual loss of 2,166,576,346 BTU/yr or 2,688.1 dekatherms/yr resulting in an annual cost of $21,101.00, and excess CO_2 emissions of 314,140 lbs (157.1 tons) using the previously presented basis and equations.

Table 1 shows the total losses calculated for Boiler 1 on an annual basis as the result of keeping the boiler in a hot standby condition. The results are an increase of 7.7% in natural gas usage, operational costs and CO_2 emissions (using data collected previously at the facility as well as supplied by the operator) as a direct result of keeping a boiler in a hot standby condition.

Losses	Cost/Year	MMBTU/Yr	Dekatherms/Year (80.6% Comb. Eff.)	CO2 from Natural Gas Combustion (lbs/yr)
Shell Loss	$1,708	175	217.56	25,425
Boiler Ends	$740	76	94.22	11,011
Stack	$21,101	2,167	2,688.06	314,140
Skimmer Blowdown	$29	3	3.65	426
Bottom Blowdown	$196	20	24.94	2,915
Total Calculated Losses	$23,773	2,441	3,028	353,916

Table 1 – Calculated Annual Losses from Boiler #1 in Hot Standby

4.0 Boiler System 2 Analysis

The second boiler system used as a basis for the analysis is located at a significantly larger hospital in the Midwest. It is a 600 HP (20,700 lb/hr) firetube boiler manufactured in 2003. It operates at a pressure of 120 psig, produces saturated steam at a temperature of 350°F, and has a measured combustion efficiency of 82.8%.

As with Boiler System 1, we will analyze the losses from the previously identified loss points namely; shell, end plates, skimmer blowdown, bottom blowdown, and stack.

Shell Losses

Using thermal imaging we looked at the shell of the boiler in standby mode and the images are presented in Figure 2. Using these images we estimate that the average shell temperature is 125°F.

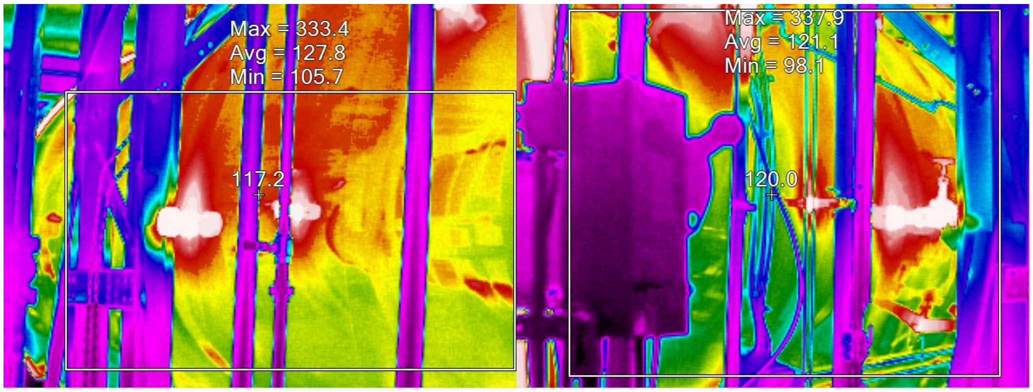


Figure 2 - Boiler 2 Shell Thermal Images

Boiler 2's shell dimensions are 16 ft x 8 ft resulting in a surface area of:

$$\text{Area} = 2\pi rh = 2 \times 3.14 \times 4\text{ft} \times 16\text{ ft} = 402\text{ ft}^2$$

We again use *3E Plus* to find the energy losses which we determine are 92.44 BTU/hr/ft^2 (using an average ambient temperature of 70°F, a horizontal tank shell and no wind). This results in an annual loss of 325,629,607 BTU/yr or 325.63 MMBTU/yr. Using the combustion efficiency to convert to dekatherms of natural gas gives us:

$$\text{NG Usage} = \text{Loss/Comb. Eff.} = (325.63\text{ MMBTU/yr})/(0.828\text{ MMBTU/dekatherm}) = 393\text{ dekatherms/yr}$$

We will again use the average delivered price of natural gas to be $7.85/dekatherm for our analysis to arrive at an excess annual cost of $3,087.00, and excess CO_2 emissions of 45,960 lbs using the previously presented basis and equations.

End Plate Losses

Using thermal imaging we looked at the end plates of the boiler and the images are presented in Figure 2. Using these images we estimated that the average end plate temperature to be 168°F.

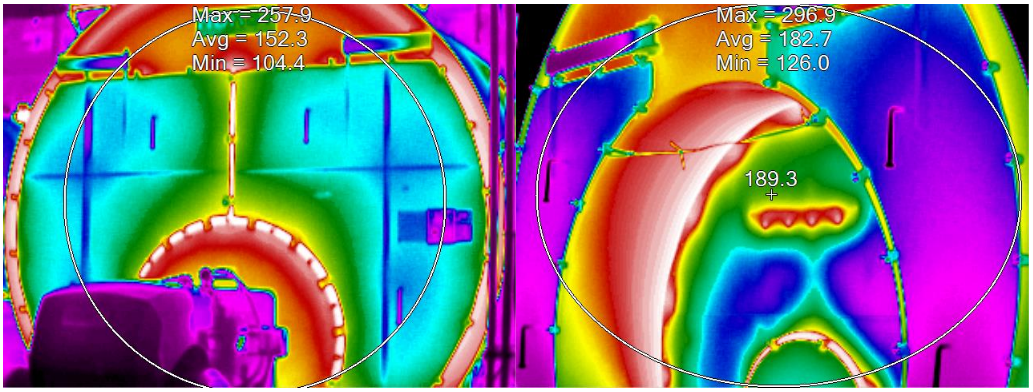


Figure 3 - Boiler 2 End Plate Thermal Images

Boiler 2’s end plate dimensions are 8 ft in diameter resulting in a surface area of:

$$\text{Area} = 2\pi r^2 = 2 \times 3.14 \times (4\text{ft})^2 = 100.5 \text{ ft}^2$$

Using *3E Plus* we calculate the energy losses to be 189.0 BTU/hr/ft^2 (using an average ambient temperature of 70°F, a vertical flat surface and no wind). **This results in an annual loss of 166,443,087 BTU/yr or 201 dekatherms/yr resulting in an annual excess natural gas cost of $1,578.00, and excess CO_2 emissions of 23,492 lbs using the previously presented basis and equations.**

Surface Blowdown Losses

Boiler System 2’s surface blowdown is activated a total of 6 minutes/day (45 seconds every three hours) resulting in an estimated discharge of 2.2 gallons/minute or 13.2 gallons/day assuming no cycling up of solids while in hot standby mode. We base our discharge estimates on water flow through a nominal 3/4” blowdown line at a pressure drop of 0.64 psi/100 ft.

At a water temperature of 350°F, and a make-up water temperature of 55°F (23 BTU/lb) we calculate an annual loss of:

$$\text{Skimmer Loss/Year} = (13.2 \text{ gallons/day})(8.34 \text{ lbs/gal})(322-23 \text{ BTU/lb})(365 \text{ days/yr})$$

This results in an annual loss of 12,014,454 BTU/yr or 14.51 dekatherms/yr resulting in an annual excess cost of $114.00, and excess CO_2 emissions of 1,696 lbs using the previously presented basis and equations.

Bottom Blowdown Losses

Boiler System 2's bottom blowdown is activated a reported 1 minute/day (20 seconds per shift) resulting in an estimated discharge of 16 gallons/day. We base our discharge estimates on water flow through a nominal 1 1/2" blowdown line at a pressure drop of 0.86 psi/100 ft.

This results in an annual loss of 15,926,731 BTU/yr or 19.24 dekatherms/yr resulting in an excess annual cost of $151.00, and excess CO_2 emissions of 2,248 lbs using the previously presented basis and equations.

Stack Losses

To calculate the Boiler System 2 stack losses we measured the draft and used the equation presented in the stack loss calculation section for Boiler System 1.

We again used a combustion gas analyzer, in draft measurement mode, and determined that the draft for Boiler 2 was - 0.03 inWC giving us a flow velocity of:

$$\text{Stack Flow Velocity (ft/min)} = \sqrt{\text{abs}(-0.03))} \times 4005 = 694 \text{ ft/min}$$

Boiler 2 has an internal stack diameter of 24" giving us a stack area of 3.14 ft^2 resulting in a volumetric flow rate of:

$$\text{Volumetric Flowrate} = \text{Velocity} \times \text{Area} = 694 \text{ ft/min} \times 3.14 \text{ ft}^2 = 2{,}179 \text{ ft}^3\text{/min}$$

The stack temperature averaged 187°F during the monitoring period however we were not able to collect extended data at this site.

Per *engineeringtoolbox.com,* the density of air at this temperature (and atmospheric pressure) is approximately 0.063 lbs/ft^3 which gives us a mass flow rate of:

$$\text{Mass Flow Rate} = \text{Vol. Flow Rate} \times \text{Density} = 2{,}179 \text{ ft}^3\text{/min} \times 0.063 \text{ lbs/ft}^3 = 137 \text{ lbs/min}$$

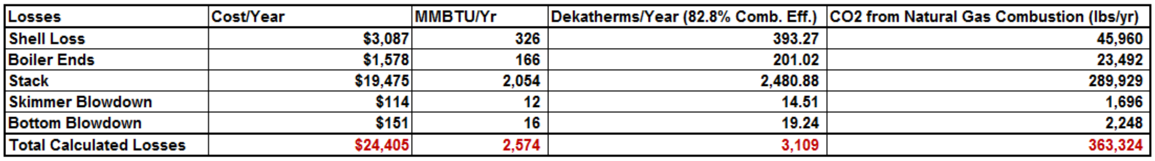
Using a heat capacity of 0.2433 BTU/lb°F, and an incoming air temperature of 70°F gives us an energy loss of:

$$\text{Energy Loss/Min} = (\text{Stack Temp} - \text{Ambient}) \times \text{Air Mass Flow} \times \text{Air Heat Capacity}$$

$$\text{Energy Loss} = (187°\text{F} - 70°\text{F}) \times 137 \text{ lbs/min} \times 0.2433 \text{ BTU/lb°F} = 3{,}908 \text{ BTU/min}$$

This results in an annual loss of 2,054,172,435 BTU/yr or 2,480.88 dekatherms/yr resulting in an annual excess cost of $19,475.00, and excess CO_2 emissions of 289,929 lbs (145.0 tons) using previously presented basis and equations.

Table 2 shows the total losses calculated for Boiler 2 on an annual basis as the result of keeping the boiler in a hot standby condition. The results are an increase of 4.3% in natural gas usage, operational costs and CO_2 emissions (using data collected previously at the facility as well as supplied by the operator) as a direct result of keeping a boiler in a hot standby condition.



Losses	Cost/Year	MMBTU/Yr	Dekatherms/Year (82.8% Comb. Eff.)	CO2 from Natural Gas Combustion (lbs/yr)
Shell Loss	$3,087	326	393.27	45,960
Boiler Ends	$1,578	166	201.02	23,492
Stack	$19,475	2,054	2,480.88	289,929
Skimmer Blowdown	$114	12	14.51	1,696
Bottom Blowdown	$151	16	19.24	2,248
Total Calculated Losses	$24,405	2,574	3,109	363,324

Table 2 – Calculated Annual Losses from Boiler System #2 in Hot Standby

5.0 Conclusion

This analysis indicates that significant savings can be obtained if a Sellers Rapid-Response Gas-Fired Boiler can be used as a cold back-up versus keeping a traditional boiler in a hot standby condition. While it is certainly recognized that some institutions, such as healthcare, may not be able to wait the reported 20 minutes for the back-up boiler to come online; other facilities such as manufacturing and food and beverage could take advantage of the significant savings afforded by using a Rapid-Response boiler in a room temperature state as a dedicated back-up.