Steam End-User Training
Steam Generation Efficiency Module
Blowdown Losses Section

Slide 1 - Blowdown Losses Module

This section will discuss blowdown loss and its affect on boiler efficiency.

[Slide Visual – Efficiency Sub-Section: Blowdown Losses]
Banner:
DOE's BestPractices
Steam End User Training

Steam Generation Efficiency
Efficiency Definition
Radiation and Convection Losses –
Shell Losses
Blowdown Losses
Stack Losses

Slide 2 – Blowdown

The next type of loss investigated is blowdown loss. Boiler feedwater is very clean water. However, in feedwater there are some dissolved chemicals. Essentially pure steam exits the boiler—the majority of the chemicals entering the boiler with feedwater are not soluble in the steam and will not leave the boiler with the steam. As a result, the concentration of these chemicals increases in the boiler. Elevated concentrations of chemicals results in many serious boiler problems—including foaming resulting in liquid carryover, scaling on the water-side of the tubes, and loose sludge in the boiler water. Blowdown is the primary mechanism that allows us to control chemical concentrations in the boiler water. Blowdown allows us to maintain an acceptable concentration of dissolved and precipitated chemicals in the boiler.

There is an energy loss associated with blowdown, because the water has been heated to the boiling point from feedwater conditions.

Slide 3 - Boiler Blowdown

There are two general types of boiler blowdown. One is typically from the lower sections of the boiler called bottom blowdown. The other type of blowdown is typically from the upper sections of the boiler and is called surface blowdown.

Bottom blowdown is actuated because some solids will precipitate from the chemicals dissolved in the feedwater. These solids tend to be heavier than water, and therefore tend to congregate in lower sections of the boiler. Bottom blowdown is used to flush these solids out. Bottom blowdown is typically a significant flow of water for a very short period of time. The intent is to sweep away any solid precipitates formed in the water. Even though while it is occurring it is a large flow rate, it continues for a short period of time. As a result, the total flow of bottom blowdown is usually much less than the total flow surface blowdown.

Surface blowdown is typically a much smaller flow rate than bottom blowdown; however, it continues for a much longer period of time—often continuously. Surface blowdown is the primary mechanism used to control the dissolved chemical concentrations in the boiler. Surface blowdown ends up removing most of the blowdown water.

> ***[Slide Visual - Boiler Blowdown]***
>
> **This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right. The bottom blowdown is shown from the bottom mud drum. The surface blowdown is shown at the top from the steam drum.**

<u>Slide 4 - Blowdown Control</u>

Generally, surface blowdown is controlled based on boiler water conductivity. Conductivity is a direct measurement that can continuously provide an indication of boiler water quality. However, conductivity must be correlated to individual chemical contaminants through periodic water analysis. Conductivity and the results of specific boiler water testing aid in adjusting the blowdown rate.

> ***[Slide Visual - Conductivity Sensor]***
>
> **This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right. The surface blowdown is shown at the top from the steam drum with a conductivity sensor controlling the blowdown valve position. The blowdown is discharged to the sewer.**

<u>Slide 5 - Blowdown Loss Estimate</u>

From the view of the boiler, feedwater enters, steam and blowdown exit. The boiler adds fuel energy to the steam and blowdown that exit the boiler. Blowdown is an energy stream that is discharged from the boiler. Blowdown is typically expressed as a fraction of feedwater mass flow and can range from less than 1 percent to much greater than 10 percent depending on water chemistry, boiler operating pressure, and other factors. However, it should be noted that 10 percent blowdown rate does not mean 10 percent energy loss—blowdown discharged from the boiler is not high-energy steam, it is moderate-energy water. From the perspective of the boiler, the energy added to the blowdown stream is blowdown flow rate times the difference in

the enthalpy of the blowdown and the feedwater. Therefore, 10 percent blowdown rate can translate into 5 percent fuel energy input. It should be noted that the relationship between blowdown mass-fraction and blowdown energy-fraction is dependent on many factors including boiler operating pressure and feedwater temperature.

[Slide Visual - Boiler Blowdown Loss - Boiler Calculation]

$$L_{blowdown} = \frac{\text{m-dot}_{blowdown}\,(h_{blowdown} - h_{feedwater})}{\text{m-dot}_{fuel} \times HHV_{fuel}}$$

Blowdown Loss is equal to the mass flow rate of the blowdown; multiplied by the difference of the enthalpy of the blowdown minus the enthalpy of the feedwater; divided by the mass flow rate of the fuel; multiplied by the Higher Heating Value of the fuel.

Where:

$L_{blowdown}$ = Loss due to blowdown (%)
$\text{m-dot}_{blowdown}$ = Mass flow rate of blowdown
m-dot_{fuel} = Mass flow rate of steam generated per pound of fuel burned
$h_{blowdown}$ = Enthalpy of blowdown
$h_{feedwater}$ = Enthalpy of feed water at 242 degrees Fahrenheit
HHV = Higher Heating Value of fuel

Slide 6 - System Loss

Again, from the perspective of the boiler, the energy added to the blowdown stream is blowdown flow rate times the difference in the enthalpy of the blowdown and the feedwater. However, every pound of blowdown discharged from the system is made-up with cold makeup water—as a result; a portion of the steam generated in the boiler is used to heat the makeup water to feedwater conditions in the deaerator. Therefore, from a system perspective, the energy associated with the blowdown stream is even larger than that identified from the boiler perspective.

[Slide Visual - Steam System Impact Schematic]

This schematic represents a three-pressure header steam system with multiple boilers and all of the system components. Feedwater is preheated by steam injection from the low-pressure steam distribution header, as well as preheated make-up water utilizing boiler blowdown heat recovery.

The top of the schematic shows the Boiler Feedwater entering the two boilers. The two boilers are connected to the high-pressure steam distribution header.

The steam exits two boilers and enters the high-pressure steam system distribution header, indicated by a line below the boilers.

Under the high-pressure steam distribution line, you will see three cone-shaped graphics, that represent the steam turbines. The one nearest to the left is a high-pressure to condensing turbine. This turbine discharges to the condenser represented by the blue circle below the turbine. The rectangular graphic to the right of the cone-shaped graphic indicates the electrical generation component of the steam turbine. The turbine in the middle receives high-pressure steam and exhausts low-pressure steam to the low-pressure steam distribution system, as well as generates electricity. This turbine is denoted as red cone and rectangle combination. The steam turbine to the most right receives high pressure steam, drives a pump (denoted as a circle/square combination) and is also called a steam turbine-driven pump, then discharges to the low-pressure steam distribution system header.

Between the condensing turbine and the high-to-low pressure turbine, a light-blue triangular graphic that represents a pressure-reducing valve, which discharges to the low pressure steam distribution header , identified by a red line below the turbines.

At the far right of the high pressure steam distribution system, the high-pressure end-user component loads are identified through a rectangular graphic and arrows entering and leaving the rectangle, indicating heat exchange with the components. The end-use components discharge condensate through a steam trap, represented by a rectangular graphic. Schematically, condensate passes through the bottom of the trap and recovered in a condensing tank which is also connected to the low-pressure steam distribution system.

Under the low-pressure steam distribution line, you will see the low-pressure end-user component loads identified as a rectangular graphic and arrows entering and leaving the rectangle, indicating heat exchange with the components. The end-use components discharge condensate through a steam trap, represented by another rectangular graphic. Schematically, condensate passes through the bottom of the trap and recovered in a condensate tank, in which steam is vented represented by a vertical arrow leaving the top of the tank.

The low-pressure end-user condensate tank uses a pump, which is denoted by a circle/square combination, to deliver the condensate to the main condensate receiver, which is a large rectangle with three inputs denoted by three arrows at the top of the rectangle. The condensate enters this main condensate receiver tank, after it passes through a control valve, denoted as an hour-glass shape with a dome on top. The third condensate input comes from the condensate from the heat exchanger that utilizes the high-pressure steam turbine. The condensate leaves this heat exchanger and is delivered via a pump (denoted as a circle/square combination) to the main condensate receiver.

The main condensate receiver then pumps (denoted by a circle/square combination) the high-pressure condensate, low-pressure condensate, and the condensing steam turbine condensate to the deaerator tank as denoted by two red rectangles, with the smaller one on the top. The top rectangle also shows two triangles, each pointed away from each other, longest ends nearly touching. The bottom triangle is connected to a control valve represented by a red hour-glass figure with a dome on the side, which provides low-pressure steam to the deaerator from the low-pressure steam distribution system to preheat the collected condensate and make-up water. Pre-heated make-up water also schematically enters at the top of the deaerator with the collected condensate.

The make-up water is preheated from the boiler blowdown and low pressure steam. Boiler blowdown from each boiler is noted as red dashed lines leading to a blowdown receiver tank denoted as a red rectangle on the right of the screen. Flash-steam is diverted from the blowdown flash-vessel to the low-pressure steam distribution line, also denoted in red dashed lines. Liquid from the blowdown flash-tank then

schematically enters the top of a heat exchanger (represented as a white and green striped rectangle). Makeup water is shown entering the heat exchanger from the right, after it passes through the water treatment equipment, denoted as two red rectangles further on the right. The liquid exiting the heat exchanger is sent to the deaerator.

The heated boiler feedwater schematically exits the deaerator from the bottom and is pumped (denoted as a circle/square combination) to the feedwater inlets of each boiler, near the top the schematic.

Slide 7 - System Loss Estimate

The actual total system impact associated with blowdown can be more than twice the impact identified from the boiler perspective. An estimate of the total system-wide impact of blowdown being lost from the system can be determined by evaluating the energy added to the blowdown stream by heating makeup water to the blowdown conditions. The loss equation noted here estimates that impact.

[Slide Visual – Boiler Blowdown Loss - System Calculation]

$$L_{blowdown} = \frac{\text{m-dot}_{blowdown}\,(h_{blowdown} - h_{makeup})}{\text{m-dot}_{fuel} \times HHV_{fuel}}$$

Blowdown Loss is equal to the mass flow rate of the blowdown; multiplied by the difference of the enthalpy of the blowdown minus the enthalpy of the make-up water; divided by the mass flow rate of the fuel; multiplied by the Higher Heating Value of the fuel.

Where:

$L_{blowdown}$	= Loss due to blowdown (%)
$\text{m-dot}_{blowdown}$	= Mass flow rate of blowdown
m-dot_{fuel}	= Mass flow rate of steam generated per pound of fuel burned
$h_{blowdown}$	= Enthalpy of blowdown
h_{makeup}	= Enthalpy of make-up water at 75 degrees Fahrenheit
HHV	= Higher Heating Value of fuel

Slide 8 - Blowdown Management

Blowdown loss is managed through two primary avenues. First, the amount of blowdown required can be reduced if the feedwater quality is improved. Second, thermal energy can be recovered from the blowdown stream. To a lesser degree, the blowdown control strategy can be improved to reduce the amount of blowdown.

Generally, feedwater quality is impacted most by the makeup water. Condensate is commonly the cleanest water in the steam system. Makeup water must be conditioned before it is added to the system. The makeup water treatment system can be improved resulting in improved makeup water quality. Common improvements include changing from sodium-cycle softening to demineralization or to reverse osmosis conditioning.

Of course feedwater quality can be improved through increased condensate recovery.

Blowdown thermal energy recovery will be discussed in more detail in this section. But, it should be noted that thermal energy recovery has proven a very successful management activity.

In any event, the first step in managing blowdown is to measure the energy loss associated with it. We will use our example boiler to further examine the blowdown issues.

Slide 9 - Blowdown Estimate

Utilizing conventional flow meters for the blowdown stream is problematic because the blowdown is ready to boil. Most flow meters will impose a sufficient pressure drop to result in two-phase flow, which is very difficult to measure. Therefore, in order to measure blowdown rate, we usually measure chemical composition in the feedwater and in the boiler water. The chemical component measured in the analysis must be of sufficient concentration to allow accurate measurement with our instruments. We take the ratio of the chemical concentration in the feedwater to the chemical concentration in the boiler water to establish the blowdown rate.

Our example boiler is operating with a nominal blowdown rate of 6 percent.

[Slide Visual – Blowdown Rate Fraction Equation]

$$\%Blowdown = \frac{C_{feedwater}}{C_{blowdown}}(100)$$

Blowdown Percent is equal to the Concentration of the feedwater divided by the Concentration of the blowdown; all multiplied by 100.

$$\%Blowdown = \frac{15\ ppm}{250\ ppm}(100)$$

Blowdown Percent is equal to the 15 parts per million divided by 250 parts per million; all multiplied by 100.

$$\%Blowdown = 6.0\%_{mass}\ \text{of feedwater flow}$$

Blowdown Percent is approximately equal to 6% mass of the feedwater flow.

Where:

$C_{feedwater}$ = Chemical concentration of feedwater (parts per million)
$C_{blowdowr}$ = Chemical concentration of blowdown (parts per million)

Slide 10 - Blowdown Flow Rate

These blowdown equations are based on a simple mass-balance on the boiler water and steam flows. It must be noted that steady flow and steady operating conditions are assumed in the analysis. Additional analysis is required for systems operating with intermittent blowdown. The blowdown flow rate for our example boiler is about 6,400 Pounds per hour.

[Slide Visual – Blowdown Flow Rate Calculation]

$$\text{m-dot}_{blowdown} = \left(\frac{B}{1 - B}\right) \text{m-dot}_{steam}$$

The mass flowrate of the blowdown is equal to the Blowdown Fraction; divided by 1 minus the Blowdown Fraction; all multiplied by the mass flow rate of the steam.

$$\text{m-dot}_{blowdown} = \left(\frac{0.06}{1 - 0.06}\right) 100{,}000 \text{ lbm/hr} = 6{,}400 \text{ lbm/hr}$$

The mass flowrate of the blowdown is equal to 0.06; divided by 1 minus 0.06; all multiplied by the 100,000 pounds per hour equals 6,400 pounds per hour.

Where:

$\text{m-dot}_{blowdown}$	= Mass flow rate of blowdown
m-dot_{steam}	= Mass flow rate of steam generated per pound of fuel burned
B	= Blowdown rate fraction (percent of feedwater)

Slide 11 - Boiler Loss Estimate

The example boiler operates with approximately 6 percent of the feedwater leaving the boiler as blowdown. This represents approximately 1 percent of the total fuel input energy.

[Slide Visual – Boiler Blowdown Loss - Boiler Calculation]

$$L_{blowdown} = \frac{\text{m-dot}_{blowdown}\,(h_{blowdown} - h_{feedwater})}{\text{m-dot}_{fuel} \times HHV_{fuel}} \times (100)$$

Blowdown loss is equal the mass flow rate of the blowdown; multiplied by the difference of the enthalpy of the blowdown minus the enthalpy of the feedwater; divided by the mass flow rate of the fuel multiplied by the High Heating Value of the fuel; all multiplied by 100.

The enthalpy of the feedwater, $h_{feedwater}$ at 242 degrees Fahrenheit is 210.42 Btu/lbm.

$$L_{blowdown} = \frac{(6{,}400\ \text{lbm/hr}) \times (428.04\ \text{Btu/lbm} - 210.42\ \text{Btu/lbm})}{(6{,}407\ \text{lbm/hr}) \times (23{,}311\ \text{Btu/lbm})} \times (100)$$

Blowdown loss is equal the 6,400 lbm/hr; multiplied by the difference of the 428.04 Btu/lbm {minus} 210.42 Btu/lbm; divided by the 6,407 lbm/hr; multiplied by 23,311 Btu/lbm; all multiplied by 100.

$$L_{blowdown} = 0.9\%_{\ energy}$$

The blowdown loss is equal to 0.9% energy.

Slide 12 - Blowdown Loss Estimate

However, as pointed out previously the impact on the steam system is even greater than this "boiler focus" blowdown energy analysis. This is because blowdown discharged from the system has to be replaced with cold makeup water. The system based blowdown energy impact is about 1.7 percent of the fuel input energy. This may be a relatively small fraction of fuel input energy; however, it translates into more than $200,000 per year of fuel cost. Additionally, and more importantly, there are cost effective measures we can employ to virtually eliminate this loss.

Two primary avenues are used to reduce the loss associated with blowdown. First, providing cleaner feedwater can dramatically reduce the required blowdown. The primary methods used to improve feedwater quality are to utilize technologies to provide cleaner makeup water—demineralization, dealkalization, reverse osmosis. Increasing condensate recovery is an excellent strategy to improve feedwater quality; because, condensate is typically the cleanest water available—and it contains valuable thermal energy.

Second, the thermal energy in the blowdown stream can be recovered. In fact, almost all of the thermal energy of the blowdown stream can be recovered with time-proven cost-effective measures.

[Slide Visual – Boiler Blowdown Loss – System Calculation]

$13,000,000 operating costs x ~1.7% yields $215,000 operating savings.

$$L_{blowdown} = \frac{\dot{m}_{blowdown}\left(h_{blowdown} - h_{makeup}\right)}{\dot{m}_{fuel} \times HHV_{fuel}} \times (100)$$

Blowdown loss is equal the mass flow rate of the blowdown; multiplied by the difference of the enthalpy of the blowdown minus the enthalpy of the makeup water; divided by the mass flow rate of the fuel multiplied by the High Heating Value of the fuel; all multiplied by 100.

The enthalpy of the make-up water, h_{makeup} at 75 degrees Fahrenheit is 43.04 Btu/lbm.

$$L_{blowdown} = \frac{(6{,}400\ \text{lbm/hr}) \times (428.04\ \text{Btu/lbm} - 43.04\ \text{Btu/lbm})}{(6{,}407\ \text{lbm/hr}) \times (23{,}311\ \text{Btu/lbm})} \times (100)$$

The blowdown loss is equal the 6,400 lbm/hr; multiplied by the difference of the 428.04 Btu/lbm minus 43.04 Btu/lbm); divided by the 6,407 lbm/hr multiplied by 23,311 Btu/lbm; all multiplied by 100.

$$L_{blowdown} = 1.7\%_{\ energy}$$

The blowdown loss is equal to 1.7% energy.

Slide 13 - Boiler Blowdown

Blowdown thermal energy recovery typically focuses on surface blowdown, because it is the largest portion of the blowdown flow and can be a relatively constant stream. The most common (and successful) blowdown thermal energy recovery systems include two stages of recovery.

[Slide Visual - Blowdown Types]

This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from

the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right. The bottom blowdown (intermittent) is shown at the bottom mud drum of the boiler schematic. The surface blowdown (continuous) is shown at the top steam drum.

Slide 14 - Blowdown Energy Recovery

First, we bring the high-pressure blowdown stream into a pressure vessel (flash tank) operating at low-pressure. This allows the saturated high-pressure liquid to generate flash steam as it comes to equilibrium in the flash tank. Part of the blowdown liquid flashes to steam and the rest remains liquid. The flash-steam is clean, so we can direct it right into the low-pressure steam system. The liquid that remains in the flash-vessel is hot, so we can still use this water in a heat exchanger to preheat makeup water. The blowdown water will eventually be discharged from the system because it contains the boiler water contaminants. We can capture almost all of the blowdown thermal energy with the installation of a simple flash-tank and a heat exchanger. The blowdown loss can be virtually eliminated with very simple, robust equipment!

[Slide Visual - Blowdown Energy Recovery]

This schematic depicts a water-tube boiler. Fuel and air enters at the lower left of the combustion zone, feedwater enters at the top into the steam drum which connects to the mud drum through many tubes. The mud drum is at the bottom of the boiler. Steam exits the boiler from the steam drum into the superheater section, which is shown at the top of the boiler. The combustion gases leaving the boiler through the ducting at the upper right. The surface blowdown is shown leaving the top steam drum and passing through a conductivity sensor which operates a control valve. Blowdown is discharged through the control valve into the low-pressure flash vessel, or flash tank. The saturated high-pressure liquid generates flash steam in the flash tank. The flash tank now contains low-pressure flash steam and saturated liquid. The low-pressure flash steam can be connected to the low-pressure steam distribution system or often directly to the deaerator. The remaining hot liquid can be utilized in a heat exchanger to preheat makeup water, but is ultimately discharged from the system for water quality control.

Slide 15 - Boiler Blowdown Recovery

In the example steam system, a blowdown thermal energy recovery system was installed and the fuel consumption decreased by $215,000 per year. The equipment required for the example system cost less than 50,000 dollars!

However, you need to be careful when selecting a heat exchanger for this service. The heat exchanger applied in this service must be capable of being cleaned because the blowdown stream can fowl the heat exchange surface.

Temperature sensors in each of the streams entering and leaving the heat exchanger allow the heat exchanger effectiveness to be determined and the frequency of cleaning evaluated.

Two types of heat exchangers offer good results in this application. A shell-and-tube straight-tube heat exchanger can be specified with the blowdown stream on the tube-side. In this arrangement, the heat exchanger ends must be removable to allow the tube internals to be cleaned periodically. Alternately, a plate-and-frame heat exchanger can be used, which allows both the blowdown side and the makeup water side to be cleaned.

[Slide Visual - Blowdown Energy Recovery Equipment]

Boiler blowdown has exited the boiler at high-pressure, passed through the blowdown control valve, and enters flash vessel at 20 psig. Low Pressure flash-steam discharges from the top of the flash vessel to the low pressure steam system.

Liquid is discharged from the bottom of the flash vessel to a heat exchanger that exchanged energy with makeup water. The temperature of the blowdown liquid entering the heat exchanger is measured by a temperature sensor, T1; the leaving temperature by sensor T2. Makeup water enters the heat exchanger from the top and its temperature is measured by sensor T3. Makeup water temperature leaves the heat exchanger and is measured by sensor T4.

A liquid level control sensor is attached to the side of the flash vessel which controls the flow through the exit of the heat exchanger through a control valve.

Slide 16 - Steam System Impact

The installation of a blowdown thermal energy recovery system will have multiple impacts on a cogeneration system. Flash-steam will be directed to the low-pressure header, which will reduce the amount of steam that can pass through the backpressure turbines. Additionally, the makeup water will be higher temperature, which will reduce the deaerator steam demand—further reducing the turbine steam flow. Finally, because the flash-steam generated from the blowdown is directed back into the steam system, the amount of makeup water required diminishes. As a result, the analysis of blowdown energy recovery becomes much more complicated when cogeneration systems are considered. This is where the Steam System Assessment Tool comes in handy!

[Slide Visual - Steam System Impact Schematic]

This schematic represents a two-header steam system with two boilers and all of the system components. Feedwater is preheated by steam injection from the low-pressure steam distribution header, as well as preheated make-up water utilizing boiler blowdown heat recovery.

The top of the schematic shows the Boiler Feedwater entering the two boilers. The two boilers are connected to the high-pressure steam distribution header.

The steam exits two boilers and enters the high-pressure steam system distribution header, indicated by a line below the boilers.

Under the high-pressure steam distribution line, you will see three cone-shaped graphics, that represent the steam turbines. The one nearest to the left is a high-pressure to condensing turbine. This turbine discharges to the condenser represented by the blue circle below the turbine. The rectangular graphic to the right of the cone-shaped graphic indicates the electrical generation component of the steam turbine. The turbine in the middle receives high-pressure steam and exhausts low-pressure steam to the low-pressure steam distribution system, as well as generates electricity. This turbine is denoted as red cone and rectangle combination. The steam turbine to the most right receives high pressure steam,

drives a pump (denoted as a circle/square combination) and is also called a steam-driven pump, then discharges to the low-pressure steam distribution system header.

Between the condensing turbine and the high-to-low pressure turbine, a light-blue triangular graphic that represents a pressure-reducing station, which discharges to the low pressure steam distribution header , identified by a red line below the turbines.

At the far right of the high pressure steam distribution system, the high-pressure end-user component loads are identified through a rectangular graphic and arrows entering and leaving the rectangle, indicating heat exchange with the components. The end-use components discharge condensate through a steam trap, represented by a rectangular graphic. Schematically, condensate passes through the bottom of the trap and recovered in a condensing tank which is also connected to the low-pressure steam distribution system.

Under the low-pressure steam distribution line, you will see the low-pressure end-user component loads identified as a rectangular graphic and arrows entering and leaving the rectangle, indicating heat exchange with the components. The end-use components discharge condensate through a steam trap, represented by another rectangular graphic. Schematically, condensate passes through the bottom of the trap and recovered in a condensate tank, in which steam is vented represented by a vertical arrow leaving the top of the tank.

The low-pressure end-user condensate tank uses a pump, which is denoted by a circle/square combination, to deliver the condensate to the main condensate receiver, which is a large rectangle with three inputs denoted by three arrows at the top of the rectangle. The condensate enters this main condensate receiver tank, after it passes through a control valve, denoted as an hour-glass shape with a dome on top. The third condensate input comes from the condensate from the heat exchanger that utilizes the high-pressure steam turbine. The condensate leaves this heat exchanger and is delivered via a pump (denoted as a circle/square combination) to the main condensate receiver.

The main condensate receiver then pumps (denoted by a circle/square combination) the high-pressure condensate, low-pressure condensate, and the condensing steam turbine condensate to the deaerator tank as denoted by two red rectangles, with the smaller one on the top. The top rectangle also shows two triangles, each pointed away from each other, longest ends nearly touching. The bottom triangle is connected to a control valve represented by a red hour-glass figure with a dome on the side, which provides low-pressure steam to the deaerator from the low-pressure steam distribution system to preheat the collected condensate and make-up water. Pre-heated make-up water also schematically enters at the top of the deaerator with the collected condensate.

The make-up water is preheated from the boiler blowdown and low pressure steam. Boiler blowdown from each boiler is noted as red dashed lines leading to a blowdown receiver tank denoted as a red rectangle on the right of the screen. Flash-steam is diverted from the blowdown flash-vessel to the low-pressure steam distribution line, also denoted in red dashed lines. Liquid from the blowdown flash-tank then schematically enters the top of a heat exchanger (represented as a white and green striped rectangle). Makeup water is shown entering the heat exchanger from the right, after it passes through the water treatment equipment, denoted as two red rectangles further on the right. The liquid exiting the heat exchanger is sent to the deaerator.

The heated boiler feedwater schematically exits the deaerator from the bottom and is pumped (denoted as a circle/square combination) to the feedwater inlets of each boiler, near the top the schematic.

Slide 17 - Steam System Assessment Tool

The Steam System Assessment Tool, also known as SSAT, was developed by the United States Department of Energy to aid in evaluating the complex interactions of steam system modifications. SSAT is a software tool based in Excel. KBC Linnhoff March's Prosteam software serves as the foundation of the tool. This tool allows the user to build a model of their steam system. This model can be used to evaluate the impacts of system changes.

[Slide Visual - Steam System Assessment Tool (SSAT)]

The first screen of the SSAT is shown.

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Industrial Technologies Program Tools Suite
Steam System Assessment Tool, v.3.0
Contact the EERE Information Center 1-877-EERE-INF (8770337-3463) eereic@ee.doe.gov.

A picture of a steam site in the background with two large towers, several buildings, and a conveyor system.

- **Developed for the U.S.DOE under contract with the Oak Ridge National Laboratory by:**
- **KBC Linnhoff March**
- **Spirax Sarco Inc.**
- **Greg Harrell, Ph.D., P.E.**

- **Steam System Assessment Tool (SSAT)**
- **Steam system modeling software**
- **Common energy recovery projects built into the model**
- **Allows "what if" evaluations**

Slide 18 - SSAT Model

The SSAT model contains the common steam system components including the boiler, steam turbines, end-use equipment, condensate recovery, feedwater conditioning components, and the interconnections of the system. This schematic demonstrates the general connectivity of the model. High-pressure steam is generated in the boiler. This steam can pass to end-use equipment, through steam turbines, or through pressure reducing valves. The medium and low-pressure steam systems are similarly arranged. Users have flexibility in arranging the model to reflect their steam systems.

[Slide Visual - Model Tab Schematic]

The top center will contain the descriptive title provided by the user, the initial template reads "SSAT Default 3 Header Model" or a similar title for whatever model you chose. Below it, you will see the Model Status, which should read "OK." The model status provides an indication of the calculation condition of the model.

To the left of the Model Status, you will see a chart in light blue, which indicates the emissions per year for carbon dioxide, sulfur oxide, and nitrogen oxide.

At the top right, it will say "Current Operation" if you are on the Model tab, or "Operation After Projects" if you are on the Projects Model tab.

The red graphic near the top left represents the boiler. From the left, there is a dotted line entering it, which represents the amount of feedwater entering the boiler from the deaerator.

Also to the left of the boiler, we see the following information highlighted in orange: the type of fuel being used in the boiler, the fuel input energy, the fuel flow rate, and the boiler efficiency.

To the right of the boiler, we see a dotted line pointing to the right and then down, with a number next to it, indicating the amount of boiler blowdown.

Below the boiler, we see the amount of steam that is entering the high-pressure header, the temperature of it, and the thermodynamic quality of the steam.

The steam exits the boiler and enters the high-pressure header, represented by a dark blue line. Under the line, to the far left, you will see a light-blue triangular graphic that represents a pressure-reducing station. The pressure reducing station is also equipped with a desuperheating station. The number at the top indicates the amount of steam entering the pressure reducing valve. The number at the center-left of the valve indicates the amount of desuperheating water entering the unit. The number below indicates the amount of desuperheated steam entering the medium-pressure header; as well as the temperature of the steam.

To the right of the pressure-reducing station, you will see light blue, cone-shaped graphics, that represent the steam turbines. The one nearest to the left is a high-pressure to condensing turbine. This turbine discharges to the condenser represented by the blue circle below the turbine. The turbine exhaust pressure is noted as the condenser pressure. The turbine in the middle receives high-pressure steam and exhausts low-pressure steam. The one to the right receives high-pressure steam and exhausts medium-pressure steam. Above each turbine is an indication of the amount of steam coming into the turbine from the header. To the right, in dark blue, you see the power generation of the turbine.

In the center of the medium-pressure and low-pressure headers, we see an arrow pointing downward, which indicates the amount of flash entering the header from the condensate collection flash vessels that are located at the far-right of the schematic.

Above the header, to the right, the amount of heat loss is expressed in orange. Below, there is a yellow box that indicates the pressure, temperature, and thermodynamic quality of the steam.

The arrow to the right of the header points to a dark blue circle with a line through it, indicating the steam end-use components. Below this symbol is an indication of the thermal energy supplied to the end-use components from the steam. The end-use components discharge condensate through a steam trap, represented by a blue circle with a "T" in it. Schematically, condensate passes to the right through the trap. Failed steam traps that are blowing steam to the atmosphere are represented with the red arrow exiting the top of the trap symbol. The condensate appropriately passing through traps, again represented as exiting to the right of the trap, can be recovered or lost. Lost condensate is represented as the unrecovered condensate discharging down from the traps and recovered condensate enters the condensate collection system further to the right.

The green figures to the far-right of the schematic represent condensate flash-vessels. The top flash-vessel receives condensate from the high-pressure end-users. Flash-steam is formed because the flash vessel operates at medium-pressure but it receives saturated liquid condensate at high-pressure. As equilibrium is reached flash-steam is formed. This flash-steam exits the vessel through the top and is directed to the medium-pressure steam header, which is shown in the center of the diagram. Condensate exits the flash vessel and enters the medium-pressure condensate collection system. The medium-pressure condensate system is equipped with similar equipment as the high-pressure system.

All of the collected condensate enters the main condensate receiver located in the lower-center of the schematic. Process condensate is mixed with turbine condensate and makeup water prior to entering the deaerator. The steam system deaerator is represented at the lower-left of the schematic. The deaerator receives low-pressure steam to preheat the collected condensate and makeup water represented as entering from the bottom of the vessel. Boiler feedwater discharges from the deaerator to the left and up to the boiler. The line pointing out from the top of the deaerator and leading to the right shows the amount of steam escaping from the vent.

Slide 19 - Basic Model Data

The power of SSAT is in the fact that it completes mass, energy, and economic balances on the steam system that is built by the user. The user can make modifications to the steam system and observe a side-by-side comparison of the system before and after the changes. This allows the impact to mass, energy, and economics to be identified.

In the model, economic impacts are only associated with fuel, electricity, and water purchases. Of course, the boiler consumes fuel in the generation of steam. The turbines can impact the amount of electricity purchased from the electrical supplier. And makeup water is supplied to the system as required.

The model is thermodynamically rigorous and allows the very complex interactions in steam systems to be accurately identified and evaluated.

The tool has great flexibility allowing various fuel types and cost to be coupled with electrical impact costs as well as steam conditions. This slide shows a small portion of the input data that can be arranged by the user.

[Slide Visual – Basic Model Data]

General Site Data	Input Data		Notes/Warnings
Site Power Import (+ for import, - for export)	15000	kW	Power import + site generated power = site electrical demand
Site Power Cost	0.0700	$/kWh	Typical 2003 value: $0.05/kWh
Operating hours per year	8760	hrs	
Site Make-Up Water Cost	0.0025	$/gallon	Typical 2003 value: $0.0025/gallon
Make-Up Water Temperature	70	F	
Note: Enter average values for the operating period being modeled			
Boiler fuel - Choose from this drop-down list			Natural Gas
Site Fuel Cost per 1000 s.cu.ft	10.00	$	Typical 2003 value: $5.78/(1,000 s cu.ft)
Steam Distribution	Input Data		
High Pressure (HP)	400	psig	
Medium Pressure (MP)	150	psig	
Low Pressure (LP)	20	psig	
HP Steam Use by Processes	5.00	klb/h	
MP Steam Use by Processes	15	klb/h	
LP Steam Use by Processes	63	klb/h	

Slide 20 - Boiler Characteristics

The characteristics of the boilers are modeled by the tool. This allows accurate system impacts to be identified.

[Slide Visual – Operating Characteristics]

Boiler			
Method for specifying boiler efficiency			**Option 2 - Enter User Defined Value**
Note: Model default efficiencies represent Best Practice values assuming good operation and the installation of an economizer			
Option 2 - Enter efficiency (%)	**78.73**	**%**	
Note: Boiler efficiency is defined as 100% - Stack Loss (%) - Shell Loss (%). The "Stack Loss" sheet gives more information on heat losses			
Note: Efficiency is based on Higher Heating Value. Economizers are included in the boiler efficiency. Boiler blowdown losses are excluded			
Blowdown Rate (% of feedwater flow)	**6.00**	**%**	
Do you have blowdown flash steam recovery to the LP system?			**No**
Please select how you wish to define your HP generation condition and then provide supplementary information below if required:			
Method for specifying HP generation condition			**Option 2- User-defined superheated Conditions**
Note: As a default, the model will use HP steam with 100 F of superheat. At HP pressure (400 psig), this corresponds to a temperature of 548 F			
Option 2 - Enter temperature	**700**	**F**	
Option 3 - Enter thermodynamic quality	**99**	**% dry**	

Slide 21 - Steam Turbines

The complexity of analyzing cogeneration systems is significant. The interaction between components can make evaluations tedious and time consuming. SSAT allows the characteristics of steam turbines to be incorporated in the model. The tool accurately evaluates the interactions between these complex components.

[Slide Visual – Operating Characteristics]

HP to LP Steam Turbine(s)	Input Data		Notes/Warnings
Isentropic efficiency	65	%	
Note: If multiple turbines are installed, the operation of the impact turbine (the turbine affected by changes to the system) should be modeled			
Note: A generator electrical efficiency of 100% is assumed by the model			
Select the appropriate turbine operating mode			Option 1 – Balances LP header (Model default option)
Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand			
Option 2 - How should the fixed turbine operation be defined?			Option 2 not selected
Option 2 - Fixed steam flow	100	klb/h	
Option 2 - Fixed power generation	2000	kW	

Option 3 - How do you wish to define the operating range?			Option 3 not selected
Option 3 - Minimum steam flow	50	klb/h	
Option 3 - Maximum steam flow	150	klb/h	
Option 3 - Minimum power generation	1500	kW	
Option 3 - Maximum power generation	2500	kW	

Slide 22 - SSAT Investigations

Built into SSAT are many projects (or system modifications) that are common to real-worlds steam systems. For example, the tool is set up to model the impact associated with reducing steam demand, changing the fuel supplied to the boiler, or improving boiler efficiency.

Again, the software provides a side-by-side comparison of the before and after operating characteristics. The tool identifies the change in fuel consumption, electrical consumption, and water consumption resulting from the change in system operation.

[Slide Visual – Projects 1, 2, and 3]

Project 1 - Steam Demand Savings (Changing the process steam requirements) **Current use - HP: 5 klb/h (4.66 MMBtu/h) MP: 8 klb/h (8.16 MMBtu/h) LP: 58.4 klb/h (65.99 MMBtu/h)**		
Do you wish to specify steam demand savings?		**Yes**
If yes, enter HP steam saving	**0 klb/h**	
If yes, enter MP steam saving	**1 klb/h**	
If yes, enter LP steam saving	**0 klb/h**	
Project 2 - Use an Alternative Fuel **Existing Boiler Fuel : Natural Gas Fuel Cost : $0.00578/s cu.ft**		
Do you wish to specify an alternative fuel?		**Yes**
If yes, choose a new fuel from this drop-down list		**Typical Green Wood**
Site Fuel Cost	**20.00 $/ton**	**Typical 2002 value: $21.00/ton**
Note: HHV for alternative fuel is 10,502,894 Btu per ton. (5,251 Btu/lb)		

Project 3 - Change Boiler Efficiency Existing Efficiency : 85%		
Do you wish to specify a new boiler efficiency?		Yes
Note: An example use of this project option is to model the effect of installing an economizer by increasing the efficiency		
If yes, enter new boiler efficiency (%)	85 %	

Slide 23 – Projects

There are many projects that are built into the tool. Projects are included that allow the user to modify blowdown characteristics or condensate recovery. Only a small sampling of projects is shown here.

[Slide Visual – Projects 4 and 13]

Project 4 - Change Boiler Blowdown Rate			
Existing Blowdown Rate : 6%			
Do you wish to specify a new boiler blowdown rate?			**Yes**
If yes, enter new rate (% of feedwater flow)	**1**	**%**	
Project 13 - Condensate Recovery			
Currently recover 50% of HP, 50% of MP and 50% of LP at 180 F			
Do you wish to specify new condensate recovery rates?			**Yes**
If yes, enter new HP condensate recovery	**50**	**%**	
If yes, enter new MP condensate recovery	**60**	**%**	
If yes, enter new LP condensate recovery	**50**	**%**	

<u>Slide 24 - Steam Turbine Projects</u>

Turbine operations can also be modified.

[Slide Visual – Project 7]

Project 7 - HP to LP Steam Turbine(s)			
Not Installed			
Do you wish to modify the HP to LP turbine operation?			**Yes, install a new turbine**
If yes, select the appropriate turbine operating mode			**Option 1 - Balances LP header**
Note: If Option 1 is chosen, the model will preferentially use the HP to LP turbine to balance the LP demand			
Specify a new isentropic efficiency (%)	**70**	**%**	
Note: A generator electrical efficiency of 100% is assumed by the model			
Option 2 - How do wish to define the fixed turbine operation?			**Option 2 not selected**
Option 2 - Fixed steam flow	**100**	**klb/h**	
Option 2 - Fixed power generation	**2000**	**kW**	
Option 3 - How do wish to define the operating range?			**Option 3 not selected**
Option 3 - Minimum steam flow	**50**	**klb/h**	
Option 3 - Maximum steam flow	**150**	**klb/h**	
Option 3 - Minimum power generation	**1500**	**kW**	
Option 3 - Maximum power generation	**2500**	**kW**	

<u>Slide 25 - Blowdown Thermal Energy Recovery</u>

As an introduction to the tool we will use SSAT to evaluate the boiler blowdown thermal energy recovery opportunity. We have developed a model that reflects the characteristics of the steam system we have been dealing with. Initially we will assume the steam system is not equipped with cogeneration components. In other words, there are no steam turbines in this system we initially investigate.

We will use the built-in projects associated with boiler blowdown thermal energy recovery to identify the economic impact associated with the real-world project.

[Slide Visual – Projects 5 and 12]

Project 5 - Blowdown Flash to LP	
Not currently installed	
Do you wish to modify the blowdown flash system?	**Option 1 - Install blowdown flash**
Project 12 - Feedwater Heat Recovery Exchanger using Boiler Blowdown	
Not currently installed	
Modify the boiler blowdown heat recovery system?	**Yes, install a new heat exchanger**

<u>Slide 26 - Before and After Comparison</u>

The results indicate that for a steam system that is generating approximately 100,000 pounds per hour of 400 psig steam, from 10 dollars per million BTU natural gas, implementing blowdown thermal energy recovery can reduce operating cost more than $260,000 per year.

The majority of the savings is developed from the reduction of fuel consumption in the boiler—approximately $262,000 per year. Minimal savings is developed from a reduction in makeup water consumption--$3,000 per year.

[Slide Visual – Results Summary]

Steam System Assessment Tool					
3 Header Model					
Results Summary					
SSAT Default 3 Header Model					
Model Status : OK					
Cost Summary ($ '000s/yr)	**Current Operation**	**After Projects**		**Reduction**	
Power Cost	9,198	9,198		0	0.0%
Fuel Cost	12,930	12,669		262	2.0%
Make-Up Water Cost	177	174		3	2.0%
Total Cost (in $ '000s/yr)	22,306	22,041		265	1.2%
On-Site Emissions	**Current Operation**	**After Projects**		**Reduction**	
CO2 Emissions	150272 t/yr	177233 t/yr		3039 t/yr	2.0%
SOx Emissions	0 t/yr	0 klb/yr		0 klb/yr	N/A
NOx Emissions	297 t/yr	291 t/yr		6 t/yr	2.0%
Power Station Emissions		**Reduction After Projects**		**Total Reduction**	
CO2 Emissions		0 t/yr		3039 tb/yr	-
Sox Emissions		0 t/yr		0 t/yr	-
Nox Emissions		0 t/yr		6 t/yr	-
Note – Calculates the impact of the change in site power import on emissions from an external power station. Total reduction values are for site + power station					

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	0 kW	kW	-	-
Power Import	15000 kW	15000 kW	642 kW	4.3%
Total Site Electrical Demand	15000 kW	15000 kW	-	-
Boiler Duty	148 kW	145 kW	3 kW	2.0%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	147606.2 s cu.ft/h	144620.9 s cu.ft/h	2985.3 s cu.ft/h	2.0%
Boiler Steam Flow	99.5 klb/h	97.5 klb/h	2.0 klb/h	2.0%
Fuel Cost (in $/MMBtu)	10.00	10.00	-	-
Power Cost (as $/MMBtu)	20.51	20.51	--	
Make-Up Water Flow	8100 m3/h	7942 m3/h	158 m3/h	2.0%

Slide 27 - Project Implementation

It is interesting to note that implementing the project in this steam system would most probably require less than $100,000. As a result, the project is very attractive from an economic standpoint.

It is also interesting to note that the economic impact is even greater than the loss estimate identified previously. This is because the model accurately identifies the boiler efficiency impacts and other energy related interactions.

[Slide Visual – Project Implementation]

For the example boiler implementing blowdown energy recovery:

- **Reduces fuel consumption more than $260,000/yr**
  - **The savings is greater than the system loss estimate provided previously of $215,000/yr**
    - **The energy recovered to the makeup water is not subjected to the boiler inefficiency**
    - **Steam generation and makeup water requirements are reduced because of flash steam**
  - **The project implementation cost should be much less than $100,000**

Slide 28 - Blowdown Energy Recovery

Effective blowdown thermal energy recovery can allow water quality to be controlled to higher levels with minimal economic impact because the blowdown energy is being recovered.

Makeup water requirements are reduced primarily because the flash steam generated in the flash recovery vessel is returned to the steam system.

Often the blowdown stream must be cooled before it is introduced to the sewer system. This can result in a large amount of purchased cooling water to be lost to the sewer system. Effective boiler blowdown thermal energy recovery can result in low-temperature blowdown being discharged to the sewer with no cooling water requirements.

Slide 29 - Steam Turbine Influences

Now we will examine the system impacts when blowdown thermal energy recovery is added to a steam system that is equipped with cogeneration components. I have constructed a model that includes steam turbines that are connected to electrical power generators. At this point we will not discuss the turbine characteristics other than to indicate the turbines are typical of what would be found in an industrial complex.

[Slide Visual - Model Tab Schematic]

The top center will contain the descriptive title provided by the user, the initial template reads "SSAT Default 3 Header Model" or a similar title for whatever model you chose. Below it, you will see the Model Status, which should read "OK." The model status provides an indication of the calculation condition of the model.

To the left of the Model Status, you will see a chart in light blue, which indicates the emissions per year for carbon dioxide, sulfur oxide, and nitrogen oxide.

At the top right, it will say "Current Operation" if you are on the Model tab, or "Operation After Projects" if you are on the Projects Model tab.

The red graphic near the top left represents the boiler. From the left, there is a dotted line entering it, which represents the amount of feedwater entering the boiler from the deaerator.

Also to the left of the boiler, we see the following information highlighted in orange: the type of fuel being used in the boiler, the fuel input energy, the fuel flow rate, and the boiler efficiency.

To the right of the boiler, we see a dotted line pointing to the right and then down, with a number next to it, indicating the amount of boiler blowdown.

Below the boiler, we see the amount of steam that is entering the high-pressure header, the temperature of it, and the thermodynamic quality of the steam.

The steam exits the boiler and enters the high-pressure header, represented by a dark blue line. Under the line, to the far left, you will see a light-blue triangular graphic that represents a pressure-reducing station. The pressure reducing station is also equipped with a desuperheating station. The number at the top indicates the amount of steam entering the pressure reducing valve. The number at the center-left of the valve indicates the amount of desuperheating water entering the unit. The number below indicates the amount of desuperheated steam entering the medium-pressure header; as well as the temperature of the steam.

To the right of the pressure-reducing station, you will see light blue, cone-shaped graphics, that represent the steam turbines. The one nearest to the left is a high-pressure to condensing turbine. This turbine discharges to the condenser represented by the blue circle below the turbine. The turbine exhaust pressure is noted as the condenser pressure. The turbine in the middle receives high-pressure steam and exhausts low-pressure steam. The one to the right receives high-pressure steam and exhausts medium-pressure steam. Above each turbine is an indication of the amount of steam coming into the turbine from the header. To the right, in dark blue, you see the power generation of the turbine.

In the center of the medium-pressure and low-pressure headers, we see an arrow pointing downward, which indicates the amount of flash entering the header from the condensate collection flash vessels that are located at the far-right of the schematic. There is a red circle around the medium and low-pressure headers.

Above the header, to the right, the amount of heat loss is expressed in orange. Below, there is a yellow box that indicates the pressure, temperature, and thermodynamic quality of the steam.

The arrow to the right of the header points to a dark blue circle with a line through it, indicating the steam end-use components. Below this symbol is an indication of the thermal energy supplied to the end-use components from the steam. The end-use components discharge condensate through a steam trap, represented by a blue circle with a "T" in it. Schematically, condensate passes to the right through the trap. Failed steam traps that are blowing steam to the atmosphere are represented with the red arrow exiting the top of the trap symbol. The condensate appropriately passing through traps, again represented as exiting to the right of the trap, can be recovered or lost. Lost condensate is represented as the unrecovered condensate discharging down from the traps and recovered condensate enters the condensate collection system further to the right.

The green figures to the far-right of the schematic represent condensate flash-vessels. The top flash-vessel receives condensate from the high-pressure end-users. Flash-steam is formed because the flash vessel operates at medium-pressure but it receives saturated liquid condensate at high-pressure. As equilibrium is reached flash-steam is formed. This flash-steam exits the vessel through the top and is directed to the medium-pressure steam header, which is shown in the center of the diagram. Condensate exits the flash vessel and enters the medium-pressure condensate collection system. The medium-pressure condensate system is equipped with similar equipment as the high-pressure system.

All of the collected condensate enters the main condensate receiver located in the lower-center of the schematic. Process condensate is mixed with turbine condensate and makeup water prior to entering the deaerator.

The steam system deaerator is represented at the lower-left of the schematic. The deaerator receives low-pressure steam to preheat the collected condensate and makeup water represented as entering from the bottom of the vessel. Boiler feedwater discharges from the deaerator

to the left and up to the boiler. The line pointing out from the top of the deaerator and leading to the right shows the amount of steam escaping from the vent.

Slide 30 - SSAT Evaluation

The results are not dramatically different that what was observed in the system without cogeneration components. The combined economic impact is $241,000 per year. Blowdown thermal energy recovery is not expected to dramatically impact steam turbine operation; but, the impacts on the turbines are accurately reflected in the model results. It is interesting that the fuel impact is significantly greater. The model indicates fuel consumption will reduce more than $300,000 per year. Electrical purchases will increase more than $70,000 per year. These are not insignificant impacts.

The point is that SSAT is a powerful and useful tool that can be relied upon to accurately reflect the system interactions of complex steam systems.

[Slide Visual – Results Summary]

Cost Summary ($ '000s/yr)	Current Operation	After Projects		Reduction	
Power Cost	9,198	9,268		-70	-0.8%
Fuel Cost	12,861	12,554		307	2.4%
Make-Up Water Cost	174	170		4	2.2%
Total Cost (in $ '000s/yr)	22,234	21,993		241	1.1%
Utility Balance	**Current Operation**	**After Projects**		**Reduction**	
Power Generation	3245 kW	3131 kW		-	-
Power Import	15000 kW	15115 kW		-115 kW	-0.8%
Total Site Electrical Demand	18245 kW	18245 kW		-	-
Boiler Duty	147 kW	143 kW		4 kW	2.4%
Fuel Type	Natural Gas	Natural Gas		-	-
Fuel Consumption	146820.3 s cu.ft/h	143313.3 s cu.ft/h		3507 s cu.ft/h	2.4%
Boiler Steam Flow	99.0 klb/h	96.6 klb/h		2.4 klb/h	2.4%
Fuel Cost (in $/MMBtu)	10.00	10.00		-	-
Power Cost (as $/MMBtu)	20.51	20.51		-	-
Make-Up Water Flow	7961 m3/h	7785 m3/h		176 m3/h	2.2%

Slide 31 - Blowdown Loss Reduction

In summary, with respect to boiler blowdown; we must measure boiler water chemistry and the blowdown rate to appropriately manage our resources in this area. We should work to improve our boiler feedwater quality. Incorporating thermal energy recovery components can almost eliminate the loss associated with blowdown.

[Slide Visual – Blowdown Loss Reduction - Summary]

- **Measure blowdown flow (chemical analysis)**
- **Control blowdown flow (conductivity and chemistry)**
- **Control water chemistry**
- **Improve feedwater quality**
- **Recover flash steam to low-pressure systems and preheat inlet streams**