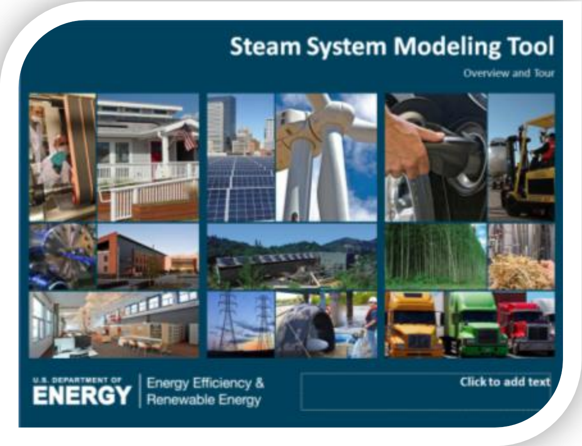
Steam System Modeling Tool

Overview and Tour

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

How to use this Document

This document is designed to be used as both a comprehensive presentation and a quick reference for the **Steam System Modeling Tool (SSMT)**



To use as a quick reference:

- The table of contents provides links to all of the key topics covered.
- Each page also includes a direct link back to the table of contents
- A direct link to SSMT is also provided a the bottom of every page (*internet connection required*)

How to use SSMT

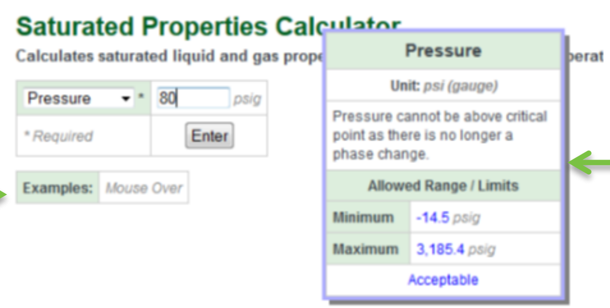
SSMT is designed to be easy to use with significant built-in documentation and detailed calculations. Specifically the examples, and pop-up hints allows users to test all features instantly and get immediate feedback:

Examples are available in all calculators and the modeler. When selected, they demonstrate the functions of the calculators by being loaded just as though it had been entered by the user. Almost all examples are randomly generated, allowing users to evaluate numerous examples.

Pop-Up Hints appear for all data fields

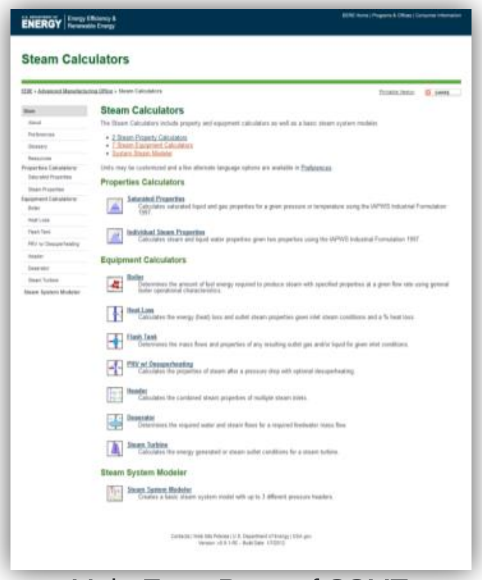
Every data field has a pop-up hint that provides details about the field units, description, acceptable range, and where the entered value is valid.

Examples



Pop-Up Hints

Table of Contents (1/2) (click links to jump to section)



Main Entry Page of SSMT

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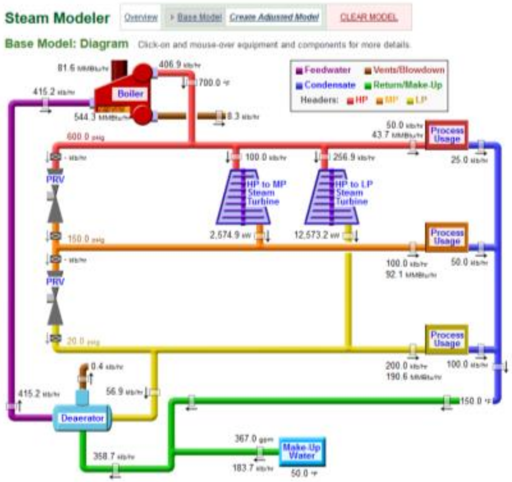
Introduction (1/2)

The **Steam System Modeling Tool (SSMT)** is designed to enable steam system operators to both better understand their systems and provide the tools to evaluate potential improvements.

Key features include:

- **Custom Steam Property Tables**
- **Equipment Calculators**
- **Steam System Modeler**
- **Web-based**
- **Customizable Units**
- **Transparent Calculations**



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Introduction (2/2) - *Key Feature Details*

Custom Steam Property Tables

Users can generate customized steam tables based on specific operating conditions of their steam system.

Equipment Calculators

Basic steam system equipment can be independently modeled and evaluated without creating a complete model.

Steam System Modeler

A 1-3 header steam system model can be generated with the associated PRVs, steam turbines, flash tanks, heat losses, and condensate return conditions. Users can then evaluate the impact of a significant number of adjustments to the model.

Web-based

Only an internet connection and the current version of any major browser are required to immediately start using SSMT. *There are no installation requirements.*

Customizable Units

Users can select and switch between a number of different units at any time.

Transparent Calculations

Calculations details are provided through tool to allow users to verify results.

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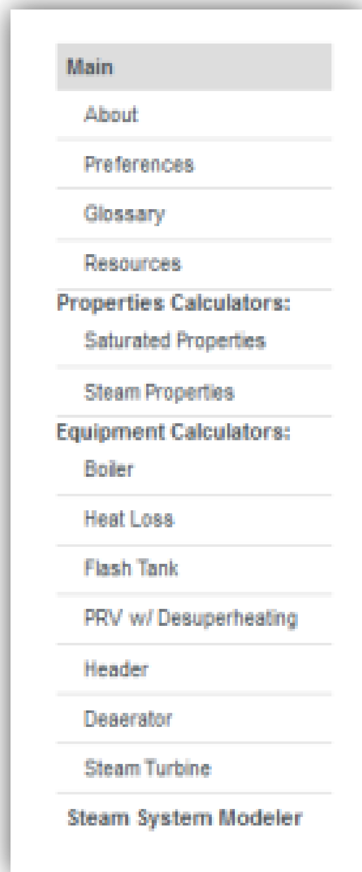
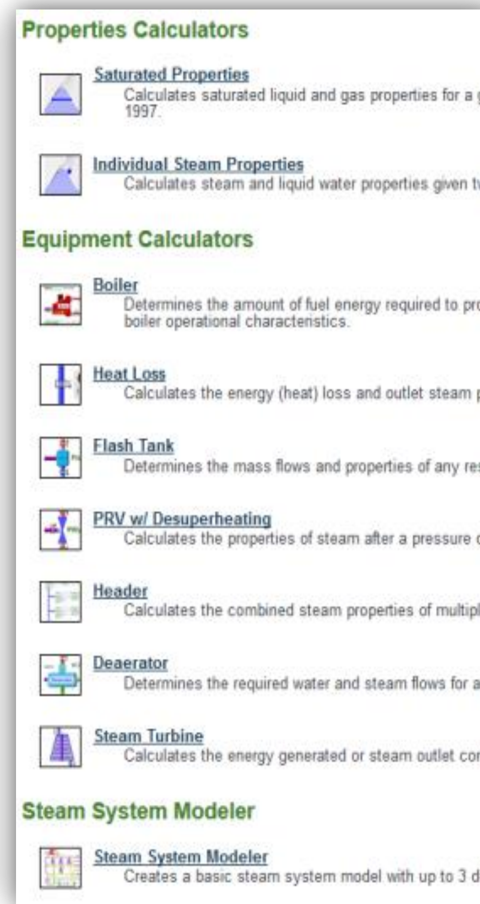
General Layout and Structure

Major Sections of SSMT:

- General Information
- Property Calculators
- Equipment Calculators
- Steam System Modeler

All calculators follow a similar format *detailed on the following page*.





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General Calculator Layout

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Data Inputs with pop-up tips and data validation

Examples for a few common configurations with random data

Assumptions specific to the calculation

Diagram of Equipment with Complete Steam Property Details

Calculation Details populated with data from current calculation

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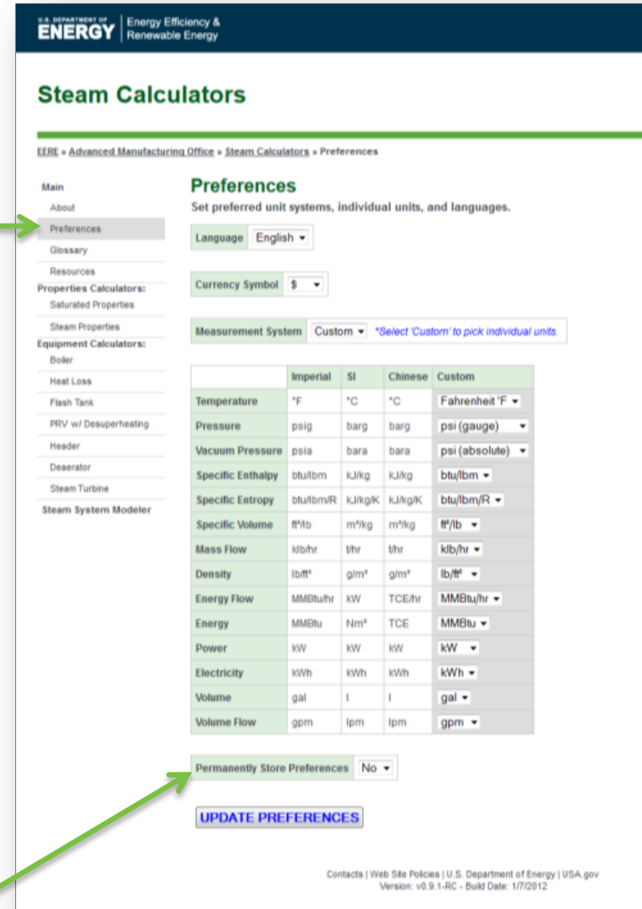
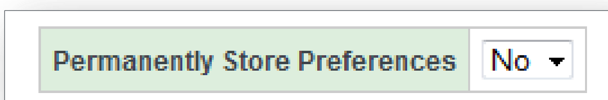
Customizing Units and Language

The **Preferences** page allows users to customize the following at anytime:

- Unit Types
- Language
- Currency Symbol



By default, NO information will be stored about the users preferences. If a user wishes to store their preferences between sessions they must switch the "Permanently Store Preferences" Option to "Yes"



Customizing Units

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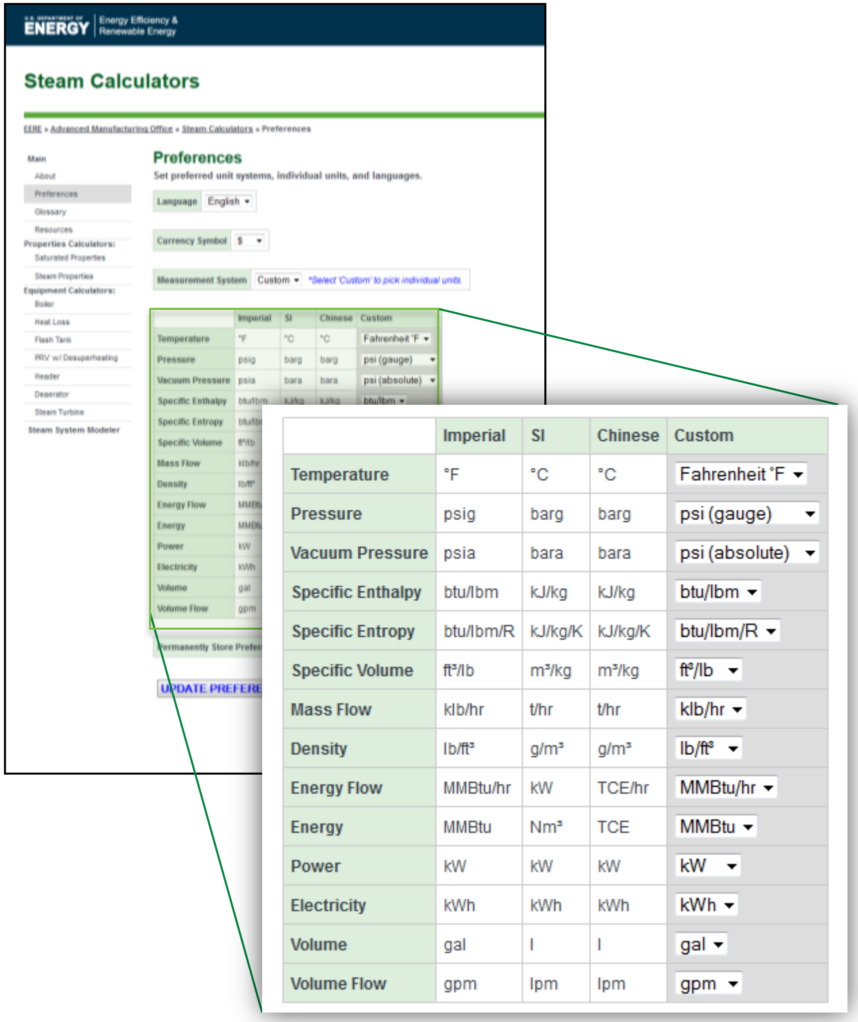
- Users may select between predefined units sets or customize each individual unit.
- This may be done at **any time**, even if a model has already been generated. The model and entered values will all be updated to match the new units.
- SSMT remembers which units were selected when any values are entered. This ensures that entered values are at most converted only 1 time regardless of how many times a user switches units.



	Imperial	SI	Chinese	Custom
Temperature	°F	°C	°C	Fahrenheit °F
Pressure	psig	barg	barg	psi (gauge)
Vacuum Pressure	psia	bara	bara	psi (absolute)
Specific Enthalpy	btu/lbm	kJ/kg	kJ/kg	btu/lbm
Specific Entropy	btu/lbm/R	kJ/kg/K	kJ/kg/K	btu/lbm/R
Specific Volume	ft³/lb	m³/kg	m³/kg	ft³/lb
Mass Flow	klb/hr	t/hr	t/hr	klb/hr
Density	lb/ft³	g/m³	g/m³	lb/ft³
Energy Flow	MMBtu/hr	kW	TCE/hr	MMBtu/hr
Energy	MMBtu	Nm³	TCE	MMBtu
Power	kW	kW	kW	kW
Electricity	kWh	kWh	kWh	kWh
Volume	gal	l	l	gal
Volume Flow	gpm	lpm	lpm	gpm

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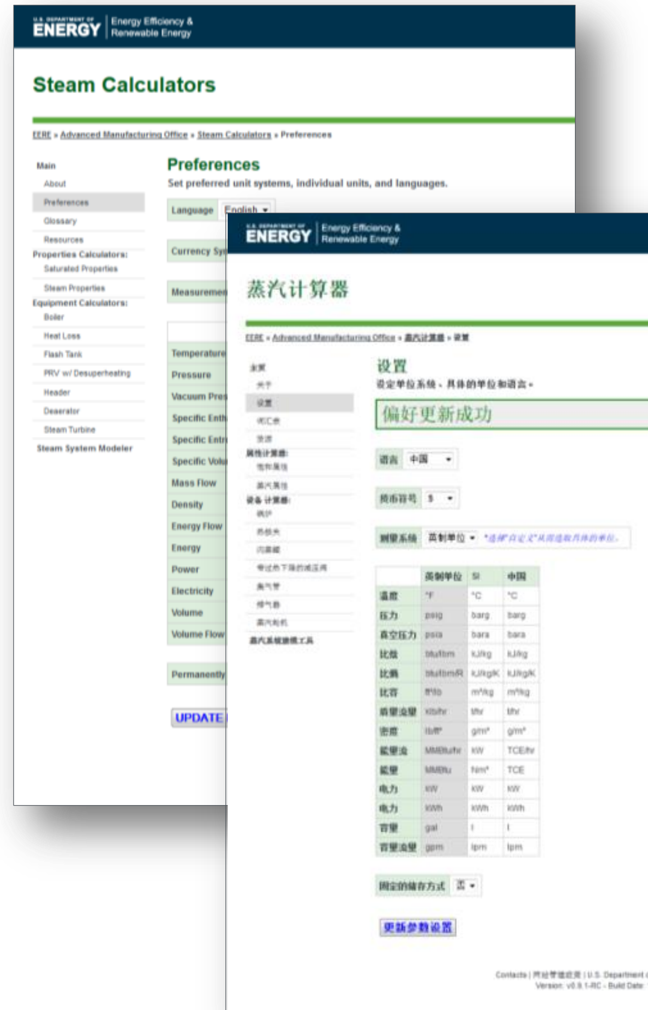
Customizing Languages

- SSMT is design to support alternate languages options. It currently includes:
  - Chinese
  - Russian
- To further support international use of the tool, users can also select an alternate currency symbol.
  - This is used in the steam system modeler which includes steam related costs and cost savings calculated from various system adjustments.



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Steam Properties

SSMT calculates *all* steam properties using the *International Association for the Properties of Water and Steam's Thermodynamic Properties of Water and Steam Industrial Formulation, IAPWS-IF97, 2007,* www.iapws.org

Calculated properties include:*

- Pressure
- Temperature
- Specific Enthalpy
- Specific Entropy
- Phase
- Quality
- Specific Volume

**Due to the complexity of the steam calculations, they are not displayed by SSMT.*


The International Association for the Properties of Water and Steam

Lucerne, Switzerland
August 2007

Revised Release on the IAPWS Industrial Formulation 1997
for the Thermodynamic Properties of Water and Steam

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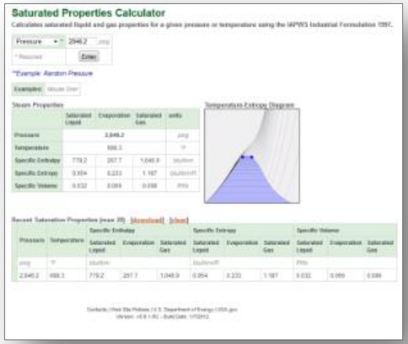
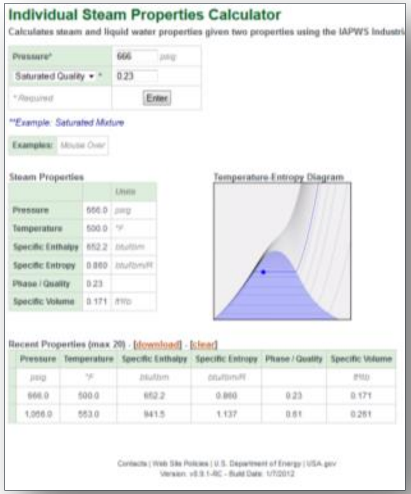
SSMT Steam Property Calculators

SSMT provides 2 steam property calculators:

- Saturated Properties Calculator
  - Determines saturated liquid and gas properties for a given pressure or temperature
- Steam Properties Calculator
  - Determines steam and liquid water properties given two properties that fix the state





Both calculators include:

- Steam Property Details
- Temperature-Entropy Diagram (Vapor Dome)
- History of 20 most recent property calculation
- Downloadable properties (*custom steam tables*)

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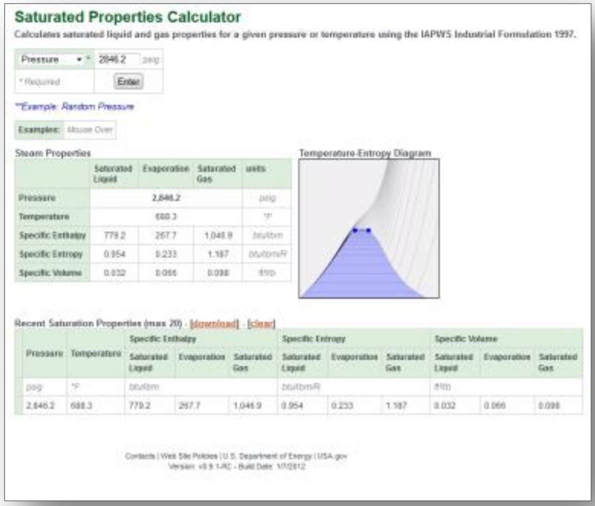
Saturated Properties Calculator



Saturated Properties Calculator

Determines saturated liquid and gas properties for a given pressure or temperature

- Saturated liquid and gas refer to the 2 separate states of water that co-exist when boiling
- Both the saturated liquid and the gas will be the same temperature and pressure
- Quality refers to the portion of the total mass of water that is a gas/vapor (0 to 1). A quality of 1 indicates that it is entirely a saturated gas/vapor
- Saturated properties can be determined given only the temperature or pressure as they both correspond to the boiling temperature at a given pressure

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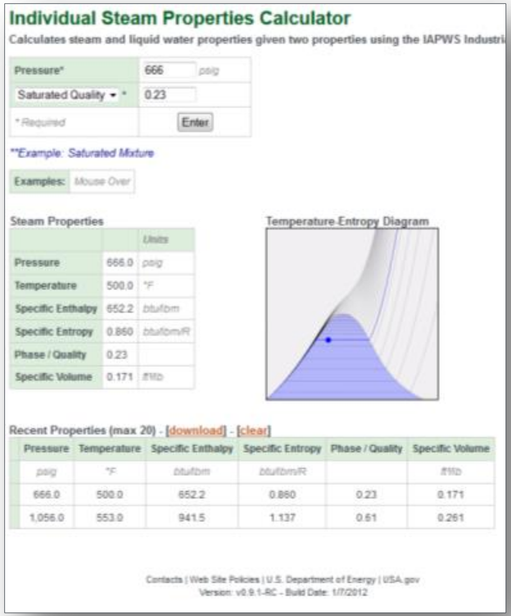
Steam Properties Calculator

Steam Properties Calculator

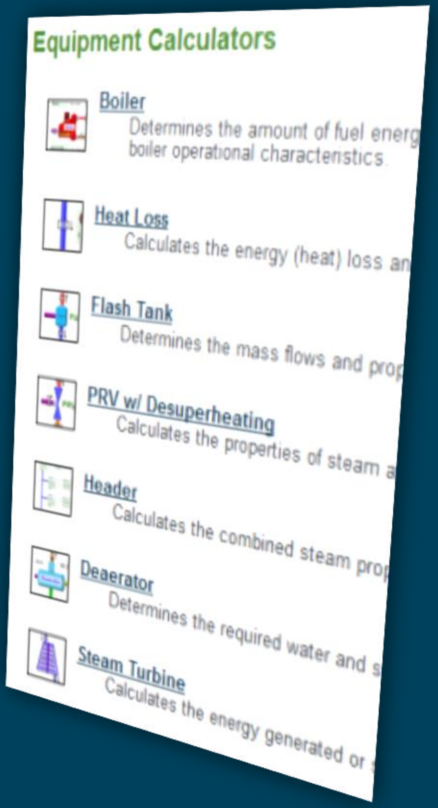
Determines steam and liquid water properties given two properties that fix the state



- Pressure and a secondary steam property are required to determine the exact state of the steam
- Potential secondary properties include:
  - Temperature
  - Specific Enthalpy
  - Specific Entropy
  - Quality
- This calculator can evaluate:
  sub-cooled liquid, saturated liquid, saturated mixture, saturated gas, superheated gas, and supercritical properties

SSMT Equipment Calculators:

- Boiler Calculator
- Heat Loss Calculator
- Flash Tank Calculator
- PRV w/ Desuperheating Calculator
- Header Calculator
- Deaerator Calculator
- Steam Turbine Calculator



Structure of Calculator Descriptions

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OVERVIEW

Description of the calculator and key features

INPUTS

Each input listed in the following format:

INPUT NAME [**property type**]:
description of input type

CALCULATIONS

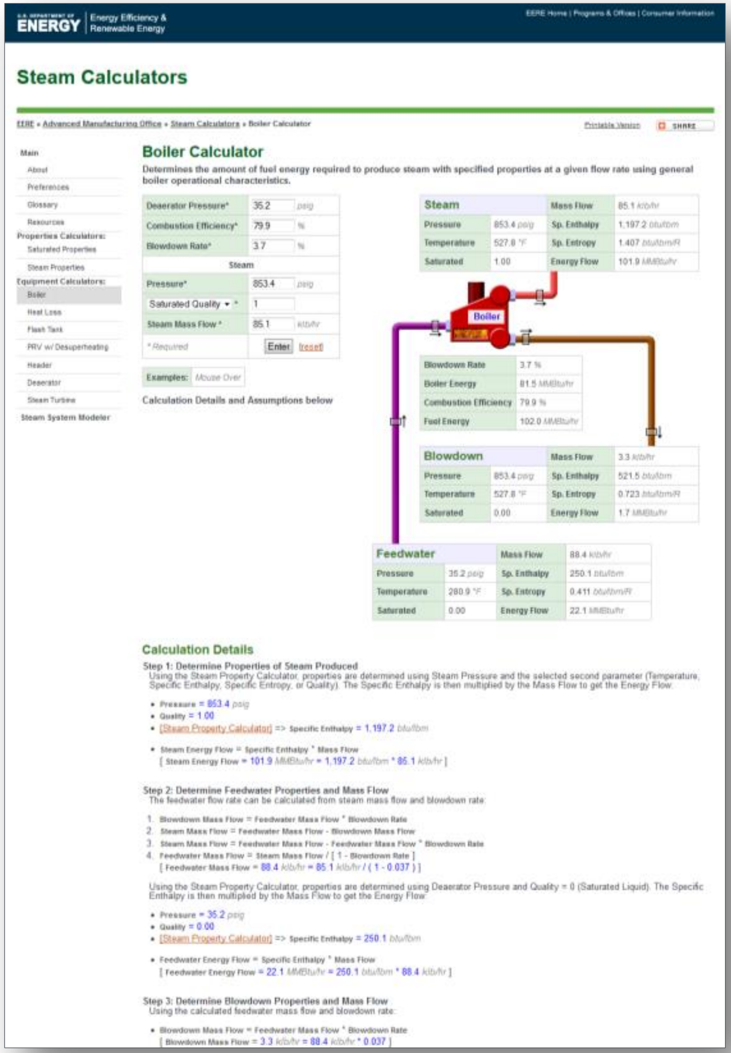
Each step listed in the following format:

Step #: Description
additional details

RESULTS

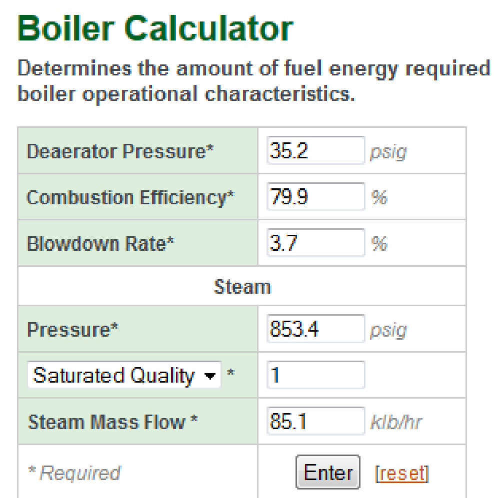
Listing of all calculations results provided by the calculator

The **Boiler Calculator** determines the amount of fuel energy required to produce steam with the specified properties at a given flow rate using general boiler operational characteristics.



Capable of evaluating generation of:

- Saturated Steam
- Superheated Steam
- Supercritical Steam



Deaerator Pressure [pressure]:

Initial pressure of the feedwater before it is increased to boiler pressure

Combustion Efficiency [%]:

% of the fuel energy that is transferred to the boiler water and steam

Blowdown Rate [%]:

% of feedwater being drained from the boiler as a saturated liquid to reduce the concentration of dissolved solids

Pressure [pressure]:

Operating pressure of the boiler, blowdown, and generated steam

Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the generated steam

Steam Mass Flow [mass flow]:

Mass flow of the steam produced by the boiler

Boiler Calculator

CALCULATION

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Step 1: Determine Properties of Steam Produced

Steam properties are determined using the **Pressure**, **Secondary Steam Property**, and **Steam Mass Flow.**

Step 2: Determine Feedwater Properties and Mass Flow

Feedwater properties are assumed to be equal to the properties of saturated liquid at **Deaerator Pressure**. The feedwater mass flow is calculated using the **Blowdown Rate** and **Steam Mass Flow**.

Step 3: Determine Blowdown Properties and Mass Flow

The blowdown properties are assumed to be equal to the properties of a saturated liquid at Boiler **Pressure.** The blowdown mass flow is calculated using the **Blowdown Rate** and feedwater mass flow.

Step 4: Determine Boiler Energy

The boiler energy is calculated as the difference between the total outlet (steam, blowdown) energy flows and inlet (feedwater) energy flows.

Step 5: Determine Fuel Energy

The total required fuel energy is determined by dividing the boiler energy by the **Combustion Efficiency.**

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Boiler Calculator

RESULTS

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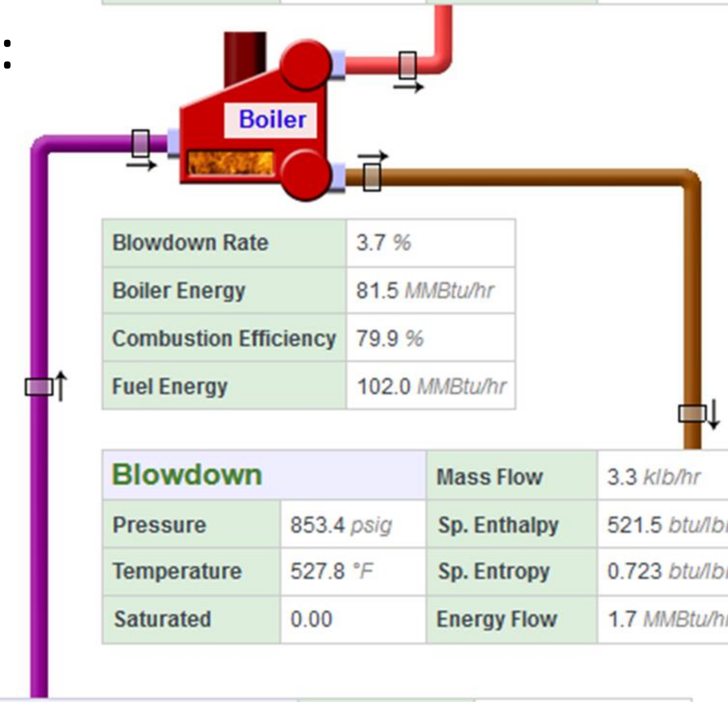
The **Boiler Calculator** provides the following results:

- Properties and Mass Flows for:
  - Feedwater
  - Blowdown
  - Generated Steam
- Boiler Energy
- Required Fuel Energy



Steam		Mass Flow	85.1 *klb/hr*
Pressure	853.4 *psig*	Sp. Enthalpy	1,197.2 *btu/lbm*
Temperature	527.8 *°F*	Sp. Entropy	1.407 *btu/lbm/R*
Saturated	1.00	Energy Flow	101.9 *MMBtu/hr*

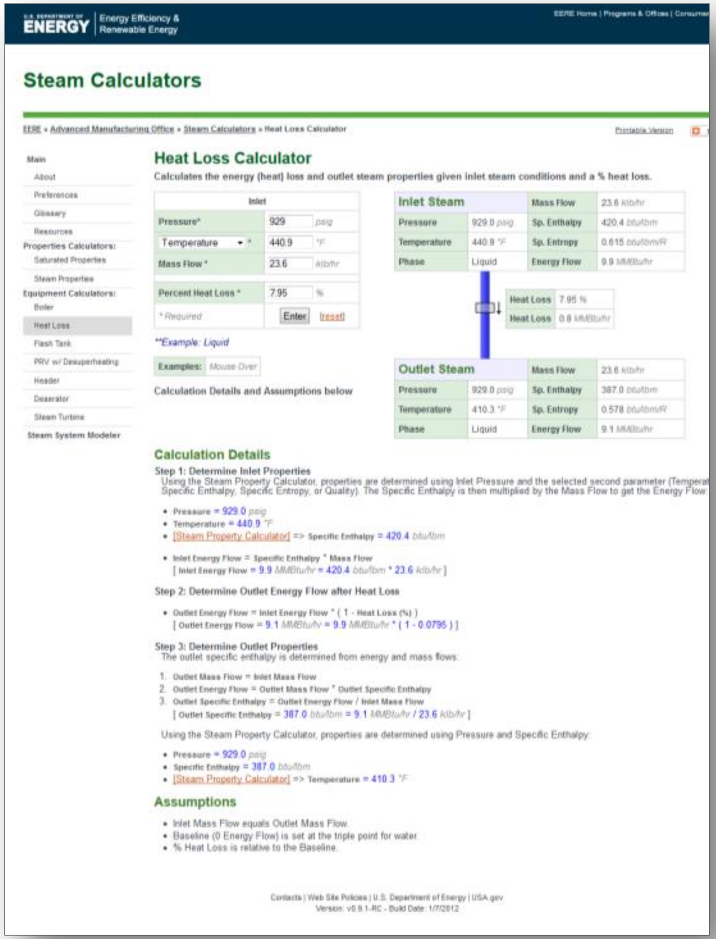
Blowdown Rate	3.7 *%*
Boiler Energy	81.5 *MMBtu/hr*
Combustion Efficiency	79.9 *%*
Fuel Energy	102.0 *MMBtu/hr*

Blowdown		Mass Flow	3.3 *klb/hr*
Pressure	853.4 *psig*	Sp. Enthalpy	521.5 *btu/lbm*
Temperature	527.8 *°F*	Sp. Entropy	0.723 *btu/lbm/R*
Saturated	0.00	Energy Flow	1.7 *MMBtu/hr*

Feedwater		Mass Flow	88.4 *klb/hr*
Pressure	35.2 *psig*	Sp. Enthalpy	250.1 *btu/lbm*
Temperature	280.9 *°F*	Sp. Entropy	0.411 *btu/lbm/R*
Saturated	0.00	Energy Flow	22.1 *MMBtu/hr*

The **Heat Loss Calculator** determines the energy [heat] loss and outlet steam properties for a steam pipe or header based on specific given inlet steam conditions and a % heat loss.

- % heat loss is relative to the triple point of water at which point the energy content of water is set a 0
- This calculator is primarily used to determine the % heat loss that best approximates the actual heat loss on a specific steam header



Heat Loss Calculator

INPUTS

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Pressure [pressure]:

Pressure of the input steam

Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

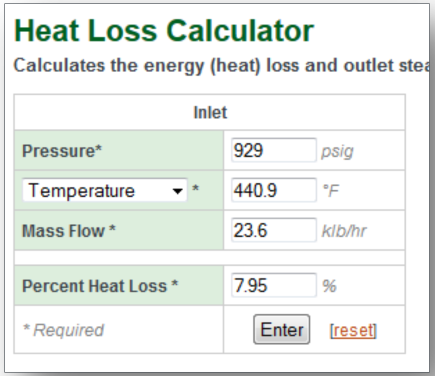
Second steam property associated with the inlet steam

Mass Flow [mass flow]:

Mass flow of the steam

Percent Heat Loss [%]:

% of steam heat [*enthalpy*] lost between the inlet and the outlet



Step 1: Determine Inlet Properties

Inlet steam properties are determined using the **Pressure**, **Secondary Steam Property**, and **Mass Flow.**

Step 2: Determine Outlet Energy Flow after Heat Loss

The outlet energy flow calculated by reducing the inlet energy flow by the **Percent Heat Loss.**

Step 3: Determine Outlet Properties

The outlet steam properties are determined using the **Inlet Pressure** and the calculated outlet energy flow.

Heat Loss Calculator

RESULTS

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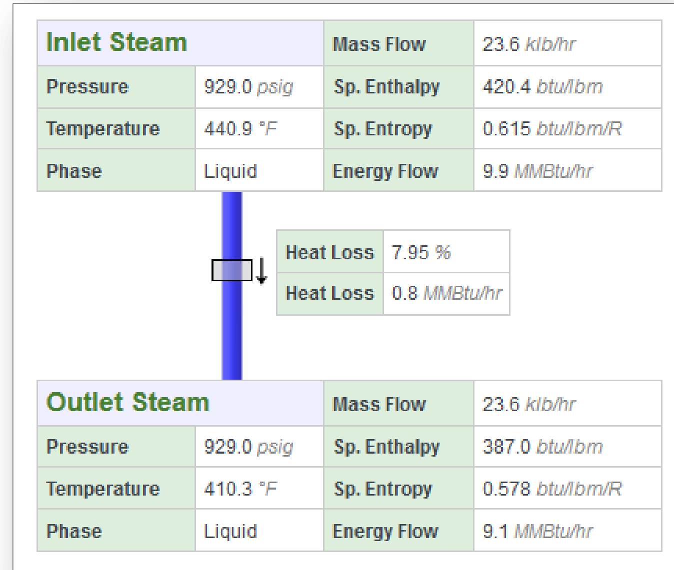
The **Heat Loss Calculator** provides the following results:

- Inlet Steam Properties
- Outlet Steam Properties
- Total Heat Loss



Inlet Steam		Mass Flow	23.6 klb/hr
Pressure	929.0 psig	Sp. Enthalpy	420.4 btu/lbm
Temperature	440.9 °F	Sp. Entropy	0.615 btu/lbm/R
Phase	Liquid	Energy Flow	9.9 MMBtu/hr

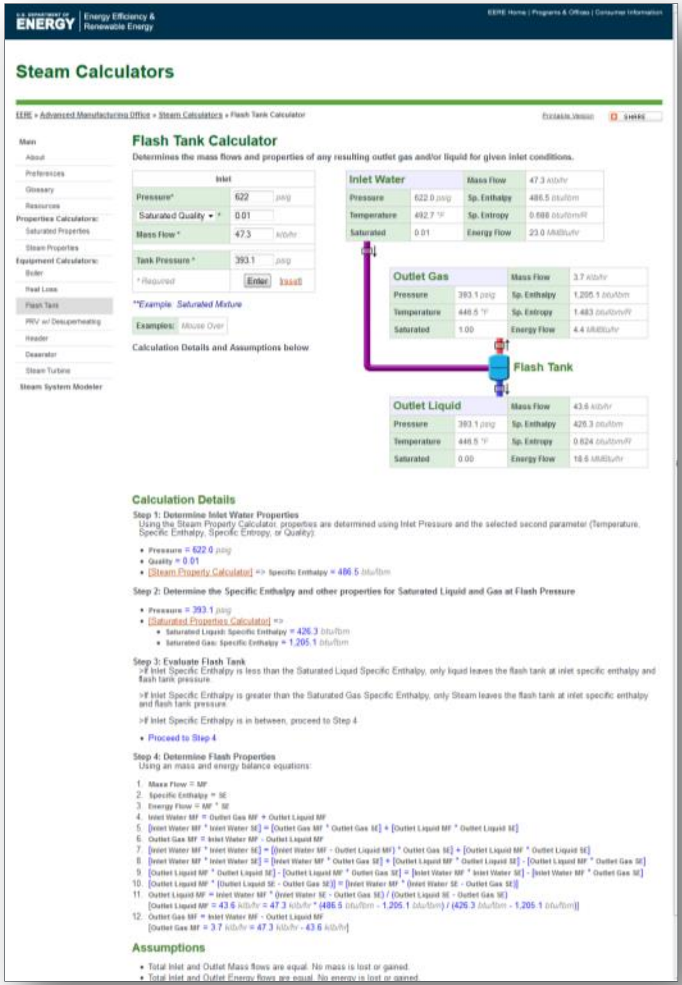
Heat Loss	7.95 %
Heat Loss	0.8 MMBtu/hr

Outlet Steam		Mass Flow	23.6 klb/hr
Pressure	929.0 psig	Sp. Enthalpy	387.0 btu/lbm
Temperature	410.3 °F	Sp. Entropy	0.578 btu/lbm/R
Phase	Liquid	Energy Flow	9.1 MMBtu/hr

Flash Tank Calculator

The **Flash Tank Calculator** determines the mass flows and steam properties of any resulting outlet gas and/or liquid from a flash tank based on inlet conditions.

A **flash tank** is used to capture the steam generated when a high pressure, high temperature liquid has its pressure reduced causing some of the liquid to vaporize, as known as flashing.



Flash Tank Calculator

Pressure [pressure]:

Pressure of the input steam

Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

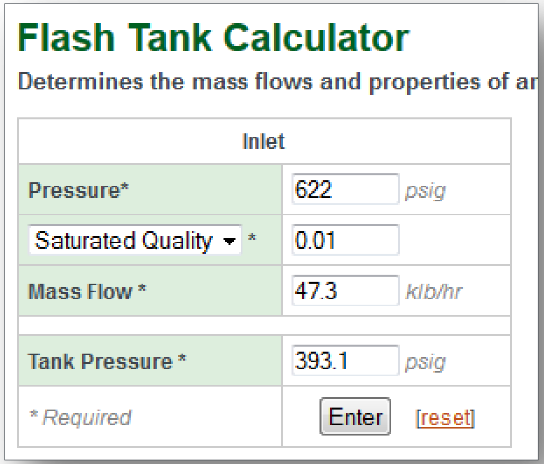
Second steam property associated with the inlet steam

Mass Flow [mass flow]:

Mass flow of the steam

Percent Heat Loss [pressure]:

Pressure inlet steam is reduced to in the flash tank



Flash Tank Calculator

CALCULATION

Step 1: Determine Inlet Water Properties

Inlet properties are determined using the **Pressure**, **Secondary Steam Property**, and **Mass Flow.**

Step 2: Determine the Specific Enthalpy and other properties for Saturated Liquid and Gas at Flash Pressure

The saturated liquid and gas/vapor properties for the **Flash Tank Pressure** are calculated**.**

Step 3: Evaluate Flash Tank

- If Inlet Specific Enthalpy is less than the Saturated Liquid Specific Enthalpy, only liquid leaves the flash tank at inlet specific enthalpy and flash tank pressure.
- If Inlet Specific Enthalpy is greater than the Saturated Gas Specific Enthalpy, only Steam leaves the flash tank at inlet specific enthalpy and flash tank pressure.
- If Inlet Specific Enthalpy is in between, proceed to Step 4.

Step 4: Determine Flash Properties

A mass and energy balance is used to determine the ratio of the saturated liquid and gas that equals the mass and energy flows of the inlet water.

Flash Tank Calculator

RESULTS

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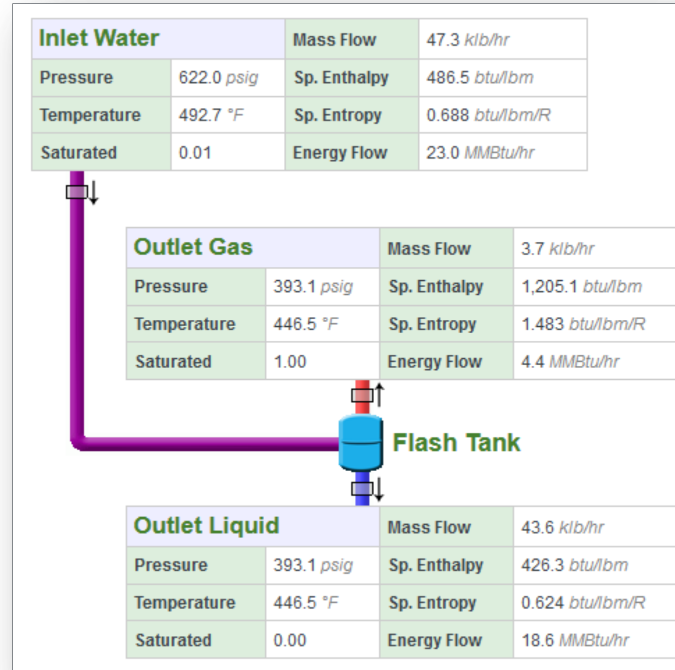
The **Flash Tank Calculator** provides the following results:

- Properties and Mass Flows for:
  - Inlet High Pressure Water
  - Outlet Gas
  - Outlet Liquid



Inlet Water		Mass Flow	47.3 klb/hr
Pressure	622.0 psig	Sp. Enthalpy	486.5 btu/lbm
Temperature	492.7 °F	Sp. Entropy	0.688 btu/lbm/R
Saturated	0.01	Energy Flow	23.0 MMBtu/hr

Outlet Gas		Mass Flow	3.7 klb/hr
Pressure	393.1 psig	Sp. Enthalpy	1,205.1 btu/lbm
Temperature	446.5 °F	Sp. Entropy	1.483 btu/lbm/R
Saturated	1.00	Energy Flow	4.4 MMBtu/hr

Outlet Liquid		Mass Flow	43.6 klb/hr
Pressure	393.1 psig	Sp. Enthalpy	426.3 btu/lbm
Temperature	446.5 °F	Sp. Entropy	0.624 btu/lbm/R
Saturated	0.00	Energy Flow	18.6 MMBtu/hr

PRV Calculator

OVERVIEW

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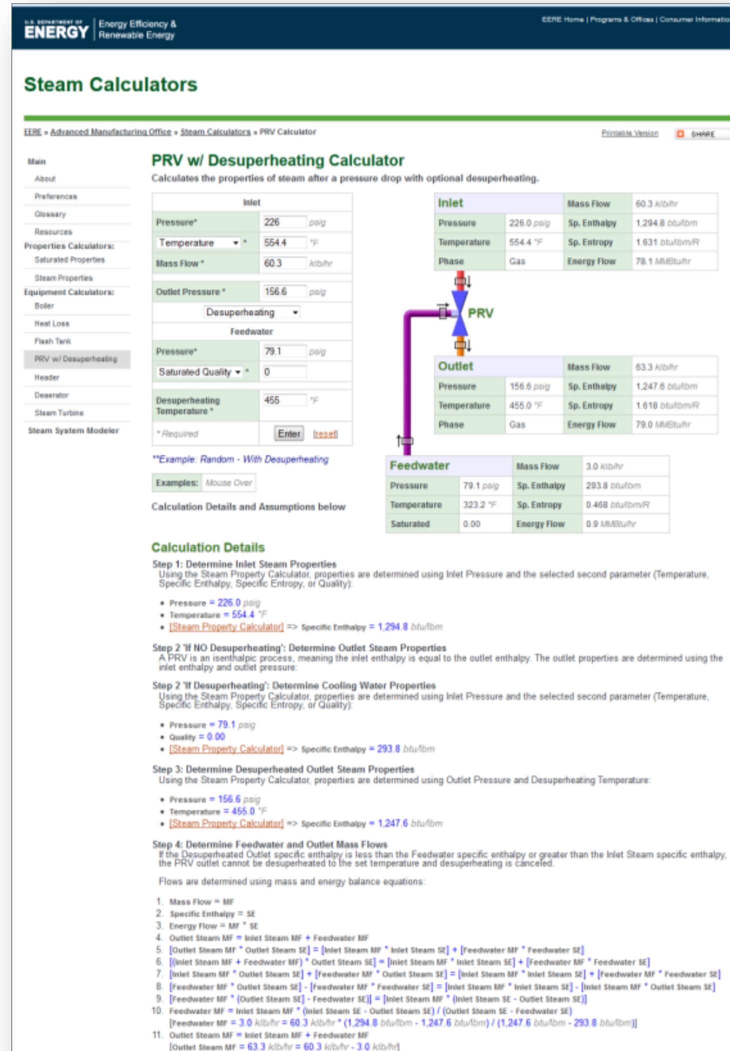
The **Pressure Reducing Valve (PRV) Calculator** determines the properties of steam after a pressure drop with optional desuperheating.

PRVs reduce the pressure of steam without adding or removing energy. This is known as an isenthalpic process.

In some cases, outlet steam needs to be reduced to a set temperature. To do this, PRVs can be configured to desuperheat the outlet steam by injecting water into the steam.



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Inlet - Pressure [pressure]:

Inlet steam pressure

Inlet - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

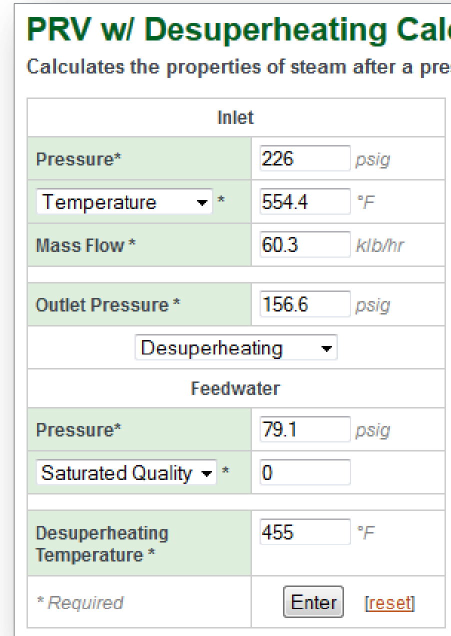
Second steam property associated with the inlet steam

Inlet - Mass Flow [mass flow]:

Mass flow of the inlet

Outlet Pressure [pressure]:

Outlet steam pressure



<u>If Desuperheating:</u>

Feedwater - Pressure [pressure]:

Feedwater pressure

Feedwater - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the feedwater

Desuperheating Temperature [temperature]:

Target temperature for desuperheating

Step 1: Determine Inlet Steam Properties

Inlet steam properties are determined using the **Pressure**, **Secondary Steam Property**, and **Mass Flow.**

Step 2: 'If NO Desuperheating': Determine Outlet Steam Properties

Outlet steam properties are determined using the **Outlet Pressure** and inlet steam specific enthalpy. **[‘NO Desuperheating’ CALCULATION COMPLETE]**

'If Desuperheating': Determine Cooling Water Properties

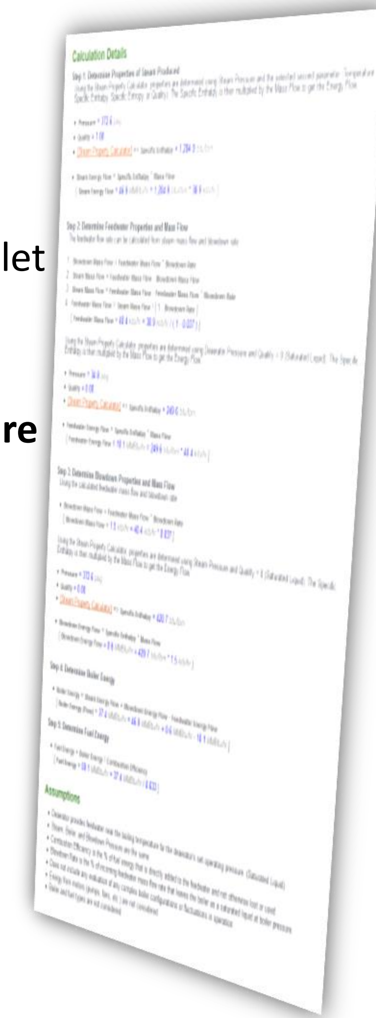
Feedwater steam properties are determined using the **Feedwater-Pressure** and **Feedwater-Secondary Steam Property.**

Step 3: Determine Desuperheated Outlet Steam Properties

Desuperheated outlet steam properties are determined using **Desuperheating Temperature** and **Outlet Pressure**.

Step 4: Determine Feedwater and Outlet Mass Flows

A mass and energy balance is used to determine the ratio of steam and feedwater required to product steam at the desuperheated temperature.



PRV Calculator

RESULTS

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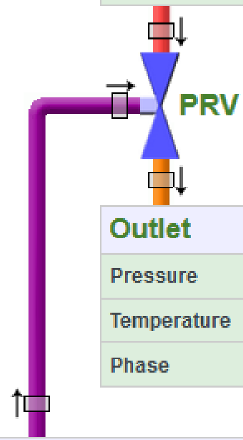
The **PRV Calculator** provides the following results:

- Inlet Steam Properties
- Outlet Steam Properties

If desuperheating:

- Feedwater Properties and Mass Flows
- Total Outlet Steam Mass Flow

Inlet		Mass Flow	60.3 *klb/hr*
Pressure	226.0 *psig*	Sp. Enthalpy	1,294.8 *btu/lbm*
Temperature	554.4 *°F*	Sp. Entropy	1.631 *btu/lbm/R*
Phase	Gas	Energy Flow	78.1 *MMBtu/hr*



Outlet		Mass Flow	63.3 *klb/hr*
Pressure	156.6 *psig*	Sp. Enthalpy	1,247.6 *btu/lbm*
Temperature	455.0 *°F*	Sp. Entropy	1.618 *btu/lbm/R*
Phase	Gas	Energy Flow	79.0 *MMBtu/hr*

Feedwater		Mass Flow	3.0 *klb/hr*
Pressure	79.1 *psig*	Sp. Enthalpy	293.8 *btu/lbm*
Temperature	323.2 *°F*	Sp. Entropy	0.468 *btu/lbm/R*
Saturated	0.00	Energy Flow	0.9 *MMBtu/hr*

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Header Calculator

OVERVIEW

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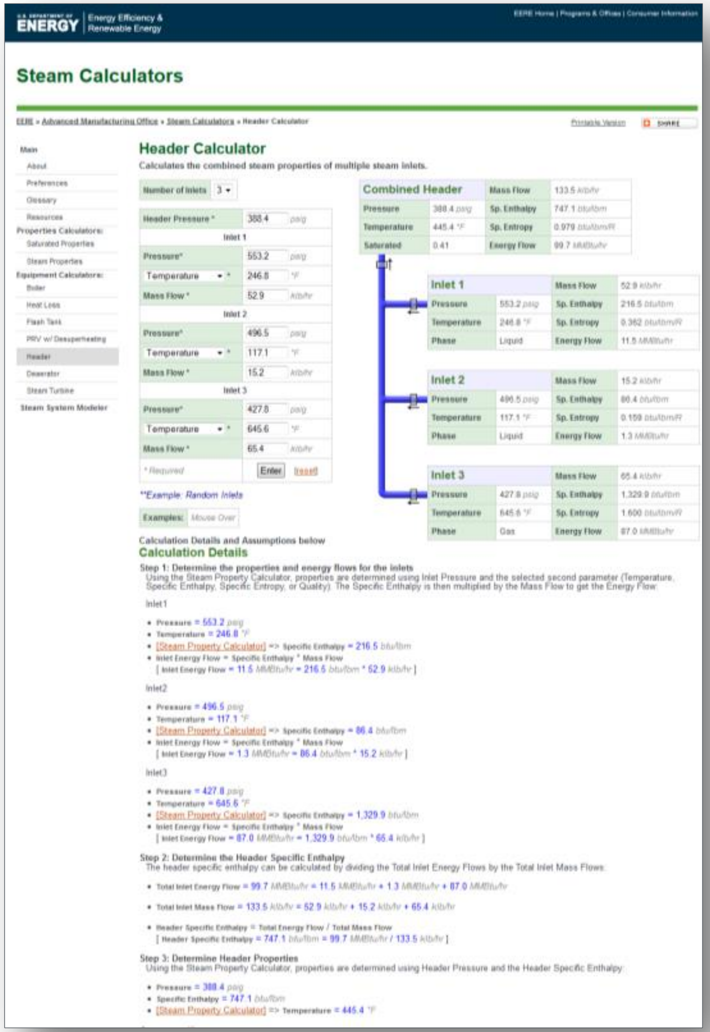
The **Header Calculator** determines the combined steam properties of multiple steam inlets.

This simulates situations commonly found in steam systems where multiple sources of steam, with varying pressures and temperatures, are combined into a single steam distribution line, referred to as a steam header.



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Header Calculator

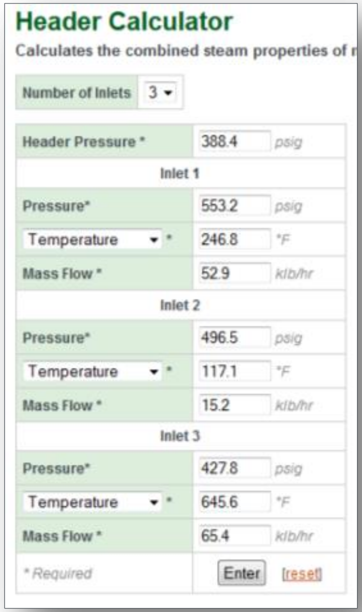
INPUTS

Number of Inlets [#]:

Specifies the number of steam inlets that the used in the calculation

Header Pressure [pressure]:

The final of the combined steam inlets



For Each Steam Inlet:

Pressure [pressure]:

Inlet steam pressure

Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the inlet steam

Mass Flow [mass flow]:

Mass flow of the inlet

Header Calculator

Step 1: Determine the properties and energy flows for the inlets

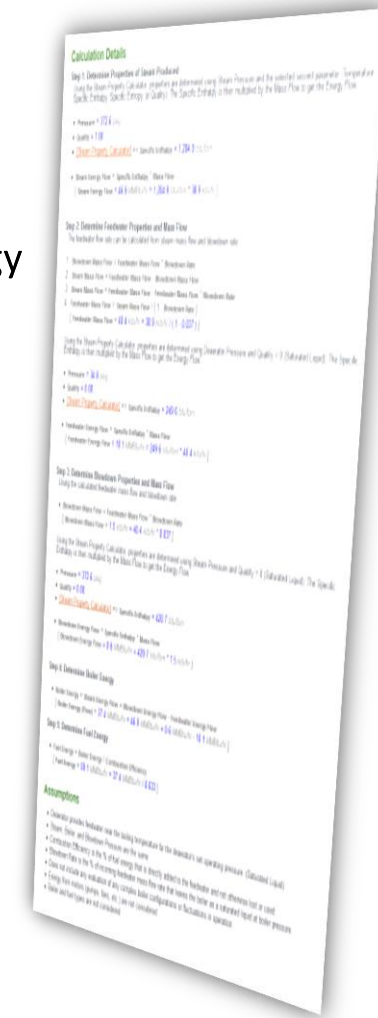
Steam properties for each inlet are determined using the associated **Pressure**, **Secondary Steam Property**, and **Steam Mass Flow.**

Step 2: Determine the Header Specific Enthalpy

The header specific enthalpy is calculated by dividing the total inlet energy flows by the total inlet mass flows.

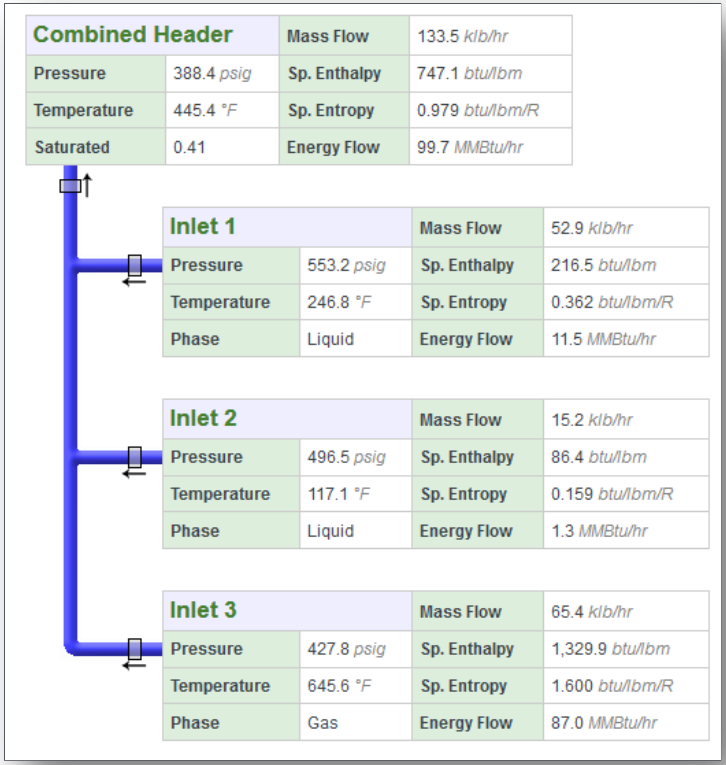
Step 3: Determine Header Properties

The header properties are determined using **Header Pressure** and the header specific enthalpy.



The **Header Calculator** provides the following results:

- Properties and Mass Flows for each Inlet
- The Combined Header Properties and Mass Flow



Combined Header		Mass Flow	133.5 klb/hr
Pressure	388.4 psig	Sp. Enthalpy	747.1 btu/lbm
Temperature	445.4 °F	Sp. Entropy	0.979 btu/lbm/R
Saturated	0.41	Energy Flow	99.7 MMBtu/hr

Inlet 1		Mass Flow	52.9 klb/hr
Pressure	553.2 psig	Sp. Enthalpy	216.5 btu/lbm
Temperature	246.8 °F	Sp. Entropy	0.362 btu/lbm/R
Phase	Liquid	Energy Flow	11.5 MMBtu/hr

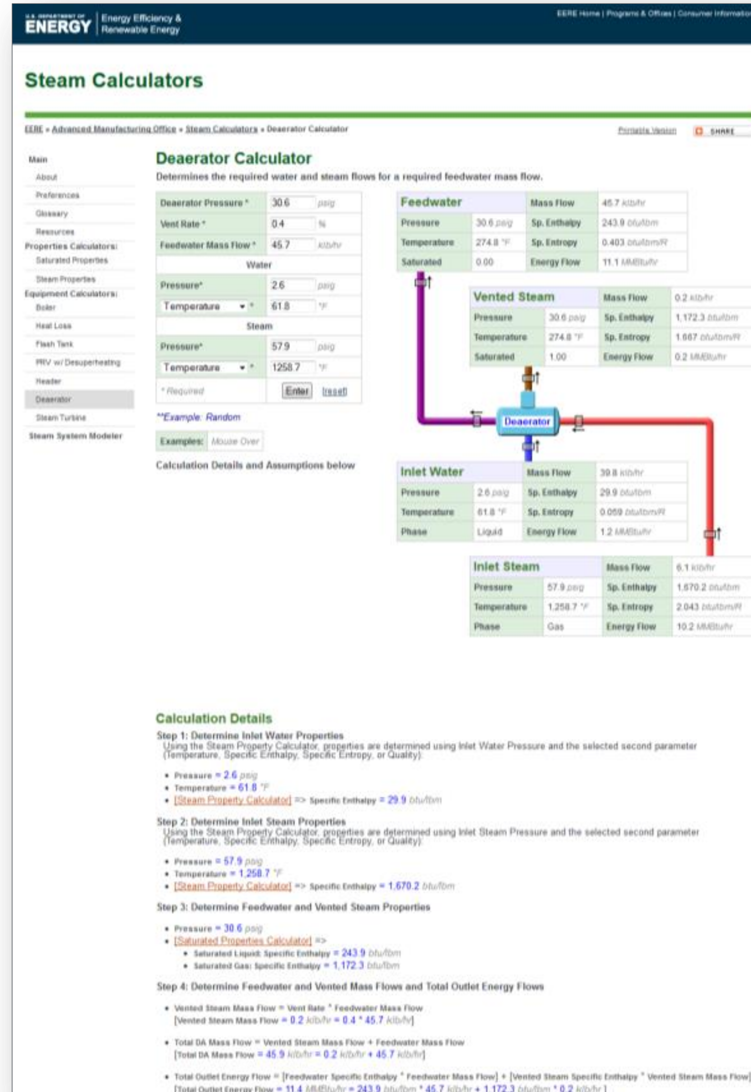
Inlet 2		Mass Flow	15.2 klb/hr
Pressure	496.5 psig	Sp. Enthalpy	86.4 btu/lbm
Temperature	117.1 °F	Sp. Entropy	0.159 btu/lbm/R
Phase	Liquid	Energy Flow	1.3 MMBtu/hr

Inlet 3		Mass Flow	65.4 klb/hr
Pressure	427.8 psig	Sp. Enthalpy	1,329.9 btu/lbm
Temperature	645.6 °F	Sp. Entropy	1.600 btu/lbm/R
Phase	Gas	Energy Flow	87.0 MMBtu/hr

Deaerator Calculator

The **Deaerator Calculator** determines the required water and steam flows for a given feedwater mass flow.

- A *deaerator* is a tank used to remove dissolved gases from the feedwater before being sent to the boiler
- The solubility of gases in water is reduced as the water temperature increases. Therefore deaerators increase feedwater to near boiling temperature to remove as much gas a possible.
- The small amount of steam is vented in the process of venting the gases
- Steam is commonly used as the heat source for the deaerator



Deaerator Calculator

INPUTS

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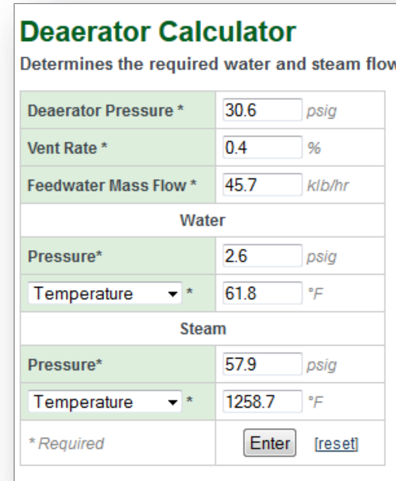


Deaerator Pressure [pressure]:

Operating pressure of the deaerator

Vent Rate [%]:

Deaerator vent rate as a % of feedwater mass flow

Feedwater Mass Flow [mass flow]:

Mass flow of the feedwater sent to the boiler

Water - Pressure [pressure]:

Inlet water pressure

Water - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the inlet water

Steam - Pressure [pressure]:

Inlet steam pressure

Steam - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the inlet steam

Deaerator Calculator

CALCULATION

Step 1: Determine Inlet Water Properties

Inlet water properties are determined using the associated **Pressure** and **Secondary Property.**

Step 2: Determine Inlet Steam Properties

Inlet steam properties are determined using the associated **Steam Pressure** and **Secondary Steam Property.**

Step 3: Determine Feedwater and Vented Steam Properties

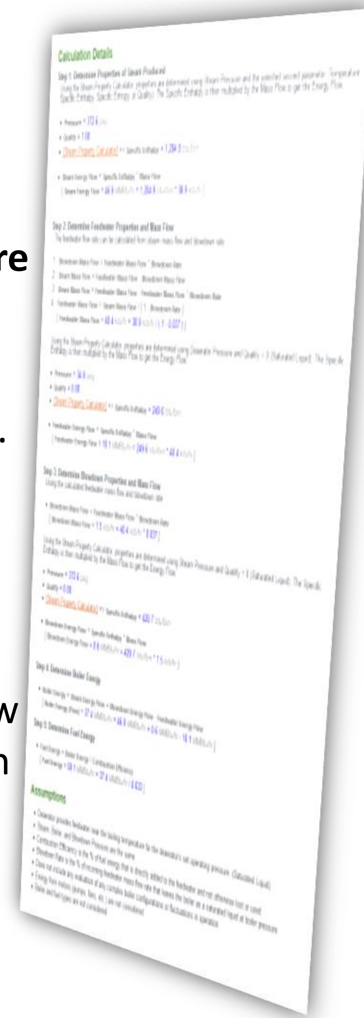
The saturated steam properties are calculated for the **Deaerator Pressure**. Feedwater properties set to that of the saturated liquid and the vented steam is set to that of the saturated gas/vapor.

Step 4: Determine Feedwater and Vented Mass Flows and Total Outlet Energy Flows

The vented steam mass flow is determined using the Feedwater Mass Flow and Vent Rate. The energy flow of the vented steam and feedwater is then totaled.

Step 5: Determine Inlet Water and Steam Mass Flows

A mass and energy balance is used to determine the ratio of inlet water and inlet steam required to match the outlet mass and energy flows.



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Deaerator Calculator

RESULTS

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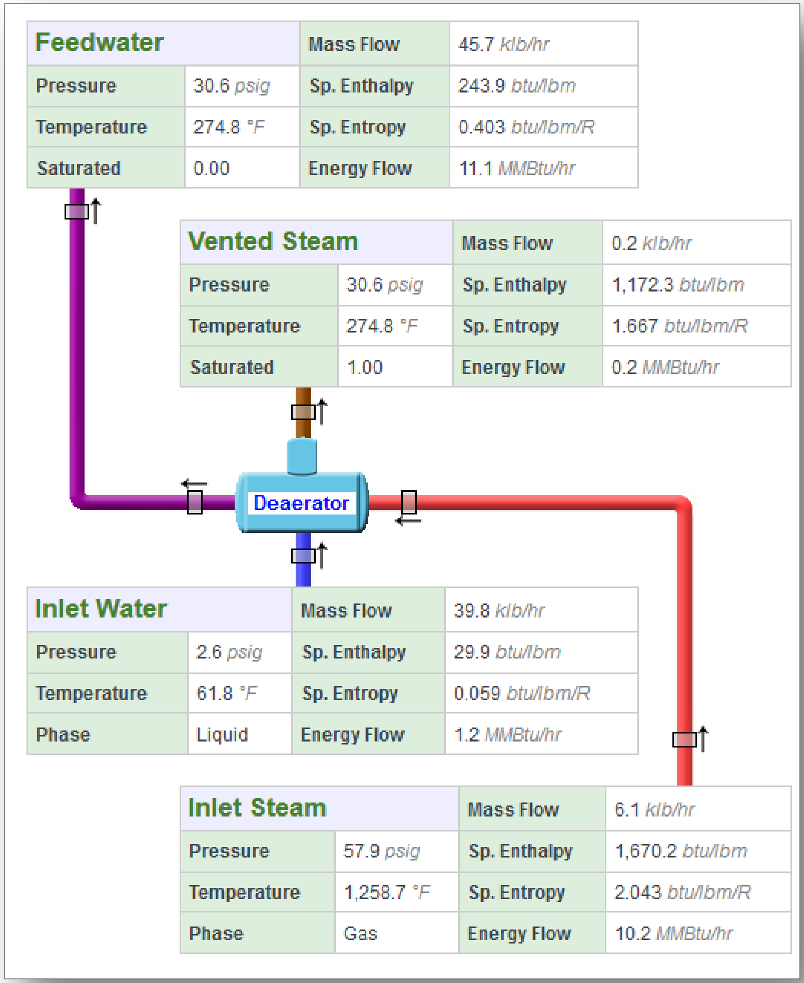
The **Deaerator Calculator** provides the following results:

- Properties and Mass Flows for:
  - Inlet Water
  - Inlet Steam
  - Feedwater
  - Vented Steam

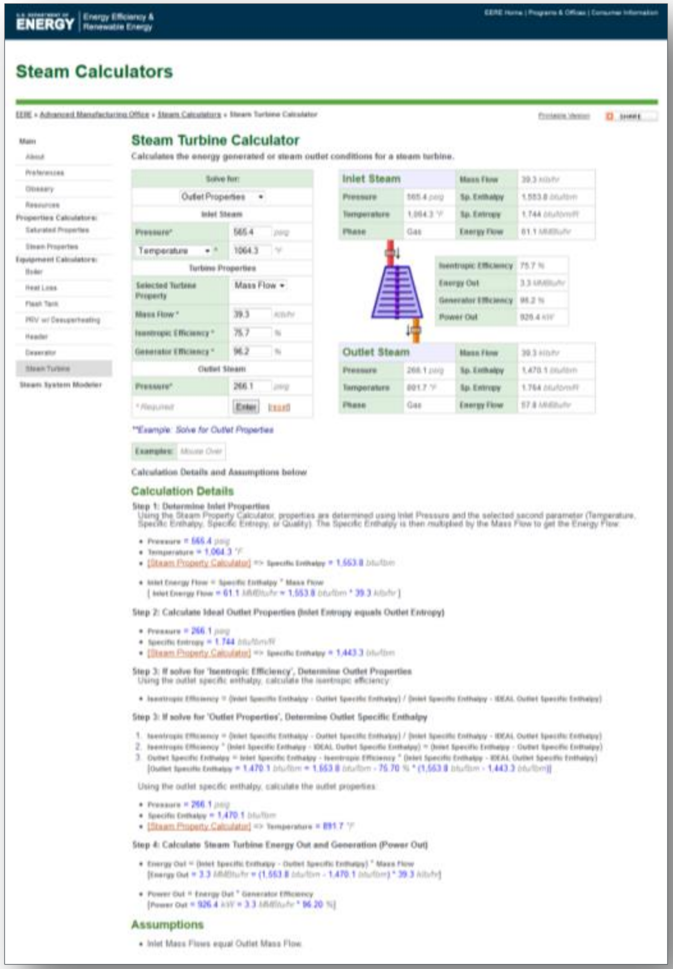


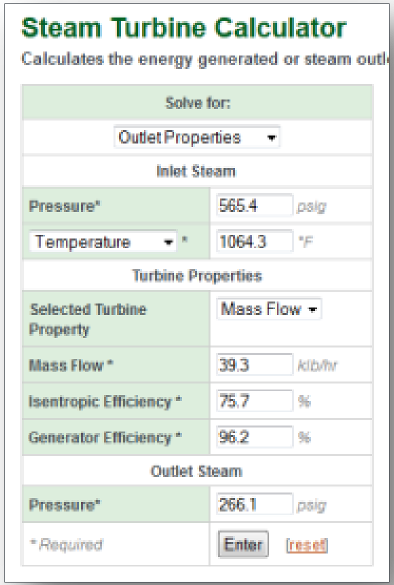
Steam Turbine Calculator

The **Steam Turbine Calculator** generates a basic steam turbine model, solving for either:

- **Outlet Steam Conditions** – given inlet steam conditions and isentropic efficiency
- **Isentropic Efficiency** – given inlet and outlet steam conditions

Users also have the option to enter either the steam mass flow or power generated and the calculator determines the value of the other





-SOLVING FOR **Outlet Properties**-

Inlet Steam - Pressure [pressure]:

Pressure of inlet steam

Inlet Steam - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the inlet steam

Isentropic Efficiency [%]:

The energy actually removed as a percent (%) of the energy removed if the turbine were an isentropic process.

Generator Efficiency [%]:

The percent of the energy extracted by the turbine that is converted to power

Either Mass Flow or Power Out:

Mass Flow [mass flow]:

Mass flow of steam

Power Out [power]:

Mass flow of the feedwater sent to the boiler

Outlet Steam - Pressure [pressure]:

Outlet water pressure

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-SOLVING FOR **Isentropic Efficiency**-

Inlet Steam - Pressure [pressure]:

Pressure of inlet steam

Inlet Steam - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the inlet steam

Generator Efficiency [%]:

The percent of the energy extracted by the turbine that is converted to power

Either Mass Flow or Power Out:

Mass Flow [mass flow]:

Mass flow of steam

Power Out [power]:

Mass flow of the feedwater sent to the boiler

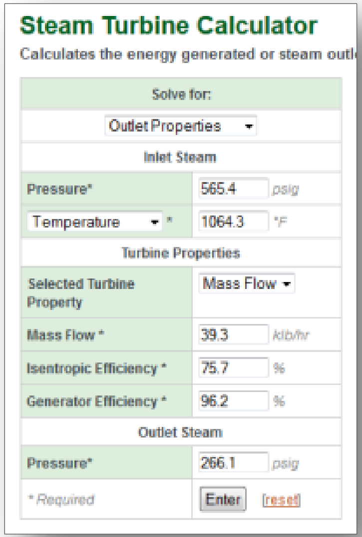
Outlet Steam - Pressure [pressure]:

Outlet water pressure

Outlet Steam - Secondary Steam Property [*varies*]:

[Either: Temperature, Specific Enthalpy, Specific Entropy, or Quality]

Second steam property associated with the outlet steam



Steam Turbine Calculator

Step 1: Determine Inlet Properties

Inlet steam properties are determined using the **Pressure** and **Secondary Property.**

Step 2: Calculate Ideal Outlet Properties (Inlet Entropy equals Outlet Entropy)

Ideal outlet steam properties are determined using the associated **Outlet Steam Pressure** and inlet specific entropy. The ideal case assumes that no entropy is created in the turbine.

Step 3: If solving for 'Isentropic Efficiency', Determine Outlet Properties

Outlet steam properties are determined using the **Outlet Steam Pressure** and **Outlet Secondary Steam Property.**

Step 3: If solving for 'Outlet Properties', Determine Outlet Specific Enthalpy

The outlet specific enthalpy is calculated using the **Isentropic Efficiency,** inlet specific enthalpy, and ideal outlet specific enthalpy. The outlet specific enthalpy and outlet pressure are used to determine the outlet properties.

Step 4: Calculate Steam Turbine Energy Out and Generation (Power Out)

The difference between the outlet and inlet steam energy flows are used to determine the energy extracted from the steam (Energy Out). The **Generation Efficiency** is then used to determine the power generated (Power Out)

Steam Turbine Calculator

RESULTS

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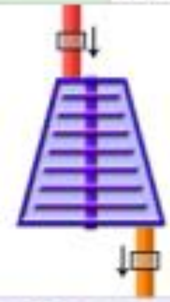
The **Steam Turbine Calculator** provides the following results:

- Inlet Steam Properties
- Outlet Steam Properties
- Isentropic Efficiency
- Energy Out (*energy extracted*)
- Power Out (*power generated*)

Inlet Steam		Mass Flow	39.3 *klb/hr*
Pressure	565.4 *psig*	Sp. Enthalpy	1,553.8 *btu/lbm*
Temperature	1,064.3 *°F*	Sp. Entropy	1.744 *btu/lbm/R*
Phase	Gas	Energy Flow	61.1 *MMBtu/hr*



Isentropic Efficiency	75.7 *%*
Energy Out	3.3 *MMBtu/hr*
Generator Efficiency	96.2 *%*
Power Out	926.4 *kW*

Outlet Steam		Mass Flow	39.3 *klb/hr*
Pressure	266.1 *psig*	Sp. Enthalpy	1,470.1 *btu/lbm*
Temperature	891.7 *°F*	Sp. Entropy	1.764 *btu/lbm/R*
Phase	Gas	Energy Flow	57.8 *MMBtu/hr*

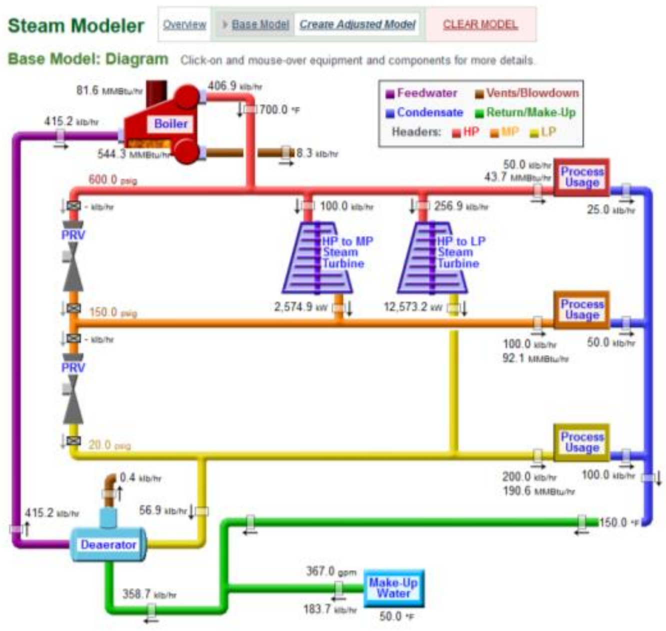
Steam System Modeler

A 1-3 header steam system model can be generated with the associated PRVs, steam turbines, flash tanks, heat losses, and condensate return conditions. Users can then evaluate the impact of a significant number of adjustments to the model.

Overview

SSMT is capable of creating a basic ***steam system model*** that can be used to better understand the current operating conditions of a system and evaluate the impacts of numerous adjustments. Steam models include the following components:

- Boiler
- Deaerator
- 1 to 3 Steam Pressure Headers
- Backpressure Steam Turbines
- Condensing Steam Turbine
- Flash Tanks
- Pressure Reducing Values (PRVs)
- Blowdown Heat Exchanger



Models are NOT saved online and must be manually downloaded and reload in later sessions.

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Key Terms

Base Model

The initial steam system model created by the user.

Adjusted Model

The model generated by applying all selected adjustments to the base model.

SSAT

The Steam System Assessment Tool which was the previous steam system modeler. The modeler is able to load examples based on the default models used by SSAT.

HP, MP, and LP

High Pressure, Medium Pressure, and Low Pressure. These terms are just relative to each other and do not have further meaning.

Using the Steam System Modeler

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The basic steps for using the Steam System Modeler are as follows:

Step 1: Generate a Base Model

There are 3 ways to generate a Base Model:

- Manually enter specific steam system details
- Load an example
- Reload a previously downloaded model

Step 2: Generate an Adjusted Model

- A series of projects and system adjustments may be selected and combined with the Base Model to generate an Adjusted Model.

Step 3: Compare Base Model to Adjusted Model

- A summary of Base Model vs Adjusted Model metrics will be generated once both a Base Model and Adjusted Model have been created.
- A generated model may also be downloaded as an excel file and re-uploaded later.

Initial Generation a Base Model

The initial generation of a base model only requires the successful submission on 1 form which is broken into 4 sections (*additional details on the following pages*):

Boiler Details

Boiler and deaerator related information

General Details

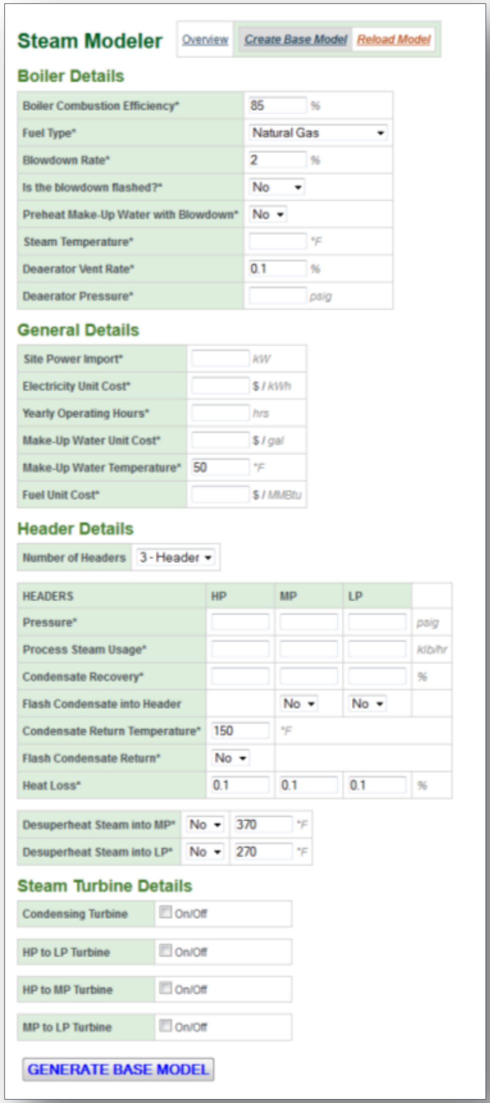
Unit costs, operating hours, make-up water, and electricity

Header Details

Pressures, steam usage, and other related data

Steam Turbine Details

Operating conditions for the various possible steam turbines configuration



Base Model – Boiler Details

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Boiler Combustion Efficiency [%]:

% of the fuel energy that is transferred to the boiler water and steam

Fuel Type [fuel type]:

Primary fuel for the boiler

Blowdown Rate [%]:

% of feedwater being drained from the boiler as a saturated liquid to reduce dissolved solids concentration

Is the blowdown flashed? [yes/no]:

Indicate if model should include flashing of blowdown

Preheat Make-Up Water with Blowdown [yes/no | temperature]:

Indicate if mode should preheat make-up water with blowdown. If 'Yes', an approach temperature can also be set

Steam Temperature [temperature]:

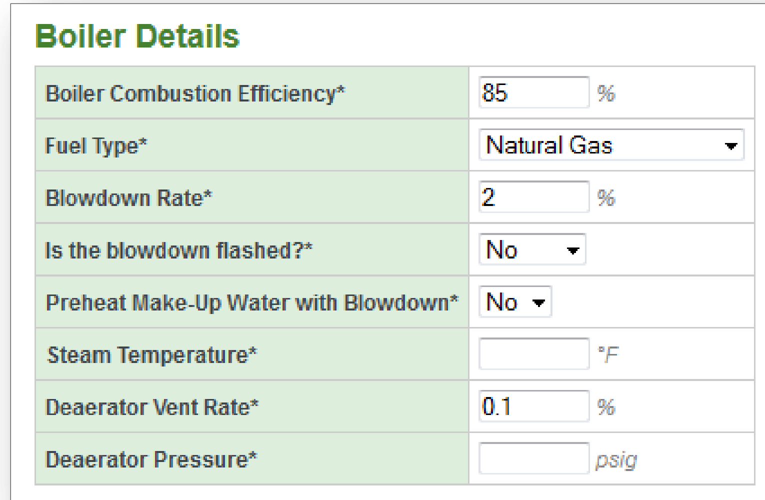
Temperature of the generated steam which must be equal to or greater than the boiling temperature

Deaerator Vent Rate[%]:

Vent rate as a % of feedwater mass flow

Deaerator Pressure [pressure]:

Operating pressure of the deaerator


Boiler Details

Boiler Combustion Efficiency*	85 %
Fuel Type*	Natural Gas
Blowdown Rate*	2 %
Is the blowdown flashed?*	No
Preheat Make-Up Water with Blowdown*	No
Steam Temperature*	°F
Deaerator Vent Rate*	0.1 %
Deaerator Pressure*	psig

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Base Model – General Details

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Site Power Import [power]:

The average power import rate of electricity for the site which is primarily used to evaluate the potential of steam turbine generation

Electricity Unit Cost [$/electricity]:

The unit cost associated with electricity

Yearly Operating Hours [hours]:

Total hours of operation for the steam system

Make-Up Water Unit Cost [$/volume]:

The unit cost associated with make-up water

Make-Up Water Temperature [temperature]:

The average temperature of the make-up water

Fuel Unit Cost [$/energy]:

The unit cost associated with the fuel

General Details

Site Power Import*		kW
Electricity Unit Cost*		$ / kWh
Yearly Operating Hours*		hrs
Make-Up Water Unit Cost*		$ / gal
Make-Up Water Temperature*	50	°F
Fuel Unit Cost*		$ / MMBtu

Base Model – Header Details

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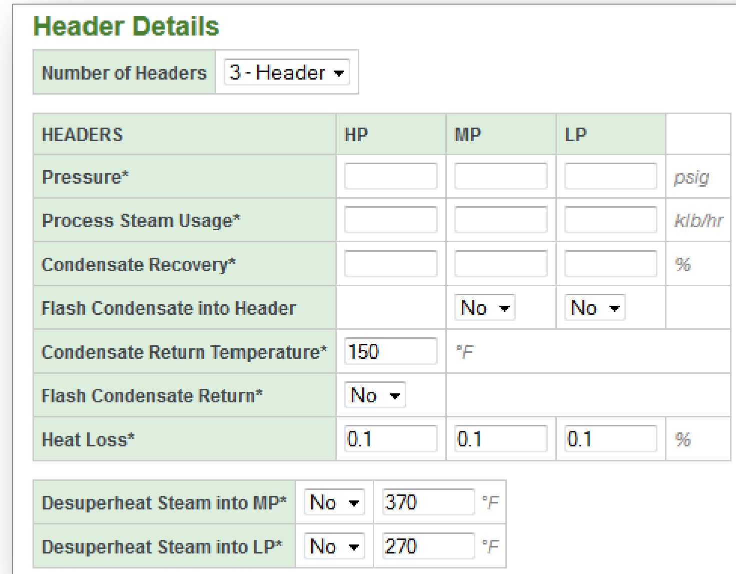

Header Details

Number of Headers	3 - Header

HEADERS	HP	MP	LP	
Pressure*				psig
Process Steam Usage*				klb/hr
Condensate Recovery*				%
Flash Condensate into Header		No	No	
Condensate Return Temperature*	150	°F		
Flash Condensate Return*	No			
Heat Loss*	0.1	0.1	0.1	%

Desuperheat Steam into MP*	No	370	°F
Desuperheat Steam into LP*	No	270	°F

Number of Headers [#]:
The total number of steam headers (1-3)

For each Header:

Pressure [pressure]:
Operating pressure of the header

Process Steam Usage[mass flow]:
The amount of header steam used for processes

Condensate Recovery [%]:
% of process steam recovered as condensate

Flash Condensate into Header [yes/no]:
Indicate if model should flash condensate into the lower pressure header (*for 3 headers: HP into MP, MP to LP*)

Condensate Return Temperature [temperature]:
Average temperature of the returned combined condensate

Flash Condensate Return [yes/no]:
Indicate if model should flash returned condensate into the lowest pressure header

Heat Loss [%]:
% heat loss for each header adjusting for numerous sources of heat loss in a header

Desuperheat Steam into MP/LP [yes/no | temperature]:
Indicate if PRV is also desuperheating and set the target temperature

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Base Model – Steam Turbine Details

Each Steam Turbine can be turned ON/OFF and the following operational conditions can be set:

Isentropic Efficiency [%]:

The energy actually removed as a percent (%) of the energy removed if the turbine were an isentropic process (*entropy in = entropy out*)

Generator Efficiency [%]:

The percent of the energy extracted by the turbine that is converted to electricity (*power*)

Condenser Pressure [vacuum pressure] (*condensing turbine only*):

The vacuum pressure at the exit of the turbine

Operation Type *(condensing turbine can only use Steam Flow and Power Gen)***:**

Balance Header

Allows enough steam flow to balance lower pressure header

Steam Flow [mass flow]:

Operates at this specific steam mass flow

Flow Range [mass flow]:

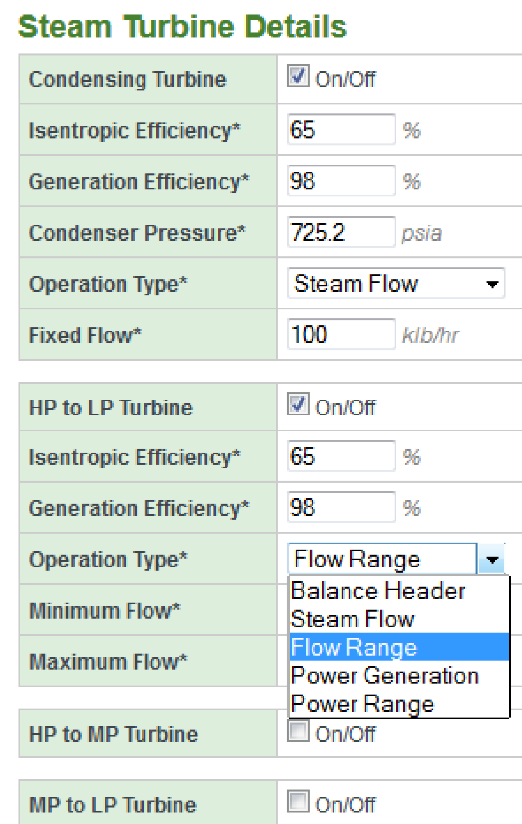
Sets minimum and maximum flow based on balancing requirements

Power Generation [power]:

Operates at this specific power generation

Power Range [power]:

Sets minimum and maximum power generation based on balancing requirements

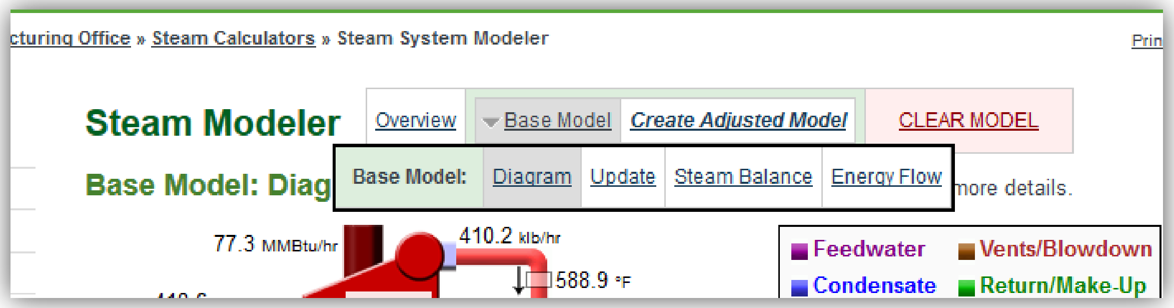


Reviewing the Base Model

Once the base model has successfully been generated, user may:

- View a **Diagram** of the Base Model
- **Update** the Base Model by modifying the initial base model form
- View a **Steam Balance** of the Base Model
- View a Sankey diagram of the base model **Energy Flow**
- And create an Adjusted version of the base model

Moving the mouse over "Base Model" will open the menu of viewing options



Model Diagram

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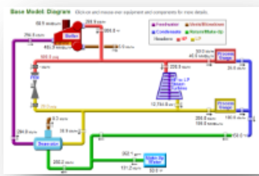
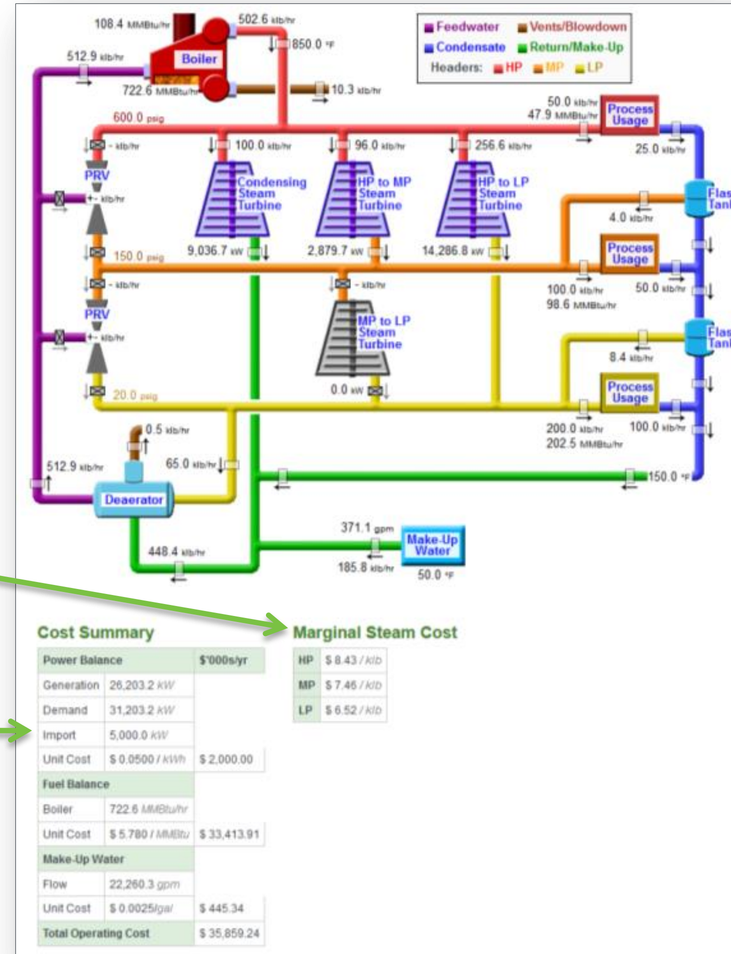
The Steam System Modeler Diagram includes:

- A customized layout of equipment and headers dependent on the specific model Example:



- Marginal Steam Costs by Header
  - these are marginal costs associated with a small increase or decrease in steam usage
- Power, Fuel, and Water Cost Summary
- Moving the mouse over each piece of equipment and steam point provides additional information
- Clicking on a specific piece of equipment provides even more detail (cont.)



Model Diagram – MouseOver Details

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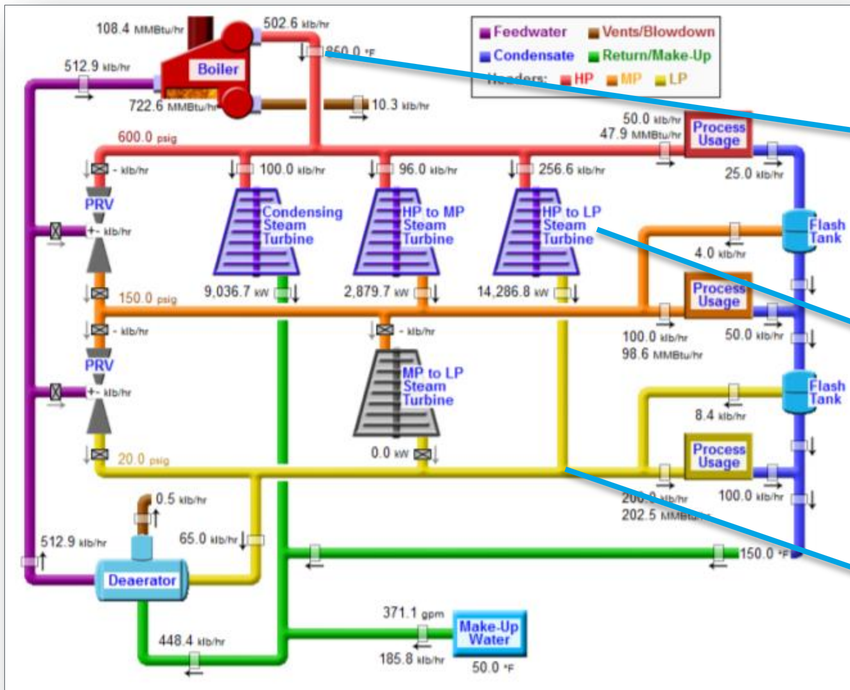
All plants of the diagram are interactive and provide additional details when a mouse is moved over it. The diagram below has ***over 50 different components*** that provide specific additional pop-up details:



Examples:

Boiler Steam		Mass Flow	403.4 *klb/hr*
Temperature	850.0 *°F*	Sp. Enthalpy	1,435.1 *btu/lbm*
Pressure	600.0 *psig*	Sp. Entropy	1.653 *btu/lbm/R*
Phase	Gas		

HP to LP Turbine			
Isentropic Eff	65.0 *%*	Energy Out	48.1 *MMBtu/hr*
Generation Eff	100.0 *%*	Power Out	14,108.9 *kW*
Click on Turbine for Details			

LP Header Details			
Pressure	20.0 *psig*	Mass Flow	253.4 *klb/hr*
Energy Loss %	0.10 *%*	Energy Loss	0.3 *MMBtu/hr*
Temperature	410.7 *°F*	Phase	Gas

Model Diagram – Equipment Details

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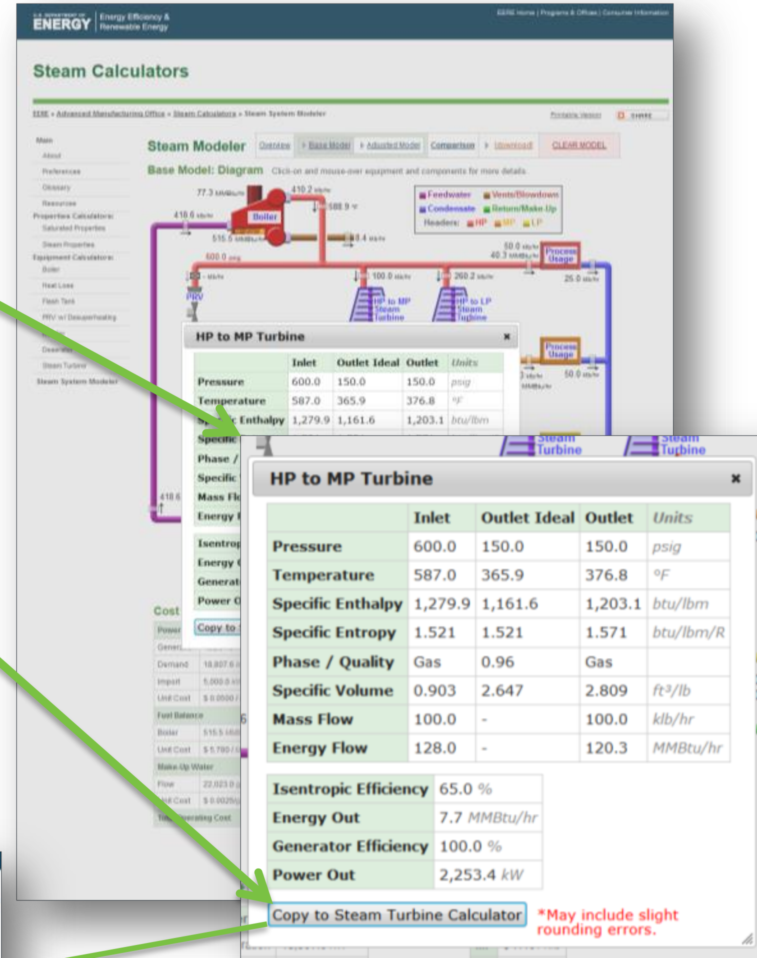
Clicking on specific equipment will open an in-page window with complete details on all associated steam properties and operational conditions.

Users also have the option to **copy** the properties of the selected piece of equipment to the associated individual equipment calculator. This allows modifications of the equipment to be evaluated without having to modify the entire model.



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Steam Balance

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Users can view a detailed *mass and energy balance* This collectively referred to a "**Steam Balance**" in SSMT.

- Validates that the steam system model has properly converged
- Includes all key sections of the model. For a 3 header steam model the sections include:
  - System Overall
  - HP Header
  - MP Header
  - LP Header
  - Condensate Return
  - Feedwater

Steam Balance

Mass and Energy flows are listed and summed system wid for and the model has correctly converged.

** TOTALs may include a small difference from rounding.

System	Base Model		
	klb/hr	*MMBtu/hr*	*btu/lbm*
Boiler Energy	-	580.0	
Boiler Energy Losses	-	-87.0	
Cond Turbine	-	-	
Cond Turbine Losses	-	-	
HP tp MP Turbine	-	-10.2	
HP to LP Turbine	-	-48.1	
MP to LP Turbine	-	-	
HP Energy Losses	-	-0.6	
HP Process Losses	-25.0	-59.8	
MP Energy Losses	-	-0.1	
MP Condensate Losses	-50.0	-116.1	
LP Energy Losses	-	-0.3	
LP Condensate Losses	-100.0	-225.7	
LP Vented Steam	-	-	
Make Up Water	183.6	3.3	18.1
Blowdown	-8.2	-3.9	474.8
Condensate Flash	-	-	
Condensate Heat Loss	-	-30.9	
Deaerator Steam Vent	-0.4	-0.5	1,163.9
TOTAL:	-	-	

HP Header	Base Model		
	klb/hr	*MMBtu/hr*	*btu/lbm*
Boiler Steam	403.4	578.9	1,435.1
Condensing Turbine Inlet	-	-	
HP to MP Turbine Inlet	-100.0	-143.4	1,433.7
HP to LP Turbine Inlet	-253.4	-363.3	1,433.7
HP to MP PRV Inlet	-	-	
HP Processes	-50.0	-71.7	1,433.7
HP Energy Losses	-	-0.6	
TOTAL:	-	-	

Energy Flow

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The energy flows of both the base model and adjusted models can be viewed in **Sankey diagrams** as seen below. Each segment is dynamically adjusted to be proportionate to the associated energy flow.

Base Energy Flows

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Creating an Adjusted Model

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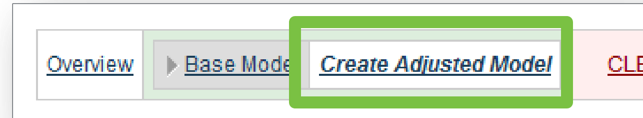
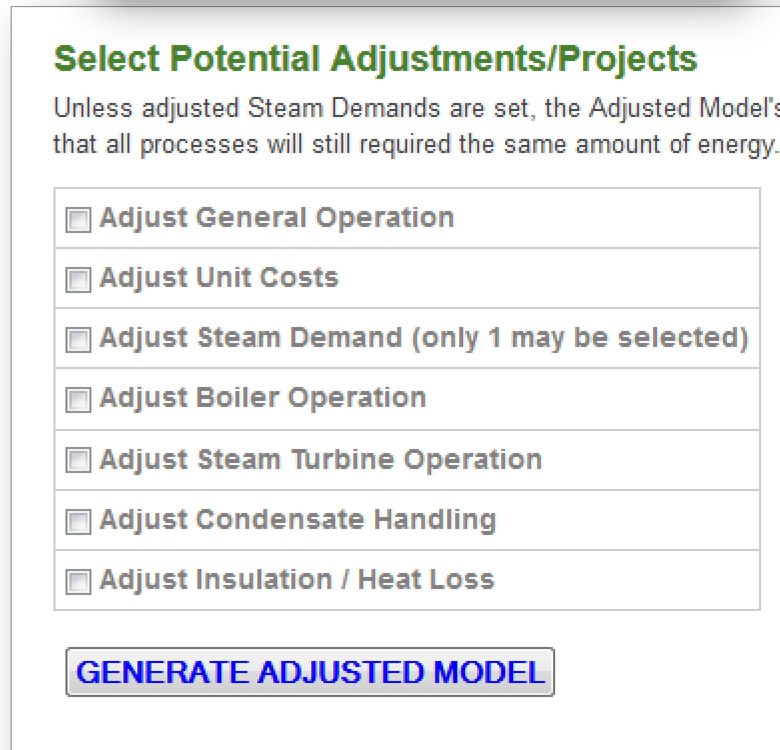




Adjusted Models are created by adding various adjustments, relative to the Base Model, grouped in these major areas: (*additional details on the following pages*)

- Adjust General Operation
- Adjust Unit Costs
- Adjust Steam Demand
- Adjust Boiler Operation
- Adjust Steam Turbine Operation
- Adjust Condensate Handling
- Adjust Insulation / Heat Loss

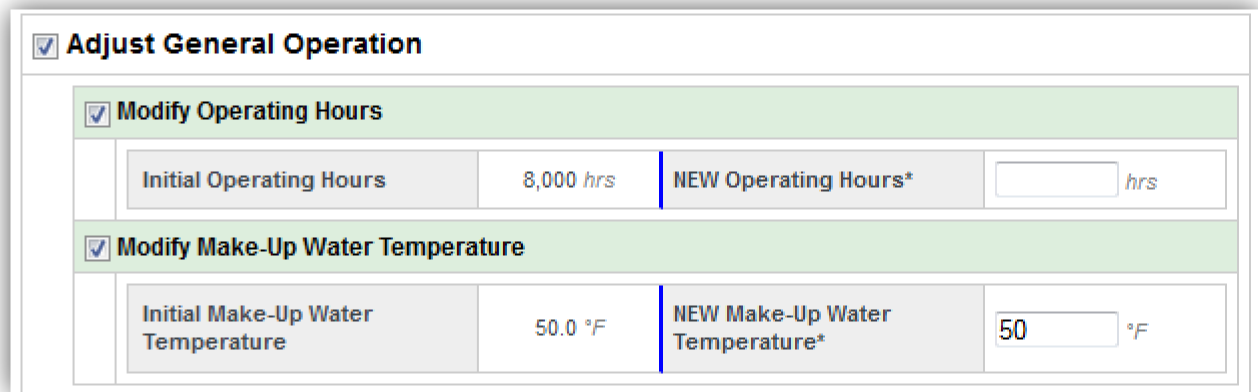
Notes:

- Users must select at least 1 adjustment
- Updates to the base model automatically update the adjusted model
- The adjusted model represents **combined impacts** of all adjustments on the base model

Adjusted Model - General Operation

General Operation adjustments include:

- **Operating Hours [hours]**
  - This reflects a potential change in yearly operation of the steam system
- **Average Make-Up Water Temperature [temperature]**
  - By changing sources, average make-up water temperatures may also change



Adjusted Model – Unit Costs

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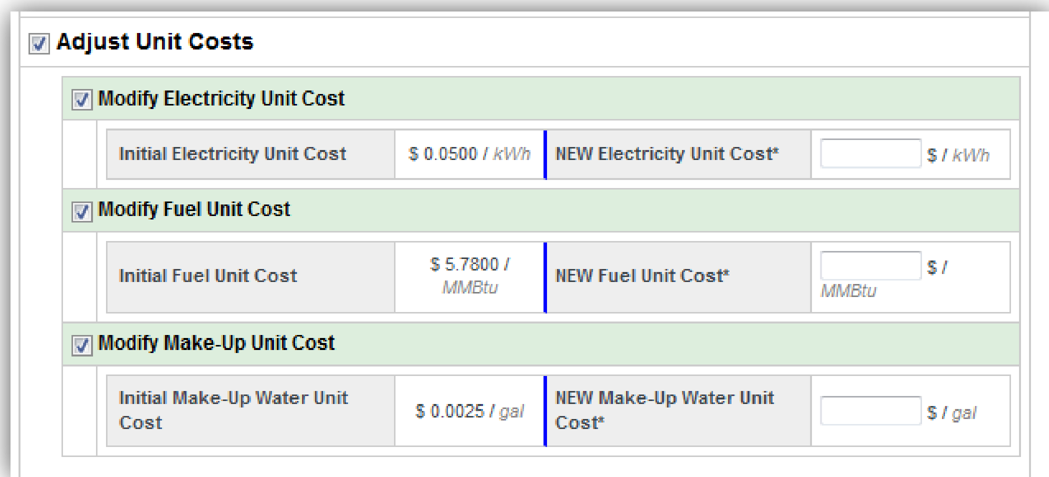
Unit Costs adjustments include:

- **Electricity Unit Cost** [$/electricity]
  - Electricity prices are generaly always subject to change
- **Fuel Unit Cost** [$/energy]
  - Normal market fluctuations as well as switching fuels and/or suppliers can adjust cost
- **Make-Up Water Unit Cost** [$/volume]
  - Changes in water source, supplier, and water treatment can all impact water cost



Adjusted Model – Steam Demand

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Steam Demand adjustments may include only 1 of the 2 subcategories:

Energy Demand – fixes the energy usage levels for each headers process steam usage. Therefore if header steam properties change, the process steam usage will be adjusted to match the energy usage.

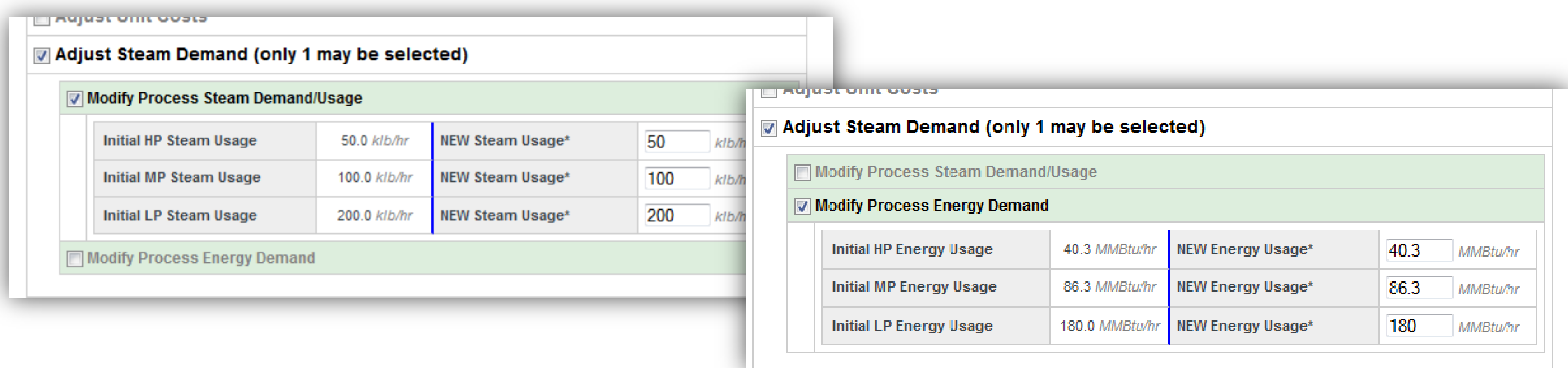
Energy Usage (*for each header*) [**energy**]

Any change in a systems process steam requirements would change energy usage requirements

Steam Demand/Usage – fixes the steam usage levels for each header's process steam usage regardless of changes in steam properties.

Steam Usage (*for each header*) [**mass flow**]

Any change in a systems process steam requirements would change steam usage requirements



Adjusted Model – Boiler Operation

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Combustion Efficiency [%]:

Various improvements to the boiler can improve combustion efficiency

Fuel Type [fuel type]:

Fuel types may sometimes be switched for a variety of reasons

Blowdown Rate [%]:

Blowdown rates can often be reduced with better controls and water treatment, saving energy and water

Is the blowdown flashed? [yes/no]:

Steam systems may add blowdown flash tanks to improve waste energy and water recovery

Preheat Make-Up Water with Blowdown [yes/no]:

Blowdown water can also be used to preheat make-up water

Steam Temperature [temperature]:

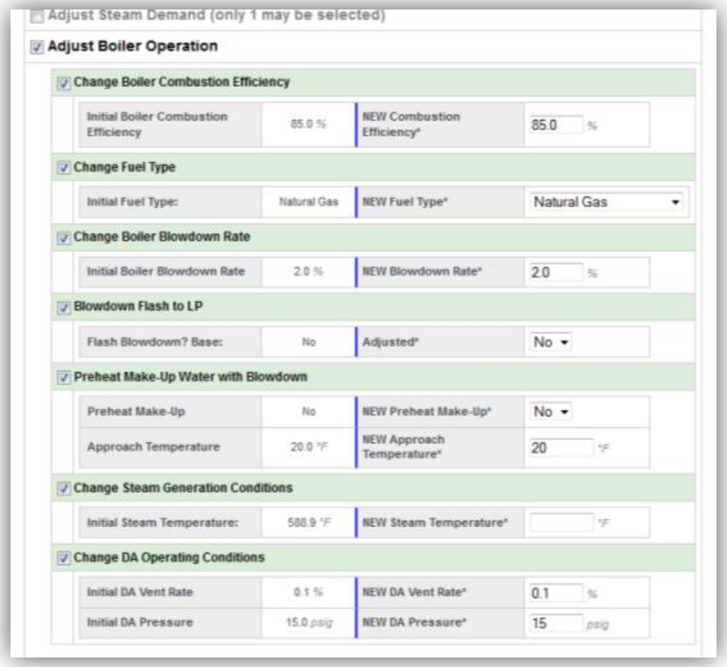
Steam generation temperature may be changed by the adjusting boiler pressure or adding a superheating section

Deaerator Vent Rate[%]:

The deaerator vent rate may be reduced with better controls, reducing associated steam losses

Deaerator Pressure [pressure]:

Operating pressure may be adjusted to match condensate return pressure



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Adjusted Model – Steam Turbine

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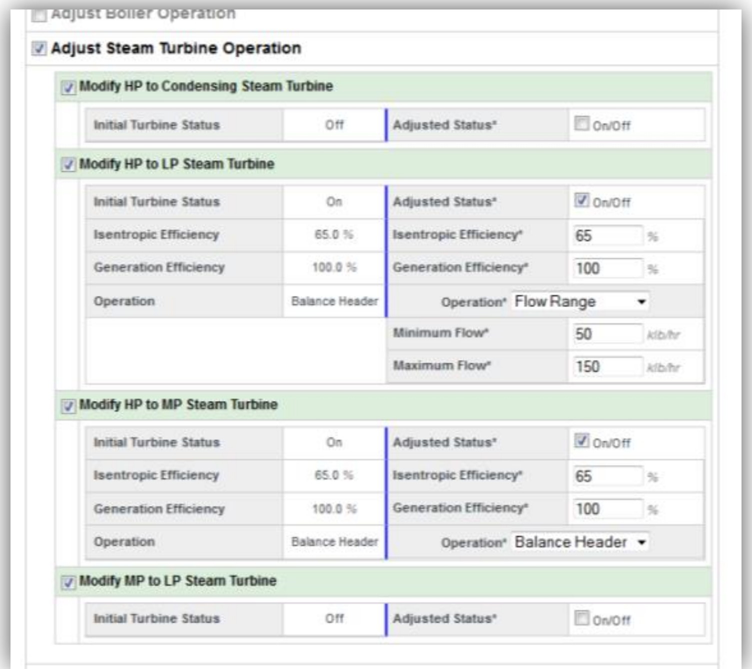
The adjustment to the Steam Turbine are the same as the base model. On/Off can be changed to add or remove a steam turbine:



Isentropic Efficiency [%]:

During turbine maintenance and overhauls isentropic efficiency can be changed inadvertently or intentionally

Generator Efficiency [%]:

Upgrading or repairing a generator can improve efficiency

Condenser Pressure [vacuum pressure] (*condensing only*):

Changes to cooling fluid flow/temperature affect pressure

Operation Type *(switching types is an allowed adjustment)*

Balance Header

Removes limits and fixed operation

Steam Flow [mass flow]:

Specifically set steam flow

Flow Range [mass flow]:

Flow might be allowed to change when it was previously fixed or unrestricted

Power Generation [power]:

Specifically set power generation

Power Range [power]:

Power generation might be allowed to change when it was previously fixed or unrestricted

Adjusted Model – Condensate Handling

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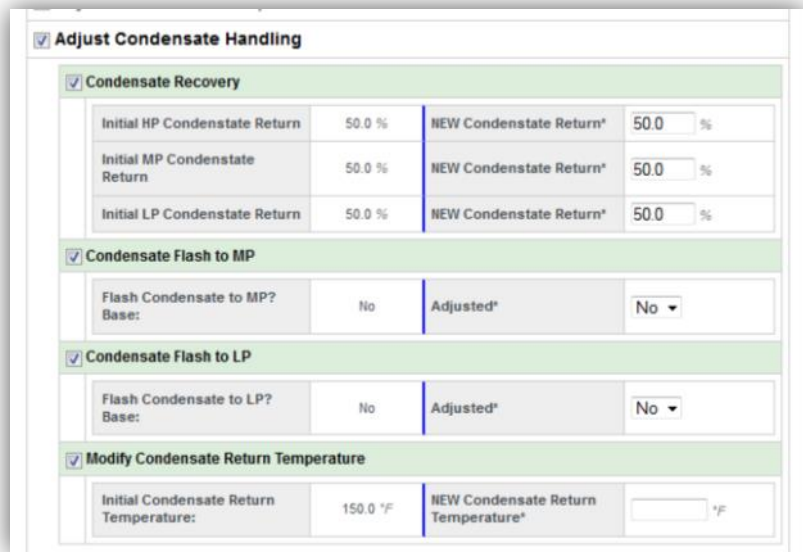
Condensate adjustments include:

- **Condensate Return Rates** [%]
  – Improvements to the condensate return system can increase the return rate
- **Condensate Flash to Header (MP/LP)** [yes/no]
  – Flash tanks can be added that will flash high pressure condensate, saving energy and water
- **Condensate Return Temperature** [temperature]
  – Improvements to the condensate return system can increase the return temperature



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Adjusted Model – Heat Loss

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Insulation / Heat Loss adjustments include:

- **Heat Loss for each Header** [%]
  - Improvements in insulation will likely reduce a header's heat loss by a certain %, the heat loss % should similarly be adjusted to reflect this improvement

    Example:

    Initial Heat Loss: 0.10%

    Potential Improvement of Insulation: 50%

    NEW Heat Loss: 0.05%

Adjust Insulation / Heat Loss

Adjust Heat Loss Percentage

Initial HP Heat Loss	0.10 %	NEW Heat Loss*	0.05	%
Initial MP Heat Loss	0.10 %	NEW Heat Loss*	0.05	%
Initial LP Heat Loss	0.10 %	NEW Heat Loss*	0.05	%

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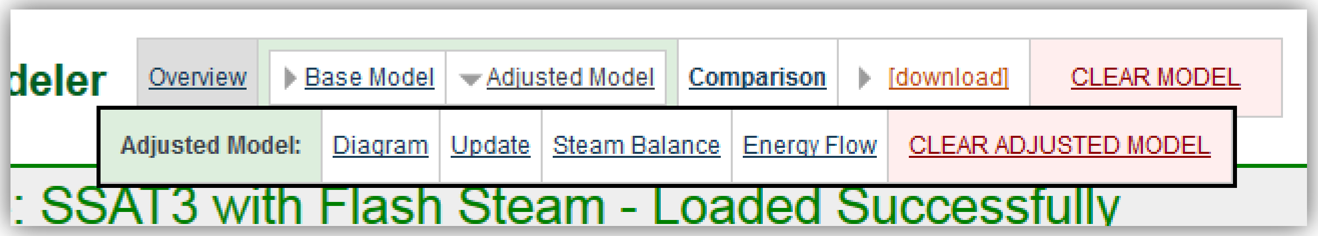
Reviewing the Adjusted Model

The Adjusted Model can be reviewed in exactly the same way as the Base Model:

- View a **Diagram** of the Adjusted Model
- **Update** the Base Model by modifying the initial base model form
- View a **Steam Balance** of the Base Model
- View a Sankey diagram of the base model **Energy Flow**
- And create an Adjusted version of the base model

*See the "Review the Base Model" section for specific details on these

Moving the mouse over "Adjusted Model" will open the menu of viewing options



Comparing Base and Adjusted Models

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The model **Comparison** page provides a detailed breakdown of the total costs and relative operating conditions. The benefit of these collective adjustments can quickly be evaluated based on the difference between both.

[Green = savings | Red = loss]

Included Tables:

Cost Summary

power, fuel, water, and total cost

Utility Balance

fuel, water, and electricity use

Lists Active Projects/Adjustments

specifically lists the name of each adjustment

Base Model vs Adjusted Model

Cost Summary	Base Model	Adjusted Model	Reduction	
	$'000s/yr	$'000s/yr	$'000s/yr	
Power Cost	$ 2,000	$ 2,265	265	13.3%
Fuel Cost	$ 23,837	$ 22,856	-981	-4.1%
Make-Up Water Cost	$ 441	$ 434	-6	-1.4%
Total Cost	$ 26,277	$ 25,555	-722	-2.7%

Utility Balance	Base	After Projects	Reduction		Units
Power Generation	13,807.6	13,144.3	-663.2	-4.8%	*kW*
Power Import	5,000.0	5,663.2	663.2	13.3%	*kW*
Total Site Demand	18,807.6	18,807.6	0.0	0.0%	*kW*
Boiler Fuel	515.5	494.3	-21.2	-4.1%	*MMBtu/hr*
Fuel Type	Natural Gas	Natural Gas			
CO_2 Emissions*	218,818	209,815	-9,003	-4.1%	*tons*
Boiler Steam	410.2	393.3	-16.9	-4.1%	*klb/hr*
Make Up Water	367.2	361.9	-5.3	-1.4%	*gpm*

*Source of CO_2 Coefficients: http://www.eia.gov/oiaf/1605/coefficients.html

Adjusted Model: Active Projects

Adjust Boiler Operation
• Blowdown Flash to LP
Adjust Condensate Handling
• Condensate Flash to MP • Condensate Flash to LP

Modeler – Saving and Reloading Models

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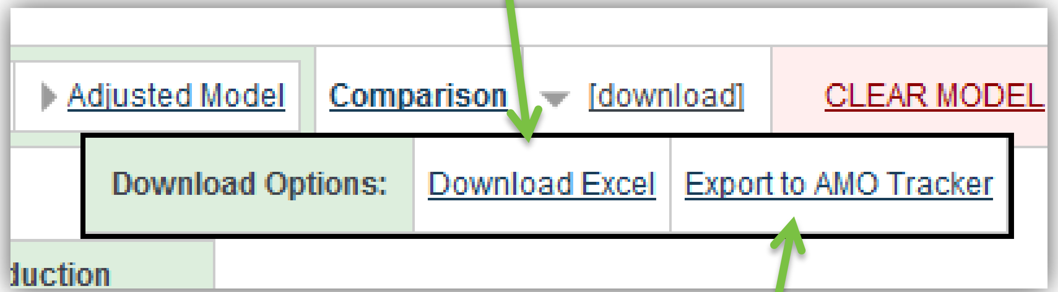
WARNING:

- **STEAM MODELS ARE NOT SAVED ONLINE**
- **IF THE WEB BROWSER IS CLOSED, THE STEAM MODELS ARE CLEARED**

To save for future use, models must be downloaded. Once downloaded, they can easily be reloaded at anytime.

To download, click on the “Download Excel” link in the model navigation menu:



For reload instruction go to Reloading Models

Models can also be exported to the AMO Opportunity Tracker by clicking on the “Export to AMO Tracker” and following the instructions. **NOTE: The AMO Tracker file cannot be used to reload a model.**

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Download Excel Spreadsheet

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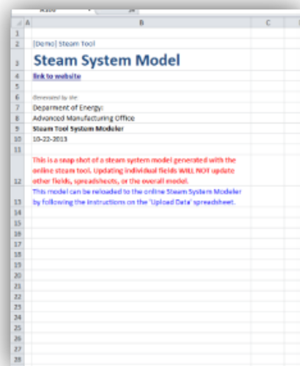
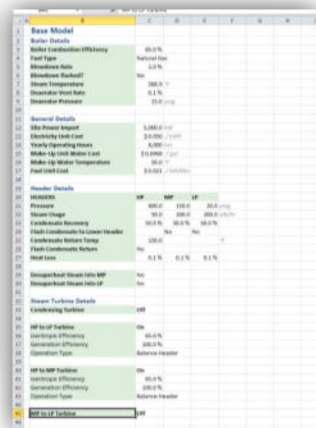
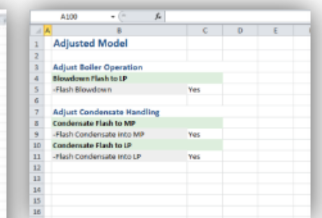
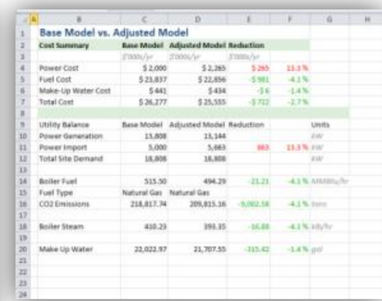
The downloadable spreadsheet has 6 sheets, most of which mirror SSMT's online forms and reports :

- Title Page
- Base Model Details
- Adjusted Model Details
- Steam Balance
- Comparison of Models
- Upload Data – *used to reload model into SSMT*









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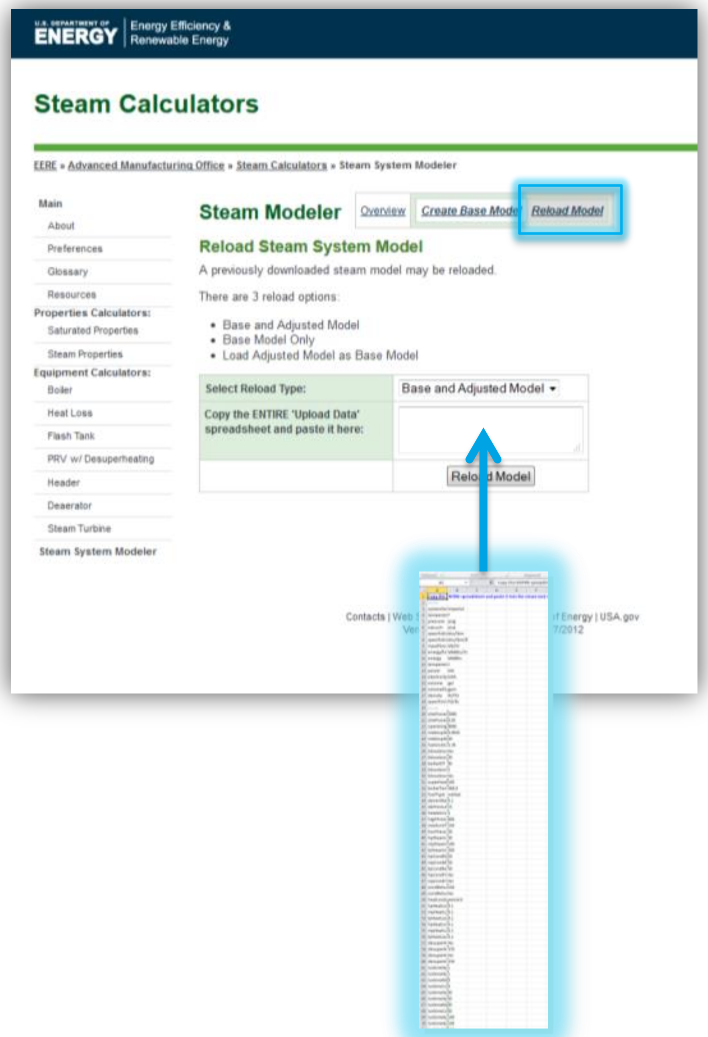
Reloading Models

To reload a Model, it must first have been downloaded as a spreadsheet.

To reload a model, copy the **ENTIRE** "Upload Data" spreadsheet and paste it into the steam tool reload/upload field on the "Reload Model" page.

There are 3 reload options:

- **Base and Adjusted Model** - reloads the model just as it was when it was downloaded
- **Base Model Only** - only reloads the base model
- **Load Adjusted Model as Base Model** - only reloads adjusted model as if it were the base model



Download/Export AMO Tracker

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The export option is limited to English using imperial units.

Instructions for Export

- Generate downloadable file by hovering your mouse over "[download]," clicking "Export to AMO tracker," and saving the file on your computer.
- Log on to the eCenter, go to the Project Opportunities Tracker, click "Import", and choose the file that you just saved
- You will now be able to sort, edit, and save data from the Steam System modeler in the Project Opportunities Tracker

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Tips and Tricks

Number of Headers can be changed at any time

Base and adjusted models will automatically update.

Units can be changed at any time

Just go to preferences and change the units at any time. All models and calculations will automatically update.

Adjusted models can be set as a new base model

If modifications have been made an adjustment model can be set as a base model, allowing further adjustments to be modeled.

All Calculations and Models can be Reset and/or Cleared

To do this look for the reset and clear model links. Be careful as resets and clears are permanent.