Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Steam Systems
Virtual INPLT Training & Assessment

Session 4

Thursday – November 3, 2022

10 am – 12:30 pm

Agenda – Session FOUR

- Safety and Housekeeping
- Today's Content:

  Discussion of Homework

  Quick Review from Session 3

  Steam System – Distribution, End-Use & Recovery
  - Understanding the steam header system
  - End-Uses of steam and steam balance
  - Steam traps, condensate collection & return

  US DOE MEASUR Tool
  - Completing the steam system model

  Better Plants Diagnostic Equipment Program (DEP)
- Kahoot Quiz Game
- Q&A

Better Buildings is an initiative of the U.S. Department of Energy

Safety and Housekeeping

- Safety Moment
  - Do not use cell-phones or get distracted while walking in the plant or when working
  - Observe areas which are cordoned off temporarily due to ongoing work
- Break points after each sub-section where you can ask questions
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

Steam Virtual INPLT Agenda

- Week 1 (October 14) – Industrial Steam Systems Fundamentals and Introduction to SSST
- Week 2 (October 21) – Focus on Steam System Generation, Boiler Efficiency & Plant Efficiency
- Week 3 (October 28) – Introduction to DOE's MEASUR Tool & Cogeneration (CHP)
- **Week 4 (November 3) – Steam System Distribution, End-Use & Condensate Recovery**
- **Week 5 (November 11) – Energy Efficiency Opportunities in the Generation Area**
- **Week 6 (November 18) – Energy Efficiency Opportunities in Cogeneration (CHP) Area**
- **Week 7 (December 2) – EE Opportunities in Distribution, End-use and Condensate Recovery**
- **Week 8 (December 9) – Industrial Steam System VINPLT Wrap-up Presentations**

Homework 3 Discussion

U.S. DEPARTMENT OF ENERGY

Homework #3

- Install and get comfortable using the MEASUR tool.
- Decide on a specific header model and work with your line diagram and develop a high-level steam system model for your facility. Use your numbers and values wherever you can otherwise use default information provided in the Steam System Assessment template.
- Use your plant's utility costs to calculate your marginal steam cost ($/klb)
- Send a screenshot of the MEASUR diagram and cost summary page

Polling Question 1

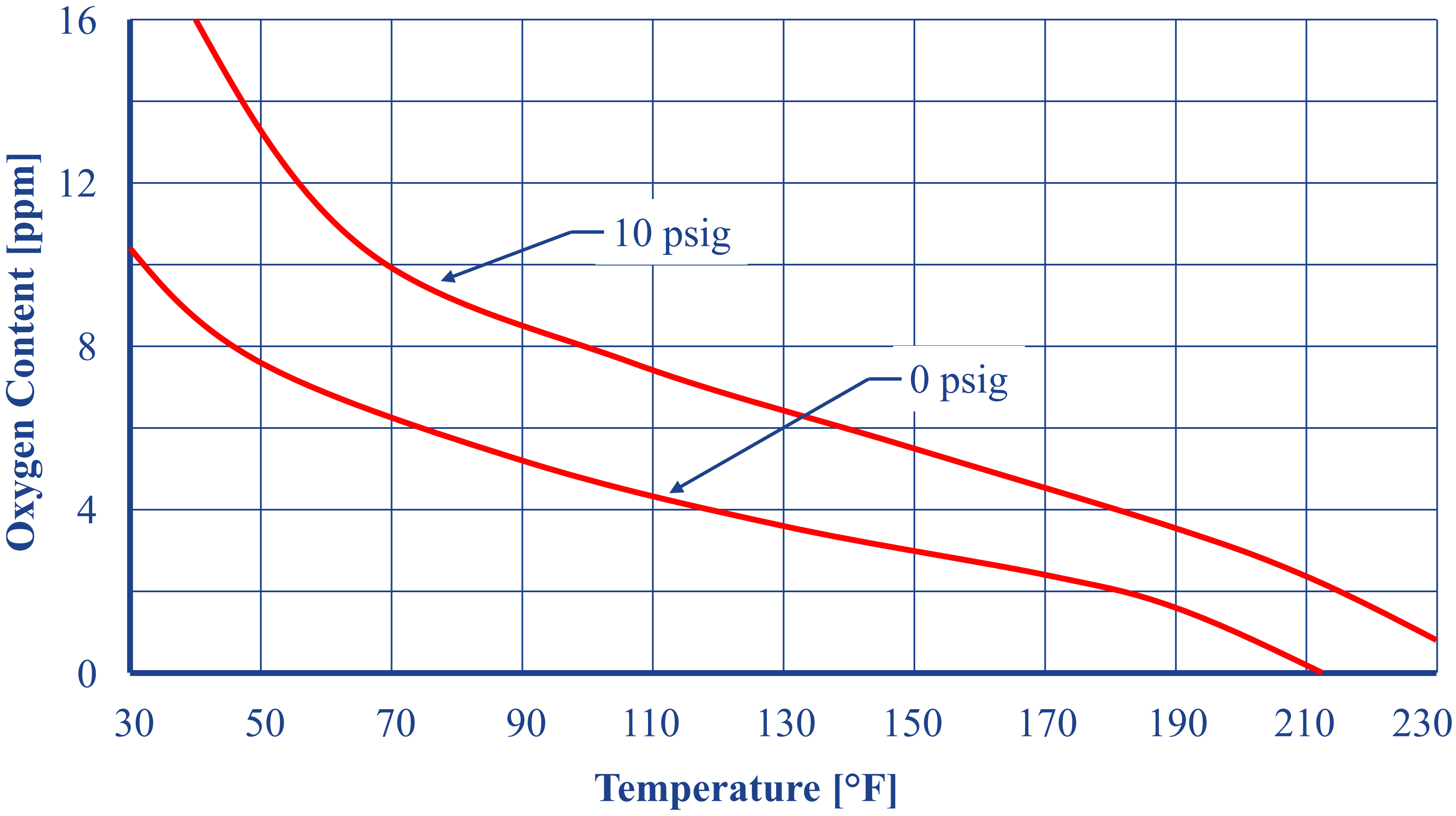
Polling Question

1) How did you model your steam system in MEASUR?
   A. 1-header model
   B. 2-header model
   C. 3-header model
   D. Multi-header model with steam turbines
   E. Did not model yet

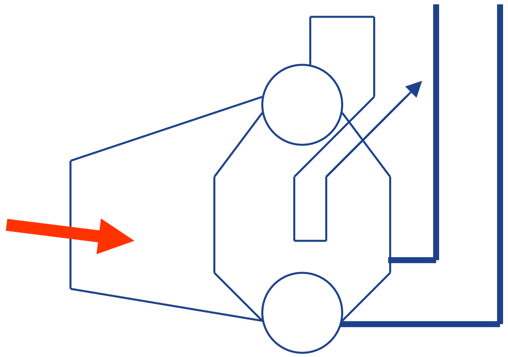
Session 3 – Quick Review

U.S. DEPARTMENT OF ENERGY

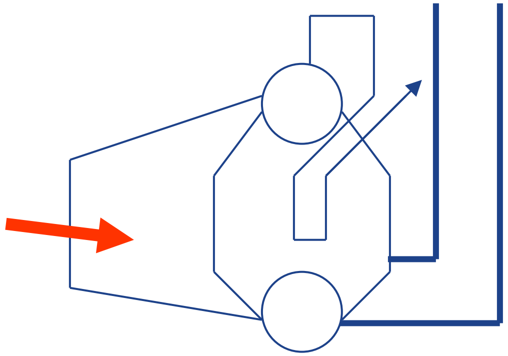
Solubility of Oxygen in Water



Impact Boiler & Fuel Selection



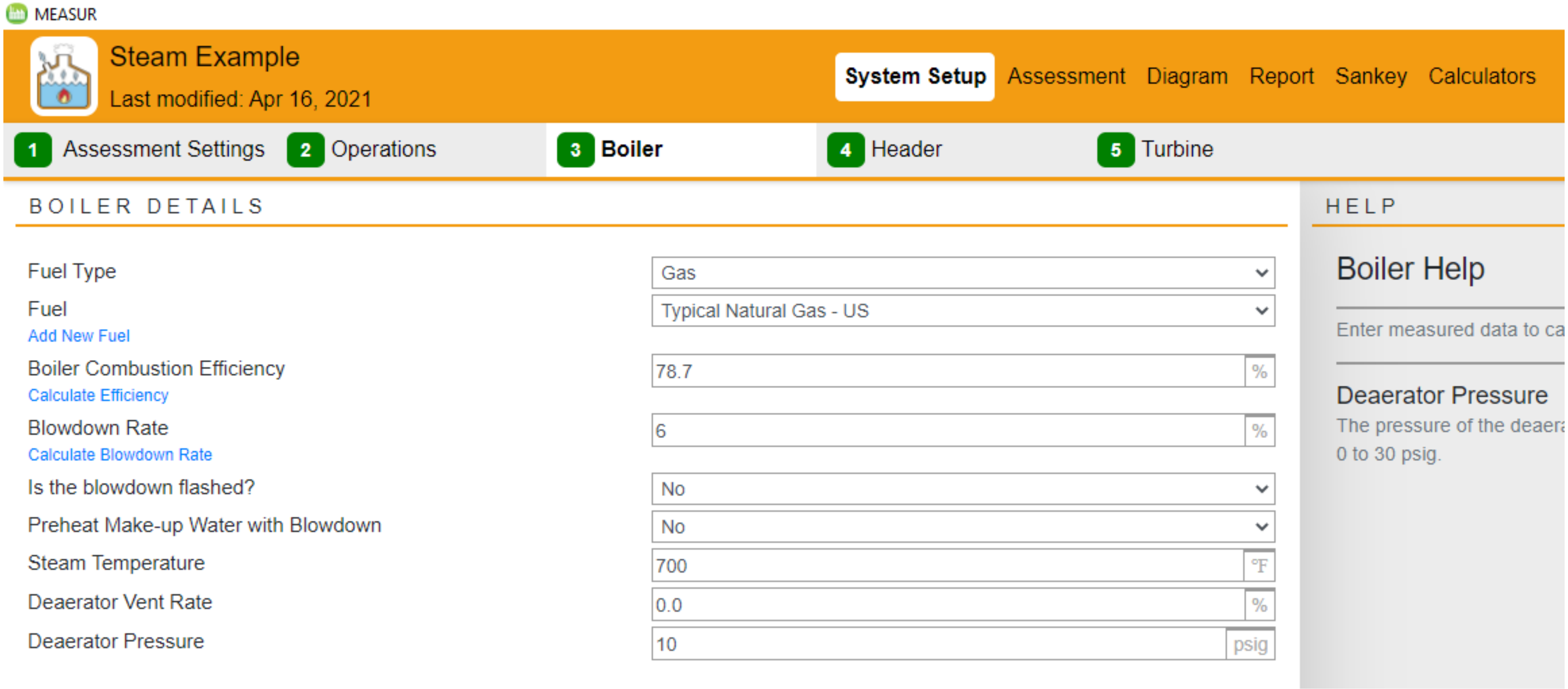
Fuel: Natural gas
Fuel cost: $5.00/MMBtu
Boiler capacity:
120,000 lbm/hr
Steam production:
100,000 lbm/hr
Boiler efficiency: 78%



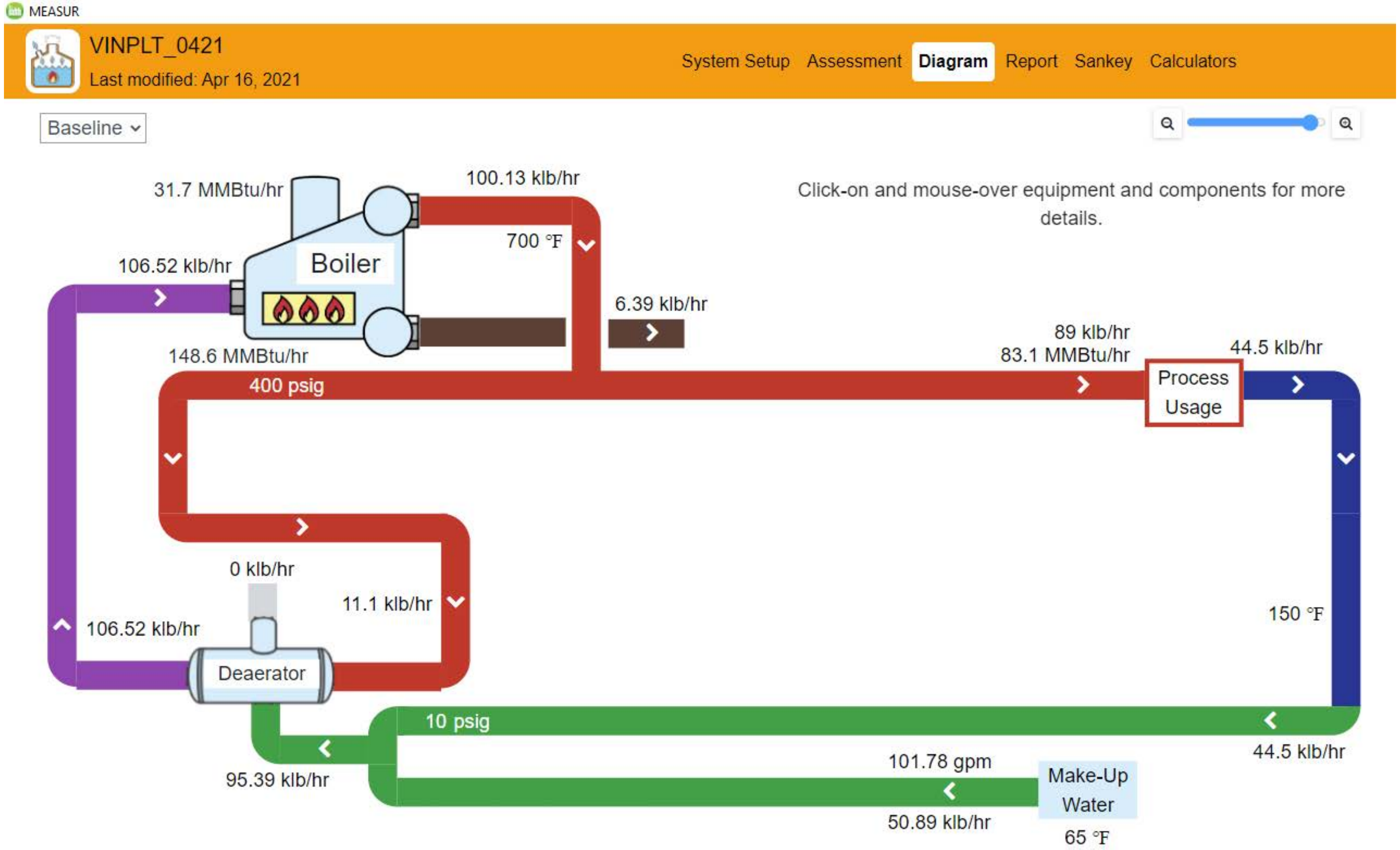
Fuel: Number 2 fuel oil
Fuel cost: $15.79/MMBtu
Boiler capacity:
50,000 lbm/hr
Steam production:
10,000 lbm/hr
Boiler efficiency: 85%

- The natural gas boiler is the **IMPACT boiler** because it responds to steam demand changes
- The #2 fuel oil boiler is a fixed operation boiler

MEASUR – System Setup



MEASUR – System Diagram



MEASUR – System Cost Summary

COST SUMMARY

Power Balance	
Generation	0 kW
Demand	5,000 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	148.63 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$6,510,187

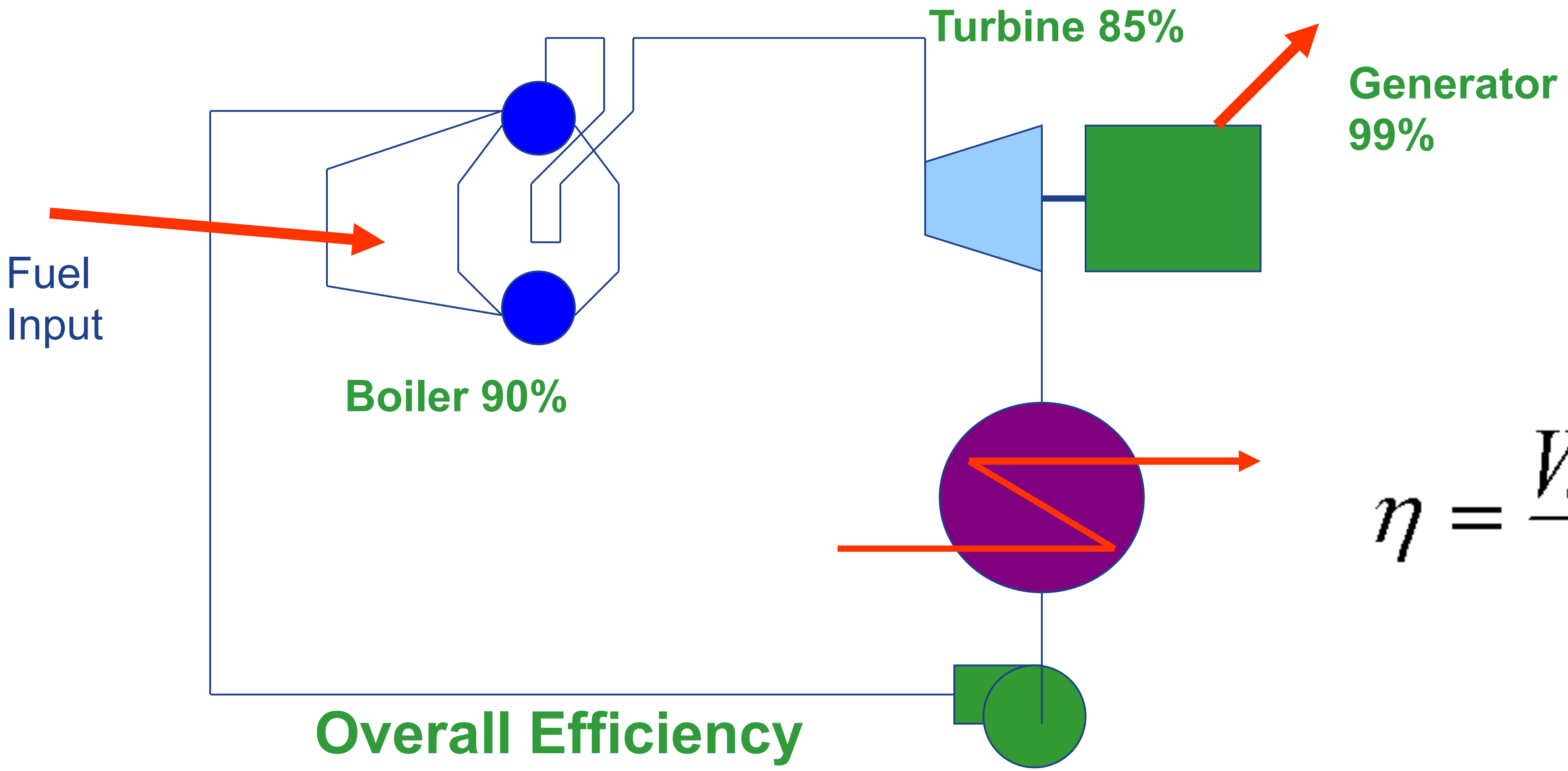
Make-Up Water	
Flow	101.78 gpm 53,497,740.14 gal
Unit Cost	$0.01 /gal
Total $/yr	$534,977

Total Operating Cost
$9,235,164

MARGINAL STEAM COST

High Pressure	$9.04 /klb
Medium Pressure	$0.00 /klb
Low Pressure	$0.00 /klb

Simple Utility Power Station



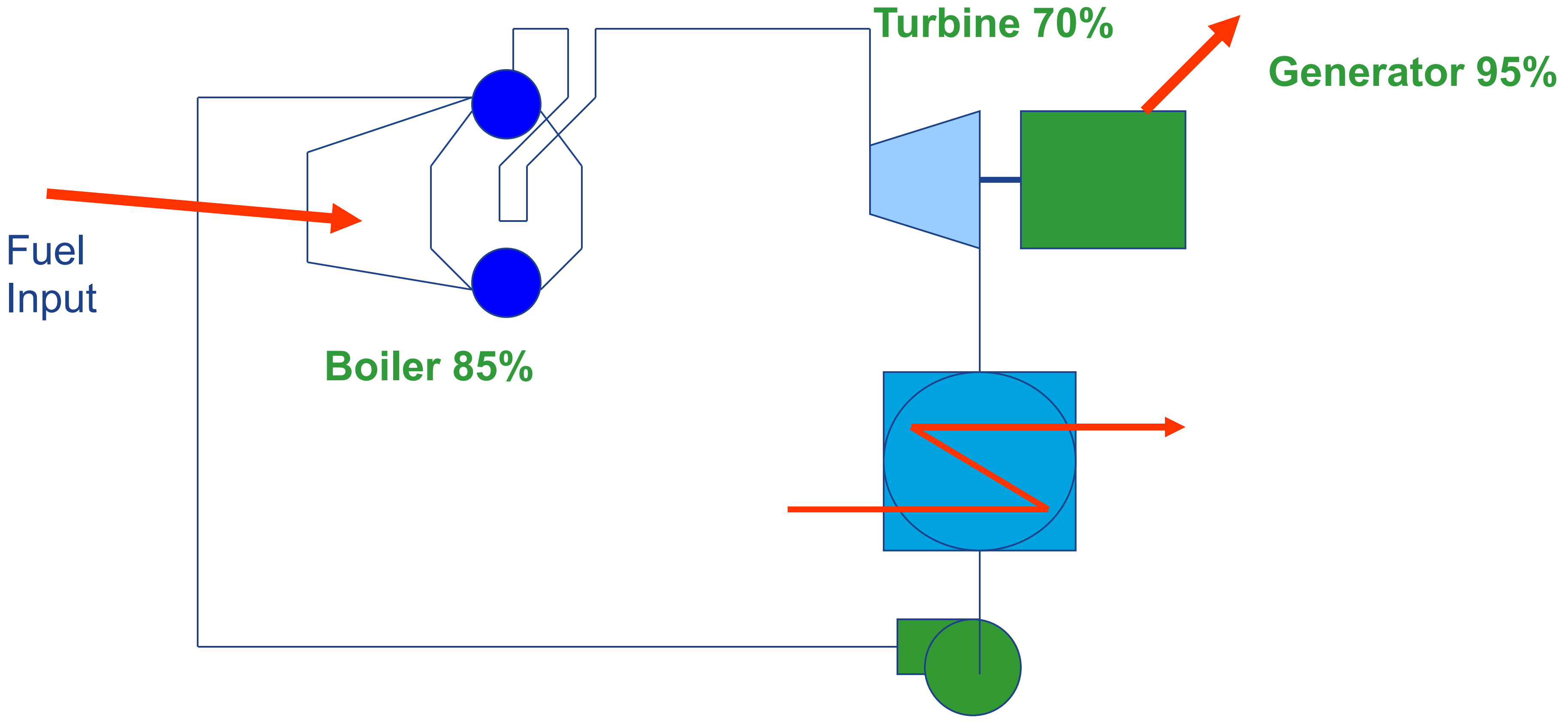
$$\eta = \frac{\dot{W}_{electrical}}{\dot{E}_{fuel}}$$

Overall Efficiency

35%

modified cycles can attain 42%

Industrial Power Station



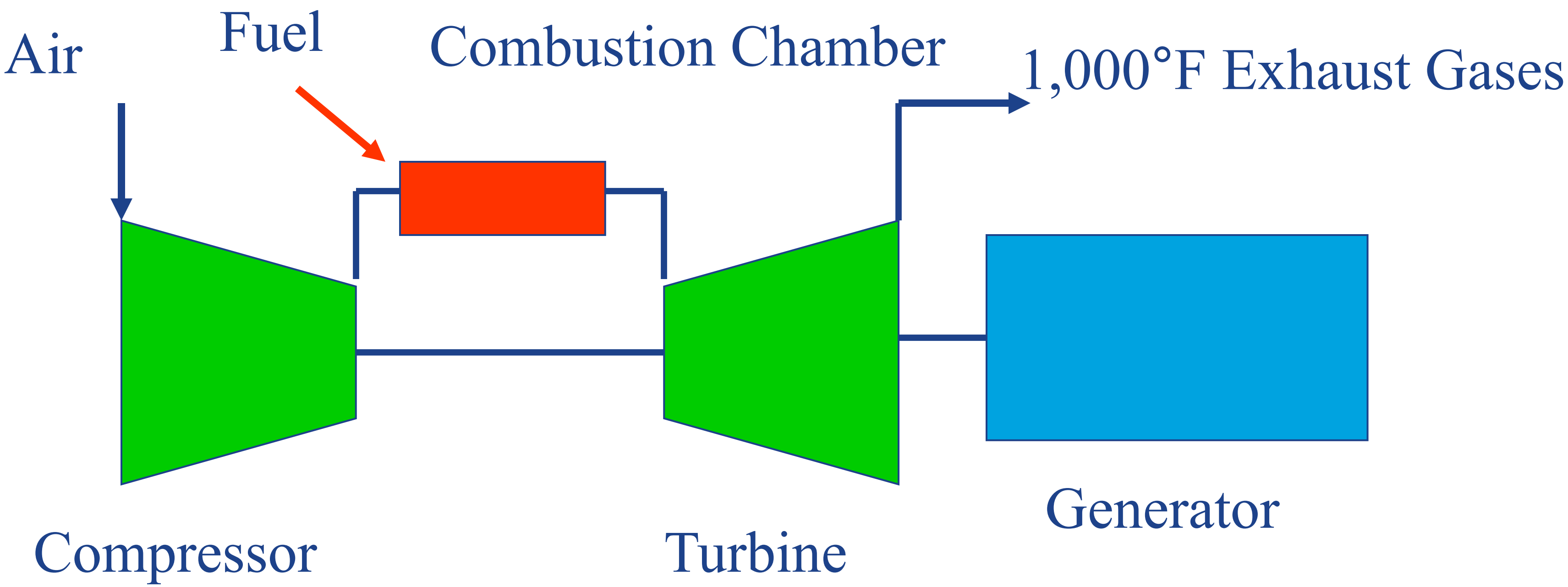
Lower efficiency components can be utilized at industrial facilities and the "overall efficiency" can approach 70% because industrial facilities have a need for thermal energy

Typical Steam Turbine Efficiency

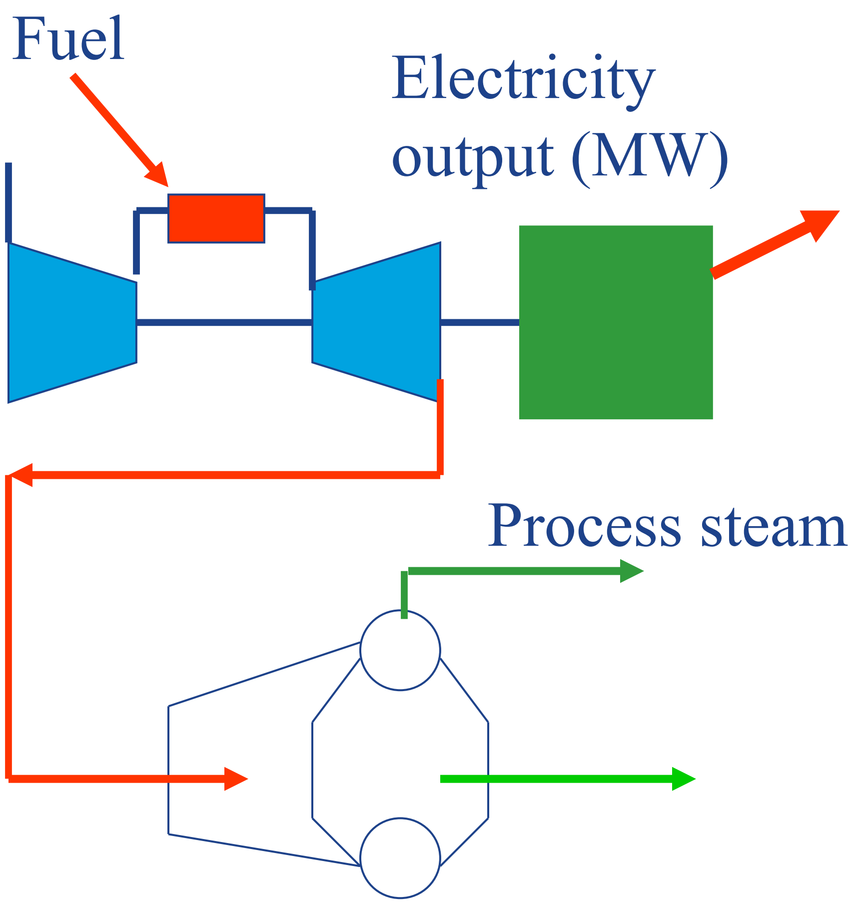
- Major contributors to isentropic efficiency
  - Turbine design
  - Control valve type
    - Single valve – throttle
    - Multi-valve – flow nozzles

$$\eta_{isentropic} = \frac{(h_{in} - h_{out})_{actual}}{(h_{in} - h_{out})_{isentropic}} = 20\% \; to \; 80\%$$

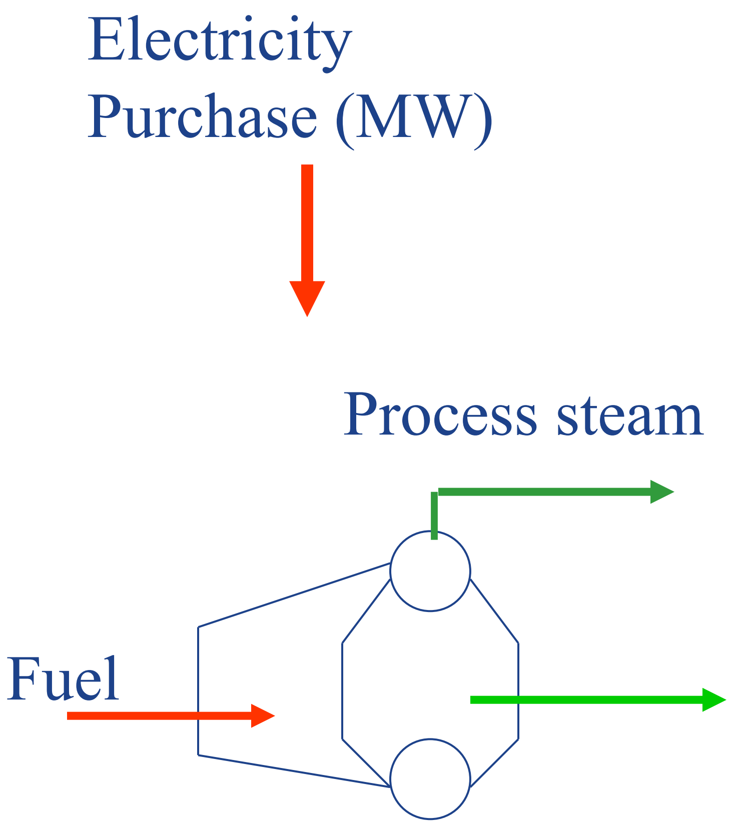
Combustion Gas Turbine



Combined Heat and Power Example

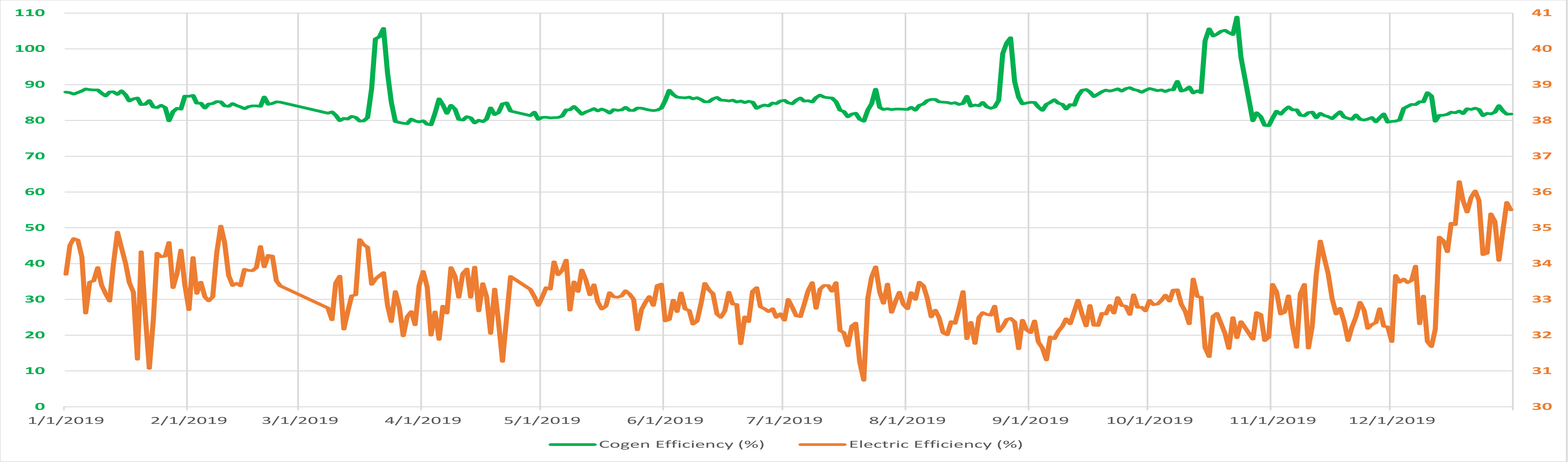


Combustion Turbine - Heat Recovery Steam Generator



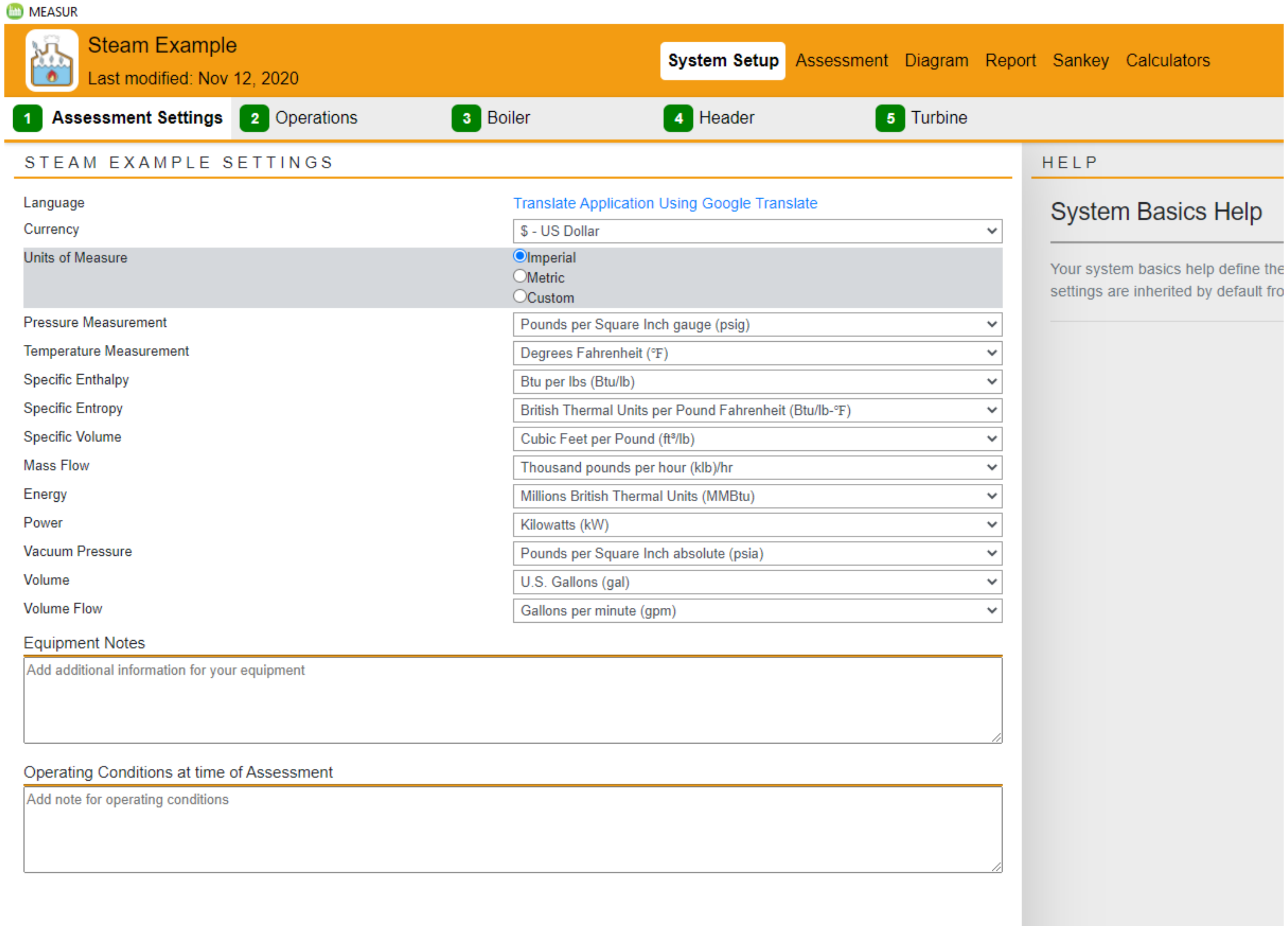
Conventional Boiler – Purchased Electricity

Example System Cogeneration Trending

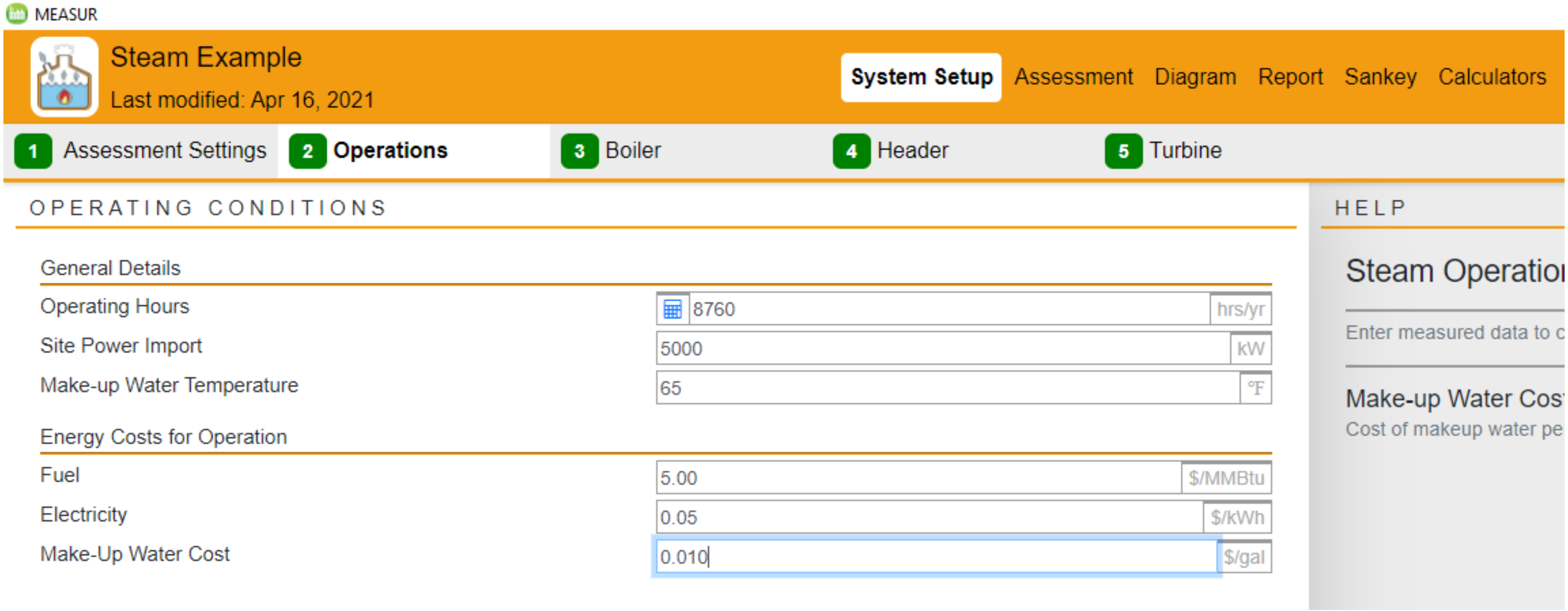


US DOE MEASUR Preferences

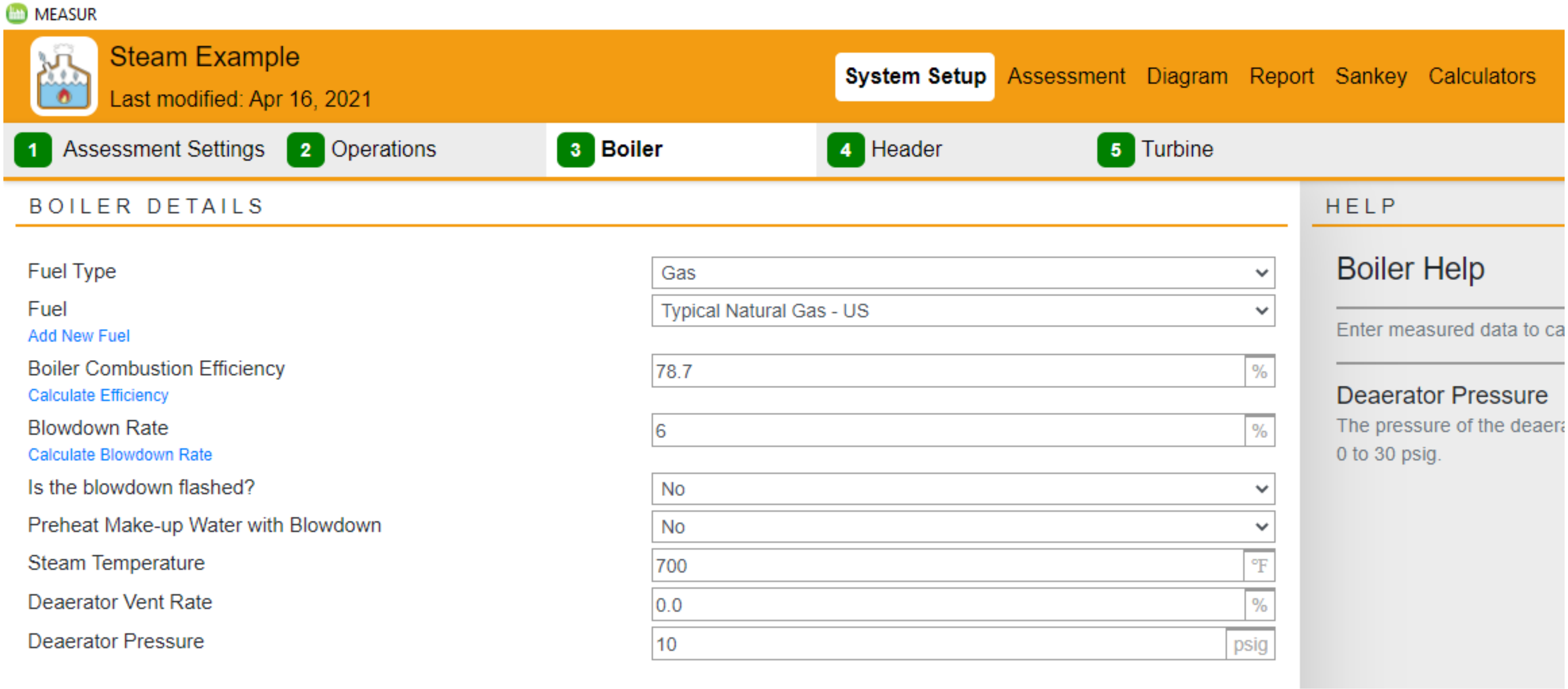
- Full flexibility is offered to the user to select default (IP) or choose Custom units for the parameters
- Generally, US$ is the easiest currency to work with but some other currencies are available
- HELP is always around



MEASUR – System Setup



MEASUR – System Setup



Distribution

- Header Pressures
- Letdown Stations
- Header Losses

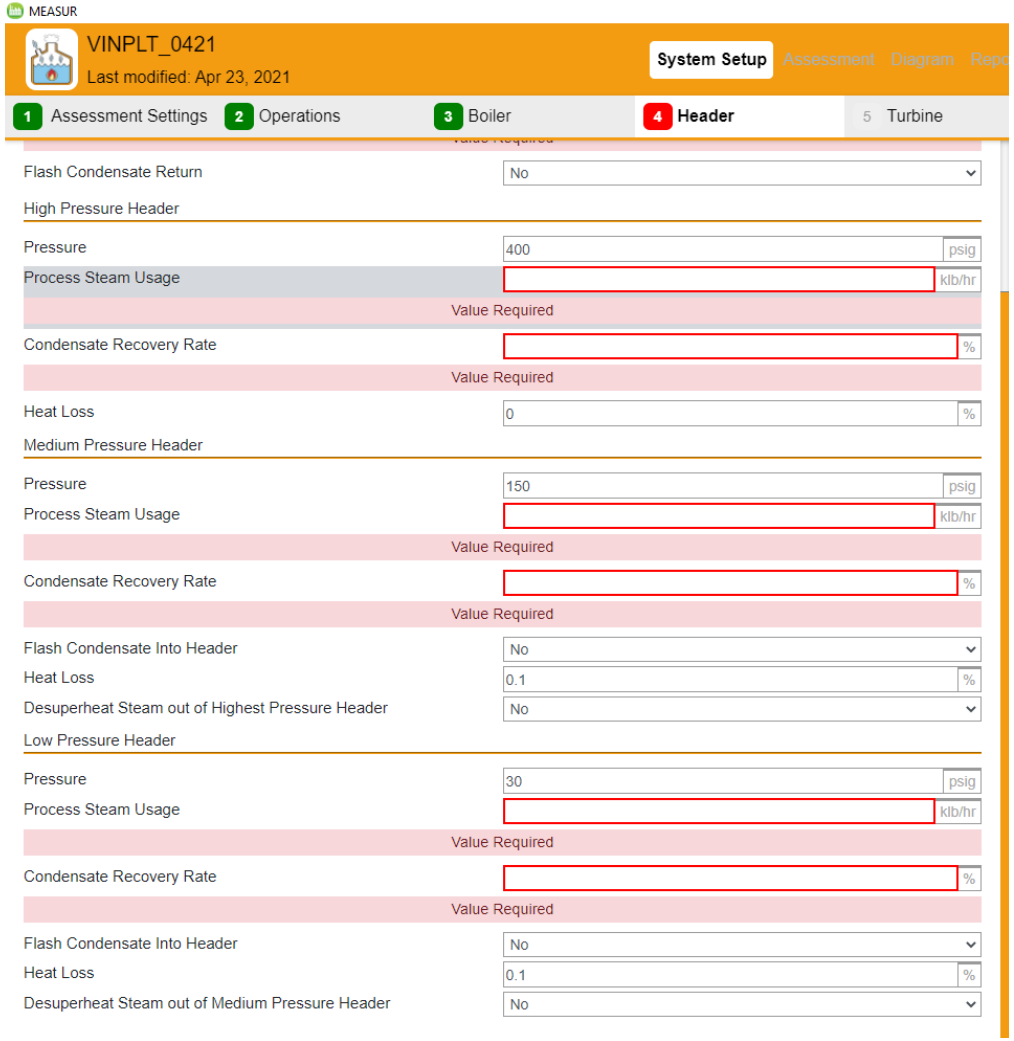
Example Steam System – Pulp & Paper Mill

- Pressure levels for steam distribution in the plant
  - High pressure – 400 psig
  - Medium pressure – 150 psig
  - Low pressure – 30 psig

- Use a 3-header steam system model

- Steam usage will be determined in the End-Use section for each header

Example Steam System – Pulp & Paper Mill



Letdowns / PRVs

- Pressure Reducing Valves (PRVs) are most prevalent method of reducing pressure in a steam system
- A steam system will have one or more PRVs between two headers
- Not all PRVs maybe controlling header pressures
- Steam temperature at the outlet of the PRVs is controlled by feedwater (Desuperheaters)
- Mainly done for
  - Protecting equipment
  - Design conditions
  - Reducing pressure drop

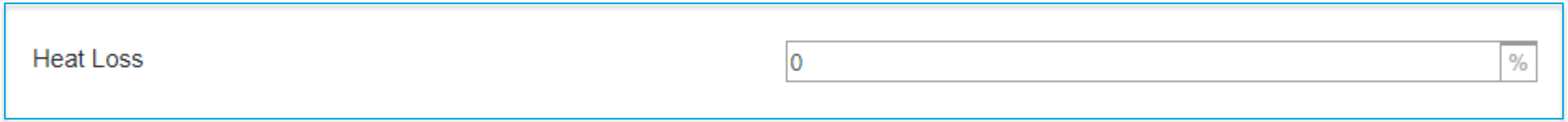
Desuperheat Steam out of Highest Pressure Header | No

Header Heat Loss

- The heat transfer loss associated with the piping distribution system is related to the total enthalpy flow entering the header in question
  - The enthalpy reference datum (h_{datum}) is 0.0 Btu/lbm
    - 32°F and 0 psig
- The loss (non-impact) can be expressed as
  - A fraction (percentage) of the total enthalpy entering the header
- 3E Plus can be utilized to estimate this loss

Header Heat Loss

- The header heat loss impacts the energy delivered to the process units
  - The mass flows to the process demands remain as specified but the energy content of the steam is diminished



End-Use

- Steam Mass Balance
- Steam Usage on Different Headers
- Significant Steam User

Process Steam Demand Evaluation

- US DOE MEASUR is a “pull type” model
  - Process steam flows “pull” steam through the boiler
  - Typically modeling activities strive to match general boiler load

- Process steam flows are established by:
  - Direct continuous flow measurement
  - Direct intermittent flow measurement
  - Mass balance
  - Energy balance
  - System or Process design information
  - Empirical standards or data

Flow Measurements

- Steam flow measurement is typically completed by conventional flow meters
  - Orifice plates
  - Vortex
- Condensate flow measurement is often completed by intermittent field observations
  - Timed volume capture
    - Condensate receiver fill and discharge
    - Known volume fill

Mass & Energy Balances

- Conservation of mass principle can often be applied very effectively

- The first law of thermodynamics (energy balance) for heat exchange is typically applied to:
  - Steam alone
  - Heated material alone

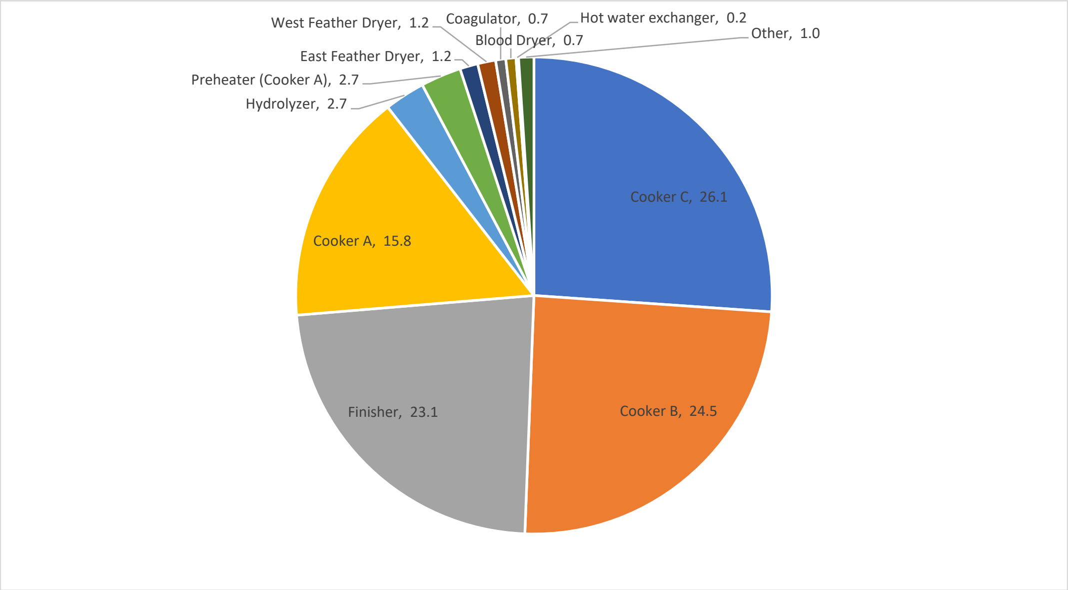
$$\dot{Q}_x = \dot{m}_x (C_p)_x (T_e - T_i)_x$$ For constant specific heats and when enthalpy is a function of temperature only

$$\dot{Q}_x = \dot{m}_x (h_e - h_i)_x$$ When material enthalpies are known

$$\dot{Q}_{steam} = -\dot{Q}_x$$ Typical heat exchanger applications

Steam Balance

- Account for significant steam energy users
- Aim to get 80-85% steam usage accounted using some form of steam flow / condensate measurement



End Use	Steam (lb/hr)	Energy (MMBtu)	% of Total (%)
Cooker C	37,983	246,131	26.1
Cooker B	35,684	231,231	24.5
Finisher	33,590	217,663	23.1
Cooker A	22,996	149,013	15.8
Hydrolyzer	4,000	25,920	2.7
Preheater (Cooker A)	4,000	25,920	2.7
East Feather Dryer	1,776	11,508	1.2
West Feather Dryer	1,776	11,508	1.2
Coagulator	1,000	6,480	0.7
Blood Dryer	1,000	6,480	0.7
Hot water exchanger	250	1,620	0.2
Other	1,505	9,753	1.0
Total	**145,560**	**943,229**	**100.0**

Significant Steam Energy Users

Polling Questions 2-3

Polling Question

2) Will you be able to prepare a list of users which account for 85% of steam in your plant?

   A. Yes
   B. No
   C. Don’t know

3) Will you be able to measure the steam used by these major users?

   A. Yes
   B. No
   C. Don’t know

Example Steam System – Pulp & Paper Mill

- Steam usage at different pressure levels for steam distribution in the plant
  - High pressure – 400 psig – 8 klb/hr
  - Medium pressure – 150 psig – 30 klb/hr (Significant energy user – Digester)
  - Low pressure – 30 psig – 50 klb/hr (Significant energy users – Paper Machines, Driers)

- Use a 3-header steam system model

Medium Pressure Header

Pressure	150	psig
Process Steam Usage	30	klb/hr

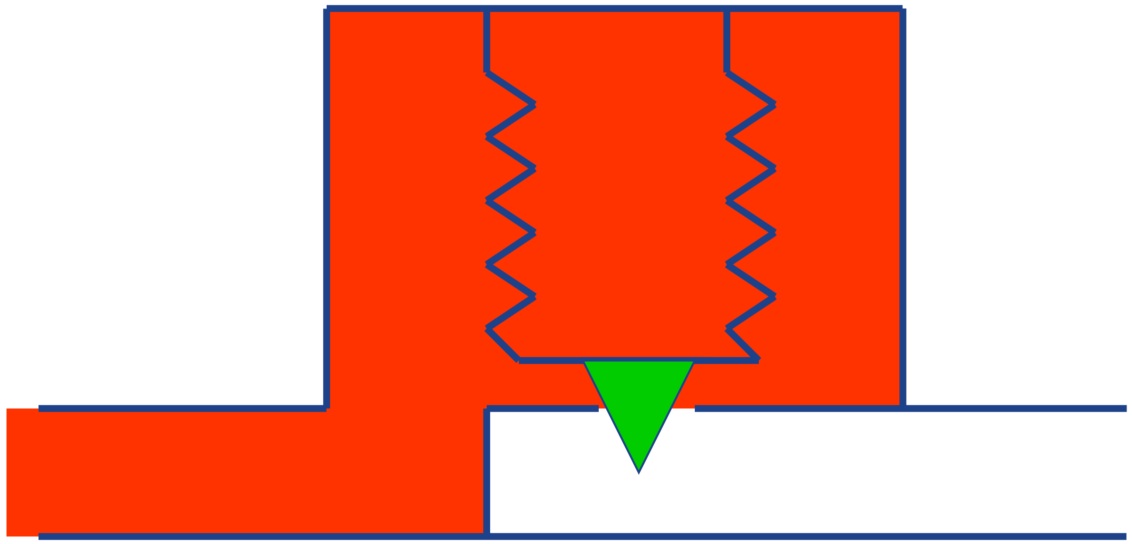
Condensate Recovery

- Steam Traps
- Condensate Collection System
- Flash Tanks
- Condensate Return

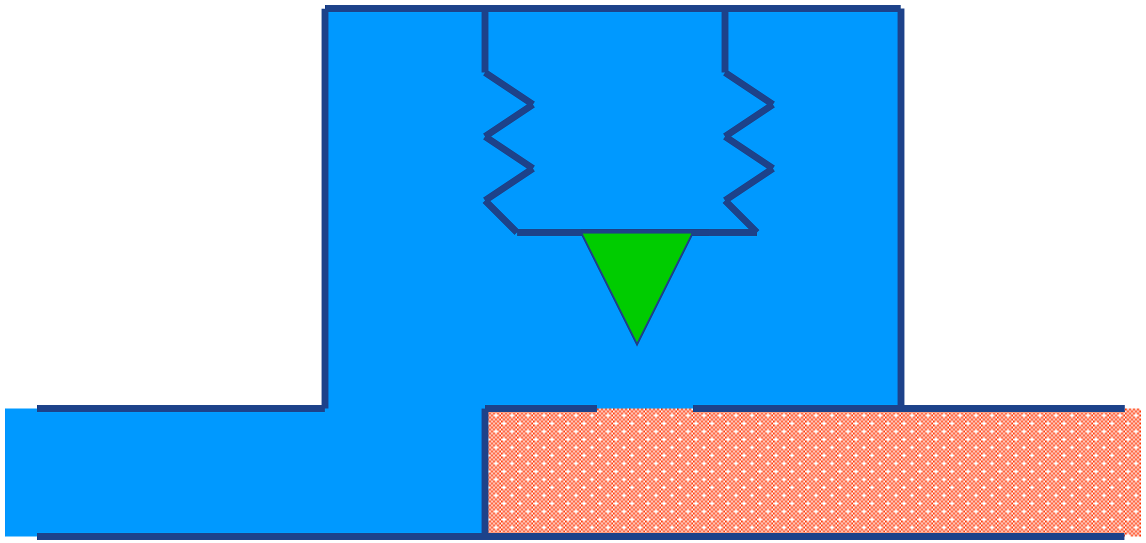
Steam Traps

- Thermostatic
- Closed Float
- Float and Thermostatic
- Open Float
- Thermodynamic
- Orifice

Thermostatic Steam Traps

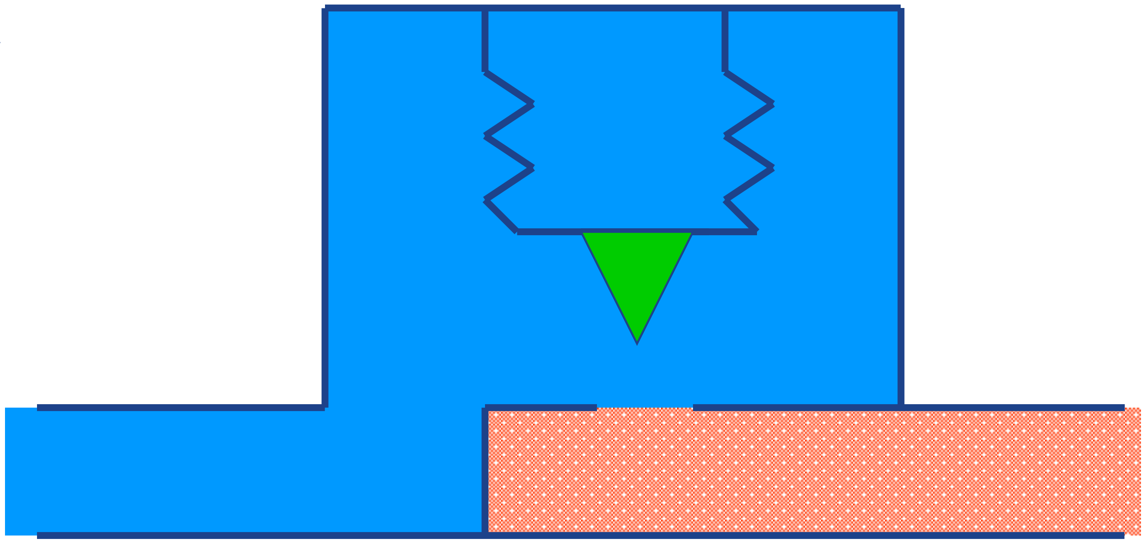


Thermostatic Steam Traps

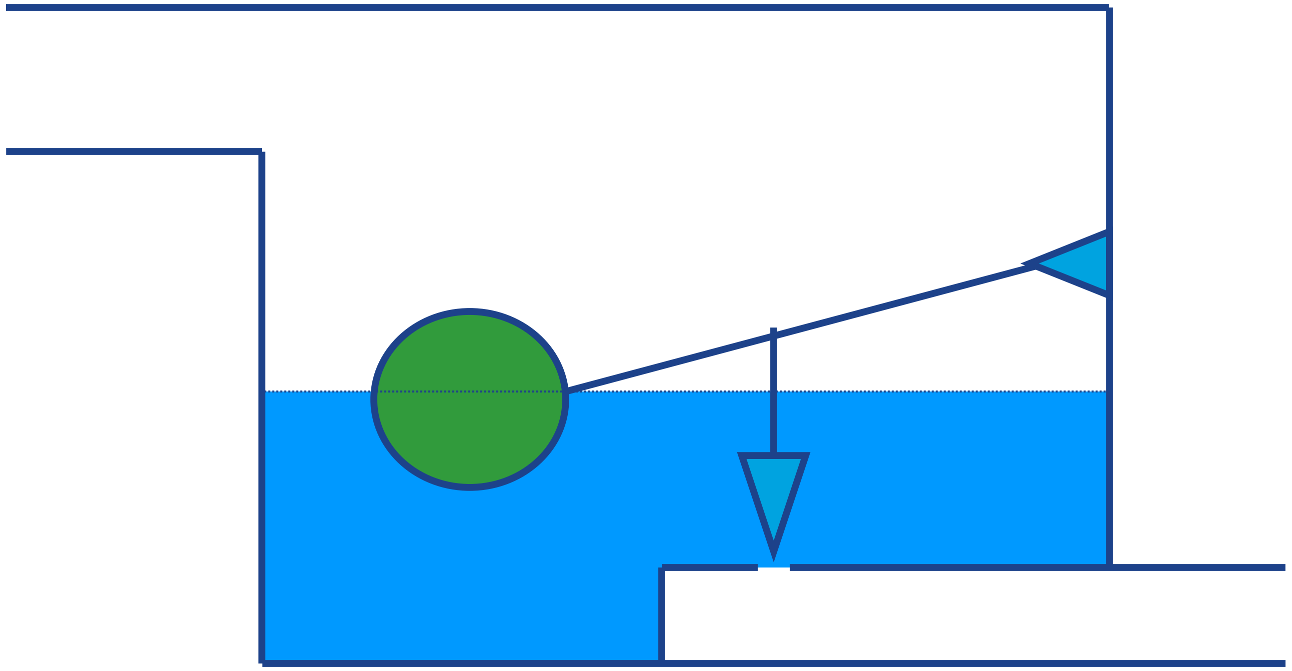


Thermostatic Steam Traps

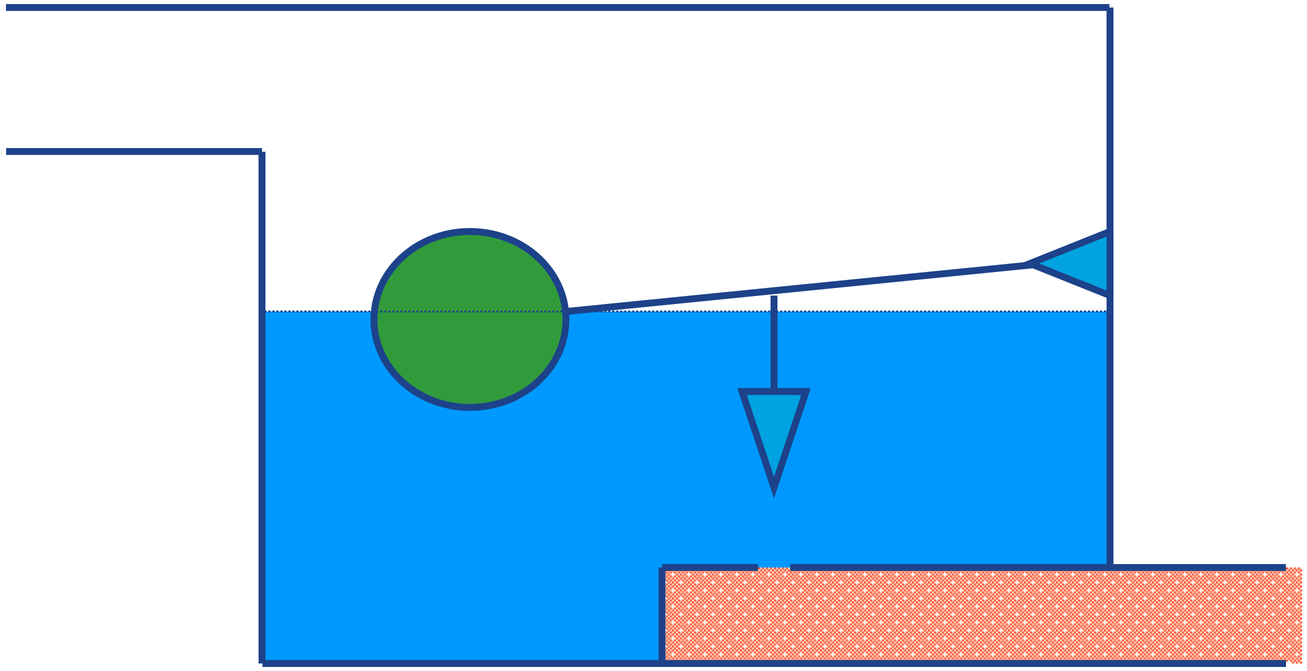
- Opens to subcooled condensate
- Can discharge condensate or condensate and flash steam depending on subcooling
- Allows energy recovery from condensate
- Significant air-removal capability



Closed Float Steam Trap

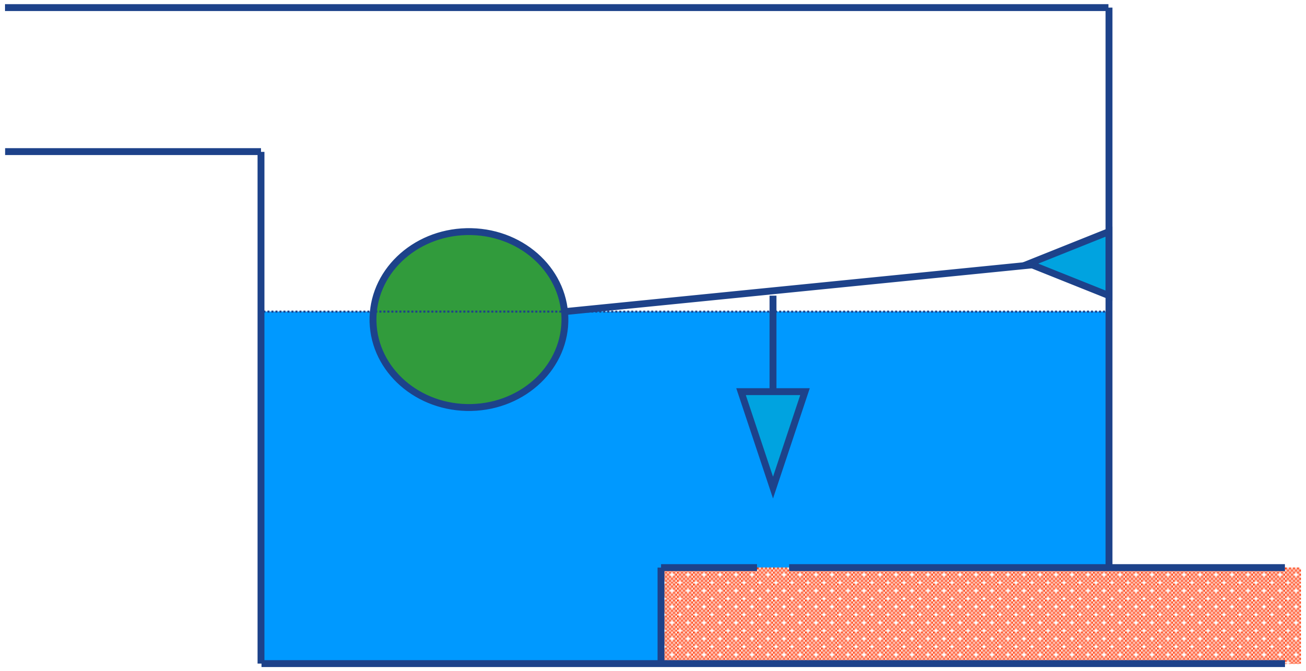


Closed Float Steam Trap

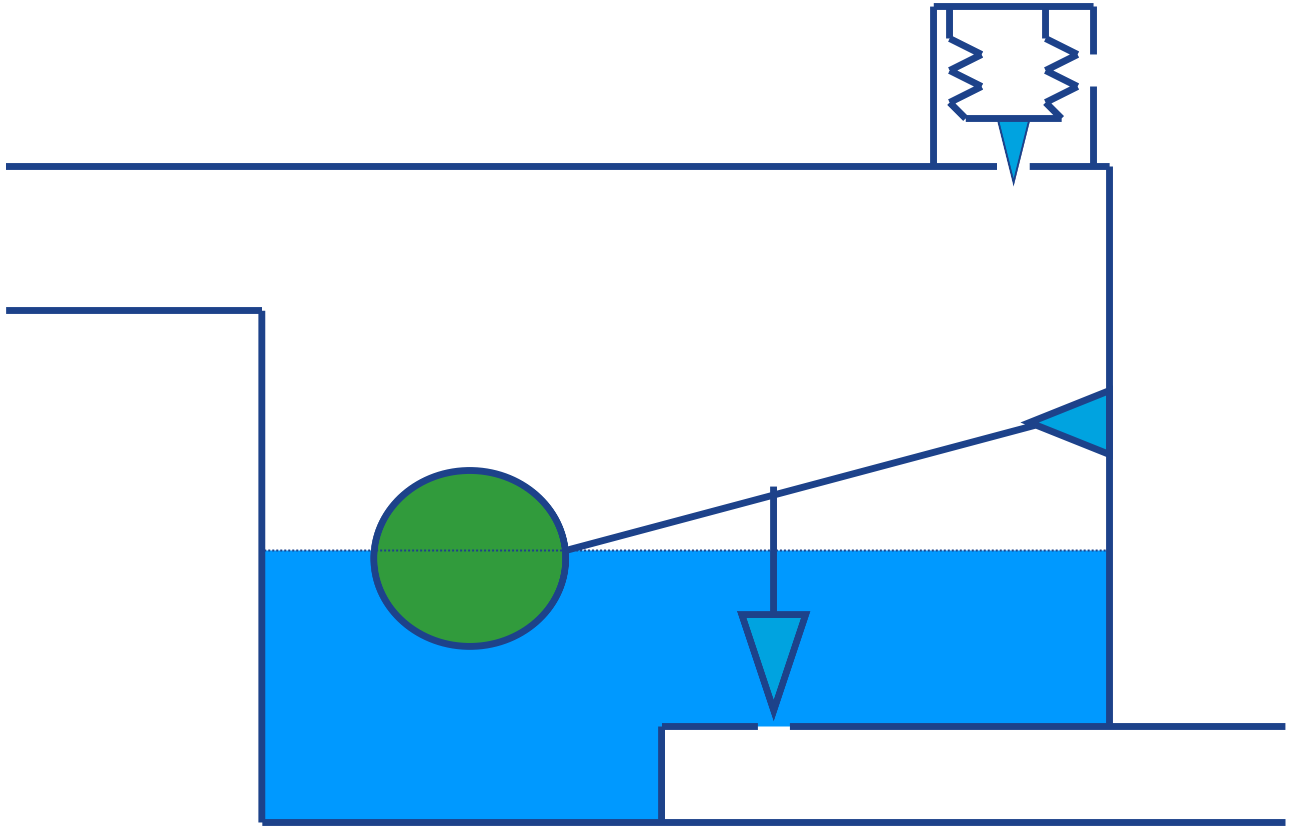


Closed Float Steam Trap

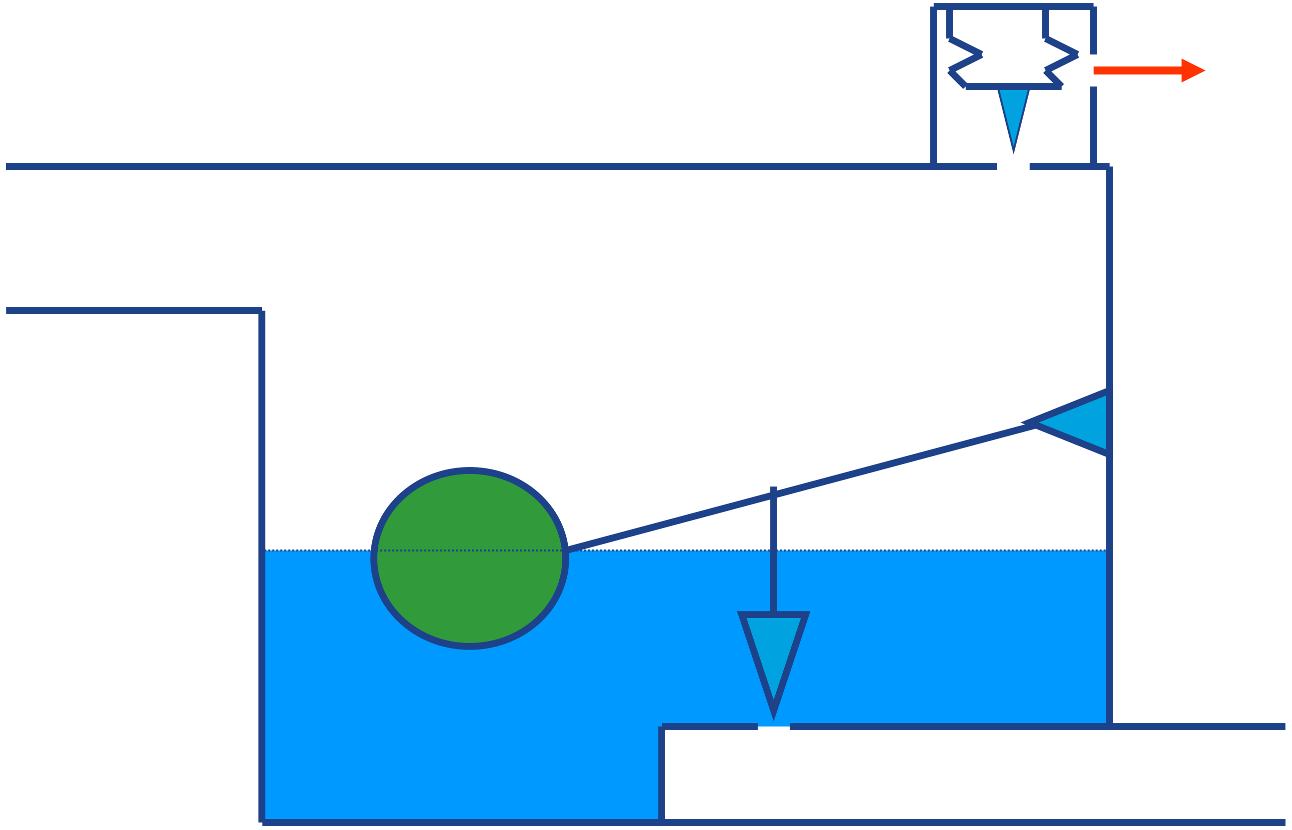
- Rarely applied in this form in steam systems
- Opens to saturated condensate
- Will discharge condensate and flash steam
- Poor (no) air-removal capability



Float and Thermostatic Steam Trap

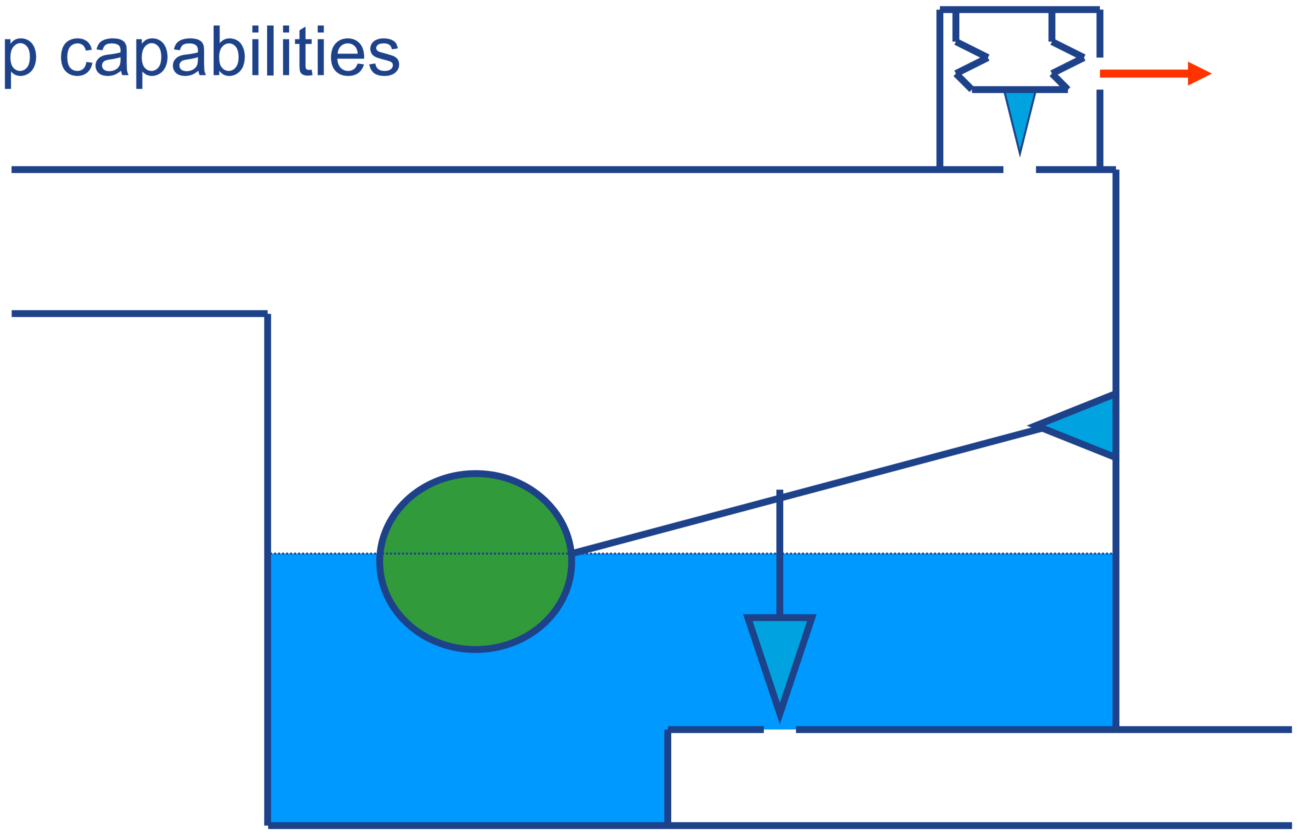


Float and Thermostatic Steam Trap

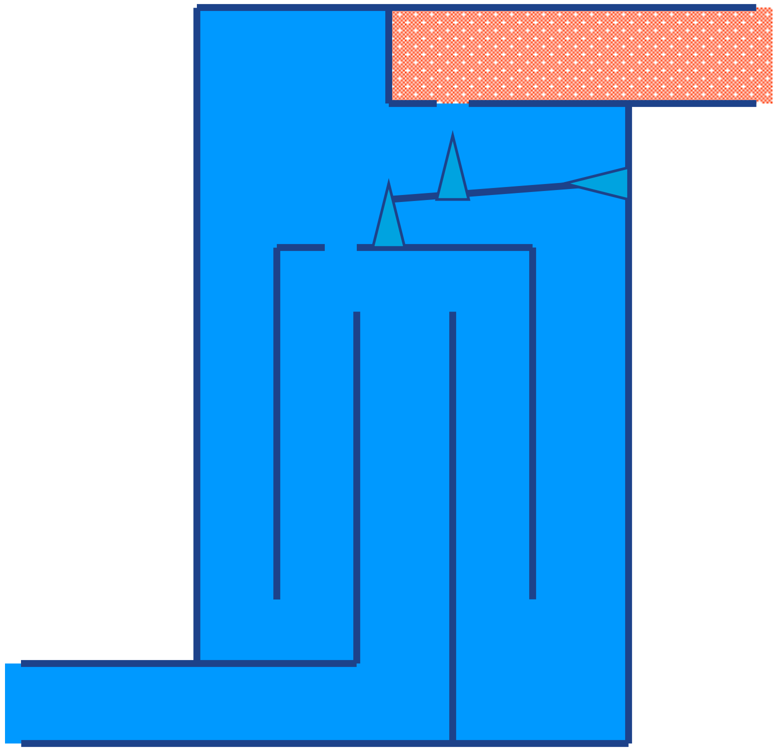


Float and Thermostatic Steam Trap

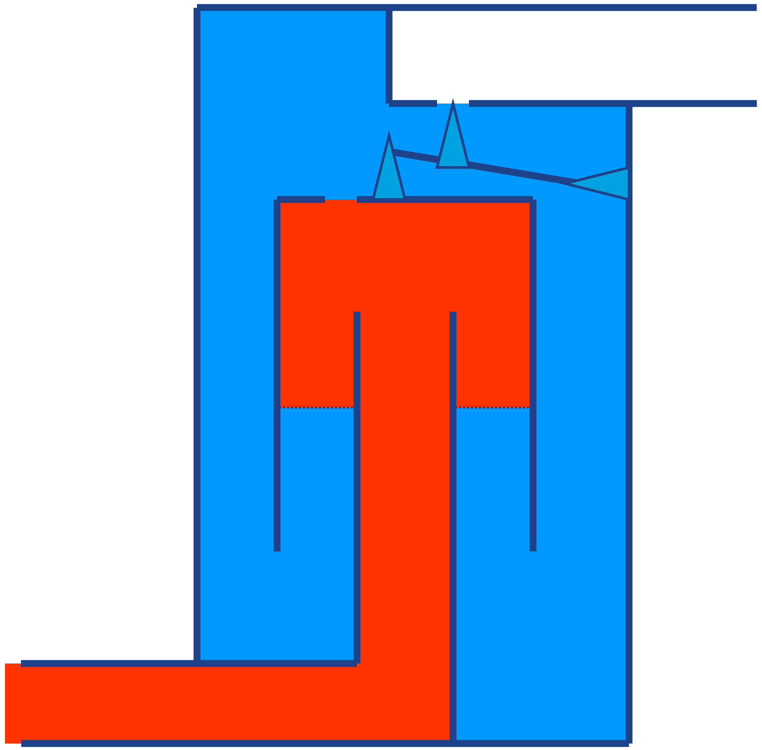
- Opens to saturated condensate
- Will discharge condensate and flash steam
- Significant air-removal and startup capabilities
- Modulating type operation



Open Float (Inverted Bucket) Steam Trap

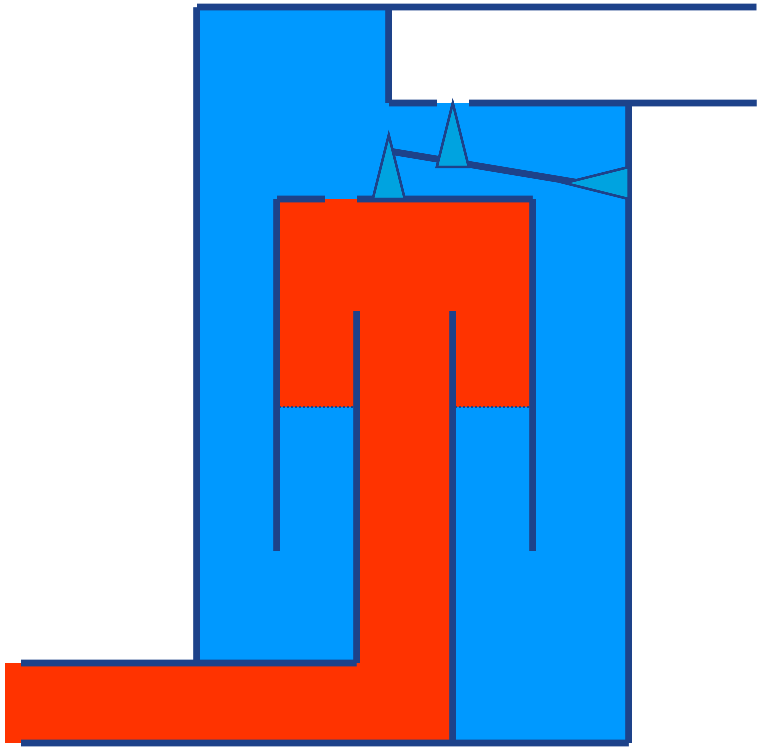


Open Float (Inverted Bucket) Steam Trap

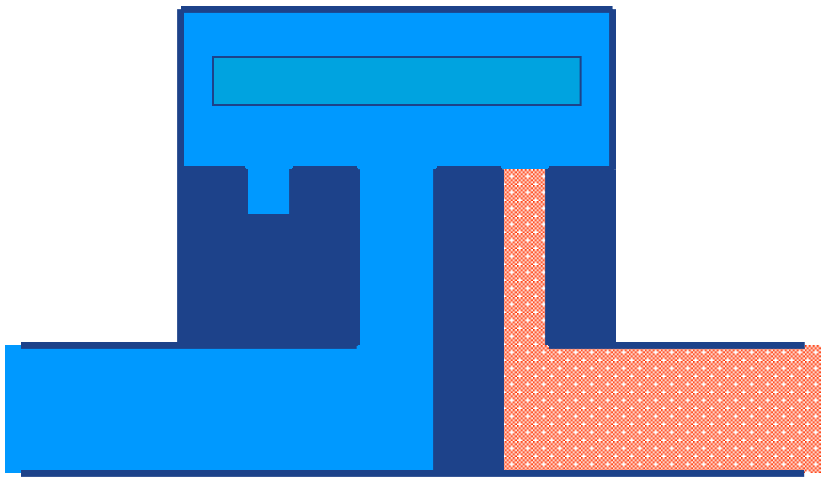


Open Float (Inverted Bucket) Steam Trap

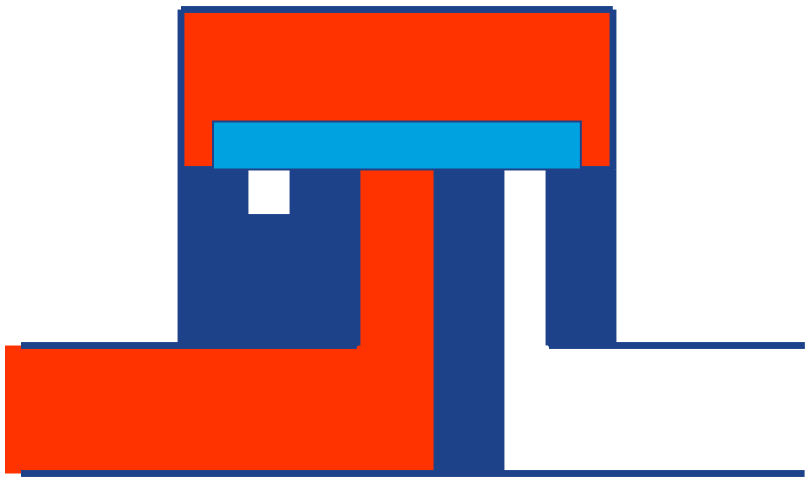
- Opens to saturated condensate
- Will discharge condensate and flash steam
- Limited air-removal capability
- Application in superheated steam service should be investigated
- Intermittent operation



Thermodynamic Steam Traps

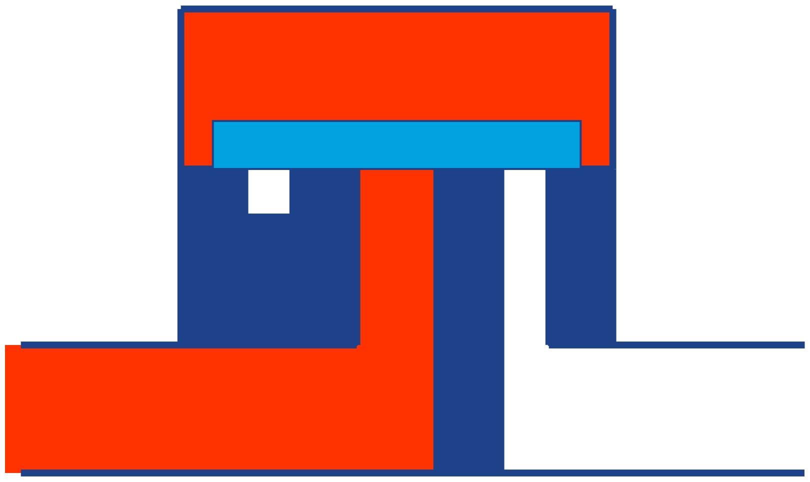


Thermodynamic Steam Traps

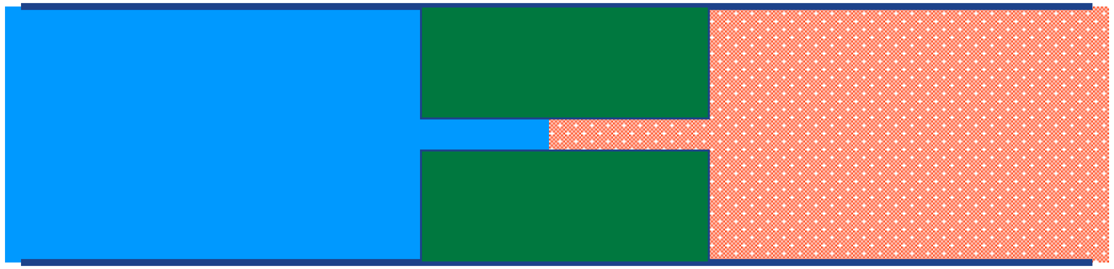


Thermodynamic Steam Traps

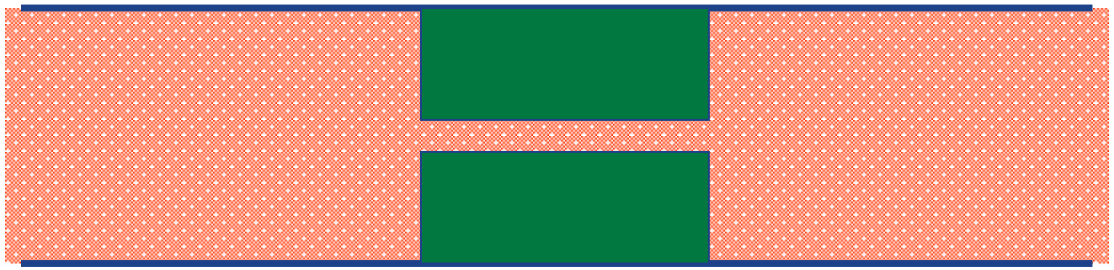
- Opens to saturated condensate
- Will discharge condensate and flash steam
- Intermittent operation
- Can be equipped with thermostatic element to improve air removal



Orifice Steam Traps

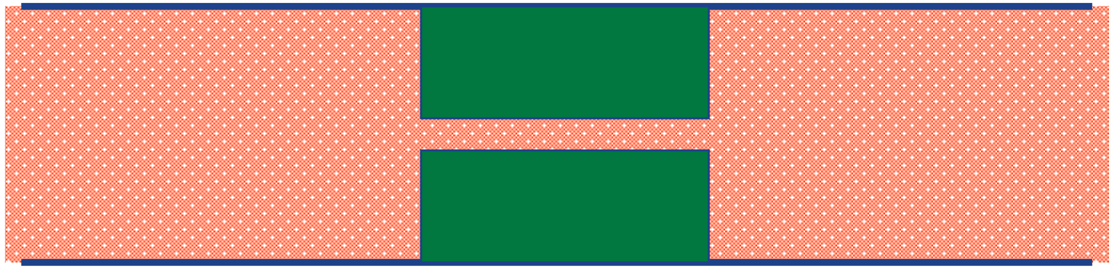


Orifice Steam Traps



Orifice Steam Traps

- No moving parts
- Continuous operation
- Common applications are steady loads
- Limited air-removal capability due to orifice limitations



Process Condensate

- MEASUR condensate receiver operates at atmospheric pressure
- MEASUR condensate return temperature provides an indication of the energy loss associated with the condensate return system
  - MEASUR condensate exits a process heat exchanger as a saturated liquid at the pressure of the heat exchanger

Condensate Return

Condensate Return Temperature	150 °F
Flash Condensate Return	No

Process Condensate

- Condensate recovery percentage describes the amount of ***process steam*** recovered in the condensate system
- Flash steam recovery systems allow recovered condensate to flash steam into lower-pressure steam systems
- Makeup water temperature impacts condensate related projects

Medium Pressure Header

Pressure	150	psig
Process Steam Usage	30	klb/hr
Condensate Recovery Rate	50	%
Flash Condensate Into Header	No	

Condensate Recovery / Flash Steam

- Condensate is saturated liquid at the header pressure
  - Some sub-cooling may occur depending on heat losses, heat exchanger design, process conditions, etc.

- This condensate has a lot of energy and can be flashed to produce steam for lower pressures

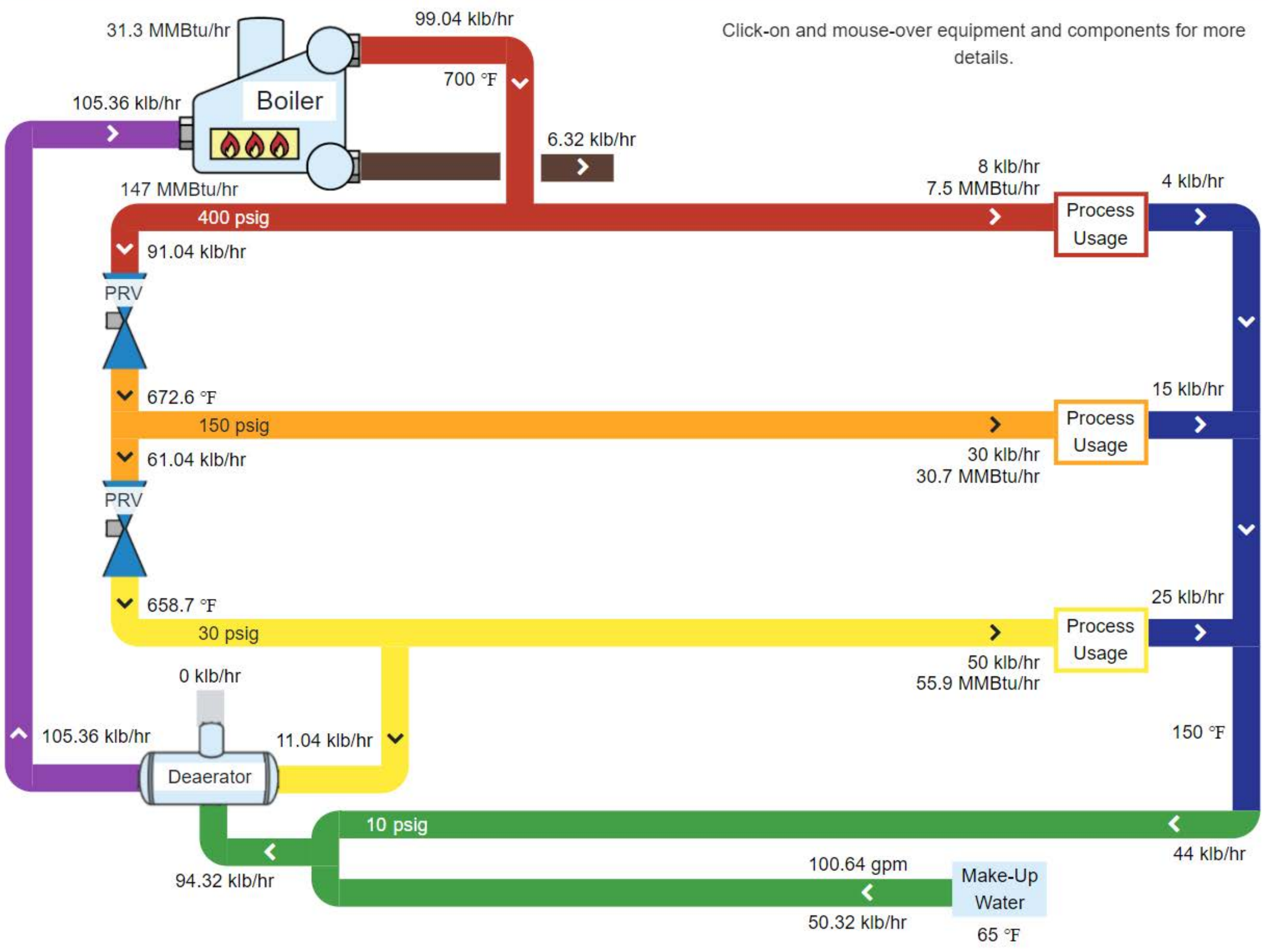
	Inlet	Steam Out	Liquid Out
Pressure (psig)	400	150	150
Temperature (°F)	448.2	365.9	365.9
Sp. Enthalpy (Btu/lb)	428.2	1,196	338.6
Sp. Entropy (Btu/lb-°F)	0.626	1.562	0.524
Quality	Liquid	Gas	Liquid
Mass Flow (klb/hr)	10	1.04	8.96
Energy Flow (MMBtu/hr)	4.3	1.2	3

US DOE MEASUR

- Building a Steam System Model

U.S. DEPARTMENT OF ENERGY

MEASUR – Pulp & Paper Mill Model



Better Plants U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY

MEASUR – Pulp & Paper Mill Model

COST SUMMARY

Power Balance	
Generation	0 kW
Demand	5,000 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	147.02 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$6,439,310

Make-Up Water	
Flow	100.64 gpm 52,898,985.56 gal
Unit Cost	$0.01 /gal
Total $/yr	$528,990

Total Operating Cost
$9,158,299

Marginal Steam Costs

- Marginal steam costs are typically used when analyzing
  - Steam leaks
  - Process changes
  - Elimination or institution of nominal steam use
- Marginal steam costs are impacted by condensate return
  - Amount
  - Temperature

MARGINAL STEAM COST

High Pressure	$9.04 /klb
Medium Pressure	$9.04 /klb
Low Pressure	$9.04 /klb

Low-pressure Header Vent

- The low-pressure header can operate in an “unbalanced” state
  - This can develop in steam systems by:
    - Operating more backpressure turbines than necessary
    - Poor control strategies
  - The low-pressure vent should always be a point of investigation
    - From the physical site operations standpoint
    - From the MEASUR model standpoint

Example Steam System – Pulp & Paper Mill

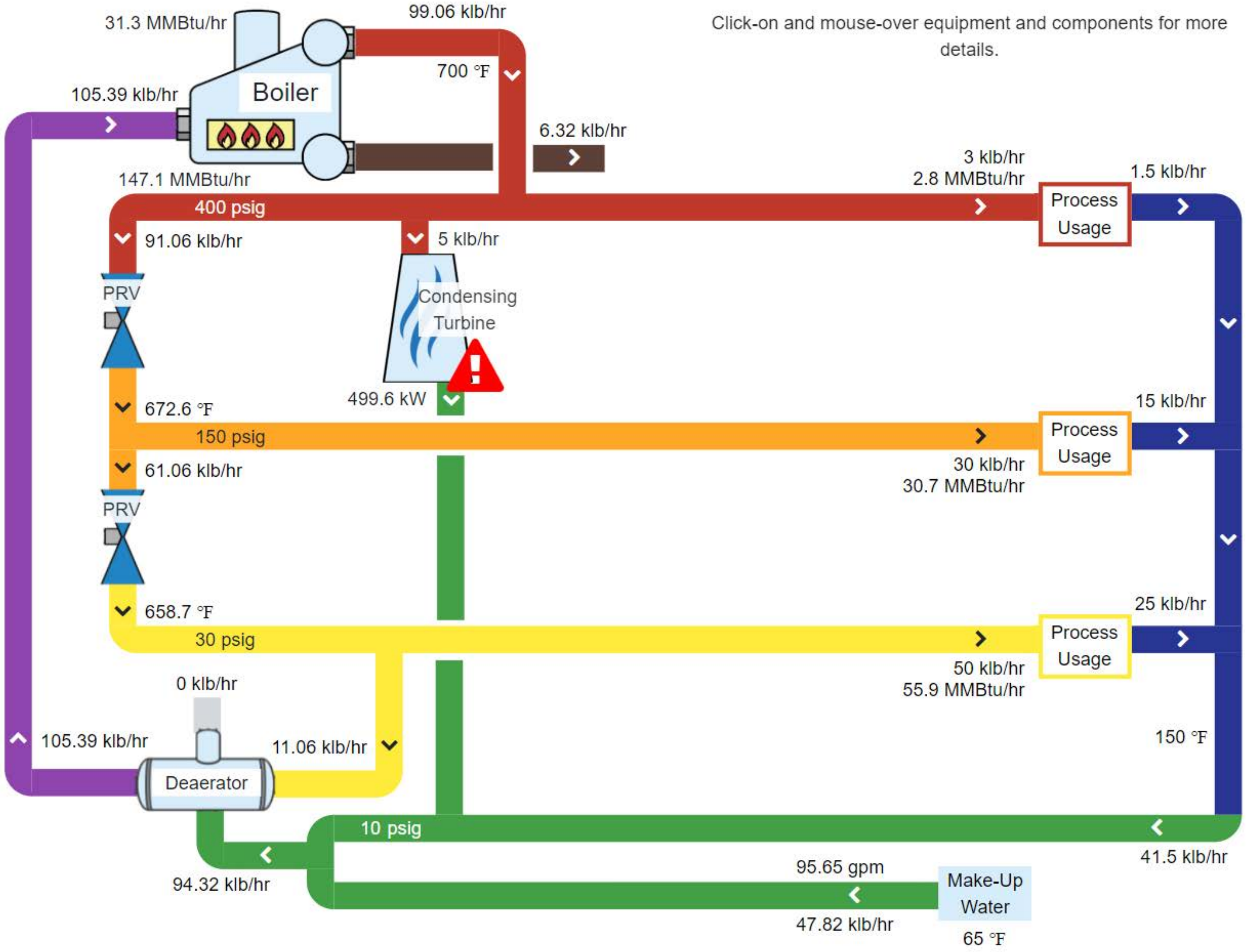
- One final modification
  - The pulp and paper mill has one condensing steam turbine to produce just enough power to allow for a safe shutdown of the mill during a power issue from the grid
  - Condensing turbine efficiency = 80%
  - Steam flow rate = 5.0 klb/hr
  - High Pressure header steam usage = 3 klb/hr

TURBINE DETAILS

☑ Condensing Turbine

Isentropic Efficiency	80	%
Generator Efficiency	95	%
Condenser Pressure	1	psia
Operation Type	Steam Flow	
Fixed Flow	5	klb

MEASUR – Pulp & Paper Mill Model



MEASUR – Pulp & Paper Mill Model

COST SUMMARY

Power Balance	
Generation	499.6 kW
Demand	5,499.6 kW
Import	5,000 kW
Unit Cost	$0.05 /kWh
Total $/yr	$2,190,000

Fuel Balance	
Boiler	147.05 MMBtu/hr
Unit Cost	$5.00 /MMBtu
Total $/yr	$6,440,979

Make-Up Water	
Flow	95.65 gpm 50,272,661.49 gal
Unit Cost	$0.01 /gal
Total $/yr	$502,727

Total Operating Cost
$9,133,705

MARGINAL STEAM COST

High Pressure	$9.04 /klb
Medium Pressure	$9.04 /klb
Low Pressure	$9.04 /klb

Better Plants Diagnostic Equipment Program (DEP)

- **Steam System Assessment Portable Tools**

Field Measurements

- Usually energy experts can do these over short durations (1 or 2 days)

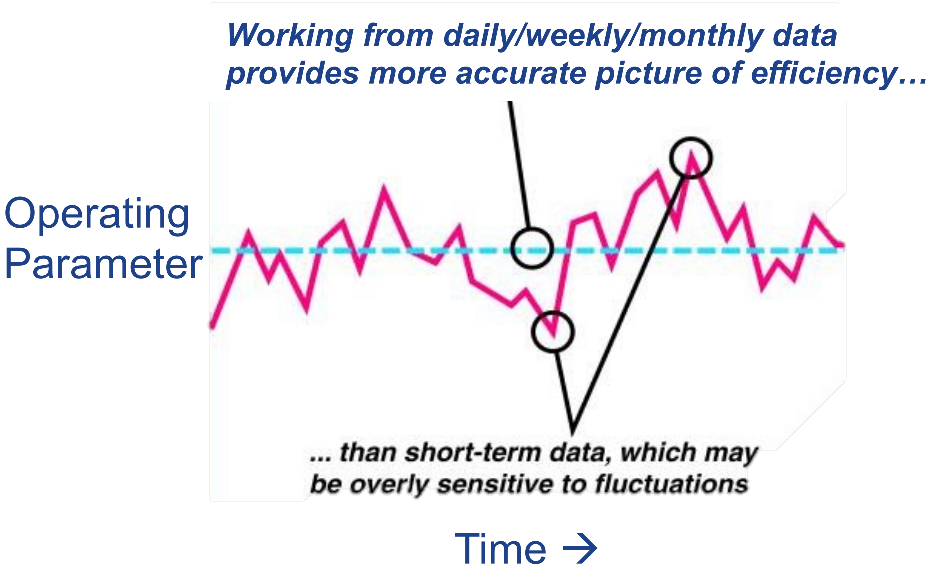
- Use of portable instrumentation is a good way to back up findings

- Portable Measurements can help to build credibility in existing in-situ instruments for accuracy

Field Measurements (Caution!)

- Instantaneous measurements
- Historical data
- Measurements over time interval

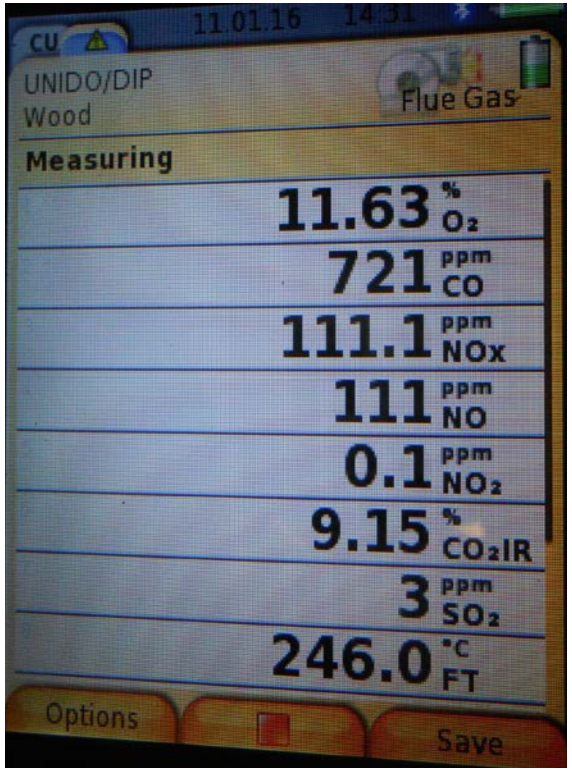
Data Gathering – Snapshot or Movie?



Combustion Flue gas Analyzer

- Main purpose – Combustion Efficiency, Stack Loss
- Additionally, it provides information on
  - Stack temperature
  - Flue gas O_2, Excess air
  - CO – unburnt fuel
  - CO_2 – generally, a calculated value
  - SO_x, NO_x – depending on the sensors
  - Draft in the stack / furnace
- Standard fuels maybe available in equipment
- Specific fuel information maybe needed

Combustion Flue gas Analyzer



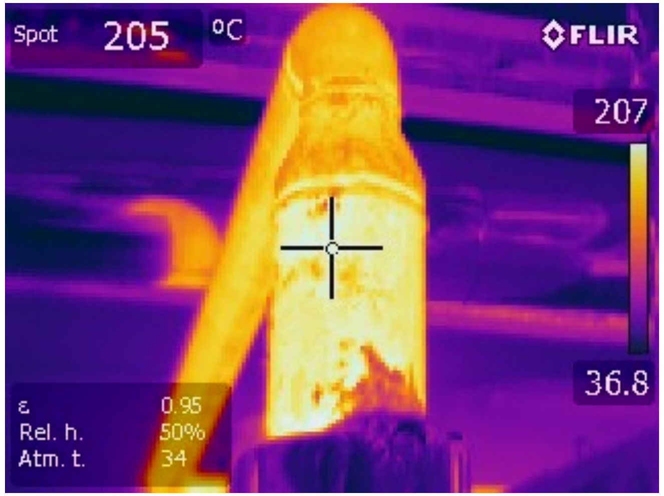
- ✓ Sensor Life (1.5-2 years)
- ✓ Location of reading
- ✓ Remember – Dry basis measurement

Infra-Red Thermographic Camera

- Main purpose – Heat Loss, Surface Temperature
- Additionally, it can be used for
  - Safety
  - Validating temperature sensors
  - Operation of steam traps
  - Boiler shell loss evaluation
  - Electrical equipment protection
- Different models
- Software may or may not be needed

Infra-Red Thermographic Camera

- ✓ Type of image
- ✓ Remember to Focus
- ✓ Emissivity; Scale Setting



Thermometer with Probes

- ✓ Can have applications where a bulk temperature needs to be measured
  - Condensate, Make-up water
  - Process fluid in a tank
  - Waste / effluent

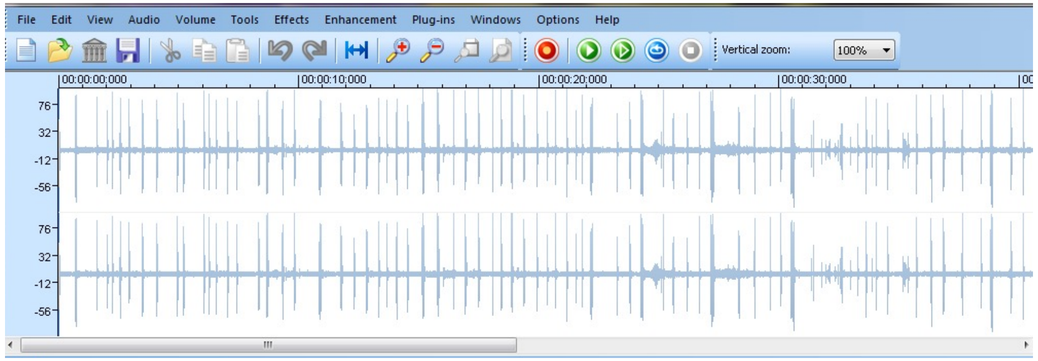
Water Conductivity Meter

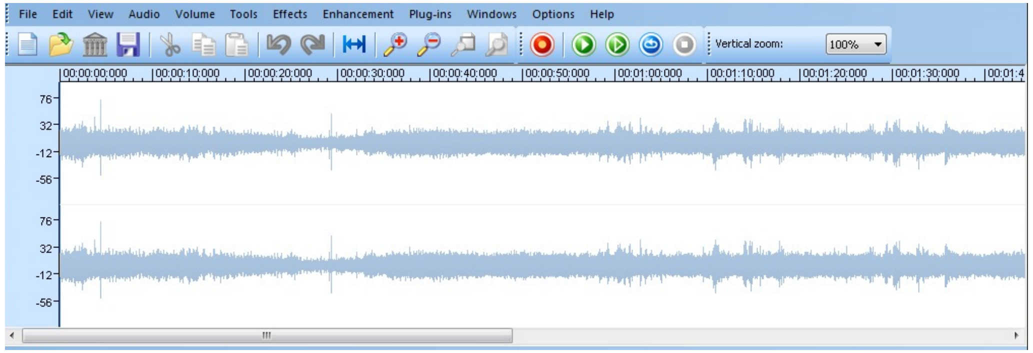
- ✓ Used for feedwater and blowdown conductivity measurement
  - TDS (ppm)
- ✓ Calibrate with distilled water

Ultrasonic Leak Detector

✓ Monitors the acoustic signal of flow through orifice

- Steam traps
- Leaks in valves





Pitot Tubes w/dP Gage / Manometer

- ✓ Can be used for measuring flow in different places
  - Air flow in duct
  - Steam venting from pipe
  - Leaks
- ✓ Water-filled manometer can be used also instead of dP gage

Other Essentials

- ✓ Safety Equipment
  - PPE
- ✓ Digital camera
- ✓ Stop watch
- ✓ Batteries / Chargers

Better Plants Diagnostic Equipment Program (DEP)

Better Plants®
U.S. DEPARTMENT OF ENERGY

Diagnostic Equipment Program (DEP)

The Better Plants **Diagnostic Equipment Program (DEP)** allows partners to borrow over 22 different kinds of tools to collect energy data and improve equipment performance in their facilities.

Through this program, partners have the opportunity to test tools firsthand before deciding to purchase a piece of equipment on their own. This not only allows for the improved testing and collection of energy data, but also helps to demonstrate the value of certain tools in different applications throughout a facility.

FULL SUITE OF DIAGNOSTIC TOOLS

- Anemometer
- Combustion Analyzer
- Conductivity Meter
- Current Transformer
- Digital Manometer
- Digital Thermometer
- Infrared Camera
- Infrared Thermometer
- Laser Distance Meter
- Light Meter
- Pitot Tube
- Power Logger
- Pressure Transducer
- Pyrometer
- Sonic Imager
- Strobe Tachometer
- Temp/RH logger
- Thermocouple
- Thermocouple Logger
- Time of Use Logger
- Ultrasonic Flow Meter
- Ultrasonic Leak Detector

EXPLORE SOME OF THE TOOLS THAT YOU CAN BORROW THROUGH BETTER PLANTS:

POWER LOGGER

This device helps you directly measure energy consumption, which can be converted into costs. It also logs data to provide electric consumption trends.

CURRENT TRANSFORMER

Use this device with a data logger to quantify the electric current flowing to a component or system and identify wasted energy.

COMBUSTION ANALYZER

This analyzer quantifies excess oxygen in boilers and combustion process exhausts, helping you save fuel and heat energy.

LEAK DETECTOR

This device helps you identify leaks in compressed air or steam systems using high frequencies that are undetectable to the human ear.

betterbuildingssolutioncenter.energy.gov/better-plants/diagnostic-tools @BetterPlantsDOE linkedin.com/showcase/better-plants

EXPLORE THE FULL SUITE OF DIAGNOSTIC EQUIPMENT AND SUBMIT AN APPLICATION:

Scan the QR Code above, or click here to download the DEP rental application.

Send this completed form to the Better Plants Diagnostic Equipment Program Manager, Daryl Cox at coxdf@ornl.gov.

HAVE QUESTIONS ABOUT BORROWING EQUIPMENT?

Scan the QR code above, or click here to email Daryl Cox, DEP Program Manager.

Daryl Cox has over 20 years of experience managing industrial technology and equipment and can help you find the right tool for your energy needs.

Polling Question 4

Polling Question

4) Will you be requiring the Better Plants Diagnostic Tools for your plant's steam energy assessment?

   A. Yes, probably most of them
   B. Maybe only one or two
   C. None at all
   D. Don't know yet

Homework #4

- Complete an end-user steam mass balance by individual header level for your plant. Ensure that you have accounted for all significant steam energy users which should total >85% of your total steam usage.
- Complete your steam system model from Homework #3 to more accurately represent your steam balance and your plant operations. If you want create two or at most three models to account for seasonality, production schedules.
- Compare actual steam generation by your boiler to steam generated as per the MEASUR steam system model.
- Compare your fuel costs with your plant's actual fuel costs.
- Use your plant's utility costs to calculate your marginal steam cost ($/klb)
- Save the file as BaseModel on your computer and send us the .json file

Thank You all for attending today's webinar.

See you all on next Friday – November 11, 2022 – 10 am ET

If you have specific questions, please stay online and we will try and answer them.

Alternately, you can email questions to me at rapapar@c2asustainable.com

U.S. DEPARTMENT OF ENERGY