Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Steam Systems
Virtual INPLT Training & Assessment

Session 1

Wednesday – October 2, 2024

10 am – 12:30 pm

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Welcome

- Welcome to the first Steam Virtual INPLT training series
- Eight, 2-1/2 hour webinars, focused on Industrial Steam Systems Energy Assessment and Optimization
- These webinars will help you gain a significant understanding of your industrial steam system, undertake an energy assessment using a systems approach, evaluate and quantify energy and cost-saving opportunities using US DOE tools and resources
- Thank you for your interest!

Acknowledgments

- Greg Harrell, PhD, PE
- US Department of Energy
- United Nations Industrial Development Organization
- Several industrial clients – both in the US and internationally

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Steam Virtual INPLT Facilitator

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Agenda – Session ONE

- Welcome and Introductions
- Safety and Housekeeping
- Agenda for Steam Virtual INPLT (8 weeks)
- Today's Content:

  Industrial Steam Systems Fundamentals
  - Steam system components, thermodynamics
  - Steam system overview

  Steam System Scoping Tool
  - Demonstration & Functionality
  - Homework
- Kahoot Quiz Game
- Q&A

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

Safety and Housekeeping

- Safety Moment
  - Steam can be extremely dangerous and extreme caution should be used while working with steam systems
  - Accidents can be life-threatening
- You are welcome to ask questions at any time during the webinar
- 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

- **Session 1 (October 2) – Industrial Steam Systems Fundamentals and Introduction to SSST**
- **Session 2 (October 3) – Focus on Steam System Generation and Introduction to DOE's MEASUR Tool**
- **Session 3 (October 16) – Steam System Generation & Cogeneration (CHP)**
- **Session 4 (October 17) – Steam System Distribution, End-Use & Condensate Recovery**
- **Session 5 (October 30) – Energy Efficiency Opportunities in the Generation Area**
- **Session 6 (October 31) – Energy Efficiency Opportunities in Cogeneration (CHP) Area**
- **Session 7 (November 13) – EE Opportunities in Distribution, End-use and Condensate Recovery**
- **Session 8 (November 14) – Industrial Steam System VINPLT Wrap-up Presentations**

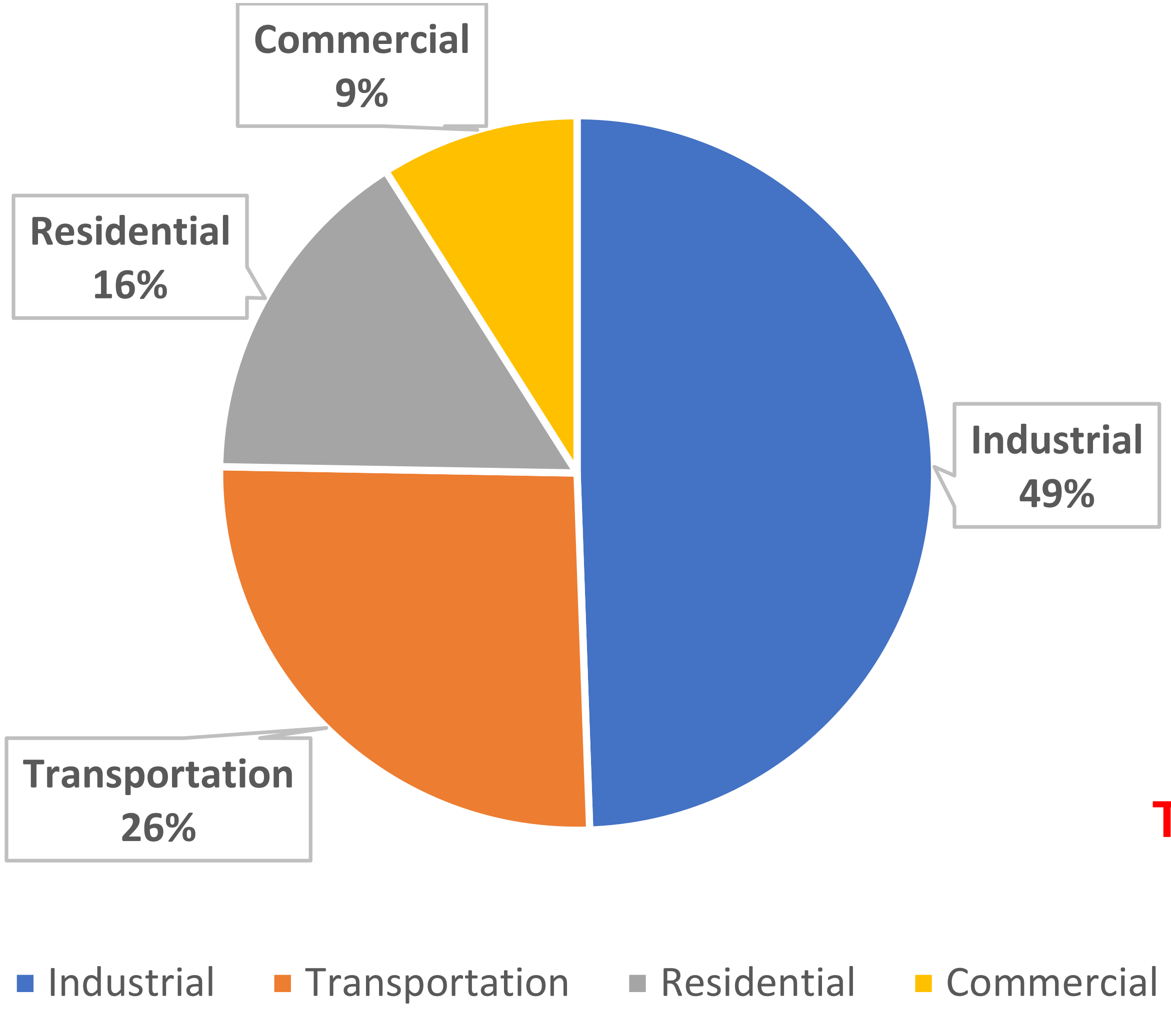
Course Objectives

- Become familiar with US DOE tools and resources to assess, optimize and manage industrial steam systems
- Identify the measurements required to manage steam systems
- Measure boiler efficiency
- Estimate the magnitude of specific boiler losses
- Identify and prioritize areas of boiler efficiency improvement
- Recognize the impacts of fuel selection
- Characterize the impact of backpressure and condensing steam turbines

Course Objectives

- Quantify the importance of managing steam consumption
- Identify the requirements of a steam trap management program
- Evaluate the effectiveness of thermal insulation
- Evaluate the impact of condensate recovery
- Recognize the economic impacts of steam system operations
- Use a systems approach to undertake a steam system energy assessment, identify opportunities and quantify the impacts
- Start thinking out-of-the-box and continue to reduce your plant's carbon footprint, reduce operating costs and enhance reliability

Total World Energy Production



Industrial Energy = ½ World's Energy

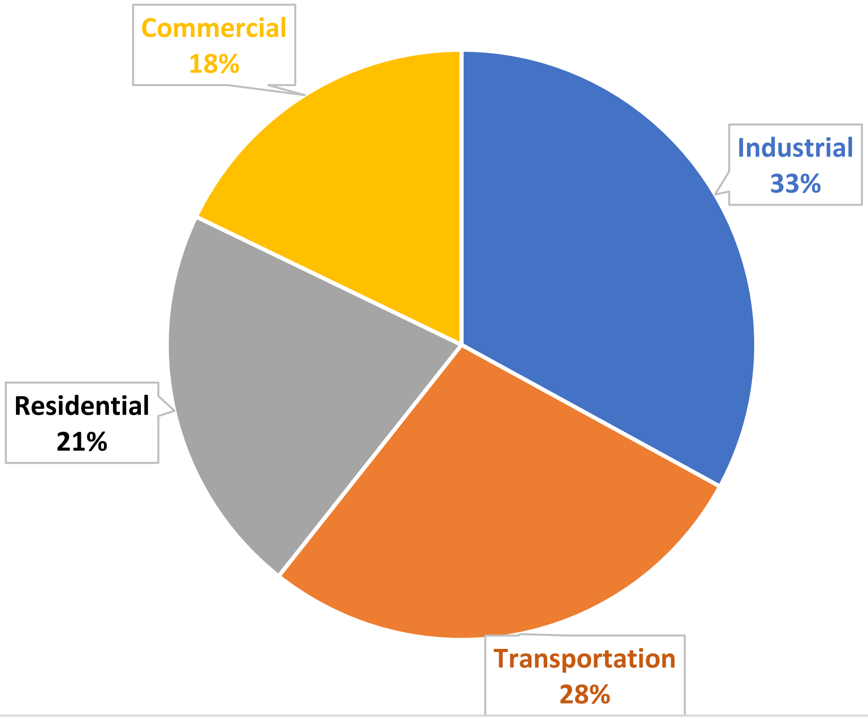
1 quad Btu = 1.055 EJ

Source: US DOE EIA; International Energy Agency (2019 data)

Total World Energy production ~ 620 quad Btu

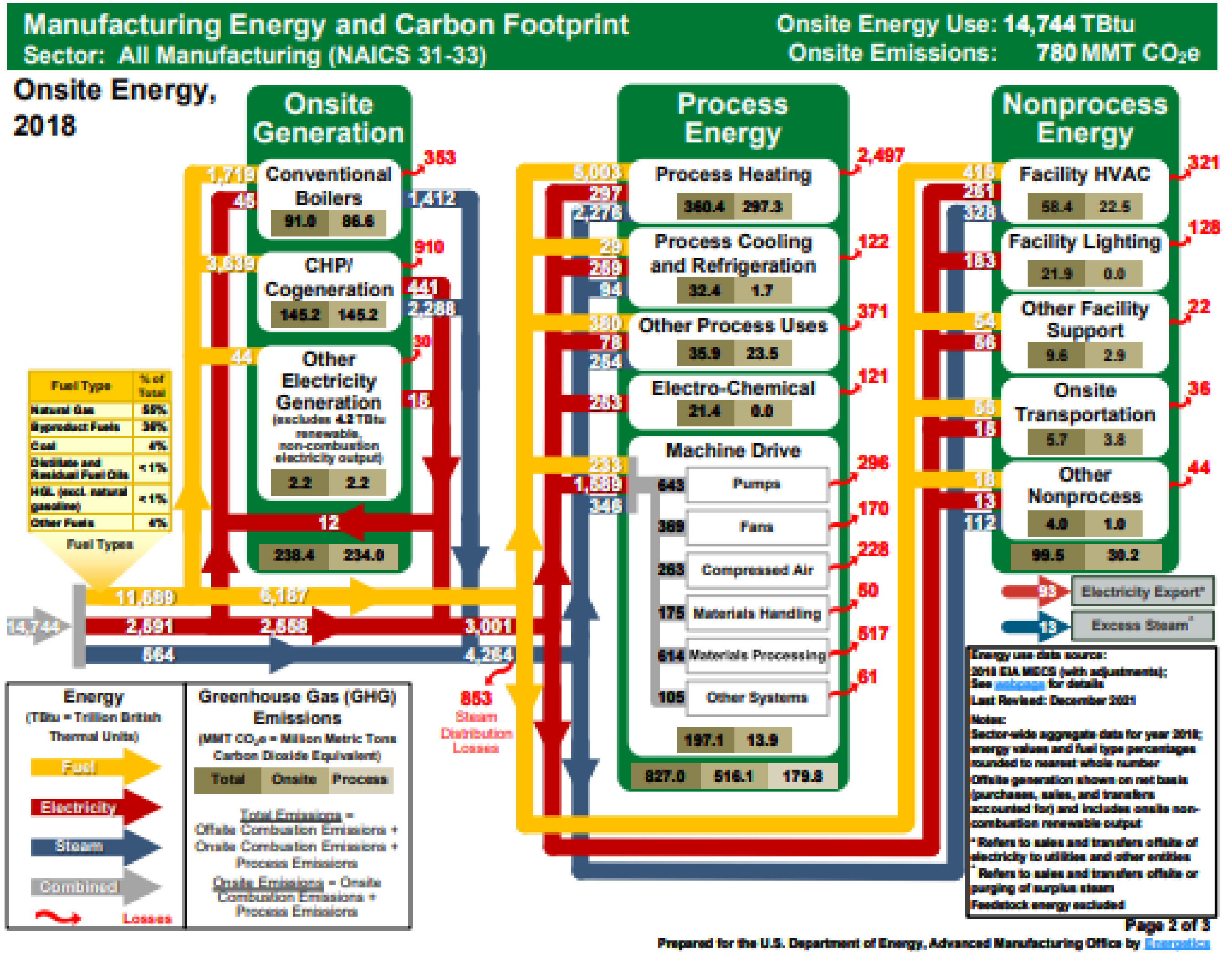
Industrial Energy Overview

- Industry consumes 1/3 of U.S. energy
- More than 40% of U.S. natural gas is consumed by industry
- Approximately 1/3 of U.S. electricity demand is industrial
- Energy is key to economic growth and maintaining U.S. jobs in manufacturing



US Primary Energy = 97.32 Quad Btus
2021 data

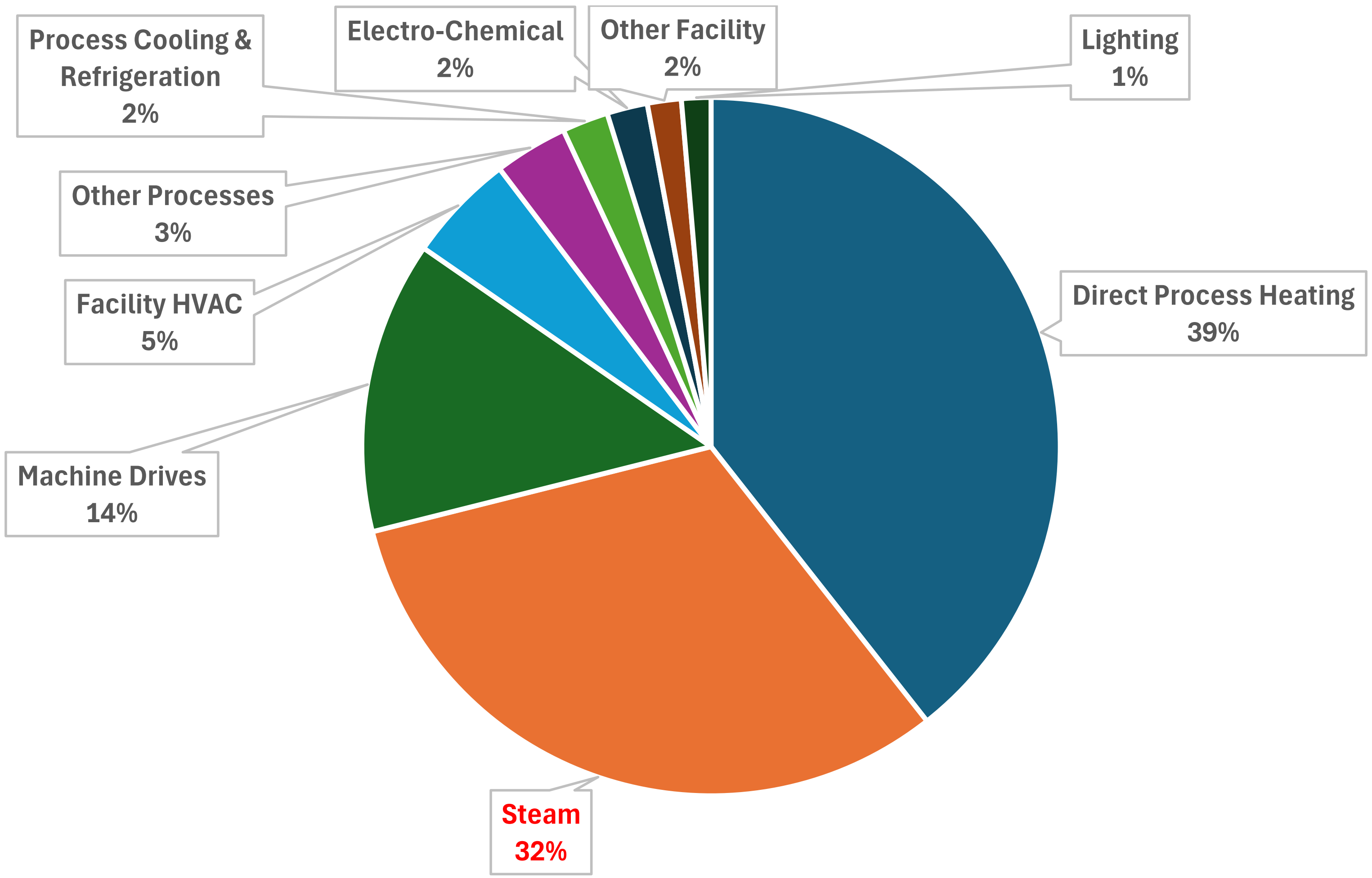
Manufacturing Energy & Carbon Footprint



Overall Manufacturing Energy Consumption and Carbon Footprint

Source: 2018 US MECS data; Energy & Carbon Footprints (developed by Energetics)

Typical Industrial Plant Energy Breakdown

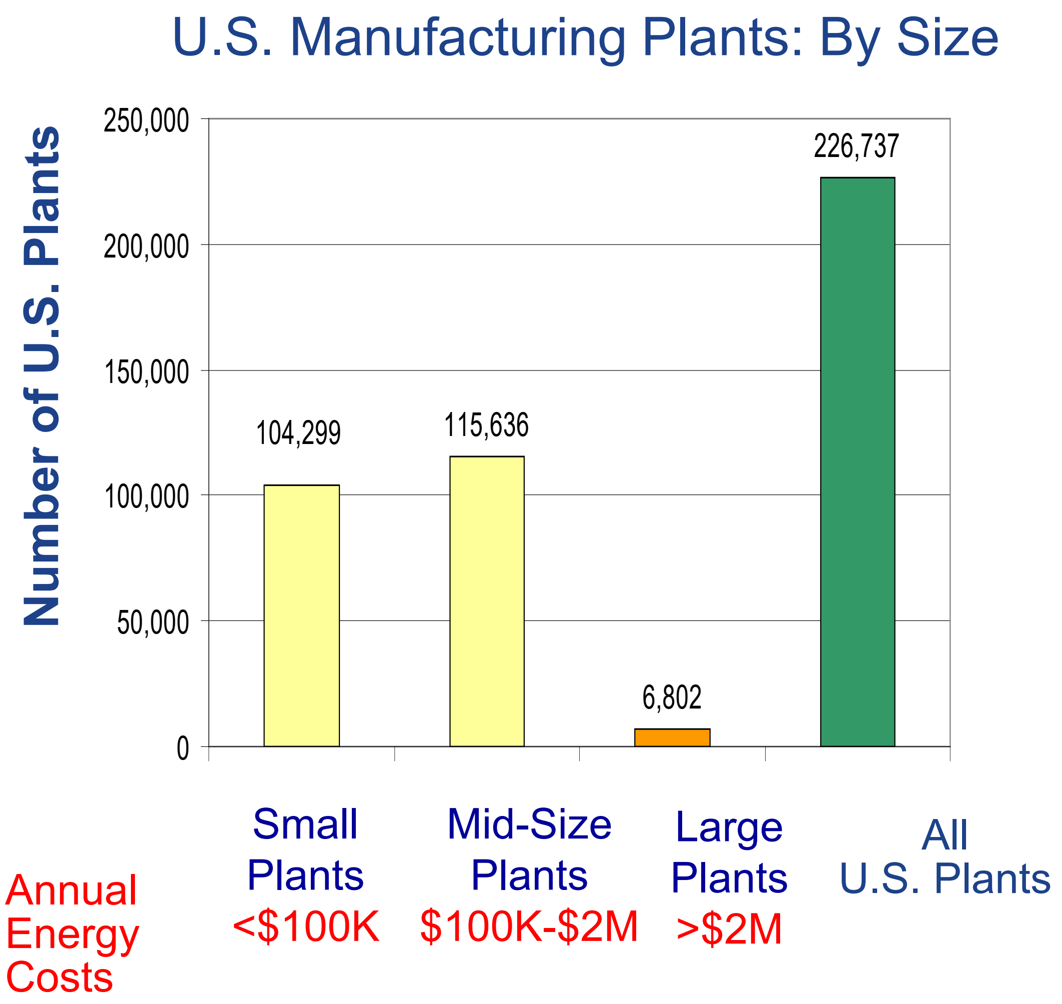


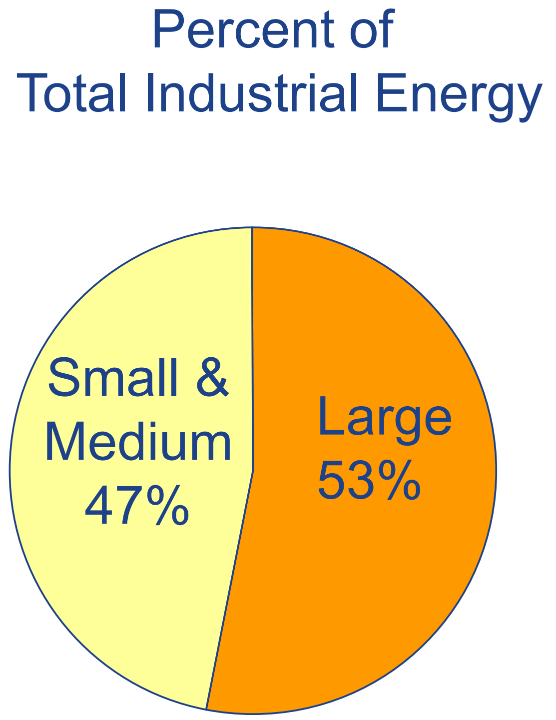
Typical Industrial Plant Energy Consumption

Note: Does not include off-site losses

Source: 2018 US MECS data; Energy & Carbon Footprints (developed by Energetics)

Industrial Energy Consumption





1998 EIA MECS

Industrial Steam Users

- Heavy Steam Users
  - Petroleum Refining
  - Forest Products (Pulp & Paper)
  - Petrochemicals
  - Inorganic chemicals
  - Large Food & Beverage
  - Rubber
  - Textiles
  - Pharmaceuticals
  - Manufacturing Assembly

Industrial Steam Users

- Medium Steam Users
  - Breweries
  - Bakeries
  - Dairies
  - Packaged Foods
  - Metal Fabrication
  - Large chiller systems

- Small Steam Users
  - Electronics
  - Paint booths
  - Humidification systems

Polling Question 1

Polling Question

1) Which industry do you belong to?

   A. Heavy steam user – Petrochemicals, Refineries, Forest Products, Chemicals
   B. Heavy steam user – Large Food and Beverage, Pharmaceuticals, Assembly, plants, etc.
   C. Medium steam user – Food, Textiles, Fabrication, etc.
   D. Small steam user – Electronics, Specialty manufacturing, etc.
   E. Not a steam user

Polling Question 2

Polling Question

2) What is your major function in your current role at your plant?

A. Engineering (Design)
B. Operations & Maintenance (Engineering / Technical)
C. Operations & Maintenance (Management)
D. Plant management
E. Corporate-level management
F. Independent consultant / contractor
G. Other

Why Use Steam?

- Extremely efficient as a heating source – constant temperature, highest heat transfer (condensing) coefficients
- Extremely cost effective to distribute to point-of-use
- Can be controlled very accurately
- A very flexible energy transfer medium – can be used for process heating as well as power generation
- Technology and applications are tried and proven at large as well as small-scale
- Significant system benefits!

An Industrial Steam System

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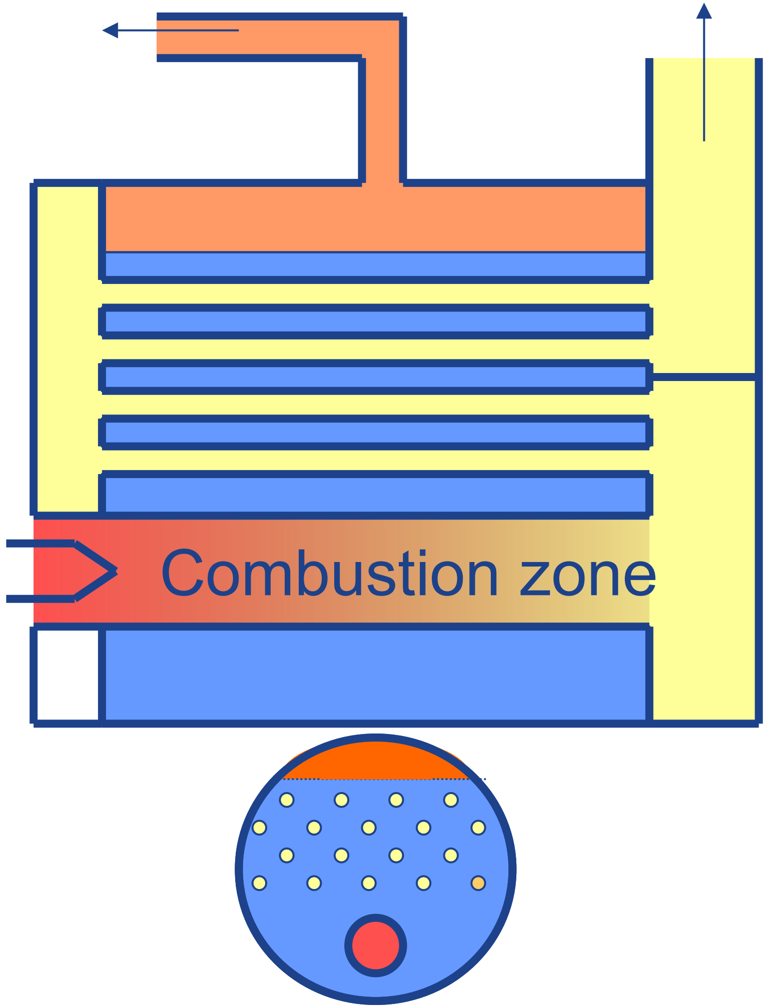
Steam System Components

- Generation
  - Boiler
  - Boiler auxiliaries
  - Water treatment equipment
  - Deaerator
  - Feedwater Pumps
  - Fuel storage and handling equipment
- Distribution
  - Steam piping
  - Pressure reducing stations
- End-use
  - Steam turbines
  - Heat exchangers
  - Live steam injection
  - Stripping columns
  - Evaporators, etc.
- Recovery
  - Steam traps
  - Condensate recovery and return system
  - Condensate pumps

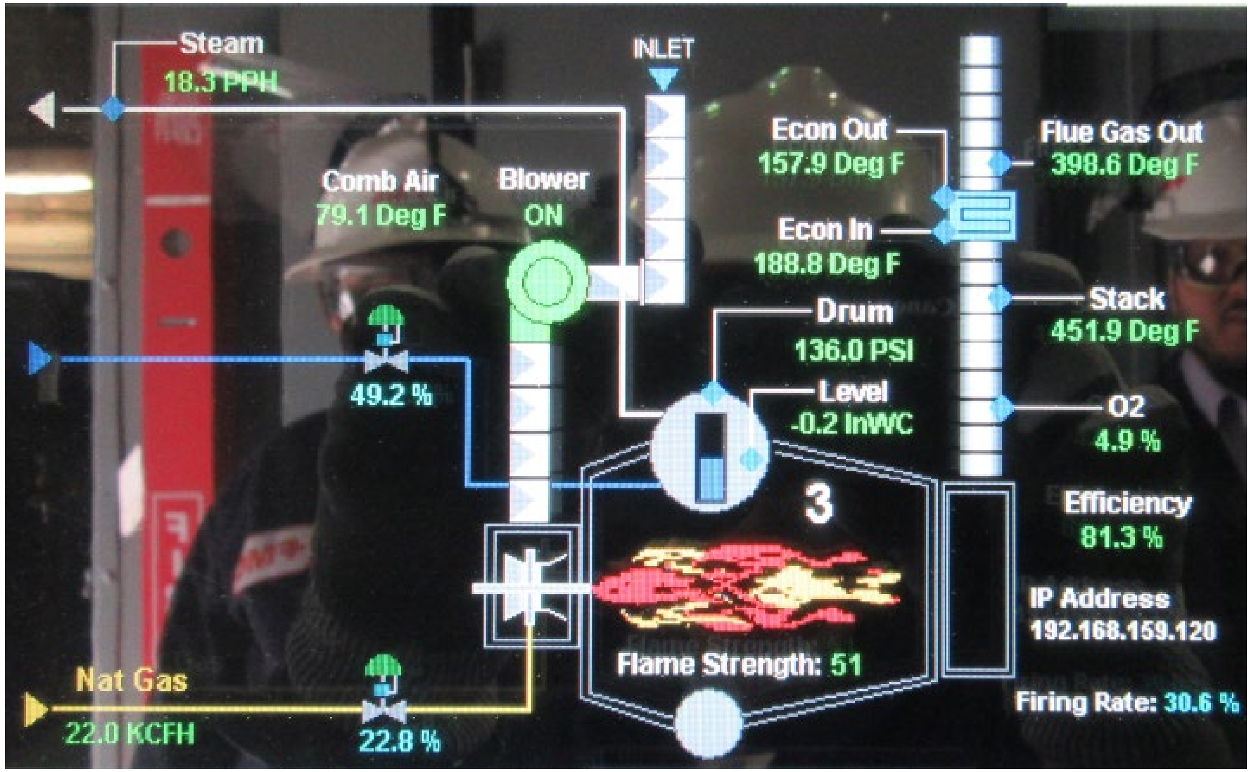
Fire-Tube Boiler

- Steam pressure limited
  - Typical 300 psig maximum
- Steam flow rate limited
  - Typical 1,200 BHp maximum
    - 40 klb/hr
- Saturated steam output
- One inherent efficiency advantage over water tube type – shell loss is minimal
- Generally manufactured offsite
- Many different styles



Water-Tube Boiler

- Operating pressures range from atmospheric to in excess of 3,000 psig
- Steam production ranges from 5,000 lb/hr to 10,000,000 lb/hr
- Saturated or superheated steam output
- Constructed onsite or offsite
- Many different styles
- Compact units now on the market!



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Boilers

Fire Tube Boiler

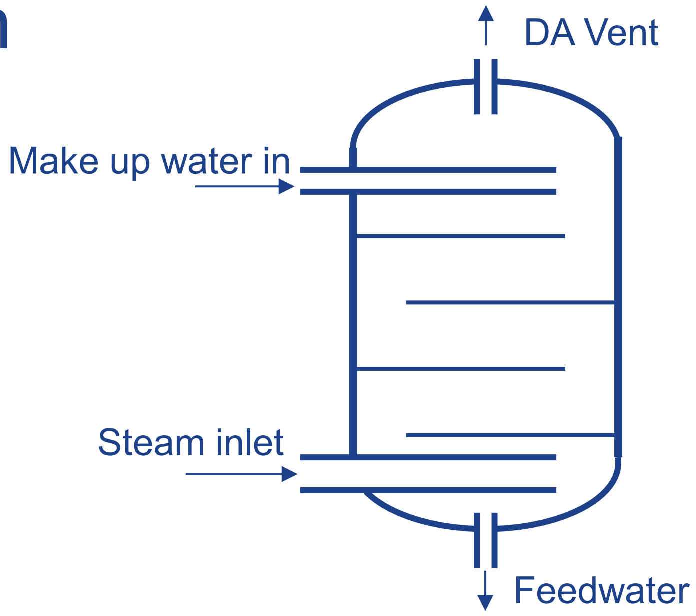
Water Tube Boiler

Boiler Auxiliaries

- Fans - Air flow configuration
  - Forced draft
  - Induced draft
  - Balanced draft
- Combustion air preheaters
- Feedwater economizers / condensing economizers
- Fuel flow valves and combustion controls
- Excess air controls
- Sensors
- Soot blowers – steam or compressed air
- Pollution control equipment

Deaerator

- Removes dissolved oxygen from make-up water and condensate
- Boiler integrity
- Several different styles
  - Spray type
  - Tray type
- Maybe combined with feedwater heater and storage
- Will always have a steam vent!



Pumps

- Boiler Feedwater (BFW)
- Condensate
- Make-up water
- Other auxiliary services

Water Treatment Equipment

- Extremely important boiler water chemistry
- Integrity of boiler
- Depends on boiler pressure and water quality
- Several options
  - Softening
  - Dealkalization
  - Demineralization
  - Reverse osmosis
  - Condensate polishing
  - Chemical treatment

Steam Piping

- Transports steam to end use
- Pipe racks
- Pressure headers
- Isolation valves
- Relief valves
- Drain points, etc

Pressure Reducing Stations

- Also known as Letdown valves
- Provide steam flow control
- Provide pressure header balancing
- Operates on a feedback loop
- Always need a bypass for emergency and repair conditions

Steam Turbines

- Devices which convert thermal energy into shaft power
- Can generate electrical power through a generator
- Can drive a mechanical equipment – fan, pump, compressor, chiller, etc.
- Different types
  - Backpressure
  - Extraction
  - Condensing
  - Combination of the above

Polling Question 3 and 4

Polling Questions

3) Do you have steam turbines in your plant?
   A. Back-pressure ONLY
   B. Back-pressure and Condensing
   C. Condensing ONLY
   D. Do NOT have any steam turbines
   E. Don't know

4) Do you have gas turbines in your plant?
   A. Yes
   B. No
   C. Don't know

Heat Exchangers

- Different types
  - Shell & Tube
  - Plate / Frame
  - Tube in tube
  - Spiral, etc.
- Based on applications
- Steam transfers thermal energy to process fluid and forms condensate
- Industry standards for designs and applications

Other End Use Equipment

- Distillation tower
  - Stripping column
- Reboilers
- Reformers
- Separators
- Steam ejectors
- Steam injectors
- Thermocompressors

Evaporators

Other End Use Equipment

Cooker

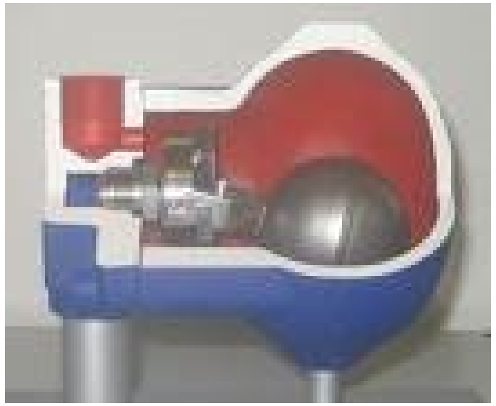
Feed Heater

Washing, Dyeing & Finishing

Hot water heater

Steam Traps

- Prevent steam from escaping without transfer of heat
- Several different types of traps
  - Thermostatic
  - Mechanical
  - Thermodynamic
  - Orifice
- Application – very important
- Steam Trap Management



Flash Tanks

- Recover flash steam from condensate
- Eliminate potential condensate return problems
  - Water hammer
  - Back-pressure
  - 2-phase flow
- Blowdown flash tanks reduce temperature of water before discharging to sewer

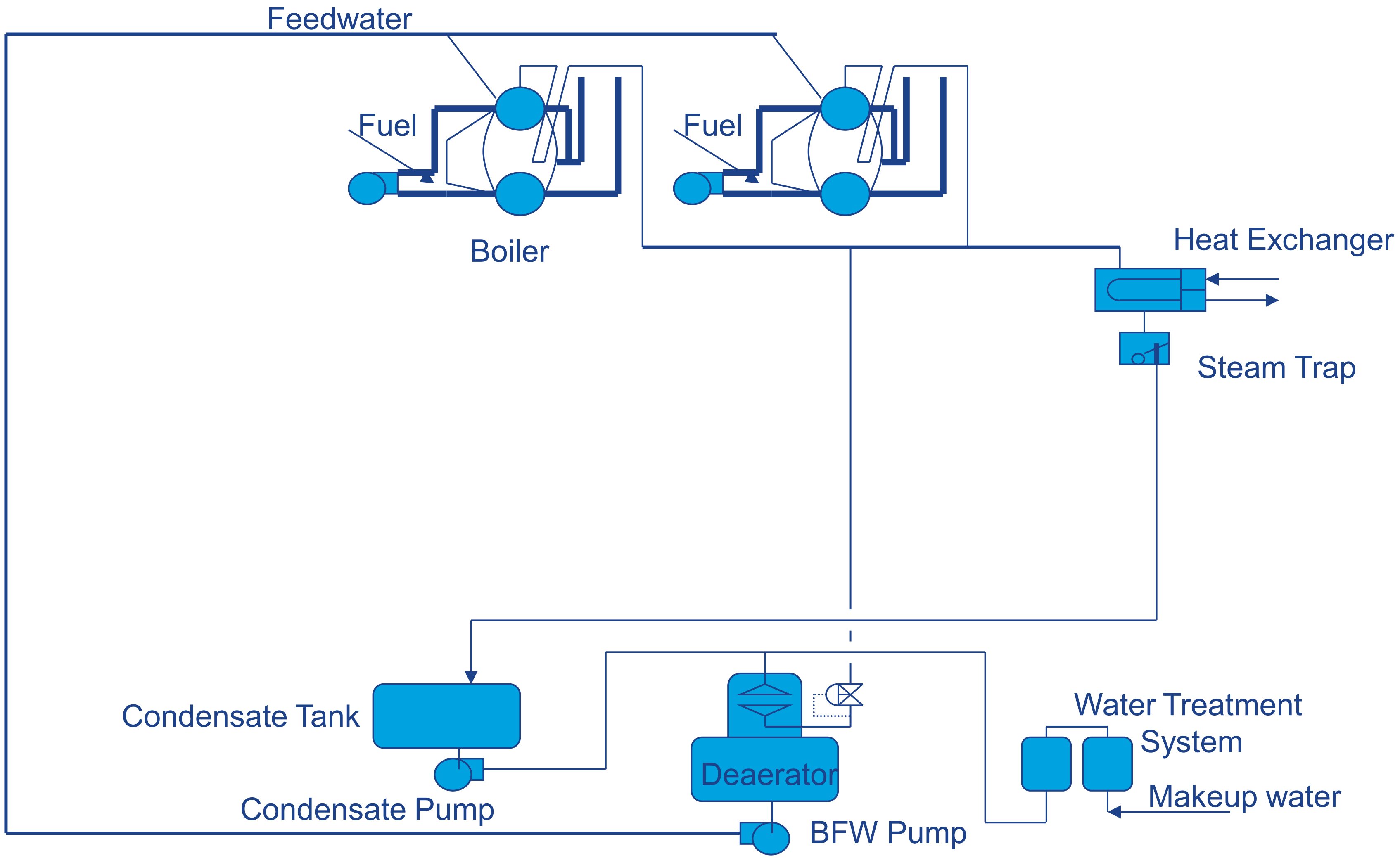
Condensate Recovery System

- Primary / Secondary
- Pumped / Pressure-driven
- Pumped – Electric-driven or Steam-driven
- Returns condensate back with the highest thermal energy to the boiler house

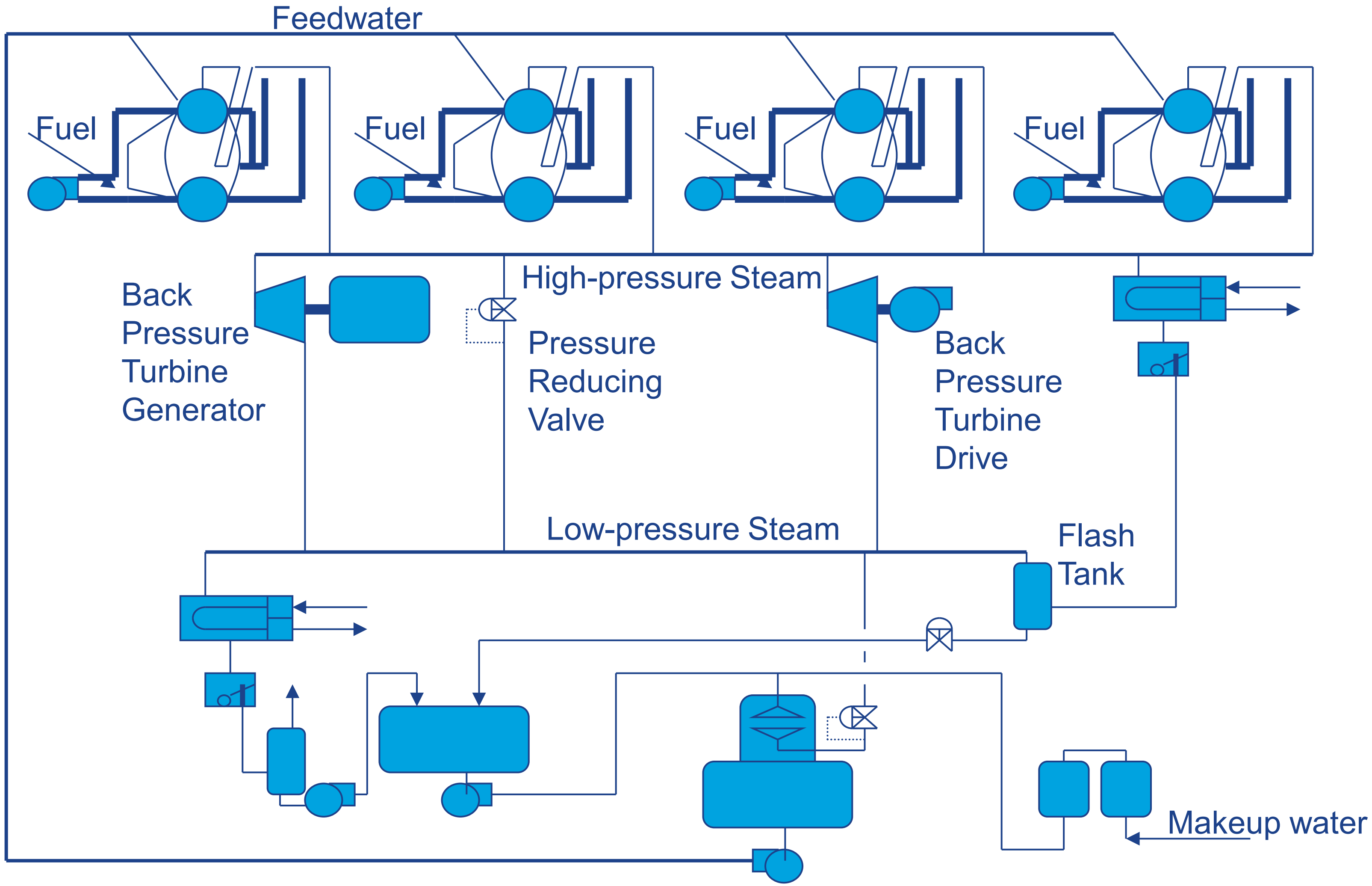
Condensate Tank

- Provides for a common receiver
- Typically, located above grade to provide for pump suction requirements
- May be combined with deaerator and feedwater heater and storage

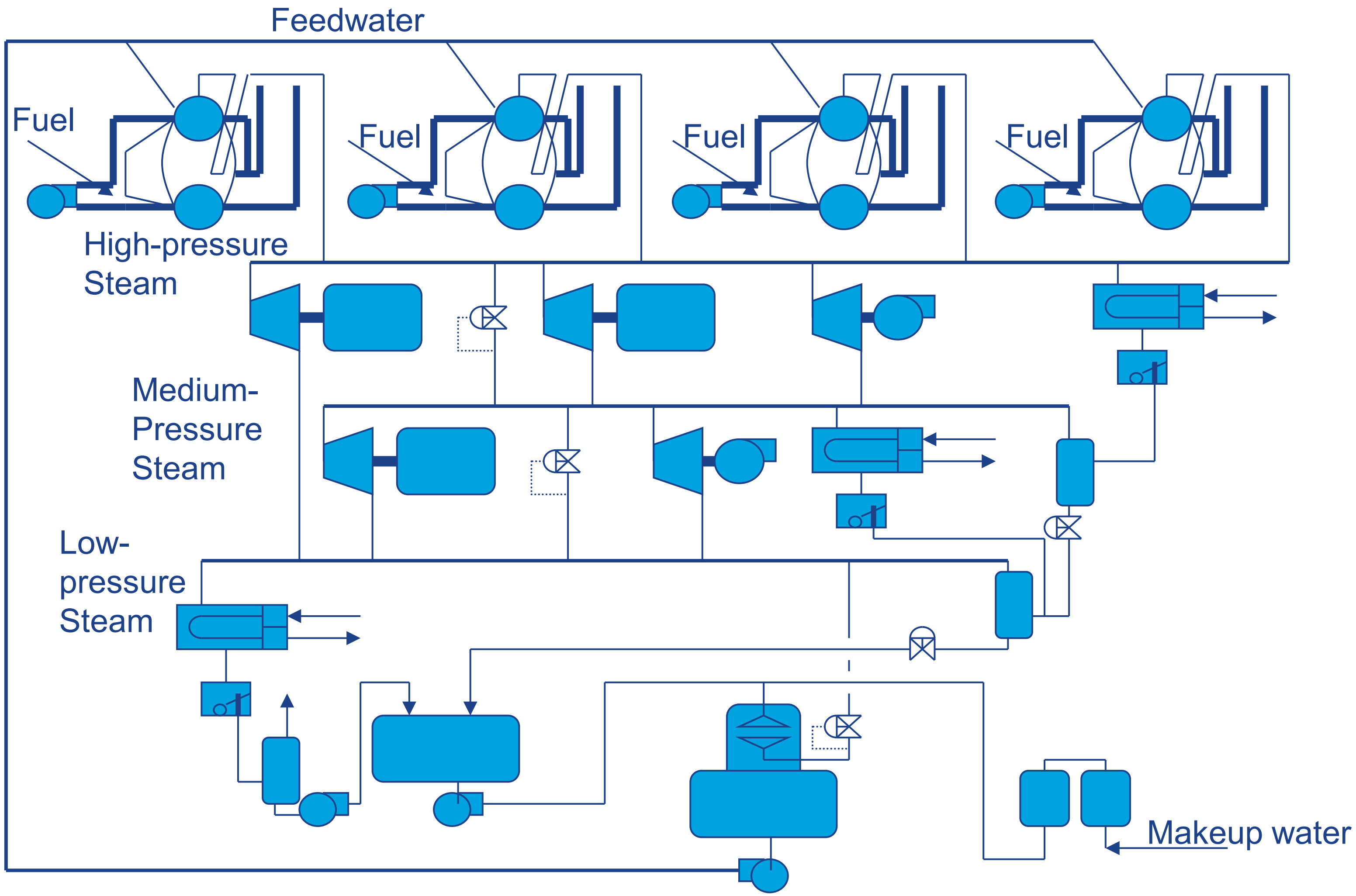
One-Header Steam System



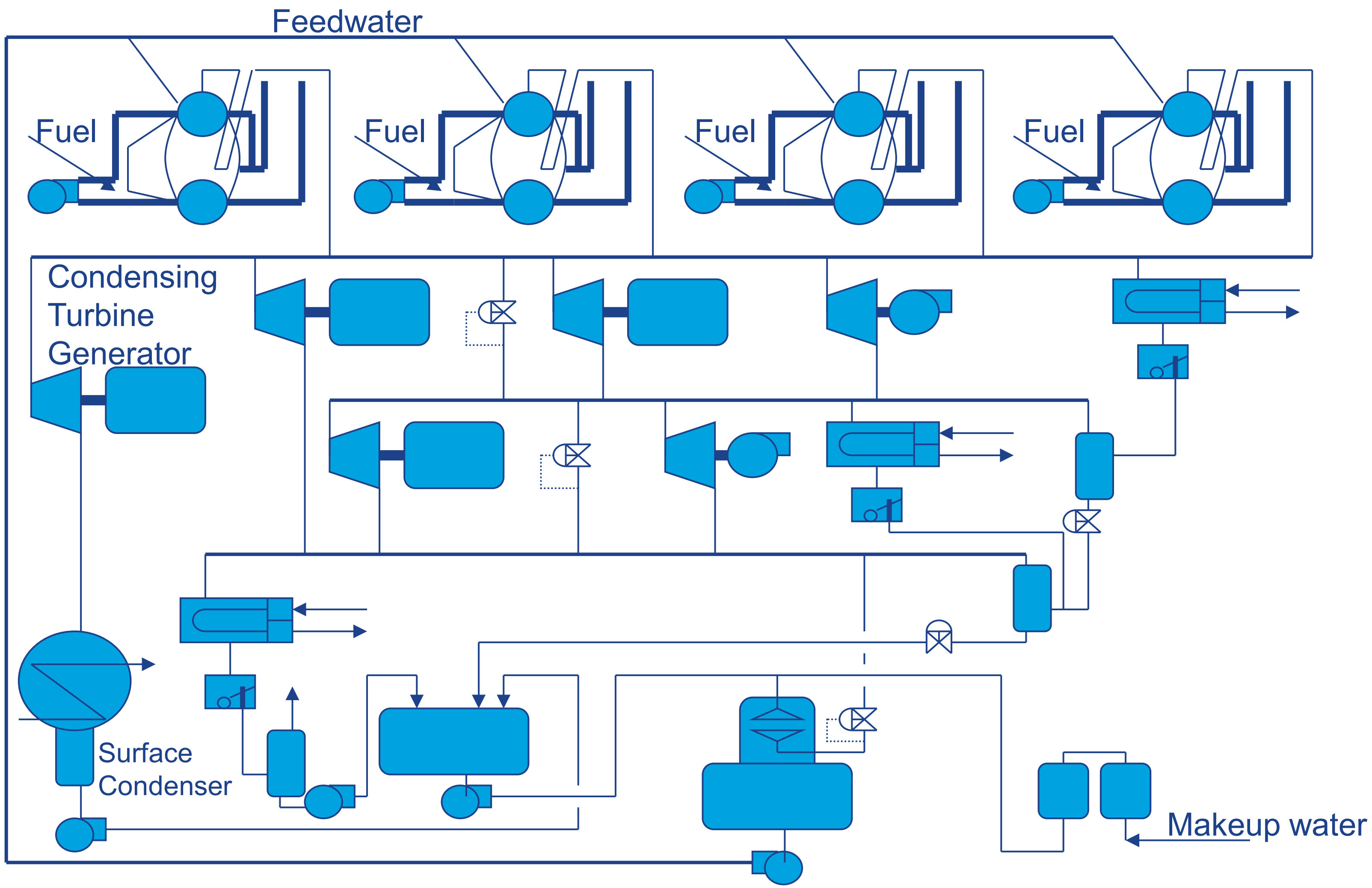
Two-Header Steam System



Three-Header Steam System



Three-Header Steam System



Polling Question 5

Polling Questions

5) What is the closest representation of the steam system in your plant?
   A. One-header
   B. Two-headers
   C. Three-headers
   D. Three-headers with steam turbines
   E. Complex with more than Three-headers
   F. Don’t know
   G. None of the above

The Systems Approach

- **Establish** current system conditions, operating parameters, and system energy use
- **Investigate** how the total system presently operates
- **Identify** potential areas where system operation can be improved
- **Analyze** the impacts of potential improvements to the plant system
- **Implement** system improvements that meet plant operational and financial criteria
- Continue to **monitor** overall system performance

Tools

- In order to properly evaluate steam systems, the physics of each process must be understood
  - Thermodynamics
  - Heat transfer
  - Fluid flow
- US DOE Tools
  - Steam System Survey Guide
  - Steam System Scoping Tool (SSST)
  - MEASUR - Steam System
  - Insulation Evaluation Software – 3E Plus
- Process measurements

Steam System Thermodynamics

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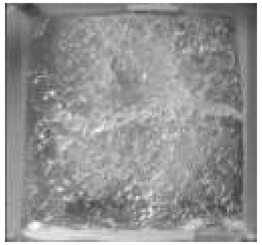
Steam Thermodynamics

- Thermodynamic States of a Pure Substance
  - Subcooled
    - Liquid (Water)
    - Temperature and Pressure are independent
    - Energy content ∝ Temperature

  - Saturated
    - Liquid / 2-Phase / Vapor
    - Temperature and Pressure are **dependent**
    - $0 \leq$ Quality ≤ 1



  - Superheated
    - Vapor (Steam)
    - Temperature and Pressure are independent
    - Energy content ∝ Temperature & Pressure

Steam Thermodynamics

- Steam Properties
  - MEASUR
  - Steam Tables
    - Mollier Diagrams
  - ASHRAE Fundamentals Handbook
    - Tabulated Data
    - P-h diagram
  - Software Programs
    - Equation of State for different refrigerants
    - Engineering Equation Solver (EES)
    - Other
  - National Institute of Standards & Testing (NIST)
- Reference Point
  - Maybe different for different sources!!

Steam System Analysis

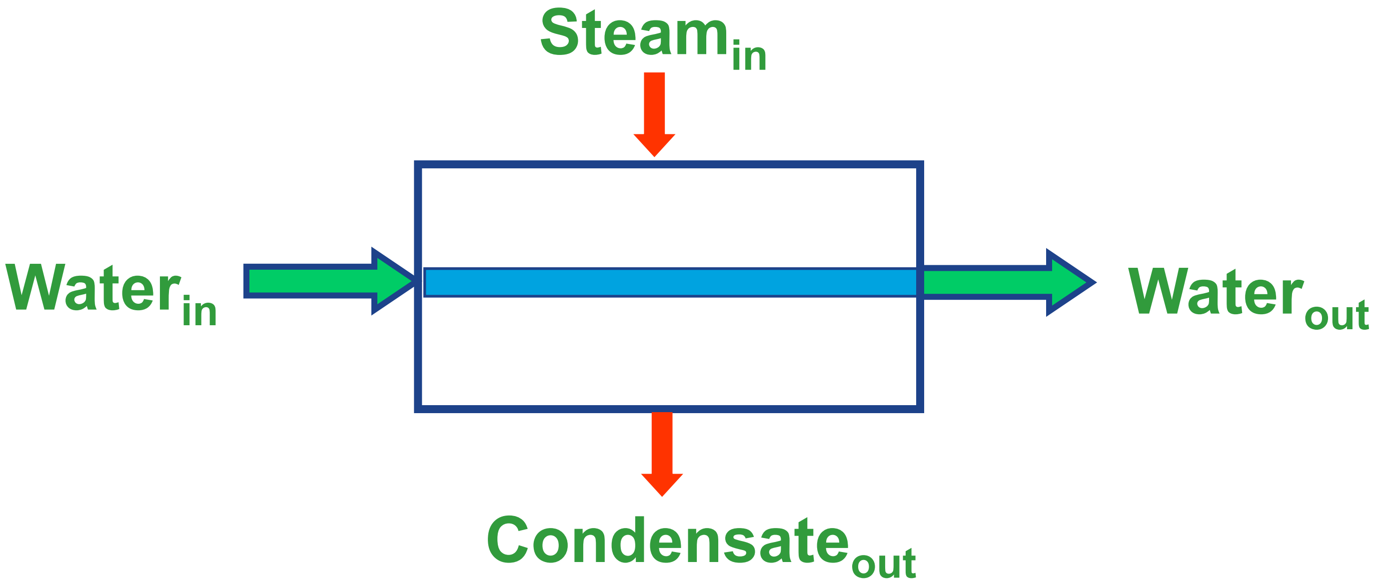
- Steady State Steady Flow (SSSF) analysis
  - Neglect the time dependent terms
  - Dynamic responses are not considered
  - Start-up, Shut-down and upset (or trip) conditions are neglected
- Average operating conditions are used
- Seasonality, Production rates can be dealt with “bin analysis” methodology
- IMPACT level-analysis is conducted on systems

Conservation of Mass

- Law: Mass is neither created nor destroyed in the control volume
- Mathematically,
  - Mass flow in = Mass flow out
- Equation format
  - $\Sigma M_{in} = \Sigma M_{out}$
- State of substance & Volume flow can change

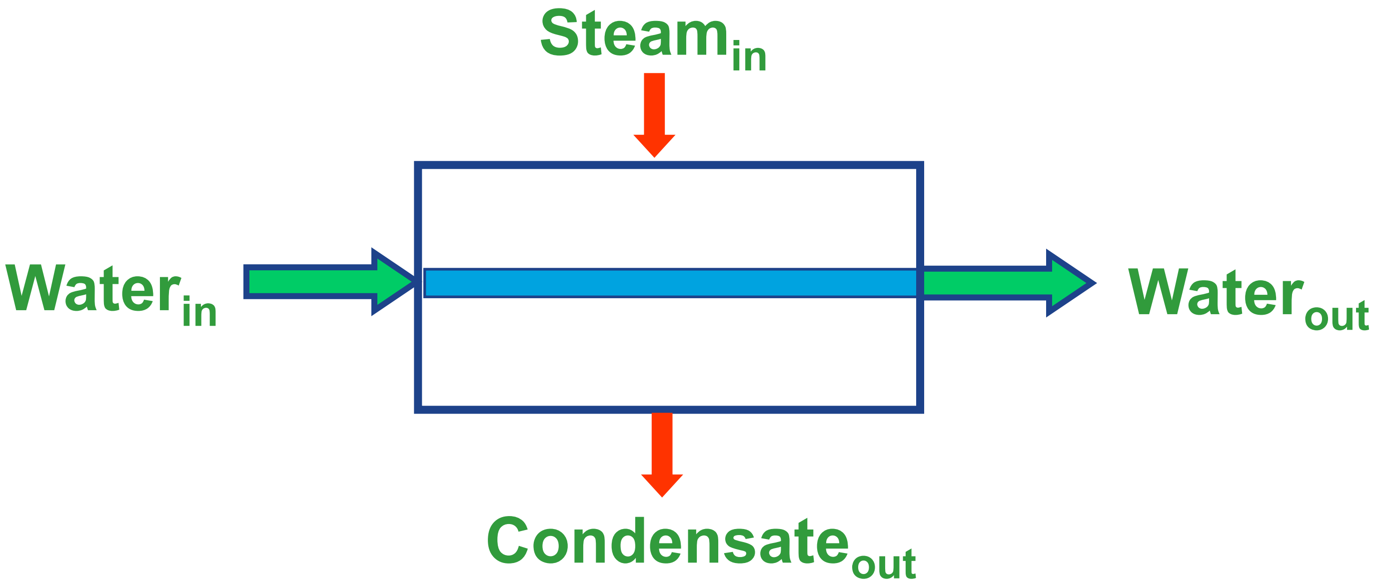
Example: F1

- A shell and tube heat exchanger is used to heat water using steam
- Water flow rate measured as 100 gpm
- Steam flow rate is not known



Example: F1

- Apply Steady State Steady Flow – **Conservation of Mass**
- Water side: Water flow in = Water flow out
- Steam side: Steam flow in = Condensate flow out



Example: F1

- Apply Steady State Steady Flow – **Conservation of Mass**

- Water side:
  - Water flow in = 100 gpm = 50,000 lb/hr
  - Water flow out = 100 gpm = 50,000 lb/hr

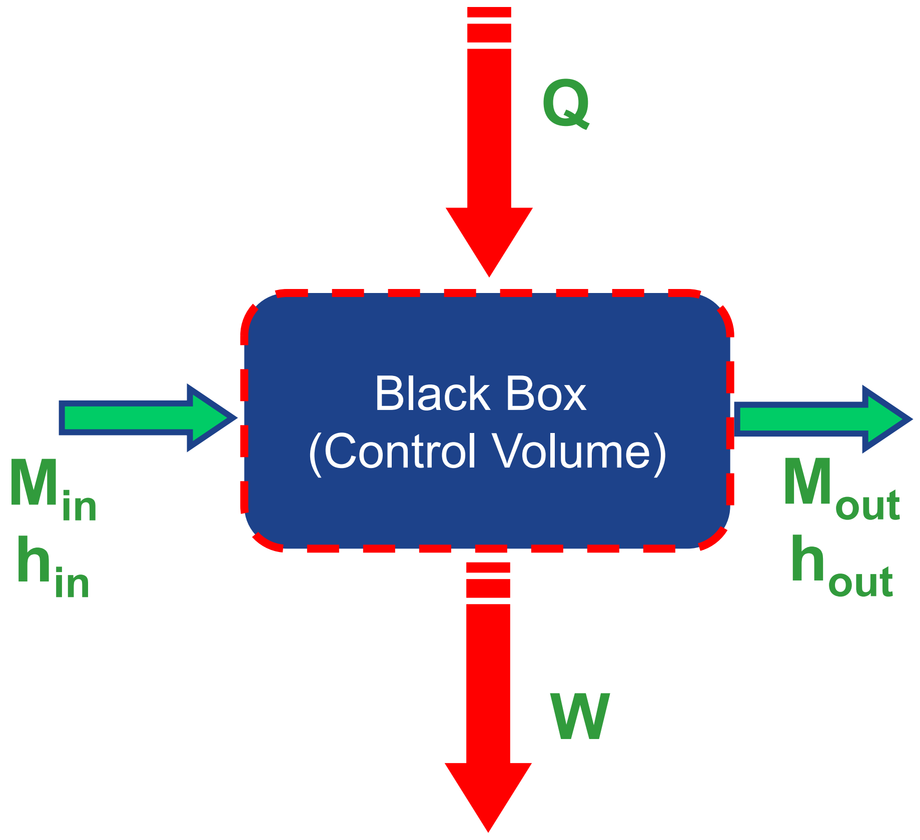
- Steam side: Steam flow in = Condensate flow out

Conservation of Energy

- Law: Energy can neither be created nor destroyed in the control volume. It can only be changed from one form to another.

- Mathematically,
  - Energy flow in + Heat = Energy flow out + Work

- Equation format
  - $\Sigma M_{in} * h_{in} + Q = \Sigma M_{out} * h_{out} + W$
  - h – specific enthalpy (Btu/lb)



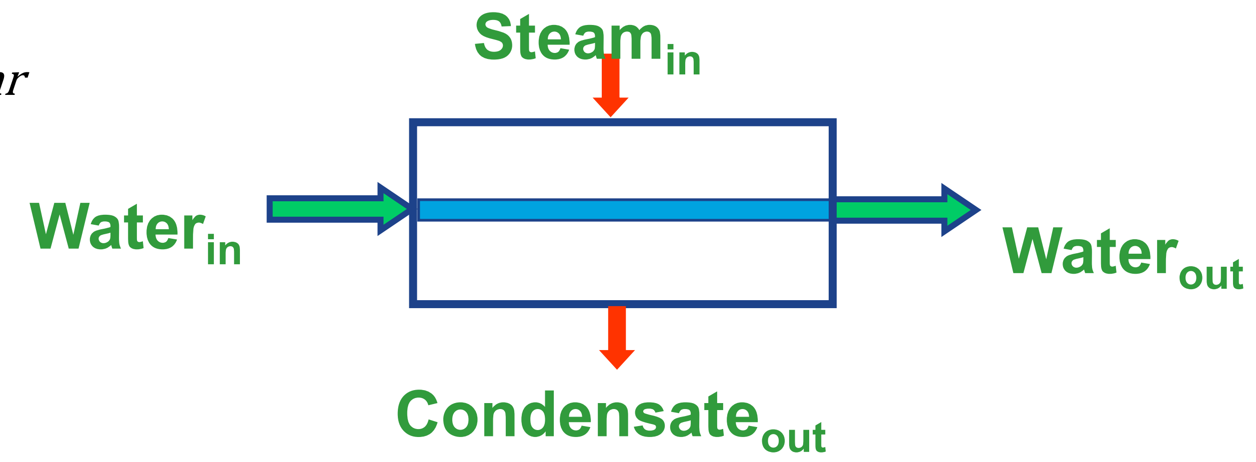
Example: F1

- Water inlet temperature = 65°F
- Water outlet temperature = 135°F
- Specific heat of water = 1.0 Btu/lb°F
- Heat transferred to water = $M_{water} * C_p * (T_{out} – T_{in})$

$$Q = 50{,}000 \times 1.0 \times (135 - 65)\ Btu/hr$$

$$Q = 3{,}500{,}000\ Btu/hr$$

$$Q = 3.50\ MMBtu/hr$$



Example: F1

- Steam inlet conditions: Saturated steam at atmospheric pressure (0.0 psig)
- Condensate outlet conditions: Saturated at T = 212°F
- Heat transferred by steam =

  $$M_{steam} * h_{steam} - M_{condensate} * h_{condensate}$$

- No shaft work is done in the control volume: W = 0
- Heat transferred **to** water = Heat transferred **from** steam
- Conservation of Mass: $M_{steam} = M_{condensate}$

Example: F1

- $Q = M_{steam} * (h_{steam} – h_{condensate})$
- Steam Property tables provide information on steam and condensate enthalpies
- h_{steam} – Saturated steam at 0.0 psig = 1,150 Btu/lb
- $h_{condensate}$ – Saturated condensate at 212°F = 180 Btu/lb

$$Q = M_{steam} \times (1{,}150 - 180)$$

$$3{,}500{,}000 = M_{steam} \times (970)$$

$$M_{steam} = 3{,}608 \frac{lb}{hr} = 3.61 \frac{klb}{hr}$$

Example: F1

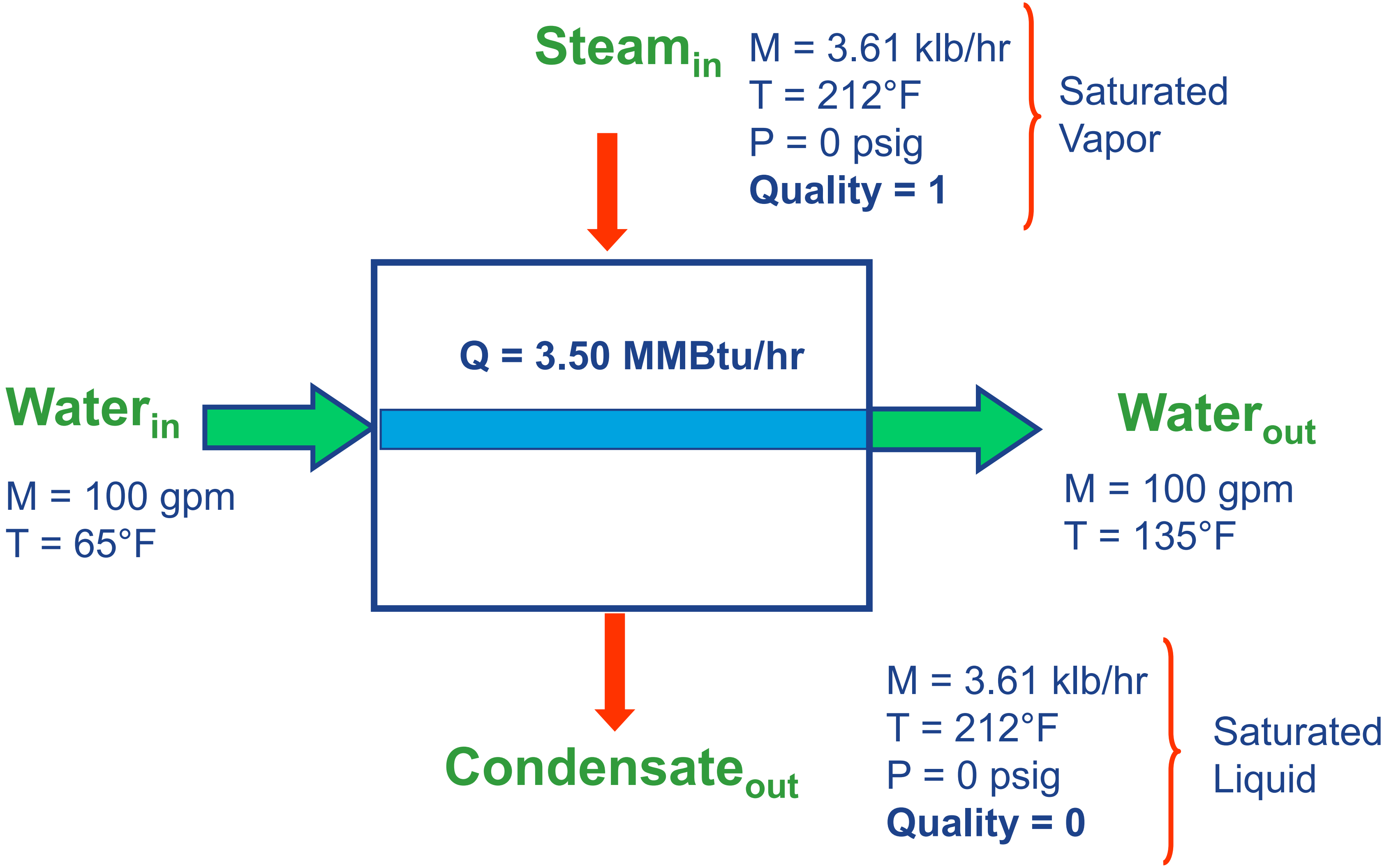
SATURATED PROPERTIES

Pressure or Temperature	Saturated Pressure
Saturated Pressure	0 psig
Pressure	**0.0 psig**
Temperature	**211.9539 °F**
Liquid Specific Enthalpy	**180.1338 Btu/lb**
Liquid Specific Entropy	**0.3121 Btu/lb-°F**
Liquid Specific Volume	**0.0167 ft³/lb**
Gas Specific Enthalpy	**1,150.2716 Btu/lb**
Gas Specific Entropy	**1.7566 Btu/lb-°F**
Gas Specific Volume	**26.8036 ft³/lb**
Evaporation Specific Enthalpy	**970.1378 Btu/lb**
Evaporation Specific Entropy	**1.4445 Btu/lb-°F**
Evaporation Specific Volume	**26.7869 ft³/lb**

Saturated Condensate

Saturated Steam

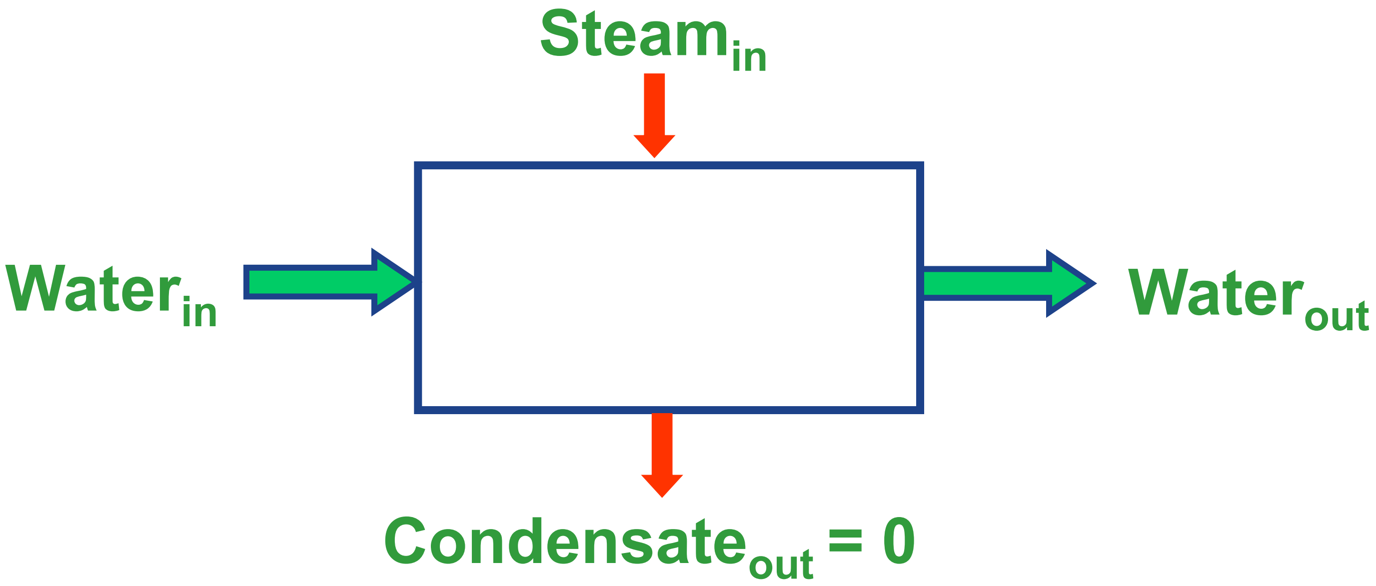
Example: F1



Steam$_{in}$
M = 3.61 klb/hr
T = 212°F
P = 0 psig
Quality = 1
Saturated Vapor
Q = 3.50 MMBtu/hr
Water$_{in}$
M = 100 gpm
T = 65°F
Water$_{out}$
M = 100 gpm
T = 135°F
Condensate$_{out}$
M = 3.61 klb/hr
T = 212°F
P = 0 psig
Quality = 0
Saturated Liquid

Example: F2 (Food for thought!)

- Steam is directly injected in a vessel to heat water
- Water flow rate required (& measured) by process is 100 gpm
- Steam flow rate is unknown



Fuel Heating Value

- The energy content of a fuel is determined by a combustion process
  - The combustion process begins and ends at ambient temperature
    - Constant pressure analysis provides the most accurate heating value
  - The energy released during the combustion process is measured
    - The energy released is the *Heat of Combustion* for the fuel
      - This is also the *calorific value*, the *Btu value*, and the *heating value*
- Fuels containing hydrogen will form water during combustion

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{Energy Release}$$

Higher Heating Value

- Water (H_2O) formed during the combustion process is initially steam but condenses during the heating value test
  - Each pound of water releases approximately 1,000 Btu of energy by condensing
    - This energy release is measured in the **Higher Heating Value**
- In the United States *Higher Heating Value* is the most common convention
  - The primary exception is the combustion turbine arena

$$CH_4 + 2O_2 \rightarrow CO_2 + \underbrace{2H_2O}_{condensate} + \text{Energy Release}$$

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Lower Heating Value

- The Lower Heating Value is the energy liberated from a combustion process with no latent energy release from condensation
- The Lower Heating Value is generally determined by calculation from the higher heating value and the fuel composition
- In most boiler operations the flue gas will exit the boiler with no condensate
- The Lower Heating Value is the convention in most of the world

$$CH_4 + 2O_2 \rightarrow CO_2 + \underbrace{2H_2O}_{Steam} + \text{Energy Release}$$

Higher and Lower Heating Value

- The numeric difference between the higher and lower heating values depends on the hydrogen content of the fuel
  - Natural gas difference is 10%
  - Fuel oil difference is 6%
  - Coal difference is ~4%
  - Green wood difference can be more than 20%
- In the United States most fuels are marketed based on the fuel higher heating value
- The primary point of concern is consistency

Polling Question 6

Polling Questions

6) What fuels are used in your plant to generate steam (Select all that apply)?

A. Natural gas
B. #2 Oil
C. #6 Oil
D. Coal
E. Wood
F. Biomass, Biogas, etc.
G. Other
H. Don't know
I. I don't generate Steam

Key Points / Action Items

1. Use a Systems Approach to optimize steam systems
2. There are four major areas of a steam system – Generation, Distribution, End-Use & Recovery
3. An understanding of the laws of thermodynamics, heat transfer, fluid flow and steam properties is required for a steam system analysis
4. Steam is used all across industry to do various tasks and is the most effective medium to transport energy and produce shaft work (or power)

Steam System Scoping Tool – (SSST)

Steam System Scoping Tool - SSST

- SSST is a software-based questionnaire designed to enhance awareness of areas of steam system management
- Divided into typical steam system focus areas
- Provides the user a score that is indicative of management intensity and serves as a guide to useful information
- Tool to identify potential improvement opportunity areas
- Will NOT quantify the energy savings opportunities

Intended SSST Users

- Industrial manufacturers
  - Plant managers
  - Utility managers
  - Plant process engineers
- Energy experts/consultants for assessment
- Can also be used by institutional, commercial steam users

SSST Organization

- Introduction
- Steam system basic data
- Steam system profiling
- Overall system operating practices
- Boiler plant operating practices
- Distribution, end use and recovery operating practices
- Summary results
- Next steps

Obtaining Data for SSST Input

- Sources of data:
  - Actual current measurements
  - Computerized or print copy historical records
  - Information on procedures from:
    - Plant engineer/utilities/maintenance manager(s)
    - Boiler operator
- Full Completion:
  - 26 questions – expected time: 45 min (max)

Steps for Use of SSST

- Open SSST
- Review SSST sections to identify needed input data
- Obtain input data
- Optionally complete steam system basic data section
- Insert answer choices into SSST sections

Steps for Use of SSST (Continued)

- On summary results screen note scores achieved in major tool sections
- Compare scores achieved with those for similar plants
- Identify and prioritize steam system improvement opportunities
- Utilize resources identified in “next steps” section for assistance in implementing steam system improvements

Interpreting Summary Results

- Average score (65%) reported based on results collected from several industrial steam plants:
  - Steam system profiling: 63%
  - Steam system operating practices: 69%
  - Boiler plant operating practices: 63%
  - Distribution, End-Use, Recovery: 58%
- Your scores will vary!
- Excellent place to start understanding the steam system and its operations including management practices

Next Steps Directed by SSST

- Focus on areas requiring attention
- Investigate resources
  - Consult the U.S. DOE Web site
    - http://energy.gov/eere/amo/advanced-manufacturing-office
  - Steam System Survey Guide
  - U.S.DOE Steam Tip Sheets
  - Improving Steam System Performance: A Sourcebook for Industry
- Use US DOE's MEASUR
  - Calculators
  - Steam Assessment
- Use the Insulation Tool (3E Plus)

Common BestPractices - Generation

- Minimize excess air
- Install heat recovery equipment
- Clean boiler heat transfer surfaces
- Improve water treatment to reduce boiler blowdown
- Recover energy from boiler blowdown
- Add/restore boiler refractory
- Minimize the number of operating boilers
- Optimize deaerator vent rate

Common BestPractices - Distribution

- Repair steam leaks
- Minimize vented steam
- Ensure that steam system piping, valves, fittings and vessels are well insulated
- Isolate steam from unused lines
- Minimize flows through pressure reducing stations
- Reduce pressure drop in headers
- Drain condensate from steam headers

Common BestPractices – End-Use

- Reduce steam usage by a process
  - Improving the efficiency of the process
  - Shifting steam demand to a waste heat source
- Reduce the steam pressure needed by process, especially in cogeneration systems
- Upgrade low pressure (or waste) steam to supply process demands
- Process integration leading to overall energy optimization of the plant

Common BestPractices - Recovery

- Implement an effective steam-trap management and maintenance program
- Recover as much as possible of available condensate
- Recover condensate at the highest possible thermal energy
- Flash high-pressure condensate to make low-pressure steam

Key Points / Action Items

1. Use a systematic approach (gap analysis, comparison to BestPractices) to identify potential energy saving opportunities that may exist in steam systems

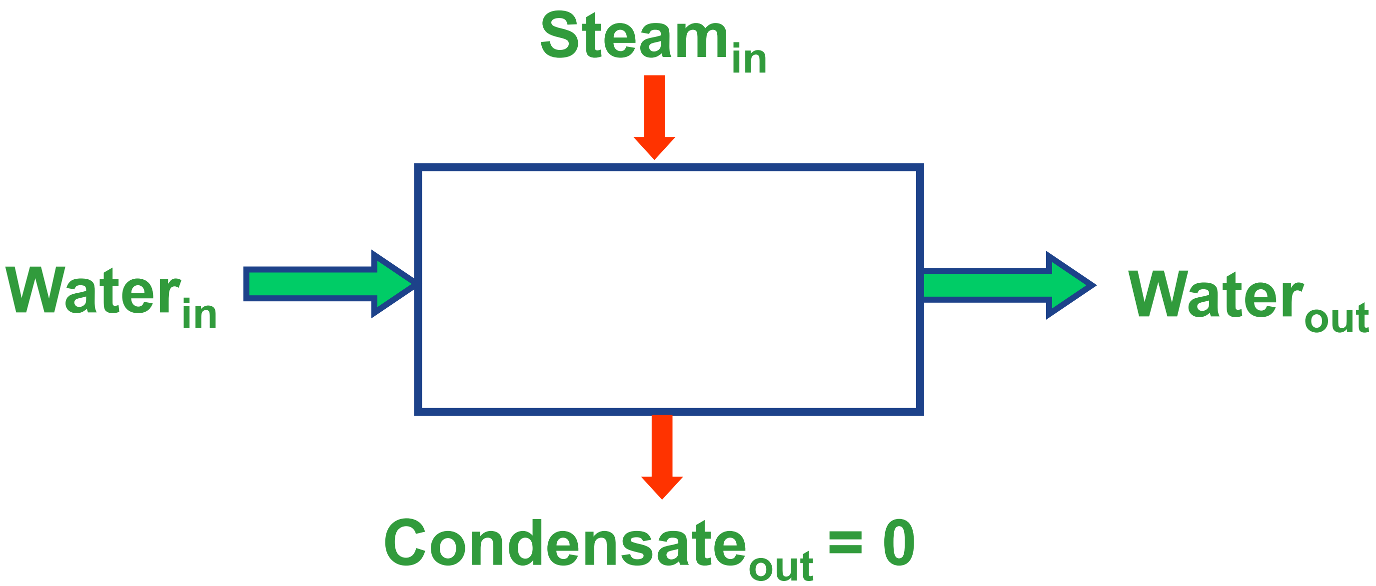
2. Use the Steam System Scoping Tool (SSST) to provide a high-level overview of operational, maintenance and management BestPractices

3. Once gaps are identified, delve into more detail using the other US DOE's tools and resources

4. Quantify, prioritize, implement and continue to monitor

Homework #1

- Steam is directly injected in a vessel to heat water from 65°F to 135°F and the required flow for the process need is 100 gpm.
  - Calculate the steam flow rate required
  - Compare the results with the indirect heat exchange application and comment on which method would you recommend for use in your plant.



Homework #1

- Use the Steam System Scoping Tool (SSST) on your industrial plant steam system and prepare a high-level list of potential areas for investigation in a steam system energy assessment over the next 6 weeks.

- Prepare a line diagram for your steam system showing the boilers, headers, major end-users and condensate return system. Indicate pressures, steam flows and anything important for your system.

Thank You all for attending today's webinar.

See you all on tomorrow - Thursday – October 3, 2024 – 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 paparra@ornl.gov