



## **Industrial Steam Systems** **Virtual INPLT Training & Assessment**

Session 3

Friday – October 28, 2022

10 am – 12:30 pm ET

# Agenda – Session THREE

- Safety and Housekeeping

- Today's Content:

Discussion of Homework

Quick Review from Session 2

Steam System Generation

- Boiler Efficiency Methods & Comparisons, Special Cases
- Impact Boiler
- Cogeneration

US DOE MEASUR Tool

- Boiler Calculator
- Building a steam system model

- Kahoot Quiz Game

- Q&A



# Safety and Housekeeping

- Safety Moment

- Stay within marked walking paths during the plant walk-through
- Make sure you know where emergency exits and gathering places are located

- 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 2 Discussion

# Homework #2

- Pay a visit to your boiler plant (generation) area and make a list of all the boilers, their design steam flow, pressure, fuel used and heat (input or output) rating.
- Understand how the boiler plant is controlled – how many boilers are running, how many are hot standby, etc. How does seasonality and production change the operations of these boilers.
- Pick one or more boilers and complete the exercise to calculate direct boiler efficiency and indirect boiler efficiency with specific boiler losses. You can use 1Q 2021 average data or representative operating data.
- Calculate your steam cost (\$/klb).



# Polling Questions 1-3

Polling Question

1) Were you able to calculate boiler efficiency using the direct method?

A. Yes

B. No

2) Were you able to calculate stack loss for your boiler?

A. Yes

B. No

3) Were you able to use US DOE MEASUR?

A. Yes

B. No

## Session 2 – Quick Review



# Steam Cost Indicator

$$\text{Steam Cost} = \frac{\text{Fuel Cost}}{\text{Steam Produced}}$$

$$\text{Steam Cost} = \frac{745}{100}$$

$$\text{Steam Cost} = 7.45 \frac{\$}{\text{klb}}$$

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$$\text{Steam Cost} = \frac{6,526,200}{100 \times 8760}$$

$$\text{Steam Cost} = 7.45 \frac{\$}{\text{klb}}$$

# Classic Boiler Efficiency

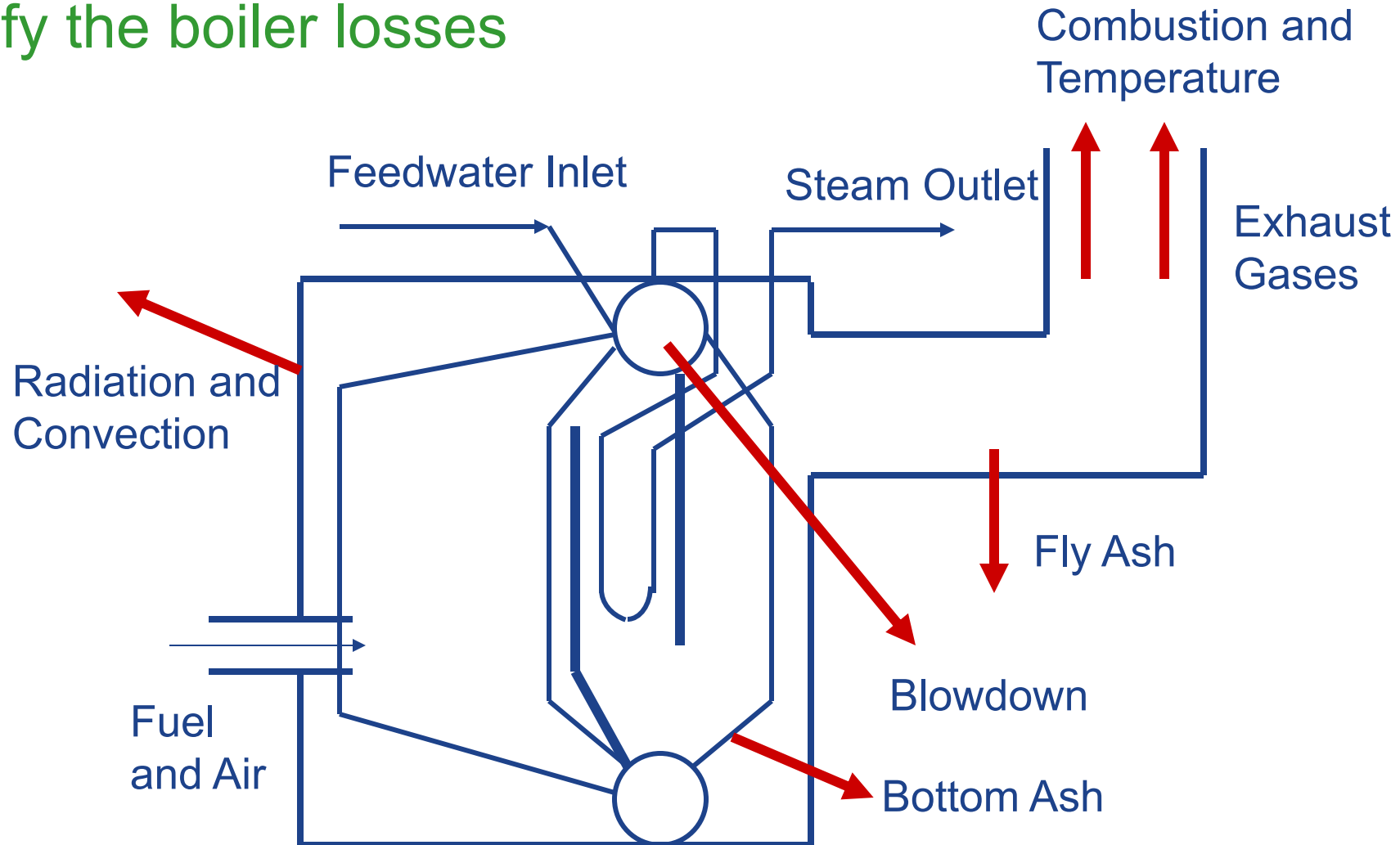
- Steam generating unit efficiency is defined as the heat absorbed by the steam divided by the fuel input energy

$$\eta_{boiler} = \frac{\text{energy desired}}{\text{energy that costs}} (100)$$

$$\eta_{boiler} = \frac{\dot{m}_{steam} (h_{steam} - h_{feedwater})}{\dot{m}_{fuel} HHV_{fuel}} (100)$$

# Boiler Losses

- Identify the boiler losses



# Indirect Efficiency

- Boiler efficiency can also be determined in an indirect manner by determining the magnitude of the losses
  - Primary losses are typically
    - Shell loss
    - Blowdown loss
    - Stack loss

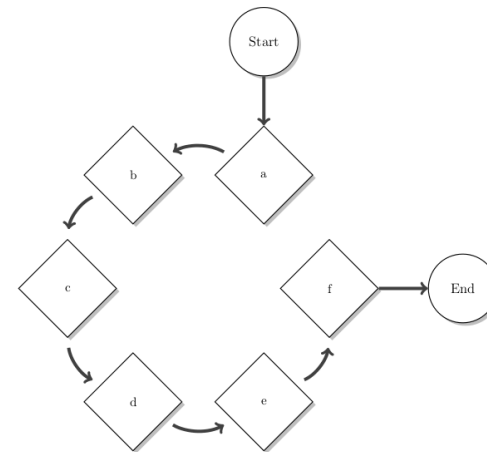
$$\eta_{indirect} = 100\% - \sum_{losses} \lambda_i$$

$$\eta_{indirect} = 100\% - \lambda_{shell} - \lambda_{blowdown} - \lambda_{stack} - \lambda_{misc}$$

# Which Method should be used?



Direct Method



InDirect Method

# Boiler Efficiency Evaluation – Direct Method

## ■ Advantages

- All-in-one
- Very quick and easy – minimal data required
- Can be done for instantaneous, hourly, daily, monthly, annually or any time period
- Trends, dashboards – programmable for operators

## ■ Disadvantages

- Need flow rates (steam and fuel) – maybe difficult to obtain – larger time periods needed with totalizers
- Can have significant errors – calibration + human
- No information on how to improve boiler efficiency

# Boiler Efficiency Evaluation – InDirect Method

- Advantages

- Can be very accurate since errors in measurements are very minimal
- Provides gap analysis for boiler efficiency improvement
- Stack loss, blowdown can be trended and programmed – main variable losses

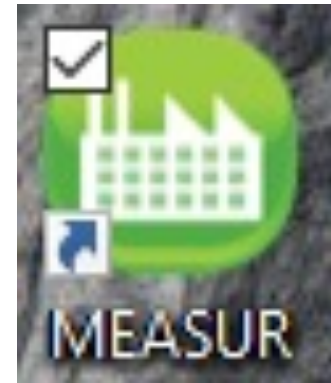
- Disadvantages

- Significant data collection (in-situ and portable instruments + human intervention)
- Mostly done instantaneously or over shorter periods of time only
- Boiler shutdown maybe needed to initiate data collection



# Example Boiler – US DOE MEASUR

- Boiler fired with natural gas
  - HHV is 1,000 Btu/scf
- Steam conditions: 400 psig, 700°F
- Output: 100,000 lb/hr (steady)
- Fuel cost: \$5.00 per MMBtu
- Blowdown: 6%
- Deaerator: 10 psig
- Combustion efficiency: 78.7%
  - Shell loss can be added to more accurately reflect the energy flow numbers but it is generally not an impact parameter



# Example Boiler – US DOE MEASUR



## BOILER

Deaerator Pressure  psig

Combustion Efficiency  %  
[Calculate Efficiency](#)

Blowdown Rate  %

### Steam

Pressure  psig

Known Variable  ▼

Temperature Value  °F

Steam Mass Flow  klb/hr

Generate Example

Reset Data

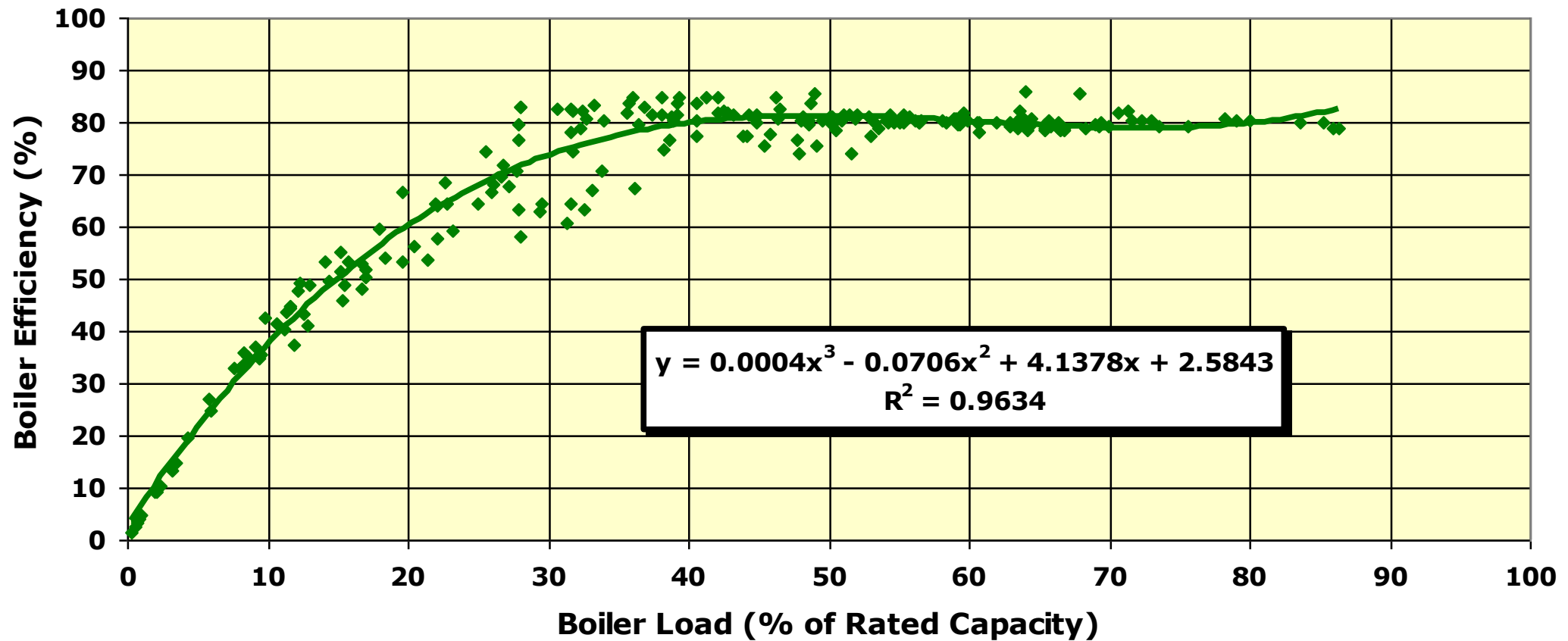
## RESULTS

## HELP

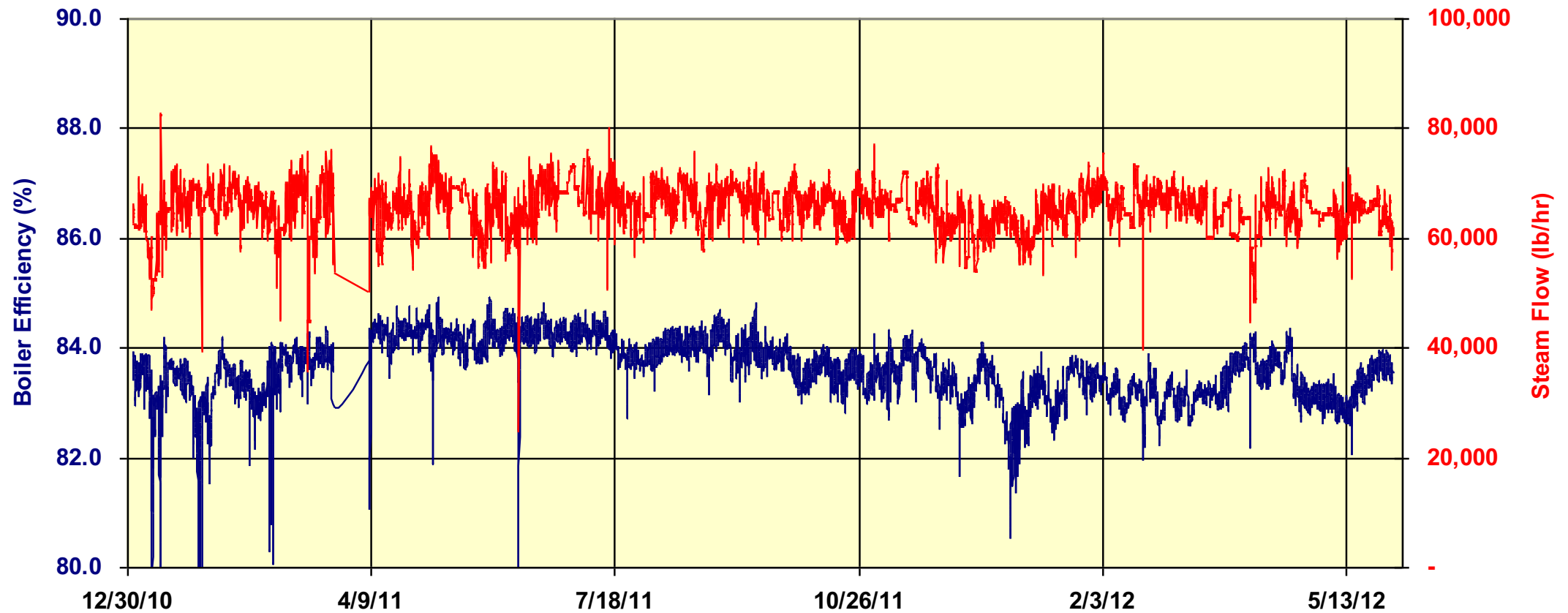
Blowdown Rate		6 %	
Boiler Energy		116,825.4 MMBtu/hr	
Combustion Efficiency		78.7 %	
Fuel Energy		148,444 MMBtu/hr	
	Feedwater	Blowdown	Steam
Pressure (psig)	10	400	400
Temperature (°F)	239.4	448.2	700
Saturated	Liquid	Liquid	Gas
Mass Flow (klb/hr)	106,382.98	6,382.98	100,000
Sp. Enthalpy (Btu/lb)	207.8	428.2	1,362
Sp. Entropy (Btu/lb-°F)	0.352	0.626	1.636
Energy Flow (MMBtu/hr)	22,108.6	2,732.9	136,201.2

Copy Table

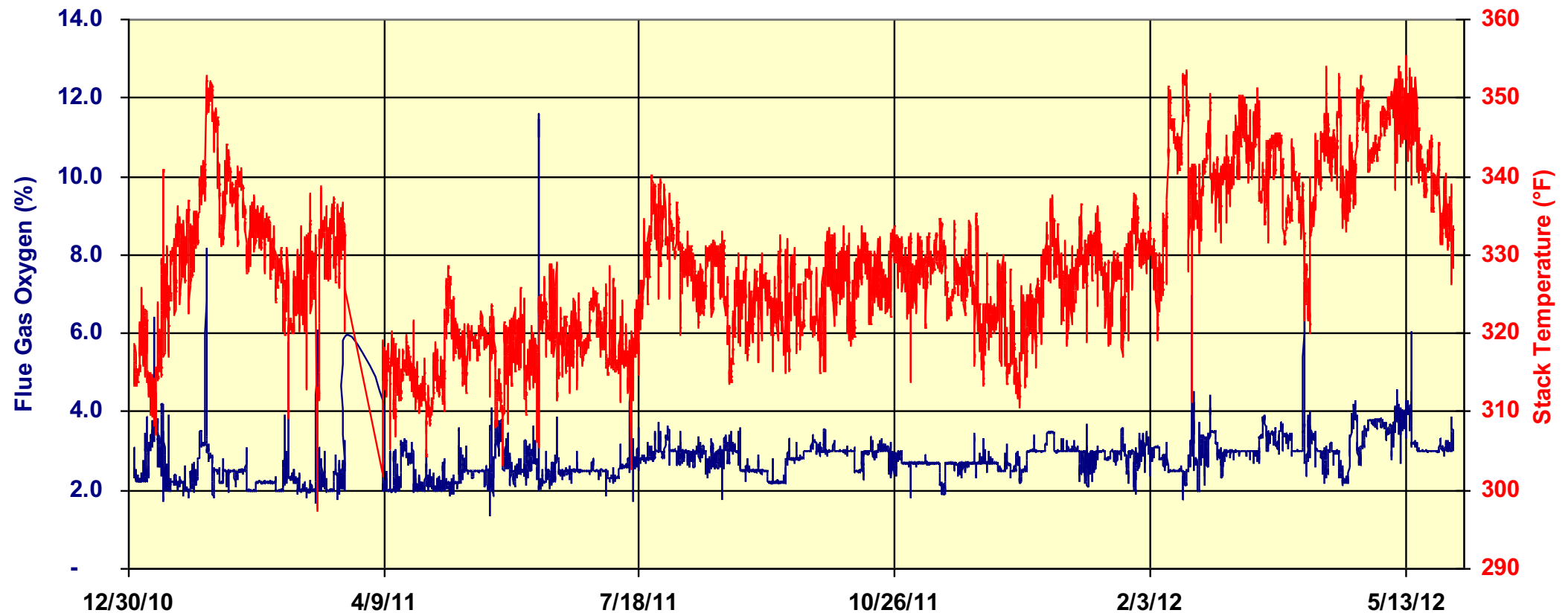
# Typical Boiler Efficiency Curve



# Boiler Efficiency Curve



# Boiler Efficiency – Key Parameters Monitoring



# What about Boiler Plant Direct Efficiency?

- If the fuel is the same for all boilers and boilers have same steam generation conditions and feedwater conditions

$$\eta_{plant} = \frac{m_{total-steam}(h_{steam} - h_{feedwater})}{m_{total-fuel} \times HHV_{fuel}} \times 100$$

- If the fuel is different for boilers and boilers have different steam generation conditions and feedwater conditions

$$\eta_{plant} = \frac{\sum_1^n m_{steam}(h_{steam} - h_{feedwater})}{\sum_1^n m_{fuel} \times HHV_{fuel}} \times 100$$

## Generation Area

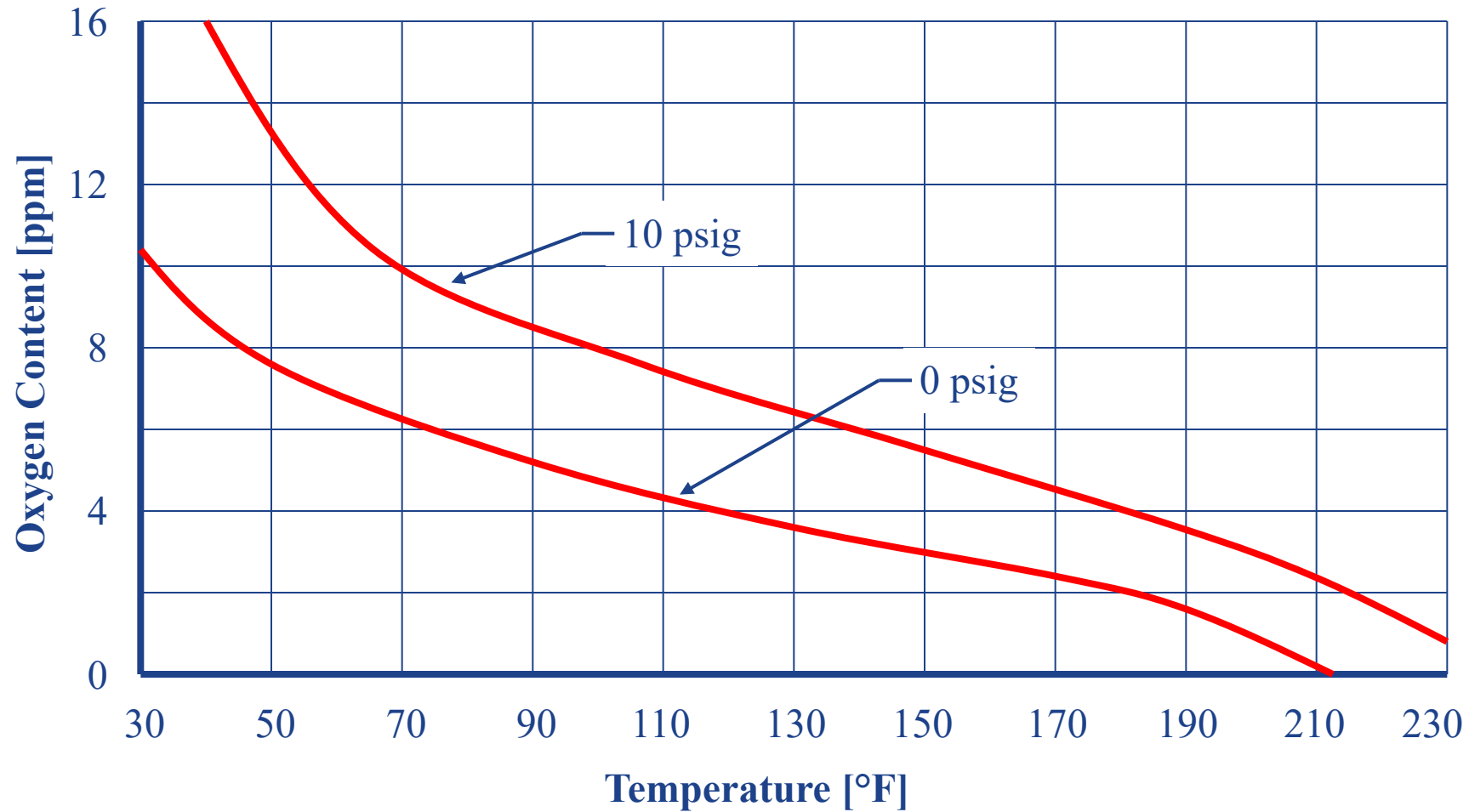
- Deaerator



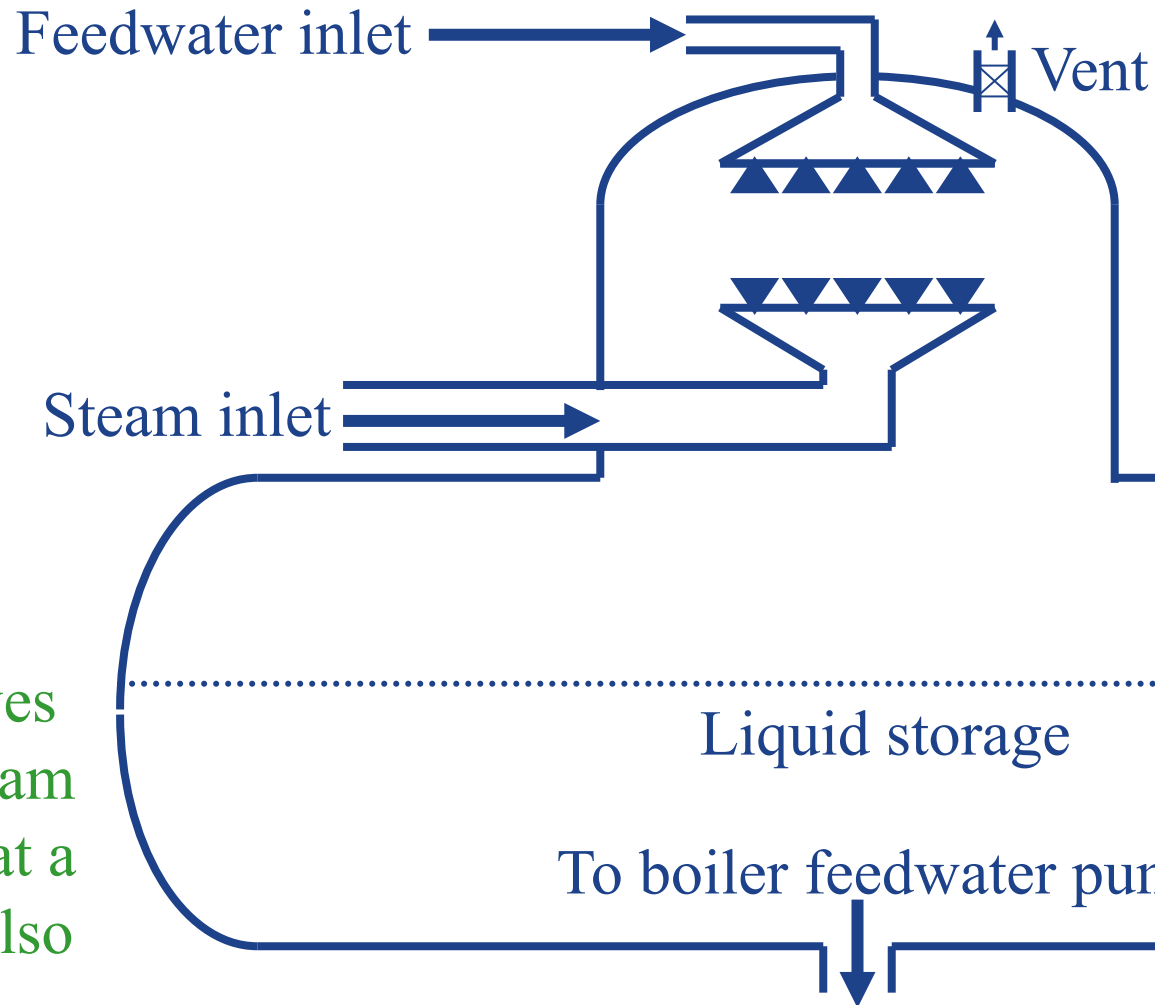
# Deaeration

- Oxygen, carbon dioxide and other gases are soluble in water
  - These chemicals are detrimental to the steam system
    - Oxygen results in corrosion generally in the form of pitting
    - Carbon dioxide results in corrosion generally from acidic condensate
- Open condensate receivers are a location where gases can become dissolved in condensate
- Makeup water usually contains significant amounts of dissolved gases
- The solubility of gases in water decreases as temperature increases
  - Deaeration is used to reduce the effects of dissolved gases

# Solubility of Oxygen in Water



# Deaerator



Vent flow is specified in MEASUR as a percentage of boiler feedwater flow

Deaerator receives low-pressure steam but can operate at a pressure lower also

## US DOE MEASUR

- Plant / System Information Required
- Building a Steam System Model

# 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

Steam Example  
Last modified: Nov 12, 2020

System Setup Assessment Diagram Report Sankey Calculators

1 Assessment Settings 2 Operations 3 Boiler 4 Header 5 Turbine

### STEAM EXAMPLE SETTINGS

Language	<a href="#">Translate Application Using Google Translate</a>
Currency	\$ - US Dollar
Units of Measure	<input checked="" type="radio"/> Imperial <input type="radio"/> Metric <input type="radio"/> Custom
Pressure Measurement	Pounds per Square Inch gauge (psig)
Temperature Measurement	Degrees Fahrenheit (°F)
Specific Enthalpy	Btu per lbs (Btu/lb)
Specific Entropy	British Thermal Units per Pound Fahrenheit (Btu/lb-°F)
Specific Volume	Cubic Feet per Pound (ft³/lb)
Mass Flow	Thousand pounds per hour (klb)/hr
Energy	Millions British Thermal Units (MMBtu)
Power	Kilowatts (kW)
Vacuum Pressure	Pounds per Square Inch absolute (psia)
Volume	U.S. Gallons (gal)
Volume Flow	Gallons per minute (gpm)

Equipment Notes

Add additional information for your equipment

Operating Conditions at time of Assessment

Add note for operating conditions

### HELP

#### System Basics Help

Your system basics help define the settings are inherited by default from

# Site Power Import (or Export)

- MEASUR requires an input for the normal amount of import electrical power
- Import electrical power combined with site generated power is the site load
- If the site is a net exporter of power a negative value should be provided for the import power

# Electric Rate Structure

- A thorough understanding of the electric rate structure is essential to evaluate the true impact of any process change
- The average electric cost is generally not the unit cost a facility will be impacted by as a result of an increase or decrease in electrical consumption



# Makeup Water Costs

- Water purchase price
- Pumping costs
- Treatment costs
- Wastewater costs ???
- Makeup water temperature is an important variable

# Fuel Pricing

Typical Fuel Properties					
Fuel	Sales Unit	Example Price [\$/sales unit]	HHV [Btu/lb]	LHV [Btu/lb]	Unit Price [\$/MMBtu]
Natural Gas	10 <sup>3</sup> std ft <sup>3</sup>	5.00	23,311	21,032	5.00
Number 2 Fuel Oil	gallon	2.20	19,400	18,275	15.79
Number 6 Oil (LS)	gallon	1.50	18,742	17,757	9.77
Number 6 Oil (HS)	gallon	1.25	18,815	17,780	8.27
Eastern Coal	ton	45.00	13,710	13,201	1.64
Western Coal	ton	30.00	10,088	9,547	1.49
Green Wood	ton	11.00	5,250	4,357	1.05

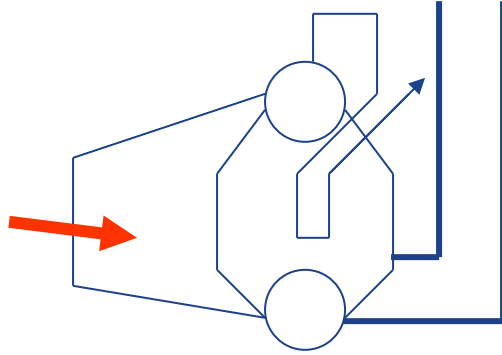
# Fuel Cost Structure – Impact Fuel

- Analyses should be completed utilizing *impact costs*
- Gross indications of savings opportunities can be attained by use of *average impact cost* or *projected cost*
- Multiple models may need to be developed reflecting various pricing conditions
  - Fuel prices typically vary seasonally
- The USDOE MEASUR fuel cost should be close to the actual energy related fuel cost for building confidence in the system model

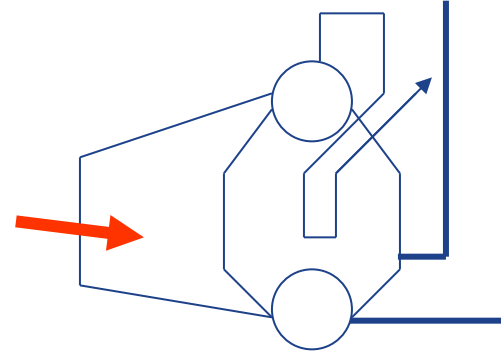
# Boiler & Fuel Selection

- What is Impact fuel?
  - The fuel that will change consumption if steam demand changes
  - Typically, the highest cost fuel in use
  - “Blended costs” generally do not reflect actual system changes
    - Blended costs do provide a confidence level in the model results
- What is Impact boiler(s)?
  - The boiler(s) that will change consumption if steam demand changes
  - Typically, the boiler with the highest steam cost indicator
  - “Blended boiler” configuration generally does not reflect actual system changes
    - Blended costs do provide a confidence level in the model results

# Impact Boiler & Fuel Selection



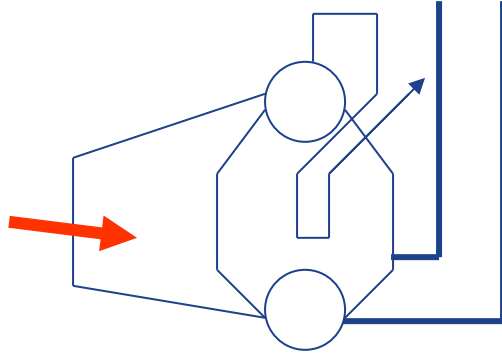
Fuel: Natural gas  
Fuel cost: \$5.00/MMBtu  
Boiler capacity:  
120,000 lbm/hr  
Steam production:  
100,000 lbm/hr  
Boiler efficiency: 78%



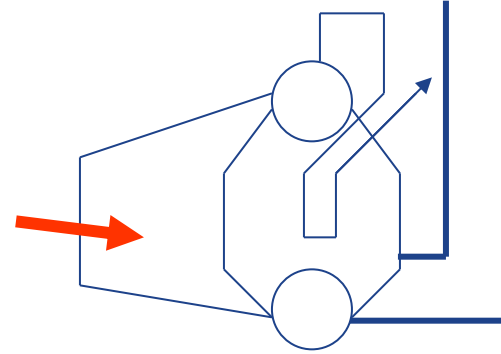
Fuel: Number 2 fuel oil  
Fuel cost: \$15.79/MMBtu  
Boiler capacity:  
50,000 lbm/hr  
Steam production:  
10,000 lbm/hr  
Boiler efficiency: 85%

- For the example system, variations in steam demand and reliability concerns will require both boilers to operate

# 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

# Plant Information

- The industrial plant chosen for this assessment is a Pulp & Paper Mill
- Typical electrical demand for the plant is 5 MW
- The plant has the following electrical costs
  - Energy charge is \$0.030/kWh
  - Demand charge: \$14.6/kW on a monthly basis
  - If both charges are applicable to a load contributing to the billing demand the electrical cost can be considered \$0.050/kWh
- The site operates 24 hours each day 365 days each year
  - 8760 hours



# Plant Information

- Average annual bundled cost for water is \$10/kgal (0.01 \$/gal)
- Impact fuel – Natural gas
  - Fuel cost - \$5.00/MMBtu
- Make-up water temperature – 65°F

# MEASUR – System Setup

MEASUR



Steam Example

Last modified: Apr 16, 2021

System Setup

Assessment

Diagram

Report

Sankey

Calculators

1 Assessment Settings

2 Operations

3 Boiler

4 Header

5 Turbine

## OPERATING CONDITIONS

### General Details

Operating Hours  hrs/yr

Site Power Import  kW

Make-up Water Temperature  °F

### Energy Costs for Operation

Fuel  \$/MMBtu

Electricity  \$/kWh

Make-Up Water Cost  \$/gal

## HELP

### Steam Operation

Enter measured data to c

### Make-up Water Cost

Cost of makeup water pe

# Plant Information

- Impact boiler efficiency to be used in the US DOE MEASUR tool
  - Combustion efficiency – 78.7%
  - Blowdown rate – 6%
- Boiler blowdown is sent to drain/sewer directly
  - No heat recovery
  - No flash steam generation
- Deaerator operating pressure – 10 psig
- Deaerator vent is NOT (generally) an impact parameter
  - Can be set to 0
- Steam generation conditions: 400 psig, 700°F

# MEASUR – System Setup

MEASUR



Steam Example

Last modified: Apr 16, 2021

System Setup

Assessment

Diagram

Report

Sankey

Calculators

1

Assessment Settings

2

Operations

3

Boiler

4

Header

5

Turbine

## BOILER DETAILS

Fuel Type

Gas

Fuel

Typical Natural Gas - US

[Add New Fuel](#)

Boiler Combustion Efficiency

78.7

%

[Calculate Efficiency](#)

Blowdown Rate

6

%

[Calculate Blowdown Rate](#)

Is the blowdown flashed?

No

Preheat Make-up Water with Blowdown

No

Steam Temperature

700

°F

Deaerator Vent Rate

0.0

%

Deaerator Pressure

10

psig

## HELP

### Boiler Help

Enter measured data to calculate

### Deaerator Pressure

The pressure of the deaerator should be set to 0 to 30 psig.

# MEASUR – System Setup

MEASUR



VINPLT\_0421

Last modified: Apr 16, 2021

System Setup

Assessment

Diagram

Report

Sankey

Calculators

1 Assessment Settings

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## HEADER DETAILS

Number Of Headers

1

Condensate Return

Condensate Return Temperature

150

°F

Flash Condensate Return

No

High Pressure Header

Pressure

400

psig

Process Steam Usage

89

klb/hr

Condensate Recovery Rate

50

%

Heat Loss

0

%

## HELP

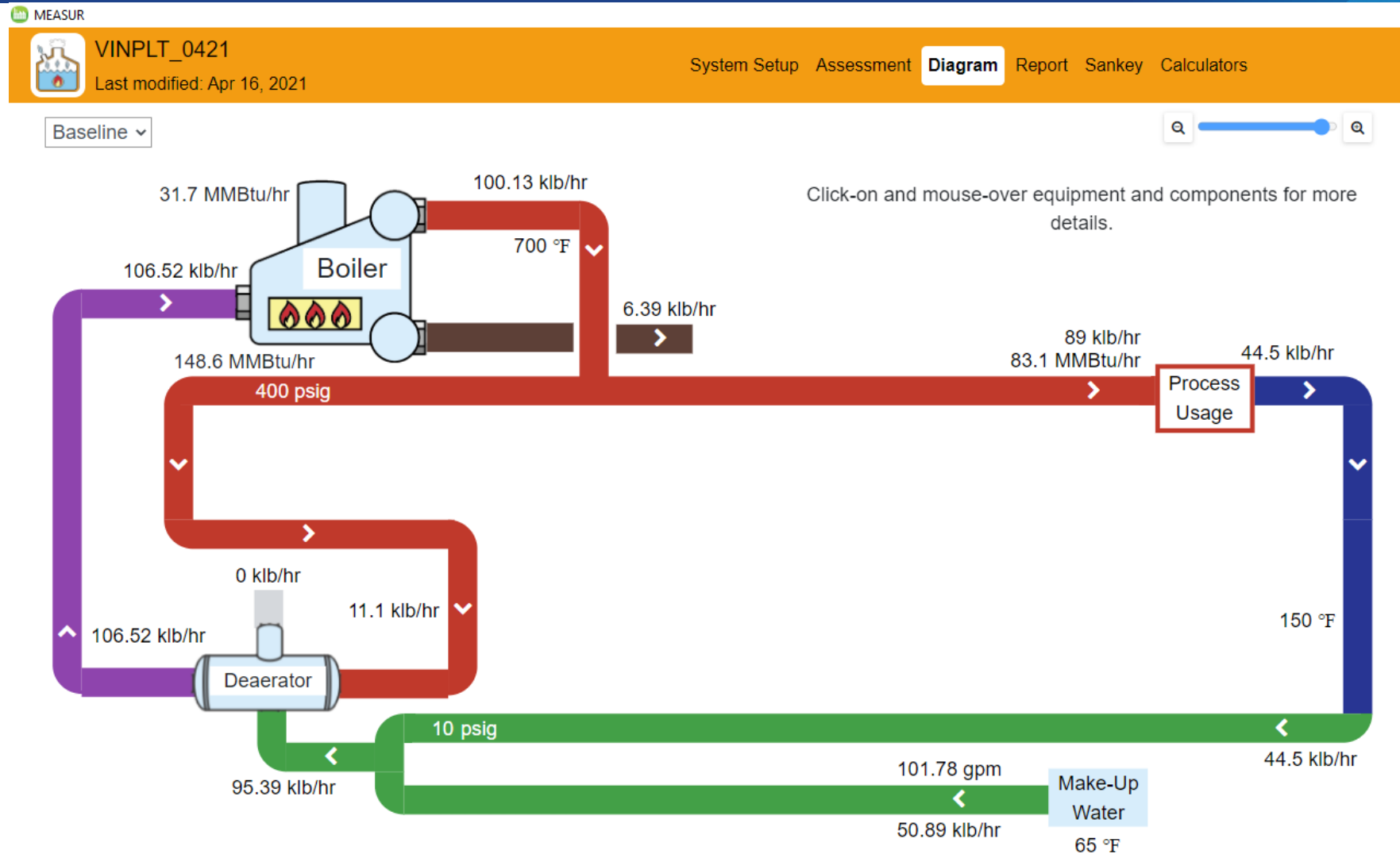
### Header Help

Enter measured data to

### Process Steam Usage

Mass flow of steam used

# 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

## CoGeneration (Combined Heat & Power)

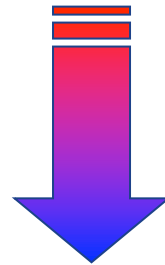
- **Steam Turbines**



# Turbines 101

- What is a Turbine?
  - Energy Conversion Device

**Potential / Kinetic / Pressure / Thermal Energy**



**Rotational Shaft Energy**

# Market Penetration

- No easy reference to determine number and size of steam turbines out in the field
  - Some estimates indicate ~85% US power generated by steam turbines
- Some studies state that U.S. industry employs ~20 GW of power generation from steam turbines
  - Shaft power generation (direct drive and electrical generator drives)
- Industrial turbines range in capacity from 10 kW (13.5 hp) to several hundred MW

# Examples of Industrial Systems

- Very common in industry
  - Direct power generation
  - Boiler feed water pumps
  - Cooling tower water pumps
  - Chilled water pumps
  - Boiler forced draft fan
  - Exhaust fans
  - Air compressors
  - Refrigeration machines
  - Chiller systems
  - Other utility services
- Less common in industry
  - Process equipment drives
  - Highly critical equipment



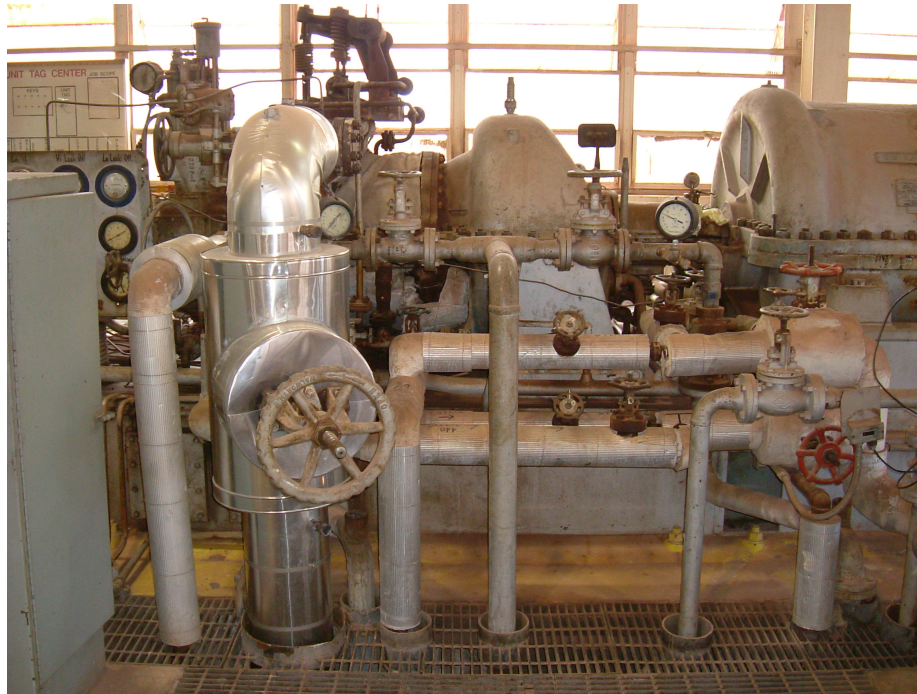
Compressor

Backpressure  
Steam Turbine

Steam Exhaust

# Examples of other Industrial Systems

## Backpressure Steam Turbine-driven Application





# Industrial Applications



**4,000 RT Steam Turbine Driven Chiller**



**Compressor**

**Direct Drive Shaft**

**Condensing  
Steam Turbine**

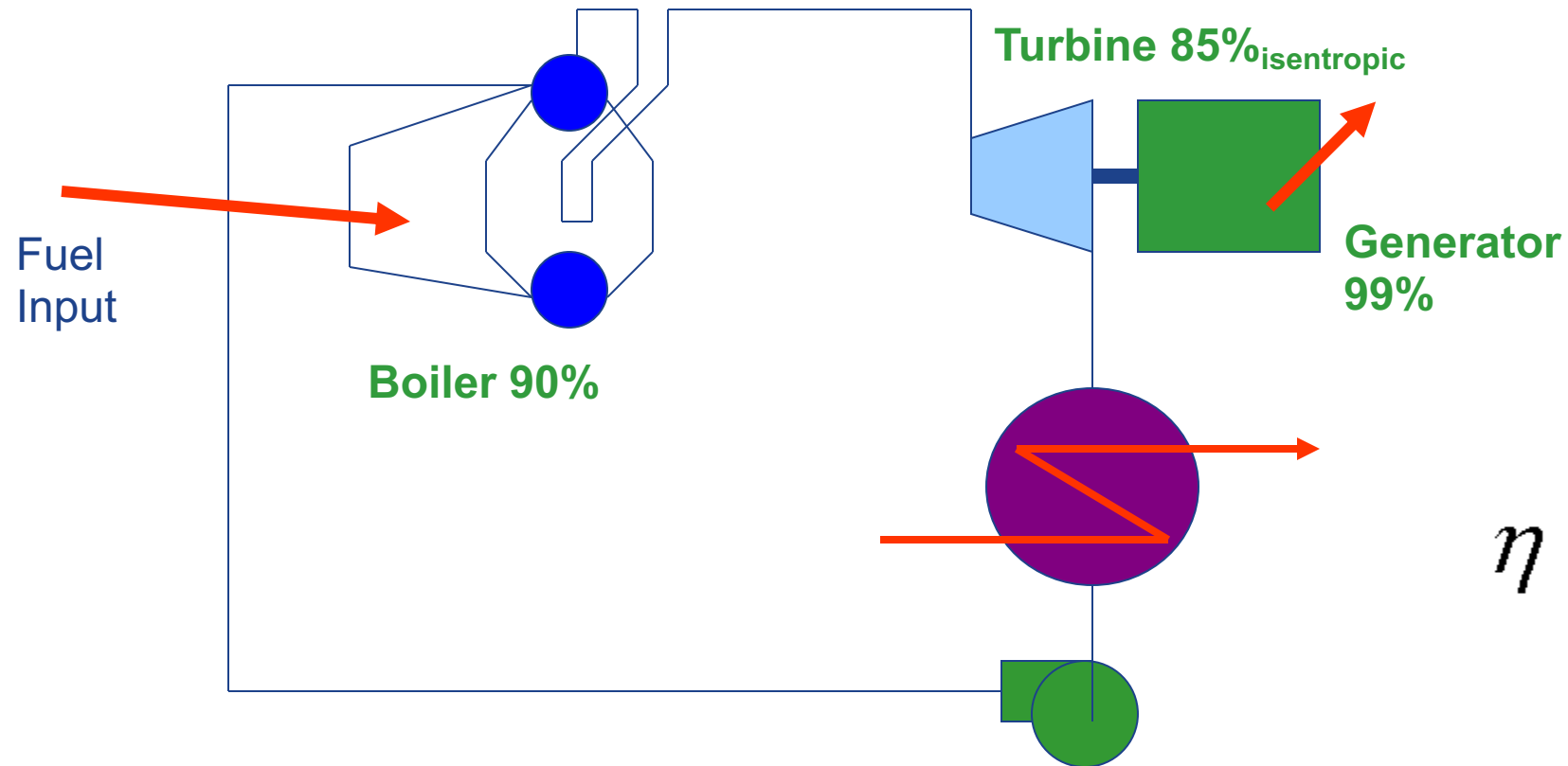
# An Industrial System



**2,250 hp  
backpressure  
steam turbine  
(600/200)**

**2-stage refrigeration (R134a) compressor**

# Simple Utility Power Station



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

What would be the overall fuel to power conversion efficiency?



# Polling Question 4

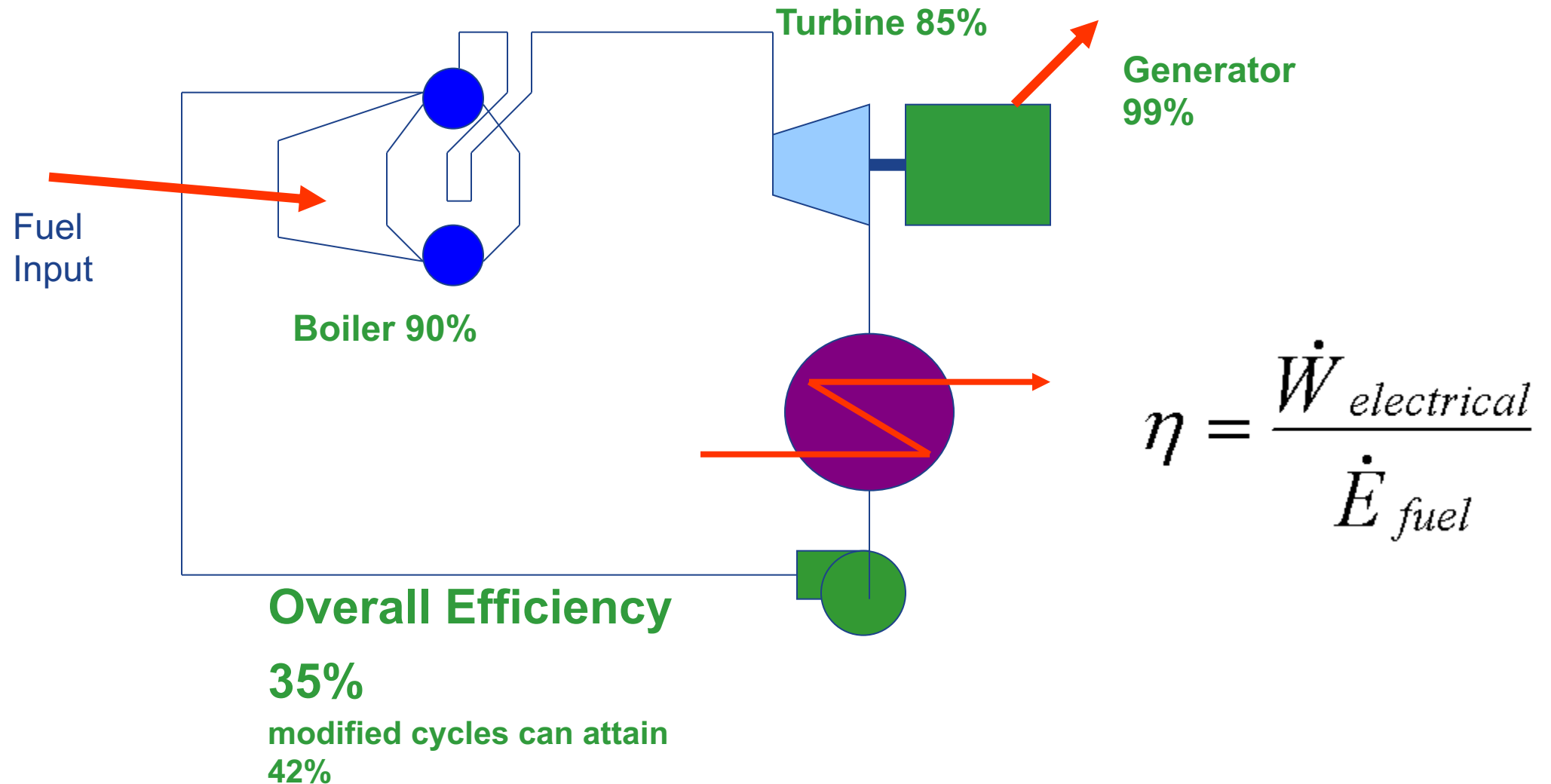
Polling Question

4) What would you expect to be the efficiency of the simple utility thermal power station?

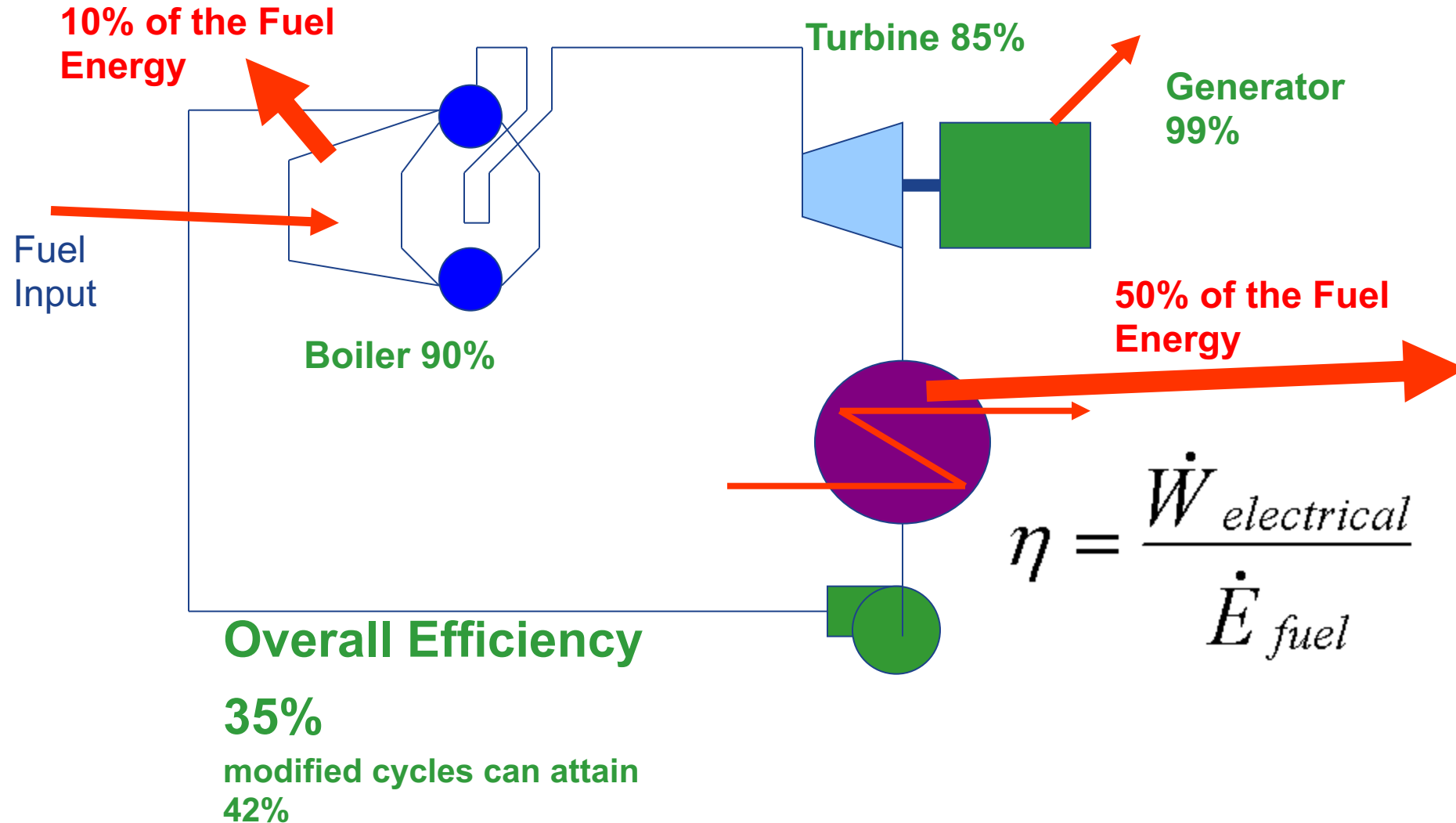
- A. 25%
- B. 35%
- C. 50%
- D. 75%



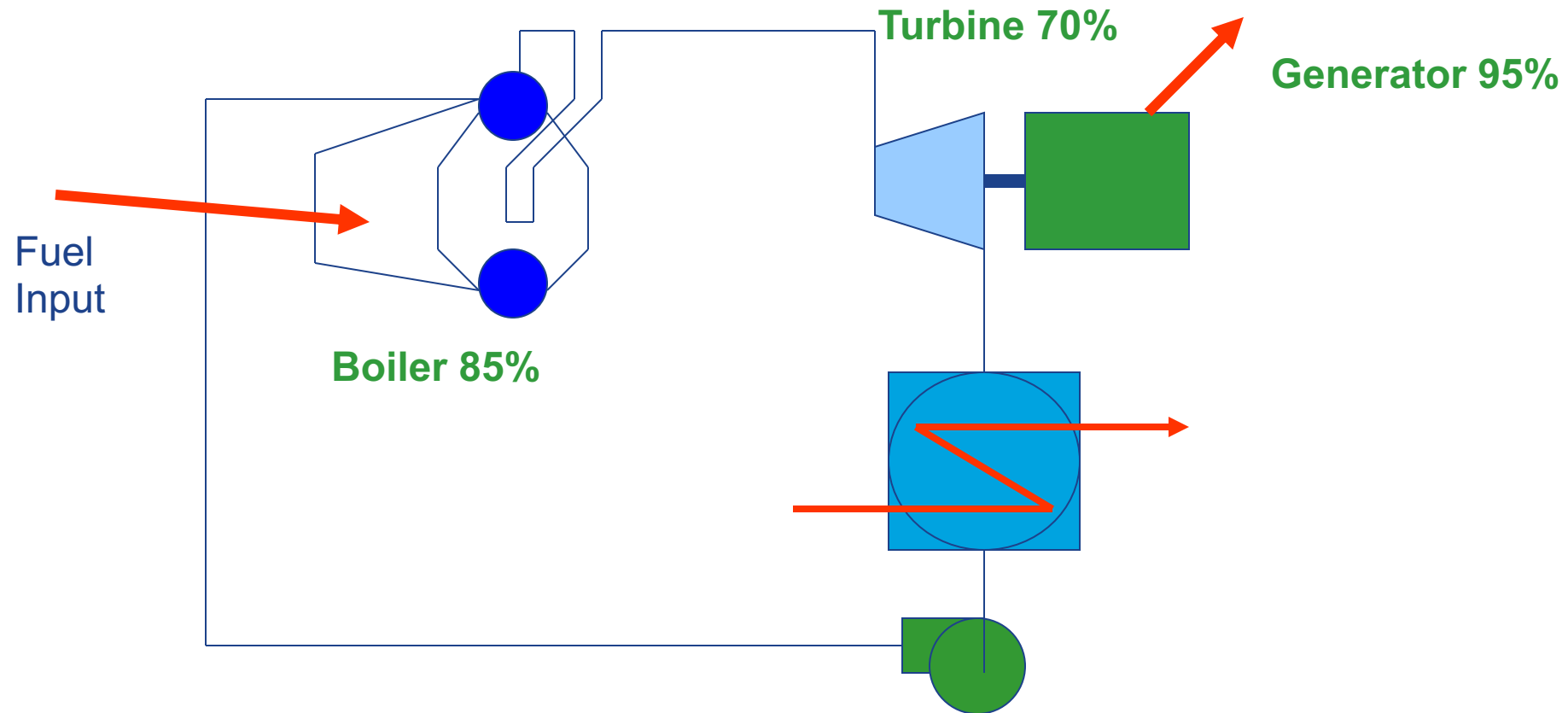
# Simple Utility Power Station



# Simple Utility Power Station



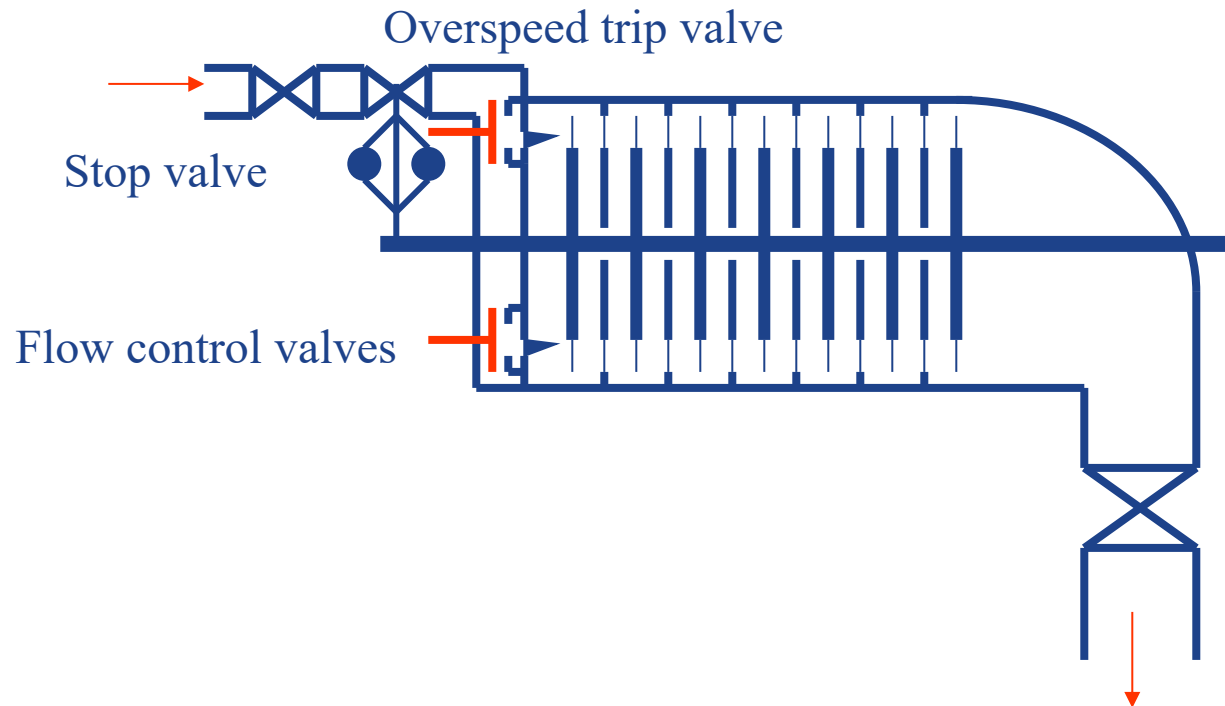
# Industrial Power Station



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

# Steam Turbines

- Steam turbines are devices used to convert thermal (steam) energy into shaft energy
  - High-pressure steam enters and low-pressure steam exhausts

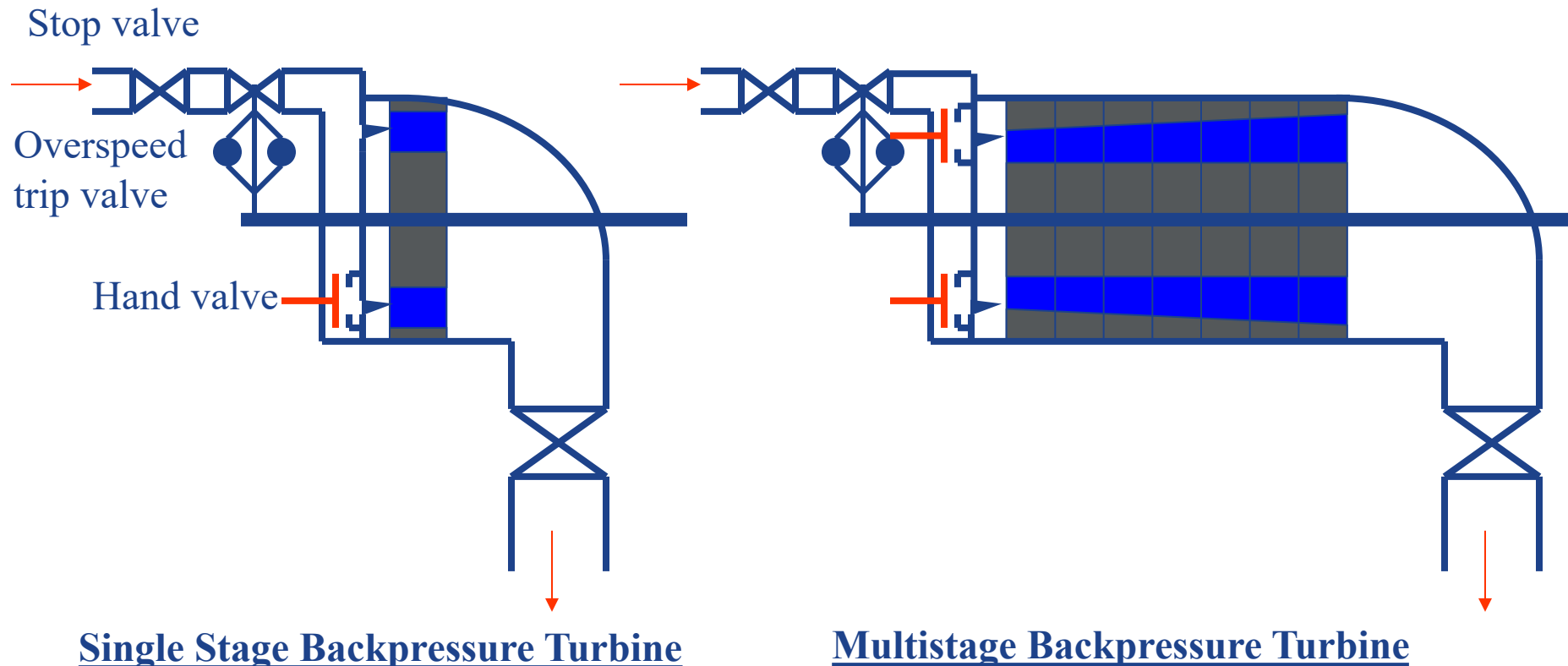


# Steam Turbine Types

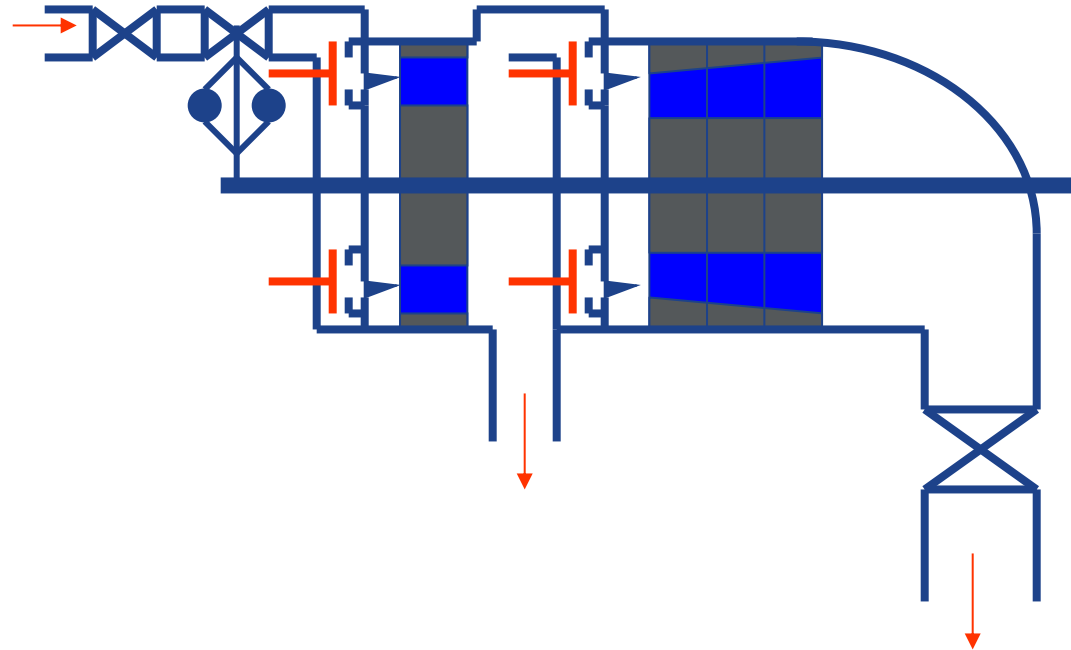
- Topping turbine (backpressure)
- Extraction turbine
- Extraction condensing turbine
- Straight condensing turbine
- Multiple extraction

# Backpressure Steam Turbines

- Backpressure steam turbines discharge steam at a pressure greater than (or equal to) atmospheric pressure



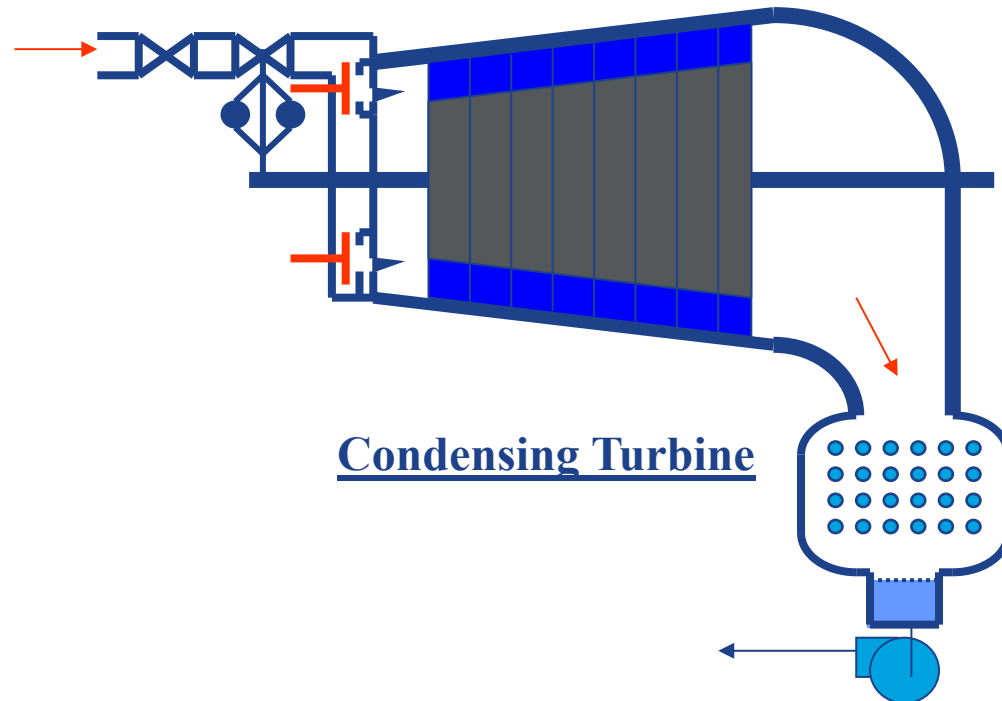
# Extraction Steam Turbines



Extraction Turbine

# Condensing Steam Turbines

- Condensing steam turbine discharge steam at a pressure less than atmospheric pressure
- The steam must be condensed to pump it back into the boiler
- Exiting steam quality is typically much greater than 90%





# Typical Steam Turbines Operations

- Operating pressures
  - Minimum – 150 psig
  - Maximum – 3,000 psig
  - Vacuum conditions exist at the exhaust in condensing turbines!
- Operating steam temperatures
  - Few degrees of superheat
  - Significantly superheated
- Summary – Steam turbine technology is very diverse and operates over a broad range of pressures and temperatures

# Pressure Ratio

- This is the DRIVING FORCE
- Pressure Ratio =  $\pi = \frac{\text{Inlet Pressure (psia)}}{\text{Outlet Pressure (psia)}}$
- This is the first dependent variable that should be calculated
- Pressure Ratio >2.5

# Turbine First Law Efficiency

- An energy balance conducted on a steam turbine will reveal an exceptionally high efficiency
  - Essentially all of the energy taken out of the steam is converted into shaft energy

$$\eta_{first\ law} = \frac{\dot{W}_{shaft}}{\dot{m}_{steam}(h_i - h_e)} \approx 100\%$$

- Steam turbines operate with only minor “losses”
  - Bearing friction
  - Heat transfer
  - Gland losses

# The Perfect Turbine

- Steam turbines are evaluated using the *Second Law of Thermodynamics*
  - The Second Law of Thermodynamics identifies that thermal energy cannot be converted completely into power
    - Power can be converted completely into thermal energy
  - This defines the maximum amount of shaft power that could possibly be produced (based on the laws of physics)
    - This defines a *perfect turbine*, which would operate *isentropically*
      - *Isentropic* is *constant entropy (no losses)*
        - No entropy generation

# Isentropic Efficiency

- Steam turbine efficiency is described as *isentropic efficiency*
  - A comparison of the actual work produced compared to a perfect (isentropic) turbine

$$\eta_{isentropic} = \frac{\text{Actual Work}}{\text{Isentropic Work}} = \frac{\dot{W}_{actual}}{\dot{W}_{isentropic}}$$

$$\eta_{isentropic} = \frac{\dot{m}_{steam}(h_{inlet} - h_{exit})_{actual}}{\dot{m}_{steam}(h_{inlet} - h_{exit})_{isentropic}} = \frac{(h_i - h_e)_{actual}}{(h_i - h_e)_{isentropic}}$$

# Typical Steam Turbine Efficiency

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

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

# Turbine Efficiency Summary

- US DOE MEASUR requires turbine isentropic efficiency
- Methods of obtaining isentropic efficiency:
  - Manufacturer specifications
    - Turbine Map / Curve
  - Actual operating conditions (superheated cases)
    - Steam inlet and outlet conditions known
  - Steam inlet conditions and power generation known
    - Typically, used for electrical power generation units

# MEASUR – Steam Turbine Calculator



## STEAM TURBINE

### Solve For

Isentropic Efficiency

### Inlet Steam

Pressure

400

psig

Known Variable

Temperature

Temperature Value

700

°F

### Turbine Properties

Selected Turbine Property

Mass Flow

Mass Flow

40

klb/hr

Generator Efficiency

95

%

### Outlet Steam

Pressure

20

psig

Known Variable

Temperature

Temperature Value

350

°F

## RESULTS

## HELP

Isentropic Efficiency	64.1 %		
Energy Out	6 MMBtu/hr		
Generator Efficiency	95 %		
Power Out	1,660.1 kW		
	Inlet	Outlet Ideal	Outlet
Pressure (psig)	400	20	20
Temperature (°F)	700	350	350
Phase	Gas	Gas	Gas
Sp. Enthalpy (Btu/lb)	1,362	1,213	1,213
Sp. Entropy (Btu/lb-°F)	1.636	1.748	1.748
Mass Flow (klb/hr)	40	—	40
Energy Flow (MMBtu/hr)	54.5	—	48.5

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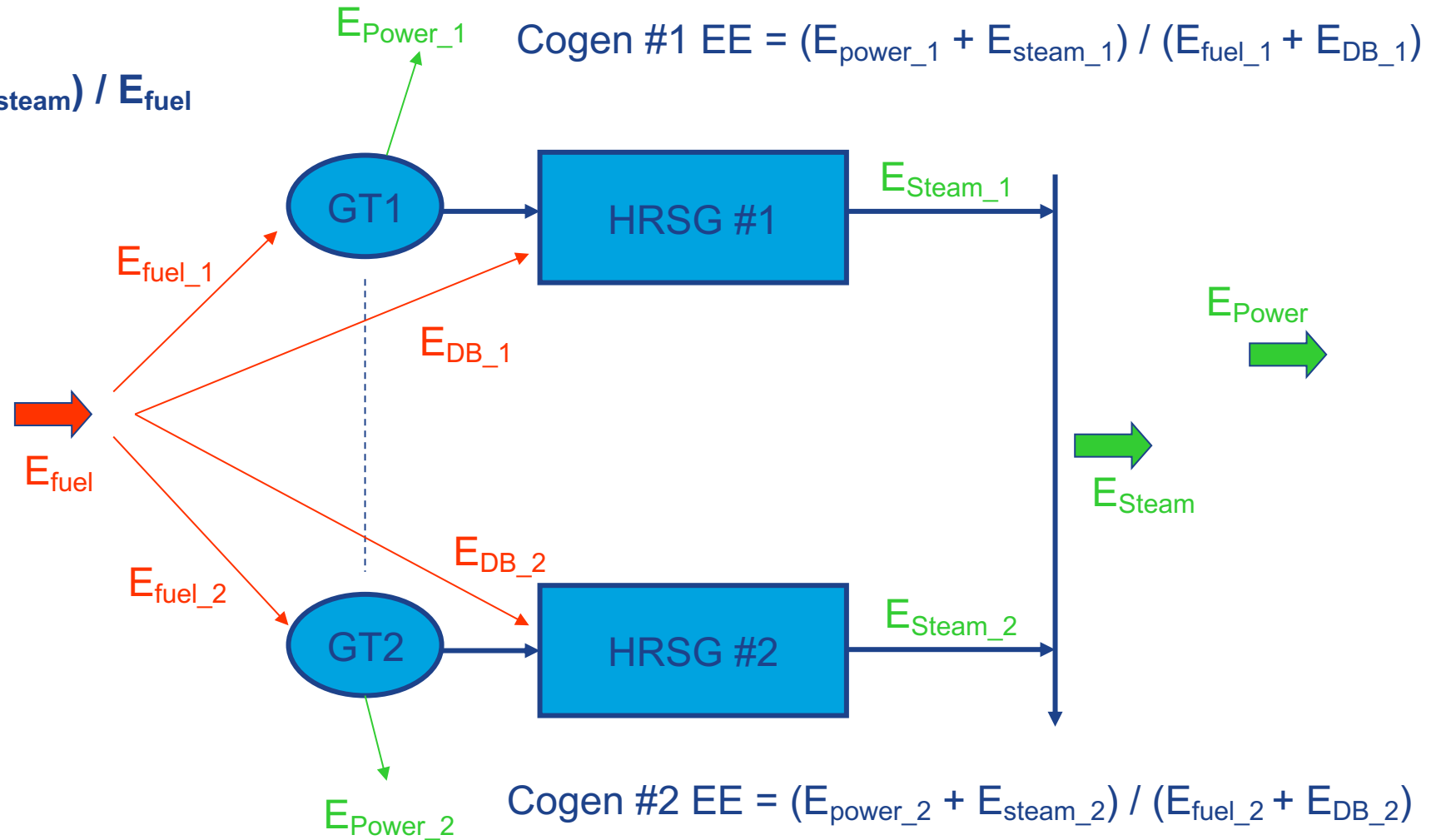


## CoGeneration (Combined Heat & Power)

- Gas Turbines

# An Example Gas Turbine / HRSG Cogeneration System

$$\text{Overall Cogen EE} = (E_{\text{power}} + E_{\text{steam}}) / E_{\text{fuel}}$$



# Metrics for Cogeneration

## ■ Heat Rate

- $\text{Heat Rate} = E_{\text{fuel}} / E_{\text{Power}}$
- $E_{\text{fuel}}$  is in Btu/hr – using LHV (or net)
- $E_{\text{power}}$  is in kW

## ■ Net Electric Efficiency

- $\eta_E = E_{\text{Power}} / E_{\text{Fuel}}$

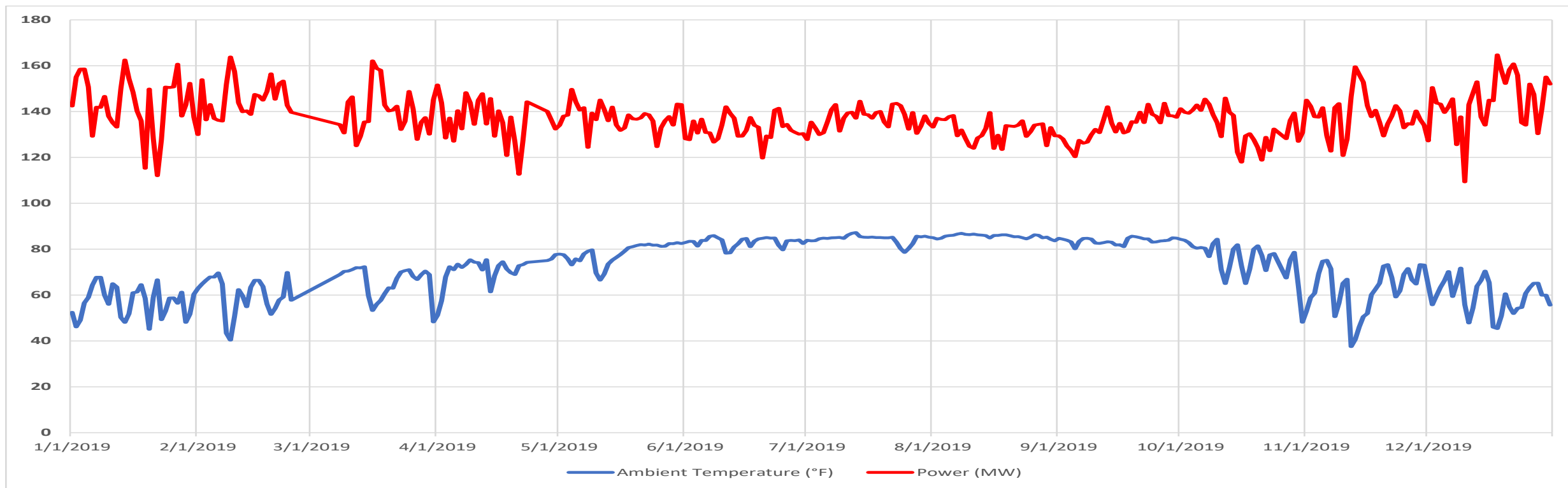
## ■ Cogeneration System Efficiency

- $\eta_{\text{Cogen}} = (E_{\text{Power}} + E_{\text{steam}}) / E_{\text{Fuel}}$

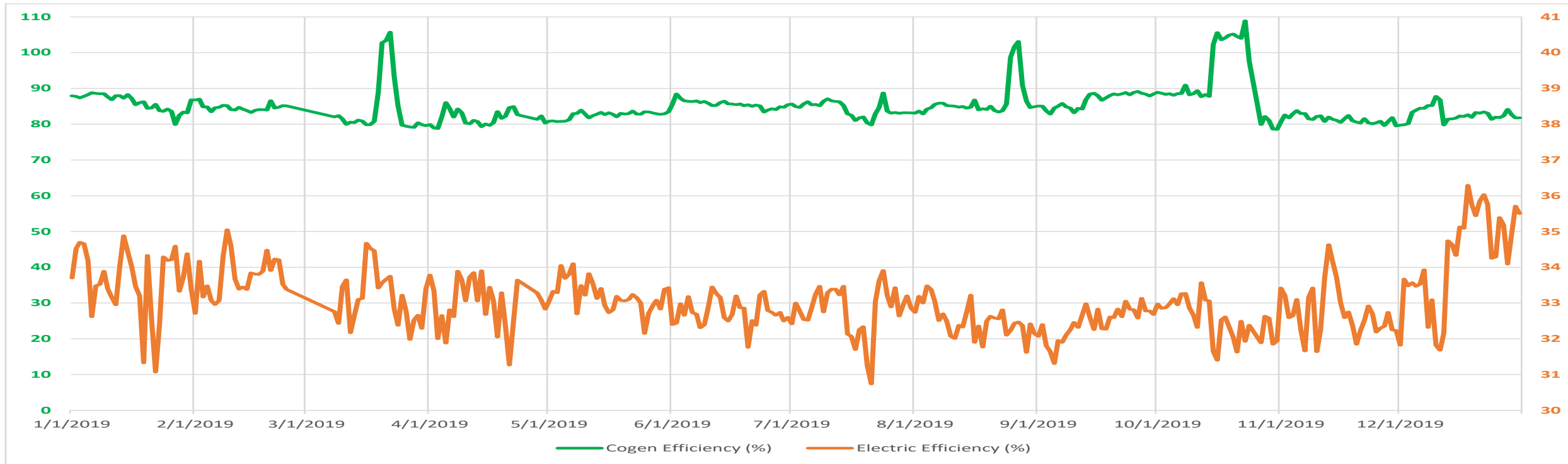
## ■ Cogeneration Electric Effectiveness

- $\epsilon_{EE} = E_{\text{Power}} / (E_{\text{Fuel}} - E_{\text{steam}} / \eta_{\text{boiler}})$

# Example System Cogeneration Trending



# Example System Cogeneration Trending



# 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

**Thank You all for attending today's webinar.**

**See you all on next Thursday – November 3, 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](mailto:rapapar@c2asustainable.com)**