Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Steam Systems
Virtual INPLT Training & Assessment

Session 5

Tuesday – May 4, 2021

10 am – 12:30 pm

U.S. DEPARTMENT OF ENERGY

Agenda – Session FIVE

- Safety and Housekeeping
- Today's Content:

  Discussion of Homework

  Baseline Model System

  Generation – Energy Efficiency & Savings Opportuinities
    - Stack Heat Recovery
    - Combustion
    - Blowdown Loss Reduction
      - Reduce blowdown
      - Heat recovery
- Kahoot Quiz Game
- Q&A

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

Safety and Housekeeping

- Safety Moment
  - Eliminate trip hazards – watch out for extension cords, hoses, ropes, etc.
  - Avoid walking through puddles of water / standing water
- 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 (April 6) – Industrial Steam Systems Fundamentals and Introduction to SSST**
- **Week 2 (April 13) – Focus on Steam System Generation and Introduction to DOE's MEASUR Tool**
- **Week 3 (April 20) – Steam System Generation & Cogeneration (CHP)**
- **Week 4 (April 27) – Steam System Distribution, End-Use & Condensate Recovery**
- **Week 5 (May 4) – Energy Efficiency Opportunities in the Generation Area**
- **Week 6 (May 11) – Energy Efficiency Opportunities in Cogeneration (CHP) Area**
- **Week 7 (May 18) – Energy Efficiency Opportunities in Distribution, End-use and Condensate Recovery**
- **Week 8 (May 25) – Industrial Steam System VINPLT Wrap-up Presentations**

Homework 4 Discussion

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

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.

Session 4 – Pulp & Paper Mill Base Model (MEASUR)

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Example Steam System – Pulp & Paper Mill

- Steam usage at different pressure levels for steam distribution in the plant
  - High pressure – 400 psig – 3 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)

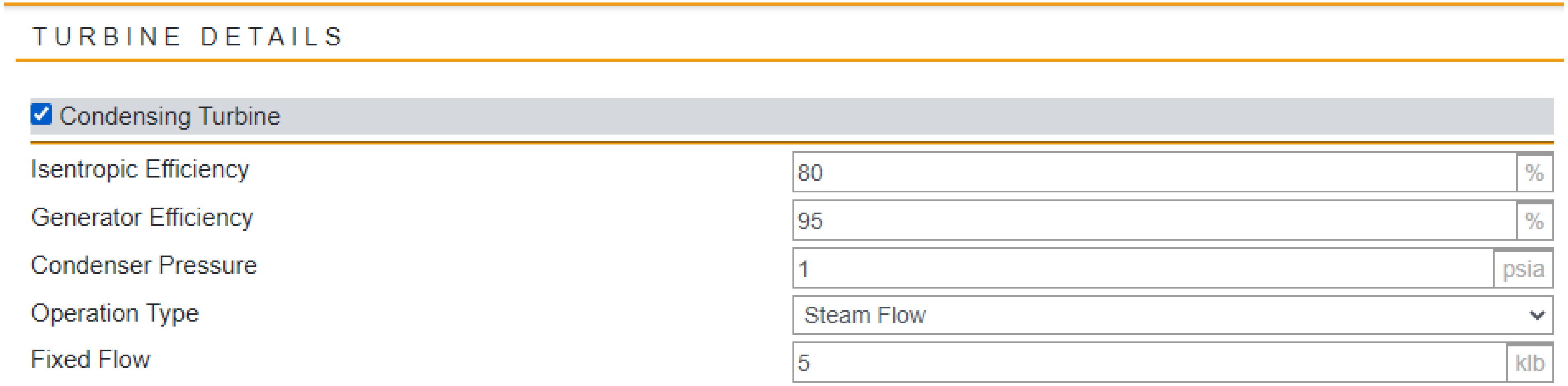
- Use a 3-header steam system model

Medium Pressure Header

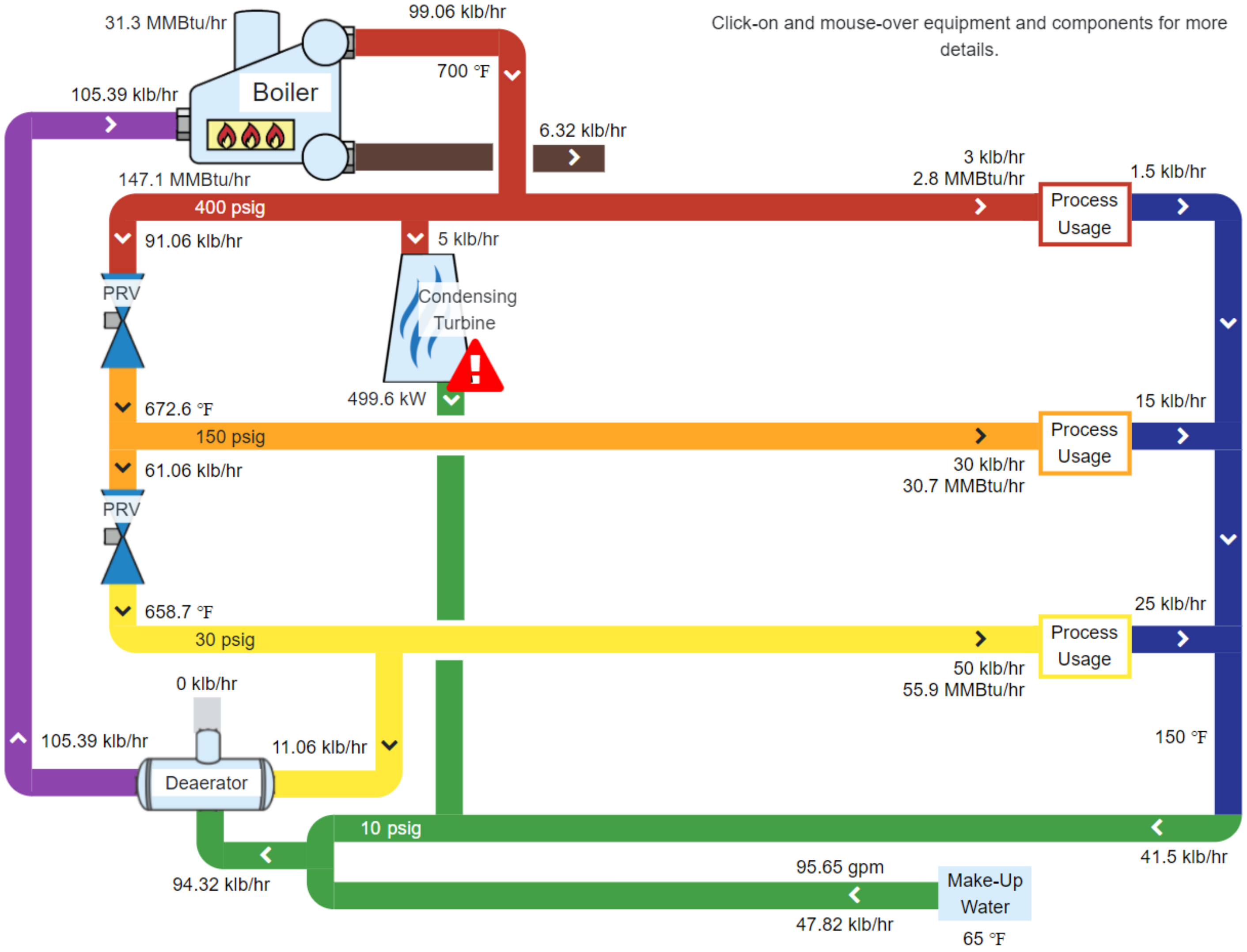
Pressure	150	psig
Process Steam Usage	30	klb/hr

Example Steam System – Pulp & Paper Mill

- Condensing turbine
  - 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



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

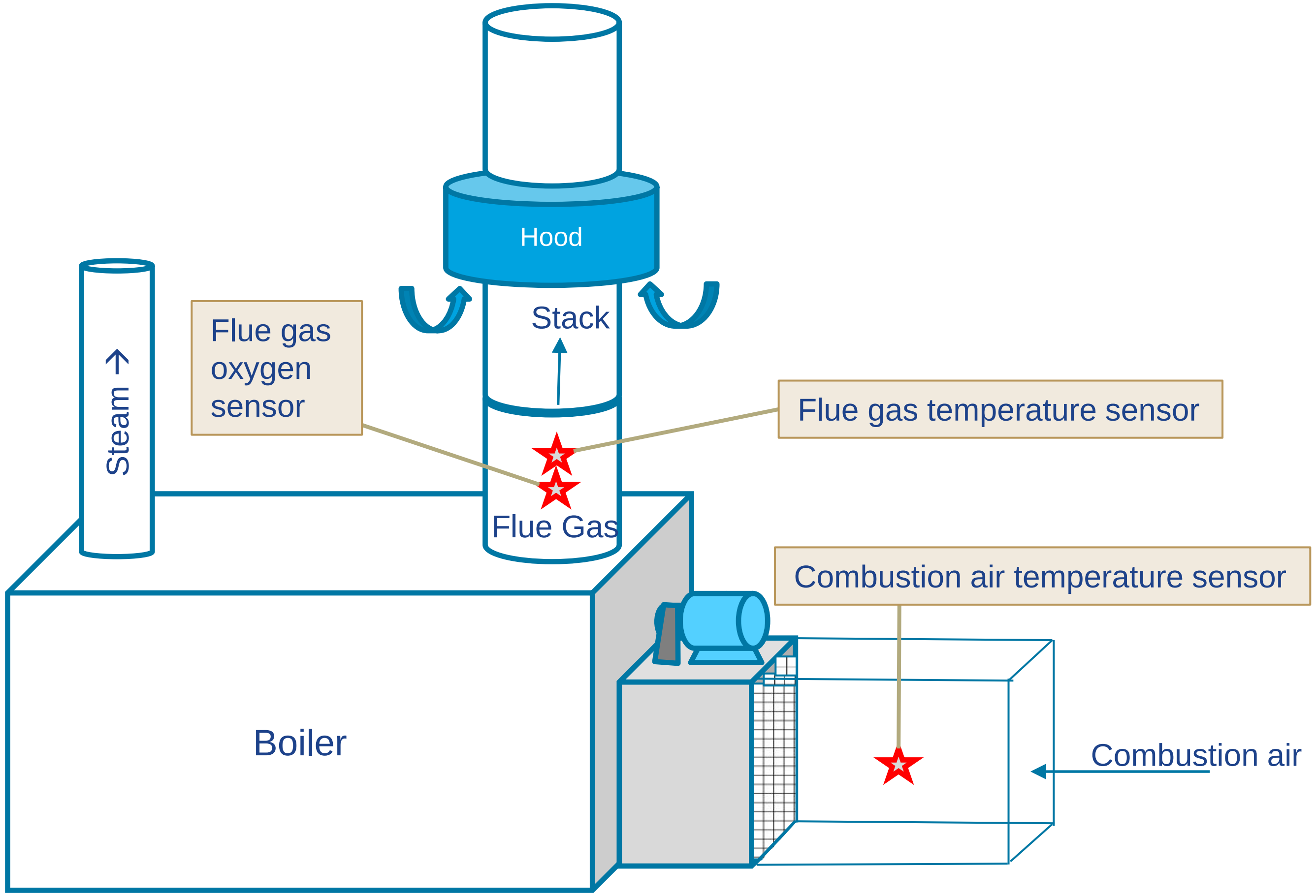
Common BestPractices - Generation

- 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

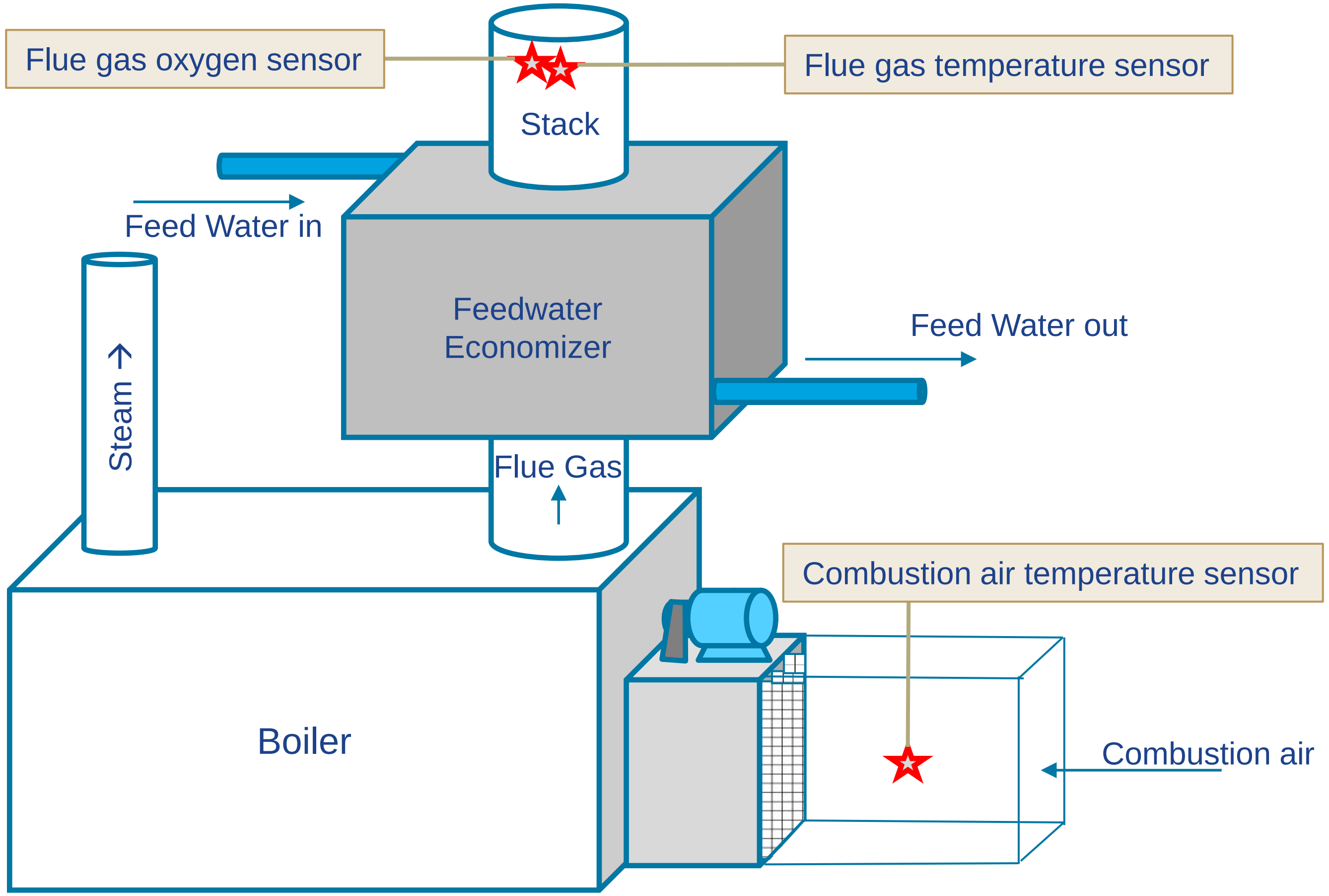
Energy Efficiency Opportunities (Generation)

- **Stack Heat Recovery**

Boiler with No Heat Recovery



Boiler with Feedwater Economizer



Polling Question 1

Polling Question

1) Do you have a feedwater economizer in your boiler?
   A. Yes
   B. No
   C. Do not know

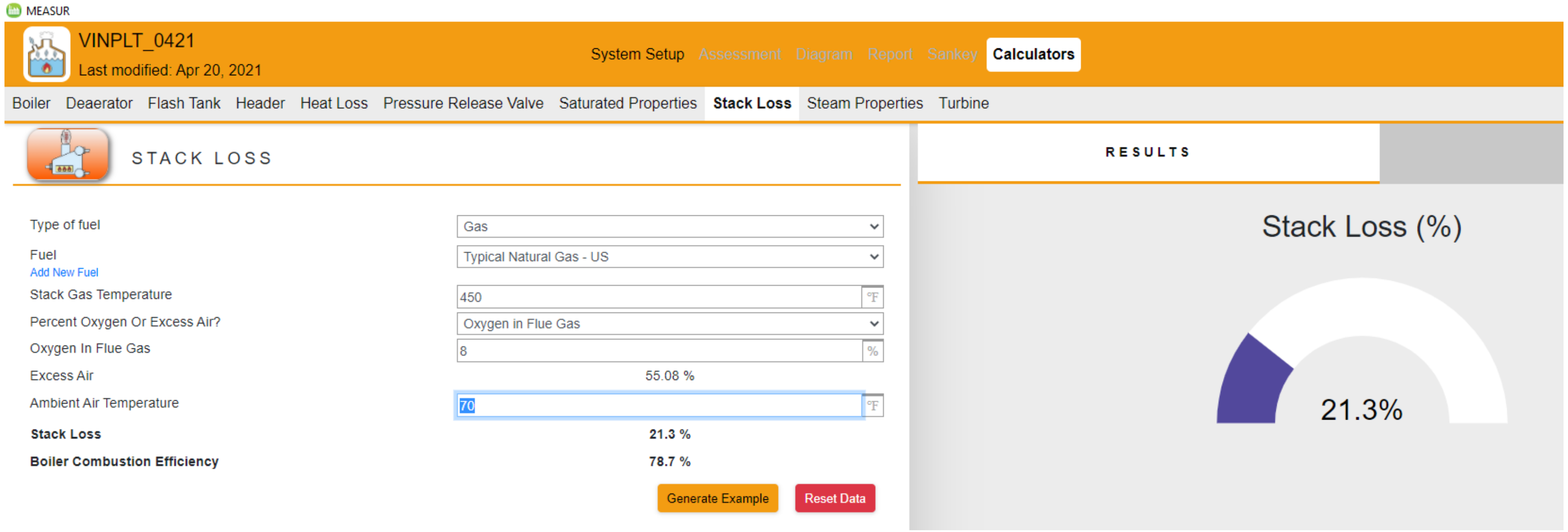
Flue Gas Temperature Loss

- A significant amount of energy resides in the flue gas
  - The temperature of the flue gas indicates the energy content

- A feedwater economizer recovers energy from the flue gas to the boiler feedwater through a heat exchanger
- A combustion air preheater recovers energy from the flue gas to the combustion air
  - Solid fuel boilers are more likely to have these components to aid in combustion by pre-drying the fuel

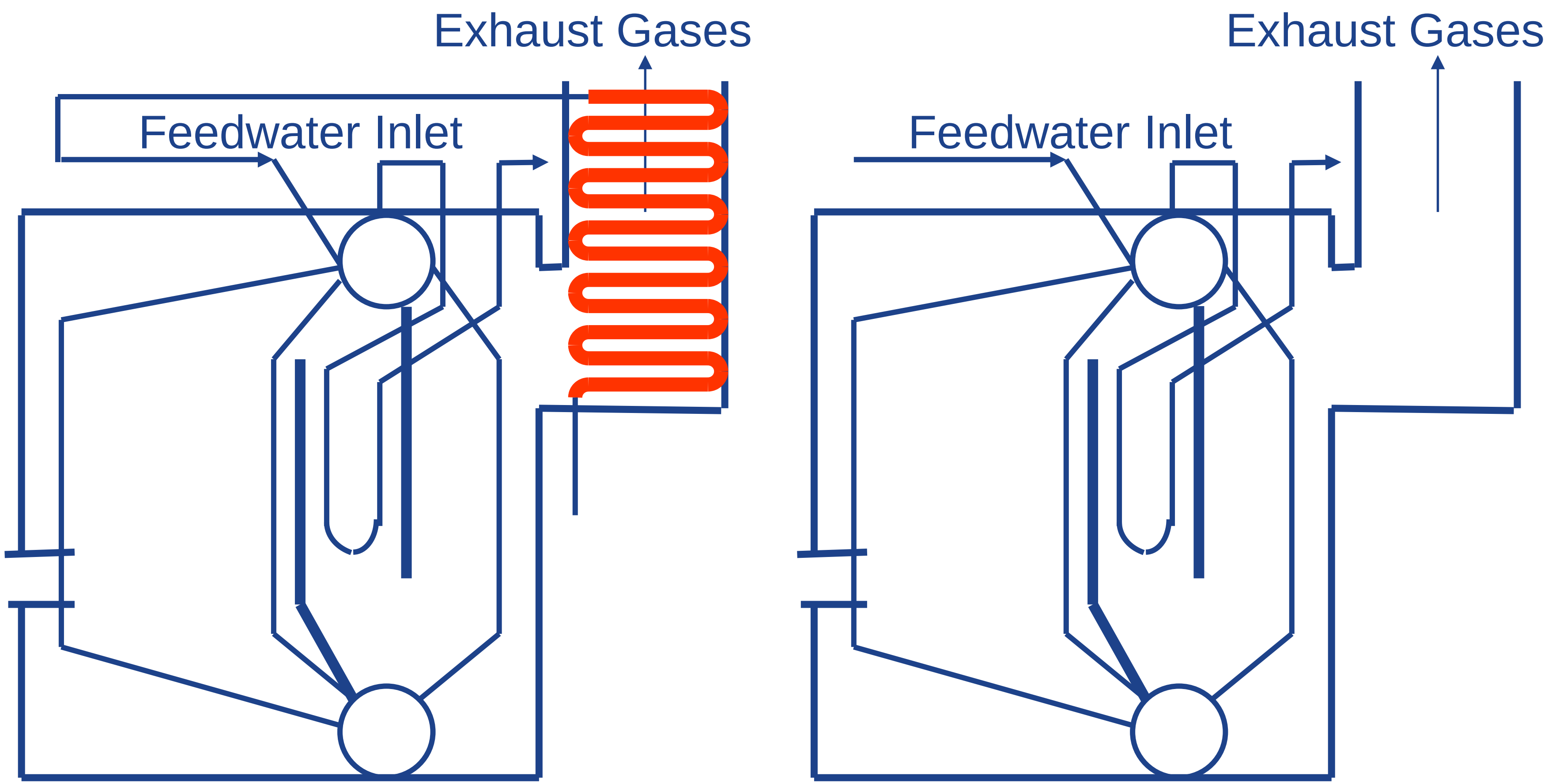
Example Steam System – Pulp & Paper Mill

- Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 8%



Energy Recovery Components

- Feedwater economizers can significantly improve boiler efficiency

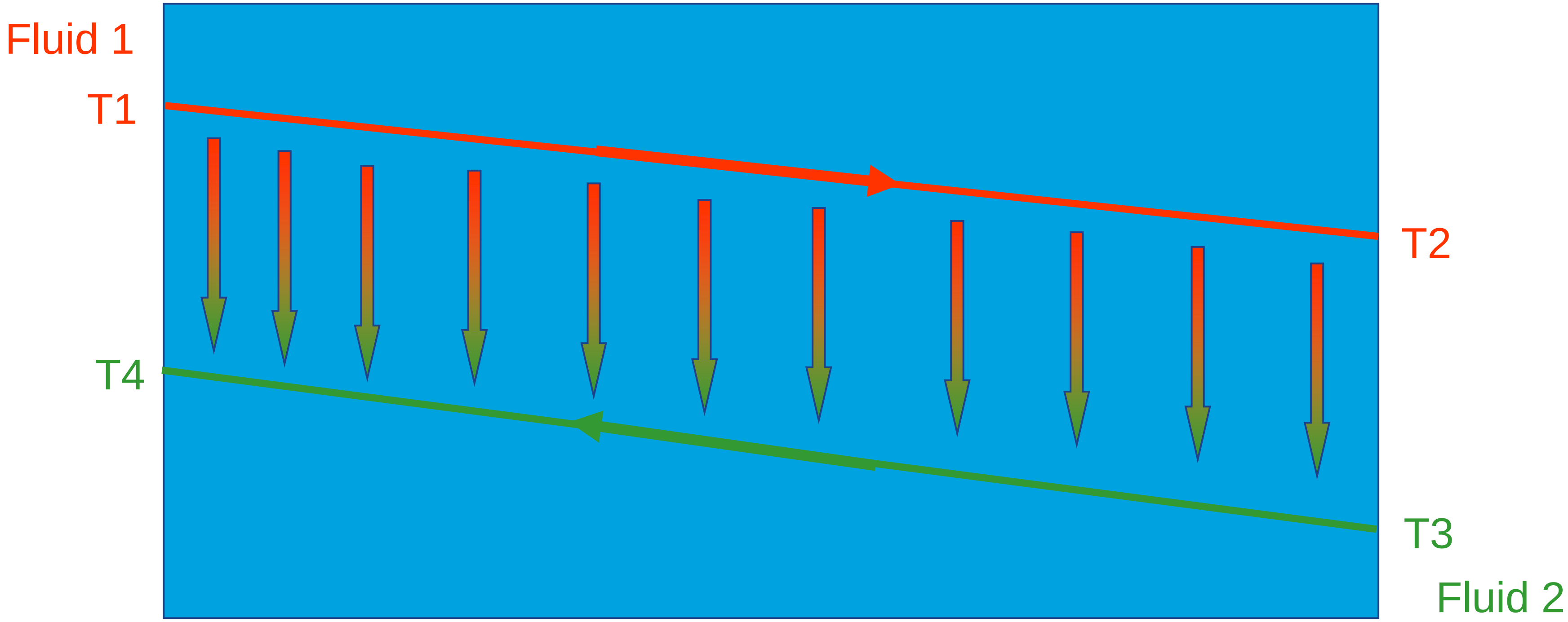


Concept of Heat Recovery

- Heat Recovery
  - Amount of available heat that can be recovered (Btu/hr)
  - Temperature at which this heat is available (°F)

- Equipment used to recover this heat
  - Indirect contact
    - Heat Exchangers – Shell & Tube, Tube coils, Plate/Frame
    - Most common
    - A finite temperature difference exists between the heat exchange media
  - Direct contact
    - Columns, Mixing chambers
    - Very application specific
    - Very close temperature approaches

Concept of Heat Recovery



T1 > T2

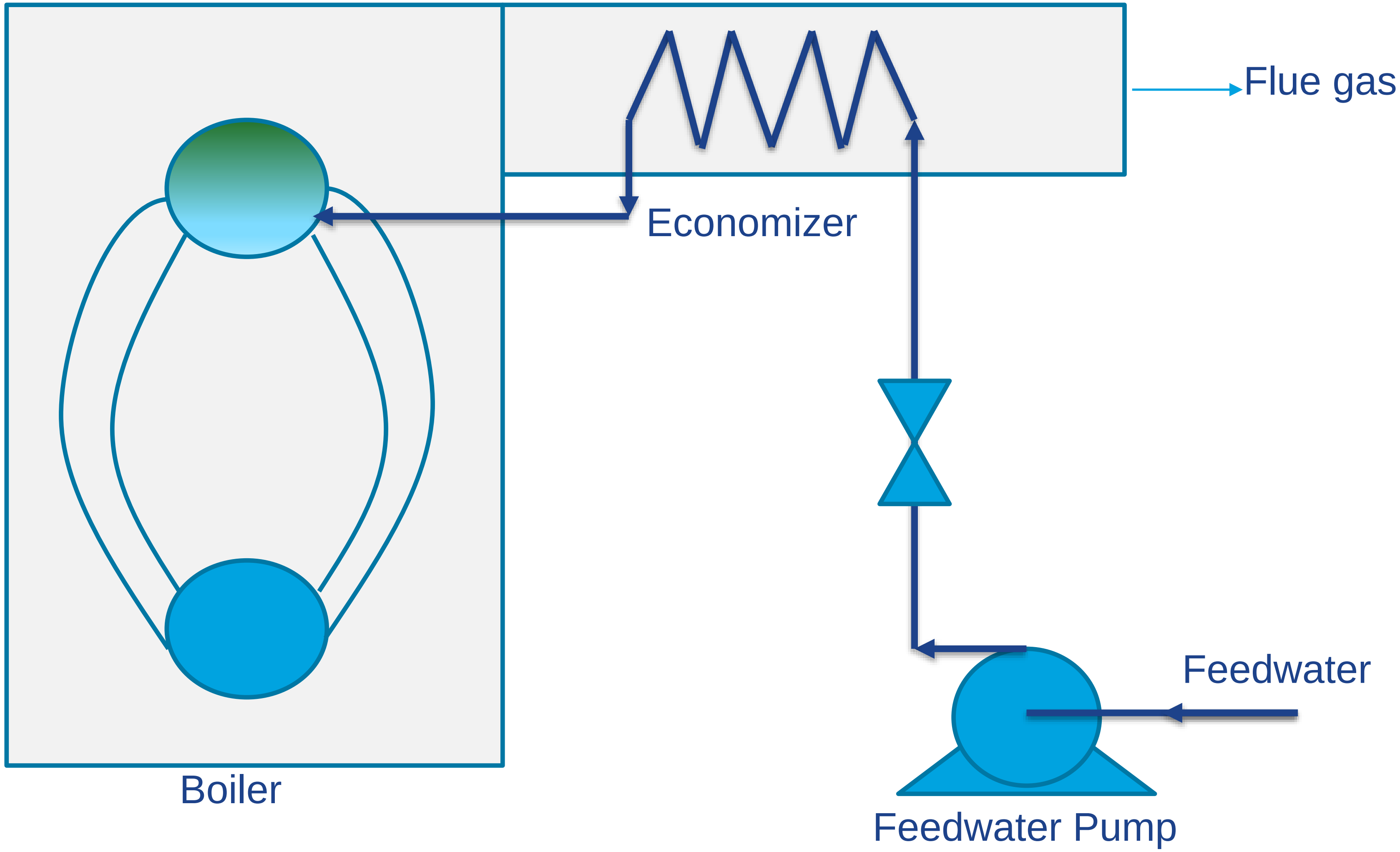
T3 < T4

Approach : T1 – T4; T2 – T3

Feedwater Economizers

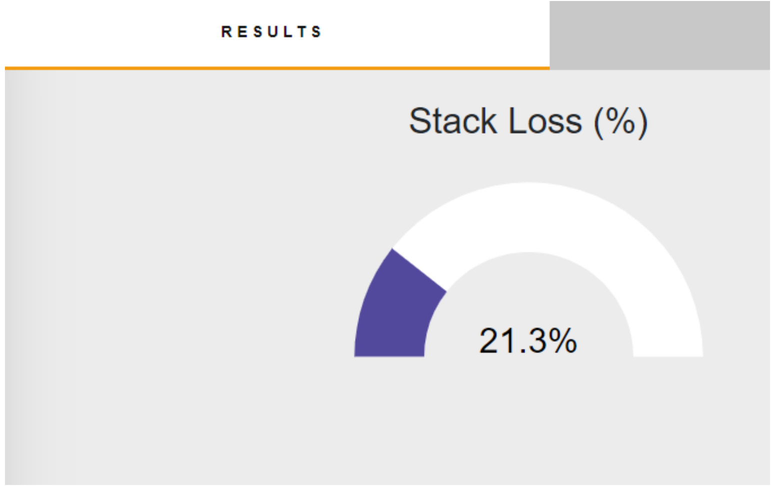
- Feedwater economizers are a special case of sensible stack (flue gas) heat recovery
- Feedwater exits the deaerator at saturation temperature equivalent to the deaerator pressure
- Typical feedwater temperatures are ~220 - 250°F
- Typical stack temperatures can be upwards of 400°F
- Hence, there exists an excellent opportunity to heat the feedwater before it enters the boiler
- This will lead to a reduction in the final stack gas temperature (~275 – 300°F)
- Eventually, it will reduce the amount of fuel required to generate steam since boiler feedwater is at a higher temperature

Feedwater Economizer (Simplest Configuration)

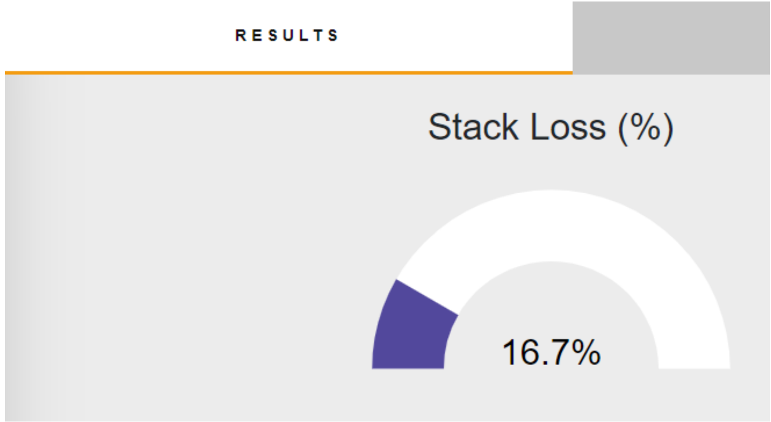


Example Steam System – Pulp & Paper Mill

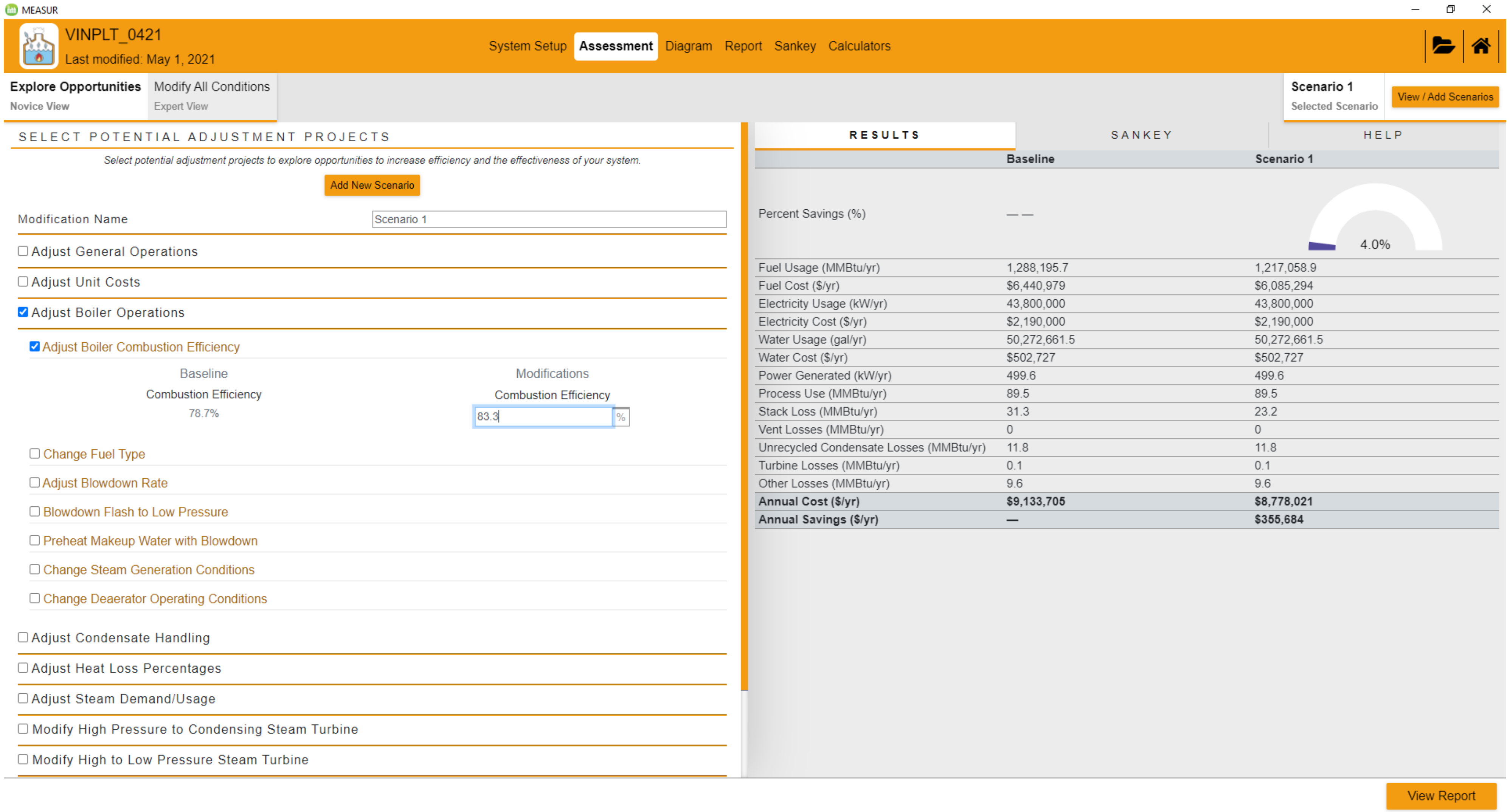
- Base Case Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 8%



- Modified Case Boiler information
  - Stack temperature = 300°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 8%



Example Steam System – Pulp & Paper Mill



	Baseline	Scenario 1
Percent Savings (%)	— —	4.0%
Fuel Usage (MMBtu/yr)	1,288,195.7	1,217,058.9
Fuel Cost ($/yr)	$6,440,979	$6,085,294
Electricity Usage (kW/yr)	43,800,000	43,800,000
Electricity Cost ($/yr)	$2,190,000	$2,190,000
Water Usage (gal/yr)	50,272,661.5	50,272,661.5
Water Cost ($/yr)	$502,727	$502,727
Power Generated (kW/yr)	499.6	499.6
Process Use (MMBtu/yr)	89.5	89.5
Stack Loss (MMBtu/yr)	31.3	23.2
Vent Losses (MMBtu/yr)	0	0
Unrecycled Condensate Losses (MMBtu/yr)	11.8	11.8
Turbine Losses (MMBtu/yr)	0.1	0.1
Other Losses (MMBtu/yr)	9.6	9.6
Annual Cost ($/yr)	**$9,133,705**	**$8,778,021**
Annual Savings ($/yr)	**—**	**$355,684**

Example Steam System – Pulp & Paper Mill

MEASUR

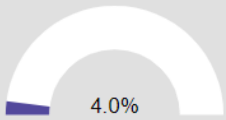
VINPLT_0421
Last modified: May 1, 2021

System Setup | Assessment | Diagram | **Report** | Sankey | Calculators

VINPLT_0421
Last Modified 5/1/21, 8:09 AM

Print | Export to CSV

Executive Summary | Energy Summary | Losses | Diagram | Report Graphs | Input Summary | Facility Info | Sankey

($/yr)	Baseline	Scenario 1
Percent Savings (%)	—	
Power Cost	$2,190,000	$2,190,000
Savings	—	$0
Fuel Cost	$6,440,979	$6,085,294
Savings	—	$355,684
Make-up Water Cost	$502,727	$502,727
Savings	—	$0
Annual Cost	**$9,133,705**	**$8,778,021**
Annual Savings	—	**$355,684**
Implementation Cost	—	—
Payback Period (months)	—	—
Selected Energy Projects	—	**Adjust Boiler Operations**
Modifications	—	**Boiler**

Feedwater & Make-up Water Economizer Examples

Feedwater & Make-up Water Economizer Examples

Feedwater Economizers

- Feedwater temperature control
  - Very important – should not be compromised
  - Will control flow to ensure that steam doesn’t form in the economizer tubes
  - Required for start-up conditions
  - Needed for low-fire conditions

- Flue gas temperature control
  - Required for start-up conditions
  - Needed for low-fire conditions
  - Required for steady-state operation also

- An increased maintenance can be avoided by ensuring that proper controls and strategy is implemented at installation

Polling Question 2

Polling Question

2) Do you monitor stack (inlet/outlet) and feedwater (inlet/outlet) temperatures for the economizer?

   A. Yes, all of them
   B. Only stack (inlet/outlet) temperatures
   C. Only feedwater (inlet/outlet) temperatures
   D. None of them
   E. Do not know

Condensing Economizers

- CONDENSING economizers are used for LATENT stack (flue gas) heat recovery
- Make-up water enters the condensing economizer at ambient temperatures
- Typical make-up water temperatures are ~70 - 80°F
- Typical condensing stack temperatures are 140 - 145°F
- Hence, there exists an excellent opportunity to heat the make-up water before it enters the deaerator
- This will lead to a reduction in the final stack gas temperature (~100 – 145°F)
- Eventually, it will reduce the amount of steam required in the deaerator since make-up water is at a higher temperature

Condensing Economizers

- Every application can benefit from a feedwater economizer
- Condensing economizer benefit is extremely **application specific** and cannot be generalized
- The main criterion to be satisfied for the condensing economizer application - Is there a need for a large amount of heat at a lower temperature (140°F)?

Condensing Economizers

- **LARGE** amount of **LOW** temperature heat available

- Condensing Economizer applications include:
  - Boiler make-up water heating, especially in cases where there is NO condensate return
  - Industrial process water heating
  - Pre-heating for feed streams in process industries
  - Clean-up/wash-down water heating
  - Laundry wash water
  - Domestic water heating
  - Space heating (HVAC)
  - Central plant and District heating systems
  - Absorption / Adsorption chiller systems

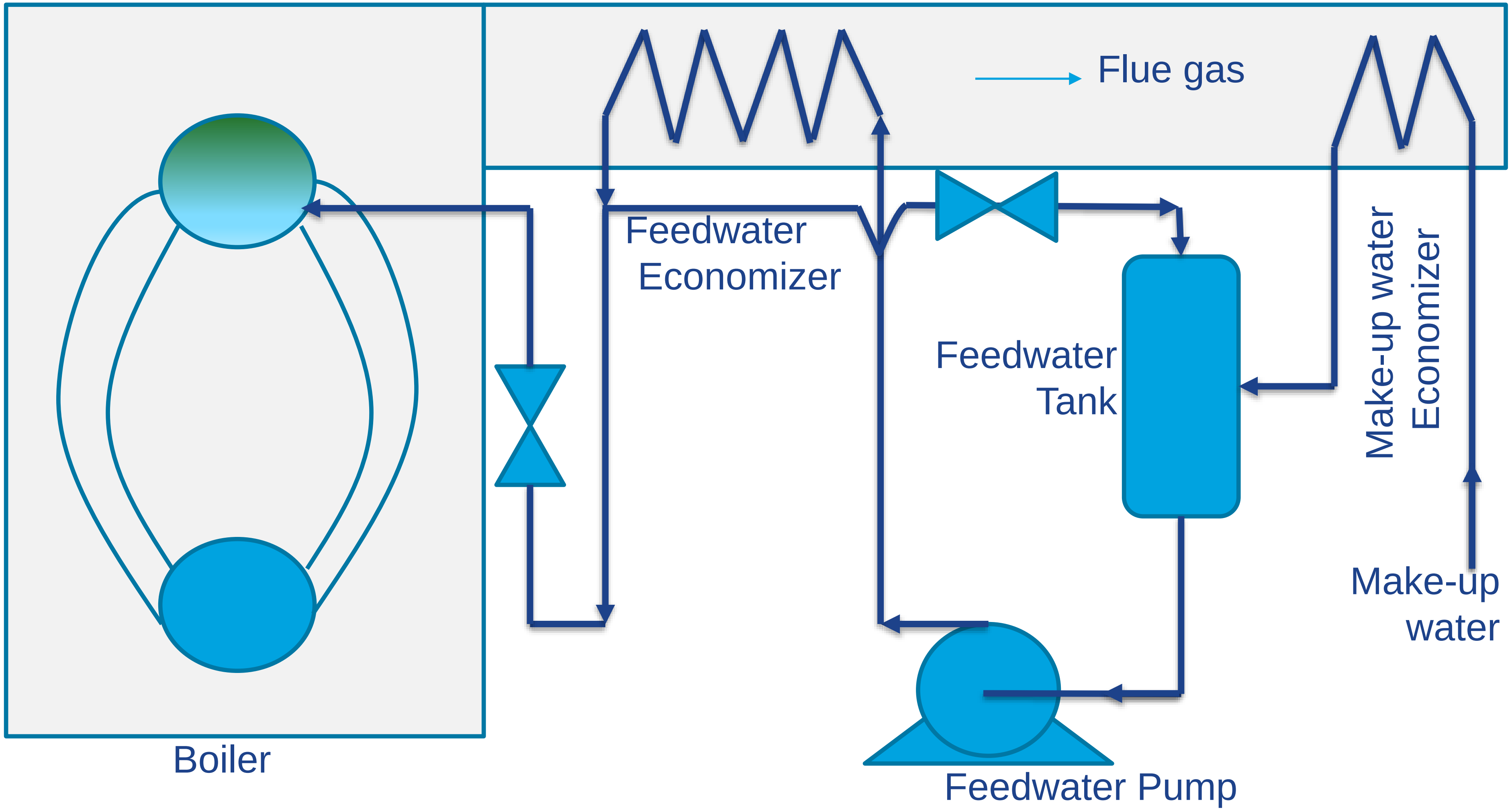
Condensing Economizers

- Some commercial / industrial facilities where Condensing Economizers can be found include:
  - Food processing industry
  - Specialty Chemicals – Rubber, Plastics, etc.
  - Breweries
  - Wineries
  - Greenhouses
  - Hospitals and Health Centers
  - Schools and Universities
  - Laundries
  - Hotels
  - Government Campuses and Buildings
  - HVAC – space heating applications

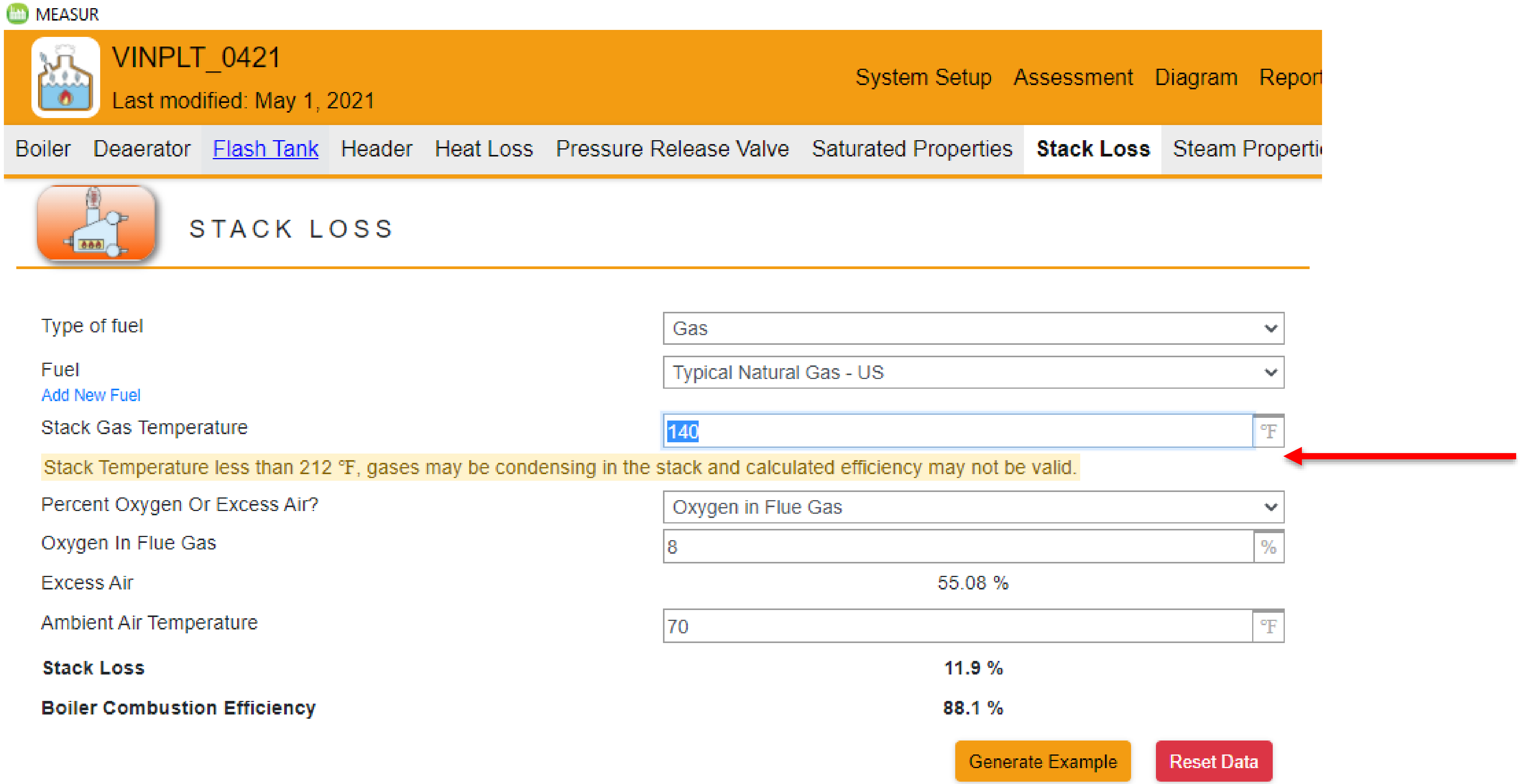
Condensing Economizers

- Similar to feedwater economizers, there are several manufacturers of condensing economizers
- Materials of construction (very important!)
  - Stainless Steel
  - Teflon coated aluminum
  - Other….
- Since they are custom designed – it is sometimes beneficial to involve an Engineering / Construction company for a turnkey project
- Condensed water is available
  - Mildly acidic due to carbonic acid but can be neutralized
- Additional controls required

Feedwater & Make-up Water Economizer (Complex Configuration)



Example Steam System – Pulp & Paper Mill



Condensing Economizers

Polling Question 3

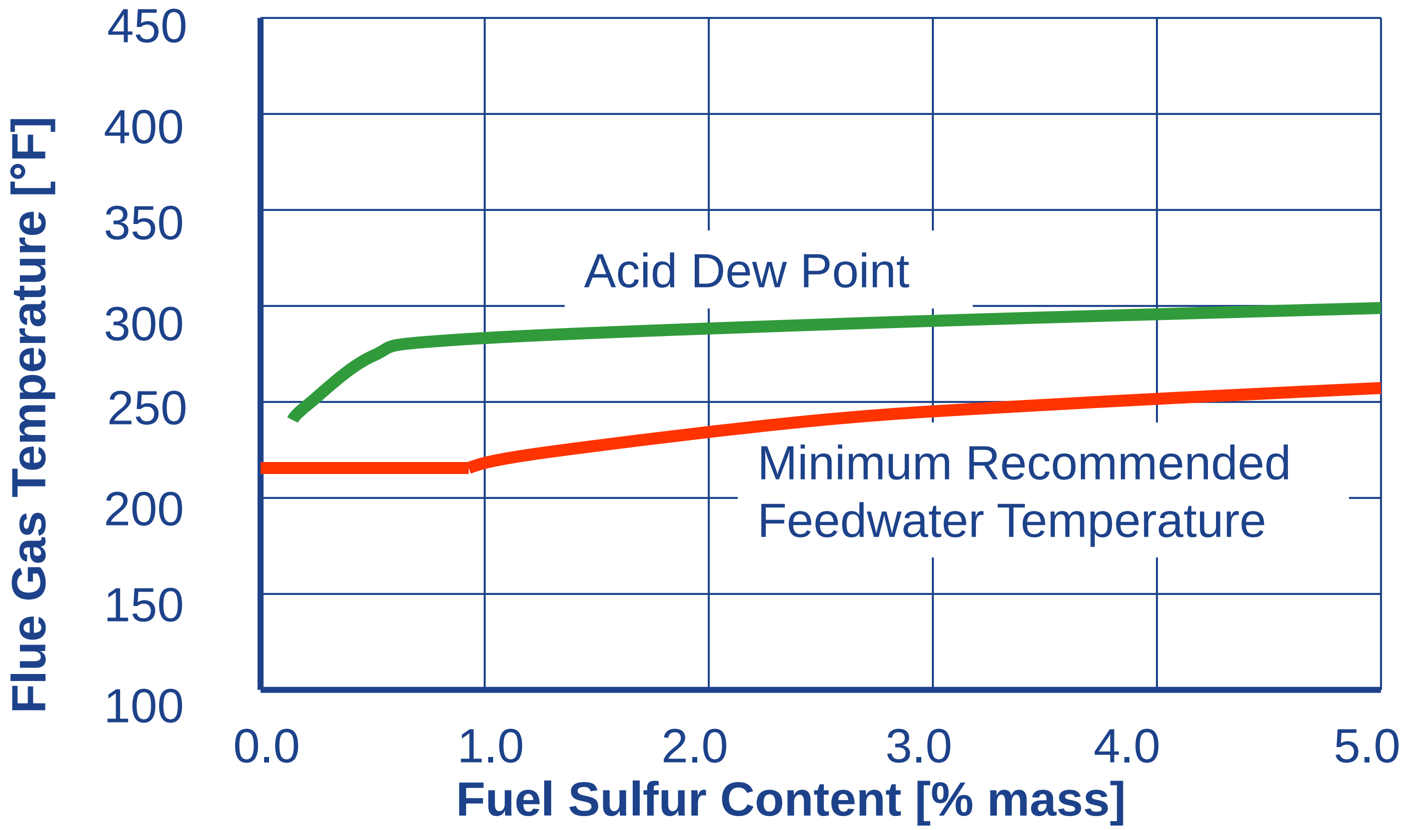
Polling Question

3) Do you have a condensing economizer in your boiler?

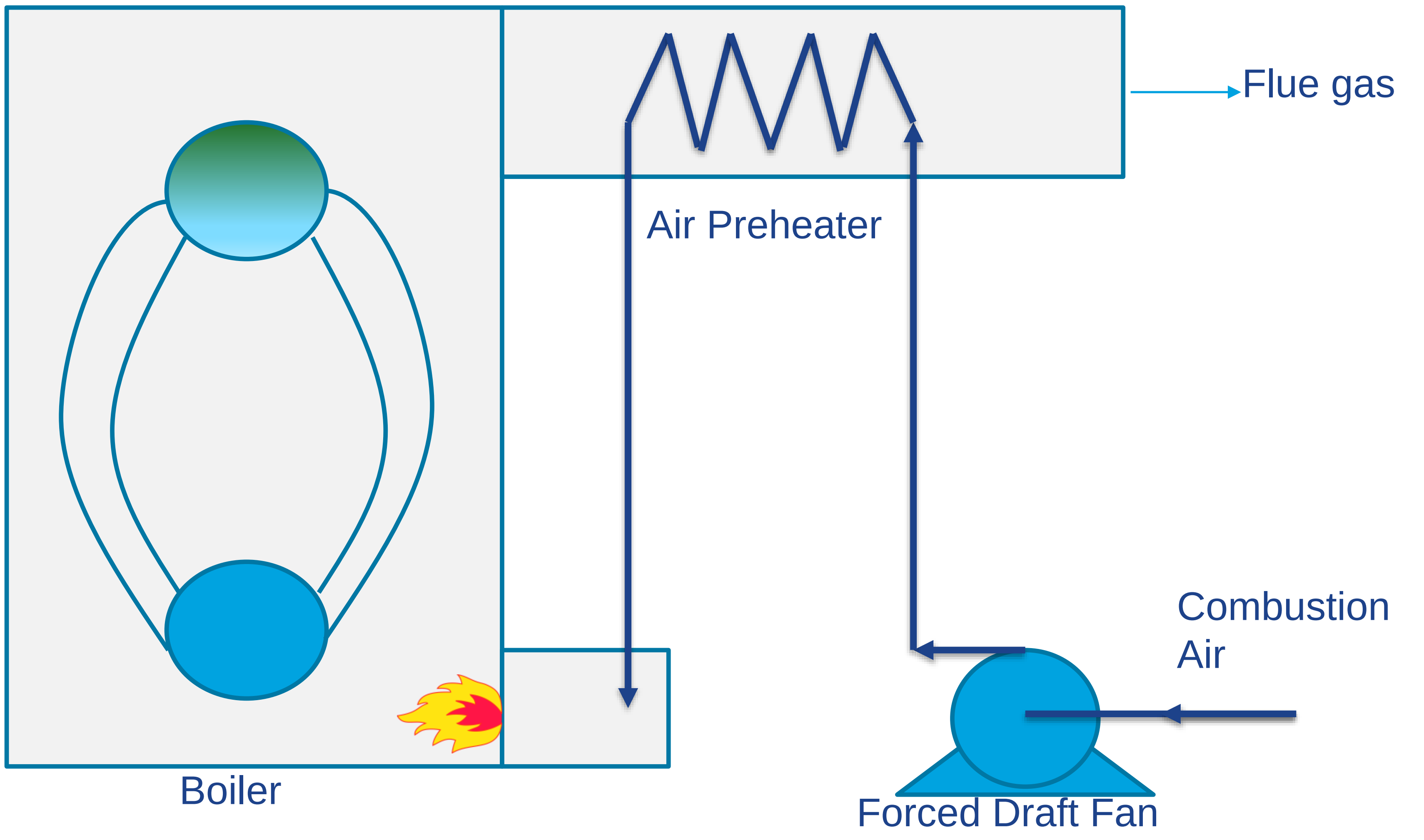
A. Yes
B. No
C. Do not know

Flue Gas Temperature Limitations

- Flue gas temperature is maintained above the dew point of acidic components
  - Fuels containing sulfur produce sulfuric acid
  - Hydrocarbon fuels not containing sulfur produce carbonic acid



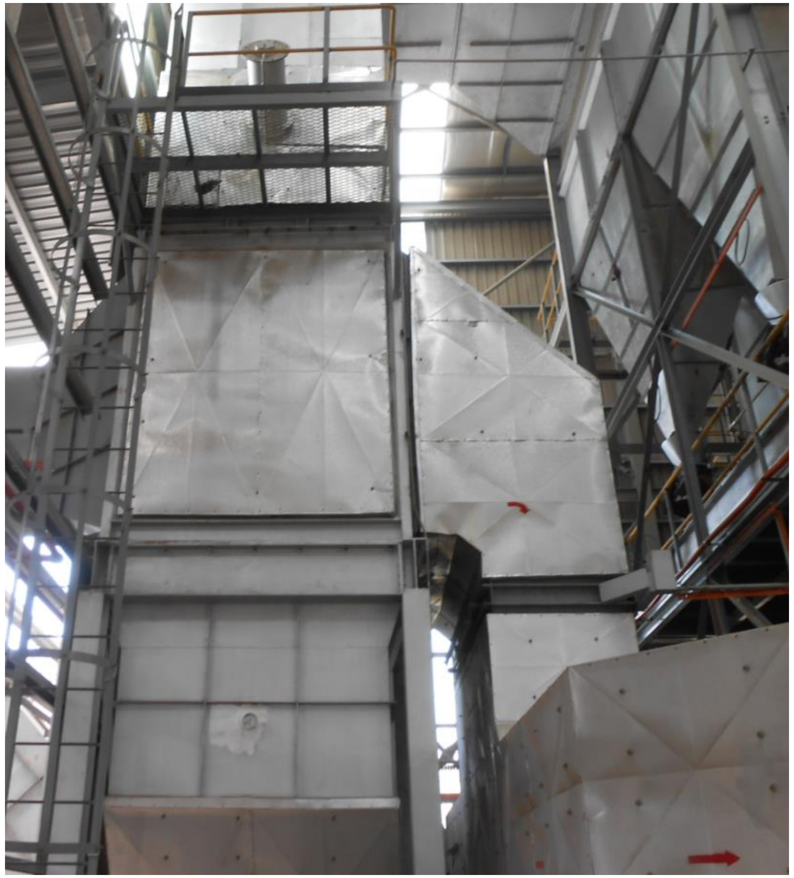
Air Preheaters

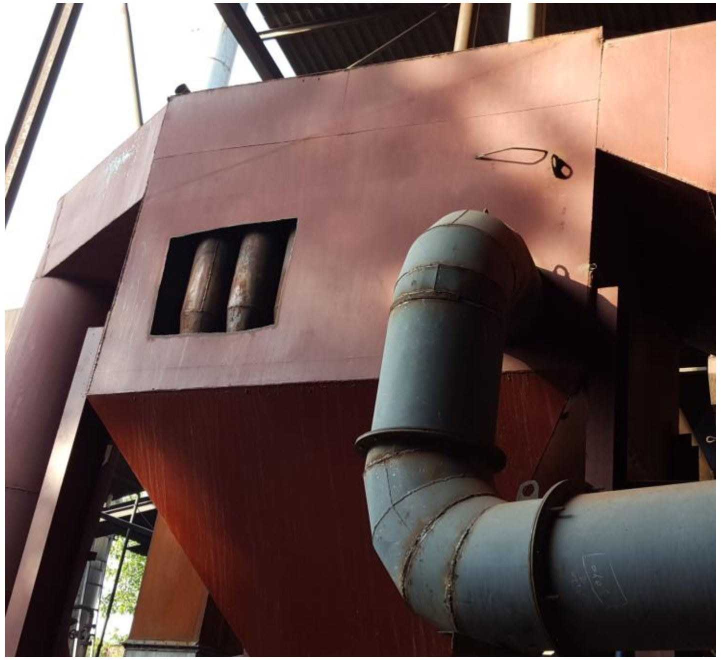


AirPreheater Options

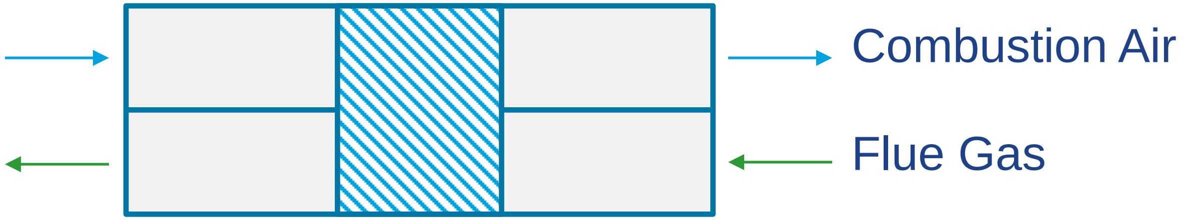
- Just one configuration when by itself
- With a feedwater economizer, almost always feedwater economizer is upstream in the flue gas
  - But there are a few exceptions where the air preheater is upstream of the economizer
- Very large surface area and cross-sectional area needed
  - Minimize pressure drop – reduce velocity
  - Air-to-Air heat transfer coefficient is very bad
  - Leads to higher first cost
- Generally, will need an induced draft fan to avoid backpressure on furnace
- Solid fuels (biomass) require drying (removing moisture) and air preheaters can be used very effectively for that purpose

AirPreheater Examples





AirPreheater Examples



Rotary Wheel

Temperature Loss Management - Summary

- Monitor and record flue gas temperature with respect to:
  - Boiler load
  - Ambient temperature
  - Flue gas oxygen content
- Compare flue gas temperature to previous, similar operating conditions
- Maintain appropriate fire-side cleaning
- Maintain appropriate water chemistry
- Evaluate heat recovery component savings potential

Energy Efficiency Opportunities (Generation)

- Combustion

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Theoretical Air

- In a perfect world air and fuel would mix completely and complete combustion would occur
  - Each molecule of fuel would find exactly the correct amount of oxygen for the combustion reaction to take place
    - This is referred to as stoichiometric combustion

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

Actual Combustion

- In actual combustion processes the fuel and oxygen do not react perfectly
  - Other chemicals are formed

$$CH_4 + 2O_2 \underbrace{\rightarrow}_{\text{Energy Release}} \alpha\, CO_2 + \beta\, H_2O + \gamma\, CO + \delta\, H_2 + \varepsilon\, CH_4 + \zeta\, O_2$$

- Un-reacted CH_4, CO, and H_2 result from incomplete combustion
  - Safety
  - Health
  - Efficiency
- O_2 exits the combustion region relatively benign
  - If excess O_2 is provided to the combustion process un-reacted fuel is *essentially* eliminated.
    - Therefore, excess oxygen is added to the combustion process to *virtually* eliminate un-reacted fuel.

Combustion Management – Principle 1

- Un-reacted CH_4, CO, and H_2 harm combustion operations
  - Safety problems
  - Health issues
  - Efficiency detriments

- Combustion management strives to eliminate un-reacted fuel by adding extra *oxygen* to the combustion zone
  - Excess O_2 provided to the combustion zone ***essentially* eliminates un-reacted fuel**

$$CH_4 + 2O_2 \underbrace{\rightarrow}_{\text{Energy Release}} \alpha CO_2 + \beta H_2O + \gamma CO + \delta H_2 + \varepsilon CH_4 + \zeta O_2$$

Actual Combustion

- The extra oxygen is added to ensure the fuel reacts completely
  - The extra oxygen is heated by fuel from ambient temperature to the temperature of the exhaust gas

$$CH_4 + \underbrace{2O_2}_{+2(3.76)N_2} \underbrace{\rightarrow}_{\text{Energy Release}} \alpha\, CO_2 + \beta\, H_2O + \gamma\, CO + \delta\, H_2 + \varepsilon\, CH_4 + \underbrace{\zeta\, O_2}_{+2(3.76)N_2}$$

- For most combustion processes air is used as the source for oxygen
  - Air contains approximately 79% nitrogen (N_2), which *basically* does not enter into the combustion reaction

Combustion Management – Principle 2

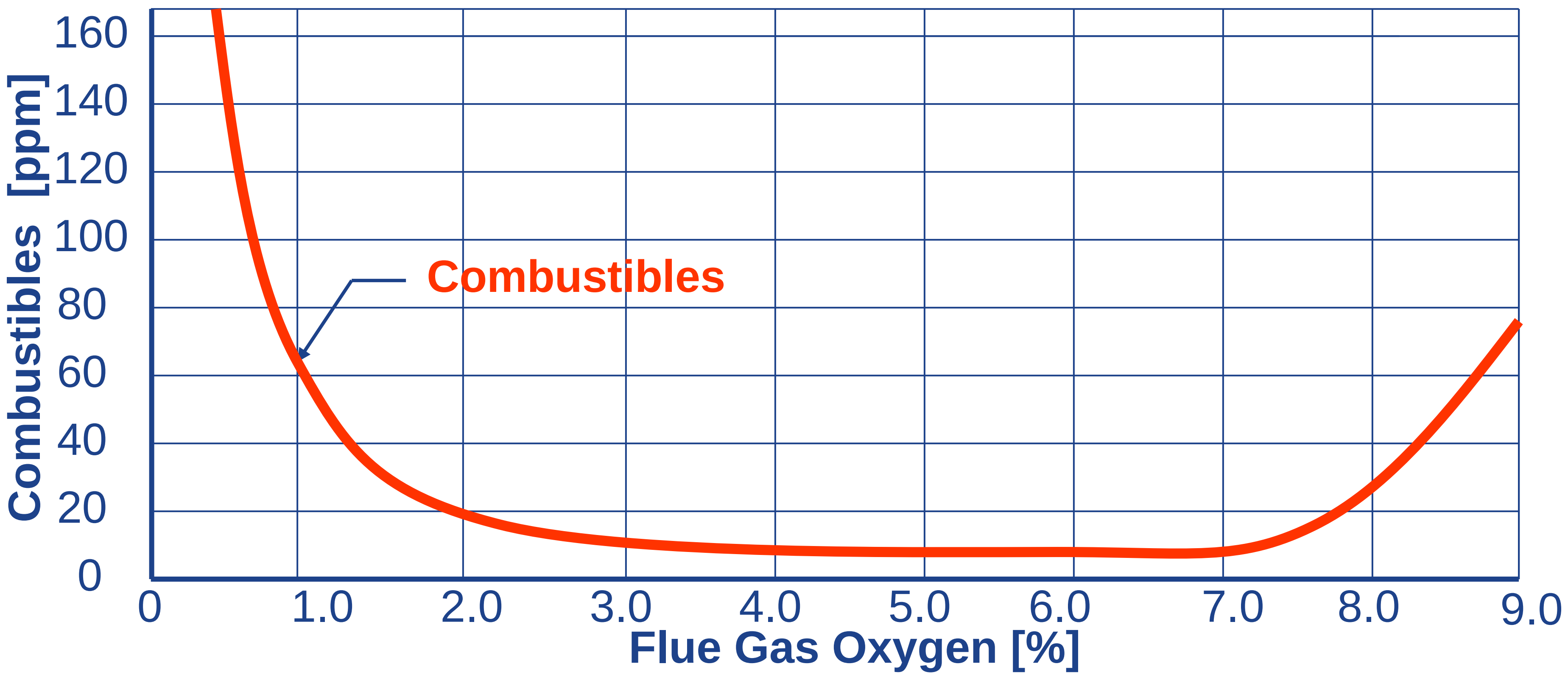
- The extra oxygen added to ensure complete reaction of the fuel is heated by fuel from ambient temperature to the temperature of the exhaust gas

$$CH_4 + \underbrace{2O_2}_{+2(3.76)N_2} \underset{\text{Energy Release}}{\rightarrow} \alpha CO_2 + \beta H_2O + \gamma CO + \delta H_2 + \varepsilon CH_4 + \underbrace{\zeta O_2}_{+2(3.76)N_2}$$

- For most combustion processes *air* is used as the source of oxygen
  - A large amount of N_2 is heated from ambient temperature to exhaust gas temperature by fuel energy

Minimum Oxygen Evaluation

- Minimum oxygen limits are determined by measuring combustibles



Oxygen Limits

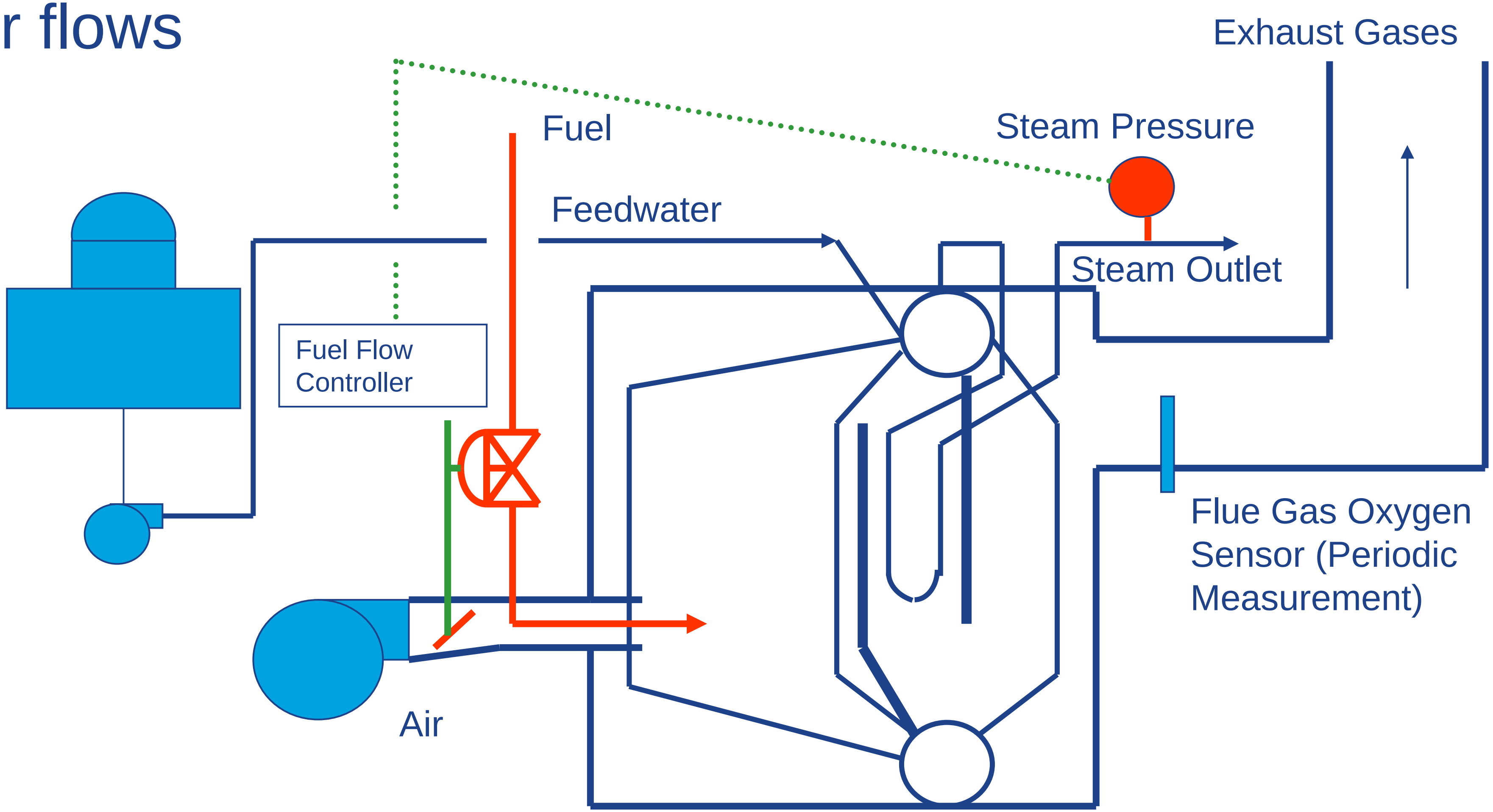
- What are the factors affecting oxygen limits?
  - Fuel
  - Control method
  - Boiler load
  - Sensing location
  - Burner condition

Typical Flue Gas Oxygen Content Control Parameters

Typical Flue Gas Oxygen Content Control Parameters								
Fuel	Automatic Control Flue Gas O_2 Content		Positioning Control Flue Gas O_2 Content		Automatic Control Excess Air		Positioning Control Excess Air	
	Min. [%]	Max. [%]	Min. [%]	Max. [%]	Min. [%]	Max. [%]	Min. [%]	Max. [%]
Natural Gas	1.5	3.0	3.0	7.0	9	18	18	55
Numb. 2 Fuel Oil	2.0	3.0	3.0	7.0	11	18	18	55
Numb. 6 Fuel Oil	2.5	3.5	3.5	8.0	14	21	21	65
Pulverized Coal	2.5	4.0	4.0	7.0	14	25	25	50
Stoker Coal	3.5	5.0	5.0	8.0	20	32	32	65

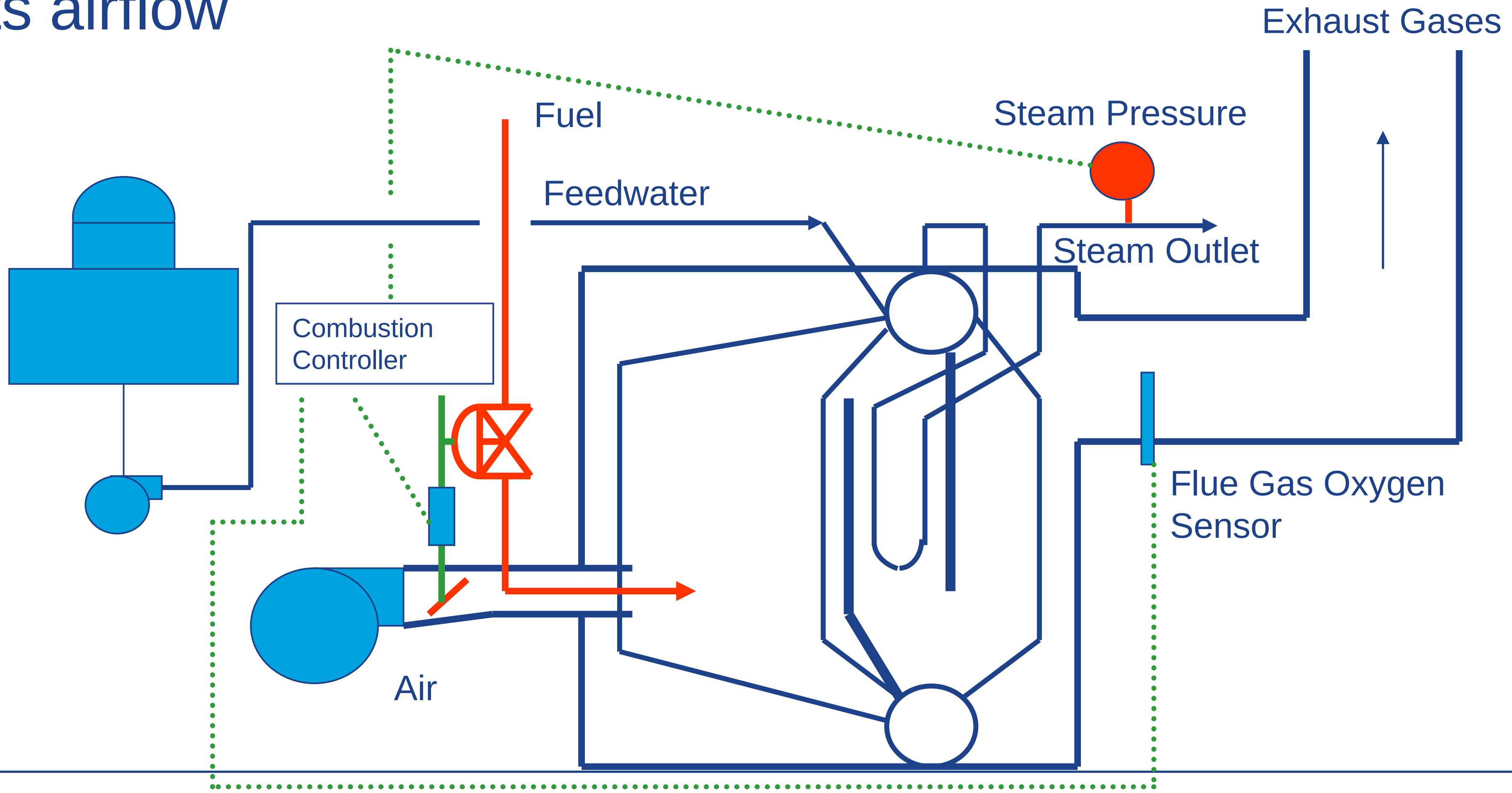
Positioning Control

- *Positioning control* maintains a position relationship between the fuel and air flows



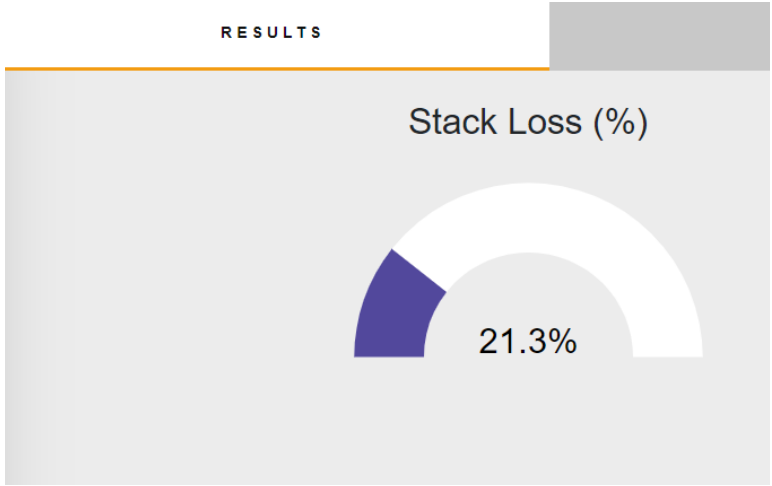
Trim Control

- *Trim* or *automatic control* continuously monitors oxygen and adjusts airflow

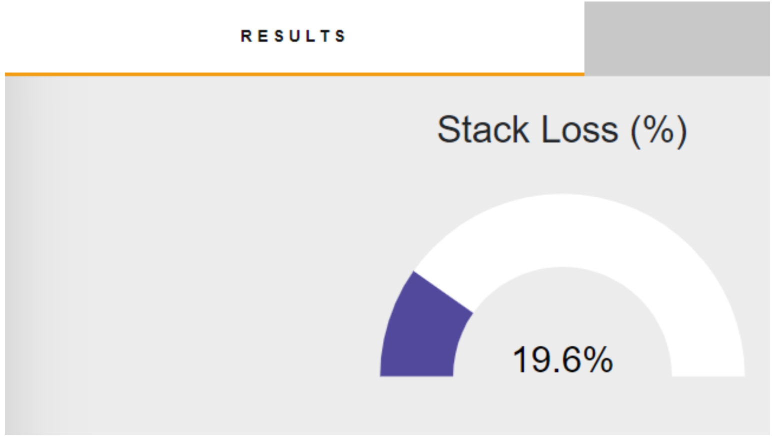


Example Steam System – Pulp & Paper Mill

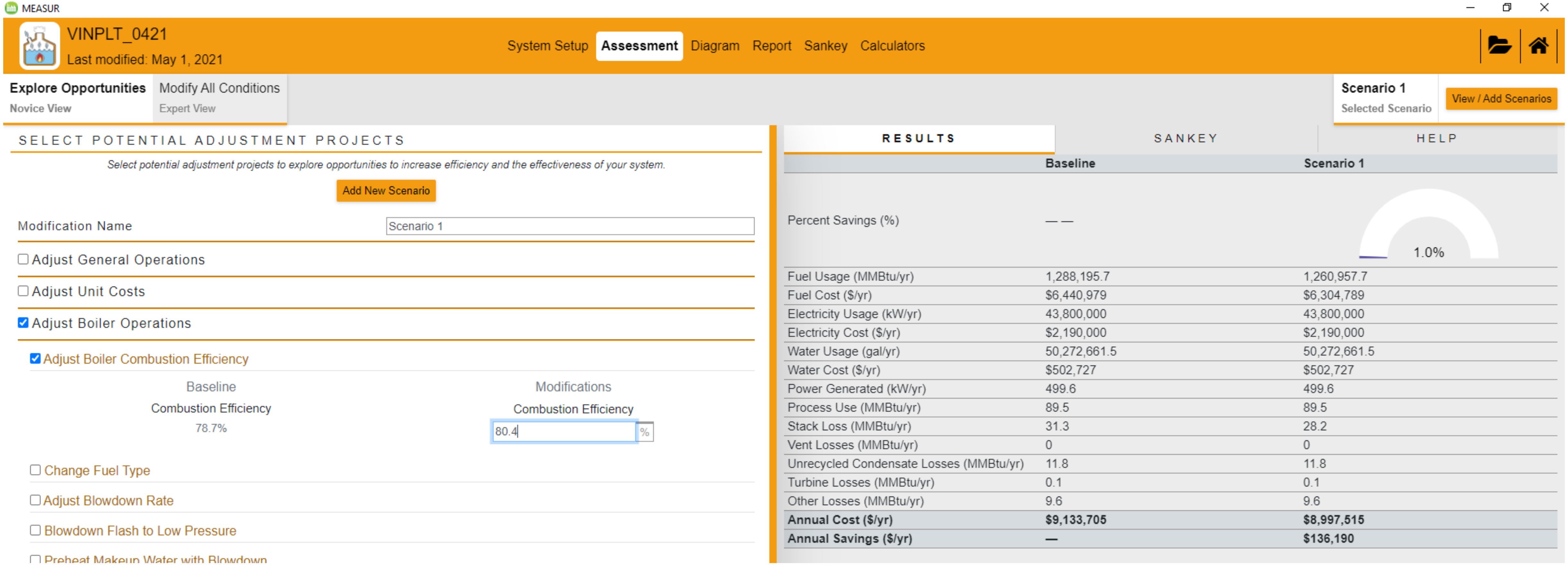
- Base Case Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 8%



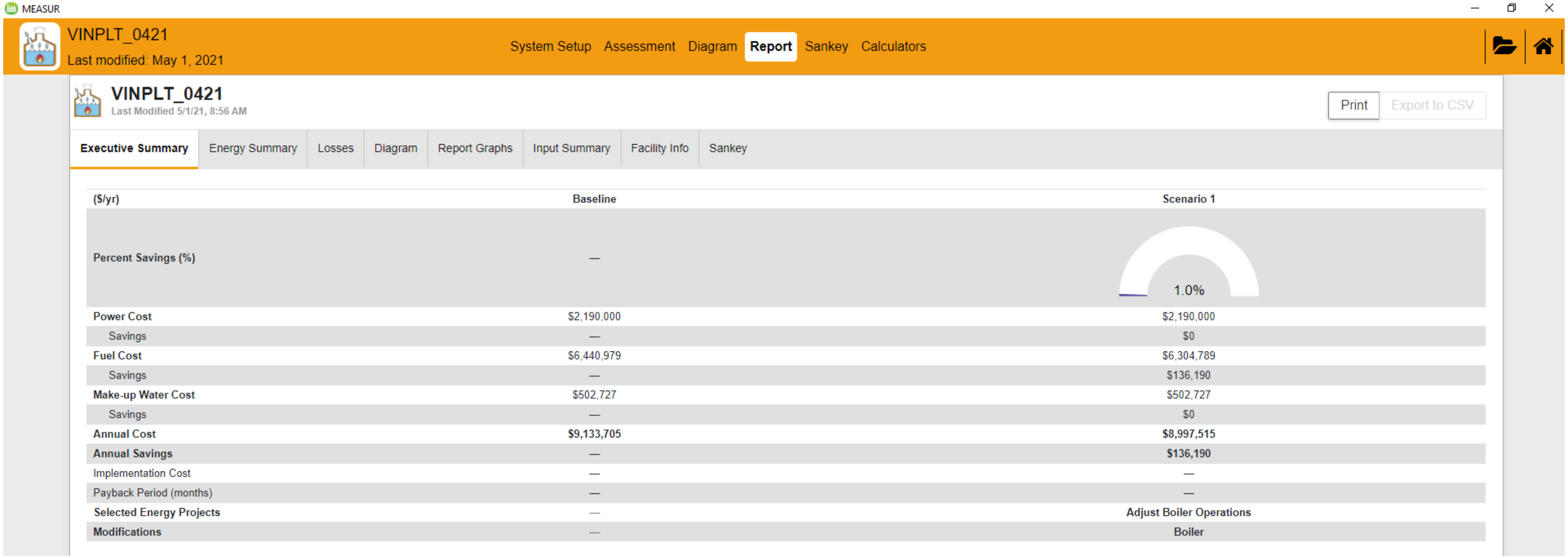
- Modified Case Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 5% (Positional control)



Example Steam System – Pulp & Paper Mill



Example Steam System – Pulp & Paper Mill



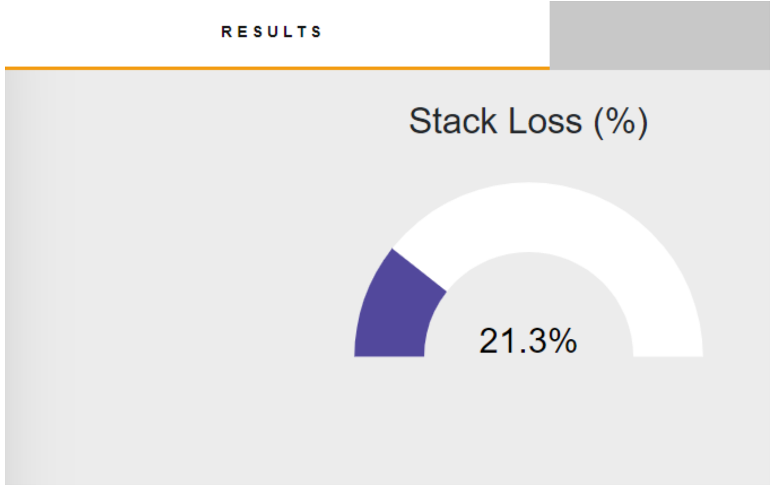
($/yr)	Baseline	Scenario 1
Percent Savings (%)	—	1.0%
Power Cost	$2,190,000	$2,190,000
Savings	—	$0
Fuel Cost	$6,440,979	$6,304,789
Savings	—	$136,190
Make-up Water Cost	$502,727	$502,727
Savings	—	$0
Annual Cost	**$9,133,705**	**$8,997,515**
Annual Savings	—	**$136,190**
Implementation Cost	—	—
Payback Period (months)	—	—
Selected Energy Projects	—	**Adjust Boiler Operations**
Modifications	—	**Boiler**

Typical Flue Gas Oxygen Content Control Parameters

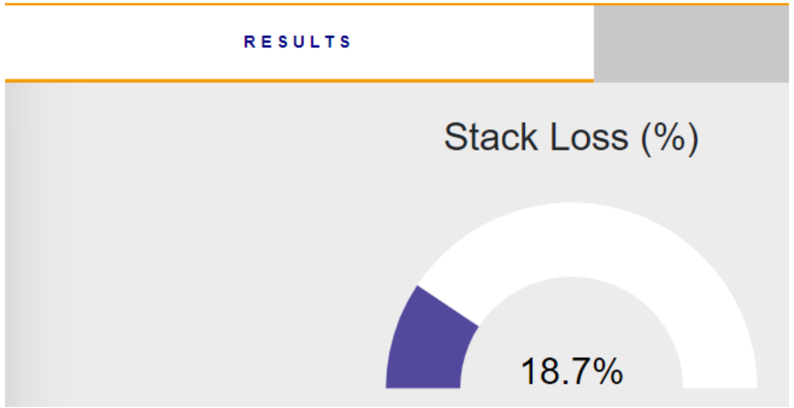
Typical Flue Gas Oxygen Content Control Parameters								
Fuel	Automatic Control Flue Gas O_2 Content		Positioning Control Flue Gas O_2 Content		Automatic Control Excess Air		Positioning Control Excess Air	
	Min. [%]	Max. [%]	Min. [%]	Max. [%]	Min. [%]	Max. [%]	Min. [%]	Max. [%]
Natural Gas	1.5	3.0	3.0	7.0	9	18	18	55
Numb. 2 Fuel Oil	2.0	3.0	3.0	7.0	11	18	18	55
Numb. 6 Fuel Oil	2.5	3.5	3.5	8.0	14	21	21	65
Pulverized Coal	2.5	4.0	4.0	7.0	14	25	25	50
Stoker Coal	3.5	5.0	5.0	8.0	20	32	32	65

Example Steam System – Pulp & Paper Mill

- Base Case Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 8%



- Modified Case Boiler information
  - Stack temperature = 450°F
  - Feedwater temperature = 240°F
  - Ambient temperature = 70°F
  - Flue gas oxygen = 3% (Trim control)



Example Steam System – Pulp & Paper Mill

MEASUR

VINPLT_0421
Last modified: May 1, 2021

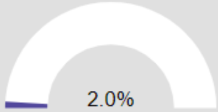
System Setup | Assessment | Diagram | **Report** | Sankey | Calculators

VINPLT_0421

Last Modified 5/1/21, 9:03 AM

Print | Export to CSV

Executive Summary | Energy Summary | Losses | Diagram | Report Graphs | Input Summary | Facility Info | Sankey

($/yr)	Baseline	Scenario 1
Percent Savings (%)	—	 2.0%
Power Cost	$2,190,000	$2,190,000
Savings	—	$0
Fuel Cost	$6,440,979	$6,234,994
Savings	—	$205,985
Make-up Water Cost	$502,727	$502,727
Savings	—	$0
Annual Cost	**$9,133,705**	**$8,927,721**
Annual Savings	—	**$205,985**
Implementation Cost	—	—
Payback Period (months)	—	—
Selected Energy Projects	—	**Adjust Boiler Operations**
Modifications	—	**Boiler**

Polling Question 4

Polling Question

4) Do you have an automatic oxygen control trim system in your boiler?

A. Yes
B. No
C. Do not know

Combustion Control Opportunity

- Improving combustion control often presents an energy management opportunity
- Controlling excess air (flue gas oxygen) to optimized levels increases boiler efficiency
- Several factors need to be considered to optimize excess air but the main factors are:
  - Fuel
  - Control mechanism
  - Emission regulations

Combustion Management - Summary

- Combustion management principles:
  - Add enough oxygen to react all of the fuel
  - Minimize the amount of extra air to limit the energy loss
  - Monitor combustibles to identify problems

1. Measure the oxygen content of boiler exhaust gas
   a. Continuously
   b. Periodically
2. Control oxygen content within a minimum and maximum range
   a. Continuous-automatic control
   b. Positioning control
3. Challenge the control range
   a. Combustibles measurement
   b. Burner repair
   c. Control upgrade

Example Steam System – Pulp & Paper Mill

Executive Summary | Energy Summary | Losses | Diagram | Report Graphs | Input Summary | Facility Info | Sankey

($/yr)	Baseline	Economizer	Trim Control	Econ + Trim
Percent Savings (%)	—	4.0%	2.0%	5.0%
Power Cost	$2,190,000	$2,190,000	$2,190,000	$2,190,000
Savings	—	$0	$0	$0
Fuel Cost	$6,440,979	$6,085,294	$6,234,994	$5,970,613
Savings	—	$355,684	$205,985	$470,366
Make-up Water Cost	$502,727	$502,727	$502,727	$502,727
Savings	—	$0	$0	$0
Annual Cost	**$9,133,705**	**$8,778,021**	**$8,927,721**	**$8,663,339**
Annual Savings	—	**$355,684**	**$205,985**	**$470,366**
Implementation Cost	—	—	—	—
Payback Period (months)	—	—	—	—
Selected Energy Projects	—	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations
Modifications	—	Boiler	Boiler	Boiler

Energy Efficiency Opportunities (Generation)

- Blowdown Control (Reduction)
- Blowdown Heat Recovery

Blowdown Management

- Blowdown amount is primarily dependent on:
  - Water quality
  - Boiler operating pressure
- Blowdown management typically takes two forms:
  - Water quality improvement
  - Improved blowdown control
  - Heat recovery
- Blowdown management begins with *measurement*
  - Typically, blowdown amount is estimated from boiler water chemical analysis

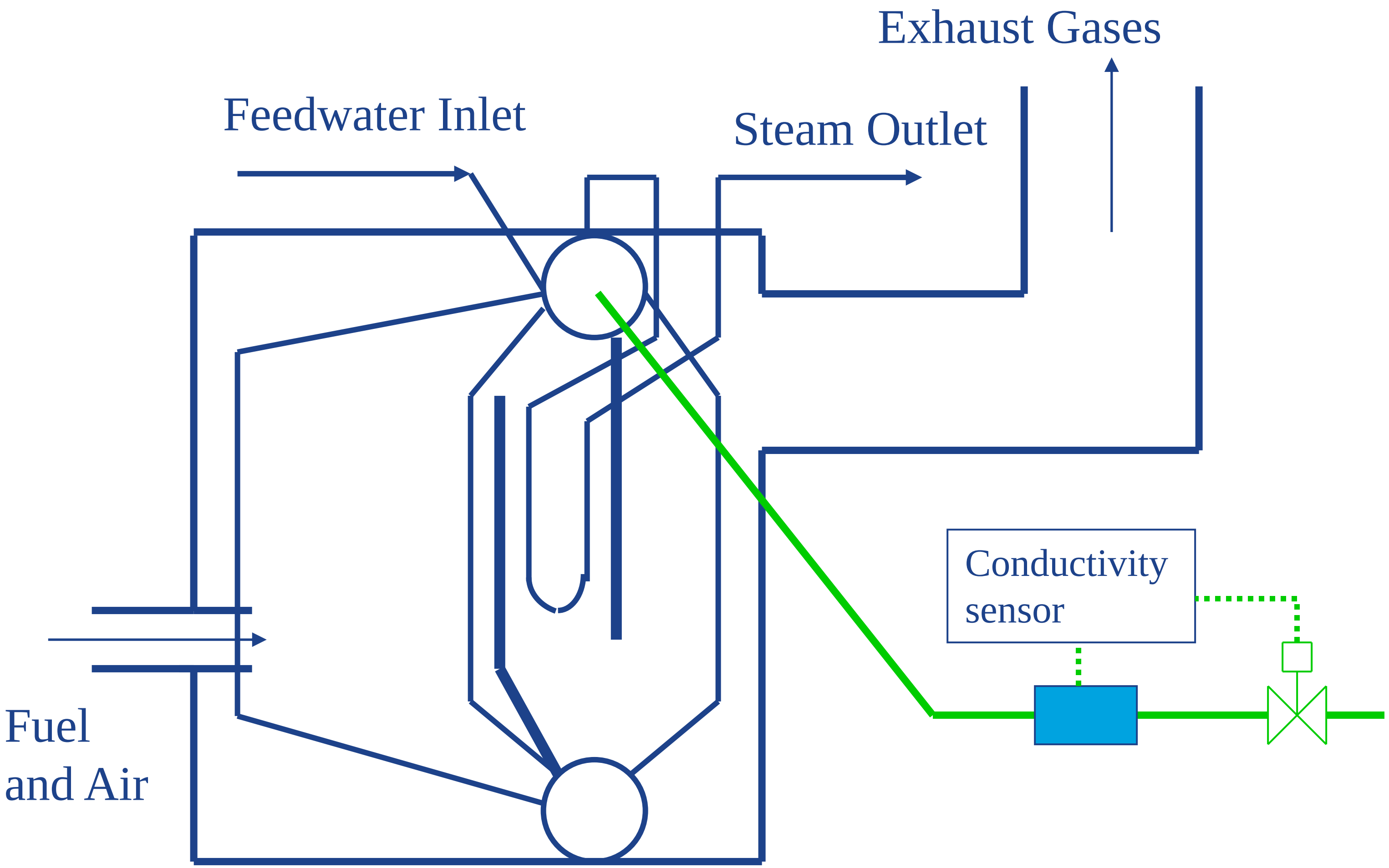
Blowdown Management

- Blowdown rates can be less than $1\%_{mass}$ in high quality water systems or higher than $10\%_{mass}$ in low quality water systems
- Most facilities require makeup water softening as a minimum form of water treatment
- Increasing condensate recovery can improve feedwater quality, which can reduce blowdown requirements

Blowdown Control

- A change in the boiler blowdown amount of all of the boilers will generally reduce the impact fuel consumption
- Increased condensate return will typically allow the blowdown rate to be reduced
- Primary control of continuous blowdown is typically based on boiler water conductivity
- Conductivity must be correlated to actual water quality through specific analysis

Blowdown Control



Blowdown Control (Reduction)

- Blowdown is required based on water quality

- What would allow a reduction in boiler blowdown?
  - Cleaner feedwater
    - Increased condensate return
    - Additional makeup water conditioning
    - Condensate polishing
    - Change in water treatment
  - Continuous versus intermittent blowdown

Example Steam System – Pulp & Paper Mill

MEASUR

VINPLT_0421
Last modified: May 1, 2021

System Setup | **Assessment** | Diagram | Report | Sankey | Calculators

Explore Opportunities Novice View | Modify All Conditions Expert View

Blowdown Control Selected Scenario | View / Add Scenarios

SELECT POTENTIAL ADJUSTMENT PROJECTS

Select potential adjustment projects to explore opportunities to increase efficiency and the effectiveness of your system.

Add New Scenario

Modification Name: Blowdown Control

- [ ] Adjust General Operations
- [ ] Adjust Unit Costs
- [x] Adjust Boiler Operations
  - [ ] Adjust Boiler Combustion Efficiency
  - [ ] Change Fuel Type
  - [x] Adjust Blowdown Rate

Baseline	Modifications
Blowdown Rate	Blowdown Rate
6%	2 %
	Calculate Blowdown Rate

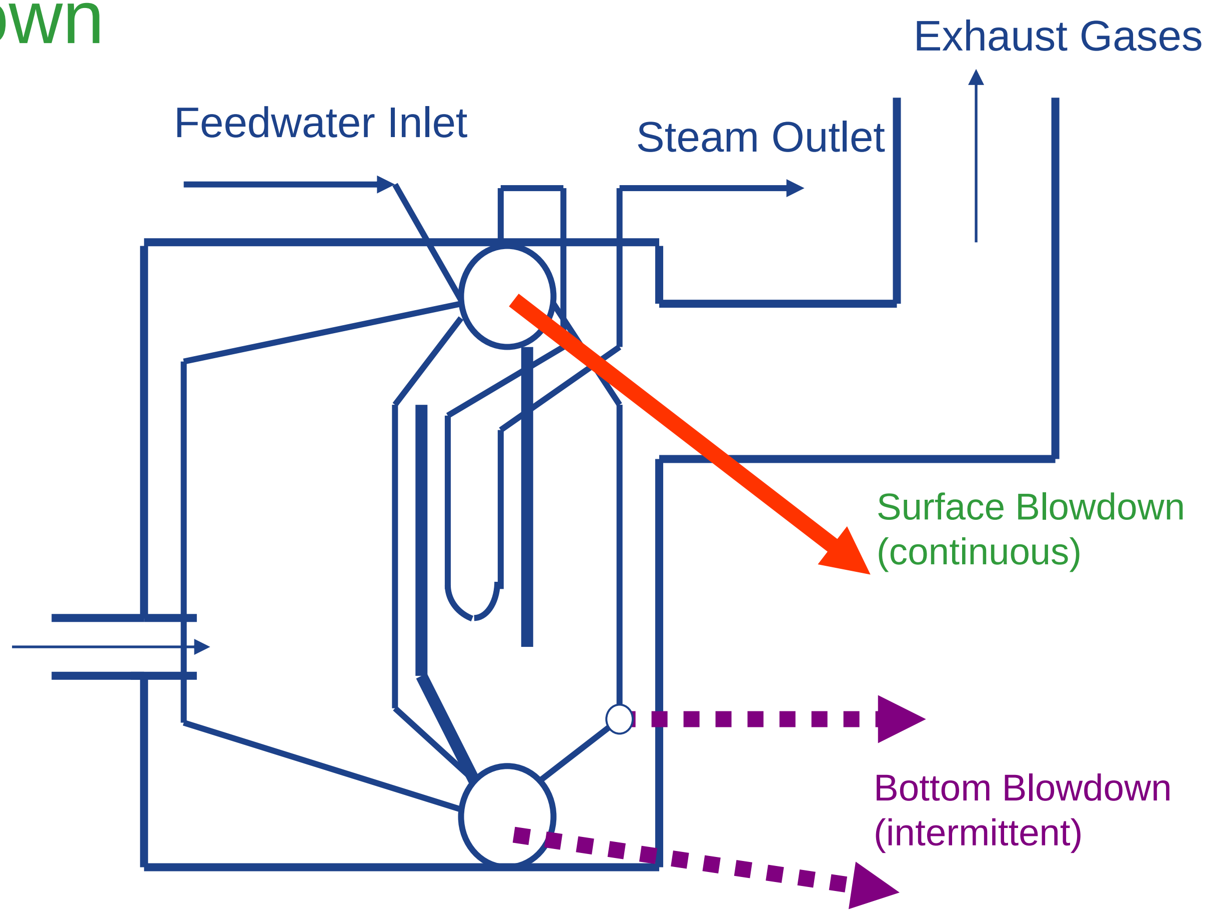
- [ ] Blowdown Flash to Low Pressure

RESULTS | SANKEY | HELP

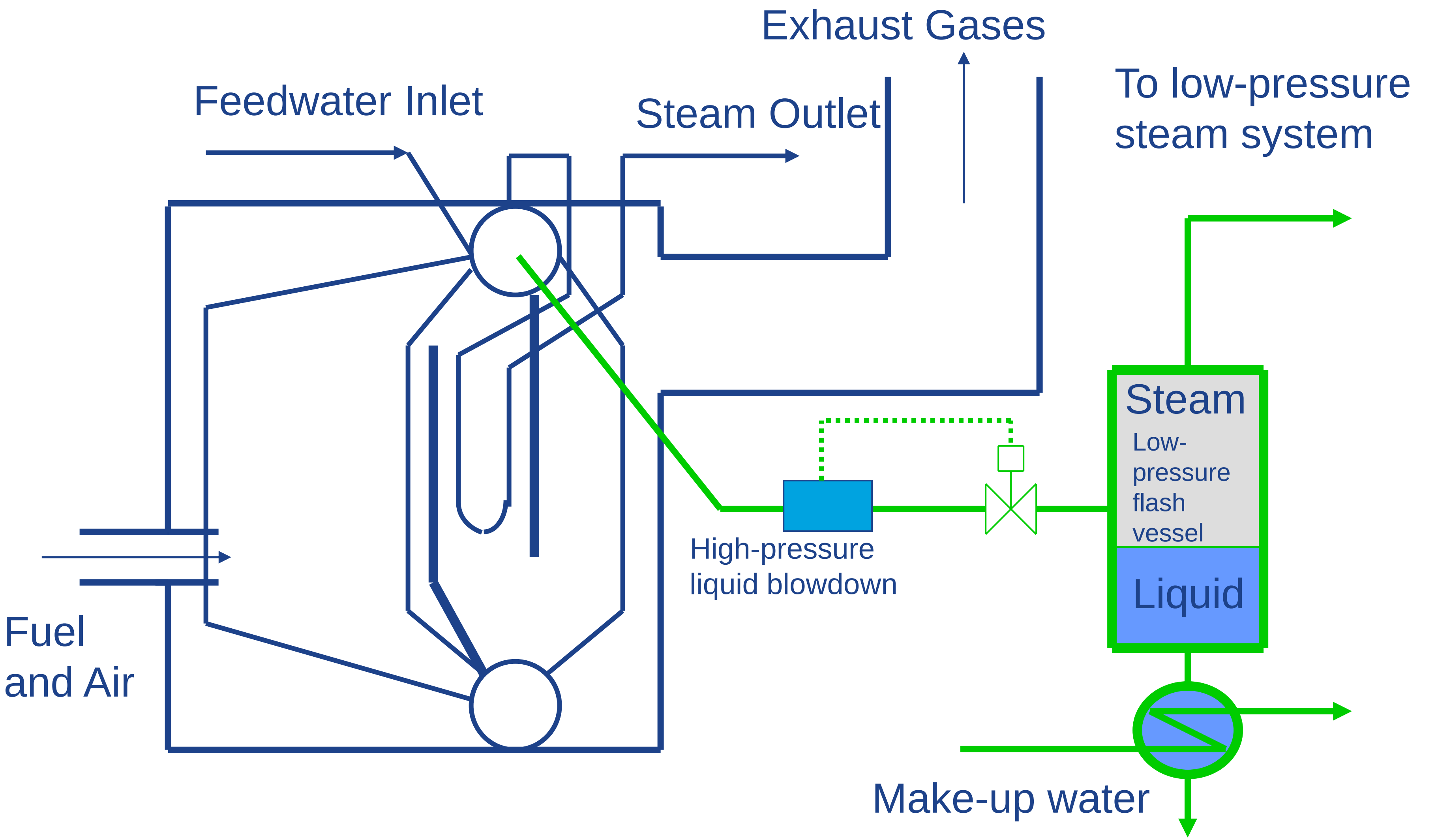
	Baseline	Blowdown Control
Percent Savings (%)	——	2.0%
Fuel Usage (MMBtu/yr)	1,288,195.7	1,269,223.2
Fuel Cost ($/yr)	$6,440,979	$6,346,116
Electricity Usage (kW/yr)	43,800,000	43,800,000
Electricity Cost ($/yr)	$2,190,000	$2,190,000
Water Usage (gal/yr)	50,272,661.5	45,736,820.8
Water Cost ($/yr)	$502,727	$457,368
Power Generated (kW/yr)	499.6	499.6
Process Use (MMBtu/yr)	89.5	89.5
Stack Loss (MMBtu/yr)	31.3	30.9
Vent Losses (MMBtu/yr)	0	0
Unrecycled Condensate Losses (MMBtu/yr)	11.8	11.8
Turbine Losses (MMBtu/yr)	0.1	0.1
Other Losses (MMBtu/yr)	9.6	7.8
Annual Cost ($/yr)	**$9,133,705**	**$8,993,484**
Annual Savings ($/yr)	**—**	**$140,221**

Blowdown Energy Recovery

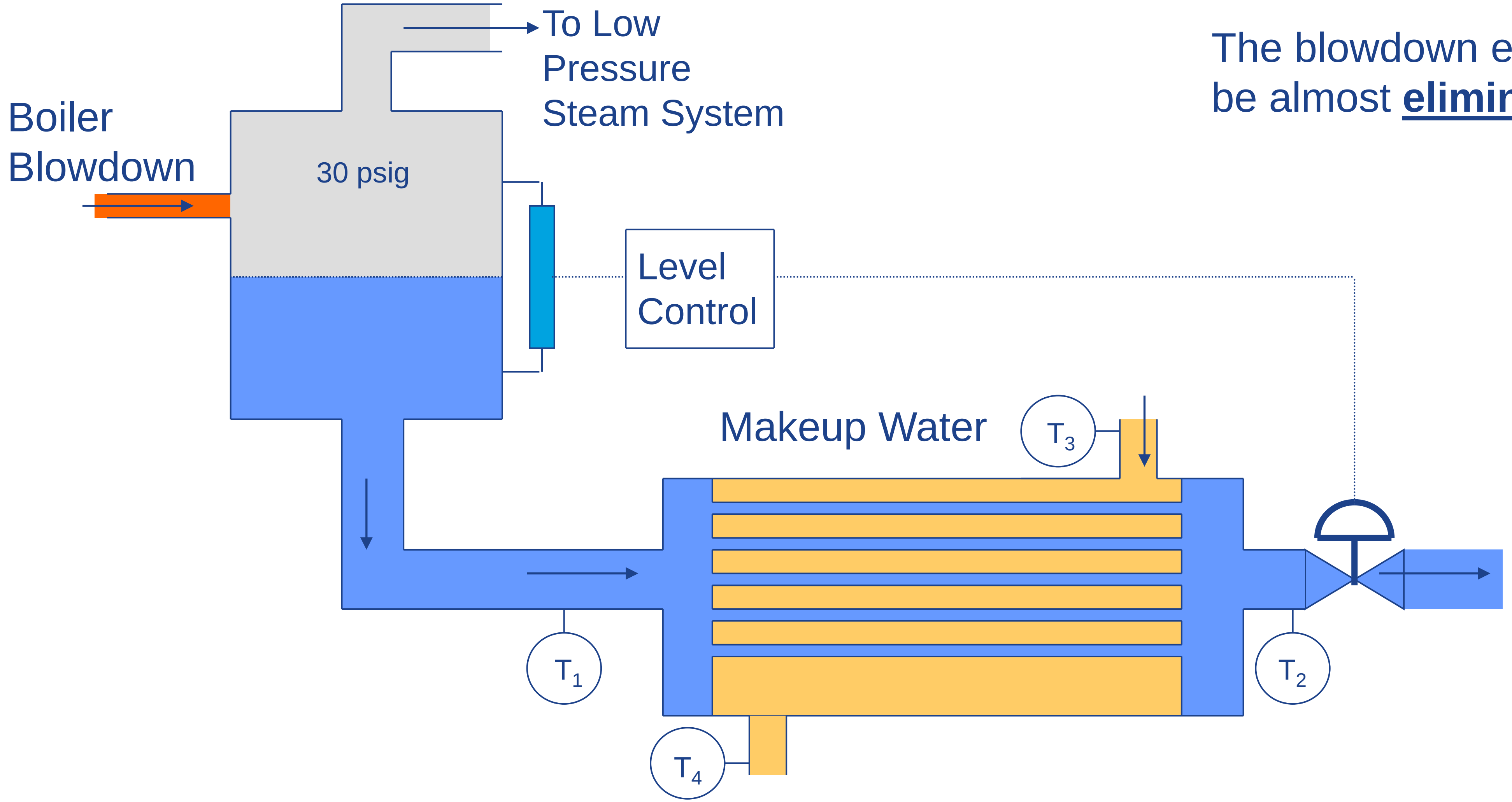
- Boiler blowdown thermal energy recovery typically focuses on continuous surface blowdown
  - Recovering energy from blowdown can dramatically reduce blowdown losses and release water chemistry requirements



Blowdown Energy Recovery

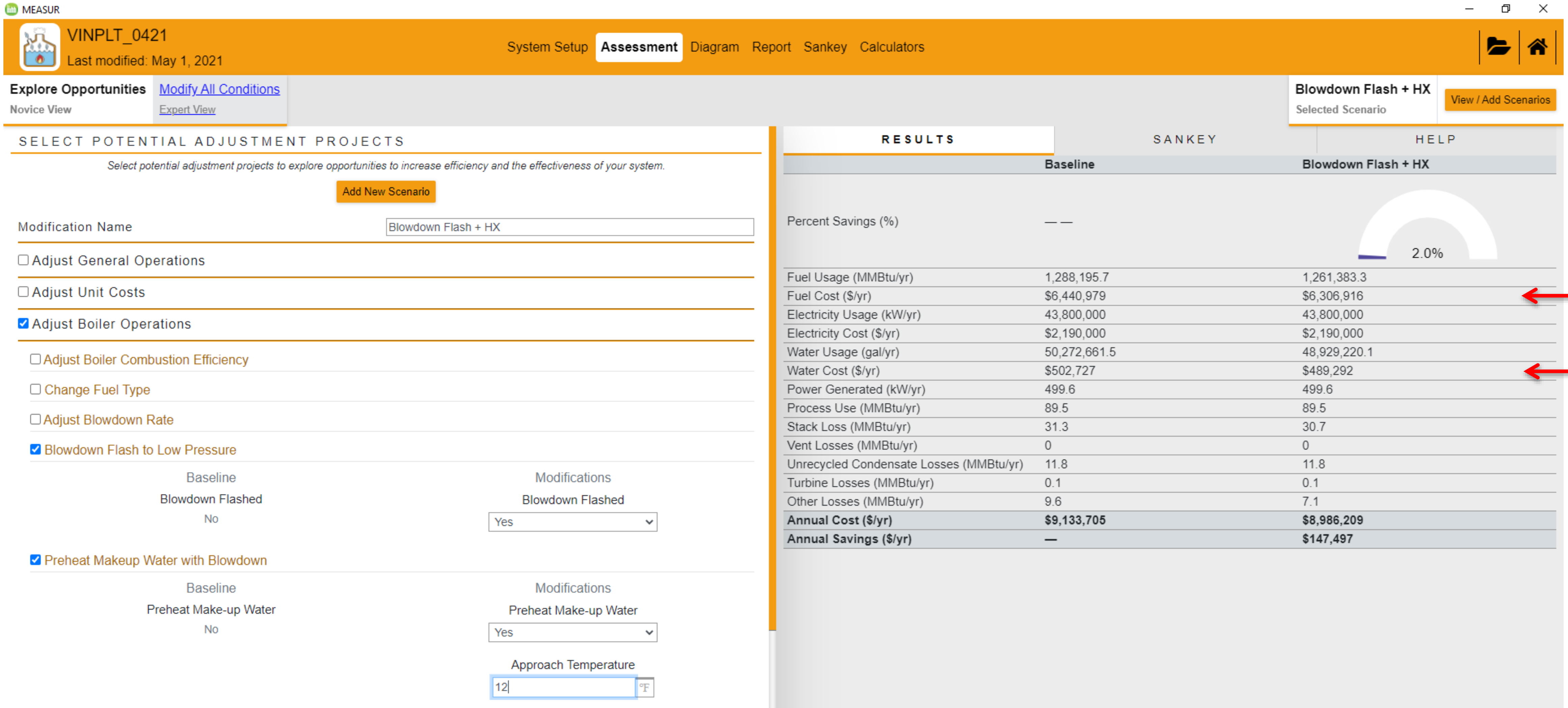


Boiler Blowdown Energy Recovery



The blowdown energy loss can be almost **eliminated**

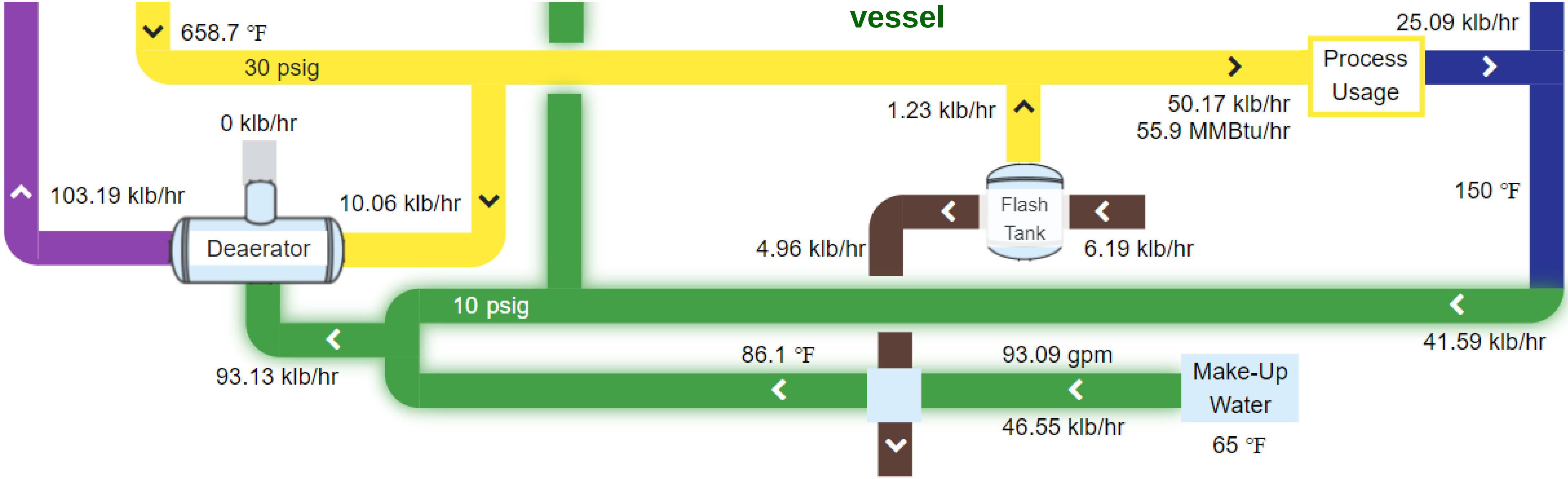
Example Steam System – Pulp & Paper Mill



	Baseline	Blowdown Flash + HX
Percent Savings (%)	— —	2.0%
Fuel Usage (MMBtu/yr)	1,288,195.7	1,261,383.3
Fuel Cost ($/yr)	$6,440,979	$6,306,916
Electricity Usage (kW/yr)	43,800,000	43,800,000
Electricity Cost ($/yr)	$2,190,000	$2,190,000
Water Usage (gal/yr)	50,272,661.5	48,929,220.1
Water Cost ($/yr)	$502,727	$489,292
Power Generated (kW/yr)	499.6	499.6
Process Use (MMBtu/yr)	89.5	89.5
Stack Loss (MMBtu/yr)	31.3	30.7
Vent Losses (MMBtu/yr)	0	0
Unrecycled Condensate Losses (MMBtu/yr)	11.8	11.8
Turbine Losses (MMBtu/yr)	0.1	0.1
Other Losses (MMBtu/yr)	9.6	7.1
Annual Cost ($/yr)	**$9,133,705**	**$8,986,209**
Annual Savings ($/yr)	**—**	**$147,497**

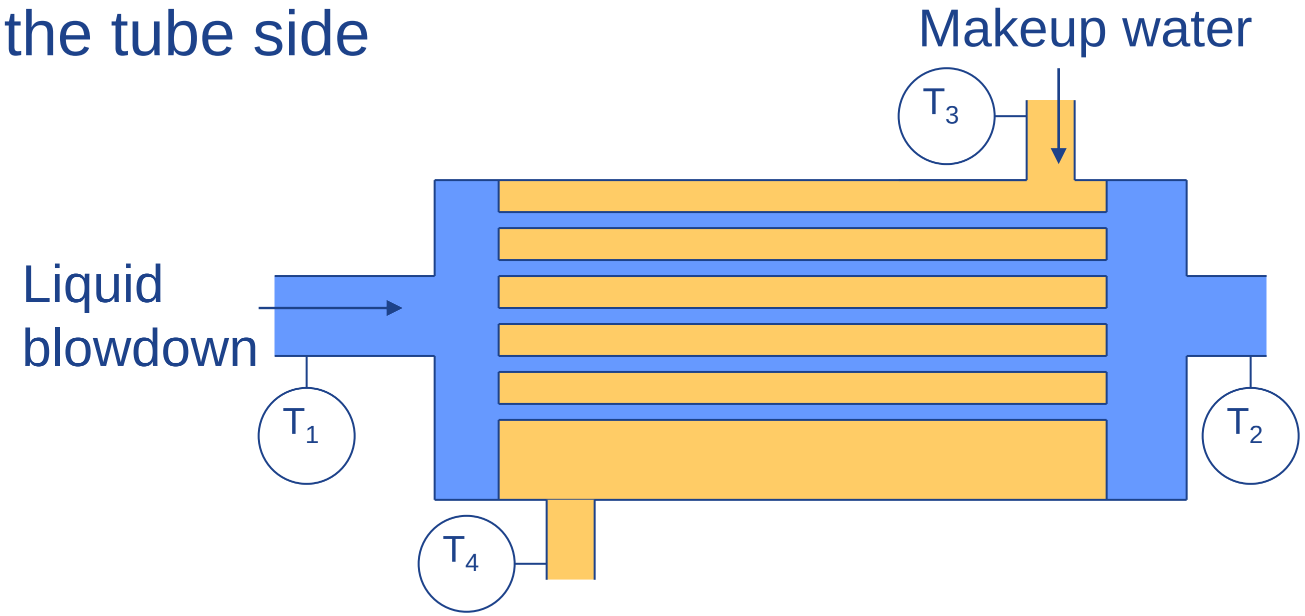
Example Steam System – Pulp & Paper Mill

The amount of flash steam formed is dependent on the pressure of the boiler and the pressure of the flash vessel



Heat Exchanger Caution

- The blowdown stream presents a significant fouling potential (even in a cooling environment)
- The capability of cleaning the heat transfer surfaces of blowdown heat exchangers must be provided
  - Straight tube with blowdown on the tube side
  - Plate and frame



Example Steam System – Pulp & Paper Mill

- Flash steam recovery from blowdown
  - ~75-80% of thermal energy was recovered
  - US DOE MEASUR model was used to quantify the savings opportunity
  - Additionally, control valve position on the steam from header to deaerator verified steam savings

Example Steam System – Pulp & Paper Mill

MEASUR

VINPLT_0421
Last modified: May 1, 2021

System Setup | **Assessment** | Diagram | Report | Sankey | Calculators

Explore Opportunities — Novice View | Modify All Conditions — Expert View

BD Flash + HX + Control — Selected Scenario | View / Add Scenarios

- [ ] Adjust Unit Costs
- [x] Adjust Boiler Operations
  - [ ] Adjust Boiler Combustion Efficiency
  - [ ] Change Fuel Type
  - [x] Adjust Blowdown Rate

	Baseline	Modifications
Blowdown Rate	6%	2 %

Calculate Blowdown Rate

- [x] Blowdown Flash to Low Pressure

	Baseline	Modifications
Blowdown Flashed	No	Yes

- [x] Preheat Makeup Water with Blowdown

	Baseline	Modifications
Preheat Make-up Water	No	Yes
Approach Temperature		12 °F

RESULTS | SANKEY | HELP

	Baseline	BD Flash + HX + Control
Percent Savings (%)	— —	2.0%
Fuel Usage (MMBtu/yr)	1,288,195.7	1,260,711.6
Fuel Cost ($/yr)	$6,440,979	$6,303,558
Electricity Usage (kW/yr)	43,800,000	43,800,000
Electricity Cost ($/yr)	$2,190,000	$2,190,000
Water Usage (gal/yr)	50,272,661.5	45,334,364.9
Water Cost ($/yr)	$502,727	$453,344
Power Generated (kW/yr)	499.6	499.6
Process Use (MMBtu/yr)	89.5	89.5
Stack Loss (MMBtu/yr)	31.3	30.7
Vent Losses (MMBtu/yr)	0	0
Unrecycled Condensate Losses (MMBtu/yr)	11.8	11.8
Turbine Losses (MMBtu/yr)	0.1	0.1
Other Losses (MMBtu/yr)	9.6	7
Annual Cost ($/yr)	**$9,133,705**	**$8,946,902**
Annual Savings ($/yr)	**—**	**$186,804**

Options for Blowdown Energy Savings

- Reduce boiler blowdown
  - This will reduce energy in the blowdown stream proportionately
  - But water quality will need to be improved significantly
    - Economic considerations
    - Infrastructure considerations

- Implement energy recovery equipment
  - Capture almost all of the blowdown energy
  - No impact on water treatment, it may actually help if there are bottlenecks
  - System effects need to considered, especially in a cogeneration plant

- A combination of the above two options

Example Steam System – Pulp & Paper Mill

Executive Summary | Energy Summary | Losses | Diagram | Report Graphs | Input Summary | Facility Info | Sankey

($/yr)	Baseline	Economizer	Trim Control	Econ + Trim	Blowdown Control	Blowdown Flash + HX	BD Flash + HX + Control
Percent Savings (%)	—	4.0%	2.0%	5.0%	2.0%	2.0%	2.0%
Power Cost	$2,190,000	$2,190,000	$2,190,000	$2,190,000	$2,190,000	$2,190,000	$2,190,000
Savings	—	$0	$0	$0	$0	$0	$0
Fuel Cost	$6,440,979	$6,085,294	$6,234,994	$5,970,613	$6,346,116	$6,306,916	$6,303,558
Savings	—	$355,684	$205,985	$470,366	$94,863	$134,062	$137,421
Make-up Water Cost	$502,727	$502,727	$502,727	$502,727	$457,368	$489,292	$453,344
Savings	—	$0	$0	$0	$45,358	$13,434	$49,383
Annual Cost	**$9,133,705**	**$8,778,021**	**$8,927,721**	**$8,663,339**	**$8,993,484**	**$8,986,209**	**$8,946,902**
Annual Savings	—	**$355,684**	**$205,985**	**$470,366**	**$140,221**	**$147,497**	**$186,804**
Implementation Cost	—	—	—	—	—	—	—
Payback Period (months)	—	—	—	—	—	—	—
Selected Energy Projects	—	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations
Modifications	—	Boiler	Boiler	Boiler	Boiler	Boiler	Boiler

Homework #5

- Evaluate the opportunities to improve your steam generation efficiency by:
  - Reducing stack loss heat recovery (in the absence of feedwater economizer)
  - Comparing stack temperature to design conditions
  - Evaluating flue gas oxygen content and the control mechanism
- Evaluate implementation of blowdown control & energy recovery
  - Reduction of blowdown w/control
  - Flash tank heat recovery
  - Blowdown/Make-up water HX
- Save the file w/different scenarios on your computer and send us the .json file

Thank You all for attending today's webinar.

See you all on next Tuesday – May 11, 2021 – 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