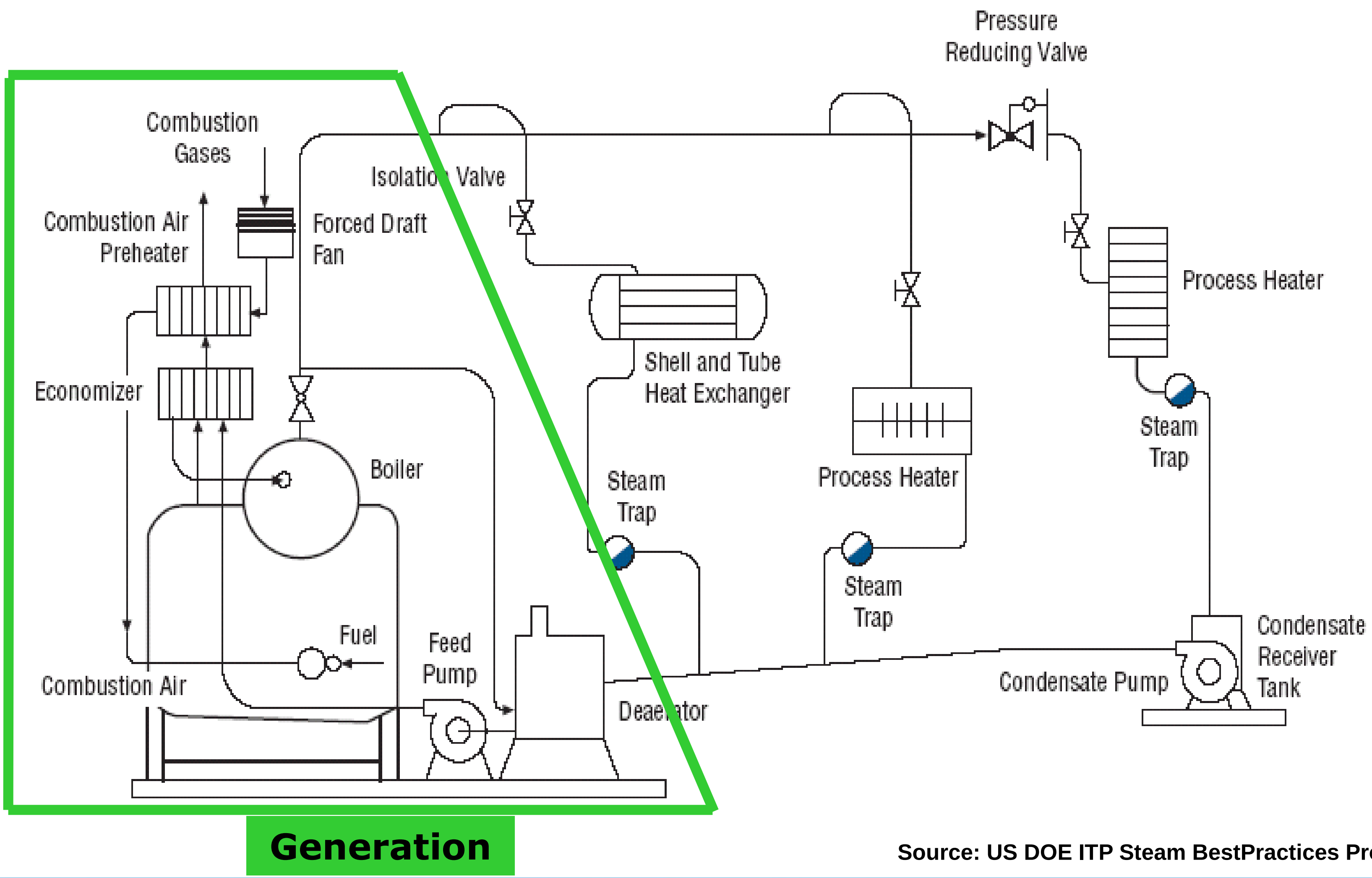
Section 6

Steam System Optimization - Generation

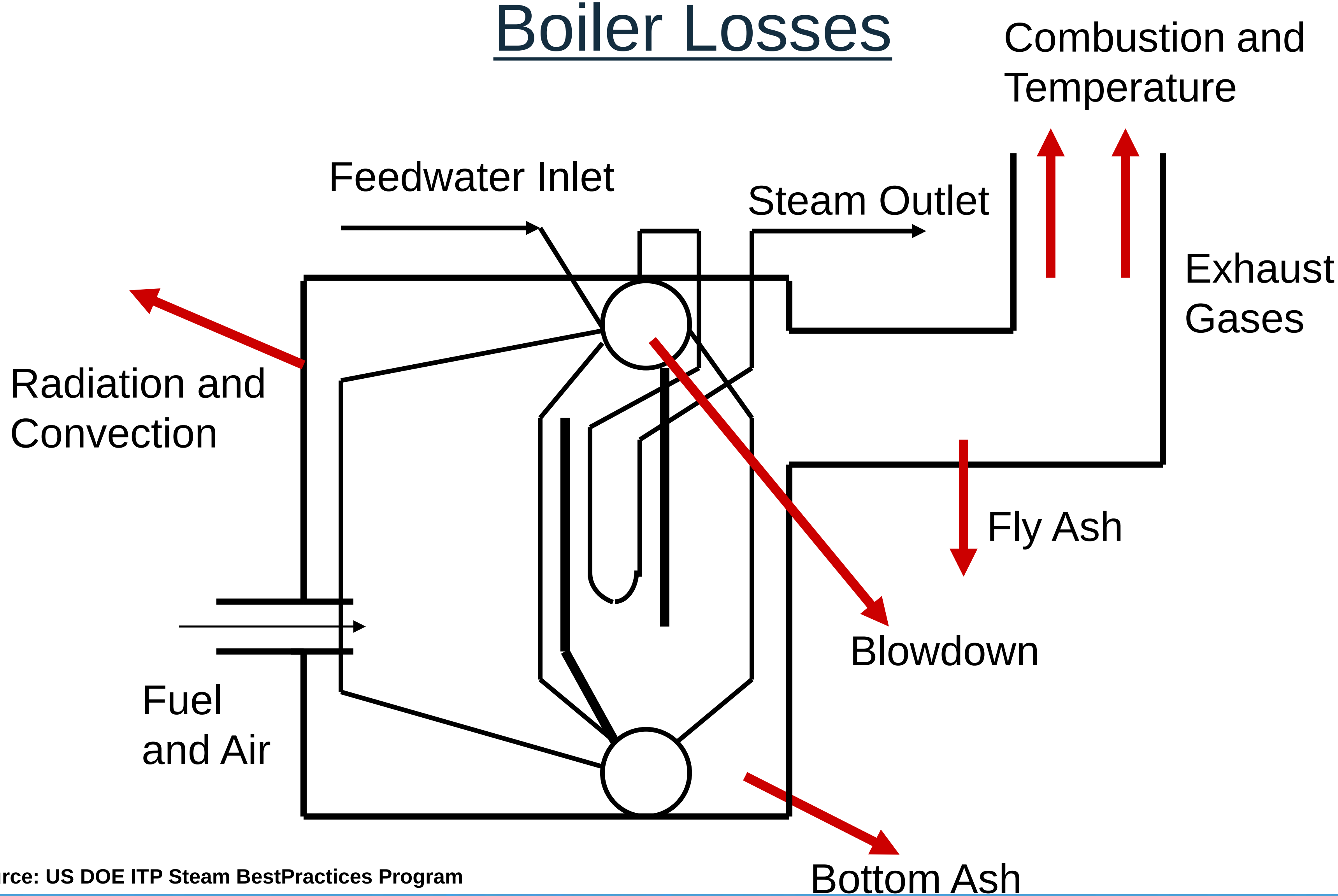
Boiler Efficiency Improvement
Blowdown Management
Blowdown Energy Recovery
Feedwater Economizers
Combustion AirPreheaters
Excess Air Control
Fuel Switching
Hands-On Student Exercises

Steam System Optimization – Generation



Source: US DOE ITP Steam BestPractices Program

Boiler Losses



Source: US DOE ITP Steam BestPractices Program

Boiler 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

$$\eta_{boiler} = 100 - Losses$$

$$\eta_{boiler} = 100 - \lambda_{shell} - \lambda_{blowdown} - \lambda_{stack} - \lambda_{other}$$

Shell Losses

- Full-load radiation and convection losses are typically:
  - Less than 1.0% for water-tube boilers
  - Less than 0.5% for fire-tube boilers
- Shell loss *percentage* increases as boiler load decreases because shell loss magnitude is essentially constant
  - Shell loss of ~0.5% *at full-load* will become ~2.0% *at quarter-load*
  - The primary opportunity in this area is to reduce the number of boilers in operation to reduce the total site shell loss
    - Stack loss impacts must be considered
- Reducing steam demand will NOT result in any change in shell loss….. Unless a boiler is shut down!

Key Points / Action Items

1. *Search for "hot spots"*
2. *Measure boiler surface temperatures*
   - *Infrared thermography*
   - *Typical surface temperature should range between 55℃ and 70℃*
3. *Repair refractory*
4. *Monitor surface cladding integrity*
5. *Reduced boiler load can present an opportunity*
   - *Minimize number of operating boilers*

Blowdown Management

- Water quality must improve as steam pressure increases
- Most facilities require makeup water softening as a minimum
- Higher pressure systems may require dealkalization, demineralization, or reverse osmosis treatment of makeup water
- High quality water systems may have less than 1% blowdown
  - Low quality water systems may have as much as 10% blowdown
- Additional condensate recovery will typically allow the blowdown rate to be reduced

Blowdown Management

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

Source: US DOE ITP Steam BestPractices Program

Options for Blowdown Energy Savings

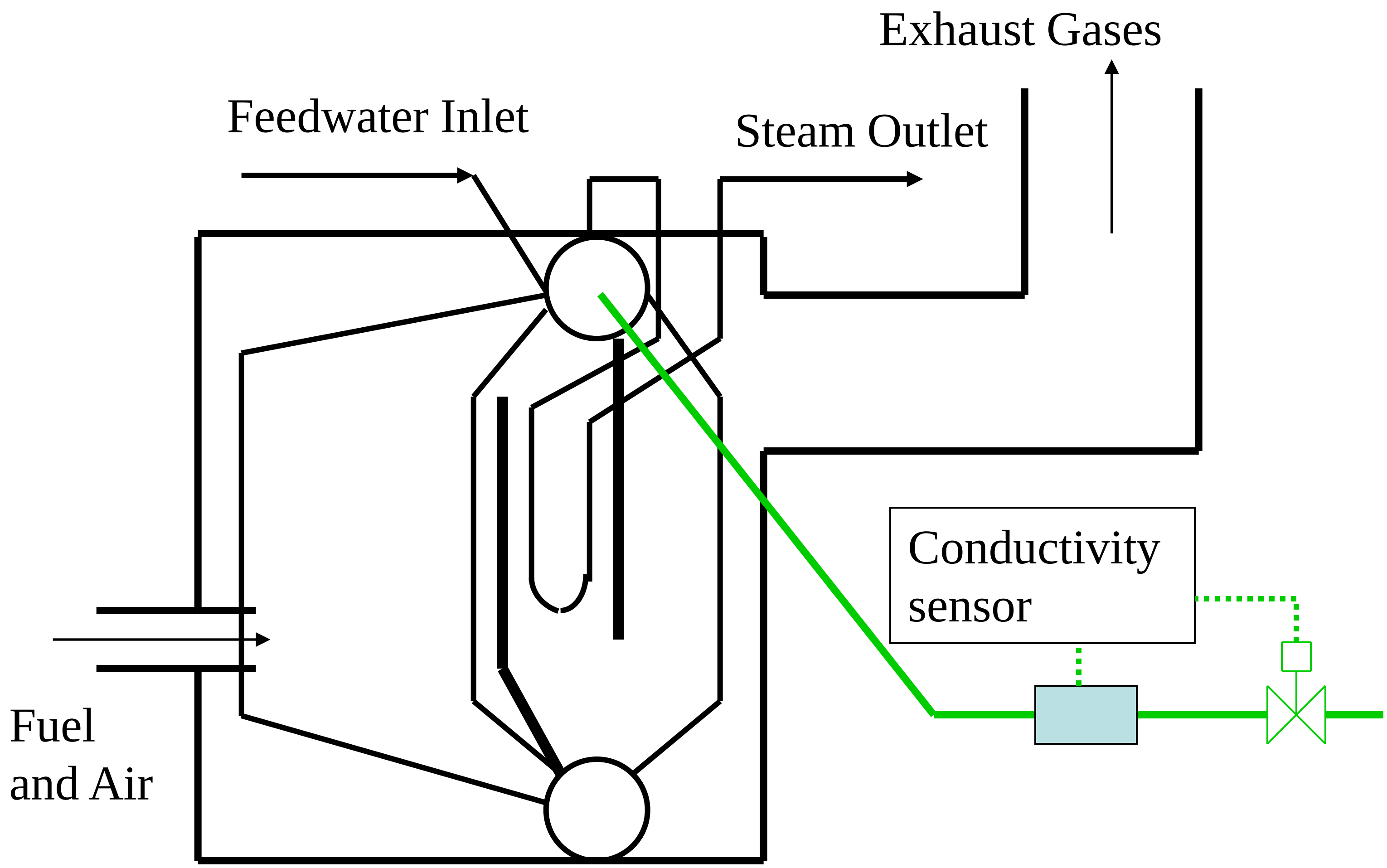
- Reduce boiler blowdown
  - This will reduce energy in the blowdown stream proportionately
  - But water quality will need to be improved significantly
    - Economic considerations
    - Infrastructure considerations
- Implement energy recovery equipment
  - Capture almost all the blowdown energy
  - No impact on water treatment, may actually help
  - System effects need to considered, especially in a cogeneration plant
- A combination of the above two options

Blowdown Control

- 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 Loss

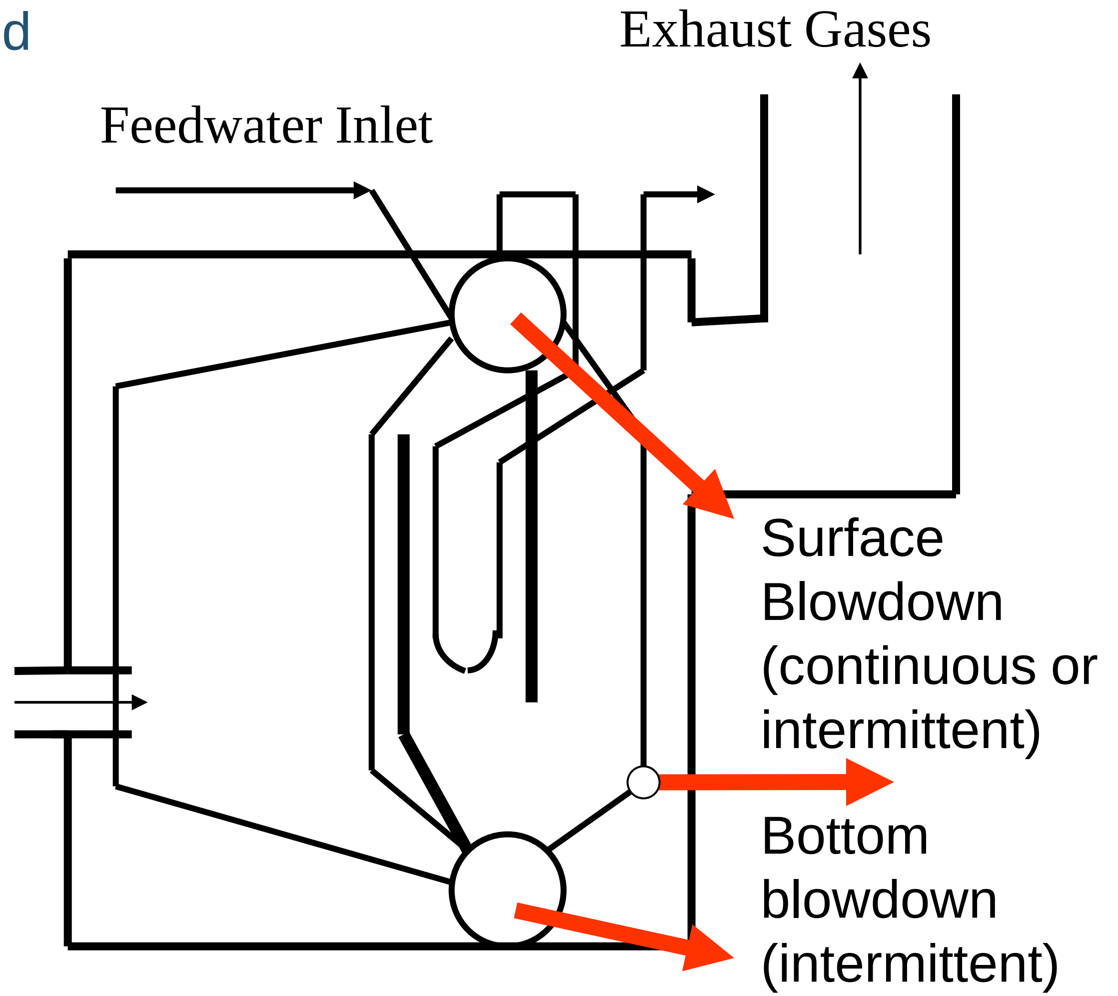
- A change in the boiler blowdown amount of all of the boilers will generally reduce the impact fuel consumption

- Economic analysis will require either multiple models for different fuels
  - Blended fuel cost may provide a good ball-park estimate

- Increased condensate return will typically allow the blowdown rate to be reduced

SSAT Project 4 - Reduce Boiler Blowdown

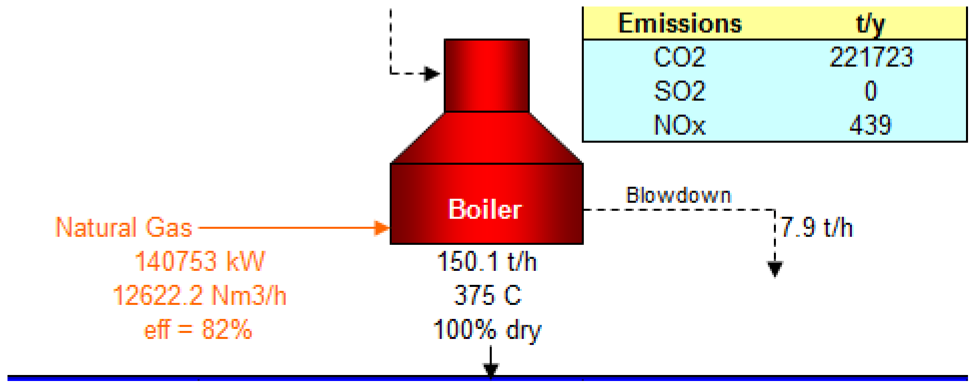
- Blowdown is required based on water quality
- What would allow a reduction in boiler blowdown?
  - Cleaner feedwater
    - Increased condensate return
    - Additional makeup water conditioning
    - Condensate polishing
    - Change in water treatment
  - Continuous versus intermittent blowdown



Reduce Boiler Blowdown

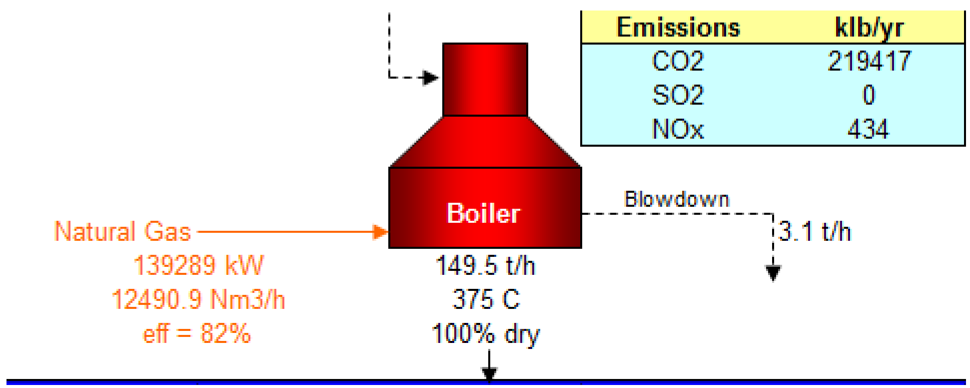
- Use the 3-header SSAT Example System model and quantify the total economic impact of reducing boiler blowdown from 5% to 2%.
- This reduction in blowdown is possible with an improvement (upgrade) in the water treatment system.

Reduce Boiler Blowdown



Emissions	t/y
CO2	221723
SO2	0
NOx	439

Base Model



Emissions	klb/yr
CO2	219417
SO2	0
NOx	434

Projects Model

Reduce Boiler Blowdown

Results Summary

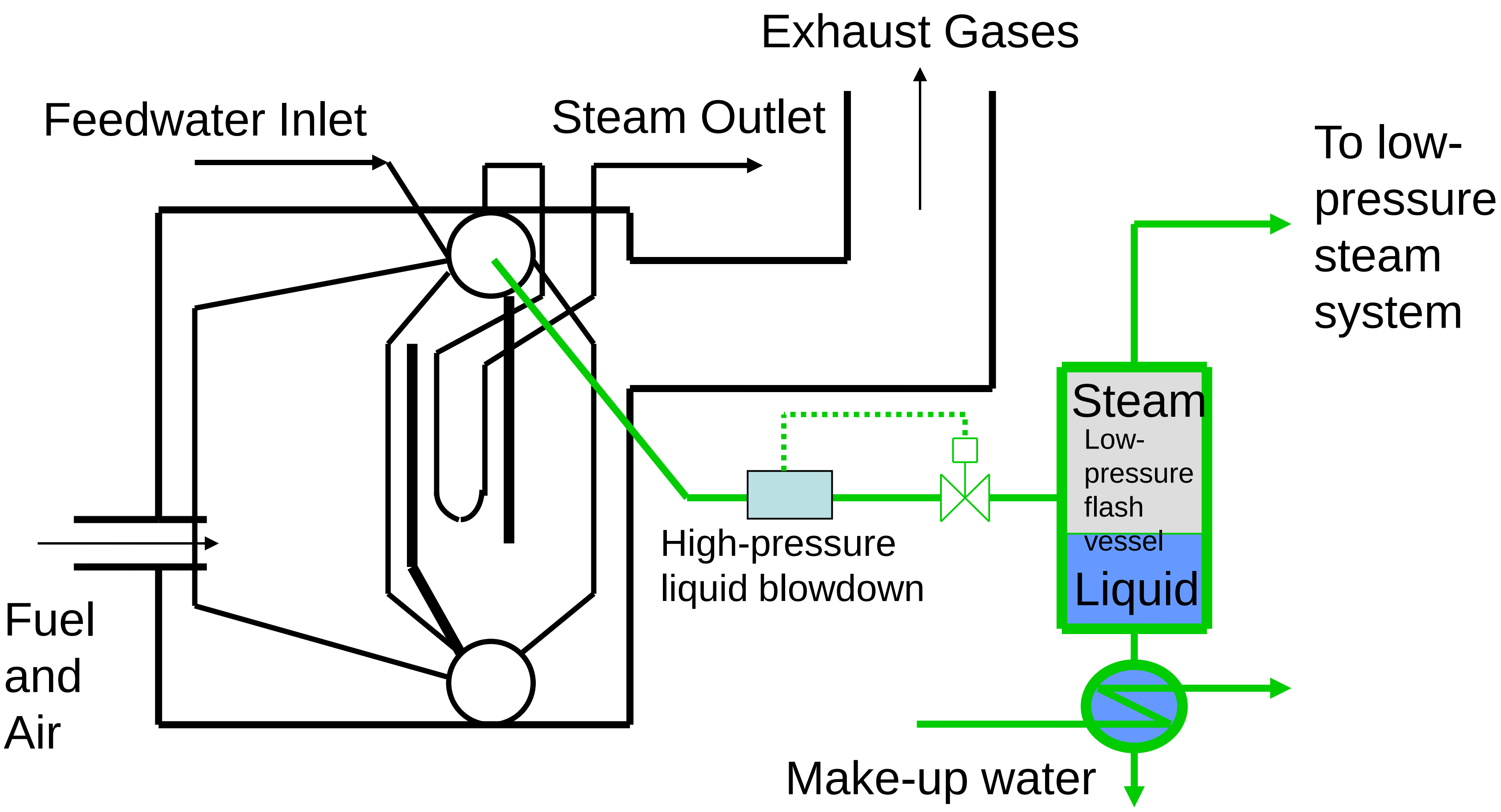
SSAT Default 3 Header Metric Model Moldova Ex 4

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	55,285	54,710	575	1.0%
Make-Up Water Cost	1,130	1,058	72	6.4%
Total Cost (in $ '000s/yr)	**62,547**	**61,900**	**647**	**1.0%**

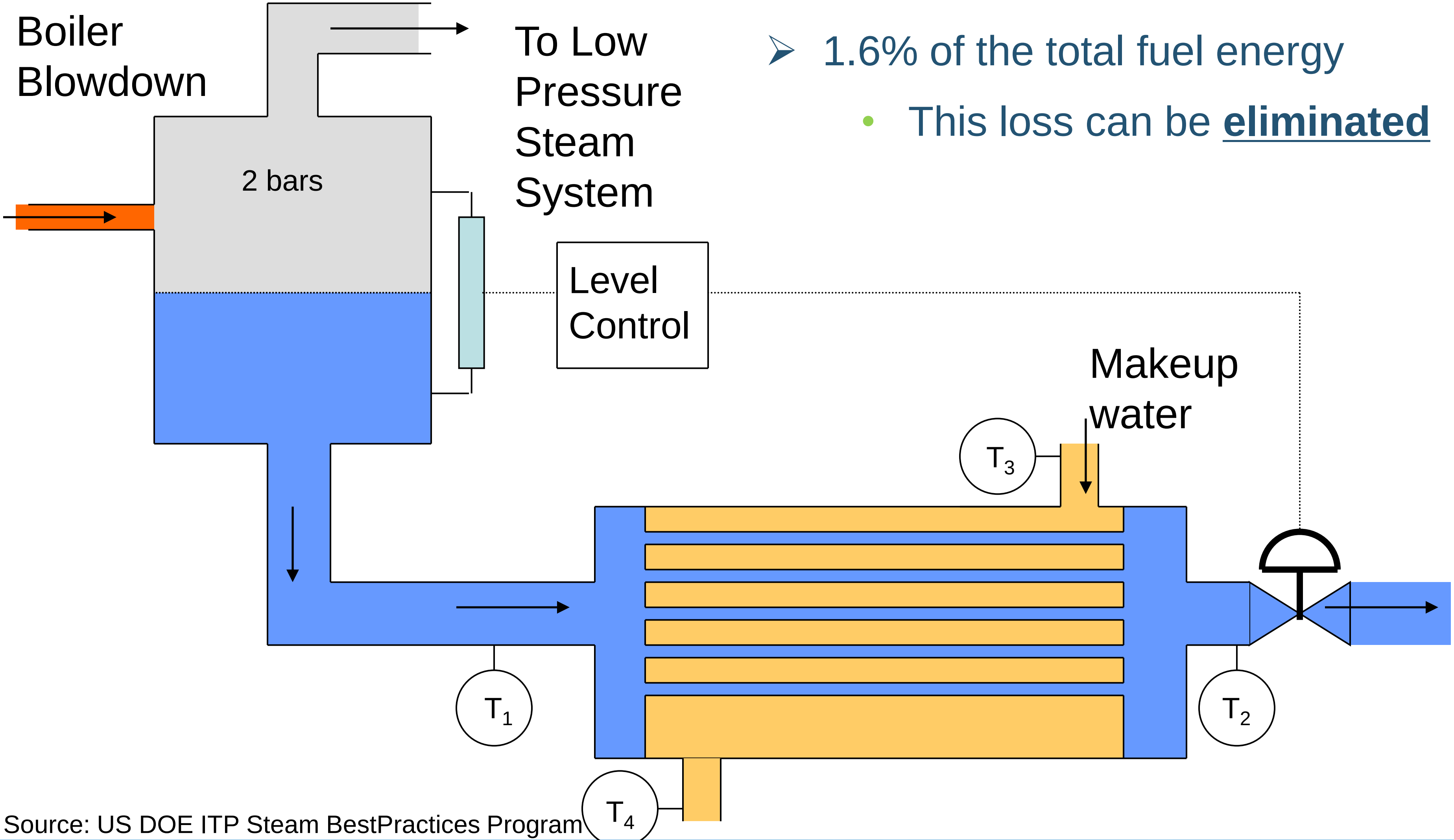
Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	0 kW	0 kW	-	-
Power Import	5000 kW	5000 kW	0 kW	0.0%
Total Site Electrical Demand	5000 kW	5000 kW	-	-
Boiler Duty	140753 kW	139289 kW	1464 kW	1.0%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	12622.2 Nm3/h	12490.9 Nm3/h	131.3 Nm3/h	1.0%
Boiler Steam Flow	150.1 t/h	149.5 t/h	0.7 t/h	0.4%
Fuel Cost (in $/MWh)	44.84	44.84	-	-
Power Cost (as $/MWh)	140.00	140.00	-	-
Make-Up Water Flow	76 m3/h	71 m3/h	5 m3/h	6.4%

Blowdown Energy Recovery



Source: US DOE ITP Steam BestPractices Program

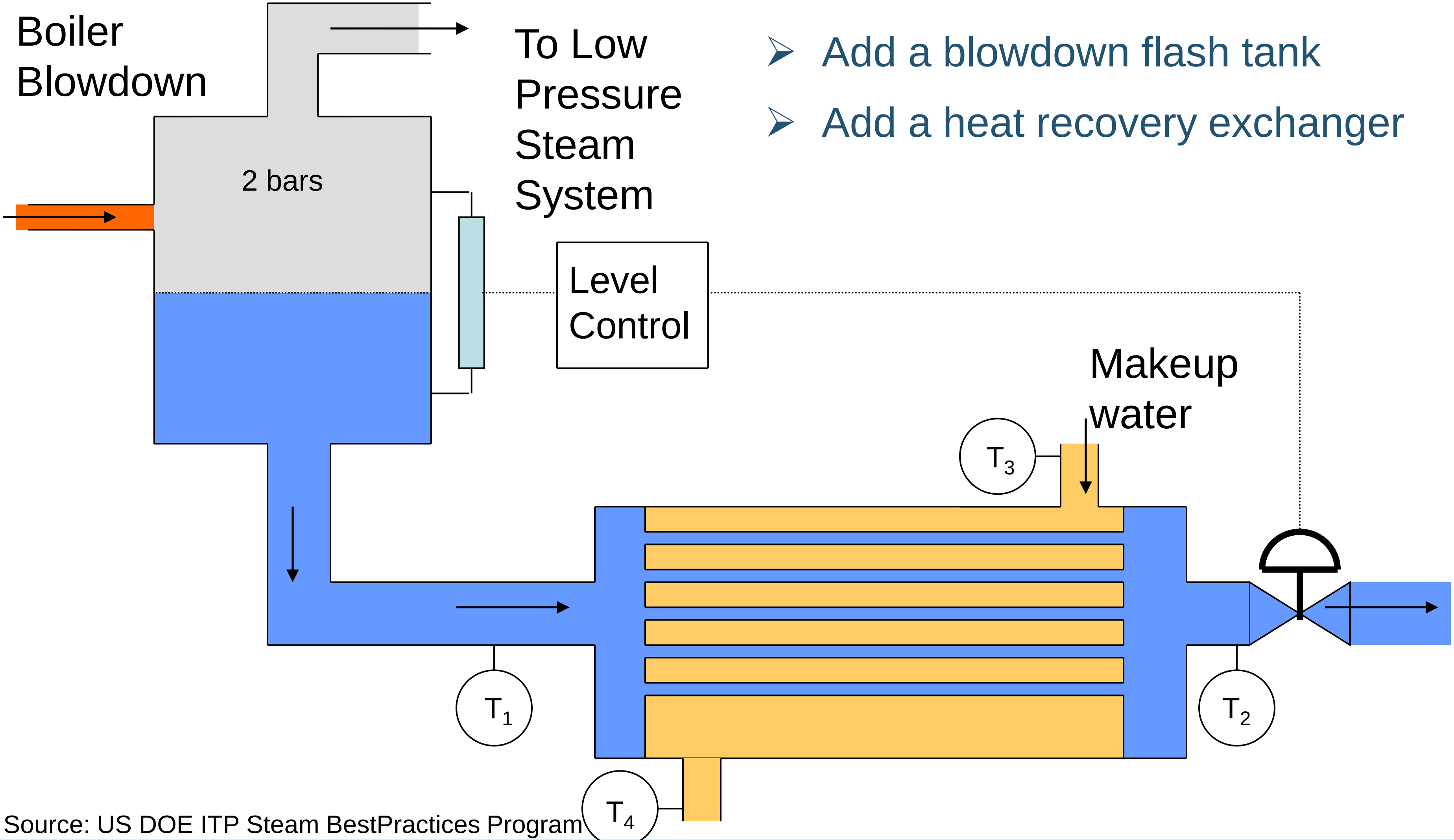
Blowdown Energy Recovery



- 1.6% of the total fuel energy
  - This loss can be **eliminated**

Source: US DOE ITP Steam BestPractices Program

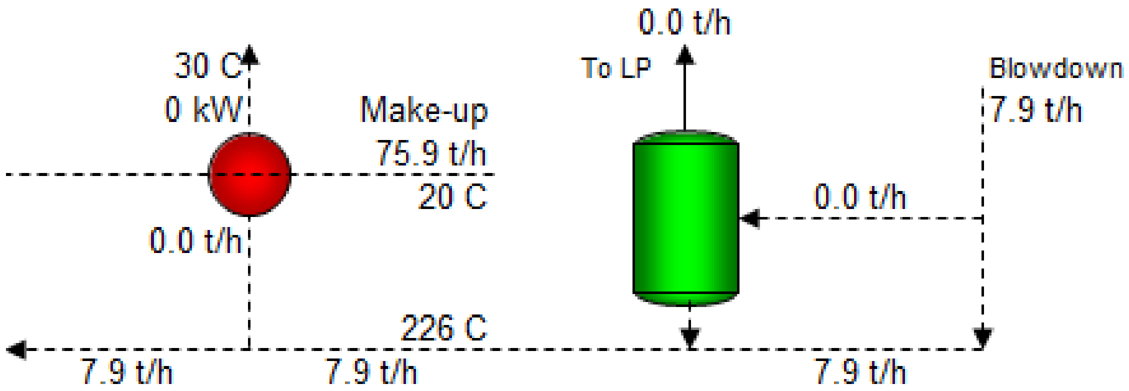
SSAT Projects 5 and 12



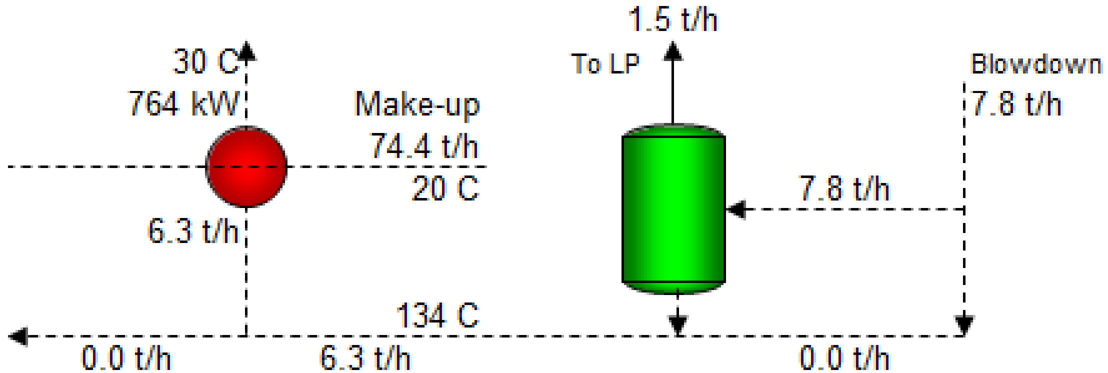
- Add a blowdown flash tank
- Add a heat recovery exchanger

Source: US DOE ITP Steam BestPractices Program

Projects 5 and 12 - Boiler Blowdown Energy Recovery



Base Model



Projects Model

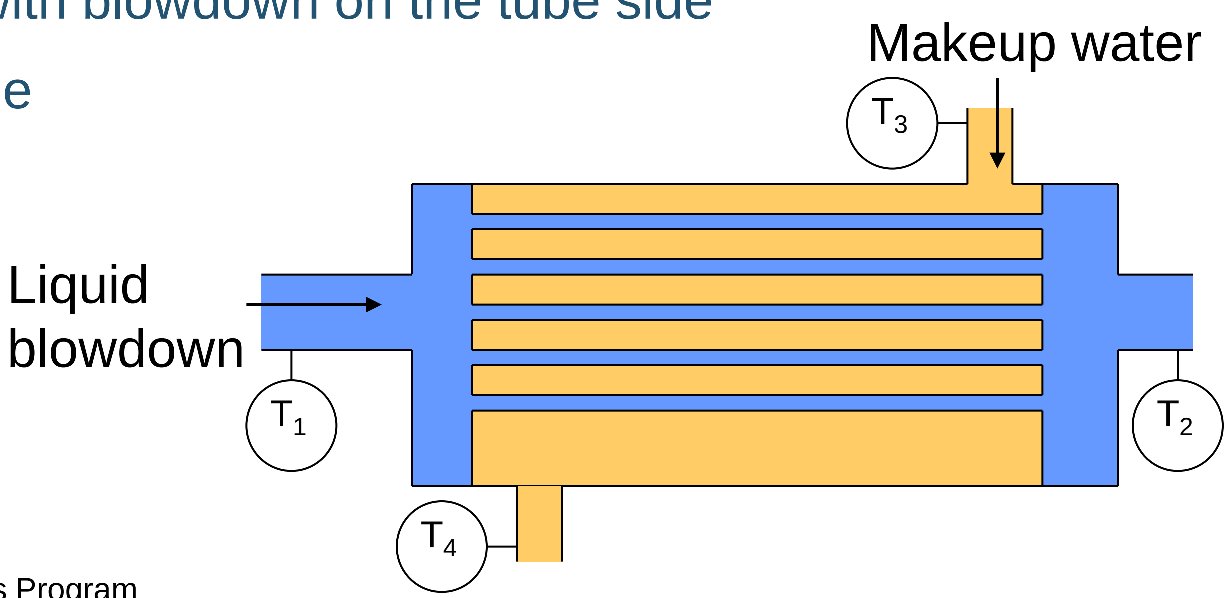
Blowdown Energy Recovery

Blowdown / Make up Water
Heat Exchanger

Blowdown Flash Tank

Heat Exchanger Caution

- The blowdown stream presents a significant fouling potential (even in a cooling environment)
- Co-current heat exchange may also be a good option
- 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



Source: US DOE ITP Steam BestPractices Program

Blowdown Change with Heat Recovery

- The impact of reducing blowdown is minimized when blowdown heat recovery equipment is in place
  - Blowdown rate can be increased to protect the boiler and the energy cost at the site will not be significantly impacted

Key Points / Action Items

1. *Estimate amount of blowdown using boiler and feedwater conductivities*
2. *Quantify the boiler and system-level energy loss due to blowdown*
3. *Evaluate installation of an automatic blowdown controller*
4. *Evaluate and install flash steam and heat recovery equipment*
5. *Work closely with plant's water chemists to maintain and manage appropriate blowdown*

Stack Losses

- *Stack losses* are the largest of the boiler losses

- *Stack losses* are made up of two parts and defined as
  - Temperature losses
  - Combustion losses

- *Combustion analysis* is the method generally used to determine stack losses

Boiler Efficiency Improvement Projects

- SSAT boiler efficiency is primarily dictated by stack loss
  - Real-world boiler efficiency is primarily dictated by stack loss
  - Primary stack loss factors
    - Exhaust temperature
    - Excess air

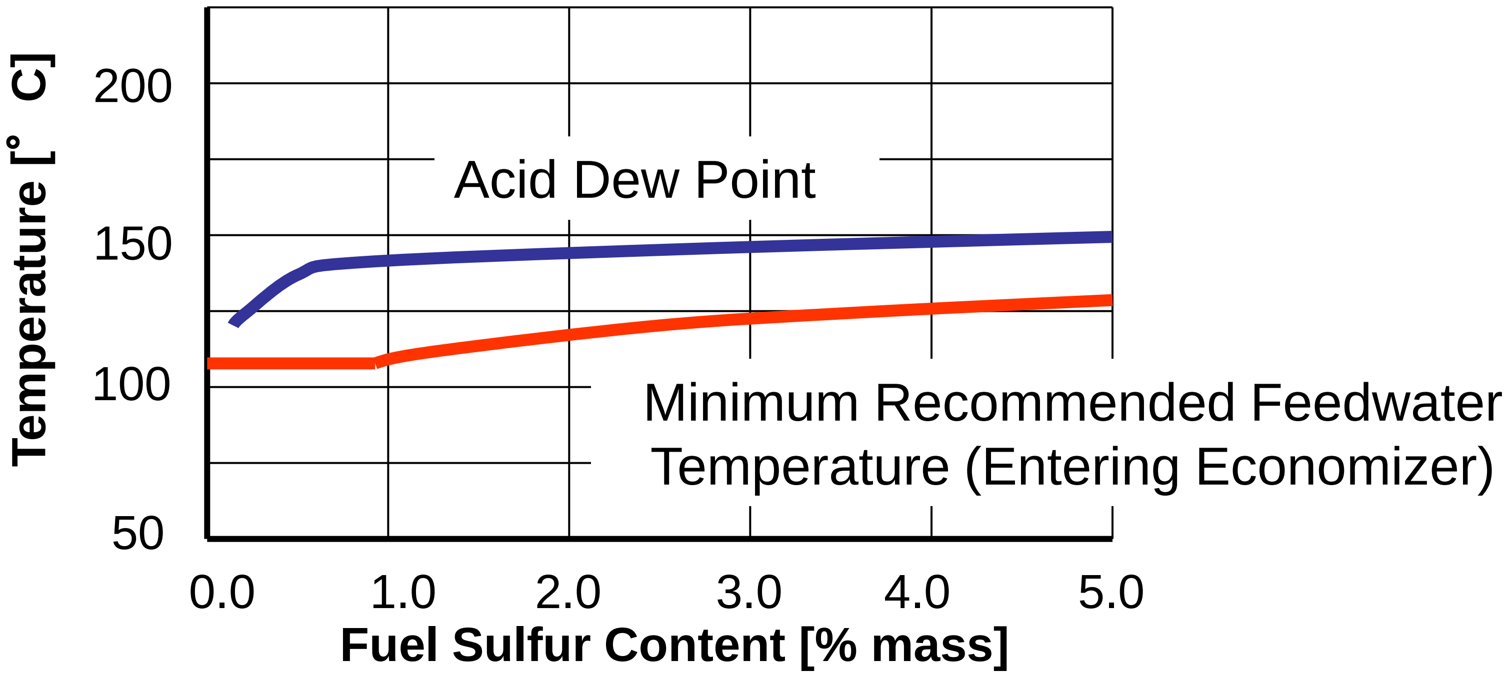
Flue Gas Temperature Loss

- A significant amount of energy resides in the flue gas
  - The temperature of the flue gas indicates the energy content
- The most common factors influencing flue gas temperature are presented are:
  - Boiler design
  - Fuel
  - Availability of heat recovery equipment
    - Feedwater economizers
    - Combustion air-preheaters
  - Failed flue gas component – baffle
  - Fireside or waterside fouling
  - Boiler load

Energy Recovery Components

- 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

Flue Gas Temperature Limitations



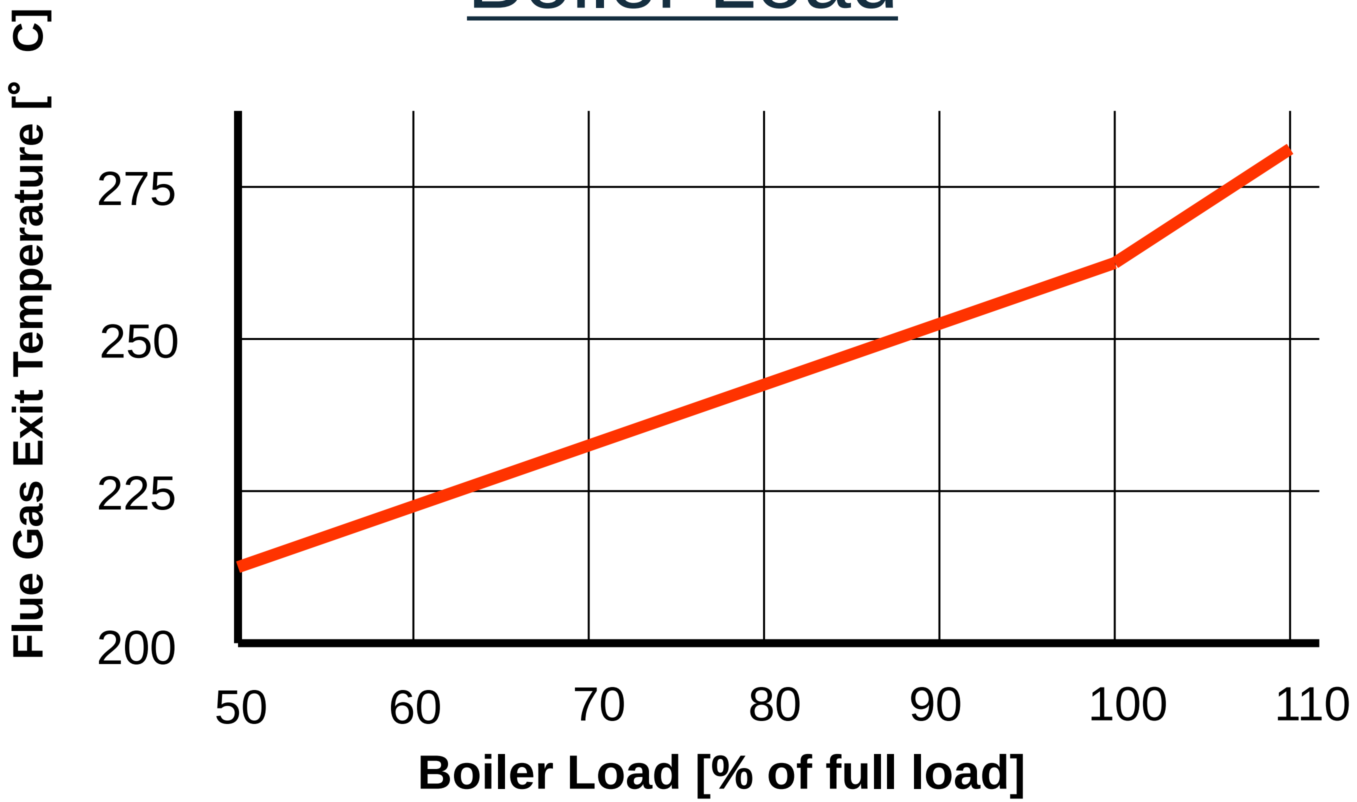
- Flue gas temperature is maintained above the dew point of acidic components
  - Fuels containing sulfur produce sulfuric acid
  - All hydrocarbon fuels can produce carbonic acid

Source: US DOE ITP Steam BestPractices Program

Condensing Economizers

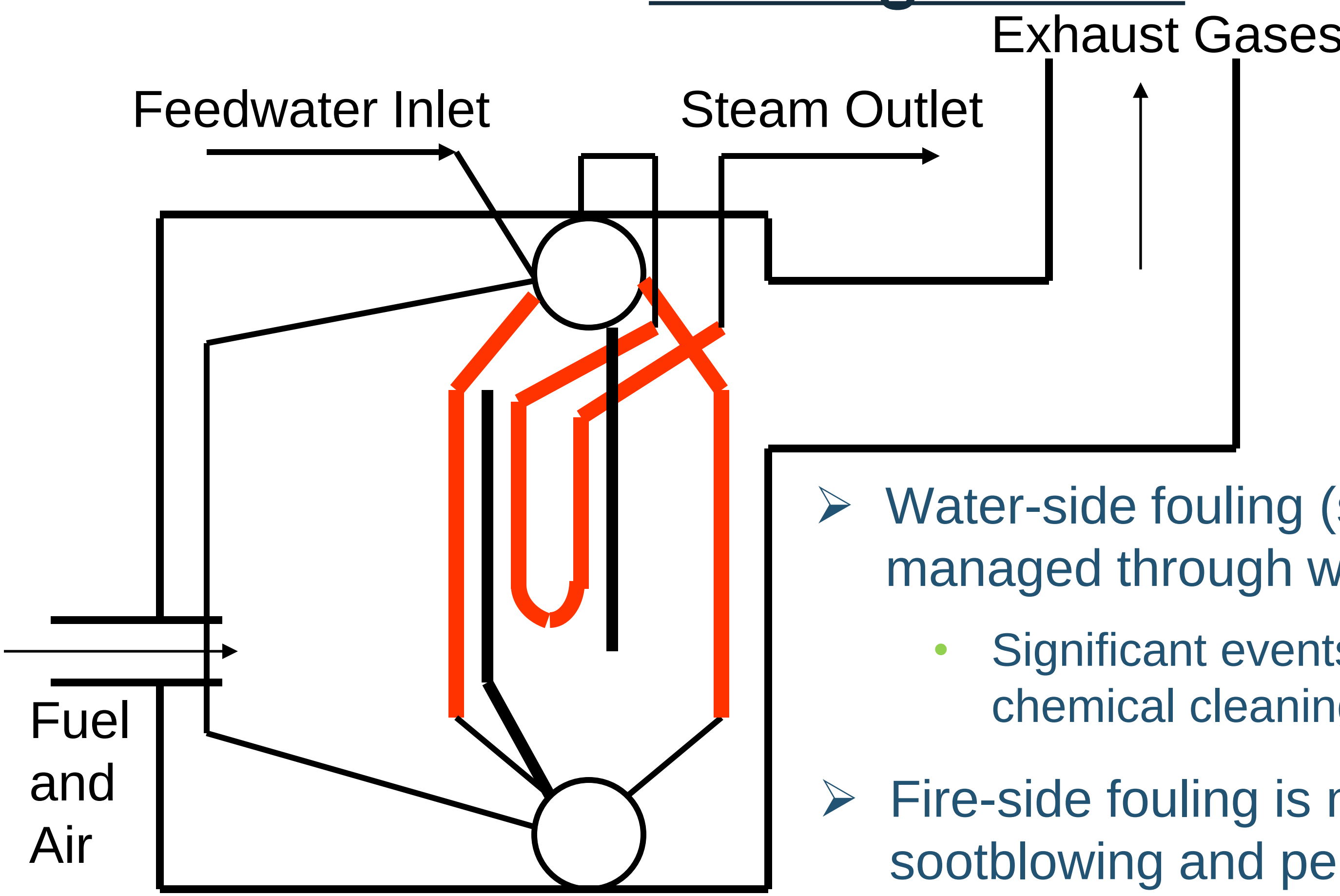
- Condensing economizers can improve boiler efficiency more than 10% in comparison to conventional boilers
  - Final flue gas temperature can approach 25°C
  - Indirect units can heat streams to 90°C
  - Direct units can heat streams to 70°C
  - A significant amount of relatively *low-temperature* energy is recovered
  - Equipment is limited to *clean fuels*
    - Methane gas
    - Light fuel oil

Boiler Load



- Flue gas exhaust temperature typically increases as boiler steam production increases

Fouling Issues

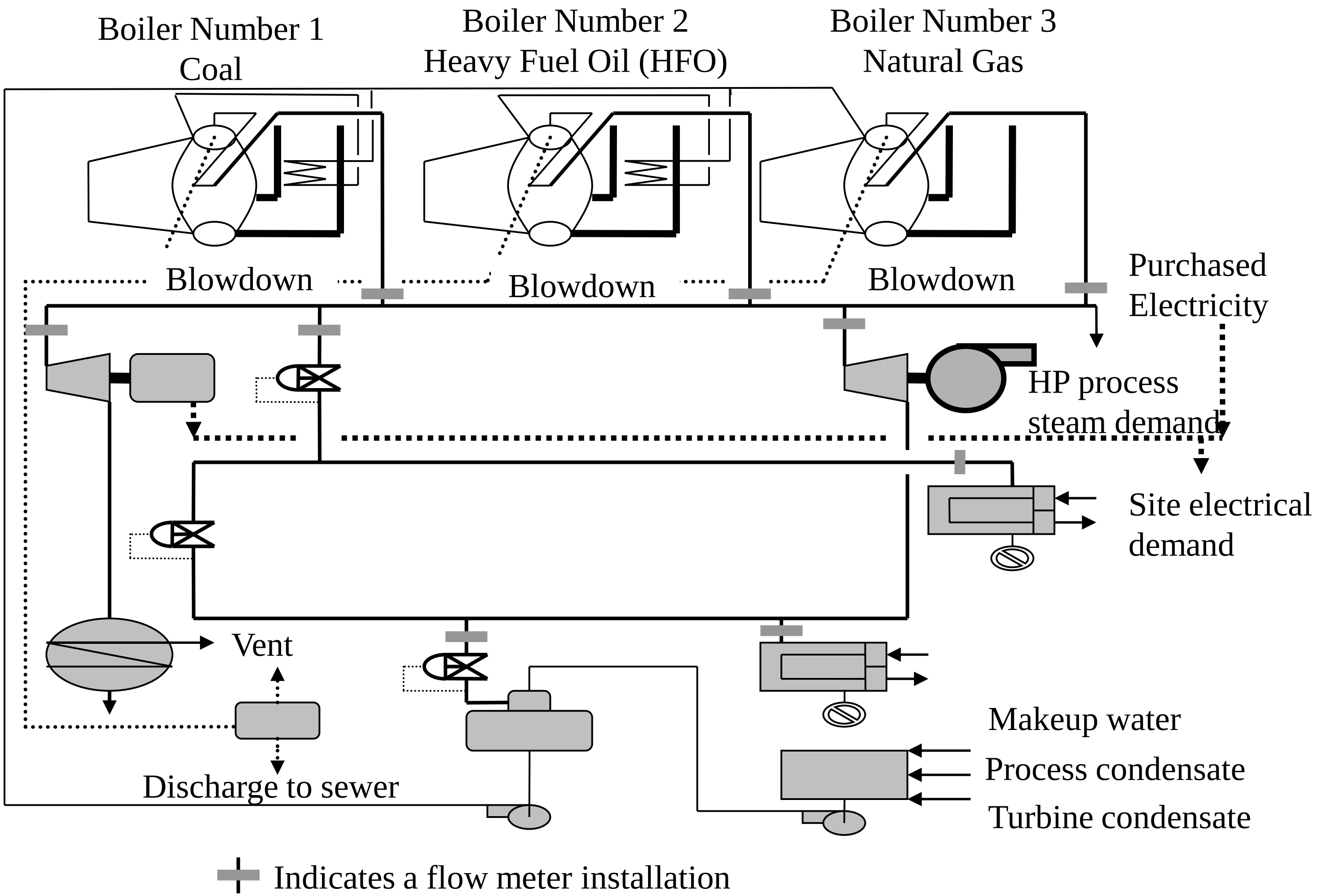


- Water-side fouling (scale) is typically managed through water treatment efforts
  - Significant events are corrected through chemical cleaning and hydro-blasting
- Fire-side fouling is managed through sootblowing and periodic off-line cleaning
  - Sootblowing is critical for solid fuel and heavy fuel oil combustion

Common Stack Loss Reduction Opportunities

- Remove fireside fouling
  - Sootblowing
  - Offline cleaning
- Remove water side fouling
  - Prevention
  - High-pressure jet wash
  - Chemical cleaning
- Repair failed internal components
- Install heat recovery equipment

Steam System

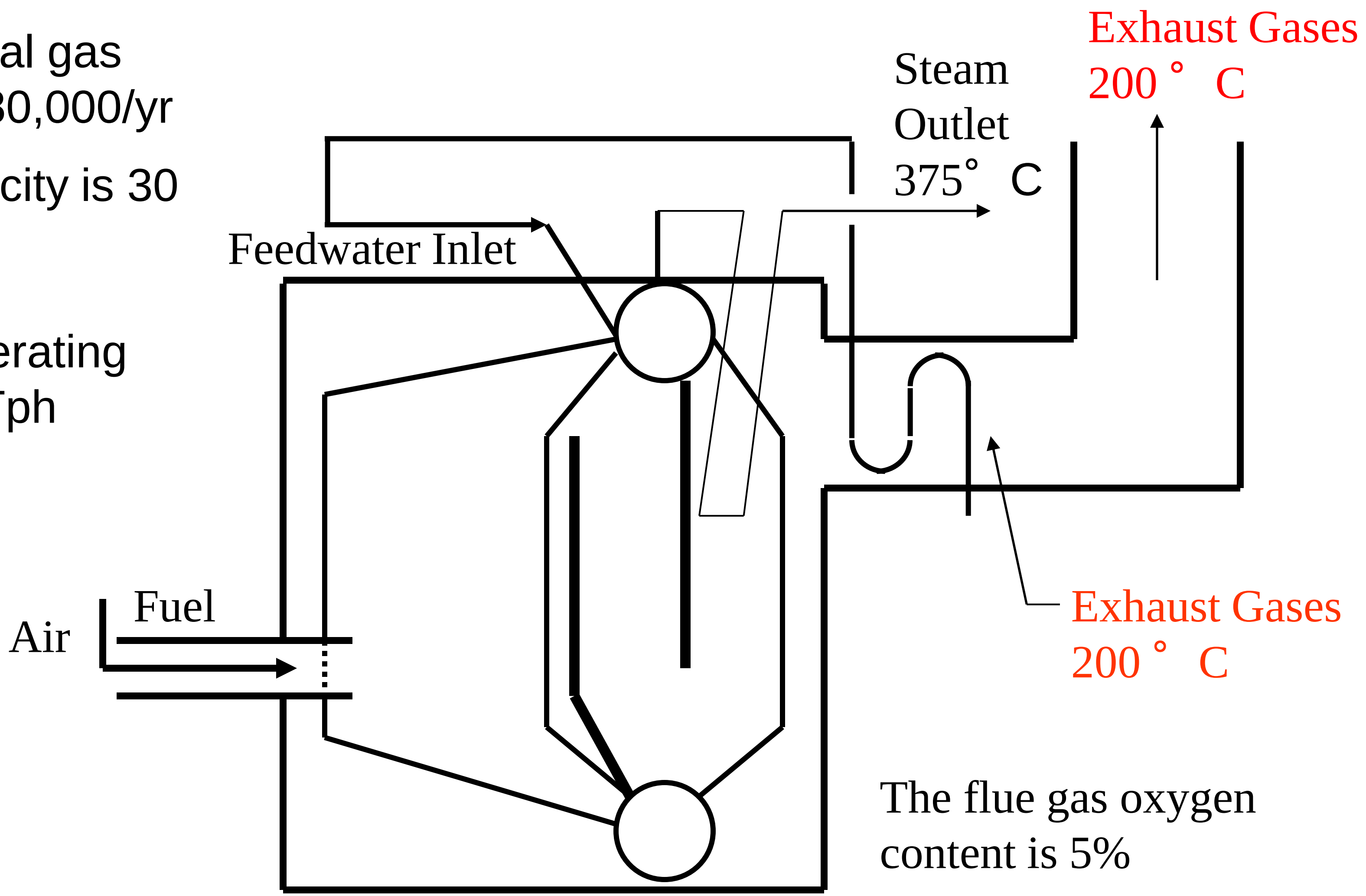


Stack Loss Reduction Example

Fuel: Natural gas
Cost: $7,680,000/yr

Boiler capacity is 30 Tph

Current operating load is 20 Tph



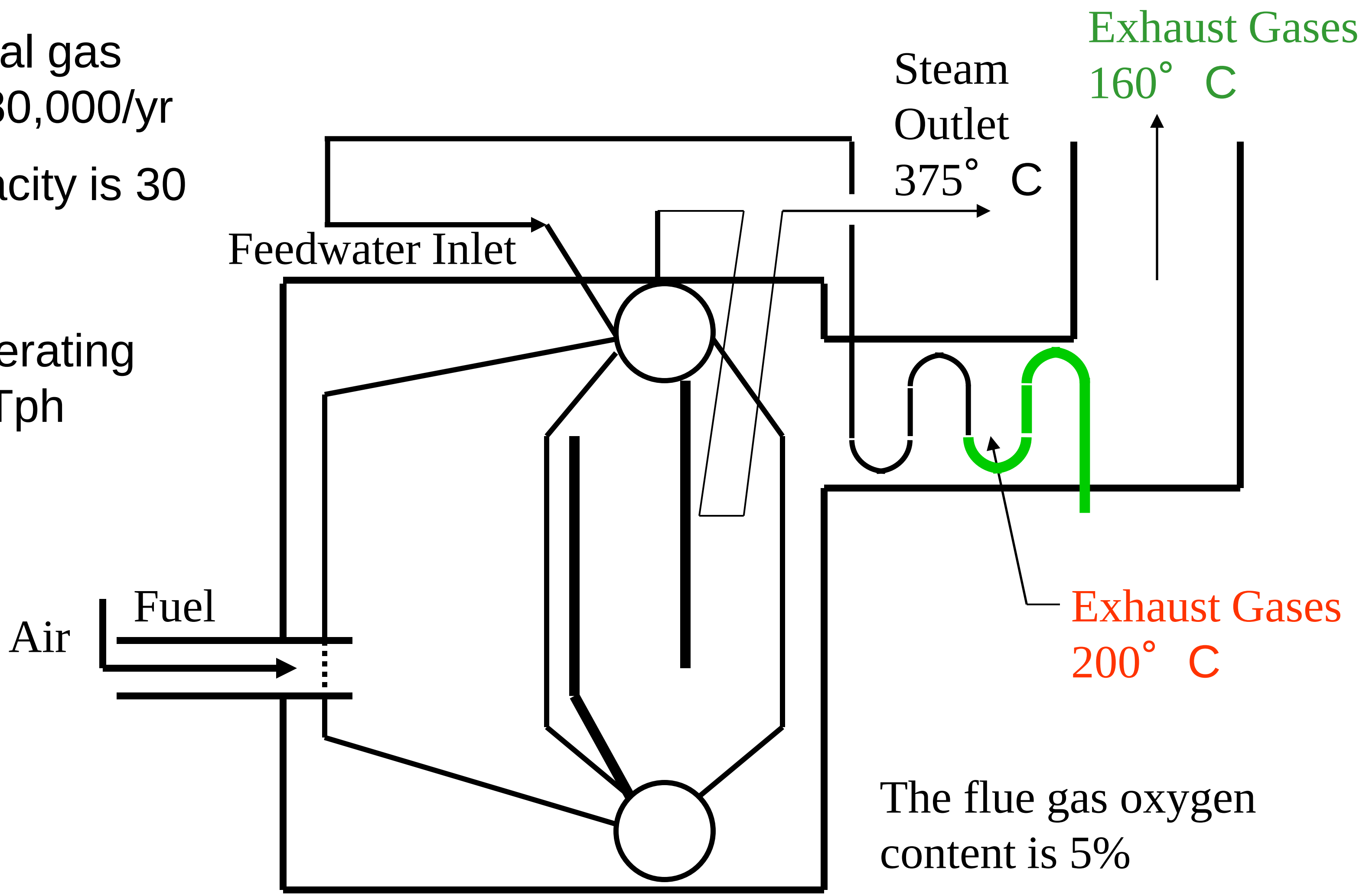
The flue gas oxygen content is 5%

Stack Loss Reduction Example

Fuel: Natural gas
Cost: $7,680,000/yr

Boiler capacity is 30 Tph

Current operating load is 20 Tph



The flue gas oxygen content is 5%

Savings Analysis

$$\sigma_{savings} = \left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)\dot{E}_{steam} = \left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)\left[\dot{m}_{steam}\left(h_s - h_{fw}\right)\right]$$

where

η_1 and η_2 represent the current and the new boiler operating efficiencies

E_{steam} represents the energy transferred in the boiler to make steam

Savings Analysis

$$\sigma_{savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\frac{\dot{E}_{steam}}{\eta_1} = \left(1 - \frac{\eta_1}{\eta_2}\right)\dot{E}_{fuel1}$$

$$\sigma_{savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\dot{K}_{fuel1}$$

where

$E_{fuel\ 1}$ represents the current fuel input energy to the boiler

$K_{fuel\ 1}$ represents the cost of the current fuel input energy to the boiler

Stack Loss – Methane gas (Natural gas in SSAT)

- Stack loss table is developed for negligible combustibles and no condensation

Input Data

Stack Gas Temperature (°F)	200 °C	Stack Temperature - Ambient Temperature = 180°C
Ambient Temperature (°F)	20 °C	

Stack Gas Oxygen Content (%)	5 %	

Note: Stack gas oxygen content is expressed on a molar or volumetric basis

Results

Estimated Stack Losses for each of the default fuels are as follows:

Natural Gas	**18.3 %**

- Base Model Combustion Efficiency = 100 – 18.3 = 81.7%

Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Stack Loss – Methane gas (Natural gas in SSAT)

- Stack loss table is developed for negligible combustibles and no condensation

Input Data

Stack Gas Temperature (°F)	160 °C	Stack Temperature - Ambient Temperature = 140°C
Ambient Temperature (°F)	20 °C	

Stack Gas Oxygen Content (%)	5 %	

Note: Stack gas oxygen content is expressed on a molar or volumetric basis

Results

Estimated Stack Losses for each of the default fuels are as follows:

Natural Gas	**16.3 %**

- Projects Model Combustion Efficiency = 100 – 16.3 = 83.7%

Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Savings Analysis

$$\sigma_{savings} = \left(1 - \frac{\eta_{existing}}{\eta_{adjusted}}\right) \dot{K}_{boiler}$$

$$\sigma_{savings} = \left(1 - \frac{81.7\%}{83.7\%}\right) 7{,}680{,}000 \frac{\$}{yr} \approx 184{,}000 \frac{\$}{yr}$$

- SSAT analysis indicates the same savings opportunity
- Corrosion and boiler loading must be considered
- Based on this analysis installation of a feedwater economizer will most probably result in less than a 1.0 year simple payback

SSAT Project 3 – Boiler Efficiency Improvement Project

Project 3 - Change Boiler Efficiency
Existing Efficiency : 81.7%

Do you wish to specify a new boiler efficiency?	Yes

Note: An example use of this project option is to model the effect of installing an economizer by increasing the efficiency

→ If yes, enter new boiler efficiency (%)	83.68487 %	←

Note: Typical Best Practice boiler efficiency for Natural Gas is 85%

SSAT Project 3 – Boiler Efficiency Improvement Project

SSAT 1 Header Metric Model for Methane Gas Boiler

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	0	0	0	N/A
Fuel Cost	14,253	13,915	338	2.4%
Make-Up Water Cost	59	59	0	0.0%
Total Cost (in $ '000s/yr)	**14,312**	**13,974**	**338**	**2.4%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO_2 Emissions	28581 t/yr	27903 t/yr	678 t/yr	2.4%
SOx Emissions	0 t/yr	0 t/yr	0 t/yr	N/A
NOx Emissions	57 t/yr	55 t/yr	1 t/yr	2.4%

Power Station Emissions	Reduction After Projects	Total Reduction	
CO_2 Emissions	0 t/yr	678 t/yr	-
SOx Emissions	0 t/yr	0 t/yr	-
NOx Emissions	0 t/yr	1 t/yr	-

Note - Calculates the impact of the change in site power import on emissions from an external power station. Total reduction values are for site + power station

Utility Balance	Current Operation	After Projects	Reduction	
Power Generation	0 kW	0 kW	-	-
Power Import	0 kW	0 kW	0 kW	N/A
Total Site Electrical Demand	0 kW	0 kW	-	-
Boiler Duty	18143 kW	17713 kW	430 kW	2.4%
Fuel Type	Natural Gas	Natural Gas	-	-
Fuel Consumption	451952.2 Nm3/h	441232.6 Nm3/h	10719.6 Nm3/h	2.4%
Boiler Steam Flow	20.0 t/h	20.0 t/h	0.0 t/h	0.0%
Fuel Cost (in $/MWh)	89.68	89.68	-	-
Power Cost (as $/MWh)	100.00	100.00	-	-
Make-Up Water Flow	10 m3/h	10 m3/h	0 m3/h	0.0%

Warnings and Selected Projects

- Always check the status of the model
  - Excel status at bottom of screen
  - Model Page
  - Projects Model Page
  - Results Page
- Always check the warnings listed on the Results Page
- Always check the List of Selected Projects
- Always check both low-pressure vents

Key Points / Action Items

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

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 Analysis

- In a perfect world air and fuel would mix thoroughly and complete combustion would occur
  - Each molecule of fuel would find exactly the correct amount of oxygen for the combustion reaction to continue to completion

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

- In actual combustion processes fuel and oxygen do not react perfectly

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

- Un-reacted CH_4, CO and H_2 are *fuels* resulting from incomplete combustion

Source: US DOE ITP Steam BestPractices Program

Combustion Management – Principle 1

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

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

- 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**

Source: US DOE ITP Steam BestPractices Program

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

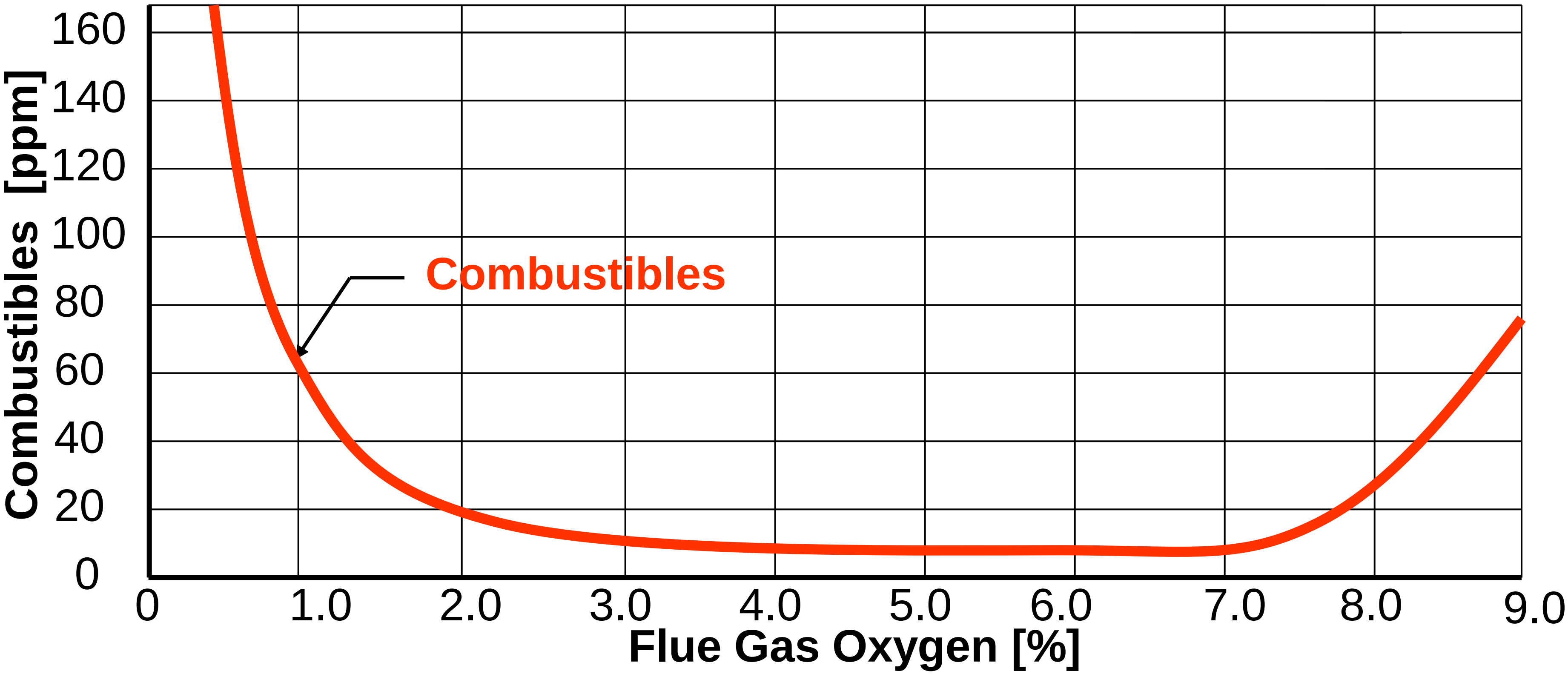
$$CH_4 + \underbrace{2O_2}_{+2(3.76)N_2} \underbrace{\rightarrow}_{\text{Energy Release}} \alpha CO_2 + \beta H_2O + \gamma CO + \delta H_2 + \varepsilon CH_4 + \underbrace{\zeta O_2}_{+2(3.76)N_2}$$

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

Source: US DOE ITP Steam BestPractices Program

Minimum Oxygen Evaluation

- Minimum oxygen limits are determined by measuring combustibles

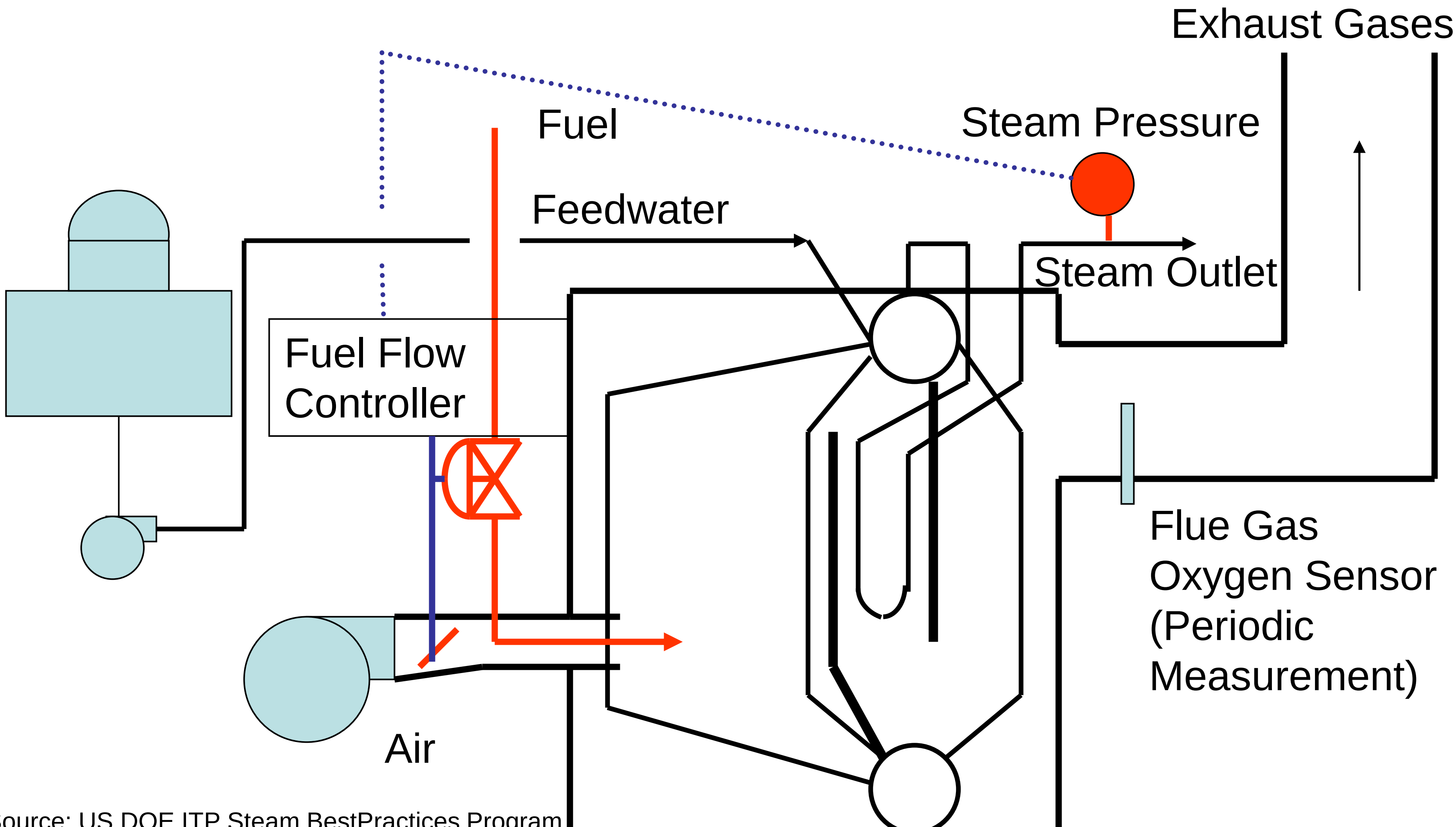


Source: US DOE ITP Steam BestPractices Program

Combustion Management Strategy

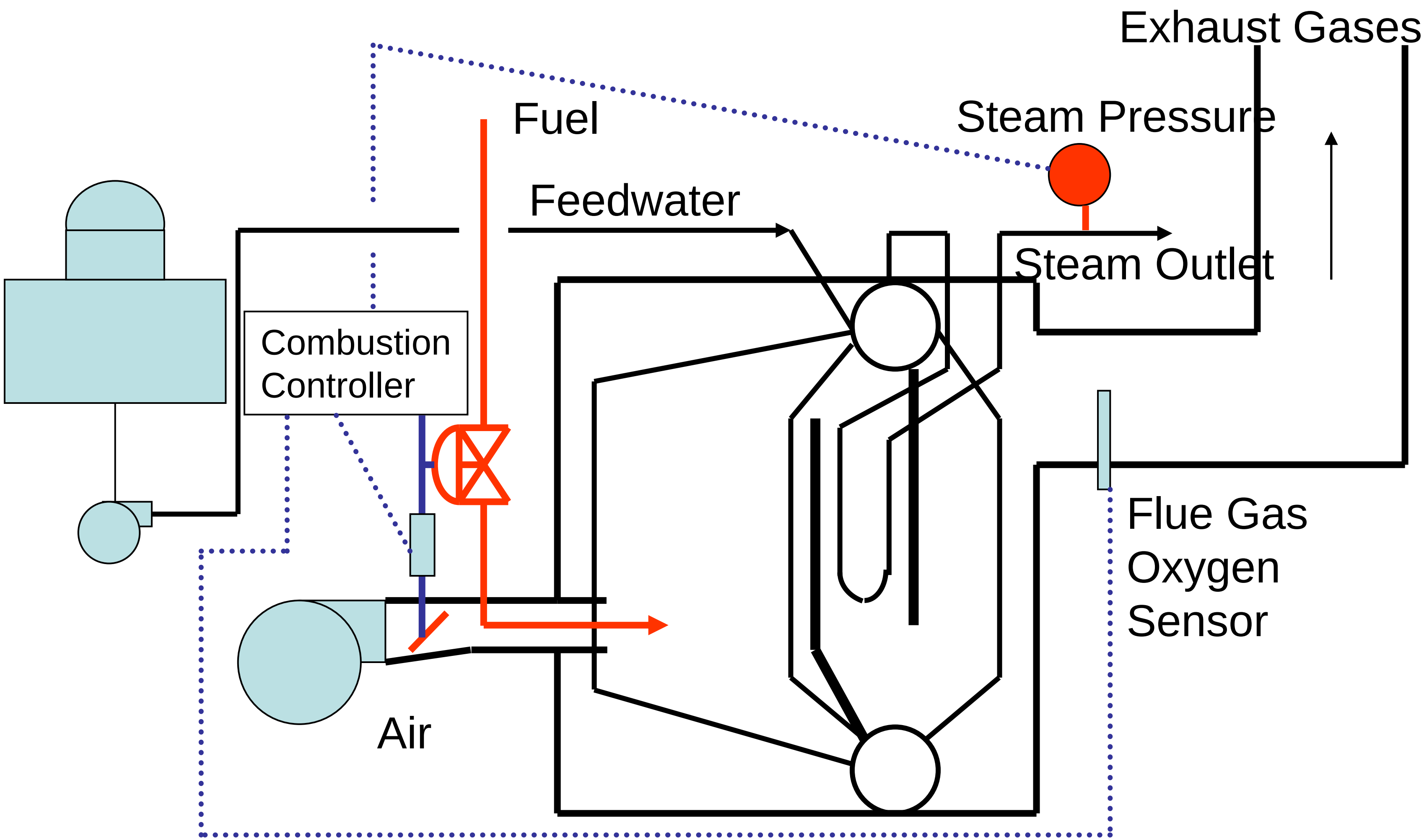
- It is clear that excess air (amount of Oxygen) for the combustion process has to be controlled
- There are two main control strategies
  - Positional control
  - Automatic trim control
- Control of combustion air is done by
  - Dampers
  - Variable Frequency Drives
- Excess air is also a function of Boiler load
- Combustion zone (fire-box) pressure also needs to be controlled

Positioning Control



Source: US DOE ITP Steam BestPractices Program

Automatic O2 Trim Control



Source: US DOE ITP Steam BestPractices Program

Typical Flue Gas Oxygen Content Control Parameters

Typical Flue Gas Oxygen Conten Control Paramenters								
Fuel	Automatic Control Flue Gas O2 Content		Positioning Control Flue Gas O2 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
Num. 2 Fuel Oil	2.0	3.0	3.0	7.0	11	18	18	55
Num. 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

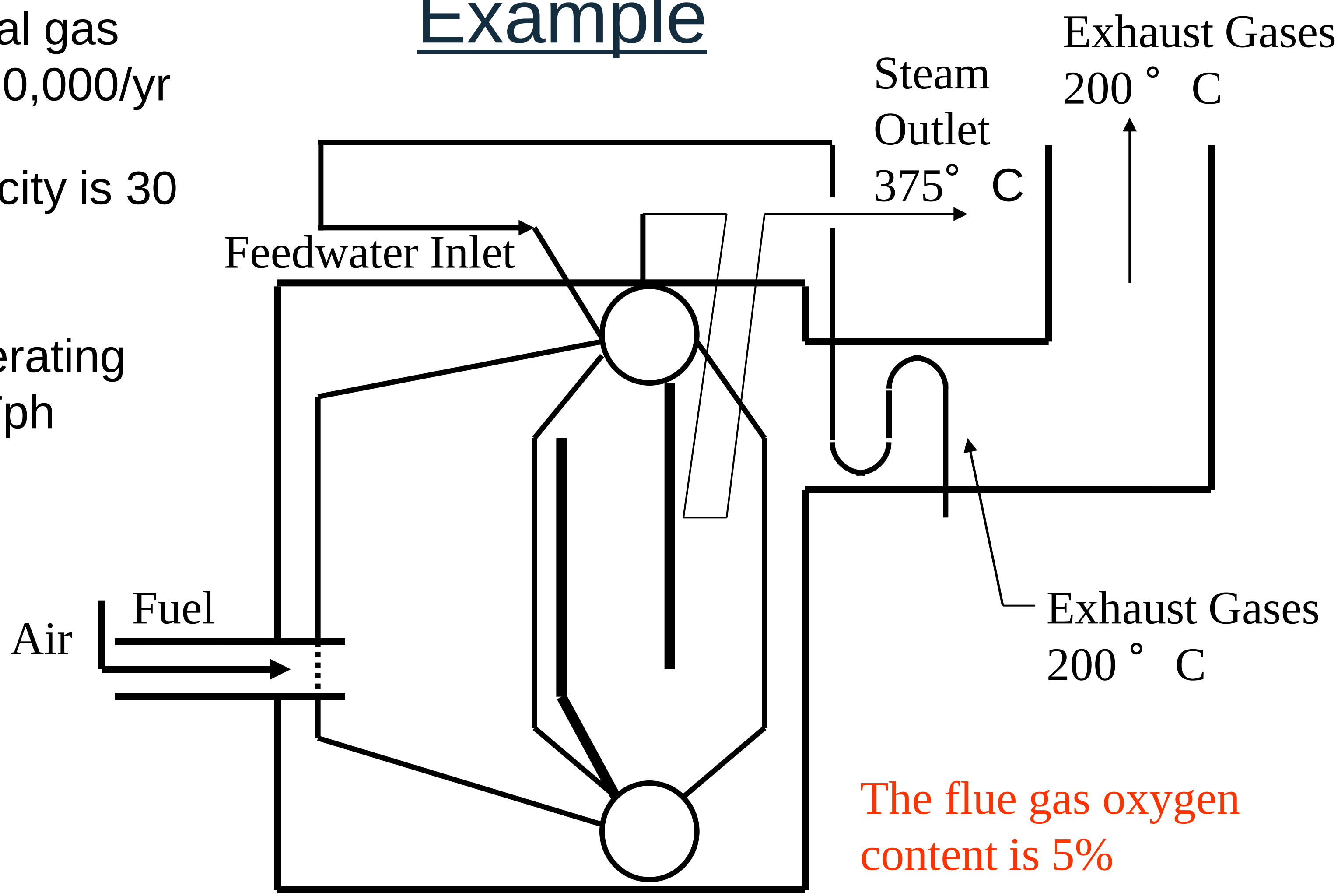
Source: US DOE ITP Steam BestPractices Program

Stack Loss Reduction (Positional Controller) Example

Fuel: Natural gas
Cost: $7,680,000/yr

Boiler capacity is 30 Tph

Current operating load is 20 Tph



The flue gas oxygen content is 5%

Stack Loss – Methane gas (Natural gas in SSAT)

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Input Data

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Note: Stack gas oxygen content is expressed on a molar or volumetric basis

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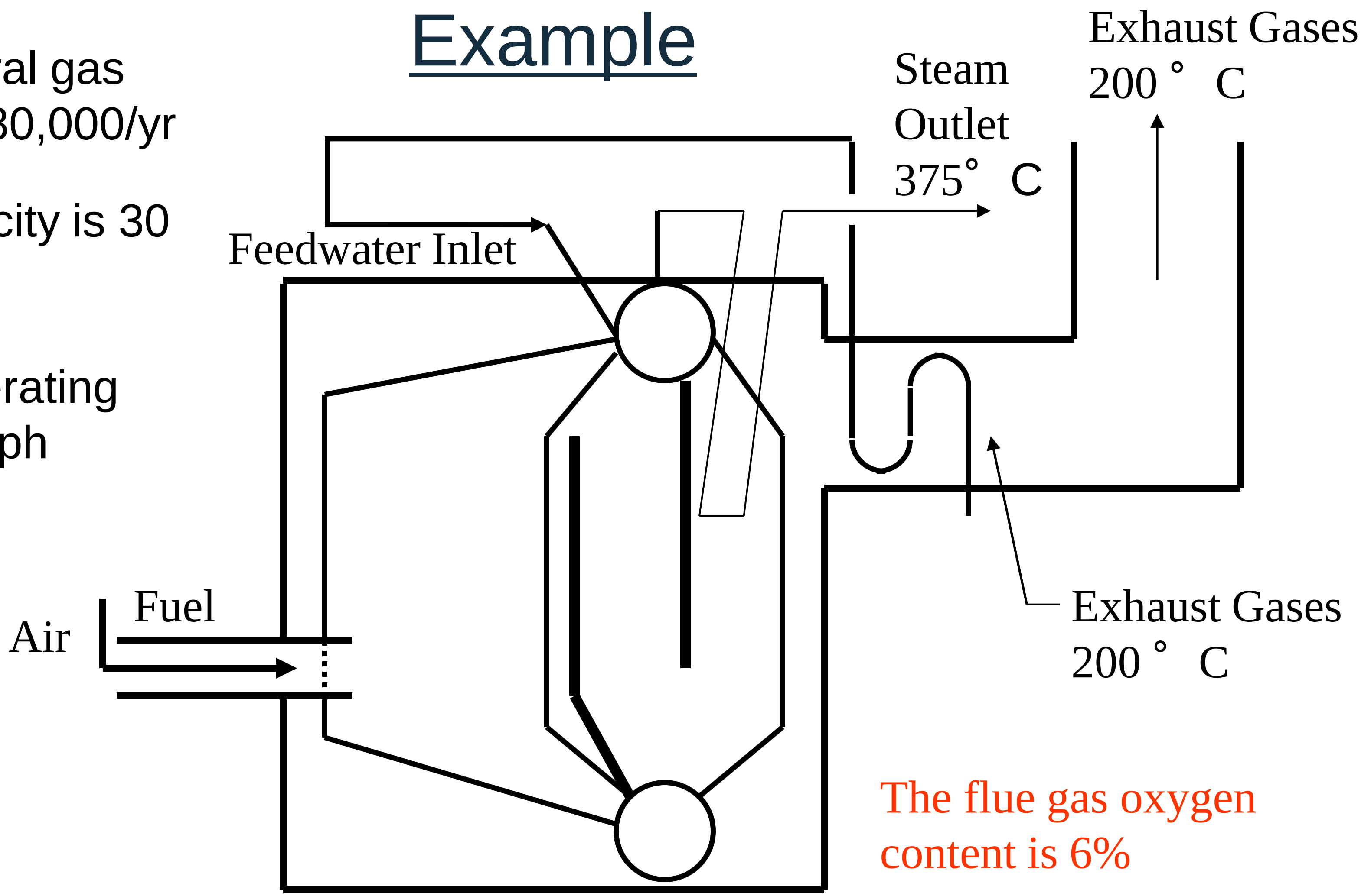
Boiler capacity is 30 Tph

Current operating load is 20 Tph



The flue gas oxygen content is 6%

Stack Loss – Methane gas (Natural gas in SSAT)

- Stack loss table is developed for negligible combustibles and no condensation

Input Data

Stack Gas Temperature (°F)	200 °C	Stack Temperature - Ambient Temperature = 180°C
Ambient Temperature (°F)	20 °C	

Stack Gas Oxygen Content (%)	6 %	

Note: Stack gas oxygen content is expressed on a molar or volumetric basis

Results

Estimated Stack Losses for each of the default fuels are as follows:

Natural Gas	**18.9 %**

- Projects Model Combustion Efficiency = 100 – 18.9 = 81.1%

Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Savings Analysis

$$\sigma_{savings} = \left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)\dot{E}_{steam} = \left(\frac{1}{\eta_1} - \frac{1}{\eta_2}\right)\left[\dot{m}_{steam}\left(h_s - h_{fw}\right)\right]$$

where

η_1 and η_2 represent the current and the new boiler operating efficiencies

E_{steam} represents the energy transferred in the boiler to make steam

Savings Analysis

$$\sigma_{savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\frac{\dot{E}_{steam}}{\eta_1} = \left(1 - \frac{\eta_1}{\eta_2}\right)\dot{E}_{fuel1}$$

$$\sigma_{savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\dot{K}_{fuel1}$$

where

$E_{fuel\ 1}$ represents the current fuel input energy to the boiler

$K_{fuel\ 1}$ represents the cost of the current fuel input energy to the boiler

Positional Controller Re-Tuning

Energy Cost savings = Base Case Operating Cost– New Operating Cost

$$Savings = \left(1 - \frac{\eta_{base}}{\eta_{new}}\right) \times K_{boiler}$$

$$Savings = \left(1 - \frac{81.7}{81.1}\right) \times 7{,}680{,}000$$

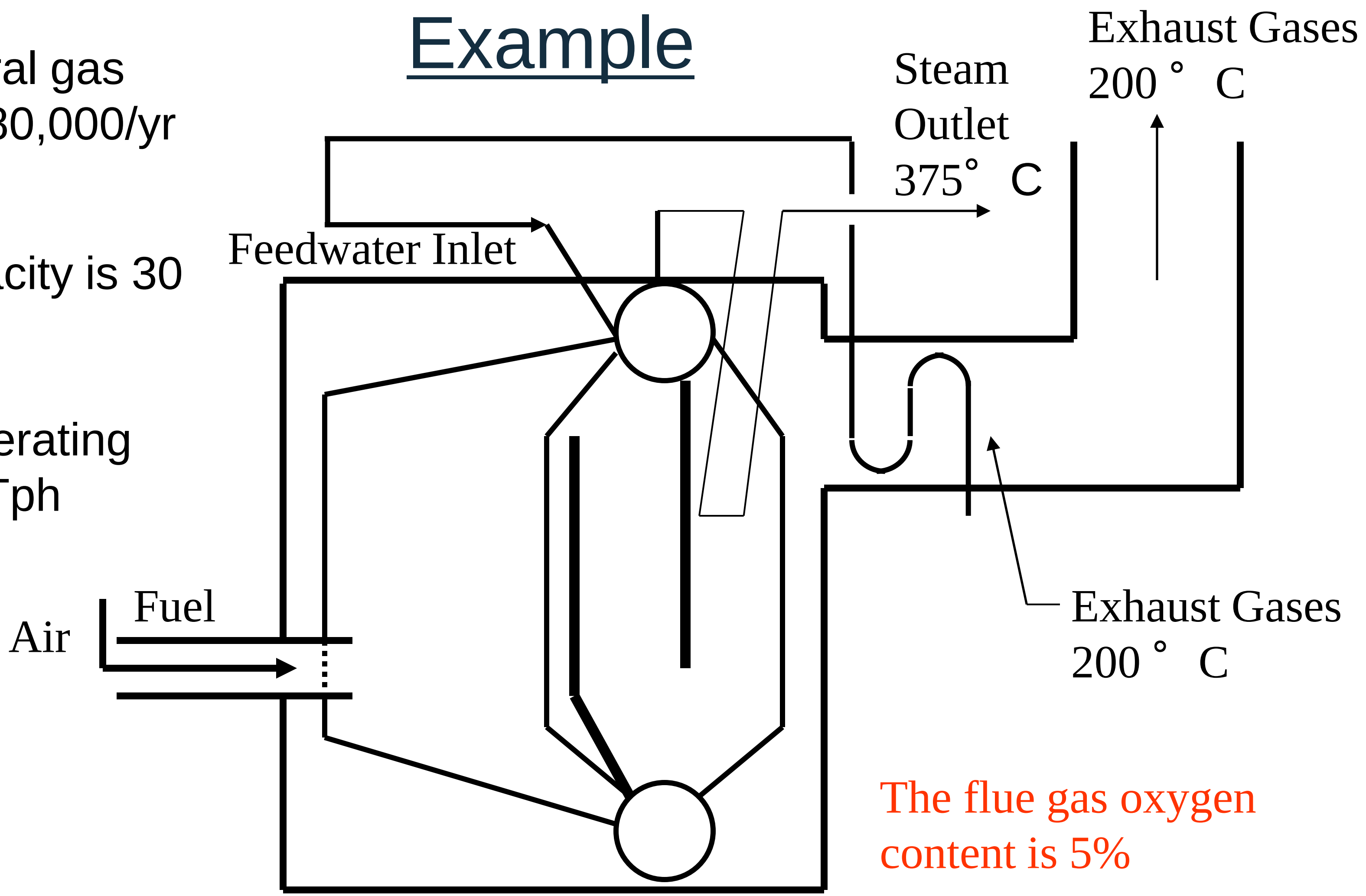
$$Savings \approx -\$57{,}000 / yr$$

Stack Loss Reduction (Positional Controller) Example

Fuel: Natural gas
Cost: $7,680,000/yr

Boiler capacity is 30 Tph

Current operating load is 20 Tph



The flue gas oxygen content is 5%

Stack Loss – Methane gas (Natural gas in SSAT)

- Stack loss table is developed for negligible combustibles and no condensation

Input Data

Stack Gas Temperature (°F)	200 °C	Stack Temperature - Ambient Temperature = 180°C
Ambient Temperature (°F)	20 °C	

Stack Gas Oxygen Content (%)	5 %	

Note: Stack gas oxygen content is expressed on a molar or volumetric basis

Results

Estimated Stack Losses for each of the default fuels are as follows:

Natural Gas	**18.3 %**

- Base Model Combustion Efficiency = 100 – 18.3 = 81.7%

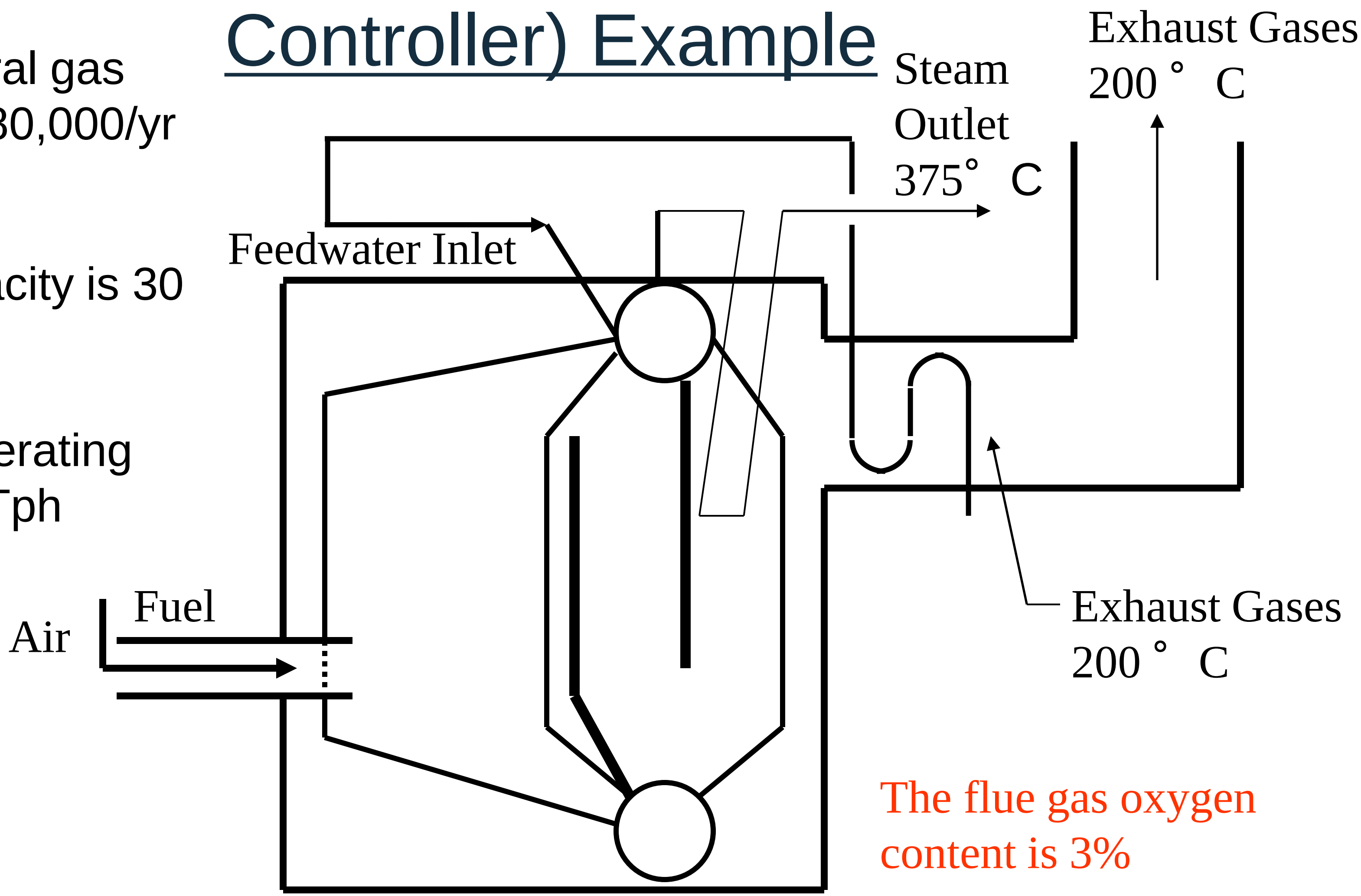
Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Stack Loss Reduction (Automatic O2 Trim Controller) Example

Fuel: Natural gas
Cost: $7,680,000/yr

Boiler capacity is 30 Tph

Current operating load is 20 Tph



The flue gas oxygen content is 3%

Stack Loss – Methane gas (Natural gas in SSAT)

- Stack loss table is developed for negligible combustibles and no condensation

Input Data

Stack Gas Temperature (°F)	200 °C	Stack Temperature - Ambient Temperature = 180°C
Ambient Temperature (°F)	20 °C	

Stack Gas Oxygen Content (%)	3 %	

Note: Stack gas oxygen content is expressed on a molar or volumetric basis

Results

Estimated Stack Losses for each of the default fuels are as follows:

Natural Gas	**17.4 %**

- Projects Model Combustion Efficiency = 100 – 17.4 = 82.6%

Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Install Automatic Oxygen Trim Controller

Energy Cost savings = Base Case Operating Cost – New Operating Cost

$$Savings = \left(1 - \frac{\eta_{base}}{\eta_{new}}\right) \times K_{boiler}$$

$$Savings = \left(1 - \frac{81.7}{82.6}\right) \times 7,680,000$$

$$Savings \approx \$84,000 / yr$$

SSAT Project 3 – Boiler Efficiency Improvement Project

- Complete the “Install Automatic Oxygen Trim Controller” analysis utilizing the SSAT one header model – Project 3

SSAT Project 3 – Boiler Efficiency Improvement Project

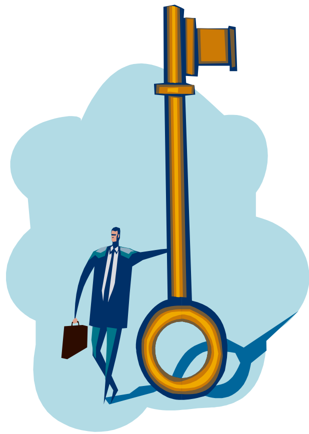
Results Summary

SSAT Default 1 Header Metric Model Moldova Ex 1

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	7,937	7,850	86	1.1%
Make-Up Water Cost	142	142	0	0.0%
Total Cost (in $ '000s/yr)	**14,211**	**14,125**	**86**	**0.6%**

On-Site Emissions	Current Operation	After Projects	Reduction	
CO2 Emissions	30606 t/yr	30272 t/yr	333 t/yr	1.1%
SOx Emissions	0 t/yr	0 t/yr	0 t/yr	N/A
NOx Emissions	61 t/yr	60 t/yr	1 t/yr	1.1%



Key Points / Action Items

1. Combustion management principles:
   - Add enough oxygen to react all of the fuel
   - Minimize the amount of extra air
   - Monitor combustibles to identify problems
2. Measure the oxygen content of boiler exhaust gas
3. Control oxygen content within a minimum and maximum range
   - Continuous - automatic O_2 trim control
   - Positioning control
4. Challenge the control range
   - Control upgrade
   - Combustion tuning

Fuel Switching & Boiler Operation Optimization

Fuel Switching

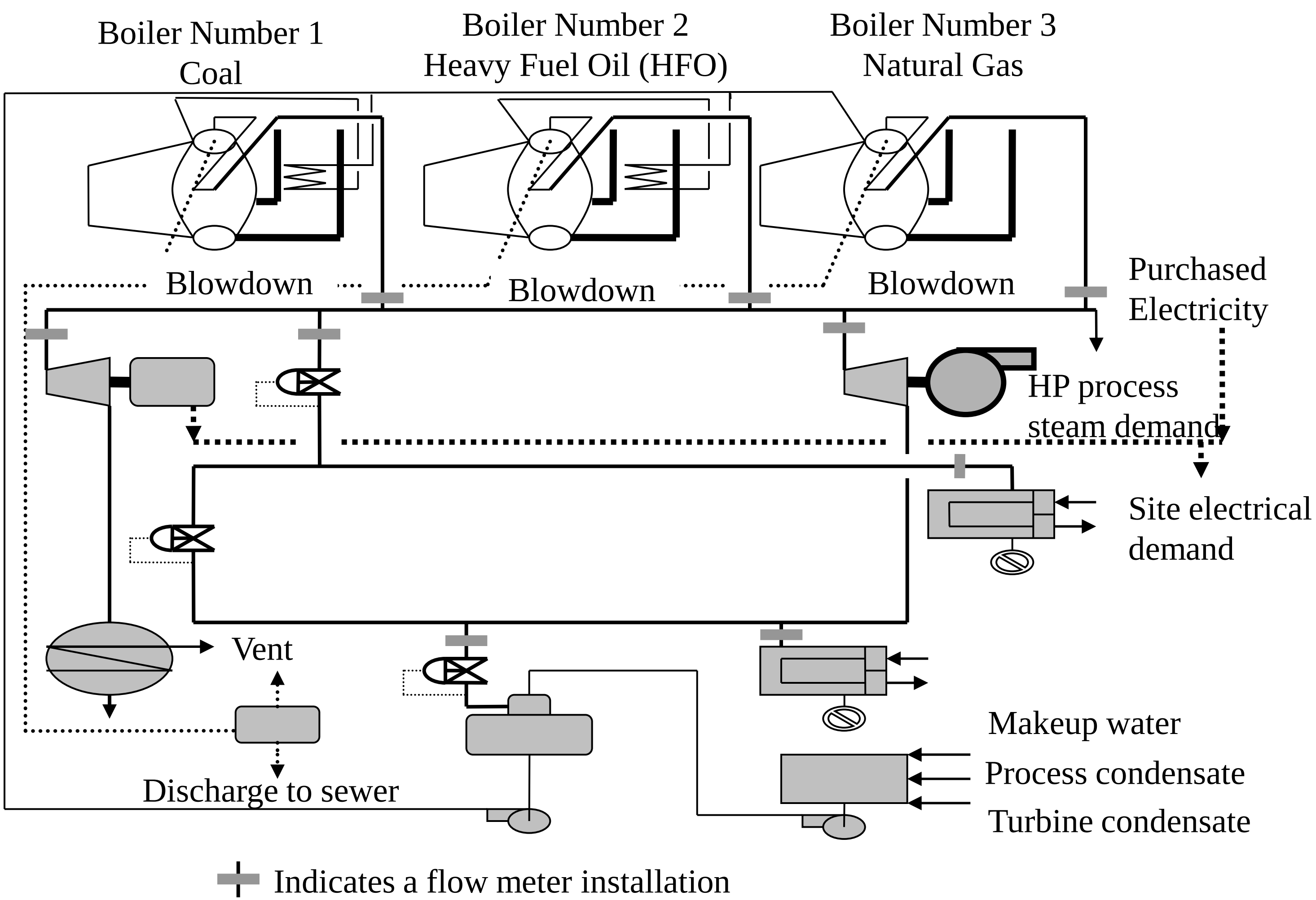
- Fuel selection can provide significant reductions in operating costs due to differences in energy costs and boiler efficiencies
  - Sometimes energy costs and maintenance expenditures are offsetting
  - Environmental issues are a significant concern associated with fuel selection
  - Fuel efficiency will generally be an influencing factor when changing fuel

- Each application will need an independent evaluation – there are NO thumb rules!

Boiler Operation Optimization

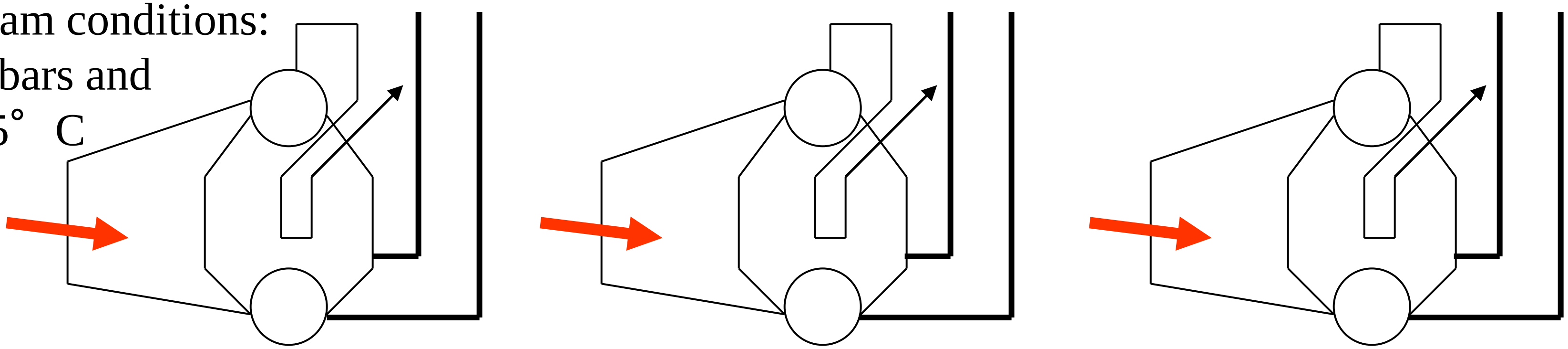
- Typically, very common scenario in multiple boiler configurations in industry
- Boiler operational optimization can take several forms
  - Shutdown a boiler
  - Reduce operations of the most expensive boiler while shifting load to other cost effective boilers
  - Dual fuel-firing and fuel hedging strategies may need to be considered
  - System reliability will need to be considered
  - Both steady state as well as dynamic load profile will need to be evaluated
- Each application will need an independent evaluation – there are NO thumb rules!

Steam System



Fuel Switching & Steam Generation Optimization

Steam conditions:
25 bars and
375° C



Fuel: Coal	Fuel: Heavy Fuel Oil	Fuel: Natural gas
Fuel cost: $7.8/GJ	Fuel cost: $22.9/GJ	Fuel cost: $12.8/GJ
Boiler capacity: 90 Tph	Boiler capacity: 90 Tph	Boiler capacity: 30 Tph
Steam production: 65 Tph	Steam production: 65 Tph	Steam production: 20 Tph
Boiler Efficiency: 85%	Boiler efficiency: 84%	Boiler efficiency: 80%

- Quantify the economic benefit of increasing steam production by 1 Tph in the HFO boiler
- Quantify the economic benefit of increasing steam production by 1 Tph in the Coal boiler

Fuel Switching Calculation (1 Tph with HFO Boiler)

$$Savings\ from\ fuel\ switching = \sigma = Initial\ operating\ cost - Final\ operating\ cost$$

$$\sigma = \left(\dot{K}_1 - \dot{K}_2\right)\tau = \left(\frac{\dot{E}_{steam}}{\eta_1}\kappa_{fuel1} - \frac{\dot{E}_{steam}}{\eta_2}\kappa_{fuel2}\right)\tau = \dot{E}_{steam}\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = \dot{m}_{steam}\left(h_{steam} - h_{fw}\right)\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = 1{,}000\,\tfrac{kg}{hr}\left(3{,}181\,\tfrac{kJ}{kg} - 463.5\,\tfrac{kJ}{kg}\right)\left(\frac{12.8\,\frac{\$}{GJ}}{0.80} - \frac{22.9\,\frac{\$}{GJ}}{0.84}\right)8{,}760\,\tfrac{hrs}{yr}$$

$$\sigma = -268{,}000\,\tfrac{\$}{yr}$$

Fuel Switching Calculation (1 Tph with Coal Boiler)

$$Savings\ from\ fuel\ switching = \sigma = Initial\ operating\ cost - Final\ operating\ cost$$

$$\sigma = \left(\dot{K}_1 - \dot{K}_2\right)\tau = \left(\frac{\dot{E}_{steam}}{\eta_1}\kappa_{fuel1} - \frac{\dot{E}_{steam}}{\eta_2}\kappa_{fuel2}\right)\tau = \dot{E}_{steam}\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = \dot{m}_{steam}\left(h_{steam} - h_{fw}\right)\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = 1{,}000\,\tfrac{kg}{hr}\left(3{,}181\,\tfrac{kJ}{kg} - 463.5\,\tfrac{kJ}{kg}\right)\left(\frac{12.8\,\frac{\$}{GJ}}{0.80} - \frac{7.8\,\frac{\$}{GJ}}{0.85}\right)8{,}760\,\tfrac{hrs}{yr}$$

$$\sigma = 162{,}000\,\tfrac{\$}{yr}$$

Fuel Switching Calculation (1 Tph with Coal Boiler)

$$Savings\ from\ fuel\ switching = \sigma = Initial\ operating\ cost - Final\ operating\ cost$$

$$\sigma = \left(\dot{K}_1 - \dot{K}_2\right)\tau = \left(\frac{\dot{E}_{steam}}{\eta_1}\kappa_{fuel1} - \frac{\dot{E}_{steam}}{\eta_2}\kappa_{fuel2}\right)\tau = \dot{E}_{steam}\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = \dot{m}_{steam}\left(h_{steam} - h_{fw}\right)\left(\frac{\kappa_{fuel1}}{\eta_1} - \frac{\kappa_{fuel2}}{\eta_2}\right)\tau$$

$$\sigma = 1{,}000\,\tfrac{kg}{hr}\left(3{,}181\,\tfrac{kJ}{kg} - 463.5\,\tfrac{kJ}{kg}\right)\left(\frac{12.8\,\frac{\$}{GJ}}{0.80} - \frac{7.8\,\frac{\$}{GJ}}{0.85}\right)8{,}760\,\tfrac{hrs}{yr}$$

$$\sigma = 162{,}000\,\tfrac{\$}{yr}$$

NOTE: Analysis utilizes direct boiler efficiency (or complete indirect efficiency)

SSAT Project 2 – Alternate Fuel

- Fuel switching is a common energy management activity
- SSAT Project 2 allows
  - The user to choose an alternate fuel from the standard fuel list
  - Input a fuel unit cost
- In general boiler efficiency will change as the fuel is changed
  - Fuel characteristics will impact stack loss
  - Boiler characteristics may change
    - Flue gas temperature may increase due to fouling
    - Flue gas oxygen content may change because of combustion characteristics
  - Use SSAT Project 3

Fuel Switching in SSAT

- Economic impact can be calculated
  - By manual thermodynamic calculations
  - Using SSAT model and turning on projects 2 and 3 with appropriate steam generation as impact parameter

Project 2 - Use an Alternative Fuel
Existing Boiler Fuel : Natural Gas Fuel Cost : $1/Nm3

Do you wish to specify an alternative fuel?		Yes
→ If yes, choose a new fuel from this drop-down list		User Defined Fuel ←
→ Site Fuel Cost	5.40 $/GJ	Typical 2003 values: $1-7/GJ ←

Note: Example HHV values - Nat Gas 54,220 kJ/kg, No. 2 FO 45,125 kJ/kg, Typical Eastern Coal 31,890 kJ/kg, Green Wood 12,215 kJ/kg

Project 3 - Change Boiler Efficiency
Existing Efficiency : 81.7%

Do you wish to specify a new boiler efficiency?		Yes

Note: An example use of this project option is to model the effect of installing an economizer by increasing the efficiency

→ If yes, enter new boiler efficiency (%)	86.7 %	←

Fuel Switching – in SSAT

- Economic impact of switching 20 tph steam from the Natural gas boiler to the coal-fired boiler

SSAT Default 1 Header Metric Model Moldova Ex 1

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	7,937	4,526	3,410	43.0%
Make-Up Water Cost	142	142	0	0.0%
Total Cost (in $ '000s/yr)	**14,211**	**10,801**	**3,410**	**24.0%**

- Economic impact of switching 1 tph steam from the Natural gas boiler to the coal-fired boiler

$$\sigma = \frac{3{,}410{,}000}{20} \frac{\$}{yr}$$

$$\sigma = 170{,}000 \frac{\$}{yr}$$

Fuel Switching – in SSAT

- Economic impact of switching 20 tph steam from the Natural gas boiler to the HFO-fired boiler

SSAT Default 1 Header Metric Model Moldova Ex 1

Model Status : OK

Cost Summary ($ '000s/yr)	Current Operation	After Projects	Reduction	
Power Cost	6,132	6,132	0	0.0%
Fuel Cost	7,937	13,399	-5,462	-68.8%
Make-Up Water Cost	142	142	0	0.0%
Total Cost (in $ '000s/yr)	**14,211**	**19,673**	-5,462	-38.4%

- Economic impact of switching 1 tph steam from the Natural gas boiler to the HFO-fired boiler

$$\sigma = -\frac{5{,}462{,}000}{20}\frac{\$}{yr}$$

$$\sigma = -273{,}000\,\frac{\$}{yr}$$

Factors Limiting Fuel Switching

- Environmental regulations
- Fuel storage and handling
- Boiler capabilities

Key Points / Action Items

1. *Use a steam system model based on the laws of thermodynamics to quantify energy and cost savings opportunities*

2. *Fuel switching and boiler plant operations are excellent areas for optimization of steam systems – significant cost savings can be realized by applying optimal operating strategies*

3. *Each application will need an independent evaluation – there are NO thumb rules!*

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
- Investigate fuel switching
- Optimize deaerator vent rate

Source: US DOE BestPractices Steam System Sourcebook