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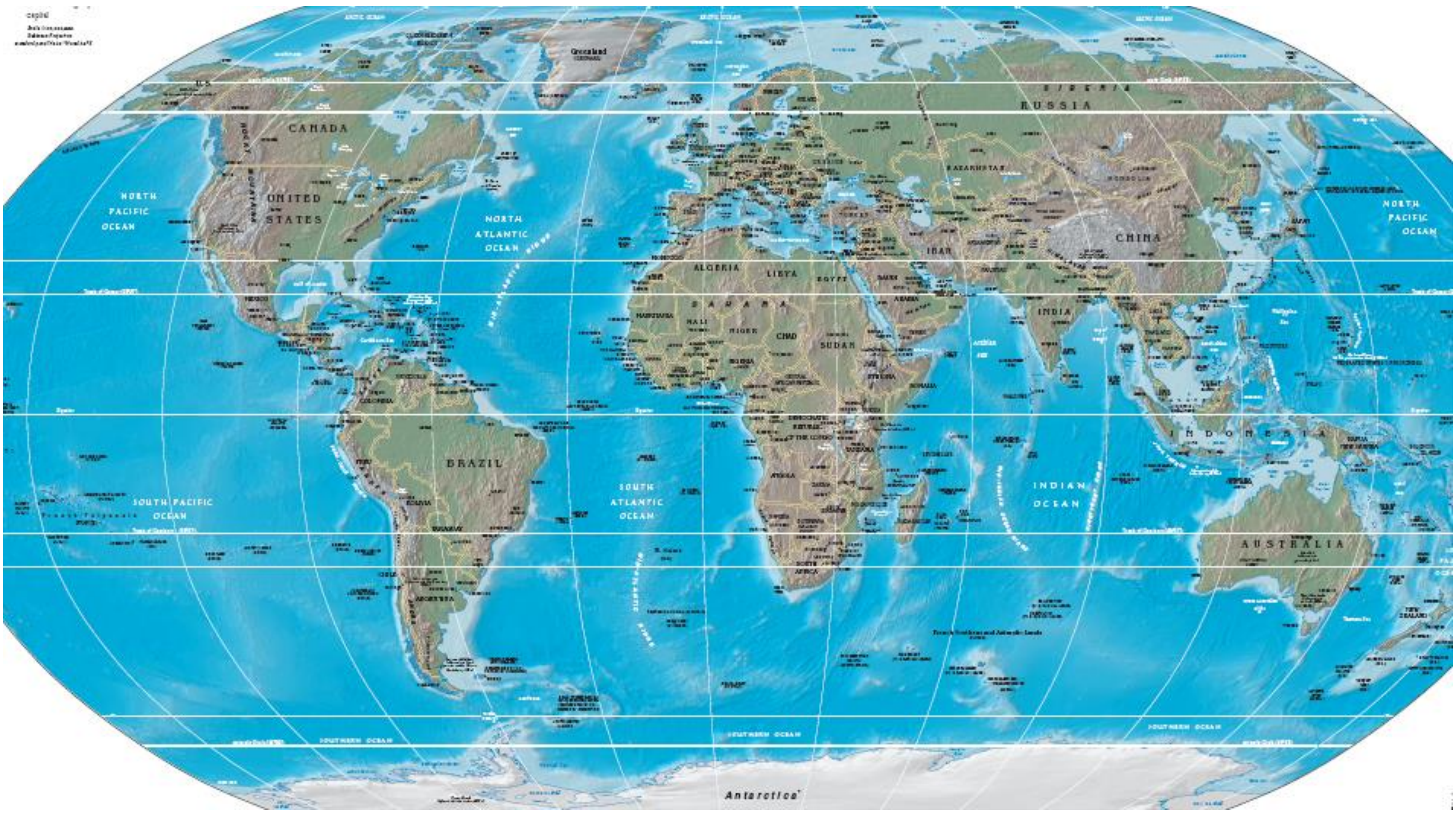
Steam and Cogeneration System Assessments Overview

Energy Management Services

Milligan Engineering



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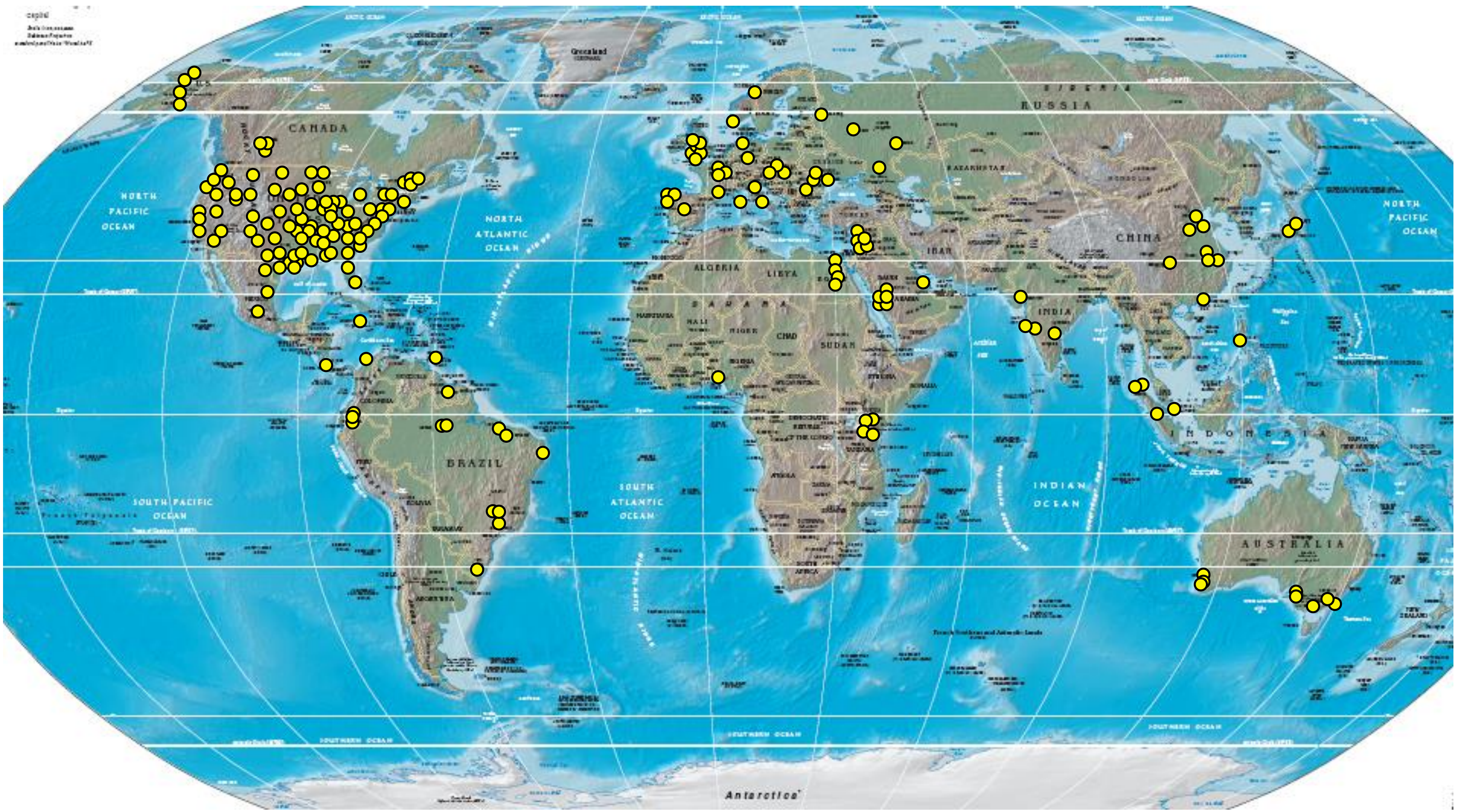

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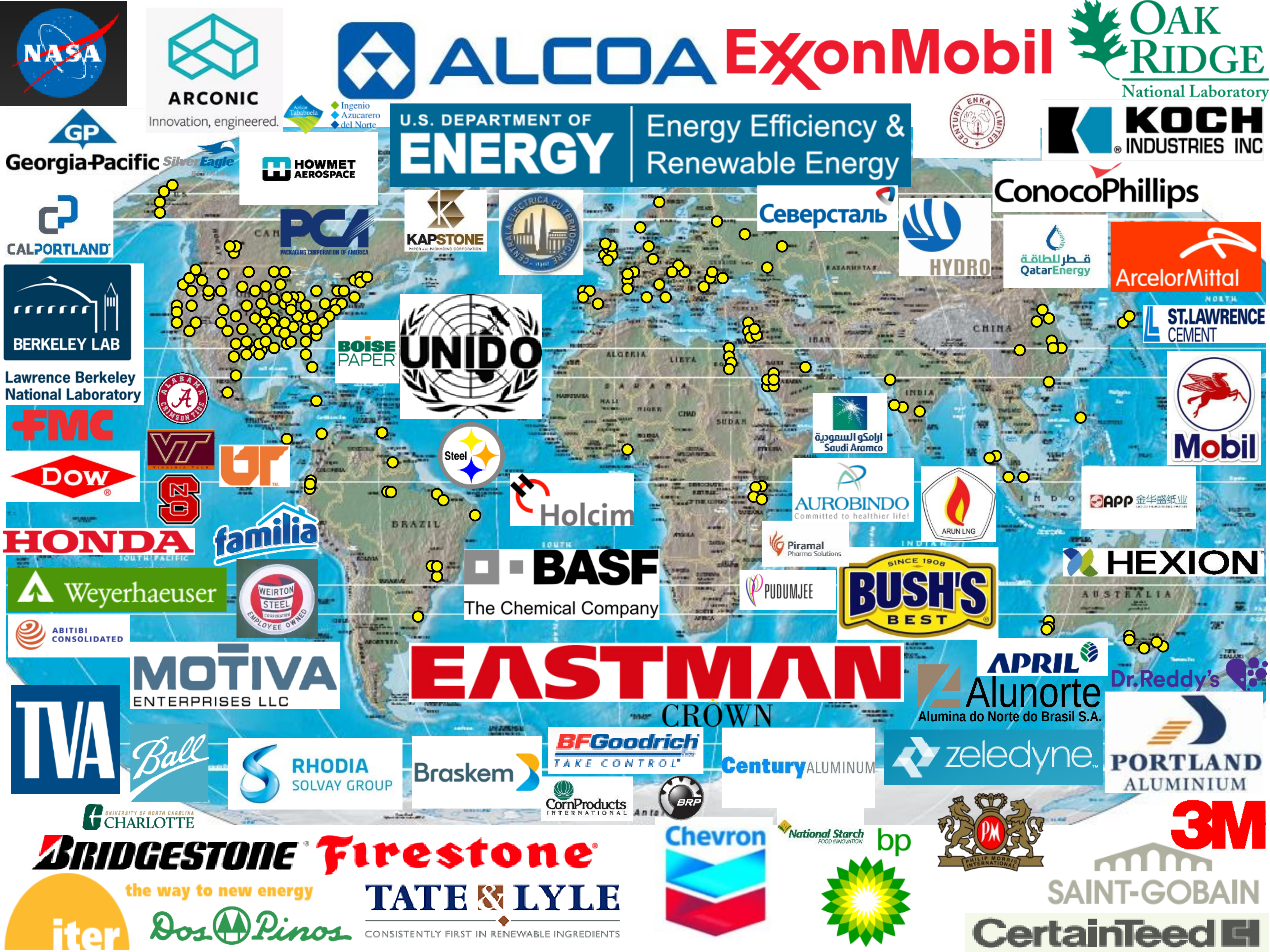
NASA
ARCONIC
Innovation, engineered.
ALCOA
ExxonMobil
OAK RIDGE
National Laboratory
Ingenio Azucarero del Norte
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
CENTURY ENKA LIMITED
KOCH INDUSTRIES INC
GP
Georgia-Pacific
Silver Eagle
HOWMET AEROSPACE
ConocoPhillips
CALPORTLAND
PCA
PACKAGING CORPORATION OF AMERICA
KAPSTONE
CENTRALA ELECTRICA CU TERMOFICARE
Северсталь
HYDRO
قطر للطاقة
QatarEnergy
ArcelorMittal
BERKELEY LAB
Lawrence Berkeley National Laboratory
BOISE PAPER
UNIDO
ST.LAWRENCE CEMENT
ALABAMA CRIMSON TIDE
FMC
VT
UT
Steelers
Holcim
أرامكو السعودية
Saudi Aramco
Mobil
DOW
NC
AUROBINDO
Committed to healthier life!
ARUN LNG
APP 金华盛纸业
HONDA
familia
Piramal
Pharma Solutions
BASF
The Chemical Company
PUDUMJEE
BUSH'S BEST
SINCE 1908
HEXION
Weyerhaeuser
WEIRTON STEEL
EMPLOYEE OWNED
ABITIBI CONSOLIDATED
MOTIVA
ENTERPRISES LLC
EASTMAN
APRIL
Alunorte
Alumina do Norte do Brasil S.A.
Dr.Reddy's
CROWN
TVA
Ball
RHODIA
SOLVAY GROUP
Braskem
BFGoodrich
TAKE CONTROL
CornProducts
INTERNATIONAL
BRP
CenturyALUMINUM
zeledyne
PORTLAND ALUMINIUM
UNIVERSITY OF NORTH CAROLINA CHARLOTTE
Chevron
National Starch
bp
PHILIP MORRIS INTERNATIONAL
3M
BRIDGESTONE
Firestone
the way to new energy
iter
Dos Pinos
TATE & LYLE
CONSISTENTLY FIRST IN RENEWABLE INGREDIENTS
SAINT-GOBAIN
CertainTeed

STEAM AND COGENERATION SYSTEM ASSESSMENTS

BOILERS


2
CAUTION


PERIGO
110.CV.01
TPM
PERIGO

$$\eta_{Boiler} = \frac{\dot{m}_{Steam}(h_{Steam} - h_{Feedwater})}{\dot{m}_{Fuel} HHV_{Fuel}}$$

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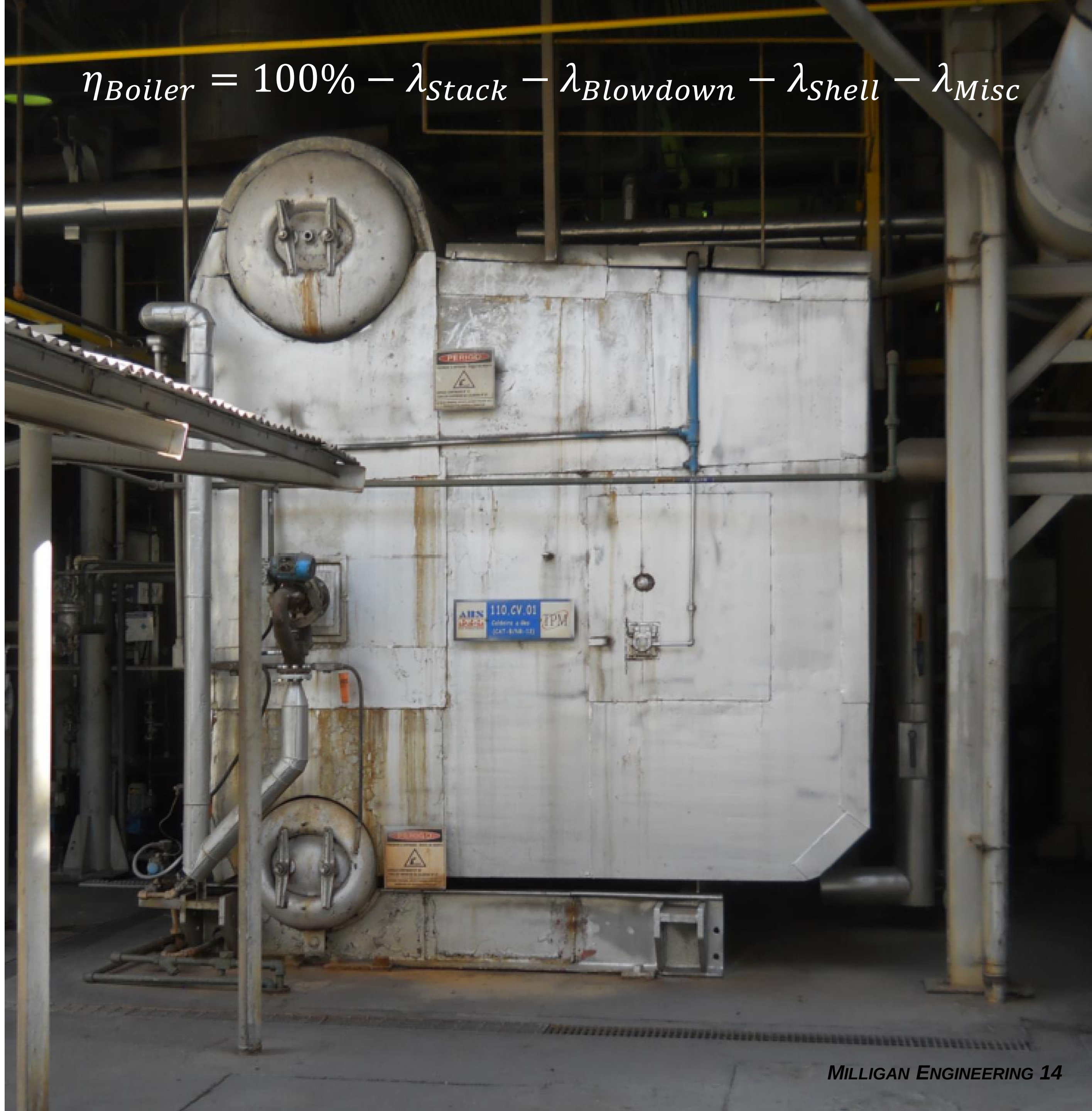
$$\eta_{Boiler} = 100\% - \lambda_{Stack} - \lambda_{Blowdown} - \lambda_{Shell} - \lambda_{Misc}$$

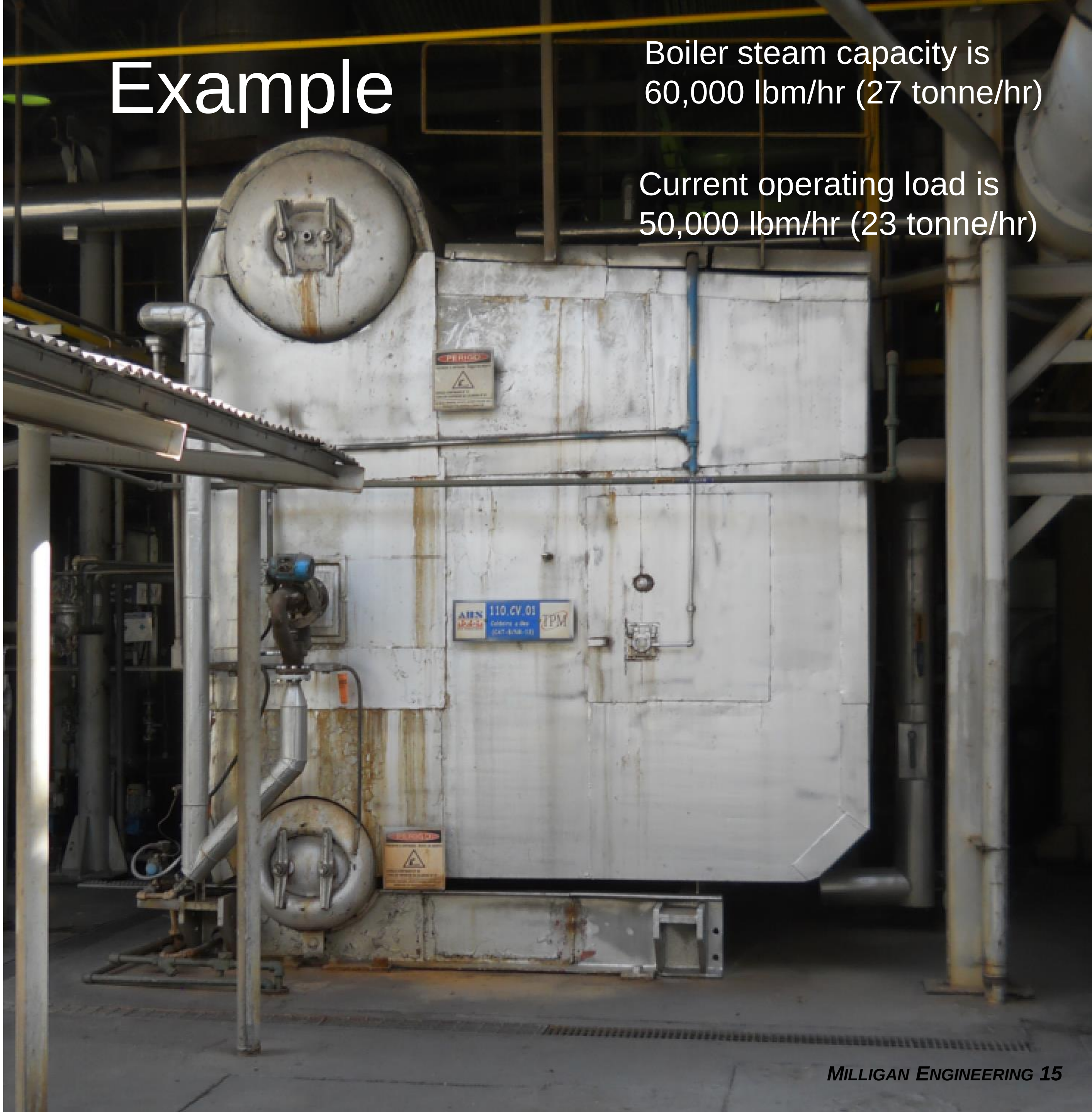


Example

- Natural gas fired boiler
  - $\$^{US}5/10^6$Btu ($\$^{US}4.7$/GJ)
  - Steam pressure is 120 psig (830 kPaG)
  - Steam temperature is 350°F (177°C saturated)
  - Ambient temperature is ~70°F (~20°C)

Boiler steam capacity is 60,000 lbm/hr (27 tonne/hr)

Current operating load is 50,000 lbm/hr (23 tonne/hr)



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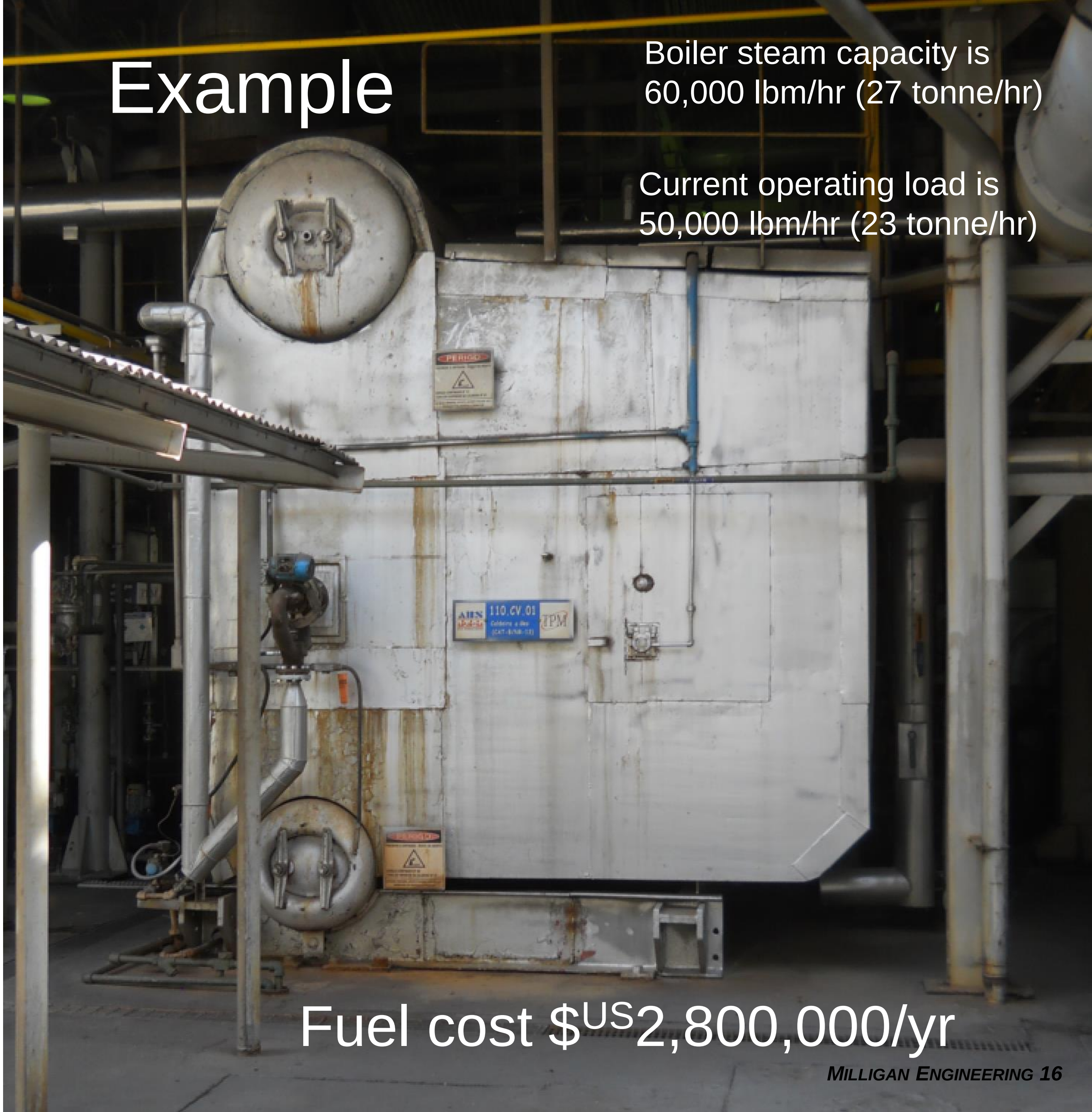

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Current operating load is 50,000 lbm/hr (23 tonne/hr)

Fuel cost $$^{US}2,800,000/yr

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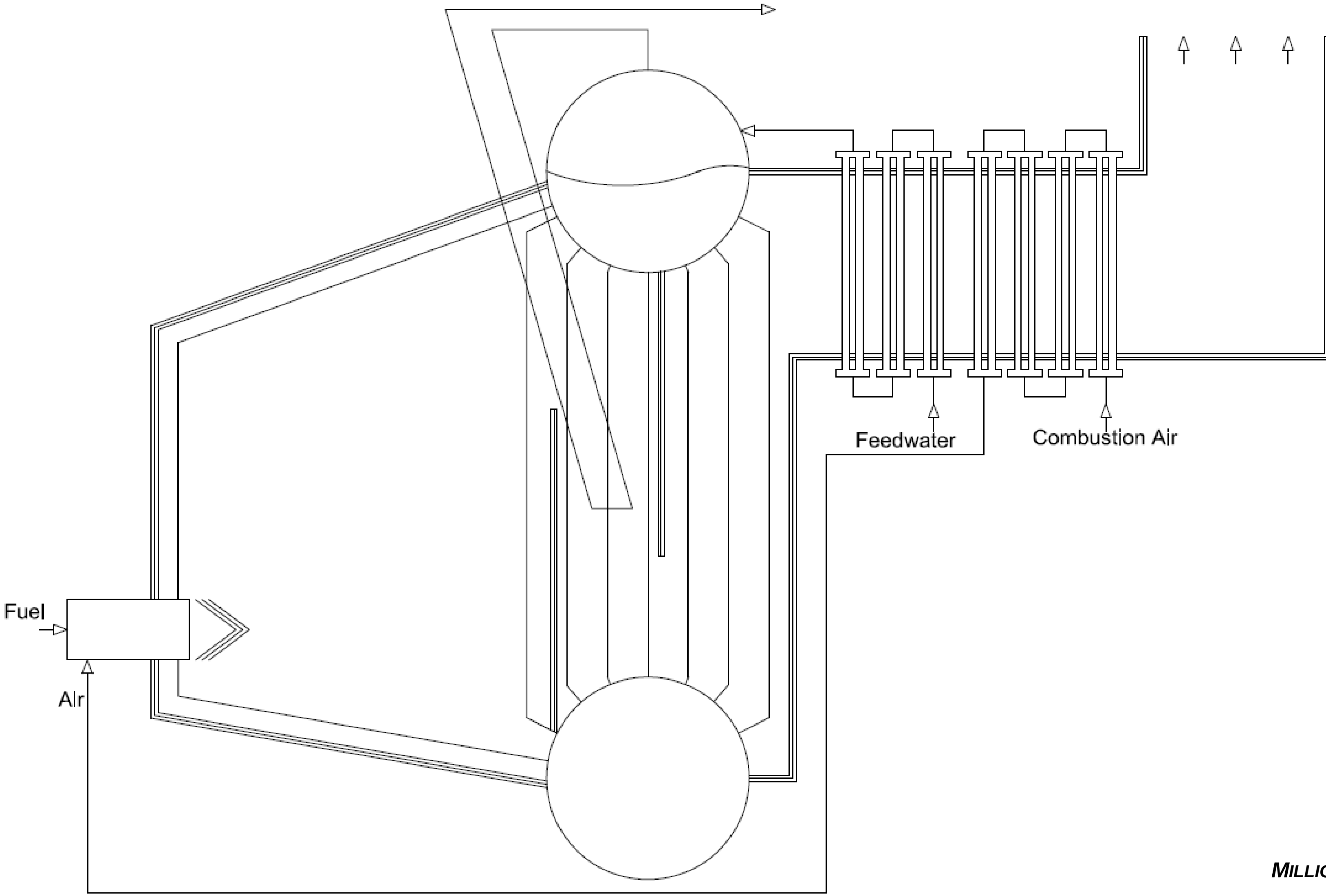
Boiler Efficiency

- Fuel type, thermal energy recovery, and combustion control are the primary factors affecting boiler efficiency



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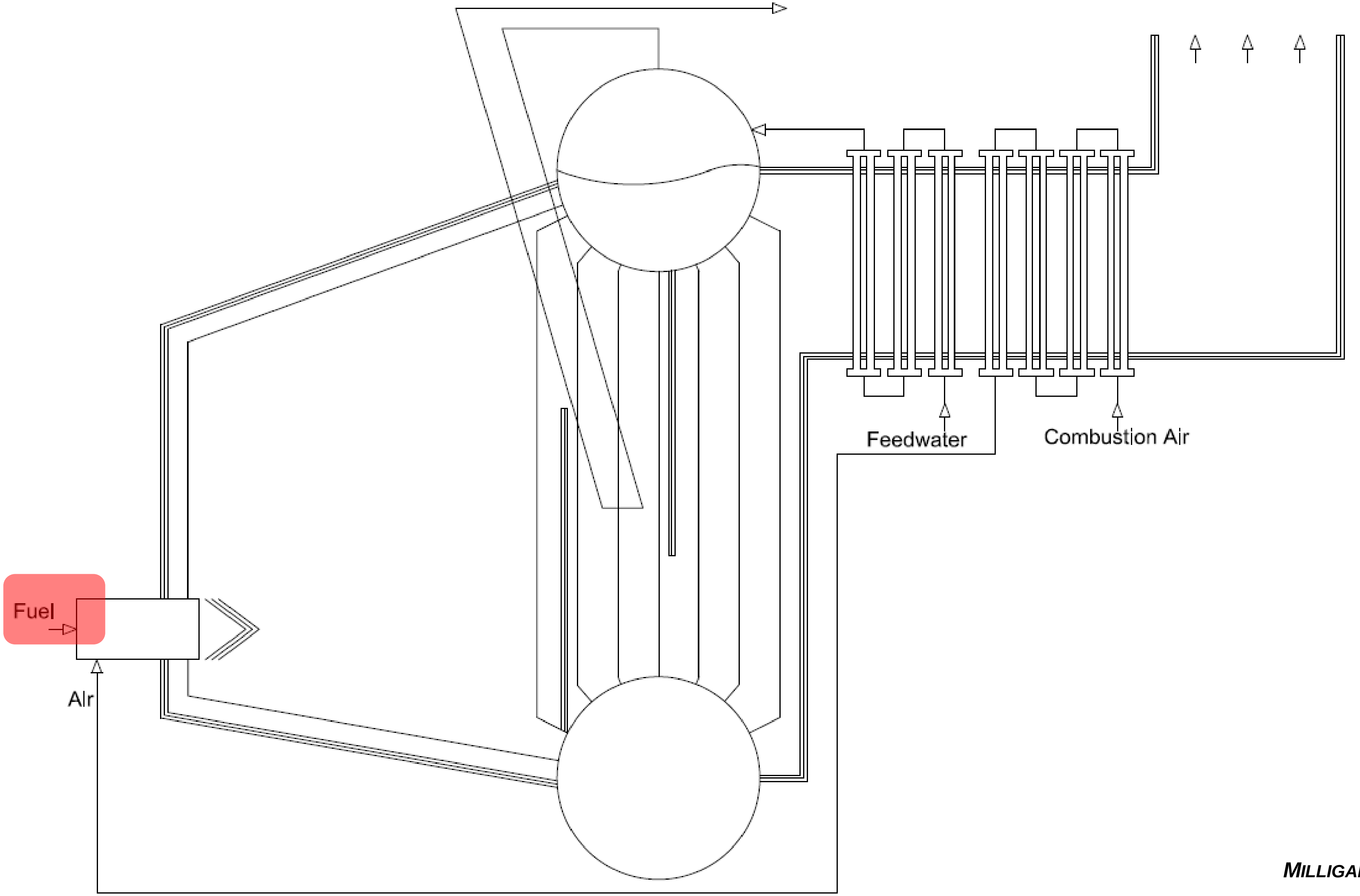

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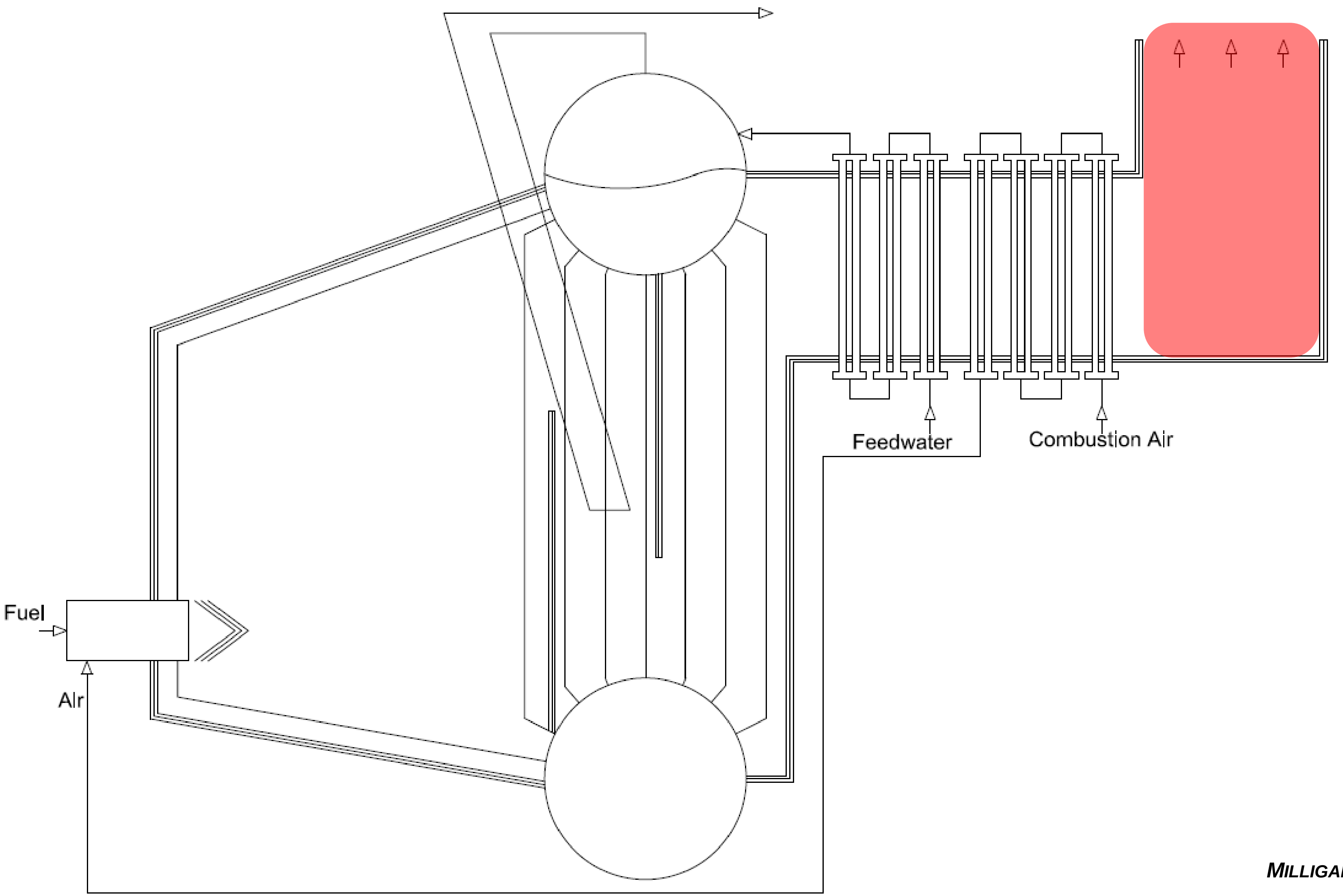

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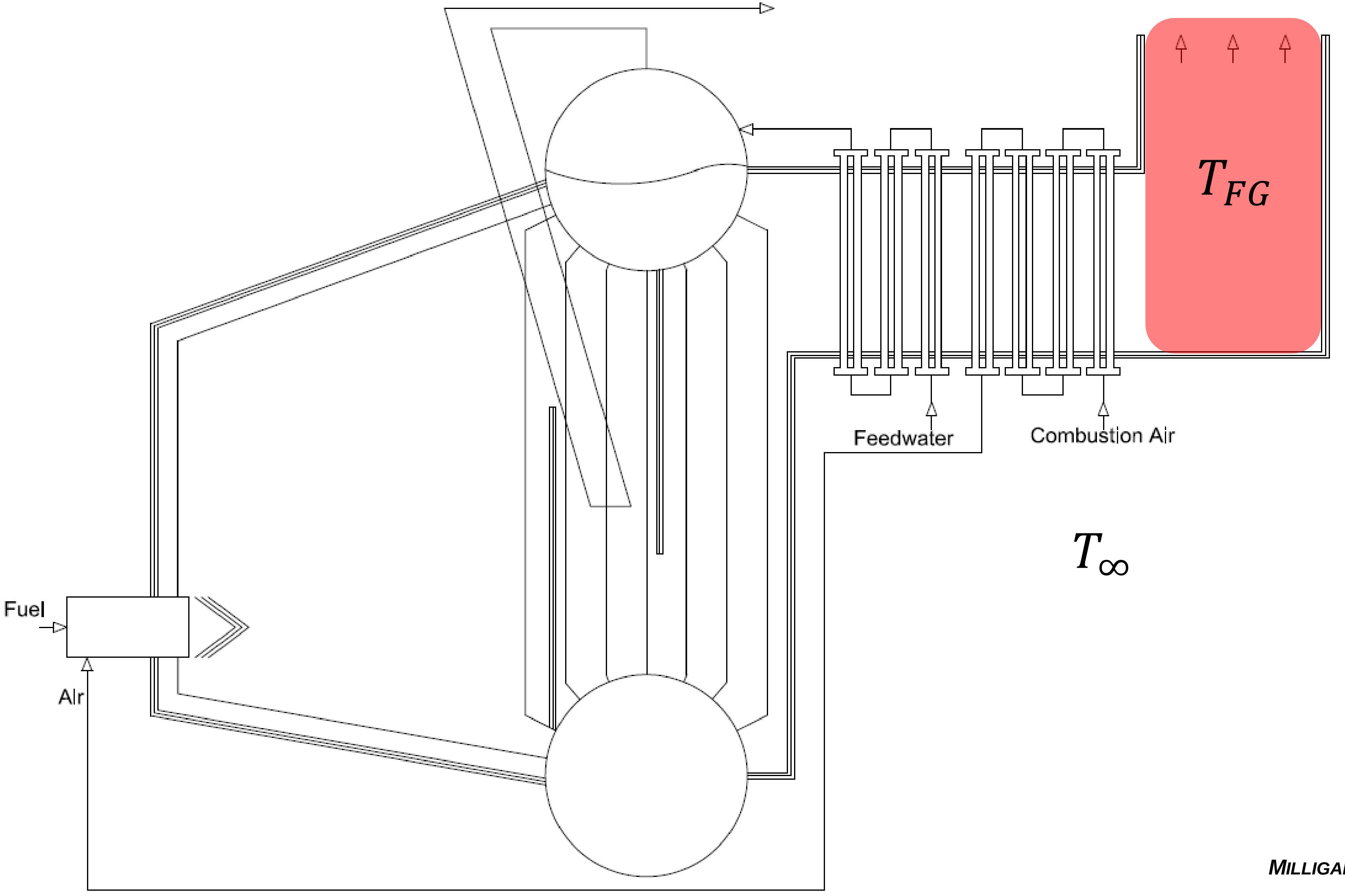

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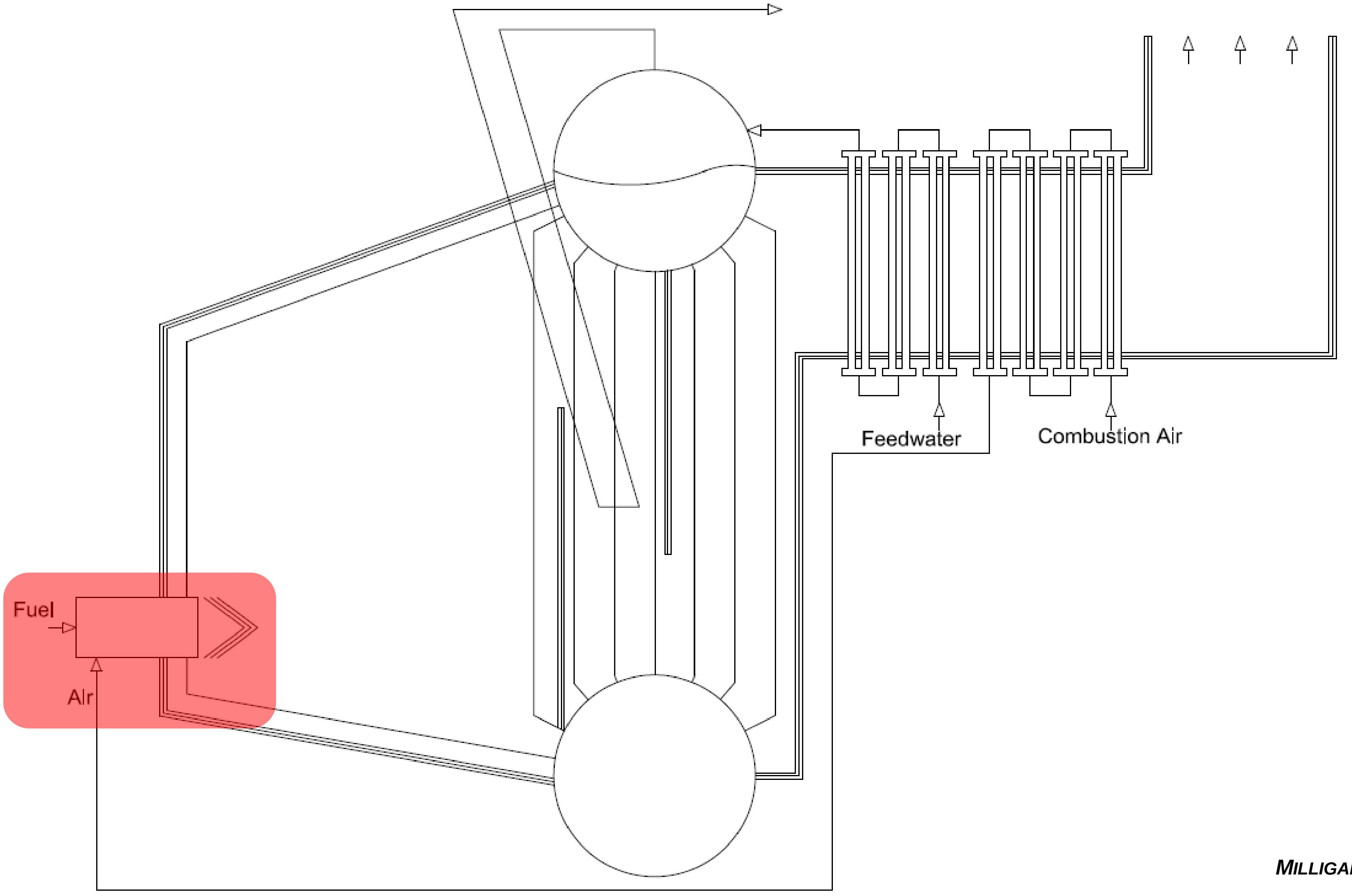

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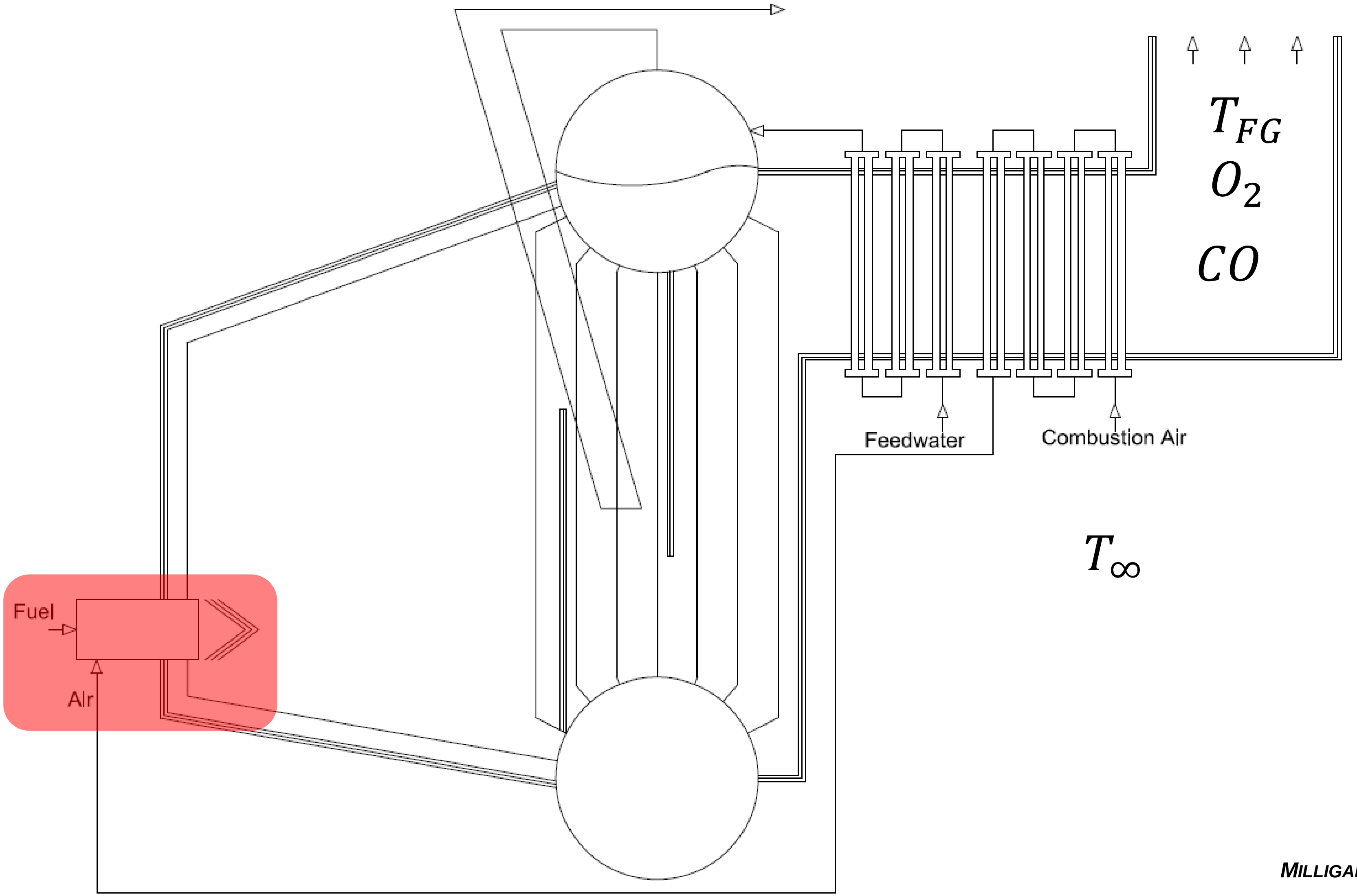

Measurement Tools

- The primary tools used to measure boiler performance are:
  – Combustion analyzer
  – Contact thermometers
    - For flue gas temperatures
  – Infrared thermometers
    - Shell loss and other indications
  – Manometers
  – Water chemistry measurements

Stack Loss - Natural Gas

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

Stack Loss Table for			Typical Natural Gas											
Flue Gas Oxygen Content Wet Basis [%]	Flue Gas Oxygen Content Dry Basis [%]	Comb Conc [ppm]	Stack Loss [% of fuel Higher Heating Value input] Net Stack Temperature [Δ°F] {Difference between flue gas exhaust temperature and ambient temperature}											
			180	205	230	255	280	305	330	355	380	405	430	455
1.0	1.2	0	13.6	14.1	14.7	15.2	15.8	16.3	16.9	17.4	18.0	18.5	19.1	19.6
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5.0	5.8	0	14.5	15.1	15.8	16.5	17.2	17.8	18.5	19.2	19.9	20.5	21.2	21.9
6.0	6.9	0	14.8	15.5	16.2	16.9	17.6	18.3	19.1	19.8	20.5	21.2	22.0	22.7
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Ambient T [°F]			**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**

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

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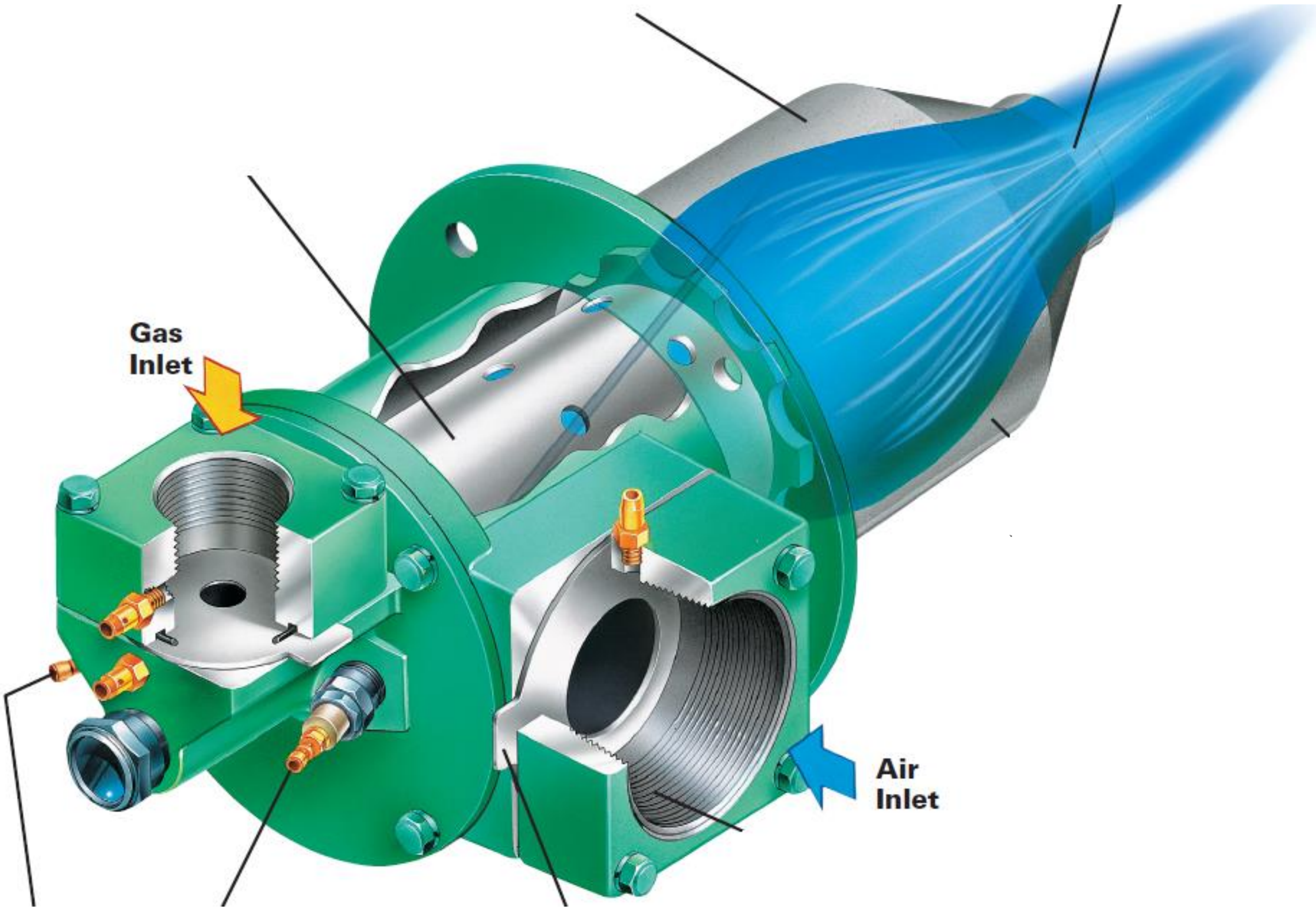
Burners



Actual Combustion

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

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

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

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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**

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Cleaver Brooks
B3


TABLERO ELECTRICO CALDERO

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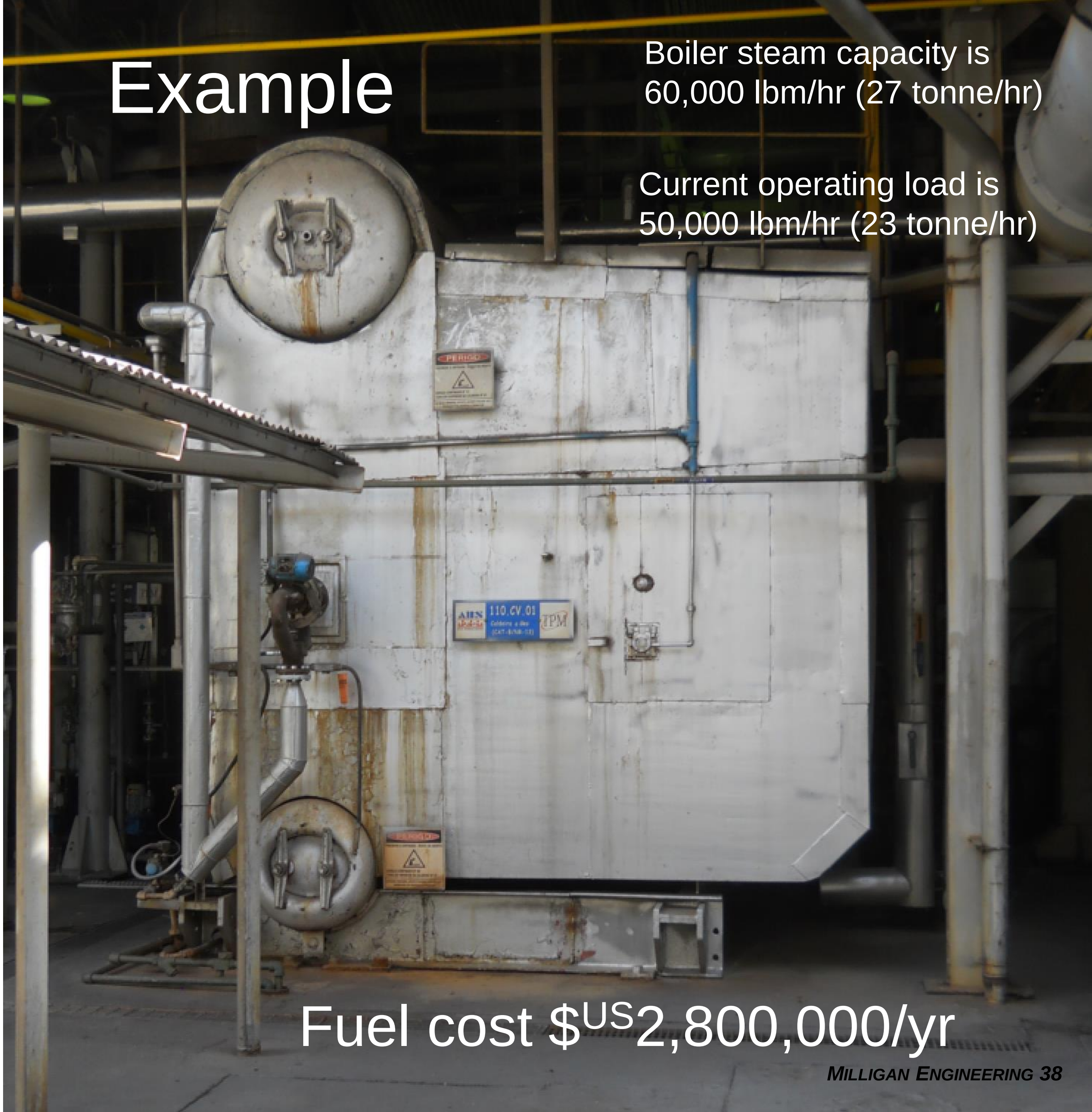
Example



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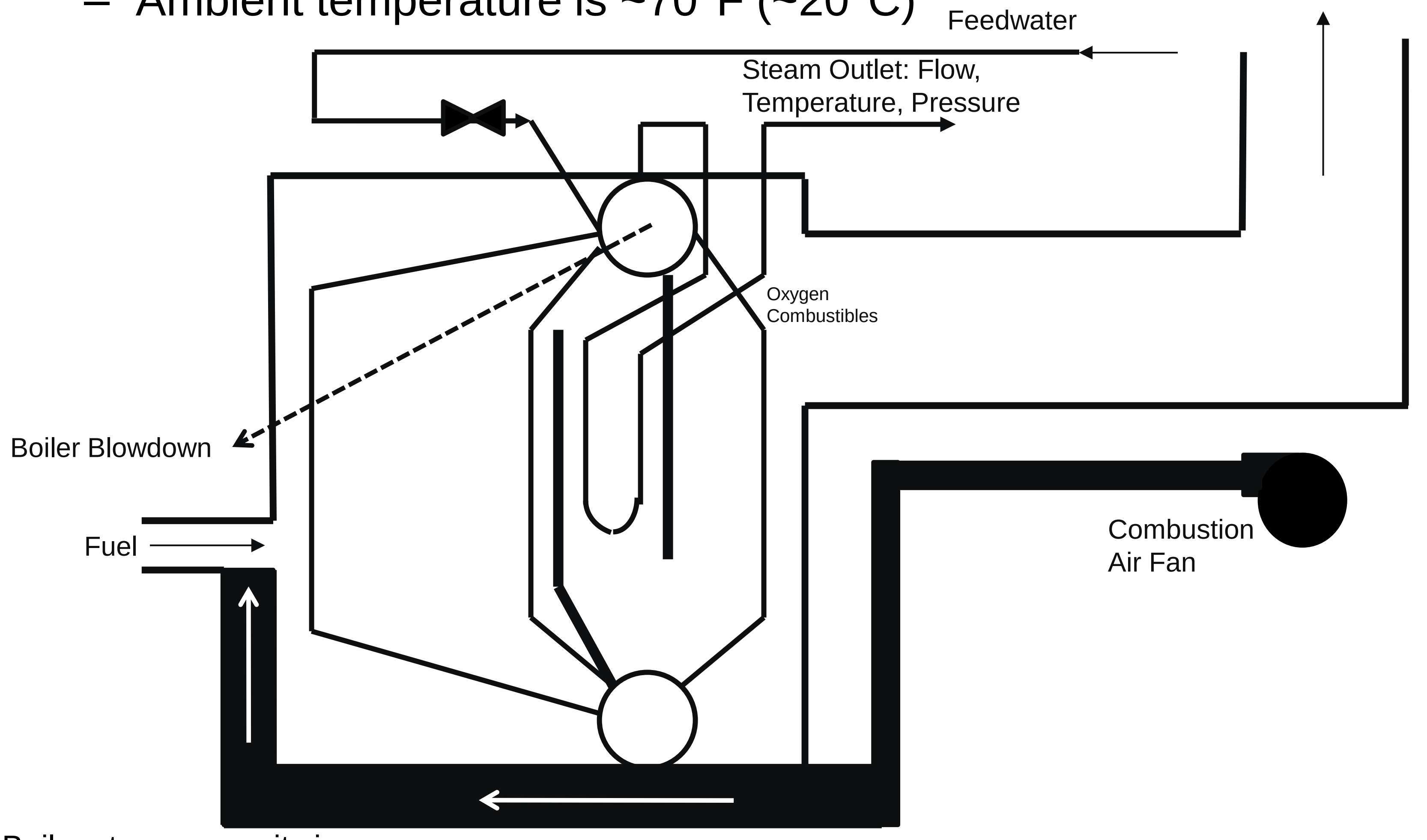

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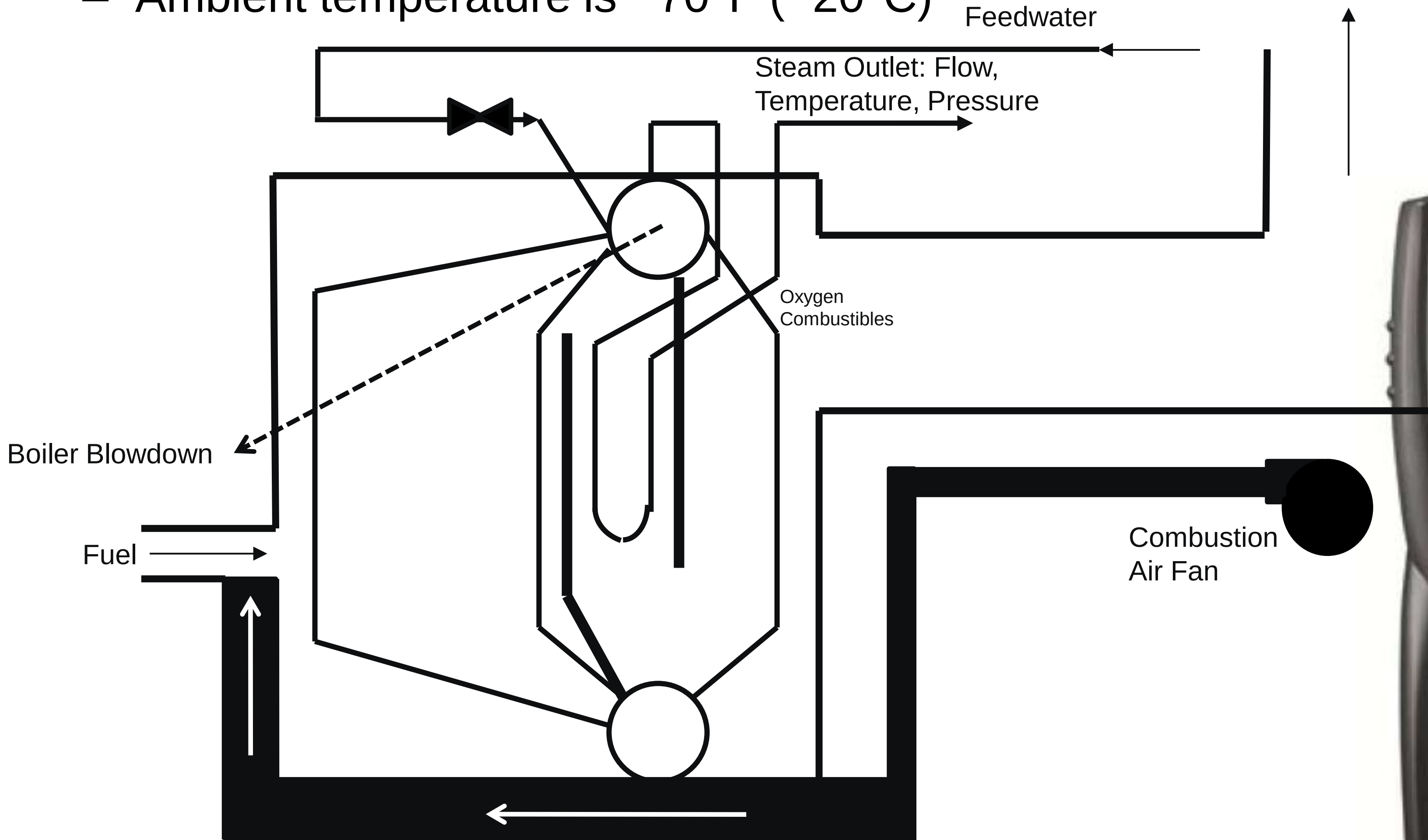

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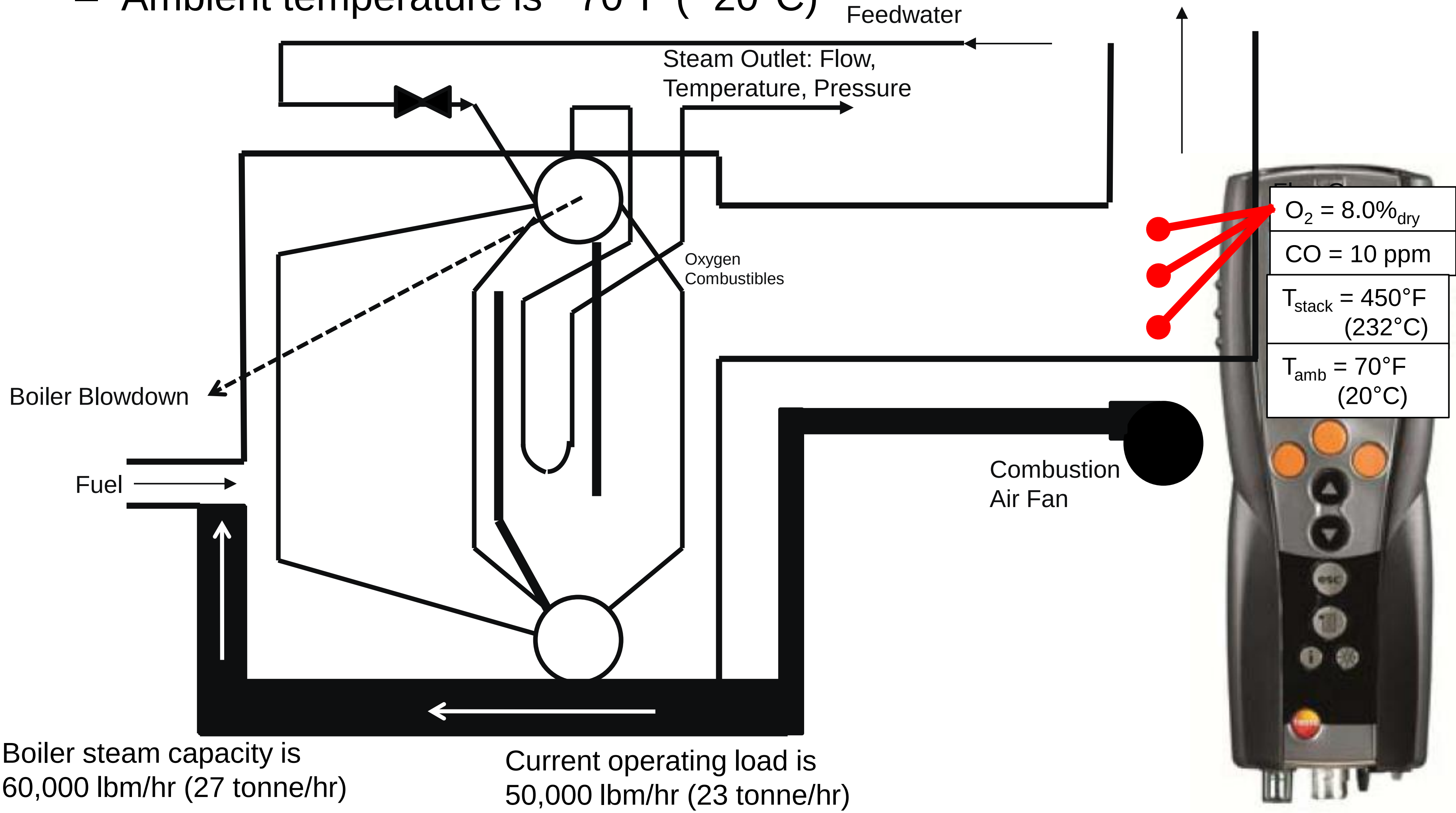

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4.0	4.7	0	14.2	14.8	15.5	16.1	16.7	17.4	18.0	18.7	19.3	20.0	20.6	21.2
5.0	5.8	0	14.5	15.1	15.8	16.5	17.2	17.8	18.5	19.2	19.9	20.5	21.2	21.9
6.0	6.9	0	14.8	15.5	16.2	16.9	17.6	18.3	19.1	19.8	20.5	21.2	22.0	22.7
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9.0	10.1	0	16.0	16.8	17.7	18.6	19.5	20.4	21.2	22.1	23.0	23.9	24.8	25.7
10.0	11.1	0	16.5	17.4	18.4	19.4	20.3	21.3	22.2	23.2	24.2	25.2	26.1	27.1
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$$\eta_{Boiler} \approx 100\% - 21.2\% = 78.8\%_{HHV}$$

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7.0	8.0	0	15.1	15.9	16.6	17.4	18.1	18.9	19.7	20.5	21.2	22.0	22.8	23.6
8.0	9.1	0	15.5	16.3	17.1	17.9	18.8	19.6	20.4	21.2	22.1	22.9	23.7	24.6
9.0	10.1	0	16.0	16.8	17.7	18.6	19.5	20.4	21.2	22.1	23.0	23.9	24.8	25.7
10.0	11.1	0	16.5	17.4	18.4	19.4	20.3	21.3	22.2	23.2	24.2	25.2	26.1	27.1
Actual Exhaust T [°F]			**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
Ambient T [°F]			**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**

$$\eta_{Boiler} \approx 100\% - 17.4\% = 82.6\%_{HHV}$$

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

Savings Analysis

$$\sigma_{Savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\frac{\dot{E}_{Steam}}{\eta_1}\ \kappa_{fuel}$$

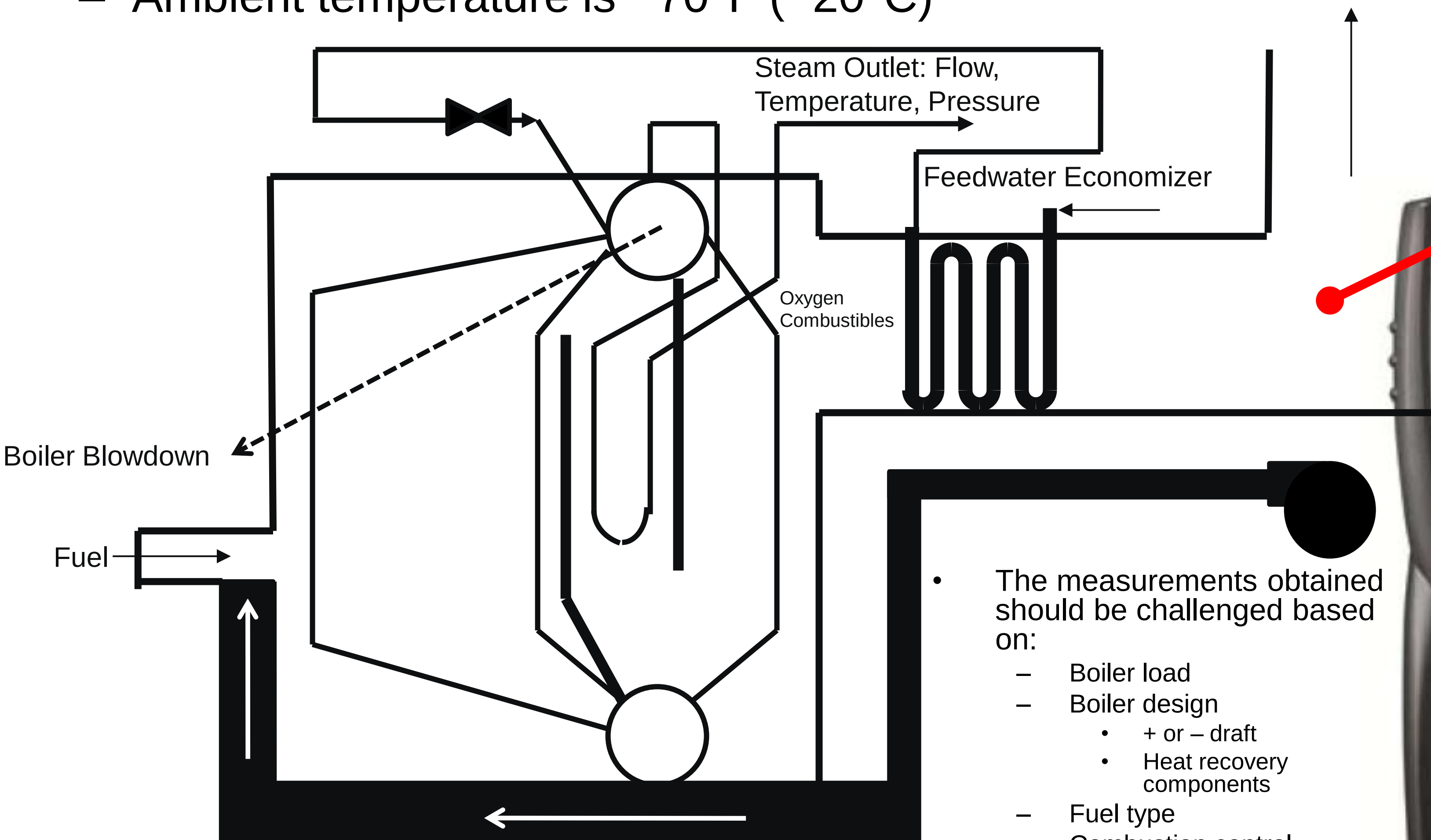
$$\sigma_{Savings} = \left(1 - \frac{78.8\%}{82.6\%}\right)\ 2{,}800{,}000\frac{\$}{yr}$$

$$\sigma_{Savings} = 128{,}000\frac{\$}{yr}$$

Measurements$_{(US)}$

- Natural gas fired boiler
  - \$^{US}5/10^{6}Btu (\$^{US}4.7/GJ)
  - Steam pressure is 120 psig (830 kPaG)
  - Steam temperature is 350°F (177°C saturated)
  - Ambient temperature is ~70°F (~20°C)

Fuel cost
\$^{US}2,670,000/yr



- The measurements obtained should be challenged based on:
  - Boiler load
  - Boiler design
    - \+ or – draft
    - Heat recovery components
  - Fuel type
  - Combustion control
    - Positioning
    - Oxygen control

Boiler steam capacity is 60,000 lbm/hr (27 tonne/hr)

Current operating load is 50,000 lbm/hr (23 tonne/hr)

Stack Loss - Natural Gas

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

Stack Loss Table for			Typical Natural Gas											
Flue Gas Oxygen Content Wet Basis [%]	Flue Gas Oxygen Content Dry Basis [%]	Comb Conc [ppm]	Stack Loss [% of fuel Higher Heating Value input] Net Stack Temperature [Δ°F] {Difference between flue gas exhaust temperature and ambient temperature}											
			180	205	230	255	280	305	330	355	380	405	430	455
1.0	1.2	0	13.6	14.1	14.7	15.2	15.8	16.3	16.9	17.4	18.0	18.5	19.1	19.6
2.0	2.4	0	13.8	14.3	14.9	15.5	16.1	16.6	17.2	17.8	18.4	18.9	19.5	20.1
3.0	3.6	0	14.0	14.6	15.2	15.8	16.4	17.0	17.6	18.2	18.8	19.4	20.0	20.6
4.0	4.7	0	14.2	14.8	15.5	16.1	16.7	17.4	18.0	18.7	19.3	20.0	20.6	21.2
5.0	5.8	0	14.5	15.1	15.8	16.5	17.2	17.8	18.5	19.2	19.9	20.5	21.2	21.9
6.0	6.9	0	14.8	15.5	16.2	16.9	17.6	18.3	19.1	19.8	20.5	21.2	22.0	22.7
7.0	8.0	0	15.1	15.9	16.6	17.4	18.1	18.9	19.7	20.5	21.2	22.0	22.8	23.6
8.0	9.1	0	15.5	16.3	17.1	17.9	18.8	19.6	20.4	21.2	22.1	22.9	23.7	24.6
9.0	10.1	0	16.0	16.8	17.7	18.6	19.5	20.4	21.2	22.1	23.0	23.9	24.8	25.7
10.0	11.1	0	16.5	17.4	18.4	19.4	20.3	21.3	22.2	23.2	24.2	25.2	26.1	27.1
Actual Exhaust T [°F]			**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
Ambient T [°F]			**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**

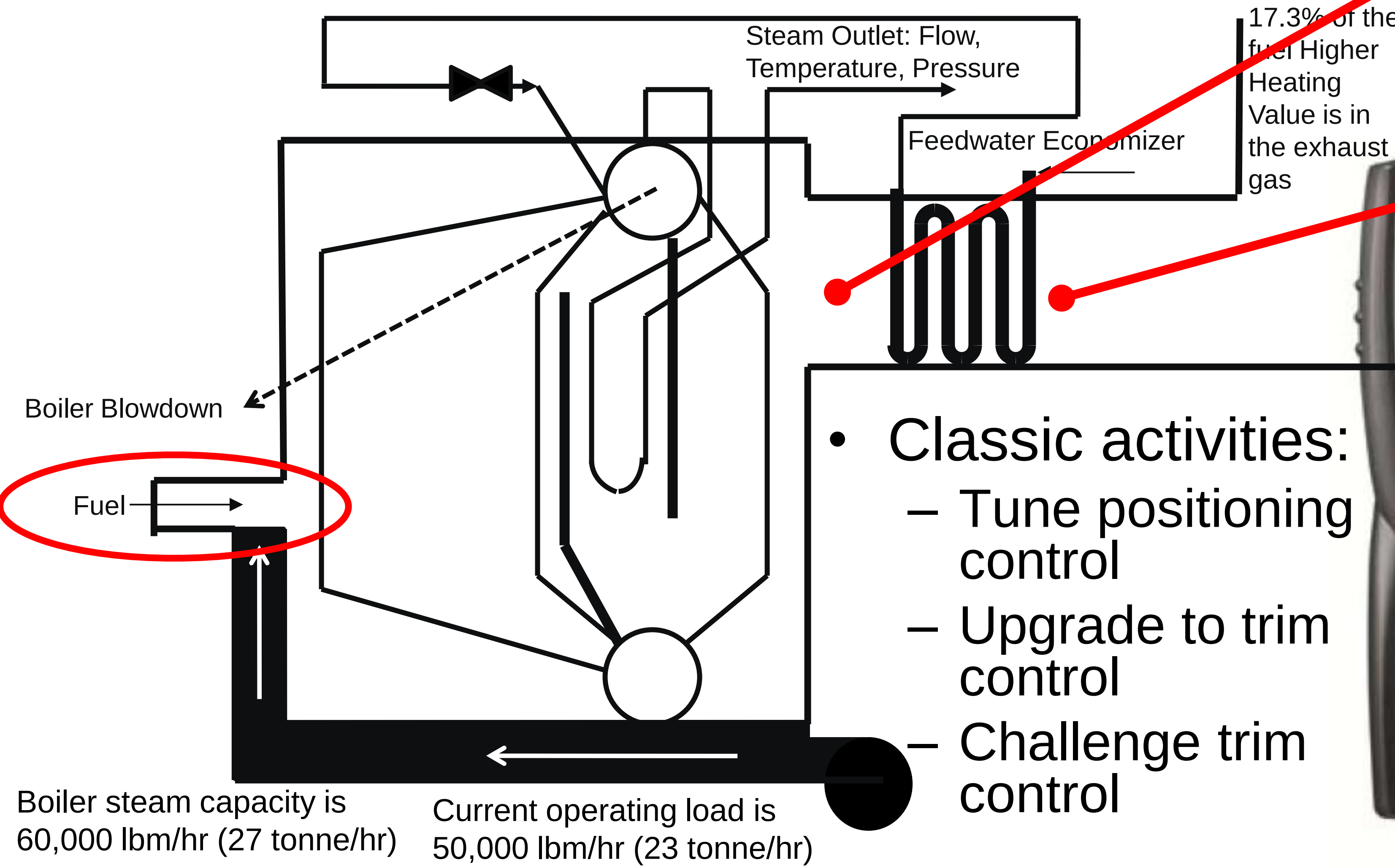
$$\eta_{Boiler} \approx 100\% - 17.4\% = 82.6\%_{HHV}$$

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

Measurements$_{(US)}$

- Natural gas fired boiler
  - $\$^{US}5/10^6$Btu ($\$^{US}4.7$/GJ)
  - Steam pressure is 120 psig (830 kPaG)
  - Steam temperature is 350°F (177°C saturated)
  - Ambient temperature is ~70°F (~20°C)

Fuel cost
$\$^{US}2,670,000$/yr



- Classic activities:
  - Tune positioning control
  - Upgrade to trim control
  - Challenge trim control

Stack Loss - Natural Gas

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

Stack Loss Table for			Typical Natural Gas											
Flue Gas Oxygen Content Wet Basis [%]	Flue Gas Oxygen Content Dry Basis [%]	Comb Conc [ppm]	Stack Loss [% of fuel Higher Heating Value input]											
			Net Stack Temperature [Δ°F] {Difference between flue gas exhaust temperature and ambient temperature}											
			180	205	230	255	280	305	330	355	380	405	430	455
1.0	1.2	0	13.6	14.1	14.7	15.2	15.8	16.3	16.9	17.4	18.0	18.5	19.1	19.6
2.0	2.4	0	13.8	14.3	14.9	15.5	16.1	16.6	17.2	17.8	18.4	18.9	19.5	20.1
3.0	3.6	0	14.0	14.6	15.2	15.8	16.4	17.0	17.6	18.2	18.8	19.4	20.0	20.6
4.0	4.7	0	14.2	14.8	15.5	16.1	16.7	17.4	18.0	18.7	19.3	20.0	20.6	21.2
5.0	5.8	0	14.5	15.1	15.8	16.5	17.2	17.8	18.5	19.2	19.9	20.5	21.2	21.9
6.0	6.9	0	14.8	15.5	16.2	16.9	17.6	18.3	19.1	19.8	20.5	21.2	22.0	22.7
7.0	8.0	0	15.1	15.9	16.6	17.4	18.1	18.9	19.7	20.5	21.2	22.0	22.8	23.6
8.0	9.1	0	15.5	16.3	17.1	17.9	18.8	19.6	20.4	21.2	22.1	22.9	23.7	24.6
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Actual Exhaust T [°F]			**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
Ambient T [°F]			**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**	**70**

$$\eta_{Boiler} \approx 100\% - 15.5\% = 84.5\%_{HHV}$$

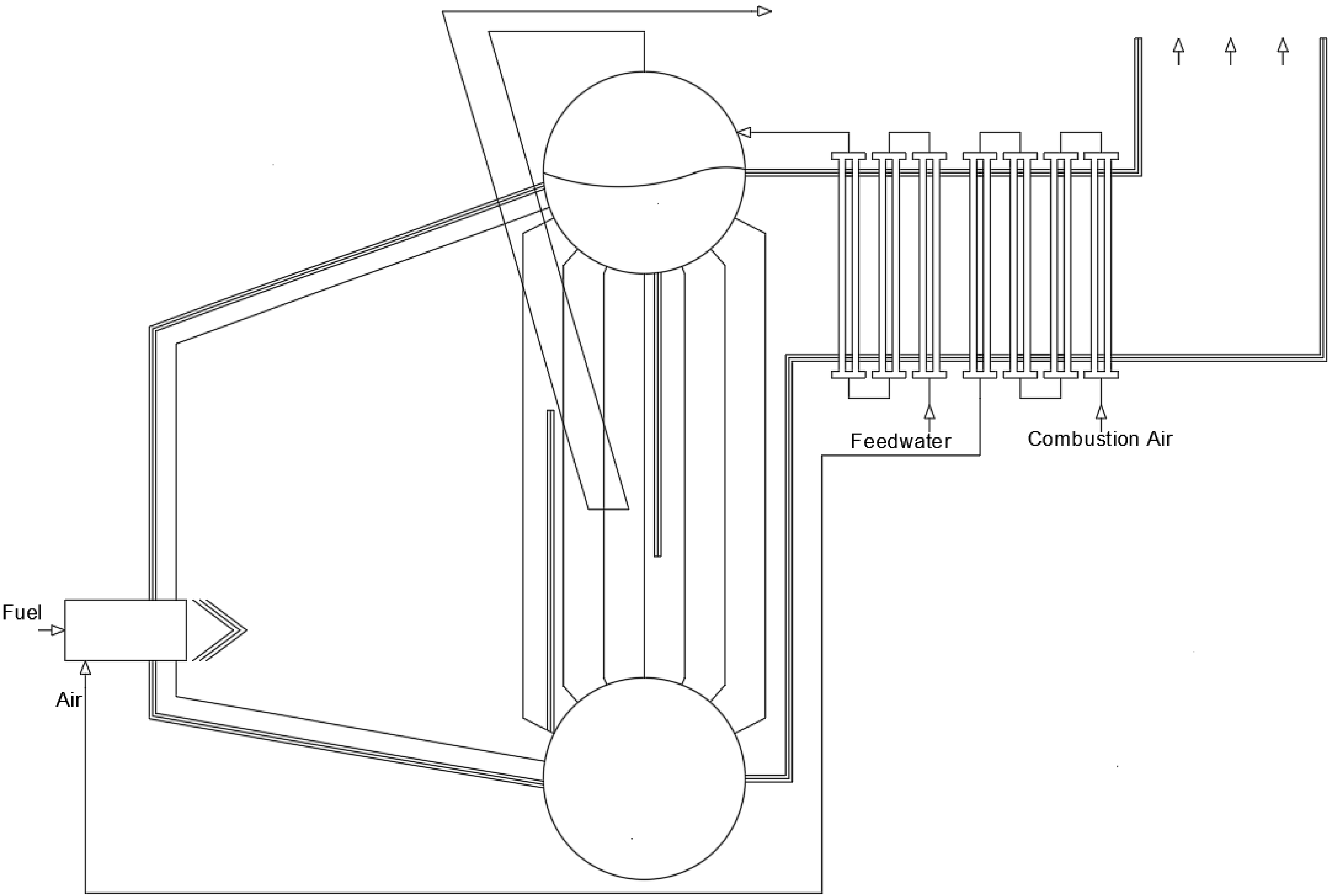
Reference: Combustion model developed by Greg Harrell, Ph.D., P.E.

Savings Analysis

$$\sigma_{Savings} = \left(1 - \frac{\eta_1}{\eta_2}\right)\frac{\dot{E}_{Steam}}{\eta_1}\ \kappa_{fuel}$$

$$\sigma_{Savings} = \left(1 - \frac{82.6\%}{84.5\%}\right) 2{,}670{,}000\frac{\$}{yr}$$

$$\sigma_{Savings} = 60{,}000\frac{\$}{yr}$$



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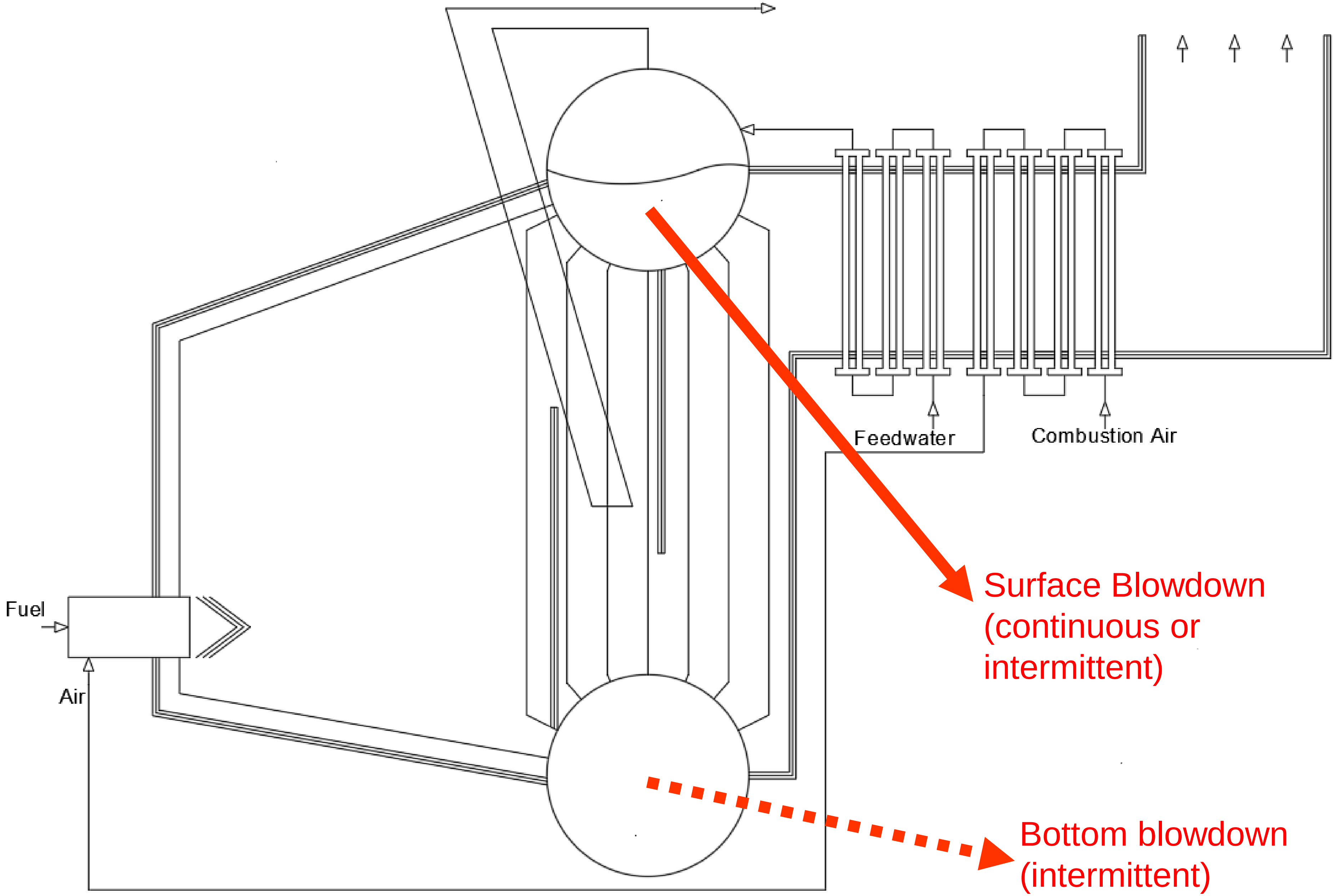

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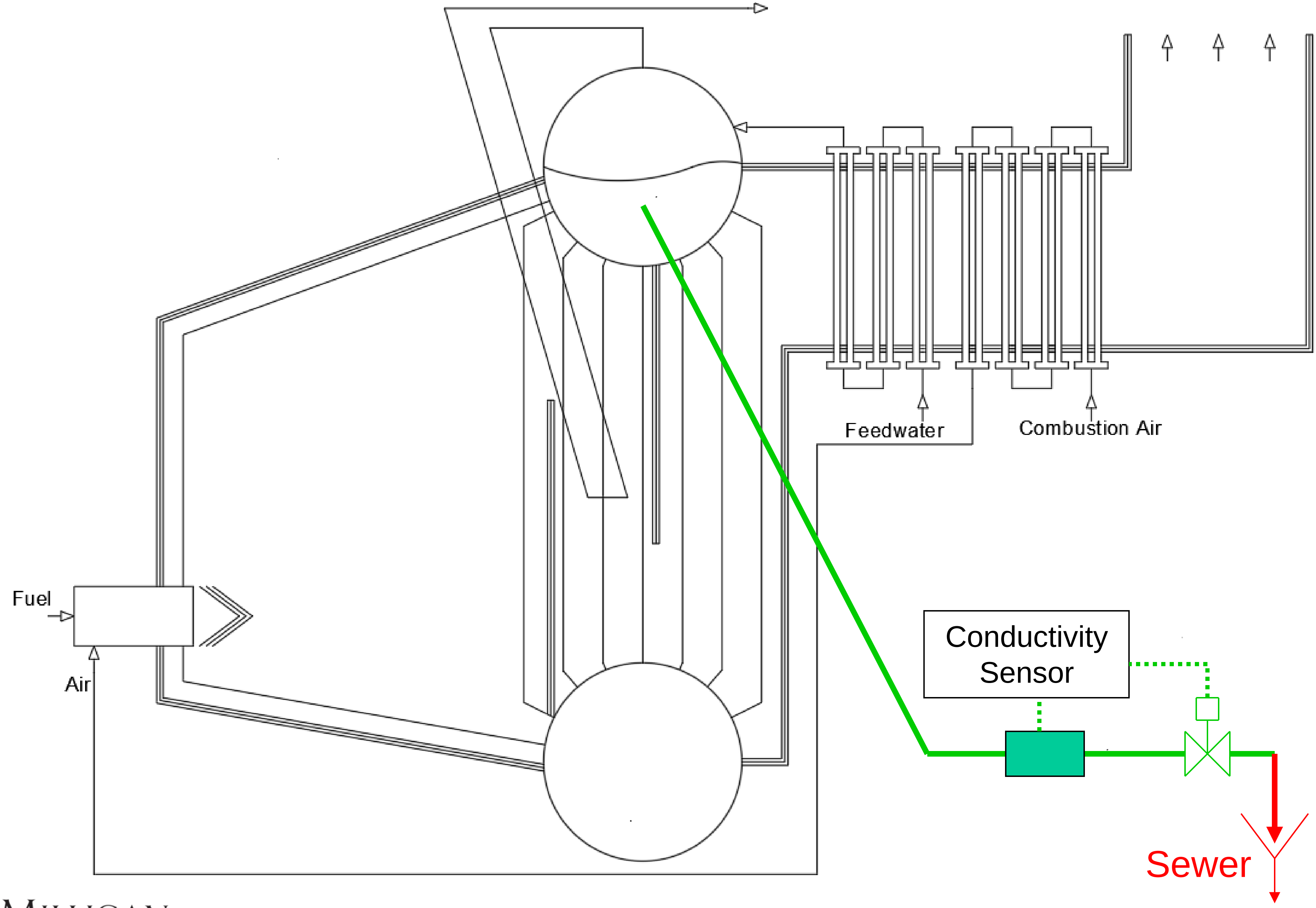
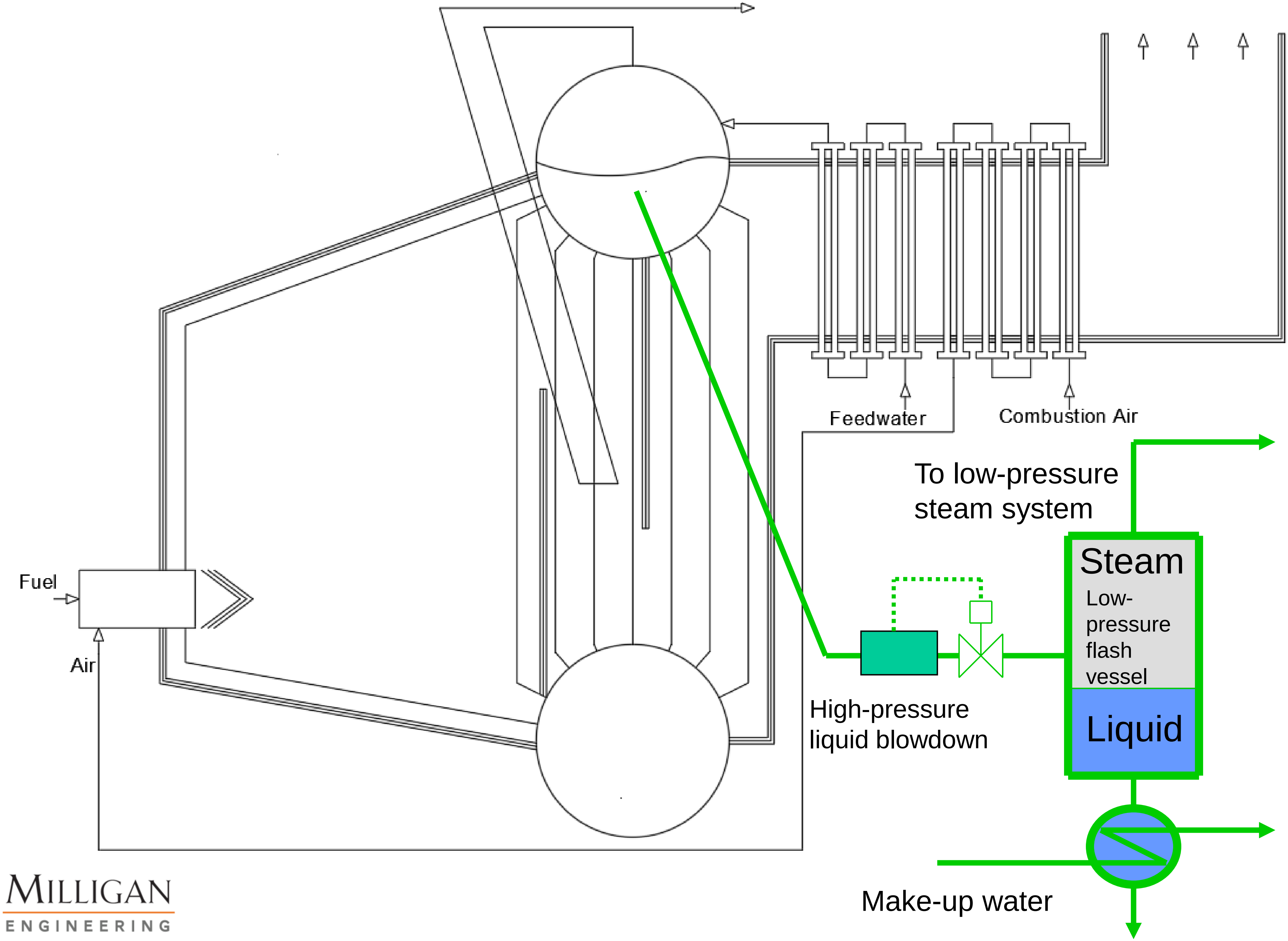


Feedwater
Combustion Air
Fuel
Air
Conductivity Sensor
Sewer



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Simple Installation

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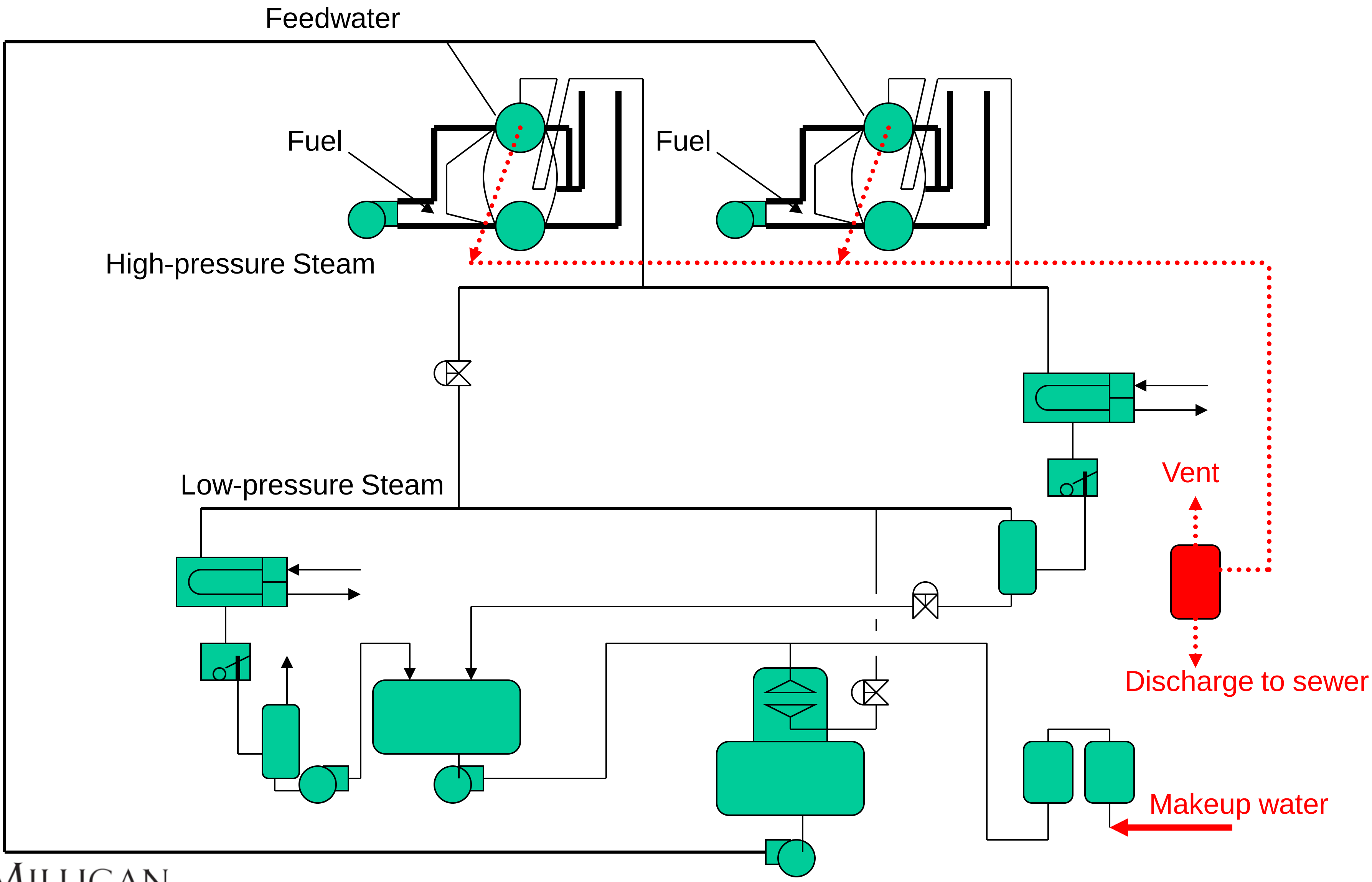
Blowdown Related System Loss



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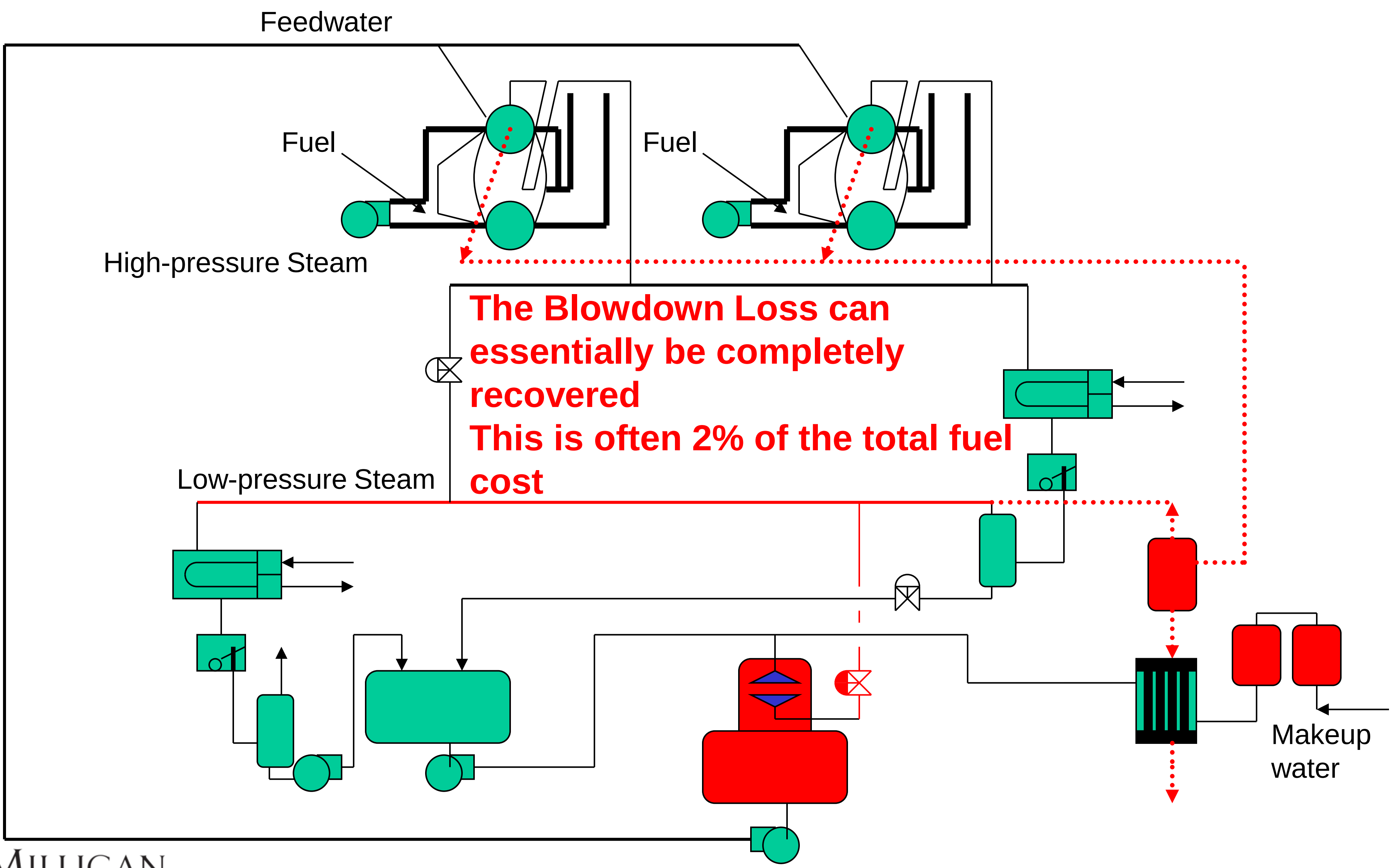
Steam System Impact



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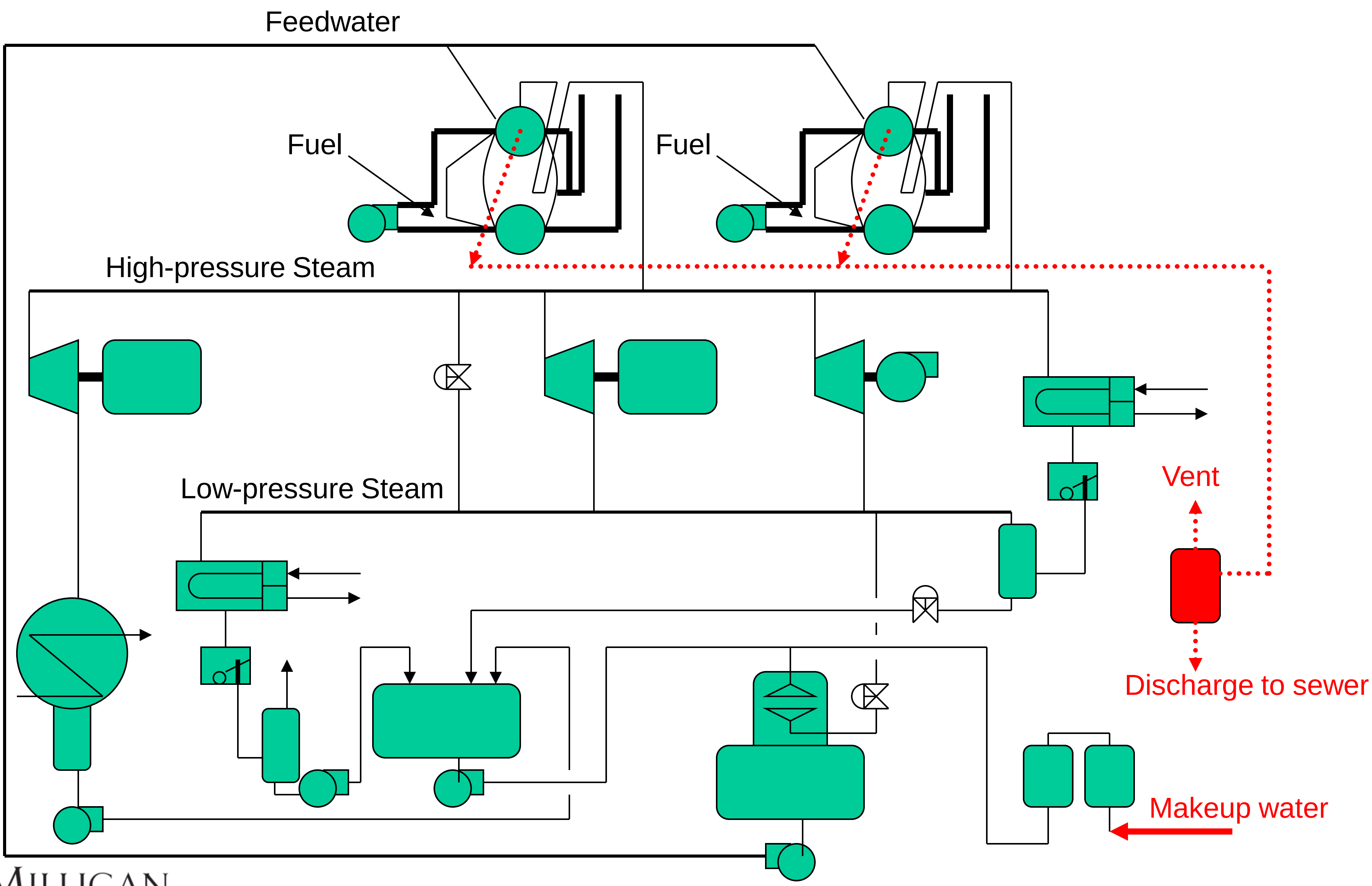
Blowdown Related System Loss



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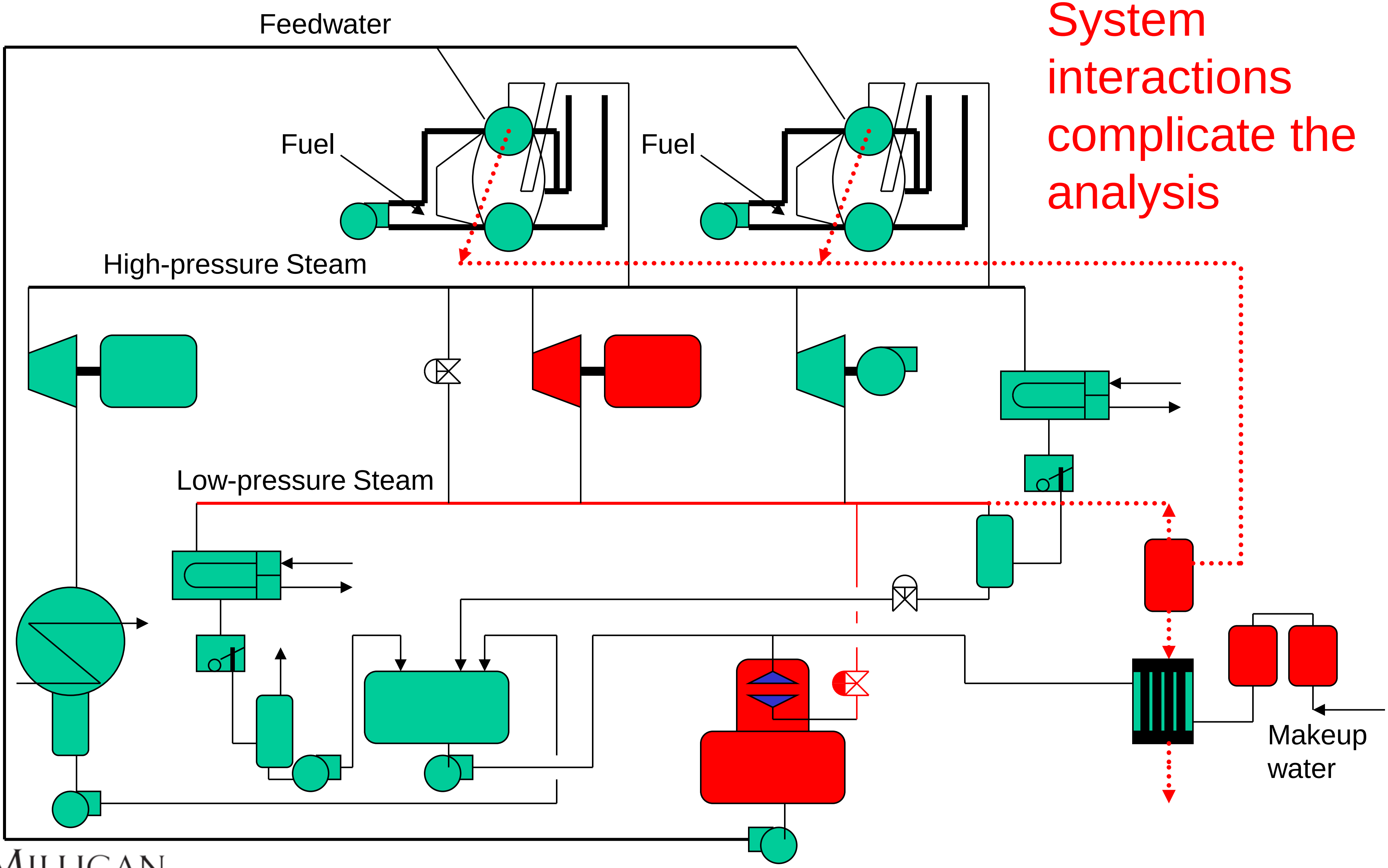
Steam System Impact



System interactions complicate the analysis

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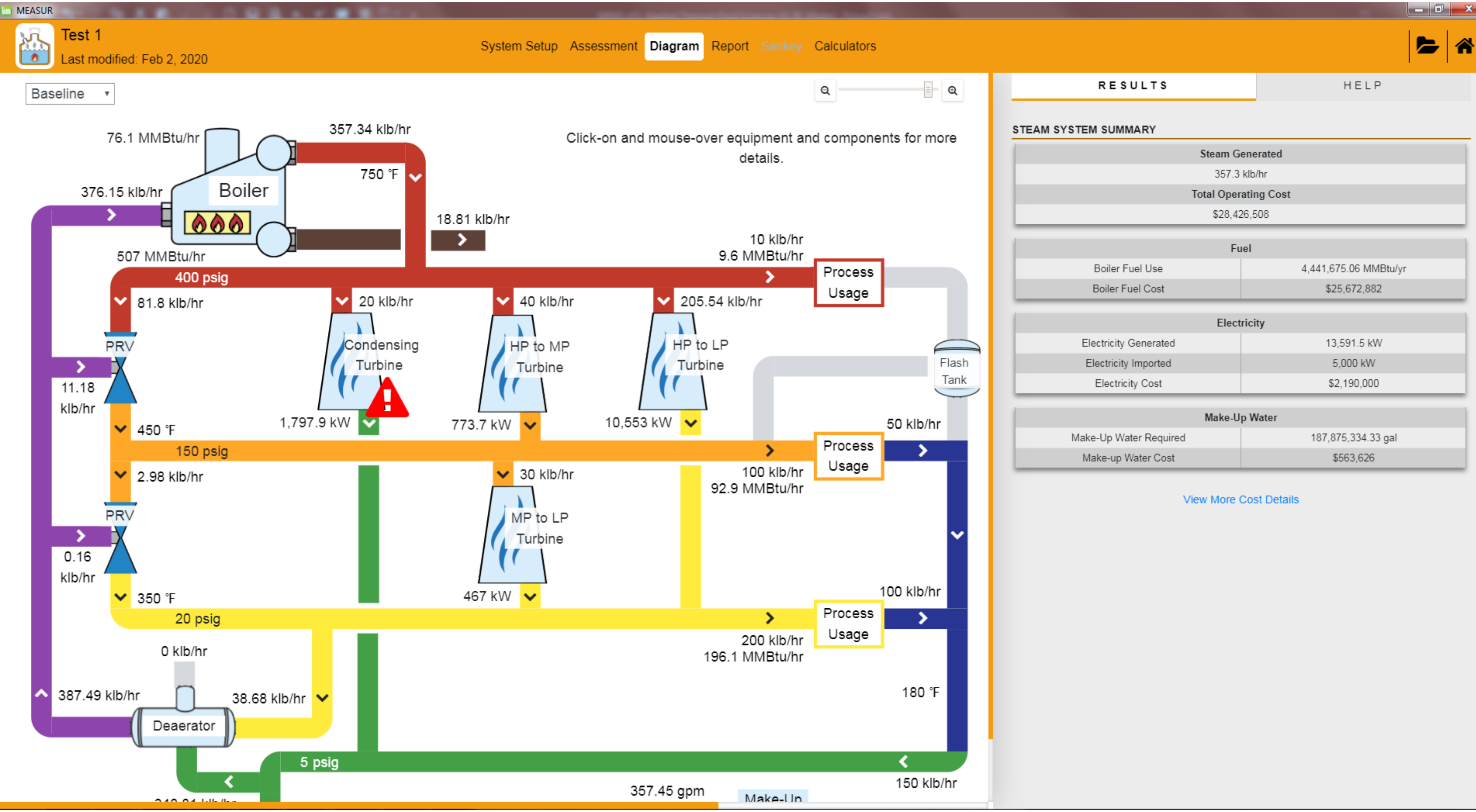

- https://www.energy.gov/eere/amo/measur

Steam Leaks

Orifice Diameter [inch]	Leak Rate [lbm/hr]						
	Steam Supply Pressure [psig]						
	20	50	100	150	300	400	500
1/16	3	6	11	16	30	39	49
1/8	13	25	43	62	119	157	195
3/16	30	55	98	140	268	353	439
1/4	53	98	174	249	477	628	780
5/16	82	153	271	390	745	981	1,218
3/8	118	221	391	561	1,073	1,413	1,754
7/16	161	300	532	764	1,460	1,924	2,388
1/2	210	392	695	998	1,907	2,513	3,118
	3	18	43	68	143	193	243
	Discharge Pressure [psig]						
Discharge coefficient		0.6	dimensionless				

Steam Leaks

Orifice Diameter [inch]	Leak Rate [lbm/hr]						
	Steam Supply Pressure [psig]						
	20	**50**	**100**	**150**	**300**	**400**	**500**
1/16	3	6	11	16	30	39	49
1/8	13	25	43	62	119	157	195
3/16	30	55	98	140	268	353	439
1/4	53	98	174	249	477	628	780
5/16	82	153	271	390	745	981	1,218
3/8	118	221	391	561	1,073	1,413	1,754
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1/2	210	392	695	998	1,907	2,513	3,118
	3	**18**	**43**	**68**	**143**	**193**	**243**
	Discharge Pressure [psig]						
Discharge coefficient		0.6	dimensionless				

Steam Leaks

Orifice Diameter [inch]	Leak Rate [$/yr]						
	Steam Supply Pressure [psig]						
	20	50	100	150	300	400	500
1/16	300	500	1,000	2,600	3,400	4,300	1,400
1/8	1,200	2,100	3,800	10,400	13,800	17,100	5,500
3/16	2,600	4,800	8,600	23,500	31,000	38,400	12,300
1/4	4,600	8,600	15,200	41,800	55,000	68,300	21,900
5/16	7,200	13,400	23,800	65,200	86,000	106,700	34,100
3/8	10,400	19,300	34,200	94,000	123,800	153,700	49,200
7/16	14,100	26,300	46,600	127,900	168,500	209,200	66,900
1/2	18,400	34,300	60,900	167,000	220,100	273,200	87,400
	3	18	43	68	143	193	243
	Discharge Pressure [psig]						
Discharge coefficient		0.6	dimensionless				
Steam cost		10.00	$/10^{3}lbm				

World Class Steam Trap Maintenance Program

- Investigate each trap at least one time each year (problem areas and high pressure should be more frequent)
  - Performance
    - Testing equipment is required
    - An order of magnitude leak rate should be determined for failed traps
      - Orifice calculations set the maximum steam flow
  - Trap type
    - Trap selection should match the application
    - Universal mounts can be a good option
  - Installation
  - Establish an investigation route
  - Condensate return
  - Outsourcing can be a good option


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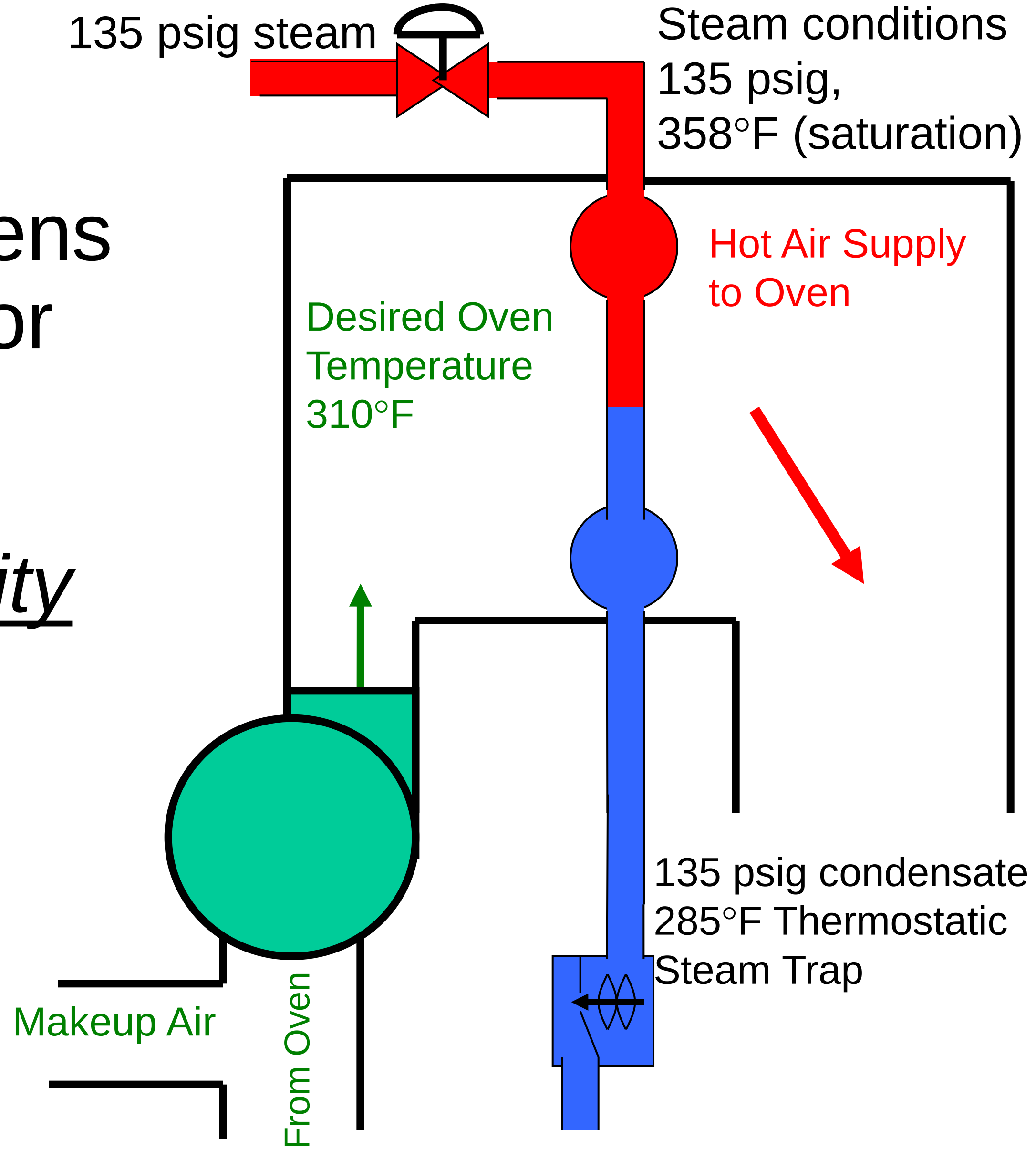
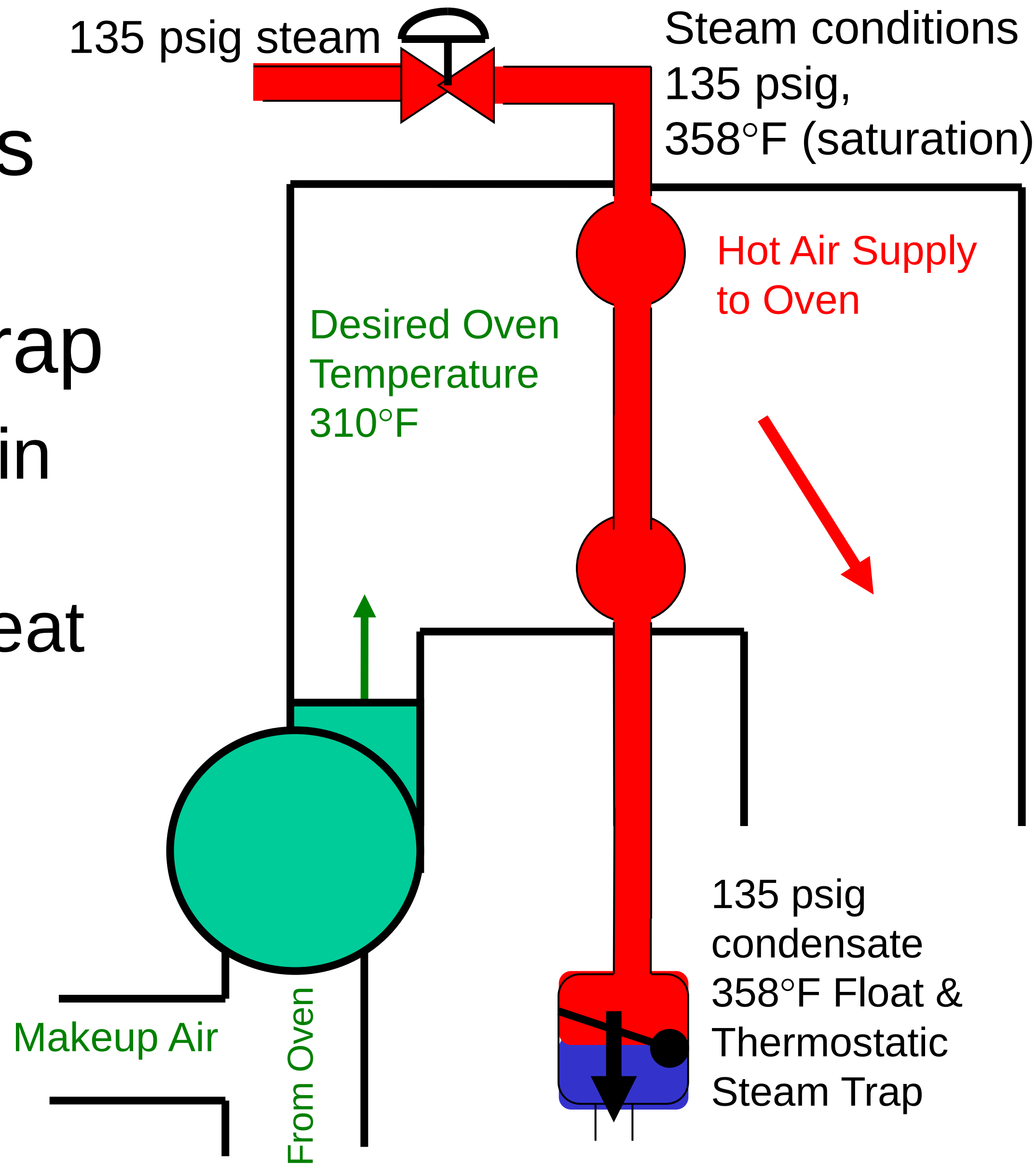
Steam Trap Selection

- Steam heated ovens were scheduled for replacement because of *insufficient capacity*



Steam Trap Selection

- The steam trap was changed to a float-thermostatic type trap
  - Dramatic increase in condensate temperature and heat transfer



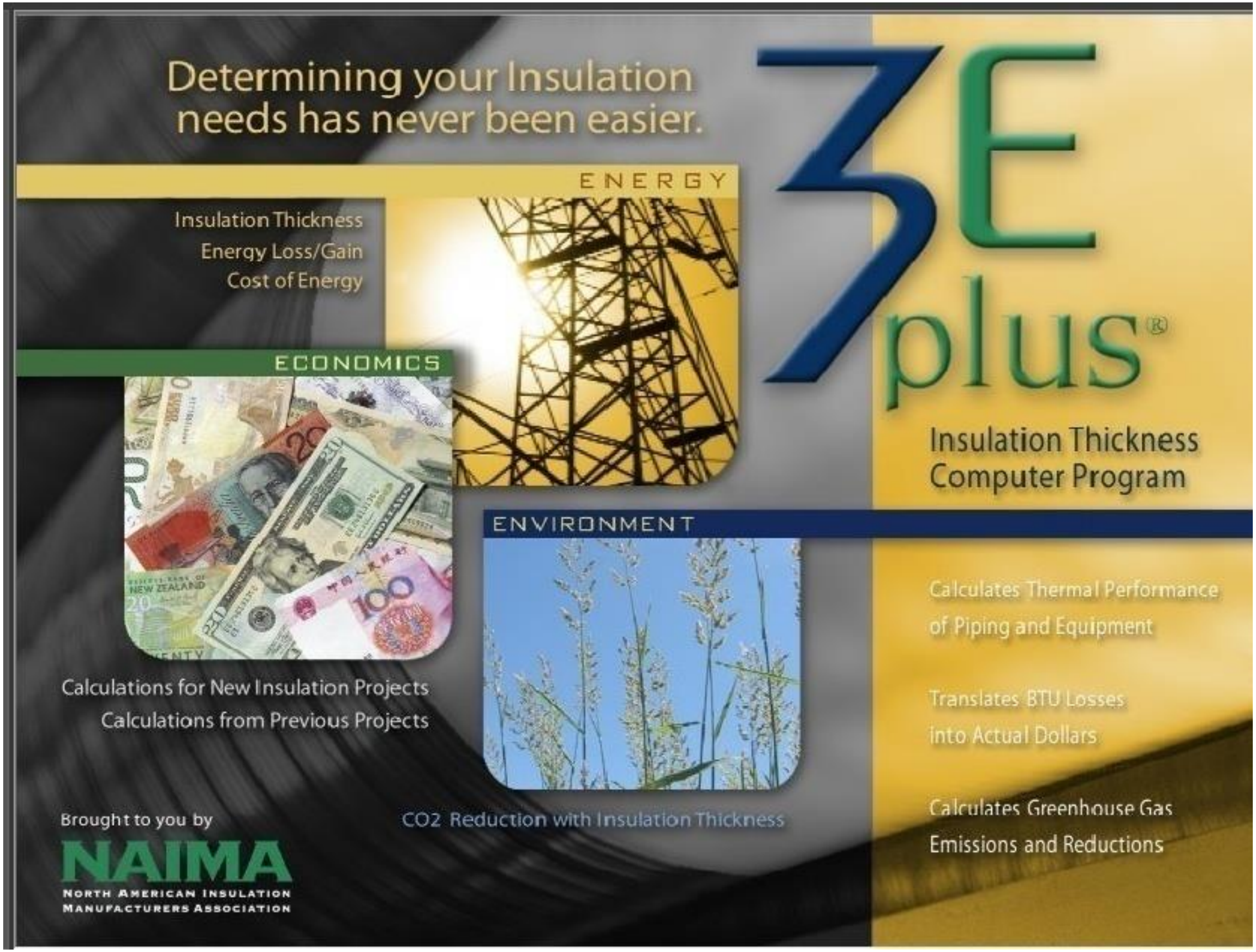
Steam Trap Selection Guide

Application	Trap Type				
	Float & Thermostatic	Thermo-static	Inverted Bucket	Thermo-dynamic	Orifice
Header Drip-legs	Preferred		Alternate	Alternate	
Heat Exchangers: Shell-and-Tube	Preferred		Alternate	Alternate	
Plate-and-Frame	Preferred		Alternate	Alternate	
Air-Finned Tube	Preferred		Alternate	Alternate	
Cylinder Dryer	Alternate		Preferred		Preferred
Tank Jacket	Preferred		Alternate	Alternate	
HVAC Radiator	Preferred		Alternate	Alternate	
Steam Tracing	Alternate	Preferred	Alternate	Alternate	

Missing Insulation

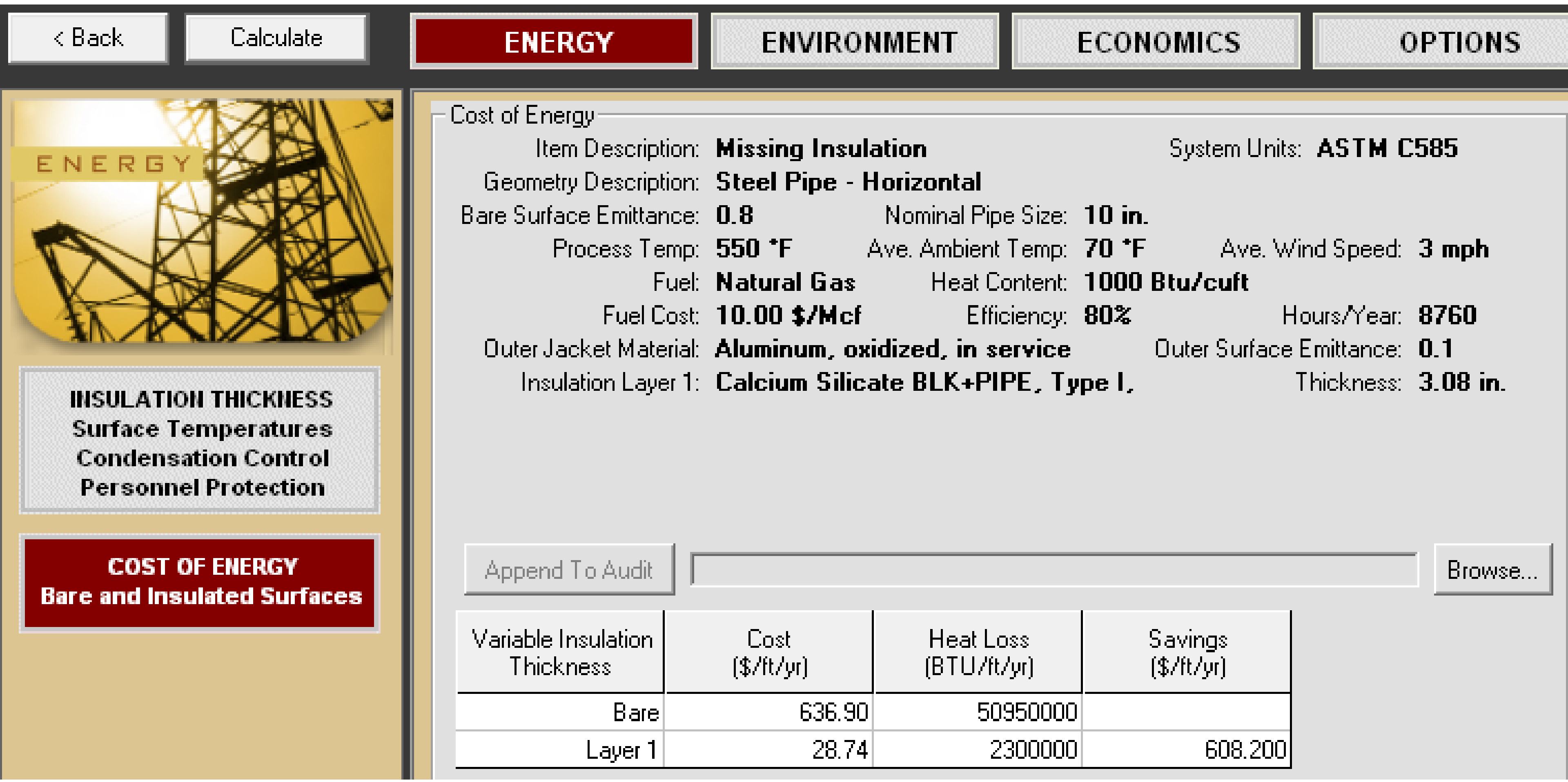
- A 20 foot long section of 150 psig header is observed to be un-insulated
  - 10 inch nominal diameter
  - Steam temperature is approximately 550°F

Insulation Evaluation Software



Insulation Savings

- If the energy impact is realized “at fuel cost”:



$$\sigma = 608\frac{\$}{ft\ yr}\left(20\ ft\right) = 12{,}000\frac{\$}{yr}$$

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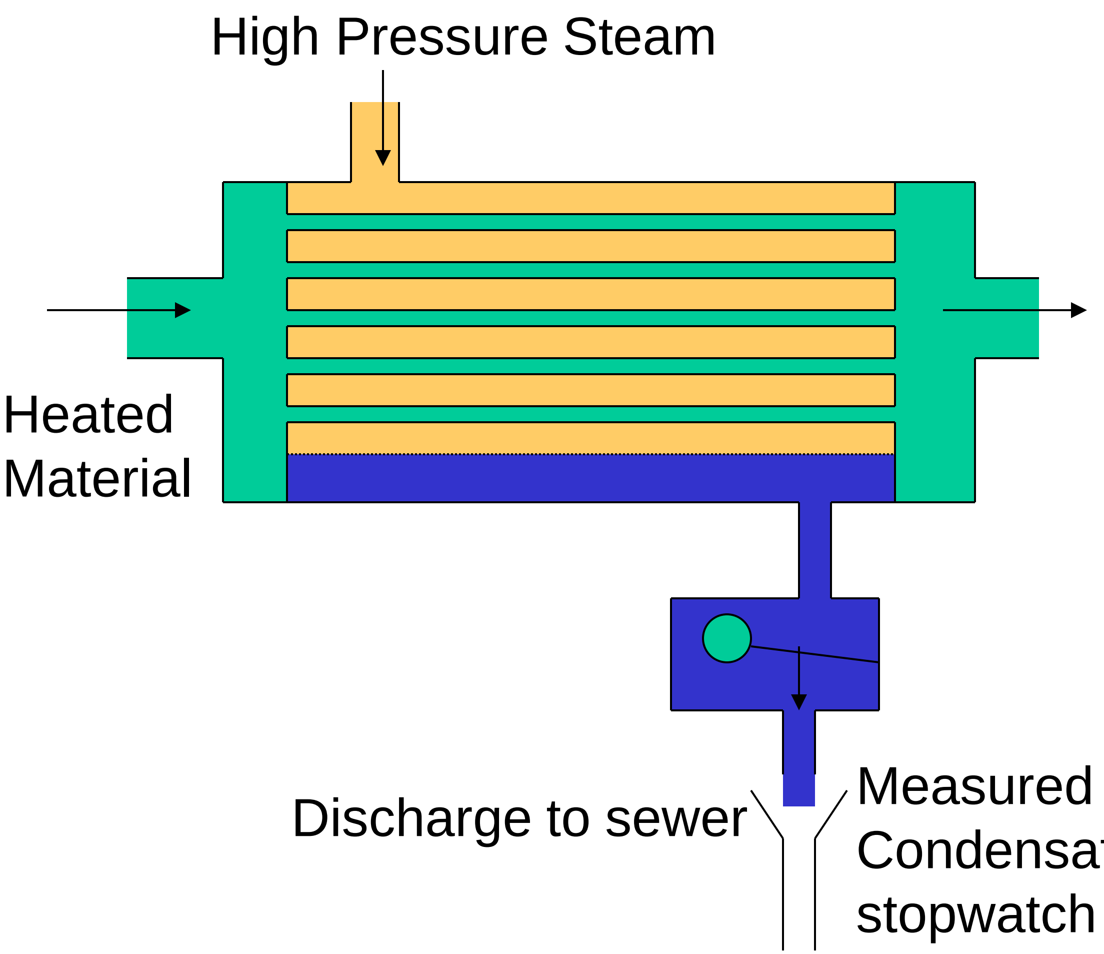
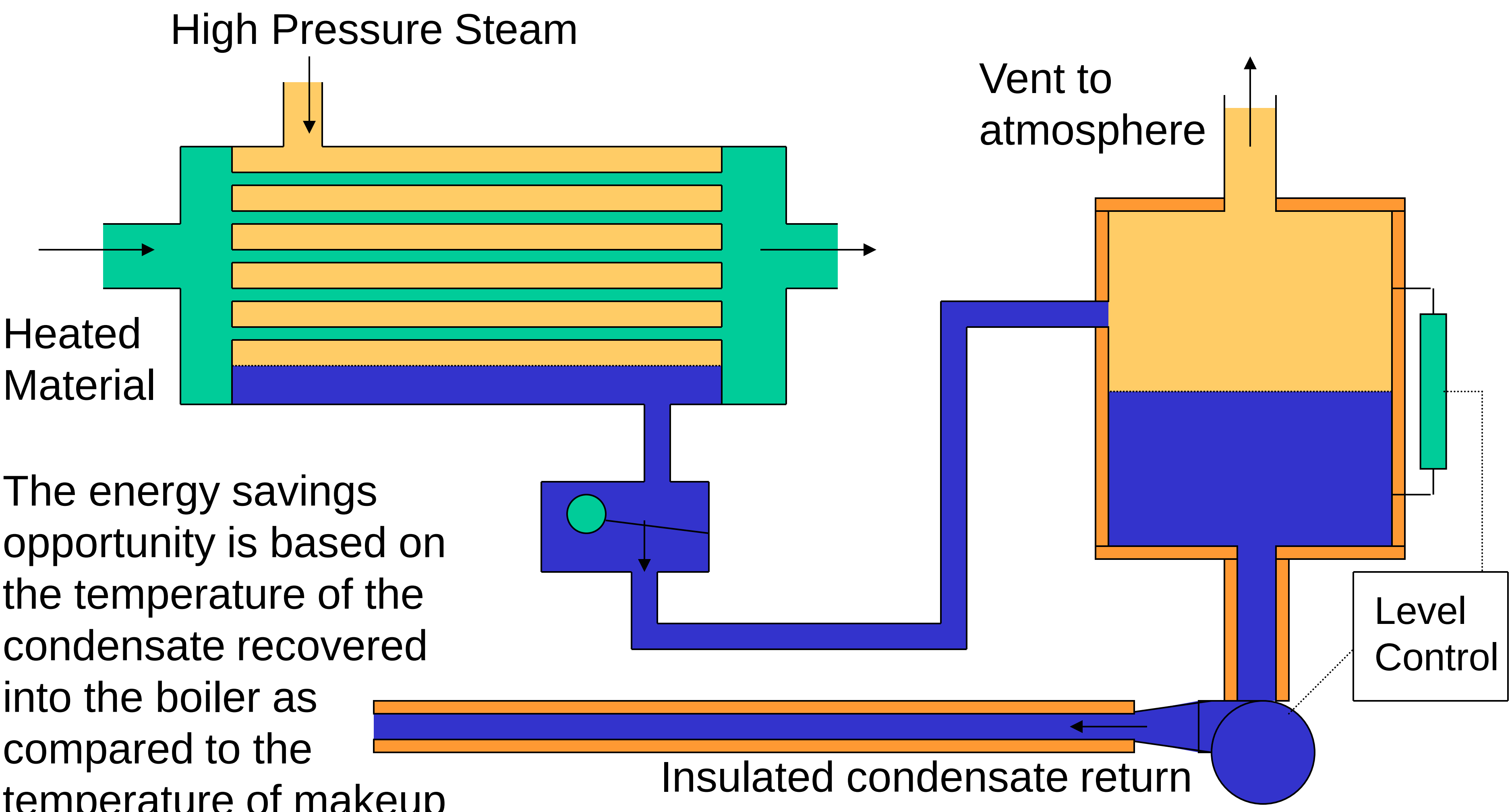
Condensate Return Example



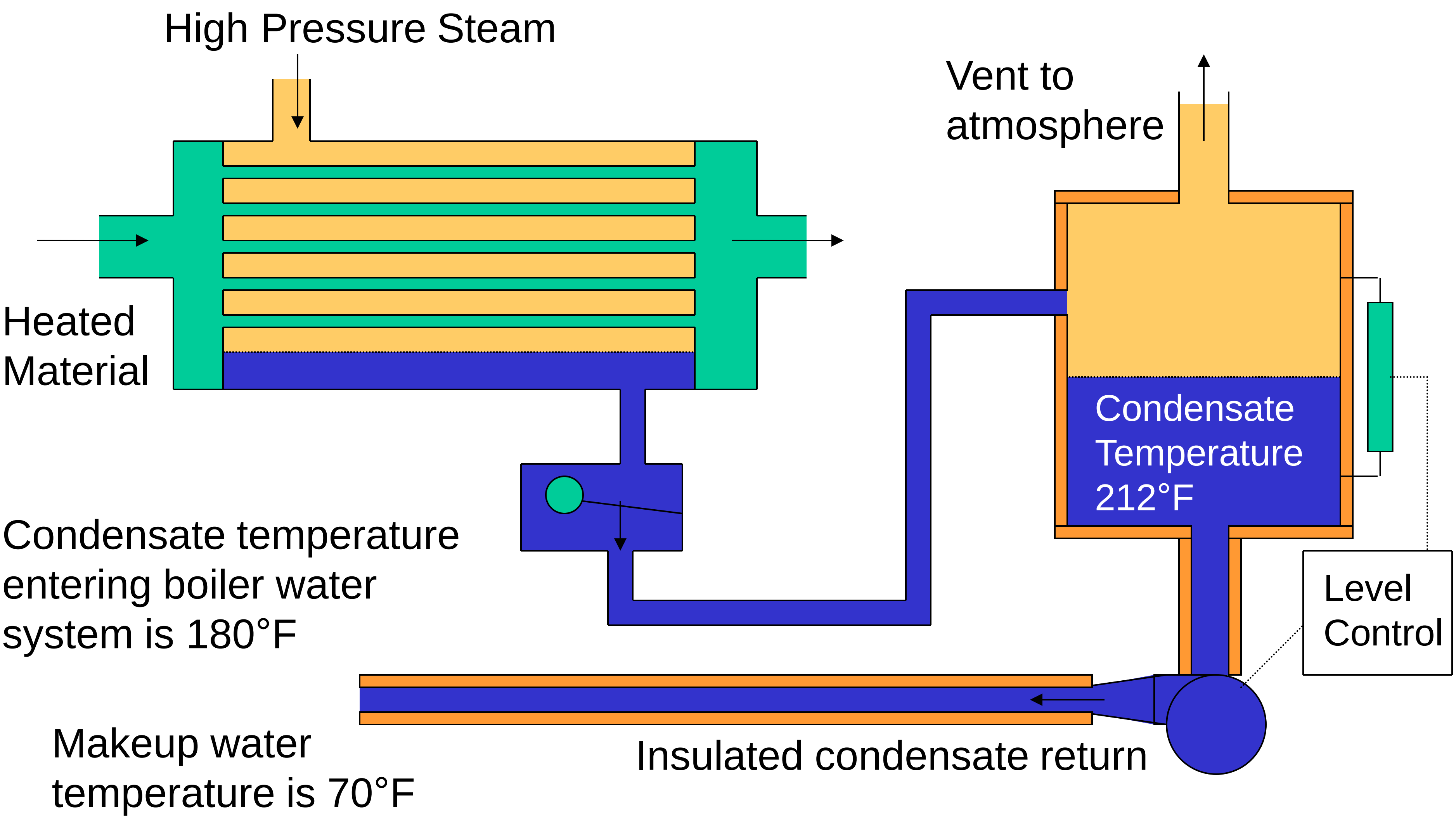
Measured condensate temperature 212°F. Condensate flow measured by bucket and stopwatch (mass and energy balance is also a common method) to be 10 gallons/minute (5,000 lbm/hr)

Condensate Return Example



The energy savings opportunity is based on the temperature of the condensate recovered into the boiler as compared to the temperature of makeup water

Condensate Return Example



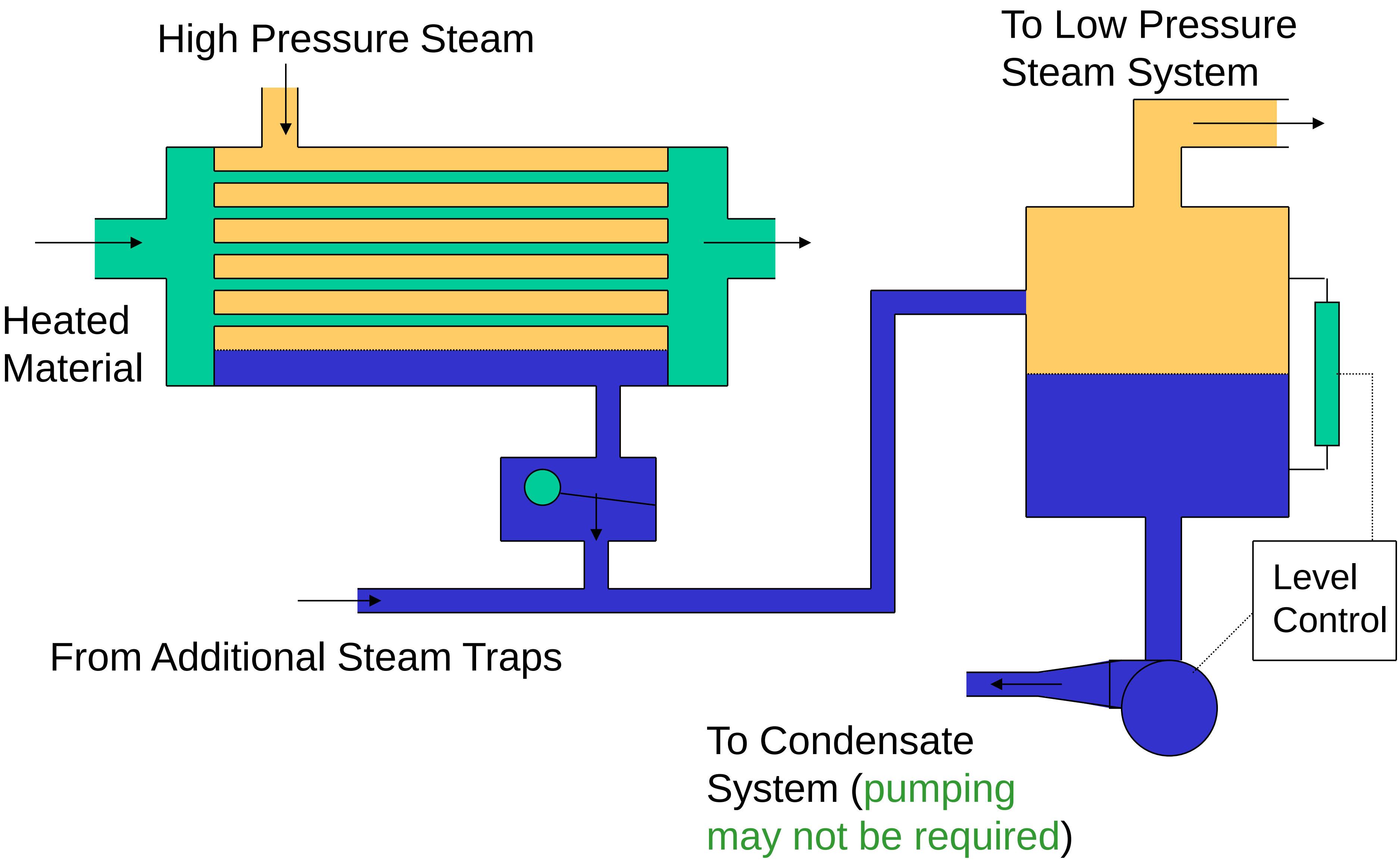
Condensate Return Example

$$\sigma_{condensate} = \frac{\dot{m}_{condensate}\left(h_{condensate} - h_{makeup}\right)T\ \kappa_{fuel}}{\eta_{boiler}}$$

$$\sigma_{condensate} = 5{,}000\,\frac{lbm}{hr}\left(147.91\,\frac{Btu}{lbm} - 38.05\,\frac{Btu}{lbm}\right)\left(8{,}760\,\frac{hrs}{yr}\right)\left(10.0\,\frac{\$}{10^6 Btu}\right)\left(\frac{1}{0.80}\right)$$

$$\sigma_{condensate} = 60{,}000\,\frac{\$}{yr}$$

Cascade Condensate Systems



NPSH

- Net Positive Suction Head (NPSH) is the head required at the pump inlet to keep the liquid from cavitating (boiling)
- The pump inlet or suction side is the low-pressure point where cavitation will first occur

$$P_2 - P_1 = -\rho\vec{g}(z_2 - z_1)$$

NPSH

- Increasing the height of the storage tank above the pump inlet is a very effective method to reduce cavitation potential

$$P_2 - P_1 = -\rho \vec{g}(z_2 - z_1)$$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BALDOR
PACO PUMPS


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ASBESTOS FREE

Driving Force

- What is the main driving force for change??

Driving Force

- What is the main driving force for change??

$

Driving Force

- What is the main driving force for change??

$\$$

- Energy
- Reliability
- Maintenance
- Productivity
- Quality
- Cost avoidance
- Emissions reductions

Measure

- You are not managing what you do not measure

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