MINISTRY OF
INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY
TRANSITION PROGRAMME (SETP)

Global Gateway
Funded by
the European Union

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Project “Accelerating energy efficiency (EE) in large industries through energy management system, system optimisation and the promotion and adoption off EE in SMEs” (IEEP)

EXPERT TRAINING
INDUSTRIAL STEAM SYSTEM OPTIMISATION

Ha Noi, 25 - 28/06/2024

AGENDA

Expert Training on Steam System Optimization
From 25-28 June 2024
At Adonis Hotel - 55 Quang Trung Street, Hai Ba Trung District, Ha Noi
And HOST plants in Bac Giang province and Me Linh district, Hanoi

Day 1: 25 June 2024

(Training at Adonis Hotel, 55 Quang Trung, Hai Ba Trung District, Hanoi)

Time	Contents	Speakers
8.00-8.15	Registration and welcome	
8.15-8.20	Participants Introduction	Representative of UNIDO Project Office
8.20-8.30	Opening speech	Representative of the Project Management Board
8.30-9.00	Introduction	International Expert & National Expert
9.00-10.00	- Review of topics from 2-Day User Training - ASME Steam Standard & Assessment Protocol	International Expert & National Expert
10.00-10.15	**Tea-break**	
10.15-12.00	Student Exercise: An energy assessment for industrial steam system	International Expert & National Expert
12.00-13.15	**Lunch at the hotel**	
13.15-15.00	- Preview of HOST plant – High-level overview of the plant to be assessed	International Expert & National Expert
15.00-15.15	**Tea-break**	
15.15-17.00	- Instrumentation briefing and Demonstration of all the instruments to be used in the assessment - Planning & Logistics for HOST plant visit on 26 and 27/6/2024	International Expert & National Expert

Day 2: 26 June 2024

(Onsite training at HOST plants in HABECO in Me Linh district, Hanoi and Xuong Giang Paper Company in Bac Giang province)

Time	Contents	Speakers
7.15-7.30	Trainees gathering at the Adonis hotel and moving to the HOST plants by cars	All the class
9.00-9.10	- Coming to the HOST plants - Introduction	All the class
9.10-9.20	Welcome speech	Enterprise representative
9.20-9.45	Safety instruction	International Expert & National Experts
9.45-10.00	Tea break	
10.00-11.45	Investigate and measure in boiler plant	All the class
12.00-13.30	**Lunch near the HOST plants**	
13.30-16.30	Continue to investigate and measure in boiler plant	All the class
17.00 – 18.00	Come back Ha Noi (**Group 1**) or Check-in at the hotel in Bac Giang (**Group 2**)	

Day 3: 27 June 2024

(Onsite training at HOST plants in HABECO in Me Linh district, Hanoi and Xuong Giang Paper Company in Bac Giang province)

Time	Contents	Speakers
7.15-7.30	Trainees gathering at the hotel lobby and moving to the HOST plants by cars	All the class
8.30-8.40	Come to the HOST plants, Safety instruction	International Expert & National Experts
8.40-11.45	Survey piping system, valve system, end users and condensate recovery system	All the class, International Expert & National Experts
11.30-13.15	**Lunch near the HOST plants**	
13.30-15.00	Learner groups discuss the measurement results	All the class, International Expert & National Experts
15.00-15.30	Tea break	
15.30-16.30	Learner groups present identified energy saving opportunities	Enterprise representative, All the class, International Expert & National Experts

Day 4: 28 June 2024

(Learning theory at Adonis Hotel, 55 Quang Trung, Hai Ba Trung District, Hanoi)

Time	Contents	Speakers
8.00-8.30	Registration and welcome	All the class
8.30-9.30	- Questions and Answers about the on-site training - Assessing "Special" steam system structure: ▪ Extraction Turbine ▪ Waste heat recovery	International Expert & National Experts
9.30-10.00	Presenting case studies selected from Steam System Optimization projects	International Expert & National Experts
10.00-10.15	**Tea-break**	
10.15-10.45	Planning and carrying out energy assessment for steam system (HOST plants)	International Expert & National Experts
10.45-11.30	- Contents of energy assessment report for steam system - Tools & Resources - Conclusion	International Expert & National Experts
11.30-12.00	- Reviews on the training - Closing remarks	UNIDO Project Office
12.00-13.00	**Lunch at the hotel**	All the class

MINISTRY OF INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY TRANSITION PROGRAMME (SETP)

Accelerating energy efficiency (EE) in large industries through energy management system, System optimisation and the promotion and adoption of EE in SMEs -(IEEP project)

Global Gateway

Funded by the European Union

UNIDO
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Industrial Steam System Optimization (SSO) – Experts Training

Developed by:

Riyaz Papar, P.E., CEM, Fellow – ASME, ASHRAE; C2A Sustainable Solutions, USA

Greg Harrell, Ph.D., P.E.; Energy Management Services, USA

Acknowledgments

- UNIDO Team
- United States Department of Energy, USA
- Oak Ridge National Laboratory, USA

Riyaz Papar, P.E., CEM, Fellow – ASME, ASHRAE

Education:

- M.S. (Mechanical Engineering), University of Maryland, College Park
- B.Tech. (Mechanical Engineering), Indian Institute of Technology, Mumbai

Professional Experience:

- CEO, C2A Sustainable Solutions, USA
- Industrial Energy Efficiency & Decarbonization Advisor, Oak Ridge National Laboratory (US DOE)
- Engineering Fellow, Hudson Technologies Company, USA
- Other Past Employers - Enron Energy Services, Lawrence Berkeley National Laboratory, Energy Concepts Company

Other Qualifications & Affiliations:

- US DOE Steam & Process Cooling BestPractices Lead Instructor & Technical Advisor
- US DOE Steam Energy Expert
- UNIDO Energy Expert – Steam, Refrigeration & Chillers and Waste Heat Recovery
- Chair, ASME Process Industries Division, 2003-04
- Chair, ASHRAE Technical Committee 8.2: Centrifugal Machines, 2009-10
- Chair, ASHRAE Technical Committee 1.10: Cogeneration Systems, 2010-11

Contact Information

Riyaz Papar

CEO; C2A Sustainable Solutions, LLC

Phone: +1 346 610 8787

E-mail: rapapar@c2asustainable.com

Training Objectives

- To train end-users and consulting engineers to become national experts for assessing and optimizing steam systems

- Help industry optimize steam systems and achieve energy and cost savings through
  - Proper operation and controls
  - System maintenance
  - Appropriate process uses of steam
  - Cogeneration and
  - Application of state-of-the-art technologies

Training Objectives

- To conduct field assessments and identify projects to demonstrate actual energy, cost savings and GHG emission reductions achievable using the Systems Approach

- Build expertise in the use of US DOE publicly available steam system optimization assessment software tools

Experts Training – Day 1 (Classroom) - Outline

- Review of topics from 2-Day User Training
- ASME Steam Standard & Assessment Protocol
- Student Exercise - An industrial Steam System energy assessment
- Preview of HOST Plant – High-level overview of the plant to be assessed
- Instrumentation briefing and Demonstration of all the instruments to be used in the assessment
- Planning & Logistics for HOST plant visit on Day 2 & 3

Experts Training – Day 2 & 3 - Outline

- Host Plant SSO Assessment
  - International Experts and national expert trainees visit the Host plant
  - National expert trainees are divided into teams and provided portable instrumentation to be used in the steam system assessment
  - International experts work w/expert trainees to identify potential improvement opportunity areas
  - Due-diligence including data gathering is done onsite
  - National expert trainees are given hands-on opportunity and training to do a steam system assessment
  - Report Generation

Experts Training – Day 4 (Classroom) - Outline

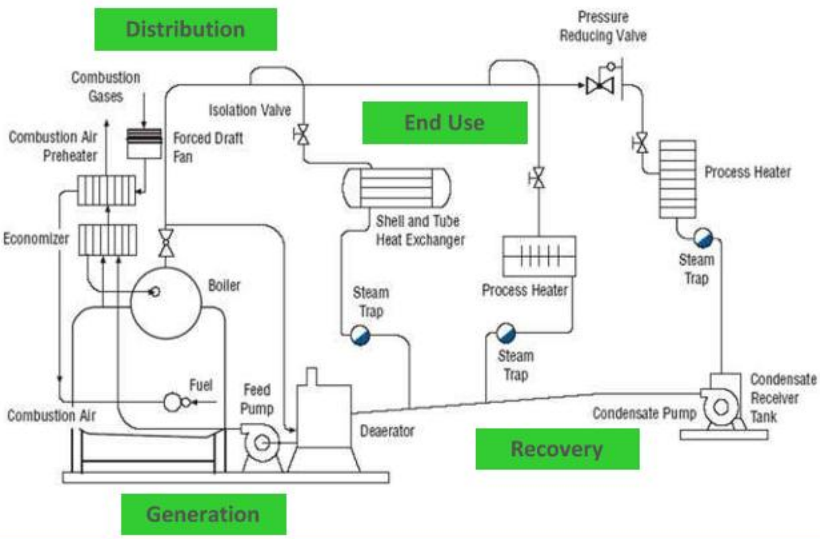
- Q&A from Day 2 & 3 HOST plant visit
- Evaluating “special” steam system configurations
  - Extraction turbines
  - Waste heat recovery
- Presentation of select Case Studies from Steam System Optimization projects
- Planning & Conducting a Steam System Energy Assessment (Candidate Plant)
- Elements of a Steam Energy Assessment Report
- Tools & Resources
- Conclusions

Experts Training – Post HOST Assessment - Outline

- Next 4 months
  - Candidate Plant
    - Each national expert trainee works with an assigned candidate plant to conduct a steam system optimization energy assessment
    - Works with international expert to review the assessments, observations, models and results
    - Completes final report and presents to plant
  - Three Webinars (1 per month)
    - Technical support and guidance provided by international experts to national expert trainees
    - Ongoing review of expert trainee progress and their level of SSO understanding

Experts Training – Post HOST Assessment - Outline

- After 4 months
  - ½ Day Review
    - Classroom training to review fundamentals of SSO
    - Functionality and use of steam system tools
    - Questions and Answers
    - Discussion of experiences from Candidate plants
  - Qualifying Exam
    - National expert trainees will take a 4-hour exam as their final qualification test before they are qualified as SSO NATIONAL EXPERT



Generic Steam System

Source: US DOE Steam Best Practices Program

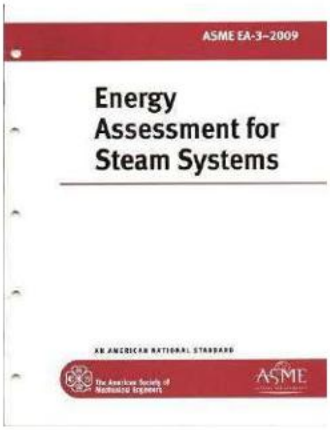
Industrial Steam System Energy Assessment:

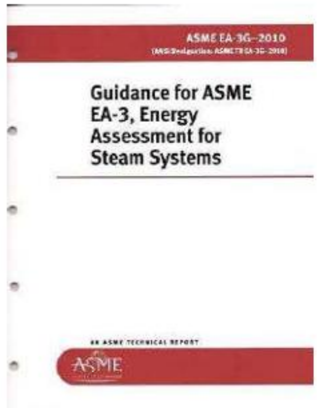
- An ASME Standard
- Scope & Deliverables
- Reporting

Industrial Energy Assessments

- There are several levels of industrial plant energy assessments (audits)
  - Overall plant-wide
  - System focused – steam, compressed air…..
  - 1-day, 3-day……
- But the overall goal is typically, focused on reductions in energy usage (and/or intensity)
- Identification of energy savings opportunities and path to implementation
- Expectations vary significantly between plant personnel and energy auditor

Energy Assessment Standard for Steam Systems





http://www.asme.org/products/codes---standards/energy-assessment-for-steam-systems

Energy Assessment Standard for Steam Systems

- Scope
  - Covers steam systems containing steam generator(s) or other steam source(s), a steam distribution network, end-use equipment and recovery
  - Cogeneration and power generation components may be included
  - Sets the requirements for conducting and reporting the results of a steam system energy assessment that considers the entire system, from energy inputs to the work performed as the result of these inputs
  - Resulting assessment will identify the major opportunities for improving the overall energy performance of steam system
  - Designed to be applied primarily at industrial facilities, but most of the specified procedures can be used in other facilities such as those in the institutional and commercial sectors

Energy Assessment Standard for Steam Systems

- Use of this Standard and accompanying Guidance Document should increase the quantity and quality of energy assessments performed, with significant potential savings in implemented energy costs
- **Intended for** energy managers, facility managers, plant engineers, energy consultants, maintenance managers, plant managers, EH&S managers, across a broad range of industries

Energy Assessment Standard for Steam Systems

- The standard clearly identifies the processes, protocols and deliverables of a steam assessment
- The sections of the steam assessment standard are:
  - Scope & Introduction
  - Definitions
  - References
  - Organizing the Assessment
  - Conducting the Assessment
  - Assessment Data Analysis
  - Report & Documentation
  - Appendix A – Key References
- An accompanying guide provides more detailed information for each of the sections

Typical Project Areas in a Steam System Assessment

- Boiler efficiency improvement
- Fuel switching
- Boiler blowdown thermal energy recovery
- Steam demand reduction
- General turbine operations
- Thermal integration
- Process/Utility integration
- Turbine-PRV operations
- Condensing turbine operations
- Thermal insulation
- Condensate recovery
- Flash steam recovery
- Steam leaks management
- Steam trap management
- Waste heat recovery

Energy Savings Opportunities

	Near-Term	Mid-Term	Long-Term
Definition	Improvements in operating and maintenance practices	Require purchase of additional equipment and/or system changes	New technology or confirmation of performance in plant
Capital Expense	Low cost actions or equipment purchases	Rules of thumb estimates can be made	Additional due-diligence required
Payback	Less than one year	One to two year	Two to five-year
Examples of Projects	• Boiler combustion tuning • Insulation • Steam leaks and trap management	• Automatic combustion control • Blowdown energy recovery • Feedwater economizer	• Combined Heat & Power • Steam turbine driven process components • Boiler fuel switching

Student Exercise:

- Industrial Steam System Assessment
- Steam System Scoping Tool (SSST)
- US DOE MEASUR
- 3EPlus

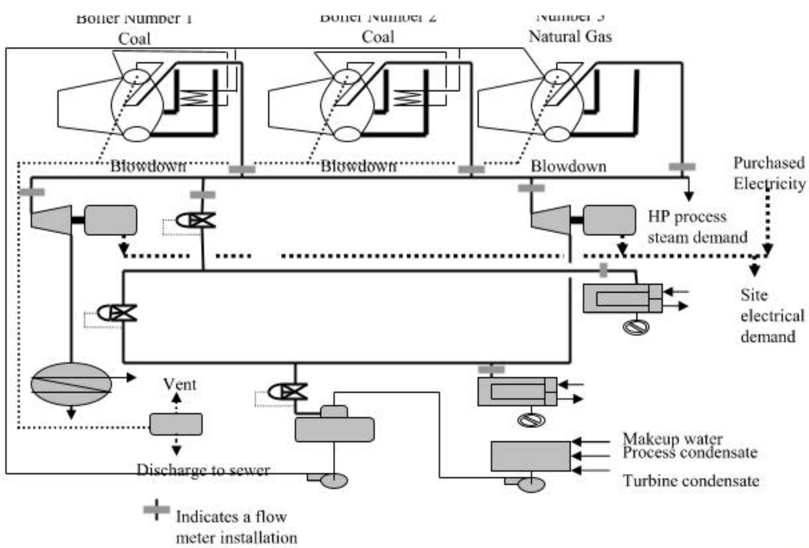
Student Exercise Instructions

- You have been tasked to undertake a 3-day industrial steam system energy assessment at a chemicals manufacturing plant
- The plant utilities manager and an energy engineer are available to work with you all throughout the assessment and answer any system and process based questions that you may have
- Your goal – Identify and quantify major energy efficiency improvement opportunities at this plant

Student Exercise Instructions

- Define the approach that you would take to
  - Identify current BestPractices at the plant
  - Develop a list of priority actions to achieve energy efficiency improvement opportunities and determine areas that require system level analysis
  - Complete data collection
  - Undertake system level analysis for the opportunities that are identified
  - Develop summary report & present it to the plant
  - Future follow up and action items

Example Steam System



Student Exercise Steam System Information

- The plant (and steam system) operates 24 hours/day, 365 days/year;
- There are 3 boilers: two are coal-fired and one is natural gas fired
- The coal-fired boilers are operated continuously and they take care of the steam demand
- The natural gas boiler is operated at minimum fire and serves as a standby boiler due to its fast response in case one of the coal-fired boiler trips
- Typical average loads correspond to ~70% of total available capacity
- Fireside heat transfer surfaces are normally found to be clean
- Waterside surfaces have had to be cleaned about every three years
- Feedwater economizers exist on the coal-fired boilers

Student Exercise Steam System Information

- Electricity is generated onsite and purchased from a local utility supplier
- Purchased electrical costs are ~$0.105/kWh
- Purchased electricity is typically 7 MW
- Natural gas is purchased under contract with a price of $10/GJ; Coal prices are ~$150/tonne ($4.70 per GJ)
- The fuel properties contained in MEASUR are appropriate to describe the fuels
- Makeup water is supplied to the facility with a cost of $0.75/m^3 and a temperature of 20°C
- Feedwater is supplied to the boilers at 25 bars and 110°C

Student Exercise Steam System Information

- The boilers are field erected, water-tube type boilers
- The coal fired boilers were the original boilers for the site
- The natural gas fired boiler has been recently installed with the availability of pipeline natural gas
- Steam exported from the boilers is significantly superheated

Student Exercise Steam System Information

- Boiler water treatment data indicates all three boilers operate with similar water conditions
- The boilers operate continuously with a boiler water conductivity of ~2,500 µmho/cm
- Feedwater conductivity is ~125 µmho/cm
- Chlorides measurements of the boiler water typically indicates 280 ppm
- Feedwater chloride measurements indicate 14 ppm

Student Exercise Steam System Information

- The boiler is safety inspected annually by a boiler consultant who also verifies the operation of the combustion control equipment and measures efficiency
- There are no problems related to wet steam (corrosion, water hammer), the ability to maintain normal boiler water levels or the ability to maintain steam pressure to within 1.5 bars of the set-point
- Automatic boiler blowdown systems are installed but have not operated properly recently so blowdown has been adjusted manually based on once-a-day measurement of boiler water conductivity

Student Exercise Steam System Information

- High pressure steam is supplied to only one process unit
- This process unit utilizes steam in a direct contact process application
- This process steam demand is not equipped with a flow meter but the steam supply to this process is relatively constant
- Each of the boilers is equipped with a flow meter indicating steam production
- All the turbines receiving high-pressure steam are equipped with flow meters

Student Exercise Steam System Information

- Boiler operations and controls are as follows
  - Boiler #1
    - Flue gas temperature = 200°C
    - Flue gas oxygen = 5% (managed by positional controller)
  - Boiler #2
    - Flue gas temperature = 230°C
    - Flue gas oxygen = 7% (managed by positional controller)
  - Boiler #3
    - Flue gas temperature = 250°C
    - Flue gas oxygen = 4% (managed by automatic trim controller)

Student Exercise Steam System Information

- Combined boiler steam production - 160 Tph
  - Boiler #1 – 70 Tph (20 bars; 300°C)
  - Boiler #2 – 70 Tph (20 bars; 300°C)
  - Boiler #3 – 20 Tph (20 bars; 300°C)
- Medium pressure header – 10 bars
- Low pressure header – 2 bars
- HP-LP backpressure turbine steam flow – 104 Tph
- Condensing turbine steam flow - 15 Tph
- High pressure to medium pressure PRV flow – 35 Tph

Student Exercise Steam System Information

- Steam flow meters are in place on the medium-pressure and low-pressure steam headers
- These flow meters record the total steam flow to the process steam demands
- During normal operation steam supply to the medium pressure users is ~35 Tph
- Low pressure process steam demand is ~90 Tph
- It has been estimated that one half of the medium and one half of the low-pressure steam users are connected to the condensate collection system

Student Exercise Steam System Information

- The site is equipped with two steam turbines as noted on the system schematic
- HP-LP Backpressure Turbine
  - Connected to an electrical generator and which is rated to produce 5 MW of electric power (Generator Efficiency = 95%)
  - Manages the steam supply into the low-pressure header
  - Operates with a load between 65% and 80% of full load
  - Receives high pressure steam — boiler outlet conditions
  - Discharges steam with a temperature of 214°C and a pressure of 2 bars

Student Exercise Steam System Information

- Condensing Turbine Operations
  - The steam turbine is connected to an electrical generator
  - This component was installed with the original plant construction when two coal fired boilers served the site
  - Steam supply to the turbine is 15 Tph of high pressure steam — to produce 2.150 MW of electrical output
  - The condensing turbine operates with a condensing pressure of 0.15 bara
  - Generator efficiency is ~95%.

Student Exercise Steam System Information

- Pressure Reducing Stations
  - The steam system is equipped with two pressure reducing stations
  - One operates between the high pressure and the medium pressure systems
  - The other operates between the medium pressure and the low pressure systems
  - These pressure reducing stations are not equipped with desuperheating stations

Student Exercise Steam System Information

- Condensate Recovery System
  - The condensate recovery system is extensive
  - Recovered condensate is collected in many individual area condensate receivers
  - All of the receivers are vented to the atmosphere
  - A thorough steam trap survey was completed recently
  - There had not been a steam trap evaluation for a significant period of time prior to this
  - Maintenance activities have not been initiated in response to the steam trap survey at this point
  - The last significant maintenance activity associated with steam traps was four years ago

Student Exercise Steam System Information

- Other system information
  - The main condensate receiver for the facility is vented to the atmosphere
  - The vent piping presents a minor (negligible) amount of steam but this indicates the condensate entering the receiver is saturated liquid
  - Steam leaks appear to be well managed with only very minor (negligible) leaks observed
  - Insulation has been well maintained in the utilities area
  - Insulation on the steam distribution and end-use area may need investigation

Student Exercise Questions

- Steam System Scoping Tool
  - Complete the SSST sections related to "Steam System Operating Practices" and "Boiler Plant Operating Practices" based on the information provided
  - Also, indicate how you would proceed to obtain any additional information you would need beyond that provided
  - Finally, based on completion of these SSST sections, list the specific areas on which you would focus your attention to achieve boiler-related energy savings in the example plant

Student Exercise Questions

- Boiler #2 Efficiency Calculations
  - Estimate the fuel related operating cost of the boiler
    - Use "Typical Bituminous Coal" and only the largest boiler loss
    - The calculation should be completed using steam flow, steam conditions, and an estimate of boiler efficiency
  - Estimate the loss associated with boiler blowdown
  - Determine the direct and indirect boiler efficiencies
    - Assume shell loss is 0.4% of fuel input energy
    - Assume LOI is 2.1% provided by laboratory analysis
    - Assume a field evaluation has been completed and the average fuel flow rate is 165 tonne/day
    - The fuel higher heating value is 31,890 kJ/kg

Student Exercise Questions

- Boiler #2 Efficiency Calculations
  - Estimate the *impact* of installation of an automatic oxygen trim controller
    - The controller will reduce the flue gas oxygen content to 4.5% for the general boiler load
    - Assume a field evaluation has been completed and the average fuel flow rate is 165 tonne/day
    - The fuel higher heating value is 31,890 kJ/kg

Student Exercise Questions

- HP-LP Backpressure Turbine Efficiency Calculations
  - Determine the isentropic efficiency of the main steam turbine operating between the high pressure and low pressure systems

- Condensing Turbine Efficiency
  - Determine the isentropic efficiency of the condensing turbine based on the information provided

Student Exercise Questions

- US DOE MEASUR Steam Assessment Tool
  - Develop the US DOE MEASUR model that best represents the general characteristics of the example facility for an evaluation that will provide representative marginal steam costs
  - This model should also provide a good description of the steam mass balance through the system
  - The analyses required for this exercise should be considered preliminary; as a result do not include boiler shell losses and LOI (Loss on Ignition)
  - Outputs for this exercise are marginal steam costs for the system and the steam flows through the pressure reducing valves

Student Exercise Questions

- US DOE MEASUR Steam Assessment Tool
  - Blowdown Energy Recovery
    - Using the US DOE MEASUR model developed for the general steam system determine the economic impact of recovering thermal energy from boiler blowdown
    - Present the individual areas of economic impact contributing to the results

Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

❑ Condensate Flash Steam Recovery

- Using the US DOE MEASUR model developed for the general steam system determine the economic impact of recovering flash steam produced from the existing condensate recovery system
- Present the individual areas of economic impact contributing to the results

Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

❑ Steam Demand

- Process water was being unnecessarily heated from 40°C to 70°C with low-pressure steam
- The steam trap serving the heat exchanger is functioning properly and is discharging saturated liquid
- Steam entering the heat exchanger is from the low pressure system at saturated conditions—heat transfer losses in this branch line account for the energy loss from the superheated supply condition
- The process water has a flow rate of ~400 l/min
- Determine the steam system operational cost impact of eliminating this steam demand

Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

❑ Steam Turbine versus Electric Motor

- Determine the economic impact of replacing a 100 kW process drive electric motor with a steam turbine
- Assume the process turbine will operate continuously between the high-pressure and medium-pressure systems
- The turbine will have an isentropic efficiency of 35%

Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

❑ 3E Plus Piping Insulation Problem

- One of the process units is supplied medium-pressure steam through a 150 mm nominal diameter header
- A 10 m long section of the header was observed to be un-insulated—the result of a past maintenance activity
- The rest of the piping system is covered with a 50 mm thick calcium silicate insulation and aluminum jacket
- Ambient conditions are typical for an industrial facility
- The piping is located outside on a pipe bridge
- Determine the energy loss reduction and economic impact associated with replacing the missing insulation

HOST Plant:

- High-level Overview of HOST Plant
- Planning & Logistics for Day 2 and 3 at HOST Plant

Portable Instrumentation & Tools:

- Functionality & Demonstration of Portable Instruments
- Specific Instruments to be used for Day 2 and 3 at HOST Plant

Industrial Steam System Assessment

- Portable Instrumentation to be used for the steam system energy assessment
  - Infra-red thermographic camera
  - Combustion flue-gas analyzer
  - IR temperature guns
  - Thermometers with k-type probes
  - Pitot tube with digital manometer
  - Pressure gages
  - Digital camera
  - Stop watch

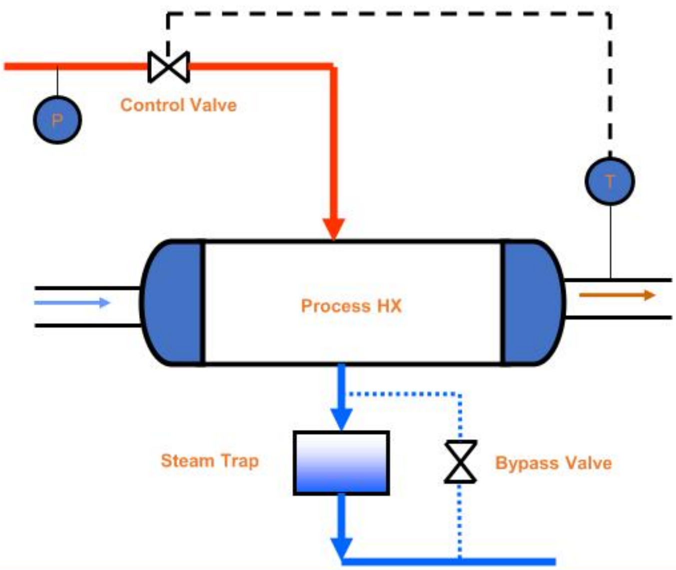
Q&A from Day 2 & 3 – HOST Plant Visit

- Understanding of steam system
- US DOE MEASUR, 3EPlus
- Evaluation of specific opportunities
- Completion of all activities

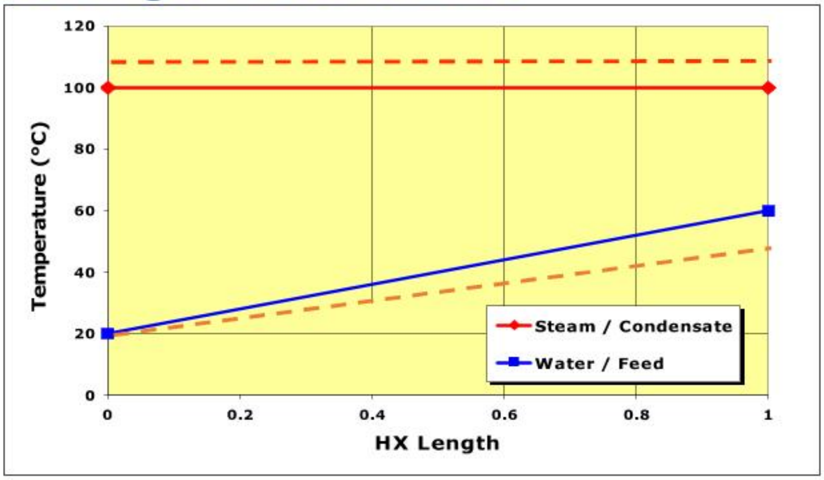
Common Specific Steam System Applications

- Heat Exchangers & Fouling
- Extraction Steam Turbines
- Steam Accumulators
- Waste Heat Recovery Boilers
- Industrial Heat Pumps
  - ❑ Thermocompressors
  - ❑ Absorption Chillers

Heat Exchanger Operation



Heat Exchanger Performance

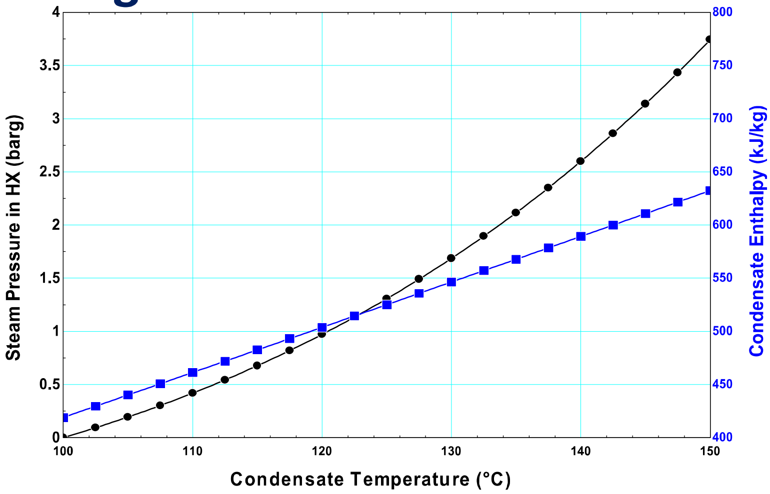


Heat Exchanger Performance

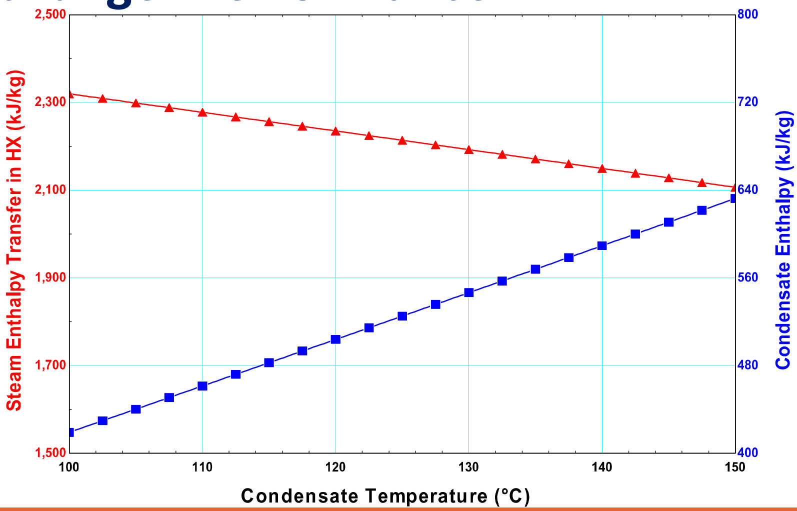
$$Q = m_{steam} * \left(h_{steam} - h_{cond}\right)$$

- Heat Exchanger fouling results in the following
  - Driving temperature (steam) increases
  - Steam pressure increases
  - Condensate enthalpy increases
  - Enthalpy difference (steam and condensate) reduces
  - For the same heat duty, more mass flow of steam is required
  - If condensate is not collected – leads to additional penalty
  - If condensate goes to atmospheric flash – energy loss occurs due to more flashing

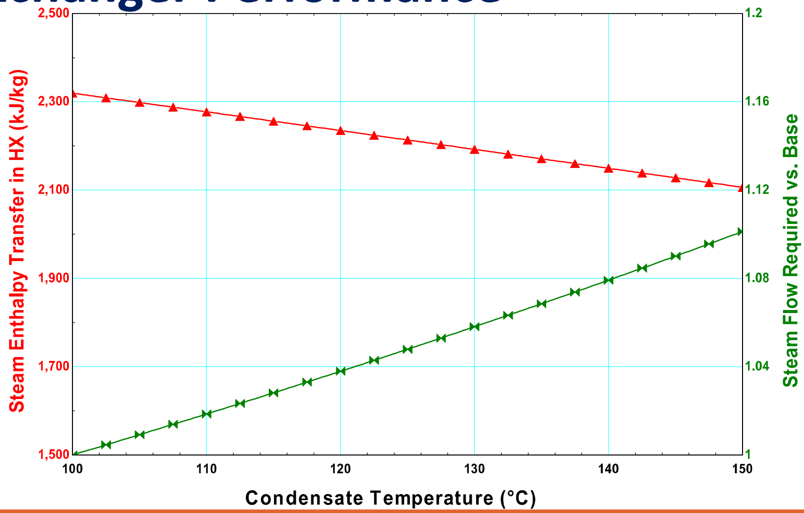
Heat Exchanger Performance



Heat Exchanger Performance

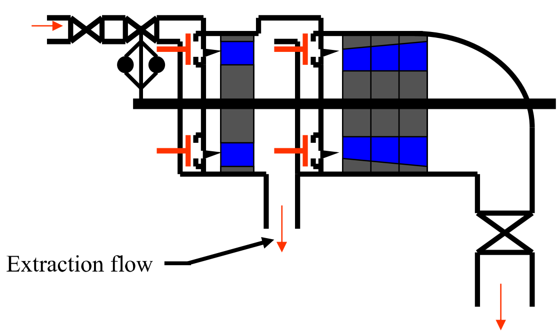


Heat Exchanger Performance



Extraction Steam Turbines

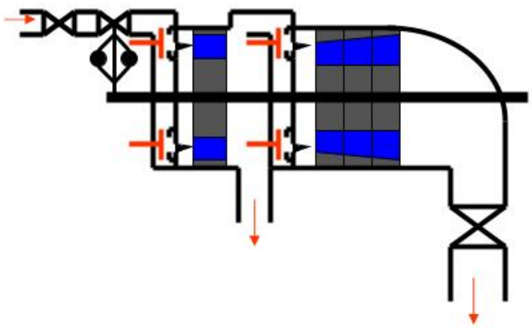
- Extraction turbines require special attention in MEASUR models



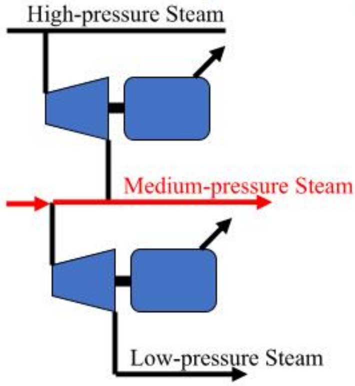
Extraction Turbine

Extraction Steam Turbines

➢ A simple approach can result in a robust representation of the system but slight thermodynamic changes



Extraction Turbine

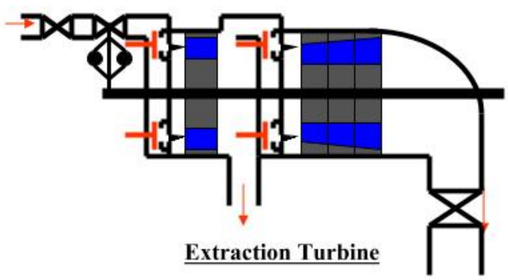


US DOE MEASUR Model Arrangement

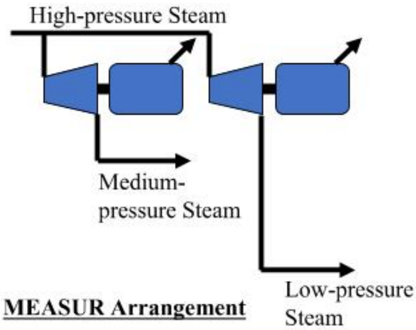
Extraction Steam Turbines

➢ Neither of the two techniques is perfect

- ❑ HP-MP coupled with MP-LP compromises the steam condition entering the MP-LP turbine
- ❑ HP-MP coupled with HP-LP requires judicious flow/power management
  - More accurate method from a thermodynamic standpoint

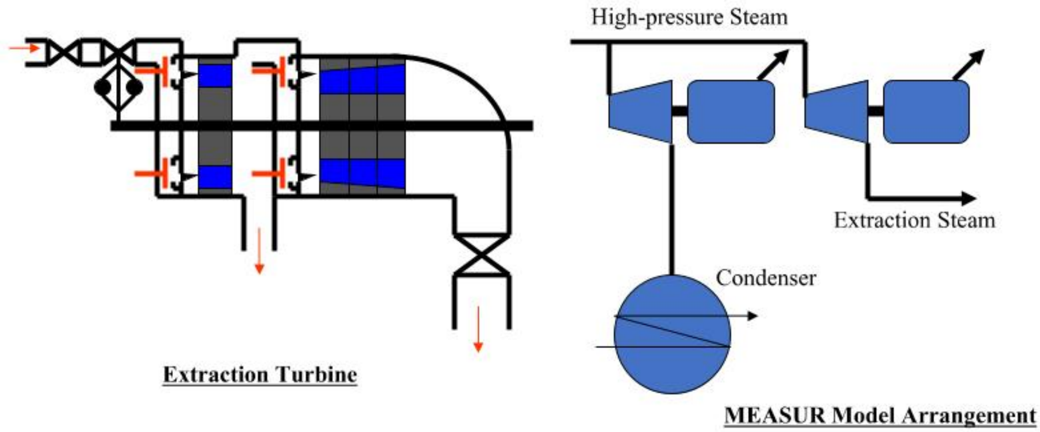


Extraction Turbine



MEASUR Arrangement

Extraction-Condensing Steam Turbines



Steam Accumulators

- Primary purpose - Thermal Energy Storage
- Significant impact on operations
  - Boiler plant capacity
  - Energy efficiency
  - Water savings; Environmental issues; Noise issues, etc.
- Classic applications
  - Batch operations
  - Intermittent high and low steam demands
  - Periods of very small high peaks of steam demand

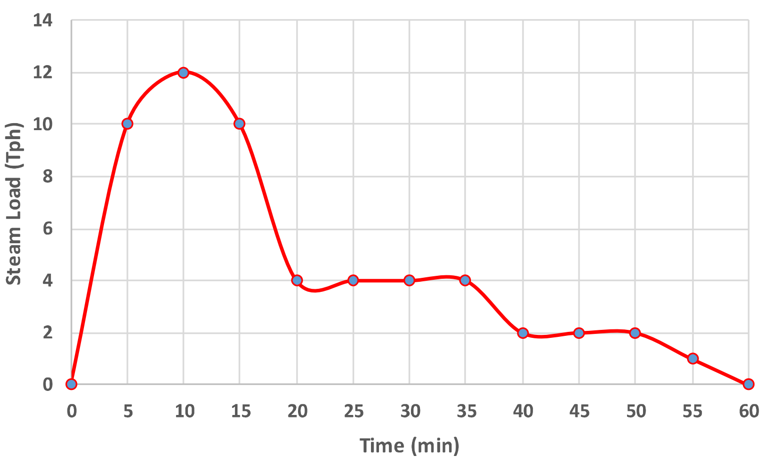
Steam Accumulators

Batch Operation

Venting – Difficult Boiler Control

Accumulate Excess Steam

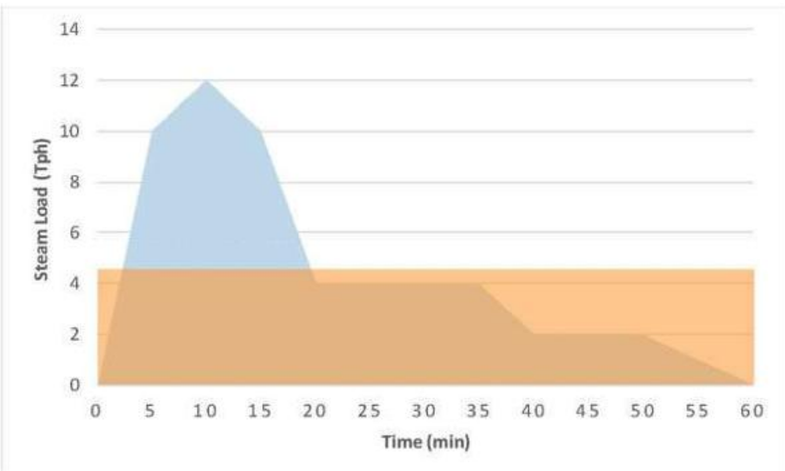
Steam Accumulators - Steam Load Profile: Cycle time



Steam Accumulators

- Add a properly sized steam accumulator
- Maintain boiler at steady state operations
- Ramp up time for 15 minutes
  - Steam from boiler and accumulator
- Slow down for 25 minutes
  - Steam from boiler and/or accumulator
  - Steam supply to accumulator
- Next 20 minutes
  - Steam from boiler
  - Steam supply to accumulator

Steam Accumulators



Steam Accumulators

- Boiler runs a steady load of 4.6 Tph
- Total steam supplied in an hour = 4.6 Tonnes
- Area under the profiles is the same
- Plant benefits
  - Energy savings due to better boiler efficiency
  - Operating minimum number of boilers
  - No steam venting
  - Higher reliability of operations
  - Other system optimization opportunities (steam turbines)

Waste Heat Recovery Boilers

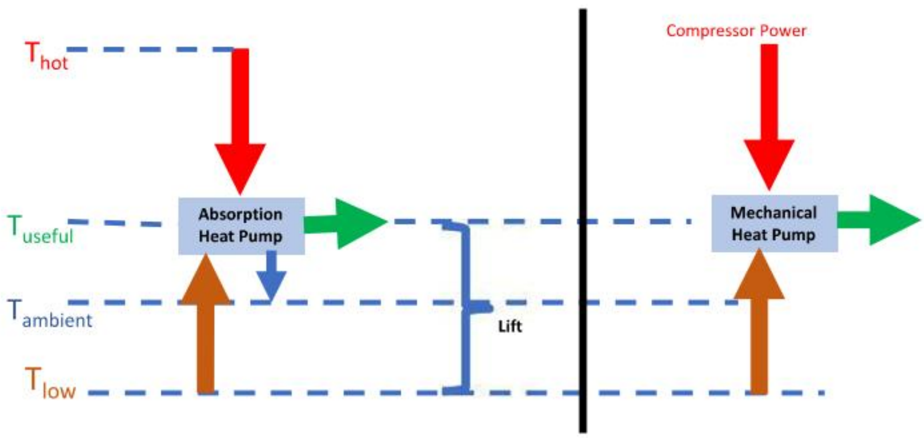
- Waste Heat Recovery (WHR) boilers can take several forms depending on the source of waste heat
  - Heat Recovery Steam Generators (HRSGs) on exhaust of combustion turbines
  - Exothermic reaction in a process
  - Heat of combustion of burning waste liquids, etc. in an incinerator
  - Recovery of chemicals
  - Stack loss from a process heater, furnace, etc.
- In most cases, WHR boilers are NOT Impact boilers
- In several cases, WHR boilers may be generating steam at a medium or lower pressure

Waste Heat Recovery Boilers

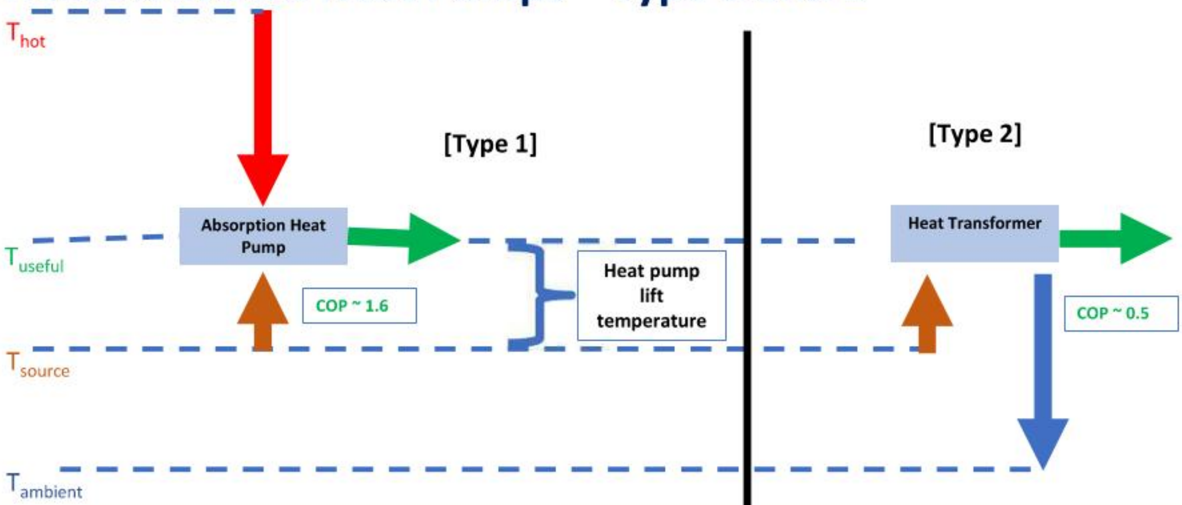
- The main questions that need to be answered in an analysis with WHR boilers
  - Can more steam be produced from the WHR boilers?
  - If yes, then is the steam system still balanced from a demand and supply perspective?
  - Can steam produced from the WHR boiler offset steam produced from a fuel-fired boiler?

- From a modeling perspective, WHR boilers are best handled by Steam demand savings, if there is a fuel-fired impact boiler in the plant whose load can be reduced due to the steam produced by the WHR boiler

Industrial Heat Pumps

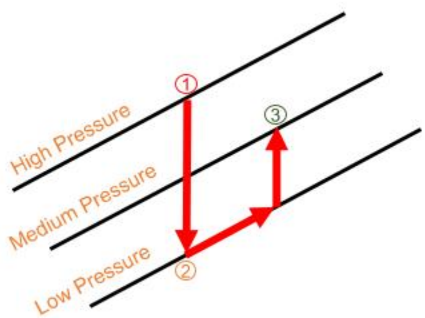


Heat-Activated Heat Pumps – Type 1 and 2

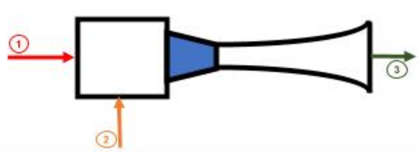


TVR - Thermocompressors

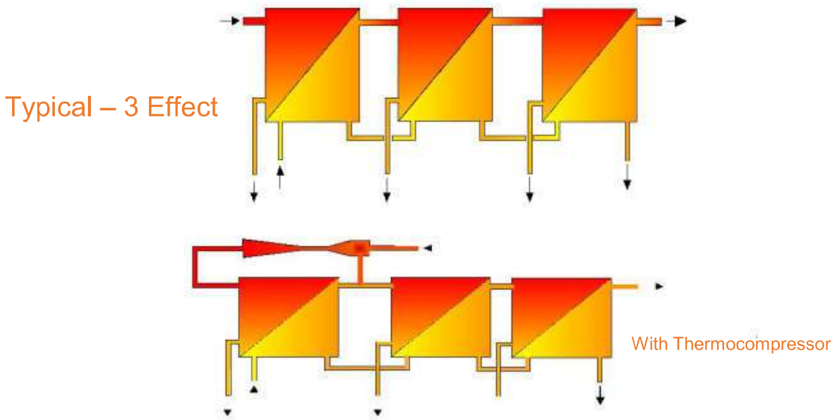
- Provide the ability to upgrade low pressure (waste) steam to medium pressure steam thereby reducing the amount of high pressure steam required



- Mechanical vapor compression can also be an alternate option for thermocompressor applications

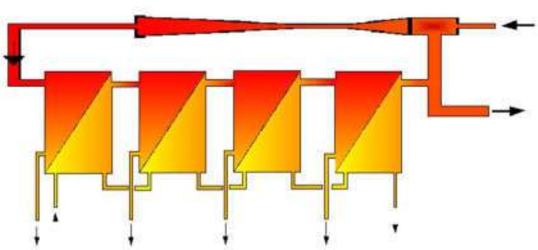


Evaporators & Use of Thermocompressors



4-Effect Thermocompressor

- Contamination in condensate?
- Temperature difference / Pressure ratio
- Very application and site specific

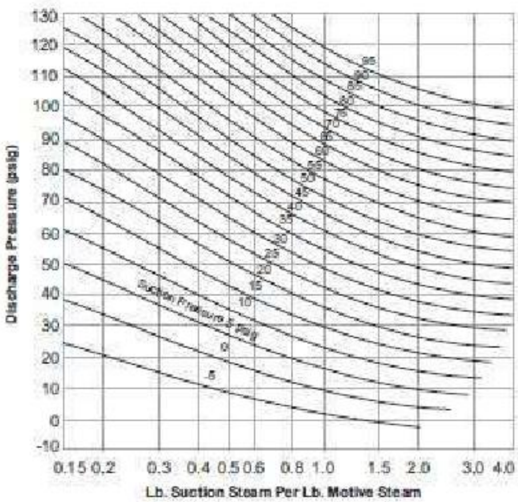


Thermocompressor Analysis

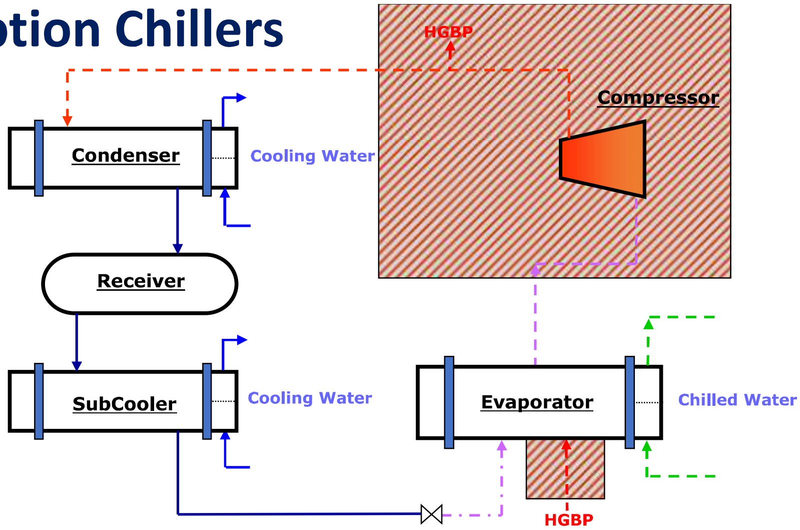
- Thermocompressor analysis requires a thorough understanding of process demands
- Identify the source of waste (or low pressure) steam that is currently vented
- Identify a process that requires steam and is currently using high or medium pressure steam
- Identify motive steam (typically, highest pressure steam) available in the plant
- Work with a manufacturer to select a thermocompressor
  - Pressure ratios
  - Steam flows

Thermocompressor Analysis

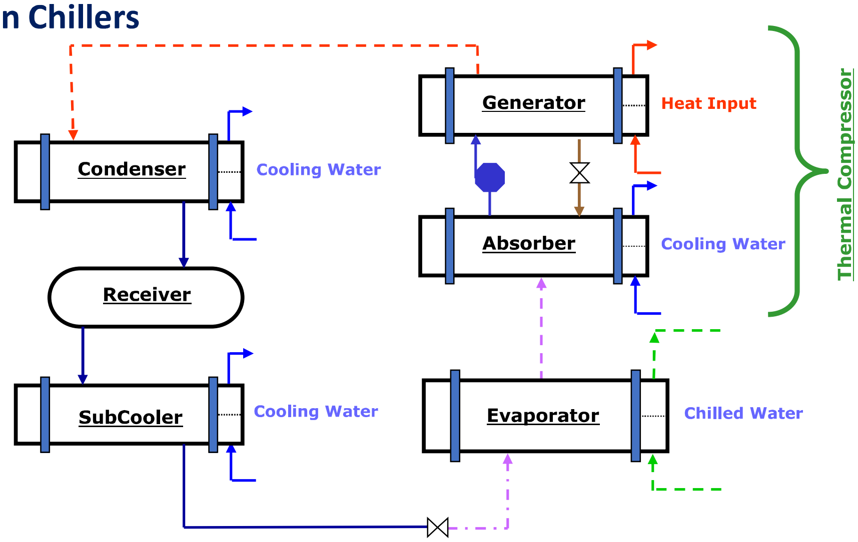
- Mass balance
- Energy balance
- Bernoulli's equation
- Motive steam
  - Eg. 20 barg
- Suction pressure
- Ratio
- Discharge pressure



Absorption Chillers



Absorption Chillers



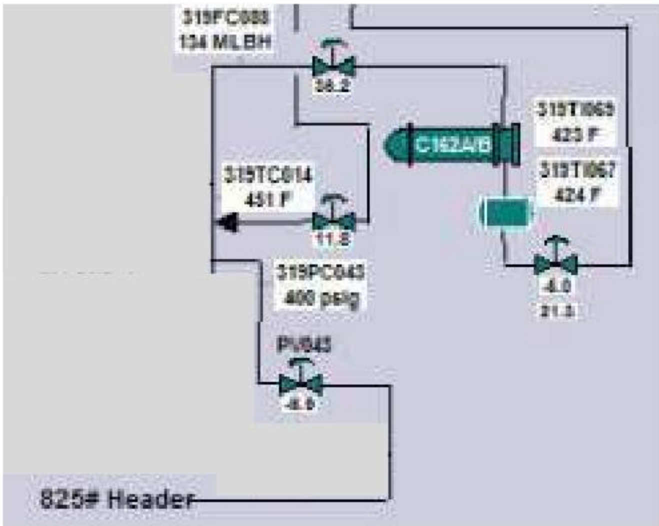
Case Studies

Case Studies

- Petroleum Refinery – Upgrading Low Pressure Steam
- Chrysler Corporation – Steam System Optimization
- Del Monte Foods 1 - Economizers
- Del Monte Foods 2 – Backpressure Turbines
- Food Plant – Heat Pump Application

Case Study: Thermocompressor

- Petroleum refinery
- Steam demand
  - ❑ Pressure ~27 barg
  - ❑ Temperature ~220°C
  - ❑ Flow rate ~60 Tph
- Current Operation
  - ❑ Use Pressure Reducing Valve
  - ❑ HP steam header ~ 57 barg; 450°C superheated
  - ❑ Desuperheating with boiler feedwater

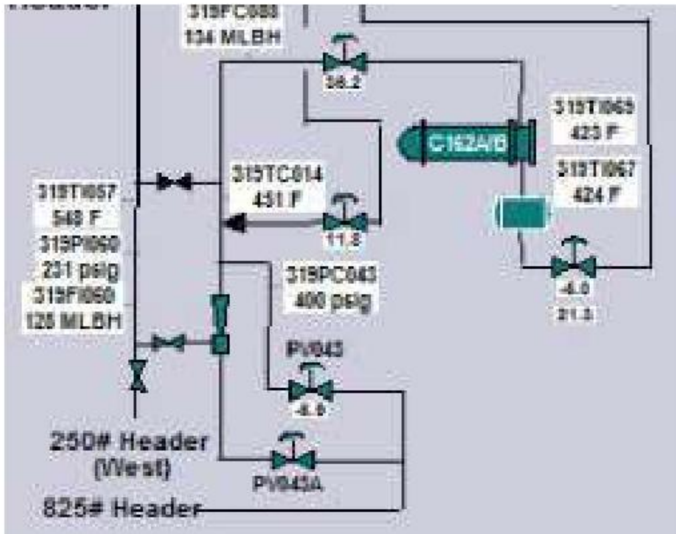


Case Study: Thermocompressor

- Energy assessment revealed that the process has exothermic reactions and generates 17 barg saturated steam

- New Operation
  - ❑ Use an industrial heat pump – TVR - thermocompressor
  - ❑ Motive steam - HP steam header ~ 57 barg; 450°C superheated
  - ❑ Suction steam – 17 barg
  - ❑ Discharge steam – 27 barg; 220°C
  - ❑ Desuperheating, if needed, with feedwater

Case Study: Thermocompressor



- TVR Operation
  - Motive steam - HP steam header ~ 57 barg; 450°C superheated
  - Suction steam – 17 barg
  - Discharge steam – 27 barg; 220°C

Case Study: Thermocompressor

- Implemented TVR as recommended
- Benefits
  - Reduction in HP steam generation
    - Fuel: Natural gas ($8/GJ)
    - Energy savings ~ 6.4 GJ/hr
  - **Annual Cost savings ~$450,000**
  - Installed cost ~$150,000
    - Explosion proof refinery environment
  - No moving parts – no maintenance costs for life
  - Reduced feedwater usage
    - Estimated savings ~$20,000

Case Study – Chrysler Corporation

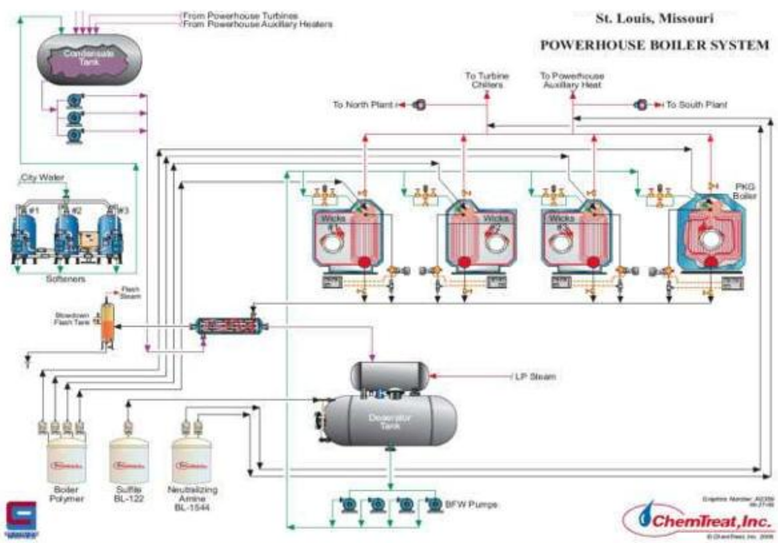
- Plant: St. Louis Assembly Plant, St. Louis, MO, USA
- Steam System Assessment & Optimization
- Boiler Plant Specifications
  - 4 Boilers
    - Total capacity: 185 Tons/hr
    - Fuel: Natural gas & Land fill gas (originally – coal)
    - Pressure: 10 bars
    - Saturated steam production
  - 3 Condensing Turbines driving centrifugal chillers (4,300 RT each)

Summary of BestPractices

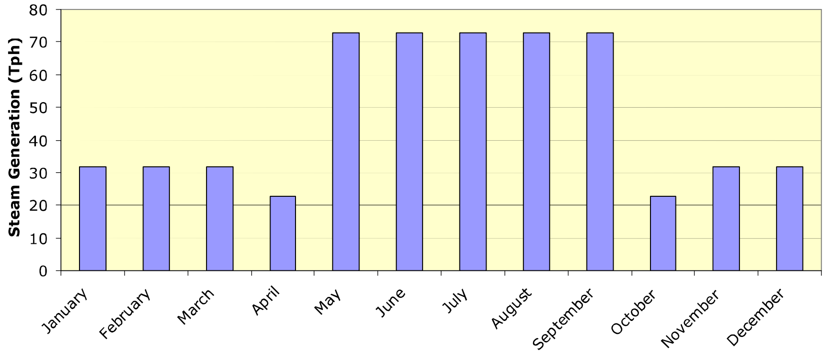
- Overall Plant Operating Practices
  - Significant amount of instrumentation across the plant for detailed mass, energy balances and analysis
  - Easy availability of historical data and equipment design information
- Generation
  - All boilers have automatic oxygen trim controllers
  - All boilers have feedwater heat recovery economizers
- Distribution
  - "No visible" steam leaks – tight plant
  - Good overall insulation
- End Use
  - Excellent PM BestPractices on chiller plant
  - Load management between North and South plants in winter
- Recovery
  - Above average (>90%) condensate return during summer

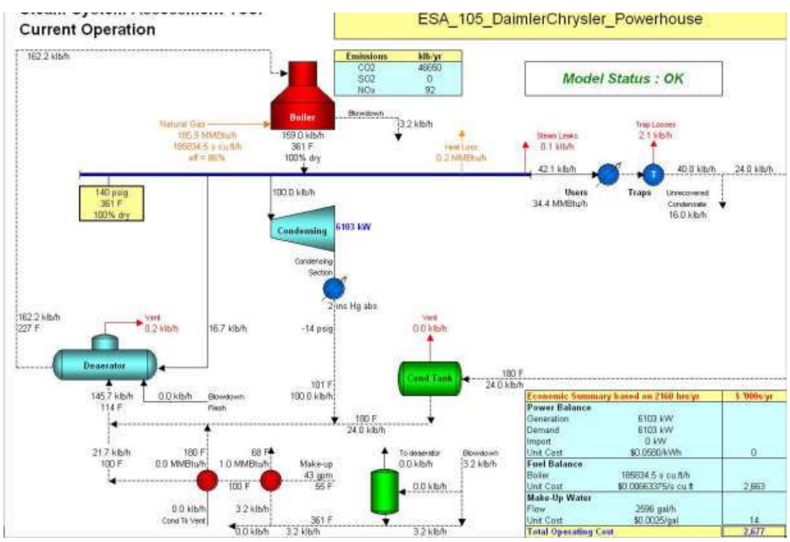
Approach for the Steam SEN Assessment

- Core Plant Team
- Understanding of Powerhouse steam and chiller load balance, process use
- Four steam boilers @ 10 bars
  - ❑ Boiler #1, 2 and 3 rated at 50 Tph (max – 42 Tph)
  - ❑ Boiler #4 rated at 40 Tph (max – 35 Tph w/NG only)
- Three steam-condensing turbine-driven chillers – 4,300 RT
- Twelve electric-drive chillers ~25,000 RT total
- Model overall plant in Steam System Assessment Tool
  - ❑ Use one-pressure header model – generation & condensing turbine
  - ❑ Load profile – summer, shoulder, winter



Average Steam Load Profile





Steam System Assessment Findings (1st Level Due-Diligence)

ENERGY SAVINGS OPPORTUNITY SUMMARY INFORMATION					
Identified Opportunity	Savings/yr				
	$	kWh	GJ	Fuel Type	N, M
Optimize boiler operation and load management strategy	160,819	0	22,000	Natural gas	N
Raise boiler operating pressure in summer	39,474	0	5,400	Natural gas	N
Reduce flue gas oxygen in Boiler #1	68,421	0	9,360	Natural gas	N
Enhance feedwater economizer in Boiler #1	84,211	0	11,520	Natural gas	M
Reduce boiler blowdown	5,848	0	800	Natural gas	N
Implement blowdown heat recovery	21,053	0	2,880	Natural gas	N
Implement a steam trap management program	43,860	0	6,000	Natural gas	N
Replace condensing steam turbine w/electric motor	740,842	-6,000,000	135,000	Natural gas	M

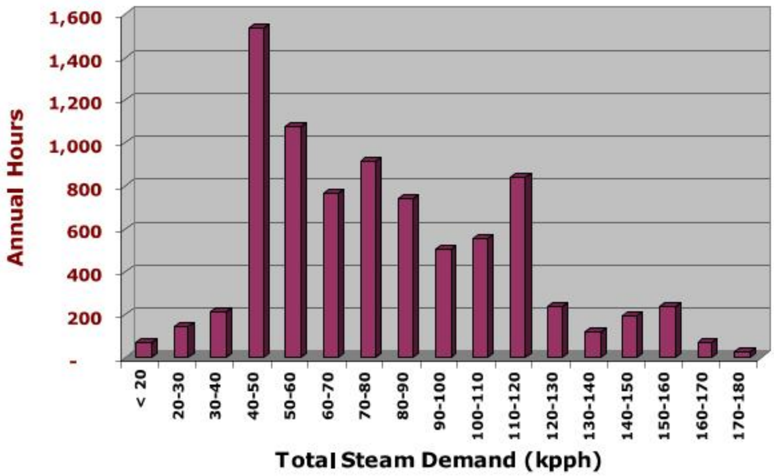
Assessment Implementations

ENERGY SAVINGS SUMMARY INFORMATION					
Implemented Opportunities	Savings/yr				
	$	kWh	GJ	Fuel Type	
Optimized boiler operation and load management strategy	**430,000**	**0**	**48,000**	**Natural gas**	
[redacted]					
Reduced flue gas oxygen in Boiler #1	**84,000**	**0**	**9,400**	**Natural gas**	
[redacted]					
Reduced boiler blowdown	**24,000**	**0**	**3,000**	**Natural gas**	
[redacted]					
Implemented a steam trap management program	**89,000**	**0**	**10,000**	**Natural gas**	
[redacted]					

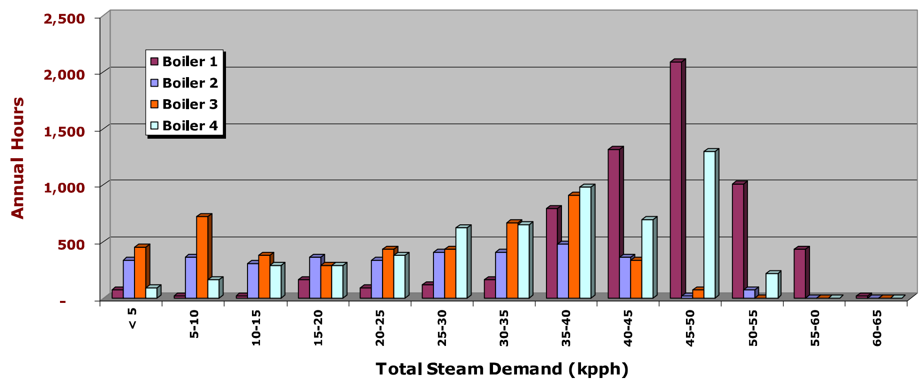
Boiler Plant Optimization

- Develop an optimized boiler operation and load management strategy
  - Minimize number of boilers that operate
    - Without sacrificing reliability
  - Part-load vs. full load efficiency
  - Tasks
    - Data analysis – 2.5 years
    - Development of load scenarios and how to manage the loads
    - Risk assessment
    - Management and business case study
    - Transition Oversight
    - Training for operators
    - Monitoring and Verification protocol

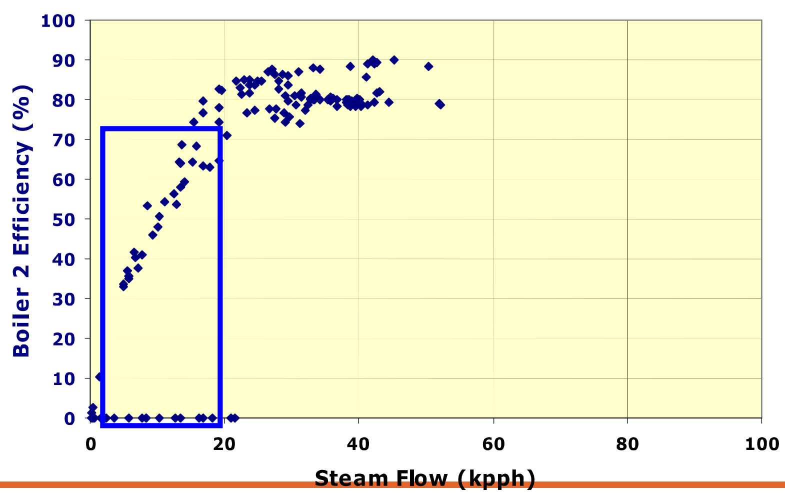
Load Profile

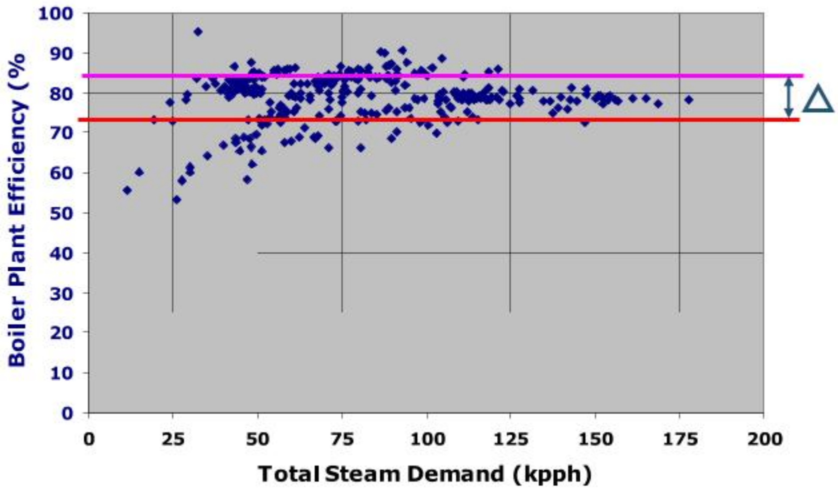


Load Profile



Energy Savings Potential





Development of Optimization Strategy

- Need to understand individual boiler operation
  - Boiler efficiency
  - Maximum and minimum firing capabilities
- Need to understand steady and dynamic responses
  - Steam demand variation from daily averages
  - Boiler response times
    - Warm standby
    - Cold startup, etc.
- Ease of operation
- Reliability of operation
- Production plant risk assessment

Field Testing

- Boiler #1, 2, 3 and 4
  - Warm start-up tests
  - Cold start-up tests
  - Minimum-fire tests
  - Maximum-fire tests
- Steam header test
- Temperature – Time relationship for warm boiler standby
- Dynamic response
- Risk analysis
  - Steam usage – Process & Non-process
  - North & South plants

Field Testing

- Work with boiler operator who has the least experience – would provide highest comfort level for tests
- Operator to work in a manner such that it is a non-emergency situation – will provide longest start times
- A plant holiday and a slower production day were chosen as field testing dates

Optimization Strategy

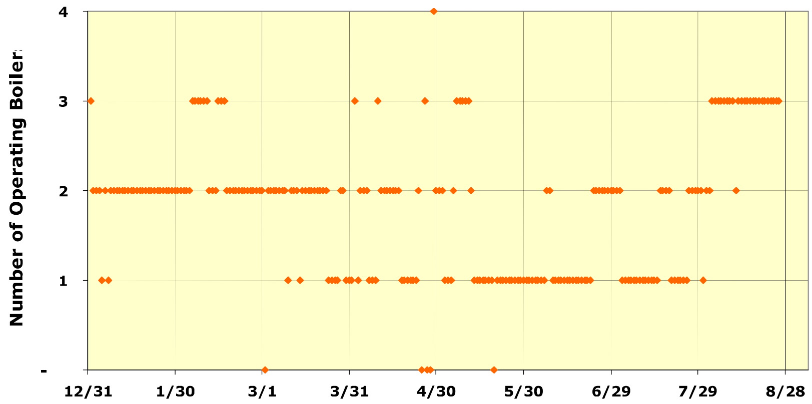
- Load management
  - Use all the landfill gas that is available
  - Use the most efficient boilers
    - Mainly applies to low load conditions <35 Tph
  - Ensure that operational reliability exists in all scenarios
  - Level of redundancy (n+1)
- Maintain a warm standby boiler at all times
  - Eliminates boiler operation at low loads
  - Similar to a "spinning reserve"
  - Maintain at least 125°C in flue gas chamber
  - Operate standby boiler for a short period (15-20 minutes) to regain temperatures in boiler

Optimization Strategy

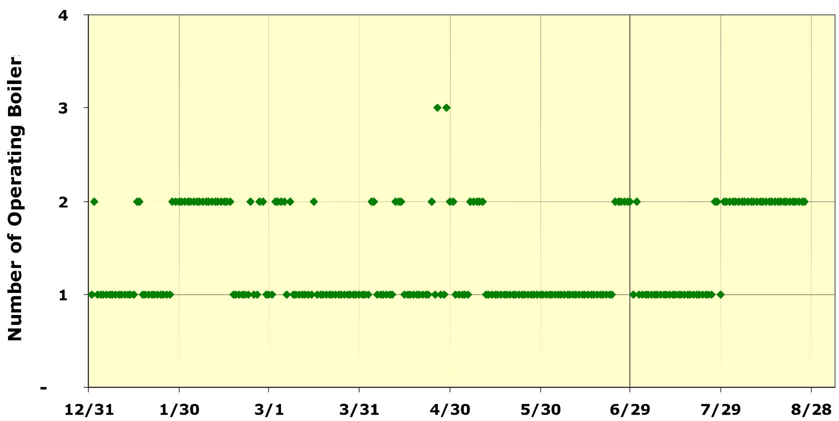
Steam Load (Tph)	Boiler #1	Boiler #2	Boiler #3*	Boiler #4
0 - 25	STB	OFF	OFF	ON
25 - 35	ON	OFF	OFF	STB
35 - 60	ON	STB	OFF	ON (NG)**
60 - 75	ON	ON	STB	OFF
75 -	ON	ON	ON	STB

* Boiler #2 and #3 can be substituted for one another
** Indicates operation with natural gas only

Current Number of Boilers in Operation



Optimized Number of Boilers for Operation



Note: One additional boiler will be on Warm Standby

Risk Assessment

	Steam End-Use	Season			
		Winter	Spring	Summer	Fall
North Plant	Body Wash (BIW/Paint)	♦	♦	♦	♦
	Phosphate Tank	♦	♦	♦	♦
	Powder Booth (Reheat)	♦	♦	♦	♦
	Main Color #1 & #2 (Reheat)	♦	♦	♦	♦
	Maintenance Steam	♦			
South Plant	Body Wash (BIW/Paint)	♦	♦	♦	♦
	Phosphate Tank	♦	♦	♦	♦
	ASH Dehumidification*			♦	
	Facility Cooling (HVAC)*			♦	
	Powder Booth (Reheat)	♦	♦	♦	♦
	Main Color #1 & #2 (Reheat)	♦	♦	♦	♦
	Maintenance Steam	♦			
	Facility Heating	♦			

* Chilled water supplied from steam-turbine driven chillers

Risk Assessment

- Main risks
  - ❑ Loss of production and downtime of equipment
  - ❑ Loss or damage of product (quality impact)
- Main event - ***Loss of steam for 15-20 minutes***
- North and South Plant Risk Assessment Matrix
  - ❑ Seasonality issues
  - ❑ Steam load
  - ❑ Risk Level and impact
    - None; Small; Moderate; High
  - ❑ Risk Mitigation (or elimination)
  - ❑ Additional comments

Risk Assessment Matrix

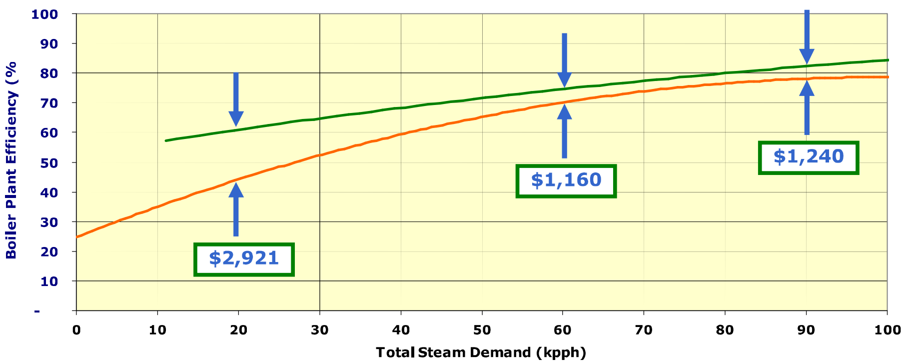
DaimlerChrysler St. Louis Assembly Plant

PowerHouse Boilers Risk Analysis & Mitigation Matrix

North Plant - Spring, Summer & Fall

End-Use System	System Type	Steam Load (kpph)	Impacts		Risk Mitigation		Comments
			$/event	Risk			
Body Wash (BIW/PAINT)	Process	2.5	0	None			Large tank provides for good thermal storage
Phosphate Tank	Process	2.5	0	None			Tank #5 - 67,500 gal; Temperature - 110-130F Tank #2 - 32,000 gal; Temperature - 100-130F Tank #1 - 5,000 gal
Powder Booth (Reheat)	Process	5	10,500	Small	1 2 3	90% Air Recirculation FIS automatic alarm Banking availability	There are 7 units which may be at risk. "Loss of steam" test scheduled for 12/16 Investigate impact on powder inventory
Main Color #1 (Reheat) - Base Coat (B/C)	Process ASH units	5	15,000	Small to Moderate	1 2	FIS automatic alarm Banking availability	There are 10 units which may be at risk. Some of the coils are direct steam and some have hot water. Hot water allows for some buffer.
Main Color #2 (Reheat) - Base Coat (B/C)	Process ASH units	5	15,000	Small to Moderate	1 2 3	FIS automatic alarm Banking availability	There are 10 units which may be at risk. All the coils are hot water loops. Hot water allows for some buffer.
Main Color #2 (Reheat) - Clear Coat (C/C)	Process ASH units	2.5	0	None	1 2	FIS automatic alarm Banking availability	All the coils are hot water loops. Hot water allows for some buffer. Booth equipped with reheat coils but they are not used.
		22.5	**40,500**				

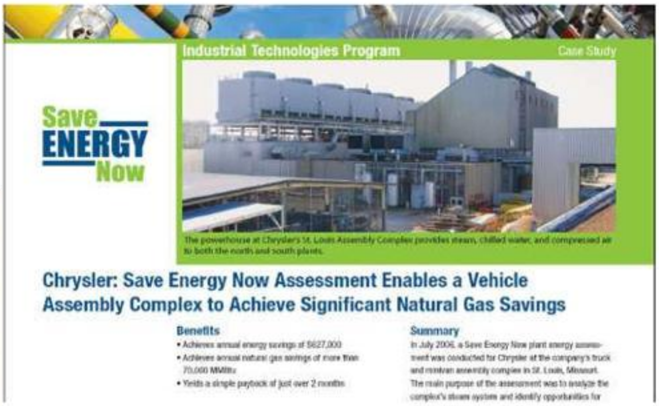
Comparison of Boiler Efficiency



Note 1: $9.7 per GJ – Natural gas

Note 2: Dollar savings based on per day (24 hr operation)

Case Study – Success Story



Industrial Technologies Program

Case Study

Save ENERGY Now

The powerhouse at Chrysler's St. Louis Assembly Complex provides steam, chilled water, and compressed air to both the north and south plants.

Chrysler: Save Energy Now Assessment Enables a Vehicle Assembly Complex to Achieve Significant Natural Gas Savings

Benefits

- Achieves annual energy savings of $627,000
- Achieves annual natural gas savings of more than 70,000 MMBtu
- Yields a simple payback of just over 2 months

Summary

In July 2006, a Save Energy Now plant energy assessment was conducted for Chrysler at the company's truck and minivan assembly complex in St. Louis, Missouri. The main purpose of the assessment was to analyze the complex's steam system and identify opportunities for

Case Study - Conclusions

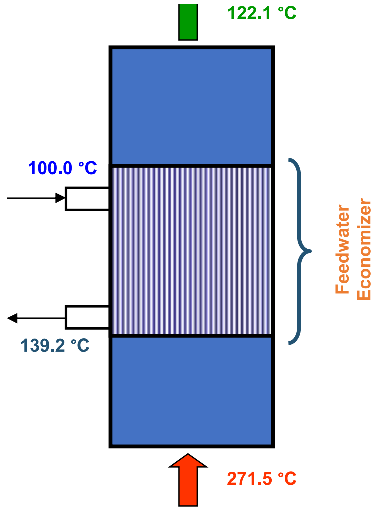
- The steam assessment provided Chrysler with a targeted list of energy savings opportunities
- Chrysler's approach with an Energy Champion paid off from implementing the projects with the highest efficiency
- For the implemented projects, Chrysler had a payback of just over 2 months!
- Almost all boiler plants have multiple boilers and an optimal operating strategy must be implemented as BestPractices
- Operator buy-in and training is extremely important
- A thorough risk assessment paved the way for implementation and buy-in from plant management and production leads

Case Study – Del Monte Foods 1

- Plant: Del Monte Foods, Modesto, California, USA
- Installation of Feedwater Economizer and Condensing Economizer on boilers
- Boiler Specifications
  - Boiler 1:
    - Capacity: 70 Tons/hr
    - Pressure: 10 bars
    - Saturated steam production

Stack Heat Recovery

- Typical operating data from Boiler 1
  - Flue gas side
    - Stack temperature: 271.5 °C
  - Feedwater side
    - DA water outlet temperature: 100.0 °C
- Hence, there exists a potential opportunity to do heat recovery
- Heat recovered = $M*Cp*\Delta T$ = **2,000 kW**



Feedwater Economizer

- Feedwater Economizer Economics
  - Fuel savings = $250,000
  - Project cost ~ $250,000
  - Simple Payback ~ 1 year
- There were other retrofit projects bundled with this project to keep total project cost down
  - SCR implementation
  - FGR controls

Condensing Economizer

- Flue gas exit from the feedwater economizer on Boiler 1 was 122.1°C
- The plant has NO condensate return and so is 100% make-up water
  - Process requires live steam injection into cookers and water heaters
- Make-up water temperature is 20°C and there exists a significant opportunity to do condensing heat recovery
- Make-up water is heated up to at least 60°C
- Heat recovered = M*Cp*ΔT = **2,000 kW**

Condensing Economizers

Case Study – Del Monte Foods 2

- Plant: Del Monte Foods, Modesto, California, USA
- Installation of a HP-LP Backpressure steam turbine to directly drive a screw chiller compressor and offset electrical power for the air-cooled chiller units
- Objectives
  - Perform an energy system assessment of can cookers to identify opportunities for system optimization
  - Use a backpressure steam turbine driven chiller for process cooling and exhaust steam for process heating at a canning plant

Energy System Supply Side

1 twin-screw packaged air-cooled (for retort cooling)
Manufacturer: Carrier Corporation
Model Number: 30GX-161-630EB
Refrigerant: R134a
Capacity: 152 RT

1 reciprocating air-cooled chiller (for retort cooling)
Manufacturer: York International
Model Number: Millennium YCAJ110-46PA
Refrigerant: R22
Capacity: 110 RT

Energy System Supply Side

2 natural gas-fired boilers (produces steam for process heating)

Manufacturer: Babcock & Wilcox

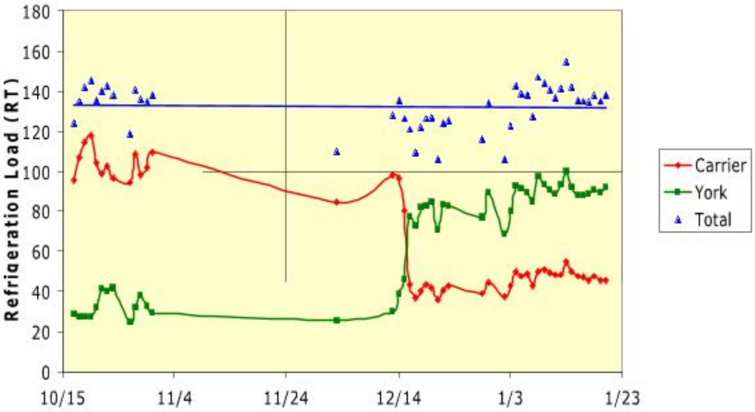
Model Number: FM1737 and FM2688

Capacity: 70 Tph each

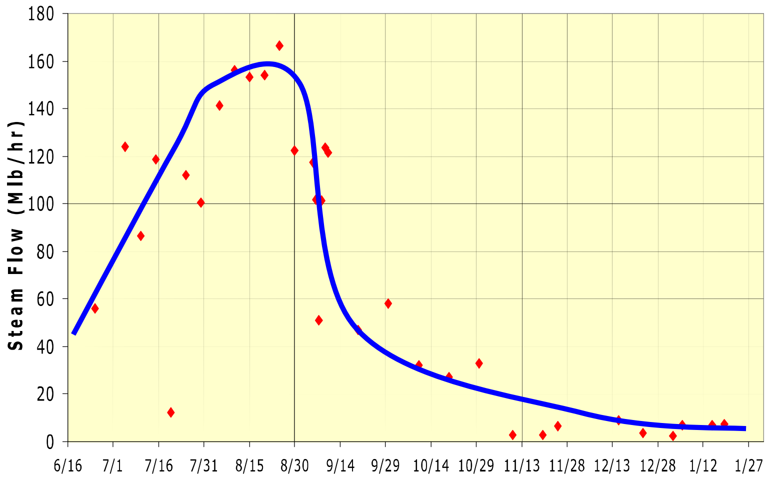
Operating pressure: 10 bars

Cooling Tower Bank

Cooling Load Supply

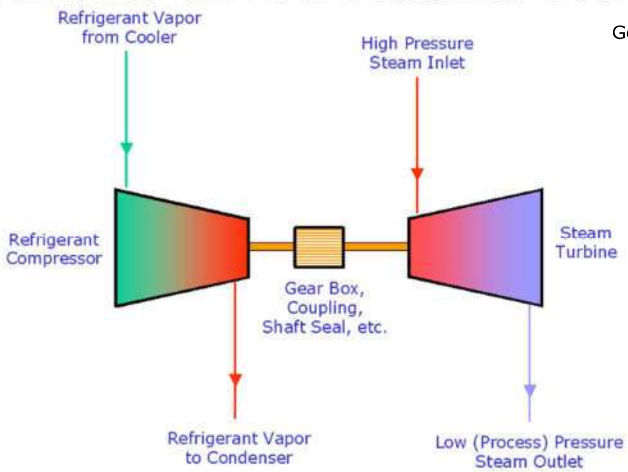


Steam Load Profile



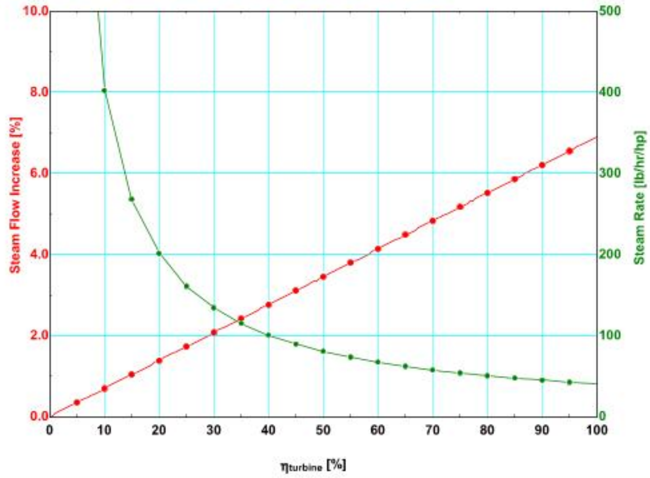
Steam Turbine-driven Topping Cycle

Generation = 10 bars



Process use = 3 bars

Steam Turbine Characteristics

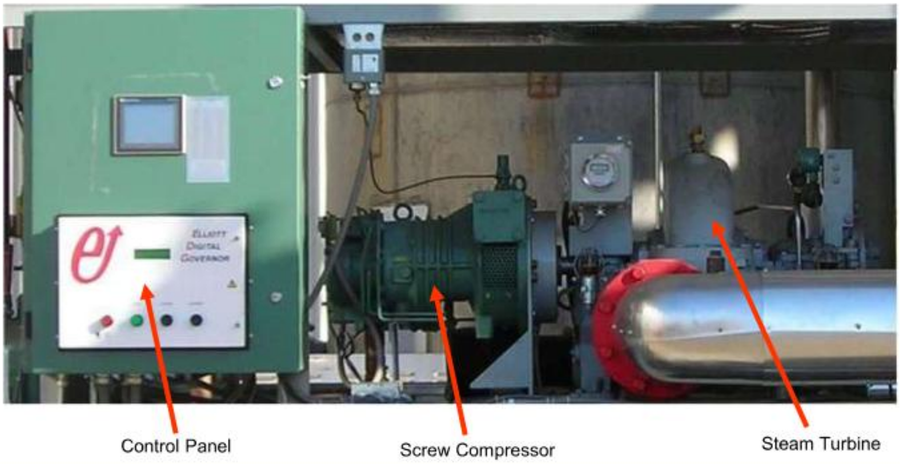


Equipment Specifications

- A steam turbine (Elliott 2BYRT: 65 kW; 4000 rpm; 5 Tph) is directly coupled to a screw chiller (Bitzer 86 ton refrigeration capacity)

- Plant boiler (10 bars) provides steam to turbine with the low pressure exhaust (3 bars) providing steam to operations and retorts

Equipment Installed



Project Cost-Benefits Summary

- Cost Summary
  - Steam turbine and controls: $30,000
  - Bitzer Chiller and Controls: $56,000

- Savings Summary
  - Steam turbine-driven chiller vs electric unit: 104 kW and 540,000 kWh (in-season)
  - Natural gas net increase of 2,100 GJ due to an increase in steam generation to offset the steam enthalpy change across the steam turbine
  - Net annual savings: $45,000

Case Study - 100 RT Heat Pump/Chiller in Livingston, California, USA

- The unit supplies 350 kW (100 RT) of chilling and 950 kW water heating
- Driving force - Steam - 1 Tph at 2 barg

Case Study - 100 RT Heat Pump/Chiller

- The hot water and chilled water are required 20 hours per day, five days per week at a processing plant
- 5ºC chilled water and 60ºC hot water
- Saves 30% of water heating energy and 80% of chilling energy
- Operating cost savings **~$120K per year**
- Installation cost **~$200K**

Undertaking a Steam System Energy Assessment

- Pre-Assessment Activities & Analysis
- Onsite Energy Assessment
- Post-Assessment Analysis
- Industrial Steam System Energy Assessment Report
- Follow-up

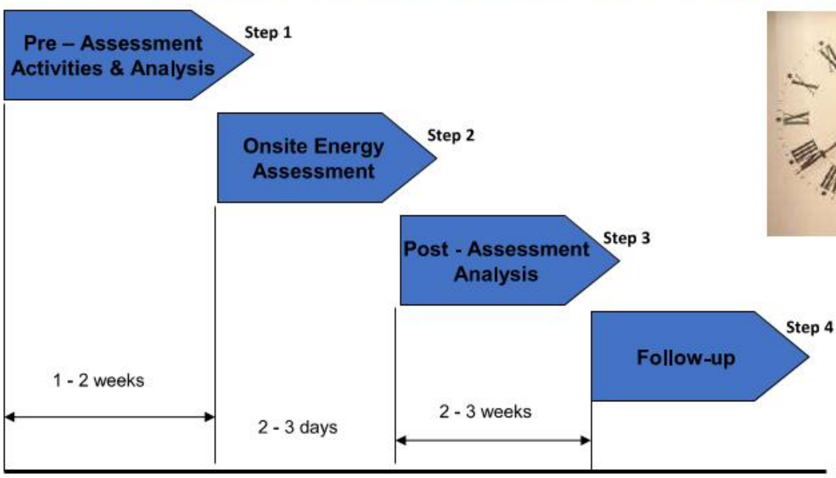
Candidate Plant SSO Assessments

- Uses a systems approach
- Will require strong engagement with plant personnel and understanding of steam process demands
- Operational Data Collection will be a MUST – portable instruments, in-situ instruments with plant historian and/or local readouts and dashboards should be used effectively
- Detailed simulation and modeling of Energy Conservation Measures will be REQUIRED
- No Thumb-rules will be allowed
- Experience from other plants as it relates to BestPractices surely encouraged but each facility analysis should be done
- System scope should be well-defined apriori
- A closing meeting after the ONSITE work is highly encouraged to summarize the activities to management
- A final report to be provided to the plant – a presentation to the management is encouraged
- Time management is key – Complete SSO assessment within 3-4 weeks!

Goals of SSO Assessments

- Extremely important to ensure that all stakeholders are on the same page
- Expectations need to be aligned and agreed upon before kick-off meeting is over
- There could be multiple goals, and different approaches may be required
- The goals of SSO Assessments are:
  - Identify energy efficiency and cost savings opportunities (optimization)
  - Identify projects for implementation and maintenance BestPractices
  - Categorize identified opportunities as near, mid and long-term based on potential capital expense and complexity
  - Predict and avoid costly unplanned emergency events (improve system reliability)

Agree on Timeline & Schedule w/Plant Team



Step 1 - SSO Assessment

Pre – Assessment Activities & Analysis

- Understanding customer requirement
- Develop scope of SSO assessment
- Introduction and connect with Plant Lead and other personnel
- Start planning an assessment strategy
- Complete all confidentiality agreements
- Understand PPE and other safety/contractor training requirements
- Complete information requests (Utility bills, Plant layout, System diagrams, Equipment list etc.)
- Webinars / Conference calls / Emails

Ground Zero System Understanding

- Don't get into the weeds yet!
- Understanding system is most important at this stage
- At a minimum, the SSO system expert should have
  - Identified major pieces of equipment – boilers, distribution headers, end users, steam turbines, etc.
  - Design information of all boilers, large end-users, etc.
  - List of significant process heat end-uses
  - Line drawing / schematic of steam system
  - High level understanding of controls and operation of steam plant
- Complete the SSST
  - Email to plant lead and/or interview via conference call
- Finalize scope of steam system

Steam System P&IDs

- Piping & Instrumentation Diagrams are the most valuable documents while undertaking any system energy assessment
- CAUTION 1: Stay focused and don't get caught in every detail of P&IDs
- CAUTION 2: Ensure that P&IDs are current and very closely represent what is current on the CR system rather than an older version
- Nomenclature and Convention can vary from one P&ID to another depending on the engineering company that developed that specific P&ID
- If hard-copies can be made or obtained best to use multi-colored high-lighters to indicate different lines – steam, condensate, etc.
- Spending a good amount of time on them will save a lot of time in the field and in the site visit

Steam System Instrumentation Gap Analysis

- Using operations information, line diagrams and P&IDs identify
  - Instruments already existing in-situ
  - Define if they are local and/or transmitted values
  - Define the gaps in the instrumentation
- Depending on plant's proximity and availability of plant personnel, setup a webinar / conference call to finalize a data acquisition plan
- Define data to be collected during the site visit via
  - Portable instruments
  - In-situ local readouts / dashboards
- Define data to be captured from the plant's historian (time period and sampling interval)

Steam System Energy Assessment

Onsite Energy Assessment

- Introduction (Discussion with plant team)
- Discussion on process & operations
- Plant walk-through
- Brainstorming w/plant personnel
- Data collection (Snapshots, Measurements, Infrared Pictures etc.)
- Wrap-up meeting

Install Steam System Portable Instrumentation

- Depending on plant's proximity and availability of plant personnel, this activity can be done much earlier than the actual steam system energy assessment site visit
- Ensure all the required instrumentation is setup ahead of time
- Data loggers (if any) should be all setup for the proper sensors along with their sampling intervals (which should be the same for all data loggers) and their delayed synchronized time-start
- Ensure battery levels are sufficient for the time period that the data loggers will be required to log data
- Clear all previous data from the data loggers to avoid any confusion
- Follow instructions for proper installation of sensors and data loggers in the field – preview Youtube videos for reference

Get back to the Meeting Room

- Start with the Core plant team in the meeting room
- Review your understanding of the steam system, its operations and its main end-users
- Review the SSST with the plant team, if needed
- Get all system-level questions answered and get ready to go back into the plant and do a thorough walk-through, system data capture, etc.
- Use proper PPE and other safety equipment, as needed by the site

Plant Walk-through, Data Collection

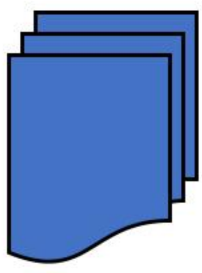
- Start at the Generation Area
- Collect manual data, pictures of nameplates of different pieces of equipment of interest in the steam system energy assessment
- Use the line diagram to match up the different pieces of equipment and ask questions to make sure that you understand the steam system
- Use hand-held portable measuring devices – infra-red camera, combustion gas analyzer, clamp-meter, thermometer, etc. to measure data that maybe of interest in the steam system assessment

Completing all the Site Visit Requirements

- First and foremost – collect all the installed portable measurement equipment and the associated data loggers, power supplies, cables, etc.
- If there is time, download all the collected data from the data loggers on the laptop using the appropriate software
- Collect historical data from the plant's historian – it is generally difficult to get this data after you have left the plant site
- Request a debriefing and reporting meeting with the plant core team and invite senior management, if its okay with the plant personnel
- Review onsite activity and provide a high-level perspective of the plant's operations, BestPractices and some highlights

Steam System Energy Assessment Report

- Engineering analysis (Utility bills & Data collected)
- Cost-Benefit Analysis
- Feasibility study & refine energy savings opportunities
- First order estimates of implementation cost and payback
- Report generation and submission

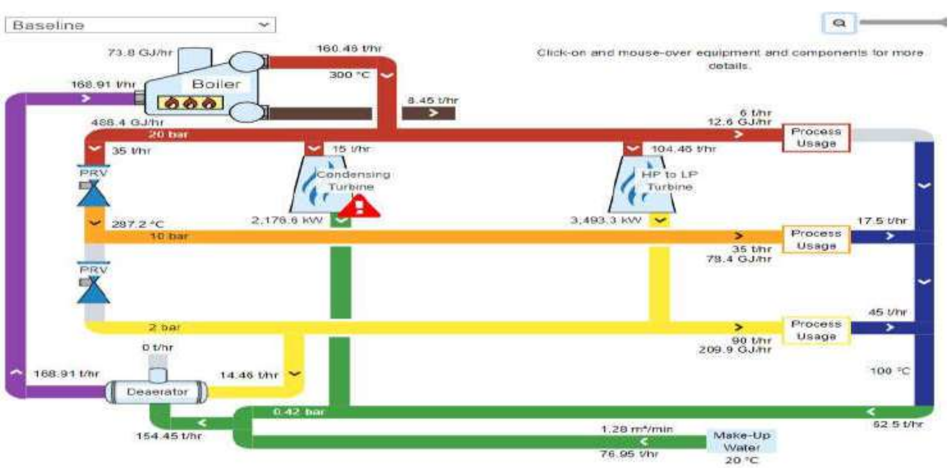


Now the Real WORK begins!

Post – Assessment Analysis

- Start working on this As Soon As Possible
- The information collected is fresh and will help to finish this task fast
  - Some out-of-the-box thinking will still be needed and that may take some time

Now the Real WORK begins!



Steam System Energy Assessment Report

- ➢ General Information about the plant
  - ❑ Industry type
  - ❑ Size
  - ❑ Location
  - ❑ Plant personnel
  - ❑ Energy Expert, etc.

General Assessment Information	
Company: ABC Company	Assessment Type: :Energy Assessment
Plant:	Assessment Dates:
Location:	
Plant Information	
NAICS:	Address:
Principal Products:	
Participant Contact Information	
Plant Contact 1	**Energy Expert Contact 1**
Name:	Name: Riyaz Papar, PE, CEM
Title:	Title: Director, Global Energy Services
Phone:	Phone: 281-298-0975
Email:	Email: rpapar@hudsontech.com
Plant Contact 2	**Energy Expert Contact 2**
Name:	Name: Subodh Chaudhari, CPEnMS, CEM
Title:	Title: Energy Engineer
Phone:	Phone: 918-938-2318
Email:	Email: schaudhari@hudsontech.com
Additional Plant Attendees There were additional plant personnel from Operations, Maintenance and Utilities who participated in the assessment through interviews, meetings and data collection activities	

Table of Contents

- ➢ The best way to put together a Table of Contents is to use Microsoft WORD or an equivalent word processor to do it automatically for the report

Create the table of contents in Word

1. Put your cursor where you want to add the table of contents.
2. Go to **References** > **Table of Contents**. and choose an automatic style.
3. If you make changes to your document that affect the table of contents, update the table of contents by right-clicking the table of contents and choosing **Update Field**.

See More...

Create the table of contents in Word
support.office.com/en-us/article/insert-a-table-of-contents-882e8564-0edb-435...

- ➢ Make sure that in the Template provided, the Table of Contents is updated periodically so that you can ensure that everything is working correctly

Executive Summary

- Probably the most read part of the report
- Provide basic plant information
- Provide high-level assessment information
- Acknowledge BestPractices & SSST score
- Provide Summary Table of Findings

Executive Summary

Summary of Energy Saving Opportunities

Assessment Opportunities		Estimated Annual Savings					Simple Payback (years)
ESO#	Recommended Opportunities	kWh[1]	kW[2]	GJ[3]	CO_2 (Metric Tons)	Cost Savings ($)	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

[1] - Electricity Savings [2] - Electrical Demand Savings [3] - Natural Gas or Other Fuel Savings

Chapter 1 – (1-2 pages)

- General Notes about the Steam System Operations
- Utility costs – Most important
  - Unit Electric and Water Costs
  - Overall annual energy consumption and costs
- Plant's Criteria & Objectives
- SSST score and some observed Best Practices
- Potential issues that were identified during the steam plant assessment

Steam System Energy Assessment Report

- Observed Best Practices in the plant should be highlighted
- These should be encouraged by the Energy Expert
- These are Winners that the plant needs to be congratulated for

Observed Best Practices
1: Overall site level integration Steam is generated at several different areas in the refinery but there is a central distribution system and site-wide steam header network and integration.
2: Significant instrumentation for energy balance analysis There is a significant amount of instrumentation that monitors critical operating parameters and a PI historian system that helps plant personnel to do a mass and energy balance analysis.
3: High level of system-based and equipment-based energy efficiency metrics and KPIs With the significant amount of real-time data collection, the plant has a program to determine system-based and equipment-based efficiency metrics and KPIs. Some examples include: amount of fuel used per lb of steam produced, energy intensity index, etc.
4: Record and log of water treatment, blowdown, etc. Plant personnel manually log information from water testing that is done on a regular basis.
5: Stack heat recovery on boilers Most of the boilers (CO, Aux and Package) have feedwater economizers that capture stack loss from the boilers and improve boiler efficiency.
6: Blowdown flash heat recovery Most boilers and waste heat steam generators have blowdown flash steam recovery.
7: Oxygen trim controllers on all boilers Oxygen trim controllers allow to keep very tight excess air levels and minimize stack losses.

Chapter 2: Steam System Operations (2 pages)

- Line diagram of the steam plant (or Baseline Model)
- List of boilers, steam turbines (provide high-level information - design capacity, manufacturer, age)
- Provide the M&V Baseline for the steam system
- Provide information on the type of data collected
  - What was collected during onsite visit by local readouts
  - What was collected with data loggers and plant's historian
  - NOTE: This is just descriptive information. Don't include data historian or time graphs here. If required, then can be placed in the Appendix
- Provide tabulated information
- Indicate how the steam plant is operated at different load conditions, seasonality, etc.

Chapter 3 – Steam System Data (3 pages)

- Create a sub-section for each boiler, steam turbine, major end-user to briefly describe the operation of that specific unit
- Include the results from any statistical data analysis to indicate overall operational parameters and critical efficiency information
- Indicate any issues or specific problems observed during the onsite visit
- A graph can also be provided if a visual description is to be provided

Chapter 4 – Energy Conservation Measures (1 ECM per page)

- This is the meat of the report and where all the work by the Expert is highlighted
- It should be focused, detailed but at the same time not get into the weeds where the reader loses interest / focus
- It should provide all the numerical information – energy savings, cost savings and a simple payback estimate
  - GHG emissions reductions can be included
- It should indicate a brief methodology of how the savings were calculated
- It should provide information on how to proceed to next steps and implementation
- Any risks and downsides should also be indicated

Chapter 4 – ECMs (1 ECM per page)

- Each Energy Saving Opportunity should be described in detail:
  - Background
  - Exact Recommendation
  - Estimated Savings
  - Methodology for Calculations of Savings
  - Implementation Cost
  - Methodology for Calculations of Implementation Cost
  - Next steps towards implementation

ESO # 1 : Improve generation efficiency of boiler

ARC: 2.2412	Estimated Annual Savings			Estimated Project Cost		Simple Payback (years)
	Resource	CO_2 (metric ton)	Dollars	Low	High	
Natural Gas	ZZ GJ	CC	$$$$			
Total		CC	$$$$	$LLLL	$HHHH	1.0 - 2.0

Background

The boiler averages ~XX Tph of steam production over the whole winter season. It operates at a maximum of YY Tph and there are times during the winter when this rental boiler is at its maximum firing rate. It doesn't have a feedwater economizer. According to plant personnel, it has a positional oxygen (excess air) control system but no in-situ measurements exist on this boiler. Due to unavailability of port holes in the stack, readings could not be taken with the Energy Expert's portable combustion analyzer either. Based on past experience with rental boilers and plant personnel's observations, it is estimated that the rental boiler operates at ~76% boiler efficiency.

Recommendation

It is recommended to incorporate an automatic oxygen trim controller that maintains 2-3% flue gas oxygen and install a modular feedwater economizer in the flue gas stack.

Estimated Savings

Based on a new potential stack temperature of 275°F and 3% oxygen, stack loss can be reduced to 15% from the current operation at 22%. Using a SSAT model, the annual energy savings (with only winter operation) are expected to be ~ZZ GJ. This would be equivalent to natural gas savings of ~$$$$.

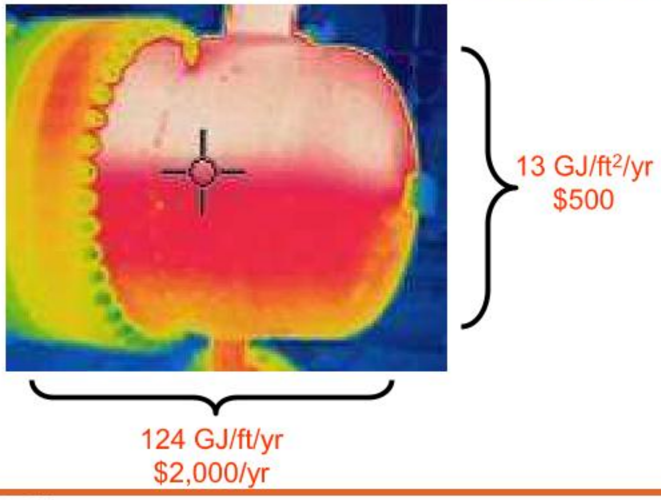
Implementation Cost and Simple Payback

Typical feedwater economizer projects result in less than a year simple paybacks. Adding automatic oxygen trim controllers can have much faster paybacks. Given that this boiler is only used during the "winter" operating season, it is anticipated that simple paybacks on this ESO will be 1-2 years.

Next Actions Towards Implementation

Plant personnel should work with their rental boiler company to come up with a possible quotation on adding a modular feedwater economizer in the flue gas stack of the boiler. Additionally, they should investigate the cost of adding an automatic oxygen trim controller on this boiler.

Chapter 4 – ECMs (1 ECM per page)



An Example of Savings Calculation Methodology

Chapter 5 - Qualitative Recommendations

- This section is reserved for providing list of recommendations that are
  - BestPractices
  - Out of scope of this assessment but clearly can provide significant benefits
  - Couldn't be completed due to time constraints
  - Couldn't be completed due to unavailability of certain data
- Every report should have this section even if it includes out-of-the-box thought processes that would make a difference to plant operations

Chapter 5 - Qualitative Recommendations

- Qualitative recommendations should capture
  - Opportunities that were NOT evaluated during the assessment and the plant is a good candidate for them
  - Areas which may NOT directly lend to quantification of energy savings by implementing them

Qualitative Recommendations	
1.	Continue with the steam trap management program
2.	Increase condensate return to the Conservation area
3.	Reduce the amount of steam to flares
4.	Reduce the amount of steam to equalization tank
5.	Combined Heat and Power (CHP) installation
6.	Steam system optimization
7.	Calibration of Instruments
8.	Portable instruments to be used by Lead
9.	Continue monitoring and trending equipment efficiency

Appendix (Optional)

- Steam system design information
- Specific data tables, graphs that relate to explaining an Energy Conservation Measure (ECM) that is mentioned in the report
- Additional supporting pictures
  - Boilers / nameplate
  - Installation and location of sensors on equipment (if needed)
  - Plant instrumentation & Data Acquisition
  - Screenshot of US DOE MEASUR, 3EPlus indicating specific references
- DO NOT include Excel tables of the logged data – instead provide a separate Excel file of the data

Follow-Up

Follow-up

- Submission of Energy Assessment Report
- Presentation of report findings via webinar or in-person

Other Tools & Resources

Tools

- In order to properly evaluate steam systems the physics of each process must be understood
  - Thermodynamics
  - Heat transfer
  - Fluid flow
- US DOE Tools Suite
  - Steam System Survey Guide
  - Steam System Scoping Tool (SSST)
  - MEASUR
  - Insulation evaluation software – 3E-Plus
- Several other commercially available software tools for steam systems
- Process measurements

Training Manual

Industrial Steam System Optimization (SSO) Experts Training

Developed by:

Riyaz Papar, P.E., CEM, Fellow – ASME, ASHRAE
C2A Sustainable Solutions, USA
UNIDO International Energy Expert (Steam)

Greg Harrell, Ph.D., P.E.
Milligan University, USA
UNIDO International Energy Expert (Steam)

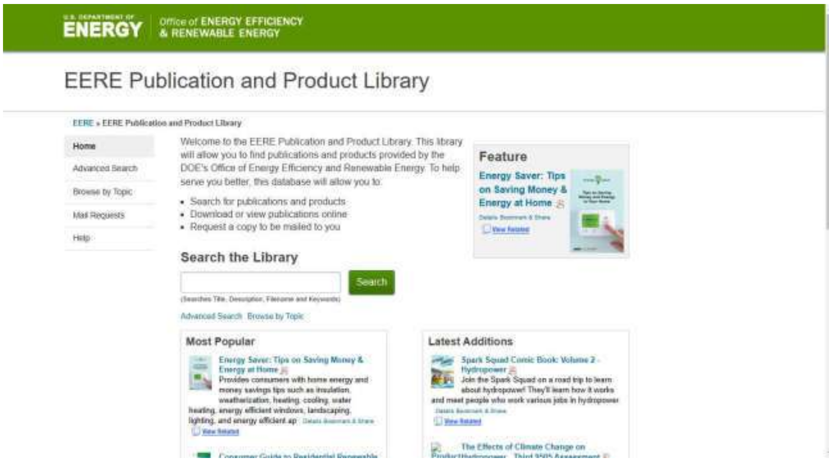
Developed for:
UNIDO Industrial Energy Efficiency Project
Vienna, Austria

January 2023

Industrial Steam System Optimization (SSO) Experts Training Manual

- Developed by UNIDO
- Text-book for the Experts SSO training

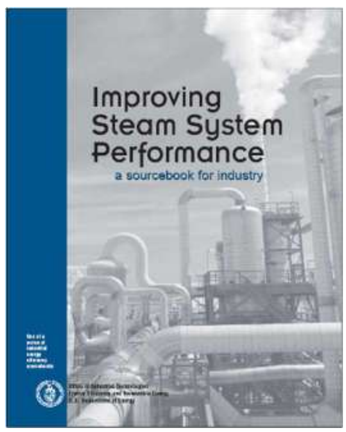
Where to go for Technical Resources



https://www1.eere.energy.gov/library

Steam System Sourcebook

- Includes Three Main Sections:
  - Steam System Basics
  - Performance Improvement Opportunities
  - Programs, Contacts, and Resources



Steam Energy Tips

- 1- Page Tips For Improving Steam System Areas
- Available On BestPractices Web Site and in Steam Sourcebook


Energy Tips

Replace Pressure-Reducing Valves with Backpressure Turbogenerators

US DOE Tip Sheets

- Benchmark the Fuel Cost of Steam Generation
- Clean Boiler Water-side Heat Transfer Surfaces
- Consider Installing a Condensing Economizer
- Consider Installing High-Pressure Boilers with Backpressure Turbine-Generators
- Consider Installing Turbulators on Two- and Three-Pass Firetube Boilers
- Consider Steam Turbine Drives for Rotating Equipment
- Considerations When Selecting a Condensing Economizer
- Cover Heated, Open Vessels
- Deaerators in Industrial Steam Systems
- Flash High-Pressure Condensate to Regenerate Low-Pressure Steam
- Inspect and Repair Steam Traps
- Install an Automatic Blowdown Control System
- Install Removable Insulation on Valves and Fittings
- Insulate Steam Distribution and Condensate Return Lines
- Improve Your Boiler's Combustion Efficiency
- Minimize Boiler Blowdown
- Benchmark the Fuel Cost of Steam Generation
- Return Condensate to the Boiler
- Upgrade Boilers with Energy-Efficient Burners
- Use Feedwater Economizers for Waste Heat Recovery
- Use Low Grade Waste Steam to Power Absorption Chillers
- Use Steam Jet Ejectors or Thermocompressors to Reduce Venting of Low-Pressure Steam
- Use Vapor Recompression to Recover Low-Pressure Waste Steam
- Use a Vent Condenser to Recover Flash Steam Energy

MINISTRY OF INDUSTRY AND TRADE

Global Gateway

Funded by the European Union

UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

MINISTRY OF INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY TRANSITION PROGRAMME (SETP)
Accelerating energy efficiency (EE) in large industries through energy management system, System optimisation and the promotion and adoption of EE in SMEs -(IEEP project)

Global Gateway
Funded by the European Union

UNIDO
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Student Exercise Questions

- Steam System Scoping Tool
  - Complete the SSST sections related to "Steam System Operating Practices" and "Boiler Plant Operating Practices" based on the information provided
  - Also, indicate how you would proceed to obtain any additional information you would need beyond that provided
  - Finally, based on completion of these SSST sections, list the specific areas on which you would focus your attention to achieve boiler-related energy savings in the example plant

MINISTRY OF INDUSTRY AND TRADE
Global Gateway
UNIDO

Student Exercise Answers - SSST

2. STEAM SYSTEM OPERATING PRACTICES		
STEAM TRAP MAINTENANCE		
ST1: Steam Trap Maintenance Practices	40	5
WATER TREATMENT PROGRAM		
WT1: Water Treatment - Ensuring Function	10	0
WT2: Cleaning Boiler Fireside/Waterside Deposits	10	5
WT3: Measuring Boiler TDS, Top/Bottom Blowdown Rates	10	5
SYSTEM INSULATION		
IN1: Insulation - Boiler Plant	10	10
IN2: Insulation - Distribution/End Use/Recovery	20	0
STEAM LEAKS		
LK1: Steam Leaks - Severity	10	8
WATER HAMMER		
WH1: Water Hammer - How Often	10	10
MAINTAINING EFFECTIVE STEAM SYSTEM OPERATIONS		
MN1: Inspecting Important Steam Plant Equipment	20	5
STEAM SYSTEM OPERATING PRACTICES SCORE	140	48

Student Exercise Answers - SSST

3. BOILER PLANT OPERATING PRACTICES		
BOILER EFFICIENCY		
BE1: Measuring Boiler Efficiency - How Often	10	5
BE2: Flue Gas Temperature, O2, CO Measurement	15	0
BE3: Controlling Boiler Excess Air	10	7
HEAT RECOVERY EQUIPMENT		
HR1: Boiler Heat Recovery Equipment	15	7
GENERATING DRY STEAM		
DS1: Checking Boiler Steam Quality	10	10
GENERAL BOILER OPERATION		
GB1: Automatic Boiler Blowdown Control	5	0
GB2: Frequency Of Boiler High/Low Level Alarms	10	10
GB3: Frequency Of Boiler Steam Pressure Fluctuations	5	5
BOILER PLANT OPERATING PRACTICES SCORE	80	44

Student Exercise Answers - SSST

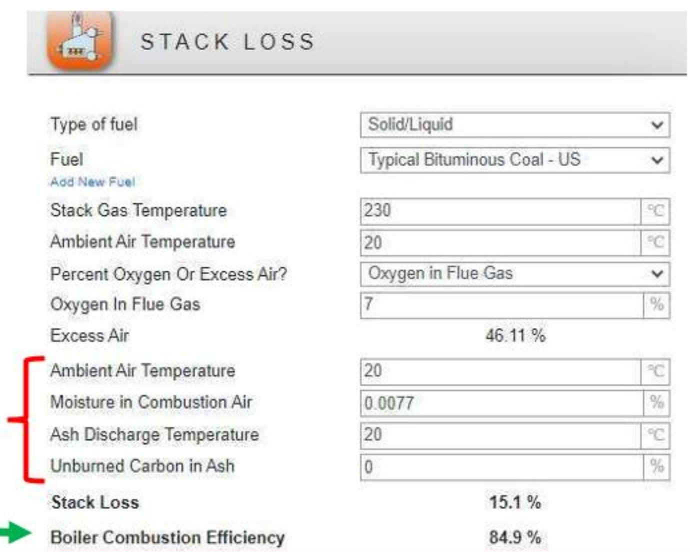
- Potential List of Improvement Opportunities
  - Steam Trap Management Program
  - Insulation opportunities in the process areas
  - Boiler plant efficiency improvement
    - Monitoring and trending parameters
    - Implementing oxygen trim controllers
    - Feedwater economizer installation and operations
    - Blowdown control
    - Blowdown energy recovery
  - Condensate recovery
  - Turbines operation evaluation

Student Exercise Questions

- Boiler #2 Efficiency Calculations
  - Estimate the fuel related operating cost of the boiler
    - Use "Typical Bituminous Coal" only and the largest boiler loss
    - The calculation should be completed using steam flow, steam conditions, and an estimate of boiler efficiency
  - Estimate the loss associated with boiler blowdown
  - Determine the direct and indirect boiler efficiencies
    - Assume shell loss is 0.4% of fuel input energy
    - Assume LOI is 2.1% provided by laboratory analysis
    - Assume a field evaluation has been completed and the average fuel flow rate is 165 tonne/day
    - The fuel higher heating value is 31,890 kJ/kg

Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Fuel related operating cost



Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Fuel related operating cost

$$\eta_{boiler} = \frac{Energy\ absorbed\ by\ steam}{Fuel\ input\ energy} \times 100$$

$$\eta_{boiler} = \frac{m_{steam}\left(h_{steam} - h_{feedwater}\right)}{m_{fuel}\ HHV_{fuel}} \times 100$$

Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Fuel related operating cost

Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m³/kg)
20	300	3,021.34	6.7418	Gas	Temperature	0.1191
25	110	463.15	1.4166	Liquid	Temperature	0.0011

$$m_{fuel} = \frac{m_{steam}\left(h_{steam} - h_{feedwater}\right)}{\eta_{boiler} HHV_{fuel}} \times 100$$

$$m_{fuel} = \frac{70{,}000\ (3{,}021.3 - 463.2)}{(100{-}15.1)\ \times 31{,}890} \times 100$$

$$m_{fuel} = 6{,}614\,\frac{kg}{hr}$$

Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Fuel related operating cost
    - Fuel consumption = 6.614 tonne/hr
    - Fuel cost = $150 per tonne
    - Fuel operating cost = 6.614 x 150 = $992 per hour
    - Fuel operating cost = 992 x 8,760 ~ **$8,690,000 per yr**

Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Loss associated with blowdown

$$\beta \approx \frac{Feedwater\ Conductivity}{Blowdown\ Conductivity} \times 100$$

$$\beta \approx \frac{125}{2{,}500} \times 100 = 5.0\%$$

$$m_{blowdown} = \left(\frac{\beta}{1-\beta}\right) m_{steam} = \left(\frac{0.05}{1-0.05}\right) 70{,}000 = 3{,}684 \text{ kg/hr} = 1.02 \text{ kg/s}$$

Student Exercise Answers

- Boiler #2 Efficiency Calculations
  - Loss associated with blowdown

Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m³/kg)
20	214.9	920.14	2.4704	Liquid	Saturated Quality	0.0012
0	20	84.01	0.2965	Liquid	Temperature	0.001

Boiler $$Q_{blowdown} = m_{blowdown}\left(h_{blowdown} - h_{feedwater}\right) = 1.02\ (920.1 - 463.2) = 466\ \text{kW}$$

System $$Q_{blowdown} = m_{blowdown}\left(h_{blowdown} - h_{makeup}\right) = 1.02\ (920.1 - 84.0) = 853\ \text{kW}$$

Student Exercise Answers

- Boiler #2 Direct Efficiency Calculations
  - m_{steam} = 70,000 kg/hr
  - M_{fuel} = 165 tonnes per day
  - HHV_{fuel} = 31,890 kJ/kg

Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m³/kg)
20	300	3,021.34	6.7418	Gas	Temperature	0.1191
25	110	463.15	1.4166	Liquid	Temperature	0.0011

$$\eta_{boiler} = \frac{m_{steam}\left(h_{steam} - h_{feedwater}\right)}{m_{fuel}\ HHV_{fuel}} \times 100$$

$$\eta_{boiler} = \frac{70{,}000\ (3{,}021.3 - 463.2)}{165\ \times 1000 \times 31{,}890} \times 24 \times 100$$

$$\eta_{boiler} = 81.7\%$$

Student Exercise Answers

- Boiler #2 InDirect Efficiency Calculations

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

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

$$\lambda_{blowdown} = \frac{m_{blowdown}(h_{blowdown} - h_{feedwater})}{m_{fuel}\, HHV_{fuel}} \times 100 = \frac{3{,}672\ (920.1 - 463.2)}{165 \times 1{,}000 \times 31{,}890} \times 24 \times 100 = 0.77\%$$

Student Exercise Answers

- Boiler #2 InDirect Efficiency Calculations

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

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

$$\eta_{boiler} = 100 - 0.4 - 0.77 - 15.1 - 2.1$$

$$\eta_{boiler} = 81.6\%$$

Student Exercise Questions

- Boiler #2 Efficiency Calculations
  - Estimate the *impact* of installation of an automatic oxygen trim controller
    - The controller will reduce the flue gas oxygen content to 4.5% for the general boiler load
    - Assume a field evaluation has been completed and the average fuel flow rate is 165 tonne/day
    - The fuel higher heating value is 31,890 kJ/kg

Student Exercise Answers

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

Source: US DOE ITP Steam BestPractices Program

Student Exercise Answers

- Installation of an automatic oxygen trim controller

Type of fuel	Solid/Liquid
Fuel	Typical Bituminous Coal - US
Add New Fuel	
Stack Gas Temperature	230 °C
Ambient Air Temperature	20 °C
Percent Oxygen Or Excess Air?	Oxygen in Flue Gas
Oxygen In Flue Gas	7 %
Excess Air	46.11 %
Ambient Air Temperature	20 °C
Moisture in Combustion Air	0.0077 %
Ash Discharge Temperature	20 °C
Unburned Carbon in Ash	0 %
Stack Loss	**15.1 %**
Boiler Combustion Efficiency	**84.9 %**

Type of fuel	Solid/Liquid
Fuel	Typical Bituminous Coal - US
Add New Fuel	
Stack Gas Temperature	230 °C
Ambient Air Temperature	20 °C
Percent Oxygen Or Excess Air?	Oxygen in Flue Gas
Oxygen In Flue Gas	4.5 %
Excess Air	25.91 %
Ambient Air Temperature	20 °C
Moisture in Combustion Air	0.0077 %
Ash Discharge Temperature	20 °C
Unburned Carbon in Ash	0 %
Stack Loss	**13.8 %**
Boiler Combustion Efficiency	**86.2 %**

Student Exercise Answers

- Installation of an automatic oxygen trim controller

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

$$Savings = \left(1 - \frac{84.9}{86.2}\right) \times 8{,}690{,}000$$

$$Savings \approx \$131{,}000/yr$$

Source: US DOE ITP Steam BestPractices Program

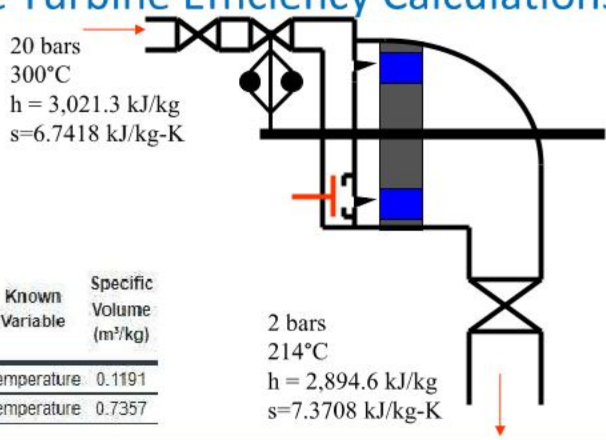
Student Exercise Questions

- HP-LP Backpressure Turbine Efficiency Calculations
  - Determine the isentropic efficiency of the main steam turbine operating between the high pressure and low pressure systems
- Condensing Turbine Efficiency
  - Determine the isentropic efficiency of the condensing turbine based on the information provided

Student Exercise Answers

- HP-LP Backpressure Turbine Efficiency Calculations

Actual Operating Conditions

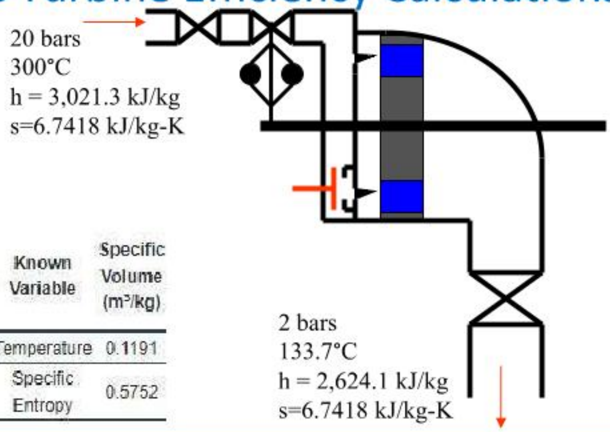


Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m^3/kg)
20	300	3,021.34	6.7418	Gas	Temperature	0.1191
2	214	2,894.58	7.3708	Gas	Temperature	0.7357

Student Exercise Answers

- HP-LP Backpressure Turbine Efficiency Calculations

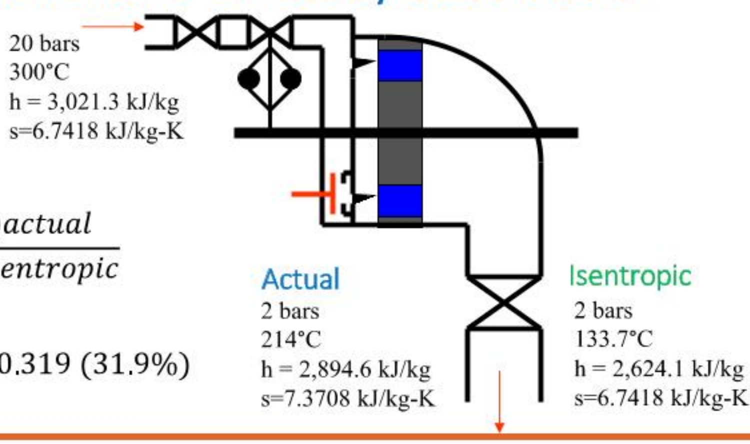
Isentropic Conditions



Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m³/kg)
20	300	3,021.34	6.7418	Gas	Temperature	0.1191
2	133.68	2,624.08	6.7418	0.95	Specific Entropy	0.5752

Student Exercise Answers

- HP-LP Backpressure Turbine Efficiency Calculations



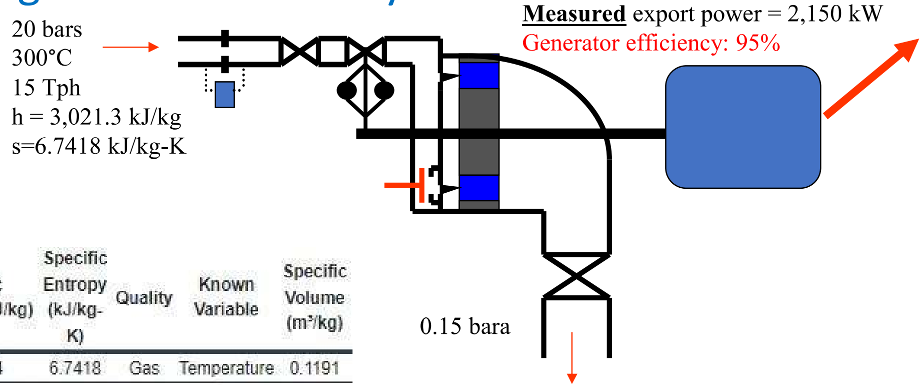
$$\eta_{isentropic} = \frac{(h_{inlet} - h_{exit})actual}{(h_{inlet} - h_{exit})isentropic}$$

$$\eta_{isentropic} = \frac{(3021.3 - 2894.6)}{(3021.3 - 2624.1)} = 0.319\ (31.9\%)$$

Student Exercise Answers

➢ Condensing Turbine Efficiency Calculations

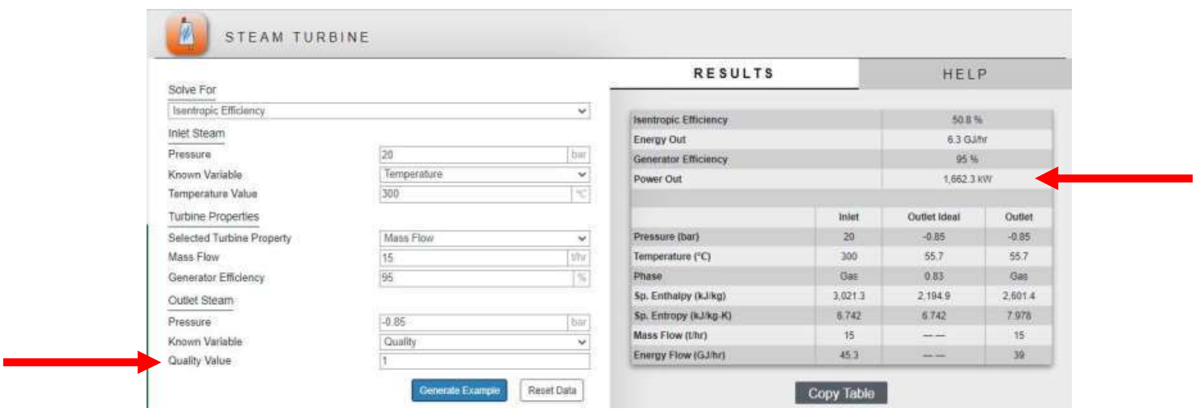
Actual Operating Conditions



Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m³/kg)
20	300	3,021.34	6.7418	Gas	Temperature	0.1191

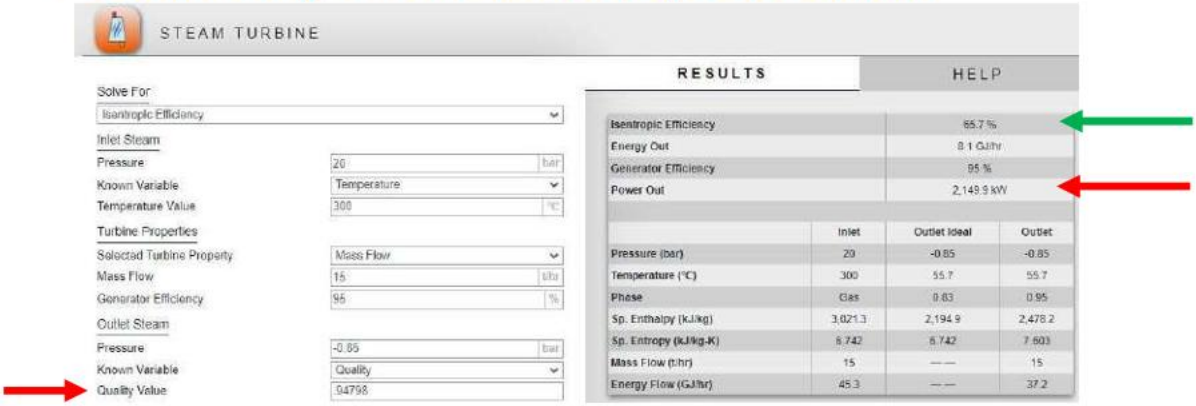
Student Exercise Answers

➢ Condensing Turbine Efficiency Calculations



Student Exercise Answers

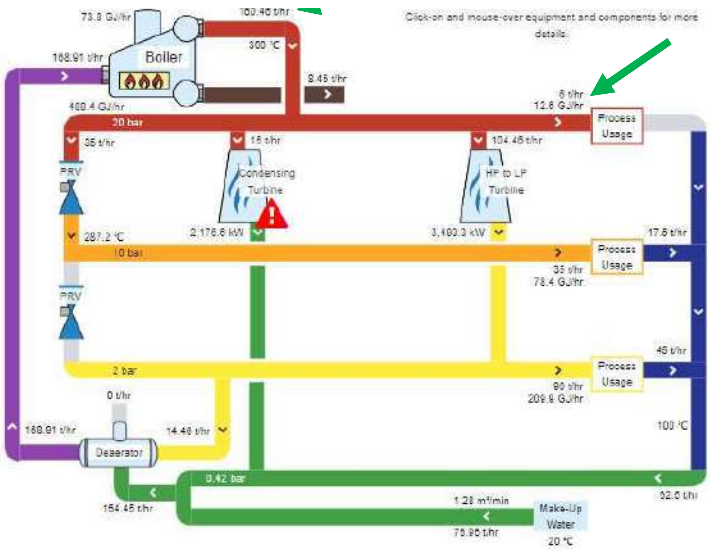
- Condensing Turbine Efficiency Calculations



Student Exercise Questions

- US DOE MEASUR Steam Assessment Tool
  - Develop the US DOE MEASUR model that best represents the general characteristics of the example facility for an evaluation that will provide representative marginal steam costs
  - This model should also provide a good description of the steam mass balance through the system
  - The analyses required for this exercise should be considered preliminary; as a result do not include boiler shell losses and LOI (Loss on Ignition)
  - Outputs for this exercise are marginal steam costs for the system and the steam flows through the pressure reducing valves

US DOE MEASUR



US DOE MEASUR

STEAM SYSTEM SUMMARY

Steam Generated
160.5 t/hr
Total Operating Cost
$27,053,977

CO_2 Emissions (tonne CO_2/yr)	
Emissions From Fuel	378,270.64
Emissions From Selling Electricity	0
Emissions From Change in Electricity Imports	0
Total Emissions	378,270.64

Fuel	
Boiler Fuel Use	4,278,497.25 GJ/yr
Boiler Fuel Cost ($)	$20,108,937

Electricity	
Electricity Generated	5,669.87 kW
Electricity Imported	7,000 kW
Electricity Cost ($)	$6,438,600

Fuel Balance	
Boiler	488.41 GJ/hr
Unit Cost	$4.70 /GJ
Total $/yr	$20,108,937

Make-Up Water	
Flow	1.28 m³/min 675,253.08 m³
Unit Cost	$0.75 /m³
Total $/yr	$506,440

Total Operating Cost
$27,053,977

MARGINAL STEAM COST

High Pressure	$16.92 /t
Medium Pressure	$15.75 /t
Low Pressure	$15.48 /t

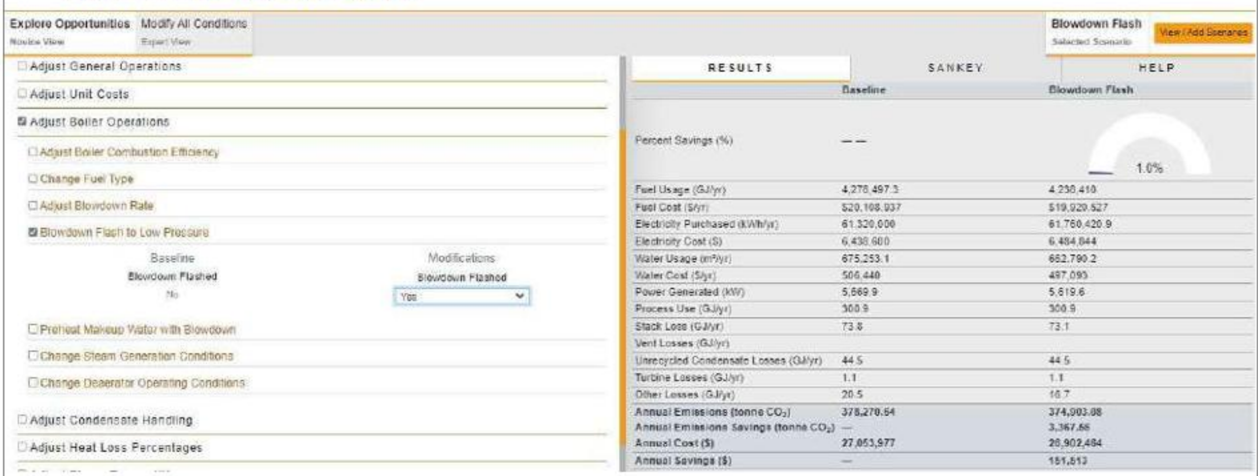
Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

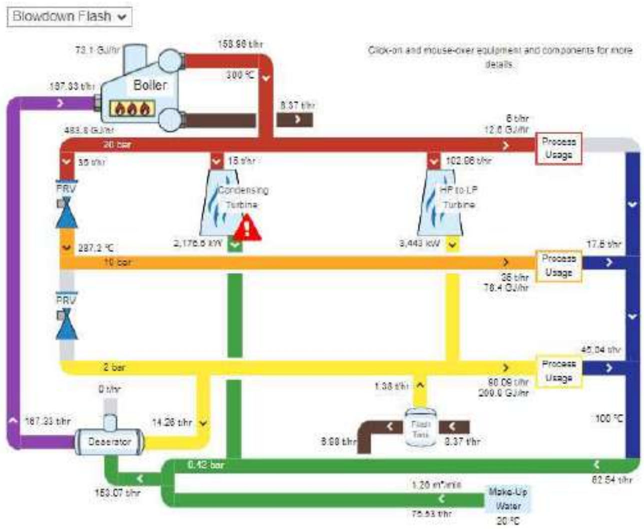
❑ Blowdown Energy Recovery

- Using the US DOE MEASUR model developed for the general steam system determine the economic impact of recovering thermal energy from boiler blowdown
- Present the individual areas of economic impact contributing to the results

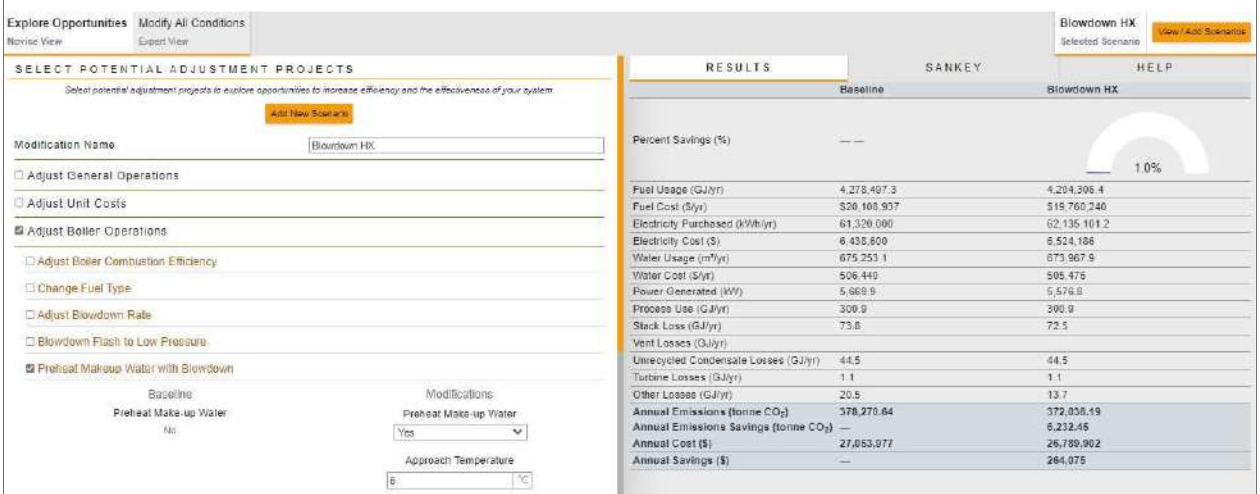
US DOE MEASUR



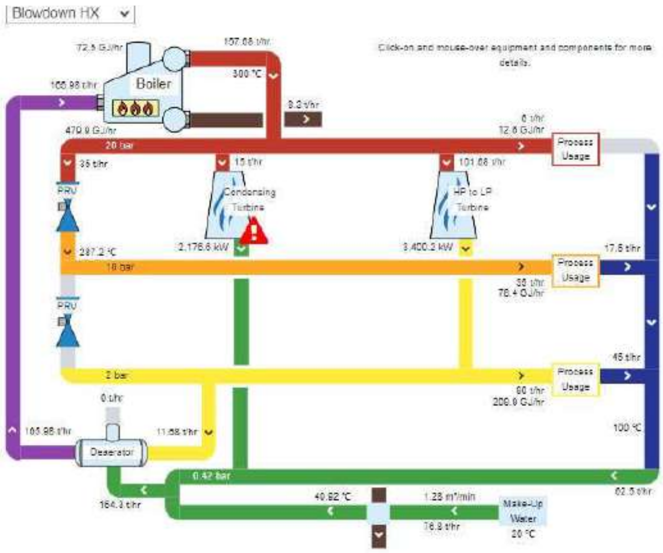
US DOE MEASUR



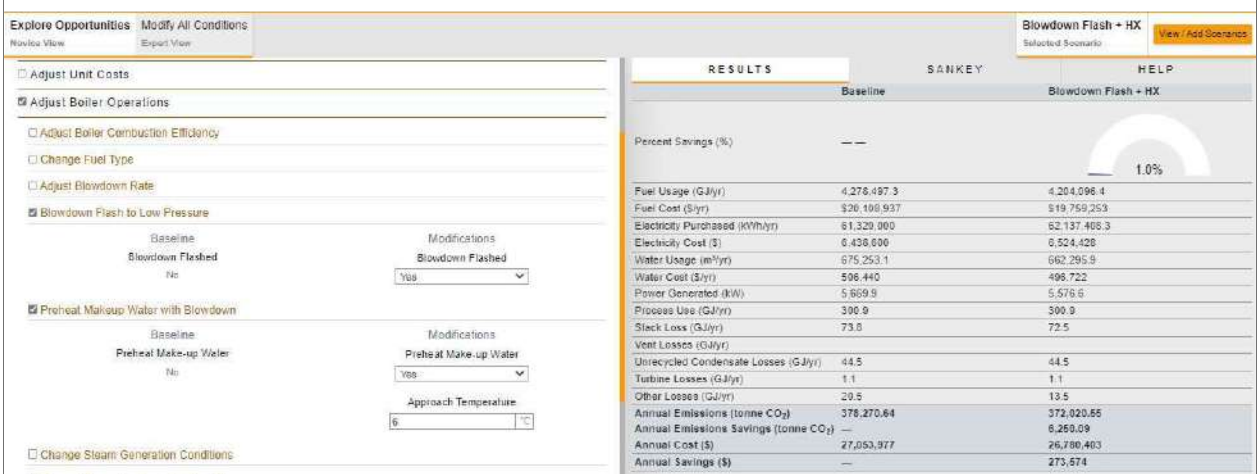
US DOE MEASUR



US DOE MEASUR

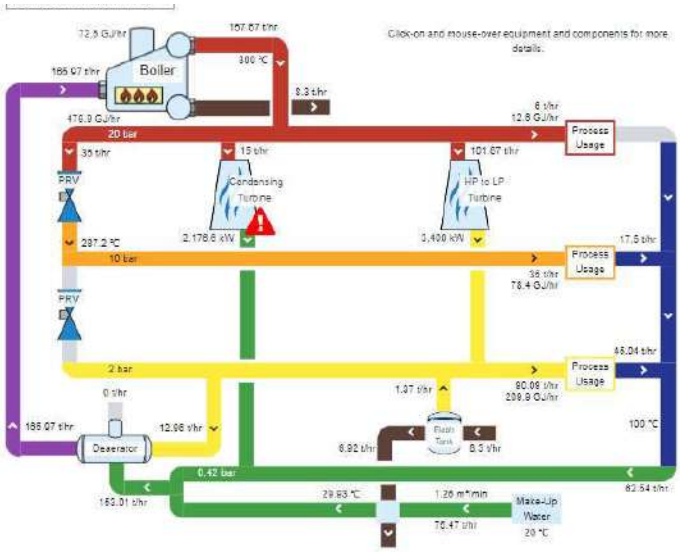


US DOE MEASUR



	Baseline	Blowdown Flash + HX
Percent Savings (%)	— —	1.0%
Fuel Usage (GJ/yr)	4,278,497.3	4,204,096.4
Fuel Cost ($/yr)	$20,108,937	$19,759,253
Electricity Purchased (kWh/yr)	61,320,000	62,137,408.3
Electricity Cost ($)	6,438,600	6,524,428
Water Usage (m^3/yr)	675,253.1	662,295.9
Water Cost ($/yr)	506,440	496,722
Power Generated (kW)	5,669.9	5,576.6
Process Use (GJ/yr)	300.9	300.9
Stack Loss (GJ/yr)	73.8	72.5
Vent Losses (GJ/yr)		
Unrecycled Condensate Losses (GJ/yr)	44.5	44.5
Turbine Losses (GJ/yr)	1.1	1.1
Other Losses (GJ/yr)	20.5	13.5
Annual Emissions (tonne CO_2)	378,270.64	372,020.55
Annual Emissions Savings (tonne CO_2)	—	6,250.09
Annual Cost ($)	27,053,977	26,780,403
Annual Savings ($)	—	273,574

US DOE MEASUR



US DOE MEASUR

	Baseline	Blowdown Flash	Blowdown HX	Blowdown Flash + HX
Percent Savings (%)	—	1.0%	1.0%	1.0%
Power Cost ($/yr)	6,433,600	6,484,844	6,524,136	6,524,428
Savings	—	-40,244	-85,580	-85,828
Fuel Cost ($/yr)	20,108,937	19,920,527	19,760,240	19,759,253
Savings	—	188,410	348,697	349,684
Make-up Water Cost ($/yr)	506,440	497,093	505,476	496,722
Savings	—	9,347	964	9,718
Annual Cost ($)	27,053,977	26,902,464	26,789,902	26,780,403
Annual Savings ($)	—	151,513	264,075	273,574
Implementation Cost	—	—	—	—
Payback Period (months)	—	—	—	—
Selected Energy Projects	—	Adjust Boiler Operations	Adjust Boiler Operations	Adjust Boiler Operations
Modifications	—	Boiler	Boiler	Boiler

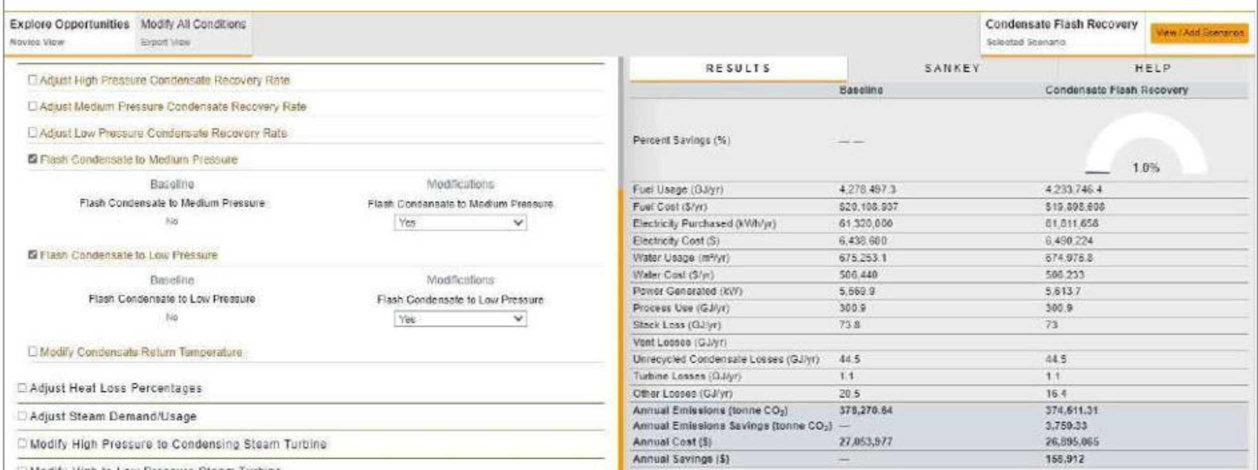
Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

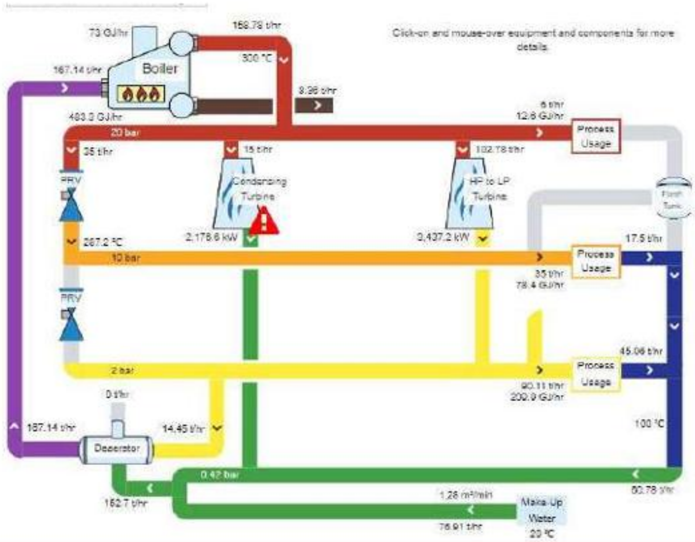
❑ Condensate Flash Steam Recovery

- Using the US DOE MEASUR model developed for the general steam system determine the economic impact of recovering flash steam produced from the existing condensate recovery system
- Present the individual areas of economic impact contributing to the results

US DOE MEASUR



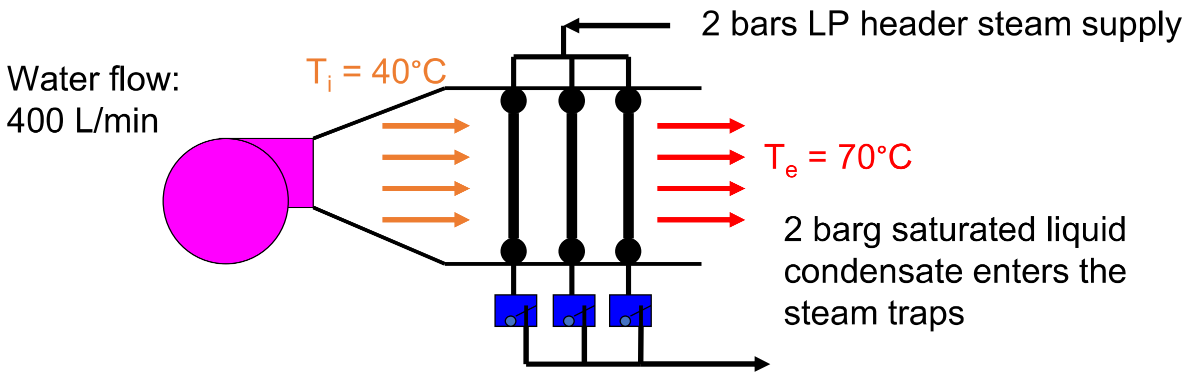
US DOE MEASUR



Student Exercise Questions

- US DOE MEASUR Steam Assessment Tool
  - Steam Demand
    - Process water was being unnecessarily heated from 40°C to 70°C with low-pressure steam
    - The steam trap serving the heat exchanger is functioning properly and is discharging saturated liquid
    - Steam entering the heat exchanger is from the low pressure system at saturated conditions—heat transfer losses in this branch line account for the energy loss from the superheated supply condition
    - The process water has a flow rate of ~400 l/min
    - Determine the steam system operational cost impact of eliminating this steam demand

Steam Demand Reduction



Steam Demand Reduction

$$Q_{water} = m_{water} C_{p\_water} \left(T_{out} - T_{in}\right)_{water}$$

$$Q_{water} = \frac{400}{1{,}000} \times 992.2 \times 4.182 \times (70 - 40) \times \frac{1}{60}$$

$$Q_{water} = 829.8\ kW$$

Student Exercise Answers

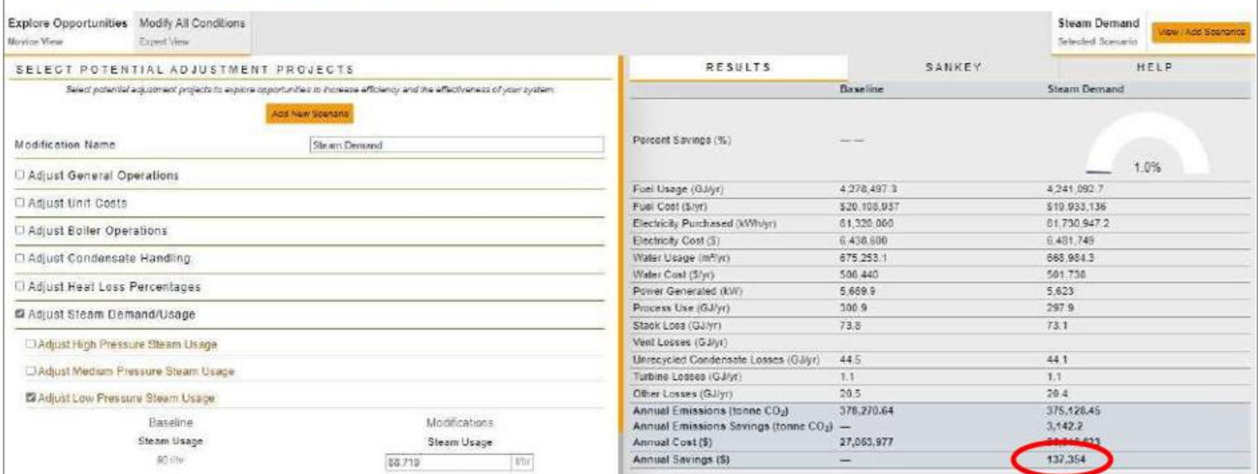
- Energy Savings = 829.8 kW

$$m_{steamsaved} = \frac{EnergySavings}{(h_{steam} - h_{condensate})}$$

$$m_{steamsaved} = \frac{829.8}{(2{,}894 - 561.5)} \times 3{,}600 = 1{,}281\ \frac{kg}{hr}$$

- Steam saved = 1.281 * 8,760 = 11,222 tonnes/yr
- Unit cost of steam generation: $15.48 per tonne
- Annual cost savings ~ $173,700
- A more realistic analysis should be done using MEASUR – Steam Demand Savings

Student Exercise Answers



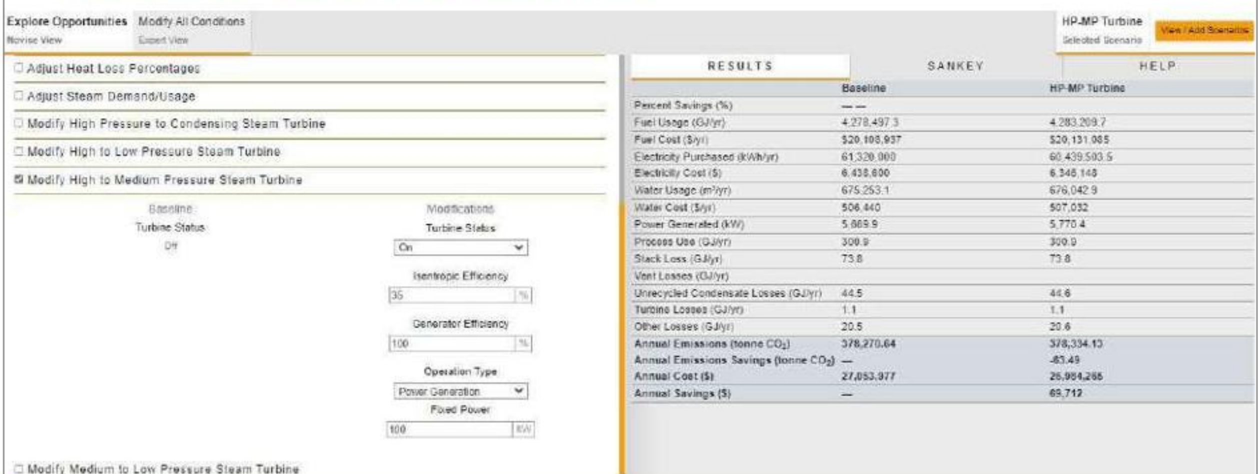
Student Exercise Questions

➢ US DOE MEASUR Steam Assessment Tool

❑ Steam Turbine versus Electric Motor

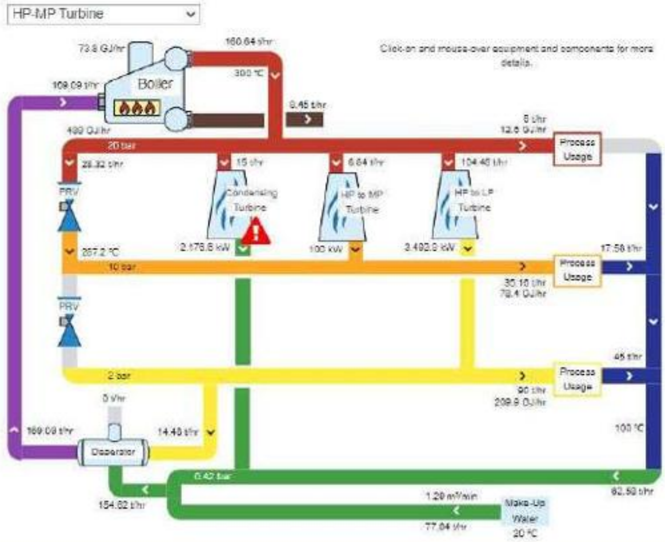
- Determine the economic impact of replacing a 100 kW process drive electric motor with a steam turbine
- Assume the process turbine will operate continuously between the high-pressure and medium-pressure systems
- The turbine will have an isentropic efficiency of 35%

Student Exercise Answers



	Baseline	HP-MP Turbine
Percent Savings (%)	— —	
Fuel Usage (GJ/yr)	4,278,497.3	4,283,209.7
Fuel Cost ($/yr)	$20,108,937	$20,131,085
Electricity Purchased (kWh/yr)	61,320,000	60,439,503.5
Electricity Cost ($)	6,438,600	6,346,148
Water Usage (m^3/yr)	675,253.1	676,042.9
Water Cost ($/yr)	506,440	507,032
Power Generated (kW)	5,869.9	5,770.4
Process Use (GJ/yr)	300.9	300.9
Stack Loss (GJ/yr)	73.8	73.8
Vent Losses (GJ/yr)		
Unrecycled Condensate Losses (GJ/yr)	44.5	44.6
Turbine Losses (GJ/yr)	1.1	1.1
Other Losses (GJ/yr)	20.5	20.6
Annual Emissions (tonne CO_2)	**378,270.64**	**378,334.13**
Annual Emissions Savings (tonne CO_2)	**—**	**-63.49**
Annual Cost ($)	**27,053,977**	**26,984,265**
Annual Savings ($)	**—**	**69,712**

US DOE MEASUR

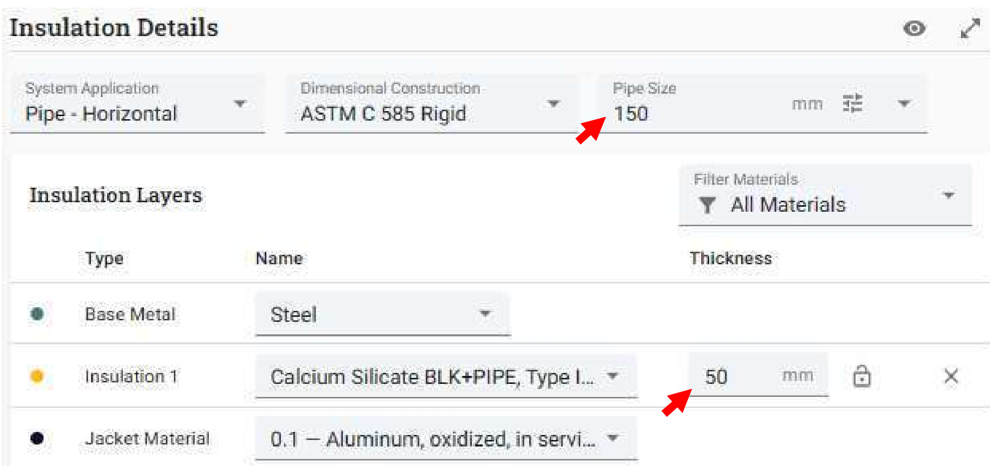


Student Exercise Questions

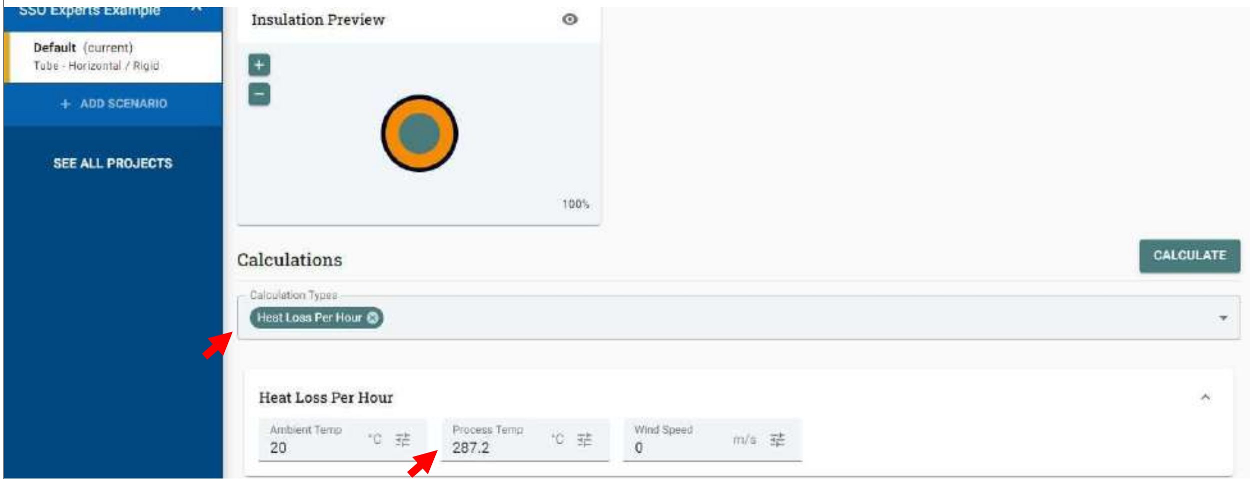
- US DOE MEASUR Steam Assessment Tool
  - 3E Plus Piping Insulation Problem
    - One of the process units is supplied medium-pressure steam through a 150 mm nominal diameter header
    - A 10 m long section of the header was observed to be un-insulated—the result of a past maintenance activity
    - The rest of the piping system is covered with a 50 mm thick calcium silicate insulation and aluminum jacket
    - Ambient conditions are typical for an industrial facility
    - The piping is located outside on a pipe bridge
    - Determine the energy loss reduction and economic impact associated with replacing the missing insulation

Student Exercise Answers

Student Exercise Answers



Student Exercise Answers



Student Exercise Answers

SSO Experts Example: Default

Calculation Results
Heat Loss Per Hour

REPORT CSV

Insulation Thickness (mm)	Surface Temp (°C)	Heat Flow (W/m)	Efficiency (%)
Bare	286.3	3258.46	–
Layer 1 (50.0)	66.1	229.9	92.94

Student Exercise Answers

$$Q_{saved} = (3{,}258 - 230) \times 10 = 30.3\ kW$$

$$Fuelsaved = 30.3\,\frac{kJ}{s} \times 3{,}600\,\frac{s}{hr} \times 8{,}760\,\frac{hr}{yr} \times \frac{1}{0.817} = 1{,}169\,\frac{GJ}{yr}$$

$$Fuelsaved = 1{,}169\,\frac{GJ}{yr} \times \frac{1}{31{,}890}\,\frac{kg}{kJ} \times 1{,}000 \times 1{,}000 = 36{,}650\,\frac{kg}{yr}$$

$$Savings = 36{,}650\,\frac{kg}{yr} \times 150.0\,\frac{\$}{tonne} \times \frac{1}{1{,}000} = \sim 5{,}500\,\frac{\$}{yr}$$

Student Exercise Answers

➢ If the energy impact is realized at "steam cost"

$$Q_{saved} = (3{,}258 - 230) \times 10 = 30.3\ kW$$

MARGINAL STEAM COST

High Pressure	$16.92 /t
Medium Pressure	$15.75 /t
Low Pressure	$15.48 /t

Student Exercise Answers

- If the energy impact is realized at "steam cost"

Pressure (bar)	Temperature (°C)	Specific Enthalpy(kJ/kg)	Specific Entropy (kJ/kg-K)	Quality	Known Variable	Specific Volume (m^3/kg)
10	287.2	3,021.33	7.0278	Gas	Temperature	0.2278
10	184.12	781.43	2.1794	Liquid	Saturated Quality	0.0011

$$Q_{saved} = (3{,}258 - 230) \times 10 = 30.3\ kW$$

$$m_{steam} = \frac{Q_{saved}}{(h_{steam} - h_{condensate})} = \frac{30.3}{(3{,}021.3 - 781.4)} = 0.013\frac{kg}{s} = 46.8\ \frac{kg}{hr}$$

Student Exercise Answers

- If the energy impact is realized at "steam cost"

$$Q_{saved} = (3{,}258 - 230) \times 10 = 30.3\ kW$$

$$m_{steam} = \frac{Q_{saved}}{(h_{steam} - h_{condensate})} = \frac{30.3}{(3{,}021.3 - 781.4)} = 0.013\frac{kg}{s} = 46.8\ \frac{kg}{hr}$$

$$Savings = m_{steam} \times Cost_{steam} = 46.8 \times 8{,}760 \times 15.75 \times \frac{1}{1{,}000} = \$6{,}457\ per\ yr$$

- US DOE MEASUR can also be used to estimate savings

Industrial Steam System Optimization (SSO) Expert Training Programme

Webinar 1

Date

Facilitator

Name, Affiliation of Expert candidate(s)

Instructions

- Submission is 2 workings days before the webinar
- Submission must include your applicable SSO Tools
- You have 5-10 minutes to present your progress - stick to the highlights and limit detail
- Each Expert candidate must have an opportunity to present (rotational presenter)
- Ensure pictures are legible and label graphs properly
- Don’t remove slides, rather discuss what you have and your challenges

Agenda

- Add the main topics you are planning to address today

Identification of CANDIDATE Plant

- Name & Location:
- Sector:
- Minimum criteria (Highlight in **RED** what is not met)
  - The plant has all the steam sub-systems – generation, distribution, end-use and recovery (for plants purchasing steam – national trainers will determine the scope of the assessment to cover generation)
  - Minimum boiler rating pressure of 10 bars
  - Steam production for process (or product) heating and NOT just for heating space or just for power generation
  - Should have some level of minimum onsite instrumentation – steam flow meter or feed water flow meter, pressures, temperatures, etc.
  - The plant will allow for the national expert to use instrumentation such as infra-red camera, combustion analyzer, if required, after proper permissions are obtained

Identification of CANDIDATE Plant

- Good-to-have criteria (Highlight in **GREEN** what is met)
  - A steam generation or demand of a minimum of 10 Tons/hr
  - Boilers with dual-fuel fire capability or different fuel boilers operating under normal conditions
  - Has the ability to take water samples and test them for conductivity
  - Minimum two pressure headers for plant-wide steam distribution and end-use
  - The plant has turbines used for power generation and/or driving mechanical equipment
  - The plant produces superheated steam
  - The plant has a Data Acquisition System with historical trends and data storage capability
  - The plant has detailed P&ID's of the steam system and process areas
  - An Energy Team exists at the Plant that is comprised of plant and/or corporate personnel.

Plant Engagement

- Completed paperwork
  - Letter of Intent
  - Confidentiality agreements / NDA
- Conference calls / meetings / webinars
  - List activities
- Exchange of information
  - List type of information exchanged between Expert and plant
  - Additional slides can be used to show details, if any
- Next meeting w/plant personnel
  - Dates, agenda, etc.

Steam System Scoping Tool (SSST)

- Update on SSST
- Scores & Potential Ideas

Challenges and Lessons Learned

- List any challenges and/or Lessons Learned experienced thus far
- Include actions taken and/or planned to overcome these

Challenge/ Lesson Learnt	Impact	Actions taken	Actions planned

Industrial Steam System Optimization (SSO) Expert Training Programme

Webinar 2

Date

Facilitator

Name, Affiliation of Expert candidate(s)

MINISTRY OF INDUSTRY AND TRADE
Global Gateway
Funded by the European Union
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Instructions

- Submission is 2 workings days before the webinar
- Submission must include your applicable SSO Tools
- You have 5-10 minutes to present your progress - stick to the highlights and limit detail
- Each Expert candidate must have an opportunity to present (rotational presenter)
- Ensure pictures are legible and label graphs properly
- Don’t remove slides, rather discuss what you have and your challenges

Agenda

- Add the main topics you are planning to address today

CANDIDATE Plant Information

- Name & Location:
- Sector:
- High-level details of the Steam system at the plant
  - Steam Generation capacity
  - Line drawings / schematics
  - Major pieces of equipment identified
- Completed SSST and results
  - Submit Excel file separately
- Instrumentation Gap Analysis spreadsheet
  - Identify what instrumentation / historian is available

CANDIDATE Plant Steam System Drawings / Pictures (Use multiple slides)

Plant Engagement

- Conference calls / meetings / webinars
  - List activities
- Exchange of information
  - List type of information exchanged between Expert and plant
  - Additional slides can be used to show details, if any
- Assessment Dates (Completed / Finalized)
  - Dates, agenda, etc.
- Borrow instruments from UNIDO (Completed / Finalized)
  - List of instruments
  - Dates needed, location, etc.

Steam System Assessment Plan - Onsite

- Data collection methodology and justification
  - How
  - Time period
- Steam system scope – show boundary of what's going to be included
- Energy balances
- Steam system modelling methodology
- Any immediate energy savings / optimization opportunities that have been identified in discussions, SSST, etc. so far that would be investigated in more detail onsite during the steam system assessment

Steam System US DOE MEASUR - Baseline

Challenges and Lessons Learned

- List any challenges and/or Lessons Learned experienced thus far
- Include actions taken and/or planned to overcome these

Challenge/ Lesson Learned	Impact	Actions taken	Actions planned

Industrial Steam System Optimization (SSO) Expert Training Programme

Webinar 3

Date

Facilitator

Name, Affiliation of Expert candidate(s)

Instructions

- Submission is 2 workings days before the webinar
- Submission must include your applicable SSO Tools
- You have 15 minutes to present your progress - stick to the highlights and limit detail
- Each Expert candidate must have an opportunity to present (rotational presenter)
- Ensure pictures are legible and label graphs properly
- Don’t remove slides, rather discuss what you have and your challenges

Agenda

- Add the main topics you are planning to address today

CANDIDATE Plant Information

- Name & Location:
- Sector:
- High-level details of the steam system at the plant
  - Steam generation capacity
- Summary of candidate plant steam system assessment
  - Dates, etc.
- Summary of completed results from steam system assessment
  - High level table (as shown on later slide)
  - Submit models separately
  - Submit Excel files for data collected separately

CANDIDATE Plant Steam System Drawings / Pictures (Use multiple slides)

Current BestPractices in the Plant

- List all current BestPractices in the Plant that deserves a shout-out to the great job that plant personnel are doing currently with their limited resources.

CANDIDATE Plant Steam System Results

- Include an overall Baseline Table which can include
  - Energy usage per each boiler
  - Operating hours
  - Average load (Tons/hr; GJ/hr)
  - Estimated annual operating costs
  - Optional – Carbon footprint (Metric tons/yr)
- Include a table that identifies the savings opportunity and includes
  - Description title of opportunity
  - Annual Energy savings (GJ)
  - Annual Cost savings
  - Possible capital cost
  - Simple payback (years)
  - Indication of near, mid and long-term opportunity
  - Optional - Annual carbon savings

Energy Savings Opportunity (Template, use multiple slides, if needed, for each opportunity)

- Title / Description of Opportunity
- Current status
  - Include 1 or 2 bullets and/or figure/picture
- Describe what is the modification that is proposed
- Present the methodology used to quantify the opportunity
  - MEASUR models
  - Other tools and resources
- Present energy savings (GJ, kWh and currency), capital cost needed (if any), payback, etc.
- Describe next steps, action items for plant personnel and time-line to complete the modification

Additional Opportunities (not Quantified)

- List all energy savings opportunities that couldn't be quantified either due to the scope of the energy assessment, data availability, etc.

Risks and Opportunities

- List key risks and opportunities and indicate how can you and/or plant personnel will address each of them

Challenges and Lessons Learned

- List any challenges and/or Lessons Learned experienced thus far
- Include actions taken and/or planned to overcome these

Challenge/ Lesson Learned	Impact	Actions taken	Actions planned

Next Steps

- Completion of Draft Report
  - Provide date/time-line
- Presentation of Report to Plant
  - Provide date/time-line
- Anything else that would be of interest to the group

DISCLAIMER

This document was developed within the framework of the project "Accelerating energy efficiency in large industries through energy management systems, system optimization and the promotion and adoption of energy efficiency in small and medium-sized enterprises (IEEP)", funded by the European Union (EU), managed by the Ministry of Industry and Trade (MOIT), and implemented by the United Nations Industrial Development Organization (UNIDO). The content of this document is the sole responsibility of the Project and does not necessarily reflect the views of any individual or organization.