Section 11: Steam System Optimization – Conclusions

Industrial Steam System Energy Assessment

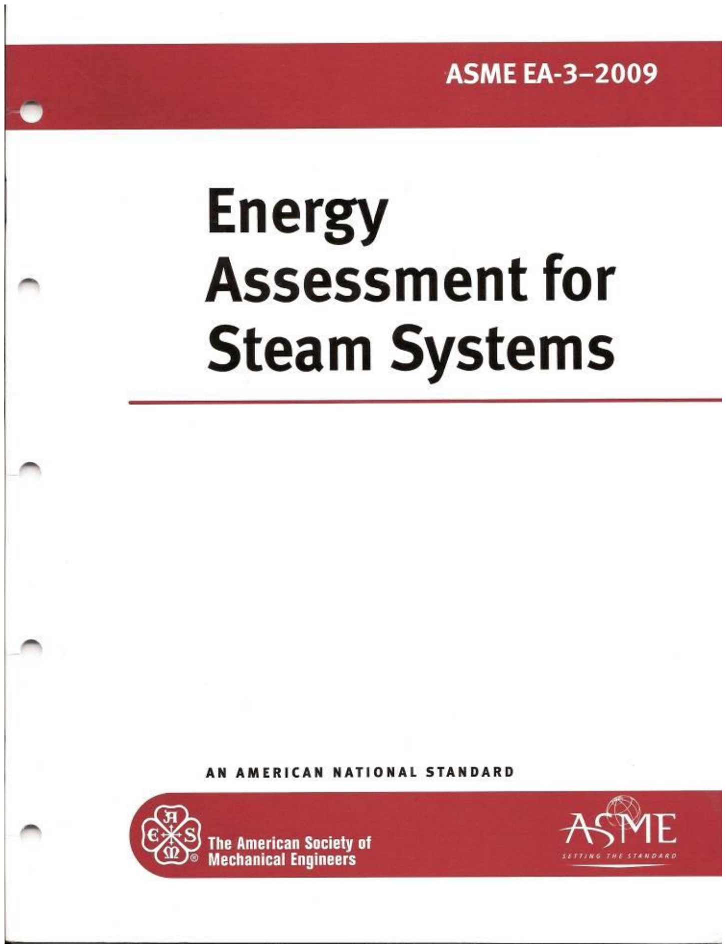
Conclusions

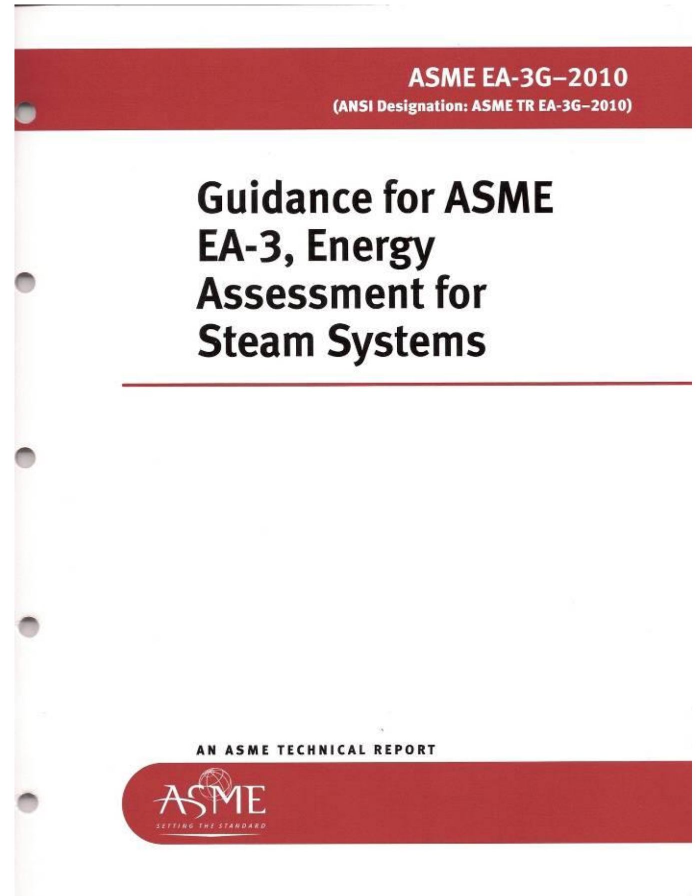
Tools & Resources

Industrial Energy Assessment

- ✓ 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

Steam Energy Assessment Standard





Steam Energy Assessment Standard

- ✓ 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 Saving 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

Industrial Steam System Energy Assessment Report

Save Energy Now Assessment Report

ESA-043-5

General Assessment Information

Company: Citgo Refining Company
Plant: CITGO Petroleum Corporation
Location: Lemont, IL

Assessment Type: Steam
Assessment Dates: 1/17/2011 - 1/20/2011

Plant Information

NAICS: 324110
Principal Products: Gasoline & other blends
Address: 135th and New Avenue, Lemont, IL, 60439

Employed: 800
Floor Area: 1,000 acres

Participant Contact Information

Plant Contact

Name:
Phone:
Email:

Energy Expert Contact

Name: Riyaz Papar
Company: Hudson Technologies Company
Phone: 281 298 0975
Email: rpapar@hudsontech.com

Corporate Contact

Name:
Phone:
Email:

Technical Account Manager Contact

Name:
Phone:
Email:

Additional Plant Attendees

- ✓ Example – US DOE Steam Energy Assessment Report
- ✓ General Information about the plant
  - Industry type
  - Size
  - Location
  - Plant personnel
  - Energy Expert, etc.

Appendix A: Basic Plant Information

Basic Plant Information:			
Plant Name:	CITGO Petroleum Corporation	Address:	135th and New Avenue
Primary Product:	Gasoline & Other fuel blends	State:	IL
Industry Type:	Petroleum	City:	Lemont
NAICS Code:	324110	ZIP:	60439

Plant Background and Process Description

The CITGO Petroleum Corporation refinery is located in Lemont, IL and has a capacity of ~170,000 barrels per day crude oil throughput.

Annual Utility Consumption

	Annual Usage	Avg. Annual Demand	Annual Cost	Unit Cost	CO_2 Emission (Metric Tons)
Electricity	kWh	kW	$$$$	$/kWh	XXX
Natural Gas	GJ		$$$$	$/GJ	YYY
Other Gas	GJ		$$$$	$/GJ	
Total	**GJ**		**$$$$**		

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

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

- ✓ 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

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.

8: Operation with NO extra boilers
The plant demand is such that every steam generating asset is utilized to its fullest in winter Then, in summer, the rental boiler doesn't operate.

9: Use of backpressure turbines for pressure letdown
There are several backpressure steam turbines that drive mechanical equipment and maintain a

- ✓ 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

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

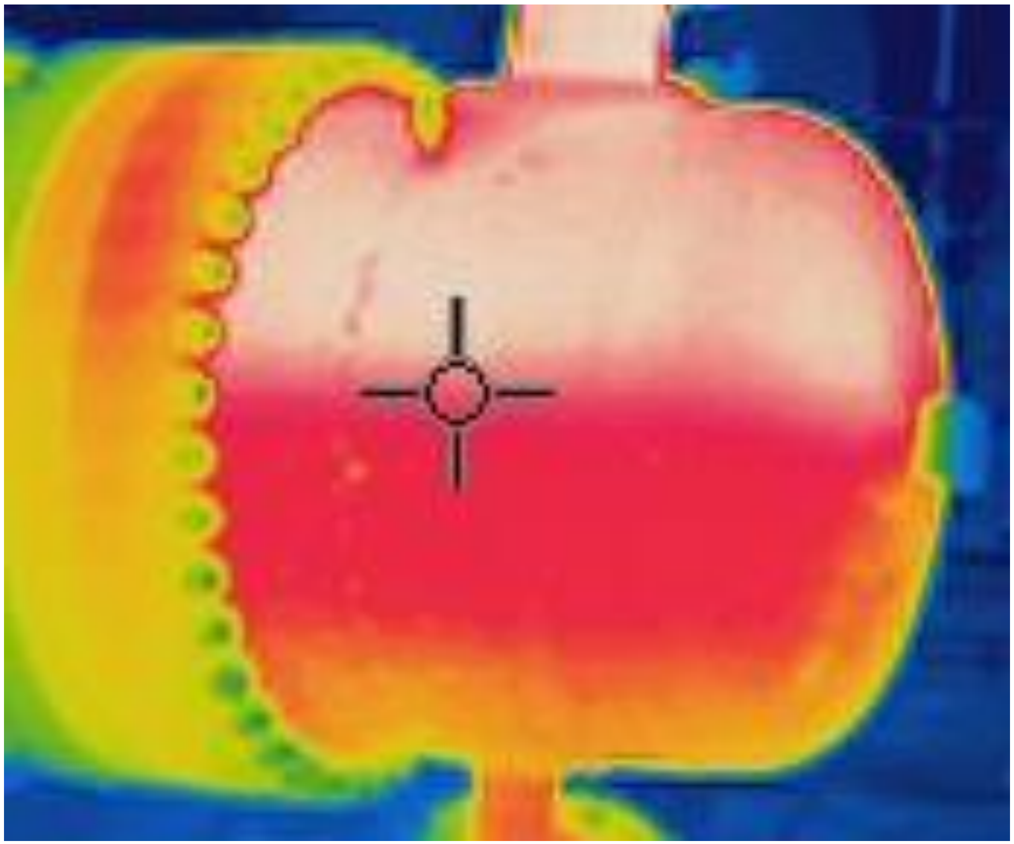
Typical feedwater economizer projects result in less than a year simple paybacks. Adding automatic oxygen trim controllers can have much faster paybacks. Given that this boiler is only used during the "winter" operating season, it is anticipated that simple paybacks on this ESO will be 1-2 years.

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.

✓ 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

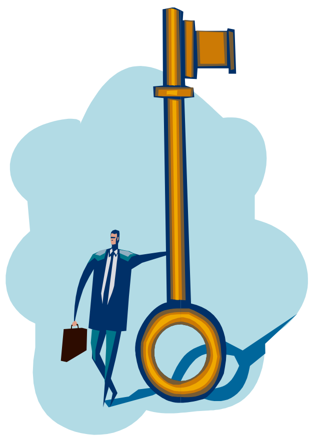


13 GJ/ft^2/yr
$500

124 GJ/ft/yr
$2,000/yr

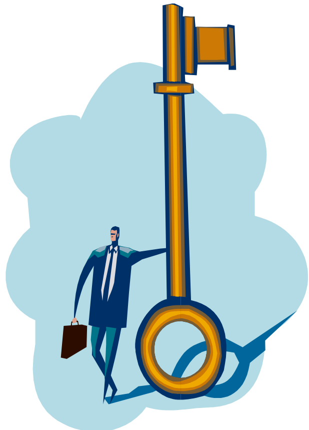
An Example of Savings Calculation Methodology

Conclusions



Key Points / Action Items - Fundamentals

1. *Use a Systems Approach to optimize steam systems*
2. *There are four major areas of a steam system – Generation, Distribution, End-Use & Recovery*
3. *An understanding of the laws of thermodynamics, heat transfer, fluid flow and steam properties is required for a steam system analysis*
4. *Use a systematic approach (gap analysis, comparison to BestPractices) to identify potential energy saving opportunities that may exist in steam systems*



Key Points / Action Items – Boiler Efficiency

1. Determine boiler plant operating cost
2. Determine unit cost of steam generation
3. Determine boiler operating efficiency

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

4. There are three major losses in steam generation – shell loss, blowdown loss and stack loss

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

Key Points / Action Items – Shell Loss

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

Key Points / Action Items – Blowdown Loss

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

Key Points / Action Items – Stack Loss

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

Key Points / Action Items – Stack Loss

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

Key Points / Action Items – Boiler Plant Optimization

1. *Use a steam system model based on the laws of thermodynamics to quantify energy and cost savings opportunities*
2. *Fuel switching and boiler plant operations are excellent areas for optimization of steam systems – significant cost savings can be realized by applying optimal operating strategies*
3. *Each application will need an independent evaluation – there are NO thumb rules!*

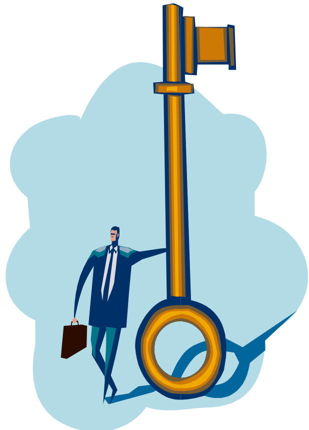
Key Points / Action Items – Leaks

1. *Steam leaks occur in all plants and a continuous improvement type steam leak management program should be implemented in industrial plants*

2. *An "order of magnitude" steam loss estimate can provide enough information to determine if the repair must be made immediately, during a future shutdown, or online*

Key Points / Action Items - Insulation

1. There are several reasons for damaged or missing insulation
2. These areas result in significant energy losses and a continuous improvement type insulation appraisal (audit) program should be implemented in industrial plants
3. Some basic instruments, heat transfer models and process data are required to quantify the economic impact of missing or damaged insulation



Key Points / Action Items – End Use

1. *There are several end-uses of steam in industrial plants*
2. *Do a steam end-use balance in an industrial plant and identify the largest steam end-users in a plant*
3. *Reduce steam end-use by*
   - *Improving the efficiency of the process*
   - *Shifting steam demand to a waste heat source or lower pressure steam available in the plant*

Key Points / Action Items – Heat Exchangers

1. *Heat exchangers have a 1st Law efficiency of ~100%*
2. *Heat exchanger InEffectiveness leads to significant system level energy loss*
3. *Monitor and trend heat exchanger effectiveness by measuring inlet and outlet temperatures and calculating U-values*
4. *Clean heat exchangers on a periodic basis to minimize fouling build-up*

Key Points / Action Items – Process/Utility Integration

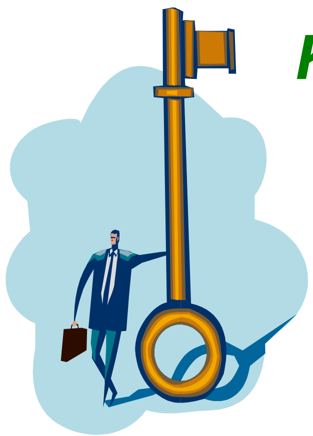
1. Upgrade low pressure (or waste) steam to supply process demands
2. Several plants need heating and cooling for process
3. Process integration can lead to significant energy savings opportunities and plant optimization
4. These opportunities will need significantly higher amounts of due-diligence

Key Points / Action Items – Steam Traps

1. There are different kinds of steam traps and hence, functionality and principles of operation must be understood
2. Major steam trap failure modes - open / closed
3. An effective steam trap management program must be in place
4. There are several commercially available tools for steam trap investigations
5. Conduct a steam trap audit at least once a year and repair/replace defective traps
6. Steam trap manufacturers are a valuable resource

Key Points / Action Items – Condensate Recovery

1. Returning condensate
   - Reduces energy
   - Reduces make-up water
   - Reduces chemicals for water treatment
   - Reduces quenching water
   - May reduce blowdown
2. Condensate recovery is often neglected but it can provide significant energy savings
3. Quantify the amount of condensate being recovered in a plant using a simple mass balance on the entire steam system
4. Identify potential areas of condensate recovery



Key Points / Action Items – Backpressure Turbines

1. Backpressure turbines are used instead of pressure letdown stations
2. Turbine efficiency is NOT 1st law efficiency but a comparison of actual turbine versus an ideal turbine
3. Continuous operations with a simultaneous thermal and electric demand are good candidates for backpressure turbines
4. Each facility analysis is unique and will depend on several economic as well as operating factors
5. Turbine analysis will need a solid thermodynamic steam system model

Key Points / Action Items – Condensing Turbines

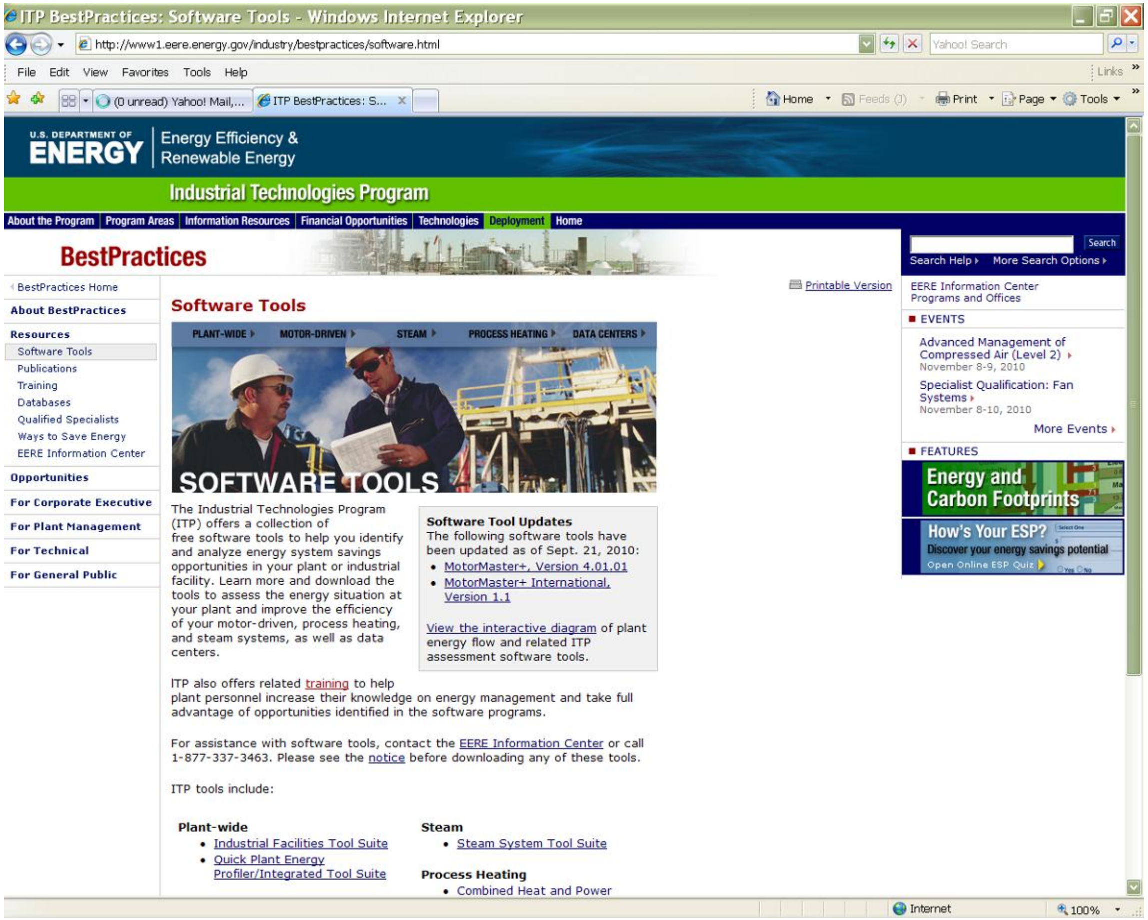
1. *Condensing turbines are used strictly for power generation or driving large mechanical equipment*
2. *They serve niche applications in the industry*
3. *Condensing turbines provide maximum shaft power per unit of steam flow*
4. *Each facility analysis is unique and will depend on several economic as well as operating factors*
5. *Turbine analysis will need a solid thermodynamic steam system model*

Tools & Resources

Tools

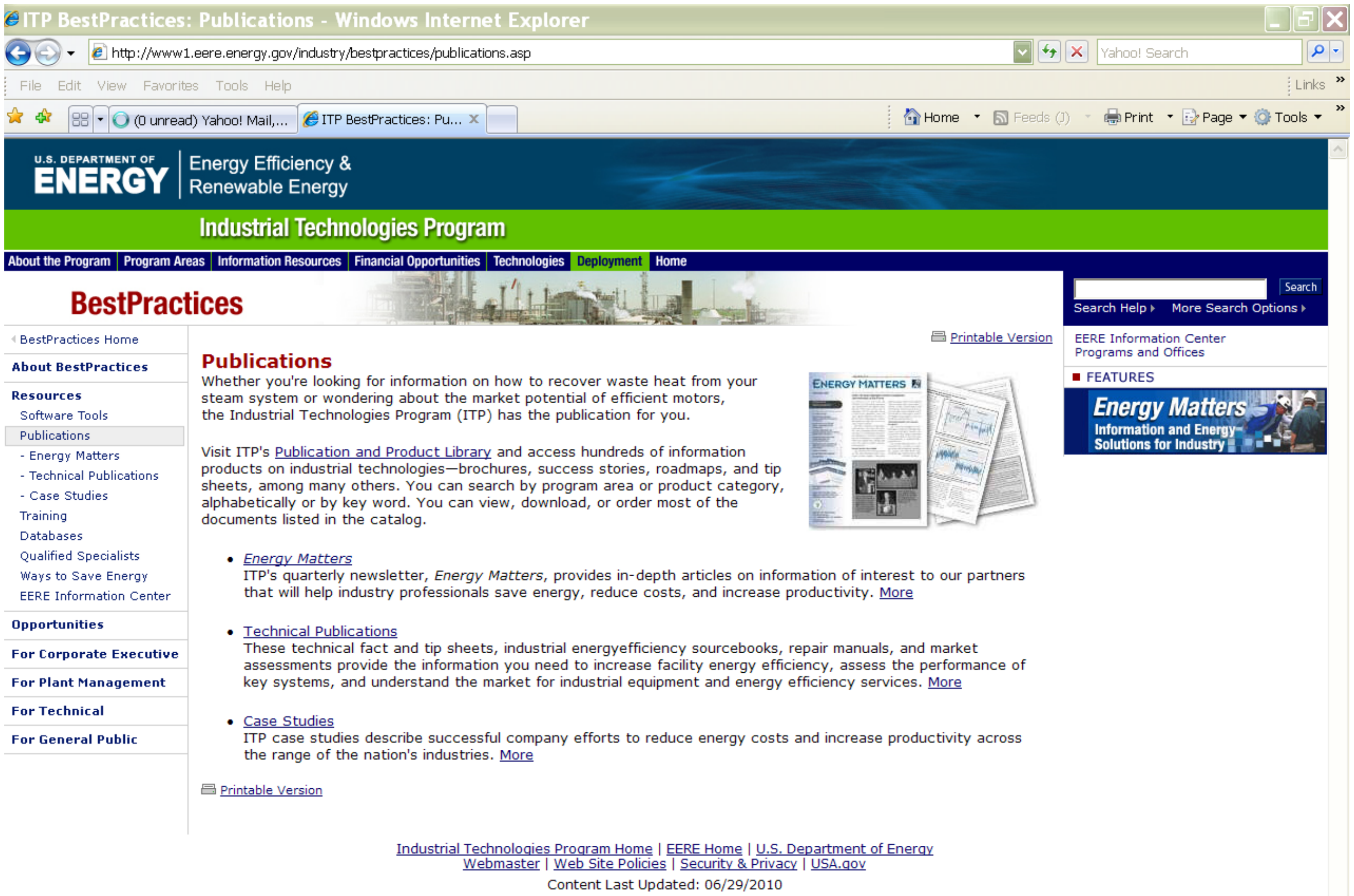
- In order to properly evaluate steam systems the physics of each process must be understood
  - Thermodynamics
  - Heat transfer
  - Fluid flow
- US DOE Tools Suite
  - Steam System Survey Guide
  - Steam System Scoping Tool (SSST)
  - Steam System Assessment Tool (SSAT)
  - Insulation evaluation software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

Where to Download the Tools



US DOE website -http://www1.eere.energy.gov/industry/bestpractices/software.html

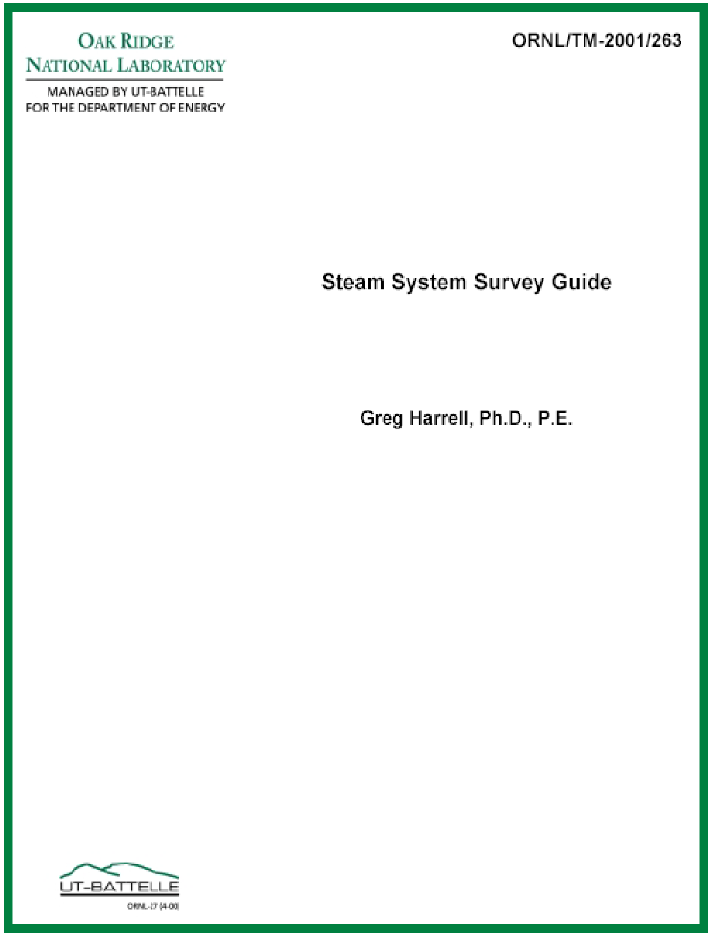
Technical Publications & Resources



http://www1.eere.energy.gov/industry/bestpractices/publications.asp

Steam System Survey Guide

- ✓ Technical Guide
- ✓ Covers 5 Areas:
  - Steam system profiling
  - Identifying steam properties
  - Improving boiler operations
  - Improving resource utilization
  - Improving steam distribution


OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2001/263

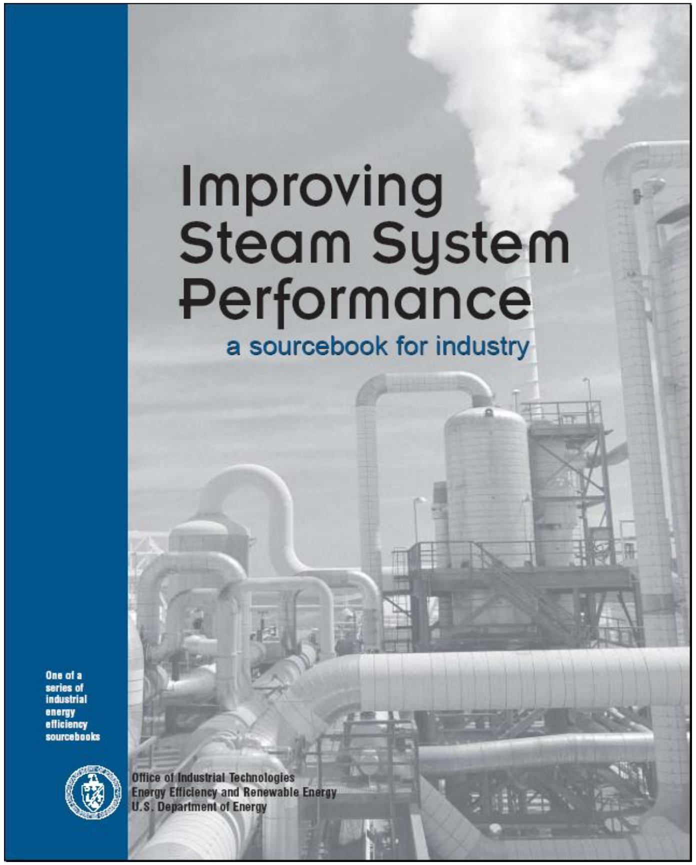
Steam System Survey Guide

Greg Harrell, Ph.D., P.E.

UT-BATTELLE

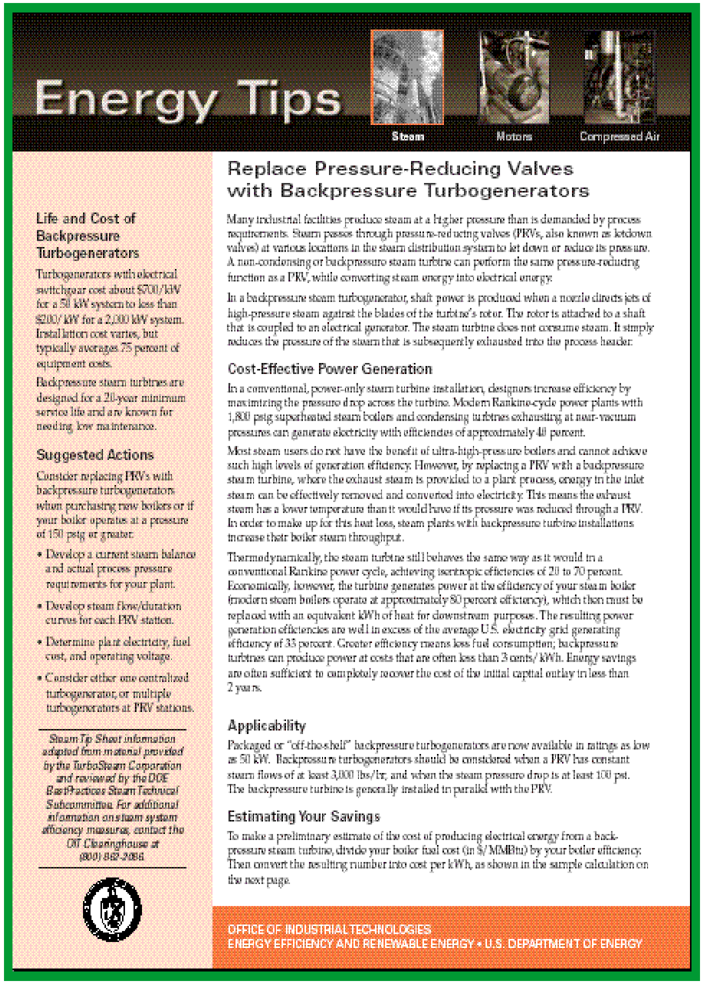
Steam System Sourcebook

- ✓ 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

Steam Motors Compressed Air

Replace Pressure-Reducing Valves with Backpressure Turbogenerators

Many industrial facilities produce steam at a higher pressure than is demanded by process requirements. Steam passes through pressure-reducing valves (PRVs, also known as letdown valves) at various locations in the steam distribution system to let down or reduce its pressure. A non-condensing or backpressure steam turbine can perform the same pressure-reducing function as a PRV, while converting steam energy into electrical energy.

In a backpressure steam turbogenerator, shaft power is produced when a nozzle directs jets of high-pressure steam against the blades of the turbine's rotor. The rotor is attached to a shaft that is coupled to an electrical generator. The steam turbine does not consume steam. It simply reduces the pressure of the steam that is subsequently exhausted into the process header.

Cost-Effective Power Generation

In a conventional, power-only steam turbine installation, designers increase efficiency by maximizing the pressure drop across the turbine. Modern Rankine-cycle power plants with 1,800 psig superheated steam boilers and condensing turbines exhausting at near-vacuum pressures can generate electricity with efficiencies of approximately 40 percent.

Most steam users do not have the benefit of ultra-high-pressure boilers and cannot achieve such high levels of generation efficiency. However, by replacing a PRV with a backpressure steam turbine, where the exhaust steam is provided to a plant process, energy in the inlet steam can be effectively removed and converted into electricity. This means the exhaust steam has a lower temperature than it would have if its pressure was reduced through a PRV. In order to make up for this heat loss, steam plants with backpressure turbine installations increase their boiler steam throughput.

Thermodynamically, the steam turbine still behaves the same way as it would in a conventional Rankine power cycle, achieving isentropic efficiencies of 20 to 70 percent. Economically, however, the turbine generates power at the efficiency of your steam boiler (modern steam boilers operate at approximately 80 percent efficiency), which then must be replaced with an equivalent kWh of heat for downstream purposes. The resulting power generation efficiencies are well in excess of the average U.S. electricity grid generating efficiency of 33 percent. Greater efficiency means less fuel consumption; backpressure turbines can produce power at costs that are often less than 3 cents/kWh. Energy savings are often sufficient to completely recover the cost of the initial capital outlay in less than 2 years.

Applicability

Packaged or "off-the-shelf" backpressure turbogenerators are now available in ratings as low as 50 kW. Backpressure turbogenerators should be considered when a PRV has constant steam flows of at least 3,000 lbs/hr, and when the steam pressure drop is at least 100 psi. The backpressure turbine is generally installed in parallel with the PRV.

Estimating Your Savings

To make a preliminary estimate of the cost of producing electrical energy from a backpressure steam turbine, divide your boiler fuel cost (in $/MMBtu) by your boiler efficiency. Then convert the resulting number into cost per kWh, as shown in the sample calculation on the next page.

Life and Cost of Backpressure Turbogenerators

Turbogenerators with electrical switchgear cost about $700/kW for a 50 kW system to less than $200/kW for a 2,000 kW system. Installation cost varies, but typically averages 75 percent of equipment costs.

Backpressure steam turbines are designed for a 20-year minimum service life and are known for needing low maintenance.

Suggested Actions

Consider replacing PRVs with backpressure turbogenerators when purchasing new boilers or if your boiler operates at a pressure of 150 psig or greater:

- Develop a current steam balance and actual process pressure requirements for your plant.
- Develop steam flow/duration curves for each PRV station.
- Determine plant electricity, fuel cost, and operating voltage.
- Consider either one centralized turbogenerator, or multiple turbogenerators at PRV stations.

Steam Tip Sheet information adapted from material provided by the TurboSteam Corporation and reviewed by the DOE BestPractices Steam Technical Subcommittee. For additional information on steam system efficiency measures, contact the OIT Clearinghouse at (800) 862-2086

OFFICE OF INDUSTRIAL TECHNOLOGIES
ENERGY EFFICIENCY AND RENEWABLE ENERGY • U.S. DEPARTMENT OF ENERGY

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
- Minimize Boiler Short Cycling Losses
- Recover Heat from Boiler Blowdown
- Replace Pressure-Reducing Valves with Backpressure Turbogenerators
- 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

US DOE Technical Documents

- Improving Steam System Performance: A Sourcebook for Industry
- Achieve Steam System Excellence: Industrial Technologies Program BestPractices Steam Overview Fact Sheet
- BestPractices Steam Technical Brief: Steam Pressure Reduction-Opportunities and Issues
- BestPractices Steam Technical Brief: How to Calculate the True Cost of Steam
- BestPractices Steam Technical Brief: Industrial Heat Pumps for Steam and Fuel Savings
- BestPractices Steam Technical Brief: Industrial Steam System Heat-Transfer Solutions
- BestPractices Steam Technical Brief: Industrial Steam System Process-Control Schemes
- Guide to Combined Heat and Power Systems for Boiler Owners and Operators
- Guide to Low-Emission Boiler and Combustion Equipment Selection
- Review of Orifice Plate Steam Traps
- Save Energy Now in Your Steam Systems
- Steam Digest: Volume IV (2003)
- Steam Digest 2002
- Steam Digest 2001
- Steam Systems Energy Efficiency Handbook
- Steam Systems Survey Guide

Course Evaluation & Feedback

Your input is greatly appreciated and it will be acted upon to refine this training program as well as better provide further complementary technical assistance to be offered by the UNIDO project to Egyptian Engineers and Enterprises

THANK YOU !