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U.S. DEPARTMENT OF ENERGY

Leading Technical Solutions for Energy Systems: Expert-led Seminars Covering Steam Pumps, Process Heating, and Compressed Air

Better Buildings Summit

Monday, May 9, 2016

Better Plants
U.S. DEPARTMENT OF ENERGY

The Economic Impact Of Pumping System Control Choices

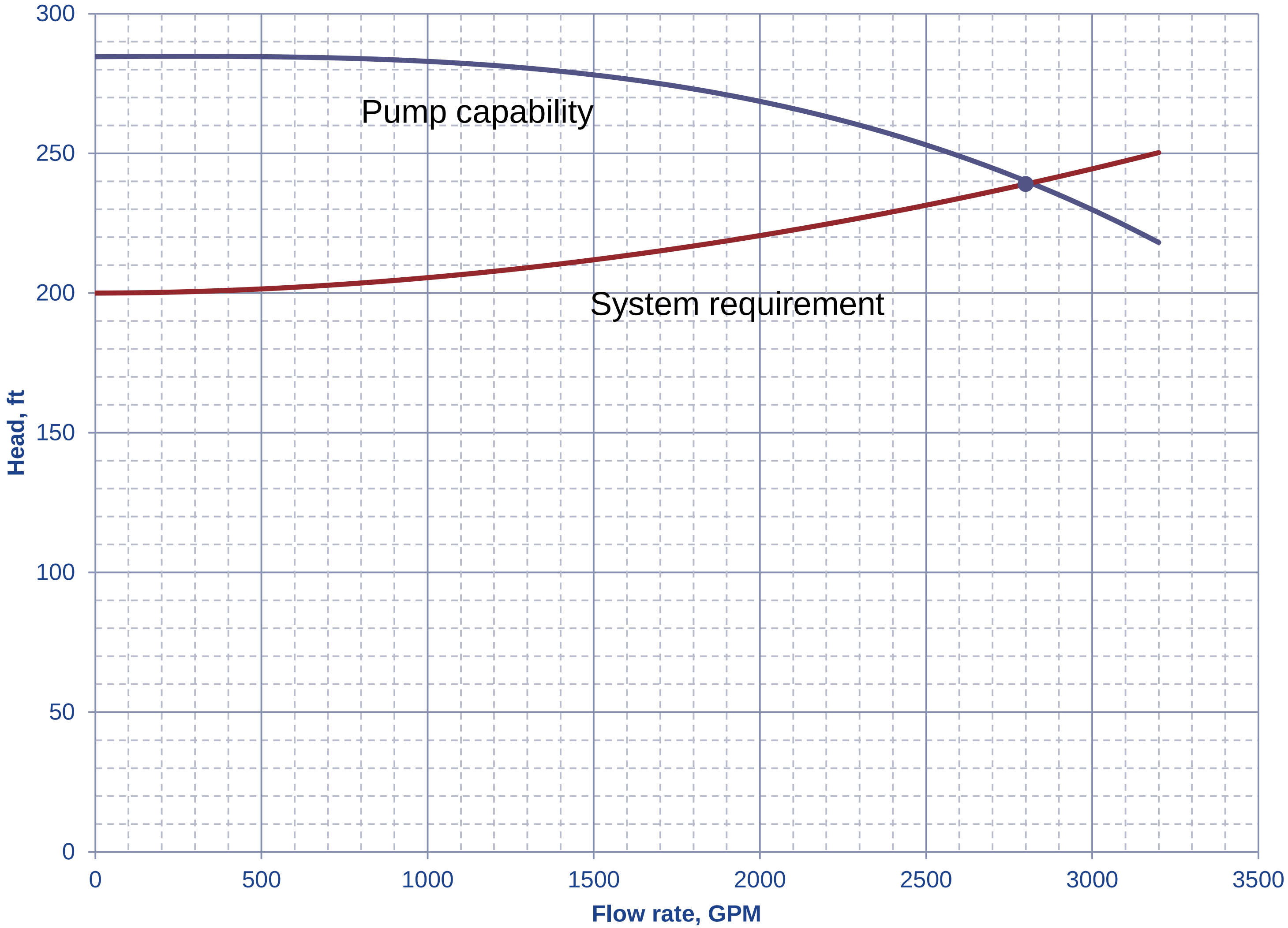
May 7, 2016

U.S. DEPARTMENT OF ENERGY

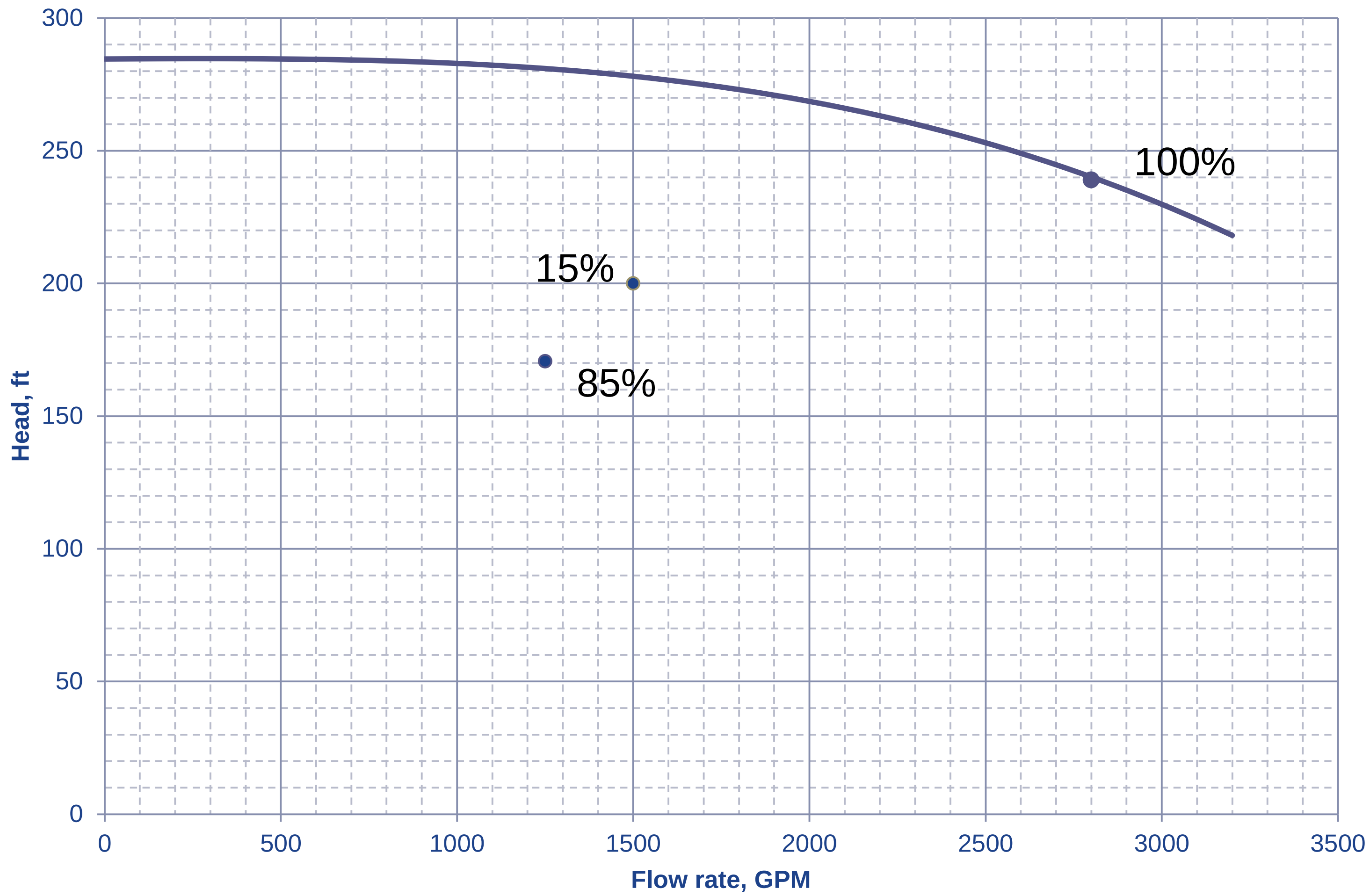
Change can create opportunity for improvement

- New process
- New product line
- Facility purchased or acquired in merger

Original application



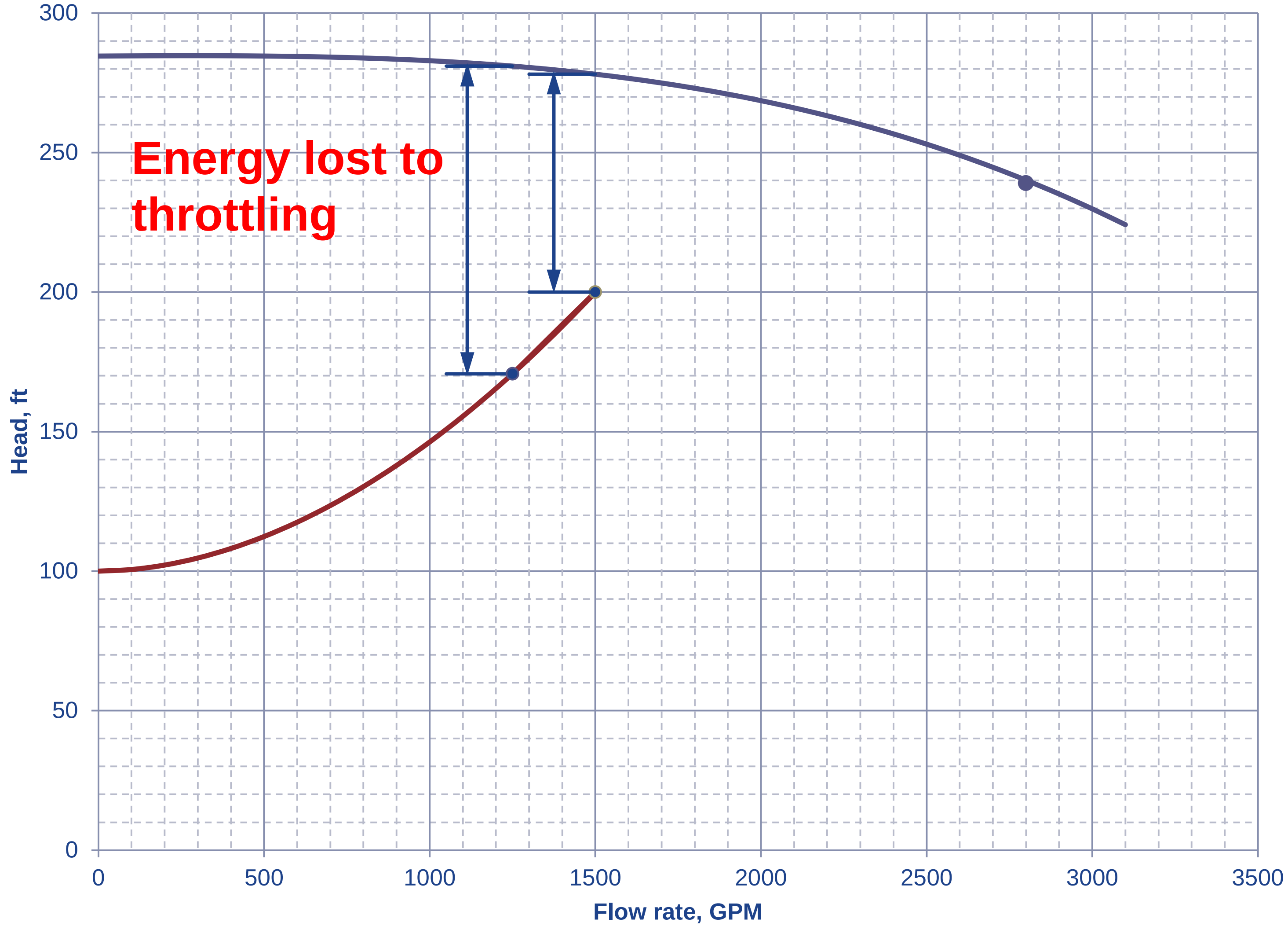
The operating point changed since the original design



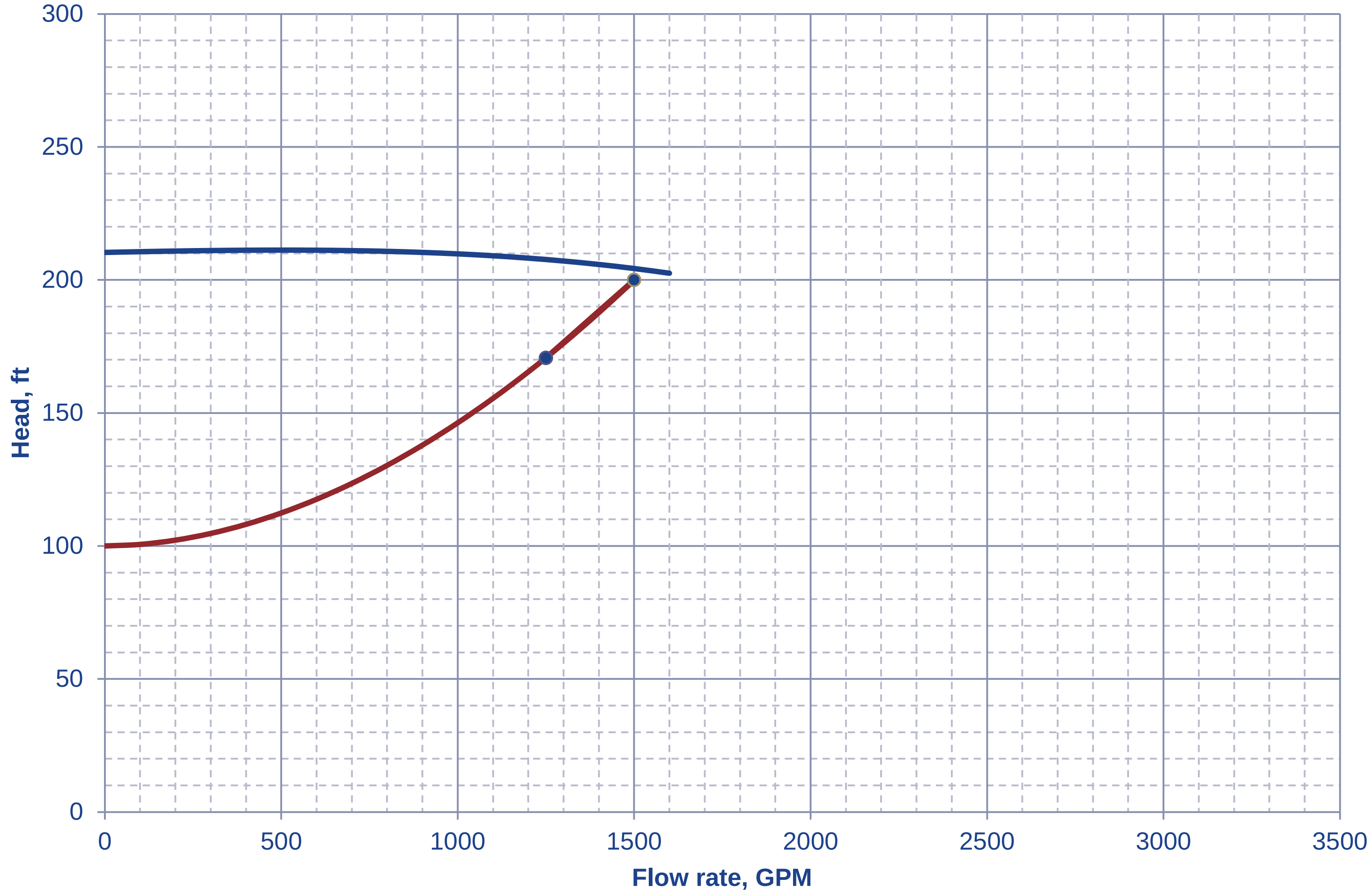
Options

- Throttle the discharge valve
- Trim the impeller
- Control pump speed with a variable speed drive
- Replace the pump

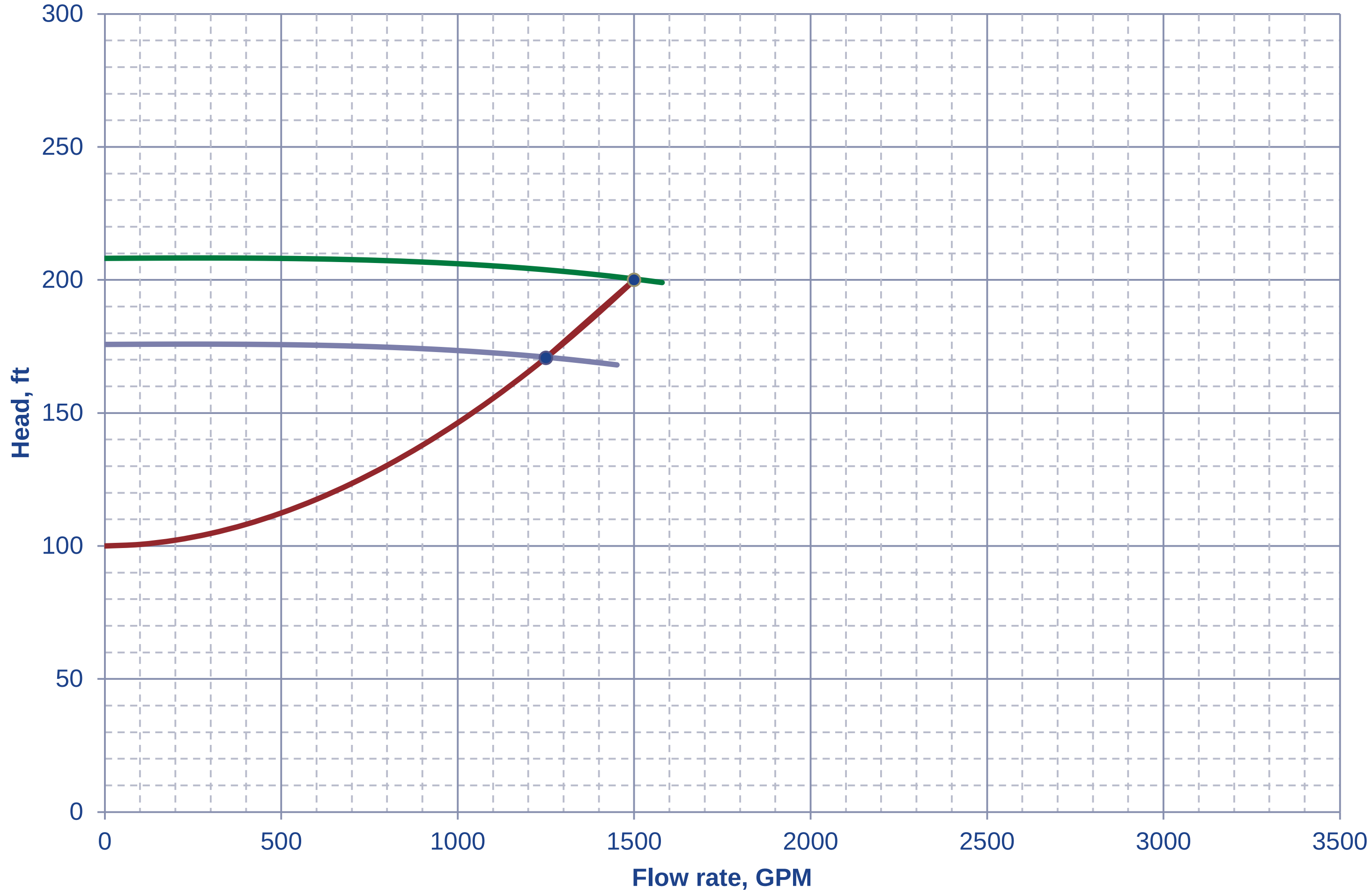
Original pump – throttle discharge



Combined impeller trim and throttle control



Match requirements with speed control



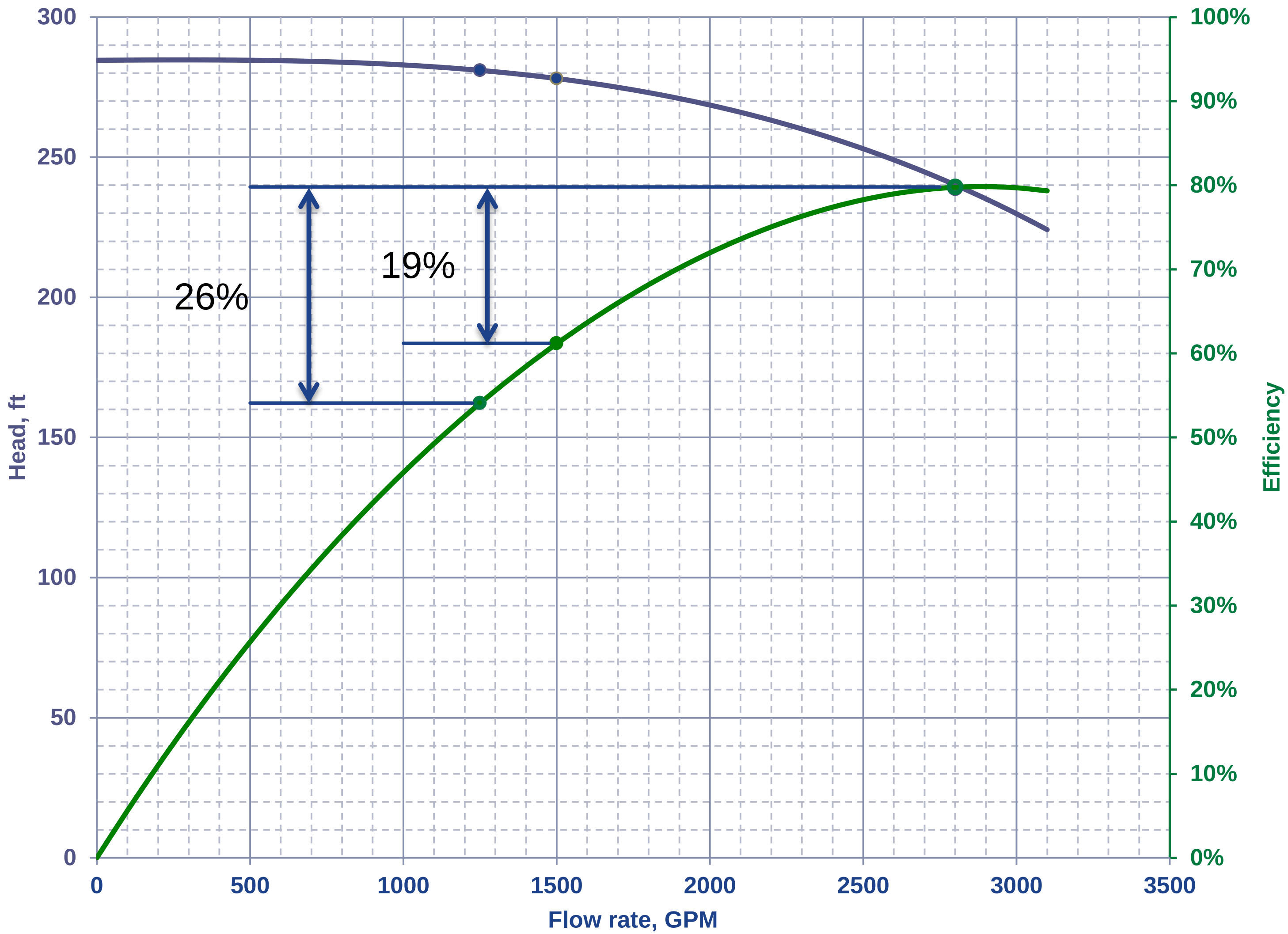
Implementation cost and recovery

Option	Initial cost, $	Annual operation, $	Annual savings, $	Cost recovery (years)
Throttle discharge	—	78,500	0	–
Impeller trim	5,100	43,900	34,600	0.15
Speed control (VFD)	30,000	40,800	37,700	0.80

Considerations

Option	Pros	Cons
Throttle discharge	• No cost • Easily reversible	• Most expensive option • Manual response to system changes
Impeller trim	• Easy to install • Minimum impact to system availability • 92% of VFD savings	• Some throttling still required • Manual response to system changes
Speed control (VFD)	• Greatest flexibility • Largest savings • Automatically responds to system changes	• Expensive
New Pump	• Higher pump efficiency	• Some throttling still required • Manual response to system changes

The cost of change



Compare with motor efficiency

250 hp, 1800 rpm, TEFC,600V class induction motor efficiencies*

Efficiency rating	Minimum	Nominal
Energy Efficient	94.1	95
Premium Efficiency	95.4	96.2

*NEMA MG 1-2014, Tables 12-11 and 12-12

Questions

Why Not Use Bypass Flow Control?

$$\text{Brake hp} = \frac{\text{Flow rate (gpm)} * \text{head}\left(\text{ft}\right) * \text{specific gravity}}{3960 * \text{pump efficiency}}$$

Parameter	Throttled	Bypass
Flow rate (gpm)	1500	2800
Head (ft)	278.1	240.1
Pump efficiency (%)	61.2	79.8
Brake hp	**172.1**	**212.7**

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CAES
CENTER FOR ADVANCED ENERGY SYSTEMS

A “smart” approach to managing compressed air systems”

Michael R. Muller
Professor and Director
Center for Advanced Energy Systems

Not another Compressed Air Talk!

Oh No!

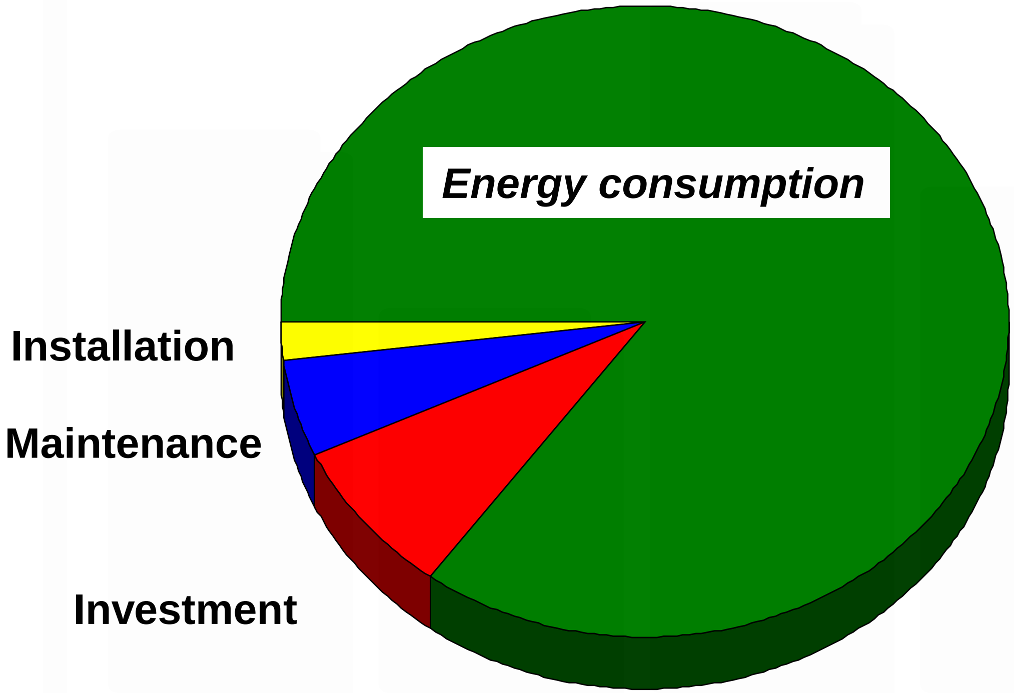
Lower Air Pressure

Sequence Multiple Compressors

Fix Air Leaks

Cold Air at Intake

Life Cycle Cost of an air compressor

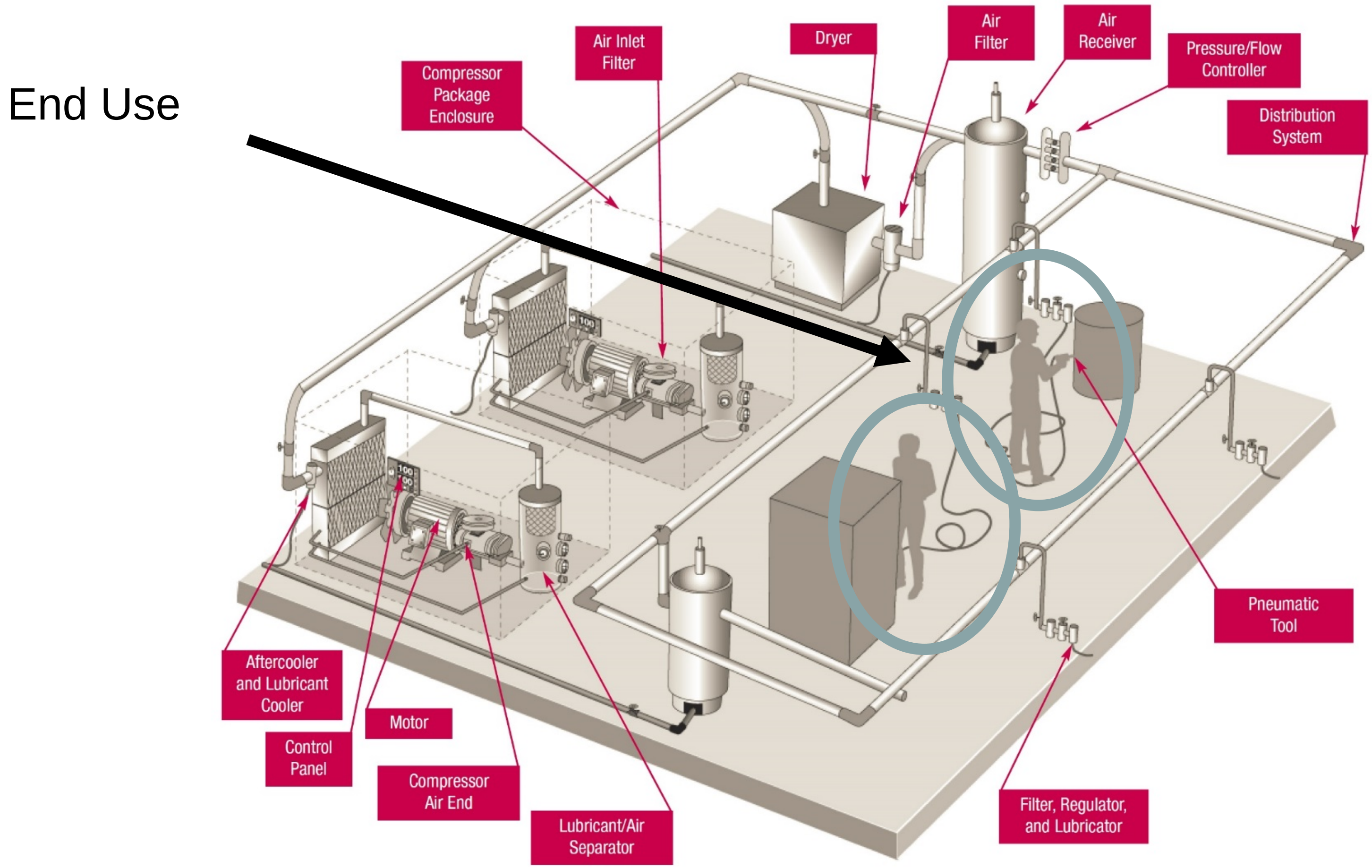


- Energy consumption by far is the most significant factor in operating cost of an air compressor
- Energy cost can account for up to 90% over a ten year working life
- Within 12 months, the capital cost is usually exceeded by the running costs

OK, so the need to manage air use is obvious

Strategies for system improvement

- System includes generation, distribution and end use



Today's Focus

- End Use
  - Known (as much as possible)
  - Appropriate
  - Best practice
- Smart Operations
  - Enough information
  - Not too much information

Enduse: Actuators

- Wide variety of types and air use
- Length of motion and frequency of motio… determine CF…
- Can be 1… material h…
- We are seei… …e reduction in use

Very difficult to account for air use

Enduse: Hand tools

- Again, variety in both type of tool, use of tool
- Battery powered to[illegible] are competing[illegible]
  - Weigh[illegible]
  - Have les[illegible]
  - Batteries ru[illegible]

Very difficult to account for air use

AIR TOOL	AVERAGE CFM @ 90 PSI
7" Angle Grinder	5-8
Brad Nailer	[illegible]
Chisel/Hammer	[illegible]
Cut-off To[illegible]	[illegible]
Dri[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	4
[illegible]	4
[illegible]rench	2.5-4
[illegible]pact Wrench	4-5
1" Impact Wrench	10
Mini Die Grinder	4-6
Needle Scaler	8-16
Nibbler	4
Orbital Sander	6-9
1/4" Ratchet	2.5-4
3/8" Ratchet	4-5
Rotational Sander	8-12.5
Shears	8-16
Speed Saw	5

Enduse: big users

- Air knives
- Spot coolers
- Sandblasting
- Paint spraying
- Sparging
- Injection
- Aeration
- Oxygen generation

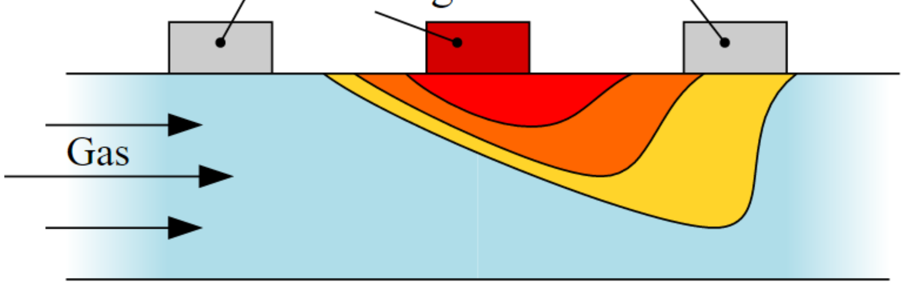
Should be able to account for air use

What is going to happen

- Compressed air is not going away
  - Lighter and smaller tools than those that are electrically operated
  - Smooth power, equipment is not damaged by overloading
  - Variable speed and torque control
  - Do not have potential hazards of electric tools
- End Use Accounting by individual end use is not being done and likely not worth the effort
- Accounting CAN be done by using strategic flow measurement throughout the system

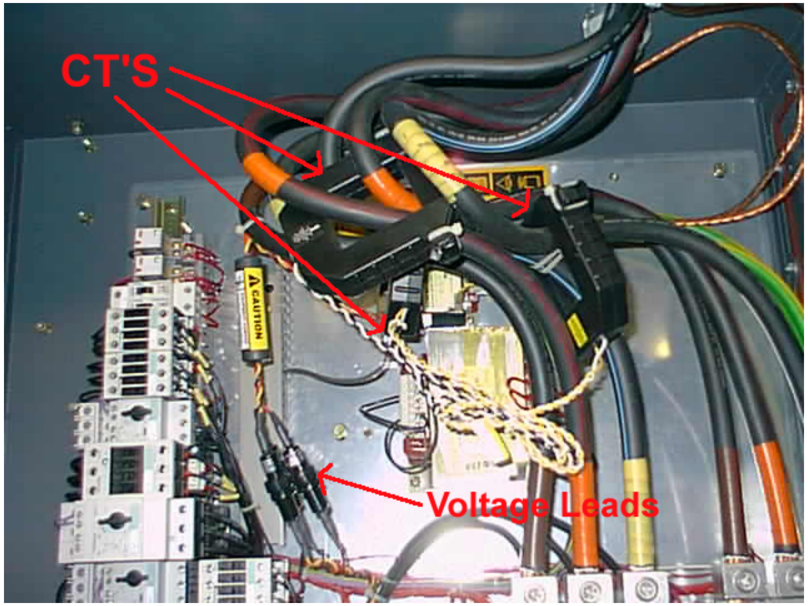
Compressed Air Flow Meters

- Thermal Dispersion is taking hold
- Hot Tapping getting easy



Benchmark Your System's Efficiency = benchmark generation

CT = Current Transformer



- kWh/MCF
- One flow rate needed

Data sheets give benchmark

COMPRESSOR DATA SHEET
Rotary Compressor: Fixed Speed

MODEL DATA - FOR COMPRESSED AIR			
1	Manufacturer: [illegible]		
2	Model Number: [illegible]	Date:	12/13/2011
	[X] Air-cooled [ ] Water-cooled	Type:	Screw
	[X] Oil-injected [ ] Oil-free	# of Stages:	1
3*	Rated Capacity at Full Load Operating Pressure [a, e]	414	acfm [a,e]
4	Full Load Operating Pressure [b]	125	psig [b]
5	Maximum Full Flow Operating Pressure [c]	132	psig [c]
6	Drive MotorNominal Rating	100	hp
7	Drive Motor Nominal Efficiency	95.1	percent
8	Fan Motor Nominal Rating (if applicable)	5.1	hp
9	Fan Motor Nominal Efficiency	83	percent
10*	Total Package Input Power at Zero Flow [e]	24.8	kW [e]
11	Total Package Input Power at Rated Capacity and Full Load Operating Pressure [d]	87.0	kW [d]
12*	Specific Package Input Power at Rated Capacity and Full Load Operating Pressure [e]	21.0	kW/100 cfm [e]

*For models that are tested in the CAGI Performance Verification Program, these items are verified by the third party administrator.
Consult CAGI websitefor a list of participants in the third party verification program: www.cagi.org

Member:

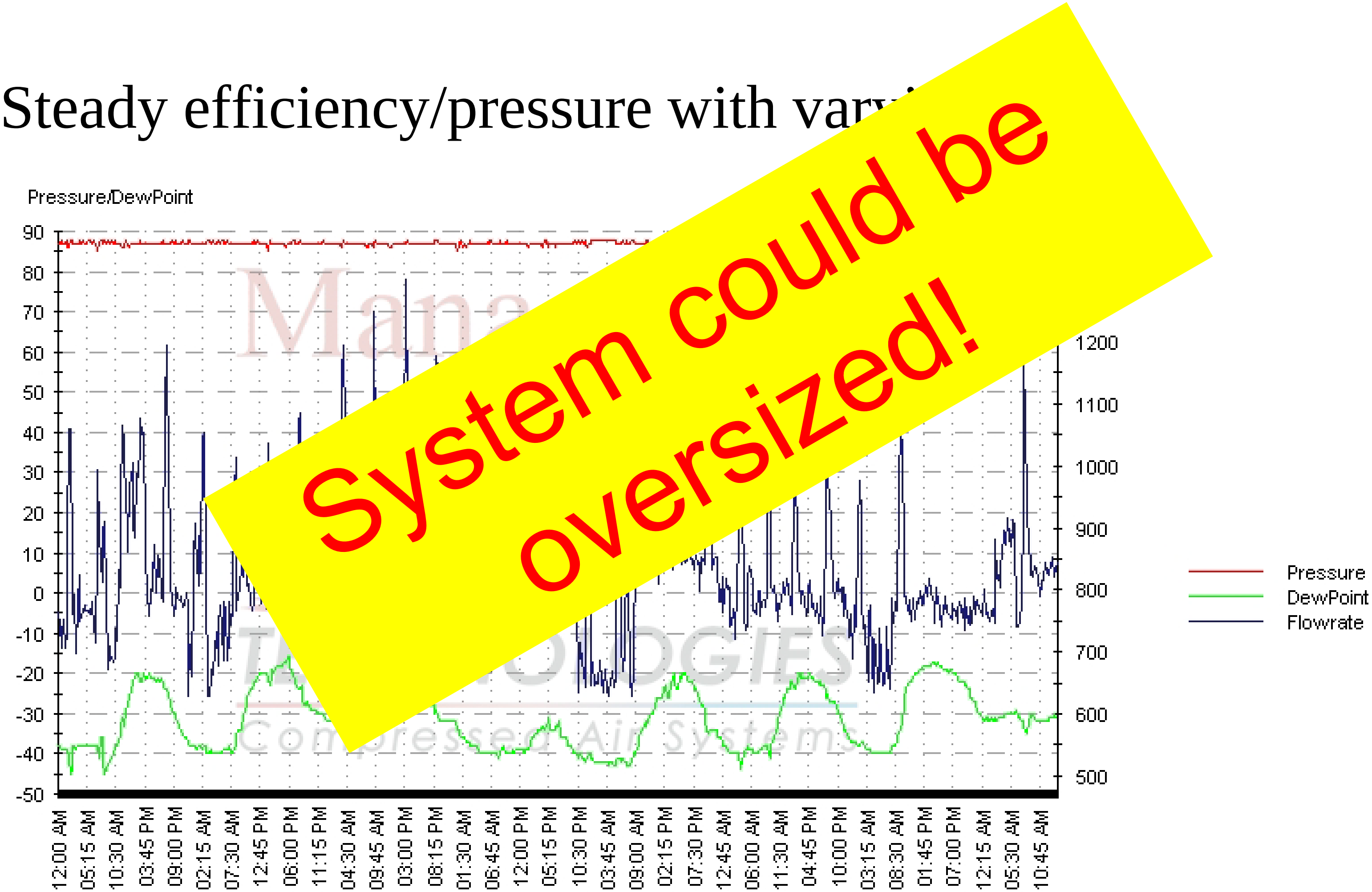
NOTES:
a. Measured at the discharge terminal point of the compressor package in accordance with ISO 1217, Annex C; ACFM is actual cubic feet per minute at inlet conditions.
b. The operating pressure at which the Capacity (Item 3) and Electrical Consumption (Item 11) were measured for this data sheet.
c. Maximum pressure attainable at full flow, usually the unload pressure setting for load/no load control or the maximum pressure attainable before capacity control begins. May require additional power.
d. Total package input power at other than reported operating points will vary with control strategy.
e. Tolerance is specified in ISO 1217, Annex C, as shown in table below:

Volume Flow Rate at specified conditions		Volume Flow Rate	Specific Energy Consumption	No Load / Zero Flow Power
m^3 / min	ft3 / min	%	%	
Below 0.5	Below 15	+/- 7	+/- 8	+/- 10%
0.5 to 1.5	15 to 50	+/- 6	+/- 7	
1.5 to 15	50 to 500	+/- 5	+/- 6	
Above 15	Above 500	+/- 4	+/- 5	

ROT 030

Good Case

- Steady efficiency/pressure with vary



Lousy result – pressure being used as storage

Receiver Tanks

- Used to store compressed air to satisfy peak demand.
- Prevents large fluctuations in pressure when demand is high.
- Generally sized to store 10 seconds of compressor capacity. For example:
    - 25 hp compressor x 4 cfm/hp = 100 cfm
    - 100 cfm x 10/60 min = 17 ft^3
- Can FILL with water
    - install either a manual or automatic drain on the receiver tank to remove water from the system

Smart Draining

- Automated, reporting with alarms
- No air loss
- Feedback on dryer performance

What is this and why do we care?

FRL

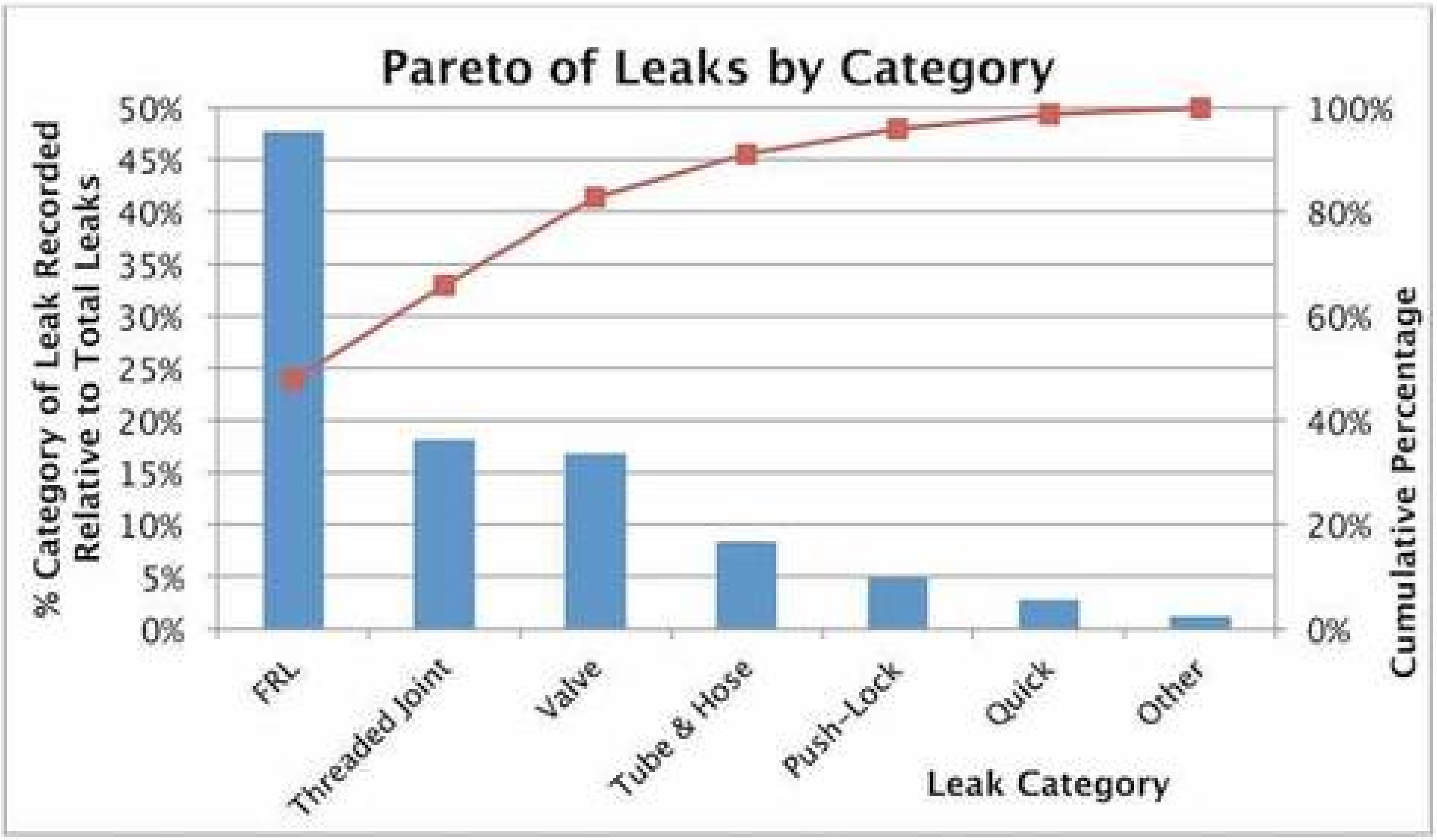
Pressure Regulator

Filter

Lubricator

FRL's

- Primary source of system leaks



“SMART” FRL

Step One, Flow Meters; Step two, Wireless

- Emerson Process Management system on existing flow meters
- Case Study: Dubai Aluminum Company Limited connected 20 Rosemount wireless transmitters onto its existing, hardwired air flow meters
- The wireless transmitters form a self-organizing field network transmitting to a Smart Wireless Gateway.
- Installation was completed in less than three weeks without removing and reinstalling equipment or shutting down operations.
  - Each device was commissioned in only 15 to 20 minutes

Step One, Flow Meters; Step two, Wireless

- Wireless systems will become inexpensive (not yet)
- Cloud systems seem easiest (with security concerns)
- Protocols come from wired controls (some date to the 1980's)
  - HART (Highway Addressable Remote Transducer)
  - Profibus DP/PA
  - Foundation fieldbus
- Lack of standardization is hurting implementation

Rosemount 3051s Wireless

Daily System Report and graph faxed or e-mai[illegible]l to you [illegible]tically

Manag*AIR*® by *Air Technologies*®

System Report for
Alarm: No Faults Detected
Current System Readings- Pressure=108 Flowrate=1347 Sequence=2,1,3

Previous 8hrs Data:	Hour1	Hour2	Hour3	Hour4	Hour5	Hour6	Hour7	Hour8
Min Pressure	104	104	104	104	104	104	104	104
Avg Pressure	108	108	109	109	109	109	109	109
Max Pressure	114	114	114	114	114	114	114	114
Min FlowRate	1274	1274	1311	1322	1324	1349	1311	1305
Avg FlowRate	1448	1468	1648	1647	1739	1870	1644	1718
Max FlowRate	2274	2298	2504	2485	2545	2629	2409	2432
Min DewPoint	-44	-43	-43	-43	-40	-36	-32	-21
Avg DewPoint	-41	-41	-36	-40	-37	-33	-25	-15
Max DewPoint	-39	-39	-11	-37	-35	-30	-19	-10

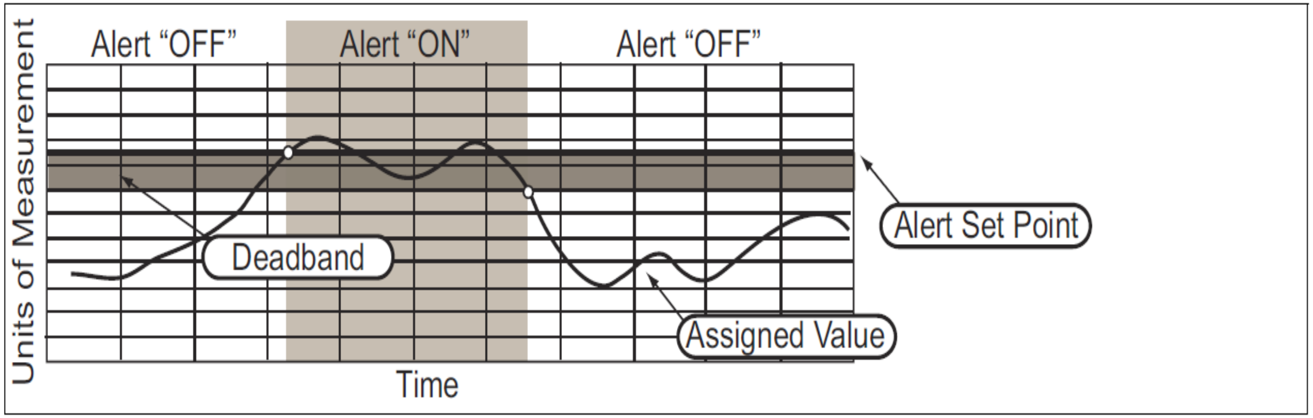
Compressor Data	#1 ZT25	#2 ZT25	#3 ZT25	NONE	NONE	NONE	NON[illegible]
Delivery Air Press	110	113	107				
DP Air Filter	-.01	-.1	.01				
Intercooler Pressure	-9	30	1				
Oil Injection Press	28	28	0				
Delivery Air Temp	93	93	86				
Oil Injection Temp	122	124	90				
LP Outlet Temp	351	352	95				
HP Outlet Temp	363	372	91				
HP Inlet Temp	99	104	[illegible]				
Cooling Medium Inlet Temp	91	91	[illegible]				
MD Regen Air Out Temp	129	[illegible]	[illegible]				
MD Wet Air In Temp	97	[illegible]	[illegible]				
LP Element Temp Rise	[illegible]	[illegible]	[illegible]				
HP Element Temp Rise	[illegible]	[illegible]	[illegible]				
Cooling Water Temp Rise	[illegible]	[illegible]	[illegible]				
Oil Cooler Approach Temp	[illegible]	[illegible]	[illegible]				
Aftercooler Approach Temp	[illegible]	[illegible]	0				
Intercooler Approach Temp	[illegible]	[illegible]	5				
MD Regen Temperature Drop	234	210	7				
MD Inlet Temperature Diff	4	6	-5				
Loaded Hours	7358	7579	8773				
Running Hours	11048	11616	12606				
Compressor Status	UNLOADED	LOADED	STOPPED				
Motor Starts	1717	1042	1060				
Link Type	MKIII	MKIII	MKIII				
Isolated/Integrated	CENTRAL	CENTRAL	CENTRAL				
Full Feature Dew Point							
Oil Filter Remaining Lifetime	2423	1413	952				
Oil Filter Total Lifetime	4000	4000	4000				
Oil Remaining Lifetime	4952	4383	3475				
Oil Total Lifetime	16000	16000	16000				
Hours Until Regrease Bearings	848	286	3471				
Hours Between Bearing Regreasing	4000	4000	4000				

TMI ... TLDR...

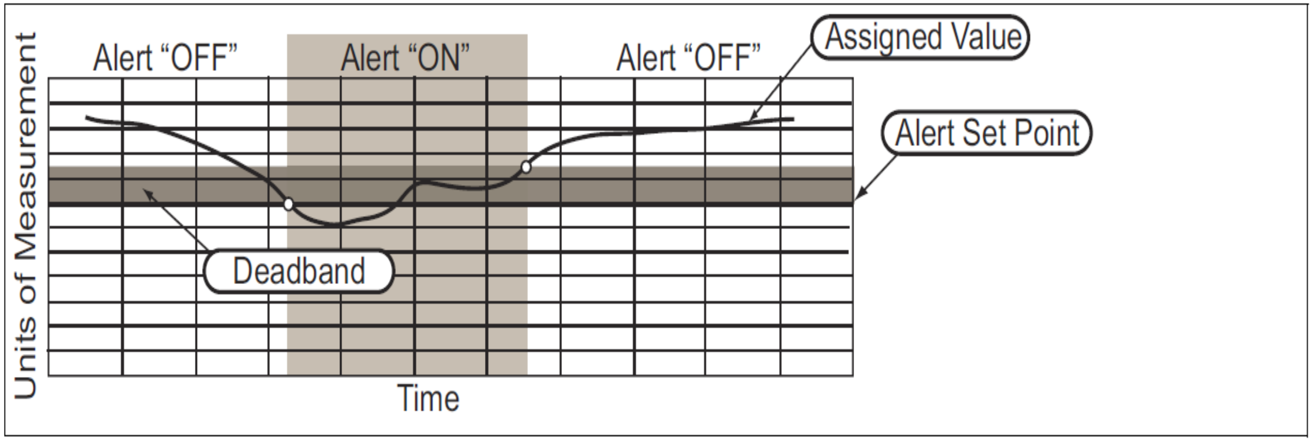
Important that data do two things

- Tracking
  - trending
- Alarms
  - email

Example 1: Alerts Rising



Example 2: Alerts Falling



Siemens Intosite

- PLM (process life cycle) software
- Mapping/GIS on the plant floor
- There is an APP for that!

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Energy Efficiency Improvements in Process Heating Equipment

Better Buildings Summit 2016
Washington DC

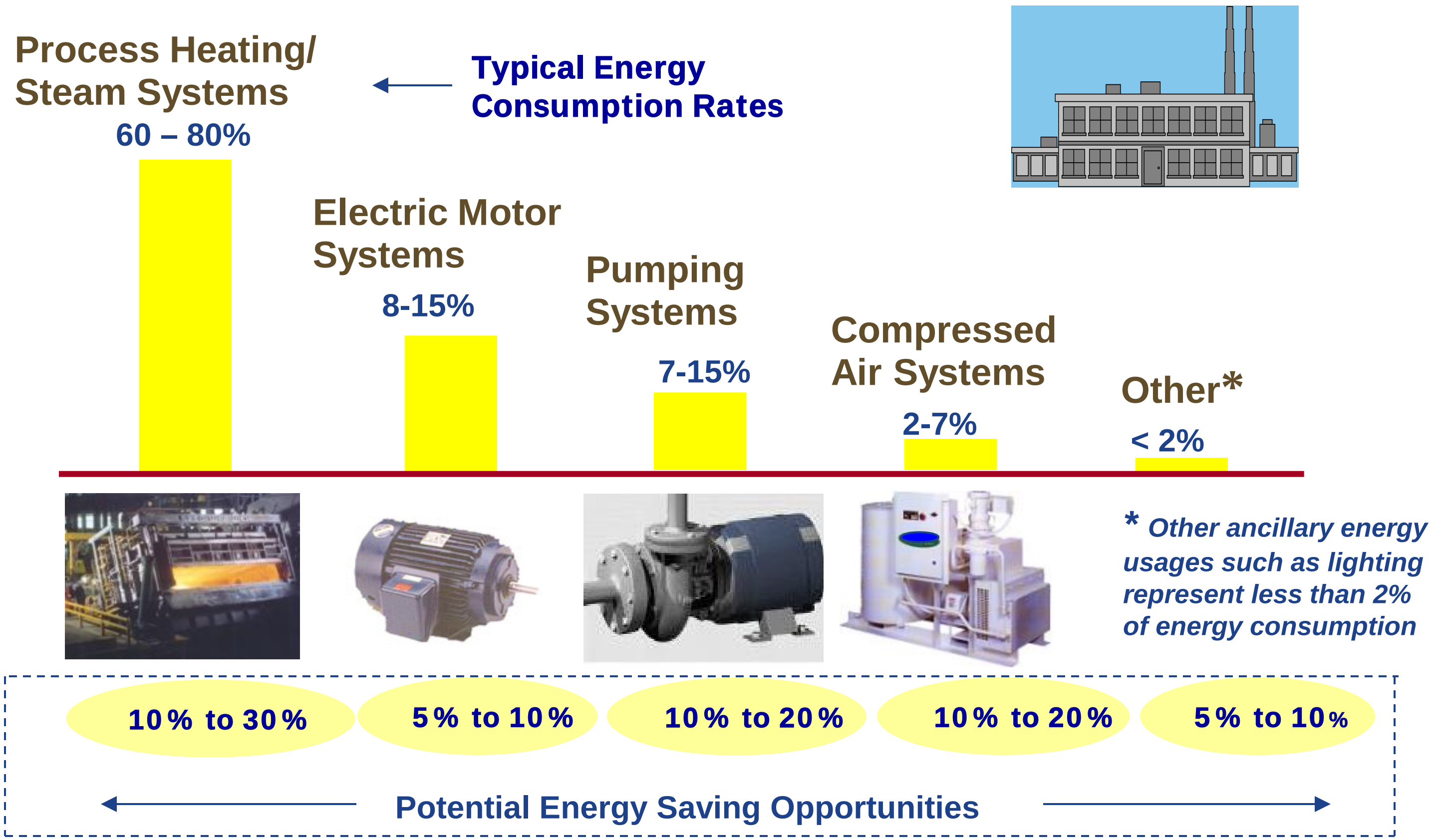
Monday, May 9th, 2016
3:45 to 5:00 pm EST

Sachin Nimbalkar, PhD
Oak Ridge National Laboratory

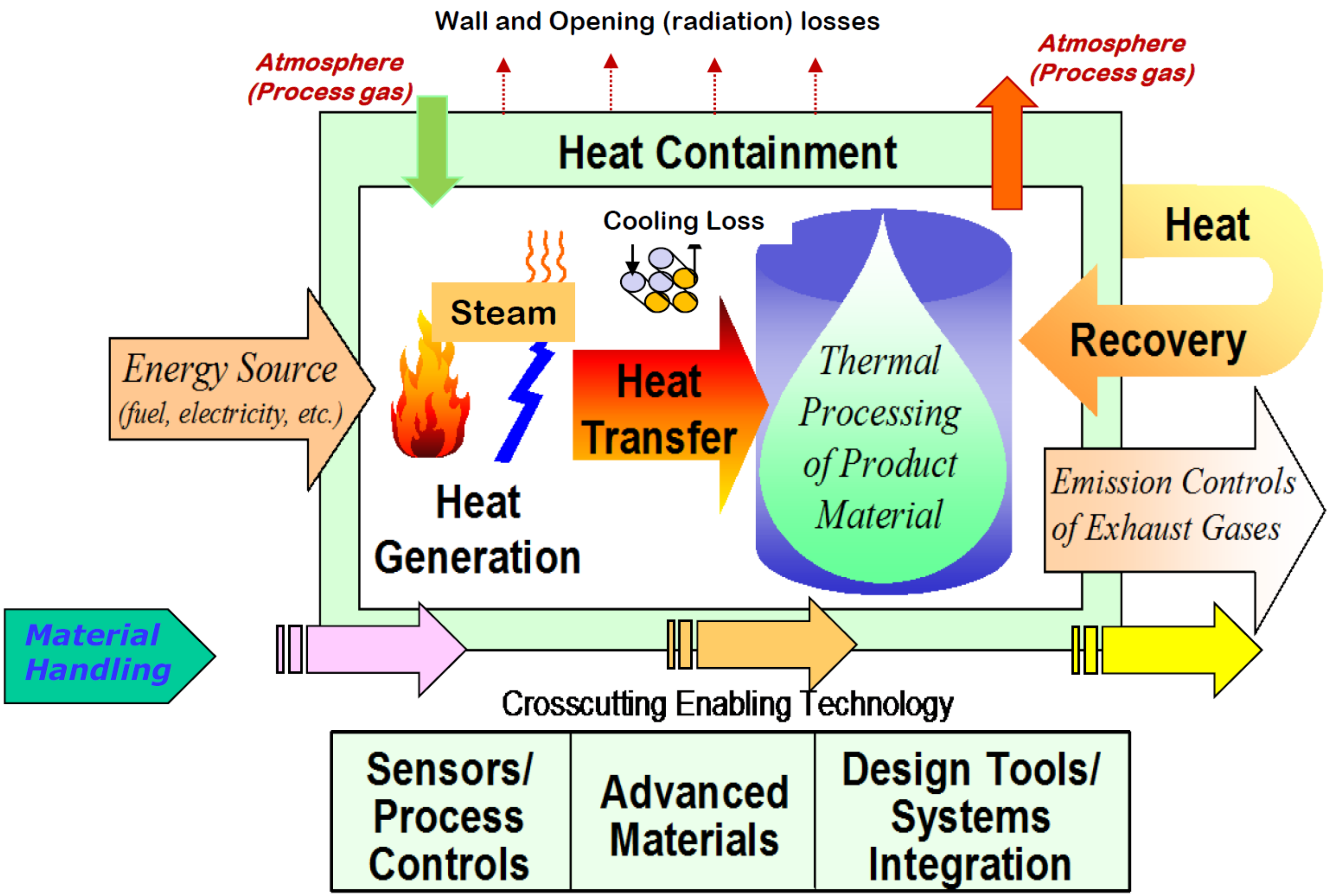
Arvind Thekdi, PhD
E3M Inc. (PH Expert)

U.S. DEPARTMENT OF ENERGY

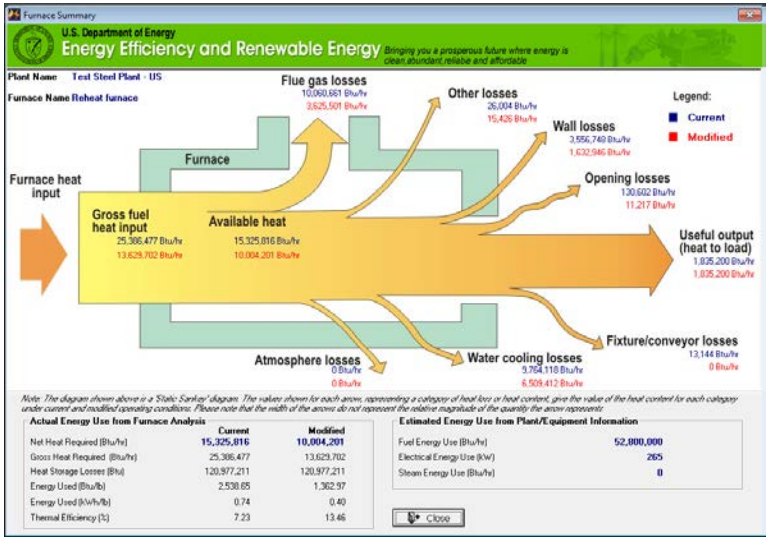
Energy Consumption and Savings Potential



Process Heating System Components



Major Areas for Energy Savings Potential in Process Heating System



1. Load/charge material
2. Material handling
3. Heat supply/heat generation (combustion system, electric, and other)
4. Furnace exhaust and heat recovery
5. Furnace-oven walls
6. Furnace openings and doors
7. Water or air cooling (furnace internals – if any)
8. Control system
9. Auxiliary systems
10. Other losses (i.e. atmosphere, makeup air, ex-filtration of gases etc.)

Range of Energy Use and Savings Potential

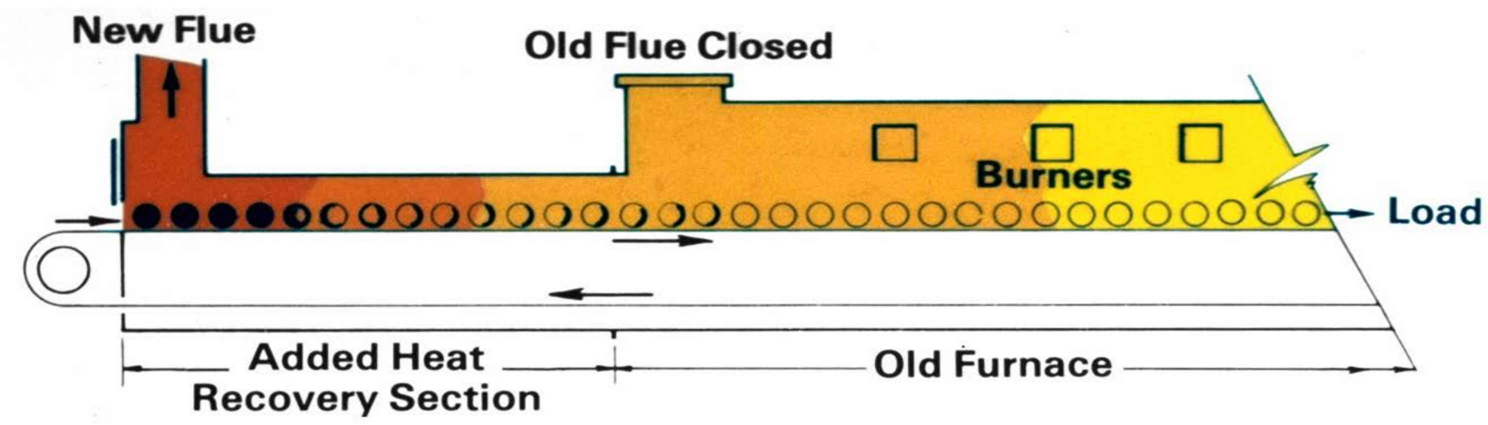
Area of energy use or loss	Range of energy use as % of the input	Range of energy savings use as % of energy use
Load/charge material	15 to 75	0 to 25
Material handling	0 to 20	0 to 50
Heat supply/heat generation (combustion system, electric, and other)	N/A	0 to 50
Furnace exhaust and heat recovery	10 to 60	0 to 50
Furnace-oven walls	2 to 15	0 to 25
Furnace openings and doors	0 to 20	0 to 100
Water or air cooling (furnace internals – if any)	0 to 15	0 to 50
Control system	N/A	0 to 10
Auxiliary systems	2 to 10	0 to 25
Other losses (i.e. atmosphere, makeup air, ex-filtration of gases etc.)	0 to 50	0 to 50

Note: The exact values depend on a number of factors and they can be obtained only by conducting a good heat balance. The US DOE tool – PHAST can be used effectively to prepare a heat balance and estimate range of values.

1. Load Charge Material

- Hot charging of the load where possible
- Preheating of the load or charge:
  - External preheating
    - Using heat from furnace flue gases
    - Using auxiliary preheating
  - Internal preheating
- Drying or moisture removal
- Charging at or near design capacity and frequency
- Proper load arrangement for optimum heat transfer
- Use of new processes and technologies

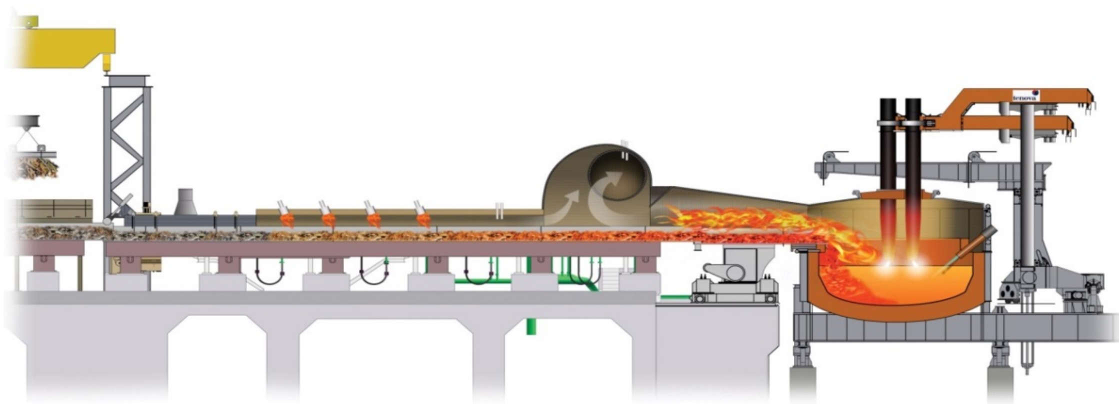
Load Preheating: Steel Reheat Furnace

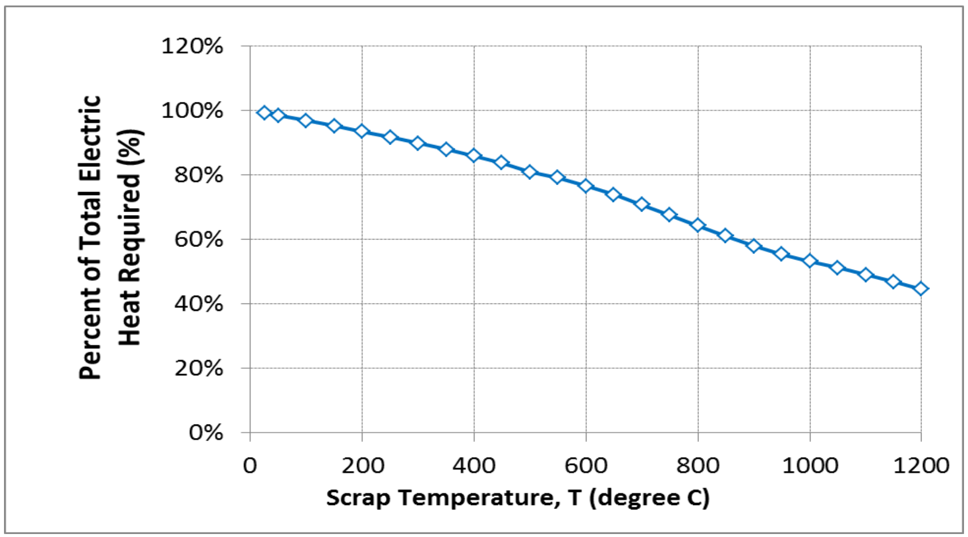


- Use of the furnace flue gases to preheat the furnace charge material in continuous heating or heat treating furnaces
- Furnace flue gases are passed “over” the charge material
- Potential energy savings – 15% to 20% for steel reheating furnaces

Steel Scrap: EAF

Dryer and Preheater





If we increase the scrap temperature from 200°C to 600°C (or 390°F to 1110°F), the amount of electric energy needed for melting the scrap drops by over 15%.

- Steel scrap is separated by using a magnetic separation system
- Off gases from EAF are diverted to a conveyor carrying a steel scrap charge for the EAF
- Necessary to use air for combustion of CO, H_2, and other combustible components of off gases
- Temperature control is crucial to avoid unsafe conditions, overheating of the system, or damage to property or personnel

Savings: Load Preheating Aluminum Furnace – Gas Fired

Charge preheating in a typical gas-fired heat treat furnace can save up to $30,000/year in energy cost and may help increase production

Calculations for Savings - Furnace Charge Preheating using Exhaust Gases			
		Base	**New**
11	Charge Material	Aluminum	
12	Charging rate (as charged with moisture) (Lbs./hr)	4,000	
13	*Base* Charge Initial temperature (°F)	82	
14	*New* Charge Preheat temperature (°F)		400
15	Specific heat of the charge in temp. range of preheat (Btu/lb. F)	0.21	0.21
16	*Base* % moisture content in the charge (cold)	1.00%	
17	*New* % moisture content in the charge (preheated)		0.25%
18	Net heat reduction due to preheat (Btu/hr)	300,269	
19	Flue gas temperature from oven/furnace (°F)	1100	1100
20	Air preheat temperature (°F)	80	80
21	Current O2 in flue gases (%)	4.50	4.50
22	Available heat (%)	63.00%	63.00%
23	Savings in gross heat supplied to oven/furnace (Btu/hr.)	Base	476,607
24	Total energy savings (MM Btu/hr)	Base	0.477
25	Energy Cost ($/MM Btu)	$8.00	$8.00
26	Operating Hrs (per year)	8000	8000
27	**Energy savings (MM Btu/year)**	**Base**	**3,813**
28	**Savings - Energy cost ($/year)**		**$30,502.82**
29	**CO2 savings based on fuel: natural gas(tons/year)**		**223**

Summary for Load/Charge Related Measures

Actions	Potential energy savings*
Hot charge load wherever possible	5% to 30%
Preheat load or charge material using furnace flue gases or an auxiliary externally fired preheater	5% to 30%
Moisture removal prior to loading in the furnace	10% to 25%
Charge at near design capacity and frequency - minimize hold or idling	2% to 5%
Proper load arrangement for optimum heat transfer	1% to 2%

* Percentage of total furnace heat supply

3. Combustion System Energy Saving Measures

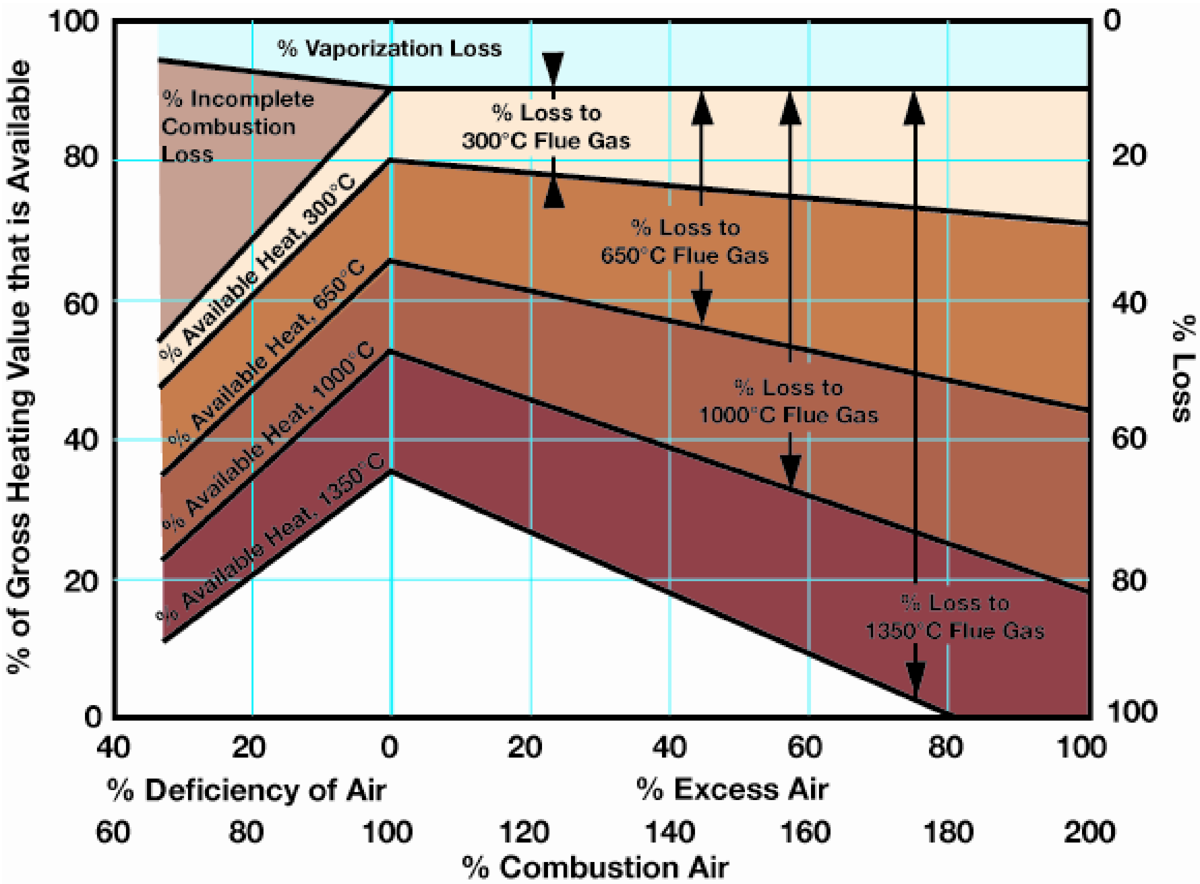
- Use proper burners
- Use proper fuel-to-air ratio control system
  - Eliminate or reduce excess air operation
  - Maintain proper fuel-to-air ratio at all times
  - Avoid fuel-rich operating conditions
- Use preheated air
- Use preheated fuel where possible
- Use oxygen-enriched combustion air
- Use an alternate burner control system (pulse firing) to extend the operating range (turn-down) for the burners

Excess Air Control

The Most Cost-Effective Methods to Save Energy for Furnaces and Ovens

- Excess air may enter from several sources:
  - Combustion air in burners
  - Air-leakage from openings
  - Make-up air used for ovens and dryers
- Control furnace pressure to eliminate or minimize cold air entering the furnace
- Reduce the size and number of openings
- Control make-up air to the minimum required value
- Review the burner firing control system to avoid use of high excess air at low fire conditions
- Use sealed burners to avoid cold air “draft” through hot tubes for radiant tubes with and on/off control

Effect of Excess Air on Available Heat and Heat Loss



Adapted from ***North American Combustion Handbook, Second Edition***. Courtesy Fives North American

Note: This information can be used for fuel oil with less than 5% error.

Energy Savings: Reduction of Excess Air

Control Air-Fuel Ratio or Reduction of Excess Air (or Oxygen) in Flue Gases			
		Current	New
11	Furnace flue gas temperature (°F.)	1,200	1,200
12	Percent O2 (dry) in flue gases	8.00	3.00
13	% Excess air	55.08	14.92
14	Combustion air temperature (°F.)	70	70
15	Fuel consumption (MM Btu/hr) - Avg. current	20.00	17.32
16	Available Heat (%)	53.8%	62.2%
17	Fuel savings (%)	Base	13.39%
18	No. of operating hours (hours/year)	8000	8000
19	Heat energy used per year (MM Btu/year)	160,000	138,579
20	**Heat energy saved (MM Btu/year)**	**Base**	**21,421**
21	Cost of fuel ($/Million Btu)	$ 10.00	$ 10.00
22	**Annual savings ($/year)**	**Base**	**$ 214,210**
23	**CO2 savings (Tons/year)**	**Base**	**1,253**

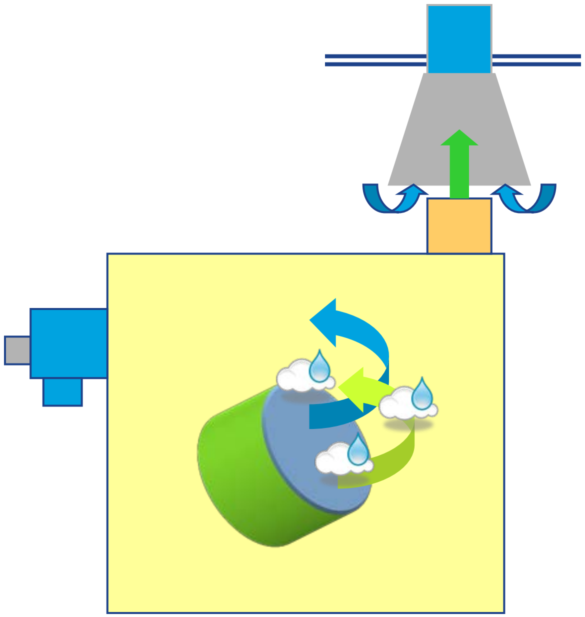
- Firing rate: 20 MMBtu/hr
- Current flue gases
  - O_2 (dry) in flue gas: 8%
  - Flue gas temperature: 1,200°F
- After burner tune-up, leak check, and sealing of the heater:
  - O_2 (dry) in flue gas : 3.00%
  - Flue gas temperature: 1,200°F
- Fuel savings: 13.4%
- Energy cost savings: $214,000/year
- Basis for calculations:
  - Fuel cost – $10/MMBtu
  - Operating hours – 8,000/year

Summary for Combustion System Related Measures

Actions	Potential energy savings*
Use proper burner type	2% to 5%
Use proper air-to-fuel ratio control system	5% to 15%
Use preheated air	5% to 30%
Use oxygen-enriched combustion air or oxy-fuel burners where economically justified or required	5% to 35%
Use alternate burner control system to extend burner turn-down if necessary	1% to 5%

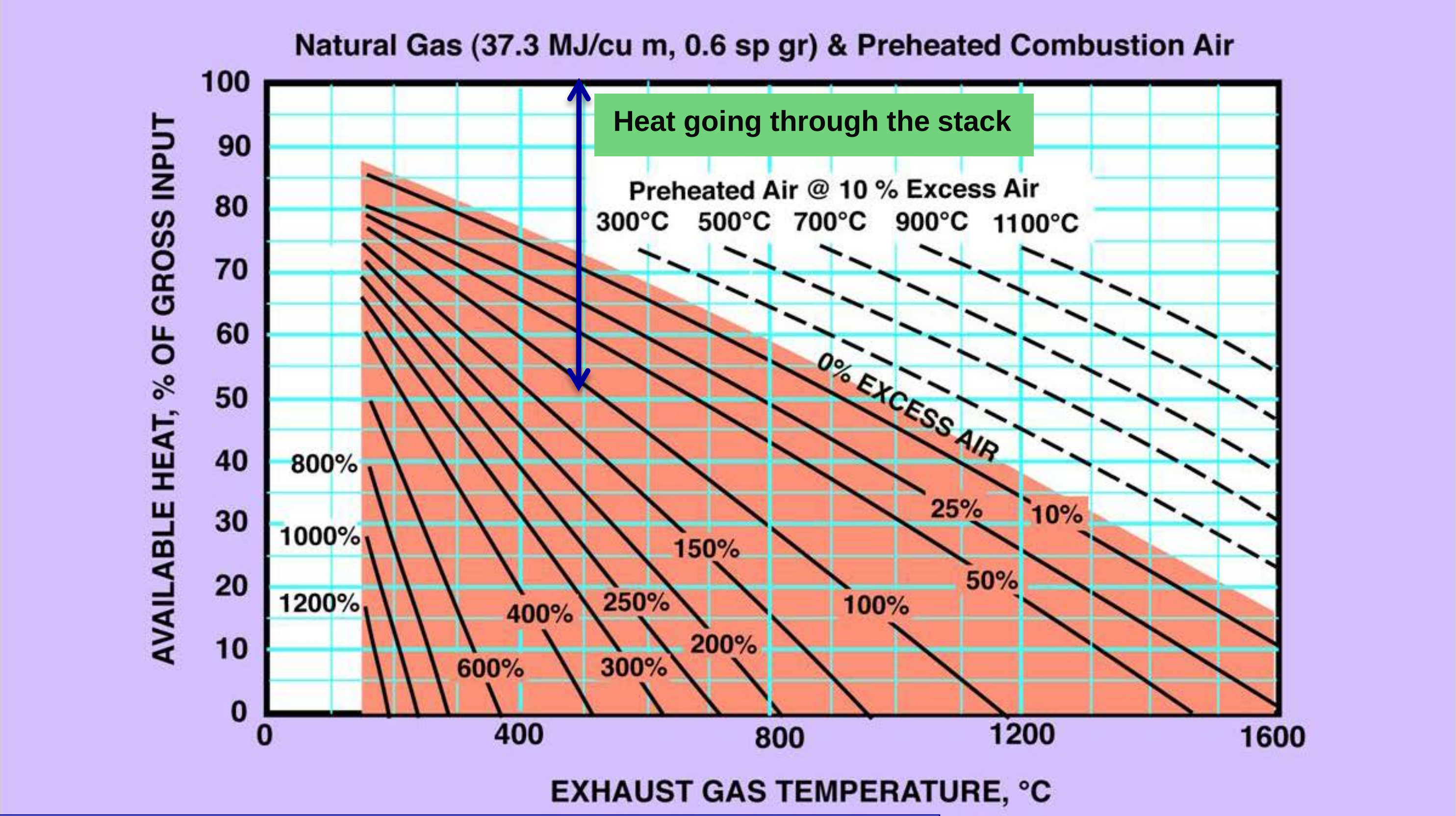
4. Energy Saving Measures Exhaust Gases or Flue Gases

The words “Exhaust Gases” and “Flue Gases” are used interchangeably.



- Flue gases from a furnace may contain:
  - Combustion products
  - Water vapor
  - Liquid vapors
  - Volatiles
  - Condensable solids
  - Non-condensable particles
  - Furnace “atmosphere” or gases
- Flue gas analysis (FGA) such as percentage of O_2 and percentage of CO_2 given by most commonly used analyzers is affected by the presence of non-condensable gases
- Care must be taken to correct the analysis for the presence of these gases, if any, in using FGA results for thermal calculations

Heat Going Through the “Stack”?

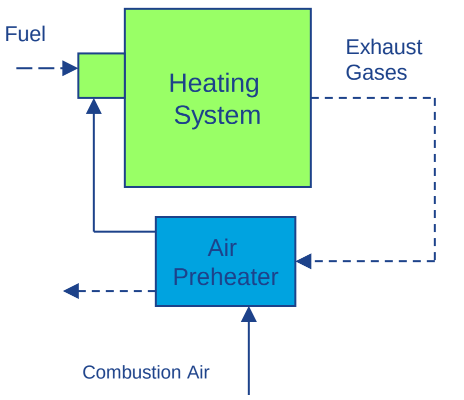


This figure is for natural gas fired systems. For fuel oil available heat can be about 5% higher and the loss would be 5% lower. Values would be different when the flue gases contain additional gases or moisture from non-combustion sources

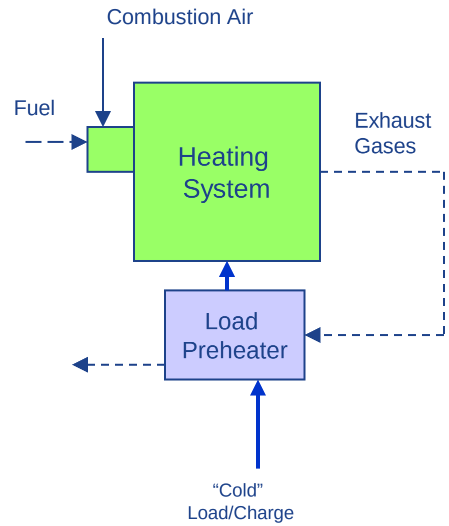
Options for Exhaust Gas Waste Heat

- Waste heat **Reduction** within the heating system itself
- Waste heat **Recycling** within the heating system itself
- Waste heat **Recovery**:
  - Use of waste heat outside the heating system – utilize heat in (or for) other systems within the plant or outside the plant.
  - Waste heat to power conversion

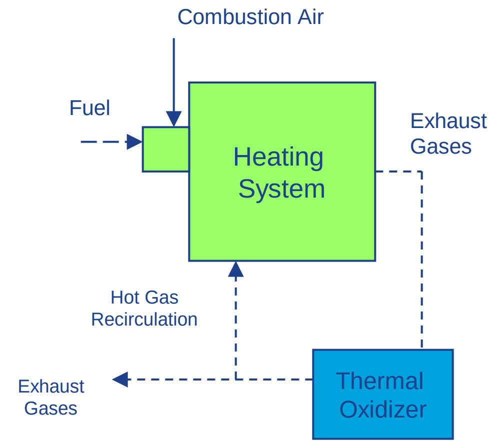
Waste Heat Recycling Options



1. Combustion Air Preheating



2. Load-Charge Preheating



3. Internal heat recycling - cascading

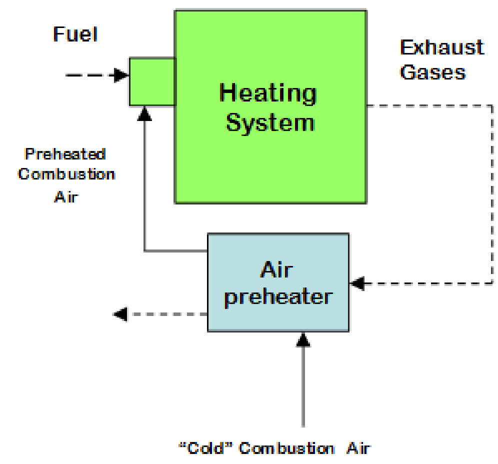
These other options: use similar technology and hardware as the systems 1,2 and 3.

4. **Make up air heating**
5. **Water (liquid) heating**

Combustion Air Preheating Savings

Gas fired reheat furnace saves approx. $23,000 per year. This is a preliminary evaluation for possible heat recovery using heat of exhaust gases.

	Use of Preheated Combustion Air **Note: The combustion air is heated by using heat from flue or exhaust gases.**		
		Current	**New**
11	Furnace flue gas temp. (°F)	1,000	1,000
12	Percent O2 (dry) in flue gases	3.00	3.00
13	% Excess air	14.92	14.92
14	Combustion air temperature (°F)	60	600
15	Fuel consumption (MM Btu/hr) - Avg. current	5.00	4.36
16	Volume of fuel gas scfh - based on fuel heating value	4,945.19	4,308.71
17	Available Heat (%)	66.89	76.77
18	Fuel savings (%)	Base	12.87%
19	No. of operating hours (hours/year)	6000	6000
20	Heat used per year (MM Btu/year)	30,000	26,139
21	**Heat saved per year (MM Btu/year)**	**Base**	**3,861**
22	Cost of fuel ($/Million Btu)	$ 6.00	$ 6.00
23	**Annual savings ($/year)**	**Base**	**$ 23,167**
24	**CO2 savings (tons/year)**	**Base**	**227**



Heat Recovery Options

Heat recovery system	Waste heat Temperature (deg. C)	Typical applications	Typical installed cost
Steam generation	350^0 C and higher	Large furnaces with >25 GJ /hr. firing rate. Reheat furnaces, process heaters, glass melting furnaces etc.	$35 to $60 per 500 kg lb. steam generation
Hot water heating	150^0 C and higher	Heating equipment of all sizes. Heat treating, reheating, forging, ovens, dryers etc.	$30,000 to $50,000 per GJ heat transferred
Plant or building heating	100^0 C and higher	Mostly in cold climate areas. Can be used for medium to large size (5 GJ/hr. and larger size).	$25,000 to $50,000 per GJ transferred
Absorption cooling systems	175^0 C and higher	Low to medium temperature systems, large size furnaces, ovens, heaters etc.	$750 to $1500 per ton of refrigeration capacity
Cascading to lower temperature heating processes	400^0 C and higher	For gases from medium to large size systems supplying heat to lower temperature heating systems.	$40,000 to $100,000 per GJ transferred

Note:

The costs are very preliminary and based on US conditions hence given in US$.

They can be different for other countries and even vary by as much as 100%.

DO NOT use the costs for economic analysis for site specific cases.

Waste Heat to Power Options

Comparison	Steam Rankine	Organic Rankine (ORC)	Ammonia (NH_3) - Water	CO2 Power Cycle
Source Temperature Range Deg. C.)	400 plus	150 to 300	100 to 450	225 to 650
Working Fluid	Treated water	HCFCs or Hydrocarbons	Ammonia - water mixture	Caron Dioxide
Working Fluid Attributes	Requires treatment to reduce corrosion and mineral deposition	Limited temperature range, flammability, thermally unstable at higher temperature	Limited temperature range, corrosive, ammonia leaks	Non-corrosive, non-toxic, non-flammable, thermally stable
Conversion Efficiency (%)	20% plus	8% to 12%	8% to 15%	13% to 17%
Reported Cost ($/kW)	$600 plus	$2500 plus	$2500 plus	$2000 plus

Note: This is a fast changing field. The efficiency values highly dependent on the source temperature. Cost could vary significantly with size, supplier and incentives from several sources.

The costs are very preliminary and based on US conditions hence in US$. They can be different for other countries and even vary by as much as 100%

Thank you!

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Q&A

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Recent Developments and Trends

- Regenerative burners – combustion air preheating
- Regenerative burners – low calorific value gas fuel preheating
- Self-recuperating burners for direct fired and radiant tube applications
- Low NOx burners of various designs and applications
- Oxy-fuel burners for melting applications (glass, steel, aluminum etc.)
- Oxygen enriched air burners (by various names) for medium to high temperature heating applications
- Oxygen enrichment of combustion air for low calorific fuels in boilers and other low to medium temperature applications
- Mass flow control for air and fuel
- Sub-stoichiometric burners for steel reheating applications
- "Radiant" burners of various types and designs for drying applications
- Burners for low calorific value fuels

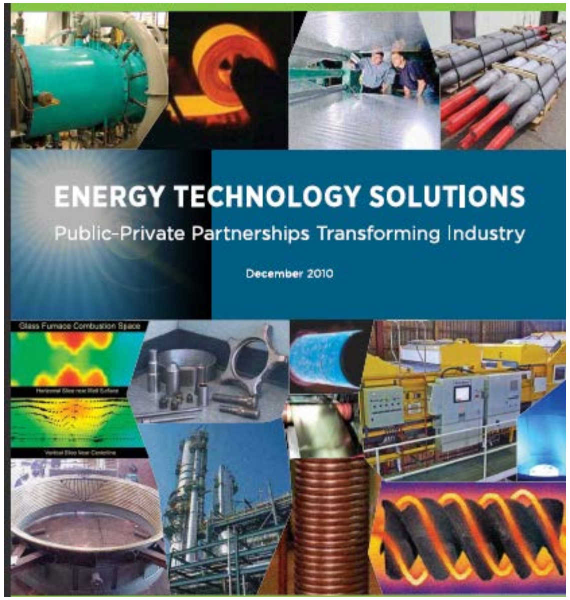
Exhaust Gas Waste heat Reduction

- Reduce mass flow rate
  - Reduce/control excess air for burners
  - Control make-up air
  - Reduce/eliminate air leaks
  - Reduce moisture content of exhaust gases where possible
  - Process specific actions (i.e. pretreatment of charge material)
  - Use of oxygen enriched air
  - Use of air and/or fuel preheating
- Reduce temperature of exhaust gases
  - Use of proper temperature controls Use of advanced controls to optimize zone temperature (i.e. on-line process modeling)
  - Avoid over-firing of burners
  - Control air-fuel ration to avoid sub-stoichiometric (rich) combustion

Summary for Exhaust Gas Reduction Related Measures

Reduce excess air used for fuel combustion in burners	2% to 10%
Control and minimize the amount of make-up air, if used, in ovens and dryers	5% to 20%
Minimize air leakage by reducing the size and number of openings	1% to 5%
Use pressure control to reduce/eliminate air infiltration or hot gases exfiltration	1% to 5%
Use proper controls for zone temperature and furnace firing rate to avoid excessively high exhaust gas temperature	2% to 10%
Avoid discharge of excessive moisture or process gases if possible by pre-processing the load/charge material	0% to 2%

Application of Emerging or New Technologies



- New technology application can result into substantial energy savings together with other benefits.
- New technologies are available for use or commercialization from many sources including the National Laboratories, R&D organizations, equipment suppliers and the industrial companies.

http://www1.eere.energy.gov/manufacturing/about/pdfs/impacts2010_full_report.pdf

Process Heating Tip Sheets

The tip sheets can be downloaded from the AMO Tip Sheet site at http://energy.gov/eere/amo/tip-sheets-system.

- Preheated Combustion Air (recovery)
- Check Burner Air to Fuel Ratios (generation)
- Oxygen-Enriched Combustion (recovery)
- Check Heat Transfer Surfaces (transfer)
- Reduce Air Infiltration in Furnaces (containment)
- Furnace Pressure Controllers (generation)
- Reduce Radiation Losses from Heating Equipment (containment)
- Install Waste Heat Recovery Systems for Fuel-Fired Furnaces (recovery)
- Load Preheating Using Flue Gases from a Fuel-Fired Heating System (recovery)
- Using Waste Heat for External Processes (recovery)
- Use Lower Flammable Limit Monitoring Equipment to Improve Oven Efficiency

Where to Find Help

Advanced Manufacturing Office
U. S. Department of Energy
Office of Energy Efficiency and Renewable Energy
www.energy.gov/eere/amo

Industrial Heating Equipment Association (IHEA)
5040 Old Taylor Mill Rd., PMB 13
Taylor Mill, KY 41015 Phone: 859-356-1575 ihea@ihea.org *www.ihea.org*

Electrotechnology Applications Center
3835 Green Pond Road Bethlehem, PA 18020-7599
Phone: 610-861-5081
Fax: 610-861-4101
www.etctr.com

Electric Power Research Institute
3420 Hillview Avenue Palo Alto, CA 94304
Phone: 650-855-2000
www.epri.com

Gas Technology Institute (GTI)
1700 S. Mount Prospect Road Des Plaines, IL 60018 Phone: 847-768-0500
www.gastechnology.org

National Insulation Association
12100 Sunset Hills Road
Suite 330
Reston, VA 20190
Phone: 703-464-6422
www.insulation.org

Better Buildings®
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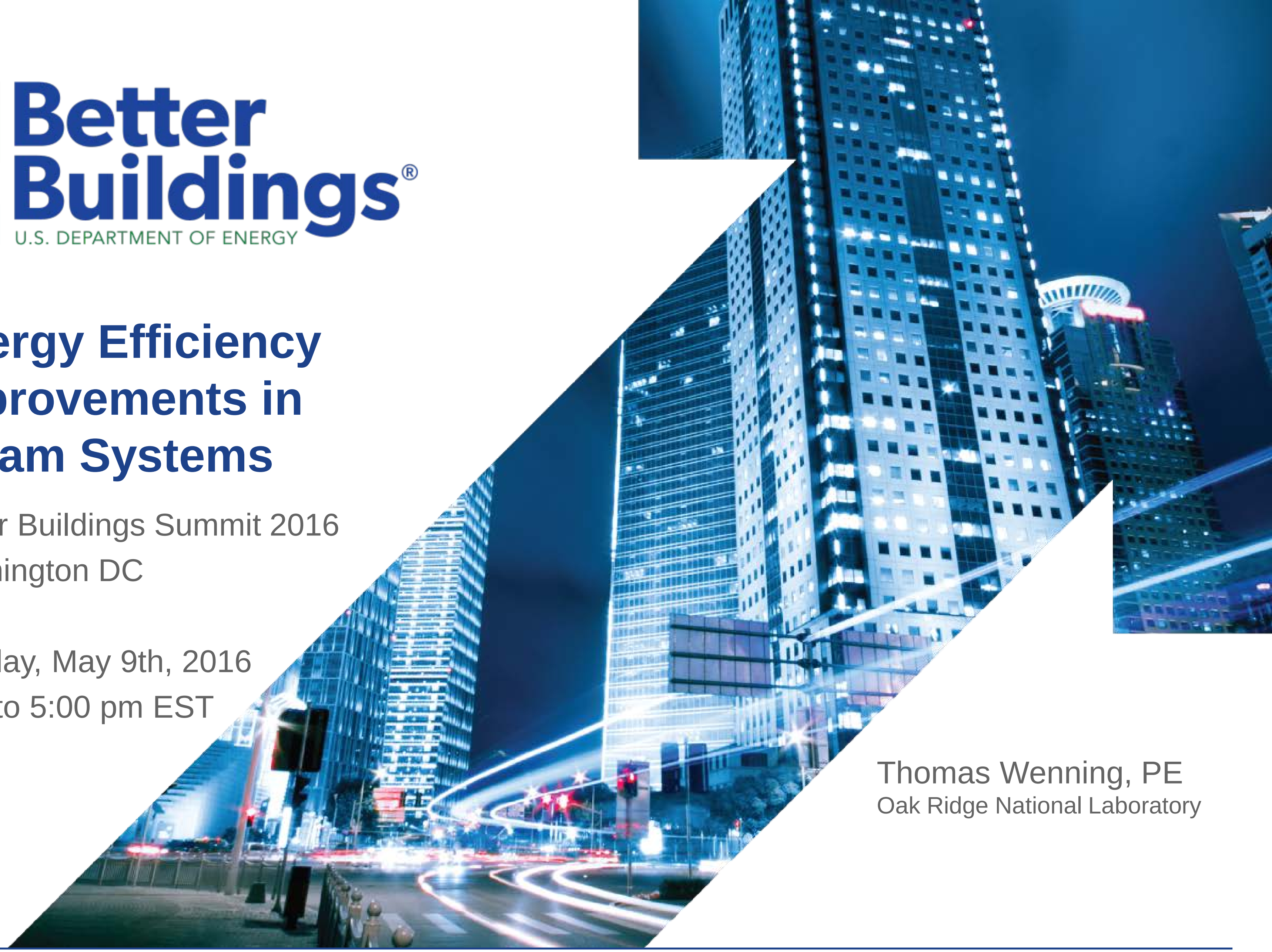
Energy Efficiency Improvements in Steam Systems

Better Buildings Summit 2016
Washington DC

Monday, May 9th, 2016
3:45 to 5:00 pm EST



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Oak Ridge National Laboratory

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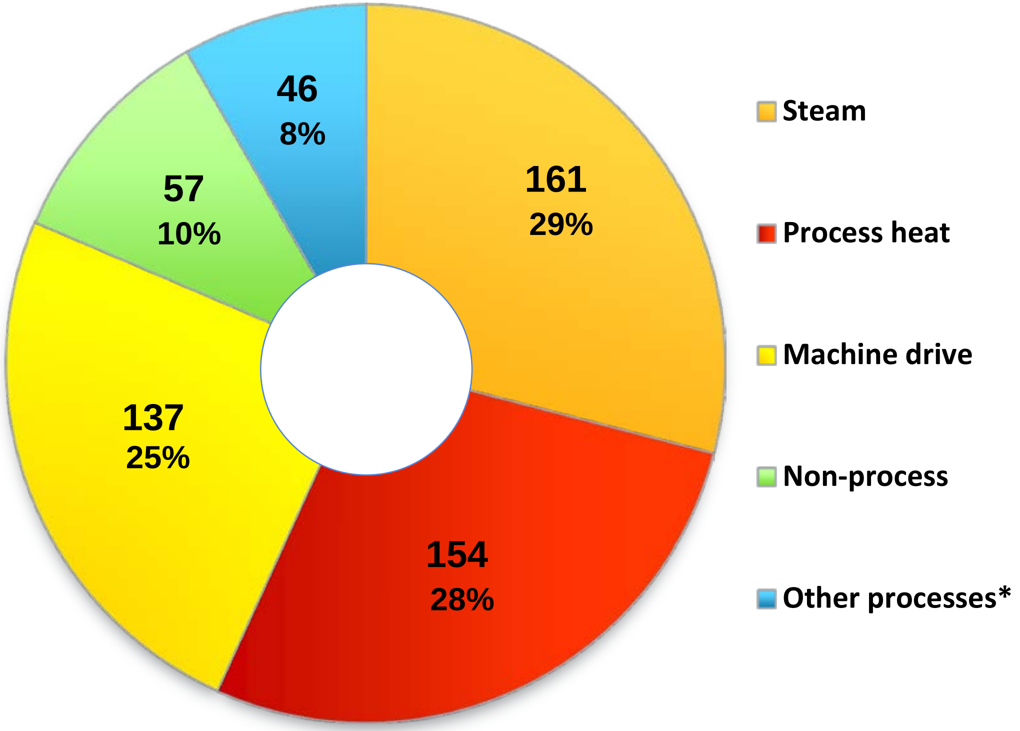
Energy Use by Industrial System

Energy use in manufacturing is dominated by (thermal) processes.

Primary Million TOE/Year of Energy Use



* Other processes include: process heating for controlling chemical reactions (thermo-chemical processes) and establishing favorable physical or mechanical conditions, such as in plastics, food, or textile production.

1 toe = 1.00 x 10^7 kcal = 41.868 GJ = 39.68 MMBtu

Source: Manufacturing Energy and Carbon Footprint, derived from 2006 Manufacturing Energy Consumption Survey data

Identified Savings Per Plant Summary

System Type

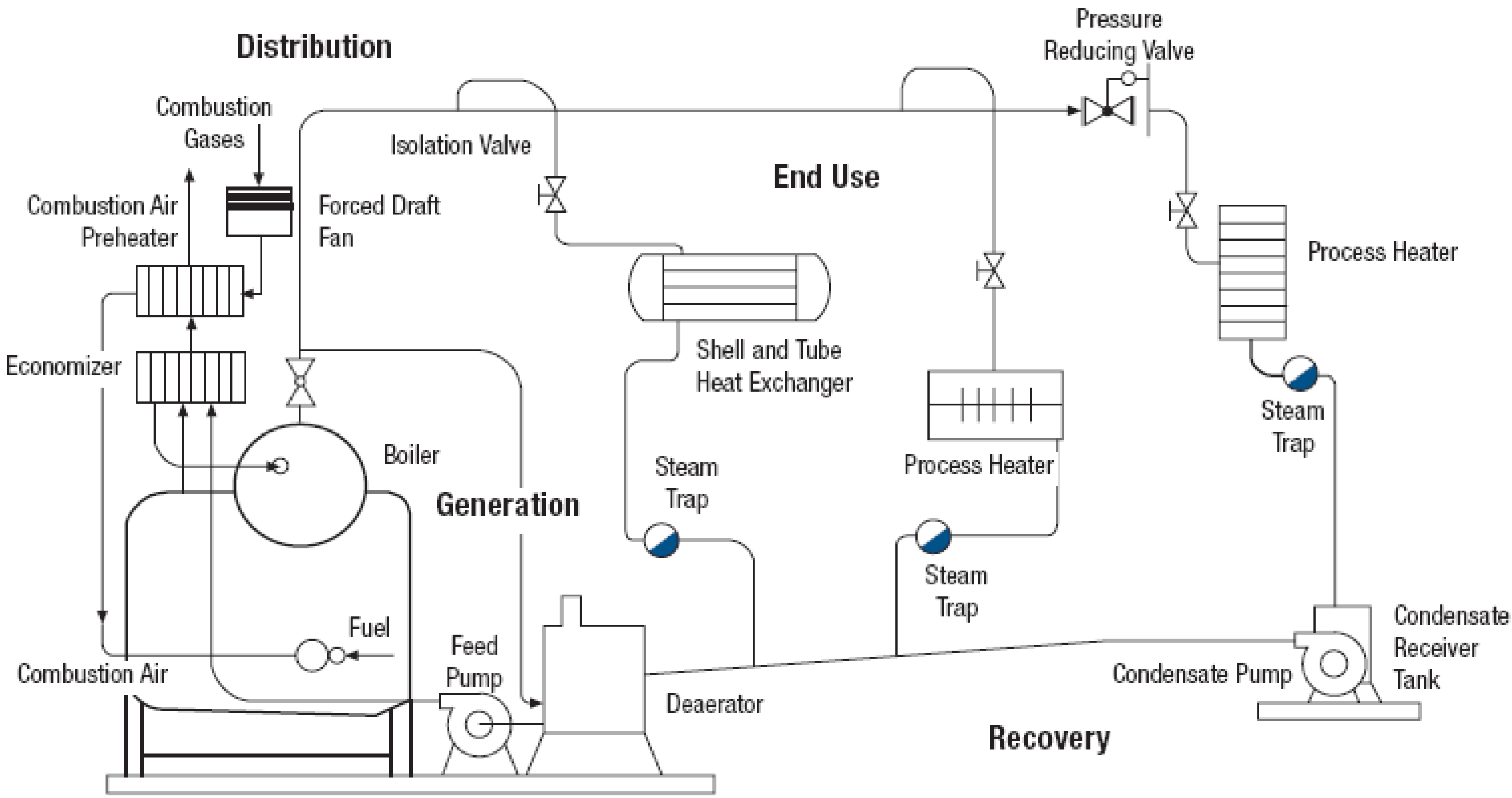
System Type (No. of SENAs)	Average Identified Source Energy Savings (MMBtu/plant per year)	Average Percent Source Energy Savings Identified (%)	Average Identified Cost Savings ($/plant per year)	Average Natural Gas Savings Identified (MMBtu/plant per year)	Average CO2 Savings Identified (Metric Tons/plant per year)	Average Payback Period Identified (Years)
Compressed Air (174)	32,300	2.7	$192,000	400	1,800	1.1
Fans** (50)	105,000	3.1	$624,000	33,000	6,000	2.6
Process Heating (237)	218,600	7.7	$1,474,000	167,200	12,400	1.5
Pumps (94)	38,800	1.2	$210,000	1,000	2,300	1.7
Steam (343)	256,000	6.1	$2,000,000	199,900	17,900	1.6
Multi-System-Paper (31)	354,900	5.2	$2,259,000	173,200	18,600	0.5

** Fan results are based on 48 ESAs instead of 50 ESAs. Two large outliers are not considered in this analysis.

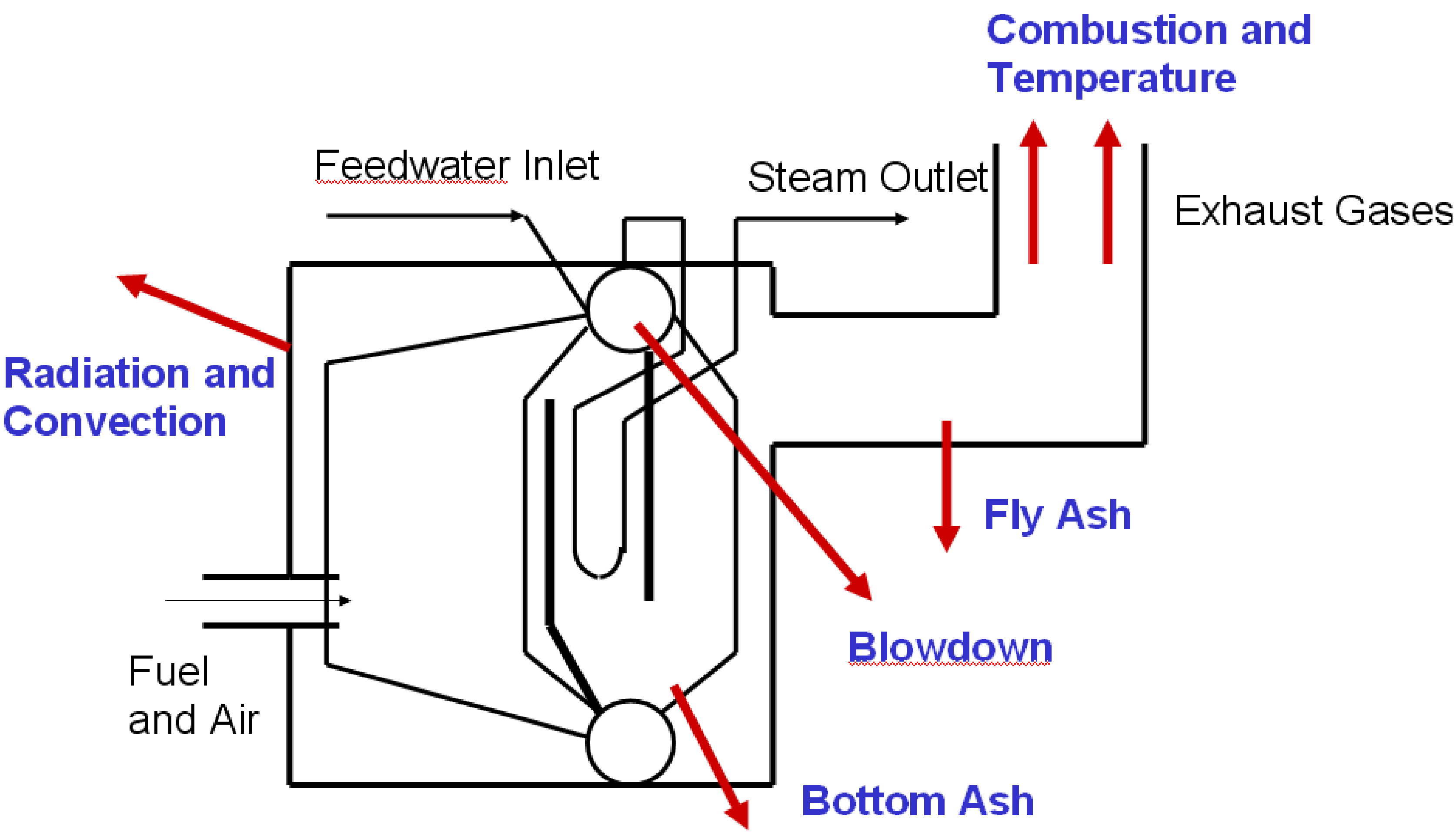
Source: Based on Energy Saving Assessments conducted between 2006 to 2011. Numbers are as of October 1, 2011.

Industrial Steam Systems

GENERATION, DISTRIBUTION, END USE, RECOVERY



Major sources of boiler energy losses



Typical Boiler Efficiency

- A typical boiler will have an efficiency of ----?

Typical Boiler Efficiency

- A typical boiler will have an efficiency of ----?

65% to 82% to 90%

Green-Wood Natural Gas Oil and Coal

Efficiency is dependent on the type of fuel and the installed equipment.

Today's Focus

- O2 Trim Control (Combustion)
- Heat Recovery Options (in the boiler room)
- Steam Trap Management

O2 Trim Control

Theoretical Air - Stoichiometric Combustion

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

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

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Actual Combustion

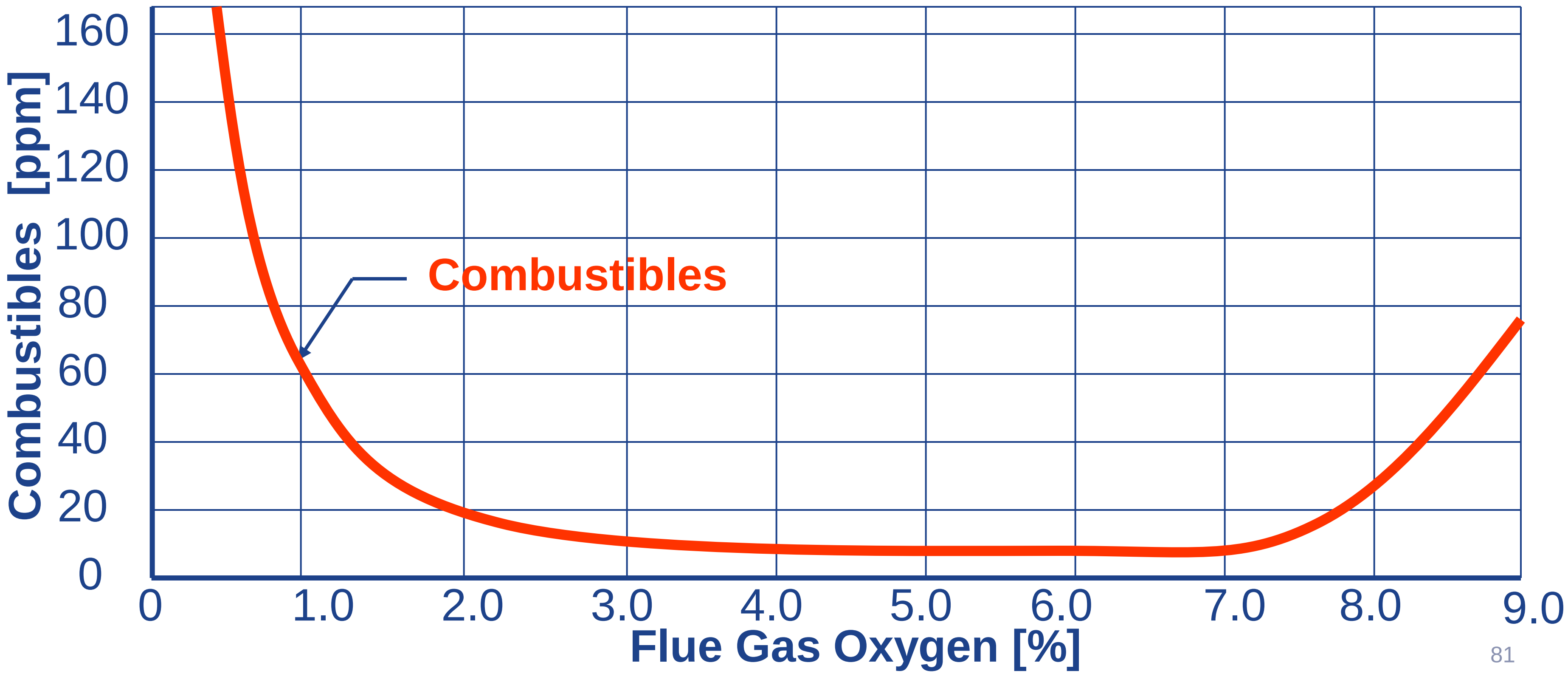
- The extra oxygen added to ensure complete reaction of the fuel is heated by fuel from ambient temperature to the temperature of the exhaust gas.

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

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

Minimum Oxygen Evaluation

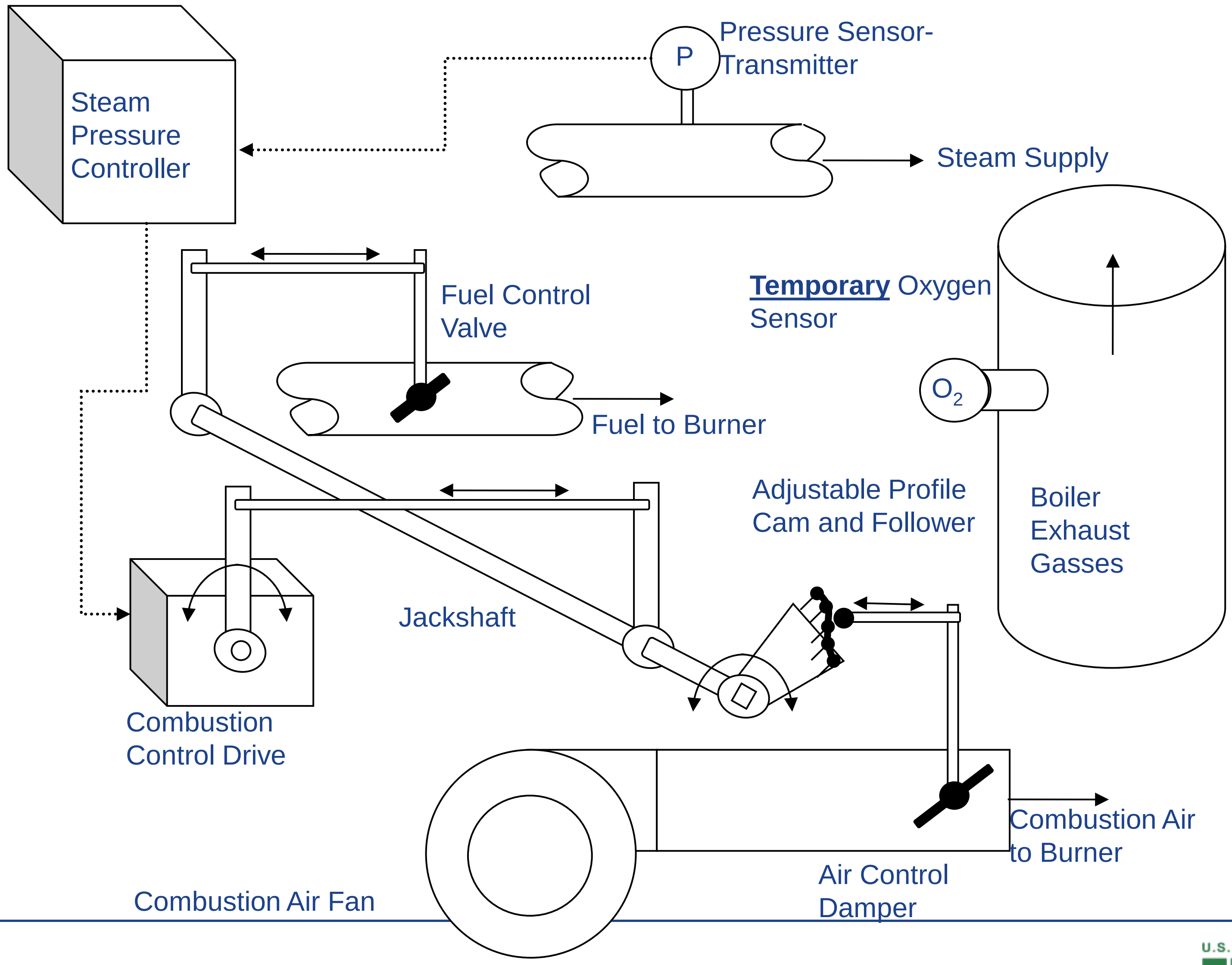
- Minimum oxygen limits are determined by measuring combustibles



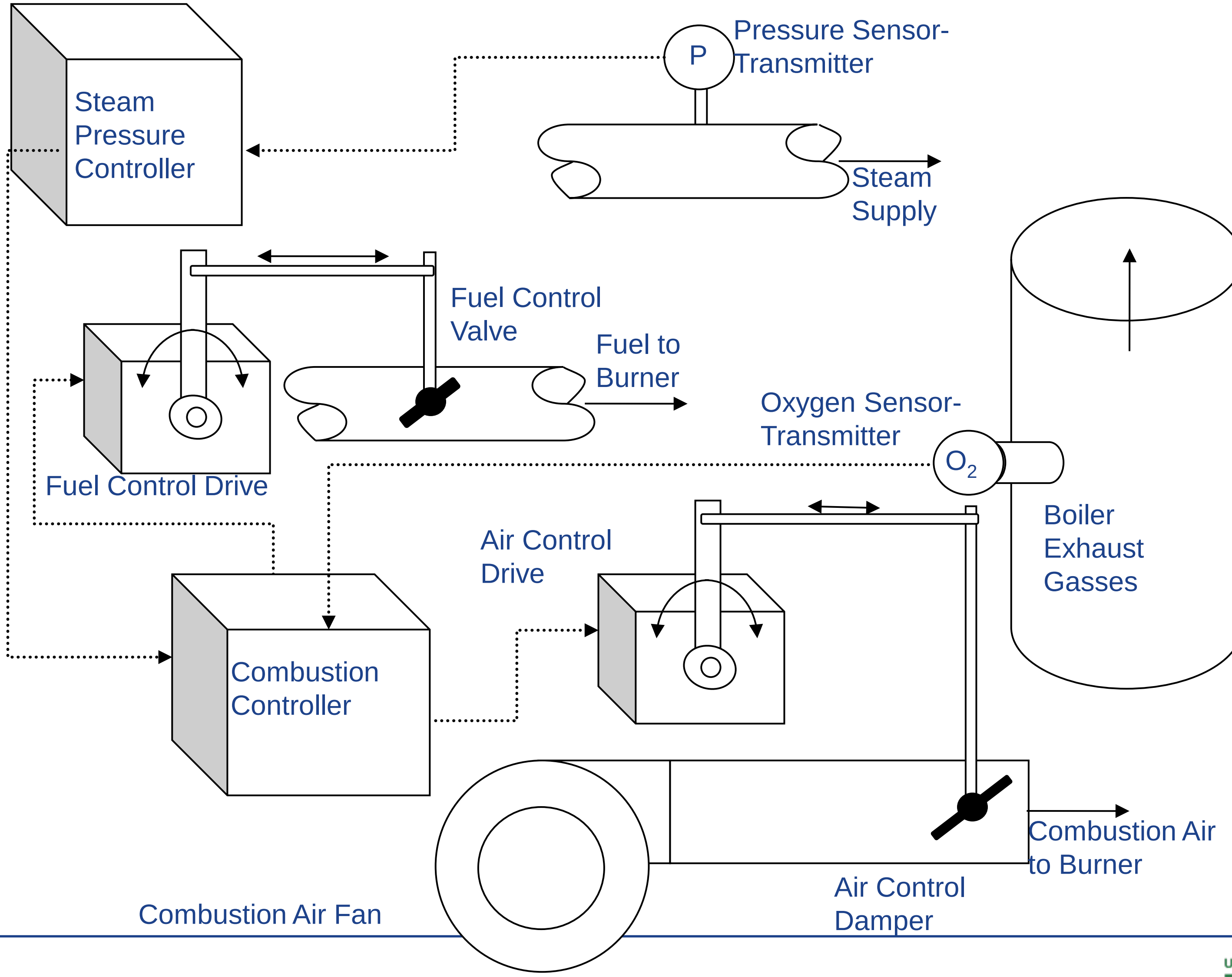
Oxygen Limits

- Primary factors affecting oxygen limits:
  - Fuel type
  - Monitoring and control method
  - Oxygen sensing location
  - Burner condition
  - Boiler load

Positioning Control



Oxygen (Trim) Control



Typical Combustion Control Parameters

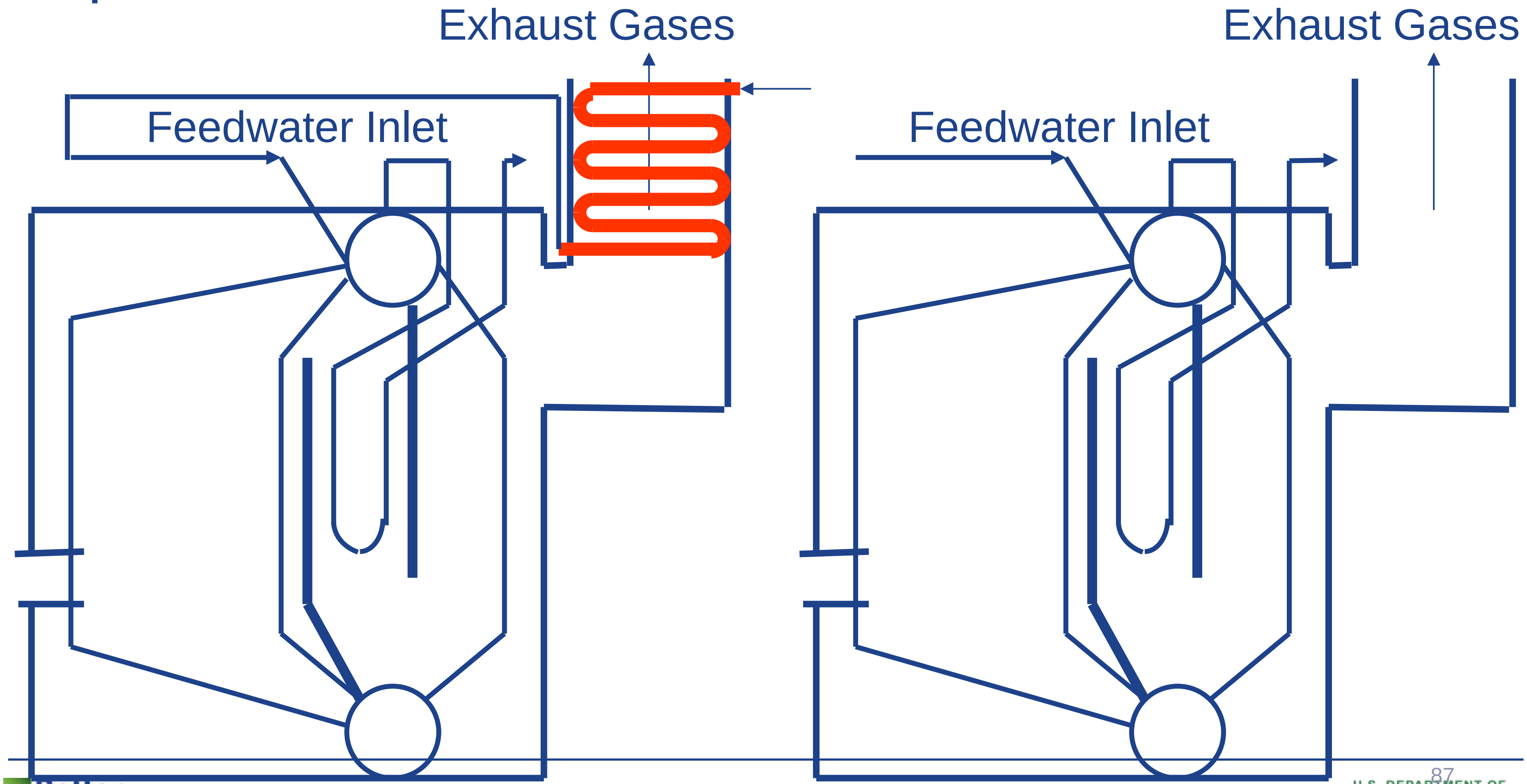
Typical Flue Gas Oxygen Content Control Parameters								
Fuel	Automatic Control Flue Gas O_2 Content				Positioning Control Flue Gas O_2 Content			
	Minimum		Maximum		Minimum		Maximum	
	Full Gas Sample [%]	Dry Gas Sample [%]	Full Gas Sample [%]	Dry Gas Sample [%]	Full Gas Sample [%]	Dry Gas Sample [%]	Full Gas Sample [%]	Dry Gas Sample [%]
Natural Gas	1.5	1.8	3.0	3.6	3.0	3.6	7.0	8.0
Numb. 2 Fuel Oil	2.0	2.2	3.0	3.3	3.0	3.3	7.0	7.6
Numb. 6 Fuel Oil	2.5	2.8	3.5	3.8	3.5	3.8	8.0	8.5
Pulverized Coal	2.5	2.7	4.0	4.3	4.0	4.3	7.0	7.4
Stoker Coal	3.5	3.7	5.0	5.3	5.0	5.3	8.0	8.4

- Heat Recovery Options

  (in the boiler room)

Energy Recovery Components

- Feedwater economizers and combustion air preheaters.



Economizer Applications

Steam Boiler Feedwater Preheat

Make-up water

Process Water

- Run feedwater from a boiler feed system or deaerator through the economizer and into the boiler
  - Modulating boiler feedwater control
  - On/off feedwater control

Economizer Design

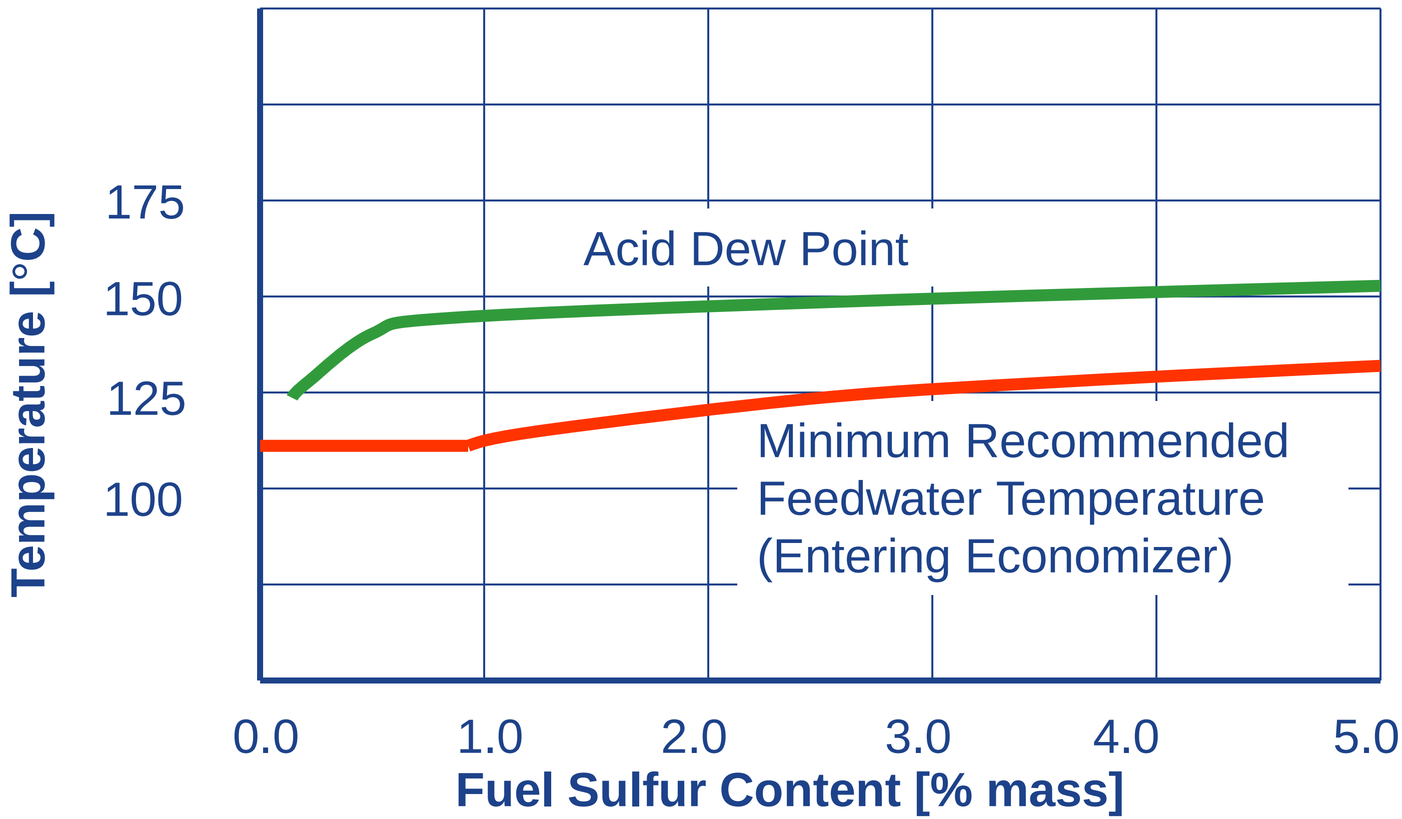
Non-Condensing

- Most common design
- Recover sensible heat only
- Single stage
- Cross or counter flow
- Applications
  - Steam boiler feedwater preheat
    - Proportional feedwater control
    - On/off feedwater control
  - Process water (higher temperatures)

Condensing

- Recover sensible and latent
  - Saturation temperature
    - Natural gas ~135ºF
- Single stage
  - Condense on natural gas only
- Applications – water temperature less than ~120ºF
  - Cold make-up water
  - Process flow (lower temperature)
  - Hot water return

Flue Gas Temperature Limitations



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

Condensing Economizers

- Condensing economizers can improve boiler efficiency more than 10% in comparison to conventional boilers
  - Final flue gas temperature can approach 70°F
  - Indirect units can heat streams to 212°C
  - Direct units can heat streams to 140°F
  - A significant amount of relatively *low-temperature* energy is recovered
  - Equipment is limited to *clean fuels*

Steam Trap Management

Steam Trap Management

- In many facilities steam traps present a significant loss potential
  - Industrial facilities may have steam trap populations numbering in the thousands and even tens-of-thousands
- Steam traps must be investigated to determine if they are functioning properly
- The operating principles of steam traps must be understood to properly manage the equipment

Steam Trap Types

- Thermostatic
- Float and Thermostatic
- Open Float
- Thermodynamic
- Orifice

Thermostatic Steam Traps

- Opens to subcooled condensate
- Depending on subcooling can discharge condensate or condensate and flash steam
- Allows energy recovery from condensate
- Significant air removal capability

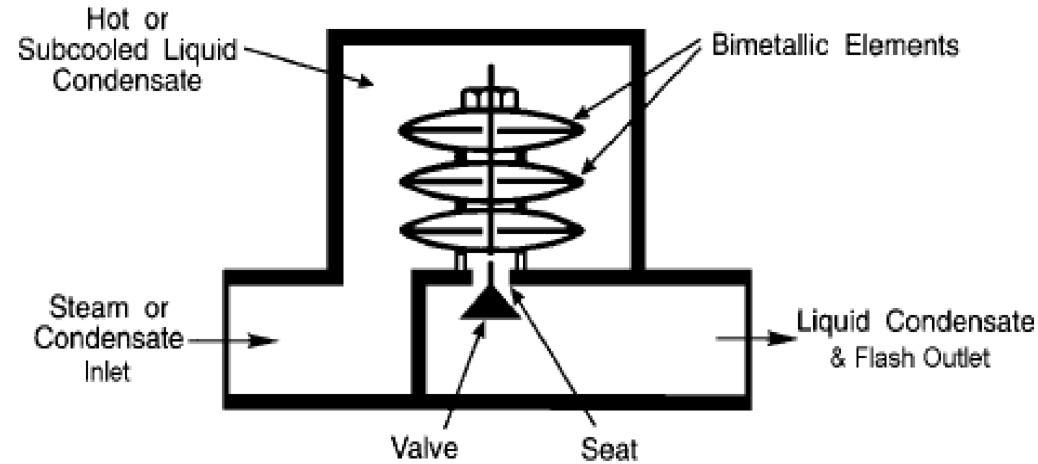
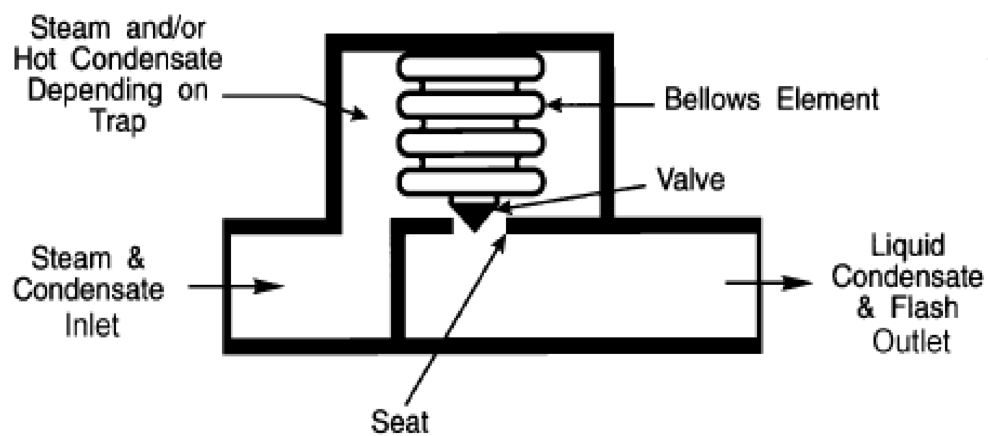
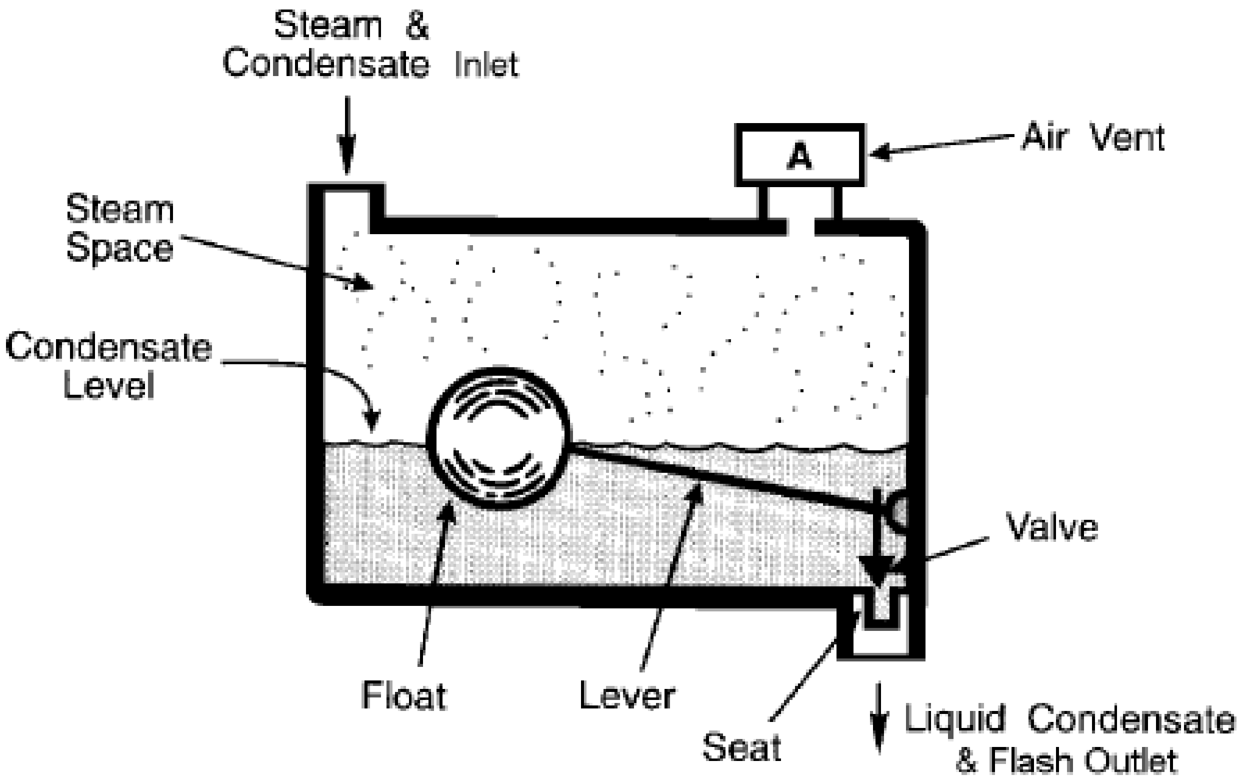


Figure 2. Bimetallic steam trap

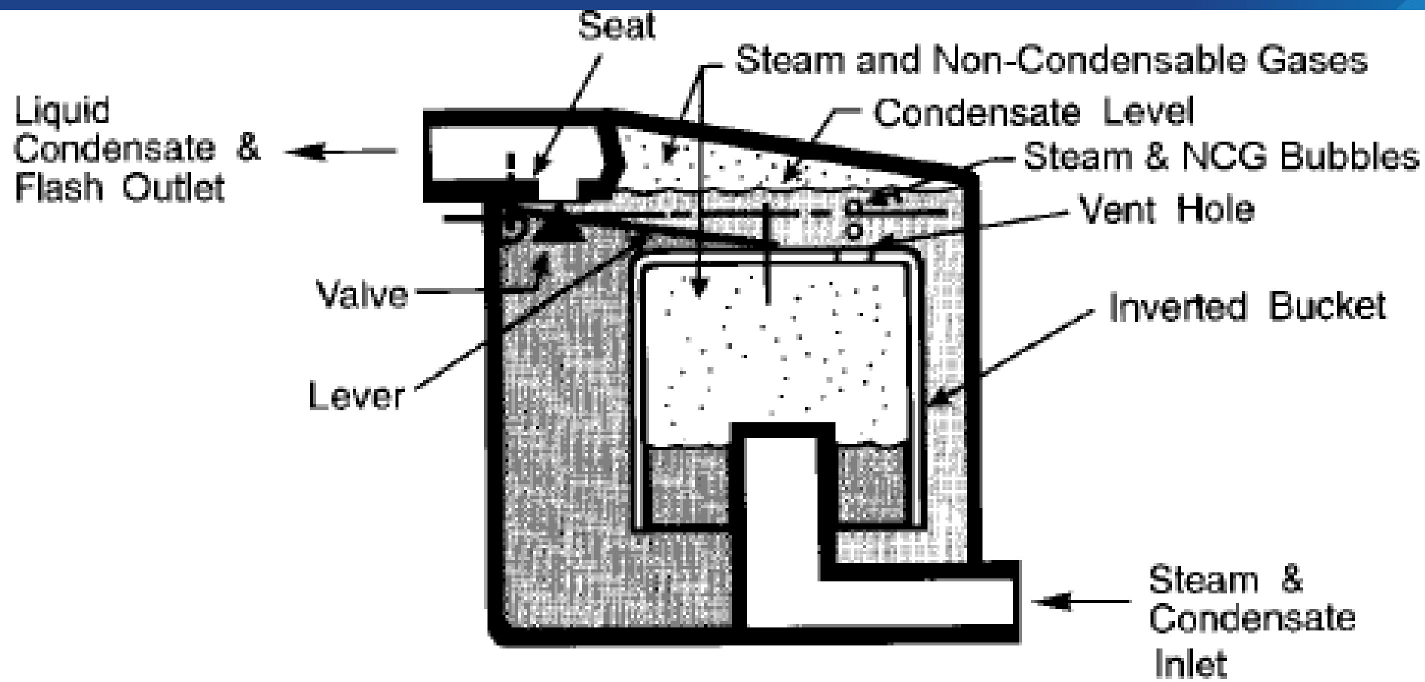


Float and Thermostatic Steam Trap

- Opens to saturated condensate
- Will discharge condensate and flash steam
- Significant air removal and startup capabilities
- Modulating type operation



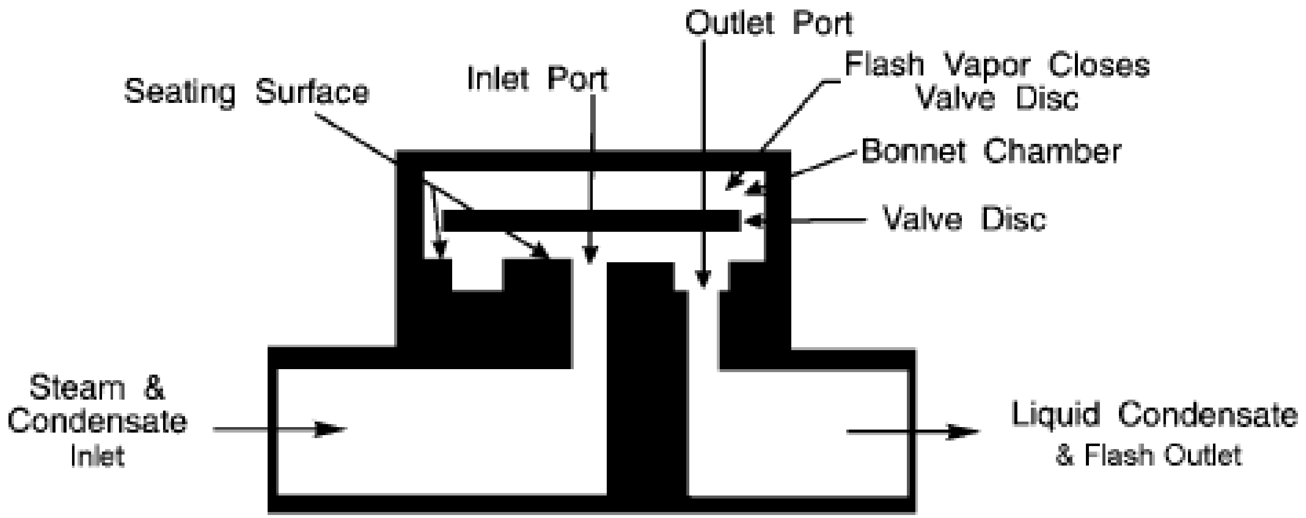
Open Float (Inverted Bucket) Steam Trap



- Opens to saturated condensate
- Will discharge condensate and flash steam
- Limited air removal capability
- Application in superheated steam service should be questioned
- Intermittent operation

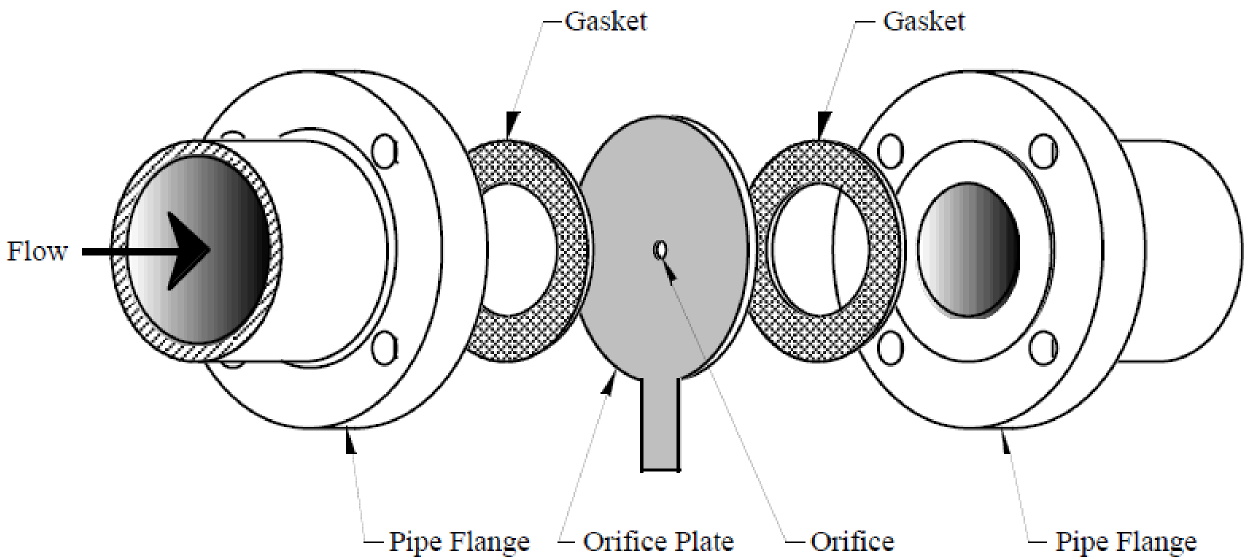
Thermodynamic Steam Traps

- Opens to saturated condensate
- Will discharge condensate and flash steam
- Intermittent operation
- Can be equipped with thermostatic element to improve air removal



Orifice Steam Traps

- No moving parts
- Continuous operation
- Common applications are steady loads
- Limited air removal capability due to orifice limitations



Steam Trap Failures

- Failure modes
  - Failed closed
  - Failed open
  - Failed partially leaking or partially closed
- Failed open and failed closed result in the greatest system impacts
  - These failure modes are the most readily recognized
  - These failures should be of first priority

Steam Trap Investigation

- Visual
- Acoustic
- Thermal
- Combined methods
- In-line monitoring

Wireless Monitoring

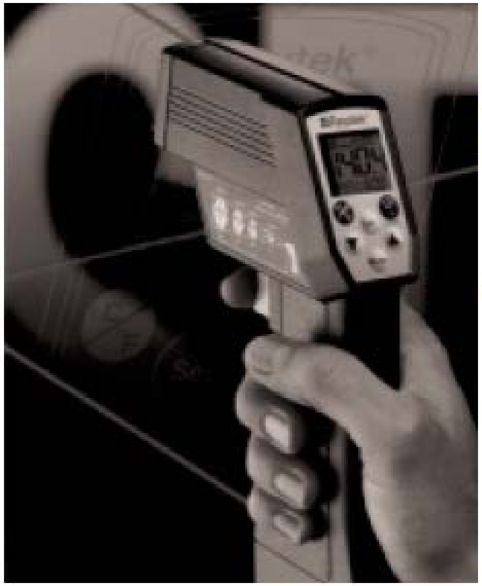
- Steam trap monitoring
- Real-time system health
- Non-intrusive temperature monitoring

World Class Steam Trap Maintenance Program

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

World Class Steam Trap Maintenance Program

- Maintain a steam trap database
- Prioritize repairs based on loss estimates
- Daily monitor receiver vents
- Training is essential



Acknowledgments

- Dr. Greg Harrell, Energy Management Services
- Riyaz Papar, Hudson Technologies
- Cleaver Brooks
- Armstrong International
- DOE’s FEMP Program

Thank you!

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Q&A

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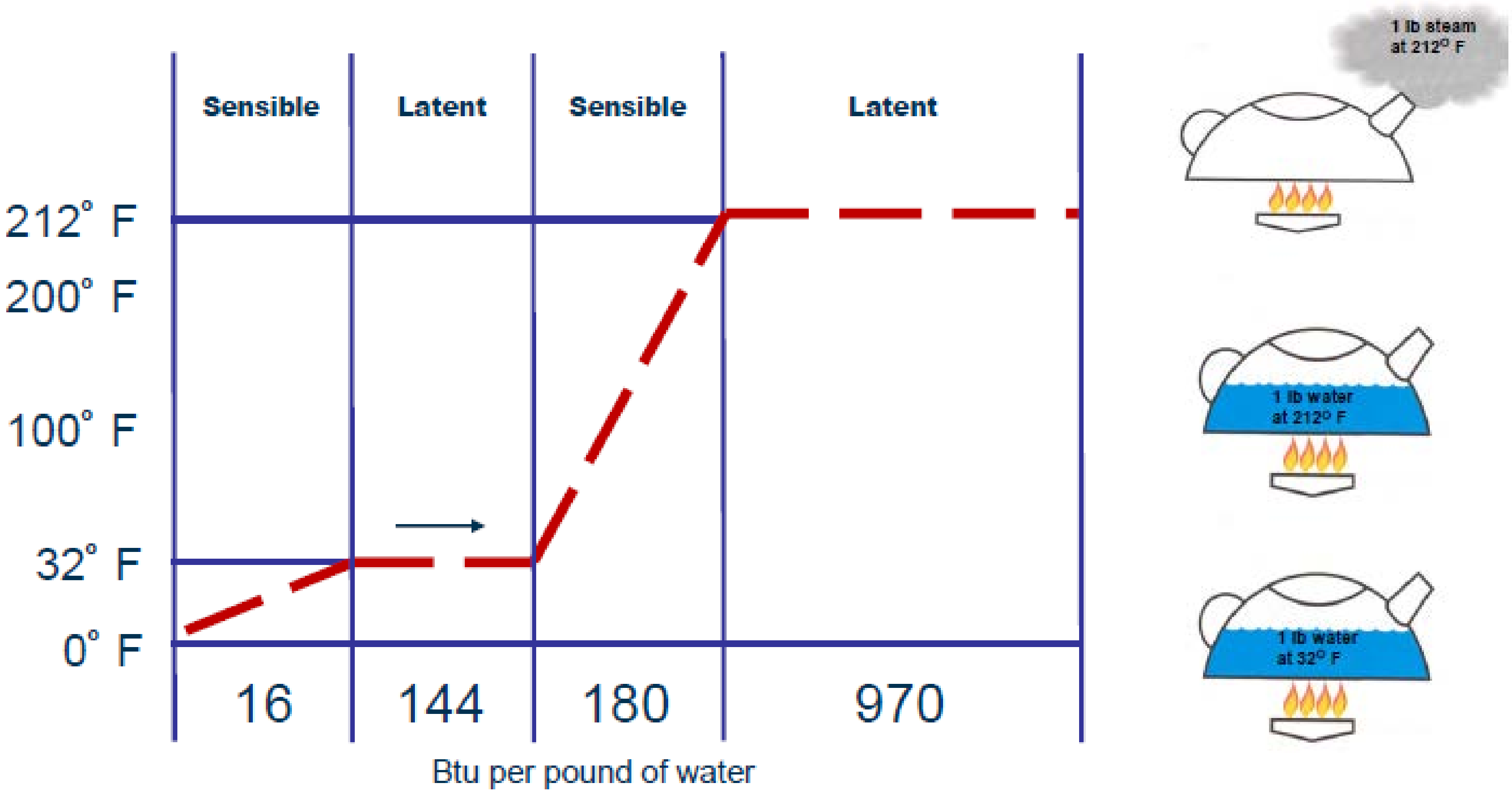
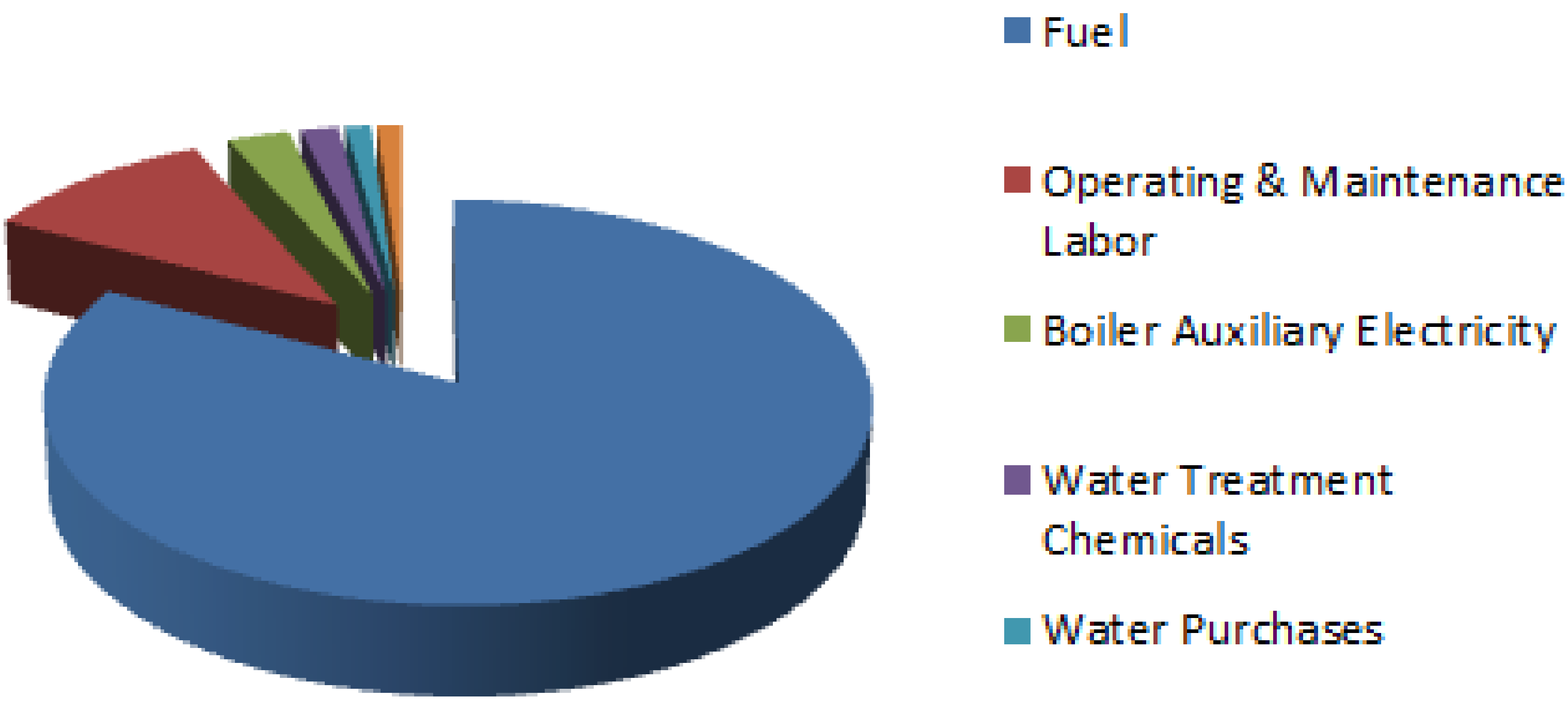
Steam – Basic Concepts

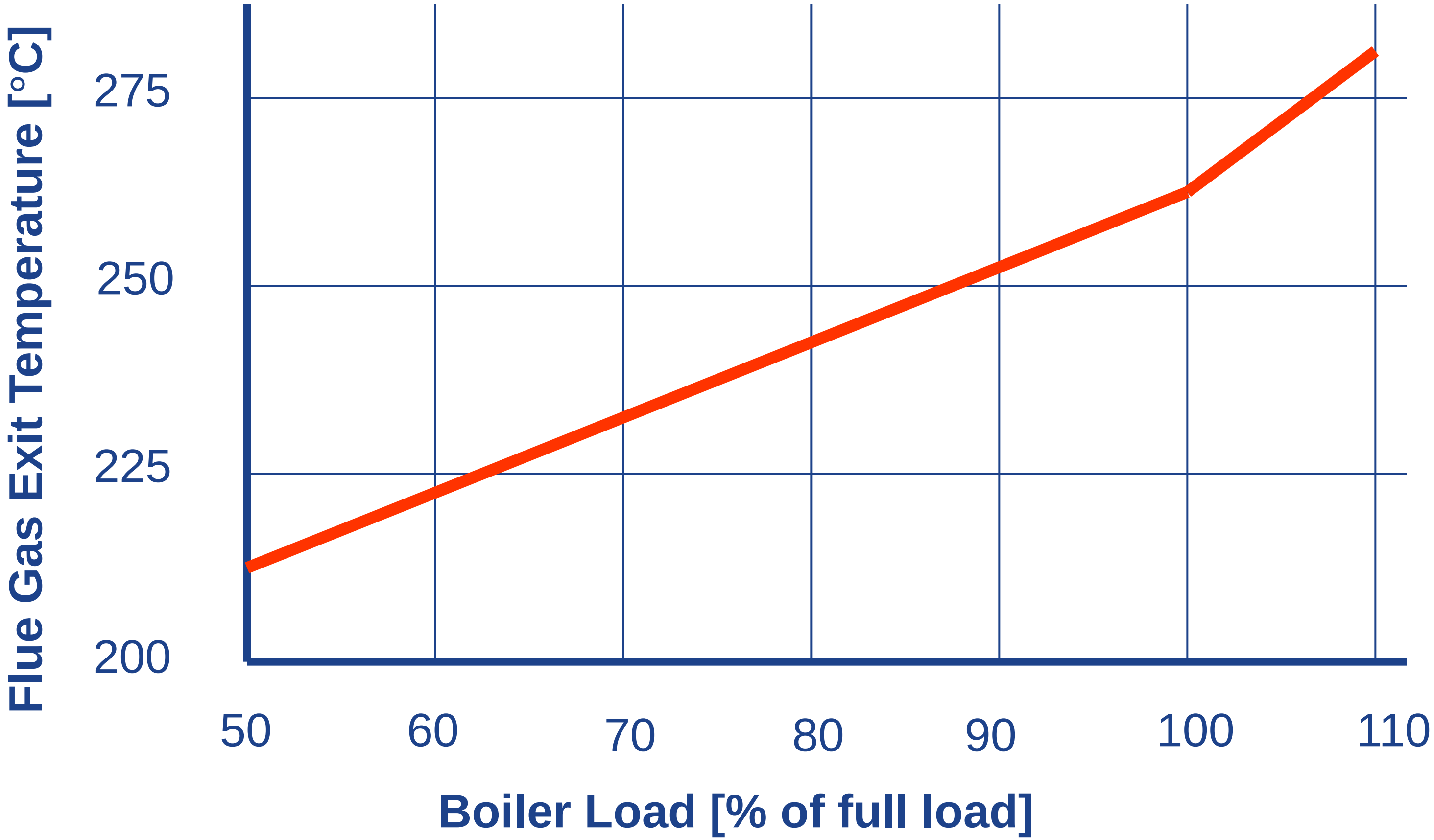
Temperature-Heat Diagram For 1 lb Of Water At Atmospheric Pressure (14.7 psia)



Typical Boiler Costs

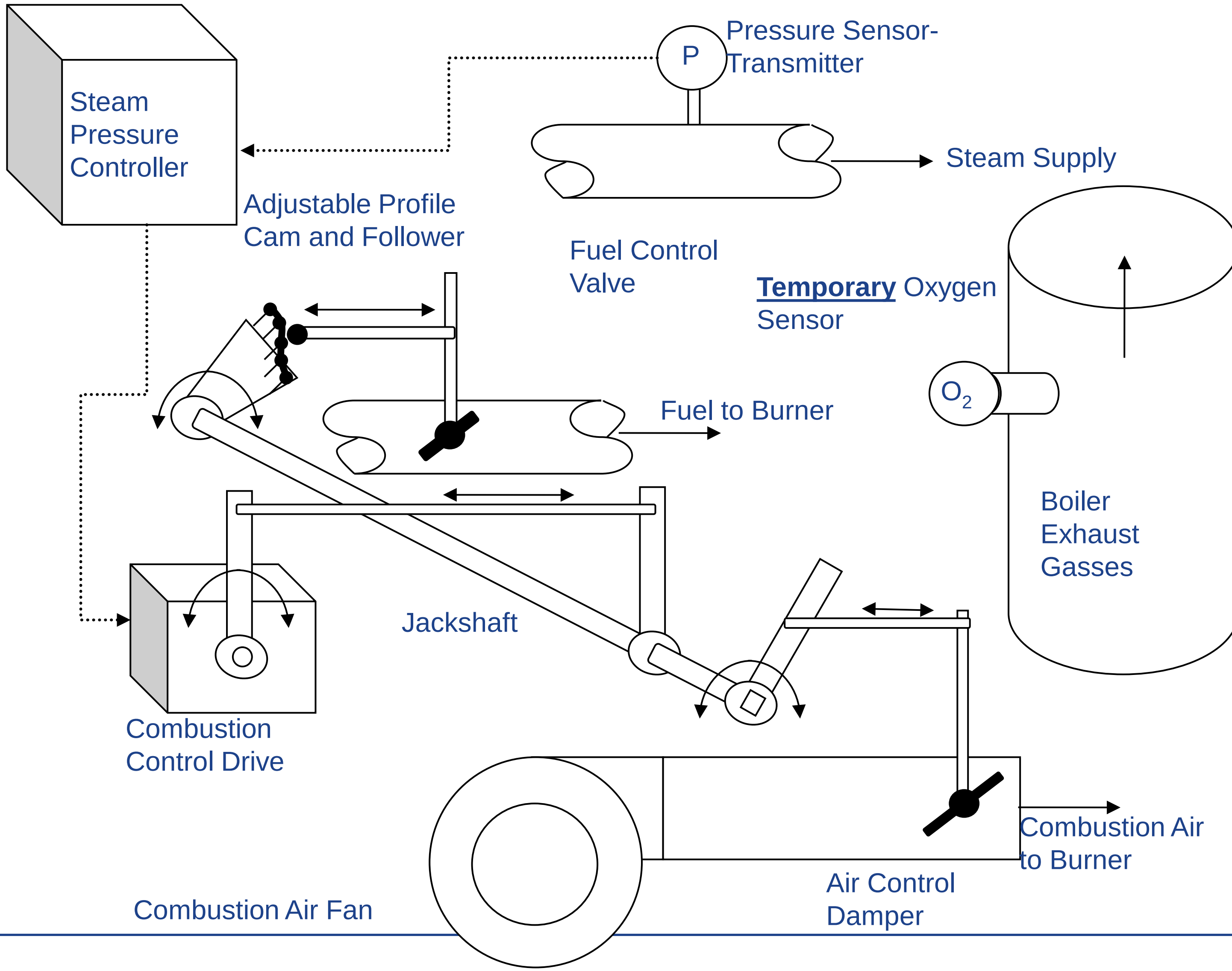


Boiler Load

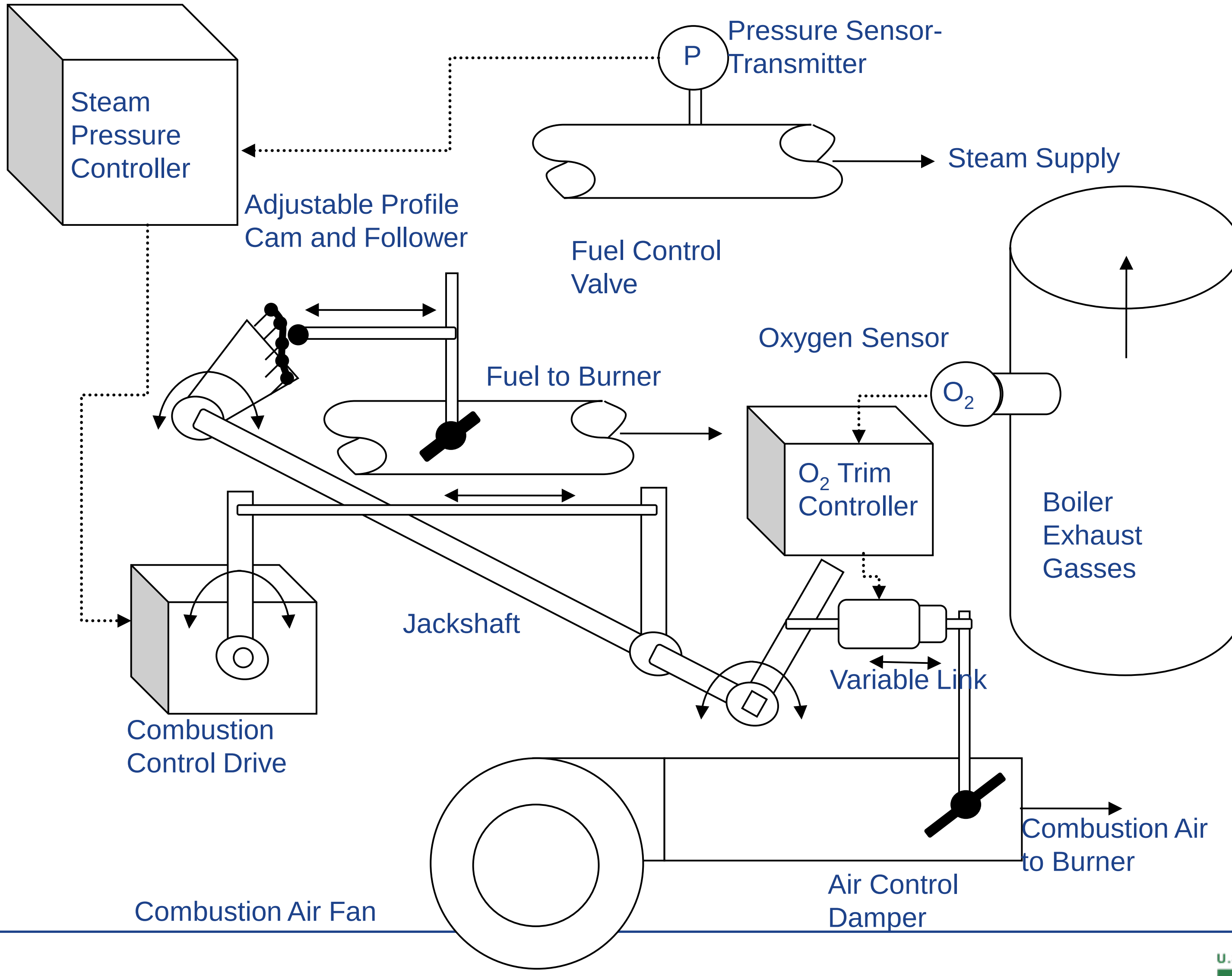


- Flue gas exhaust temperature typically increases as boiler steam production increases

Positioning Control



Oxygen (Trim) Control



TOP TEN STEAM RECOMMENDATIONS
SEN ASSESSMENTS – 2006 to 2008

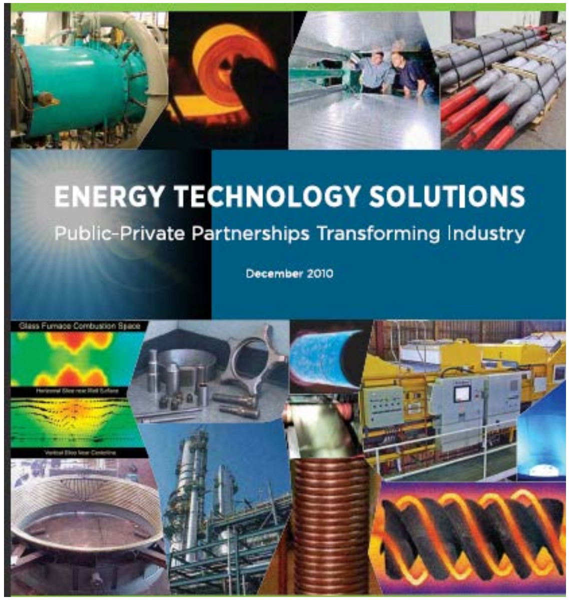
Steam Recommendations (SEN – 2006 to 2008)	Frequency	Average Energy Cost Savings Percent Recommended (%)	Average Source Energy Savings Percent Recommended (%)
1.2 - Use an Alternate Fuel	27	11.4	1.3
1.1 - Reduce Steam Demand by Changing the Process Steam Requirements	165	2.9	2.2
1.7 - Add or Modify Operation of Backpressure Steam Turbine	79	2.4	1.0
1.20 - Multiple Boiler Optimization	17	2.3	1.2
1.17 - Other	91	1.9	1.2
1.18 - Feedwater Heat Recovery - General	20	1.6	1.3
1.3 - Change Boiler Efficiency	230	1.3	1.0
1.12 - Modify the Medium Pressure Condensate Flash System	4	1.2	0.8
1.8 - Add or Modify Operation of Condensing Steam Turbine	17	1.2	0.5
1.21 - Reduce or Recover Vented Steam	37	1.1	0.9
1.19 - Deaerator Heat Recovery - General	5	1.0	1.0

US DOE Steam 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

The tip sheets can be downloaded from the AMO Tip Sheet site at http://energy.gov/eere/amo/tip-sheets-system.

Application of Emerging or New Technologies



- New technology application can result into substantial energy savings together with other benefits.
- New technologies are available for use or commercialization from many sources including the National Laboratories, R&D organizations, equipment suppliers and the industrial companies.

http://www1.eere.energy.gov/manufacturing/about/pdfs/impacts2010_full_report.pdf