Becoming
ClimatEEfficient™

A WEBINAR SERIES
Showcasing Best Practices in
Energy Efficiency & Carbon Management

Effective Energy Efficiency Strategies : Waste Heat Management

Thank you for joining us today, we'll begin the webinar shortly.

November 2, 2011

Hosted by Southern California Gas Company &
The Climate Registry's Cool Planet Project

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Showcasing Best Practices in
Energy Efficiency & Carbon Management

Introductions
The Cool Planet Project
Discussion of Waste Heat Management

*During the webinar, please submit any questions using your control panel.
*To minimize your control panel, click on the red arrow button.
*Slides from today's presentation will be available at www.theclimateregistry.org> Past Events later this week

The Climate Registry

- The only government endorsed registry in North America, capturing corporate inventories
- A community of 440 business, governmental and NGO leaders
- Referenced in the US EPA's mandatory reporting rule; SEC financial disclosure guidance; Congressional climate bills; CARB Scoping Plan

The Climate Registry

Registry's Program: Measuring & Managing Carbon Output

- General Reporting Protocol – "How to" Manual
- Climate Registry Information System (CRIS)
  Online GHG calculation, reporting, and verification tool
- Reporter technical help line
- Regular web-based training; educational webinars and newsletters; policy forums to keep members informed
- Community of Members provides shared best practices among industry sectors
  - Sector specific workgroups
  - Interactive best practices database – 'Carbon Collaborative'

Community of Members

Southern California Gas Company
A Sempra Energy utility
Ford
Hershey's
Dean Foods
Walmart Save money. Live better.
fresh & easy Neighborhood Market
Rio Tinto
Timberland
Virgin America
Alcoa
Safeway
San Diego County Water Authority
UCSD
Levi's
City of Chula Vista
Red Bull Energy Drink
NRDC The Earth's Best Defense
Amtrak
Kodak
Davis California
Mission
IBM
Shell
United States Postal Service
County of San Diego
Kaiser Permanente
West Basin Municipal Water District
Delta
Raytheon
Qualcomm
Armstrong
Johnson & Johnson
the market
Bentley Prince Street
Tamco
Clif Bar
County of Los Angeles
CBS
City of Seattle
The Port of Los Angeles
Brown-Forman
Unified Port of San Diego

The Climate Registry

The Cool Planet Project

Reducing Energy Usage Reduces Greenhouse Gas Emissions!

1,400 kWh = One metric ton of CO2e
200 therms = One metric ton of CO2e
118 gallons = One metric ton of CO2e

One ton of CO2e is emitted when you:

Run an average US household for 60 days

Drive 1,900 miles in a mid-sized car

Graze one Ugandan dairy cow for 8 mos

A Call to Action!

- Utility business customers installing energy efficiency projects are saving energy, money, *and* reducing their carbon footprint.
- Cool Planet **helps customers** manage their associated GHG emissions, establish a baseline, and document reductions.
- Cool Planet **helps customers** communicate their leadership

Mobilizing Energy Efficiency

California's Investor Owned Utilities have a $3.8 billion portfolio of Energy Efficiency programs for their customers. Business customers might consider:

- Energy Audits
- Rebates for qualifying energy-efficient equipment:
  - Pipe & Tank Insulation
  - Steam Traps
  - Boilers
  - Water Heaters
  - Ovens & Fryers
- Financial incentives for qualifying energy-efficient equipment or technologies:
  - Thermal Oxidizers
  - Waste Heat Recovery Systems
  - Energy Management Systems
- On-bill Financing – 0% interest, pay back on monthly bills

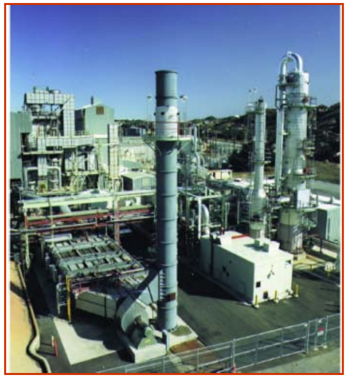
The Climate Registry

Waste Heat Management

Dr. Arvind Thekdi, President, E3M, Inc.

- Over 40 years of experience in research, development and design of industrial process heating equipment and waste heat recovery systems for all major industries.
- Developed training programs in the area of process heating and delivered trainings to the US Department of Energy, utility companies, and private industries in many countries.
- Developed several software tools such as Process Heating Assessment and Survey Tool (PHAST), NOx Emission Reduction Tool and Combined Heat and Power (CHP) Application tool for the US and other countries.
- Conducted energy assessments at more than 50 plants worldwide.
- Contributed energy assessment standards to the American Society of Mechanical Engineers (ASME) and the American National Standards Institute (ANSI).
- Continues to publish papers and contribute to books and trade articles on the subject.

Effective Energy Efficiency Strategies: Waste Heat Management



November 2, 2011

By

Dr. Arvind C. Thekdi
E-mail: athekdi@e3minc.com
E3M, Inc.

Source of Waste Heat

- Furnace exhaust or flue gases
  - high temperature such as fired heaters, melting systems, gas turbines etc.
  - lower temperature such as gases from boilers, steam, blow down water, cooling water etc.
- Hot products at discharge after reactions are completed.
- Cooling water or air used in reactors, product cooling, compressor after coolers etc.
- Heat of reaction for processes.
- Hot surfaces
- Steam leaks, boiler blow down water, condensate etc.
- Thermal oxidizer and emission control system exhaust streams.

Waste Heat Recovery Considerations

Characteristics of Exhaust Gases

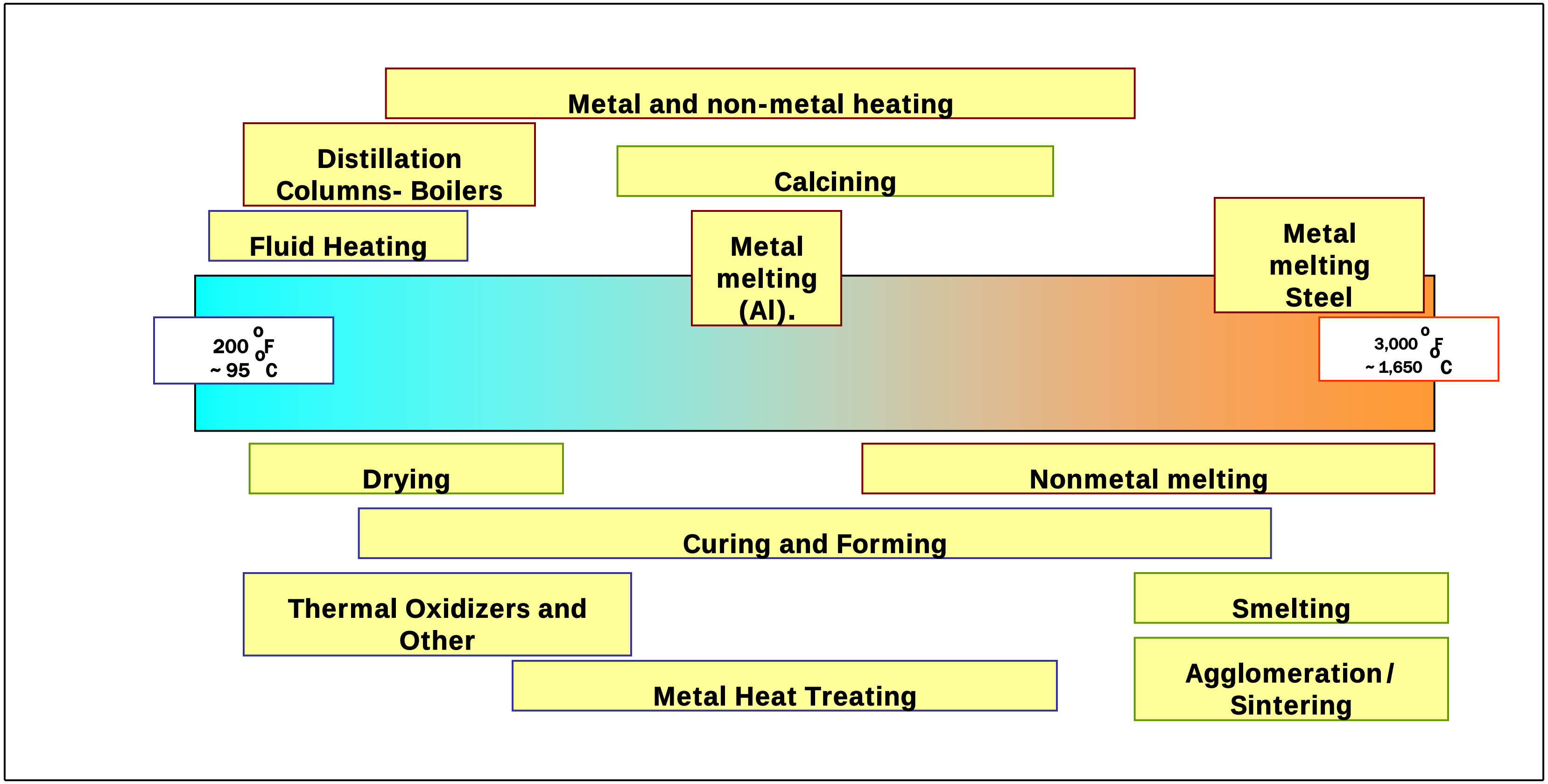
- **Availability of waste heat**
  - Continuous, cyclic or intermittent - unpredictable?
- **Temperature of the waste flue gases**
  - Low (<600 Degree F.) to very high (>1800 Degree F.)?
  - Constant, cyclic- variable with time?
  - Predictable or random variations with time?
- **Flow rate**
  - Constant or variable with time?
  - Predictable or random?

- **Composition- presence and nature of contaminants**
  - Particulates (product, oxides, carbon-soot, additives etc.)
  - Condensable from product (metals and non-metals)
  - Moisture with particulates (possibilities of sludge formation)
  - Corrosive gases (SO2, halogens, H2S etc.)
  - Combustible gases (CO, H2, unburned hydrocarbons – vapors etc)
- **Available Pressure**
  - At positive pressure (psi or inch w.c.) or negative pressure (inch w.c.)
  - Constant or variable?

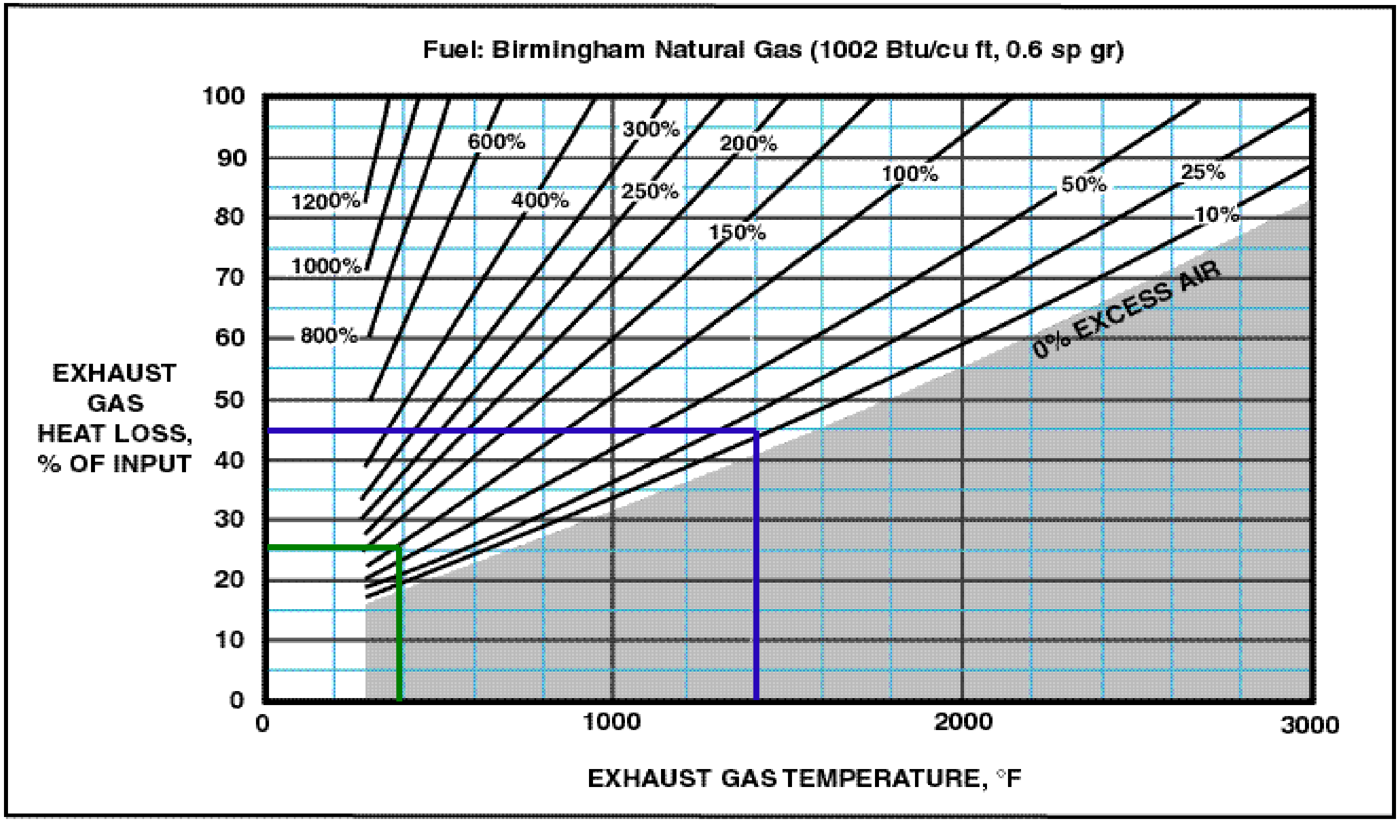
Temperature Range for Waste Heat Streams

Heat source	Temperature Range (Degree F.)	Characteristics
Gas (combustion) turbine exhaust gases	900 to 1,100	Clean
Recip engines		
Jacket cooling water	190 to 200	Clean
Exhaust gases (for gas fuels)	900 to 1,100	Mostly clean
Hot surfaces	150 to 600	Clean
Compressor after-inter cooler water	100 to 180	Clean
Hot products	200 to 2,500	Mostly clean
Steam vent or leaks	250 to 600	Mostly clean
Condensate	150 to 500	Clean
Emission control devices - thermal oxidizers etc.	150 to 1,500	Mostly clean

Range of Temperature for Waste Heat from Industrial Heating Processes



How Much Heat Goes Through the Stack ?

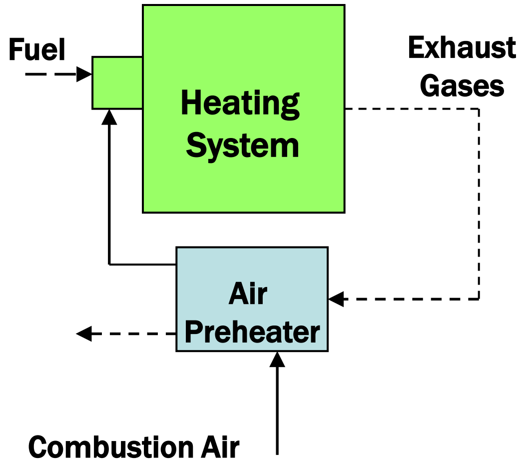


Recoverable heat can vary from 25% to as high 45% even for relatively low temperature exhaust gases (400 deg. F. to 1,400 deg. F.)

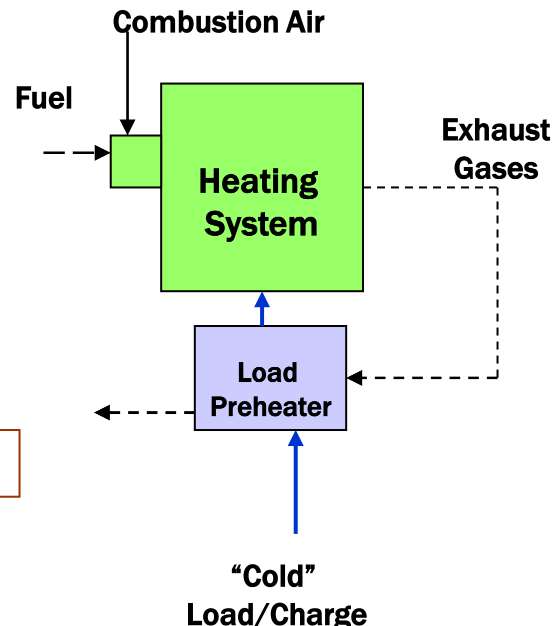
Options for Waste heat Use

- **Waste heat use within the heating system itself - <u>Recycling</u>:** *Combustion air preheating, load or charge preheating, make-up air heating*
- **Waste heat recovery for other systems within the plant - <u>Recovery</u>**: water heating, steam generation, plant air (HVAC) heating, application, in lower temperature processes (cascading)
- **Waste heat to power conversion - <u>Recovery</u>**

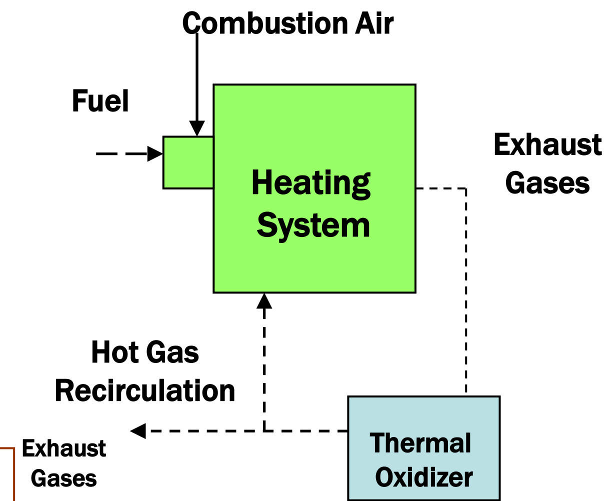
Waste Heat Recycling Options



1. Combustion Air Preheating



2. Load-Charge Preheating



3. Internal heat recycling - cascading

Other options:

4. Make up air heating

5. Water (liquid) heating

Waste Heat Recycling

Summary

Method	Temperature range (Deg. F.)	Energy savings potential (%)	Typical Applications
Combustion air preheat			
Recuperators	1,200 to 1,600	10% to 30%	Furnaces, ovens, thermal oxidizers, heater, kilns etc.
Regenerators	1,000 to 1,800	10% to 40%	
Load/Charge preheating	600 and higher	5% to 25%	Furnace, ovens, kilns etc.
Internal heat recycling	300 to 1,000	10% to 20%	Ovens, dryers etc.
Make-up air heating	200 to 1,000	10% to 25%	Ovens, dryers, air heaters etc.
Water heating	150 and higher	3% to 7%	Heat treating operations, metal coating, ceramic kilns, etc.

Note:

The numbers for temperature and savings are for typical applications. There are lots of exceptions. Use this with care!

Advantages of Waste Heat Recycling

- Compatible with process demand and variations in operating conditions.
- Can be used as retrofit for existing equipment.
- Relatively easy and inexpensive to implement.
- Heat recovery – 30% to 90% of the waste heat.
- Implementation cost: $30,000 to $75,000 per MM Btu recovered heat (includes normal installation). *<u>Very much site and size specific.</u>*
- Typical payback periods – one year to three years
- Application temperature range – Typically, it ranges from 400 deg. F. and higher. Depends on specific process conditions.

Waste Heat Recycling
Economic Considerations

- **Saving:**
  - Energy savings based on average operating conditions
  - Emission reduction
  - Productivity gain
  - Quality improvement
  - Other (labor, waste disposal cost etc.)

- **Cost:**
  - Equipment (i.e. recuperators, regenerators) cost
  - Auxiliary equipment (i.e. burners, controls, piping etc.) cost
  - Added supplemental energy cost (for blower motor, pumps etc.)
  - Changes in emissions (increase?) and environmental permits
  - Equipment relocation etc.
  - Other cost or penalties (if any)

Energy Savings

With Use of Preheated Combustion Air

Exhaust Gas Temperature (Degrees F)	Combustion Air Preheat Temperature (Degrees F)						
	400	500	600	700	800	900	1,000
1,400	10%	13%	16%	18%	20%	22%	25%
1,500	11	14	16	19	21	23	25
1,600	11	14	17	19	22	24	26
1,700	12	15	18	20	23	25	27
1,800	13	16	19	21	24	26	29
1,900	13	16	19	22	25	27	30
2,000	14	17	20	23	26	29	31
2,100	15	18	22	25	28	30	33
2,200	16	20	23	26	29	32	34
2,300	17	21	24	28	31	34	36
2,400	18	22	26	30	33	36	38
2,500	20	24	28	32	35	38	41
2,600	22	26	30	34	37	40	43

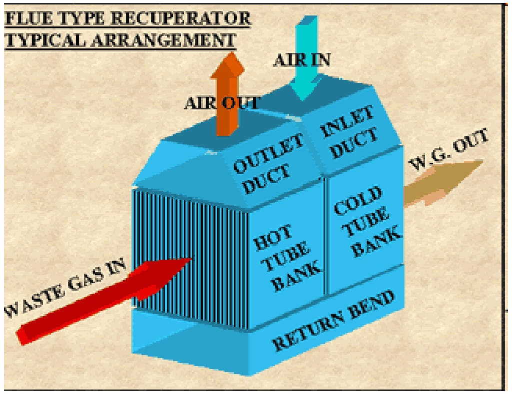
Percent Fuel Savings with Use of Preheated Combustion Air

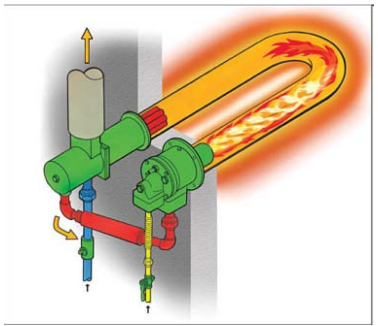
Calculations for N. Gas, 10% Excess air

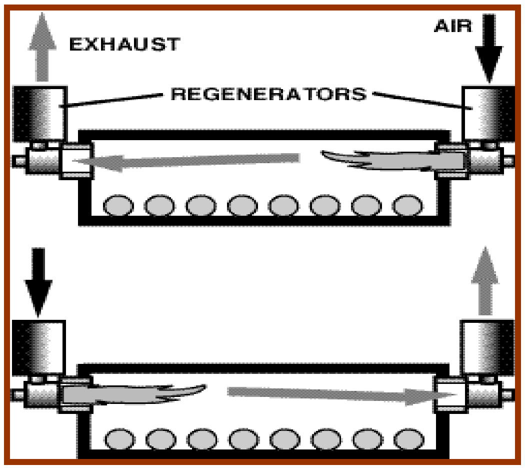
Savings - Use of Preheated Combustion Air		
	Current	New
Furnace flue gas temp. (F)	1,400	1,400
Percent O2 (dry) in flue gases	2.10	2.10
% Excess air	9.94	9.94
Combustion air temperature (F)	80	700
Fuel consumption (MM Btu/hr) - Avg. current	10.00	8.14
Available Heat (%)	58.00	71.29
Fuel savings (%)	Base	18.64%
No. of operating hours	8000	8000
Therms used per year (Therms/year)	800,000	650,843
Therms saved per year (Therms/year)	Base	149,157
Cost of fuel ($/Million Btu)	$ 10.00	$ 10.00
Annual savings ($/year)	Base	$ 149,157
CO2 savings (tons/year)	Base	873
Carbon equivalent savings (tons/year)	Base	238

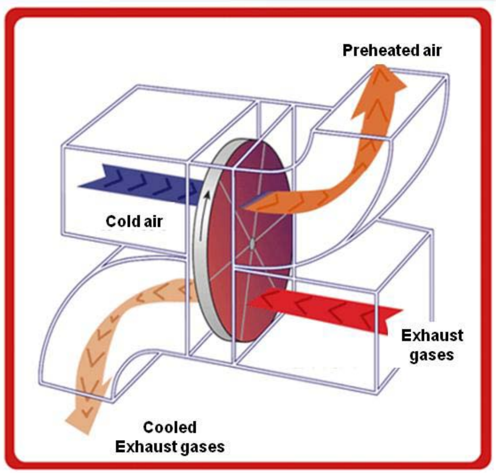
Savings can be calculated by using equations, tables or calculators

Combustion Air Preheating Equipment Options





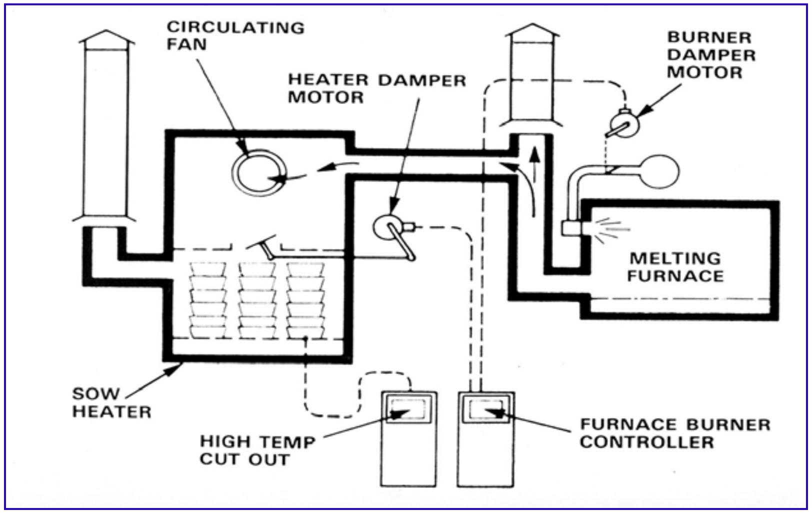




- **Recuperators**
  - External or Self-recuperating burners
  - Temperature range: up to 1,600 deg. F. flue gases
  - Heat recovery: 30% to 60%

Regenerators
  - External or regenerative burners
  - Temperature range: up to 2,400 deg. F.
  - Heat recovery: 50% to 80%

Charge or Load Preheating



Aluminum melter charge Preheater using furnace flue gases

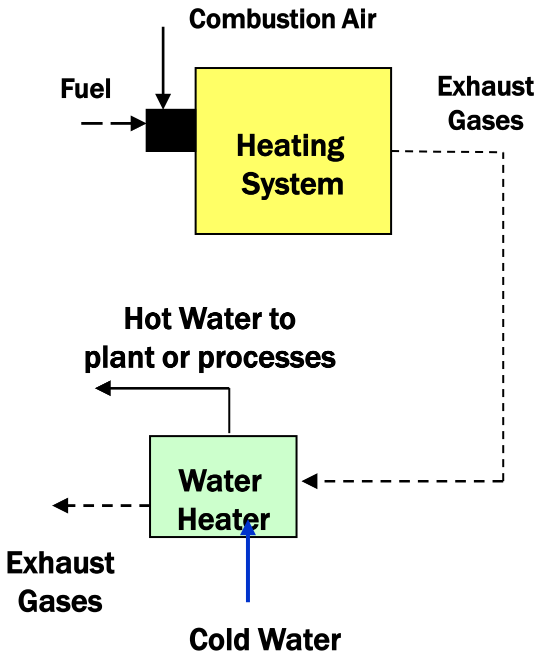
Boiler economizer

Fluid Preheater

Load or Charge Preheating including use of economizer on a boiler

- Most common method – use of exhaust gases to raise temperature or remove moisture from the charge material.
- Perhaps the efficient and beneficial method of heat recovery
- Can be used for increased production
- Requires changes in material handling system
- Can reduce **Energy Intensity (**energy use per unit of production) from 5% to as much as 40%.
- May result in higher yield and improved product quality

In-Plant Waste Heat Recovery



- Recovery of heat for plant utility supplement or auxiliary systems energy use in a plant or neighboring plants
  - For fired systems
    - **Steam generation**
    - **Hot water heating**
    - **Plant or building heating (HVAC)**
    - **Absorption cooling systems**
    - **Cascading to lower temperature heating processes**
    - **Reaction heat for endothermic processes**
- Can be used as retrofit for existing equipment
- Application temperature range – typically for temperature as low as 250 deg. F. and higher
- May require heat exchanger(s) to transfer heat from hot gases to secondary heating medium

Waste Heat Recovery Considerations

- Most important consideration is **matching of heat supply to the heat demand** for the selected utility within a plant or a neighboring plant
- Moderately expensive to implement.
- Heat recovery – 10% to 75% of the waste heat
- Installed cost varies with the type of system selected.
- Implementation cost:
  - Application and site specific.
  - Varies with the selection of the heat recovery method.
  - Typical cost could vary from $25,000 to $200,000 per MM Btu recovered heat (includes normal installation)
- Typical payback periods: six months to five years

Saving and cost considerations are same as in case of waste heat recycling.

Heat Recovery Systems - Summary

Heat recovery system	Waste heat Temperature (F)	Typical applications	Typical installed cost
Steam generation	600^0 F and higher	Large furnaces with >25 MM Btu/hr. firing rate. Reheat furnaces, process heaters, glass melting furnaces etc.	$35 to $60 per 1,000 lb. steam generation
Hot water heating	200^0 F and higher	Heating equipment of all sizes. Heat treating, reheating, forging, ovens, dryers etc.	$30,000 to $50,000 per MM Btu heat transferred
Plant or building heating	150^0F and higher	Mostly in cold climate areas. Can be used for medium to large size (5 MM Btu/hr. and larger size).	$25,000 to $50,000 per MM Btu transferred
Absorption cooling systems	300^0 F and higher	Low to medium temperature systems, large size furnaces, ovens, heaters etc.	$750 to $1,500 per ton of refrigeration capacity
Cascading to lower temperature heating processes	800^0 F and higher	For gases from medium to large size systems supplying heat to lower temperature heating systems.	$40,000 to $100,000 per MM Btu transferred

Note:

The costs are very preliminary and can vary by as much as 100%.

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

Waste Heat to Power

Options for Industrial Applications

- “Conventional plant" using a steam boiler, steam turbine and generator
- Organic Rankin Cycle (ORC) plant
- Ammonia – water systems (i.e. Kalina, Neogen systems)
- Thermo-electric power generation (TEG)

Caution: This is a fast-changing field. Technology, performance and cost can vary significantly. Take the numbers as typical only.

Waste Heat to Power
Application Considerations

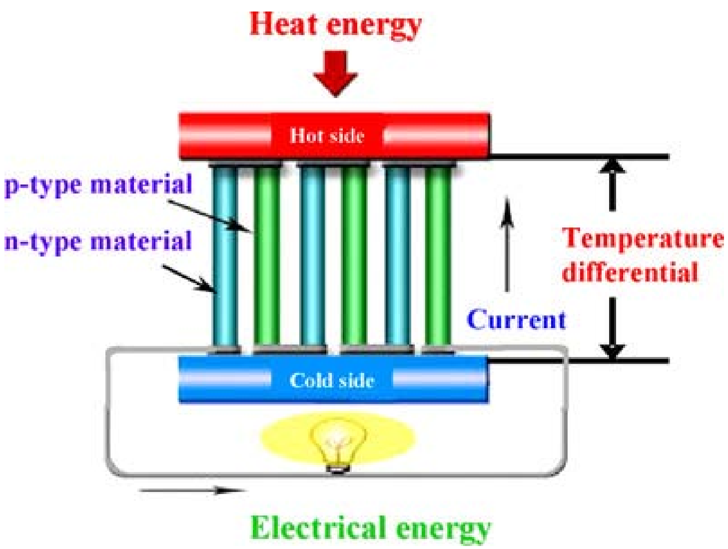
- Need relatively clean and contamination free source of waste heat (gas or liquid source). Avoid heavy particulate loading and/or presence of condensable vapors in waste heat stream.
- Continuous or predictable flow for the waste heat source.
- Relatively moderate waste heat stream temperature (at least 300^o deg. F., but >600^o F. is preferred) at constant or predictable value.
- Cannot find or justify use of heat within the process or heating equipment itself.
- Cannot find or justify alternate heat recovery methods (steam, hot water, cascading etc.) that can be used in the plant.
- Try to avoid or reduce use of supplementary fuel for power generation. It can have negative effect on overall economics unless the power cost can justify it.

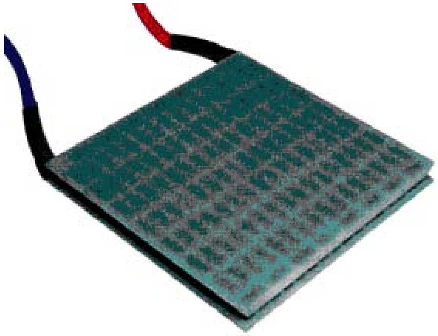
Power Cycle Comparison

Comparison	Steam Rankine	Organic Rankine (ORC)	Ammonia (NH_3) - Water	CO2 Power Cycle
Source Temperature Range Deg. F.)	800 plus	200 to 500	200 to 800	400 to 1200
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.

Waste Heat to Power
Thermo-Electric Power Generation (TEG)





Note: The operating data and costs are derived from available literature and their accuracy cannot be guaranteed.

– Technology in infancy and unproven for industrial application
– Waste heat temperature range from 400 Degree F. to 900 Degree F.
– Relatively low efficiency – less than 5%
– Very expensive (>$5000 per kW) and unproven for industrial use
– Will require considerable R&D and technology pilot demonstration before it can be used for waste heat to power applications

Waste Heat Options Summary
Recycling and Recovery

- Three possible options should be considered and evaluated for use of waste heat from a heating system.
  1. Use waste heat within the process or system itself. This is the most economical and effective method of using waste heat.
  2. Use waste heat within the plant boundary itself. Options include use in or for plant utilities or use in other processes.
  3. Waste heat to power conversion.
- Very few options are available for recycling or recovery of "contaminated" waste heat streams, particularly at higher temperatures.

Waste Heat Options Summary
Power Generation

- Conventional steam turbine-generator option is the most attractive option for clean, contamination-free waste heat at higher (>800^o F) temperature.
- Three options are available for lower temperature waste heat: ORC, Ammonia-water based systems and CO_2 based systems. However none of these have long and “proven” history in industrial applications to offer economically justifiable power generation as of today.
- Waste heat to power projects are difficult to justify for low (~400^{o}F or lower) temperature waste heat, especially if the waste heat supply is not continuous and auxiliary energy is required.
- Thermo-electrical systems are in early development stage and their use cannot be economically justified at this time.

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