Waste Heat to Power

Economic Tradeoffs and Considerations

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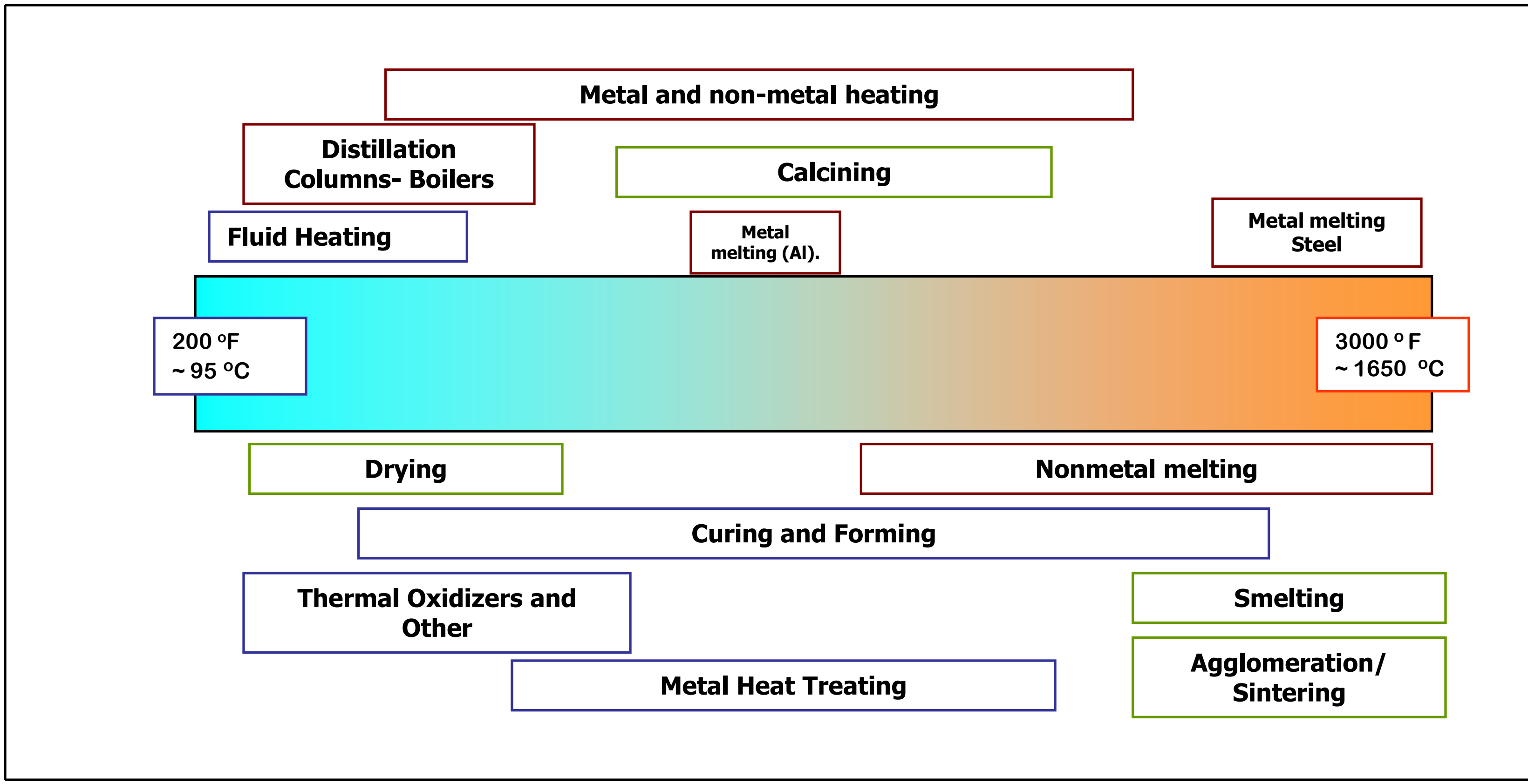
Waste Heat Sources from Process Heating Equipment

- Hot gases – combustion products
  - Temperature from 300 deg. F. to 3000 deg.F.
- Radiation-Convection heat loss
  - From temperature source of 500 deg. F. to 2500 deg. F.
- Sensible-latent heat in heated product
  - From temperature 400 deg. F. to 2200 deg. F.
- Cooling water or other liquids
  - Temperature from 100 deg. F. to 180 deg. F.
- Hot air or gas from cooling-heating system
  - From temperature 100 deg. F. to higher than 500 deg. F.

For fuel fired systems and boilers,
the single largest energy loss is in hot flue gases

Range of Temperature for Waste Heat from Industrial Heating Processes



Waste Heat Stream Characteristics Considerations for Waste heat to Power

- Availability of waste heat
  - Continuous, cyclic or intermittent - unpredictable?
- Temperature of the waste heat stream
  - Low (<600 Deg. F.) to very high (>1800 Deg. F.)?
  - Constant, cyclic- variable with time?
  - Predictable or random variations with time?
- Flow rate
  - High or low (exact definition depends on selected application)
  - Constant or variable with time?
  - "Turn-down" or high/low flow rate
  - Predictable or random?

Waste Heat Stream Characteristics Considerations for Waste heat to Power

- <u>Composition- presence and nature of contaminants</u>
  - Particulates (product, oxides, carbon-soot, additives etc.)
  - Condensable from product (metals and non-metals)
  - Moisture with particulates (possibilities of sludge formation)
  - Corrosive gases (SO_2, halogens, H_2S etc.)
  - Combustible gases (CO, H_2, unburned hydrocarbons – vapors etc)
- <u>Available Pressure</u>
  - At positive pressure (psi or inch w.c.) or negative pressure (inch w.c.)
  - Constant or variable?

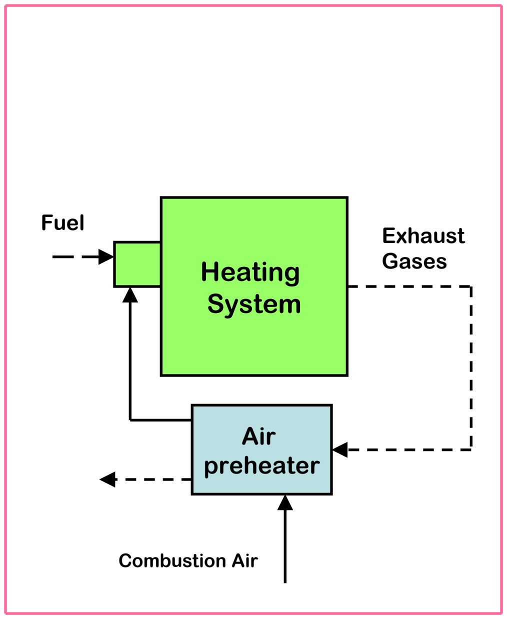
Options for Waste heat Use

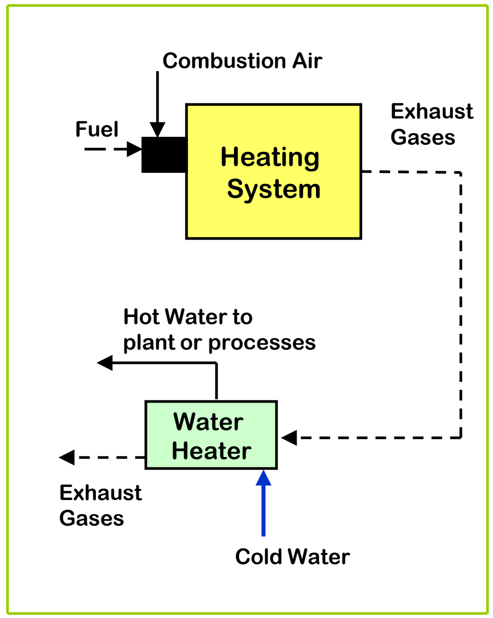
- Waste heat recycling within the heating system itself

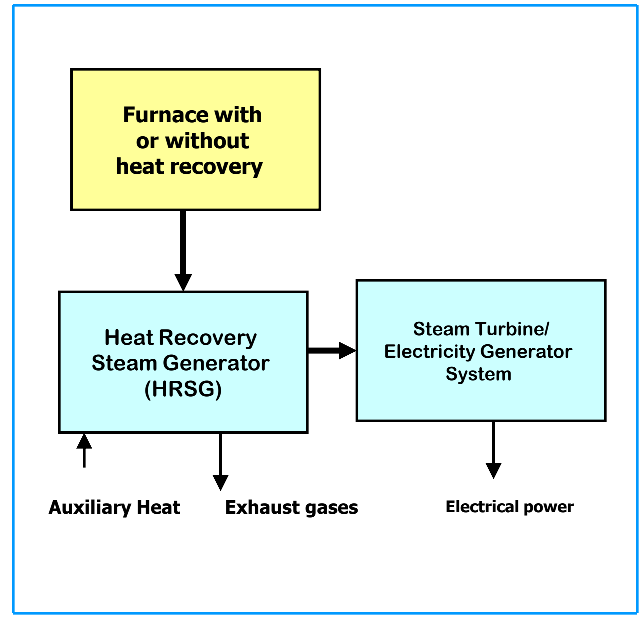
- Waste heat recovery for auxiliary or adjoining systems within a plant

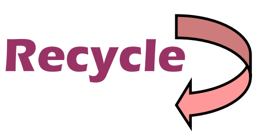
- Waste heat to power conversion

Options for Waste heat Use: Examples







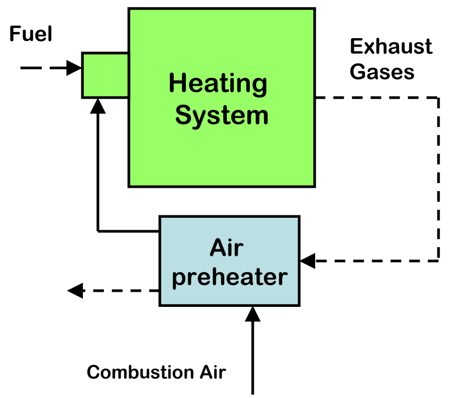


Waste Heat Recycling Options

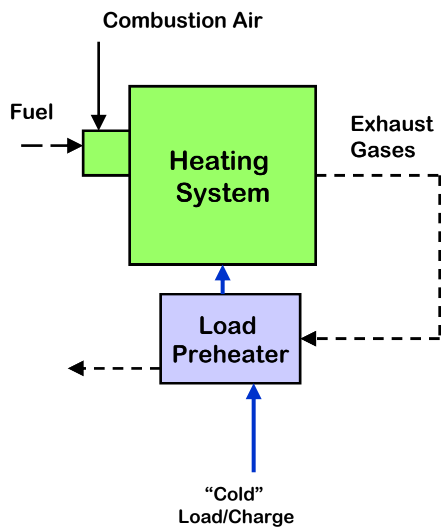
Three most commonly used options for fired systems

1. Combustion air preheating
2. Load or charge preheating
3. Internal heat recycling - cascading

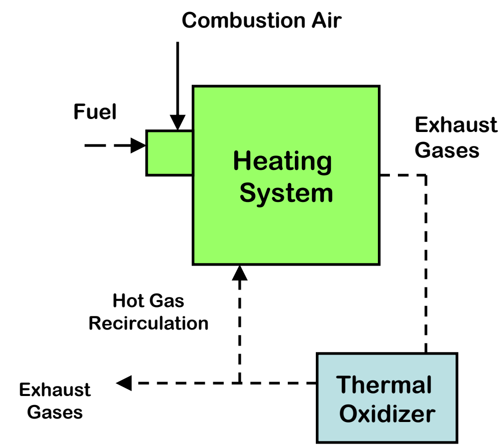
Waste Heat Recycling Options



Combustion Air Preheating



Load-Charge Preheating

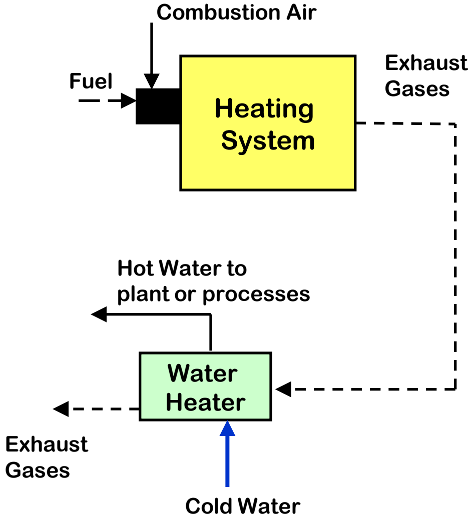


Internal heat recycling - cascading

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). Site specific.
- Typical payback periods – one year to three years
- Application temperature range – Ranges from 400 deg. F. and higher. Depends on specific process conditions.

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**
    - **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

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- 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: one-half year to five years

Heat Recovery Systems - Summary

Heat recovery system	Waste heat Temperature (F)	Typical installed cost
Steam generation	600^0 F and higher	$35 to $60 per 1000 lb. steam generation
Hot water heating	200^0 F and higher	$30,000 to $50,000 per MM Btu heat transferred
Plant or building heating	150^0F and higher	$25,000 to $50,000 per MM Btu transferred
Absorption cooling systems	300^0 F and higher	$750 to $1500 per ton of refrigeration capacity
Cascading to lower temperature heating processes	300^0 F and higher	$40,000 to $100,000 per MM Btu transferred

Waste Heat to Power
Options for Industrial Applications

The waste heat power plant does not influence the industrial process

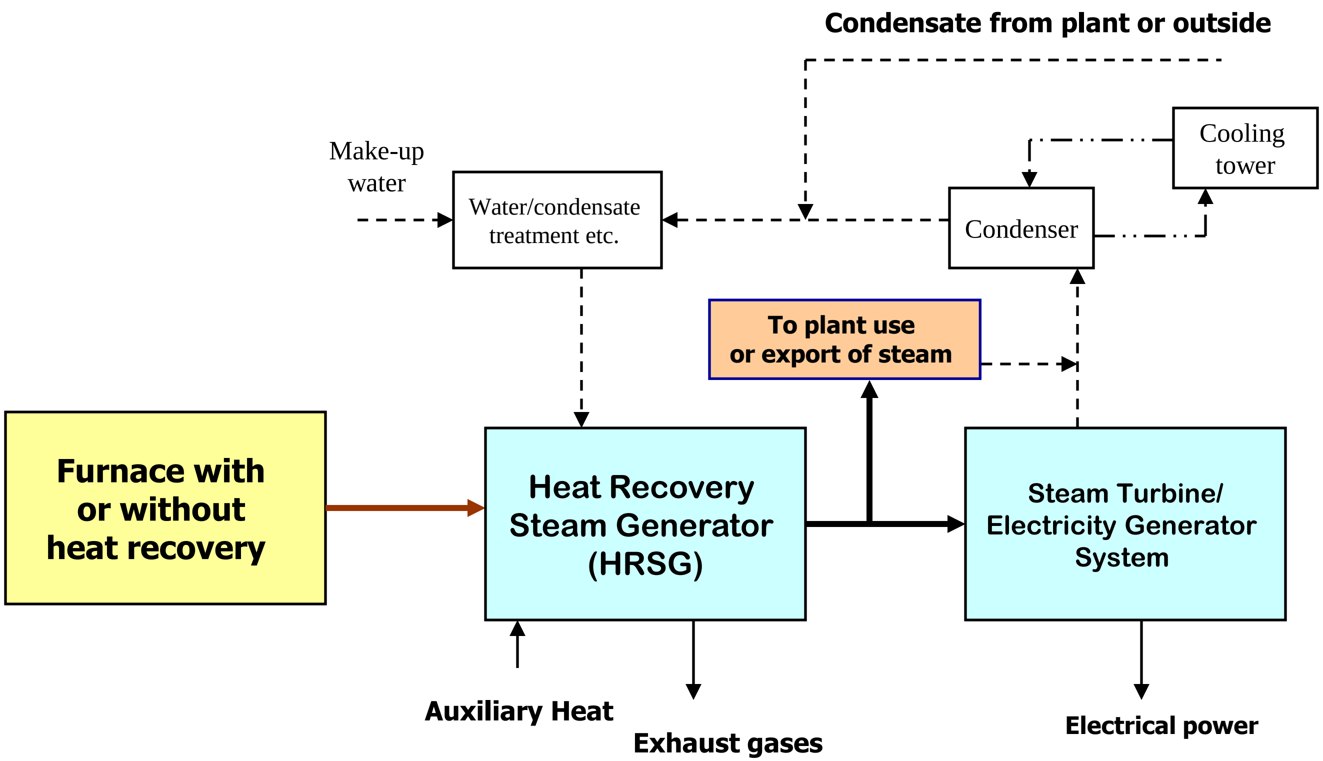
- **“Conventional plant" using a steam boiler, steam turbine and generator**
- **Kalina cycle plant**
- **Organic Rankin Cycle (ORC) plant**
- **Thermo-electric power generation (TEG)**

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.

Waste Heat to Power System

"Conventional" Steam – Power Generation

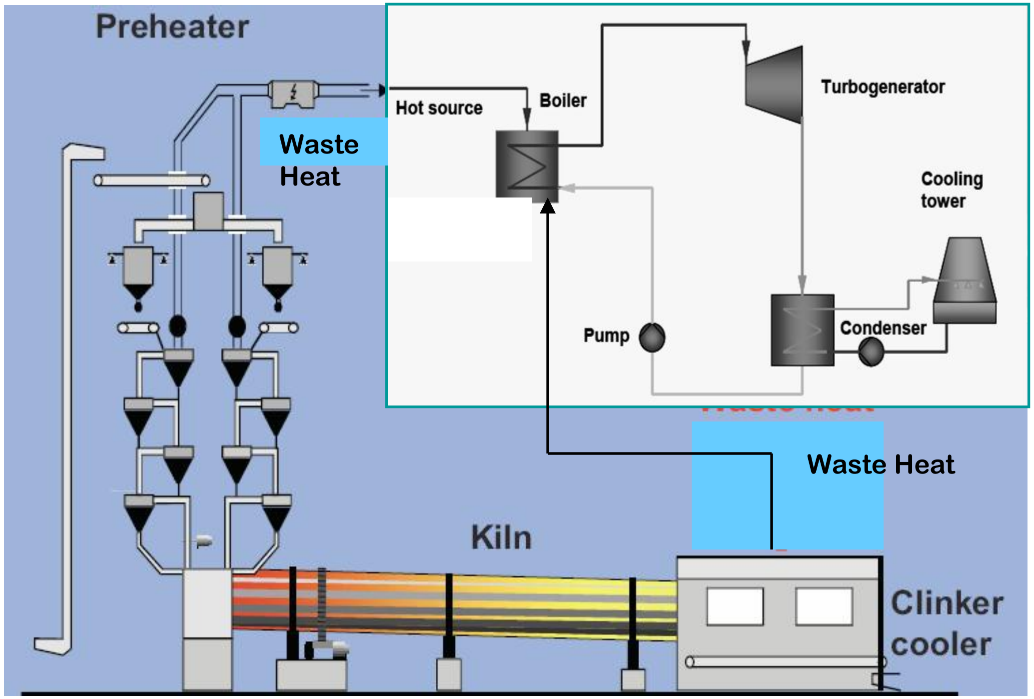


Waste Heat to Power
Options for Industrial Application

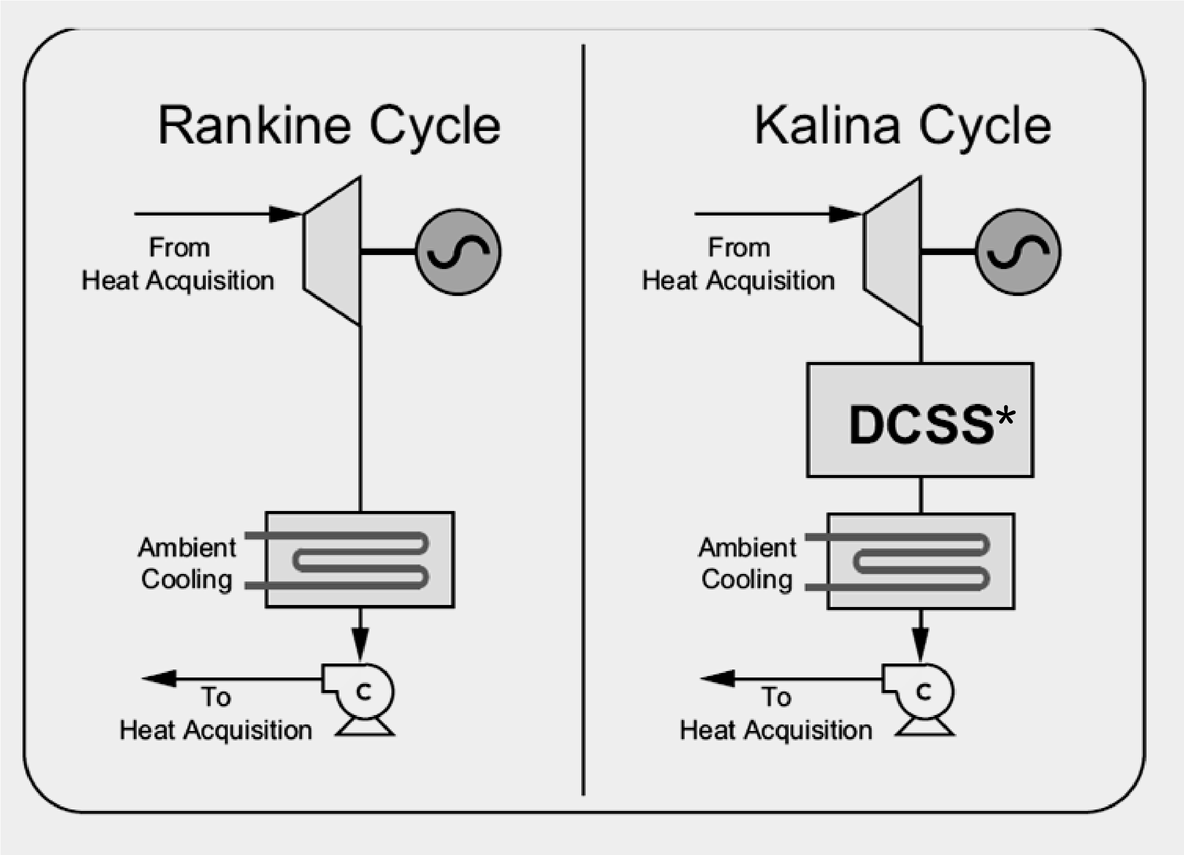
- **"Conventional plant" using a steam boiler, steam turbine and generator**
  - Working medium: water vapor
  - Mainly suitable for waste heat at high temperatures (>600 deg. F.)
  - Relatively low cost option ($800 to $1800 per kW capacity)
  - Operating efficiency (power produced/waste heat supplied) ranges from 20% to 30%.
  - Use of steam for process and power generation (Combined Heat and Power - CHP) can increase energy use efficiency to as high as 70%.

Power Generation from Waste Heat

Example: Cement Kiln

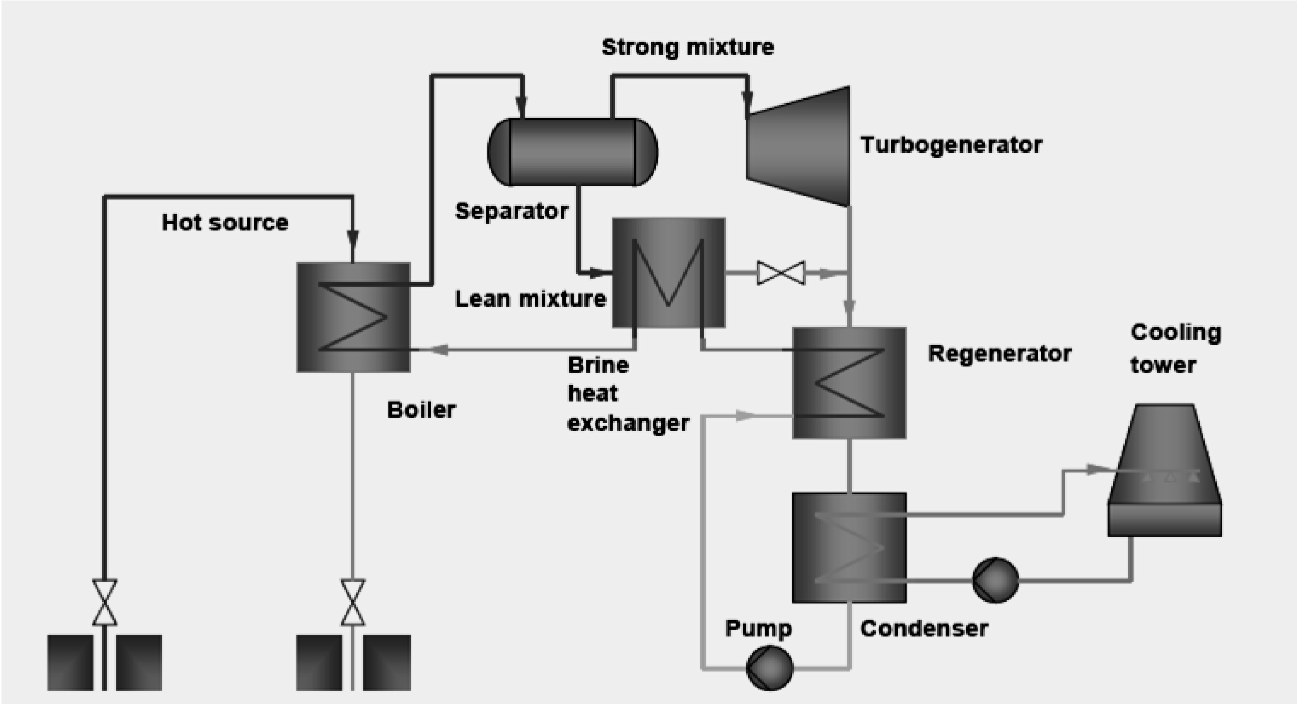


Binary Fluid (ORC and Kalina) Cycles



* DCSS: Distillation – Condensation Subsystem. The DCSS consists of a series of separators, heat exchangers and pumps

Typical Kalina Cycle for Power Generation



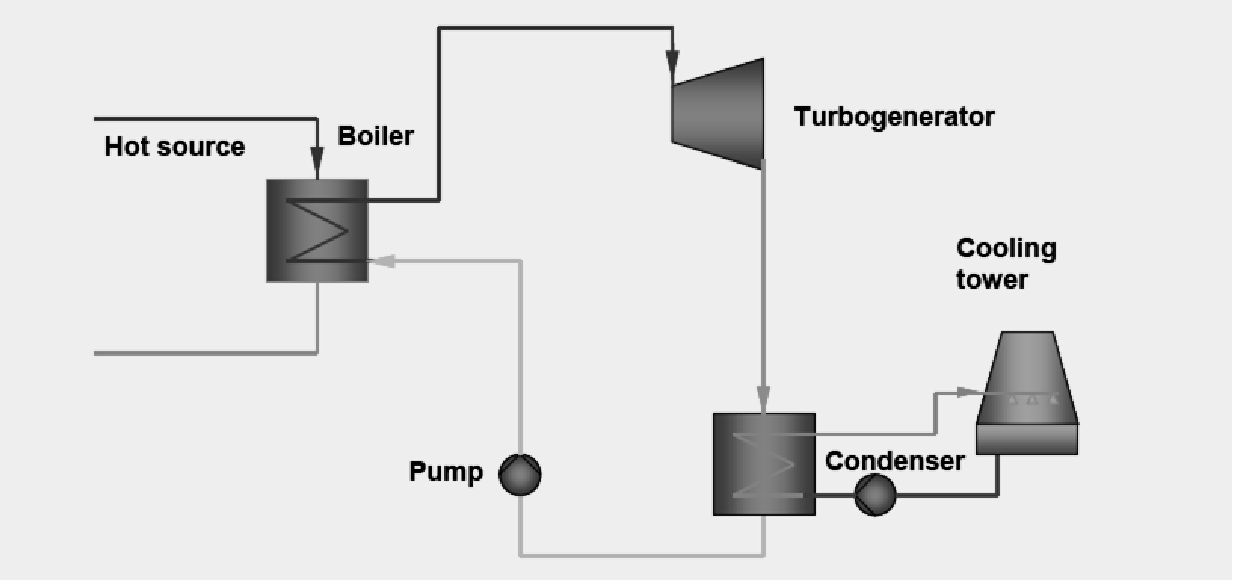
Kalina cycle is 15% to 25% more efficient than ORC cycle at the same temperature level

Waste Heat to Power
Options for Industrial Application

Kalina cycle plant

- Bottoming cycle - working medium: Ammonia - water vapor
- Operating temperature range: 250 deg. F. to as high as 1000 deg. F. waste heat with proper heat exchanger equipment.
- Operating efficiency (~15%) with waste heat temperature in the range of 300 deg. F. to is at a relatively low temperature.
- Relatively high cost ($2000 to $3000 per kW capacity)
- Large percentage of total cost (capital and maintenance) is in heat exchangers
- Most applications in geo-thermal and other non heavy industrial areas

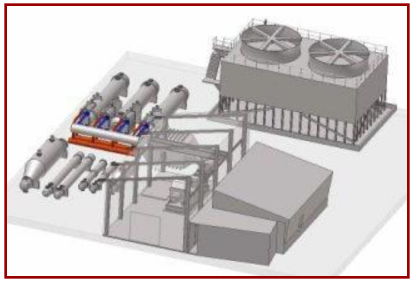
Typical Organic Rankin Cycle (ORC) for Power Generation



Several other variations of ORC have been are developed to improve its efficiency

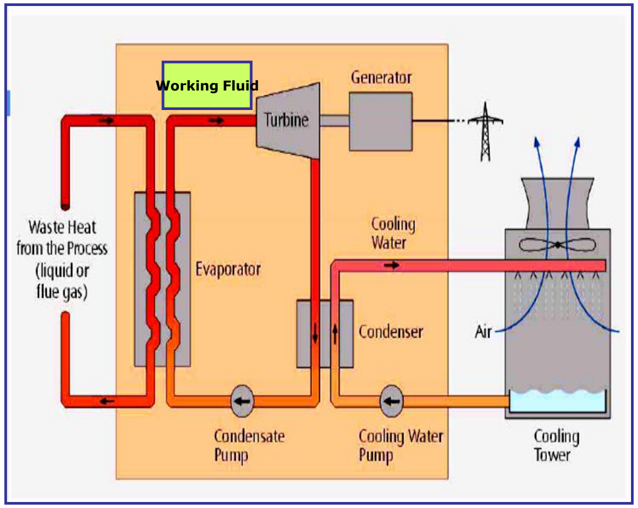
Waste Heat to Power
Options for Industrial Application

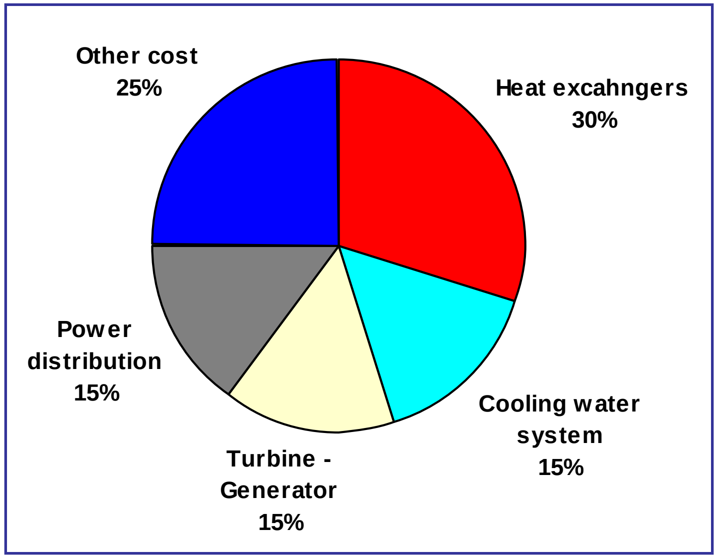
Organic Rankin Cycle (ORC) plant



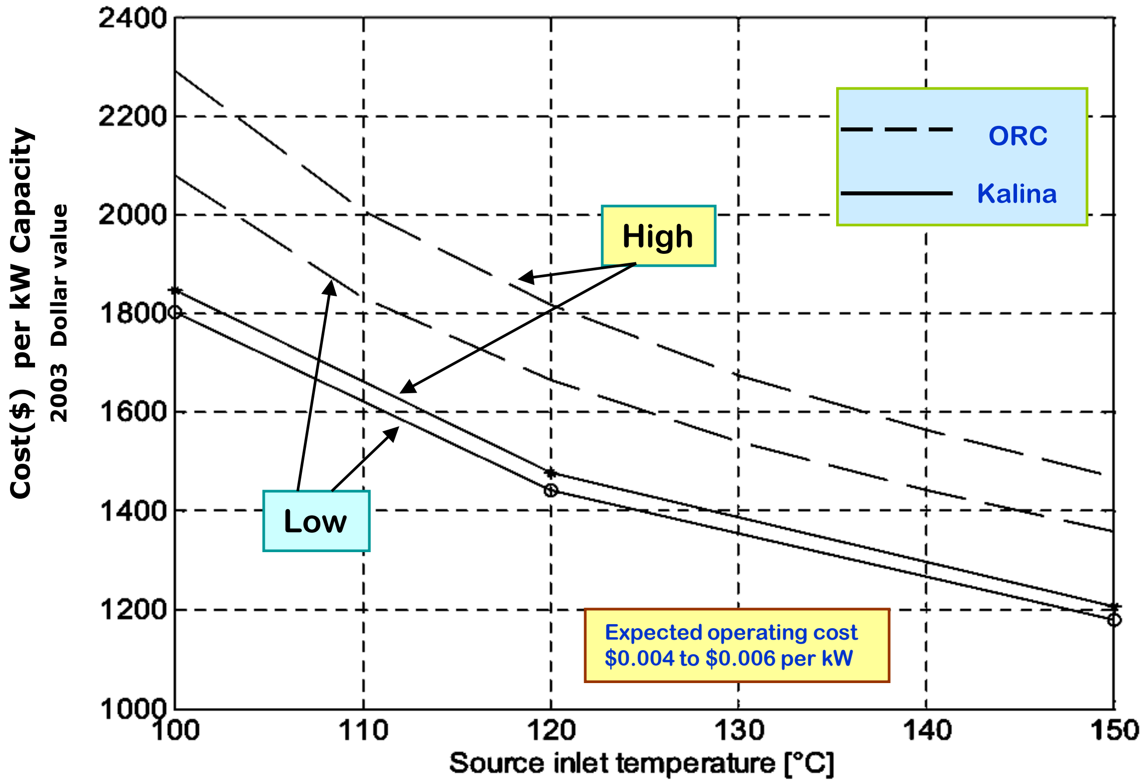
- Working medium: variety of organic liquids such as Freon, butane, propane, ammonia, and the new environmentally-friendly" refrigerants
- Waste heat temperature range is 300 deg. F. and up with proper temperature control for the evaporator heat exchanger
- Operating efficiency (~8% to 15%) for low (300 deg. F.) to medium (800 deg. F.) temperature range for waste heat
- Relatively high cost ($2500 to $3500 per kW capacity)
- Most applications in geo-thermal and other non-heavy industrial areas

Cost Distribution for ORC Power Plant

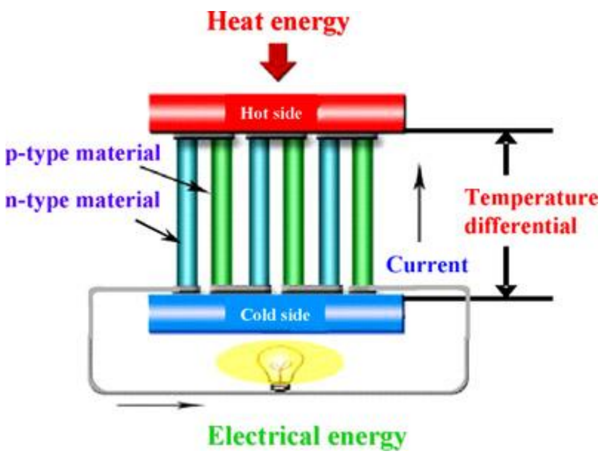


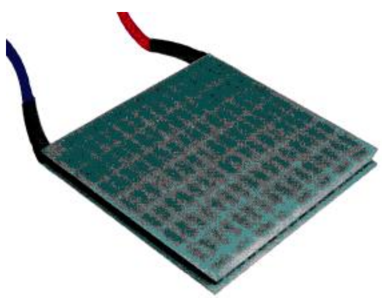


Kalina vs. ORC Cost Comparison



Waste Heat to Power
Options for Industrial Application





Thermo-electric power generation (TEG)

- Technology in infancy and unproven fro industrial application
- Waste heat temperature range from 400 deg. F. to 900 deg. 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 to Power Summary

- Three possible options should be considered and evaluated for use of waste heat from a heating system – equipment.
  - The first option is to use the heat within the process or equipment itself. This is the most economical and effective method of using waste heat.
  - The second option is to use waste heat within the plant boundary itself. This means generation of plant utilities or use of heat in other processes.
  - The third option is to consider waste heat to power conversion.
- Conventional steam turbine-generator option is the most attractive option for clean, contamination free waste heat at higher (>600^{o} F) temperature.
- Two options are available for lower temperature waste heat: ORC and Kalina cycle. However none of these have long and "proven" history in industrial applications to offer economically justifiable power generation.
- No good option is available for heat to power conversion using contaminated waste heat at any temperature.
- 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.