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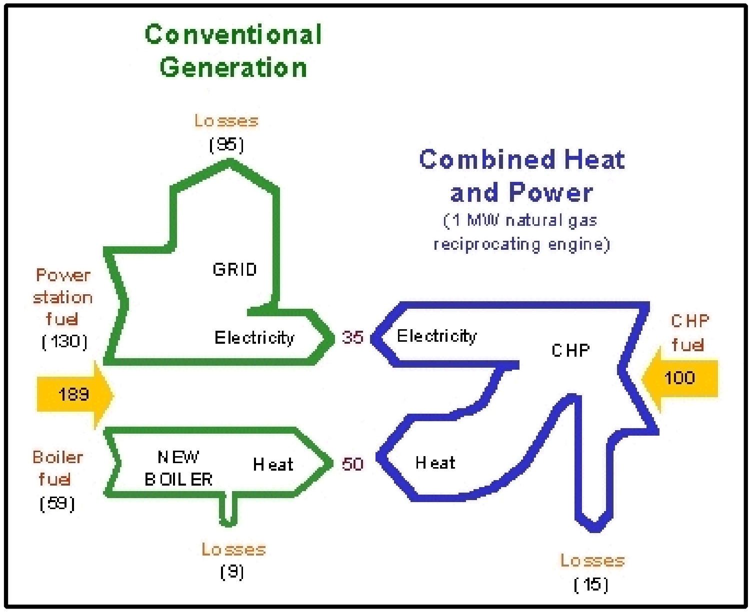
Heat Recovery

- In order to achieve CHP efficiencies of 80% the recovery of waste heat for <u>useful</u> purposes is more significant than the electric efficiency
- This isn't necessarily in sync with the economics of CHP except for rebates



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Heat Recovery

- CHP Efficiency = Total kW converted to Btu's plus total useful thermal energy in Btu's divided by the total fuel input in Btu's (HHV or LHV)
- Heat Recovery Basis:
  - CHP Efficiency = (kW x 3.414 + HR MBH)/Fuel MBH
  - (Favors low efficiency thermal conversion equipment)
- Output Basis:
  - CHP Efficiency = (kW x 3.414 + Output MBH)/Fuel MBH
  - (Favors high efficiency thermal conversion equipment)
- Optimal basis depends on incentive program rules, emissions regulations, etc.

Heat Recovery

- Heat Recovered = Flow x Sp Heat x Sp Gravity x Δ-T
  - Δ-T = Inlet Temp – Outlet Temp
- Heat Recovery Inlet Temp is determined by the type and specific design of the prime mover
- Outlet Temp is defined by the HR equipment and the thermal product quality required
- Flow and Temp are also subject to inlet air temperature and equipment elevation (combustion air density)
- Turbine generators use a higher air to fuel ratio than IC engines and are more affected by air density

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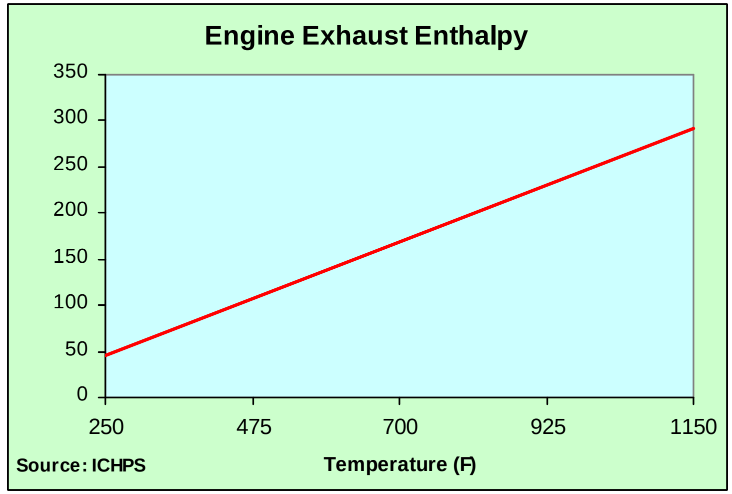
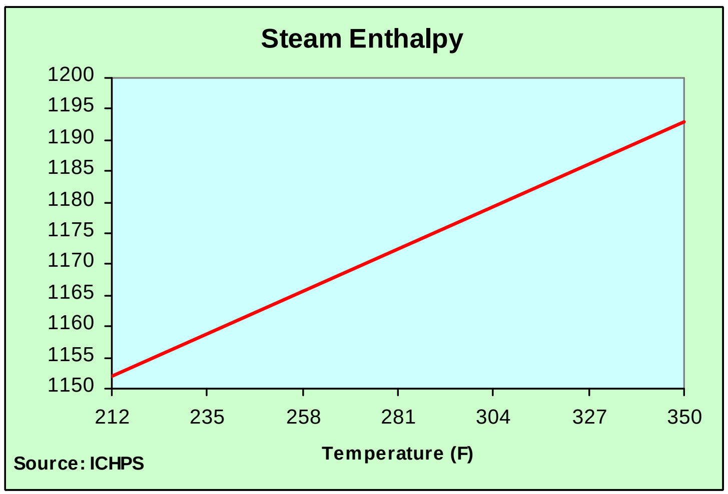
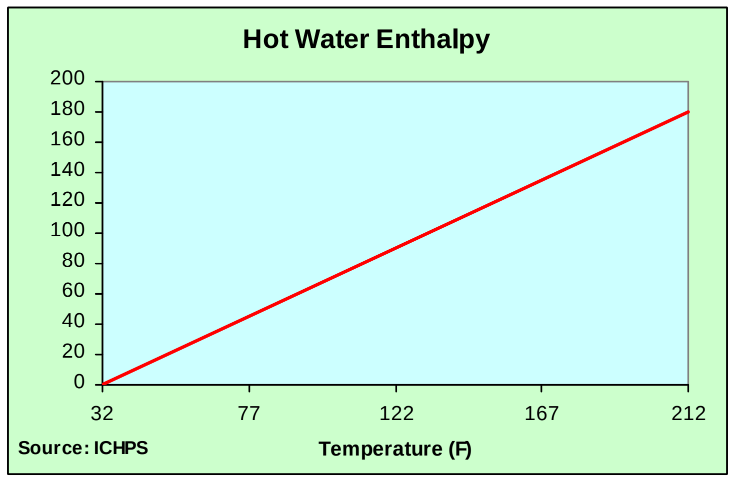
Heat Recovery

- Enthalpy is the total energy of a flowing medium.
- It is a product of the specific heat, specific gravity and the temperature.







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Heat Recovery

- HR = Flow x (Inlet Enthalpy – Outlet Enthalpy)
- Steam = HR/(Steam Enthalpy – Feedwater Enthalpy)
- Hot Water = HR/(HW Out Enthalpy – HW Return Enthalpy)
- Cooling = Steam or HW x Equipment Efficiency (COP)
  - e.g. 10,000 lbs/hr Exhaust Stream at 900 F in and 300 F out
  - 150 psig Steam w/ 200 F Feedwater (Condensing System)
  - Steam Turbine Chiller, 44 F & 83 F, 90% Nom Capacity => 9 lbs/Ton
  - HR = 10,000 x (223 – 59) = 1,640,000 Btu/hr
  - Steam = 1,640,000/(1198 – 168) = 1,592 lbs/hr
  - Chiller Output = 1,592/9 lbs per Ton = 177 Tons

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CHP Prime Movers

- Combustion Turbines 0.5–10 MW
- Microturbines 30–250 kW
- IC Engines 30 kW–5 MW
- Fuel Cells 200 kW–1 MW

- 65% - 50% WASTE HEAT
- 25% - 40% Electricity

Generator Thermal Output

- Simple Cycle Combustion Turbine:
  - High Volume, High Temp Exhaust (900 – 1000 F)
- Recuperated Microturbine:
  - High Volume, Medium Temp Exhaust (500 – 600 F)
- IC Engine:
  - Low Volume, High Temp Exhaust (900 – 1000 F)
  - + Hot Water (200 – 220 F)
- Fuel Cell (SOFC):
  - Low Volume, Medium Temp Exhaust (600 – 700 F)

CHP System Thermal Output

- CHP system thermal output is determined by the host facility needs for heating, cooling or process.
- These can vary from 40 F chilled water to 300 psig steam and typically involve a mixture of forms.

- Technologies:
  - **Hot Water HEX**
  - **Boilers/Steam Generators**
  - **Steam Turbines**
  - **2E Absorbers**
  - **1E Absorbers**
  - **Desiccants**

- Applications:
  - **Process Heat**
  - **Space Conditioning Heat**
  - **Pool Heat**
  - **Domestic Hot Water**
  - **Cooling**
  - **Freezing**
  - **Dehumidification**

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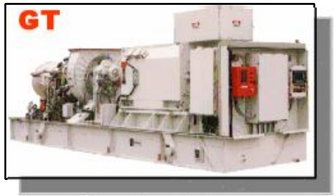
DG/TAT Match

Distributed Generation Technologies



Gas-turbine

Solid Oxide Fuel Cell

Microturbine

I.C. Engine Exhaust

I.C. Engine Jacket + Exhaust

800°F

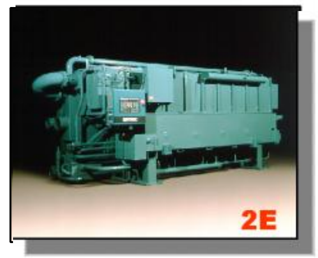
600°F

360°F

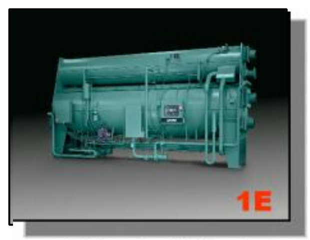
180°F

Thermally-Activated Cooling Technologies

Steam Turbine Centrifugal Chiller



Double-Effect Absorption Chiller

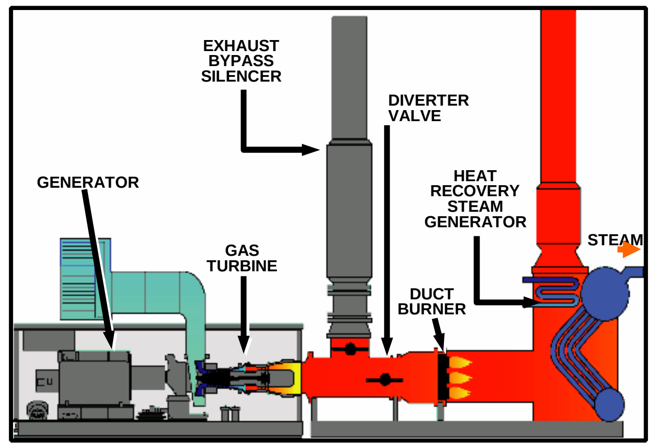


Single-Effect Absorption Chiller

Desiccant Technology

Gas Turbines

- Recouperated or Non-Recouperated
  - Exhaust Temperature & Electric Efficiency
- Ambient Conditions, Elevation, TIAC
  - Exhaust Temperature & Volume
- Duct Burner
  - Exhaust Volume/Temp
- HR Boiler Feedwater Temp
  - Steam Production
- Back Pressure
  - Generator Performance



Source: Solar Turbines

- Direct Exhaust Fired Absorbers
  - 1E Exhaust Temp = 250 F, 2E Exhaust Temp = 350 F

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Gas Turbines

Generator		Recuperated	Non-Recouperated		
Generator Nominal Output	kW	4,506	5,329		
Fuel Input LHV	MBH	40,300	59,300		
Heat Rate LHV	Btu/kW	8,990	11,128		
Nominal Electric Efficiency	%	35%	28%		
Exhaust Flow	Mlb/hr	140.4	167.6		
Exhaust Temp	F	707	954		
HRSG		No Duct Burner	No Duct Burner	No Duct Burner	Duct Burner
Duct Burner Input	MBH	-	-	-	30,226
Temp after Duct Burner	F	707	954	954	1,600
Exhaust Temp	F	350	350	275	350
Heat Recovered as Steam	MBH	13,713	27,696	31,135	57,317
Feedwater Temp	F	200	200	200	200
Steam Output	lb/hr	13,379	27,020	31,260	55,919
Steam Temp	F	352.9	352.9	249.7	352.9
Steam Pressure	psig	150	150	15	150
Chiller		Steam Turbine	Steam Turbine	1E Absorber	Steam Turbine
Total Output	tons	1,445	3,050	1,786	6,311
Tons/kW (nom)	#	0.32	0.57	0.34	1.18
Number of Units	#	1	2	2	3
Full Load COP	#	1.26	1.32	0.69	1.32
Efficiencies (LHV)					
Thermal/Electric Ratio	#	0.32	0.57	0.34	1.18
Electric Efficiency	%	35%	28%	28%	28%
Heating Efficiency	%	72%	77%	83%	84%
Cooling Efficiency	%	79%	91%	65%	104%
Heat Recovery Efficiency	%	55%	67%	76%	80%
Basis: Standard 60 Hz Generator at ISO conditions, 60% RH, sea level and operating on natural gas.					

Source: ICHPS/Solar/York

IC Engines

- Exhaust + Jacket, Exhaust Only or Jacket Only
- Ambient Conditions, Elevation
  - Small Effect on Exhaust Temperature & Volume
- Coolant Makeup (% Glycol)
  - Flow & Outlet Temperature
- Jacket Coolant Return Temperature
  - Basis for HW Temperature & Chiller Efficiency
- Low Temperature Circuits
  - Low or No Heat Recovery Potential

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Heat Recovery

Generator			
Generator Nominal Output	kW	1,100	1,100
Heat Rate LHV	Btu/kWh	8,334	8,334
Full load fuel input LHV	MBH	9,167	9,167
Nom Electric Efficiency	%	41%	41%
Jacket Heat Loop			
HT Circuit Outlet Temp	°F	210.0	-
Ethylene Glycol Percentage	%	50	Use for Heat
HT Circuit Flow	GPM	400	or
HT Circuit Return Temp	°F	197.5	Send to Dump
HT Circuit Heat Recovery	MBH	2,248	-
Exhaust Heat Recovery			
Exhaust mass flow	lbs/hr	13,224	13,224
Exhaust Temperature to HEX	°F	756	756
Exhaust Temperature after HEX	°F	275	275
Exhaust Heat Recovery	MBH	1,740	1,740
Total Heat Recovery		Jacket + Exhaust	Exhaust Only
Total Heat Recovery	MBH	3,988	1,740
Coolant Temperature after HEX	°F	219.7	125 psig
Delta-T	°F	22.2	Steam
Low Temp Dump Loop			
LT Circuit Out	°F	146	146
LT Circuit In	°F	130	130
LT Circuit Flow	GPM	125	125
Total Heat Dump	MBH	923	923
Chiller		1E Absorber	2E Absorber
Cooling Output	Tons	233	174
Tons/kW (nom)	#	0.21	0.16
Number of Units	#	1	1
Full Load COP	#	0.7	1.2
Basis: ISO conditions, sea level and operating on natural gas.			

Source: ICHPS/Waukesha