Waste Heat Utilization Using a Combined Heat and Power (CHP) System

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Background

Combined Heat and Power system use a technology that combines two processes into one. Typically there are coal powered plants that have the sole purpose of creating electricity by heating water to create steam and running it though a turbine that powers a generator. There are also plants whose sole purpose is to that provide steam for urban areas called district heat. A CHP system combines these two plants: create steam that rotates the turbine for generating electricity, and steam that come from the turbine goes to an urban area. This system drastically increases the efficiency of energy consumption. CHP systems are defined by what kind of engine produces electricity such as a turbine or reciprocating engine. There are several other components that make up a CHP system such as prime mover, generator, heat recovery system, electrical interconnection equipment configured into a integrated system, as shown Figure 1.

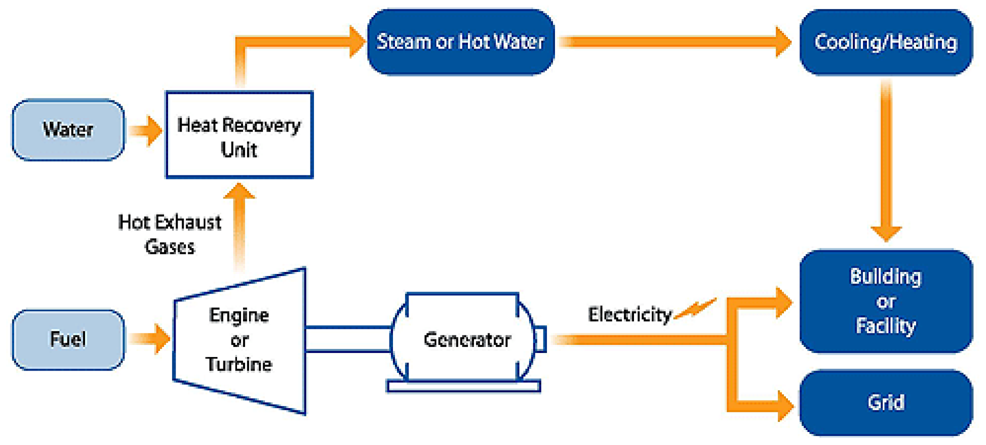

Figure 1: CHP system

Objectives

Completing literature review of CHP technologies and summarizing them

Power plants generate heat in order to boil water to power steam turbines that generate electricity. During this heat transfer process only about 30% of the heat is actually used to convert electricity. The other 70% of heat is expelled into the surrounding atmosphere. CHP technology utilizes this wasted heat to heat up potable water and heating environments that need it rather then the atmosphere.

CHP can be a stand-alone system from power grids. Generally two resources would be required for a CHP system: fuel (such as natural gas) and water. Both sources are typically routed through sub-terrain systems that are more stabile than power lines. CHP systems would become most effective in times of disasters or power outages where supply of electricity is at risk.

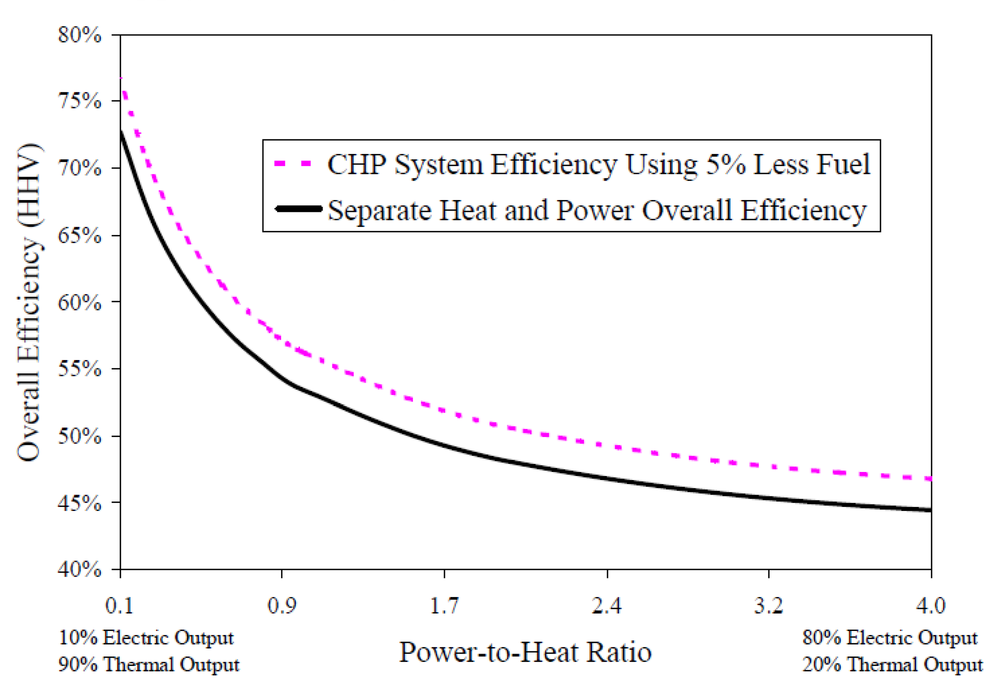

Figure 2: Equivalent separate heat and power efficiency*

Comparison of CHP Technologies

The different CHP technologies (gas turbine, reciprocating engines, steam turbines, microturbines, and fuel cells) were characterized and summarized in Table 1. Table 2 provides snapshots of the five technologies, and a comparison of key cost and performance characteristics across the range of technologies that highlights the distinctiveness of each.*

CHP system	Advantages	Disadvantages	Available sizes
Gas turbine	High reliability. Low emissions. High grade heat available. No cooling required.	Require high pressure gas or in-house gas compressor. Poor efficiency at low loading. Output falls as ambient temperature rises.	500 kW to 250 MW
Microturbine	Small number of moving parts. Compact size and light weight. Low emissions. No cooling required.	High costs. Relatively low mechanical efficiency. Limited to lower temperature cogeneration applications.	30 kW to 250 kW
Spark ignition (SI) reciprocating engine	High power efficiency with part-load operational flexibility. Fast start-up. Relatively low investment cost. Can be used in island mode and have good load following capability. Can be overhauled on site with normal operators. Operate on low-pressure gas.	High maintenance costs. Limited to lower temperature cogeneration applications. Relatively high air emissions. Must be cooled even if recovered heat is not used. High levels of low frequency noise.	< 5 MW in DG applications
Compression ignition (CI) reciprocating engine (dual fuel pilot ignition)			High speed (1,200 RPM) ≤4MW Low speed (102-514 RPM) 4-75 MW
Steam turbine	High overall efficiency. Any type of fuel may be used. Ability to meet more than one site heat grade requirement. Long working life and high reliability. Power to heat ratio can be varied.	Slow start up. Low power to heat ratio.	50 kW to 250 MW
Fuel Cells	Low emissions and low noise. High efficiency over load range. Modular design.	High costs. Low durability and power density. Fuels requiring processing unless pure hydrogen is used.	5 kW to 2 MW

Table 1: Summary of CHP Technologies*

Technology	Steam Turbine[1]	Recip. Engine	Gas Turbine	Microturbine	Fuel Cell
Power efficiency (HHV)	15-38%	22-40%	22-36%	18-27%	30-63%
Overall efficiency (HHV)	80%	70-80%	70-75%	65-75%	55-80%
Effective electrical efficiency	75%	70-80%	50-70%	50-70%	55-80%
Typical capacity (MW_e)	0.5-250	0..01-5	0.5-250	0.03-0.25	0.005-2
Typical power to heat ratio	0.1-0.3	0.5-1	0.5-2	0.4-0.7	1-2
Part-load	ok	ok	poor	ok	good
CHP Installed costs ($/kW_e$)	430-1,100	1,100-2,200	970-1,300 (5-40 MW)	2,400-3,000	5,000-6,500
O&M costs ($/kWh_e$)	<0.005	0.009-0.022	0.004-0.011	0.012-0.025	0.032-0.038
Availability	near 100%	92-97%	90-98%	90-98%	>95%
Hours to overhauls	>50,000	25,000-50,000	25,000-50,000	20,000-40,000	32,000-64,000
Start-up time	1 hr - 1 day	10 sec	10 min - 1 hr	60 sec	3 hrs - 2 days
Fuel pressure (psig)	n/a	1-45	100-500 (compressor)	50-80 (compressor)	0.5-45
Fuels	all	natural gas, biogas, propane, landfill gas	natural gas, biogas, propane, oil	natural gas, biogas, propane, oil	hydrogen, natural gas, propane, methanol
Noise	high	high	moderate	moderate	low
Uses for thermal output	LP-HP steam	hot water, LP steam	heat, hot water, LP-HP steam	heat, hot water, LP steam	hot water, LP-HP steam
Power Density (kW/m^2)	>100	35-50	20-500	5-70	5-20
NO_x (lb/MMBtu) (not including SCR)	Gas 0.1-.2 Wood 0.2-.5 Coal 0.3-1.2	0.013 rich burn 3-way cat. 0.17 lean burn	0.036-0.05	0.015-0.036	0.0025-.0040
$lb/MWh_{TotalOutput}$ (not including SCR)	Gas 0.4-0.8 Wood 0.9-1.4 Coal 1.2-5.0.	0.06 rich burn 3-way cat. 0.8 lean burn	0.17-0.25	0.08-0.20	0.011-0.016

* Data are illustrative values for typically available systems; All costs are in 2007$
[1]For steam turbine, not entire boiler package

Table 2: Typical Cost and Performance Characteristics*

Efficiency of CHP Systems

Many of the benefits of CHP stem from the relatively high efficiency of CHP systems compared to other systems. Because CHP systems simultaneously produce electricity and useful thermal energy, CHP efficiency is measured and expressed in a number of different ways

System	Component	Efficiency Measure	Description
Separate heat and power (SHP)	Thermal Efficiency (Boiler)	$EFF_Q = \frac{\text{Net Useful Thermal Output}}{\text{Energy Input}}$	Net useful thermal output for the fuel consumed.
	Electric-only generation	$EFF_P = \frac{\text{Power Output}}{\text{Energy Input}}$	Electricity Purchased From Central Stations via Transmission Grid.
	Overall Efficiency of separate heat and power (SHP)	$EFF_{SHP} = \frac{P + Q}{P/EFF_{Power} + Q/EFF_{Thermal}}$	Sum of net power (P) and useful thermal energy output (Q) divided by the sum of fuel consumed to produce each.
Combined heat and power (CHP)	Total CHP System Efficiency	$EFF_{Total} = (P + Q)/F$	Sum of the net power and net useful thermal output divided by the total fuel (F) consumed.
	FERC Efficiency Standard	$EFF_{FERC} = \frac{(P + Q/2)}{F}$	Developed for the Public Utilities Regulatory Act of 1978, the FERC methodology attempts to recognize the quality of electrical output relative to thermal output.
	Effective Electrical Efficiency (or Fuel Utilization Efficiency, FUE):	$FUE = \frac{P}{F - Q/EFF_{Thermal}}$	Ratio of net power output to net fuel consumption, where net fuel consumption excludes the portion of fuel used for producing useful heat output. Fuel used to produce useful heat is calculated assuming typical boiler efficiency, usually 80 percent.
	Percent Fuel Savings	$S = 1 - \frac{F}{P/EFF_P + Q/EFF_Q}$	Fuel savings compares the fuel used by the CHP system to a separate heat and power system. Positive values represent fuel savings while negative values indicate that the CHP system is using more fuel than SHP.

Key:
P = Net power output from CHP system
Q = Net useful thermal energy from CHP system
F = Total fuel input to CHP system
EFF_P = Efficiency of displaced electric generation
EFF_Q = Efficiency of displaced thermal generation

Table 3: the key elements of efficiency as applied to CHP systems*

Summary and future work

- **The different CHP technologies (gas turbine, reciprocating engines, steam turbines, microturbines, and fuel cells) were characterized and summarized.**
- **Future work 1:** Setting up an apparatus for harnessing energy: create a small scale CHP system
- **Future work2:** Measuring temperature profiles of heat pump of CHP using an Infrared (IR) camera
- **Future work3:** 3D modeling and simulation for analyzing heat transfer in CHP system

*Source from Combined Hear and Power Partnership US EPA http://www.epa.gov/chp/basic/catalog.html