CHP Technologies

Midwest Cogeneration Association
February 17, 2016

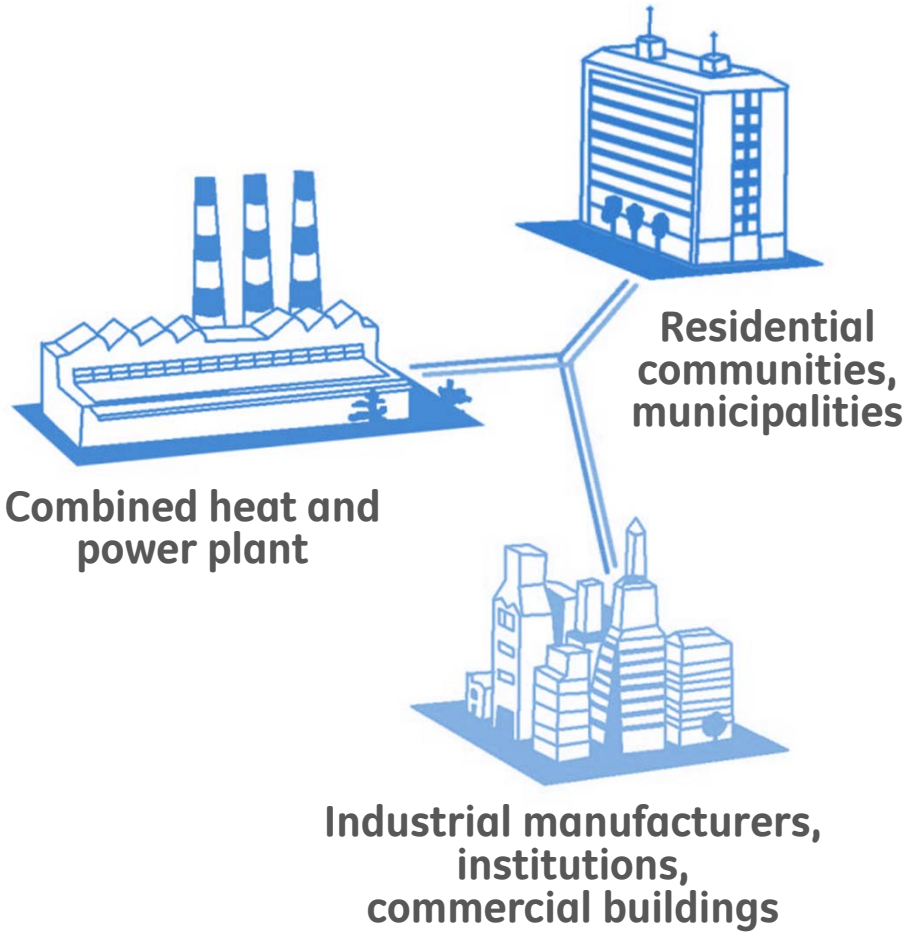
Imagination at work

GE Information – U.S. Government approval is required prior to export from the U.S., re-export from a third country, or release to a foreign national wherever located.

Melvin George

CHP Technology Distribution in the US today

CHP solutions are applicable in a wide variety of energy-intensive facilities



- **Industrial manufacturers** - chemical, refining, pulp and paper, food processing, glass manufacturing, cement, steel mills
- **Institutions** - colleges and universities, hospitals, prisons, military bases
- **Commercial buildings** - hotels and casinos, airports, high-tech campuses, large office buildings, nursing homes
- **Municipal** - district heating systems, wastewater treatment facilities
- **Residential** - multi-family housing, planned communities

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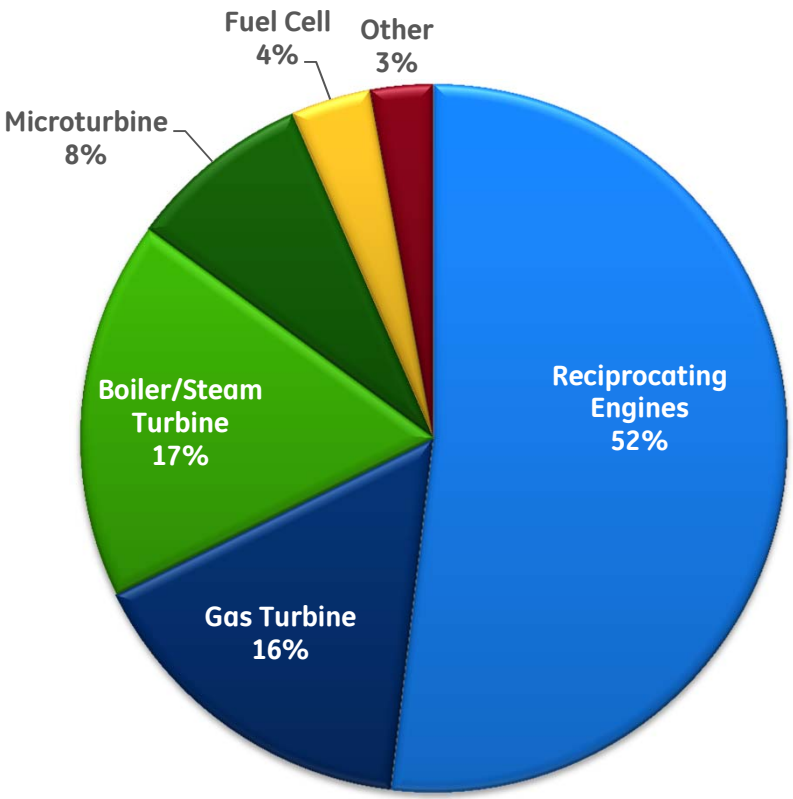
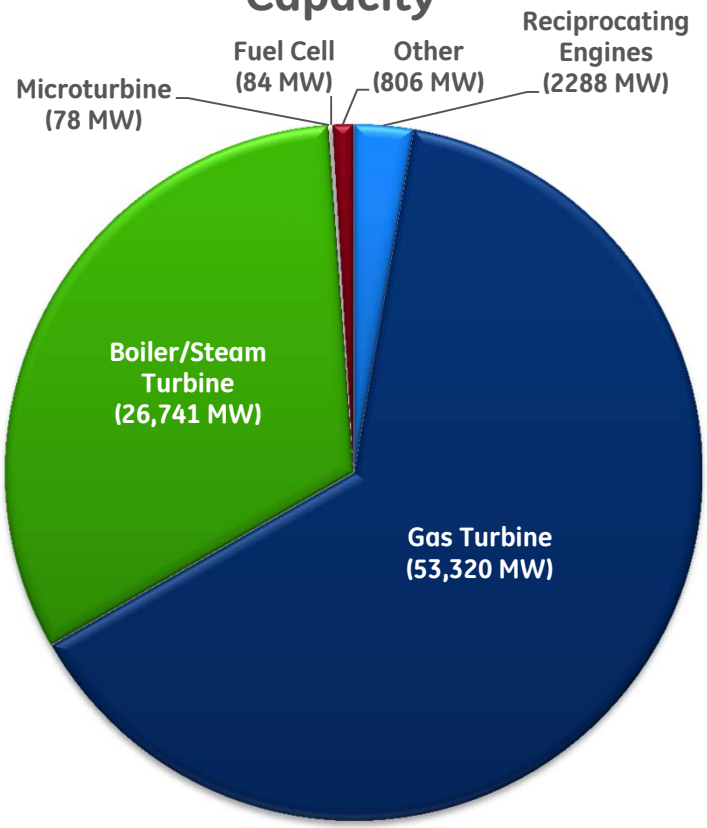
US CHP Installation Data

CHP Distribution by # of Sites



CHP Distribution by Installed Capacity



Source: ICF CHP Installation Database, April 2014

Although Reciprocating Engines are installed at a majority of US CHP Sites, the installed MW are dominated by GTG CC and Steam Plants

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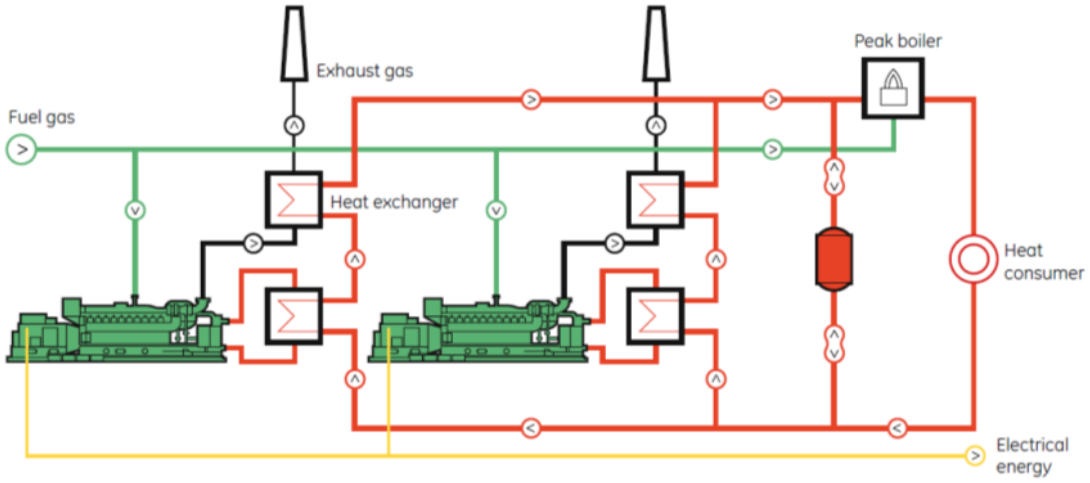
Small (<35MWe)

Configuration/cycle: Reciprocating engines and hot water system, small GTs, fuel cells

Typical site: Large buildings, campuses, new distributed heat schemes

Typical owner: Utility/ESCO, local government, hospitals/universities



Fun facts

- More than 9,000 of GE's cogeneration plants have been delivered around the world with an overall electrical output of ~11,000 MW.
- The GE fleet of Gas Engines produces in excess of 66 million MWh of electricity and 60 million MWh of heat – annually … enough to power about 3.6 million US homes and heat about 5 million US households.
- This deployed fleet also reduces CO2 by 4 million tons – the amount of emissions from about 800,000 US cars per year.

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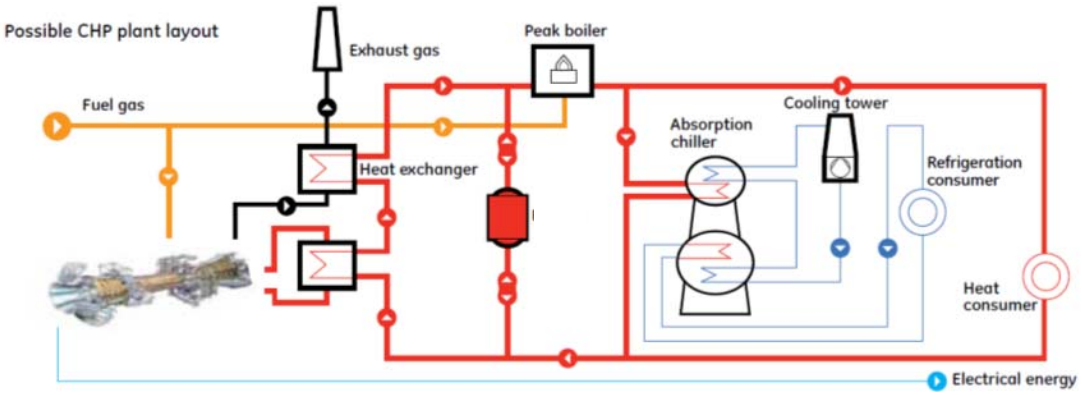
Medium (35-100 MWe)

Configuration/cycle: GTs and STs with heat extraction

Typical site: Industrial, energy parks, inner city district heat schemes

Typical owner: Industrials, municipalities, ESCO



Fun facts

- GE's 6FA can provide heating and electricity for more than 80,000 homes while lowering CO2 emissions by approximately 100,000 tons per year when compared to decoupled heat and electricity production.

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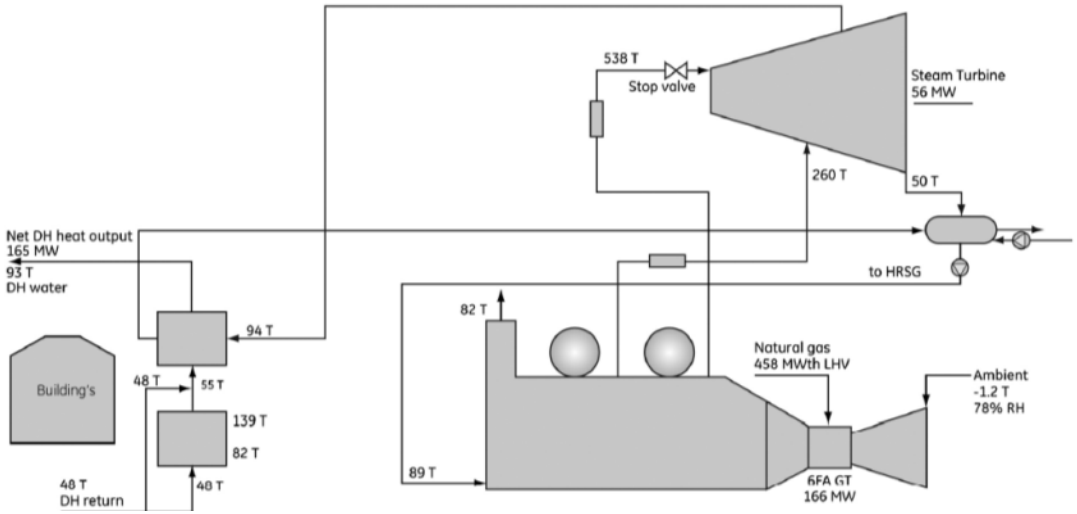
Large (100+ MWe)

Configuration/cycle: Large combined cycles with heat extraction

Typical site: Major energy users, larger city district heat schemes

Typical owner: City governments/stadtwerke, ESCOs, large industrials



Fun facts

- The average global efficiency of fossil-fueled power generation is <40% … which means that "energy conversion loss" is the largest energy user at over 60%.

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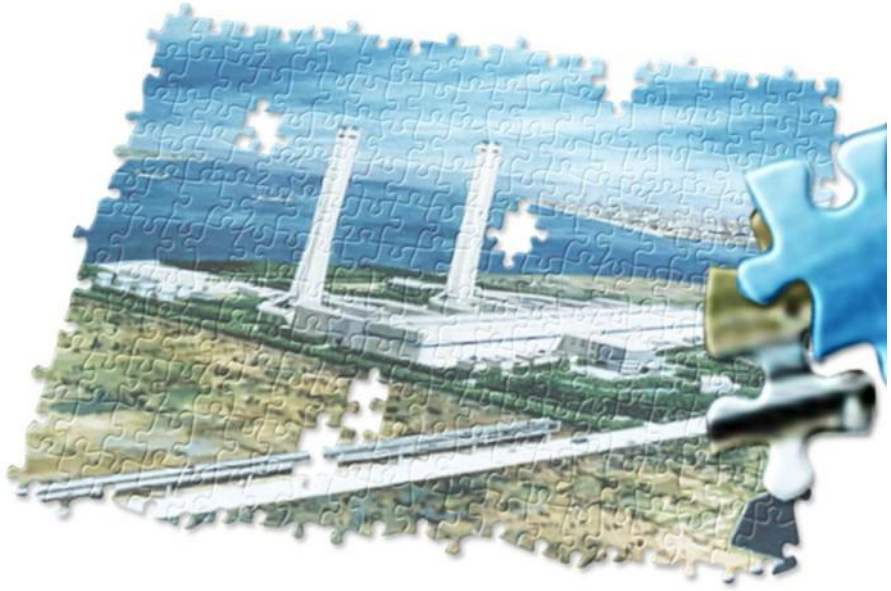
CHP is an application…not a product

Design must accommodate system complexity

- Balance fluctuations in seasonal thermal load demand
- Complete understanding of application requirements dictates plant size
- Systems integration of components and configuration to drive resiliency, flexible and reliable operation
- Optimize around financial returns and policy incentives



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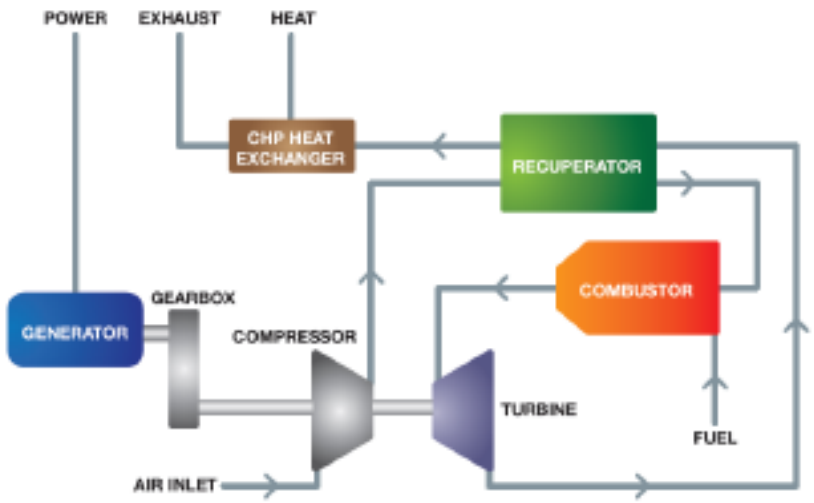
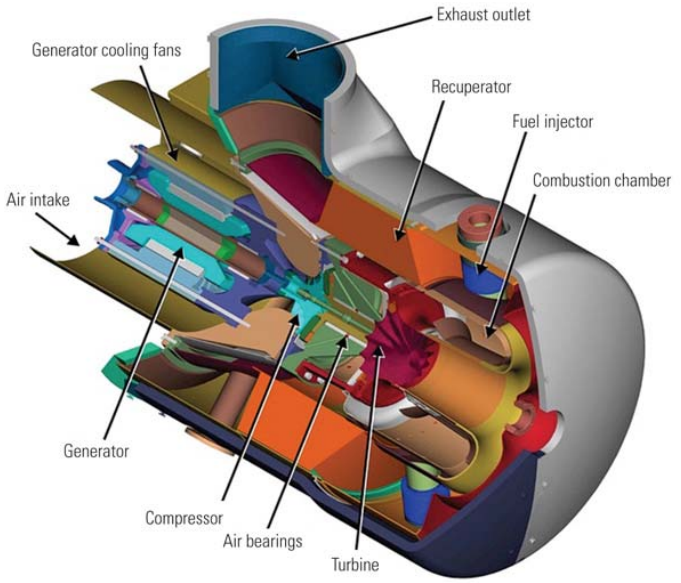
Technology Overview

Microturbines



Source: FlexEnergy



Source: Captsone Turbine Corp

Technology

- Technology is an evolution of small stationary and automotive turbines/ turbochargers
- Commercial available for more than a decade.
- Operates very similar to a gas turbine which utilizes a recuperator to increase efficiency.
- Generator output is converted to 60Hz via a power conditioning unit which rectifies the high frequency AC to DC and then inverts it back to 60Hz.
- Power storage unit (battery) is used to power the generator for startup in blackstart operation

Performance Basics

Output Range: 30 to 330kW (modular packages up to 1MW)
Exhaust Temp: 500-600°F
Gas Pressure: 50-140psig

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Microturbines

Pros

- Compact design with simplified customer interfaces for easy customer installation
- Low emissions without the use of catalyst reduction system
- Can be easily scaled for large MW footprints which has ancillary benefit for part loading.
- Exhaust temperature makes it a good fit for adsorption cooling or steam production
- Single rotating shaft minimizes reliability concerns
- Capable of burning a wide variety of liquid and gaseous fuels.

Cons

- Highest relative installed cost ($2500/kW - $4300/kW)
- Low simple cycle electrical efficiency (22-33%) LHV
- Performance degradation due to elevated ambient conditions and elevation

Source: Captsone Turbine Corp

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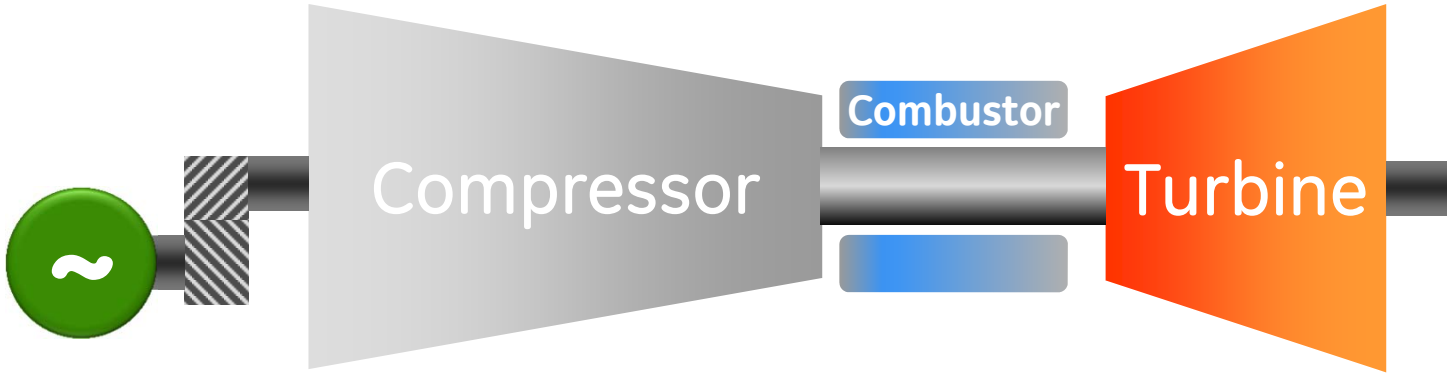
Gas Turbines



Technology

- Gas turbines have been used in stationary electric power since the late 1930s; Aeroderivative gas turbines have been in power generation since the 1990s.
- Gas Turbines comprise 63%, or 51.5GW of total installed CHP capacity in the US. [1] 80% of this capacity is in large combined cycle power plants. [2]
- Industrial gas turbines are generally less expensive, more rugged, and have longer maintenance intervals that aeroderivative gas turbines; generally have lower simple cycle efficiency and are significantly heavier.

Performance Basics

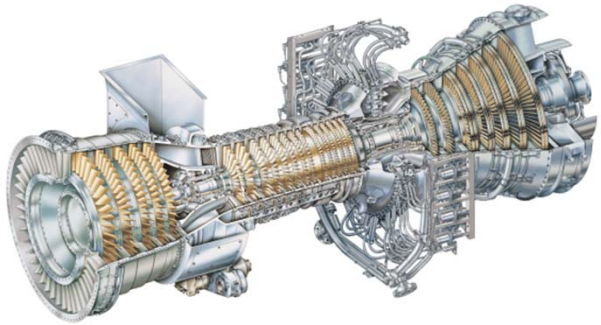
Output Range: 500kW to 300MW
Exhaust Temp: Small GTGs: 800-900F; Large GTGs: up to 1100F
Gas Pressure: 100-500 psig

1. Electric utility sector gas turbine capacity is from EIA data (2014). CHP gas turbine total capacity based on the ICH CHP Installations database.
2. 2. ICH CHP Installations Database, 2014

Gas Turbines

Pros

- High exhaust temperatures lend well to steam production.
- Low emissions without the use of catalyst reduction system
- Capable of burning a wide variety of liquid and gaseous fuels.
- Proven reliability evidenced by broad experience base.



Cons

- High gas pressure requirements (typically requires gas compression).
- Poor efficiency at low loads
- Performance degradation due to elevated ambient conditions and elevation
- Maintenance typically needs to be performed by highly specialized personnel.

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Reciprocating Engines

Reciprocating Engines

Compression Engines (Diesel Cycle)

Spark Ignited Engines (Otto Cycle)

Diesel

- Very high simple cycle efficiency.
- Low upfront capital cost
- Fast start up time (up to 10s)
- Emissions are often a constraint to extensive operation
- Primary operation: emergency standby or limited duty

Dual Fuel

- Utilizes diesel fuel as a pilot fuel for combustion. Operates on natural gas.
- Can generally be switched to 100% diesel.
- Allows user to have cost effectiveness of natural gas operation, but also capable of meeting emergency generation fuel requirements.
- Not yet widely used in CHP

Rich Burn

- Rich-burn engines operate at an almost stoichiometric air/fuel ratio (AFR), which is exactly enough air to burn all of the fuel
- Generally High Nox, low CO. After treatment generally requires a three-way catalyst.
- Alternative gases could poison 3-way catalyst

Lean Burn

- Utilizes significantly more air than required for complete combustion (up to 2X)
- Excess air cools peak combustion temperature = NOX emissions.
- Cooler temperature allows for high BMEP = higher power density and efficiency
- Wide fuel flexibility

2,000 active reciprocating engine CHP installations in the US providing nearly 2.3GW of power capacity. [1]

1. ICF CHP Installation Database. Maintained for Oak Ridge National Laboratory by ICF International. 2013.

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Reciprocating Engines

Pros

- High power efficiency with relatively minor part load performance impacts (relative to gas turbines)
- Low first cost (comparable with large GTGs)
- Fast start up (10s for Diesel, <1 min Rich Burn, <5 min Lean Burn)
- High reliability
- Great for hot water applications
- Can operate on low-pressure gas

Cons

- Generally more frequent maintenance (relative to gas turbines), but routine maintenance activity does not require high expertise.
- Steam product generally requires the use of a peak boiler.
- Relatively high unabated emissions
- High levels of low frequency noise.

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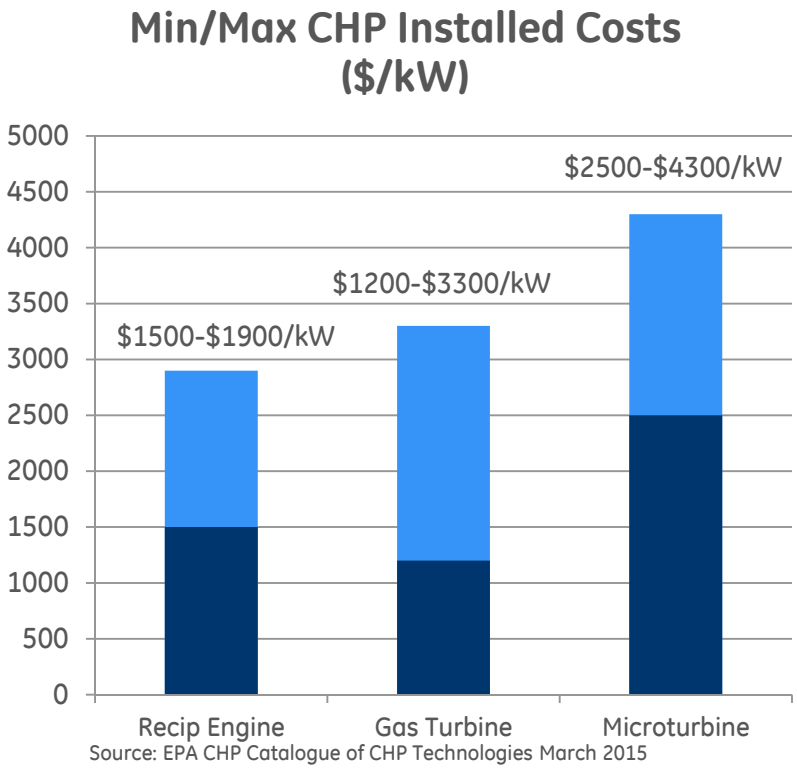
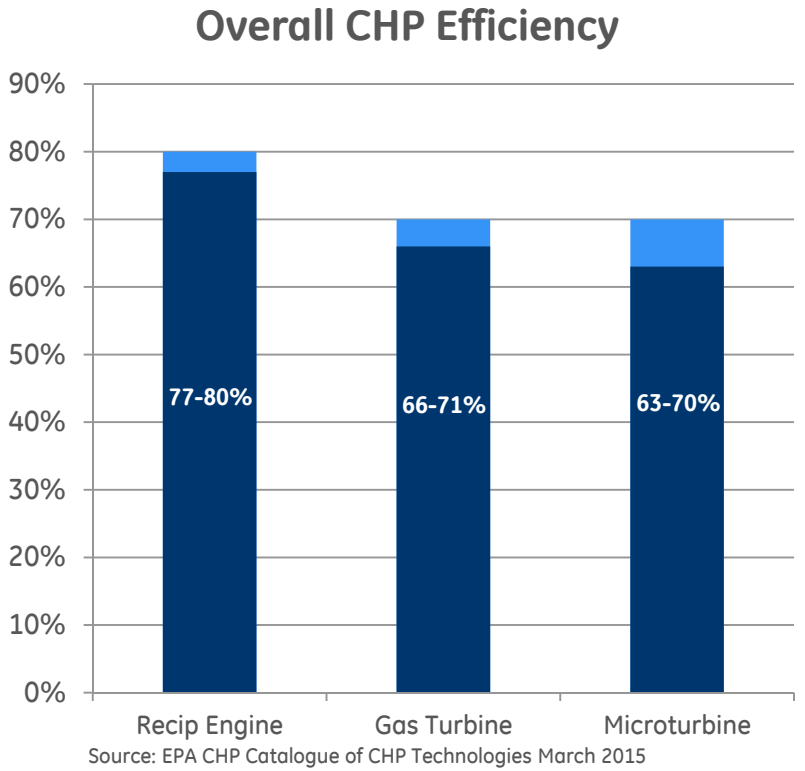
Performance Considerations

Capital Costs and Overall CHP Efficiency





Reciprocating engines are a cost competitive solution with high CHP efficiencies

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Performance Differences

Plant Size	Engine Type	Unit Power (kW)	No. Units	Total Output (kW)	Heat Rate @ ISO (Btu/kW-hr LHV)	Exhaust Gas Flow (lb/hr)	Exhaust Temp (deg F)
1MW	Microturbine	1000	1	1000	10300	52920	535
	Small GTG	1210	1	1210	14025	51890	940
	Reciprocating Engine	1121	1	1121	8264	13680	797
5MW	Microturbine	1000	5	5000	10300	264600	535
	Small GTG	5670	1	5670	10830	172810	950
	Reciprocating Engine	2654	2	5308	7468	32564	687
10MW	Microturbine	1000	10	10000	10300	529200	535
	Small GTG	9450	1	9450	10710	318760	870
	Reciprocating Engine	8570	1	8570	6994	99675	617
25MW	Microturbine	1000	25	25000	10300	1323000	535
	Small GTG	21745	1	21745	8775	541590	865
	Aero GTG	22000	1	22000	9465	536400	990
	Reciprocating Engine	8570	3	25710	6994	299025	617

Reciprocating engines demonstrate a significantly better electrical efficiency when compared to similarly sized GTG and Microturbine solutions

GTGs & Microturbines demonstrate a noticeable thermal advantage over reciprocating engines

Source: Capstone Turbine Corporation (www.capstoneturbine.com), Solar Turbines Incorporated (www.mysolar.cat.com), General Electric (www.ge.com)

It is critical to have a good understanding of both your electrical and thermal needs in order to properly choose a technology

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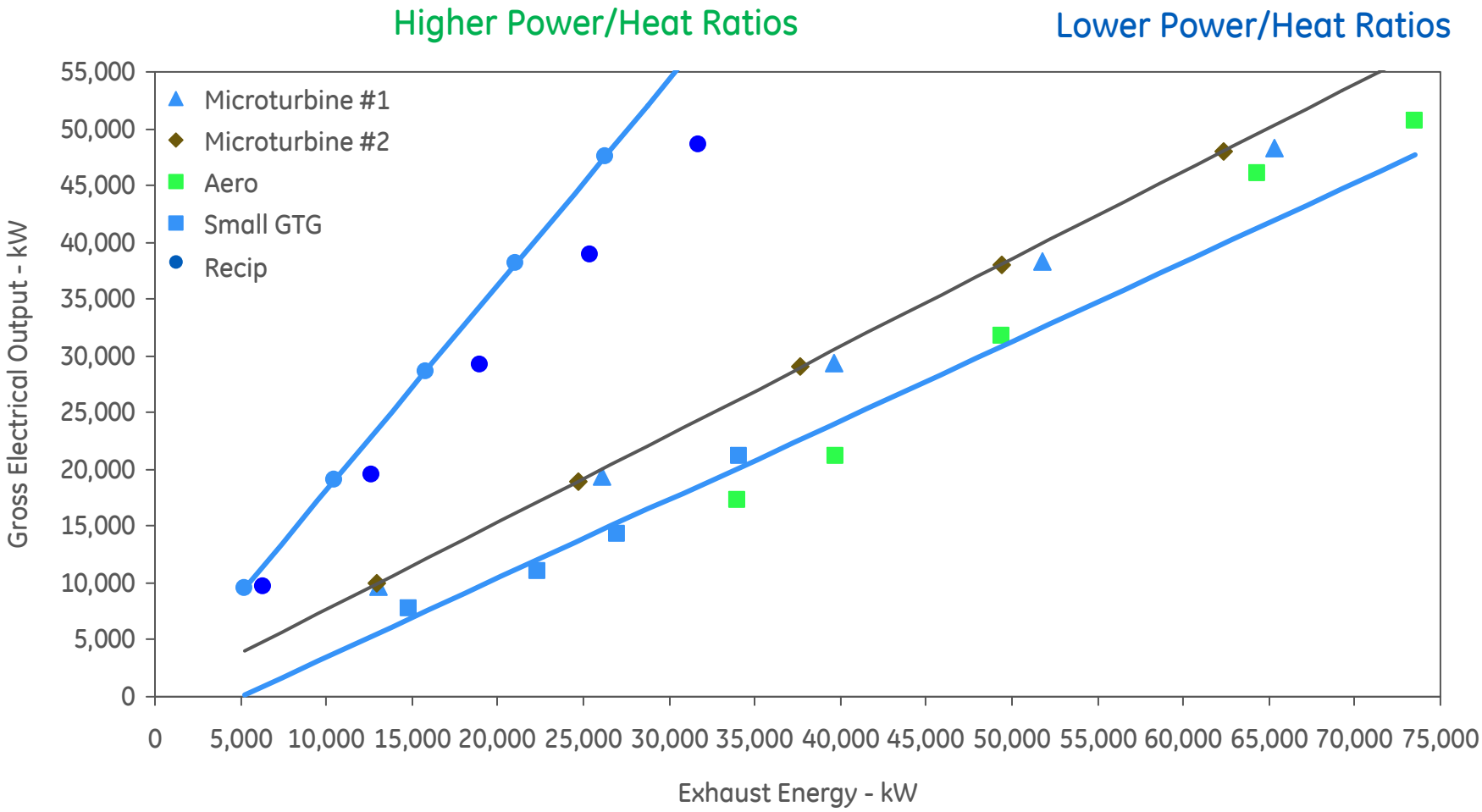
CHP Electricity to Exhaust Heat Coverage



With Recips, higher electrical output for the same exhaust energy

ISO conditions, 50Hz, 100mm/250mm H2O inl/exh losses for turbines

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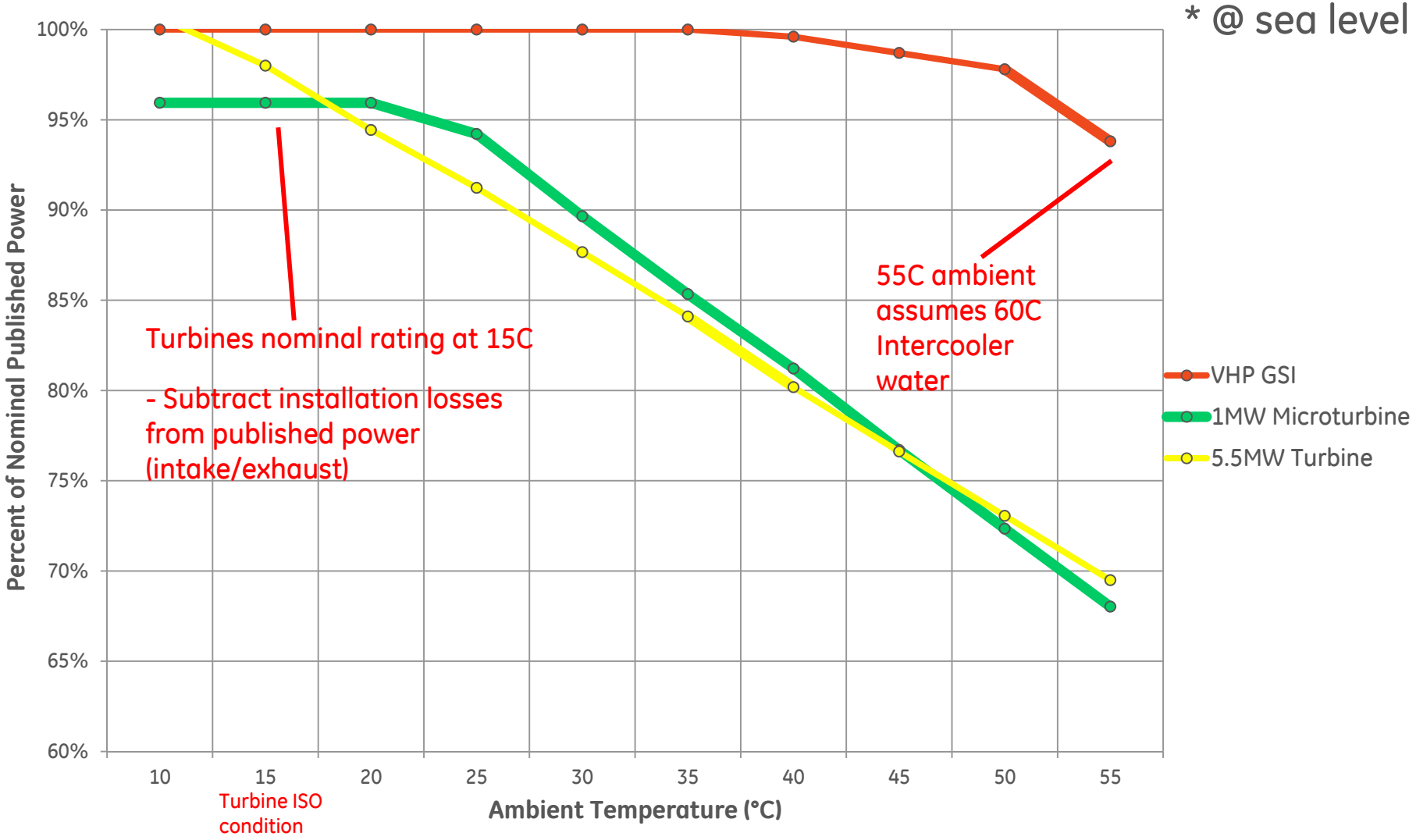
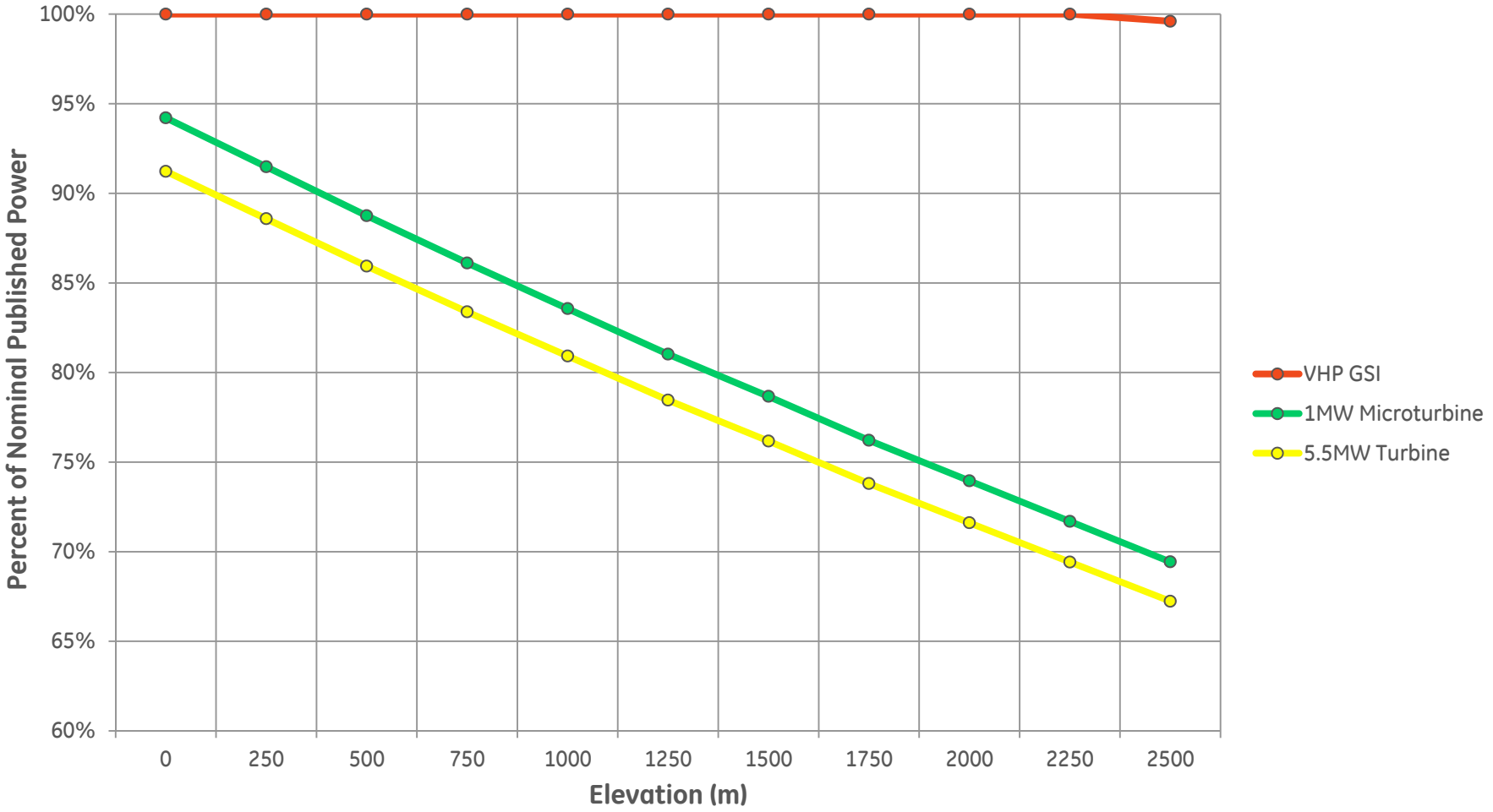
Hot Climates – Power vs Ambient Temperature

* @ sea level



Site Power vs Elevation

@ 25C ambient temp



Typical O & M

Typical Rich Burn Engine		
2,000 hrs	Oil / filters Sparkplugs	Replace
4,000 hrs	O2 sensors Microspin liner Air filters	Replace
8,000 hrs	Breather (filter), gaskets, belts	Replace, adjustments
16,000 hrs	Starter, regulator, sparkplug extensions	Replace
24,000 hrs	Top end overhaul	
48,000 hrs	Bottom end overhaul	

$0.006 – $0.008[2] prev. maintenance contract, through major overhaul

Typical Lean Burn Engine		
2,000 hrs	Oil / filters Sparkplugs	Replace (5-11hrs)
10,000 hrs	Sparkplugs Turbocharger (Pre-Chamber) Gas mixer Pumps	Inspect, Replace, adjustments (1-4d)
30,000 – 40,000 hrs	Minor Overall Cylinder Heads Pistons Con Rods	<11d
60,000 – 80,000 hrs	Major Overhaul Re-Furb unit exchange On-site Overhaul Alternator	1-3w

$0.006 – $0.008[2] prev. maintenance contract, through major overhaul

Typical O & M

5.5 MW Turbine[6]		
2,000-4,000 hrs	Offline water wash	Typical on-condition, site and filter dependent
4,000 hrs	Semi-annual	Inspections & consumables
8,000 hrs	Annual	Inspections, consumables, bleed valve rebuild
30,000 – 40,000 hrs	Overhaul / Exchange	Typically exchange program

$0.008 - $0.0013[5] / kWh Service Contract, w/ one overhaul/exchange

- Rate is at standard conditions; site derate = ↑ $/kW

Microturbine[4]		
4,000 hrs	Air Filters	Clean/replace
	Fuel Filter	Replace
	Igniter	Replace
20,000 hrs	Injectors	Replace
	Battery Pack*	Replace
	Thermocouple	Replace
40,000 hrs	Engine & Generator	Replace

*Battery life can decrease significantly at high ambient temperatures and/or high cycling

$0.009 - $0.013[3] / kWh Service Contract, w/ one overhaul/exchange.

- Rate is at standard conditions; site derate = ↑ $/kW

Lower site power ratings = higher $/kW

Sources/References

A) U.S. EPA, CHP Partnership Catalog of CHP Technologies, March 2015

B) U.S. EPA, Technology Characterization: Gas Turbines, September 2008

C) Conference presentation, http://www.cogeneration.org/111011Conf/

D) Public tender, Air Force, from gov website, https://www.fbo.gov/index?s=opportunity&mode=form&id=cbbae461788aaac1e1ef754a4a5253a7&tab=core&_cview=1

Turbine performance estimated from product assessments

Case Studies

A showcase of CHP systems

- GE's Distributed Power business offers a portfolio of products and services ideally suited for CHP systems.
- These CHP systems can utilize the inherent power and heat to bring forth flexible offerings to all sorts of energy users.
- GE's innovation and systems knowledge brings value to a wide range of customers—from commercial and industrial businesses, to local and national governments—creating either new energy solutions or expanding the capability of existing facilities. GE can work with customers through the entire project cycle—enabling them to achieve the full benefits of GE's integrated systems from concept to execution.

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CNPC Data Center, China

Requirements	
Total construction area	64,000 m^2 (including data center 31,000 m^2, energy station 9,000 m^2, and office building 14,000 m^2)
Number of racks	2,500 (phase I)
Power load (peak)	14,323 KW
Cooling load	20,200 KW
Thermal load (winter)	1,950 KW
Solution	
CCHP gas engines	GE J620 x 5 (4 + 1)
CCHP power capacity	14.3 MW
Annual power output	100,146.5 MWh
Investor and operator	Beijing Gas Company
Value	
Data center availability	LEVEL A
Environmental benefits	Emission reduction of 61, 800 tons of CO_2, and 5,100 tons of SO_2.

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Coca-Cola Hellenic Bottling Company, Romania

Requirements
To achieve a 20% reduction in emissions by 2020, Coca-Cola Hellenic Bottling Company and energy development company ContourGlobal needed to find an efficient solution to power their new plant in Romania.

Solution	
CCHP gas engines	GE J620 x 2
CCHP power capacity	3 MW
Fuel	Natural Gas
Hot water	2,048 KW
Commissioning	2009

Value	
Electrical Efficiency	42.4%
Total Efficiency	90%+
Environmental benefits	CO_2 emissions by 40%; supports European Commission's goal to achieve a 20% reduction in emissions by 2020; reduces operational costs

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Plaza Indonesia, Indonesia

Requirements
Constant electricity shortages are a reality in Indonesia. To ensure a continuous power supply to the Plaza Indonesia, a new onsite power plant with Jenbacher gas engines was installed as part of a multi-year expansion of the complex, which features a five-star hotel, shopping and entertainment center, office building, and residential facility.

Solution	
CHP gas engines	GE J620 x 9
CHP power capacity	24.58 MW
Fuel	Natural Gas
Emissions	500 mg/Nm³ NOx
Commissioning	2009

Value	
Electrical Efficiency	42.1%
Environmental benefits	Significantly lower emissions and costs due to onsite cogeneration; patented LEANOX® lean mixture combustion ensure minimum emissions

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Houweling's Tomatoes, USA

Requirements
Houweling's Tomatoes, a leading North American greenhouse grower with a strong environmental record, sought an ultra-efficient CHP system for its 125-acre greenhouses in Camarillo, California. The system would need to generate flexible power for the local utility and establish one of the lowest carbon dioxide (CO_2) emissions and water usage levels of any similarly sized power plant in the region.

Solution	
CHP gas engines	GE J624 x 2
CHP power	8.7 MW (elec.); 10.6 MW (thermal)
Fuel	Natural Gas
Commissioning	2009

Value	
Total efficiency	90%
Water savings	9,500 gallons/day
Environmental benefits	Significantly lower emissions and costs due to onsite cogeneration; eliminates need for CO_2 transport from factories

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Rosenheim, Germany

Requirements
• High overall efficiency to support district heating needs, which require more CHP capacity • Due to growing renewable installations in the area, Rosenheim wanted to provide summer peak load
Solution
Stadtwerke Rosenheim municipal plant in Germany (50 Hz)
1 x J920 FleXtra with 9,520 kW; 48.2% electrical efficiency
Entered service in 2013
Value

Winter	• CHP mode from October to April • 5 days/week - 8 to 24 hrs/day
Summer	• Peaking (power only mode) • 5 days/week on avg.~4 hrs/day
Total OPHs ***Total starts***	Oct. 2014: ~5,000 Oct. 2014: >700

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Guy's and St. Thomas' Hospitals, UK

Requirements
As part of its initiatives for cleaner energy, the UK's National Health Service (NHS) needed a highly-efficient, on-site power generation system which met the emissions and environmentally-friendly standards set for hospitals. Guy's and St Thomas' are two of the oldest hospitals in the UK and located in central London.

Solution	
CHP gas engines	GE J620 x 2
CHP electrical output	6.08 MW
CHP thermal output	6.04 MW
Fuel	Natural Gas
Total Efficiency	85.7% (43% electrical; 42.7% thermal)
Commissioning	2009

Value	
Energy cost savings	GBP 2 million annually
CO_2 savings	11,300 tons annually
Payback period	<3 years
Recognition	First Trust to get Mayor of London Green500 Platinum award; finalist for E.U. International Sustainability Award

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Kirin Brewery Company Okayama Plant, Japan

- Waste heat is transferred to the steam water tank providing steam for pasteurization of cans for wine and liquor
- Okayama Plant is proactively dedicated to the introduction of green production technologies and energy-saving programs to ensure minimal environmental impact promote of energy-saving production and effectively control greenhouse gases (CO2).

Project profile

Okayama Plant is possession of complete "Zhuhai Kylin Frozen Product" production line and exclusive 135ml can production line. Its major products include beer, sparkling wine and new wines.

The opportunity

Targeted 35% reduction in unit energy consumption, CO2 emissions and unit emissions.

The results

- 45% reduction in unit steam production by canned wine and liquor processes
- 27% reduction in unit heat consumption by the whole plant
- 30% reduction in CO2 emissions

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Texas Medical Center Houston, TX

- Electricity and waste heat are used to produce steam and chilled water, which are piped underground to more than 18 million square feet of buildings
- Reducing CO2 emissions by approximately 305,455 tons per year—the equivalent of removing 53,000 US cars from the roads

Project profile

Provide economical and reliable thermal services to institutions in the Texas Medical Center.

The opportunity

Eliminate the need for an older, lower-efficiency plant to come online to meet facility energy needs

The GE solution

GE's LM6000 PD Sprint® aeroderivative gas turbine powers a 48MW CHP plant

The results

Since installation:

- 122k tons of chilled water
- 850k PPH of steam
- 61MW power generation
- 82% efficiency

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Immingham CHP2
United Kingdom

- Generating capacity of 730MW makes it Europe's largest CHP plant
- Steam and power produced supply the Humber and Lindsey oil refineries

Project profile

Immingham Combined Heat and Power Plant is a gas-fired CHP power station in North Lincolnshire, England. It is situated on the south bank of the Humber, north of Immingham.

The opportunity

Refinery operations requiring 25MW of electricity and steam

The GE solution

Two 260MW 9001FA gas turbines generate electricity and provide exhaust heat.

The results

Europe's largest CHP plant

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Qatalum
Qatar

- Heat product of energy generation used in the aluminum smelting process
- The integrated solution included a predictable maintenance program, which helps meet the April to October peak demand due to the intense climate of the region

Project profile

Qatalum is Qatar Aluminum Ltd's most productive plant, creating more than 585,000 tons of high-quality aluminum products per year. For a business creating aluminum, loss of power means loss of production and at $2,000/ton, that impact on their business is great.

The opportunity

Reliability in an industry requiring consistently available power for aluminum production

The GE solution

The plant consists of two combined cycle power blocks. Each block has two GE 9FA gas turbines, one GE C7 steam turbine, two heat recovery steam generators and three GE 324 generators

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Oresundsverket Sweden

- Largest Swedish energy project in the last 25 years
- At full cogeneration, the CHP plant produces 400 MW of electricity and 250 MW of heat at 90 percent efficiency while decreasing carbon dioxide emission levels by about 1,000,000 tons per year

Project profile

CHP plant provides electricity for 70 percent of the households in southern Sweden along with 40 percent of Malmo's heating requirements.

The opportunity

Large, environmentally conscious power producer

The GE solution

9FB gas turbine and DLN 2.6+ combustion system

The results

Produces 3 TWh of electricity and 1 TWh of district heat annually

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For more information about GE's Distributed Power solutions:

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