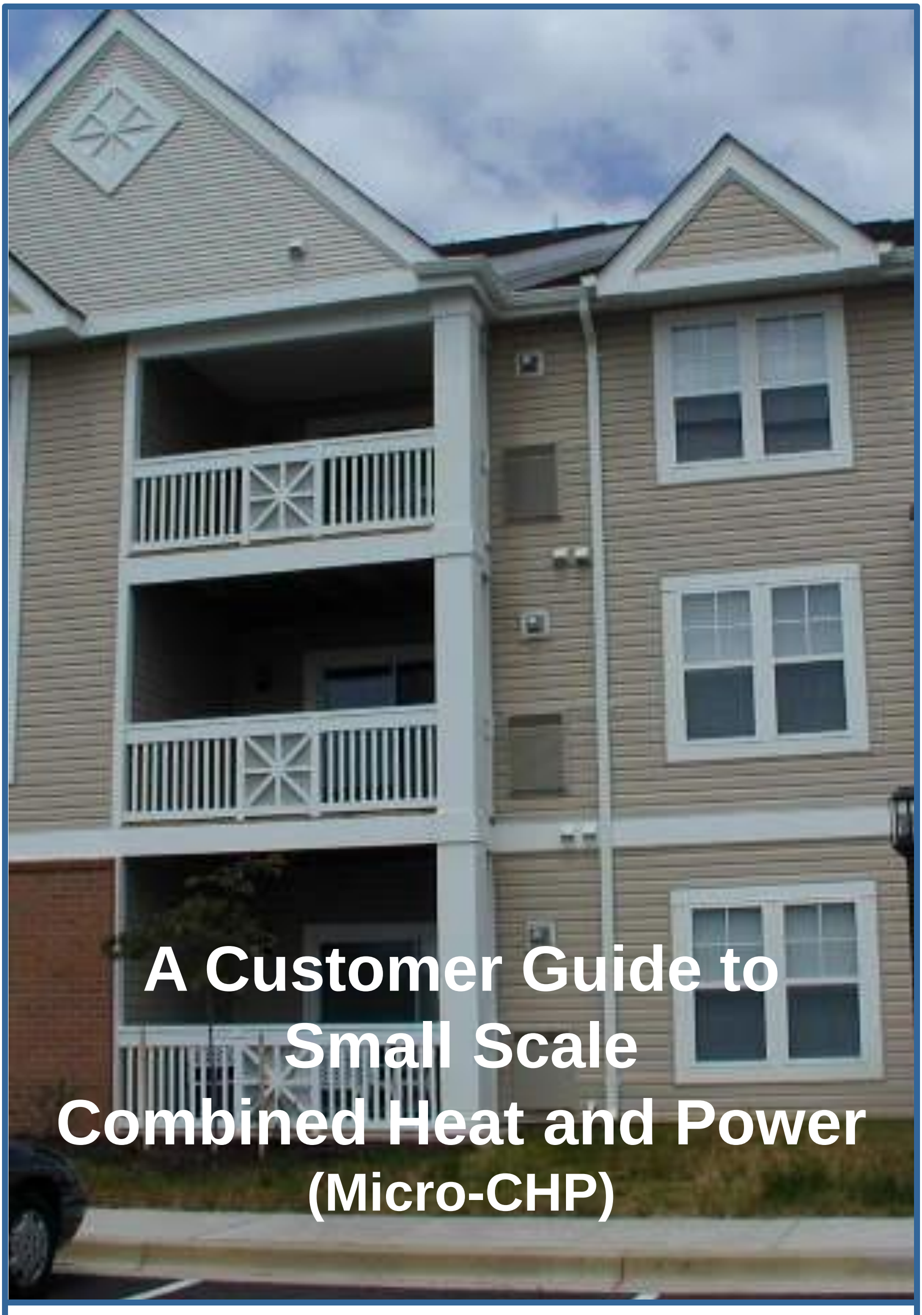

A Customer Guide to Small Scale Combined Heat and Power (Micro-CHP)

ESC

A product of the
CHP Consortium
Energy Solutions Center Inc.

This guide is intended to provide an overview of small scale combined heat and power systems, benefits associated with such systems, as well as market opportunities.

The background and understanding of the applications for Micro-CHP is a good starting point to take the next steps and get involved in more detail about the facets of the market, specifically the technology, drivers, economics, environmental benefits, and future potential of Micro-CHP.

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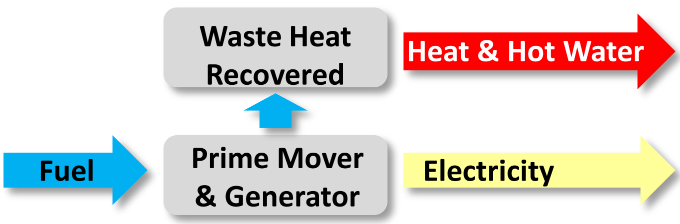
What is Combined Heat and Power (CHP)?

CHP is an integrated energy system that is:

- located at or near a residence or building
- generates electricity and/or mechanical power
- recovers waste heat for heating, cooling, hot water or dehumidification
- can utilize a variety of technologies for power
- is also referred to as Cogeneration

Combined heat and power by definition is the generation of two forms of energy from one common source of fuel.



The purpose of this guidebook is to explain small scale combined heat and power system technologies, applications, and market opportunities for cogeneration in the residential and light commercial market. These small scale CHP systems are called micro-CHP or mCHP.

Micro-CHP Defined: Size

For the purpose of this guide, micro-CHP appliances are cogeneration systems less than or equal to 50kWe in size.

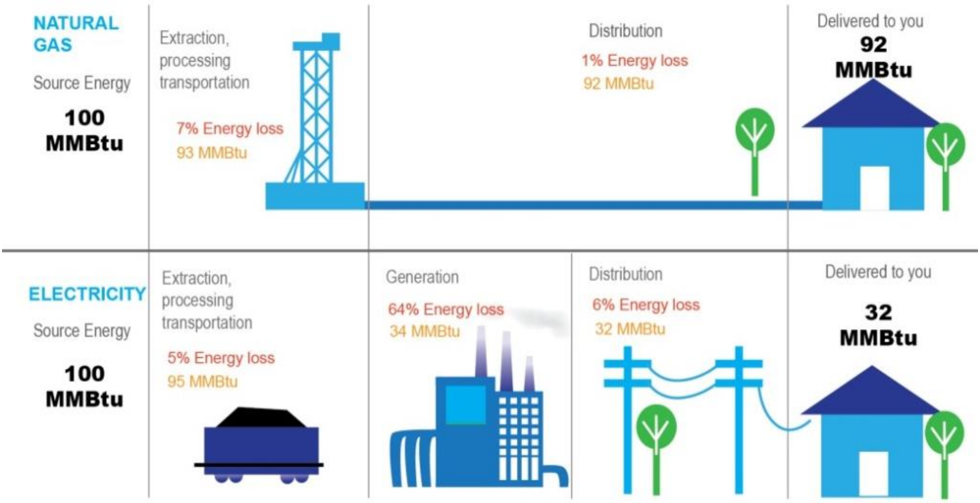
Difference between micro-CHP & large CHP

Many large commercial and industrial CHP applications are Electricity-led where electricity is the main output and heat is a byproduct. These systems are typically sited in “campus” type environments such as office complexes, hospitals, and college buildings where the heat can be efficiently utilized for space heating or cooling applications.

Micro-CHP systems in residences or smaller commercial applications are more often Heat-led. Heat is the main output and electricity is the byproduct. Depending on application, the CHP system can be either electric or heat led.

Energy Efficiency

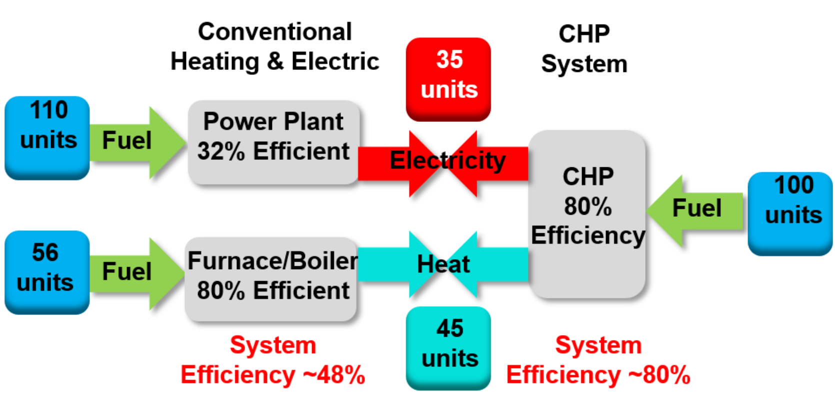
Traditional power plants were built to produce electricity, which they did adequately, but because many of these plants were located in remote areas, the heat could not be efficiently transported any distance and therefore was “wasted”.



Source: 2018 AGA Playbook

As shown above, approximately 92% of the usable energy in **natural gas** is delivered to your home or business. Conversely, approximately only 32% of the source energy used to **create electricity** is delivered for use.

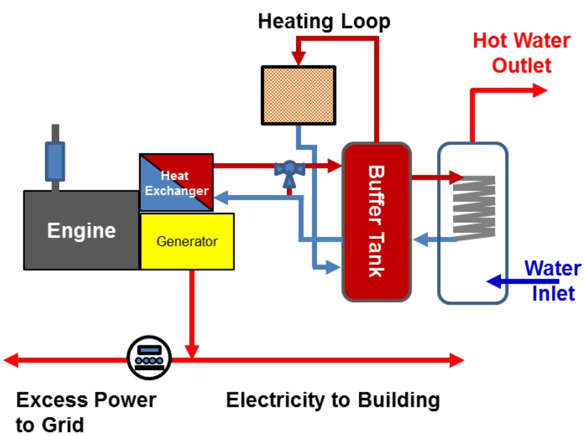
The diagram below shows the difference between conventional heating with grid power compared to that of a micro-CHP system. The combination of grid electric plus on-site heating efficiency is approximately 48% compared to system efficiencies of approximately 80% with a micro-CHP system.



Micro-CHP Today

Over the past decade electric prices have steadily increased. Conversely natural gas prices have dropped and stabilized in recent years mainly due to the abundant new supply of natural gas. It is estimated that North America has 100+ years of natural gas based on current consumption levels. At the same time, micro-CHP technologies are evolving and demonstrating longer lifespans.

Micro-CHP can generate two forms of energy (heat and electricity) on a scale that can provide a residence or a small commercial building with enough power as well as heat and hot water to be self-sufficient. The system efficiencies are typically 80% and the emissions low enough to satisfy the ever tightening requirements related to air quality. The schematic below is a representation of a micro-CHP system.



Natural gas is fed to the power source, which is coupled to a generator, and produces power that is consumed on-site or sent back into the grid when more electricity is being generated than needed on site.

The heat is recovered from the engine and sent through a heat exchanger to a buffer tank for storage. Hot water is then used to provide space heating or for domestic hot water use.

Virtually any application that requires heat/hot water is a candidate for a micro-CHP appliance. Some examples:

- Residences
- Multifamily buildings
- Health Clubs, schools, community swimming pools
- Nursing homes/Assisted living
- Restaurants
- Car washes
- Hotels
- Greenhouses/hydroponic farms

Drivers and Advantages of Micro-CHP

Micro-CHP product development started in the 1990's in Europe and Japan and was spurred on by increasing energy prices as well as a keen concern for air quality/emissions issues in those regions. Energy awareness is the main driver for the changes coming in the micro-CHP field. Interest in mCHP is growing due to:

- High electric costs versus natural gas costs (spark spread)
- Increased # of power outages and duration
- Interest in renewable energy, and energy efficiency both from a consumer and utility standpoint
- System costs are decreasing as the market grows.
- More new products are entering the market
- Government policies and utility awareness are making changes to incorporate new technologies.

Opportunities and Challenges

The drivers noted above serve as catalysts to accelerate the markets for micro-CHP technologies moving forward. The table below outlines the key points for both.

OPPORTUNITIES

- **Large Market** – US and Canada
- **Technology is proven**- More installations will improve acceptance.
- **Clean and Efficient –** Significantly less CO_2, NO_x, and SO_2 with mCHP.
- **System efficiencies over 80%.**
- Units can be **multiplexed** for larger applications.
- Can supply **backup power**.
- **Leasing options** starting to be offered
- Can satisfy **Demand Response** options.
- **Controllable and dispatchable** from a remote/external source.

CHALLENGES

- **High system costs**
- **Sales channel –** Distribution and sales channels are fragmented and not fully developed.
- **Stigma** that mCHP is not renewable.
- **Electric Utility** reluctance to accept.
- **Education** of the consumer, utility and policy makers.
- **Legislation is fragmented** (by State) and slow to change at the Federal level.
- **Few companies** providing product, with little or no advocacy.

Internal Combustion Engines

At present, there are more manufacturers of internal combustion engines for micro-CHP appliances than other technologies. This is due in part to the proliferation of the technology that stems from the automotive industry. The standard automobile engine is much the same as those used in micro-CHP units throughout the world. It is estimated that almost 80% of the units in service throughout the world are powered by IC engines.

IC engine systems are proven power sources, relatively efficient, and are good “heat generators” when the thermal energy is recovered properly - typically from the engine oil cooler and/or an exhaust recuperator. A good rule of thumb for the relationship between the heat output and the electrical output is 3:1 for IC engine systems.

Some current IC engine technologies can run as long as 10,000 hours (almost fourteen months) between maintenance intervals which like a car, typically includes oil, filters, and spark plug(s). Engine size is directly proportional to the electrical output of the micro-CHP. The smallest units generate about 1kWe up to about 50kWe for mCHP applications. For the larger applications systems up to several MW are available. There is no question that IC engine powered micro-CHP units will be around for many years in the future.

IC Engines are ideal for heat-led applications where they are capable of operating on a load following cycle. This allows the system to follow specific power, heating and cooling loads drastically improving the economics.

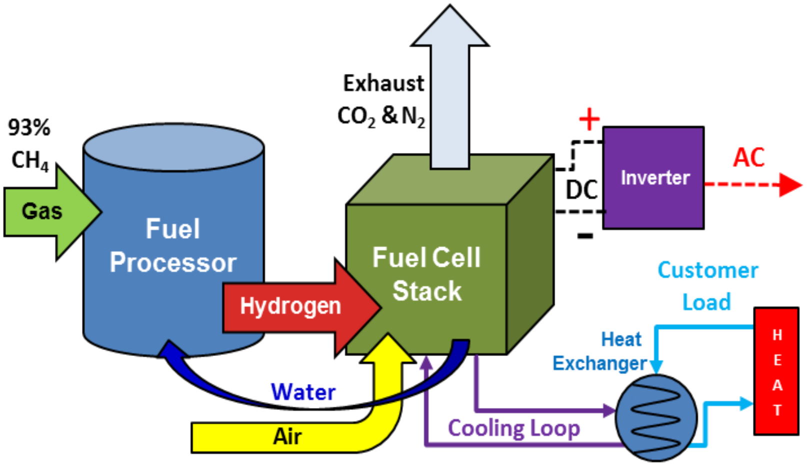
Fuel Cells

Over the past 25 years, a great deal of R&D has gone into fuel cells. However, there is still significant work to be done to make these appliances competitive in the marketplace.

All fuel cells work essentially the same way --- an electrochemical reaction between hydrogen and a catalyst. The catalyst splits the hydrogen atom and the resulting electron flow provides electricity; with the by-products of this reaction being heat and water. As can be imagined, this is a perfect micro-CHP scenario — heat, electricity and water out, with low emissions and no moving parts. The hydrogen is usually "generated" by a reformer (fuel processor) from a hydrogen-rich fuel — typically natural gas.

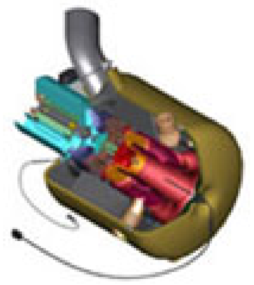
Fuel cells are differentiated based on the catalyst used in the processing of hydrogen. For micro-CHP applications the two applicable catalysts are: Solid Oxide (SOFC) and Polymer Electrolyte Membrane (PEMFC). The SOFC appliances are high temperature devices and have a higher efficiency. On the other hand, PEM cells operate at a lower temperature and are better suited for on/off applications as they have a faster start up capability.

Fuel cell based systems are scalable and their size can range from less than 1kWe up to hundreds of kilowatts. The majority of micro-CHP systems coming available into the market are in the 1 – 5kWe range and are considered electric-led. This means that they are running continuously and providing base load power with the heat generated satisfying the domestic hot water needs. The schematic below is representative of a micro-CHP based fuel cell system.



Microturbines

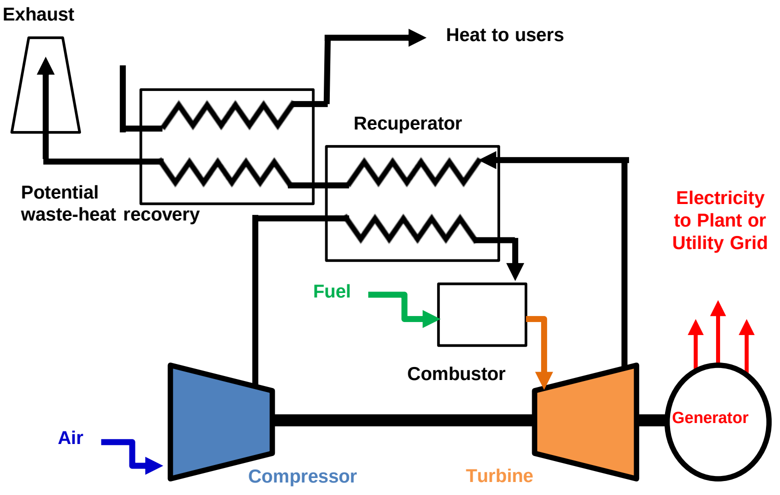
Microturbines are small combustion turbines that produce power. Microturbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units (APUs). Most microturbines are single-stage, radial flow devices with high rotating speeds of 75,000 to 250,000 revolutions per minute.



Microturbine generators can be divided in two general classes:

- Recuperated microturbines, which recover the heat from the exhaust gas to boost the temperature of combustion and increase the efficiency
- Un-recuperated microturbines, which have lower efficiencies, but also lower capital costs.

Many of the early microturbines were un-recuperated designs but, today's products are generally recuperated systems. The figure below illustrates a recuperated microturbine system.



Prime Movers

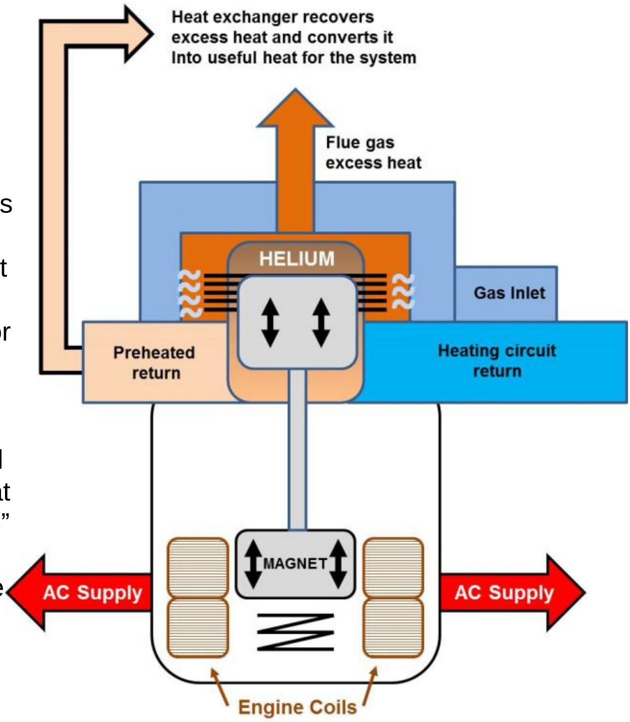
The development of micro-CHP technology has progressed at a rapid rate with over thirty companies throughout the world working on the deployment of such products. This amount of research and development indicates that there is significant market potential for micro-CHP throughout the world.

Currently, there are five technologies (prime movers) that are used to supply power today for micro-CHP systems:

Internal Combustion Engines (ICE)	• Proven Technology • Electrical Efficiency: 27-42 % • Heat to Electric ratio: 3 to 1 • Size range: 1kW – several MW • Overall Efficiency: 80-92%
Stirling Engine (SE)	• Electrical Efficiency 10-20%. • Heat to electric ratio: 4.5 to 1 • Can use various heat sources • No maintenance; high reliability • Overall Efficiency: 80-90%
Fuel Cells (FC) **PEM** (Polymer Electrolyte Membrane)	• Most FC mCHP's use this technology. • Electrical Efficiency: 30-35% • Low Emissions • Low Temp. and Fast Startup
SOFC (Solid Oxide)	• High Temp—up to 1000º C • Electrical Efficiency: up to 60% • Mostly for continuous running apps • Some under development
Rankine Cycle (ORC)	• Developing technology • Low cost to manufacture • Electric Efficiency: 10-24%
Microturbines (µT)	• Likes to run 24/7 • Electrical efficiency 22-27% • Heat to electric ratio: 3.5:1 • Overall Efficiency: 64% - 75%

Emerging Technologies

Stirling (External Combustion) Engines



One of the oldest technologies supporting micro-CHP systems are those powered by Stirling engines. The Stirling engine was invented in 1816 and has become very popular in micro-CHP development — especially in Europe. What makes the case for this technology is the fact that it can utilize many fuel sources because it is an external combustion engine. Heat is applied to the 'outside" of the engine and not confined in an enclosure such as the cylinder of an IC engine. Because of this, biogas, solar concentrators, and conceivably recycled cooking oil can be used as a fuel source. Most conventional designs use natural gas because of the consistency of the heat. Other major benefits are no maintenance, low noise and high reliability.

Rankine Cycle

Rankine cycle systems are considered "external" combustion engines instead of the more common internal combustion engine (ICE). Large scale Organic Rankine Cycle (ORC) systems have been a viable technology for the last forty years, however, the use of an organic working fluid has limited its application in smaller scale products, until recently. Steam is a more robust working fluid and is being used in smaller steam-based Rankine cycle products now in development.

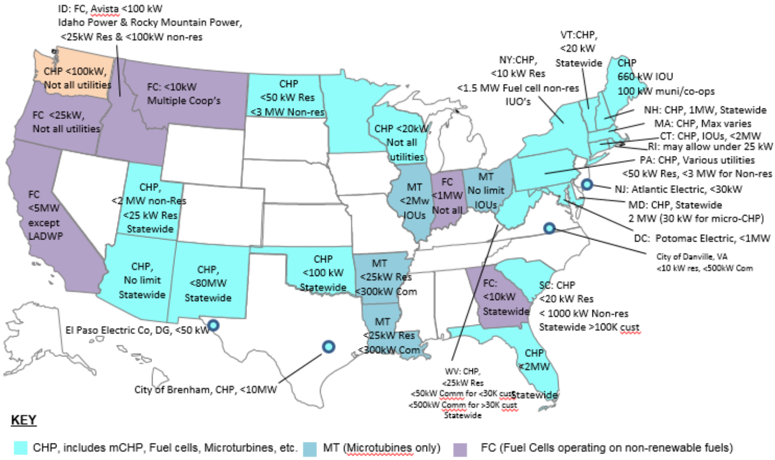
Policy and Economics: A Key Relationship

Most policies that are in place relating to small scale cogeneration are on a state or regional level and are influenced by politics directed by the Public Service Commissions (PSC) of those areas.

In order to get a better understanding of the interaction between Policy and Economics, a number of terms need defining in discussing this topic:

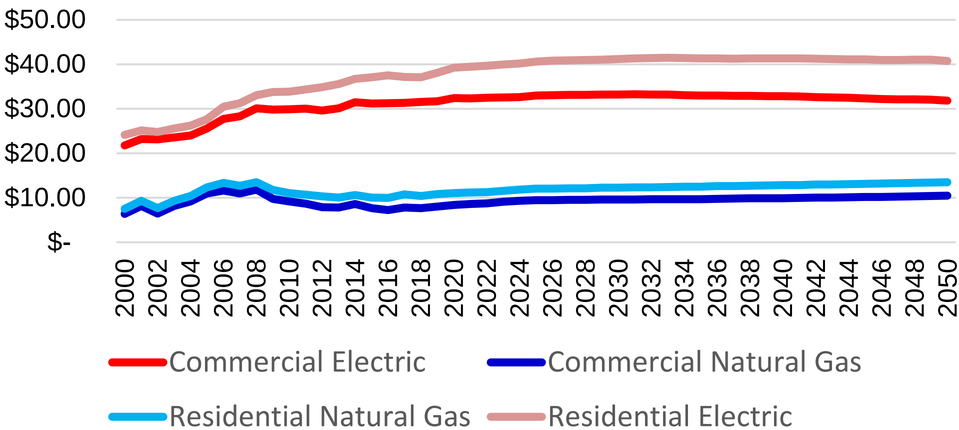
- **Interconnection Standards**—Because cogeneration appliances (of any size) can potentially connect to the electric grid, there must be some control and/or guideline in place to accommodate them. The electric distribution utility must review and approve the proposed system to ensure that it's within the framework established by the state's Public Utilities Commission (PUC). This is public information and is explained by the specific utility under its interconnection policy. In the absence of mandatory interconnection policies, the process can be cumbersome and difficult.
- **Certification** – There is general agreement throughout North America that if the product meets the UL 1741 Standard (for Inverters, Converters, Controllers and Interconnection Equipment to be used for Distributed Energy Resources) the product will be accepted for use. Other standards that could come into consideration would be NFPA 70 – Nat. Electric Code; IEEE 1547 Interconnect Code to Electric Power Systems. (From a Canadian perspective, the Standard is CSA 22.2).
- **Net Metering** – When a micro-CHP appliance generates more power than is used on site, the excess electricity is "sold" back to the utility. The utility has an obligation to accept the power, however, the price paid to the customer is up to what the utility is willing to pay. The $/kW price can be at the market rate or significantly less, which is called "avoided cost". Net Metering policies allow the consumer to spin the meter backwards and send power back to the grid at times when more power is being produced than consumed. This is an ideal generation program for a micro-CHP consumer. It allows the consumer to sell power to the electric utility at the same retail rate that they pay from the electric utility. Note that this buying and selling of electricity is typically capped at not more than the total power needed by the consumer. Generating additional power beyond the sites total needs is generally bought by the electric utility at wholesale rates and is typically known as Excess Power and purchased at Buy-back rates. In cases where the utility is not paying an attractive price for excess power, the excess electricity could be stored in batteries for later use such as peak shaving or for resiliency purposes.

States with Net Metering Policies



- **Spark Spread** – This is a very common and important term used in the discussion of cogeneration and is probably the key metric (along with Net Metering) in understanding the economics of a micro-CHP system. It is the ratio of the cost of electricity to the cost of fuel (usually natural gas) compared with a common currency and using the same energy units. A ratio of 3:1 has been considered a good Spark Spread in the past, but with the current divergence of higher electric prices to lower natural gas prices, higher ratios (4-5:1) are becoming common in some areas. The graph below shows the historical and predicted price difference between electric and natural gas. This key metric helps make the case for micro-CHP appliances in the future.

Average Retail U.S. Residential and Commercial Energy Prices including Short Term EIA Outlook ($/MMBTU)



Source – US DOE Energy Information Administration

Future / References

It should be determined from the information presented here that the future looks very promising for Small Scale Cogeneration. In order to aid the search for more information on these technologies and policies, the following websites could be helpful:

ESC Energy Solutions Center

www.UnderstandingCHP.com
www.GasAirConditioning.com

U.S. Environmental Protection Agency (EPA)
http://www.epa.gov/CHP

Name	Type	Output kWe	Output Thermal	Website
2G St. Augustine, FL 904-579-3217	Engine	50 kWe	359,283 BTU/hr	www.2-g.com/en/
Capstone Turbine Chatsworth, CA (818) 734-5300	Micro-turbine	30 kWe	153,500 BTU/hr	www.capstoneturbine.com
Lochinvar Lebanon, TN 615-889-8900	Engine	24 kWe	163,000 BTU/hr	www.Lochinvar.com
Marathon Engine East Troy, WI (262) 642-6436	Engine	4.4 kWe	47,000 BTU/hr	www.ecopowermicrochp.com
M-Trigen Houston, TX 713-469-6735	Engine	6.8-8 kWe	72,000 BTU/hr heat & 5 Tons Cooling	www.mtrigen.com
Tecogen Waltham, MA 781-466-6400	Engine	35 kWe 50kWe	237,144 350,000 BTU/hr	www.tecogen.com
Yanmar America Adairsville, GA (770) 877-9894	Engine	5kWe 10kWe 35 kWe	34,100 57,300 204,040 BTU/hr	www.yanmar-es.com

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