

MINI AND MICRO COGENERATION

Jan de Wit and Mikael Näslund
Danish Gas Technology Centre, (www.dgc.dk)

ABSTRACT

Combined heat and Power (CHP), or cogeneration, is an efficient and well-proven principle for power and heat production. Natural gas offers a wide range of technologies to be used and offers the widest power range for CHP production units. This also includes small units in the power range of 5-50 kW_e and even smaller units for CHP production in individual houses (micro CHP).

This paper presents a number of products and installation examples within the mini CHP segment and also presents products within the micro CHP segment. Technologies, key performance numbers, lay-out and operational considerations are discussed.

INTRODUCTION

Cogeneration, or Combined Heat and Power (CHP) production, is an important tool for achieving significant fuel and CO₂ savings. Compared to fossil fuel based production of power and heat separately, the cogeneration fuel savings and corresponding CO₂ savings will often be in the order of magnitude of some 30 %. The CO₂ savings are sometimes higher as a fuel switch from coal or oil to natural gas may be included.

These benefits are recognized by the EU Commission and several initiatives have been launched to increase the use of cogeneration within the heat and power supply. Figure 1 shows how much power is produced in various countries based on CHP.

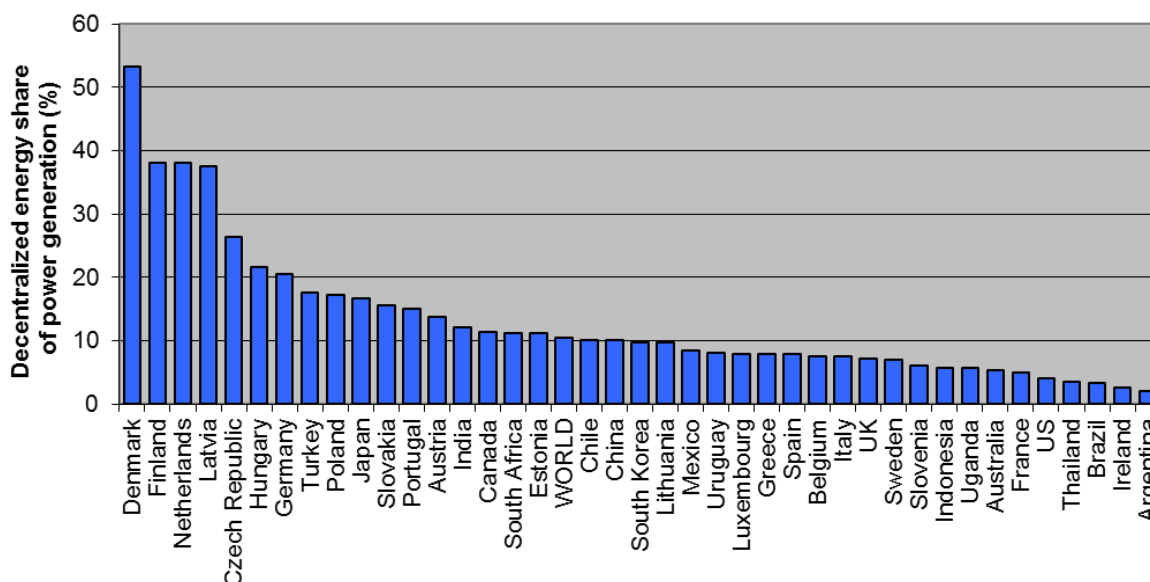


Figure 1 Distributed electricity generation (including cogeneration) in some countries (1)

The current CHP installations are often found in district heating networks or in industrial plants. The technologies used are combined cycle, back-pressure steam turbines and combustion engines. In mini and micro cogeneration other technologies are more suitable.

This paper presents a number of natural gas fired cogeneration technologies and installation examples within the power range of 1-50 kW_e. By installing units of this size power production becomes decentralized/distributed.

MINI CHP UNITS ON THE MARKET

Cogeneration or CHP units of 5-50 kW_e are commercially available on the market. Most of these are based on reciprocating engine technology (gas engines), but also a few small appliances based on gas turbines can be found. They have a power-to-heat ratio of approximately 1:2, and the heat output of these units will generally then be within 15-120 kW. Internal combustion engines (ICE) dominate the market, but gas turbine is also a possible technology. The gas engines are spark ignited (Otto cycle) and operate either close to stoichiometric conditions allowing three-way

catalysts to be used for emission reduction or are designed for lean-burn operation. Examples of a few selected mini CHP units in the 5-50 kW range are presented in Table 1. These units are also suitable for biogas operation.

Table 1 Selected mini CHP units available in Europe (/2/)

Product, examples	Technology	Electric output (kW)	Electric eff. (%)	Total eff. (%)
Senertec Dachs 5.5	Gas engine (ICE)	5.5	27	88-99
EC Power XRGI 15	Gas engine (ICE)	15	30	92
Viessmann Vitobloc 200	Gas engine (ICE)	18	32	96
Buderus Loganova EN50	Gas engine (ICE)	50	34	88
Capstone C30 LP	Gas turbine	28	25	-

INSTALLATION AND OPERATION

Often the system comprising a CHP unit also includes heat storage and additional boilers. The heat storage has several purposes, and the boilers are used for the heating demand when it exceeds the CHP heat output. To achieve the best electrical production efficiency and to benefit the most from the investment, the CHP units should (if possible) be operated at full load and for many hours per year. This means a sort of base load operation seen from a heat supply point of view. Ordinary and less costly boilers must then cover peak load heating periods or periods with low value for the electricity produced. The images in Figure 2 show two mini CHP installations. In the left image the mini CHP unit is the blue/steel coloured appliance. The all-blue vertical unit far left in the left picture is heat storage. The blue box on the wall behind the mini CHP unit in the left picture is the water-side coupling box. The right image shows an installation where additional heat is produced in several wall-hung gas boilers in a cascade lay-out.



Figure 2 Two examples of a mini CHP unit system (EC-Power) installed in boiler houses

Most often CHP units in this power range, 5-50 kW_e, produce low voltage power (400 V AC). The power produced can be used internally for the connected house only or be fully or partly exported to the grid if tariffs are attractive and the national regulations allow it. In a fully deregulated market services such as power balancing and/or standby services may also be offered (and paid for) from such units.

Easy access to the public electrical grid and fair pricing for power exported (feed-in tariffs) are important parameters for implementation of mini and micro CHP. In some countries this is a critical barrier for the mini and micro CHP market.

To achieve maximum number of operation hours per year it might an option to include production of cooling (tri-generation – power, heat, cooling). Especially for office buildings, shopping centres and hospitals there is often an additional need for cooling. Production of cooling can be based on using the thermal energy from the CHP unit in an absorption cooler.

HEAT STORAGE TANKS

To ensure operation flexibility a heat storage or buffer tank can be connected to the system. Such a tank will, depending on size, allow the unit to operate full load for a number of hours despite the fact that the actual heat demand is less than the heating output of the CHP unit. Surplus heat is stored in the tank. When the tank is fully “charged” with hot water, the CHP unit is stopped, and heat is supplied from the tank. By operating the CHP unit on full load only, the best electricity production efficiency is achieved and the most electricity is produced on a given heat basis.

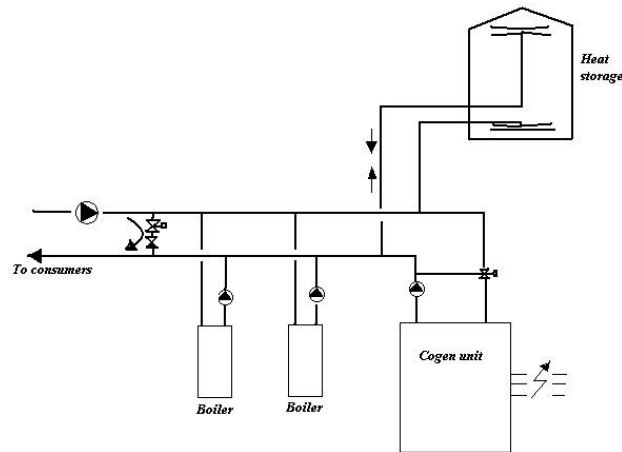


Figure 3 Principle drawing of a mini CHP installation with boilers and heat storage

Maximum electricity production can be moved to time slots with the best electricity price by operating the heat storage tank wisely. The heat storage also enables shutdown of the unit for a short period to carry out maintenance etc.

Heat storage tanks can be located indoors or outdoors (see Figure 2); they can be vertical or horizontal. They are often insulated steel tanks with inlet and outlet designed to avoid mixing of the hot and cold layers in the tank. Tanks can be fully or partly underground. If above ground level they can act as advertising/bill boarding.

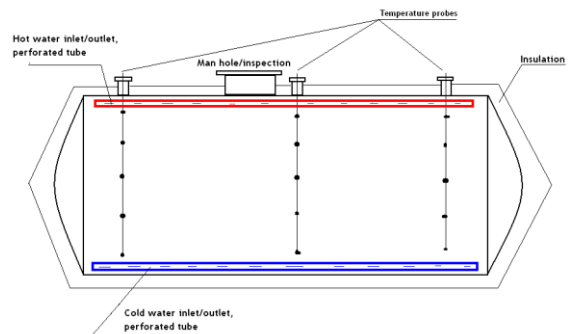


Figure 4 An underground horizontal heat storage tank for a small CHP unit for a multi-family housing area

INTEGRATION WITH RENEWABLE ENERGY SOURCES

By installing a heat storage tank, sustainable/renewable energy resources such as solar heating can easily be integrated in the system.

TYPICAL INSTALLATION SEGMENTS

CHP units in the power range 5-50 kW_e can be installed in various types of buildings, examples are given below:

- Multi-family houses
- Institutions (hospitals, schools, museums, senior citizens centres etc.)
- Offices/light industry
- Sport centres
- Greenhouses
- Camping centres
- Shopping centres

PERFORMANCE CHARACTERISTICS

Small CHP units in the power range 5-50 kW_e typically have electrical production efficiency in the range of 25-30 %. The total efficiency from these units is often 85-95 %; however, condensing operation is possibly leading to total efficiencies close to or even above 100 %.

Electrical efficiency is defined as electrical production related to fuel input based on lower heating value (LCV). Total efficiency is defined as the sum of electricity (kWh/h) and heat production (kWh/h) related to the fuel input (kWh/h) based on LCV.

For most technologies part load operation will significantly affect (lower) the electrical efficiency. Part load operation should, therefore, be avoided, if possible. This can be done by using heating storage to store surplus heat for a period and enable full load operation for a period. Installation of multiple units may also allow "part load" operation by operating only for example one unit instead of two.

HIGH ELECTRICAL EFFICIENCY IS IMPORTANT

The overall fuel and CO₂ saving effect of Combined Heat and Power production is closely linked to the fuel saved elsewhere, typically from central power plants with power-only production. The more power production efficient the mini or micro CHP is, the more fuel is saved elsewhere and the most electricity is produced based on a given heat base.

If the fuel consumption of decentralised units is corrected for the fuel saved elsewhere, the net heating production efficiency can be found; an example is shown in Figure 5. It is clearly seen that high electrical efficiency of the small units is important. Figure 5 also shows that the production efficiency will go significant above 100 %, making these appliances - a "Next Generation" highly efficient appliance - comparable with other fuel saving appliances such as heat pumps etc.

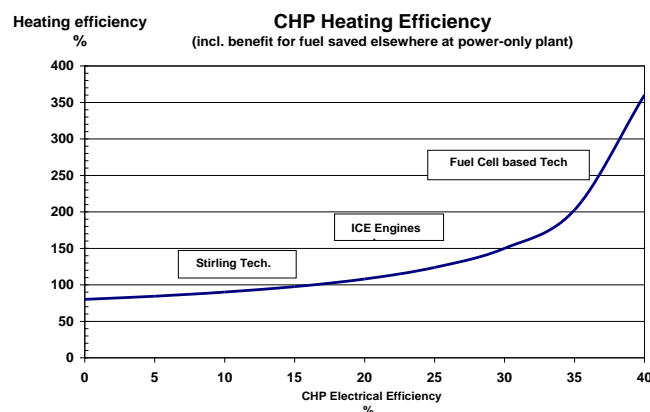


Figure 5 Heating efficiency for CHP units, including the benefit of substituting power generation in larger power plants. The technology labels on the graph shows typical efficiency ranges for the technologies mentioned regarding mini and micro CHP products. The labels are not representative for CHP units for higher power ranges. More technologies will then be available and gas engines (ICE) are now close to an efficiency of 45 % for the largest unit as an example.

MICRO CHP

Through the last 25 years heat producing boilers for individual houses have gone through a number of technology steps. Seen from a fuel efficiency point of view boilers have gone from simple non-condensing units to condensing, well-insulated units with advanced circulation pump and control/operation system technologies. Well-installed boilers operate with efficiencies of some 100-104 % in practical operation. From an efficiency point of view there are very limited possibilities for further efficiency improvements. Boiler manufacturers have put a strong effort into a broad spectrum of the next-generation appliances. Such appliances might be boilers/units combined with renewable energy such as solar heating, heat pumps (electrical or gas fired) and micro cogeneration units, which all reduce the primary energy consumption.

Different prime movers (engines) can be used in the micro CHP units. The most sold unit is based on a one-cylinder gas engine (the Honda Ecovill product), a number of other early market products use Stirling engine technology. A number of manufacturers have put tremendous efforts and resources into development of fuel cell based units; these units are the far most efficient ones and have no moving parts in the prime mover leading to a low noise level and an important

assumption of achieving little service need and long lifetime. Further developments, testings and significant cost reductions are needed for the fuel cell based units.

More than 100,000 Honda Ecowill micro CHP units are installed in Japan and a number of field testings are ongoing there with micro CHP units based on fuel cells. Sale of the Ecowill product is about to start in Europe via the boiler manufacturer Vaillant.

Micro CHP units in single-family houses meet a more complex demand pattern regarding both electricity, heating and hot water. Heat storage is more or less necessary to obtain operation with long steady-state conditions. This is especially important for fuel cells due to degradation and the risk of reduced life time. A micro CHP system typically consists of the CHP unit, heat storage (200-300 litre volume) and an auxiliary heat source, which can be either an integrated part of the CHP unit or a separate gas boiler. Several investigations have found that a suitable nominal electric generating capacity is approximately 1 kW. The CHP unit can be controlled either by the electricity demand in the house or the heat demand. In the latter case electricity will have to be exported to the grid in most installations. Heat demand controlled operation will also increase the operation of the CHP unit as seen in the figure below.

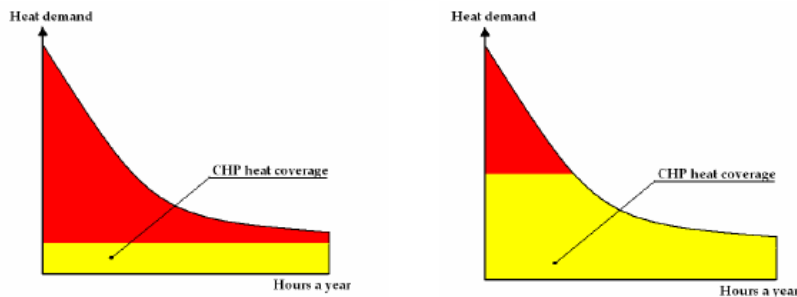


Figure 6 Illustration of heat generation with electricity controlled and heat controlled operation

In Europe, micro CHP seems to be close to market introduction in the UK, Netherlands and Germany. Energy utilities have participated and are expected to be active players in the market introduction by giving financial grants or by establishing Service Provider companies to own, operate and maybe service such units. The first products are often called electricity producing gas boilers. A number of micro CHP products can be seen in Table 2.

Table 2 Current micro CHP products and future natural gas fired fuel cell products as comparison

Product	Technology	Electric output (kW)	Electric eff. (%)	Total eff. (%)
Baxi Ecogen	Stirling	1	15	91
Vaillant ecoPower 1.0/ Honda ECOWILL	Gas Engine (ICE)	1	26	92
Panasonic Ene-farm	Fuel cell, PEM	1	35	85
Hexis Galileo 1000N	Fuel cell, SOFC	1	30	90-105
CFCL BlueGen	Fuel cell, SOFC	1.5	60	<85

It is clear that the different technologies show a wide range of electric efficiency where the commercially available technologies, such as the Stirling engine unit and the combustion engine based units, are less efficient. Fuel cells for micro CHP purposes are still in the development and field test phase, except for Japan where they have been available for everybody since 2009. The energy balance for single-family houses in north-western Europe (UK, the Netherlands, Germany and Denmark) with an annual demand of approximately 5,000 kWh electricity and 17,000 kWh heating and hot water is roughly as follows: The micro CHP unit ($\eta_{el}=30\%$) produces 5,000 kWh electricity, of which half is exported to the grid, and 10,000 kWh heat to be used for heating and hot water.

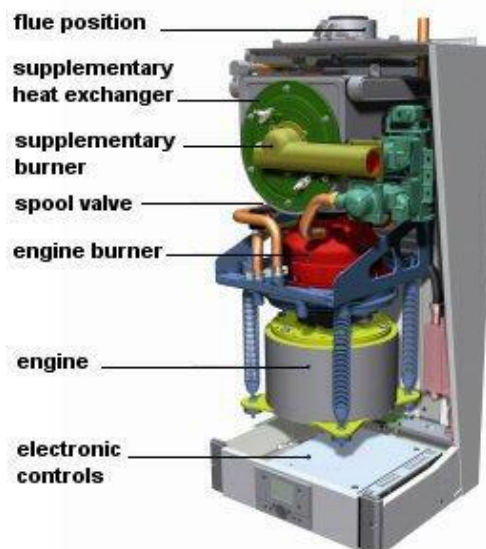


Figure 7 Examples of 2 micro CHP products: The Honda Ecovill/Vaillant ecoPower unit (ICE engine) and insight details of the Baxi Ecogen unit (Stirling engine)

The Remeha eVita Stirling based unit is today (May 2011) offered at approx. 10,500 Euro on the German market and 13,000 Euro including heat storage and accessories. The energy utilities and public authorities may also offer subsidies on the investment cost or offer favourable tariffs for electricity exported to the grid. The target is to significantly reduce the additional cost for the micro CHP units. A pay-back time in the order of 5 years has been mentioned. Panasonic announces that the cost for the fuel cell unit has been reduced by 5,000 Euro from 2009 to 2011.

REFERENCES

- /1/ "2006 World Survey of Decentralized Energy", WADE, www.localpower.org
- /2/ "BHKW-Kenndaten 2011. Module, Anbieter, Kosten", Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch ASUE (In German), www.asue.de
- /3/ Pedersen, A. H., "Operating Experiences from 18 Microturbine Applications for CHP and Industrial Purposes", International Gas Research Conference (IGRC) 2004, Vancouver
- /4/ de Wit, J., "Micro-CHP in Denmark?", Cogeneration Europe Annual Conference 2011, Brussels

SUMMARY/CONCLUSION

Based on the discussions above the main drivers/arguments for implementation of mini and micro CHP are seen below.

- Boilers have reached their efficiency limit; new technologies should be introduced in this market.
- On-site combined heat and power production saves transmission losses and saves primary fuel elsewhere (fossil-based power-only production).
- The gas system is an important "player" also in future energy systems; introduction of micro CHP secures the return of investment for connections to individual gas consumers with decreasing heating energy needs.
- Mini and micro CHP pave the way for interesting ownership and operational models.
- Mini and micro CHP might be valuable for power balancing issues.
- Improves security of supply along with other local producers.
- Micro CHP with intelligent control systems can be valuable in smart grid networks.
- Easy access to grid will give best operational foundation and maximum fuel and CO₂ savings.
- Micro CHP supports the EU Cogeneration Directive, the Energy Service Directive and others.

Multiple mini CHP products are on the market and are to be considered proven technology.

Micro CHP can be made based on various technologies/prime movers. Products based on gas engines are introduced in large numbers in Japan and the first units based on Stirling engines are at the brink of market introduction.