FINAL REPORT

Deliverable 8 (D8) of Green Lodges Project (EIE/04/252/S07.38608)

Micro CHP systems: state-of-the-art

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Picture on front page: 5 kW_{el}/12,3 kW_{th} micro CHP unit with storage tank (courtesy of Senertec)

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1 Introduction

The project “Green Lodges” aims at promoting and facilitating RES heat & electricity applications (biomass, solar & micro CHP mainly) in rural lodges, usually located in areas with high environmental value.

Delivery 8 (D8) report – as the first deliverable of work package 3 – provides information regarding the state of the art of micro CHP systems. All kind of CHP applications and technologies below of 1 MW_{el} (combustion technologies like internal combustion engines, diesel engines, stirling engines, micro turbines, ORC, fuel cells, etc) and RES (rape oil/biodiesel, biogas, etc) will be considered. The focus of the analysis will be laid on micro CHP units up to an electrical output of 50 kW following the definition of the CHP directive.

As micro CHP systems are not very developed in all European regions/countries participating in “Green Lodges” project, this report also identifies critical economic success factors in order to facilitate further projects. Beside of the technical and economic characteristics, barriers for the further deployment of micro CHP plants were identified. Site specific aspects like planning, integration into the heat system, interconnection to the grid, stand-alone versions, etc. were discussed in detail in order to qualify the project partners themselves for implementing micro CHP systems in their own regions. In this context tables and figures giving precise planning guidelines will round up the content of the report.

The identification of best-practice and good-practice examples in form of case studies in each region will be the next step within work package 3 (as D9 – delivery 9). Furthermore, all the information regarding the current available technologies and applications will be gathered in a flag brochure aimed to the equipment and service suppliers. Goal is that they receive latest knowledge about the advances and the existing possibilities of micro CHP systems. Information will encourage the offer, and this will promote the growing of the micro CHP market (D10 – delivery 10) in each region and/or country.

2 Definition of micro CHP

In the past several definitions concerning micro CHP were used in the literature. The publication of the cogeneration directive in February 2004 [Lit 3] finally clarified this situation in Europe because of the following definitions:

(i) micro-cogeneration unit shall mean a cogeneration unit with a maximum capacity below 50 kW_{el}, and

(ii) small scale cogeneration shall mean cogeneration units with an installed capacity below 1 MW_{el}.

Cogeneration production includes the sum of produced electricity and mechanical energy and useful heat from the cogeneration units. This generally means that conventional heating systems are replaced by electricity generators equipped with heat exchangers to additionally use/recover the waste heat. The heat is used for space and water heating and possibly for cooling, the electricity is used within the building or fed into the grid.

However, in the literature several authors refer to smaller power outputs (< 15 kW_{el}) when they talk about micro CHP. Arguments that support the definition of smaller power range are:

(i) CHP systems < 15 kW_{el} are clearly systems for the deployment in single buildings like small hotels, small business enterprises, guest houses, apartment houses, inns, etc. which can be distinguished from systems supplying heat to a district or neighbourhood (f. ex. district heating systems).

(ii) Systems in a power regime (< 15 kW_{el}) substantially differ from larger ones with respect to electricity distribution, ownership models, restructuring of supply relationships, and consumer behaviour. Compared to conventional CHP, for example based on district heating, no additional heat distribution grid is required. Systems below 15 kW_{el} can be directly connected to the three-phase grid. The implementation barriers for small scale CHP systems are more pronounced than for the larger ones.

In central Europe micro CHP products are typically run as heating appliances, providing space heating and warm water in residential, suburban, rural or commercial buildings like conventional boilers. But unlike a boiler, micro CHP generates electricity together with the heat at very high efficiencies and therefore helps to save fuel, cut greenhouse gas emissions and reduce electricity costs. Most units operate in grid-parallel mode, so that the building continues to receive some of its electrical needs from the electrical network, but it may also export some electricity to the electrical network. These can be used to provide heating and electricity to district heating schemes, apartment buildings, hotels, guest houses, commercial buildings and small industries. They can run on natural gas, light oil gas, biogas, rape oil and/or RME. These products are either already available commercially or they are close to market entry.

A number of different conversion technologies have been developed for the application in micro CHP systems.

- **Reciprocating engines** are conventional internal combustion engines coupled with a generator and heat exchangers to recover the heat of the exhaust gas and the cooling cycle.
- **Stirling engines** are thermal engines where the heat is generated externally in a separate combustion chamber (external combustion engines). They are also equipped with a generator and heat exchanger(s).
- **Micro gas turbines** are small gas turbines belonging to the group of turbo machines up to an electric power output of 300 kW_{el}. In order to raise the electrical output micro gas turbines are equipped with a recuperator (heat/heat exchanger). They are also equipped with a regular heat exchanger in order to use the waste heat from the exhaust gases.
- **ORC**: The Organic Rankine Cycle (ORC) is similar to the cycle of a conventional steam turbine, except for the fluid that drives the turbine, which is a high molecular mass organic fluid. The selected working fluids allow exploiting efficiently low temperature heat sources to produce electricity in a wide range of power outputs (from few kW up to 3 MW electric power per unit).
- **Fuel cells** are electrochemical energy converters similar to primary batteries. Fuel cell micro CHP systems are either based on the low temperature polymer electrolyte membrane fuel cells (PEFC or PEMFC) which operate at about 80 °C, or on high temperature solid oxide fuel cells (SOFC) working at around 800 - 1000 °C.
- Various other technologies, such as **steam cells, thermoelectric devices**, etc. are still under development.

While reciprocating plants are already commercially available, stirling engines, ORC and micro-gas turbines are close to it with a substantial number of pilot and demonstration plants being in operation. Fuel cells are still in the R&D phase[1] with a number of pilot plants currently being tested. (see Table 1 for comparison of the state of the art micro CHP technologies).

[1] R&D is the abbreviation for research and development.

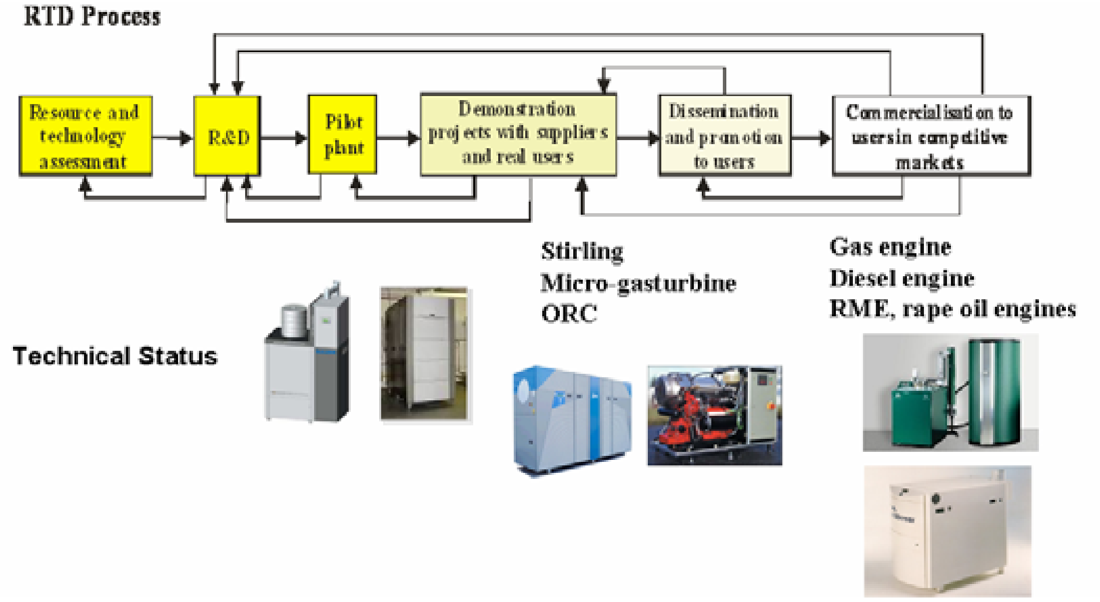

Figure 1 Comparison of the technological state of the art of micro CHP technologies – using R&D cycles (Source: characterisation is based on the EU ATLAS project, http://europa.eu.int/comm/energy_transport/atlas/homeu.html)

Prototypes - “proof of concept” of technology

Pilot plants - first operation experience, final system design not fixed yet

Demonstration plants - (“Pre-commercial plants”) - Field test units in order to achieve operation and market experience, final system design fixed

Commercial plants - Already implemented systems in competitive markets

3 State of the art of micro CHP technologies

The previous chapter showed an overview of the available technology portfolio available for micro CHP systems. This chapter provides a detailed description of the different technologies up to an electrical power output of 1000 kW_{el}. A special focus is given to the available product portfolio in this power range. Due to the many technology providers, distributors and the many available products the descriptions receive a special focus on a power range < 50 kW_{el}.

3.1 Conversion Technologies

3.1.1 Reciprocating Engines

Reciprocating engines are well known from cars. They can be defined as “machines that obtain mechanical power by using the energy produced by the expenditure of a gas burned within a chamber integrated to the engine”: For this reason reciprocating engines are also called internal combustion engines or endothermic engines. If used for CHP generation, the engine drives an electric generator while the heat from the engine exhaust, cooling water and oil is additionally used for respective heat demand. Engines have high efficiencies even in small sizes. They are widely used in small plants because they allow compact modular systems; depending on the application several small modules are assembled in on system. This allows to follow the load curves better within the optimum level of the modules. It also eases maintenance. Reciprocating engines can be spilt into two main categories:

- Diesel engines, and
- spark ignition engines.

3.1.1.1 Diesel engines (incl. the usage of biodiesel and rape oil)

They are also called compression-ignition engines. Most Diesel engines running in CHP units are four stroke engines with a cycle consisting of intake, compression, combustion and exhaust. During the first stroke air is drawn into the combustion chamber through an intake valve, and then during the second stroke, a little part of the air is compressed bringing its temperature to about 440 °C. At the end of the compression phase vaporised fuel is injected within the chamber. The high temperature provokes the instant combustion of the fuel-air mixture. The final stroke consists in the exhaust of the combustion gases. This kind of engine presents a higher power to heat ratio compared to spark ignition engines, and operates through a large scale of very small sizes from 5 kW_{el} for small units to a power equivalent of some 10 MW_{el} for large systems.

In the last few years a trend for using biodiesel and rape oil in diesel engines could be monitored. Due to the excellent biodegradability and to its low ecotoxicity of rape oil/biodiesel the deployment of CHP plants in ecological sensible regions receives major attention. Furthermore such systems achieve high efficiencies, do not produce any direct CO_2 emissions and contribute to a sustainable energy supply in “green lodges”. For these reasons several alpine refuges were equipped with rape oil/biodiesel CHP systems mainly in Austria and Germany.

However, some particular details have to be taken into account when using biodiesel or rape oil in diesel engines:

- Usage of biodiesel in CHP plants:

By using biodiesel in diesel engines it has to be taken into account that the diesel engine (especially the rubber parts and the seals/gaskets) is capable to use biodiesel. A mixture of biodiesel and fossil diesel can be used without any problems; even a 100 % usage of bio-diesel. When using biodiesel in CHP systems the emissions of particles, NMHC, CO are lower than with fossil diesel. The usage of Oxi-catalysts further improves the emissions. Due to the fact that biodiesel shows hygroscopic characteristics unintended water uptake should be avoided. Otherwise the storage of biodiesel should be as careful as with fossil fuel.

- Usage of rape oil in CHP plants:

Due to the specific characteristics of rape oil in comparison with diesel and/or light fuel oil the CHP system requires adjusted plant components in the fuel storage system, in the fuel system, in the fuel preheating unit, in the injection system and in the engine itself. Principally a number of vegetable oils could be used in diesel engines. However, most experience exists by using rape oil. Furthermore minimum requirements of the characteristics of rape oil have already been defined by the “Weihenstephaner quality standard” and consecutively by a German prenorm DIN V 51605.

3.1.1.2 Spark ignition engines

This type of engine works similar to the Diesel engine, but the system follows the so-called Otto cycle, and ignition is provoked through an electrical spark at the end of the second stroke. Spark ignition engines range between 3 kW_{el} and 6 MW_{el} capacities. The heat to power ratio is lower than the one of compression engine, yet the overall efficiency of this technology is higher.

The next table summarises the characteristics both of diesel and spark ignition engines.

Table 1 Characteristics of reciprocating engines

	Thermo dynamical cycle	**Fuel used**	**Efficiencies**		**Power size range**
			total	**electrical**	
Diesel engine	Diesel cycle	Gas, biogas, ELFO*), LFO **), HFO***), rape oil, RME ****)	65 - 90	35 - 45	5 kW_{el} to 20 MW_{el}
Spark ignition engine	Otto cycle	Gas, biogas, naphtha	70 - 92	25 – 43	3 kW_{el} to > 6 MW_{el}
Average cost investment in €/kW_{el} (Fuel oil engine)			340 – 2000		
Average cost investment in €/kW_{el} (spark ignition gas engine)			450 – 2500		
Operation and maintenance costs in €/kWh_{el}			0,0075 – 0,015		

*) Extra Light Fuel Oil, **) Light Fuel Oil, ***) Heavy Fuel Oil, ****) rapeseed methyl ester

The investment costs for micro CHP systems vary significantly depending on the kind of technology. Furthermore there exists a high dependency of the specific investment costs from the electrical power output. Figure 2 gives an overview for standard prices for CHP systems based on reciprocating engines for natural gas CHP, fuel oil CHP, biogas CHP and rape-oil CHP plants. The prices include hardware, transport, assembly, starting, commissioning and acceptance tests. The lines in Figure 2 represent average price levels based on 250 quotations from over 40 suppliers.

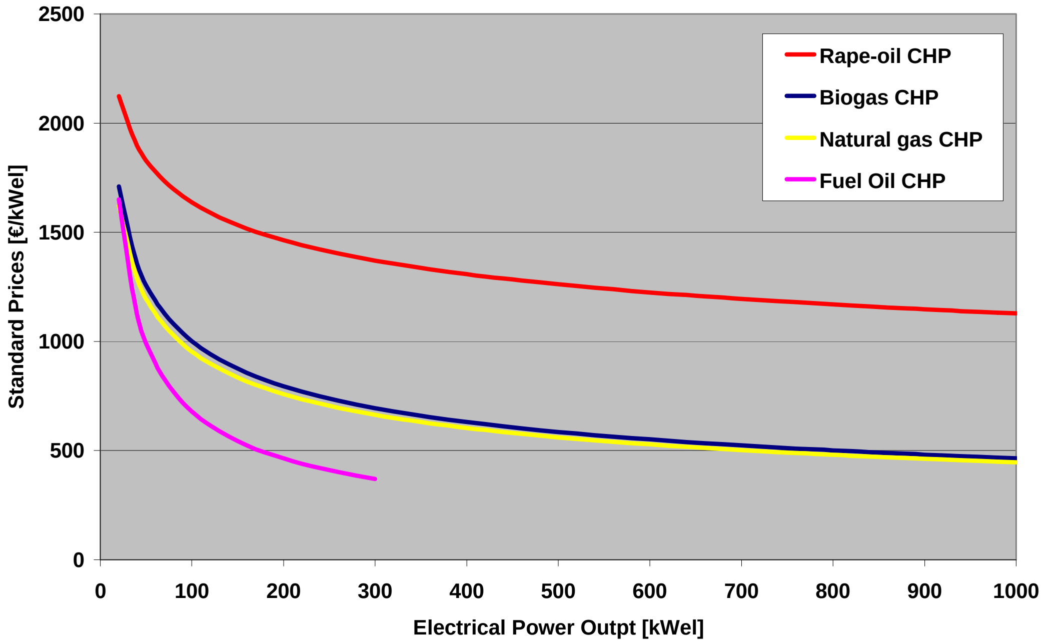

Figure 2 Dependency of specific investment prices for reciprocating engines as function of the electrical power output for rape-oil CHP, biogas CHP, natural gas CHP and fuel oil CHP(< 300 kW_{el}) plants (Source: based on [Lit 18])

Concerning the maintenance of reciprocating CHP systems many forms of service contracts may be agreed with the suppliers and/or distribution companies. The simplest form includes only the delivery of spare parts and the repair work is done by the plant operator’s staff. In case of no available staff by the operator full service contracts are closed to provide the continuous maintenance of the CHP plant.[2] Figure 3 gives an overview of average standard prices for full maintenance contracts showing again a high dependency of the prices from the electrical power output. The lines represent average price levels based on over 180 quotations.

[2] Principles for drafting of service contracts are provided in VDI 4680: “Combined heat and power systems (CHPS) - principles for the drafting of service contracts”.

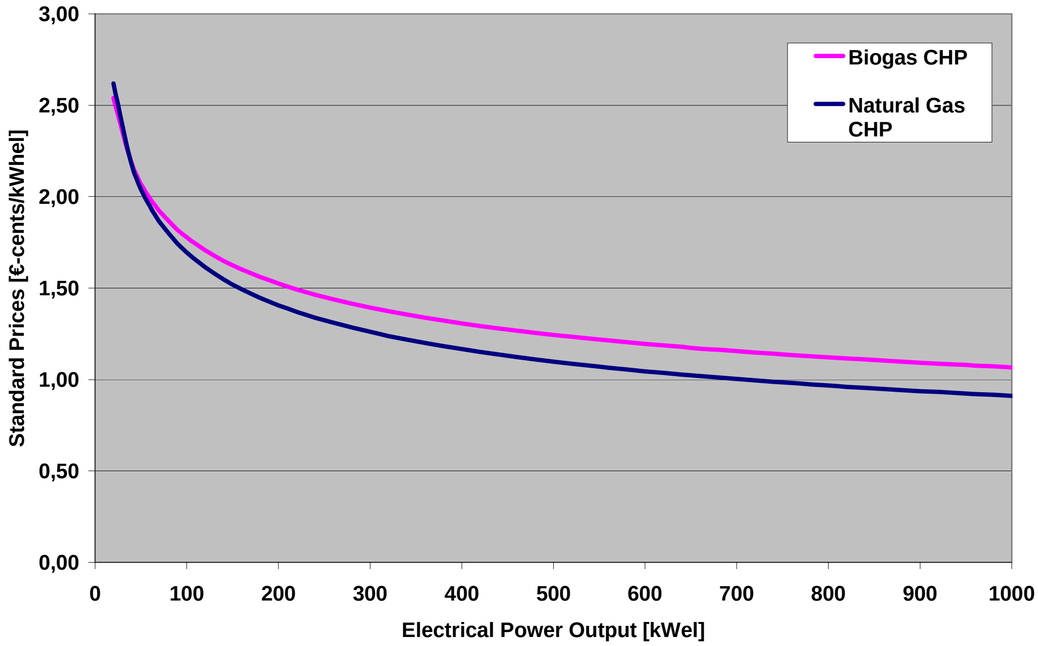

Figure 3 Dependency of specific maintenance prices for reciprocating engines as function of the electrical power output for biogas CHP and natural gas CHP (Source: based on [Lit 18])

Principally the standard prices of natural gas CHP can be also used as orientation for oil/diesel CHP systems including a supplement due to higher maintenance intervals. Roughly the prices are between 1 and 5 cents/kWh for full service contracts. This price level also applies for rape-oil CHP plants. Due to the higher price levels for oil/diesel CHPs a trend to LPG systems could be observed in Austria in the last years. Companies offering LPG additionally offered special financing and operation modes to support and foster this trend.

3.1.2 Micro Gas Turbines

The basic technology of micro turbines is derived from aircraft auxiliary power systems, diesel engine turbochargers, and automotive designs. Micro turbines stick out for their reliability, small size and low weight. Presently, R&D efforts are dedicated to the construction of a micro turbine with a power output only of a few kilowatts. Today's devices have achieved almost the same efficiency than internal combustion engines at lower emission levels of NO_x and CO. Micro turbines' high outlet temperature (> 500 °C) is suitable for numerous high-value applications, such as direct drying or heating processes; furthermore for cooling applications including absorption systems.

Micro turbines function similar to their large-scale counterparts, but their electrical efficiency is only about 15%. However, this figure can be improved with the installation of a recuperator (heat/heat exchanger) that preheats air used during the combustion process by reusing exhausting gas heat. This device also allows varying the power to heat ratio (see Figure 4). The core component of micro turbine systems could achieve in the last years very compact technical designs (see Figure 5).

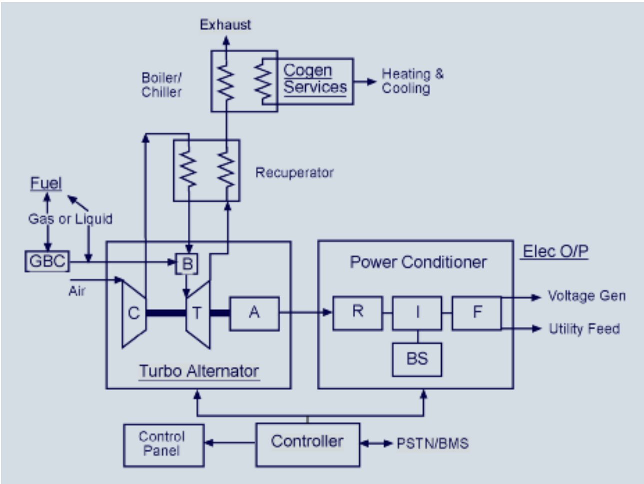

Figure 4 left side: system diagram of micro CHP gas turbine (Source: Bowman Power Systems Ltd.); right side: µT28-60/80L plant in the heating station in Delmenhorst (Germany) (Source: Austrian Energy Agency)

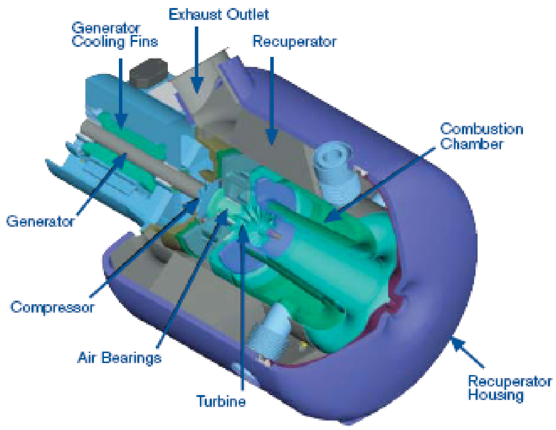

Figure 5 Capstone's C30 micro turbine generator (Source: Capstone Turbine Corporation)

Micro turbines are still more expensive than internal combustion engines (see the comparison of investment costs in Figure 6). Because of the few moving parts of the device lower operation and maintenance costs are possible compared to combustion engines. The life expectancy of micro turbines is over 40.000 hours. The principle characteristics of micro gas turbines are shown in the next table.

Table 2 Characteristics of micro gas turbines (Source: Lit 21]

	Power to heat ratio	Fuel used	Efficiencies		Power size range
			Total	electrical	
Micro turbine	0,2 – 0,8	Natural gas, gas oil, diesel, propane, Kerosene, biogas, flare gas, etc.	65 – 90	15 - 30	15 kW_{el} to 300 kW_{el}
Average cost investment in €/kW_{el} (Diesel engine)			900 – 2.500		
Operation and maintenance costs in €/kWh_{el}			0,006 – 0,21		

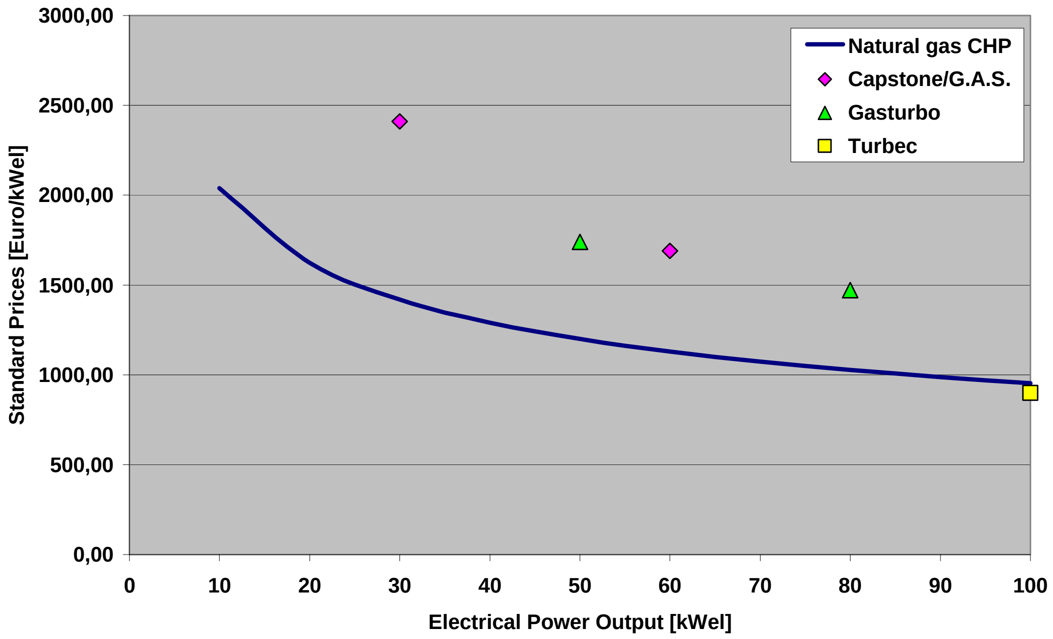

Figure 6 Dependency of specific investment prices for selected micro gas turbines in comparison with reciprocating engines as function of the electrical power output in a power range till 100 kW_{el} (Source: price function of reciprocating engines is based on [Lit 18], prices for micro turbines are based on [Lit 20], [Lit 21], [Lit 22])

3.1.3 Stirling Engines

Stirling engines promise advantages with a particular view to small-scale CHP in units as small as < 1 kW_{el}: High efficiency, good performance at partial load, fuel flexibility, and low noise and air emission levels. Compared to internal combustion engines, the stirling engine is an external combustion device where the cycle medium is not exchanged during each cycle, but remains within the cycle whilst the energy driving the cycle is applied externally. The burner supplying heat to the process can operate on different fuels (gasoline, alcohol, natural gas or butane). The external combustion facilitates the control of the combustion process and supports a cleaner and more efficient process.

The so-called stirling cycle consists of the expansion and compression of a working gas, generally helium or hydrogen, inside a chamber featuring a system of pistons and crank/-shaft mechanisms to move the gas around. The pistons can be arranged in different ways, e.g. two pistons in one cylinder, two pistons and two cylinders per cycle, or four cylinders with four double acting pistons leading to four separated cycles.

The stirling engine technology is on the verge of commercialisation. For this reason almost no statistical data on reliability, availability or prices are available. Stirling engine developments in the car industry during the 70s could not beat the conventional diesel and Otto engines. Yet, the promising prospects in terms of emission, noise, vibration and efficiency stimulate the further R&D into this device for CHP applications.

Table 3 Characteristics of Stirling Engines (Source: [Lit 20])

	Thermo dynamical cycle	**Fuel used**	**Efficiencies**		**Power size range**
			Total	electrical	
Stirling engine	Stirling cycle	Natural gas, gas oil, alcohol, butane	65 – 95	~ 25	3 kW_{el} to 1,5 MW_{el}
Average cost investment in €/kW_{el}			Ca. 2.500 – 4.500 (for < 10 kW Systems)		
Operation and maintenance costs in €/kWh_{el}			N.A.		

3.1.4 Organic Rankine Cycle – ORC

The Organic Rankine Cycle (ORC) is similar to the cycle of a conventional steam turbine, except for the fluid that drives the turbine, which is a high molecular mass organic fluid. The selected working fluids allow exploiting efficiently low temperature heat sources to produce electricity in a wide range of power outputs (from few kW up to 3 MW electric power per unit).

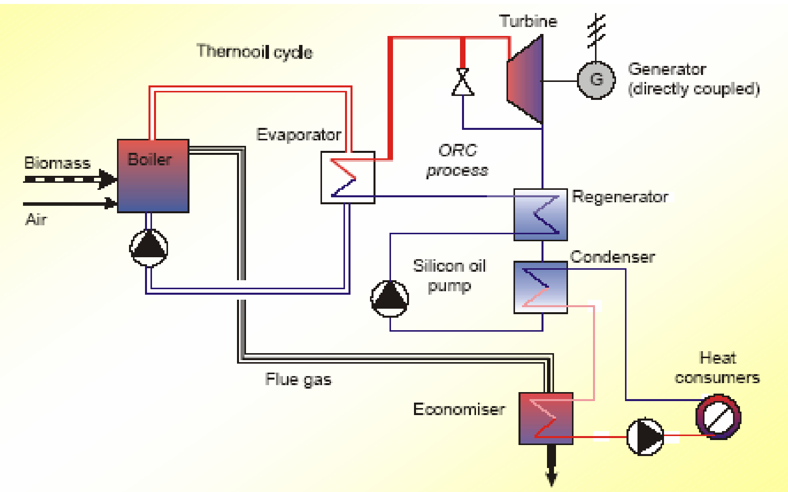

Figure 7 Working principle of a biomass-fired ORC process (Source: [Lit 13]

The organic working fluid is vaporised by application of a heat source in the evaporator. The organic fluid vapour expands in the turbine and is then condensed using a flow of water in a shell-and-tube heat exchanger (alternatively, ambient air can be used for cooling). The condensate is pumped back to the evaporator thus closing the thermodynamic cycle. Heating and cooling sources are not directly in contact with the working fluid nor with the turbine. For high temperature applications (e.g. combined heat and power biomass-powered plants, high temperature thermal oil is used as a heat carrier and a regenerator is added, to further improve the cycle performance.

Key technical benefits of ORC plants include:

- high cycle efficiency
- very high turbine efficiency (up to 85 percent)
- low mechanical stress of the turbine, due to the low peripheral speed
- low RPM[3] of the turbine allowing the direct drive of the electric generator without reduction gear
- no erosion of blades, due to the absence of moisture in the vapour nozzles
- long life
- no operator required

The system also has practical advantages, such as simple start-stop procedures, quiet operation, minimum maintenance requirements, good part load performance.

Typical applications are:

- low enthalpy geothermal plants, up to 3 MW electric per unit
- combined Heat and Power (CHP) biomass powered plants, in the range 400 to 1500 kW electric
- heat recovery applications, in the range 400 to 1500 kW electric
- solar applications

The company Turboden – presently the European market leader in ORC product developments – located in Brescia (Italy) has developed a standard range of turbo generators using as working fluid silicone oil.

Table 4 Sizes of standard ORC turbo generators for biomass powered CHP proposed as standard by Turboden (Source: [Lit 14])

	T450-CHP	T500-CHP	T600-CHP	T1100-CHP	T1500-CHP
Heat source	Thermal oil in a closed loop	Thermal oil in a closed loop	Thermal oil in a closed loop	Thermal oil in a closed loop	Thermal oil in a closed loop
Thermal power input from thermal oil	2550 kW	2900 kW	3500 kW	6380 kW	8700 kW
Hot water temperature (in/out)	60 / 80 °C	60 / 80 °C	60 / 80 °C	60 / 80 °C	60 / 80 °C
Thermal power to the cooling water circuit	2025 kW	2320 kW	2800 kW	5115 kW	6975 kW
Net electric power output	450 kW	500 kW	600 kW	1100 kW	1500 kW

[3] RPM is the abbreviation for revolutions per minute.

So far biomass fuelled ORC systems have been mainly applied in the wood processing industry and in the local district heating systems. For green lodges the standard power outputs seem too large in order to realise feasible technical and economic solutions.

Figure 8 The Admont (Austria) T450-CHP unit during installation on site in 1999 (Source: Turboden)

Turboden presently refers to 34 reference projects; 16 of these systems are already in operation (mainly in Austria and Germany). The other ones are under construction.

3.1.5 Fuel Cell Technology

Fuel cell systems are presently still in the R&D phase. There are currently 5 to 6 competing technologies, all of which have specific pros and cons; two developments dominate the demonstration activities:

(i) 5 kW_{el}/7 kW_{th} PEFC system from Vaillant, and
(ii) 1 kW_{el}/3 kW_{th} SOFC system from Sulzer Hexis.[4]

Both systems are equipped with auxiliary burners and boilers in order to be used for heat driven operation modes. In the years 2002 till 2006 five micro CHP systems were tested in Austria confirming the early R&D stage of fuel cell systems.

[4] By the end of 2005 Sulzer Hexis company announced that they are discontinuing its SOFC R&D activities. Latest news point to a continuation of the Hexis product development on a smaller level.

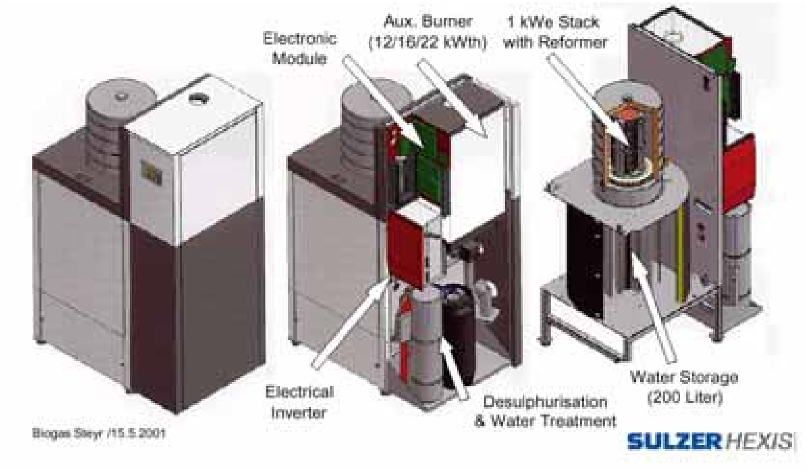

Figure 9 Sulzer Hexis 1 kW_{el}/3kW_{th} Fuel Cell Systems equipped with aux. Burner (Source: Sulzer Hexis)

Presently major R&D programmes are carried out world-wide in order to push forward these technologies (f. ex. as part of the 6th and 7th EU R&D programme, R&D programmes from USA, Japan, etc.).

3.2 Product characteristics of micro CHP technologies

3.2.1 Reciprocating Engines

Reciprocating engines are commercially available and produced in large numbers by a variety of companies worldwide. The market leader is the Germany based company Senertec. The Senertec model – called Dachs – generates around 5,5 kW_{el} and a thermal power of 14 kW depending on the product model (see Figure 10 and Table 5). By the end of 2004, Senertec announced that over 10.000 of these units were sold.

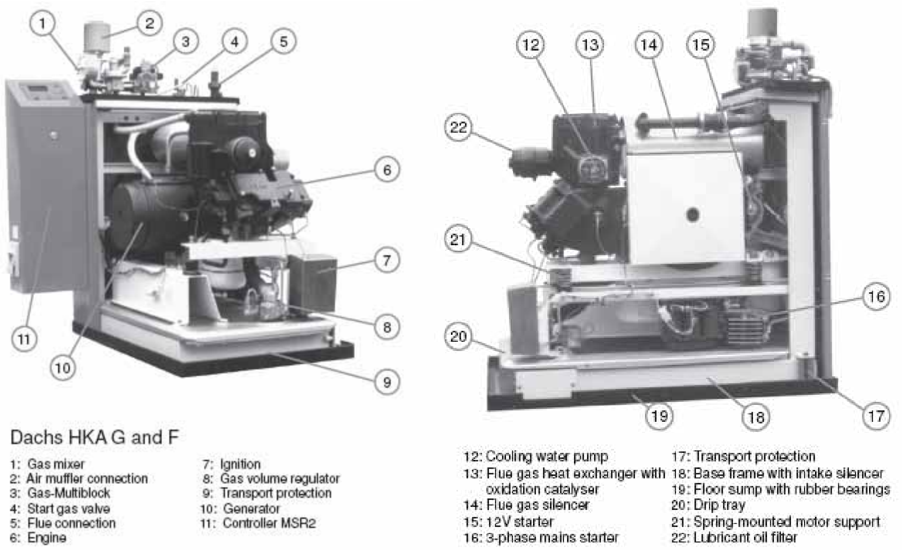

Figure 10 Front and side view of Sachs 5 kW_{el}/12,5 kW_{th} HKA G and F (courtesy of Senertec)

Table 5 Technical data sets of Dachs HKA (Source: www.senertec.de, January 2006)

Type DACHS	**HKA G 5.5**	**HKA G 5.0**	**HKA F 5.5**	**HKA HR 5.3**	
		Low NO_x	Low NO_x		
Fuel	Natural gas	Natural gas	LPG *)	ELFO **)	Biodiesel
Electrical output [kW]	5,5	5,0	5,5	5,3	5,3
Electrical output [kW]	12,5	12,3	12,5	10,5	10,3
Fuel input [kW]	20,5	19,6	20,5	17,9	17,6
Max. water flow temp.	83 ˚C				
Max. water return temp.	70 ˚C				
Voltage / frequency	3 ~ 230 V / 400 V			50 Hz	
Efficiency					
- electrical	27%	26%	27%	30%	30%
- thermal	61%	63%	61%	59%	59%
-Fuel efficiency	88%	89%	88%	89%	89%
CHP coefficient	0,44	0,41	0,44	0,50	0,51
Noise level at 1 m dB(A)	52 - 56			54 - 58	
Emissions < TA-Luft	X			X	X
Emissions < 1/2TA-Luft		X	X		
Service intervals [running hours]	3.500	3.500	3.500	2.700	Recom-mended: 1400
Minimum methane number	35	35	35		

*) Liquefied petroleum gas; **) Extra Light Fuel Oil

Other companies offering micro CHP products based on reciprocating engines include Power Plus (recently purchased by the boiler company Vaillant) with its 4,7 kW_{el} Ecopower module, capable of modulating its capacity (see Figure 11 and Table 6).

Figure 11 Ecopower's 1,3 - 4,7 kW_{el} (modulating) / 4 - 12,5 kW_{th} (modulating) micro CHP system (Source: www.minibhkw.de, January 2006)

Table 6 Valentin's small scale CHP unit distributed by Ecopower (Source: Power Plus)

Fuels	Natural gas, LPG
Electrical output	1,3 - 4,7 kW, modulating [1)]
Thermal output	4,0 – 12,5 kW, modulating [2)]
Total efficiency, fuel usage	> 90%
Speed range	1200 – 3600 rpm
Fuel consumption (natural gas)	0,8 m³ - 1,9 m³ per hour
Engine temperature	In operation: 75°C; maximum: 95°C
Cooling water temperatures	In operation: 75°C; maximum: 95°C
Exhaust gas temperature	< 90°C; Maximum: 120°C
Emission levels	NO_x < 70 mg pro Nm³ @ 5% O_2 CO < 300 mg pro Nm³ @ 5% O_2
Noise level	56 dB(A) at 2 meters
Dimensions (H x W x L)	108 x 74 x 137 cm
Weight	395 kg
1) Depending on gas quality and ambient air pressure 2) Ratio between thermal and electrical output is approximately constant over the total power output.	

Other companies offering engine based micro CHP systems are: Spilling Energie Systeme GmbH (see Figure 12 and Table 7), Buderus (see Table 8), Oberdorfer (< 150 kW_{el}) (see Table 9) and GE Jenbacher (> 100 kW_{el}) (see Table 10). A product list of all producers and distributors would be beyond of this report. Nevertheless a list of the most known companies is provided in Annex 7.1.

As already outlined in section 3.1.1.1 in the last few years a trend for using biodiesel and rape oil in diesel engines could be monitored. Compared to fossil diesel advantages are given by its excellent biodegradability and its low ecotoxicity. CHP systems based on bio-diesel/rape oil achieve also high efficiencies, do not produce any direct CO_2 emissions and contribute to a sustainable energy supply in "green lodges". A list of suppliers has been compiled and this list is attached to Annex 7.2.

Figure 12 Spilling's 20 kW_{el}/40 kW_{th} Power Therm micro CHP product

Table 7 Spilling Energie System's PowerTherm product

Fuels	Natural Gas, LPG, biogas, sewage gas
Electrical output	7 - 20 kW, modulating
Thermal output (at 70 °C return temperature)	12 - 40 kW, modulating
Fuel input	24 - 66 kW
Total efficiency	88 – 91 % (depending on the return temperature)
Speed range	900 - 2.300 rpm
Engine	Kubota industrial engine, 4 cylinders, 2200 cm^3 Lean-burn engine, Oxy cat
Return temperature	30 - 85 °C
Flow temperature	40 - 95 °C
System pressure	max. 4,5 bar
Rated Voltage, frequency	400 V, 50 Hz
Operation mode	Operation in parallel to the grid, emergency operation in case of main grid failure, independent operation
Noise level	60 - 62 dB(A) at 1 meter
Weight incl. control box	720 kg
Dimensions (H x W x L)	150 x 74 x 135 cm
Dimensions control box (H x W x L)	55 x 43 x 135 cm

Table 8 Logano CHP product series from Buderus company (Source: Buderus Heiztechnik)

CHP Module	**DN-20**	**MN-20**	**DN-50**	**DN-70**	**DN-100**	**TE-150**	**LE-190**	**DN-200**
Electr. output [kW]	18	18	50	70	120	143	190	238
Therm. output [kW]	34	32	81	115	200	220	290	363
Fuel input [kW]	56	54	145	204	350	407	560	667
Electr. efficiency [%]	32,1	33,3	34,5	34,3	34,3	35,1	35,5	35,7
Therm. efficiency [%]	60,7	59,3	55,9	56,4	57,1	54,1	51,8	54,4
Total efficiency [%]	92,9	92,6	90,3	90,7	91,4	89,2	87,3	90,1
Engine producer	VW	VW	MAN	MAN	MAN	MAN	MAN	MAN
Engine type	AEG	AEG	E 0824 E	E 0836 E	E 2876 E	E 2876 E	E 2876 LE	E 2842 E
Engine speed [1/min]	1500	1500	1500	1.500	1500	1500	1500	1500
Characteristics	$\lambda = 1$, three way catalyst	$\lambda > 1$ lean operation (no turbo charging)	$\lambda = 1$, three way catalyst	$\lambda = 1$, three way catalyst	$\lambda = 1$, three way catalyst	$\lambda > 1$ lean operation (incl. biogas and sewage)	Lean operation $\lambda \sim 1,6$ (with turbo charging) (incl. biogas and sewage)	$\lambda = 1$, three way catalyst

Table 9 Power plants from Oberdorfer company (Source: Oberdorfer)

	OD 70 NG V02	**OD 90 NG V02**	**OD 70 PG V02**	**OD 70 BIO V01**	**OD 50 BIO V03**	**OD 150 BIO V01**	**OD 150 BIO V03**
Fuel	Natural gas	Natural gas	LPG	Biogas	Biogas	Biogas	Biogas
Electrical output [kW]	70	90	70	70	49	98	143
thermal output [kW]	119	136	123	114	90	150	221
Fuel input [kW]	220	270	225	220	17,6	293	416
max. feed temperature	90°C	90°C	90°C	90°C	86°C	90°C	90°C
max. return temperature	70°C	70°C	70°C	70°C	70°C	70°C	70°C
Electrical efficiency	32%	33,2%	31,3%	32%	29,5%	33,4%	33,4%
Thermal efficiency	54%	50,4%	54,2%	51,8%	54,5%	54,2%	53,9%
Fuel usage	86%	83,6%	85,5%	83,8%	84%	84,7%	87,3%
NO_x emissions [mg/Nm^3] 1)	500	250	250	500	500	500	500
CO emissions [mg/Nm^3] 1)	650	200	200	650	650	650	1000
Dimensions: Width [cm] Length [cm] Height [cm]	85 330 191	85 330 191	85 330 191	85 330 191	91 330 185	110 360 230	110 360 230
Weight [kg]	2470	2470	2470	2470	2800	4000	4000
All given information is based on full load. 1) Based on 5% O_2							

Table 10 GE Jenbacher's natural gas CHP systems (Natural gas / NOx < 500 mg/Nm^3)[5] (Source: GE Jenbacher)

	Electrical output 1)		**Thermal output 2)**		**ICWT 3)**
	50 Hz	60 Hz	50 Hz	60 Hz	
	kW_{el}	kW_{el}	kW_{th}	kW_{th}	°C
JMS 208 GS-N.L	330	335	361	409	40
JMS 212 GS-N.L	526	539	633	706	40
JMS 312 GS-N.L	625	633	746	815	40
JMS 316 GS-N.L	836	848	997	1,087	40
JMS 320 GS-N.L	1,065	1,060	1,197	1,322	40
JMS 420 GS-N.L	1,413		1,505		40
JMS 612 GS-N.L	1,644	1,622	1,665	1,685	40
JMS 616 GS-N.L	2,188	2,159	2,249	2,273	40
JMS 620 GS-N.L	3,047	2,991	3,047	3,081	40

1) ISO standard output, at 1.500 rpm/1.800 rpm and standard reference conditions according to ISO 3046/I-1991; at p.f. = 1.0 according to VDE 0530 REM

2) Total with a tolerance +/- 8 %

3) ICWT = inter cooler water temperature

[5] Source: Also available in models achieving NO_x < 250 mg/Nm^3.

An interesting Japanese product development is Honda's 1 kW_{el} system – named Ecowill – mainly used in single-family home applications. If available in Europe, this development would be also getting deployed in small green lodges. Honda's cogeneration unit combines the GE160V – the world's smallest natural gas engine – with a lightweight generation system. The system is based on a λ = 1 Otto engine, with a three-way catalyst and oxygen feedback control to reduce the quantity of NO_x emissions. Osaka Gas distributes this system and has already sold more than 30.000 units. [Lit 16] In Figure 13 and Table 11 the technical characteristics of this system are shown.

Figure 13 Honda's 1 kW_{el} Ecowill micro CHP system (Courtesy of Honda)

Table 11 Characteristics of Honda's Ecowill micro CHP system (Source: [Lit 16])

	Gas engine (power generation unit)		**Hot water supply and central heating system utilising waste heat**
Power output	1,0 kW	Hot water storage temperature	70 ºC or above
Thermal output	3,25 kW	Hot water storage volume	150 l
Fuel input	5,54 kW	Heating capacity	11 kW or more
Electric system	1 phase, 3 wires, 200 V/100 V (50 Hz/60 Hz)	Supplementary boiler capacity	34,9 kW
Electrical efficiency	20 % (LHV)	Maximum input	43,6 kW
Thermal efficiency	65 % (LHV)	Dimensions (H x W x L)	185 x 70 x 40 cm
Dimensions (H x W x L)	88 x 58 x 38 cm	Weight	120 kg or less
Weight	81 kg	Heat utilisation	Hot water supply, floor heating, bathroom heating and drying, etc.
Noise	44 dB(A)	Remote control	Furnished with Eco Navigation function
Frequency of periodic inspections	Once after 6000 hours of operation (or 3 years)		

Other companies from the Asian region offering micro CHP products are Yanmar, Aisin and Sanyo. From the United States Victor Cogen is also developing a micro CHP system. It is expected that these companies will start to distribute their systems in the next few years in Europe after having completed their R&D efforts using their home markets.

3.2.2 Stirling Engines

Stirling engines are in between the pilot and demonstration phases and marketing (see also Figure 1). There are still field trials being carried out; but initial commercial products are already defined and on the verge of series production. Significant marketing activities could be achieved by two companies: (i) WhisperTech (New Zealand) and (ii) Solo (Germany).

The New Zealand-based company WhisperTech is developing a stirling engine called Whisper Gen, with a capacity of up to 1,2 kW_{el} and 8 kW_{th} of heat (see Figure 14). In the WhisperGen power stations, four sets of piston cylinders are put in an axial arrangement. As stirling engines require very precisely produced components, the scale-up from small scale to series production presents a considerable challenge. The British utility Powergen, part of Germany's E.ON, has ordered 80.000 WhisperGen power stations in 2005. At this stage information about the results of the field tests could not be received by Powergen company.

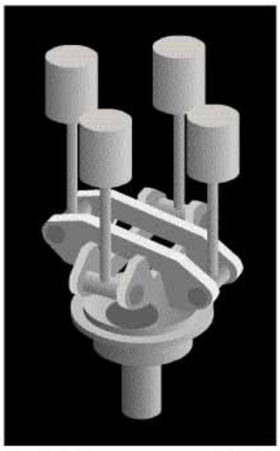

Figure 14 Whispertech's four cylinder α-stirling micro CHP plant (1.2 kW_{el}/4,8 kW_{th}; modulating system) (Courtesy of WhisperTech)

With respect to systems above of 1 kW electrical capacity, the German companies SOLO, Mayer&Cie. and Sunmachine have been developing Stirling machines. The Solo engine has sold around 60 units (including test units) by the end of 2005 in Europe.

Table 12 Technical characteristics of the Solo Stirling 161 microKWK-Modul (Source: Solo)

Fuels	Natural gas, LPG
Electrical output	2 - 9,5 kW
Thermal output	8 - 26 kW
Fuel input	16 – 40 kW
Engine speed	1500 rpm
Electrical efficiency (@ 50 – 100% load)	24 %

Total efficiency (in condensing mode)	92 - 96 %
Working gas	Helium
Service intervals	5.000 - 8.000 h
Emissions CO	40 – 60 mg/m^3
Emissions NO_x	80 - 120 mg/m^3
Emissions NMHC max.	2 mg/m^3
Dimensions (L x B x H)	128 x 70 x 98 cm
Weight	450 kg
Output and efficiencies are based on flow temperature of 50 °C in the heating system	

Figure 15 Solo Stirling 161 microKWK-Modul (Source: Solo)

Other companies developing micro CHP systems based on stirling engines are: MicroGen (UK), SunMachine (Germany), EnAtEC micro-cogen B.V. (Netherlands), Stirling Systems (CH), etc. However, the product developments of these companies are still in the R&D phase. Solo and Sunmachine are also experimenting with wood pellet burners and solar concentrators.

4 Applications of micro CHP plants (including planning, selection, integration into the heat and electricity system)

4.1 General

The main potential of micro CHP systems is mainly seen in buildings with central heating systems. This generally means that conventional heating systems are replaced by electricity generators with heat exchanger(s), peak load and storage boilers. The produced heat is used for space and water heating and possibly cooling, the electricity is used within the building or fed into the grid.

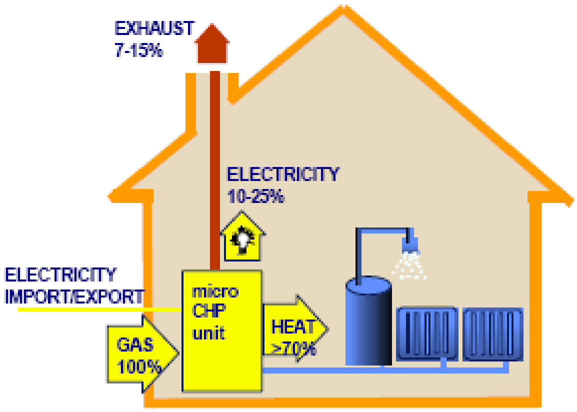

Figure 16 Conceptual visualisation of the application of micro CHP plants (Source: [Lit 2])

In the last few years a trend for the usage of micro CHP units in isolated regions could be monitored. Especially buildings with no grid connection and/or less reliable electrical energy supply were using micro CHP systems in connection with battery systems and hot water tanks. Moreover instead of using diesel as fuel, nowadays environmentally friendly rape oil and/or biodiesel is used in these micro CHP systems. Especially in ecological sensible regions like mountains due to reasons of air-, soil- and water/groundwater conservation, etc. these systems have decisive environmental advantages (especially in case of usage of natural untreated rape oil).

In the past several studies have been carried-out in order to determine the potential of micro CHP units in Europe. For example, studies, such as MicroMap ([Lit 2]) see a large potential for micro CHP plants. They developed scenarios according to which in 2020 some 5 to – in the optimistic scenario – 12 million Micro CHP systems could be delivered in Europe, with United Kingdom, Germany and Netherlands as initial markets. MicroMap concluded that stirling engines have the highest potential in domestic energy supply. The FutureCogen project estimated that under optimistic assumptions, up to 50 GW_{el} in EU15 could be installed ([Lit 5]). The mass market for micro CHP will be mainly seen in the replacement of gas and oil heating boilers.

In spite of the sustainability potential identified above, the European development of micro CHP systems in competitive markets is rather disenchanting. The large gap between expectations and reality make it important to identify the barriers which are responsible for this discrepancy. Main reasons are seen in the rather slow technology development, in the assessment of the economic opportunities, in the political framework, f. ex. the institutional and regulatory framework, in lacking innovation policies, and consumer acceptance (see also chapter 5).

As micro CHP systems are not very developed in all European regions/countries participating in “Green Lodges” project, the next chapters should provide the project partners with information and tools to make feasibility studies in their own regions/countries.

The necessary steps for planning of CHP plants are as follows:

- Determination of the energy demand
- Analysis of the energy costs
- Drawing-up of a concept for the selection of the micro CHP system
- Concept variations and selection of CHP systems
- The final concept and follow-up activities

In this context tables giving additional guidelines to the project partners are also included in the next sections.

4.2 Procedure for the determination of the energy demand

The determination of the energy demand is a preconditioning step for planning of CHP and of micro CHP systems. In case of existing energy systems, the electricity and heat consumption can be measured and, after verification, the demand is calculated.

4.2.1 Energy Supply

In order to analyse the energy supply the following procedure is suggested to determine the energy supply in existing plants: First calculate the energy supply, for example from the monthly or annual gas and electricity bills and then specify the relevant parameters for the different types of energy.

Table 13 Analysis of the existing energy demand

		Quantity $kWh/(H_{LHV})/a$*) l/a t/a kWh_{th}/a kWh_{el}/a	Output $kW/(H_{LHV})/a$ l/a t/a kW_{th}/a kW_{el}/a	Temperature °C	Pressure bar	Heat value $kWh/(H_{LHV})/m^3$ $kWh/(H_{LHV})/l$ $kWh/(H_{LHV})/kg$	Methane number
Fuel							
Gaseous	Type of gas						
Liquid	ELFO **)						
	LFO ***)						

	HFO ****)						
Solid	Coal/coke Wood fuels						
Heat	Warm water						
	Hot water						
	Steam						
Electricity	HT *****)						
	LT *****)						

*) Lower Heating Value; **) Extra Light Fuel Oil; ***) Light Fuel Oil; ****) Heavy Fuel Oil;

*****) HT = high tariff, LT = low tariff)

4.2.2 Determination of the energy demand structure for electricity and heat; drawing up and evaluation of load curves

This step includes the determination of the consumption patterns for electricity and heat while taking into account physical parameter (required temperature levels, etc.) and the operational hours. The measurements have to cover representative time periods.

Typical daily/weekly load curves and annual load curves should be determined. In practise, daily load curves for the heat and electricity demand or heat and electricity generation are rarely available for the days over a representative period. This means that it is necessary to determine the demand and generation as realistically as possible on the basis of a few, typical daily load curves. It will be necessary to assure in each individual case whether that representative figures are available.

The following periods could be used for the determination of typical daily load curves both for heat and electricity:

- **Heat demand including hot water supply (five daily load curves)**

“winter” (October to February), differentiated according to overcast and hotter days

“transitional” (March, April, May, September), differentiated according to overcast and hotter days

“summer” (June, July, August)

- **Electricity demand (four daily load curves)**

“winter tariff period” (e.g. October to February), differentiated according to workdays, Sundays and bank holidays

“summer tariff period” (e.g. March to September), differentiated according to workdays, Sundays and bank holidays.

A more detailed understanding of the requirements for heat and electricity may be obtained by analyzing additional typical daily load curves. The identification of typical daily load curves has to be undertaken with caution. For example, the typical load curve for a “winter’s working day” should be one which is representative for all 125 working days!

The heat demand should be covered by the heat generated by the micro CHP plant system and, when applicable, by the additional installed boiler. While the electricity demand should be covered by the electricity generated by the micro CHP plant system, when applicable supplemented by additional electricity from the grid and/or other systems (other generators, batteries, etc.). An example of a yearly load curve is shown in Figure 17.

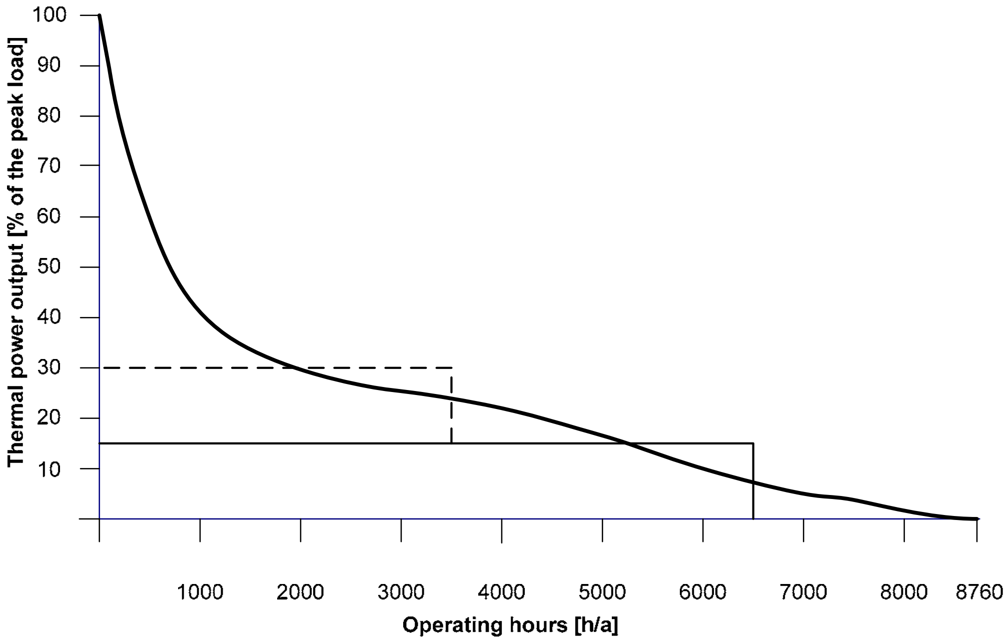

Figure 17 Example of an annual load duration curve of the heat demand (Source: Lit 27])

The rectangels present thermal power ranges that could be delivered by micro CHP systems (continuous lines with 6.500 hours; interrupted lines with 3.500 hours). The areas in which the heat generation of the CHP is above the heat demand curve corresponds to the charging time of the storage tanks (normally part of the CHP system). These operations can extend the operation times of the micro CHP plants.

4.3 Analysis of actual energy costs

The costs of energy supply are determined from the annual accounts or from multiplications of quantities and outputs with the relevant prices (see Table 14).

Table 14 Energy costs

		Power generation costs €/a	Output costs €/a	Total costs €/a
Fuel				
Gaseous	Type of gas:			
Liquid	ELFO *) LFO **) HFO ***)			
Solid	Coal/coke Wood fuels			
Heat				
Electricity				

*) Extra Light Fuel Oil; **) Light Fuel Oil, ***) Heavy Fuel Oil

It is preferable to know how the individual types of energy are used both in terms of quantities, outputs, temporal usage (= load curve) and temperature levels (particularly return temperature). If no data are available, measurements could be taken over representative periods to overcome these knowledge gaps.

In case of larger buildings (f. ex. hotels, hospitals, etc.) with more complex energy systems plans for the different types of energy with details of the supply and extraction points, the dimensions, the pressure and temperature zones should be available or drawn up. An energy flow diagram helps furthermore to avoid multiple accounting and misinterpretations.

Table 15 Energy systems/structure

	Plan	Dimension	Feed-in point	Extraction point
Electricity				
Heat				
Steam				
Cold				

Possible energy saving measures should be identified (as done in WP1 of green lodges project). Furthermore changes in the future energy demand (f. ex. due to renovations, expansions, etc.) should also be taken into account. The energy demand corrected by the energy saving and the anticipated demand should be taken into account in the future demand structure (corrected load curves).

Table 16 Anticipated future energy demand structure

	Quantity kWh_{el}/a kWh_{th}/a kWh_{C}/a	Output kW_{el} kW_{th} kW_{C}	Temperature °C	Pressure bar	Operating time/ load curve
Electricity					
Heat					
Steam					
Cooling energy					

4.4 Drawing up a concept for the selection of CHP plants

For the selection of applicable CHP systems a concept has to be drawn-up in order to meet the required energy demand of the building. At this stage it should be mentioned that CHP systems are generally equipped with a peak load boiler or a supplementary storage boiler to guarantee the heat supply (see Figure 18 showing the basic scheme of storage tank integration by series connection of CHP and boiler). Typical volumes of storage boilers in comparison of the thermal power output of CHP systems are listed in Table 17.

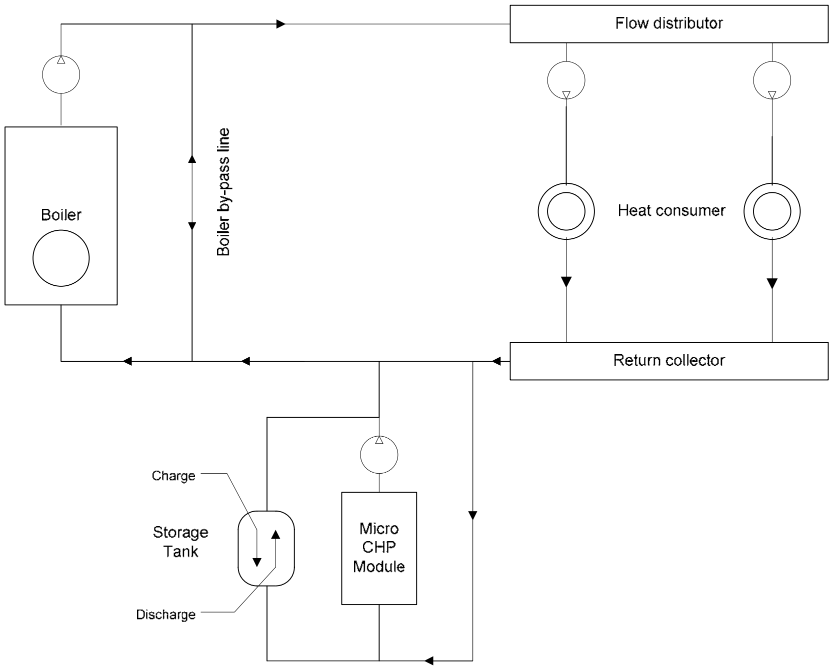

Figure 18 Basic scheme of storage tank integration by series connection of CHP and boiler (Source: Lit 27])

Table 17 Typical volumes of storage tanks in comparison of the thermal power output of CHP systems (Source: Lit 27])

	CHP Size 1	**CHP Size 2**	**CHP Size 3**	**CHP Size 4**	**CHP Size 5**
Thermal power output [kW]	12,5	32	100	194	378
Storage tank - volume [l][6]	540	1380	4300	8340	16250

The concept for selecting a CHP system includes the following steps:

4.4.1 Choice of type, size and number of CHP systems

The selection made for the CHP system (see Table 18) should ensure that the physical and technical requirements – as outlined in Table 16 – will be fulfilled. Attention should be given to available fuels and their conditions (f. ex. gas pressure, methane number, etc.).

Table 18 Selection of CHP system

CHP plant					
Model		**Type**			
Output					
electrical	kW_{el}				

[6] Temperature difference: Δ T = 30 K, 2/3 of the storage volume can be used for one full load hour.

thermal from	kW_{th}	Useful temperature:	Flow		Return
Exhaust gas	kW_{th}		°C		
Cooling water	kW_{th}		°C		
Engine oil	kW_{th}		°C		
Charge air	kW_{th}		°C		
total	kW_{th}				
Fuel requirement	kW(H_{LHV})				
Operative principle			Methane number demand		
Spark-ignition gas engine					
Diesel engine					
Diesel/gas engine					
Gas turbine					
other					
Supercharging					
Fuel			Methane number supply:		Gas pressure
Natural gas					
LPG					
Landfill gas					
Sewage gas					
Other types of gas					
ELFO/diesel fuel **)					
Other					
Exhaust gas cleaning procedure					
Lean-burn engine					
3-way catalyst					
SCR					
Oxi-cat					
other					

*) Lower Heating Value; **) Extra Light Fuel Oil; ***) Heavy Fuel Oil; ****) HT = high tariff, LT = low tariff)

4.4.2 Load curves for electricity and heat generation by the CHP system

The load curves for electricity and heat production by the CHP system should by drawn up and compared/adapted to meet the load curves of the future energy demand (see Table 16).

4.4.3 Determination of the operation mode

Depending upon the requirements CHP systems may be operated using different types of operating modes (electricity and/or head-driven). Time-variant operation modes may be implemented by means of an energy management system which selects the optimum operating mode for the specific requirements. This should already be considered in the early planning phase.

Heat-driven operation mode

The controlling variable for the operation of the CHP system is in this operation mode always the heat demand. The electricity generated has to be supplied (for own use or to be fed into the grid). The CHP system may be supported by additional boilers in order to cover the heat requirements.

Electricity-driven operation mode

For this operation mode the electricity demand is the controlling variable for the power output from the CHP system. Principally there are two operation modes possible:

(i) When working in parallel with other systems, the CHP system supplies the consumers until it reaches its maximum electrical output. Extra requirements are covered by the public grid.

(ii) When working independently, the CHP system (very often in combination with a battery system) has to cover the consumers' demand on its own.

(iii) By taking additional measures the CHP system may also be used as stand-by power supply system.

The thermal energy which is produced simultaneously by the CHP system should be used as good as possible, where appropriate heat storage tanks or other measures may be used for heat storage.

Combined operation modes

It is also possible to apply combined operating modes, for example:

(a) Heat driven with peak-electricity function,

(b) Maximum electricity and/or heat demand

(c) Minimum electricity and/or heat demand

In order to achieve an optimum match with demand and supply it is possible to implement several operation modes. The selection of the most favourable operation mode should be determined by economic criteria.

4.4.4 Energy balances for electricity and heat

The energy balances and the operational period should be determined on the basis of the future energy demand structure (see Table 16), the CHP generation structure (see Table 18) and considering which types of the energy demand should be covered by the CHP system.

Table 19 Energy balances

Module characteristics				
	Model	**Type**	**Quantity**	
Module output				
Electrical				
Thermal		When t =		
Fuel requirements				
Electricity balance				
Demand kWh_{el}/a	CHP system generation kWh_{el}/a	Supplementary demand kWh_{el}/a	Surplus kWh_{el}/a	Utilization period h/a
Thermal balance				
Demand kWh_{th}/a	CHP system generation kWh_{th}/a	Supplementary demand kWh_{th}/a	Surplus kWh_{th}/a	Utilization period h/a

4.4.5 Consideration of legal and environmental regulations for installation and operation of CHP systems

For the operation of a CHP system regional and national regulations (varying from country to country and region to region) governing energy matters have to be followed. These are:

- Imission and emission laws,
- directives/regulations on the parallel operation of generation plants with the low voltage networks of the electrical utility companies
- water pollution laws,
- laws on energy taxes,
- safety requirements,
- provisions and conditions issued by local energy utility companies,
- other

4.5 Concept variations and selection of CHP systems

4.5.1 General

Different selections and quotations for installation modules may influence the technological and economic outcome of the feasibility and planning concepts.

The economic and ecological optimum should be determined by varying the module size and module number of the CHP system. The results of the energy balances may be used as a basis for evaluating the economic efficiency.

4.5.2 Methods for evaluating economic efficiency

Although compliance with the legal conditions should be ensured during the compilation of the different concepts, one of the most essential selection criteria to take into account is the economic efficiency of the plants. The basis of every evaluation of economic efficiency is a precise determination of costs and revenue or avoided costs.[7]

The most significant factors to take into account are the investment costs, the operation and maintenance costs and profits. Furthermore the tariffs for electricity, for fuel and heat applicable for every alternative (energy price, capacity charge, LT, HT[8], demand, purchase price, feed-in price) and the energy balance meeting the daily and annual load curves (full load hours) for electricity and heat play a significant role in the economics.

The evaluation of the economic efficiency of CHP systems may be performed using familiar methods used in investment mathematics. Preference should be given to the following methods:

(i) the annuity method,
(ii) the net present value method,
(iii) internal rate of return method.

By using the **annuity method** (with reference to VDI 2067 Part 7 [Lit 12] and Part 1 [Lit 11]) the annual capital costs are calculated from the investments determined on the basis of an interest rate fixed with the owner and the corresponding period of use using the subsequent annuity. The annual costs are added up and the value of the electricity generation is subtracted to produce the annual costs of heat production or the specific costs of heat production for each individual variant (in case of calculating the specific costs for electricity the value of heat is subtracted). However, this calculation is based on the assumption of constant, annual flow of funds. Price increases, and particularly the different price increases for individual types of energy, are not taken into consideration.

The **net present value** method is used to calculate the present value of an investment. This is made up of the difference between all discounted cash outflow costs and inflows at a specific point in time. This method may also take price increases into consideration. The trend of the net present value over the years of useful life shows both the payback period and the profit at the end of the useful period. The payback period which reflects the time between the time of investment and the time at which the capital investment is recovered provides information of economic efficiency and is also an important parameter for assessing the financial risk. The shorter the payback period, the lower is the risk of the investment. Both the information on the risk and details of the achievable profit are helpful when selecting a suitable concept.

The **internal rate of return method** calculates the actual percentage rate of return on the capital investment. A comparison between the calculated internal rate of return and a pre-

[7] For detailed information concerning the economic efficiency of building installations see also VDI 2067, Part 1 and 7 [Lit 9], [Lit 10].

[8] LT and HT are the abbreviations for low and high tariff.

set, internal calculation rate may be used for an investment appraisal. This method can also take price increases into account. It may be helpful to use a sensitivity analysis when evaluating future economic development, for example, price increases. The variation of individual influential factors within a feasible, apparently realistic bandwidth reveals their effect on the economic efficiency of the plant.

Even though the economic efficiency of a concept for CHP systems is an important criterion in the selection procedure, it is also necessary to take into account other arguments like reliability of the supply, emissions (f. ex. noise, emissions, etc.) produced by the individual concept, construction requirements, etc.

4.5.3 Investment costs

During the first rough evaluations of economic efficiency, specific investment figures for the CHP system referring to the installed energy outputs are useful. To determine these costs, it is necessary to obtain precise data from manufacturers regarding the costs of the components listed in the next table. For the average price levels of CHP plants see Figure 25 in Section 3.1.1; for supplier information reference is given in Annex 7.1 and 7.2).

Table 20 Investment costs

Position Nr.	Plant	Investment (€)
1	**CHP System**	
	Module/quantity	
	Electrical switch gears	
	Lubricant supply/disposal	
	Exhaust gas system	
	Emergency cooler	
	Ventilation system	
	Integration	
	Electricity	
	Fuel	
	Heat	
	Water	
	Miscellaneous	
2	**Peak load boiler and or storage boiler(s)**	
3	**Water treatment**	
4	**Fuel supply**	
5	**Water supply**	
6	**Transformer**	
7	**Process automatic**	
8	**Remote control technology**	
9	**Chimneys**	
	CHP System	
	Peak load boiler	

10	**Constructions/foundations**	
	CHP module(s)	
	Peak Load boiler	
	Chimney(s)	
11	**Building**	
12	**Sound proofing**	
13	**Estate**	
14	**Planning costs**	
15	**Delivery**	
16	**Approval costs**	
17	**Acceptance costs**	

4.5.4 Fuel consumption costs

Taking into account the kind and quantity of fuel the prices – in case of several suppliers – have to be compared. In case of natural gas as fuel the energy costs are very often a combination of a demand charge (basic charge) and a running charge. Advantageously the prices are referred to the lower heating value (H_i).

4.5.5 Operation and maintenance costs

Information has to be requested on the costs of maintenance, repair, and supervision (see also Figure 3 in Section 3.1.1.2). Confirmation by suppliers and/or operators of comparable plants is necessary. Any costs which accrue in the period of observation for general overhauls or partial renovation should be taken into account. The different maintenance concepts ranging from routine maintenance to full maintenance concepts ranging from routine maintenance to full maintenance should be subject to a comparative evaluation.

4.5.6 Simplified examples for the economics of micro- and mini CHP plants

In this section simplified examples of the economics of micro- and mini CHP plants are introduced. Three typical micro-/mini CHP plants fuelled with natural gas and with an electrical power output of < 100 kW have been taken into account as typical examples for possible applications in small and medium sized hotels (green lodges). These are: (i) the low NO_x 5,0 kW_{el} micro CHP plant from Senertec company, and (ii) the 70 and 90 kW_{el} mini-CHP plants from Oberdorfer Kraft-Wärme-Kopplung GmbH in Austria. Furthermore a 60 kW_{el} micro gas turbine from Capstone packaged by G.A.S. company in Germany was also included. The data sets used for the economic analysis are summarized in Table 21.

Table 21 Parameters for the economic analysis (Source: Austrian Energy Agency)

	Unit	**ICE 5,0 kW**	**ICE 70 kW**	**ICE 90 kW**	**Micro gas turbine 60 kW**
Electr. Output	kW	5,0	70	90	60
Therm. Output	kW	11,7	118,3	147	145
Electr. Efficiency	%	26	32	33	26
Therm. Efficiency	%	61	54	54	63

Price	€	13.500	78.000	91.000	101.000
Maintenance costs (Full Service Contract)	€-Cents/kWh	2,0	1,8	1,7	1,0
Life time	Years	15	15	15	10 *)
Interest rate	%	6	6	6	6
Fuel costs for natural gas	€-Cents/kWh	3,5	3,1	3,1	3,1

*) Because of missing experience for the micro gas turbine a life time of 10 years was assumed.

Figure 19 gives an overview of payback periods for four micro-/mini-CHP plants as function of full load hours in possible "green lodges" projects. Because of the lower specific investment and maintenance costs of larger CHP systems (f. ex. the 70 kW_{el} and 90 kW_{el} CHP plants) the payback periods of the larger ones are much lower than for the 5 kW unit. Projects with 4000 to 4500 full load hours can achieve payback periods of < 5 years. For micro CHP systems longer pay back periods have to be accepted. Any decrease of costs (f. ex. in form of subsidies, low integration costs, etc.) improve the payback periods significantly.

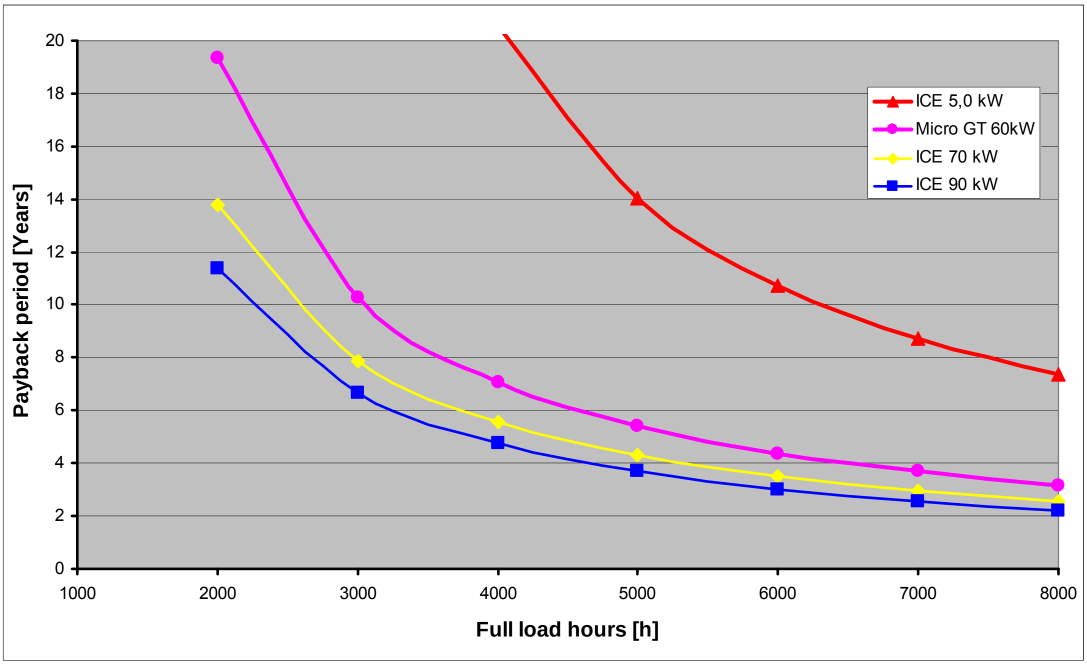

Figure 19 Dependency of the return on investment upon the achieved full load hours (Source: Austrian Energy Agency)

When implementing a concrete project the cost effectiveness of the project has to be analysed by using sensitivity analysis. In Figure 20 a sensitivity analysis was carried involving the 90 kW_{el} system. The base case (with 5000 full load operating hours) involves the 90 kW_{el} CHP plant with the parameters introduced in Table 21 and in Figure 19.

Both the fuel price and the full load hours have the biggest influence on the payback period of the project. If the full load hours increase by 10 % the pay back period will improve to 3,3 years (from 3,7 years). On the opposite if the full load hours decrease by 10 %, the pay back period will increase by 4,2 years. Similar effects have an increase of the fuel prices by 10 %. In this case the payback period increases by around 20 % (from 3,7 years to 4,4 years). A decrease of the natural gas price of 10 % also has the effect that the payback period decreases by 14 % (to 3,2 years).

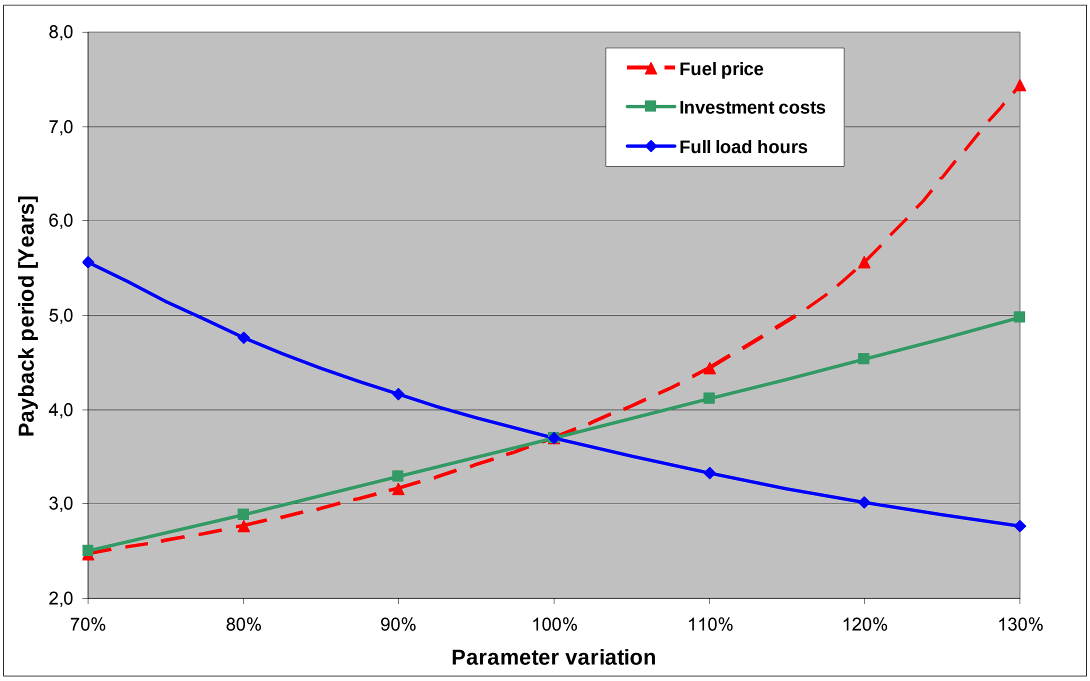

Figure 20 Parameter variation of the fuel prices, the investment costs and the full load hours
Base case: 90 kW_{el} CHP micro CHP plant, 5000 full load hours, other parameters: see Table 21 (Source: Austrian Energy Agency)

4.6 The final concept and follow-up activities

The final concept should be selected taking into account the different analysed alternative solutions and the economic efficiency of each alternative (using Table 18 and Table 19). Beside of the several technical and economical issues special consideration should be given to integration aspects:

4.6.1 Integration into the heat distribution system (heat driven operation mode)

The micro CHP gets installed like any additional boiler. The return flow temperature should be as low as possible (< 70 °C) and the micro CHP should take priority over the boiler (base load) to achieve a long operation time and to keep the pulse rate as low as possible. The priority operation of the micro CHP is ensured by the central control unit.

Because the micro CHP is only designed for the thermal part load; the additional installed boilers have a higher thermal output. Furthermore it is recommended to equip the boilers with modulating burners in order to avoid high temperature changes in the return flow of the heating system.

Generally the hydraulic integration should be cost-efficient and safe to operate. In case of already existing heating systems bigger reconstructions should be avoided. Important criteria for the hydraulic integration of the micro CHP system are:

- State of repair of the heating system and of the control system
- Operation temperature of flow and return flow
- Circulating water amount and size of the circulation pump
- Space conditions

Basically there are two ways of hydraulic integration of micro CHP plant and boiler: (i) the series connection and (ii) the parallel integration.

4.6.1.1 Series connection

Series connection means that the CHP is connected to the main return flow of the heating system. The CHP receives the return flow prior to the boiler (see Figure 21). The CHP takes a part of the return flow at the connection point A and raises the temperature. In point B this water gets injected in the main return flow again. This causes a temperature rise of the boiler return flow. If necessary the boiler increases the water temperature to the desired flow temperature.

It is advisable to install a boiler by-pass line to avoid a flow through the boiler if the boiler isn't needed (off-peak periods). Experience of the past could show that the series connection is very safe to operate and long CHP operation periods can be achieved.

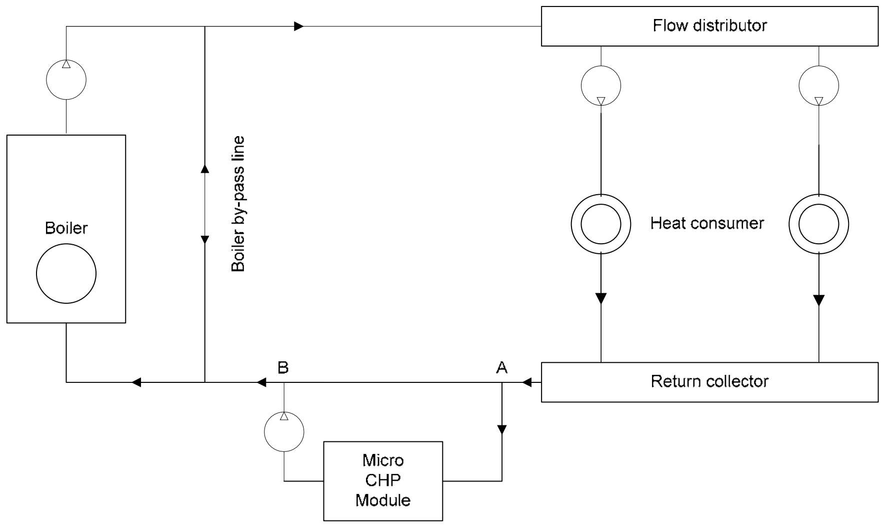

Figure 21 Basic scheme of series connection of Micro CHP and boiler (Source: Lit 27])

4.6.1.2 Parallel integration

The parallel integration of boiler and CHP gets used for very low return flow temperatures (e.g. in case of condensing boilers). The parallel integration is used for bigger CHP units and more complex heating systems.

In case of the parallel integration the water of the return flow is distributed proportional to the performance of the individual system (a higher performance of every individual system can be reached). To avoid any adverse effects by flow rate changes it is advisable to decouple heat generators (primary side) and heat consumers (secondary side) by a compensating line (hydraulic switch).

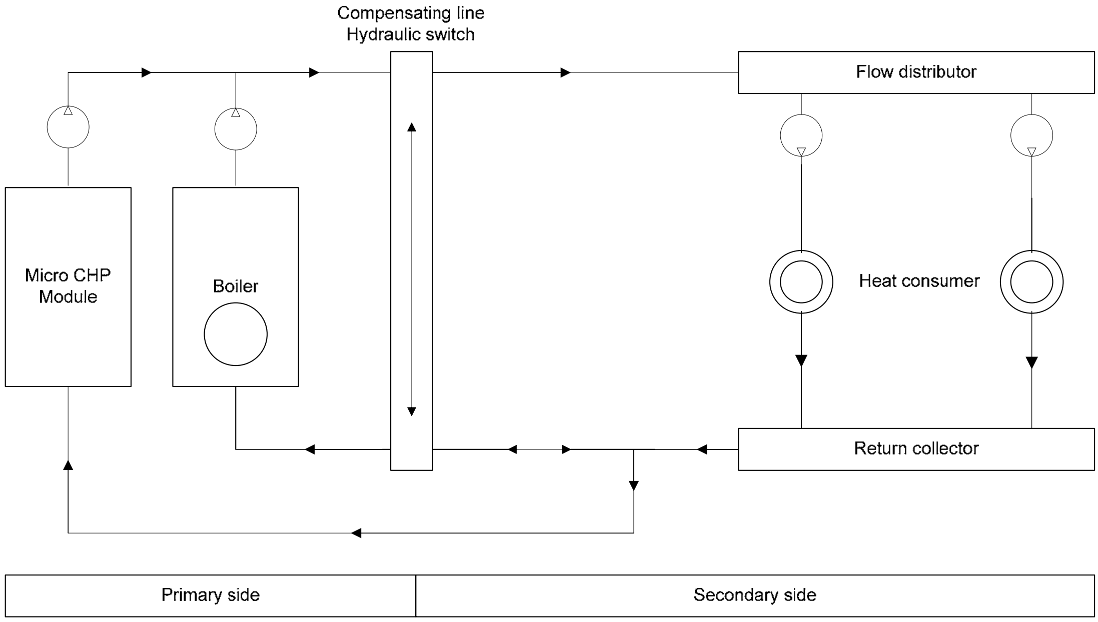

Figure 22 Basic scheme of parallel integration of Micro CHP and boiler (Source: Lit 27])

4.6.1.3 Control system and integration

Basically a module control unit is used for the operation of the CHP. The module control is an integral part of the CHP system and included in the delivery. This unit takes over all necessary control functions.

The essentially features of the module control are:

- Engine management system (performance control)
- grid and generator monitoring (incl. synchronisation, frequency and performance control)
- waste gas purification control
- emergency shut down

If the CHP system is only equipped with a module control the CHP operates till the temperature of the return flow passes the desired flow temperature (f. ex. approx. 70 °C).

Usually the heat demand is covered by a CHP unit and a peak load boiler. For this reason a central control unit for the whole system is necessary.

The following tasks have to be carried-out by the central control system:

- Guarantee of a continuous CHP operation (reducing the CHP start-ups to a minimum)
- Maximum operation time of the CHP
- Charge and discharge of the storage tank (if available)

To reduce the start-ups and maximise the operation time the CHP has to take priority over the boiler. First the central control system switches on the CHP modules (in case of installation of multiple modules) and if the heat demand is still raising the installed boilers gets switched on sequential. The switching should be almost stepless or in continuous form in order to provide the appropriate heat demand.

Basically there has to be differed between the integration of a control system

- into a new heating system, or
- into an already existing heating system.

4.6.2 Integration into the electric distribution system

The nature of the integration or the planned mode of operation is decisive when selecting the generators and the electrical equipment.

The following types are possible:

- Operation of systems in parallel – connection to the public grid with the same voltage and same frequency; asynchronous or synchronous generators may be used
- Independent operation – no connection to the public grid; only synchronous generators may be used
- Emergency operation – if required, this may be an emergency standby in case of main failure; synchronous generators are required.

4.6.2.1 Technical and organisational rules for the operation of micro CHP systems in parallel with the grid

In Austria the basic technical framework for the integration of decentralised energy resources is defined by the "Technical and organisational rules for operators and users of transmission and distribution networks (TOR)" as part of the ElWOG the Austrian Electricity Act (see Table 22). The TOR represent the national grid code and the TOR is also part of the so called "Market rules" for the liberalised electricity market, which have a special legal status, similar to a law.

Table 22 Austrian "market rules" for the liberalised electrcity market (Source: [Lit 25])

Document title	Last revision	Abstract	Issued by/responsible Technical Committee (TC)
ELWOG – "Elektrizitätswirtschafts- und Organisationsgesetz" (Electricity Act)	2002 2004	This law implements the EU electricity directive and regulates the liberalised Electricity market in Austria	Ministry of Economy and Labour Section Energy

The first edition of the TOR was published in 2001, following the opening of the electricity market, by E-Control Ltd. the official body responsible for the monitoring of the liberalised energy market in Austria. In this function E-Control also coordinates the development of the national grid code. Meanwhile, several parts were updated and adapted to the latest developments.

Out of the 6 main parts of the TOR, there are 2 documents which are of special relevance for DG and grid connection. The first one TOR D2 describes procedures for the assessment of network interferences and states limits for the permissible impact. Although it is primarily dedicated to the assessment of loads, there is a special section that provides guidelines for the treatment of generators.

Parallel operation issues like installation, protection devices, voltage control and others are covered by the TOR D4 (Parallel operation of generation units connected to distribution networks). This document is rather less detailed and contains more basic guidelines for DNOs[9] than specific requirements. These specific requirements are laid down by the DNOs themselves, based on the local grid situation and the capacity and technology of the distributed generator.

Table 23 Austrian national grid-code (Source: [Lit 25])

Document title	Last revision	Abstract	Issued by /responsible TC
TOR – "Technische und organisatorische Regeln für Betreiber und Benutzer von Übertragungs- und Verteiler-netzen gemäß ELWOG" ("General technical and organisational rules for operators and users of transmission and distribution grids according to the Austrian electricity act (ELWOG)")	Various dates	The TOR series of documents represent the national grid code. This series consists of 6 parts which cover almost all issues related to the technical and organisational operation of electricity grids. For DG, two parts are relevant, Part D2 (grid interference and PQ) and D4 (grid-interconnection of DG)	Energie-Control GmbH (Austrian regulator), Working group TOR, experts from E-Control, DNOs and Austrian Utility Association
TOR – Part D2 "Recommendations for the assessment of network interferences" TOR D2: 2004	01.06.2004	General guidelines for the assessment of grid interference caused by equipment connection of power supply systems. Section 9 provides special guidelines for the assessment of impacts caused by DG units.	Energie-Control GmbH (Austrian regulator), Working group TOR, experts from E-Control, DNOs and Austrian Utility Association
TOR – Part D4 "Parallel operation of generation units connected to distribution networks" TOR D4: 2001	2001	Technical rules for the grid interconnection and operation of DG units in parallel with the distribution grid.	Energie-Control GmbH (Austrian regulator), Working group TOR, experts from E-Control, DNOs and Austrian Utility Association

Concerning the international cogeneration standards the draft EN 50438 „Requirements for the connection of micro-cogenerators in parallel with public low voltage distribution networks" is of special interest. With this draft international harmonisation requirements for the connection of micro CHP systems operating in parallel with public low-voltage distribution networks get created.

[9] Distribution Network Operators

Table 24 International cogeneration standards (Source: [Lit 27])

Standard no.	Stage	Technical Committee	Standard
IEEE 502	Published		IEEE Guide for Protection, Interlocking and Control of Fossil-Fuelled Unit-Connected Steam Stations
UL 2200	Published		STANDARD FOR SAFETY Stationary Engine generator Assemblies
PrEN 50438	Draft	CLC/TC8X WG 2	Requirements for the connection of micro-cogenerators in parallel with public low-voltage distribution networks

4.6.3 Planning of a stand alone power supply system

For a stand alone power supply system basically the following unit parts are required:

- Batteries
- inverters
- micro CHP
- battery management system
- storage tank
- cooling unit

The stand alone system has to be adapted to the thermal and electrical demand of the object. Basically a stand alone power supply can be designed for the usage of

- multiple CHPs in parallel
- CHP and boilers in parallel to cover the thermal peak load or
- a combination of CHP and other RES systems

The stand alone micro CHP supplies buildings with electricity by means of a battery and three one-phase inverters to build up a three phase supply network. An additional inverter is recommended to guarantee the supply. If the batteries are charged, the continuous power output of the inverters has to guarantee constant electrical power supply. When the micro CHP is in operation, the power output of the micro CHP and the permanent power of the inverters sum up to supply the total available power. When the micro CHP is not in operation the total supply period is determined by the battery capacity and depends on the total consumption. How much of the heat requirement can be covered by the micro CHP depends on the chosen hydraulic connection.

Additionally a battery management system is recommended by most of the suppliers. These management systems guarantee the special operation procedures of the batteries resulting in improved life times. In case that the produced electrical energy cannot be used by any consumers or stored in the batteries the energy will be used by an electrical heating element in order to produce hot water in the buffer boiler. The boiler stores also the produced thermal energy that is not used. In case that the thermal energy is both not used and cannot be stored in the boiler it is cooled away.

It is worth mentioning that the maximum rated electrical output of the CHP unit decreases with increasing sea level. Standard levels of this power loss are listed in the next table.

Table 25 Rated output dependend on sea level (Source: [Lit 27])

Rated output [kW]	5,5	5,0	4,5	4,0
Corresponds to sea level [m]	Up to 1000	Up to 1500	Up to 2000	Up to 2500

The following figure shows an example of the electrical integration of a stand alone micro CHP.

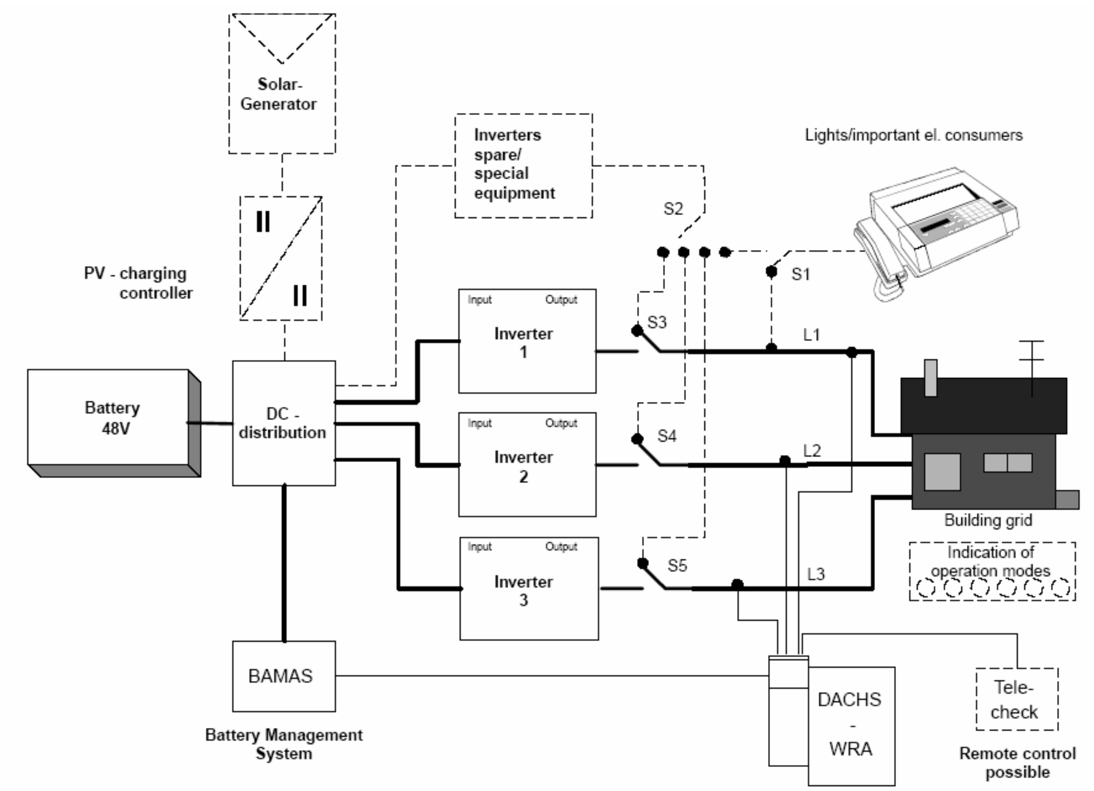

Figure 23 Block diagram of a stand alone grid (Source: [Lit 27])

Generally, a battery capacity is dimensioned for the electric base load (1/3 to 1/4 of the peak load). The electric peak has to be covered by the CHP. Standard values for selecting the battery size are listed in Table 26.

Table 26 Standard values for selecting the battery size (Source: [Lit 27])

Average electrical consumption in kWh per day	**Up to 15 kWh**	**Up to 20 kWh**	**Up to 30 kWh**	**Up to 50 kWh**	**Up to 70 kWh**	**Up to 90 kWh**	**Above 90 kWh**
Minimum size of the battery in Ah at a battery system voltage of 48 V	420 Ah	490 Ah	600 Ah	800 Ah	1000 Ah	1200 Ah	1500 Ah and more

A battery with a larger capacity than necessary can reduce the charging/discharging cycles and increase the battery life. Also if a larger energy demand (exceeding the output of the

CHP) occurs over a long period of time (more than two hours) a larger battery should be selected.

The next table gives an overview about standard values for the time period until next re-charging (charging level < rated value) and the possible supply time for the different battery sizes (based on lead acid batteries) depending on the average connected consumption when the CHP unit is not in operation.

Table 27 Standard values for selecting the battery size (Source: [Lit 27])

Battery voltage	Battery capacity	Average consumption [kW]	Estimated time period until recharging [hours]	Possible supply time in hours (battery is fully charged) [hours]
48 V	420 Ah	0,5	6,5	24
		1,0	3,5	13
		2,0	2	6,5
		4,0	1	2,5
		6,0	0,5	1
48 V	600 Ah	0,5	9,5	35
		1,0	5,5	19
		2,0	3	10
		4,0	1,5	4
		6,0	1	2
48 V	800 Ah	0,5	13	48
		1,0	7	26
		2,0	4	14
		4,0	2	6
		6,0	1,2	3,5
48 V	1000 Ah	0,5	16	57
		1,0	9	29
		2,0	5	16
		4,0	2,5	8
		6,0	1,5	4,5

4.6.4 Hydraulic integration for off-grid operation

In general the system needs to be equipped with a storage tank (capacity at least 500 l). The storage tank stores the heat generated during the electricity generation. The heat can later be used for domestic hot tap water and for heating purposes.

For guaranteed power generation the increase of the return flow temperature must be limited by suitable means (if the heat consumption of the building is too low). The emergency cooling unit always has to be installed in the return flow of the micro CHP. If heating plates are used to lead off heat it is optimal to use them as good as possible for example in a drying room. If a swimming pool is used as emergency cooling the excess heat can also be led into the pool by means of heat exchangers.

If a heat driven operation mode is applied to the building, an additional heat generator (electrical heating device or boiler) is compulsory.

As follows three possible cases for the hydraulic integration of stand alone micro CHPs are shown:

1. Hydraulic connection primarily for electricity generation: The micro CHP is only operated according to the criteria of electricity generation. In general the micro CHP system is controlled by the battery management system. If no cold start device[10] is required, there is also no additional electrical heating device necessary.

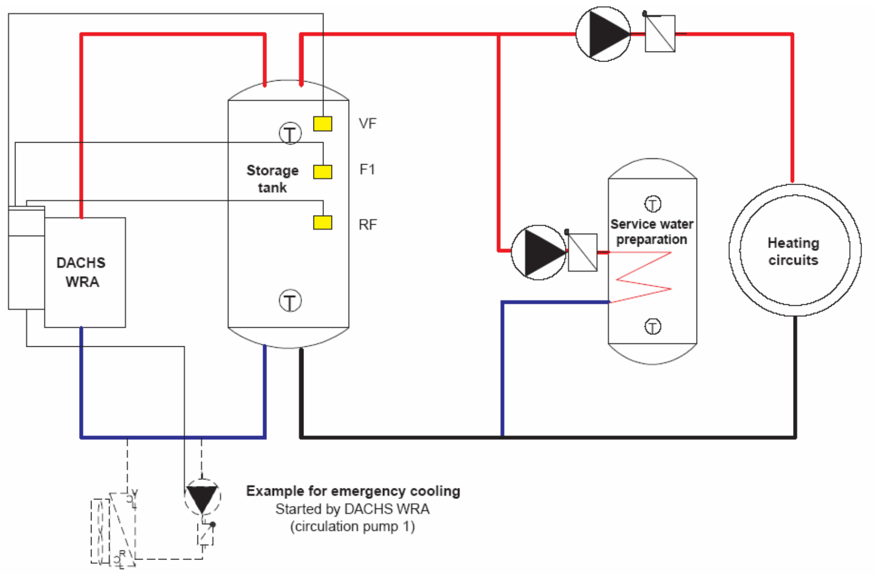

Figure 24 Example of a hydraulic connection for electricity generation (Source: [Lit 27])

2. Hydraulic integration in the case of heat and power generation with electrical heating device: The micro CHP operates according to the criteria of power generation as well as heat generation. If no cold start device is necessary the electrical heating device should be installed in the storage tank. If an emergency cooling is necessary it has to be installed in the return flow of the micro CHP.

[10] By continuous temperated system no cold start system is necessary. In case of Senertec's model Dachs WRA a cold start system is recommended at temperatures below 5 °C.

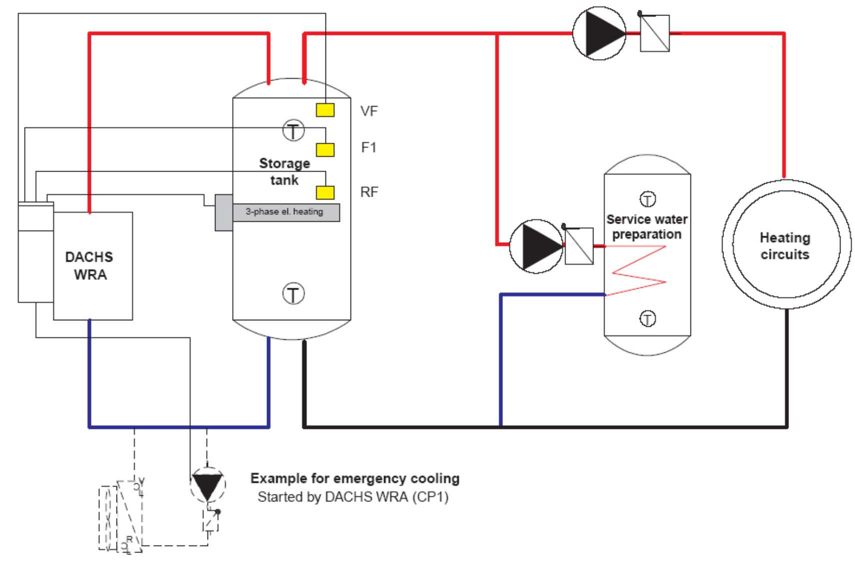

Figure 25 Example of a hydraulic integration for heat and power generation including electrical heating (Source: [Lit 27])

3. Hydraulic integration with additional boiler: The micro CHP operates only according to the criteria of power generation. In this case the boiler has to cover the basic heat demand of the building.

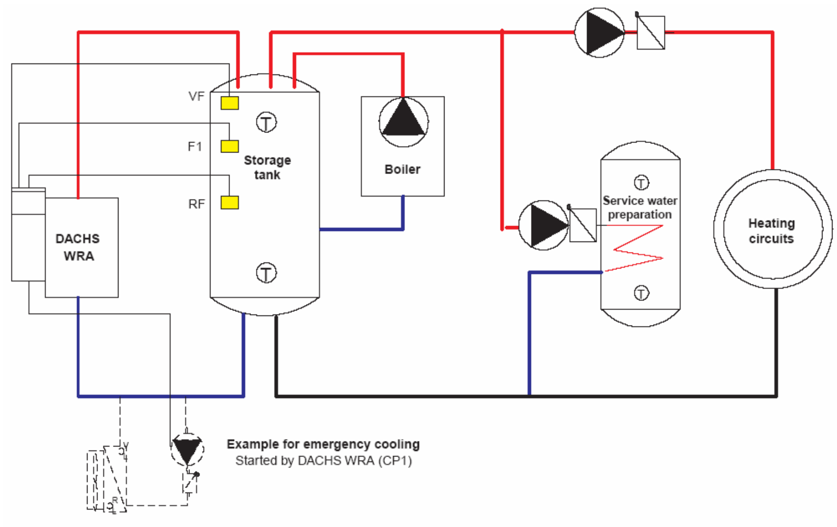

Figure 26 Example of a hydraulic integration including an additional boiler (Source: [Lit 27])

5 Barriers for the further introduction of micro CHP systems

There are a number of likely barriers to the widespread deployment of micro CHP technologies. Differentiations of these barriers result in three groups. These are:

• **cost constraints** — the lack of demand for micro generation technologies has restricted the extent to which the industry has been able to exploit scale economies and learning effects in their production. Combined with the infancy of the industry and the significant expenditure on R&D associated with product development this means that the costs of these products are currently very high and act as an economic barrier to their uptake.

• **information constraints** — inadequate promotion and provision of information on micro generation, and the lack of a widely understood accreditation system for products and installers, reduces the incentive for consumers to purchase micro generation products due to insufficient signals regarding the quality and characteristics of these products; and

• **technical constraints** — the lack of metering arrangements that meet the needs associated with the management of electricity distribution and the needs of the consumer, and the lack of a comprehensive approach to dealing with the issues surrounding the connection of micro generators to the distribution network, constitute barriers of a technical nature that could be preventing take-up of micro generation technologies.

As already outlined in section 4.1 the main target market for micro CHP is the domestic mass market within the European Union as a replacement for conventional gas and oil boilers with central heating systems. The MicroMap project [Lit 2] reported that 80% of replacement/upgrade boiler purchases are estimated to be “distressed purchases” i.e. where the existing boiler breaks down and a replacement is required at short notice as the buildings owner has no heating and/or hot water.

These circumstances mean that the whole process for replacing a boiler with a micro CHP must be both simple and quick. Customers will not choose micro CHP systems if there is any scope for delay, additional network costs or any additional paperwork. It is essential, therefore, that procedures adopt a “plug and play” approach.

Micro CHP units are similar in size to other buildings’ appliances. Their electrical output is equivalent to the load of their appliances and therefore these appliances can be considered as negative loads.

The impact of a micro CHP unit on the low voltage network is minute and there is no need for any additional works outside the domestic premises. A study recently funded by the UK government [Lit 24] and conducted in co-operation with electricity distribution companies has concluded that existing distribution networks could accommodate up to a 50% penetration of all households with micro CHP before there is any noticeable impact on the electricity networks.

For this reason there is principally no need for distribution network operators (DNO) to receive prior notification of installation, though notification after installation is necessary in order to allow DNOs to track the long-term trends of micro CHP penetration and plan ahead for any necessary network reinforcements. This is clearly not the case for larger units where the impact on the network does indeed warrant prior notification to the DNO and may involve additional works to be undertaken.

Because micro CHPs target at the mass market, individual certification and testing of each customer's installation by the DNO is neither possible nor necessary. Therefore a type-certified approach, where the quality of the appliance is already guaranteed by CE-marking, is required. Again, this necessitates a different approach for micro CHP than for larger systems.

Recognising the specific requirements for micro CHP in 2001 work started on standardisation of the electrical interface between the unit and the low voltage network. At the European level CEN[11] created a Workshop Agreement on this area and this was completed and published by CEN and the National Standards Bodies in February 2003.

Following the completion of the CWA, the work on standardisation was moved to Cenelec for the development of a European Norm. This work started in February 2003 and is ongoing. The work is undertaken under the auspices of Cenelec technical committee TC8X WG2[12].

In parallel, some Member States have been developing their own regulations for the installation of micro CHP. The UK has already brought forward related changes in legislation, and published engineering recommendations in this area. Germany, Belgium, The Netherlands and Austria are also developing regulatory and pseudo-regulatory changes in this area.

Both European and some national standards for the connection of small-scale embedded generators are developing fast (these are generally up to 16 amps per phase, but in some countries higher ratings are permitted) in parallel with public low voltage distribution networks. There have also been related changes to statutory requirements. This recommendation adopts the "plug and play approach" i.e. the installation of a single micro co-generation unit within a single customer's installation can be connected in parallel with the public distribution network without the prior permission of the local DNO. The installer is required to provide the DNO with information on the installation once commissioned.

There is a need for a harmonised approach at EU level because there is a danger that each country, or region within a country, will develop differing standards, or guidelines, or it will be left to DNOs to develop individual requirements. This will create distortions between Member States, limit trade, the size of the potential market and in some domains be a barrier to entry (see also Lit 29).

Moreover, the continued presence of vertical integration in the electricity industry in some Member States creates poor incentives for utilities to accommodate highly energy efficient measures such as micro CHP. These poor incentives are amplified by the direct and active involvement of some electricity companies in the development of their own micro CHP

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[11] CEN is the abbreviation for "European Committee for Standardization".

[12] Draft Cenelec standard prEN50438: "Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks".

products. For example, a DNO could, through administrative burden, make it difficult for a competitor's micro CHP product to be connected, and allow much easier passage for the micro CHP technology in which it holds a direct commercial or financial interest.

Apart from the technological potential, from private and social costs, corporate strategies and consumer acceptance, the further implementation of micro CHP systems is importantly influenced by the institutional structures. Institutions guide the strategies of different actors, producers, consumers and regulators in choosing or not choosing micro CHP systems. Institutions here are defined as the social rules that enable or constrain action by setting incentives, providing orientation or prescribing or forbidding specific behaviour. The next figure shows an exemplaric institutional setting for the deployment of micro CHPs in Germany.

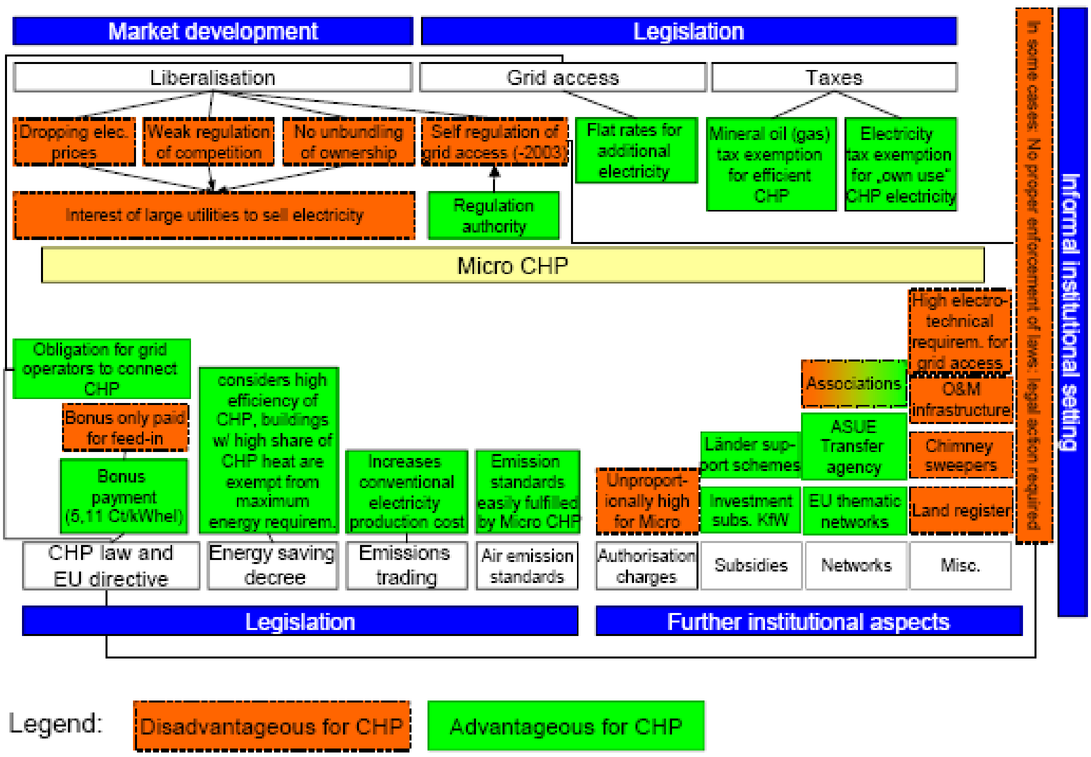

Figure 27 Exemplaric institutional setting for micro CHP in Germany [Lit 1]

6 Summary

The project “Green Lodges” aims at promoting and facilitating RES heat & electricity applications (biomass, solar & micro CHP mainly) in rural lodges, usually located in areas with high environmental value. D8 report as first deliverable of work package 3 delivers information regarding the state of the art of micro CHP systems. All kind of CHP applications and technologies below of 1 MW_{el} (internal combustion engines, diesel engines, stirling engines, micro gas turbines, ORC plants, fuel cells, etc) using different energy sources (like gas, fuel oil, rape oil/biodiesel, biogas, etc) were considered. Described products are either already available commercially or they are close to market entry. The focus of the analysis was on micro CHP units up to an electrical output of 50 kW following the current definition outlined in the CHP directive.

Micro CHP products are typically run as heating appliances, providing space heating and warm water in residential or commercial buildings like conventional boilers. But unlike a boiler, micro CHP systems generate electricity and heat at very high-efficiencies and therefore help to save fuel, cut greenhouse gas emissions and reduce electricity costs. Most units operate in grid-parallel mode, so that the building continues to receive some of its electrical needs from the electrical network, but it may also export some electricity to the network. Cooling applications based on micro CHP and absorption systems still need major R&D efforts to introduce them in competing markets.

In the last few years a trend for the usage of micro CHP units in isolated regions could be monitored. Especially buildings with no grid connection and/or less reliable electrical energy supply were using micro CHP systems in connection with battery systems and hot water storage tanks. Moreover instead of using diesel/light fuel oil as fuel, nowadays environmentally friendly rape oil and/or biodiesel is used in these micro CHP systems. Especially in ecological sensible regions like mountains due to reasons of air-, soil- and water/groundwater conservation, etc. these systems have decisive environmental advantages (especially in case of usage of natural untreated rape oil).

As micro CHP systems are not very developed in all the regions/countries of the partner organisations of green lodges project, Austria is in the position of transferring experience of the installation and operation of several hundred units in the past few years. Beside of the technical product portfolio a special focus was laid in this report in the identification of critical economic success factors like investment costs, O&M costs, calculation methods, and parameter variations for selecting the final concept. Planning aspects for heat and electricity integration but also for stand alone versions were described in detail including the different possible operation modes (i.e. heat and electricity driven modes, or a combination of both). Tables and Figures giving precise planning guidelines for the analysis of the energy demand and for the selection of the “right” micro CHP system were included to enable the partner organisations for the further deployment of micro CHPs in their own regions/countries.

There are a number of likely barriers to the widespread deployment of micro CHP technologies. Three types of barriers were highlighted: (i) cost constraints, (ii) information, and (iii) technical constraints. For the operation of micro CHP systems regional and national regulations (varying from region to region and country to country) governing energy and environmental matters have to be followed. However, instead of individual region and/or country specific solutions to overcome these barriers it is suggested that a harmonised approach at EU level will be achieved as good as possible.

7 Annex

7.1 List of suppliers for reciprocating engines

Supplier	Electrical power range	Model series	Fuels
Senertec Kraft-Wärme-Energiesysteme GmbH Carl-Zeiss-Straße 18 97424 Schweinfurt Germany Tel: +49 9721/651-0 www.senertec.de	5,0 – 5,5	Dachs HKA	Natural gas LPG ELFO, biodiesel
PowerPlus Technologies GmbH Fasaneninsel 20 07548 Gera Germany Tel: +49 365 / 830403-00 www.ecopower.de	1,3 – 4,7 (modulating)	Ecopower	Natural gas LPG
Spilling Energie Systeme GmbH Werftstraße 5 20457 Hamburg Germany Tel: +49 40 789 175 – 0 www.powertherm.de	7 – 20 (modulating)	PowerTherm	Natural Gas LPG Biogas, Sewage gas
EC Power A/S Samsøvej 25 DK-8382 Hinnerup Denmark Tel: +45 8743 4127 www.ecpower.de	4 – 13 (modulating)	XRGI 13	Natural gas
	4 – 17 (modulating)	XRGI 17	ELFO, LFO
Buderus Austria Heiztechnik GmbH Karl-Schönher-Straße 2 4600 Wels Austria Tel:+43 7242 29850 http://www.buderus.at	18 – 238	Loganova	Natural gas
Oberdorfer Kraft-Wärme-Kopplung GmbH Bahnhofstrasse 10	70 – 245		Natural gas
	70 – 250		LPG

9711 Paternion Austria Tel: +43 (0) 4245 2419 www.oberdorfer.at	70 – 250		Biogas, Sewage gas, Landfill gas
GE Jenbacher Achenseestraße 1-3, 6200 Jenbach Austria Tel: +43 5244 600-0 www.jenbacher.com	330	Baureihe Type 2	Natural gas LPG Biogas
	525 – 1065	Baureihe Type 3	Natural gas LPG Biogas
	1413	Baureihe Type 4	Natural gas, LPG, Biogas
	1644 - 3047	Baureihe Type 6	Natural gas LPG Biogas
Zeppelin Österreich GmbH Zeppelinstraße 2 2401 Fischamend Austria Tel: +43 2232 790 www.zeppelin-cat.at	188 – 5950		Natural gas
	199 – 1090		Coal mine gas
	173 – 2090		Biogas
	190 – 930		LPG
KraftWerk Kraft-Wärme-Kopplung GmbH Zur Bettfedernfabrik 1 30451 Hannover Germany Tel: +49 511 262 9970 www.kwk.info www.kraftwerk-bhkw.de	25 29	Mephisto G16 Mephisto G18	Natural gas, LPG Sewage gas and biogas for the model Mephisto G16
	24 34	Mephisto G26 Mephisto G34	Natural gas LPG Sewage gas and biogas for the model Mephisto 26.
Energiewerkstatt **Gesellschaft für rationelle Energie mbH & Co. KG** Bartweg 16 30453 Hannover Germany Tel: +49 511 / 949 740 www.energiewerkstatt.de	18	BHKW ASV 18/43	Natural gas LPG Usage of biogas and sewage gas is possible
Reindl Maschinenbau **GmbH** Steinhausen 20	6,3	BHKW BK 07/H	LFO RME

85625 Glonn Germany Tel: +49 8093 / 90 38 – 0 www.reindl-mb.de			
Heinke Döring Energie GmbH Fischbach 15 35418 Buseck – Gewerbegebiet Ost Germany Tel:+49 6408-504 684 www.heinke-doering.de	9	BHKW 9/16,5	LFO The models can be adapted for the usage of natural gas and rape oil
	22	BHKW 22/40	
	37	BHKW 37/66	
KW Energie Technik e.K. Neumarkter Str. 157 92342 Freystadt/Rettelloh Germany Tel: +49 9179 / 96 434 0 www.kw-energietechnik.de	8 – 25		Rape oil
	8 – 43		Natural gas LFO Biogas
	10 – 75		Diesel, LFO
Pro2-Anlagentechnik GmbH Schmelzerstraße 25 47877 Willich Germany Tel: +49 2154 / 488-0 www.pro-2.net	191 – 1703		Landfill gas Biogas Sewage gas
	212 – 2014		Natural gas Coal mine gas
Communa Metall GmbH Uhlandstraße 17 32051 Herford Germany Tel.: +49 5221 9151- 0 www.comuna-metall.de	52	BHKW Type 2725	Natural gas LPG Sewage gas Biogas
	112	BHKW Type 5450	Natural gas LPG Sewage gas Biogas
SOKRATHERM GmbH & Co. KG Energie- und Wärme-technik Milchstr. 12 32120 Hiddenhausen, Germany Tel: +49 5221.9621-0, www.sokratherm.de	50 – 383	Model series GG	Natural gas
	38 – 345	Model series FG	Biogas
	104 – 345	Model series BG	Biogas
EAW Energieanlagenbau GmbH Oberes Tor 106	5,3 - 170		ELFO, LFO Retrofits for biodiesel (RME) are possible on request

98631 Westenfeld Germany Tel: +49 36948 84132 www.eaw-energieanlagenbau.de	5,5 – 238		Nautral gas Retrofits for biogas are possible on request
Kuntschar + Schlüter GmbH Unterm Dorfe 8 34466 Wolfhagen-Ippinghausen Germany Tel: +49 05692 98 80-0 www.kuntschar-schlueter.de	78 – 585	Biogas BHKW	Biogas
	18 – 228	Natural gas Lambda 1 BHKW	Natural gas
	40 – 1280	Lean natural gas operation	Natural gas
	16 – 580	BHKW Lean sewage gas operation	Sewage gas
Emslandstrom GmbH & Co. KG Am Deverhafen 2 26871 Papenburg Germany Tel: +49 49 61 - 66 92 93 www.emslandstrom.de	311 – 1942		Natural gas, Biogas
2G Energietechnik GmbH Benzstr. 10 48619 Heek Germany Tel: +49 25 68 / 9 60 33 www.2-g.de	105, 230		Biogas
	100, 180, 340, 526		Biogas
IET Intelligente Energie Technik GmbH Chromstrasse 2 9500 Villach Austria Tel: + 43 424 33223 www.iet-energietechnik.at	30 – 346		Biogas
	35 – 380		Natural gas
Köhler & Ziegler Anlagen-technik Auweg 10 c 35457 Lollar Germany Tel: +49 64 06/91 03-0 www.koehler-ziegler.de	65 – 1010		Natural gas
	53 – 800		Sewage gas, biogas
Koller Innovative Ener-gietechnik Taubergasse 30	1,3 – 4,7	Powerbox	Natural gas

1170 Wien Tel.: +43 1 804 3382 www.eigenstrom.at			
DEUTZ Power Systems GmbH & Co. KG Carl-Benz-Str. 1 68167 Mannheim Germany Tel: +49 621 384 0 http://www.deutzpowersystems.com	240 – 4000		Natural gas
Menag Energie AG Bachmatten 5 CH-4435 Niederdorf Switzerland Tel: +41 61 956 2500 http://www.menag-group.com/de/	25 – 3916		Natural gas
	25 – 1696		Biogas Sewage gas
ETW Energietechnik GmbH Ferdinand-Zeppelin-Straße 19 47445 Moers Germany Tel: +49 2841 99 90-0 http://www.etw-energie.de/downloads.htm	130 – 1560		Natural gas
	110 – 1370		Biogas
GIESE Energie- und Regeltechnik GmbH Huchenstr. 3 82178 Puchheim bei München Germany Tel: + 49 89 / 800 653-00 www.energator.de	5 – 63		LFO / Diesel / RME
	7,5 – 35		Rape oil
	5,5 - 63		Natural gas /LPG/Biogas
Höfler Blockheizkraftwerke Ladestraße 26 88131 Lindau Germany Tel: +49 8382 25057 www.hoefler-bhkw.de	22 – 1030		Natural gas
	21 – 142		Biogas
SCHMITT-ENERTEC GmbH Kottenheimer Weg 37 56727 Mayen, Germany Germany Tel: +49 2651.409310 www.schmitt-enertec.de	105 – 812		Natural gas
	20 – 771		Biogas

SEF Energietechnik GmbH & Co. KG Lessingstraße 4 08058 Zwickau Germany Tel: +49 375 54 1608 www.sef-energietechnik.de	25	G3000A	Natural gas
Henkelhausen GmbH & Co. KG Hafenstraße 51 47809 Krefeld Germany Tel: +49 2151 574 – 207 www.henkelhausen.com		BHKW with Deutz engines	LFO Biogas
MWB Motorenwerke Bremerhaven AG Barkhausenstraße 27568 Bremerhaven Postfach 120352 27517 Bremerhaven Germany Tel: +49 3631 918-325 www.mwb.ag	150 - 335		Rape oil LFO Natural gas Low calorific gases
FIMAG Finsterwalder Maschinen- und Anlagenbau GmbH Grenzstraße 41 03238 Finsterwald Germany Tel: +49 3531 5080 www.fimag-finsterwalde.de	bis 2000		Natural gas, Sewage gas, LFO
HAASE Energietechnik AG Gadelander Straße 172 24531 Neumünster Germany Tel: +49 4321 878-0 http://www.haase-energietechnik.de		Container BHKW	Natural gas Biogas Sewage-, landfill gas
		Stationary BHKW	Natural gas Biogas Sewage-, landfill gas
	171 - 1703	Compakt BHKW	Biogas
SEnergie GmbH Neuer Weg 1 79423 Heitersheim Deutschland Germany Tel: +49 7634 - 50569-0 www.senergie.de	50 - 280		Sewage gas, biogas and natural gas

PEWO Energietechnik GmbH Geierswalder Straße 13 02979 Elsterheide Germany Tel: +49 3571 4898-0 www.pewo.de	26 – 386	pewoGS	Natural gas
	32 – 347	pewoBGS	Biogas
WILHELM SCHMITT Robert Bosch Str.5 Industriegebiet Ost 1 56727 Mayen Germany Tel: +49 2651/9887-30 www.schmitt-mayen.de	40, 50, 65		Natural gas
MDE Dezentrale Energiesys-teme Dasinger Str. 11 86165 Augsburg Germany Tel: +49 821 / 7480-0 www.mde-online.com MDE Dezentrale Energiesys-teme wurde von MTU Frie-drichshafen übernommen.	119 – 386	ME	Natural gas
	116 – 323	ME	Natural gas
	192, 370	MB	Biogas, sewage gas
Ochtruper Energietechnik Feldevert Deipenbrook 31 48607 Ochtrup Germany Tel: +49 02553 / 80907 www.oet.de	8 – 50	OET	Gas Alternative: rape oil, biogas, mine gas
	8 – 50	OET	LFO Alternative: rape oil, biogas, mine gas
	Weitere Modelle bis 1000 kW		Alternative: rape oil, biogas, mine gas
Mothermik GmbH Industriestr. 3 56291 Pfalzfeld/Hunsrück Germany Tel +49 6746 / 8003-0 www.mothermik.de	100 – 3000		ELFO, RME
			Natural gas, sewage gas, biogas, mine gas, wood gas and other low caloric gases in connection with ELFO or RME as injection stream
SES Service EnergieSysteme GmbH Kömmlitzer Straße 5	25 – 100	UNIT HPC Ready for connec-tion compact modules	Natural gas

D-04519 Rackwitz Germany Tel: +49 34294 8360 www.ses-energiesysteme.com	194 – 1974	CHP plants in the construction forms: industrial plants and container	Natural gas, biogas, sewage gas
tvp-energysystems GmbH Lange Zeile 112 7311 Neckenmarkt AUSTRIA Tel: +43 2610 423 54 www.tvp-austria.com	100 – 20000		Natural gas Biodiesel
ABL-Energietechnik GmbH Mühlberger Str. 6 83527 Moosham Germany Tel: +49 0 8072 3747 04 www.abl-energietechnik.de	30 – 340		Biogas lean operation
	35 – 340		Natural gas lean operation
	70 – 300		LFO, rape oil operation

7.2 List of suppliers for rape oil engines

Supplier	Electrical power range	Fuels	Comments
BioEnergieTann GmbH Eiberger Straße 2 84367 Zimmern Germany Tel: +49 8572 96060	11 – 500	Rape oil	All rape oil CHP systems can be also delivered as biogas/injection gas engines
	170, 230	Biogas, landfill gas	
Hoepfl Thomas Elektrounternehmen Hauptstr. 39 94336 Hunderdorf / Ndby Germany Tel: +49 9422 / 85 21 - 0 www.block-heiz-kraft-werk.de	6 – 15	LFO, RME	Rape oil cold pressed with conversion kit
Hubert Tippkötter GmbH Velsen 49 48231 Warendorf Germany Tel: +49 2584 9302-0 www.tippkoetter.de	13 – 160	LFO	
	229 – 415	LFO	CHP system with MAN diesel engines
	8 – 1000	Rape oil	

EUROENERGIE Billstrasse 28 D-20539 Hamburg Germany Tel: +49 40 819 78 466 www.euroenergie.info	10 – 500	Rape oil	
Neue Energie Technik NET Moosstraße 195 A-5020 Salzburg Austria Tel: +43 662 828729 www.neue-energie-technik.net	8 – 144	LFO/Diesel/RME, etc.	
	12 – 30	Rape oil	
	8 – 30	Gas	
	6 – 20	LFO/Diesel	
Nutz GmbH Rudolfstraße 121 f 8010 Graz Austria Tel: +43 0316 30156 www.nutz-gmbh.at	12 – 20	Rape oil	Customer specific plants can be manufactured
	120	Rape oil	Customer specific plants can be manufactured
Johann Söllinger Ökotec Straß im Attergau 34 4881 Straß im Attergau Austria Tel: + 43 7667 7205-0 www.soellinger.at www.oekotec.at	8 – 25	Rape oil Biodiesel	
Öko-Energiesysteme GmbH Hauptstraße 8 37355 Deuna Germany Tel: +49 36076 51313 www.energie-as.de	8,2 – 35	Rape oil LFO	
	52 – 320	Natural gas Biogas	
StarmoTec Energie Systeme Rosenstraße 1 86495 Eurasburg bei Augsburg Germany Tel: + 49 8208 9599511 http://www.starmotec.de	5,5 – 11	Diesel/LFO, Rape oil	Parallel operation with electrical grid
	3 – 8	Diesel/LFO, Rape oil	Independent operation to electrical grid

KW Energie Technik e.K Neumarkter Str. 157 92342 Frey-stadt/Rettelloh Germany Tel: +49 9179 / 96 434 0 www.kw-energietechnik.de	8 – 25	Rape oil	
GIESE Energie- und Regeltechnik GmbH Huchenstr. 3 82178 Puchheim bei München Germany Tel: +49 089 800 653-0 www.energator.de	7,5 – 35	Rape oil	
MWB Motorenwerke Bremerhaven AG Barkhausenstraße 27568 Bremerhaven Germany Tel: +49 3631 918-325 www.mwb.ag	150 - 335	Rape oil	
ABL-Energietechnik GmbH Mühlberger Str. 6 83527 Moosham Germany Tel: +49 0 8072 3747 04 www.abl-energietechnik.de	70 – 300	LFO and Rape oil	Rape oil operation achie-ves minus 10 % of the rated power

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