Micro-CHP technologies for distributed generation

Subtask 5, Report n:o 2

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International Energy Agency Demand-Side Management Programme

Task XVII: Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages

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EXECUTIVE SUMMARY - Micro-CHP technologies for distributed generation

TASK XVII: INTEGRATION OF DEMAND SIDE MANAGEMENT, DISTRIBUTED GENERATION, RENEWABLE ENERGY SOURCES AND ENERGY STORAGES

Task extension: The effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system

Background

Energy policies are promoting distributed energy resources such as energy efficiency, distributed generation (DG), energy storage devices, and renewable energy resources (RES), increasing the number of DG installations and especially variable output (only partly controllable) sources like wind power, solar, small hydro and combined heat and power.

Intermittent generation like wind can cause problems in grids, in physical balances and in adequacy of power.

Thus, there are two goals for integrating distributed energy resources locally and globally: network management point of view and energy market objectives.

Solutions to decrease the problems caused by the variable output of intermittent resources are to add energy storages into the system, create more flexibility on the supply side to mitigate supply intermittency and load variation, and to increase flexibility in electricity consumption. Combining the different characteristics of these resources is essential in increasing the value of distributed energy resources in the bulk power system and in the energy market.

This Task is focusing on the aspects of this integration.

Objectives

The main objective of this Task is to study how to achieve a better integration of flexible demand (Demand Response, Demand Side Management) with Distributed Generation, energy storages and Smart Grids. This would lead to an increase of the value of Demand Response, Demand Side Management and

Distributed Generation and a decrease of problems caused by intermittent distributed generation (mainly based on renewable energy sources) in the physical electricity systems and at the electricity market.

Approach

The first phase in the Task was to carry out a scope study collecting information from the existing IEA Agreements, participating countries with the help of country experts and from organized workshops and other sources (research programs, field experience etc), analyzing the information on the basis of the above mentioned objectives and synthesizing the information to define the more detailed needs for the further work. The main output of the first step was a state-of-the art report.

The second phase (Task extension) is dealing with the effects of the penetration of emerging DER technologies to different stakeholders and to the whole electricity system.

The main subtasks of the second phase are (in addition to Subtasks 1 – 4 of the phase one):

Subtask 5: Assessment of technologies and their penetration in participating countries

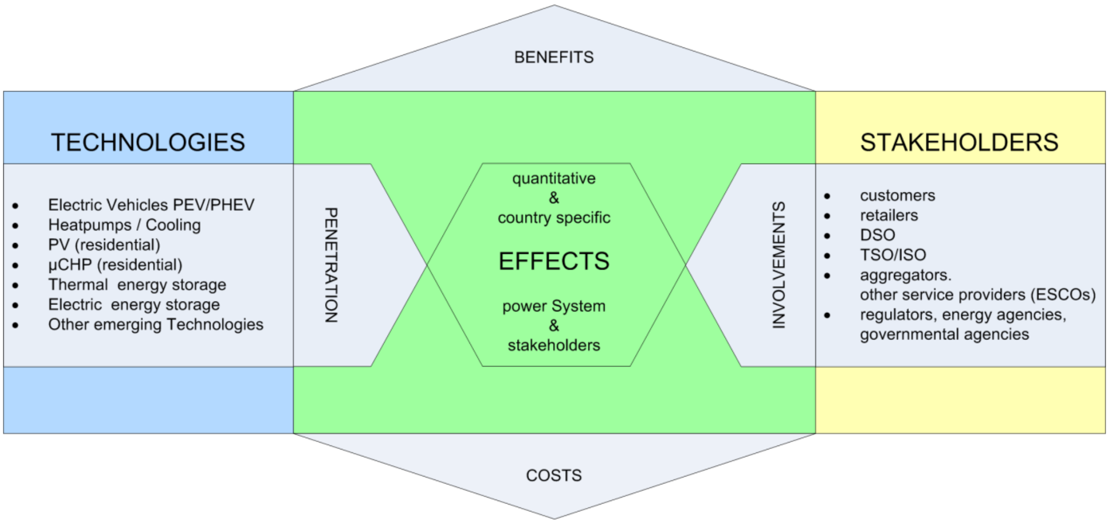
Subtask 6: Pilots and case studies

Subtask 7: Stakeholders involved in the penetration and effects on the stakeholders

Subtask 8: Assessment of the quantitative effects on the power systems and stakeholders

Subtask 9: Conclusions and recommendations

The figure below describes the concept of this extension.



Results

µ-CHP technologies generate both heat and power and can thus be considered in sites where a sufficient heat load is present. µ-CCHP (micro combined cooling, heating and power), which produces cooling by absorption chiller, is being studied but not widely available commercially. Energy saving with µ-CCHP compared to compression chiller is not evident in all cases.

In this report different µ-CHP technologies were reviewed. Typical features of µ-CHP units based on internal combustion engine are: low costs, high efficiency, wide power range and ability to run on different fuels. Internal combustion engine power plants are modular, i.e. standardised units can easily be combined. Their weak points include noise, high emissions and high maintenance costs. Advantage of gas turbines is small size. Disadvantages include poor efficiency at part load and high investment cost. Advantages of Stirling engine, when compared with internal combustion engines, include stable combustion, low noise and emissions and longer maintenance intervals. Advantages of fuel cells are: high electrical efficiency (also at part load), low noise and emissions. Disadvantages are very high costs and fuel quality requirements.

Besides natural gas and heating oil, wood chips or other biomass may be used in ICE, stirling engines or microturbines. Gasification stage and gas purification is required with ICE and microturbine. The benefit is the wide availability, renewability and often low cost of biomass.

Finally, µ-CHP can use solar radiation as energy source. The disadvantage will be that output cannot be modulated according to user and system needs.

Status and perspectives of µ-CHP in the participating countries

The appendices describe the current status, policies and projects related to µ-CHP in the Netherlands, Austria and France. The following conclusions can be made.

In Finland, the penetration of µ-CHP's is very low, with only few units operational. The natural gas distribution network is very limited, which restricts the use of gas-consuming µ CHP units. Also the size of these units is on the high end of the µ-CHP power range, and household-sized units do not exist. Also there is no support for µ-CHP's in Finland. For this reason there is no separate report from Finland. In Spain there is a similar situation.

In France the penetration of µ-CHP's is very low, with only few dozen units operational. There are no household-sized units but the units have been installed in hospitals, sport centers, research centers, etc. There is a purchase obligation, according to which EdF must purchase the produced electricity for 80 €/MWh. The future success of µ-CHP depends on incentives and competitiveness of other heating technologies. According to low scenario, there would be 200 MWe µ-CHP's in France by 2020.

In Austria there are a few hundred µ-CHP's operational and most of them are residential-sized gas engines. All but the smallest µ-CHP's using gas are applicable for subsidies of up to 25% of environmentally related investment costs. However, there are restrictions to the subsidy, for example private citizens are ruled out, the applicants have to run a business. The experience in Austria is that from the point of view of distribution grids, µ-CHP's produce far more revenue losses to the DSO than what they can create savings by reducing peak loads. In other words, from the perspective of a grid operator, µ-CHP's reduce revenues in low voltage grids disproportionately.

In the Netherlands the expectations for the introduction of µ-CHP were high a few years ago. It was expected that the traditional high-efficiency boilers could be replaced by µ-CHP . However, the prices of the technology have not gone as expected and also discontinuation of investment subsidies has had the effect that the real penetration of the technology is lagging behind. There used to be an investment support of about 5000 € for domestic µ-CHP units but at the moment this has been discontinued.

Horticultural sector is quite important in the Netherlands with regard to µ-CHP and some units were already installed in the 1990's. Currently there are about 1500 µ-CHP units installed in NL. The total market, if prices could be lowered, is several million units. In NL, as opposed to Finland, the gas distribution network is extensive, thus gas-based µ-CHP can be installed almost anywhere.

DR is easily implemented with µ-CHP because thermal storages are becoming more commonplace. In the horticultural sector they have existed for years. In the residential sector the thermal storage can be used either to store hot tap water or hot water for heating.

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1. CHP technologies for distributed generation

Cogeneration (combined heat and power, CHP) systems have the ability to produce both useful thermal energy and electricity from a single source of energy. This means that the efficiency of energy conversion to useful heat and power is potentially significantly greater than in separate generation of heat and power. There are also solutions of *trigeneration* or combined cooling, heat and power (CCHP) technology. In this case an absorption chiller has been integrated with the machine so that cold water or air can be produced in summer conditions.

Small combined heat and power units are called micro-CHP or µ-CHP units. An exact power limit has not been defined. In this report we assume a rough limit of 50 kW_e, inspired by the EU Directive 2004/8/EC.

This report aims to provide an up-to-date review of the various micro-CHP technologies. As residential scale cogeneration technologies have just begun entering the market with heavy subsides. Technologies available for residential, i.e. single-family (< 5 kW_e) and multifamily (3 – 50 kW_e) applications, commercial and institutional cogeneration applications include:

- fuel cell systems,
- reciprocating internal combustion engine systems,
- reciprocating external combustion Stirling engine systems and
- microturbines.

In addition there are other technologies under development. The review covers the performance and cost of these technologies where the information was available.

At the time of writing (2011) the use of small-scale commercial cogeneration plant in applications like hospitals, leisure facilities, (particularly those incorporating swimming pools), hotels or institutional buildings is well established and some of the technology fairly mature. These products are used to meet electrical and heat demands of a building for space and domestic hot water heating, and potentially absorption cooling of a building. However, the use of cogeneration plant for residential buildings has yet to become commercially viable though several manufacturers have developed products or are developing products suitable for residential scale use.

The next chapters will review each of the technologies in turn. Despite their benefits fuel cells are lagging very much behind other technologies in commercialization (Figure 1). Internal combustion engine based µ-CHP's as well as larger microturbines and some Stirling engines are already commercially available.

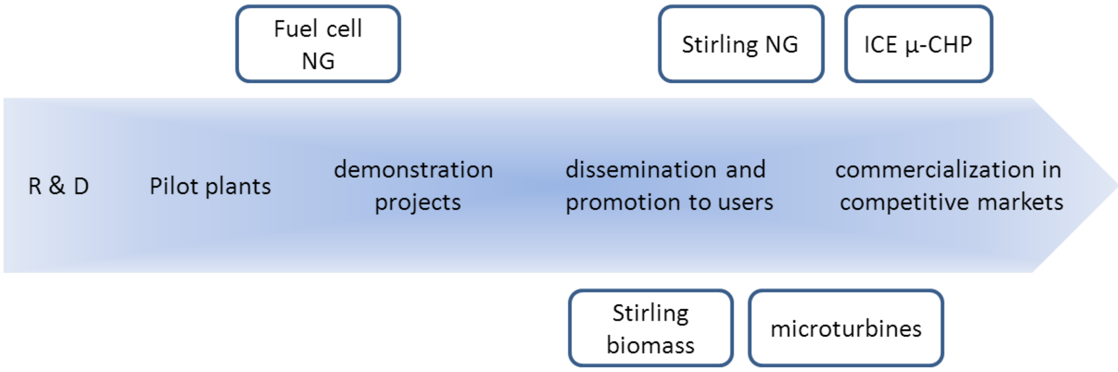

Figure 1: Stage of commercialization of different µ-CHP technologies according to Zach et al (2010). NG = natural gas.

2. Fuel cells

A fuel cell (abbr. FC) converts the chemical energy of a fuel and oxygen continuously into electrical energy. Typically, the fuel is hydrogen. Thus, the energy incorporated in the reaction of hydrogen and oxygen to water will be transformed into electrical energy. The "secret" of fuel cells is the electrolyte which separates the two reactants, hydrogen and oxygen, to avoid an uncontrolled explosive reaction. Basically, the fuel cell consists of a sandwich of layers which are placed around this central electrolyte: the anode at which the fuel is oxidized, the cathode at which the oxygen is reduced, and bipolar plates which feed the gases, collect the electrons, and conduct the reaction heat. To achieve higher powers of fuel cells, a number of single cells are connected in series. This is called a fuel cell stack. Fuel cells can be categorised according to the electrolyte material and, correspondingly, the required operating temperatures into low, medium and high temperature applications. Table 1 lists the main characteristics of the main fuel cell types.

Table 1. Types of fuel cells and main characteristics (DOE 2011, Pehnt 2003)

	AFC	**PEMFC**	**PAFC**	**MCFC**	**SOFC**
Electrolyte	KOH	Proton conducting membrane	Phosphoric acid	Carbonate melt	Y stabilised ZrO_2
Temperature	90–100 °C	50–100 °C	150–200 °C	650 °C	800 – 1000 °C
Ion	OH^-	H^+	H^+	CO_3^{2-}	O^{2-}
$\eta_{system,el}$ **(natural gas)**		30–42 %	38–42 %	50–55 % (w/ ST > 55%)	30–55 % (w/ GT> 60%)
$\eta_{system,el}$ **(hydrogen)**	60 %	38–50 %	47–50 %	n.a.	n.a.
Favoured application	Space, military, portable	Mobile, portable, CHP	CHP	CHP	CHP, auxiliary power
Power range [kW_{el}]	10–100	1 – 100	50 – 10 000	300 – 3000	1 – 2000
Status	First commercial production	Subsidised commercial production	Small series production (200 kW_{el})	Subsidised commercial production	Subsidised commercial production

2.1 Fuel cell systems

Fuel cell systems include not only the fuel cell stack but also

- a fuel processor to allow operation with available hydrocarbon fuels,
- a power conditioner to regulate the output power of the cell and where necessary convert it to alternating current,
- an air management system to deliver air at the proper flow rate, temperature, pressure and humidity,
- a thermal management system to remove heat from the stack and to transfer heat among various system components and, in some cases,
- a water management system to ensure that water is available for fuel processing and reactant humidification.

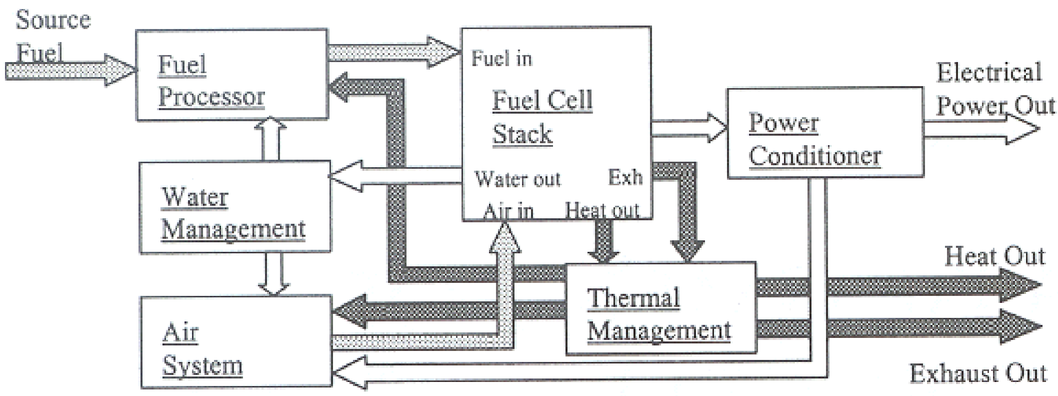

Figure 2. Fuel cell system schematic (Ellis 2002).

The low-temperature stacks, PEMFC and PAFC, require more extensive fuel processing and yield thermal energy at a lower temperature. The high-temperature stacks, MCFC and SOFC, are more flexible in their fuel requirements and yield thermal energy at a higher temperature. All four types have similar requirements with respect to power conditioning.

2.1.1 Fuel processing

PEMFCs and PAFCs require hydrogen for operation. MCFCs and SOFCs can use hydrogen and carbon monoxide as fuel and may even be able to reform a simple hydrocarbon, such as methane, to a usable fuel within the cell. In addition, virtually all fuels require some type of "clean-up" operation. The development of compact, efficient, and economical fuel processors that respond quickly to load changes is currently an active area of research. (Ellis 2002)

2.1.2 Power conditioning

The power conditioning system transforms DC power from the fuel cell into AC power for the grid and possibly provides reactive power. An inverter with suitable controls is used for this purpose.

2.1.3 Air, water and thermal management

Air is required for the fuel cell stack and for the fuel processor. Air can be supplied by a compressor (at pressures 2 to 10 atmospheres) or by a blower. The flow rate of air is determined by the reaction rate of the oxygen at the cathode. The air system has an important effect on the fuel cell system performance – power density and efficiency improve with increasing air pressure. However, if the compressor power is provided by the fuel cell stack, the best system performance occurs at an optimum operating pressure. In addition to the air compressor, the air supply system includes heat exchangers and humidifiers (for the PEMFC) to ensure that the temperature and humidity of the air stream are compatible with the stack.

Water is required for fuel processing in all fuel cell systems and also for humidification of the reactant gases in the PEMFC. Since water is produced by the cell reaction it can often be condensed from the exhaust stream and reused.

The thermal management system consists of the network of heat exchangers, fans, pumps, and compressors. They are all required to provide for stack cooling, heat recovery for cogeneration, and reactant preheating or precooling. The amount of heat released during the fuel cell reaction is comparable to the amount of electricity that is provided. This heat must be removed and a portion of it can be recovered to meet the thermal needs of a cogeneration application. In PEMFCs and PAFCs stack cooling is accomplished by circulating a heat transfer fluid through cooling channels in the stack. Heat transferred to the coolant can be recovered and used to meet the thermal needs of the building application. In MCFCs and SOFCs cell cooling is provided by the anode and cathode gas streams, which leave the stack at a higher temperature than they enter. In these high-temperature stacks, heat transfer from the cell reaction may also be used to supply energy to the endothermic fuel reforming reaction. (Ellis 2002)

2.1.4 Efficiency

Figure 3 provides an example of representative energy flows for a PAFC fuel cell system. Values for the fuel processor and power conditioning system are estimates. In this example the fuel processor is approximately 85% efficient, the fuel cell stack is operating at 49%, and the inverter has an efficiency of 95%. The overall electrical conversion efficiency is 40%. Approximately 40% of the input energy is available as thermal energy at temperatures ranging from 40 C to 80 ºC. Finally, 20% of the input energy cannot be economically recovered and is discharged to the surroundings through the exhaust gas and the power conditioner heat loss. The cogeneration efficiency reflects not only the electrical power but also the useful thermal energy available from the fuel cell system. The overall cogeneration efficiency of the example plant is 80%.

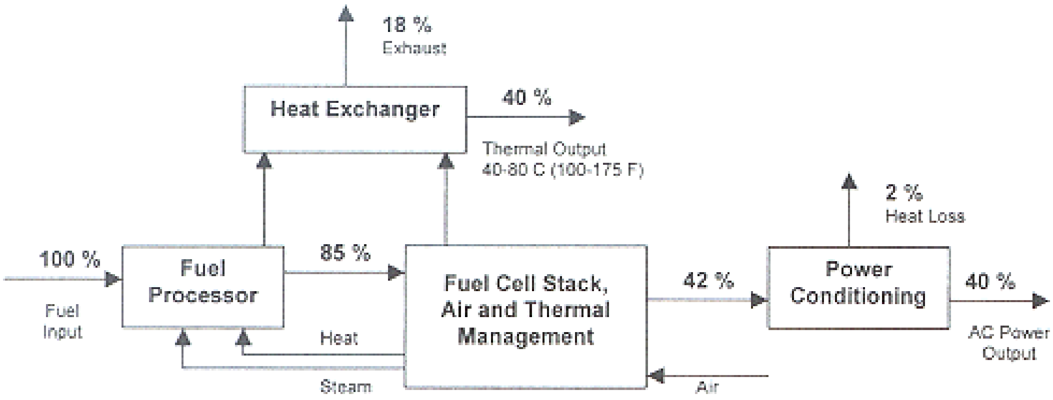

Figure 3. Block diagram for PAFC power plant (Ellis 2002).

2.2 Performance characteristics of FC-based systems

The performance of fuel cell systems is a function of the type of fuel cell and its capacity. The optimization of electrical efficiency and performance characteristics of fuel cell systems poses an engineering challenge because fuel cell systems are a combination of chemical, electrochemical, and electronic subsystems. (Onovwiona 2003)

2.2.1 Electrical efficiency

Performance data for fuel cell systems collated by Energy Nexus Group is presented in the following table:

Table 2. Performance characteristics of fuel cell based cogeneration systems (Onovwiona 2003)

Performance Characteristics	**System 1**	**System 2**	**System 3**	**System 4**	**System 5**
Fuel Cell Type	PEMFC	PEMFC	PAFC	SOFC	MCFC
Nominal Electricity Capacity [kW]	10	200	200	100	250
Electrical Efficiency [%], HHV	30 %	35 %	36 %	45 %	43 %
Fuel Input kW	29	586	557	234	586
Operating Temperature [^{o}C]	70	70	200	950	650
Cogeneration Characteristics					
Heat Output [kW]	12	211	217	56	128
Total Overall Efficiency [%], HHV	68 %	72 %	75 %	70 %	65 %
Power / Heat Ratio	0.77	0.95	0.92	1.79	1.95
Effective Electrical Efficiency [%], HHV	53.6 %	65.0 %	70.3 %	65.6 %	59.5 %
HHV = Higher Heating Value					

Source: Energy Nexus Group (2002)

2.2.2 Availability and part-load operation

The commercially available 200 kW PC25 system fleet (200-plus units) has demonstrated greater than 90% availability during over four million operating hours. As fuel cell systems mature, their reliability should improve.

The data from Japanese demonstrations indicate that mean time between failure (MTBF) rates are approaching 10000 hours for both residential PEMFC and SOFC (Staffell 2009).

Fuel cell stack efficiency normally reaches its maximum at 20–40% of rated power, above which it declines slowly. This results in a system electric efficiency that is relatively steady down to one third to one-quarter of rated power. This provides systems with potentially excellent load following characteristics. However, power consumption of auxiliary components as well as decreased fuel utilisation may decrease part load efficiency significantly (Staffell 2009). The figure below shows an example of the efficiency curve for a PEM fuel cell system.

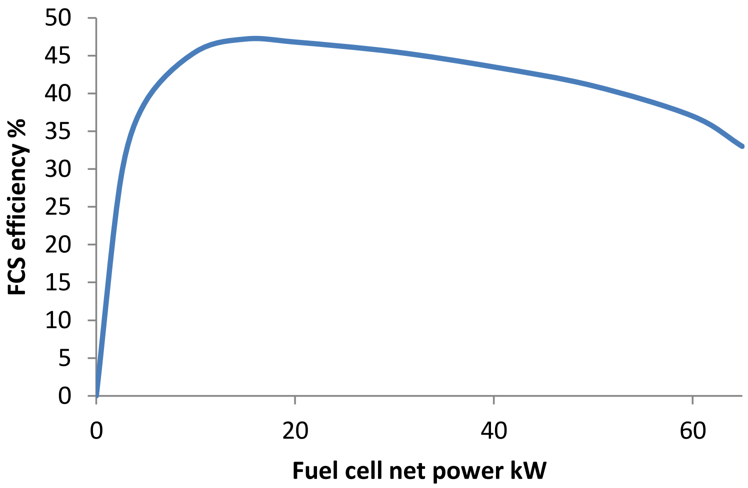

Figure 4: Example of PEMFC system efficiency as function of FC net power (Kim & Peng 2007).

While part-load efficiencies of fuel cells are generally high, MCFC and SOFC i.e. high temperature fuel cells require some time for heat-up and cool-down. For example the Bluegen SOFC can be power-modulated over its complete range 0–2 kW_e within a 15 minute time period (Föger & Rowe 2011). Low-temperature fuel cells, on the other hand, can be regulated between 30 % and 100 % of rated output power in a few seconds.

2.2.3 Costs

FC µ-CHP units are still in pilot stage and prohibitively expensive. FC based cogeneration system capital costs consists of costs of subsystems. The stack subsystem is estimated to represent 25–40% of equipment costs, the fuel processing subsystem represents 25–30% of equipment costs, the power and electronics subsystem represents 10–20% of equipment costs, the thermal management subsystem represents 10–20% of equipment costs, and ancillary subsystems represents 5–15% of equipment costs.

The cost distribution between different subsystems varies significantly depending on the source. Based on older study by Directed Technologies, Inc the system level components, excluding the stack and heat exchangers, are not strongly dependent on the system size (James 1999). This indicates that system cost per kW may be significantly larger in 1 kW systems compared to 10 kW systems.

Actual cost data from Japan (Table 3) also indicates that cost targets for 1 kW systems may be difficult to reach if fuel cell systems can not be simplified (Staffell 2009).

Table 3: Known sale prices for fuel cell micro-CHP systems. (Staffell 2009)

	System	Year	Price	Description	Ref.
PEMFC	ENEOS, Toshiba (0.7kW ENEFARM)	Sep. 2009	€22,500	Current sale prices in Japan, including local taxes. System includes a backup boiler and hot water tank, plus other ancillaries.	[81]
	Panasonic (1.0kW ENEFARM)		€23,900		[93]
	GS Fuel Cell, Fuel Cell Power, Hyosung (all 1kW systems)	2008	€80,000	Given as the current system price in 2008. (only available in limited trials in South Korea)	[289]
		2007	€70,000	Given as the individual price for the 70 demonstration units delivered in 2007.	[112]
	Plug Power (5kW)	2001-03	€55,000-85,000	The average purchase and installation costs during the US Department of Defense field trials.	[116, 290, 291]
SOFC	Kyocera (0.7kW)	2009	~€70,000 per kW	Mentioned in the METI technology roadmap and by Kyocera during the demonstration project.	[88, 292]
	Sulzer Hexis (1kW)	2000-05	~€55,000	Mentioned as the cost of demonstration systems. The later Galileo model was described as "less costly", but no price was given.	[148]
PAFC	UTC and Fuji (100+kW)	2001-08	€2800-5400 per kW	The average sale price of industrial CHP systems.	[47, 193, 195, 293, 294]
AFC	(5-10kW)	2006	€10,000 per kW	Quoted price from an anonymous manufacturer for a hydrogen fuelled CHP system.	-

In addition to the table above we can mention a 100 kW SOFC fueled by natural gas, and marketed by Bloom Energy, which is sold for $7000 per kW (Wesoff 2011).

Table 4 Expectations and targets given by the manufacturers and governments bodies involved with world-leading fuel cell demonstrations. (Staffell 2009)

Systems		Year	Cost / Price per system	Production volume	Description	Ref.
PEMFC	South Korea	2008	€56,000	100	Expected price during the third and final year of the current demonstration project.[107]	[112]
		2010	€12,000		Target cost stated in the Korean national action plan.	[112]
		2012	€8,000	10,000 cumulative	Target price set by the Ministry of Knowledge Economy.	[289]
	Japan	2004	€14,500	10,000 p.a.	Estimated manufacturing cost for ENEFARM systems made by the manufacturers.	[98, 295]
		2012	€5,000 – 8,000	50,000 p.a.	The METI technology roadmap for production cost of residential cogeneration systems.	[88]
		2015	€3,500 – 5,000	500,000 p.a.		
		2015	€3,500	200,000 p.a.	Panasonic's target price for systems set in 2008.	[296]
		2020-2030	€2,750		The METI technology roadmap for production cost of residential cogeneration systems.	[88]
SOFC	Japan	2008	~€3,800	Mass production	Kyocera's expected retail price for systems (including hot water tank).	[297]
		2015	€7,000 / kW	Several thousand p.a.	The METI technology roadmap for residential cogeneration systems.	[88]
		2020-2030	€2,750 / kW			

3. Other micro-CHP systems

The benefit of fuel cells is the high power-to-heat ratio and quiet operation. In this chapter we review some other technologies which currently are still more competitive than fuel cells. A summary comparison table for reciprocating internal combustion engine (ICE), fuel cell and Stirling engine based single-family residential cogeneration systems is presented in Table 5. The information presented in the tables is representative of the technologies, and provides an opportunity to make an approximate, yet direct comparison of the technologies.

Table 5 Basic technical characteristics of four key micro-CHP systems synthesised from published literature. (Hawkes 2009)

	Internal combustion engine	PEFC	SOFC	Stirling engine
Electrical efficiency (part load, full load)	10%, 20%	30%, 26%	45%, 40%	5%, 10%
Overall efficiency (part load, full load)	80%, 85%	80%, 85%	75%, 80%[a]	80%, 90%
Supplementary thermal system efficiency	86%	86%	86%	86%
Minimum operating set point (% of rated power)	20%	20%	20%	20%
Minimum up-time (min)	10	60	60	10
Maximum ramp rate ($kW_e\ min^{-1}$)	0.2	0.2	0.05	0.2
Start-up energy consumption (kW_e, kW_{th})	0.008, 0.5	0.017, 1.6	0.017, 2.0	0.008, 0.5

3.1 Internal Combustion (IC) Engine cogeneration systems

Reciprocating IC engines are based on the Otto cycle (spark ignition) or the Diesel cycle (compression ignition). In the Otto engine, the mixture of air and fuel is compressed in each cylinder before ignition is caused by an externally supplied spark. The Diesel engine involves only the compression of air in the cylinder and the fuel is introduced into the cylinder towards the end of the compression stroke, thus the spontaneous ignition is caused by the high temperature of the compressed mixture.

Diesel engines are mainly four-stroke direct injection engines fitted with a turbo-charger and intercooler. Intercooler (or aftercooler) is one heat source for µ-CHP. Other heat sources are exhaust gases, jacket water, and oil. Diesel engines run on diesel fuel or heating oil, or they can be set up to operate on a dual fuel mode that burns primarily natural gas with a small amount of diesel pilot fuel. Diesel engines for µ-CHP run at speeds between 1500 and 2500 rpm. Cooling systems for diesel engines are more complex in comparison to the cooling systems of spark ignition engines and temperature are often lower, usually 85^{o}C maximum, thus limiting the heat recovery potential.

In addition to the engine and generator, the µ-CHP system must include heat exchangers, switchboard (e.g. for grid parallel operation or islanding operation), engine lubrication system, acoustic insulation and catalytic converter for reducing emissions.

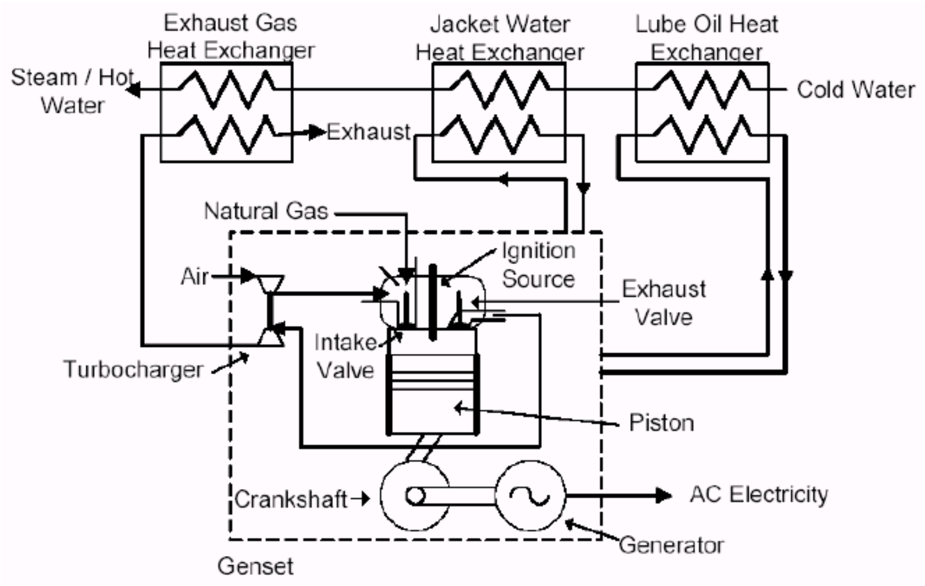

Figure 5 Typical packaged internal combustion engine based (spark ignited) cogeneration system. (Knight 2005)

Reciprocating internal combustion engines have mechanical efficiencies that range from 25–30 %. In general, diesel engines are more efficient than spark ignition engines because of their higher compression ratios. However, the efficiency of large spark ignition engines approaches that of diesel engines of the same size. The overall efficiency in cogeneration mode reaches approximately 80–85 (% HVV).

Reciprocating internal combustion engines used in cogeneration applications and power generation generally drive a synchronous generator at constant speed to produce a steady alternating current. For cogeneration applications, the heat to power ratio of the engine is critical. The percentage of fuel energy input used in producing mechanical work, which results in electrical generation, remains fairly constant until 75 % of full load, and thereafter starts decreasing. This means that more fuel is required per kWh of electricity produced at lower partial loadings, thereby leading to decreased efficiency. The amount of heat generated from the jacket coolant water and exhaust gases increases as electrical efficiency of the engine decreases; i.e. the amount of useful heat derived from a cogeneration system increases as the efficiency of electric power delivered decreases.

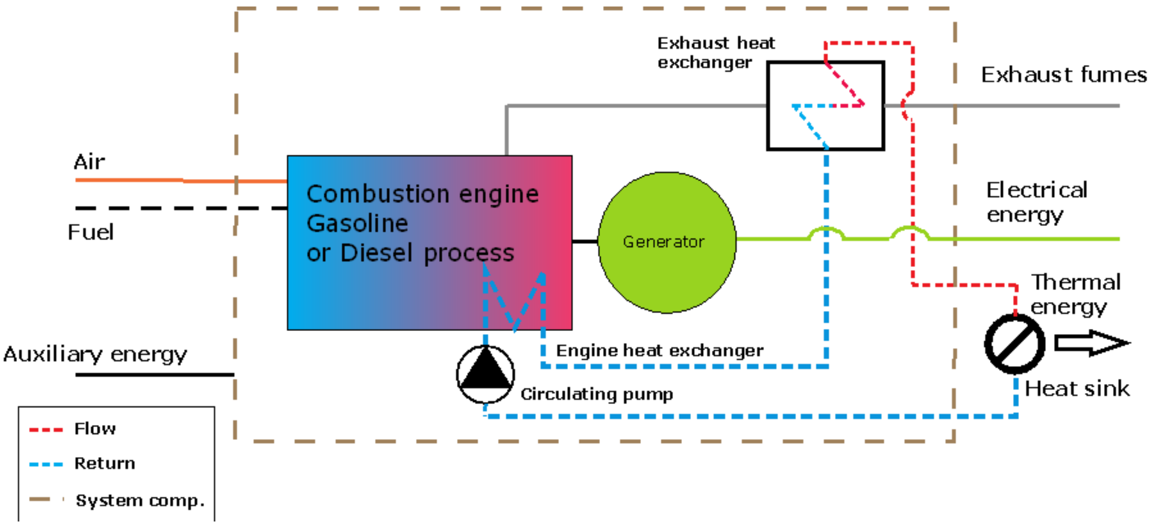

Figure 6 System configuration of a micro-CHP system based on combustion engine technology (www.bioenergy2020.eu)

Generally, reciprocating internal combustion based cogeneration systems less than 500 kW in size cost between 800 and 3,020 $/kW, with higher cost for smaller cogeneration systems (Knight 2005). Zach et al (2010) estimate the cost 3300 €/kW$_e$ for a 5.5 kW$_e$ µ-CHP unit, excluding peak heating system and installation. For 3 kW$_e$ µ-CHP unit they estimate 3960 €/kW$_e$, excluding peak heating system and installation

3.2 Stirling engine cogeneration systems

Stirling engine differs from internal combustion engine by the fact that cylinders are closed and combustion process takes place outside it. Piston is moved by pressure changes due to heating and cooling of working gas, which may be e.g. air or hydrogen (Figure 7). The Stirling engine normally drives a synchronous generator which is connected to the grid. Induction generators are also used.

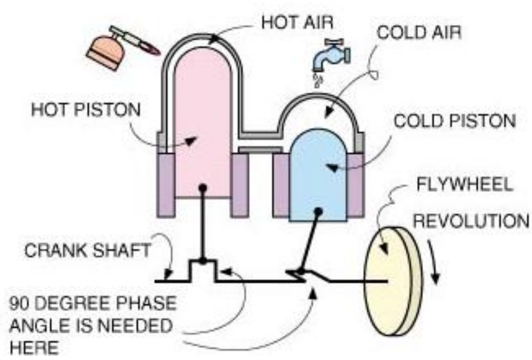

Figure 7. Operation principle of Stirling engine. (NMRI 2004)

Stirling-operated facilities are relatively expensive and until now they are especially used in the smaller size categories. In order gain a good electrical efficiency, a high temperature level is required, but that happens at a risk of fouling the heat exchanger. On the other hand, some solutions have been developed to avoid this risk.

Stirling engines operate smoothly, with lower vibration, noise level and emissions than reciprocating ICE. Also, the external combustion process allows the use of a large variety of fuels and longer fuel retention times in the combustion chamber compared to internal combustion engines. As a result, the control, and hence the efficiency of combustion is higher. Also other heat sources except combustion, such as solar heat can be used.

Presently the electrical efficiency of Stirling engines can reach 40 %, and the overall efficiency of a Stirling engine cogeneration system is 65 – 85 %. Stirling engines also have good capability to operate under part-load conditions. It is expected that the efficiency at 50 % load can be in the 34-39 % range. Since the technology is still in the development phase, there is no statistical data for the reliability and availability of Stirling engines. However, it is expected that the reliability of Stirling engines will be comparable to that of diesel engines, with an expected annual average availability in the 85–90 % range (Knight 2005). Stirling engines start more reliably in cold weather than ICE.

Capital costs of Stirling engine cogeneration systems have remained high. In 2011 in the Netherlands models with 1 kW power output were sold at 10,000 €. According to Zach et al (2010), the cost of 1 kW_e unit is about 6000 €, and in addition one has to acquire a peak heating system and chimney, which costs 1700 € in a newly-built home, and installation worth about 1500 €. This means that a Stirling engine (even with 25 % investment support) cannot compete with gas-fired boiler, which is several thousand euros cheaper. Maintenance costs of Stirling engine cogeneration systems can be lower than those of ICE driven cogeneration systems (Knight 2005).

3.3 Microturbine cogeneration systems

Most microturbines fall outside the scope of our study in terms of their rated power but there are also models in commercial production whose maximum output is less than 50 kW_e. Consequently they are not yet feasible in single-family houses but can be feasible in e.g. residential housing complexes, hotels, leisure centres, schools, hospitals, etc. However, development work is also on-going with household-sized units. It has been enabled by increasing performance and efficiency of automotive turbochargers during recent years (Visser et al 2011). At the same time, efficient high-speed motor-generators have become available at relatively low prices. With low-cost configurations, 16 % electrical efficiency can be realized, offering a solution for µ-CHP application. The Dutch company MTT Micro Turbine Technology BV plans to start field tests in 2013 to demonstrate the small microturbine in real circumstances and plans a commercial launch in 2014 (MTT 2012).

Microturbine is much more silent and easier to maintain in operation when compared to internal combustion engine (ICE), which in turn requires a good sound insulation. Microturbines are also small compared to their power output. However, small-scale CHP systems using micro-turbines are more expensive compared with ICE systems.

The heart of the microturbine is the compressor-turbine package, which is commonly mounted on a single shaft along with the electric generator. The microturbine µ-CHP also includes heat exchanger, recuperator, and an inverter. The generator can often act also as a starter motor for the turbine.

Gas turbine thermal efficiency to a large extent depends on losses resulting from flow leakage, thermal losses and friction. These losses become more dominant when down-scaling a gas turbine in size and power, due to blade tip clearance and volume-surface ratio scale effects. Moreover, in smaller turbines viscous friction losses become larger. As a result, there is a fundamental limitation to efficiency of micro turbines with a conventional configuration (MTT 2012). Microturbine µ-CHP can achieve electrical efficiency between 25–30 % and total efficiency of 70–90 %. This value requires a recuperator, a type of heat exchanger which uses the exhaust gases to warm up the inlet air to the turbine (see Figure 8). With recuperator a large portion of the exhaust gas heat is recovered and electrical efficiency can be substantially increased. There are also commercial products where an absorption chiller has been integrated, creating a CCHP (trigeneration) system.

Microturbines must have certain auxiliary systems. These include lubrication system, cooling system, air intake system, fuel gas compressor and remote control. Lubrication is needed in the shaft bearings. Lubrication oil can be circulated by a pump and cooled in oil-to-air cooler. Air intake system provides combustion air for the turbine. Fuel gas compressor compresses the fuel gas if the supply pressure is not high enough. Remote control allows an energy box (home energy management system) to control the operation of the microturbine.

Load following characteristics of microturbines are good. They can normally be power-modulated between 50 % and 100 % of rated power in a fraction of a second (Nayak & Gaonkar 2012). Partial load electrical efficiency of microturbines is relatively good. However, because of the incomplete combustion process, nitrogen oxides and carbon monoxide emissions increase multifoldly when the turbine is operated at partial load. In large installations this problem can be fought by installing several turbines in parallel.

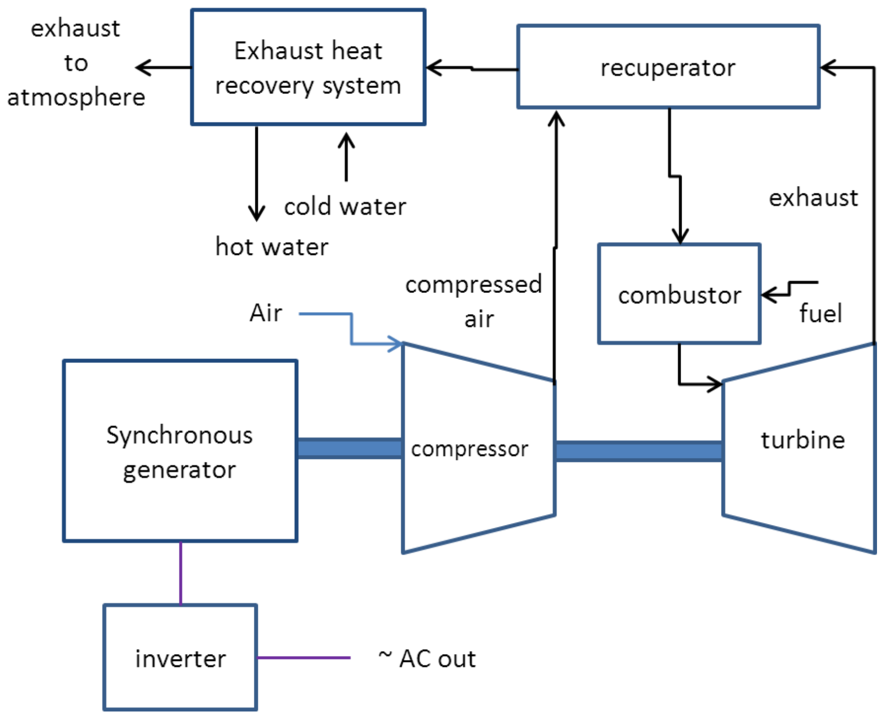

Figure 8: Schematic diagram of a microturbine µ-CHP system. The turbine drives a syncronous generator, which produces high-frequency AC power. The inverter converts this into grid-level AC power.

3.4 Micro steam engines

While reciprocating steam engines have been displaced as drivers of industrial processes by internal combustion engines and electric motors, currently their application in small-scale power generation is being studied. Steam engine is an external combustion engine, and as such is fairly tolerant of fuel quality. For example wood pellets or natural gas could be used as fuel. They also have the ability to be more quiet than internal combustion engines.

3.5 Organic Rankine cycle turbines

The organic Rankine cycle (ORC) works by pumping a working fluid is to a boiler where it is evaporated, passes through a turbine and is finally re-condensed. The working fluid that drives the turbine is a low boiling point organic fluid such as R-134a, R245fa or hexamethyldisiloxane, which allows the system to run efficiently on low-temperature heat sources (even less than 100 °C). Also investment costs of ORC are lower than those of steam boilers because of the lower working pressure. ORC requires a cool liquid resource for working fluid condensing, which can be produced e.g. from ground source. Sufficient temperature difference between the cooling liquid and input temperature must be present.

Most ORC manufacturers concentrate on larger machines, with power outputs more than 500 kWe but there are also machines in the kilowatt range. Few figures about the cost of small

ORC systems are available. Invernizzi et al. (2008) consider specific cost characteristic of ORC plants to be 2500 - 3000 €/kW in the range of 50–100 kW.

3.6 Combined solar power and heat and solar μ-CHP

Combined solar power and heat is different from the above technologies in that it is not based on fuel burning, and is a variable-output technology, i.e. its power output cannot be freely controlled. Traditional solar PV panels allow most of the sun's energy to dissipate as waste heat. However, waste heat from the solar system can also be captured and used to heat water. One way in which a cogeneration panel can be built is to let a parabolic trough collect and concentrate solar radition on a PV panel, which is located near the focus of the trough. Cooling liquid is circulated on the backside of the panel, and is then taken through insulated pipes to a heat exchanger, in which hot tap water can be produced. Such system is sometimes called PV-T unit, reflecting the fact that heat can also be utilized.

While costing more than a single unit of either type, a PV-T unit can be produced much more affordably than two separate solar thermal and PV units. Also roof space is saved by combining the collectors into one. Additional benefit is that when the PV panels are cooled, their electrical efficiency increases. A risk with this technology is that the PV panel can be destroyed if there is a malfunction in the cooling circuit. This technology is commercially available in some countries.

Combined solar power and heat generation is also possible with heat engines, which usually involves concentrated solar power (CSP). We mention solar organic Rankine cycle, which uses evacuated tube collectors or parabolic trough collectors to provide heat for an ORC turbine.

4. μ-CHP systems capable of using biomass

The most common fuel for μ-CHP systems in use is natural gas. Combined heat and power generation from solid biomass - also in smaller scale - is a strongly growing sector of industry in the world. Solid biomass may be burned directly or first converted to gaseous form as described below. This technology enables wider utilization of wood-based fuels such as wood chips, pellet, or saw dust in μ-CHP units. μ-CHP systems using wood fuels are typically based on the following technologies:

- Stirling engines,
- microturbines (gasification or anaerobic digestion followed by turbine),
- gas-fired internal combustion engines (gasification or anaerobic digestion followed by an engine).
- microturbines (external combustion and heat exchanger),
- ORC process (organic Ranking cycle).

Renewable biogas is produced by anaerobic digestion or fermentation of biodegradable materials. However, biogas purification may be needed because the hydrogen sulfide H_2S contained in the biogas may corrode machine parts. One cubic meter of biomass can produce 30–150 m^3 of biogas by anaerobic digestion. The yield depends on the properties of the biomass. The heating value of biogas is about 18–26 MJ/m^3.

Biomass gasification is refers to conversion of solid fuels into a combustible gas mixture (e.g. wood gas) by partial combustion. Partial combustion process occurs when air supply is less than adequate for the combustion of biomass to be completed. The product gas contains various quantities of nitrogen, hydrogen, carbon monoxide and methane. The composition is dependent on the gasification process and the fuel moisture. The gas has to go through gas cleaning in order to remove tar and particles, before it can be combusted in an engine. Build-up of tar can cause problems in the purification stage. The energy content of wood gas is much smaller than that of biogas, about 5 MJ/m^3. When the efficiency of internal combustion engine is accounted for, 1 kWh of electricity needs about 2.5 m^3 of wood gas as fuel. This amount of wood gas again needs about 1 kg of dry wood in the gasification process. Biomass gasifiers combined with internal combustion engines are commercially available.

Table 6 shows some commercially available µ-CHP units capable of using biomass.

Table 6: Some commercial µ-CHP products which use biofuels (Haavisto 2010). Some cells were left empty because information was not available.

Technology	*fuel*	*P_e (kW_e)*	*P_{th} (kW_{th})*	*Total efficiency*	*Price €/kW_e*	*Country*	*Manu-facturer*
Stirling	pellets	1	15			AT	KWB
Stirling	pellets	2 – 3	7 – 11	> 85 %	8000	DE	Sunmachine
Stirling	pellets, chips, peat	9	50	> 85 %	8000	FI	Ekogen Oy
Stirling	gas, biomass, pellets	2 – 9	8 – 26	90 %		SE	Cleanergy
gasification + ICE	wood, chips, pellets, bio-waste	50 – 500	100 – 1000	75 - 90 %		FI	Gasek
gasification + ICE	chips	30	80		5000	FI	Volter
gasification + ICE	chips, pellets	4 – 250				IN	Ankur Scientific
Stirling	chips, biomass, biogas	35 – 140	140 – 560			DK	Stirling.dk
external combustion microturbine	wood chips, pellets	25	80			UK	Talbott's

5. Operating µ-CHP's

µ-CHP can be used in different applications that can belong to one of the following types:

- grid independent applications in which the µ-CHP is the sole provider of power to the load or works in parallel with other types of microgeneration,
- back-up power applications in which two power sources (e.g. utility grid as primary and µ-CHP as supporting source) are required to improve reliability but do not provide power simultaneously, and
- parallel power applications in which the µ-CHP and utility power operate simultaneously and can supply power into the utility grid.

In our task we are interested in the case where µ-CHP and grid power are connected in parallel. In this case there are different control strategies that are possible with a cogeneration system. Electrical load tracking calls for the µ-CHP device to have an electrical capacity that exceeds the minimum electrical requirement for the facility. The µ-CHP output power changes in response to the needs of the facility. The thermal output of the µ-CHP system is used whenever possible, otherwise it is simply rejected to the atmosphere (heat dumping). In case of biomass fuel, excess heat can also be used for drying the fuel. A separate heat source is required to provide thermal energy when the waste heat from the unit is not adequate. With thermal load tracking, the system is designed to follow the thermal load of the facility. Power that is generated during the course of supplying the thermal load is used by the facility to replace purchased electric power. The excess power can often be sold to the utility. However, profitability of selling excess power to the utility depends very much on legislation and subsidies in each country. Subsidy schemes with good intentions may sometimes give incentives to operation and investments that are not sound from the cost and environmental point of view.

A third option is to take into account electricity prices, which may vary with time, in optimizing the output of the µ-CHP. Peak load shaving from the grid perspective is also possible, it all depends on the incentives offered by the local DSO or an aggregator. For example in the EU-DEEP project (EU-DEEP 2009) a natural-gas-fired CHP engine 12 kWe/36 kWth was implemented and the operation was optimised based on electricity market price variations and heat demand. Peak heat demand was provided by a separate boiler. The thermal inertia of the building provided was taken into account in the optimisation so that the CHP could be run when the market prices were higher. There was no separate heat storage. Electricity storage was dimensioned to allow UPS functionality so that the CHP could be started to provide back-up power without interruptions. Some electrical loads such as water heating were used as controllable loads. When connected to the grid they were controlled market based and when islanded mode they supported balancing of the local island mode network.

A thermal storage provides an opportunity to store the heat from µ-CHP units, thus decoupling the unit dispatch from local heat demand and providing economical benefits (Staffell 2009, EU-DEEP 2009). However, thermal storage (such as hot water tank) brings along more costs and space requirements.

6. Summary

µ-CHP technologies generate both heat and power and can thus be considered in sites where a sufficient heat load is present. µ-CCHP (micro combined cooling, heating and power), which produces cooling by absorption chiller, is being studied but not widely available commercially. Energy saving with µ-CCHP compared to compression chiller is not evident in all cases.

In this report different µ-CHP technologies were reviewed. Typical features of µ-CHP units based on internal combustion engine are: low costs, high efficiency, wide power range and ability to run on different fuels. Internal combustion engine power plants are modular, i.e. standardised units can easily be combined. Their weak points include noise, high emissions and high maintenance costs. Advantage of gas turbines is small size. Disadvantages include poor efficiency at part load and high investment cost. Advantages of Stirling engine, when compared with internal combustion engines, include stable combustion, low noise and emissions and longer maintenance intervals. Advantages of fuel cells are: high electrical efficiency (also at part load), low noise and emissions. Disadvantages are very high costs and fuel quality requirements.

Besides natural gas and heating oil, wood chips or other biomass may be used in ICE, stirling engines or microturbines. Gasification stage and gas purification is required with ICE and microturbine. The benefit is the wide availability, renewability and often low cost of biomass.

Finally, µ-CHP can use solar radiation as energy source. The disadvantage will be that output cannot be modulated according to user and system needs.

7. Status and perspectives of µ-CHP in the participating countries

The appendices describe the current status, policies and projects related to µ-CHP in the Netherlands, Austria and France. The following conclusions can be made.

In Finland, the penetration of µ-CHP's is very low, with only few units operational. The natural gas distribution network is very limited, which restricts the use of gas-consuming µ-CHP units. Also the size of these units is on the high end of the µ-CHP power range, and household-sized units do not exist. Also there is no support for µ-CHP's in Finland. For this reason there is no separate report from Finland. In Spain there is a similar situation.

Among the installed systems, the Kempele eco-village has gained most publicity. The village of 10 single-family houses, located near Oulu, is heated via local low-temperature heating network. Heat is produced with µ-CHP, which can also produce 30 kW electricity. The village is not connected to the public electricity grid. There is also a large lead-acid battery, which can smooth out short peak loads. The µ-CHP is based on gasification of wood chips, followed by gas purification and combustion in gas engine. The plant is almost fully automatic. In summer the heat from the µ-CHP is used, except for hot tap water, for drying the wood chips. The system has worked well and less black-outs than in most public distribution grids have occurred.

In France the penetration of µ-CHP's is very low, with only few dozen units operational. There are no household-sized units but the units have been installed in hospitals, sport centers, research centers, etc. There is a purchase obligation, according to which EdF must purchase the produced electricity for 80 €/MWh. The future success of µ-CHP depends on incentives and competitiveness of other heating technologies. According to low scenario, there would be 200 MW_e µ-CHP's in France by 2020.

In Austria there are a few hundred µ-CHP's operational and most of them are residential-sized gas engines. All but the smallest µ-CHP's using gas are applicable for subsidies of up to 25% of environmentally related investment costs. However, there are restrictions to the subsidy, for example private citizens are ruled out, the applicants have to run a business. The experience in Austria is that from the point of view of distribution grids, µ-CHP's produce far more revenue losses to the DSO than what they can create savings by reducing peak loads. In other words, from the perspective of a grid operator, µ-CHP's reduce revenues in low voltage grids disproportionately.

In the Netherlands the expectations for the introduction of µ-CHP were high a few years ago. It was expected that the traditional high-efficiency boilers could be replaced by µ-CHP . However, the prices of the technology have not gone as expected and also discontinuation of investment subsidies has had the effect that the real penetration of the technology is lagging behind. There used to be an investment support of about 5000 € for domestic µ-CHP units but at the moment this has been discontinued.

Horticultural sector is quite important in the Netherlands with regard to µ-CHP and some units were already installed in the 1990's. Currently there are about 1500 µ-CHP units installed in NL. The total market, if prices could be lowered, is several million units. In NL, as opposed to Finland, the gas distribution network is extensive, thus gas-based µ-CHP can be installed almost anywhere.

DR is easily implemented with µ-CHP because thermal storages are becoming more commonplace. In the horticultural sector they have existed for years. In the residential sector the thermal storage can be used either to store hot tap water or hot water for heating.

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Appendix 1 Present situation of micro-cogeneration in the Netherlands

Rene Kamphuis

A1.1 Cogeneration of heat/cold and power in the Netherlands

A1.1.1 Combined heat-power technology

Micro-CHPs produce heat, hot water and electricity from a fossil fuel, mostly natural gas. Technologies currently in practical use are all based on combined heat and power production by burning natural gas. Burning can be done in a gas turbine, CHP or micro-CHP (HE-e[1]). Other techniques, e.g. based on fuel cells are not in use or very early in the research phase. The Netherlands has one of the largest fossil natural gas field reserves in the world and there is a large drive to integrate upcoming biogas production facilities, especially from agricultural digesters, in the gas grid. The gas grid net transmits 8 times as much energy compared to the electricity grid. Due to the inherent flexibility in heat delivery shifting electricity production or consumption is the most valid type of demand response. Heating and hot tap water preparation systems in the Netherlands, therefore, use natural gas as a fuel. Also taken into consideration the varying heat demand during the year, cogeneration is and has been a cost-effective technique with relatively low carbon emission.

In the industrial sector, large CHP-installations are used at steel factories and in oil refineries. The generated heat is used as process heat for the primary industrial processes; the carbon dioxide is transported to horticultural installations, where assimilation by the crops occurs. The installations are geographically confined to the two major industrial areas in the Netherlands.

In the commercial segment, in the horticultural sector and the utility housing sector, gas engines producing heat and power have been extensively introduced in the 90's of the previous century as a cheap and clean means to generate power and heat, of which the investment costs were subsidized. In the new millennium, with the advent of new more renewable technologies and subsequent diminishing of subsidy, the interest in cogeneration has almost vanished and installations have been sold to eastern Europe. Since, the liberalization of the sector and especially in the last few years, the sector has recovered due to the possibilities to operate CHP resources on the real-time energy market as dispatchable power. In this respect the horticultural and the utility building sector are different. In the horticultural sector the heat demand is decoupled from the

[1] Dutch abbreviation for high-efficiency (HR) electric (e)

electricity production/electricity prices by using buffer tanks to store hot water; in office buildings heat demand and electricity demand/price peaks more or less coincide.

Specific interest for micro-CHP is in the residential sector for the larger less-well insulated homes. The Netherlands heating manufacturers cover most of the market for domestic heating systems. In this sector, replacement of current improved-efficiency heating boilers of 15 years old is the target. These new micro-CHPs typically have an electrical power of 1 kW_e and a heating power of 8-9 kW_{th}. The market in the Netherlands is in the order of 6 million units which, with a lifetime of 15 years for individual units, would lead to selling 400,000 new systems a year. This would give a aggregated power of 400 MW, operating at peak times in the Dutch grid (during cold periods) with very swift dispatch (ramp-up/ramp-down) characteristics.

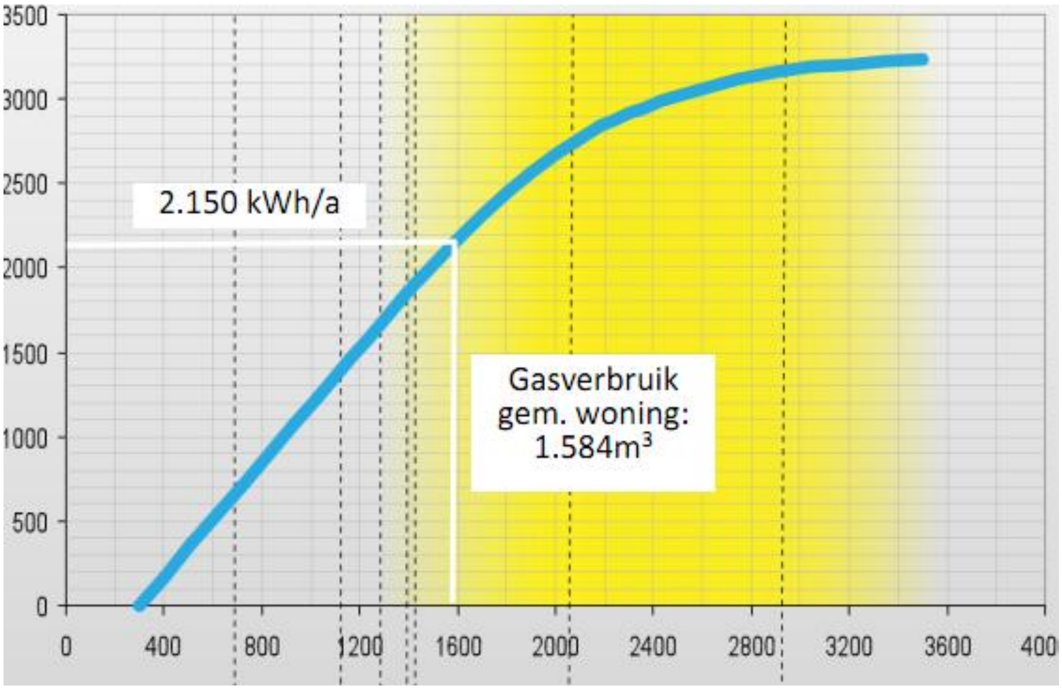

Figure A-1: Gas usage versus electricity production of a micro-CHP in a Dutch home following heat and tapwater demand

In Figure A-1, the gas consumption versus the possible electricity co-production is shown. It can be shown, that the niche in the homes, where these systems are usable (yellow region in the graph indicate), is in the larger homes with a considerable heat demand. Use cases have been calculated, that if 1600 m^3 gas is consumed, 2022 kWh of power is produced, which yields 329 Euro/yr (electricity saved minus extra gas consumed). For a home with a gas usage of 2600 m^3 2976 kWh is produced with a yearly revenue of 485 Euro.

Drivers for trade responsible parties to promote these new HR/e heaters in a clustered form of VPP are exerting active and passive control monitoring their portfolio:

- Passive. The production at customer sites at times day-ahead market prices are high, using existing profiles and in that way reducing the cost of their own energy, bought in. There is no control of production needed.
- Active. In this case demand response applications are intended. Instead of treating small DG as negative demand, small scale DG is used for optimization of portfolios and even compensation of ramp-up and ramp-down of profiled large installations, that cannot well be integrated from a market perspective. In this case, the electricity generation is partly controlled on the basis of market events.

In the Netherlands, in the domestic segment, combination of CHP with solar thermal is also considered due to the mutual complementarity of the tap water and heat demands served by PVT (Photo Voltaic systems including thermal capabilities) or CHP depending on the climate in the Netherlands. Combined cooling, heat and power production (CCHP) systems via tri-generation is currently in the research phase.

A1.1.2 Policy perspective

Micro CHP reduces CO_2 emissions by another twenty percent (5 to 4 tons on a year's basis). Compared to a traditional high efficiency heating system the energetic efficiency is increased by 20 %. The efficiency increase compared to a large thermal power plant is 60 % (if waste heat is not recovered). As for white goods, national labeling is also introduced for these types of devices. Currently discussions are ongoing what the classification will be. Indications are, that labels also will depend on the presence or absence of a control strategy. Heat demand following installations are C or D; electricity demand following systems will be B or C. Currently market introduction is hindered by the high price of the first units on the market. Currently the price is 10000 Euro[2] for a single system. The Dutch government provided a considerable subsidy to get a payback time of less than 5 years (5000 €), but prognosis of sales of the units is far below the prognosis made earlier. The micro-CHP is considered to be a transition technology to further decarbonisation of the energy infrastructure. As for PV energy, for the electricity produced, small users get the same price as they would pay at that moment. As of 2012 the subsidy on the investment in micro-CCHP has been terminated by the Dutch government. This has led to a significant ameliorisation of these technologies in the Netherlands and a shift of technology development from focus on the Dutch market to development for the German market.

A1.2 Load characteristics

The characteristics of the load profile for a typical installation during winter operation is shown in Figure A-2. The blue line gives the production, with heat demand operation and scheduling of hot tap water production, and the yellow line the amount of electricity imported from or exported to the grid. It can be seen, that electricity import during the day is considerably reduced. In the morning and the late afternoon still considerable

[2] http://www.remeha.nl/intelligentenergy/

production is present supporting the rest of the electricity system. Decoupling of heat and electricity production is due the internal thermal capacity of the home. The graph indicates the heat demand driven operation.

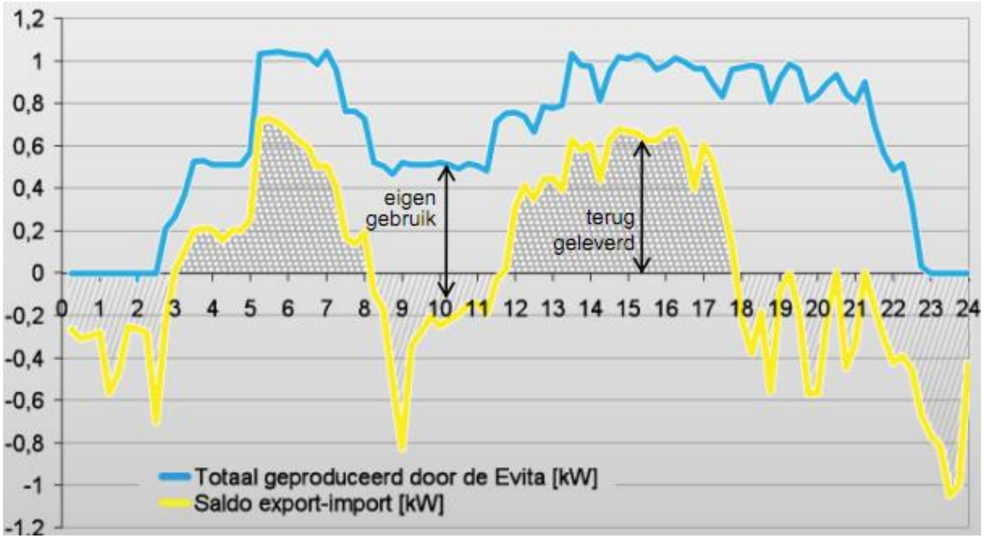

Figure A-2: Own generation (blue) and exported-imported electricity balance (yellow); kWs are on the Y-axis

A1.3 Flexibility for demand response applications

Due to the inherent thermal capacity of homes or buildings, operation of CHPs can be shifted considerably without impairing user comfort. Addition of a thermal buffer allows to decouple the electricity production and the heat demand. The thermal buffer can be used as an electric boiler to store tap water, but also concepts have been developed, in which part of the buffer is used to store heat for the heating system. In the horticultural sector, this mechanism is commonplace for several years now, but in homes, the concept is new (see Figure A-3). Compared to batteries, thermal energy storage is much cheaper, having a slightly lower energy storage density.

Figure A-3: Heating system with storage of tap water and heating water

The valorization of this type of systems in the energy system depends on institutional context conditions and the scale of application.

A1.4 Case studies in the Netherlands

In the horticultural sector, the technique is rather commonplace also in combination with assimilation lighting control. In buildings the technique is used on a commercial scale in building management systems.

During the first phase of the IEA-task annex project, green field testing the residential systems has been discussed. Several field tests are currently conducted to study the effect on electricity system operation and to develop and test business models. By May 2011 1500 micro CHPs have been rolled out in the Netherlands. The largest concentration is in the Apeldoorn area. The systems have a local control algorithm which is mostly governed by the heat demand.

Mikado in Apeldoorn, the Netherlands. 200 units have been rolled out and tested during two years; with 600 added recently.

To test the use of this type of appliance in energy system context (power markets, relieve distribution systems constraints) some smaller scale experiments have been done. Most prominent is **PowerMatchingCity** in Hoogkerk, Groningen. This setting provides a living lab with coordinated innovative heat pump systems and micro-CHPs, apart from wind, PV and EVs in the cluster. The results have been published at the Integral website (www.integraldc.eu).

A1.5 Rollout scenarios

Rollout of micro-CHP has been estimated in 2009 as shown in Figure A-4.

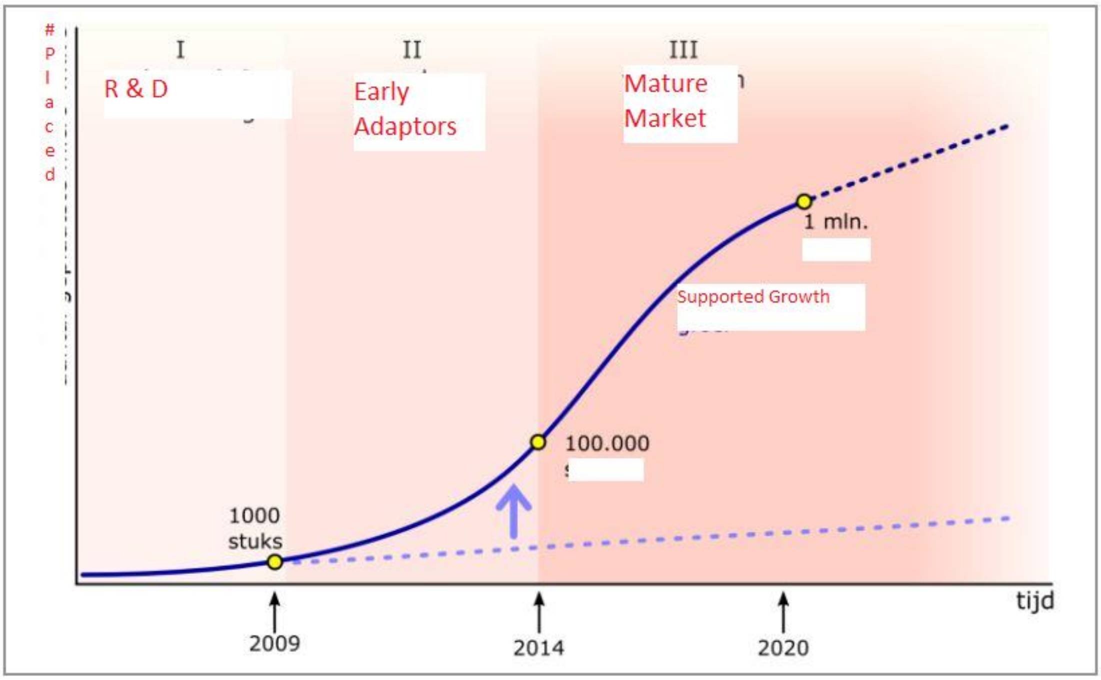

Figure A-4: Rollout of micro-CHP in the Netherlands until 2020

Starting with 1000 systems in 2009 estimates for reaching 1 million systems in 2020 have been made, targeting 30 percent of the replacement market of the traditional high efficiency heating systems. The actual rollout (mainly in pilot projects) has been depicted in Figure A-5. Generally speaking, the experiences with the technique are good and the technological improvements learned from the field tests have led to better concepts. The actual rollout lags behind due to discontinuation of investment subsidies (‘ondersteunde groei’=supported growth is less than expected) and the inability to decrease the price of the installations, while the high-efficiency heating systems have ever decreasing prices due to heavy competition.

project	start project	fabrikant	aantal
proefproject Whispergen	2006	WhisperTech	50
proefproject Microgen stirling	2007	Remeha, Vaillant	150
project Duurzaam Ameland	2009	Ariston,Elco	100
Smart Power City Apeldoorn	2009 en 2010	Remeha, Baxi	200
uitrol zeshonderd eenheden	2009 en 2010	Remeha, Baxi	600
uitrol 2011 tot nu toe	2011	diverse	400
totaal			**1.500**

Figure A-5: Actual rollout of micro-CHP in the Netherlands until 2011

Appendix 2 Present situation of micro-cogeneration in Austria

Rusbeh Rezania

A2.1 Technologies in use and application areas in Austria

According to (Simader, 2004) approximately 6.5 MW of micro-CHP capacity (plants < 100 kW_{el}) was installed until 2004 by the two leading Austrian micro-CHP vendors. The corresponding plant reference lists which was analysed in more detail by (Preiner, 2007) leads to the following micro-CHP shares depending on plant nominal power rates as shown in Table A-1.

Table A-1: Micro-CHP plants electric nominal power rates and cumulated number of plants and capacities in Austria until 2004 (Preiner, 2007)

Nominal power	*Number of CHP-plants*	*Share in % of total plants*	*Total kW_{el} installed*	*Share in % of total kW_{el}*
5 kW_{el}	305	78.6%	1525	23.2%
20 kW_{el}	8	2.1%	160	2.4%
30 kW_{el}	5	1.3%	150	2.3%
35 kW_{el}	3	0.8%	105	1.6%
40 kW_{el}	5	1.3%	200	3.0%
50 kW_{el}	3	0.8%	150	2.3%
60 kW_{el}	27	7.0%	1620	24.6%
70 kW_{el}	12	3.1%	840	12.8%
90 kW_{el}	17	4.4%	1530	23.3%
100 kW_{el}	3	0.8%	300	4.6%
TOTAL	388	100%	6580	100%

It has to be mentioned that the collected cumulated micro-CHP plant capacities do not include installations of recent years, but in general micro-CHP electricity and heat generation shows very little shares in % of total energy generation in Austria.

Furthermore, the following data interpretations can be drawn according to (Preiner, 2007):

- High shares of micro-CHP plants represents the nominal power class of 5 kW_{el}
- Plant sizes between 20 and 50 kW are rarely installed
- A plant size between 60 and 100 kW_{el} is installed frequently representing higher heat demands especially in tourism, trade and industry sectors.

To address typical micro-CHP application fields it can be said that ~43% of all installed plants are used at hotel sites, followed by boarding houses (~17%) and business realities at ~11%. Figure A-6 outlines further applications fields in more detail.

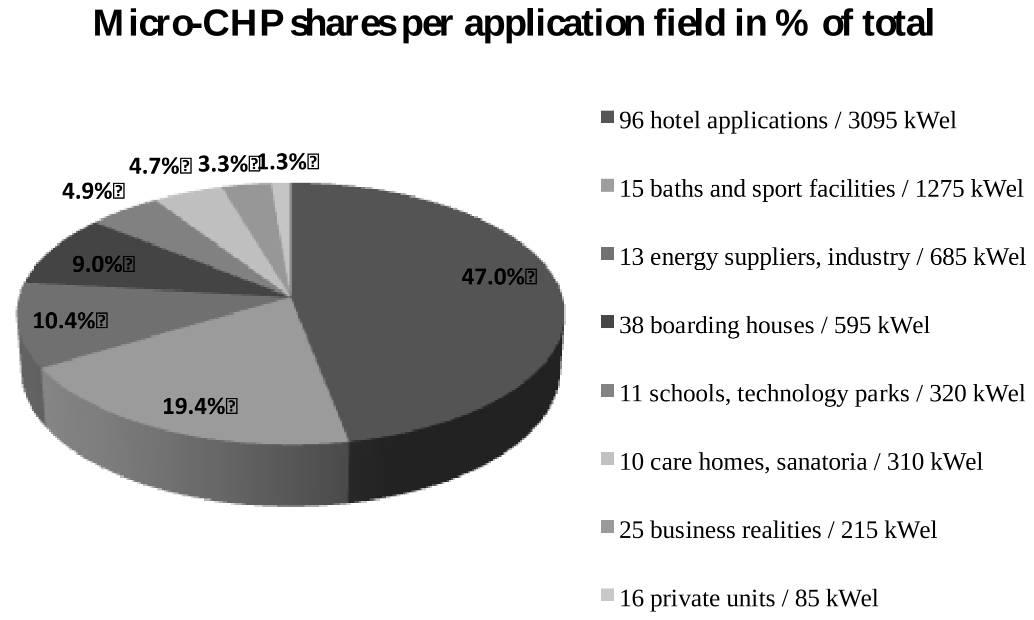

Figure A-6. Micro-CHP shares in terms of application fields (Preiner, 2007)

A2.2 Micro-CHP and CHP Policy in Austria

For micro-CHP generation units there are possibilities to qualify for nationally as well as provincially designed subsidy schemes. On national level highly efficient micro-CHP generation units < 2 MW_{el} using natural gas or LNG (liquid natural gas) are applicable for subsidies of up to 25% of environmentally related investment costs. One major criterion for subsidy grants is that applicants have to run a business. In general, the application for investment subsidies has to be initiated before the construction of the generation units begins. Even more, the investment costs have to be higher than 10,000 €, whereas the electrical usage factor has to be higher or equal to 25% and the total yearly energetic usage factor higher or equal to 75% (for more details see Publicconsulting, 2011). In addition to national grants micro-CHP operators may qualify for province specific subsidies as e.g. described in (Land Oberösterreich, 2011). Again subsidies (depending on the business type and installed generation unit's nominal power certain percentages of the national subsidy are added) are foreseen for actors running their own businesses.

Generation technologies with renewable fuel sources are applicable for renewable energy Feed-In-Tariffs (depending on the fuel type and plant size) as defined in the Austrian renewable energy act. For example a 15 year grant for a Feed-In-Tariff of 7.8 c€/kWh can be achieved for biogas plants (agricultural by products) if the generation unit qualifies for an efficient cogeneration plant design. For further details it is referred to the homepage of the Austrian regulator E-Control (see E-control, 2010).

For cogeneration units bigger than 2 MW_{el} the currently implemented micro-CHP related subsidy policy in Austria (see E-Control, 2011a), which was introduced in April 2007 according to the national cogeneration and renewable electricity act, is applicable. For a common understanding the following terms have to be defined:

- Existing cogeneration units – are generation units that got construction approval before 1st January 2003
- Upgraded cogeneration units – are generation units that started operation after 1. October 2001 and performed a system upgrade accounting to 50% of investment cost of a newly built cogeneration system (excluding the structural shell)
- New cogeneration units – they are generation units which started construction after 1st July 2006, have their legal construction permissions in the first instance until the 30th September 2012 and will start operation before 31st December 2014. This includes generation plant upgrades if the costs for a renewal are at minimum 50% of investment cost of a newly built cogeneration unit (including the structural shell).

For those units (> 2MW_{el}) the subsidy rates as described in the following subsections are applicable.

Existing and upgraded cogeneration units

Tariff based subsidies for cogenerated electricity considering higher costs of operation (cost minus revenues based) are applied. Not eligible are costs for interest payments of invested capital.

New cogeneration units

Direct investment subsidies are granted in the following way:

- Max 10% of total investments (for sewage up to 30 %)
- Units up to 100 MW_{el}: 100 €/kW_{el} (for sewage up to 300 €/kW_{el})
- 100 to 400 MW_{el}: 60 €/kW_{el} (for sewage up to 180 €/kW_{el})
- Units bigger than 400 MW_{el}: max. 40 €/kW_{el} (for sewage up to 120 €/kW_{el})

A2.3 Fuel supply infrastructure

Regarding the existing infrastructure for micro-CHP generation units the existing gas grids provide adequate access especially in urban areas of Austria. According to the Austrian gas grid regulator (see E-Control, 2011b) "the Austrian gas grid is a system that has evolved over time, and because of its geographical location has an important function as a hub that transports natural gas imports onwards to destinations in Western Europe. Grid development activities are mainly aimed at underpinning and increasing security of supply for Austrian gas consumers.

The Austrian gas grid consists of transmission and distribution pipelines, as well as the connections to them, and other auxiliary equipment such as control and metering equipment. Transmission systems are high-pressure gas transportation pipelines, or high-pressure networks which are also used for cross-border transportation or transportation to other transmission or distribution systems.

Distribution systems are pipelines largely or exclusively used for the direct supply of consumers. The total length of the Austrian transmission grid is approx. 2,900 km, and that of the distribution networks approx. 39,500 km." A detailed map of the existing Austrian gas grid is illustrated in Figure A-7.

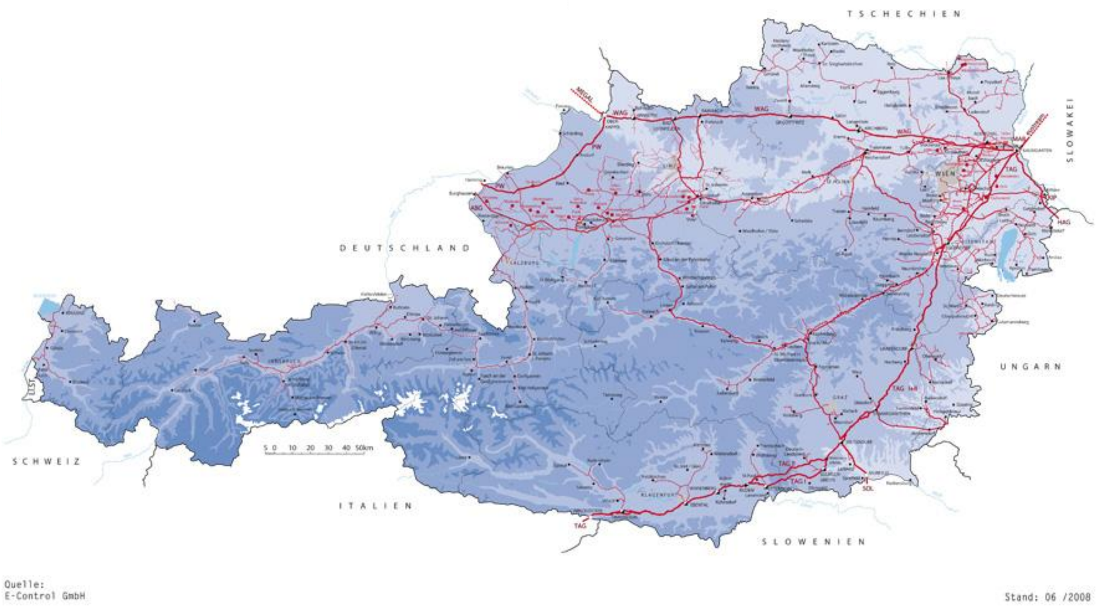

Figure A-7. Existing Austrian natural gas supply infrastructure (E-Control, 2011b)

Other fuel sources for micro-CHP units such as biomass, biogas or solar (e.g. sterling modules) energy are mostly provided locally or directly at the generation site. Adequate primary energy storage applications and supply logistics are implemented sufficiently as well.

A2.4 Possible control/use for DSM

The Austrian project Micro-CHP-Grid (Obersteiner, 2010) analysed strategies for the integration of micro-CHP plants into heating systems of residential and commercial buildings and the local (distribution) as well as global (energy market) power system economically and ecologically. The aim was both, to improve the economics through innovative operation strategies (related to demand for heat and grid situation) and to analyse effects on the low voltage grid and related cost savings in order to allow a robust technology assessment.

The practical part of the project included the installation and operation of four micro-CHP plants in the power range from 4.7 to 30 kW_{el} in buildings with different heat use characteristics. The plants are interconnected with a central control system that has been developed within the project by means of communication technology. This control system allows testing and demonstrating a power, heat and network driven operation in practice. For the theoretical analysis measured data, real costs as well as current energy prices and tariffs were used. First, economics and CO2 reductions were assessed for the heat-driven operation mode (reference). In a further step, costs and benefits of the power-driven operation were analysed and compared to the reference results. The network analysis includes the peak load reduction of the local power transformer, the reduction of grid losses and the impact on voltage stability due to management of generation in relation to local demand. Resulting cost savings were then compared with grid tariff savings.

Experience in plant operation shows that the need for system maintenance (CHP plant as well as communication infrastructure) is relatively high which means high specific costs due to the small plant size. A shift of operational times is possible, when sufficient buffer capacity is installed. The result of the economic evaluation shows that micro-CHP units in the analysed power range cannot be operated economically under current support conditions in Austria. The sensitivity of the differential heat production costs on a full load hours is low for all plants. Increased revenue from power sales in the range of 3.8% to 6.0% can be realized when operating the CHP unit power-driven (electricity). As the cost for a larger buffer exceeds additional revenues, the power-driven operation for this plant is currently not economically feasible. CO_2-savings are considerable and reach 40 to 80% for 6000 full load hours. However, CO_2 reduction costs are far above the current level of CO_2 allowance prices and are particularly high for the 4.7 kW_{el} units compared to other supply and demand-side measures. Network cost savings due to grid loss and peak load reduction are significantly lower than net grid tariff savings (for customers). Therefore, from the perspective of a grid operator, micro-CHP units reduce revenues in low voltage grids disproportionately.

Support conditions need to be improved when an increased use of micro-CHP for DSM measures is desired. Apart from the regulatory framework, the profitability can be improved through cost reductions and e.g. an increase of the CO2 allowance price. Due to the expected high proportion of fluctuating power generation, a flexible operation of Micro-CHP units needs to be incentivized. As shown in the project, a flexible CHP operation is possible in the summer and during the transitional period when units are dimensioned according to the VDI standard.

A2.5 List of recent research and demonstration projects

The following selected Austrian research and demonstration projects addressing the topics of micro-CHP and DSM have been performed or are currently ongoing:

- **Fuel cell for heating**

  In this demonstration project in Salzburg 17 accomodation units were supplied by a fuel cell based cogeneration unit. Operational data and performance indicators of this cogeneration technology were collected by the project partners Salzburg AG, Salzburg Wohnbau and Vaillant.

  Project status: ended in 2007
  Project type: research and demonstration project

  Coordination: Salzburg AG

  Contact: www.salzburg-ag.at

- **Micro-CHP-Grid**

  The project *Micro-CHP-Grid* analysed the economics of innovative operation strategies of Micro-CHP units as well as technical and economical effects of micro-CHP clusters on low voltage grids.

  Project status: ended in 2010
  Project type: demonstration and research project

  Coordination: Vienna University of Technology – Energy Economics Group

  Contact: www.eeg.tuwien.ac.at

- **Micro-CHP**

  Economic, energetic and ecological (GHG) assesment of the perspectives of micro-CHP technologies in Austria until 2050 under consideration of various system integration options in order to provide consumer-oriented energy services optimally from society's point of view.

  Project status: ended in 2010
  Project type: research project

  Coordination: Vienna University of Technology – Energy Economics Group

  Contact: www.eeg.tuwien.ac.at

- **Field test of a virtual power Plant comprising 30 pellet-boiler fired micro-CHP modules**

  A virtual biomass plant comprising 30 micro-CHP-Modules, each of them integrated into an existing pellets-boiler in the Austrian region of eastern Styria is to be tested. The goal of this project is to gain experience and to introduce a new sustainable technology.

  Project status: ongoing
  Project type: demonstration and research project

  Coordination: SPM Stirling Power Module Energieumwandlungs GmbH

  Contact: www.stirlingpowermodule.com

- **Micro Gas Turbine**

  The aims of this project are to investigated the application of a micro gas turbine for a producer gas from biomass gasification, to identify the requirements for gas cleaning, and to evaluate the performance compared to gas engines. For this purpose the micro gas turbine has to be adapted to the properties of the producer gas and to be integrated into the steam gasification biomass power plant. Further research shall be focussed to the above mentioned characteristic parameters e.g. emissions, efficiencies, availabilities, and maintenance.

  Finally, a techno-economic analysis is carried out and shall serve as basis for a fundamental comparison between the power production based on gas turbines and gas engines, in order to draw the necessary conclusions for a future market introduction.

  Project status: ongoing
  Project type: demonstration and research project

  Coordination: Europäisches Zentrum für erneuerbare Energie Güssing GmbH

  Contact: http://www.eee-info.net

For further projects, micro-CHP vendors and a list of micro-CHP units in operation it is referred to the annexes of Simader (2004).

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G. Simader et al.: Mikro- und Mini-KWK Anlagen in Österreich, project report; Energieverwertungsagentur, Vienna, 2004.

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Appendix 3 Present situation of micro-cogeneration in France

Raphael Marguet

Micro-CHP includes all CHP of power capacity inferior to 36 kWe. It is mostly designed for residential and service sector uses.

A3.1 Challenges

Micro-CHP represents a major challenge in terms of energy efficiency as well as in terms of control of electricity peak demand, especially in France where the penetration rate of electric heating is important.

Micro-CHP will need high functionality, by its combined heat and electricity production nature, but also high investment efforts since it is an individual facility (one per home for example).

But this technology possesses the advantage as a cogeneration unit to offer a potential of efficiency improvements (Figure A-8) since the heat produced is recovered for heating and is not lost. The technologies actually commercialized operate with an efficiency of more than 100% if they are coupled with a classic heater[3]. And according to the calculation method of the directive 2004/8/CE, the economies made when installing such micro-CHP are in the range of 25%.

[3] Analyse du potentiel national pour l'application de la cogénération à haut rendement – MEDDTL (Department of Ecology, Sustainable Development, Transport and Housing) - 2010

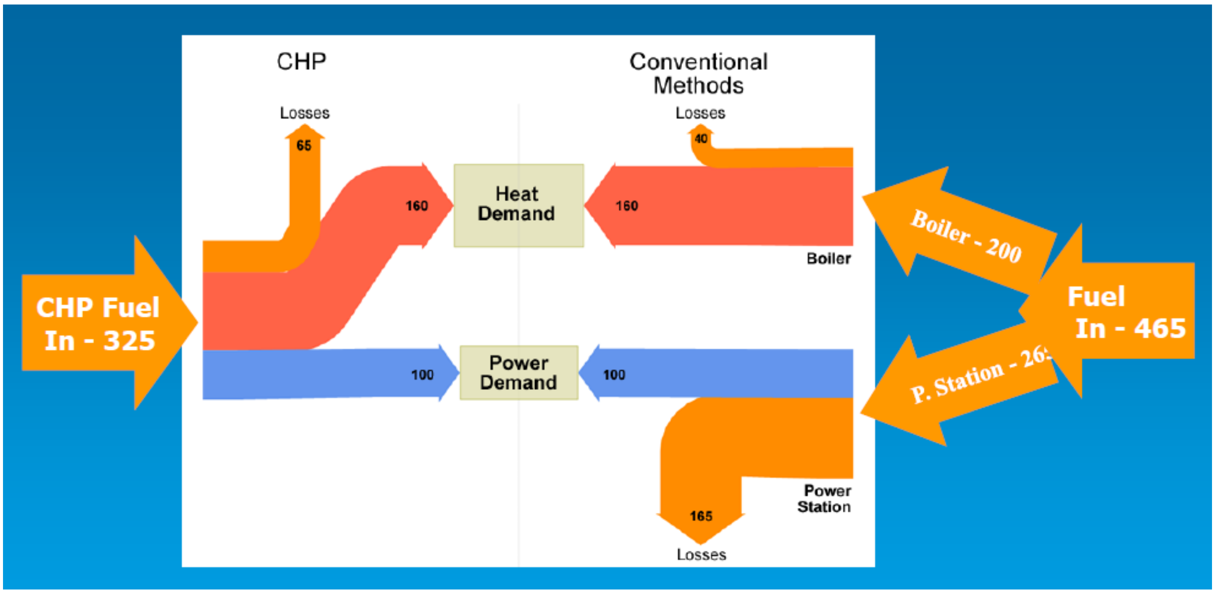

Figure A-8: Compared losses between a classic system and a CHP system[4]

A3.2 The current technological and commercial offer in France

There is a small technical and commercial offer as well as a regulatory support. But these offers will lead up to evolving and developing.

A micro-CHP offer based on the Stirling engine technology is emerging in France. The principal manufacturers (De Dietrich, Baxi, Viessmann, Bosch, Vaillant et Whispergen) are looking forward to start selling these products in 2011. They propose a product which includes a micro-CHP unit and a condensing boiler. The final module, compact, looks like a classic heater. The electric production is relatively small since the engine is about 1kWe. But the advantages of the Stirling technology are its very high global efficiency, a very low NOx emission level, an easy maintenance and low noise level. The main disadvantage is the very low electric efficiency (<20%).

The prices of the first commercialised units (before the mass-produced prices) are around 10 000€ (exclusive of taxes). With the mass-production, the prices of these micro-CHP units should come closer to the prices of a condensing heater plus a solar heater, wich is around 7 000 € (exclusive of taxes).

The website *petitcogeneration.org*, developed during the project *Cogen Challenge*, lists about 18 suppliers of micro-CHP units.

A3.3 The current state of micro-CHP

[4] http://chp.decc.gov.uk/cms/ – CHP Focus – Useful Info > Presentation > An Introduction to CHP

At the present time micro-CHP is not very developed in France. The operational units are often installed for experiments and pilot projects. However there is a strong variety of technology within these units, even though the combination combustion engine/natural gas is predominant.

From 2005 to 2007 took place the project Cogen Challenge initiated by Cogen Europe (The European Association for the Promotion of Cogeneration). Within this project, the *Rhônalpénergie Environnement* agency developed a website which focuses on small CHP in France. The following table lists the total installations (by the end of 2007) and classifies them by 2 different families: technology and application.

		Quantity
Technology	Gas engine:	45
	natural gas	39
	biogas	5
	wood	1
	Micro-turbine:	11
	natural gas	9
	biogas	1
	oil fuel	1
	Pure Plant Oil engine:	1
	Fuel cell:	2
	TOTAL	59
Application	Farms	6
	Waste treatment plants	4
	Research & Education centers	12
	Hospitals	11
	Collective housings	8
	Sports complexes	9
	Office buildings	6
	Industrial buildings	2
	Others	1
	TOTAL	59

Table 1 – Total French small CHP installations in 2007

In 2007 only 59 small CHP units were installed.

Technology

The combustion engine is the predominant technology and natural gas its predominant fuel type. But almost all the technologies are represented. Biogas and wood fuel are present for the combustion engine, natural gas, biogas and oil fuel are used in different micro-turbine installations, and fuel cells and pure plant oil engine are also present.

Application

Variety is also found in the application of these different small CHP units since they are installed as well in farms, waste treatment plants, research and education centers, hospitals, collective housings, sports complexes, office buildings, industrial buildings and even in the heating network of Versailles (in category *Others*).

However this inventory is about *small CHP* units which mean CHP units with a power inferior to 1MWe (according to the European definition). Therefore if we consider only micro-CHP units, with a power inferior to 36 kWe, the inventory lists only 17 units:

- 10 combustion engine: 9 with natural gas and 1 with biogas

- 5 micro turbines: 3 with natural gas, 1 with biogas and 1 with oil fuel

- 1 fuel cell

- 1 pure plant oil engine

Experiment

GDF Suez has started an experiment in 2007 consisting in the installation of 40 micro-CHP units in private housings. This experimentation has already shown that users have between 50 and 80% of electricity auto-consumption.

A3.4 Deployment perspectives

The following perspectives can only be drawn from various hypotheses on the future technological developments, commercial offers and evolution of the regulations.

However we can still note that:

- The electricity production is still marginal: around hundreds of GWh which represent only a few per thousands of the national electricity consumption.
- The installed electric power of CHP could be much more significant than a classic electricity production system. Indeed, CHP units are firstly designed for producing heat. Therefore the electricity production of CHP units occurs mainly during peak demand of electricity (for heating). With CHP units, electricity is produced locally and consequently it helps reducing the national peak demand. This phenomenon is all the more important as heat (hence electricity) demand is important.

The participation of micro-CHP to the grid management has not yet been considered. If the number of CHP units increases enough, it could be considered but without forgetting to take into account the electric power and thermal power management of the building. However, this improvement will probably be more significant on powerful CHP units rather than on micro-CHP units.

Deployment scenarios

Two micro-CHP deployment scenarios have been established in the report on CHP potential[5] by the French government. The market penetration model that was used is a “S-type curve new product growth model”.

In both scenarios, the only difference is the cost of the micro-CHP units. In the low scenario, the cost of a micro-CHP unit is close to the cost of a classic heat pump. In the high scenario, the cost of the unit is much less than the one of a heat pump.

The scenarios use different parameters like the technology (fuel cell of 2 kWe or Stirling engine of 1 kWe), but also the state of the installation (new or replacement of an old heating device) and where it is installed (in a collective or individual housing).

Note: the department of ecology and sustainable development made the choice of using a fuel cell scenario however this choice has not been comforted by any other studies.

- Low scenario
    - penetration only of the highly efficient micro-CHP technologies up to 10% of the market of new installation (as well on the individual market as on the collective housing market) and only 2.5% of the market of replacement of existing products (old heat boiler…)
    - on the individual market only high social categories could be interested
    - on the collective housing market it could be financially interesting

[5] Analyse du potentiel national pour l’application de la cogénération à haut rendement – Ministère de l’écologie, de l’énergie, du développement durable et de la Mer - 2010

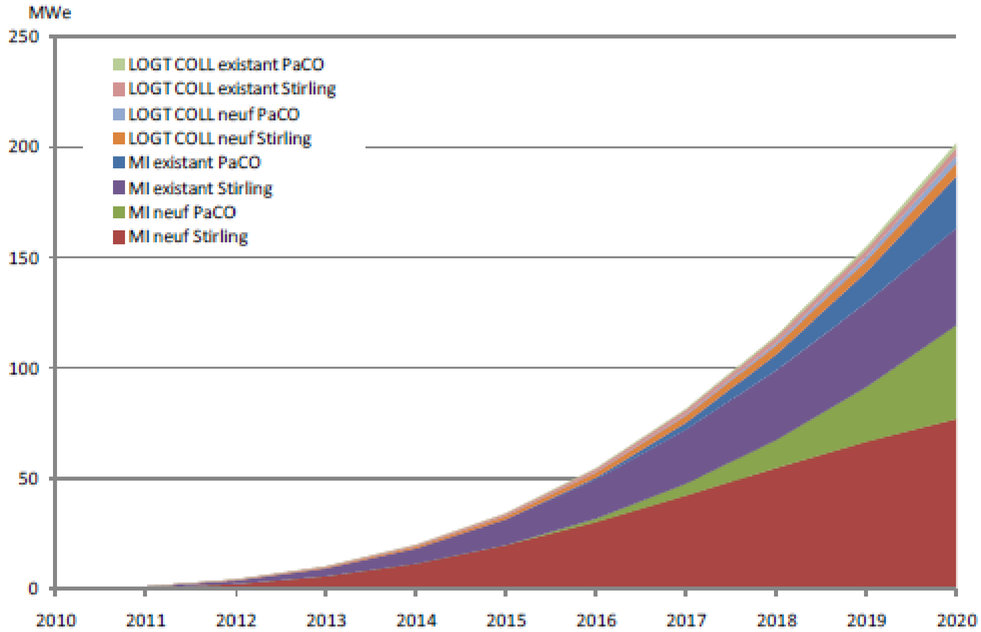

Figure A-9: Micro-CHP installed power until 2020 – Low scenario

The figure above shows, in the case of the low scenario, the share of the different technologies (fuel cell, Stirling engine) and characteristics (new installation/replacement installation, individual installation/collective installation) of the total units installed.

- High scenario
  - eventually a market penetration of 25%
  - only 10% of the market of replacement installations

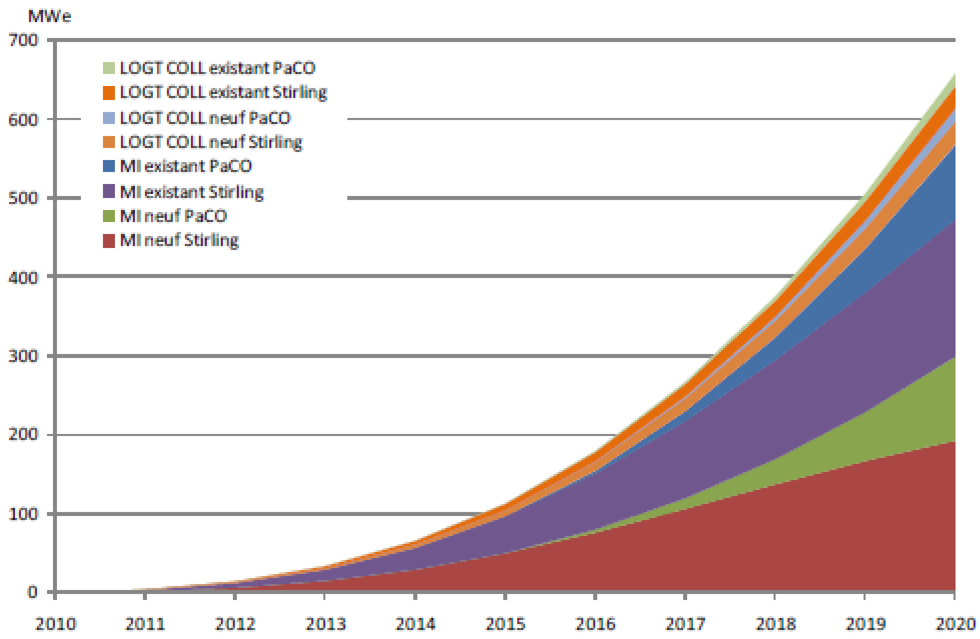

Figure A-10: Micro-CHP installed power until 2020 – High scenario.

The estimate in the high scenario is similarly the same concerning the share of the different combination technology/characteristics of the installations. But the total power installed, ≈660 MWe, is more than twice the one of the low scenario, 200 MWe.

Calculations of the yearly electricity production have also been made in both scenarios:

- Low scenario, installed power of 200 MWe → production of 350 GWhe

- High scenario, installed power of 660 MWe → production of 1300 GWhe

Regulations[6]

The first laws and regulations were published by the French government at the end of 1994 and beginning of 1995. They established the "Purchase obligation" by EDF of electricity produced by CHP throughout 12 years contracts. Since then the regulations have evolved and the first renewal of contracts occurred in 2007.

The actual regulations are based on laws and decrees of 2000/2001. Their main characteristics are listed below (for micro-CHP):

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[6] Arrêté du 3 juillet 2001 fixant les caractéristiques techniques des installations de cogénération pouvant bénéficier de l'obligation d'achat d'électricité – NOR ECOI0100342A

- There is a purchase obligation from EDF of the electricity produced by micro-CHP units (<36 kVA) at the condition that it guarantees a saving on primary energy of about 5% and a ratio Electricity/Heat inferior to 2 and if the owner of the micro-CHP unit wishes to benefit from this purchase obligation or not.
- The repurchase price of 8c€/kWh (regulated price exclusive of taxes) is inferior to the purchase price, around 11c€/kWh, hence favouring auto-consumption of the produced electricity.

The government also allows "eco"-loans at 0% interest for ecological installations. Combined heat and power is concerned about this directive.

Since 2012, the article 200 quarter of the "Code general des impôts" (the French tax code) specifies that *gas micro-CHP* benefit from the "sustainable development tax credit" at a rate of 21% of the costs of the investments.

Evolution of the regulation

In 2005 the *RT2005* (Thermal Regulation 2005), improvement of the RT2000, lowered the primary energy consumption reference of buildings to 150 kWh/m² per year. Each new or renovated building's primary energy consumption had to be lower than this reference. The regulation described clearly how the building's primary energy consumption was to be calculated.

A later addition in the text permitted to take into account "micro-CHP + boiler" solutions in the calculation of the primary energy consumption. This modification in the regulation is a first step in helping micro-CHP projects in new and renovated buildings. However it was at the time limited to individual installations only.

The RT2012 brings major changes to the RT2005. This regulation defines three criteria:

- $Bbio_{max}$: impact of the bioclimatic conception of the building on its energy consumption

- Cep_{max}: characterizes the building's primary energy consumption

- Tic_{ref}: characterizes the building's indoor conventional temperature

Those three criteria are modulated by various parameters such as for example location (cold region, hot region, etc) altitude or even urban situation (building alone or adjoining).

The reference values of the RT2005 being divided by about 3 for the reference values of RT2012, solutions including the use of renewable energies or very efficient systems (such as micro-CHP) will generally be preferred.

EDF publishes on its website[7] the following graph giving the share of the consumption of electricity of a classic French household (using only electricity):

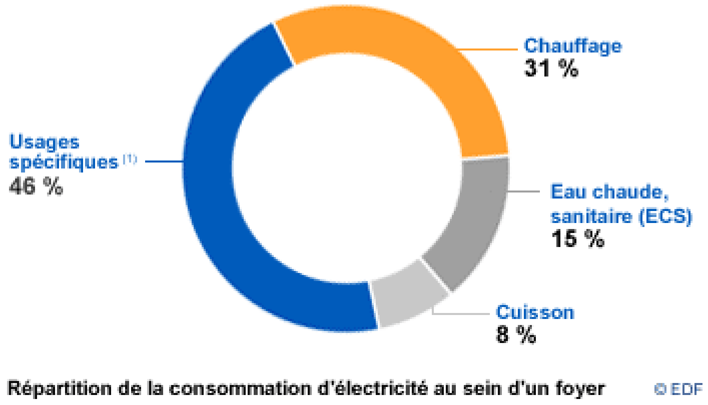

Figure A-11: Share of the electric consumption of a French household.

Heating (31%) and sanitary hot water (15%) sum up to 46% of the electric consumption of a household. Therefore, solutions like solar water heater or micro-CHP will be almost compulsory in order to reduce consequently the electric consumption of buildings to respect the RT2012. For now the cost of the micro-CHP solution (≈ 10 000 €) is higher than the cost of a solar water heater solution (≈ 7 000 €), but in the next years these costs should meet up.

A3.5 Connection to grid

It is important to note that the repurchase of the electricity by EDF is an option chosen by the owner of the micro-CHP unit. Indeed it leads to connection costs[8] which can sum up to 200–400€ and yearly counting costs of about 60 €. Therefore it is economically interesting only for surplus of electricity production superior to 1 000 kWh/year. Without the repurchase option, the electricity surplus is yielded to EDF.

Practical details

If the owner of the unit chooses to subscribe to the purchase obligation by EDF, a special meter needs to be installed in order to meter the electricity injected in the grid by the micro-CHP unit. However, apart from this meter, there are currently no products available on the market for an advanced grid connection and management.

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[7] http://www.edf.com/html/panorama/conso/usages.html

[8] Rapport potentiel CoG du MEEDM

The micro-CHP technology has not penetrated the market enough until know for that the concerned actors work on this aspect.

Yet this technology seems promising since, as explained previously, it helps to produce electricity locally right when the needs are the highest, which are during peak heat-electricity demand, therefore decreasing the national electricity peak demand.

A3.6 Pilot Projects

There are very few micro-CHP projects in France. One of the first ones is the installation in the office building of GEG (Gas and Electricity of Grenoble) as a demonstration installation.

Another pilot project has started in Grenoble as a part of the European Sesac project, part of the EU Concerto initiative.

In 2011, the Ademe and GRDF launched an experiment where 25 housings are equipped with heat pumps and measuring devices in order to measure performances, consumption and comfort. Results should be available at the end of 2012.

These pilot projects will be detailed in subtask 6.

A3.7 Conclusion

Micro-combined heat and power is almost not present in France. With approximately 20 micro-CHP installations (< 36 kWe) and 60 small-CHP installations (< 1 MWe), it is not possible to come to a general conclusion.

The future success or failure of micro-CHP development will come by its competitiveness regarding other heating technologies, such as heat pumps for example and the will of a national development carried out by the government in order to give this technology some visibility.

There are therefore no DSM strategy developments made for micro-CHP technology.

Appendix 4 Overview of the IEA Demand-Side Management Programme

IEA Demand Side Management Programme

The Demand-Side Management (DSM) Programme is one of more than 40 co-operative energy technology programmes within the framework of the International Energy Agency (IEA).The Demand-Side Management (DSM) Programme, which was initiated in 1993, deals with a variety of strategies to reduce energy demand. The following 16 member countries and the European Commission have been working to identify and promote opportunities for DSM:

Austria	Netherlands
Belgium	Norway
Canada	New Zealand
Finland	Spain
France	Sweden
India	Switzerland
Italy	United Kingdom
Republic of Korea	United States

Sponsors: RAP

Programme Vision during the period 2008 - 2012: Demand side activities should be active elements and the first choice in all energy policy decisions designed to create more reliable and more sustainable energy systems

Programme Mission: Deliver to its stakeholders, materials that are readily applicable for them in crafting and implementing policies and measures. The Programme should also deliver technology and applications that either facilitate operations of energy systems or facilitate necessary market transformations

The Programme's work is organized into two clusters:
- The load shape cluster, and
- The load level cluster.

The 'load shape" cluster will include Tasks that seek to impact the shape of the load curve over very short (minutes-hours-day) to longer (days-week-season) time periods. Work within this cluster primarily increases the reliability of systems. The "load level" will include Tasks that seek to shift the load curve to lower demand levels or shift between loads from one energy system to another. Work within this cluster primarily targets the reduction of emissions.

A total of 24 projects or "Tasks" have been initiated since the beginning of the DSM Programme. The overall program is monitored by an Executive Committee consisting of representatives from each contracting party to the Implementing Agreement. The leadership and management of the individual Tasks are the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

Task 1 International Database on Demand-Side Management & Evaluation Guidebook on the Impact of DSM and EE for Kyoto's GHG Targets - *Completed*
Harry Vreuls, NOVEM, the Netherlands

Task 2 Communications Technologies for Demand-Side Management - *Completed*
Richard Formby, EA Technology, United Kingdom

Task 3 Cooperative Procurement of Innovative Technologies for Demand-Side Management – *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 4 Development of Improved Methods for Integrating Demand-Side Management into Resource Planning - *Completed*
Grayson Heffner, EPRI, United States

Task 5 Techniques for Implementation of Demand-Side Management Technology in the Marketplace - *Completed*
Juan Comas, FECSA, Spain

Task 6 DSM and Energy Efficiency in Changing Electricity Business Environments – *Completed*
David Crossley, Energy Futures, Australia Pty. Ltd., Australia

Task 7 International Collaboration on Market Transformation - *Completed*
Verney Ryan, BRE, United Kingdom

Task 8 Demand-Side Bidding in a Competitive Electricity Market - *Completed*
Linda Hull, EA Technology Ltd, United Kingdom

Task 9 The Role of Municipalities in a Liberalised System - *Completed*
Martin Cahn, Energie Cites, France

Task 10 Performance Contracting - *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 11 Time of Use Pricing and Energy Use for Demand Management Delivery- *Completed*
Richard Formby, EA Technology Ltd, United Kingdom

Task 12 Energy Standards
To be determined

Task 13 Demand Response Resources - *Completed*
Ross Malme, RETX, United States

Task 14 White Certificates – *Completed*
Antonio Capozza, CESI, Italy

Task 15 Network-Driven DSM - *Completed*
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 16 Competitive Energy Services
Jan W. Bleyl, Graz Energy Agency, Austria
Seppo Silvonen/Pertti Koski, Motiva, Finland

Task 17 Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages
Seppo Kärkkäinen, Elektraflex Oy, Finland

Task 18 Demand Side Management and Climate Change - *Completed*
David Crossley, Energy Futures Australia Pty. Ltd, Australia

Task 19 Micro Demand Response and Energy Saving - *Completed*
Barry Watson, EA Technology Ltd, United Kingdom

Task 20 Branding of Energy Efficiency

Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 21 Standardisation of Energy Savings Calculations
Harry Vreuls, SenterNovem, Netherlands

Task 22 Energy Efficiency Portfolio Standards
Balawant Joshi, ABPS Infrastructure Private Limited, India

Task 23 The Role of Customers in Delivering Effective Smart Grids
Linda Hull. EA Technology Ltd, United Kingdom

Task 24 Closing the loop - Behaviour change in DSM, from theory to policies and practice
Sea Rotmann, SEA, New Zealand and Ruth Mourik DuneWorks, Netherlands

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