Micro Combined Heat & Power

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SYNOPSIS

Micro Combined Heat & Power (CHP) has substantial economic and environmental potential. Ultimately it may be installed in over 12 million UK homes and provide an installed generation capacity of a similar order of magnitude to the nuclear industry.

A number of micro CHP technologies are approaching commercial launch. It is anticipated that Stirling engine based units will become available in 2003, with fuel cells perhaps five years later.

This paper considers the characteristics of the leading Stirling engines (and other prime mover technologies) and their potential applications in the domestic sector, with particular reference to the WhisperTech WG800 currently undergoing its second year of UK field trials. The paper also outlines challenges facing such technologies, including interface with the home energy system and the electricity distribution network.

1 INTRODUCTION

Micro CHP promises significant economic and environmental benefits to energy suppliers and society at large. However, it also has the potential to substantially disrupt the established electricity supply industry both economically and technologically. It has a predicted capacity of similar order of magnitude to the existing nuclear generating capacity in the emerging liberalised energy markets in Europe[1].

CHP has been identified by the UK government as a key component of its CO_2 abatement programme[2] and it also represents the most significant individual measure in achieving the European Union's CO_2 reduction targets (150Mt of a total of 800Mt)[3]. In order to meet their CO_2 emission reduction targets agreed at Kyoto, the EU aims to double the proportion of power generated by CHP to 18% of total capacity.

However, it is now becoming clear that the emerging micro CHP technologies which were not included in this original target may help to make up for the disappointing growth currently being experienced in conventional CHP markets. Although CHP generally represents a cost-effective CO_2 abatement measure, it currently faces adverse market conditions. Micro CHP is potentially a significantly more cost-effective measure and should be able to compete effectively with currently available energy systems. Perhaps more importantly, it can be readily implemented in the vast majority of existing homes for which relatively few substantial, energy efficiency measures can be implemented in a realistic commercial manner[4].

1.1 What exactly is micro CHP?

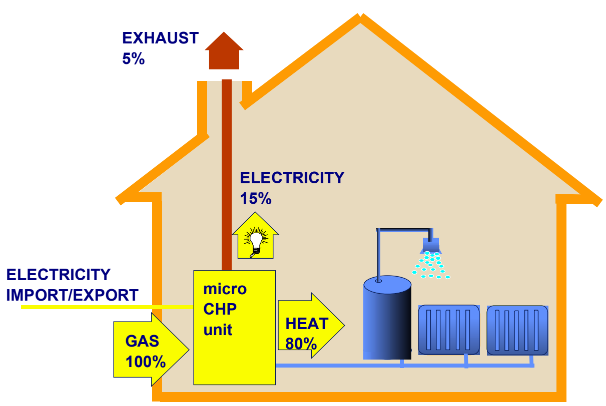
Combined Heat and Power is the simultaneous conversion of primary energy to useful heat and power at the point of consumption. "Micro" CHP has been defined[5 6] as apllying to systems with an electrical output of 16A per phase or less, but this implies units up to 3.5kWe for single phase and 11kWe for 3 phase units. In this paper, micro CHP refers only to individual units in individual homes and is, to all intents, limited to around 3kWe. However, this definition may be somewhat misleading as other characteristics than size alone distinguish "micro" from simply "very small" CHP.

For those unfamiliar with the concept of micro CHP it may be helpful to consider the basic principles of operation. Although the energy flows indicated in figure 1 apply to the WhisperTech Stirling engine, the illustration can be applied conceptually to other Stirling based units and other technologies including fuel cells.

Natural gas is consumed in a Stirling engine to provide heat and electricity for use within the home. A total of 80% (GCV) of the energy value of the gas is converted into heat, principally in the form of hot water which is used for space heating and domestic hot water as in a normal central heating system. Around 15% is converted into electricity, and the remainder (5%) is lost in the flue gases. This compares with a modern gas central heating boiler where 80% of the energy in the gas is converted into heat and the remaining 20% is lost in the flue gases. The electricity generated in the home has a value which covers the investment cost of the micro CHP unit and provides a net saving.

Although this concept might initially appear to be simply a scaled down version of large scale CHP, nothing could be further from the truth. The operational parameters and technical requirements of micro CHP are fundamentally different from larger scale CHP and the market conditions which are adversely affecting CHP in general are less likely to impact on micro CHP.

Figure 1 - Micro CHP schematic energy flows



Referring to the latter point, the "spark gap" (or gas to electricity price ratio) which is currently unattractive to large scale CHP, is virtually irrelevant to micro CHP. The gas to heat conversion ratio (~80%) is the same as for conventional gas boilers, so gas consumption compared with heat only production is unchanged and gas price becomes academic. The bulk of the micro CHP economic proposition arises from the value of electricity generated and consumed within the home, so that the vagaries of the balancing market under NETA which attribute negligible value to exports of process led generation, are unimportant.

However, whilst micro CHP might not be adversely affected by the current competitive energy market, the technical and economic challenges are, if anything, more onerous than for other CHP. Typical industrial CHP plants will operate at baseload for in excess of 6000 hours per year and hence can produce substantial amounts of electricity to rapidly recoup the investment. Domestic systems, operating thermally led to meet the space and water heating needs of a home are unlikely to operate for more than 3500 hours and often less than 2500 hours annually. The installed cost therefore needs to be significantly less than for other CHP. Perhaps more significantly, micro CHP in homes cannot be serviced more than once per year (as for gas boilers) both due to cost and intrusion into the customers lifestyle. Even with the relatively low running hours indicated above, this represents a formidable challenge. One other fundamental difference between micro and larger scale CHP is that, whilst CHP is generally sized to meet baseload, domestic electrical loads are extremely volatile. Baseload (from video, TV etc. on standby) typically lies between 100-150W, average domestic loads are 400-600W and peaks can reach well over 10kW, especially where electric cooking is used. It is uneconomic to match baseload, impractical to meet average load and practically impossible to attempt load following. It is thus fundamental to the operation and economics of micro CHP that such systems operate in parallel with the network, export surplus power to it and meet any shortfall from it. However, the level to which micro CHP is dependent on recovering the value of exported excess power is dependent on the characteristics of the unit (see section 2).

1.2 Why is micro CHP being promoted now?

Cynics might question why, given these constraints, micro CHP is raising such interest and why if it is so important, it is only now being promoted. There are three primary reasons: economics, environment and technology.

1.2.1 Economics.

Economics are the key driver in the introduction of any new technology, and micro CHP offers the potential for significant energy cost savings and substantially higher profits for energy suppliers. In the competitive UK electricity market, new retail customers generate as little as £4-6 net profit annually[7]. This is hardly surprising in a commodity market where all players have access to the same wholesale supplies (generation) at the same cost, and where all transport costs are identical for all players regardless of volume. The only conventional way to increase net profit has been to optimise customer service costs by maximising customer numbers, but profit margins remain extremely slim. However, only about half of the domestic energy supply tariff is due to energy costs, the remainder being transport. Clearly, micro CHP which generates at the point of consumption avoids transport costs and thus potentially halves the energy bill, (on average £330 per year), and creates potential profit in excess of £150, a factor of 30 higher! Energy suppliers thus have a powerful and profitable tool to acquire new customers and, equally importantly, to retain their existing customers, valued variously between £30-£400 each[8].

1.2.2 Environment

Regardless of any idealistic motivation, it is generally the case that environmental measures are only implemented if there is some parallel economic benefit. Further, energy saving, however cost effective, is often not sufficient motivation for domestic customers[9]. Experience has shown that, other than by a few enthusiasts, products such as heat pumps and condensing boilers have not been adopted even where the economic case is proven.

Depending on assumptions on displaced generation[10], micro CHP will reduce a typical household's annual CO_2 emissions by between 1.7 tonnes (WhisperTech unit compared with UK average mix) and 9 tonnes (Sigma unit compared with coal fired generation). Based on the anticipated ultimate levels of market penetration, this could represent a CO_2 emission reduction of as much as 60 million tonnes annually for the UK. However, it is the attribution of economic value to these emissions through measures such as CCL (Climate Change Levy) which is the key driver, and even this is only a significant driver for "rational" decision makers[11].

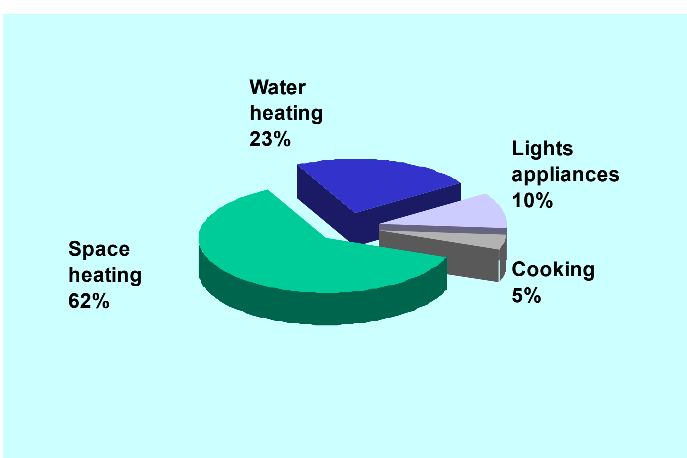
1.2.3 Technology

Given the economic and environmental drivers above it is clearly desirable that micro CHP becomes available. However, it is only with the advent of appropriate materials (high temperature alloys, dry lubricated piston seals) and maturity of design that it has become possible to produce Stirling engines at a realistic cost.

1.3 The role of micro CHP in sustainability

In general terms, micro CHP is little more than an attractive, cost-effective energy efficiency measure. As such it must stand the test of comparison with other measures. With a cost effectiveness of 1.6p/kWh saved, it rates well against cavity wall insulation and substantially better than double-glazing. However, it is less effective than loft insulation or wall insulation installed during construction. The logical conclusion then, is that micro CHP is an effective measure for existing homes, particularly when for example, there is no cavity to insulate.

Figure 2: Domestic energy consumption by end use[12]



Advocates of exotic technologies (such as photovoltaics) would do well to remember that over 60% of energy in a typical UK home is used for space heating, with an additional 23% for water heating. Only 15% in total is for appliances and lighting which require electricity[13]. These proportions are similar for other N European countries (e.g. France with 60% space heating, 19% water, 21% other)[14]. It is thus significantly more effective to invest in targeting the 85% thermal energy demand rather than the relatively small potential in electricity, particularly bearing in mind the high cost and poor generation profile of PV generation.

It is perhaps also worth bearing in mind that Stirling engines are fuel flexible and, whilst they can make use of the current natural gas infrastructure, they could in the future make use of biogas or hydrogen when those fuels become widely available. They thus represent both a transitional technology and a potential Renewable Energy converter.

1.4 What characteristics are required for micro CHP products?

In order to achieve economic viability, it is clearly essential that the product can be manufactured at a cost that can be recovered from the savings in operating costs. Operation costs include service costs which, for other small-scale CHP can be disproportionately high (3p/kWh @ 10kWe, 0.9p/kWh @ 40kWe[15]) and has been the principal obstacle to the implementation of CHP below around 30kWe. Micro CHP needs to achieve a maintenance cost less than 0.5p/kWh, a figure which is met by Sigma (0.3p/kWh[16]) and WhisperTech (no marginal cost compared with gas boiler[17]). However, in order to meet customer expectations, there are a number of other criteria which have to be met. The unit must be unobtrusive visually and acoustically, so must be no larger than the gas boiler it replaces, and must be quiet and free of excessive vibration. In the longer term it must also demonstrate low emissions. In practical terms micro CHP also needs to match the operational parameters of existing central heating systems, such as flow rates and temperatures and ease of installation.

2 POTENTIAL PRIME MOVER TECHNOLOGIES

A number of prime mover technologies have been evaluated against the performance criteria above, but it is believed that only Stirling engines will be viable for the next 2-5 years with fuel cells possibly reaching market in 10 years.

2.1 Fuel cells

Fuel cells, which convert fuel directly into electricity, appear to offer very low emissions, high efficiency and very low noise levels. Heat is produced as a by-product of the electrochemical process, with water as a waste product. Although, in theory, there are no moving parts, the reality is somewhat different. Firstly the natural gas needs to be reformed into hydrogen, requiring additional components and implying parasitic energy consumption. The exhaust gas also needs to be treated to eliminate CO and the gas supply may also need to be cleaned to remove sulphur. Although the electrical conversion itself may be quite efficient, the need to convert the DC output to AC requires power electronics and implies further costs and losses.

Current prototypes are thus too noisy, bulky, inefficient and expensive to be viable. Indeed, there is only one product (Sulzer Hexis 1kWe) specifically targeted at individual homes and this is recognised as being several orders of magnitude too expensive[18]. However, it is believed that continued development will enable them to compete within a ten year timescale.

2.2 Internal Combustion Engine

The internal combustion engine (ICE) has been continuously developed for over a century and has achieved particular success in applications where power flexibility is required. However, the internal combustion process is inherently difficult to control so that emissions are high as is the noise emanating directly from the "explosion" in the working space. The need for oil lubrication and regular, frequent servicing indicate that this technology is poorly suited to micro CHP applications. However, there are products (most notably Senertec 5.5kWe) which achieve relatively low emissions and noise levels, as well as service intervals of 3500 hours. These attributes are achieved by, amongst other measures, incorporation of substantial acoustic attenuators, catalytic converters and a substantial oil reservoir. Naturally, this results in a very expensive engine (~£1600/kWe excluding installation costs) and a very large product unsuitable for installation in an individual home. It is believed that Honda are developing a 1kWe unit, but it is unlikely that all the desirable parameters for micro CHP can be achieved with ICE technology. It is interesting to note that the relatively low heat to power ratio (and high electrical efficiency) achieved by ICE has implications for the gas supply infrastructure and makes this technology more sensitive to changes in gas prices.

2.3 Stirling engines

Stirling engines are external combustion engines, which allow continuous, controlled combustion resulting in very low pollutant emissions and high combustion efficiency. They can operate without valves or an ignition system, thus permitting long service intervals and low running costs.

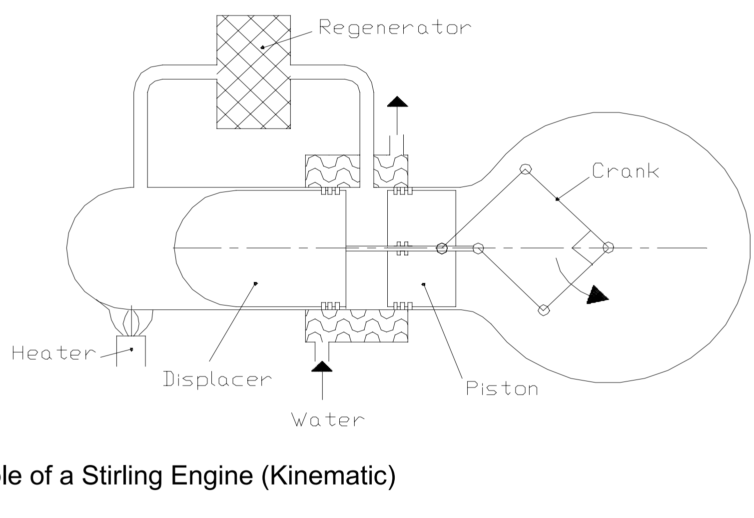


Figure 3: Example of a Stirling Engine (Kinematic)

In its simplest form the Stirling engine comprises *cylinder*, *regenerator*, *piston* and *displacer* as shown in figure 3. Fuel is burned continuously outside the engine to

maintain one end of the cylinder at high temperature while the opposite end is cooled by circulating water around it. Power is derived from the pressure fluctuations acting on the working piston, as a fixed volume of working gas (sealed within the engine) is alternately heated and cooled, forcing it back and forth between the two temperature zones via the regenerator. The working gas is moved by the displacer, which is 90^o in advance of the working piston. The sinusoidal waveform of the power output results in low vibration and noise levels. Thermal efficiency is enhanced by the regenerator, a heavy matrix of fine wires that acts as a repository for heat extracted from the working gas during the cooling pass to be returned on the heating pass.
One significant difference between ICE and Stirling engines is that, in an ICE, it is possible to adjust power virtually instantaneously by controlling the fuel supply. This makes ICE ideal for automotive applications where rapid variations in power are required. However, there is a significant time delay between fuel input and power output in a Stirling engine, as there is usually a substantial amount of heat stored in the hot end, which continues to transfer energy to the working gas long after the fuel supply to the burner is cut. Although this is not a concern in stationary applications, which do not require instantaneous power variation, it is a consideration for control that there is a delay of the order of minutes between a thermostat calling for heat, the availability of heat and finally the output of power. In addition, the stored energy must be passed to the heat distribution system before the engine shuts down at the end of a heating cycle.

2.3.1 Types of Stirling engine

All Stirling engines fall into one of the following two basic categories:

- *Kinematic Stirling Engines* have a crank arrangement to convert the reciprocal piston motion to a rotational output, say to drive a generator. The displacer is actuated through some form of mechanical linkage.
- *Free-Piston Stirling Engines (FPSE)* have no rotating parts. In the majority of cases, output power is taken from a linear (usually permanent magnet) alternator attached to the piston, while the displacer is actuated by the pressure variation in the space beneath the piston.

Stirling engines can also be characterised by the three typical configurations of the displacer and working pistons, known as alpha, beta and gamma. In the alpha type, the working gas shuttles between two pistons. One piston carries out compression in the cold space and the other, expansion in the hot space. A sub-division of the alpha type is the double-acting type, where useful work is done by symmetrical pistons. In the beta type, both compression and expansion are carried out by the working piston, the working gas being shuttled between hot and cold spaces in the same cylinder by means of a (non-working) displacer. The third version is the gamma type in which the working piston is placed in a separate cylinder[19].

It has been shown that the beta type is inherently more efficient than others[20], but as will be explained later, high efficiency alone is not necessarily a desirable goal. Indeed, measures which improve efficiency may have undesirable consequences both in technical and economic terms. Clearly there is little point in achieving a high efficiency if the production costs are so high that it could never be recovered from energy savings.

For example, it is possible to improve the Carnot efficiency of a Stirling engine by using discontinuous motion of the piston[21]. Practical implementation of this feature is possible using electromagnetic actuation of the displacer, and is to some extent simulated in the conventional crank arrangement of some engines. However, fluctuations in rotation of the working piston give rise to other complications, particularly variations in electrical output and high electrical losses as well as obvious increases in noise, vibration and mechanical stress.

Thus, the quest for high efficiency has economic and performance implications which may be undesirable. Indeed, the appearance of the WhisperTech engine with an inherently low electrical efficiency, but with reliability and production cost parameters in line with market requirements can be seen as a major landmark in the commercialisation of micro CHP.

2.3.2 Difficulties with early engines

In the 1970's the quest for improved efficiency promised by Stirling technology led to attempts to develop automotive power units. However, the lack of controllability required complex gas valving arrangements with high parasitic losses, somewhat defeating the point of the exercise.

Even after the abandonment of Stirling as direct drive automotive unit, problems with lubrication and working gas pressure loss remained significant obstacles. Due to the very high working gas pressures, particularly with "leaky" gases such as Helium (selected for their small molecular size and heat transfer efficiency), leakage to atmosphere could only be contained by high loss seals. Shaft seals were initially subject to side forces, as were the piston seals, so efforts were made to minimise lateral forces with patented mechanisms (e.g. Carlqvist[22]), reducing wear as well as frictional losses. At the same time as gas was leaking out, lubricating oil had a tendency to migrate into the hot end of the cylinders where it carbonised on the heat exchange surface, reducing heat transfer, power and efficiency.

The solution was to incorporate the generator within the hermetic envelope of the engine so that the crankcase was at mean operating pressure. The only penetrations of the crankcase were electrical leads so that no high-pressure (high friction loss) moving seals are required. This feature is now found on all micro CHP Stirling engines, although the Solo engine (10kWe) simply provides constant top-up of leaking helium by provision of a cylinder of compressed gas, replenished annually. The problem of oil contamination was resolved by use of dry seals located within the cooler area of the cylinder using Teflon type materials.

2.3.3 Sigma Elektroteknisk PCP

The Sigma unit with an output of 3kWe/9kWt represents a leading example of a high efficiency, β-type engine. EA Technology undertook extensive test and development work between 1993 -98 in collaboration with Lund University and Sigma Elektroteknisk AS and measured electrical conversion efficiency of almost 20% (based on GCV of natural gas). However, it is believed that, with modifications to the existing configuration, an efficiency in excess of 30% could ultimately be achieved. Such high performance is achieved by the use of an extremely high head temperature, sophisticated heat transfer using finned tubes, high pressure Helium as a working gas and a high efficiency regenerator. However, each of these characteristics has production cost implications and raises challenges for long-term reliability. Development work continues in collaboration with the Norwegian Oil Company Statoil[23].

2.3.4 BG linear FPSE

BG Group is developing a micro CHP unit with an output of 1kWe/5kWt (plus flow boiler of 40kWt) in collaboration with the Japanese Rinnai Corporation. Although little is known of the current product, the Sunpower engine on which it is based is a β-type, linear free piston Stirling engine (LFPSE) with an integral alternator. Although the head configuration is similar to the Sigma unit, promising potentially high efficiency, the free-piston arrangement eliminates the need for a crank mechanism, and avoids a potential source of failure. LFPSE units are thus fundamentally elegant in engineering terms, but in reality a number of technical challenges remain, which detract somewhat from their simplicity. Firstly, linear alternators are not commonly available, and developers are thus faced with the prospect of parallel development of engine and generator. The gas bearings, which avoided another potential point of failure, have, for practical reasons, been dropped in favour of diaphragm springs as used on the STC engine. There are also fundamental challenges as the displacer is operated by resonance and is thus tuned to the operating frequency of the engine. This can cause difficulties during start up and stopping and several LFPSE engines are known to suffer from the piston "slamming" against the cylinder ends during these periods. Similarly, the need for very small clearances between the components of the alternator (to minimise losses) causes problems due to differential expansion as the engine heats up.

2.3.5 WhisperGen WG800

The WhisperGen micro CHP unit, from its earliest example as a diesel-fired DC battery charger for marine applications arguably represents the first modern commercially available Stirling engine and is certainly the first viable micro-CHP product. Its success lies less in any claimed efficiency, more in its construction using conventional materials and production techniques which allow realistic manufacturing costs to be achieved. The engine uses relatively low pressure Nitrogen, low head temperature and a low efficiency regenerator, all of which result in an electrical efficiency of no more than 12%. However, the relatively low investment cost is readily recovered with these performance parameters and the key benefit of reliability and extended service intervals leads to a viable product.

It is essentially a 4-cylinder double-acting, α-type engine, similar to the configuration of the larger (10kWe) Solo engine. However, its novelty lies in the mechanism for translating the reciprocating motion of the pistons into rotation suitable for connection to a conventional generator. Whereas the Solo engine uses conventional cross heads with oil lubrication, the WhisperTech unit uses an ingenious "wobble-yoke" mechanism, the centre of which is linked through a nutating bearing to the generator rotor.

In 1999, following extensive economic and market studies[24], EA Technology demonstrated the commercial viability of the unit. Laboratory tests validated the key performance parameters and demonstrated the endurance through accelerated life testing[25]. It was decided to continue the commercialisation of the unit and limited field trials in the heating season of 2000-2001 further validated the anticipated performance[26]. However, a number of recommendations from the trials were implemented in a modified product which was installed in 20 homes in the North West of England and ran through the 2002-2002 heating season. These trials have effectively demonstrated the performance of the WhisperGen unit in a range of typical UK homes, and helped to confirm the identified target markets[27]. At the same time, a number of related issues have been raised, not least the difficulties in connecting small-scale generators to the distribution network.

3 CONNECTION ISSUES

As was explained above, micro CHP is intended to directly replace the conventional boiler in a central heating system. The diagram below (figure 4) illustrates the gas, combustion air, flue, control and electrical connection, which are essentially the same as for a gas boiler, for all except the electrical connections.

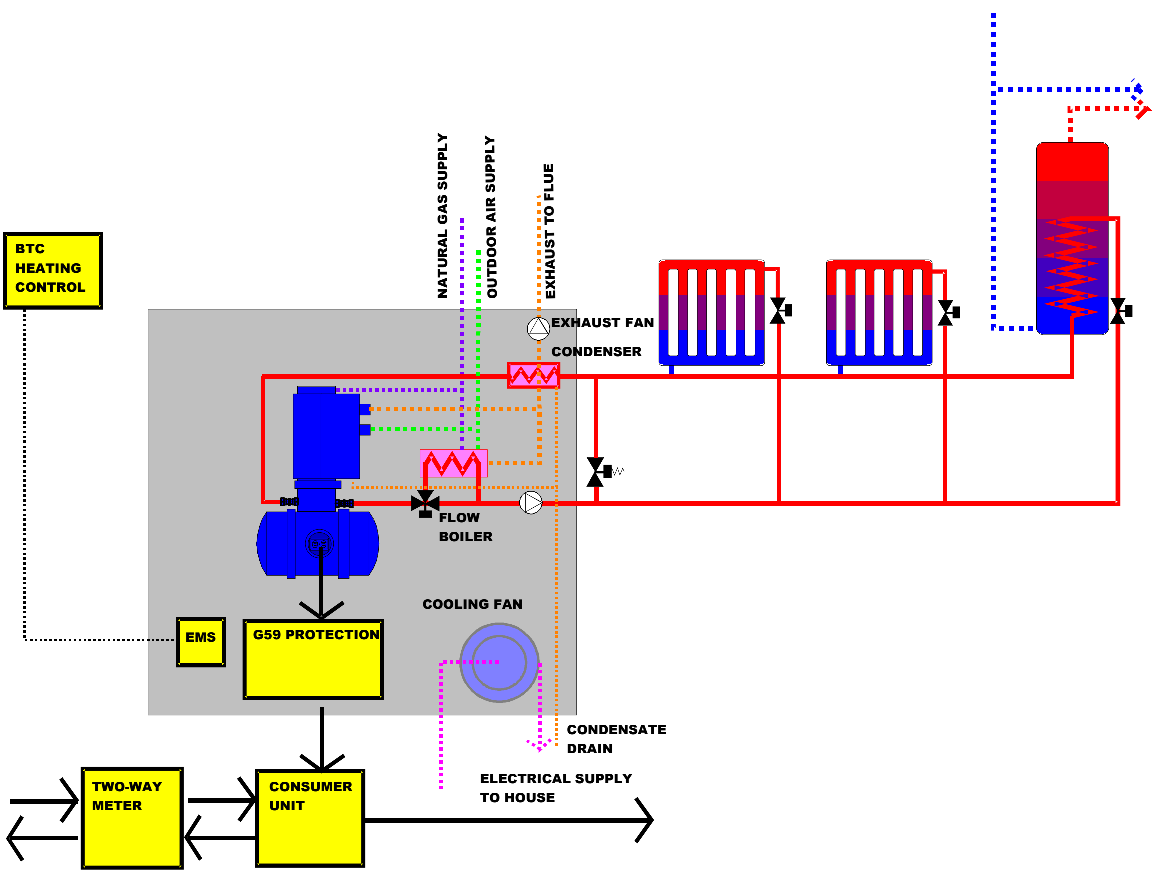


Figure 4: Schematic layout of micro CHP connection to home and network[28]

3.1 Network considerations

When a generator is connected to the public electricity supply, it is necessary to ensure the protection of the home and its occupants, the generator itself, the network and those who work on it.

3.1.1 Connection

For the latter two purposes it is customary to install a device in accordance with engineering recommendation G59. This ensures that the generator will disconnect from the network in the event of mains failure, preventing power being fed into a potential fault condition and possibly endangering the life on line workers.

However, this standard and the procedures of negotiation with the network operators are excessively onerous and practically unworkable if many thousands of units are to be installed. (The standard was envisaged for small numbers of larger generators up to 5MW).

Both at the European (CEN) and UK (Electricity Association) levels new standards are under development which aim to simplify the connection process without compromising safety or network performance. The proposals currently under consideration (known as “fit and inform”) include type approval of connection devices, certification of competent installers and post installation notification to the network operator.

3.1.2 Network design and operation

As micro CHP units are installed on the network, there may eventually come a point where the low voltage network has no net load (i.e. load matches generation). Ultimately, at certain times of day, there may even be negative load, causing a rise in voltage and network instability, as networks are designed for power flow towards the home not away from it towards the high voltage network. It will become necessary to implement new design practices and possibly active network management as is currently used for the UK transmission network, as well as distribution networks in some other European states. This clearly has cost implications and is a matter requiring resolution by OFGEM. At present, CHP systems connecting to the network have to pay connection charges reflecting the costs of network reinforcement and other changes necessary to facilitate connection. However, this has been the subject of much controversy and is clearly unworkable for individual 1kWe generators. Two alternatives are possible. The simplest is simply to spread the cost to all network customers as a component of DUoS (distribution) charges currently incorporated in supply tariffs; the other is to share the cost equally amongst all micro CHP customers, perhaps as a component of a special CHP tariff.

3.2 Integration with the home energy systems

In order to be viable in domestic installations it is essential that micro CHP is compatible with the operational parameters of central heating, such as water flow rates and temperatures and that it does not require the addition of, for example, large storage tanks to provide thermal buffering.

3.2.1 Electrical

Trial systems so far installed have been wired back to a point upstream of the consumer unit, with a cable rated to take the full starting current of the generator. This is an expensive item and is physically intrusive. It is desirable to both minimise the rating of this cable and, ideally connect it to either a high current circuit (such as cooker spur) or even the ring main[29]. However, both these options conflict with IEE regulation requirements as the circuits would be double-fed and it may be difficult to ensure isolation when required.

3.2.2 System design

There has been much discussion of the range of homes for which Stirling engine systems are appropriate. Although the thermal output is significantly lower than the boiler it replaces, this does not necessarily imply inadequate performance. Intelligent controls, with or without thermal buffering, can significantly enhance the effective output, although there are implications for extended preheat periods and consequent increases in MIT (mean internal temperature) which adversely affect SAP ratings. However, this also enhances comfort and it is not improbable that UK homes will begin to follow European practice of having "set-back" rather than "on-off" controls. It is also important to bear in mind that micro CHP dos not respond well to rapid on-off cycling and that engines (as is the case for heat pumps) are normally designed to meet about 60% of the peak design load. This maximises useful run hours under average winter conditions, and normally leads to the bulk of annual demands being met by the primary system.

However, some form of supplementary heating may be required in severe weather conditions and to achieve rapid heat up, for example, after the home has been unoccupied for some time. Sigma, ENATEC and BG all plan to incorporate some form of flow boiler, although this does have implications for the annual run hours achievable during which electricity is produced.

3.2.3 Installation

As micro CHP nears commercial introduction into real homes, it is becoming apparent that the skills shortage already facing the heating industry, could represent a significant obstacle. The level of skills required, both electrical and plumbing, are significantly more advanced than for installation of a conventional boiler and are even a step change from condensing boilers. It is widely believed that the current route to market through the installer network has been one of the major reasons why condensing boilers have failed to achieve significant market penetration and this remains a key challenge to micro CHP companies. This issue is currently being addressed by SBGI (Society of British Gas Industries) micro CHP working groups.

4 MARKETS AND APPLICATIONS

4.1 Market potential-economic viability

It is likely that micro CHP systems will be installed and operated by ESCo (Energy Service Company) rather than purchased by individual householders. However, the economic viability is still dependent on energy savings compensating for the marginal investment cost and a simplified example of paybacks is shown in figure 5.

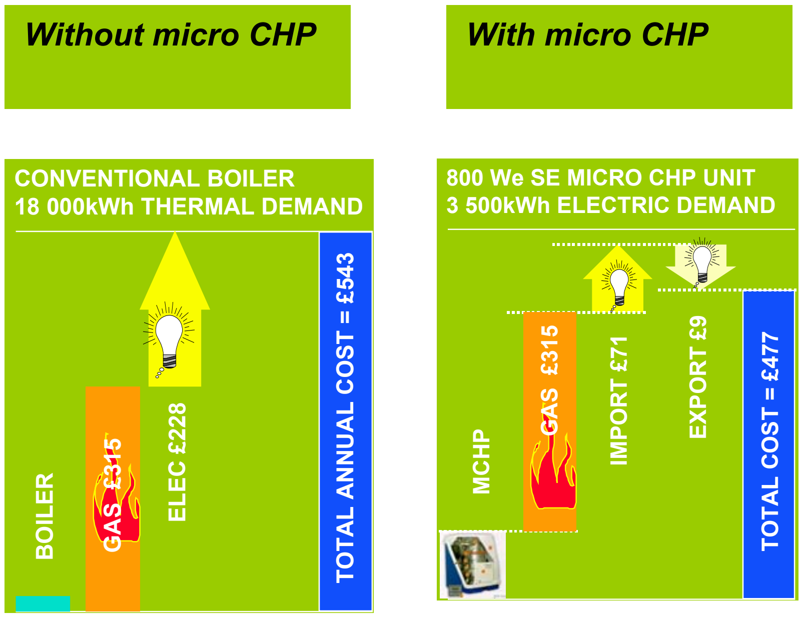


Figure 5: Illustrative example, based on a conventional boiler of 78% efficiency, gas cost of 1.4p/kWh, electricity cost of 6.5p/kWh, export worth 2.5p/kWh, 0.8kWe/6kWt Stirling engine micro CHP unit with 90% overall efficiency, own use of electricity is 85%, annual leasing charge of £100.

Figure 5: Economic viability of micro CHP

4.2 Market potential- applications

As the economic viability of micro CHP depends on achieving sufficient savings to fund the investment, it is evident that only those homes with fuel bills above a certain level will be able to achieve those savings[30]. The number of homes able to meet this criterion can be deduced from analysis of gas consumption data[31]. On this basis it is possible to segment the domestic market into those homes for which an economic case can be made for a given product as shown in the examples below.

However, there is also a need to consider the type of gas boilers being replaced, as not all micro CHP units are capable of providing the instantaneous hot water flows achieved by combi-boilers. Similarly, the weight and vibration of these units makes wall-mounting a considerable challenge, although the BG unit is claimed to provide combi functionality and to be suitable for wall-mounting, as does the ENATEC unit being developed in the Netherlands.

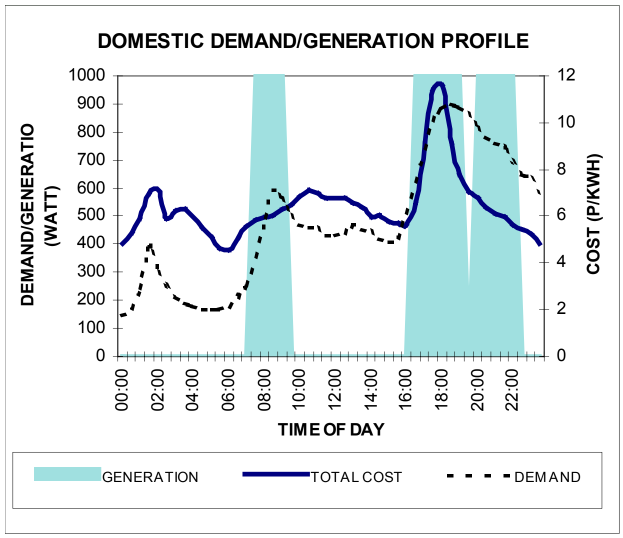
Paradoxically, although the economic and environmental rationale is most convincing for existing homes, the logistics of distribution, service and quality control may make new homes an attractive initial niche, even though 80% of gas boilers sold today are for replacements of existing units.

4.3 Metering and settlement

One key area affecting the economics, remaining unresolved, is how to recover the true value of exported power and in particular, how this is attributed to the individual householder. In the early stages of market introduction, the small value may simply be ignored and the power "donated" to the network. However, a number of metering solutions have been proposed.

Micro CHP operation is thermally led, that is the unit operates when there is a demand for heat, and electricity generation is a by-product. As the wholesale price in the UK (and other N European countries) is substantially influenced by domestic loads and these coincide with periods of peak thermal demand, micro CHP units tend to operate most during periods of highest pool price. Micro CHP generation is therefore worth considerably more than the average pool price. Even if most of this power is consumed on site by the householder so that the resulting export occurs only during less highly priced periods, (as is the case for smaller output units such as the WhisperTech product), the cost of supplying the home is reduced. Figure 6 shows this variation of cost and demand during a typical winter day, illustrating the value of micro CHP generation.

Figure 6 - Variation of electricity cost throughout a typical winter's day shows the value of micro CHP generation. Generation coincides substantially with peak supply cost, as does domestic demand. Demand weighted value of micro CHP generation is around 3.4 p/kWh over the year compared with an average pool price less than 2.8 p/kWh



However, it is not a simple task to determine the true value of micro CHP generation on a case by case basis, nor to attribute that value in an equitable fashion. The physical metering, the settlement and the attribution of an appropriate value all raise significant challenges. The value of generation varies with time, throughout every day of the year, and the complexity of half-hourly metering and settlement would be prohibitively expensive under current conditions. The cost of metering itself is expensive, but it is the administrative elements of data collection and processing which are disproportionately high for small generators. It may well be that intelligent meters, capable of half hourly point of supply settlement, will become available within the next few years, providing the benefits of precise individual value attribution without high settlement costs. However, this method does raise uncertainty with respect to storing an auditable settlement trail.

Net metering, where the same rate is used for imported and exported power has been advocated[32], both in order to simplify the settlement process and to act as an incentive to encourage environmentally benign forms of generation. This is likely to meet with justifiable resistance in a competitive market and is clearly unsustainable in the long term. Furthermore, although acting as an incentive for renewable generators (such as

PV), it does not recognise the full benefits of the micro CHP generation profile, which is thermally driven, in markets where high heat demand and peak power prices coincide.

However, net metering against a modified unit rate provides the benefits of simplification without imposing unrealistic economic demands on the DNO (Distribution Network Operator). In this case, an increased standing charge perhaps incorporating a capacity charge, could be combined with a modified kWh charge based on agreed profiles which incorporates only the energy value (i.e. not the transport cost).

Another, even simpler method, is to infer generation from the gas consumption and to attribute a nominal value to this inferred output. Although somewhat simplistic, this avoids the need for any additional metering and eliminates a potential obstacle where the meter operator is not the DNO or energy supplier.

However, the solution currently favoured in the UK[33] is for two-way metering with import settlement based on existing standard profiles, and export value based on standardised generation profiles. These export profiles do not as yet exist and will only become available following extensive field trials with micro CHP systems in representative domestic properties. This research is the key to all those methods described above which make use of profiles in the settlement process.

The concept of profile settlement itself is already widely used for domestic supply tariffs. Domestic loads and costs vary substantially with time, despite being charged at a fixed tariff. Settlement based on a relatively small number of representative load profiles is used to arrive at a demand-weighted cost of supply for domestic customers. There is no apparent reason why the same logic could not be applied in reverse, although it would require monitoring of a significant number of micro CHP installations to build up a database of representative profiles and hence, an appropriate value to be attributed to exported power.

4.4 Market potential-economic viability examples

The following two tables illustrate the significance of electrical efficiency as well as heat to power ratios for two representative micro CHP products, the WhisperTech WG800 (1kWe/6kWt) and the Sigma (3kWe/9kWt). In general, it can be concluded that the higher capital cost of the Sigma unit makes it suitable for homes with high annual energy demands (and therefore potentially higher energy cost savings to fund the investment). Typically, these consume in the region of 23-45MWh of gas to meet their annual thermal demand, representing in excess of 5 million potential installations.

The economic viability of the Sigma unit is also highly dependent on achieving a realistic value for the substantial amount of electricity exported to the grid. On the other hand, the WhisperTech unit is less dependent on export value and can satisfy the demands of homes with annual thermal demands as low as 12MWh. There are 12 million or so such homes in the UK, including an overlap with the larger homes (up to 30MWh) included in the potential market for the Sigma unit.

4.4.1 Sigma unit in large family home with annual heat demand of 30MWh

Annual heat demand	30,000	kWh
Running hours	3,330	hours
Electricity generated	10,000	kWh
Own use of generation	45	%
Unit cost of avoided import	6.5	p/kWh
Value of avoided import	315	£
Unit value of export	3	p/kWh
Value of export	165	£
Total value of generation	480	£
Additional gas cost	61	£
Marginal cost of unit	1,500	£
Simple payback	3~4	years

With a higher electrical output than average demand, this unit exports more than 50% of generated electricity. Export value is therefore relatively high. Suitable for larger family homes, with an available UK market estimated at 5 million. Marginal cost is relative to alternative conventional replacement boiler.

4.4.2 WhisperTech unit in an average sized family home with annual heat demand of 18MWh

Annual heat demand	18,000	kWh
Running hours	3,000	hours
Electricity generated	2,400	kWh
Own use of generation	85	%
Unit cost of avoided import	6.5	p/kWh
Value of avoided import	133	£
Unit value of export	2.5	p/kWh
Value of export	9	£
Total value of generation	142	£
Additional gas cost	0	£
Marginal cost of unit	500	£
Simple payback	3~4	years

With an electrical output close to average demand, this unit exports little of the generated electricity. Export value is lower as less occurs at the most valuable times. Suitable for the average UK property with an estimated available market in excess of 10 million. In both examples, real customer payback is greater when compared to existing boiler stock efficiency, such that gas savings are also realised.

5 SUMMARY

As a number of micro CHP products approach market launch, it is clear that the fundamental technology problems have been largely resolved. Developers have now moved into the phase of commercial product development and performance trials. However, micro CHP cannot realise its full economic and environmental potential until network connection has been simplified, and its economic potency will only be realised when appropriate energy trading and other commercial and regulatory issues have been resolved.

REFERENCES

1 EA Technology, June 2000, “Micro CHP-Review of emerging technologies, products, applications & markets”

2 DETR, 1998 “UK Climate Change Draft Programme”

3 EU DGXVII, October 1997, “European Commission Communication”

4 Harrison & Redford, Energy Savings Trust, 2001, “Potential benefits of micro CHP”

5 CEN, May 2002, “CWA for domestic cogeneration”

6 Electricity Association, 2002, Engineering Recommendation G83 for the connection of small scale embedded generators in parallel with public low voltage distribution networks

7 Harrison, March 2000, COSPP, “Micro CHP – the implications for energy companies”

8 Discussions with energy suppliers

9 Alan Hedges, Department of the Environment, 1991, “Attitudes to energy conservation in the home”

10 M. Brown, October 1997, COGEN Europe 4th Annual Conference- Decentralised Cogeneration, “A cost-effective response to climate change”

11 L. Nielsen, Danish Energy Agency, April 2000, “Experiences with the Danish CO2 tax scheme”, UNFCC workshop on best practices in policies and measures

12 Department of Trade and Industry, 1999, “UK energy sector indicators”

13 Evans & Herring, HMSO 1989, “Energy use and energy efficiency in the UK domestic sector up to the year 2010”

14 Brigitte Letellier, April 1996, Centre francais de l’electricite, “Les consommations electriques par usages”

15 Rodney Evans, January 1993, Energy Policy (Butterworth-Heinemann), “Environmental & economic implications of small-scale CHP”

16 Manufacturers data

17 Manufacturers data

18 Roland Diethelm, Sulzer Hexis, December 2001, “Promoting successful market entry of an SOFC system for residential applications”

19 Egnell & Gabrielsson, 1991, NUTEK, “Alternativa motorer”

20 Finkelstein, 1998, Stirling Forum, Osnabruck, 1998, “Theoretical efficiency of Stirling engines”

21 Ivo Kolin, 1991, Zagreb University, “Stirling motor”

22 Harrison, 1998, IDGTE, “Stirling engine micro CHP”

23 Hestevik & Harrison, May 1999, Energi Norge, “Desentral varme og elproduksjon”

24 Winstanley et al, 1999, EA Technology client confidential report, “WhisperTech WG800 Stirling engine micro CHP economic viability report”

25 Winstanley, 1999, EA Technology client confidential report “WhisperTech WG800 laboratory tests”

26 Winstanley, 2001, EA Technology client confidential report, “Micro CHP sheltered field trial report”

27 Green, May 2002, EA Technology client confidential report , “WhisperTech alpha trials report”

28 Harrison, 1998, Saga Petroleum report, “Design for a micro CHP system”

29 Harrison, February 2002, COGEN Europe, “Micro CHP connection issues”

30 McKinsey & Co./EA Technology, May 1997, “Micro CHP European Market Study”

31 Harrison, December 1993, EA Technology confidential report, “Micro CHP business plan”

32 Prof. J Cheshire, October 2001, “Cabinet Office PIU Energy Review Responses”

33 OFGEM Consultation document, March 2002, “Distributed Generation: price controls, incentives and connection charging”,