Micro Combined Heat & Power (CHP) for housing

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ABSTRACT: Micro Combined Heat and Power (CHP) has been identified as a key element of the UK Government's Energy Strategy. It offers environmental, economic and social benefits and fulfils the joint objectives of Carbon mitigation, elimination of fuel poverty and security of supply. The first commercial products are now being installed in UK homes and monitoring will be undertaken to evaluate the performance of a range of micro CHP technologies. However, in order to achieve the full potential for this technology, a number of regulatory and structural changes are required. This paper summarises the potential, current status and proposed activities required to exploit micro CHP in the UK housing stock.

Keywords: micro CHP, environment, economics, fuel poverty

1 INTRODUCTION

Micro Combined Heat and Power (CHP) has been identified as a key element of the UK Government's Energy Strategy[1]. It offers environmental, economic and social benefits and fulfils the joint objectives of Carbon mitigation, elimination of fuel poverty and security of supply. Additionally, micro CHP technology provides an opportunity within the competitive UK energy market for suppliers to differentiate their product offerings and provide added value services rather than simply competing on price[2].

There are, however, numerous stakeholders in the implementation of micro CHP which spans the entire range of the building and energy supply industries. As such it raises considerable challenges at a number of levels, all of which must be addressed in order to fully exploit the potential of the technology. So far, technical trials undertaken in laboratory and field conditions have identified and resolved the fundamental technical challenges[3] and a number of manufactures are approaching commercial launch of viable commercial products. Foremost amongst these is Powergen, who are currently running commercial trials of the WhisperGen Stirling engine based unit.

However, there remain a number of regulatory and industry infrastructure obstacles which must be overcome before the true value of the systems can be realised. Considerable activity is under way within industry groups, OFGEM[4], EST[5] and Carbon Trust[6] to identify and resolve the key issues.

2 FUNDAMENTALS OF MICRO CHP

2.1 What is micro CHP?

Micro CHP is the simultaneous production of heat and power in the home. It is quite distinct from other forms of residential CHP which include Community Heating from a large centralised plant, or from block CHP where a CHP unit is installed for example in the basement of an apartment block.

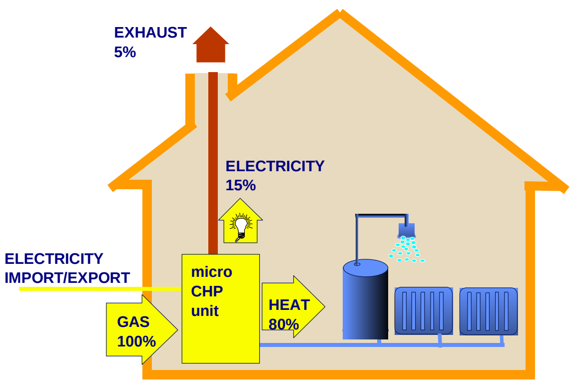


Figure 1: Schematic energy flows in micro CHP system

Essentially, the micro CHP unit replaces the conventional boiler in a central heating system, and comprises a small gas engine which drives an electrical generator. The waste heat from the engine is used in the primary circuit of the heating system and the electricity generated is either used in the house or exported to the network to be consumed by neighbours.

It has a similar conversion efficiency from gas to useful heat as a conventional boiler, typically around 80%. However, in addition, around 10-15% is converted to electrical energy which has a significantly higher value in exergy, carbon and economic terms than the heat which could be gained by simply burning it.

2.2 Challenges for technology

The technical and economic challenges are significantly more onerous for micro CHP than for larger scale systems[7]. However, once these challenges are overcome, the potential environmental, social and economic benefits are substantial.

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.

Manufacturing cost per unit power output tends to rise exponentially as size reduces. Conventional wisdom on economies of scale (based on size) therefore implies that the manufacturing cost of micro CHP would be prohibitive. Only through the economies of scale (based on volume) can cost be reduced to a viable level for micro systems. This in turn implies that very large numbers of units can be produced and that a large potential market base exists.

Operation costs include service costs which, for other small-scale CHP can be disproportionately high (3p/kWh @ 10kWe, 0.9p/kWh @ 40kWe[8]) 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 WhisperTech (no marginal cost compared with gas boiler[9]).

Clearly it is not only the cost, but the frequency of service intervals and the overall life of the product which must be reasonable. It is for this reason that manufacturers have striven to achieve service intervals and life expectancy in line with current gas boilers.

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.

2.3 Micro CHP technologies

A number of prime mover technologies have been proposed for micro CHP applications, based on ICE (Internal Combustion Engine), Stirling engines, Rankine cycles and Fuel Cells. Early attempts to apply converted automotive ICE units led to high service costs and poor life expectancy. However, more recent products such as the Baxi/Dachs unit in Germany and the Honda/Ecowill unit in Japan both applied purpose designed engines to overcome the considerable challenges of emissions and noise reduction and to achieve realistic service intervals. In both cases this has been achieved at considerable cost and it is questionable whether they will ever become truly competitive in normal domestic applications.

Fuel cells are under development by a number of companies, but all face cost and service life challenges. Leading exemplars include Vaillant/Plugpower with a 5kWe PEM (Polymer Exchange Membrane) unit suitable for small apartment blocks and the Sulzer Hexis SOFC (Solid Oxide Fuel Cell) 1kWe unit with integral gas burner to provide flexible thermal output.

A recent technological development is the Organic Rankine unit from Inergen[10], now also part of Baxi Technologies in the UK. This is based on conventional refrigeration components and, although having rather low electrical efficiency, is well matched to many domestic applications and appears to offer relatively low manufacturing costs and good service life characteristics.

Stirling engines, with their potential for low noise and vibration, low emissions and service life in line with gas boilers are the closest to fulfilling the demands of the mass domestic market and two UK energy companies Powergen and British Gas have teamed up with WhisperTech and BG Microgen respectively to introduce Stirling based micro CHP in the near future. Powergen recently announced a commercial launch of their product and the technology is described in further detail below.

2.4 The Whispergen micro CHP unit

The Whispergen micro CHP unit uses Stirling engine technology. Developed in New Zealand by WhisperTech Limited, it has its origins as a battery charger for marine applications fuelled by diesel and is still commercially available in this configuration as well as with other fuels[11]. It thus has a long pedigree demonstrating extensive running hours in numerous installations in addition to the units installed in field trials in the UK.

The unit has a thermal output of 8kWt and a peak electrical output of 1.2kWe. It is used in conjunction either with a thermal store or an optimising controller to maximise the thermal output and match it to the thermal demands of the home. It is similar in size to a domestic fridge and has similar noise levels to a large freezer. However, due to its weight (around 140kg) it must be installed on a solid ground floor and is normally installed in a utility room.

Figure 2: Whispergen micro CHP unit

2.5 Micro CHP applications

The economic and environmental benefits of micro CHP are discussed below, but it is clear that, although micro CHP does offer considerable advantages over conventional solutions in many applications, there are others where it is not the optimum solution[12].

The cost effectiveness of micro CHP is broadly in line with cavity wall insulation. In this case it provides a solution where such measures are not possible (e.g. in homes with solid walls). Generally speaking, micro CHP can be considered an ideal solution for the majority of existing homes where other energy efficiency measures are either not possible or where they have already been implemented[13].

It can also be applied to new homes, but improved levels of insulation represent a better overall investment and should always be considered first. For homes with very small heat loss, multi storey flats and extremely high density urban housing, Community Heating may be more appropriate particularly if the fuel being consumed is renewable.

2.6 Integration with 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.

2.6.1 Electrical

Several 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[14]. However, it was initially considered that 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. Although this no longer appears to be an obstacle, the implications for cable and fuse ratings for ring mains are still under review within the OFGEM working group for micro CHP.

In the meantime, the first commercial systems are being installed on a separate spur into the consumer unit.

2.6.2 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 (Standard Assessment Procedure) 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. The BG Microgen units are expected to incorporate some form of flow boiler, although this does have implications for the annual run hours achievable during which electricity is produced.

2.6.3 Installation

As micro CHP nears mass introduction into real homes, it is becoming apparent that the skills shortage already facing the heating industry, could represent a significant obstacle[15]. 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.

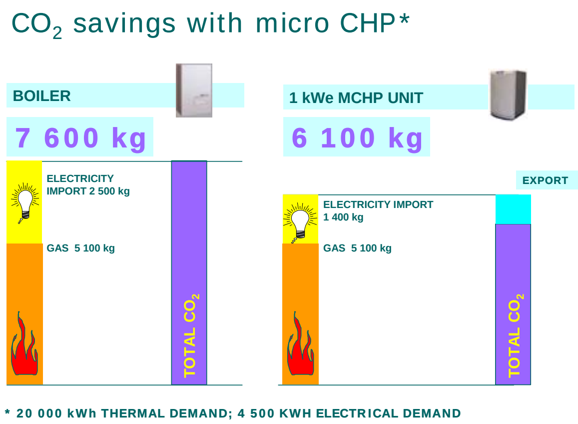
As a practical solution, Powergen have set up training courses for approved installers and are gradually developing an installer network across the UK. These installers also undertake to provide ongoing service and maintenance for the life of the systems, providing the essential customer reassurance for such a novel technology and aiming to overcome the obstacles which hindered the widespread adoption of condensing boilers for so long.

2.7 Benefits of micro CHP

2.7.1 Environmental benefits

Micro CHP operation, as for a gas boiler, is thermally led i.e. running when there is a demand for heat. Effectively the electricity generated as a by-product imposes no additional carbon burden and could be considered zero carbon electricity. However, compared with a condensing boiler with an equivalent total fuel to heat conversion factor (92%), the electricity has a carbon impact equal to that of gas (i.e. it is equivalent to gas fired central generation operating at 100% efficiency and ignoring the transmission and distribution losses of central generation). The actual savings in CO_2 as well as SOx, NOx depend on the annual operating hours and, an often overlooked fact, the time of day when electricity is produced. This latter point is quite significant as micro CHP generation is "peak following". That is, it produces power principally on cold winter days in the early morning and evening when grid demand is at its highest. Generally speaking this peak power is produced by coal fired generators or OCGT (Open Cycle Gas Turbines) which are used to provide flexible load following capacity. Thus micro CHP displaces relatively carbon intensive generation at well above the average UK average generation carbon emissions level. However, for the sake of simplicity the following diagram compares micro CHP with a conventional gas boiler and average UK grid electricity supply. In round terms, this illustrates an annual saving of 1.5 tonnes of CO_2 for a typical UK home.

Figure 3: Emissions comparison of micro CHP versus conventional boiler with electricity from grid supply.



2.7.2 Economic benefits

As outlined earlier, the economic viability of micro CHP depends on both the marginal capital investment (compared with a gas boiler) and the value of electricity produced by the unit. For any given system, therefore, the payback relies on the unit's operating hours and consequently the total kWh produced annually. The table below illustrates the economics for a typical home with 18,000kWh annual thermal demand[16]. It can be seen that the value of the electricity is also dependent on whether it is consumed within the home (avoiding purchase at 6.5p/kWh) or exported and sold to the energy supplier, where it is worth less than half this amount.

Figure 4: Economics of micro CHP in a typical home with annual heat loss of 18000kWh.

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

2.7.3 Other benefits

In addition to the economic benefits accruing to the householder, there is potential in strategic terms of alleviating fuel poverty, although there are as ever complications regarding the funding of this energy efficiency measure.

Perhaps of more significance though is the benefit which micro CHP offers in conjunction with other beneficial technologies. One example of this is the impact of the generation profile of micro CHP, which is led by thermal demand and therefore greater when network demand tends to be highest. This will therefore reduce peak generation and network capacity demand, reducing infrastructure costs. Furthermore, recent studies[17] have shown that the profile of micro CHP complements that of wind, resulting in a much reduced requirement for back-up capacity and substantially enhancing the economic case for wind generation.

Micro CHP thus fulfils the four key goals of the UK Government's Energy Policy, notably, security of supply, economic competitiveness, alleviation of fuel poverty and mitigation of climate change.

3 MARKET STATUS

3.1 Potential impacts of micro CHP

Although the impact of any one micro CHP system is insignificant on a global scale, the cumulative impact of large numbers of installations expected will have considerable impacts on the energy supply industry and the environment. Each unit will typically save around 1.5 tonnes CO_2 and generate 3000kWh of electricity annually. The ultimate market for this technology is estimated at 12-13 million installations[18], possibly more when other fuels and prime movers are considered. The impact of such numbers in terms of generating capacity is between 12-22GWe, more than the current nuclear capacity in the UK. At the same time, annual CO_2 emissions could be reduced by 20 million tonnes making a considerable contribution to the UK's Kyoto commitment.

However, one attraction of micro CHP in this context is that its impact is incremental and, unlike additional nuclear (or conventional) capacity for example can be implemented with staged investment, incremental risk and minimal detrimental environmental or other impact. It also avoids the long delay between investment and generation; each kWe capacity is available as soon as it is paid for.

Clearly, the positive benefits identified above do have a downside. Current participants in the energy industry will be faced with a substantial reduction in electrical demand, so that generators, suppliers and network operators will lose out if they are unable to actively participate in the emerging micro CHP market.

3.2 Commercial activities

Not surprisingly, therefore, a number of energy suppliers are seeking to obtain access to the technology to ensure that they are position to exploit the commercial benefits offered by micro CHP. Both of the leading UK energy suppliers, Powergen and British Gas have obtained exclusive access to Stirling engine based products. At the same time, a number of Distribution Network Operators (DNO) are seeking ways to adjust the structure of their regulated income from transporting electricity in ongoing discussions with OFGEM.

3.3 Regulatory activities

One of the most significant potential barriers to the implementation of micro CHP is the ability or otherwise to connect the system to the electricity supply network. Although it is possible to run the units in isolation (given appropriate energy storage and control systems) this would negate the economic benefits. Domestic electrical loads are extremely volatile with baseloads of around 100W, average 400-600W and peak loads upwards of 15-20kW. The simplest solution is therefore to use the network as the balancing system with surplus generation exported and any shortfall imported as is normal practice. It had been an exceedingly complex and time consuming, not to mention expensive, process to connect generators until the development of new electrical connection standard, known as G83/1. This permits the installation of type approved products by accredited installers who simply notify the DNO that a connection has been made[19].

However, there remain uncertainties about the technical impact of large numbers of installed micro CHP units and work continues in OFGEM technical groups to identify and resolve the these and their commercial implications.

Additionally, it will not be possible to obtain the full value of micro CHP export until the necessary metering and settlement issues are resolved.

3.4 Building regulations

Interestingly, micro CHP, because it involves all aspects of home energy systems, raises a number of previously unencountered challenges when attempting to make use of conventional design and accreditation methodologies. For example, SEDBUK (Seasonal Efficiency of Domestic Boilers in UK) is a methodology used to demonstrate compliance with the Building Regulations. However, it does not recognise the value of the electricity from the micro CHP system and would produce a comparative performance figure based entirely on the heat output. Not only does this fail to recognise the value of the electricity, it further fails to recognise that this has a value significantly higher than the heat which would otherwise be produced in, say, a condensing boiler. A further anomaly is that SEDBUK does not account for the parasitic losses (pumps, fans etc) incorporated in a boiler, a factor which further discriminates against micro CHP.

Considerable work is therefore being undertaken under the auspices of the EST (to develop relevant equivalent SEDBUK rating methodology) and the Carbon Trust, who are supporting extensive field trials of representative technologies in order to provide performance data to validate the methodology and to form the basis for analysis and policy making.

4 CONCLUSION

Micro CHP has finally reached commercial reality, having faced and overcome significant technical, administrative and regulatory obstacles.

However, in order to realise its full potential, considerable additional activity is required for the foreseeable future to resolve the outstanding industry infrastructure issues. These relate, in particular, to issues surrounding the attribution of true costs and values to micro CHP generation.

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