MICRO CHP TECHNOLOGY & ECONOMIC REVIEW

Sigma Elektroteknisk AS

SUMMARY & KEY RECOMMENDATIONS

Micro CHP represents a potentially disruptive force in the evolving European power markets. It is set to have a considerable impact on the technical and commercial shape of the emerging liberalised electricity market.

The combined influence of economic and environmental drivers, coinciding with technological maturity, has established a framework in which micro CHP is likely to become a reality within two years. It will achieve a significant impact within five years and market saturation within a 10-20 year timescale.

Given an equitable market framework, these drivers will be sufficient to achieve the predicted market penetration rates without artificial incentives.

However, there are two key factors determining the growth of micro CHP, which lie within the ambit of government agencies. These are, firstly, the regulation of connection agreements (both from a technical and commercial viewpoint), and the introduction of simplified metering, settlement and trading procedures.

Without the imposition of equitable, transparent connection charges and technical standards, it will be impossible to (legally) connect micro CHP systems without costly and counterproductive components in the system.

Without simplified metering and settlement procedures, it will not be possible to obtain the maximum value from micro CHP generation and thus extend the market and economic viability of the technology.

Market potential

Within the EU15, the potential for micro CHP may be summarised as follows:

- Ultimately micro CHP will provide an installed generating capacity in excess of 60GW.
- In two key markets, UK and Germany, this capacity will be roughly equivalent to the existing nuclear generating capacity.
- 40 million homes are suitable for micro CHP.
- Ultimately micro CHP will contribute an annual reduction of 200 million tonnes CO_2 to EU mitigation targets, somewhat greater than the currently anticipated total for all CHP measures, which take no account of micro CHP.
- Within the context of the Kyoto timeframe, it is anticipated that 1 million systems will be installed annually by 2010, representing an annual saving of 15 million tonnes of CO_2.

Recommendations

Urgent government action is required if the target market launch dates and subsequent growth and CO_2 mitigation levels for micro CHP are to be achieved. It is anticipated that the first Stirling engine based micro CHP products will become available on a commercial basis during the first half of 2002. These measures therefore need to be completed prior to early 2002. Specific measures proposed are:

1. Establish EU and national working groups to develop appropriate connection standards and cost methodologies for connection of micro CHP units within the home and to the network.

2. Establish an industry-wide methodology for simplified metering and settlement of micro CHP exports (this will also be required for other micro embedded generation technologies such as PV). This may take the form of profile settlement as currently used for domestic supply trading or net metering with an appropriate allocation of distribution network costs.

3. Empower national electricity industry regulators (where these exist) to implement the standards developed by these groups.

In addition to these measures, the targeted implementation of carbon tax exemptions or similar reflection of external cost mitigation may directly influence the rate of growth of the micro CHP market and the consequent rate of carbon mitigation.

INTRODUCTION TO MICRO COMBINED HEAT & POWER

Micro CHP is a "disruptive technology". It 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 key emerging liberalised energy markets in Europe.

Micro CHP, installed in individual homes, will in time remove a substantial electricity demand on a dynamic basis at the low voltage level, and may, in some instances, neutralise or even reverse the power flows in distribution transformers. This will clearly have economic consequences for the Distribution Network Operator (DNO) in terms of lost revenue, but will also have profound consequences for LV network design.

The economic opportunities, and to a lesser extent environmental drivers, which are leading to the imminent advent of micro CHP, will disrupt and will require a response from electricity companies. There are those who will no doubt seek to obstruct the new technology and maintain the status quo of their business. However, in the long term, the considerable economic benefits to the operators of micro CHP should prove irresistible. At the other extreme are those companies who will enthusiastically embrace the new technology and significantly improve their competitive position. These latter companies are already in the process of establishing strategic alliances with technology providers, manufacturers, service, installation and energy service companies and are acquiring technical and commercial experience by undertaking laboratory and field trials.

A range of micro CHP technologies are approaching commercial launch and the remaining challenges relate less to core technology and more to peripheral and interface components and commercial packaging.

It is at this stage that the implications for energy companies, suppliers and network operators, are becoming clearer. In general these challenges fall into two main areas, commercial and technical. Within the commercial area, the complexity of metering and settlement of domestic import/export represents a formidable challenge, whilst the technical standards appropriate to integrating numerous very small generators raises entirely new issues both at the customer interface and throughout the LV network.

This report aims to summarise the status of micro CHP technologies, potential applications and scope of markets. It describes the potential commercial and technical impact on existing electricity companies, their networks and customer base as well as identifying likely new market entrants.

Background

CHP has been identified by the UK government as a key component of its CO_2 abatement programme 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). 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.

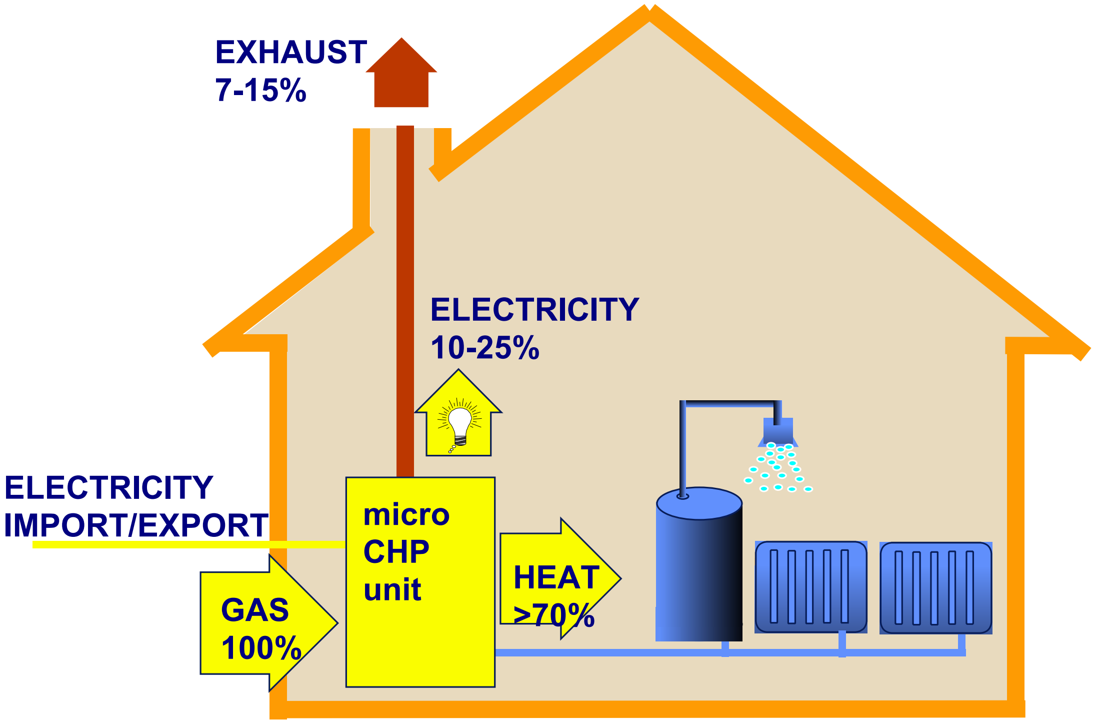
However, it is now clear that the emerging micro CHP technologies which were not included in this original target may help to make up for the disappointing growth currently being experienced in conventional CHP markets. CHP generally represents a cost effective CO_2 abatement measure and micro CHP is potentially an even more cost effective measure. 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.

Sceptics might question the potential for micro CHP on a significant scale in a market which has been so hostile to conventional CHP and where market development has stagnated and even in some countries, where existing CHP plant is no longer being operated. However, the causes of this severe economic environment are less applicable to domestic CHP. In markets which have opened to competition, prices of electricity have fallen due to the incumbent generators' use of amortised plant to undercut new market entrants who have to finance their investment from improved overall efficiency. It is not surprising that the use of anti-competitive, predatory and unsustainable pricing has had an adverse effect on CHP developers, particularly those intending to supply large industrial customers. Recent developments in gas prices have further undermined the economic case for larger scale CHP as the gas/electricity price ratio has become unattractive to those who do not have long term gas purchase contracts. Although domestic customers have seen significant real electricity price reductions since privatisation in the UK, domestic prices are still considerably higher than industrial prices. More significant though is that the element of these prices represented by the energy component is relatively small, at least 50% comprising transport charges and other overheads. The avoided cost of supply if power can be generated at a domestic customers point of use therefore has substantial economic benefits which are less susceptible to predatory energy pricing. At the same time, the gas prices which are causing such anguish to industrial CHP operators have virtually no impact on micro CHP. As will be explained later, the implementation of micro CHP has a negligible effect on gas consumption, and an increase in the price of gas has an almost identical effect with or without micro CHP.

Micro CHP concept

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

Figure 1 - Micro CHP schematic energy flows



Natural gas is consumed in a Stirling engine (or other prime mover) to provide heat and electricity for use within the home. (Note that the figures in the diagram above are for illustrative purposes and depend on the specific technology as well as the actual product under consideration.) A total of 70% (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. Between 15-25% is converted into electricity, and the remainder (5-15%) is lost in the flue gases. This compares with a conventional gas central heating boiler (representing around 95% of boilers in the UK), where 70% of the energy in the gas is converted into heat and the remaining 30% 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 there are those who consider generators of 3kWe and below to be somewhat trivial, the key to micro-CHP is the very large numbers of units which may be installed and their significant cumulative impact. Based on a simplistic model considering end-user economics as the basis for implementation, micro CHP has a potential installed capacity of 15GW in the UK alone of a similar scale to the nuclear industry. A more recent study considering the more complex, but more profitable economics from an ESCo perspective, indicates a potential market for micro CHP product sales alone in excess of 1,000,000 units or £2 billion annually throughout Europe.

Impact on energy supply companies

The economic impact of micro CHP should be a major cause of concern to energy companies. In a competitive market where wholesale power is available to all at the same price and DUoS (distribution) and TUoS (transmission) charges are equitable and transparent, there is very little margin and little scope for competitive advantage unless a company has some technological or commercial edge over competitors.

Micro CHP provides just such an edge, by delivering electricity at a lower cost than is possible through the conventional distribution chain. Let us consider first the end-user economic case. Although it is unlikely that end-users will install and own micro CHP units, this simplistic approach at least identifies and quantifies the economic issues. It is assumed that micro CHP units will be installed in homes to replace existing gas boilers which have reached the end of their useful life. The householder is then faced with the choice of installing a new gas boiler (of which 95% in the UK are conventional boilers with a seasonal efficiency around 70%), or a micro CHP unit. Naturally the micro CHP unit is more expensive than the boiler, but the additional investment cost is repaid from the savings in electricity bills as well as the value of electricity sold back to the electricity supply company. The marginal cost varies depending on the micro CHP unit selected, a factor which determines the appropriate market for each product. The two examples below consider the 3kWe Sigma unit and the 1kWe WhisperTech unit with marginal costs of £1500 and £600 as representative products for larger and smaller homes respectively.

On the basis of this simplistic model, it can be seen that both products have a payback of around 4 years. However, no account is taken of the benefits to the electricity supplier of the reduced cost of supplying such customers and, seen from the electricity supply company's perspective, the economics of micro CHP are even more attractive. The reduced demand will, however, result in loss of revenue for the DNO (Distribution Network Operator).

Table 1: Calculation of economic viability

Example 1) Sigma (3kWe/9kWt) unit installed in a large UK family home with an annual heat demand of 27000kWh.

		kWh	*£*
Annual heat demand		*27000*	
Running hours	*3000*		
Electricity generated		*9000*	
Own use of generation	*45%*	*4050*	
Unit cost of avoided import			*0.07*
Value of avoided import			*284*
Generation exported		*4950*	
Unit cost of export			*0.03*
Value of export			*149*
Total value of generation			*433*
Marginal cost			*1500*
Simple payback (years)	*3-4*		

Table 1 (cont.): Calculation of economic viability

Example 2) WhisperTech (1kWe/6kWt) unit installed in small UK family home with an annual heat demand of 15000kWh.

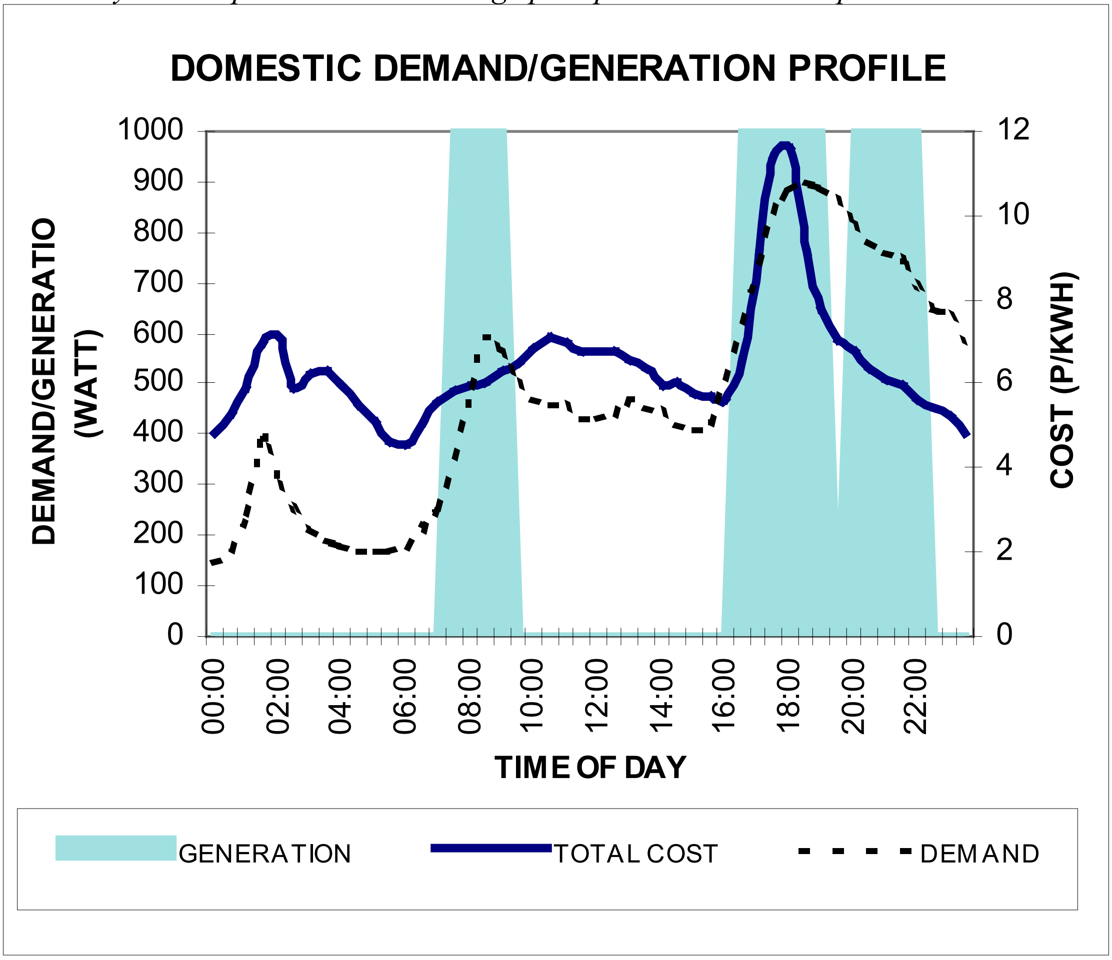
		kWh	*£*
Annual heat demand		*15000*	
Running hours	*2500*		
Electricity generated		*2500*	
Own use of generation	*70%*	*1750*	
Unit cost of avoided import			*0.07*
Value of avoided import			*123*
Generation exported		*750*	
Unit cost of export			*0.015*
Value of export			*11*
Total value of generation			*134*
Marginal cost			*600*
Simple payback (years)	*4-5*		

The electricity generated in a micro CHP unit is available to the energy company at the point of demand. Although it has high value (based on generation profile and point of generation) it can be sold to customers at a lower price, whilst simultaneously giving a higher profit margin. In the UK, a typical profit of less than £6 per customer can be increased to as much as £370 for a large family home and around £150 for a smaller home.

The reason for the high value attributable to micro CHP generation is that it is produced at the time of highest wholesale price and at the geographical location where it is required. This latter point simply means that the transport cost is eliminated and the cost of supply reduced by more than 50%.

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 pool price 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, (such as is the case for smaller output units such as the WhisperTech product), the cost of supplying the home is reduced. Figure 2 shows this variation of cost and demand during a typical winter day, illustrating the value of micro CHP generation.

Figure 2: Variation of electricity value for typical winter day
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 is around 3.4 p/kWh over the year compared with an average pool price less than 2.8 p/kWh



However, even though the value of generation varies with time, the complexity of half-hourly metering and settlement would be prohibitively expensive under current conditions. Net metering has been advocated, both in order to simplify the process and to act as an incentive to encourage such an environmentally beneficial form of generation. This is likely to meet with justifiable resistance in a competitive market and is clearly unsustainable in the long term.

However, net metering against a modified unit rate provides the benefits of simplification without imposing unrealistic economic demands on the DNO. This concept is already widely used for domestic supply settlement. Domestic loads 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 number of micro CHP installations to build up a database of representative profiles. It may well be that intelligent meters, capable of half hourly point of supply settlement, will become available within the next few years, providing an alternative settlement method.

Impact on generators

In terms of investment cost per kW, micro CHP is also set to become the cheapest form of new generating capacity, particularly if infrastructure costs are included in the calculations (assuming micro CHP units are installed as drop-in replacements for obsolete gas boilers). However, financial considerations are not the only motivating factor for companies aiming to acquire generating assets or to achieve customer growth. Compared with conventional central plant solutions, micro CHP offers a wide range of benefits including avoidance of planning, resource and pollution consent problems, low incremental risk, short lead times, flexible location, and reduction in network losses.

Micro CHP as an ESCo business

The direct competitive benefits arising from micro CHP are significant in their own right. However, having once established an energy supply business with an unassailable competitive edge, it is possible to package the offering in such a way as to exploit a range of additional commercial opportunities in the delivery chain. These may well represent a substantially greater profit stream than micro CHP itself. UK householders are notoriously reluctant to invest in energy efficiency devices even with significant, short paybacks. This inertia can be exploited by offering an ESCo package with a guaranteed total bill lower than previously. Within this bill would be profitable product supply and leasing, installation and service business as well as highly profitable energy supply.

Impact on distributors

We have seen that, from an investment and operational perspective, micro CHP offers significant competitive advantages. The competitive advantage it confers on the participants is however, seen from the outsider's perspective, a significant threat to existing and future business. It can result in loss of customers and stranded assets. At the anticipated level of market penetration, micro CHP generation, fed into the network at low voltage, may begin to have an impact on network stability within a decade, with implications for network design (to accommodate reverse power flow) and asset recovery.

The potential number of micro CHP installations will require a fundamental reassessment of network design and on technical standards for connection. The cost and manpower requirements both to micro CHP operators and to DNOs of complying with current engineering standards intended for substantial project engineered generators (such as G59) are excessively onerous and inappropriate for 1kWe generators. An agreed EU standard is therefore required as a matter of urgency and work in this area has already commenced.

Environmental considerations

The full impact of the emissions targets agreed at Kyoto has yet to be felt, but a number of EU governments have implemented pollution taxes, or incentives such as exemptions for improved performance. Already the UK has a Climate Change Levy (CCL) and Denmark has set a price of up to $13 per tonne for CO_2 emissions. It is probable that CO_2 emission quotas will become tradable and that consequently, products such as micro CHP will acquire an increased value to their owners, particularly if those owners are energy companies.

The actual mitigation effect of micro CHP will depend on the particular technologies to be implemented and the generation mix they displace. On the assumption that it will be the most cost-effective forms of emission reduction which will be implemented, micro CHP generation will initially displace the most inefficient and polluting existing generating plant, which in the UK is older coal-fired plant without flue gas desulphurisation. Compared with this plant, the annual reduction in emissions achieved by each typical (3kWe) micro CHP unit is 8.8 tonnes CO_2, 136 kg SO_2 and 50.4 kg NO_x. Taking the eventual market for the units at an estimated 15 GW in the UK and a similar figure for Germany within 15 years, the potential for reduction in CO_2 emissions alone is 45 million tonnes. On an individual basis the CO_2 quota would add about one third to the economic value of the micro CHP unit.

However, as the market develops it cannot be assumed that all displaced generation is coal and a more realistic figure would be 6 tonnes annually for this unit, based on a projected displaced generation mix of 700g/kWh.

Fuel cells with a rather high power/heat ratio would have a larger environmental impact on an individual basis, but the level of market penetration in the EU is likely to be relatively low for the foreseeable future. However, even within the Stirling engine based products there is a fairly broad range of impacts varying from the Sigma 3kWe/9kWt unit with a relatively high electrical conversion efficiency leading to 8.8 tonnes CO_2 saving per year, to the WhisperTech unit with a lower electrical output (1kWe) and efficiency resulting in only about 1.7 tonnes CO_2 saving.

Micro CHP markets

Micro-CHP is here defined as CHP installed in individual homes and as such has significantly different characteristics than larger scale CHP. It is not simply smaller; the operating constraints and economic parameters place daunting challenges to micro CHP technology. It has been this area which has attracted such considerable attention over the past decade and which is now leading to the imminent market launch of a number of micro CHP products.

Stirling engine, fuel-cell, thermo-photo-voltaics (TPV) and internal-combustion engine (ICE) based micro-CHP systems are all under development. Table 1 below lists and compares the main Stirling engine contenders. It is generally believed that Stirling engine based units will become available commercially within the next 18-24 months and that fuel cell based units suitable for EU applications may be available within 5 years, although current products are more appropriate for larger energy users typical of USA homes and small commercial premises. ICE units although currently available at 5kWe power level are not generally considered suitable for individual homes, being too bulky and noisy, but may have considerable potential in the small commercial and multiple domestic applications.

There is considerable activity world-wide directed towards production of a commercial residential CHP unit, based on Stirling engine technology. It is believed that WhisperTech is a leading player at the 1kWe level, although other companies are active at this power level. These include Advantica (using the USA Sunpower FPSE), SIG (also FPSE) and ENATEC (using USA STC FPSE). Micro CHP units at this power level are targeted at the mass housing market principally in the UK, Germany and Netherlands. The marginal investment cost of €800-1000euro (per kWe) is expected to take 4-5 years to recover in the form of reduced electricity bills and, to as lesser extent, the value of electricity exported to the grid. However, around 70% of generation is consumed within the home and the remaining 30% is exported at times of relatively low market price.

A very different picture emerges for 3kWe units such as the Sigma PCP, which is the leading product at this power level. This product, although suitable for family homes, is of greatest value when installed in the larger family homes with substantial energy bills. In this case the higher investment cost (although lower per kWe at €780euro) is recovered to a greater extent from the value of exported power (around 55%) which occurs at times when the market price is high.

All the micro CHP units identified below are fuelled by Natural Gas, although it is likely that biogas, LPG and fuel oil versions of Stirling engine based units will become available soon after the NG versions are launched commercially.

For the purposes of evaluating the market potential in Europe representative units at an advanced state of development or already commercially available are selected for each power level. Costs are manufacturers estimates based on mass production levels and marginal costs are the installed cost for the CHP unit less the cost for replacement of a conventional gas boiler. The suggested representative units are:

Table 2: Representative micro CHP units

Engine	Power output	Heat output	Electrical conversion efficiency	Cost (installed)	Cost (marginal)	Cost per kWe (marginal)
	kWe	kWt	%	£	£	£
WhisperTech	0.8	6	12	1700	500	625
Sigma	3	9	25	2700	1500	500

In order to evaluate these units in their respective markets it is necessary to calculate the overall operating costs in relation to the value of the power and heat produced. This will be a function of energy costs, annual running hours and service costs as indicated below.

Table 3: Operating costs for representative micro CHP units

Engine	Power output	Heat output	Typical annual running hours	Annual service cost (marginal)	Annual kWh generated	Maintenance cost per kWh (marginal)
	kWe	kWt		£	kWh	p
WhisperTech	0.8	6	3000	0	2400	0
Sigma	3	9	3500	30	10500	0.28

The principle market in the EU15 is based on the following key criteria:

- Significant space heating demand; this requires a heating season with a substantial number of degree days, but more importantly, the duration of the heating season is of greater impact than extreme cold temperatures in order to maximise the number of running hours for the units and consequent electricity production.
- An extensive natural gas network with existing domestic connections and hydronic, gas fired central heating systems. Although it is likely that other fuels such as LPG and fuel oil will form significant niche markets, the initial and most cost effective markets will be based on NG as a fuel.
- Equitable market conditions such as access to gas and electricity networks, simplified trading arrangements and consistent connection standards.

Although the first two factors play a significant role is defining the extent of potential markets, the latter issues effectively permit or prevent the installation of micro CHP in any significant numbers. It is therefore this latter point which should be the focus of government initiatives in ensuring free access and equitable standards.

Against this background, the market in each country is derived from the profitable investment in micro CHP. The marginal capital cost of the micro CHP unit (compared with a conventional gas boiler) is recovered from the value of electricity generated by the unit. Part of this is seen as an avoided cost of electricity to the consumer, the remainder as income from the sale of excess generation. It is therefore clear that the larger the initial energy bill for a given home, the larger the potential savings and thus the better the payback. Indeed, this criteria is used to define the potential market; for a given marginal cost, the break-even energy saving implies a certain energy bill and thus thermal demand of the property. If it is known how many homes have at least that energy bill, it may be concluded that all these homes are viable micro CHP hosts on purely economic grounds.

Behind this simplistic summary is a highly complex balance of costs and values, incorporated within the market models used in the evaluation. For illustration purposes, two typical scenarios are appended for a typical UK home with nominal 1kWe and 3kWe micro CHP units.

MINI CHP

The definition of mini and micro CHP is somewhat confusingly still under discussion. However, for the purposes of this report, micro CHP was earlier defined as individual units in individual homes. Mini CHP is therefore taken to mean small CHP units, which nevertheless are not installed in individual homes, but are applied to a number of homes or individual small commercial premises.

Technologies in this area range from ICE, Stirling engines and fuel cells at the lower limit, up to micro turbines from 30kWe and upwards. This section of the report covers only the lower end of the scale, as this represents the emerging rather than established market. Consequently the representative technologies used to evaluate the market potential are Stirling engine and ICE based units.

Table 4: Representative mini CHP units

Engine	Power output	Heat output	Electrical conversion efficiency	Cost (installed)	Cost (marginal)	Cost per kWe (marginal)
	kWe	kWt	%	€ euro	€ euro	€ euro
SenerTec	5.5	12.5	25	13000	10000	1800
Solo	9.5	24	22	18500	15500	1630

Table 5: Operating costs for representative mini CHP units

Engine	Power output	Heat output	Typical annual running hours	Annual service cost	Annual kWh generated	Maintenance cost per kWh (marginal)
	kWe	kWt		€ euro	kWh	€ cent
SenerTec	5.5	12.5	6500	480	35750	1.1
Solo	9.5	24	6500	6-1200	61750	1-2

Unlike micro CHP, which has a clearly defined market in the domestic sector, mini CHP has a wide range of applications in the retail, commercial and leisure sectors with a correspondingly broad range of requirements.

Overall, although the output of individual mini CHP units is larger than micro CHP, the number of potential installations is two orders of magnitude lower, such that the potential impact is relatively insignificant. It does however, represent a profitable niche which is addressed in the main body of this report.

TECHNOLOGIES

Advocates of the various emerging technologies make passionate representations as to the potential for their chosen product. However, before considering the particular characteristics of the respective technologies, it is important to consider the desirable characteristics of a micro CHP product. These may be summarised as follows:

1. Capital cost (marginal). It is anticipated that micro CHP units will be installed to replace conventional central heating boilers which have reached the end of their useful life. Micro CHP units necessarily have a higher capiatl cost than such boilers. It must be possible to recover the additional invetsment cost from the energy savings produced. A target marginal cost of £500 per kWe is desirable to achieve a realistic payback. Larger electrical output units will tend to find it easier to achieve this target.
2. Operating and maintenance cost. The cost per kWh of normal servicing and other maintenance strongly influences the economic viability of any unit. Early attempts at developing micro CHP systems based on conventional ICE technologies suffered severely in this respect. A target cost of no more than £0.005 is essential. Again the larger output units can achieve this more readily than smaller units as the fixed attendance cost for regular service is less significant for higher annual kWh production.
3. Service requirements. Apart from the cost of service, it is considered that, for domestic installations, it is unacceptable to require service visits more often that the current annual boiler inspection. Thus, micro CHP units must be capable of operating unattended for at least 3-5000 hours (depending on specification). In addition, the overall life of the units must be sufficient to recover a return on the initial investment, and similar to that of the conventional boiler. Taking a 10-15 year life this implies a life expectancy of around 50,000 hours. Considering the typical service interval for a car is around 200 hours and that the total life is usually no more than 4,000 hours, it is clear that micro CHP prime movers face considerable technical challenges.
4. Reliability & availability. During normal operation the unit is required to provide heat to the home without any loss of availability. However, occasional losses of power output may be acceptable without undue detriment to the overall economics.
5. Pollutant emissions. In global terms it is necessary for micro CHP to reduce overall pollutant emissions if any environmental benefit is to be gained. However, at a local level, emissions of noxious or otherwise deleterious emissions are unacceptable if they exceed current boiler emissions. Certain technologies are inherently clean (such as Stirling engines and fuel cells) whereas others may be able to minimise emissions by use of extensive and costly flue cleaners(such as catalytic converters on IC engines).
6. Noise and vibration. As micro CHP units will generally installed within the living space, the noise level may not be higher than from current domestic appliances designed for continuous operation (i.e. freezers not dishwashers). This implies a target noise level less than 40dBA (preferably 35dBA) in kitchens.
7. Safety. Domestic appliances are generally subject to stringent safety standards and the same is likely to be true for micro CHP units. Although manufacturers are aware of such issues, particular consideration must be paid to adequate pressure

containment (Stirling engines) and leakage of high temperature or toxic chemicals (fuel cells).

8. Physical dimensions, weight and installability. For floor mounted units (of which there is a significant but decreasing market) the maximum acceptable dimension is that of the boiler being replaced, generally up to 600x600 mm footprint and 850 mm high. Weight is not normally critical, but the unit must be manoeuvrable without recourse to specialist lifting equipment. Smaller, wall-mounted units also need to be light enough (less than 50kg for two man lift) and vibration free if they are to exploit the mass market. Larger floor mounted units which require installation in a separate plant room do not fall into this definition of micro CHP and will have a limited market application.
9. Drop-in compatibility. A wide range of additional criteria such as flow and return temperatures, resistance to corrosion from hydronic medium, the need for thermal storage, flueing arrangements, controllability etc are essential features of commercial products.
10. Life-cycle cost (including disposal).
11. Heat to power ratio. Although a high power to heat ratio might appear an ideal, it is also important to match the thermal output of units to the thermal demand of the home in order to maximise operating hours and hence production of valuable electricity.
12. Efficiency. As with heat/power ratio, this is not a simple issue. Higher electrical conversion efficiency is desirable, but not if it compromises the overall cost effectiveness of the system. Detailed economic evaluations need to be undertaken for each product bearing in mind its electrical and thermal outputs, operating hours and marginal investment cost.

Stirling Engines

Stirling engines are external combustion engines with very low pollutant emissions (similar to gas boilers), low vibration and noise levels and potentially long life and minimal service requirements. There is a wide range of potential Stirling engine technologies, each with particular characteristics and benefits. The Sigma engine is a kinematic type with a considerable pedigree with relatively conventional engineering and a high electrical conversion efficiency. The FPSE (Free Piston Stirling Engine) products are more elegant and more demanding in engineering terms, but require power electronics to be linked to the mains. Like the Sigma engine, the WhisperTech unit, although comprising a novel mechanism, utilises simple induction generator technology to permit simple grid connection.

Equally significant to technology status, however, is the commercial status of the various players. Little is known of current activities of the three Japanese companies Kawasaki, Mitsubishi and Toshiba other than that Toshiba seem to be directing their efforts towards developing Stirling powering air-conditioning/heat-pump units.

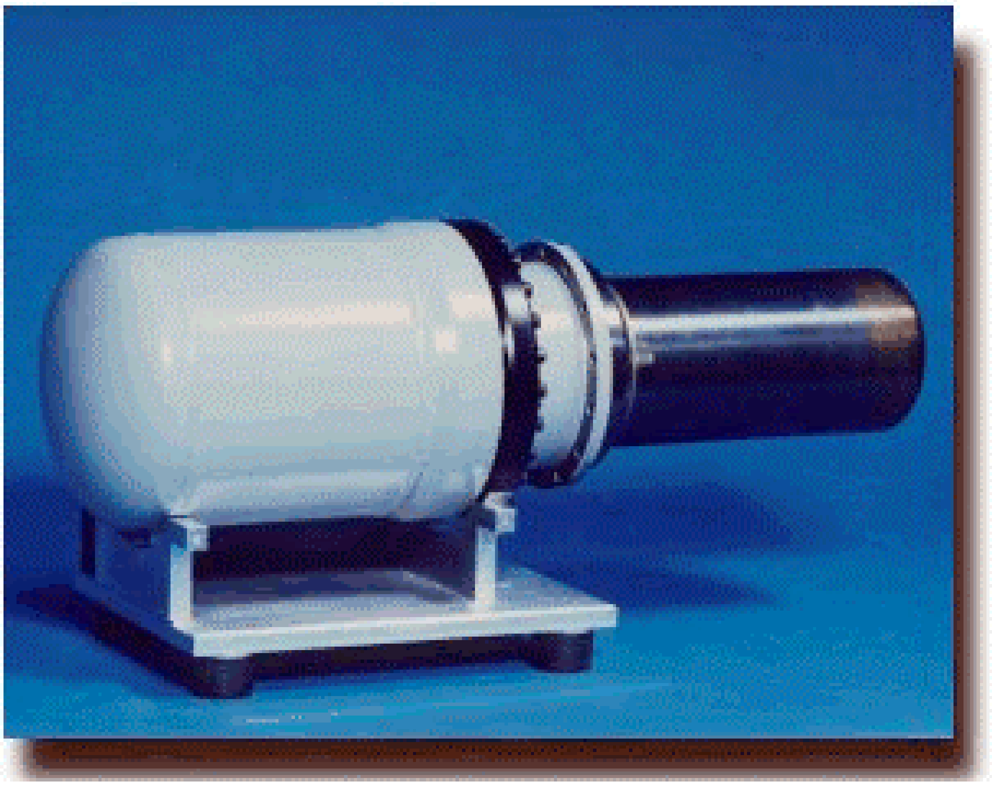
WhisperTech of New Zealand are in the process of establishing collaborative partnerships with energy companies in Europe and are manufacturing limited demonstration micro CHP units. The DC version for marine APU applications has been commercially available for some time. Electrical conversion efficiency of the WhisperGen PPS16AC is low compared with most other Stirling engine developments. However, this is not necessarily an impediment to commercialisation in domestic micro-CHP where a high heat/power ratio (in the region of 6) matches domestic energy demands, and reliability, low maintenance needs and low cost are key factors.

Figure 3: WhisperTech WG800 Stirling engine

In the UK, Advantica are promoting their Microgen unit. Advantica have packaged the American Sunpower RE100 Free-Piston Stirling Engine (FPSE) into a wall mounted unit of 1 kWe claimed capacity, using permanent-magnet (synchronous) linear alternators directly coupled to the piston. Advantica are also actively seeking government support.

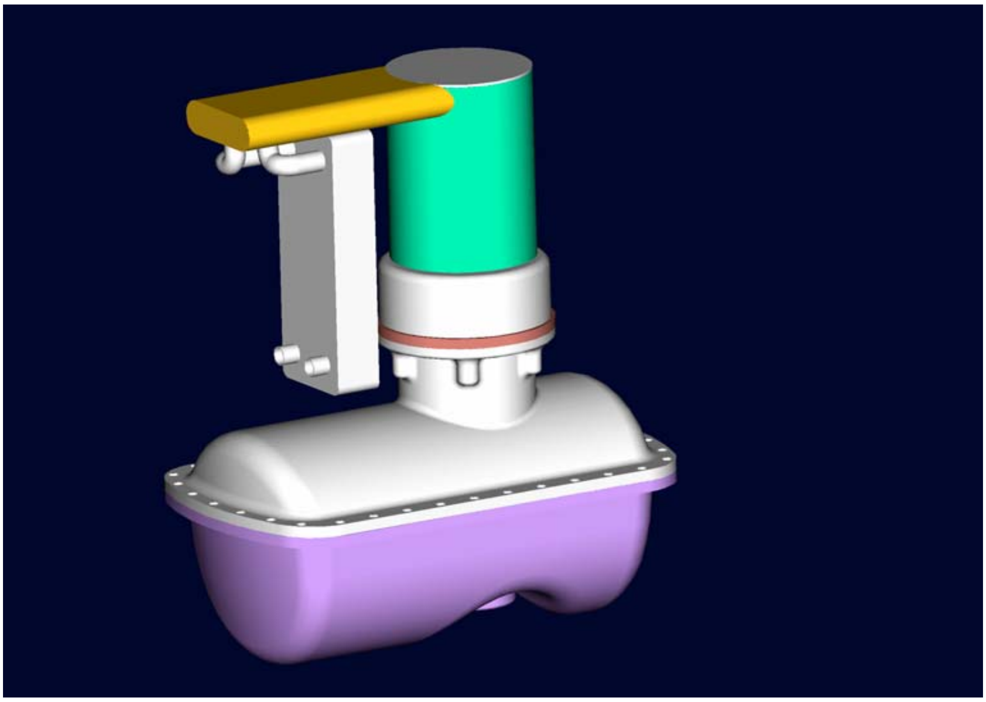
Elsewhere in Europe, a Netherlands consortium of ENECO, ATAG and ECN, collectively known as ENATEC, are working with the Stirling Technology Company (STC) of America to upgrade their 350W to deliver 1 kWe. The STC engine is of particular interest. Like the Sunpower unit it is a FPSE but uses a pair of diaphragm springs to produce the resonant oscillations of piston and displacer which also functioning as guide/supports in place of bearings and operation without sliding contact is claimed. ENATEC propose to carry out field trials of 10 units this year.

Figure 4: STC Free Piston Stirling Engine



Sigma Elektroteknisk of Norway are basing their work on technology originally from United Stirling (Sweden), now a subsidiary of Kockums. Their engine is a 3 kWe single cylinder design (kinematic β-type) known as the PCP. Sigma is currently re-engineering the PCP for volume manufacture with the assistance of the automotive engineering company, Ricardo. The volume production model of the PCP is planned for trials in September 2001.

Figure 5: Sigma PCP (production engineering model)



Another USA company, Tamin, is a relative new comer and something of an outsider in micro-CHP terms. They have so far produced few engines of very conventional design, but claim their engines have potential for low-cost production. Tamin have plans for a 1 kWe unit, as yet unbuilt; the predicted performance, from a low-pressure, air-charged engine, must, at this stage, be treated with some caution.

Table 6: Significant Stirling Engine developments

Engine	Cylinders	P kW	Electrical Conversn η *	Heater Te	Gas	Press MPa
WhisperGen PPS16AC	4	0.75	10%	650	N_2	2.0
Sunpower/Advantica RE100	1 FPSE	1.0	25%?	600	He	1.0
STC/ENATEC	1 FPSE	1	10%	650	?	?
Sigma PCP 1-130	1	3.0	25%	700	He	8.5
Kawasaki Model V	1 FPSE	1.2	27%	(650)	He	2.4
Tamin TESE004	1	1	(22%)	650	Air	1.7
SIG	1FPSE	1	(25%)	(600)	He	?
Mitsubishi NS-03M	1	3.8	36%	(780)	He	6.2
Toshiba NS-03T	2	4.1	34%	820	He	6.4

* LCV

( ) estimate

Internal Combustion Engines

SenerTec of Germany currently produce a 5 kWe micro-CHP package based on the Sachs-HKA ICE, aimed at the residential market although not on an individual house basis. The unit measures 1m high x 720mm wide x 1m deep. It uses a spark ignition IC engine with wet lubrication that requires servicing every 3500 hours or 1 year. Operational noise level is 52 dBA and emissions are claimed to beat the stringent TA Luft requirements. These parameters are achieved by extensive acoustic damping and catalytic emission reduction respectively, demonstrating that the onerous demands of small scale CHP can be met by ICE technology, albeit at a cost.

Eco Power are producing a 5kW unit based on the Marathon engine. This unit can be modulated to vary power output, offering significant advantages in terms of maximising running hours and minimising stop/start cycles.

Honda have produced a 1kW output ICE which has been tested by GasTec in the Netherlands. This is believed to have some features to extend maintenance intervals, but unconfirmed reports indicate that the anticipated reliability was not achieved and noise levels remain unacceptably high.

Table 7: Significant Internal Combustion Engine developments

Engine	Cylinders	P kW	Electrical Conversn η *
Senertec (Fichtel & Sachs)	1	5.5	25%
Ecopower (Marathon)	1	1-4	
Honda	1	1	

* LCV

Figure 6: Ecopower Internal Combustion Engine based micro CHP unit

Fuel cells

Currently, a number of companies are field-trialing fuel-cell based residential micro-CHP systems, among them Plug Power, Hamburg Gas Consult, H-Power and Sulzer-Hexis.

Plug Power/Vaillant

Plug Power is an American company based at Lantham N.Y. with over 300 employees. They are developing Proton Exchange Membrane (PEM) fuel-cell CHP systems and have recently formed a joint venture with General Electric (GE). PEM cells cannot use natural gas directly and a reformer is required to split the gas to provide a hydrogen rich supply. Units ranging from 7kW residential sets to 35 kW units. A residential system is claimed to have operated at a home since 1998 and Plug Power also claim to have run a PEM cell for over 10,000 hours. Earlier this year the company announced that they had built 52 complete systems, 37 to run on natural gas and 15 on ‘simulated’ fuel. In the EU, the major gas boiler manufacturer, Vaillant is packaging the unit for larger residential applications, with the first commercial units expected to be available during 2001.

Sulzer-Hexis

Sulzer is a Swiss company developing a 1kWe/3kWt Solid Oxide Fuel-Cell (SOFC) specifically for the residential cogeneration market. SOFC run at sufficiently high temperature for natural gas to split into its hydrogen and carbon rich components and a separate reformer is not required. During 1994 Sulzer ran two field-trials followed by a further four, second generation trials starting in autumn 1998 and planned to run under a three-year test programme (one each in Oldenburg and Dortmund, one in Tokyo and the other in Bilbao). Sulzer-Hexis claim that commercial units will be available (to existing collaborators only) in 2001 with electrical conversion efficiency much higher than Stirling engines (30-40% depending on load), and 90% efficiency overall. It should be noted, however, that although output from a SOFC can modulate down to zero, cells must never be allowed to cool and units must consume at least 10% of rated fuel capacity even at zero duty.

Hamburg Gas Consult

HGC have developed and demonstrated a small fuel cell unit of 3kWe and 8kWt output, based on an Energy Partners stack assembly. Two units were installed to serve a block of flats and further field trials are proposed.

H-Power Enterprises

H-Power Enterprises of Canada have developed a PEM fuel cell based residential micro CHP system designated RPAC claiming 40% electrical conversion efficiency. The unit measures 1.5m high x 1.4m wide and deep, with an output up to 5.2kWe/5kWt at 60°C. However, at this size and power output, it is clearly inappropriate for the majority of individual European homes.

Thermo-Photo-Voltaics (TPV)

In TPV systems gas (or other fuels) heats a ceramic emitter to incandesce and part of the radiant energy is converted to electricity by a surrounding array of photo-voltaic cells. There are no moving parts and the system should be extremely quiet and reliable but high combustion temperatures may cause emission problems. Two American organisations are currently believed to be working on TPV based micro-CHP: West Washington University and Thermo Power Corporation (Tecogen). Neither is believed to be close to market.

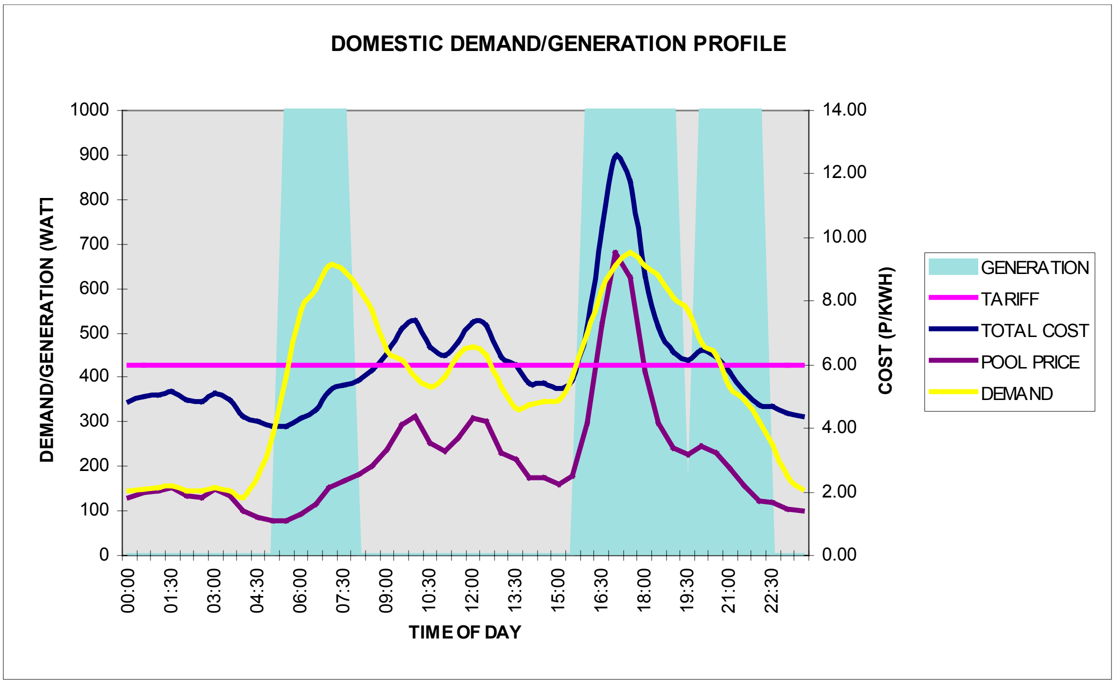
The Vehicle Research Institute (VRI) of Western Washington University is working with JX Crystals who have developed a PV cell able to work in the infra-red region of the spectrum. Gallium antimonide (GaSb) cells operate at an emitter temperature of 1500C, within the temperature range of conventional ceramic components. To date VRI have achieved 900We at a conversion efficiency of 7% from a single burner and are currently developing on a 1 kWe version.

Tecogen have followed a different strategy in developing an emitter material able to run hot enough for use with conventional, low-cost, silicon cells. Their ytterbium oxide emitter runs at 1700C and Tecogen are reported to have demonstrated that a 450W domestic unit could be built at a marginal cost of $220 above conventional boilers if produced in sufficient quantity.

APPENDIX 1:Value of micro CHP generation

A simplistic analysis of the economic benefits of micro CHP assumes an average value of exported power. However, both the tradable price of electricity and the embodied CO2 vary with time throughout each day and from day to day. The example scenarios show an average value for exported power, dependent on the size of unit (in electrical terms) with the 3kWe unit having a higher value attributed to its export than does a 1kWe unit. This reflects the fact that most of the small unit's output is consumed within the home, whereas the 3kWe unit is able to export a significant amount of power at times of peak system demand and consequently, price.

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 is around 3.4 p/kWh (for a 3kWe unit) over the year compared with an average pool price less than 2.5 p/kWh.



APPENDIX 2: Economic scenarios

The following spreadsheets show the elements in the energy and product delivery chain for a range of household types, based on annual energy consumption. The economic comparison is made between:

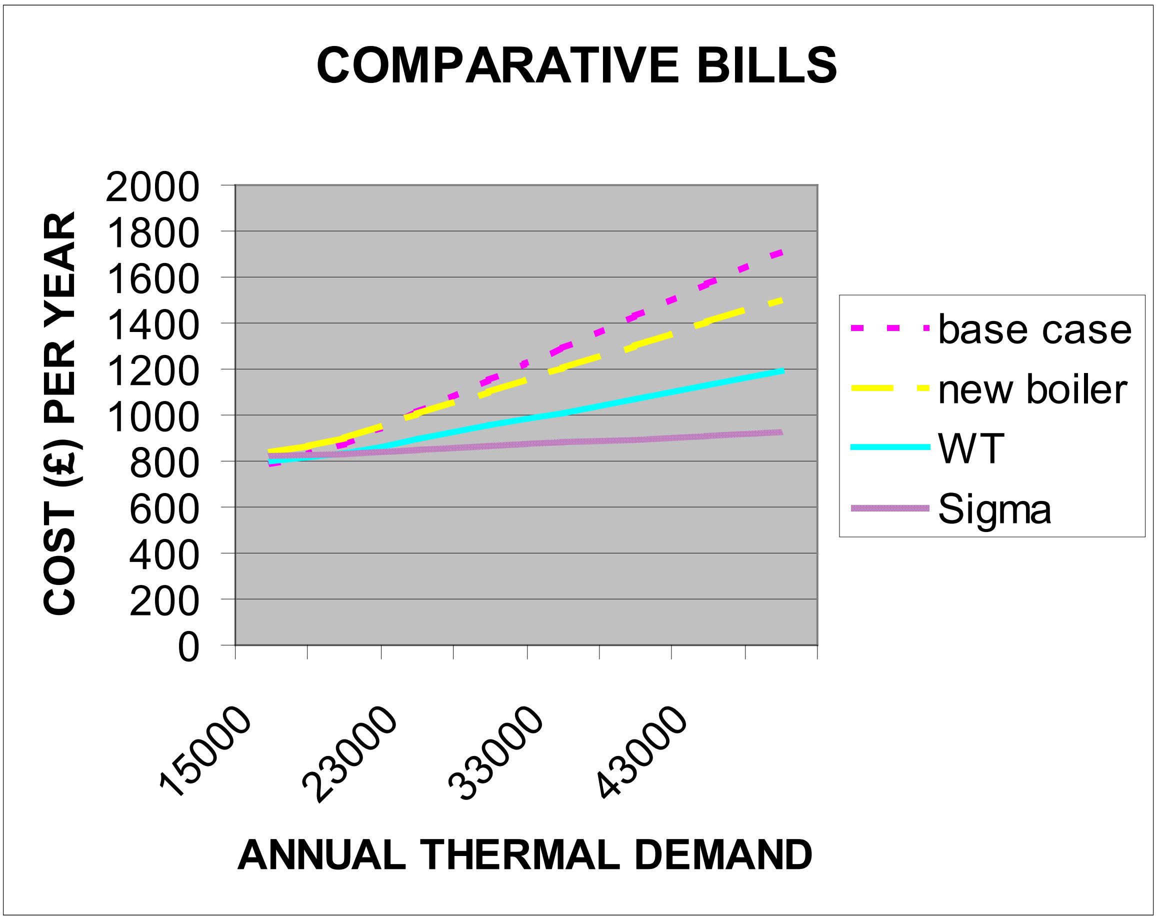
1. Base case – "do nothing". This is the current situation where the householder has a gas central heating system, powered by an ageing, inefficient gas fired boiler. He has the option of replacing it with a similar, but newer unit, a higher efficiency condensing gas boiler, a smaller (1kWe) micro CHP unit, or a larger (3kWe) micro CHP unit. The scenarios are based on representative technologies with characteristics in accordance with current leading contenders. It is interesting to note that the very low system efficiency commonly associated with such systems, makes replacement economically viable, (for moderate and high energy users,) even if the old boiler has not actually failed.

2. Condensing boiler. Although significant numbers of gas boilers in continental Europe are condensing, the existing stock of boilers due for replacement will comprise a high proportion of lower efficiency, non-condensing boilers. In the UK, less than 5% of the gas boiler market is for condensing boilers. Note that efficiency figures are based on GCV (Gross Calorific Value) of natural gas.

3. Smaller micro CHP unit, based on target performance specification of the WhisperTech WG800 unit. It can be seen that the economic value to user and ESCo alike is high for low energy users as well as the mass market of moderate energy consumers.

4. Larger (3kWe) micro CHP based on the Sigma PCP unit. It can be seen that for moderate energy consumers (18-23,000 kWh per year) the unit is competitive with the 1kWe unit, but that the relative economic benefits increase substantially for larger energy consumers.

The scenarios shown are intended only to indicate the potential market segmentation and is clearly subject to numerous other market forces, many of which are incorporated in the Sigma software evaluation packages described later.



This chart summarises the scenarios on the following spreadsheets, indicating that a larger micro CHP unit can achieve greater overall savings as total energy costs rise. The costs include all elements of the operation of the respective systems, such as amortisation, fuel costs, value of generated electricity, maintenance and finance costs.

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
				base case	new boiler	WT	Sigma
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	15000	15000	15000	15000	15000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		15000	15000	1500	0
	CHP load	kWh		0	0	13500	15000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		30000	21429	20368	21127
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		60.00	42.86	40.74	42.25
	gas bill	£pa		420.00	300.00	285.15	295.77
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	1575	2400
	electricity import	kWh		4000	4000	2425	1600
	el import bill	£pa		252	252	153	100.8
	running hours	hrs pa				2250	1667
	el generation	kWh pa				2250	5333
	utilisation %	%				70%	45%
	utilisation	kWh pa				1575	2400
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	119	78
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				675	2933
	export value	£pa				10	100
electricity bill		£pa		252	252	143	1
electric profit to ESCO		£pa		16	16	34	22
income to ESCO		£pa		252	252	153	101
gas bill		£pa		420	300	285	296
gas profit to ESCO		£pa		60	43	41	42
income to ESCO		£pa		420	300	285	296
Energy bill		£pa		672	552	428	297
Energy profit		£pa		76	59	75	65
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				792	846	802	829
ESCO profit from customer consumin		15000	kWh pa	161	178	210	231
cost of customer				631	668	592	598

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
				base case	new boiler	WT	Sigma
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	18000	18000	18000	18000	18000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		18000	18000	1800	0
	CHP load	kWh		0	0	16200	18000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		36000	25714	24442	25352
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		72.00	51.43	48.88	50.70
	gas bill	£pa		504.00	360.00	342.18	354.93
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	1890	2880
	electricity import	kWh		4000	4000	2110	1120
	el import bill	£pa		252	252	133	70.56
	running hours	hrs pa				2700	2000
	el generation	kWh pa				2700	6400
	utilisation %	%				70%	45%
	utilisation	kWh pa				1890	2880
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	103	55
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				810	3520
	export value	£pa				12	120
electricity bill		£pa		252	252	121	-49
electric profit to ESCO		£pa		16	16	30	16
income to ESCO		£pa		252	252	133	71
gas bill		£pa		504	360	342	355
gas profit to ESCO		£pa		72	51	49	51
income to ESCO		£pa		504	360	342	355
Energy bill		£pa		756	612	463	306
Energy profit		£pa		88	67	78	66
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				876	906	837	838
ESCO profit from customer consumin		18000	kWh pa	173	187	214	233
cost of customer				703	720	623	605

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
				base case	new boiler	WT	Sigma
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	23000	23000	23000	23000	23000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		23000	23000	2300	0
	CHP load	kWh		0	0	20700	23000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		46000	32857	31231	32394
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		92.00	65.71	62.46	64.79
	gas bill	£pa		644.00	460.00	437.24	453.52
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	2415	3680
	electricity import	kWh		4000	4000	1585	320
	el import bill	£pa		252	252	100	20.16
	running hours	hrs pa				3450	2556
	el generation	kWh pa				3450	8178
	utilisation %	%				70%	45%
	utilisation	kWh pa				2415	3680
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	78	16
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				1035	4498
	export value	£pa				16	153
electricity bill		£pa		252	252	84	-133
electric profit to ESCO		£pa		16	16	22	4
income to ESCO		£pa		252	252	100	20
gas bill		£pa		644	460	437	454
gas profit to ESCO		£pa		92	66	62	65
income to ESCO		£pa		644	460	437	454
Energy bill		£pa		896	712	522	321
Energy profit		£pa		108	82	85	69
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				1016	1006	895	853
ESCO profit from customer consuming		23000	kWh pa	193	201	220	236
cost of customer				823	805	676	617

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
				base case	new boiler	WT	Sigma
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	28000	28000	28000	28000	28000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		28000	28000	2800	0
	CHP load	kWh		0	0	25200	28000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		56000	40000	38021	39437
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		112.00	80.00	76.04	78.87
	gas bill	£pa		784.00	560.00	532.29	552.11
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	2940	4480
	electricity import	kWh		4000	4000	1060	-480
	el import bill	£pa		252	252	67	-30.24
	running hours	hrs pa				4200	3111
	el generation	kWh pa				4200	9956
	utilisation %	%				70%	45%
	utilisation	kWh pa				2940	4480
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	52	-24
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				1260	5476
	export value	£pa				19	186
electricity bill		£pa		252	252	48	-216
electric profit to ESCO		£pa		16	16	15	-7
income to ESCO		£pa		252	252	67	-30
gas bill		£pa		784	560	532	552
gas profit to ESCO		£pa		112	80	76	79
income to ESCO		£pa		784	560	532	552
Energy bill		£pa		1036	812	580	336
Energy profit		£pa		128	96	91	72
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				1156	1106	954	868
ESCO profit from customer consuming		28000	kWh pa	213	215	226	239
cost of customer				943	891	728	629

					base case	new boiler	WT	Sigma
ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS								
	unit spec							
		unit cost	£		0	1100	1600	2600
		overall efficiency					85%	96%
		gas input	kW GCV				8.24	12.71
		heat output	kWt				6	9
		electrical output	kWe				1	3.2
		electric efficiency					12%	25%
	energy trading							
		thermal demand	kWh	33000	33000	33000	33000	33000
		boiler efficiency	%		50%	70%	80%	80%
		load met by boiler	%		100%	100%	10%	0%
		load met by boiler	kWh		33000	33000	3300	0
		CHP load	kWh		0	0	29700	33000
		CHP efficiency	%		70%	70%	73%	71%
		gas consumption	kWh (GCV)		66000	47143	44810	46479
		gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
		gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
		gas profit	£pa		132.00	94.29	89.62	92.96
		gas bill	£pa		924.00	660.00	627.34	650.70
		el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
		electric consumption	kWh pa	4000	4000	4000	4000	4000
		avoided import	kWh pa		0	0	3465	5280
		electricity import	kWh		4000	4000	535	-1280
		el import bill	£pa		252	252	34	-80.64
		running hours	hrs pa				4950	3667
		el generation	kWh pa				4950	11733
		utilisation %	%				70%	45%
		utilisation	kWh pa				3465	5280
		ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
		DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
		DUoS/etc		2.50	2.50	2.50	2.50	2.50
		unit supply cost			5.90	5.90	4.90	4.90
		cost of supply	£pa		236	236	26	-63
		DW export value	p/kWh	from other sheet			1.50	3.40
		export	kWh				1485	6453
		export value	£pa				22	219
	electricity bill		£pa		252	252	11	-300
	electric profit to ESCO		£pa		16	16	7	-18
	income to ESCO		£pa		252	252	34	-81
	gas bill		£pa		924	660	627	651
	gas profit to ESCO		£pa		132	94	90	93
	income to ESCO		£pa		924	660	627	651
	Energy bill		£pa		1176	912	639	351
	Energy profit		£pa		148	110	97	75
	other income							
		O&M			120	120	120	120
		O&M cost			35	35	35	35
		O&M profit			85	85	85	85
		monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
		lease cost	5%		£0.00	£11.67	£16.97	£27.58
		lease profit			£0.00	£2.87	£4.17	£6.78
	CUSTOMER PAYS				1296	1206	1012	883
	ESCO profit from customer consumin		33000	kWh pa	233	230	232	241
	cost of customer				1063	977	780	642

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
				base case	new boiler	WT	Sigma
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	38000	38000	38000	38000	38000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		38000	38000	3800	0
	CHP load	kWh		0	0	34200	38000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		76000	54286	51599	53521
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		152.00	108.57	103.20	107.04
	gas bill	£pa		1064.00	760.00	722.39	749.30
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	3990	6080
	electricity import	kWh		4000	4000	10	-2080
	el import bill	£pa		252	252	1	-131.04
	running hours	hrs pa				5700	4222
	el generation	kWh pa				5700	13511
	utilisation %	%				70%	45%
	utilisation	kWh pa				3990	6080
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	0	-102
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				1710	7431
	export value	£pa				26	253
electricity bill		£pa		252	252	-25	-384
electric profit to ESCO		£pa		16	16	0	-29
income to ESCO		£pa		252	252	1	-131
gas bill		£pa		1064	760	722	749
gas profit to ESCO		£pa		152	109	103	107
income to ESCO		£pa		1064	760	722	749
Energy bill		£pa		1316	1012	697	366
Energy profit		£pa		168	125	103	78
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				1436	1306	1071	898
ESCO profit from customer consumin		38000	kWh pa	253	244	238	244
cost of customer				1183	1062	833	654

ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS								
					base case	new boiler	WT	Sigma
	unit spec							
		unit cost	£		0	1100	1600	2600
		overall efficiency					85%	96%
		gas input	kW GCV				8.24	12.71
		heat output	kWt				6	9
		electrical output	kWe				1	3.2
		electric efficiency					12%	25%
	energy trading							
		thermal demand	kWh	43000	43000	43000	43000	43000
		boiler efficiency	%		50%	70%	80%	80%
		load met by boiler	%		100%	100%	10%	0%
		load met by boiler	kWh		43000	43000	4300	0
		CHP load	kWh		0	0	38700	43000
		CHP efficiency	%		70%	70%	73%	71%
		gas consumption	kWh (GCV)		86000	61429	58389	60563
		gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
		gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
		gas profit	£pa		172.00	122.86	116.78	121.13
		gas bill	£pa		1204.00	860.00	817.44	847.89
		el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
		electric consumption	kWh pa	4000	4000	4000	4000	4000
		avoided import	kWh pa		0	0	4515	6880
		electricity import	kWh		4000	4000	-515	-2880
		el import bill	£pa		252	252	-32	-181.44
		running hours	hrs pa				6450	4778
		el generation	kWh pa				6450	15289
		utilisation %	%				70%	45%
		utilisation	kWh pa				4515	6880
		ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
		DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
		DUoS/etc		2.50	2.50	2.50	2.50	2.50
		unit supply cost			5.90	5.90	4.90	4.90
		cost of supply	£pa		236	236	-25	-141
		DW export value	p/kWh	from other sheet			1.50	3.40
		export	kWh				1935	8409
		export value	£pa				29	286
	electricity bill		£pa		252	252	-61	-467
	electric profit to ESCO		£pa		16	16	-7	-40
	income to ESCO		£pa		252	252	-32	-181
	gas bill		£pa		1204	860	817	848
	gas profit to ESCO		£pa		172	123	117	121
	income to ESCO		£pa		1204	860	817	848
	Energy bill		£pa		1456	1112	756	381
	Energy profit		£pa		188	139	110	81
	other income							
		O&M			120	120	120	120
		O&M cost			35	35	35	35
		O&M profit			85	85	85	85
		monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
		lease cost	5%		£0.00	£11.67	£16.97	£27.58
		lease profit			£0.00	£2.87	£4.17	£6.78
	CUSTOMER PAYS				1576	1406	1130	913
	ESCO profit from customer consuming		43000	kWh pa	273	258	245	247
	cost of customer				1303	1148	885	666

				base case	new boiler	WT	Sigma
ECONOMIC CASE FOR MICRO CHP ESCO BUSINESS							
unit spec							
	unit cost	£		0	1100	1600	2600
	overall efficiency					85%	96%
	gas input	kW GCV				8.24	12.71
	heat output	kWt				6	9
	electrical output	kWe				1	3.2
	electric efficiency					12%	25%
energy trading							
	thermal demand	kWh	48000	48000	48000	48000	48000
	boiler efficiency	%		50%	70%	80%	80%
	load met by boiler	%		100%	100%	10%	0%
	load met by boiler	kWh		48000	48000	4800	0
	CHP load	kWh		0	0	43200	48000
	CHP efficiency	%		70%	70%	73%	71%
	gas consumption	kWh (GCV)		96000	68571	65178	67606
	gas tariff	p/kWh	1.40	1.40	1.40	1.40	1.40
	gas cost	p/kWh	1.20	1.20	1.20	1.20	1.20
	gas profit	£pa		192.00	137.14	130.36	135.21
	gas bill	£pa		1344.00	960.00	912.49	946.48
	el tariff	p/kWh	6.30	6.30	6.30	6.30	6.30
	electric consumption	kWh pa	4000	4000	4000	4000	4000
	avoided import	kWh pa		0	0	5040	7680
	electricity import	kWh		4000	4000	-1040	-3680
	el import bill	£pa		252	252	-66	-231.84
	running hours	hrs pa				7200	5333
	el generation	kWh pa				7200	17067
	utilisation %	%				70%	45%
	utilisation	kWh pa				5040	7680
	ave pool	p/kWh	2.60	2.60	2.60	2.60	2.60
	DW import cost	p/kWh	from other sheet	3.40	3.40	2.40	2.40
	DUoS/etc		2.50	2.50	2.50	2.50	2.50
	unit supply cost			5.90	5.90	4.90	4.90
	cost of supply	£pa		236	236	-51	-180
	DW export value	p/kWh	from other sheet			1.50	3.40
	export	kWh				2160	9387
	export value	£pa				32	319
electricity bill		£pa		252	252	-98	-551
electric profit to ESCO		£pa		16	16	-15	-52
income to ESCO		£pa		252	252	-66	-232
gas bill		£pa		1344	960	912	946
gas profit to ESCO		£pa		192	137	130	135
income to ESCO		£pa		1344	960	912	946
Energy bill		£pa		1596	1212	815	395
Energy profit		£pa		208	153	116	84
other income							
	O&M			120	120	120	120
	O&M cost			35	35	35	35
	O&M profit			85	85	85	85
	monthly lease charge	10%		£0.00	£14.54	£21.14	£34.36
	lease cost	5%		£0.00	£11.67	£16.97	£27.58
	lease profit			£0.00	£2.87	£4.17	£6.78
CUSTOMER PAYS				1716	1506	1188	928
ESCO profit from customer consumin		48000	kWh pa	293	273	251	250
cost of customer				1423	1234	937	678

APPENDIX 3: Market summary

The figures in the table below summarise the individual country data from the modelling and evaluation studies. From these figures it is expected that Germany, The Netherlands and UK will be the lead markets for micro-CHP. Denmark, Belgium Italy, and Austria also represent good markets, but with a smaller potential. Ireland is a small market and will probably be seen as a subsector of the UK market. France has large potential but depends on the route that deregulation takes. Spain, Portugal and Greece are very small markets, mainly due to the relatively short duration of space heating demand.

Annual market potential for micro-CHP in EU

	Number of Boilers	Annual Heating Installations	Heat Load Factor	Annual Accessible Market
	'000	'000	%	'000
Austria	1,620	97	80%	78
Belgium	2600	156	50%	78
Denmark	850	51	80%	41
Finland	529	32	30%	10
France	13000	780	30%	234
Germany	20000	1,200	60%	720
Ireland	302	18	25%	5
Italy	30000	1,800	20%	360
Netherlands	6080	365	60%	219
Sweden	1100	66	55%	36
UK	19000	1,140	50%	570
Total	**95,081**	**5,705**		**2,350**

The heat load factor reflects the proportion of customers with a heat demand in excess of 15,000 kWh/annum, assuming that the distribution of gas demand can be scaled from UK figures. However, 15000 kWh/annum should not be viewed as a floor below which units will not be sold. In reality, the figure depends on tariff rates and unit cost, and smaller units are likely to be developed to serve these markets, though the return may not be as profitable.

APPENDIX 4: Sigma evaluation software

The methodology described earlier in which the electricity produced by micro CHP provides the payback on the marginal investment cost forms the basis of the Sigma market evaluation tools.

Sigma has developed two evaluation tools described below.

"SEE-MCHP.XLS"

Software package for the evaluation of the end user economics of domestic micro cogeneration packages based on the SIGMA PCP ™ Stirling energy converter

Background

The Microsoft EXCEL workbook "SEE_MCHP" is a complex software package examining the end user economics and market potential of domestic micro CHP packages based on the SIGMA PCP. All calculations and considerations are made for UK energy market conditions. The reason for this is that the UK is the worst case (energy prices, end user motivation, etc.) amongst SIGMA's target markets. This means that if the end user economics "work" in the UK, they will arguably also work in Germany and the Netherlands. Moreover, the UK is the country for which SIGMA has had the best market and background data.

Features and structure of the software package

The software package contains several Microsoft Visual Basic programmes, which are needed to run the sensitivity analyses of the package. These programmes are, however, not needed for the general use of the package, i.e. manipulation of the various input variables in order to observe their influence on main performance indicators and parameters.

The workbook consists of the following 12 spreadsheets:

1. front page (S1)
2. input data (S2)
3. results (S3)
4. energy prices (S4)
5. PCP production cost (S5)
6. packaging cost (S6)
7. package cost, OEM (S7)
8. market size, OEM (S8)
9. gas consumers (S9)
10. boiler efficiency (S10)
11. boiler efficiency impact (S11)
12. sensitivity (S12)

For convenience, the spreadsheets are hereinafter referred to only with their abbreviation codes; S1, S2, etc.

The spreadsheets, except S1 and S10, are interlinked and should *not* be changed or manipulated. All inputs are done in S2, i.e. the input variables that can be manipulated are gathered in S2. The Microsoft Visual Basic programmes - although they are run from and mainly related to S12 - also have an impact on the other spreadsheets and should not be modified or changed. This may entail damage to all spreadsheets, which in turn may lead to incorrect results.

The software package is implemented in Microsoft EXCEL 97 SR-1, which requires Microsoft Windows 95 as operating system.

In the following, each of the 12 spreadsheets is explained and commented in the order indicated above, which is also the order in that they appear in the workbook.

The two main spreadsheets are S7 and S8. In S7 the value/delivery chain is examined and the price for the micro CHP package is calculated. On the basis of the results from S7, S8 calculates the economic benefits and the market size. In S12, finally, the market size is the particular parameter used for evaluation of the sensitivity with respect to changes in the main influence variables. All other spreadsheets serve as data storage, processing, or output sheets.

Basic assumptions in the model of the software package

It is important to observe and acknowledge the basic assumptions in the model used in the software package. These assumptions are:

1. SIGMA produces only the PCP energy converter.

2. SIGMA sells the PCP only to companies (OEMs = Original Equipment Manufacturers) that will use it as the central component in the complete micro CHP packages that they will produce and market under their own brand names.

3. The task of the OEMs will therefore be to source the additional components necessary to make the package and then integrate these components with the PCP to produce the package. *The OEMs will thus calculate their margins on the sum of the value of all components and labour necessary to make the package*.

4. The OEM may then deliver the package further into the traditional delivery chain consisting of wholesaler and installer. Or the OEM may deliver it directly to an energy company, which in turn installs/delivers it to the end user. Both of these scenarios are considered.

5. The complete end product (i.e. the micro CHP package) is only delivered to the end user *when the boiler of the end user breaks down and therefore needs to be replaced*. The micro CHP package is designed in such a way that it will act as a “drop-in”-replacement for the boiler, i.e. it will be installed in the end user’s house exactly as a replacement boiler would be, with no changes necessary to the property.

6. The calculation of the economic performance – on the basis of the replacement strategy explained under point 5 – is based on the *marginal cost* for the micro CHP package, i.e. the difference in *purchase* price between the micro CHP package and the boiler. The same also applies with respect to the *maintenance* costs.

In the UK, the domestic boiler population consists mainly of standard non-condensing boilers, with a penetration of condensing boilers of approximately only 4%. The reason for this is that the UK boiler market is strictly price driven. Research by independent organisations – for instance EA Technology – has shown that the average seasonal efficiency of non-condensing boilers in the UK, *based on natural gas gross calorific value*, is approximately 70%. Thus, for the UK boiler population an average efficiency of 70% is assumed, *and this is defined as the base case for calculation of economic performance and market size*.

“PROFIT.XLS”

Software package for the evaluation of the potential profit enhancement for energy companies through electricity produced by micro CHP

Background

The Microsoft EXCEL workbook “PROFIT_MCHP” is a software package examining the implications of embedded domestic generation (micro CHP) from the energy company (EC) perspective. *All calculations and considerations are for UK energy market conditions*. The UK has currently the most advanced, genuinely competitive domestic electricity market and is therefore also the country for which the most comprehensive market and background data is available.

Features and structure of the software package

Embedded generation at the individual house level is an evolving concept. As such there is little definitive information or accepted methodology for analysing the implications. This software package is intended to be used as part of the evolutionary process and to help the understanding of the issues and impacts of micro CHP. It is preliminary only and subject to continuing modification.

The workbook consists of the following 14 spreadsheets:

1. front page (S1)
2. totals (S2)
3. profits (S3)
4. 1998 pool (S4)
5. gas consumers (S5)
6. summer day 23’ (S6)
7. winter day 23’ (S7)
8. spring autumn 23’ (S8)
9. summer day 33’ (S9)
10. winter day 33’ (S10)
11. spring autumn 33’ (S11)
12. summer day 43’ (S12)
13. winter day 43’ (S13)
14. spring autumn 43’ (S14)

For convenience, the spreadsheets are hereinafter referred to only with their abbreviation codes; S1, S2, etc. The spreadsheets are interlinked and should *not* be changed or manipulated (except the relevant input variables, of course), unless you have saved a copy of the original file.

The following parameters are input variables that may be altered:

Spreadsheet	Variables	Comments
S2	No. of winter days	May be used to change the annual thermal demand profile of house.
S3	Electricity price (to household)	May be used to change the local tariff for the house-hold.
	Standing charge	May be used to change the local tariff for the house-hold.
	Price for electricity purchased by EC from household	For the case that the micro CHP package is owned by the household, and the household needs to negotiate a price for surplus electricity with the EC.
	Price of micro CHP package (installed)	Depends on the production volume and delivery scenario (leasing => no VAT).

	Price of replacement boiler (installed)	The boiler that would be installed if no micro CHP package is installed.
S4	Daily consumption profiles	The profiles used are diversified (i.e. averages for the total population of houses) profiles. From the EC point of view it will probably only make sense to use such profiles to operate and manage a large number of micro CHP customers spread over a large geographical area. The profiles may be changed according to specific averages that the user may have for parts of the house population.
S6 – S14	Micro CHP package operation profiles	These profiles determine during which periods of the day the micro CHP package is operated. They are thus a function of the thermal demand or rather the living pattern of the house occupants. The running periods thus roughly correspond to the heating periods. Due to the need for minimisation of the number of daily on/off cycles, a maximum of 4 daily operating periods is foreseen.

The software package is implemented in Microsoft EXCEL 97 SR-1, which requires Microsoft Windows 95 as operating system.

In the following, each of the 14 spreadsheets is explained and commented in-depth in the order indicated above, which is also the order in which they appear in the workbook. The purpose of the workbook is to provide quantitative indications and illustrative examples with respect to the impact on electricity trading when micro CHP is used in a home and considers typical standardised house types individually and as an aggregated market. For the sake of an introductory overview, a brief explanation of each spreadsheet is given below:

Spreadsheet	**Brief explanation**
S1	Front page – provides identification information only.
S2	Summarises the existing and indicated potential future profits obtainable for ECs from the relevant house types, based on the analysis carried out in the following sheets. The sheet also summarises the seasonal running hour data produced by the analysis.
S3	Calculates and illustrates the profitability for each of the house types considered. To this end, it also calculates the micro CHP electricity generation costs. (A more detailed analysis of costs is contained in the SIGMA software package SEE_MCHP.)
S4	Contains UK *pool price data* for 1998, together with monitored diversified *electricity consumption (i.e. demand) data* for UK housing.
S5	Breakdown of the UK natural gas market incrementally by the thermal load of consumers. The sheet is used to determine the total number of houses for each of the considered typical house types.
S6 – S14	Analyse the operation of a micro CHP package (3 kWe, 9 kWth) in the selected house types. Based on the input (heat-led) micro CHP package operation profiles, the main electricity-related parameters are calculated (generated and exported electricity, utilisation, demand-weighted pool price for the given season, etc.). These parameters are then read by S2 and S3 for the calcu-lation of the profitability. The 3 typical house types that have been selected have nominal heat loads of 23 000 kWh, 33 000 kWh, and 43 000 kWh per annum. S6-S8 consider the smallest, S9-S11 the medium, and S12-S14 the largest of these homes. They represent typical family houses built prior to 1975, early 1900s, and substantial detached Victorian homes respectively. These are the homes, which are most difficult to improve thermally and which constitute SIGMA's market focus.

Basic assumptions in the software model

It is important to observe and acknowledge the basic assumptions in the model used in the software package. These assumptions are:

1. The complete end product (i.e. the micro CHP package) is only delivered to the end user *when the boiler of the end user breaks down and therefore needs to be replaced*. The micro CHP package is designed in such a way that it will act as a "drop-in"-replacement for the boiler, i.e. it will be installed in the end user's house exactly as a replacement boiler would be, with no changes necessary to the property.

2. It is assumed that the EC will install the micro CHP package, and that EC also will retain ownership of it. (The package may for instance be leased to the householder.) Thus the EC will retain ownership of all the electricity the package produces. It is then a matter for the EC to determine what share, if any, of the improved profitability is conferred to the end-user. (However, for comparative reasons, the scenario where the household is the owner of the micro CHP package is also considered and evaluated in the model).

3. The micro CHP package operates substantially as the boiler it replaces, with on/off times in accordance with typical UK practice. This means that generation is thermally led and is not optimised to coincide with peak pool or demand periods. It is recognised that such optimisation could have beneficial effects, but simulation studies have shown this to be difficult to achieve. It is, however, possible that such controls may be introduced at a later stage and this will serve to improve further the opportunities for micro CHP generation. For houses with a heat load of 30 000 kWh per year and above, a supplementary flow boiler is incorporated in the micro CHP package and provides rapid preheat as well as meeting the peak heat demand on particularly cold days. Thus for the medium and the large house, it is assumed that 80% of the heat demand is covered by the PCP, the rest by the flow boiler.

4. The calculation of the economic performance – appreciating the replacement strategy explained under point 1 – is based on the *marginal cost* for the micro CHP package, i.e. the difference in *purchase* price between the micro CHP package and the potential replacement boiler. The same also applies with respect to the *maintenance costs*.

5. In the UK, the domestic boiler population consists mainly of standard non-condensing boilers, representing 96% of the current boiler market. Research by independent organisations has shown that the average seasonal efficiency of non-condensing boilers in the UK, *based on natural gas gross calorific value*, is approximately 70%. Thus, for the UK boiler population an average efficiency of 70% is assumed, *and this is defined as the base case for calculation of economic performance and market size*.

6. Only consumers currently connected to the natural gas mains are considered. The SIGMA PCP is currently aimed at this market, although it is likely that subsequent products may include the additional potential customers who use other gaseous or liquid fuels.

7. In order to simplify the analysis, the "bin day" method is used. This method utilises data for 3 representative days, one for each of the 3 seasons defined: spring/autumn, summer, and winter. Then the outputs for each of the 3 days are multiplied by the number of such days falling into the respective seasons. Electrical demand profiles are as already mentioned seasonal averages (not individual houses) and contain therefore a strong element of diversity. Pool prices are calculated from monthly averages for every half-hour period in a given month.