Report for
Energy Saving Trust

Domestic CHP

What are the potential benefits?

A report to the Energy Saving Trust by EA Technology Limited, Capenhurst, Chester CH1 6ES
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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.

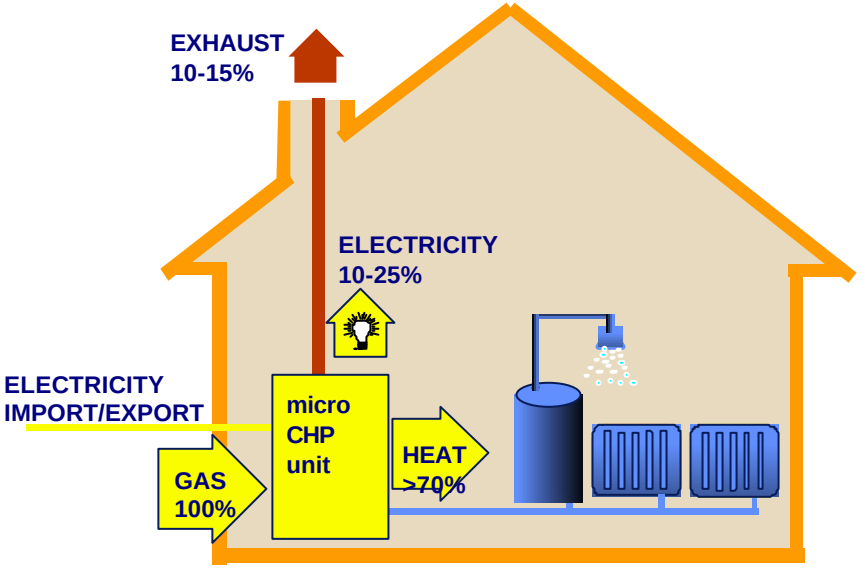
Given an equitable market framework, these drivers will be sufficient to achieve the predicted long-term market penetration rates without artificial incentives. 'Pump priming' support such as that offered by the EESoP/EEC programme would help bring the technology to the market faster.

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.

- A viable, cost effective energy efficiency measure
- Applicable to a wide variety of properties
- Applicable to properties that fall outside existing cost effective energy efficiency measures
- Mechanism to promote market competition



A viable, cost effective energy efficiency measure

Micro CHP potential

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

- Ultimately micro CHP may provide an installed generating capacity of 15~20GW.
- In the UK this capacity will be roughly equivalent to the existing nuclear generating capacity, but the annual output will be somewhat lower as micro CHP is peak following not baseload
- 13 million homes are suitable for existing micro CHP technologies.
- Ultimately micro CHP may contribute an annual reduction of 16 million tonnes of carbon equivalent to UK mitigation targets.
- Within the context of the Kyoto timeframe, it is anticipated that 250,000 systems will be installed annually by 2010, representing an annual additional saving of 1MtCe.
- Annual savings of up to 30% may be achieved on a typical domestic fuel bill.
- Micro CHP and associated equipment represents a substantial manufacturing opportunity, worth between £70 and £150 million per annum in the UK alone by the end of the decade.

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 implemented during 2001/2002. 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 for micro CHP exports, including provision for profile settlement or net metering with appropriate allocation of distribution network costs.
3. Empower OFGEM to implement the standards developed by these groups.
4. Targeted implementation of carbon tax exemptions or similar 'externality' measures and the application of EESoP/EEC funding to directly influence the rate of growth of micro CHP in the UK.

A viable, cost effective energy efficiency measure

technology

Report

Domestic CHP: What are the Benefits?

A scoping study to examine the benefits and impacts of domestic scale CHP in the UK

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Introduction

Micro CHP is defined for the purposes of this report as the simultaneous production of heat and power in an individual dwelling. It is not merely "smaller than existing" CHP, it is fundamentally different in the way it operates and in the technical and economic constraints imposed on it.

It is anticipated that the mass market for micro CHP will be for the replacement of conventional gas central heating boilers when they reach the end of their useful life.

It is therefore a prerequisite that the target households are connected to a natural gas supply and that they have a suitable thermal demand to make use of the heat generated. The electricity produced as a by-product of this process may either be used by the householder or exported to the network for use by other consumers.

Micro CHP units cost more to produce than conventional boilers and it is therefore necessary to recover the additional investment cost from the value of the electricity generated by the unit. The electricity purchased by the consumer is more valuable than the sale of export units, so it is preferable to maximise the consumption of own generation. Depending on the size of home and output of the unit, between 40~90% can be utilised by the typical household.

Micro CHP offers significant benefits to energy suppliers (improved profitability, customer retention etc.), to householders (reduced energy bills, avoided capital investment) and to society as a whole (reduced CO_2 emissions, reduced primary energy consumption, avoidance of central plant and network construction).

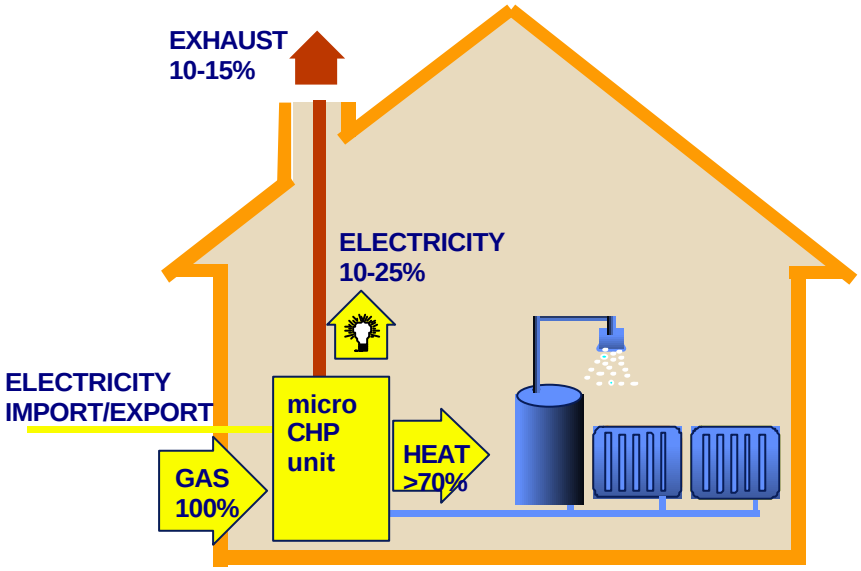
It is expected that micro CHP products will become commercially available through ESCo's during 2002, initially based on Stirling engine technology.

What is micro CHP?

- An individual heat & power producing unit in each home
- 'Drop-in' replacement for existing boilers
- Thermally led operation
- Up to 3500 hours maintenance-free operation annually
- Maintenance as for conventional boilers
- Electrical output displaces part of the network electricity consumption in the home
- Implicit import/export and energy trading
- Offers significant environmental & economic benefits

A 'Drop-in' replacement for existing boilers

Micro CHP principles of operation



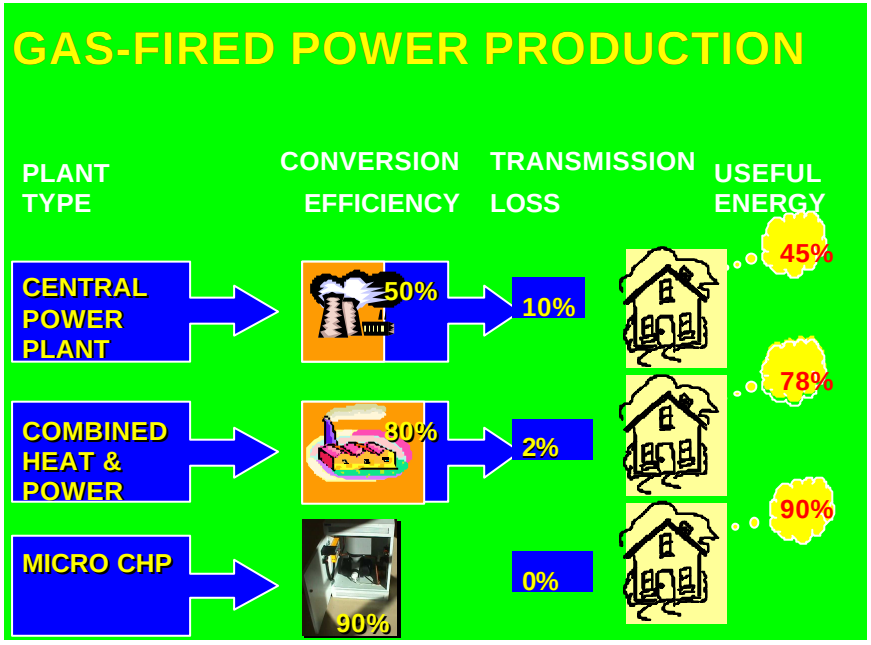
Natural gas or oil is consumed in a Stirling engine (or other prime mover) to provide heat and electricity for the home. The diagram opposite shows a typical energy balance for a Stirling engine micro CHP unit.

Typically, 70-80% (Gross Calorific Value, GCV) of the energy value of the fuel is converted to heat for central heating and hot water services. Between 10% and 25% is converted to electricity, and the remainder (10-15%) is lost in the flue gas. Overall efficiency is condensing performance at 90% (GCV). By comparison in a conventional new boiler, 70-80% of the fuel input is converted to heat and the remainder is lost in the flue gas. In many instances, micro CHP will be replacing an old boiler with conversion efficiencies between 50 and 65%.

Of the electricity generated, between 40 and 90% is used within the home displacing expensive network electricity and the remainder is exported at lower value. The avoided purchase of electricity is the principal 'income' to pay for the additional cost of the micro CHP unit, although the high efficiency provides additional value through fuel savings compared to old boilers.

High overall efficiency, electricity pays for additional cost of unit

Energy efficiency potential

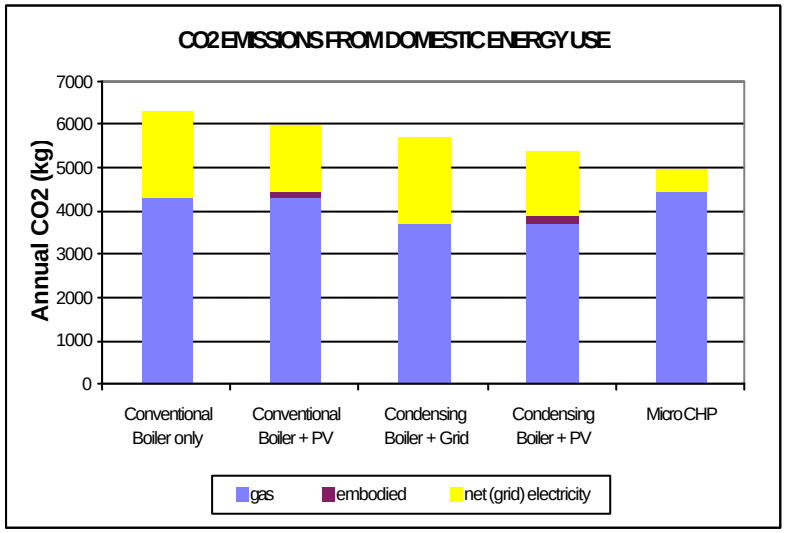


Micro CHP

- Produces heat & power at point of demand
- Produces heat & power at time of maximum demand
- Avoids distribution losses
- Maximises utilisation of primary energy

Maximum utilisation of primary energy

Environmental potential



- Micro CHP offers significant contribution to CO_2 mitigation targets
- Majority of CO_2 emissions in home are due to space and water heating
- Existing housing is often difficult to improve thermally
- Significant improvement on condensing boilers and PV systems

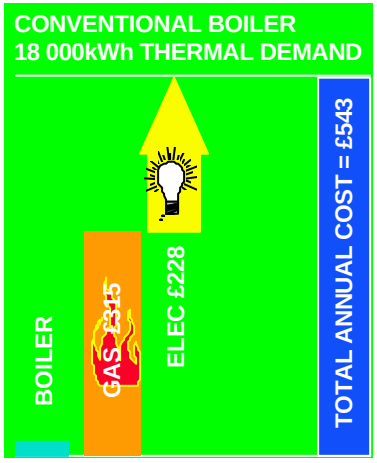
Property with 18,000kWh thermal demand

Significant contribution to CO_2 mitigation

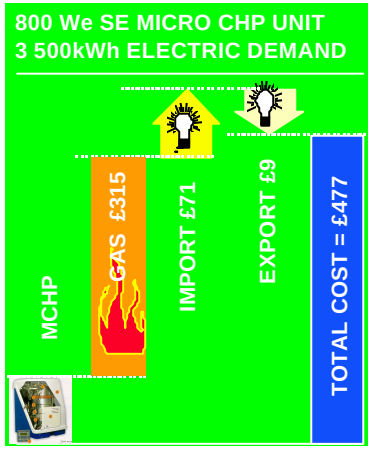
Market potential-economic viability

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

Without micro CHP



With micro CHP



Principles

- Micro CHP will be introduced to the market by ESCo's, but ESCo's are purely a route to market.
- The fundamental economic viability depends on achieving a payback, at the point of end use, on the investment in the micro CHP product.
- Additional capital cost is recovered by the savings in electricity purchased plus the value of electricity sold to the network
- Gas consumption is virtually the same for a conventional gas boiler and a micro CHP unit, and likely to be significantly less than an existing boiler
- The value of export electricity is heavily dependent on the size (electrical output) of the unit
- In practice, the electricity may be owned by an ESCo and the value is further enhanced (depending on generation profile) by the avoided cost of supply to customers during periods of peak wholesale power prices.
- The overall economic viability calculation is rather complex, but the following two scenarios are given as representative of two Stirling engine based products expected to reach market in the near future.

Significant contribution to CO_2 mitigation

Market potential-economic viability examples

Sigma 3kWe/9kWt unit in large family home with annual heat demand of 30,000kWh

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

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

WhisperTech 0.8kWe/6kWt unit in an average sized family home with annual heat demand of 18,000 kWh

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

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

Simple payback before considering additional ESCo benefits likely to be 3~ 4years

Market potential- comparison with condensing boiler

Condensing boiler with 88% seasonal efficiency (GCV*)

Annual heat demand	18,000	kWh
Running hours	3,000	hours
Electricity generated	0	kWh
Own use of generation	0	%
Unit cost of avoided import	6.5	p/kWh
Value of avoided import	0	£
Unit value of export	0	p/kWh
Value of export	0	£
Total value of generation	0	£
Additional gas cost	(-36)	£
Marginal cost of unit (EST data)	150-250	£
Simple payback	4-7	years

For houses with modest energy bills, condensing boilers have relatively long paybacks. Savings in gas consumption are worth significantly less than electricity savings achieved with micro CHP.

*GCV (Gross Calorific Value) is the total available energy in fuel as opposed to net or lower calorific value which ignores the potential contribution of latent heat resulting from the combustion process.

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Payback for micro CHP significantly quicker than for condensing boiler

Market potential - factors affecting size of market

- **Number of hydronic heating systems**
- **Duration of heating season**
- **Annual energy bills**
- **Gas / electricity consumption**
- **Thermal demand of home**

- **Number of households connected to Natural Gas supply**
- **Number of households burning heating oil**

- **Type of boilers installed and replaced**
- **Rate of boiler replacement**
- **Boiler replacement decision**

The market potential is, ultimately, defined by the number of households for which economic viability can be achieved. The potential market is derived from the number of homes (and other relevant buildings) which can achieve a profitable investment, bearing in mind the key variables of absolute and relative fuel and electricity prices, household energy consumption, potential financial incentives and the benefits accruing to ESCo such as leasing, service and generation portfolio benefits.

It is important to evaluate economic viability for specific representative house types, and average energy consumption data is therefore not suitable. Energy use must be derived from historical data of actual fuel consumption rather than theoretical calculations based on SAP/NHER, as theoretical data can be misleading.

It is generally accepted that natural gas fired micro CHP will be the major application and it is the potential for NG systems which dominates the evaluation process. However, other fuels such as fuel oil, LPG and gaseous and liquid biofuels will also contribute to the overall market potential, often with enhanced viability due to their remote location.

The market potential is limited by the type of boilers under consideration. Current micro CHP technologies are primarily targeted at replacing floor-mounted, non-combi boilers which represent a decreasing share of the market. However, it is likely that micro CHP units will evolve to meet this challenge as the market grows. See further details of boiler replacement market and the purchase decision.

Market defined by household benefits

- **Gas price**

- **Electricity price (import)**

- **Base case boiler efficiency**

- **Electricity price (export)**

- **Generation profile**

- **Utilisation of generation – load matching**

- **Cost recovery mechanism**

- **Route to market (e.g. ESCo)**

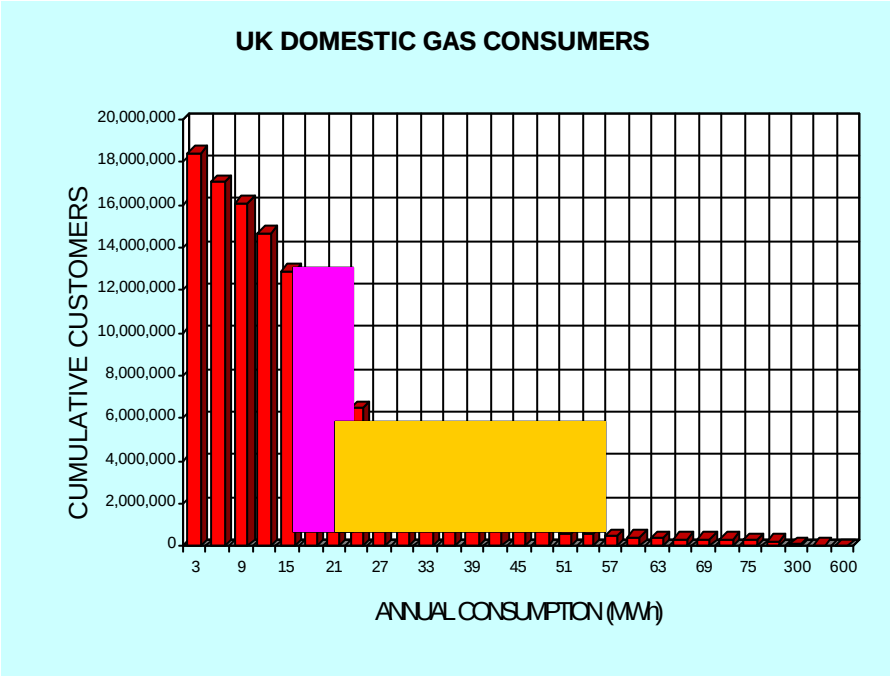
Many micro CHP units have a similar conversion efficiency (fuel to useful heat) as conventional new boilers, so that viability is relatively insensitive to fuel prices. However, electricity prices are highly significant. The high level of domestic electricity prices provide ample opportunity to recover the value of micro CHP generation.

Although comparisons for economic viability are made by comparison to new conventional boilers, for many potential customers, the real (financial) comparison is between an old boiler and the alternatives of a conventional boiler, a condensing boiler, or micro CHP. In all three cases, the customer sees benefits from reduced fuel consumption, with the conventional and micro CHP units having roughly the same (lower) consumption and a further reduction if using a condensing boiler.

Economic value is gained both from avoided purchase cost and from the value of exported electricity. The amount and value of this electricity varies considerably throughout the day and larger units tend to export more units at more valuable times. However, from the electricity supplier's point of view, the cost of supply is reduced in all cases as most generation occurs during peak periods. See later discussion of micro CHP house demand profiles.

It is therefore important that appropriate mechanisms be put in place to identify and recover the value of electricity generated and to facilitate grid connection.

Market potential by Gas Consumption



The graph indicates the number of potential customers for 1kWe/7kWt (shaded pink) and 3Kwe/9KWt (shaded yellow) Stirling engine micro CHP units.

Summary

- Domestic gas connections are now greater than 18 million in the UK
- Excluding the very small (cooking or fire only), this suggests at least 15 million gas fired central heating systems
- Potential market for 0.8~1kWe/5~6kWt units is likely to be between 12,000 kWh and 24,000 kWh, suggesting ~8 million homes
- Potential market for a larger thermal output unit is likely to be between 22,000 kWh and 40,000 kWh, suggesting ~5 million homes
- Markets exist for smaller thermal output unit to cover the <12,000 kWh heating demand and newbuild markets, say 0.8kWe/4kWt

Market Potential by Boiler Sales

- 23 million UK households
- Existing UK boiler population believed to be around 18 million units, 3 million of which are oil or other fuels
- UK boiler sales believed to be in the region of 1.2 million p.a.
- Approximately 25% are new installations (first time or newbuild)
- Suggests replacement market of 800,000 natural gas units per year, giving a replacement cycle >20 years
- Reality is that up to 8 million boilers need replacing, primarily floor mounted, cast iron, and very inefficient
- Combination boilers represent >35% of the replacement market and growing
- Condensing boilers are around 8% of the market

Of the existing boiler market, at least 15 million households now use gas as the primary heating source. Analysis of boiler sales suggests that a large pool of old and inefficient boilers exists that can continue operating for a considerable period of time. It is very difficult to get an accurate picture of the true boiler stock, but our estimate is 8 million boilers, which although still operable, should be replaced for efficiency reasons. Anecdotal evidence reveals many people needing to replace their boilers but not doing so whilst the existing boiler 'soldiers on'.

Of the newbuild market, many of these properties will have a heat demand too low for the existing micro CHP offerings. This suggests room for other products with similar electrical output but lower thermal output (i.e. more efficient units). A unit in the range 0.8 to 1kWe and 3 to 5kWt may be appropriate for this market.

A conservative estimate of the market potential within the existing market for micro CHP would be on par with condensing boilers, at around 100,000 units p.a.

Room for other market entrants to cover newbuild and smaller properties

Market Penetration and Estimated Population

- Potential market of at least 50% of boiler replacements with existing offerings, 400,000 units per year
- Market limited by growth of combination boilers
- Assume only 8% penetration (on par with condensing boilers), giving 100,000 units
- Excellent market potential via ESCo offerings to the 'pre-distress' replacement market, at 2% p.a. gives additional 150,000 units
- Conservative estimate is 250,000 units by 2008, thereafter stable, giving the following penetration;

Year	Sales p.a.	Population	Capacity	Electricity
2005	50,000	80,000	120 MW	360 GWh
2010	250,000	1.1 million	1.7 GW	5 TWh
2020	250,000	5 million	7 GW	20 TWh

Estimating the market uptake is difficult. From the existing boiler sales statistics a conservative market estimate can be made based on existing condensing boiler penetration where the ratio of marginal cost and benefits are similar. However, with all market entrants going for an ESCo approach to the market in which the energy service company finances the micro CHP unit and also trades in the fuel, electricity 'spill' and additional electricity needs, it is reasonable to assume that a considerable impact can be made on the estimated pool of old, inefficient boilers.

To produce realistic end-user costs, typical production runs will need to be in the region of 100,000 units per year minimum, such that an overall estimate of 250,000 units p.a. in the UK corresponds to this level of activity amongst a few suppliers. These estimates are very conservative, and more optimistic estimates for the whole of Europe may be as high as 5 million units per year.

With stronger market push, it may be possible to reach in excess of 50% of UK properties by 2020, representing a population of 12 million units, with installed capacity of 15~20 GW, and annual electricity production of 40~50 TWh or 15% of UK electricity consumption.

Conservative estimate of 5 million units by 2020, displacing 20% of domestic electricity consumption

Micro CHP v. Condensing Boilers

- Condensing boilers are a valid Energy Efficiency measure
- UK uptake has been poor
- Pump priming support has achieved 8%+ penetration
- Market mechanism (captive installer network) is seen as the barrier
- Micro CHP route to market via ESCos more likely to succeed
- Sufficient additional benefits to suggest micro CHP offers additional incentives to ESCo company

Condensing boilers have not been particularly successful in the UK market. Even with relatively large pump priming support, penetration is struggling to reach the 10% mark. By comparison, condensing boiler penetration in the Netherlands is almost 100%. This is attributed to better incentives, legislation and differences between the installer networks.

Although a conservative view has been taken on the potential market penetration of micro CHP (based on condensing boilers), there is a fundamentally different route to market via ESCos that overcomes the initial capital barrier and perceived installation difficulties that the local plumber network may produce in the UK. Micro CHP is unlikely to ever be sold 'across the counter' due to the need for different installations, connection agreements and mechanisms to gain the trading benefits.

It is legitimate to ask whether an ESCo may prefer to install ordinary boilers or condensing boilers rather than micro CHP. From the market assessment studies, the marginal value of micro CHP above a conventional boiler is likely to provide a payback of 3~4 years. Compared to a condensing boiler, the marginal benefits decrease, but so does the marginal cost, leading to similar payback. Such payback periods are well within the boundaries of ESCo/Leasing type arrangements, where in reality the appliance is a vehicle of the financing arrangements. In addition, micro CHP offers a more interesting market proposition for the customer.

ESCo route to market and product differentiation suggests better prospects for Micro CHP than condensing boilers

Micro CHP and Energy Efficiency Standards of Performance

Micro CHP provides benefits that should be suitable for the EESoP/EEC schemes. Irrespective of the quantity of electricity used in the home (own-use), each unit displaces central generation to its full output.

For a typical property, appropriately sized micro CHP runs for around 3,000 hours each year. For a 1kWe unit this is 3,000 kWh of displaced central electricity. As the preceding analysis suggests, gas consumption compared to a standard boiler is virtually the same (or slightly better), and can therefore be avoided in the analysis. The calculation can be further simplified by considering the marginal cost to be in the region of £500/kWe compared to a conventional boiler.

Analysis below is based on a 1kWe/6.7kWt unit operating in a 20,000 kWh thermal demand home. 90% overall efficiency is assumed for the micro CHP unit, and the comparison boiler has 78% conversion efficiency. In the first instance, the small gas saving from the micro CHP unit is ignored.

EESoP/EEC Calculation

Annual displacement of central generation		3,000kWh
Marginal cost of micro CHP (per kWe)		£500
Life of unit		15 years
Comfort factor zero for adequately heated homes		
Lifetime energy savings (* 8.56)		25,680 PEKS
Simple cost effectiveness	£500/25,680	= 1.95p/kWh
For a 20% factory gate subsidy, this is		1.3p/kWh

By comparison, if a 65% efficient comparison boiler is considered and gas savings are assumed to be worth 1/3rd of electricity savings, then cost effectiveness becomes 0.82p/kWh

A cost-effective EESoP/EEC measure

EESoP Conclusions

- Micro CHP cost effectiveness in the region of 1.3 to 2 p/kWh compared to a standard boiler (depending on size and degree of subsidy)
- Compared to existing boiler stock (ESCo programmes), may be as good as 0.8p/kWh
- Compare to:
  - Insulation measures around 1p/kWh
  - Other 'Appliance' measures around 2.5p/kWh

BUT

- Can be applied where other cost effective measures are not possible (9" brick wall properties and those already insulated)
- Has a substantial volume impact in EESoP programmes

Applicable where other measures are not cost effective

Environmental benefits – CO_2 , NO_x & SO_x

Scenario 1

5 million units by 2020,
with 50% coal, 50% gas generation displaced

- CO_2 savings pa of 4.1 MtCe (14.9 Mt CO_2)
- NOx savings pa of 22,000 tonnes
- SO_2 savings pa of 112,000 tonnes

Scenario 2

10 million units by 2020 (~ half gas heated homes),
with 25% coal, 75% gas generation displaced

- CO_2 savings pa of 6.4 MtCe (23.3 Mt CO_2)
- NOx savings pa of 17,000 tonnes
- SO2 savings pa of 112,000 tonnes

Micro-CHP has the potential to reduce emissions of CO_2, NO_x & SO_x because it is a cleaner form of generation than the central generation it displaces, while producing heat with similar amounts of pollution to a modern gas boiler.

Coal generation continues to decline from its dominant position 10 years ago, mainly being displaced by gas, while nuclear remains approximately constant. Although small, relatively inefficient gas turbines, and some hydro stations, are used for 'peak lopping', coal is the main form of marginal plant. Large CCGT gas stations are used for the remaining marginal loads, plus base load generation. Nuclear and most renewables (according to resources) provide mainly baseload. Gas generation is likely to continue to grow at the expense of coal.

Thus the average unit displaced by micro-CHP will not be an average unit of generation, but marginal unit from coal and gas stations. The scenarios here for 2020 compare a base case of boiler plus electricity from the grid, against a CHP system providing all the heat and generating electricity; depending on the technology, this may be more or less than the annual house requirements, but all generation displaces central generation.

Significant beneficial environmental impact

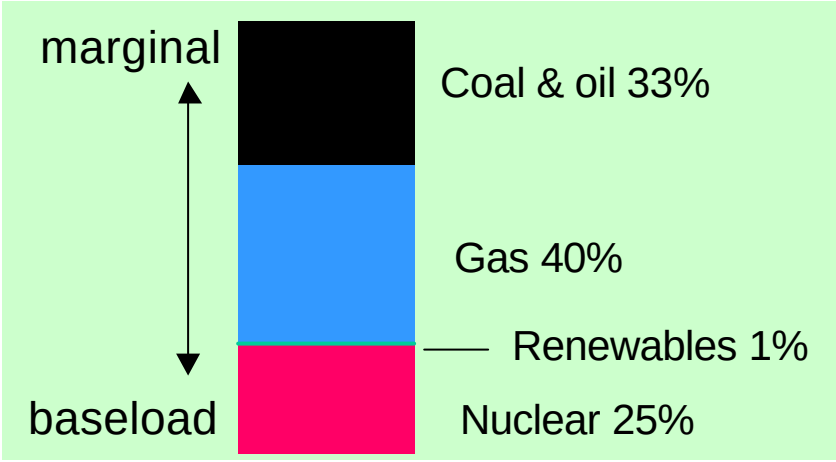


Figure 1: UK generation mix and merit order

Other assumptions are:

- typical emission figures for UK generation;
- emissions from modern boilers, most older boilers will have been replaced by 2020 but emissions are unlikely to improve dramatically from current levels, which are already low;
- emissions from existing micro-CHP; unlikely to change dramatically.

Both scenarios assume micro-CHP units in the ratio 5:8:2 for 3kWe/9kWt Stirling, 1kWe/6kWt Stirling and 1kWe/2kWt fuel cells, sized for houses with annual thermal demands of 25, 18 and 12 thousand kWh respectively and commensurate electricity demand – a range of typical UK housing.

The first scenario assumes 5 million micro-CHP units, displacing 50% coal and 50% gas marginal generation. The second scenario is for more aggressive environmental policies and assumes 10 million micro-CHP units, displacing 25% coal and 75% gas marginal generation.

CO_2 Impact

- Potential per home likely to be in the region (average) of 1.5 tonnes CO_2 p.a. compared to a conventional boiler
- By comparison, condensing boilers likely to be around 0.5 tonnes CO_2 p.a. compared to a conventional boiler
- By comparison to existing boiler stock, impact is more likely to be around 2.4 tonnes CO_2 for micro CHP (compared to ~1.4 tonnes CO_2 for condensing boiler)
- Compared to a conventional boiler, savings cost around £22/tonne CO_2 over the expected lifetime

CO_2 Comparison

Compared to a conventional boiler, micro CHP saves around 3,000 kWh p.a./kWe. Displacing central generation at approximately 0.5 kg CO_2/kWh, this is approximately 1.5 tonnes CO_2 annually, or 0.4 tonnes of carbon equivalent (tCe) per kWe. With the average mix of generators estimated to be ~1.5kWe, this suggests ~0.6 tCe per home. Given the conservative estimate of 5 million homes by 2020, this equates to 3 MtCe p.a.

Considering lifetime carbon savings per kWe, the cost effectiveness of energy savings are around £22/tonne CO_2 or £80/tCe

Significant contribution to UK carbon mitigation target

Technology Status

There are a number of technologies which offer the potential for micro CHP. Each has a different heat/power ratio and consequent match to particular market sectors. It is anticipated that the 1kWe WhisperTech Stirling engine will become commercially available during 2002 with a relatively low electrical efficiency. Initially this will be suitable for replacement of floor-mounted gas boilers in systems incorporating a hot water storage cylinder. The Advantica 1kWe/5kWt unit (based on the SunPower unit) is also likely to enter service over the next couple of years. Initial indications are that this (and the ENATEC unit from the Netherlands) will address the wall mounted market and may extend the range of viable properties downward, potentially covering some of the newbuild market.

The market is set to expand dramatically if fuel cells reach market maturity. With expected high conversion efficiencies (coupled with auxiliary burners or load following), these technologies could have a dramatic impact across the entire market, but are as yet unproven in mainstream domestic CHP applications.

A number of existing internal combustion engine units are already on the market, but economies of scale and other market factors such as maintenance and noise, suggest that these are better suited to multi-residential properties.

A survey of available literature suggests that a number of other technologies are also 'in the pipeline', including thermo-photovoltaics, thermo-electric and acoustic Stirling engines. Some developers are also considering very small gas turbines for the domestic market.

- Internal combustion engines already at market for multi-residential properties
- Stirling Engine technologies close to market
- Fuel Cells show promise for greater market coverage, particularly smaller properties where heat:power is smaller
- Other 'prime mover' technologies under development

Stirling engine micro CHP close to market, other contenders under development

Internal Combustion Engines

5kWe Ecopower IC Unit

- Commercially available and cost effective
- Sized for small multi-residential blocks (such as sheltered housing)
- Typical sizes 4.5~5.5kWe/12~15kWt
- Proven track record
- Relatively high maintenance requirement
- Likely to be less tolerant of biofuels
- Too large and noisy for individual properties

Internal combustion engines: viable for small commercial buildings

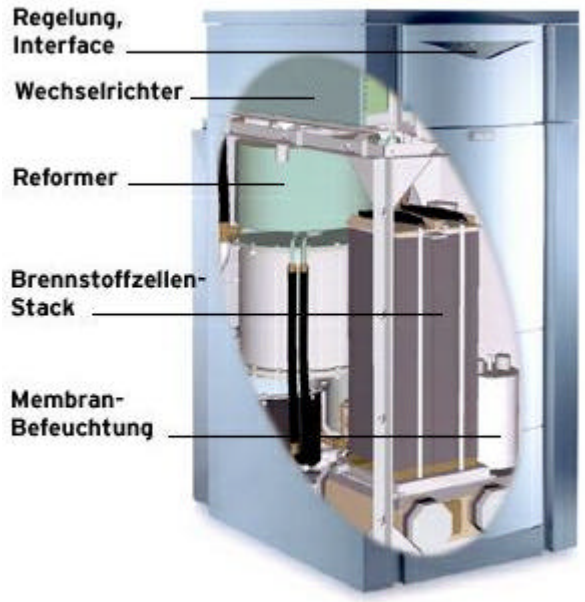
Stirling Engines

- External combustion engines
- Fuel flexible including biofuels
- Transition products towards Renewable fuels
- Near to market, in extended field trials
- Low emissions
- Low maintenance requirements
- Established, conventional manufacturing

WhisperTech Stirling Engine unit

Stirling engines: relatively conventional technology, fuel flexible, and close to market

Fuel Cells



Vaillant/Plug Power PEM fuel cell prototype

- High power to heat ratio
- May extend the range of suitable properties, particularly to better insulated smaller properties
- Larger fuel cells with high conversion efficiencies will have to rely on export value and hence lower costs per kWe
- Should be quiet, low emission systems although fuel processing is more conventional technology
- May provide load following capabilities
- Some units claim to be near market
- Considerable investment in FC technology from the automotive and aerospace industries

Fuel cells: long term solution for energy efficient homes

Market Sectors - Social

Fuel poor. Most fuel poor customers live in rented accommodation. It is not universally true that the fuel poor are small consumers, rather that they have difficulties in affording fuel. Micro CHP offers the opportunity for social housing providers to increase capital investment for reduced operational costs. This may be particularly important for customers receiving welfare benefits, where home rentals may be restricted by the cost of heating the property. As micro CHP is the 'next best' cost effective measure after accessible insulation, the technology may be particularly relevant for refurbishment of existing social housing stock. Housing Associations and Trusts have shown a particular interest in this technology.

Small homes and flats. For properties below 10,000 kWh thermal demand, the most likely existing market entrants have too much thermal output to achieve realistic running hours for an economic return. Developments in fuel cells may be particularly appropriate for this sector.

Typical family home. With heating fuel consumption in the range of 10,000 kWh to 20,000 kWh p.a., such homes are best suited to units in the size range 0.8~1kWe/5~7kWt (WhisperTech and BG units). This sector is the largest market for micro CHP, where paybacks between 3 and 5 years can be achieved.

Large family home. Although overlapping with the 'typical' home range, properties with heating demands in excess of 20,000 kWh are more likely to benefit from larger micro CHP units, such as the Sigma unit at 3kWe/9kWt. Payback is likely to be in the region of 3 to 5 years.

- Existing units cover typical and large properties
- Payback is likely to be in the region of 3 to 5 years for an appropriately sized unit
- Mass market for units of around 1kWe, estimated at 8 million
- Smaller but viable market for larger units of 1.5kWe to 3kWe, estimated at 5 million
- Opportunities for a smaller unit to address newbuild and smaller properties with lower heat demands
- Social housing/fuel poor benefits via landlords, providing opportunities to transfer costs from energy to buildings
- Flats are more likely to be covered by multi-residential schemes

Good market coverage for existing UK housing stock

Benefits to UK

- Reduced primary energy consumption
- Improved electricity supply reliability (statistical)
- Security of supply/diversity
- Improved electricity distribution efficiency
- Contributes strongly to CO_2 mitigation targets
- May help alleviate fuel poverty
- Substantial manufacturing opportunity
- Potential export business opportunity

Analysis of micro CHP markets suggests that the UK is the most viable in Europe, due to the number of existing boiler systems, access to gas networks, and housing stock that has limited potential for further energy efficiency improvement. As the technology introduces new opportunities for energy efficiency and competition in energy trading, it also meets many of the key government objectives. Micro CHP effectively increases the diversity of generation without increasing gas consumption and has no issues concerning planning consent, network infrastructure, etc.

Ultimately, any system that has a high degree of benefits in the supply chain must create losers at some other point. The primary 'income' stream for savings results from a reduced primary fuel burn. However, other savings are made in the supply chain including lost revenues for Distribution Network Operators (DNOs) that are discussed later. One potential negative impact at a state level is the loss of taxation income on the primary gas producer and on the forward supply of electricity to customers (the latter becoming a customer benefit). As a rough estimate, the loss of 5% tax on forward supplied energy for the estimated population in 2010, would amount to around £10 million p.a. (5 TWh, 70% average own use, 6p/kWh, 5% tax).

Perhaps more important from a financial point of view is the manufacturing potential. With estimated European markets as large as 5 million units per annum by 2010, and with an average factory gate price of £750, this represents a manufacturing opportunity as large as £3.7 billion p.a. However, taking more conservative estimates of the UK market, a turnover between £100 and £200 million per year can be expected by the end of the decade. None of the existing contenders for the UK market originated from within the UK, although all could be manufactured here and also represent a significant export opportunity. There are also other opportunities to manufacture control and interface equipment for the market.

Meets many key objectives of government policy

Housing and Physical Markets

- 4% of homes built between 1991 and 1996
- 45% over 50 years old
- 75% of homes built to pre-1970's energy crisis standards
- 19% are flats
- 88% have central heating
- 64% have cavity walls (20% of these are filled)
- 21% have 9'' solid walls
- 60% have some double-glazing
- Rate of double glazing installation is slowing
- £2000 per home investment required to achieve 20% savings

Information from 1996 English House Condition Survey (published in 1998)

The English House Condition Survey examined the state of housing stock and the potential to improve environmental performance. Although the survey identified some areas for improved insulation, particularly improved loft insulation and cavity fill, it is likely that many of these measures whilst improving efficiency will primarily benefit customers through added comfort.

The report identifies a large number of dwellings that are difficult to cost effectively insulate further. Such properties, particularly the 9" brick wall stock, are prime markets for micro CHP.

The survey also identifies the level of investment required to achieve CO_2 emission savings. Micro CHP typically achieves around 20% savings in household CO_2 emissions. The report suggests that to achieve this level of savings would cost over £2,000 per property with existing measures. This suggests that micro CHP would be a good candidate in many properties.

Despite the attractions of micro CHP, it is important to note that where measures such as cavity wall fill can be applied, they are likely to be more cost effective. With an ESCo approach to the market, it should be possible to take a more holistic approach in which the basic and cost effective insulation measures are tackled first before sizing the correct micro CHP system as the next most cost effective measure. Attempts to establish ESCo routes to reach the private household market have not been very successful in the past. However, micro CHP is likely to provide a vehicle for ESCo activity which could encompass a wider range of energy measures.

Micro CHP represents the 'next best' energy efficiency measure for many properties

Benefits to the Social Housing Sector

To Landlord/provider

- Likely to be financed by ESCos/Leasing companies, so freeing capital
- Will help achieve statutory obligations such as Agenda 21
- Lower fuel costs provide opportunities to charge more realistic rents to poorer tenants
- A 'bridge' to future renewable schemes

To the Tenant

- Lower fuel bills
- Affordable warmth
- More reliable service from ESCo company
- Indirect benefits via health, comfort, etc.

With considerable interest from Housing Associations and Trust's, micro CHP is highly likely to enter the social housing sector early. The logic for initial interest is several fold; providers see a mechanism to reduce their client's fuel bills in a cost effective manner, particularly in refurbishment, and many have commitments to energy efficiency and Renewables. Of particular interest is the ability to recover more realistic rentals from the poorest members of society where rent is often limited due to the costs of heating older housing stock. Alternative routes to realising such benefits are through heat and rent arrangements, where the customer pays a fixed fee for the property and the fuel consumed, such that micro CHP could represent an cost effective investment whilst achieving green objectives.

Many housing associations and similar housing providers are capital constrained, such that leasing arrangements are being actively pursued. There are already active boiler leasing schemes which form an interesting model for future ESCo-type approaches to the micro CHP market. This also provides other advantages for both the landlord and tenant through contracting out service requirements.

With a long term commitment to renewable fuels, various Stirling engine micro CHP providers have already been contacted to explore the potential for renewable gas and liquid fuels. Utilising external combustion, Stirling engines are far more fuel flexible than their IC equivalents, where undesirable gas mixes can cause corrosion. Of interest are 'sustainable urban village' concepts where there is often access to landfill gas or anaerobic digestion gas.

A mechanism to provide affordable warmth in social housing

Benefits to Private Housing Sector

Householders

- Reduced fuel bills
- Perceived independence from electricity suppliers
- 'Green Electricity' without penalty
- New opportunities to replace old boilers without finance

Housebuilders

- As a 'drop in' replacement, micro CHP does not impose serious design or construction problems
- Ability to 'green' their offerings to the public
- Potentially reduced electricity infrastructure costs
- Performance of the micro CHP unit may be traded against some elements of construction costs

The preceding sections define the advantage to householders as being primarily a financial return on micro CHP. However, in reality the ESCo/Leasing company is likely to charge more for the unit than the simple economic return would suggest, but put this to the householder in a way that is attractive (as has been successfully achieved for mobile phones).

In this way, micro CHP should be seen as a simple appliance lease, primarily freeing the householder from financing the appliance and risk of maintenance. For example, a 1kWe unit could be rented for £5 to £10 per week with a good return to the ESCo, and the householder would still more than half the lease fee through savings. When considered with maintenance benefits they could effectively upgrade their system to the latest 'green' technology at little or no cost. Although the final shape of such ESCo services is commercially sensitive at this time, initial indications are that very attractive packages can be put to customers.

Householders also get other real and perceived benefits, and many customers are likely to see micro CHP as a 'green' measure that does not require financial sacrifice.

From a housebuilders perspective, micro CHP may not be ideal unless more efficient, smaller units become available. However, several companies have shown interest on the basis of differentiation and where new developments have a deliberate 'green' theme. One potential danger is that a housebuilder may try to trade off the environmental benefits of micro CHP against the fabric performance of the property.

An attractive leasing option

Benefits to Energy Service Companies

Indications are that most manufacturers of micro CHP systems are looking for ESCo routes to market. Further that these ESCos are likely to be or be allied to energy supply companies who can benefit from the trading of both the primary fuel and 'spill' electricity. However, the largest benefits are believed to be connected to finance, servicing and other sales opportunities. Potential benefit streams include;

- Rental income (profiting from the difference between customer capital rates and corporate capital rates)
- Fuel sales associated with the 'package'
- Beneficial wholesale profile for trading
- Trading 'spill' (exported electricity)
- Service income (displacing other service organisations)
- Customer 'ownership' as a further sales opportunity (including other service and leasing opportunities)
- Customer volume building

ESCo benefits can be seen to be multifaceted. Although micro CHP appears to be justified simply in terms of the customer benefits of reduced electricity consumption (avoided cost) compared to marginal capital costs, this may only represent one element or even simply a vehicle to the full profitability of the proposition.

Although energy supply companies cannot tie customer to their supply contracts, it is likely that the micro CHP supplier can undercut all opposition and provide additional benefits such as 'one stop' billing, including the rental charges or other capital recovery techniques, that effectively cut out all other competition except another micro CHP supplier. Within such a deal, an ESCo company will have access to low cost capital compared to the customer, which in itself is a significant advantage.

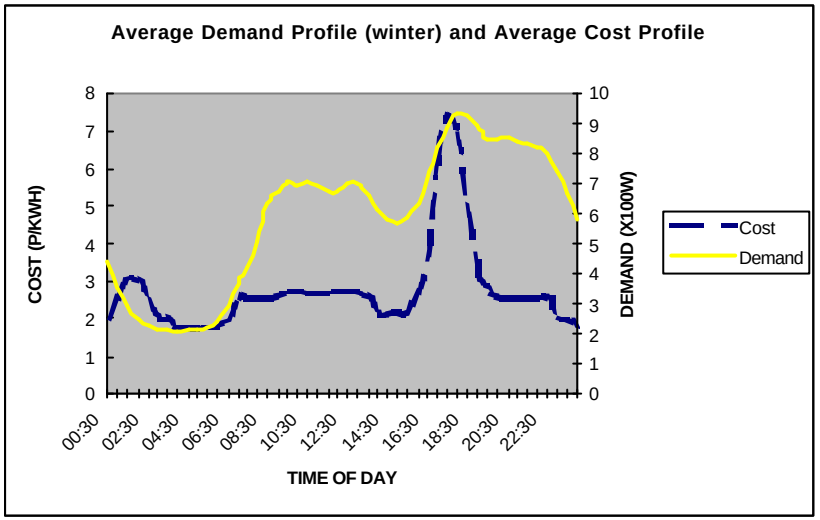
Many existing customers pay for service contracts on boilers and other appliances which is known to be a highly profitable business - trading effectively as an insurer to take customer perceived 'risk' benefits. This can be incorporated as a package benefit.

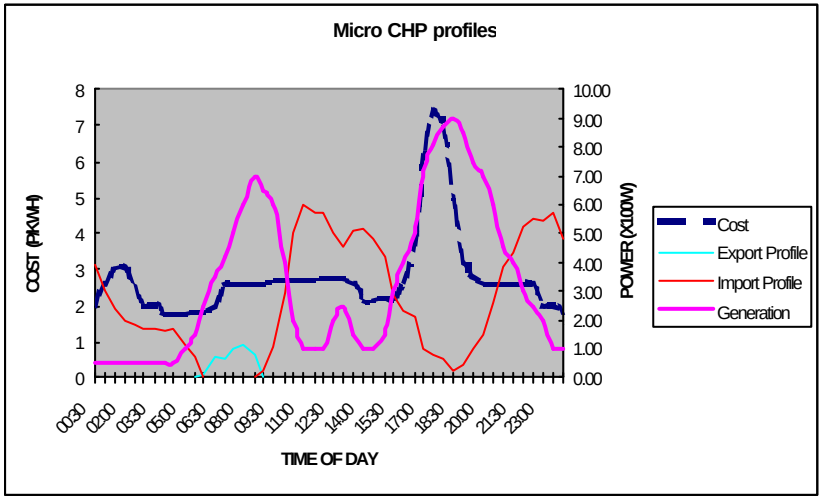
Simply 'owning' a customer has a high value as illustrated by the prices paid in recent take-over activity to acquire electricity customers (although this tends to be the purchase of incumbent customers with a higher profitability). Customer volume allows suppliers to reduce service costs, and the database of customers provides other opportunities to sell additional services, including extended service packages, telephone, insurance, finance, etc. Simply being associated with a 'green' product may have a significant market advantage, even to attract customer who do not want micro CHP.

In addition to these business advantages, the ESCo/Supplier has advantages relating to the micro CHP customer demand profile as shown on the following page.

Micro CHP provides a 'vehicle' for ESCo services to domestic customers

Micro CHP Profile - ESCo Benefit





Electricity is purchased by energy suppliers according to the demand weighted cost of supply throughout the year. The customer sees either a single or two rate tariff, reflecting the average costs of purchase over an entire year. At some times during the day, the customer is paying well below the wholesale cost (a combination of long-term contracts and balance payments), and at other they are paying well above the actual costs. The graphs opposite show a winter settlement profile for a domestic customer (the diverse average demand) and pool price (which is a good proxy for contracts and balance payments under NETA). Also shown is an example of a diverse generation profile, showing the modified trading profile and average export across a group of customers. Individually, actual export will be greater due to the 'spiky' nature of individual demand, representing a further supplier benefit.

The average cost of supplying the customer without the micro CHP unit is the sum of each half-hour demand in the normal settlement profile multiplied by the price in that half-hour. Likewise for the micro CHP customer the same calculation is performed using the (positive part of) modified demand profile. For the example given which is only a simple snapshot of one particular day, the cost per unit of supplying the normal customer is approximately 3.0p/kWh (energy only) and the cost of supplying the micro CHP customer is 2.55p/kWh. This means that although the trading volume is reduced, the supplier can make a larger profit on the residual supply of electricity and offer a rate below any other supplier.

Likewise, the supplier also owns the 'spill' electricity which is effectively free and can be sold to neighbouring customers. However, this is also subject to the same demand weighted rules, and as it is exported when the micro CHP customer least wants it, has a poorer wholesale value (open market value) of 2.47p/kWh in this example.

Beneficial wholesale electricity trading profile

Recovering Supplier Benefits

- Micro CHP has an advantageous import demand profile
- Well defined export profile
- To benefit, suppliers must be able to identify profiles in trading
- Half-hourly metering is unrealistic
- Net metering is unlikely to be a long-term solution
- Profile settlement is a viable route
- Regulatory intervention may be required to introduce import and export profiles for micro CHP

In order to access the trading benefits described earlier, the ESCo/Supplier needs to be able to identify the new profile shapes in trading mechanisms.

In theory, the supplier could install two way half-hour metering, but this is prohibitively expensive both in terms of the metering and the data collection and processing. Alternatives have been suggested such as 'net metering' in which a single meter simply turns backwards or forwards. Such solutions are not believed to have long-term market potential as they seriously bias the Distribution Use of System (DUoS) element of the income (see later) and do not identify the time of day associated with import and export.

By far the simplest method of receiving the identified trading benefits is through profile settlement as currently practised for virtually all domestic electricity customers. In profile settlement a representative profile of average demand is used to associate each suppliers' metered consumption to individual half-hourly periods for settlement against wholesale prices. A similar mechanism could be applied to the aggregate profile of micro CHP customers. This will require Regulatory intervention to achieve as no new profiles have ever been successfully introduced to identify particular customer groups. However, as micro CHP represents a particular technology solution and has a relatively well defined aggregate demand pattern, it is the author's belief that such a profile could be introduced.

With profile settlement, it may not be necessary to meter export at all. The majority of all existing meters cannot turn backwards (a fraud protection), such that export simply passes through the meter without effect. Further investigation may be required to ensure that no meters have a fraud cut-out activated by reverse current, although initial indications are that some simply indicate reverse flow has occurred (including pre-payment meters).

Profile settlement of import and export required to access all ESCo benefits

Effects on Distribution Companies

- Loss of DUoS income
- Potential technical costs associated with connection of many micro CHP units (voltage and fault level)
- Re-balance of DUoS income likely
- New connection standards required to suit the goals of both DNOs and micro CHP providers
- A very disruptive technology for Distribution Network Operators (DNO)

From the point of view of a Distribution Network Operator (DNO), micro CHP presents a number of challenges and few benefits. With average electricity consumption in the region of 3,500kWh per year and typical micro CHP electricity used in the home in the region of 2,500 kWh per year, the distribution company sees a dramatic reduction in metered units. In the UK, the vast majority of distribution use of system (DUoS) revenue is recovered from kWh charges rather than capacity charges, so their income may be severely affected.

A prudent position in formulating micro CHP business cases would be to assume that at least part of the DUoS income associated with a micro CHP customer would be reallocated to fixed charges. However, there may also be some long-term benefits through avoided reinforcement at higher voltages serving the domestic customers. Lower voltage capacity is not likely to be affected as momentary customer demand can be considerably greater than the diverse profile (i.e. they have a very poor utilisation factor).

Depending on the type of micro CHP, the DNO may also have other technical cost including reinforcement cost to maintain voltage levels within statutory limits and problems with fault levels (the size of network switches required to break current in the event of a short circuit). To some extent, these problems relate to penetration of units in a particular area and the likelihood of export at times of low customer demand, particularly during pre-heat periods.

In addition to these problems, the DNO is charged with maintaining a safe and reliable network which will depend on the type of connection the micro CHP unit makes to the network. This is the subject of both UK and European level work at present to define standards and test procedures for connection of micro CHP units.

Distribution companies likely to face challenges with micro CHP

Connection of Micro CHP to networks

Any generator connected to the electricity network requires a connection agreement with the DNO. In theory the owner of the generator and the DNO can agree whatever technical standards they choose to ensure that the generator operates in a safe manner on the network. However, in practice, DNOs refer to Engineering Recommendations which define industry-wide technical standards.

Engineering Recommendations (ER) relating to connection of embedded generators are primarily aimed at ensuring the generator can recognise fault conditions in the network and disconnect, although other issues such as power quality and earthing are also covered. The core of the connection agreement relates to technical equipment to ensure the generator disconnects from the network if either a loss of mains is detected, the voltage deviates outside set limits, or the frequency deviates outside defined limits. Times are defined within which the unit must be disconnected.

The most important document defining connection of micro CHP is currently ER G59/1. This was written with larger generators in mind and is particularly onerous for micro CHP. The difficulties identified are less to do with the technical specification, rather the recommended processes for reaching an agreement, including witness trials at each site and the need to prove conformance to the ER.

Both manufacturers and DNOs recognise that the current route towards connection of micro CHP could be a major barrier to development of the market. Two important initiatives are now in place to define acceptable procedures for the mass market. The first was instigated by the UK Electricity Industry via the Electricity Association with the goal of producing a new ER to accommodate micro CHP. In parallel, a European CEN Working Agreement which could become a standard in the future, is also being debated. In both processes, the main goal is to reach a type-tested, "fit and inform" route for connection of micro CHP units.

- Connection agreements are required
  - Protection for the generator and network
  - Disconnects the generator in the event of a fault
- Existing standards are too onerous for micro CHP
- A potential market barrier if not addressed
- Two important initiatives underway to define new standards (recommendations) for connection of micro CHP
  - UK Electricity Industry initiative to define a new Engineering Recommendation
  - European-wide CEN Working Agreement

New standards and recommendations are required to cover the connection of micro CHP

Barriers and Incentives

In previous sections the potential for micro CHP to be supported as a cost effective EESoP/EEC measure have been discussed. Although a market cannot be justified only with such support, these mechanisms can provide valuable assistance to bring technology like micro CHP to market. In particular, factory gate subsidies can help establish the market volume.

Other potential measures that may help both establish and sustain the growth of micro CHP may include tax incentives and the inclusion of micro CHP within carbon trading initiatives. Although the Climate Change Levy does not extend to domestic customers, it is apparent that although not Renewable, the export from micro CHP is 'green', and as such could potentially be regarded as levy free electricity supply to the commercial and industrial sectors.

The key barriers to micro CHP have been identified as network connection and metering/trading arrangements. The former is already being tackled. The latter is primarily a subject for Regulatory consideration and needs to be considered in association with the overall effects on the existing electricity supply chain. Of particular importance is likely to be the need to address the allocation of Distribution Use of System (DUoS) charges to ensure equitable allocation of costs amongst customers. A further potential barrier identified by ESCo/Suppliers interested in entering the micro CHP market is the current '28 day rule' concerning customer rights to choose electricity suppliers.

In association with the requirements for connection, parallel activities are required to develop technical equipment for the mass market. This is the subject of initiatives between a number of industry players at present.

Incentives

- Pump priming measures to assist the early market, such as EESoP/EEC
- Long-term 'externality' benefits through taxes and levy exemptions and/or the ability to trade export as 'clean' electricity

Barriers

- Need for new connection standards & procedures
- Regulatory action to deal with the impact through the electricity supply chain;
  - Equitable re-distribution of DUoS
  - Profile Settlement and/or other modifications to metering and trading arrangements
  - Examination of '28 day rule' and other potential commercial barriers

Additional Regulatory action required to address disruption in existing electricity supply chains

Conclusions

- Micro CHP is close to market
- Economically viable technology
- Important contribution to environmental goals
- A very disruptive technology for the existing electricity supply chain
- Pump priming support can help build market volume and ensure the success of micro CHP
- Long term 'externality' incentives are not a prerequisite for success but will fuel rapid uptake of micro CHP
- Technical barriers are being addressed, particularly network connection
- Long-term barriers will need Regulatory attention, particularly relating to the impact on DNOs
- Equitable electricity trading mechanism required to recover true economic value of micro CHP

Micro CHP is close to market launch from several manufacturers. The economics, even without considering changes to existing structures, look encouraging. However, for a long term market a number of additional benefits should be sought to recognise the 'green' nature of the technology. Although micro CHP does not require long term support for success, pump priming support for the emerging market will help ensure an early successful launch.

Micro CHP is likely to have a positive environmental impact with CO_2 savings in the region of 20% (or greater) of household emissions. Perhaps more important is the cost effectiveness of micro CHP as an energy efficiency measure. Although not as cost effective as the best insulation measures, micro CHP represents the next best measure for the majority of properties, particularly where further insulation is not possible. The ESCo route to market proposed by most players, may also provide a mechanism to take other cost effective energy efficiency measures to households.

The main technical barrier to micro CHP concerns reaching consensus on standards for connection to the Distribution Network. This area is being addressed both in the UK and at European level by micro CHP suppliers and DNOs. Long term issues relating to the impact on the electricity supply chain, particularly the impact on DNOs, requires Regulatory led action.

Micro CHP is coming!