Claverton Energy Forum
Microgeneration chapter

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## 1 What is Microgeneration?

The UK Government definition of Microgeneration[1] applies to a rather surprising mix of heat and power generating technologies with a thermal output below $45kW_t$ or an electrical output of $50kW_e$. It covers electrical generation from wind, solar photovoltaics (PV) and hydro, and heat generation from biomass, solar thermal and heat pumps as well as micro CHP which produces heat and power from renewable or fossil fuels. It is not just another term for small scale renewables, but comprises a portfolio of low carbon technologies.

There has been a tendency amongst advocates[2] and sceptics[3] alike to lump all Microgeneration technologies together, either as “all good” or “all bad”. This is particularly unhelpful when attempting to understand the potential contribution Microgeneration can make to UK energy strategy and it is important that we understand the particular characteristics and potential role of each technology.

The purpose of this chapter is to examine these characteristics and the relative merits of the main technologies included within the scope of Microgeneration.

## 2 The potential for Microgeneration

Numerous studies commissioned by Government agencies have concluded that Microgeneration can make a significant potential contribution to the long term UK energy mix. Depending on the relative costs of gas and electricity, specific microgeneration technologies offer immediate environmental and economic benefits and can be delivered in significant volumes through existing delivery chains. Foremost amongst these are micro CHP (most beneficial where gas is relatively cheap compared to electricity), and heat pumps which are more appropriate in the opposite scenario and which will almost certainly become the heating system of choice within the next couple of decades[4].

However, it must be conceded that not all forms of microgeneration necessarily represent the most cost effective means either of mitigating carbon emissions or providing security of supply, although even the more expensive measures empower and engage individual members of society who can choose to invest their own resources in an incremental and low risk way, without the need for high level bureaucratic intervention.

A recent study by Element Energy for BERR[5] demonstrated the potential for 1 – 3 million microgeneration installations together with CO2 savings of 1 and 3 million tonnes by 2020 and 2030 respectively, the leading technologies being identified as micro CHP and heat pumps. Significant subsidies would, however, be required to achieve any significant penetration of other Microgeneration technologies.

This followed an earlier study commissioned by the Energy Saving Trust (EST) in 2005[6] which concluded that up to 25% of the UK energy supply could be met from Microgeneration by 2050, without Government subsidies, based primarily on micro CHP and micro wind. Other studies[7] have indicated a wide range of potential contributions, with micro CHP alone potentially providing an installed capacity of 12-22GWe. The EST study was clear in identifying technologies which were expected to contribute to this overall potential and avoided the assumption that Microgeneration was good or bad per se.

Microgeneration enthusiasts who would promote all Microgeneration technologies equally, fall into the same trap as advocates of central plant who contend that Microgeneration is at best a distraction and at worst a white elephant simply because one or two Microgeneration technologies are not yet optimal and that all central plant solutions are inherently better.

Although the PIU review and the EWP (Energy White Paper) 2004 assessed the carbon mitigation benefits of micro CHP separately, the EWP 2007 (see Figure 1), lumps all heat producing Microgeneration together so that heat pumps (which are cost effective) are combined with solar thermal (which is not) and all electricity producing Microgeneration together so PV (with a carbon mitigation cost of £520-£1250) is combined with micro CHP (with a cost of minus £630 per tonne)[8]. Not surprisingly, Microgeneration appears as a poor option in this bizarre analysis. To mix PV, arguably the least cost effective carbon abatement technology with micro CHP which, according to EWP 2005 is the most cost effective alongside energy efficiency is patently ridiculous.

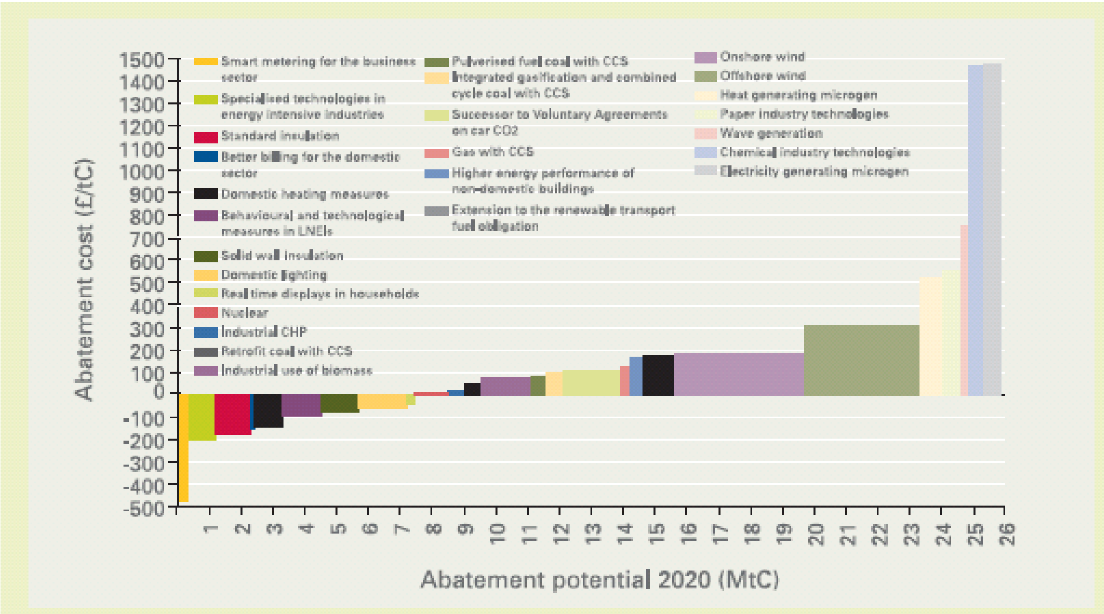

Figure 1: marginal abatement cost curve (source: EWP 2007)

The distortions arising from this simplistic analysis are compounded by the development status of different Microgeneration technologies; some are mature and have demonstrated their potential performance and production costs, whereas others are at their earliest stages of market entry and are still relatively expensive and may not perform to their ultimate potential. Commentators like George Monbiot, normally a staunch advocate of environmentally benign solutions, are sceptical of the whole Microgeneration industry on the basis of the over-hyped performance of a few fashionable technologies[9]. The questionable performance of micro wind, for example, has also cast doubts on the demonstrated performance of micro CHP. This latter technology is currently produced in small volumes, but is likely to become significantly cheaper over the next few years as it enters mass production; at the same time (electrical) efficiency levels currently at around the 10% mark, are likely to rise considerably as other products become available, with fuel cell based systems now being trialled in Japan achieving electrical conversion efficiencies of over 40%.

Unfortunately, even when well-intentioned, government intervention[10] in support of Microgeneration has created a market so distorted, that certain technologies with little real contribution have become fashionable, eco-bling icons and attract massive public subsidies and policy support, giving the impression that Microgeneration has an inherently disproportionate cost to the taxpayer. This undermines the credibility of Microgeneration and adds weight to the advocates of centralised solutions such as nuclear which are equally expensive. In this situation it would perhaps be better if the government ceased its attempt to "pick winners" and focussed on removing market barriers.

## 3 Microgeneration benefits

Microgeneration can, in its own right, deliver carbon savings, contribute to long term security of supply and help tackle fuel poverty. It can help avoid single fuel dependency and add diversity to complement large scale intermittent sources, acting as an enabler for high penetration levels of, for example, large scale wind. It will also help to minimise system losses, although that is of less relevance if Microgeneration is significantly less efficient than large scale RE.

So, although Microgeneration is no silver bullet, it does have a significant role to play as part of a mix of heat and power producing solutions. A number of studies, with a particular focus on micro CHP, have shown how Microgeneration can help deliver all four of the key policy objectives in UK Energy Policy. The results are surprising, in that the benefits identified generally exceed the earlier claims made by manufacturers. Three studies in particular show that micro CHP makes a substantial contribution to fuel poverty, carbon mitigation and diversity of supply targets.

### 3.1 Fuel Poverty

A Policy Studies Institute paper[11] shows that mCHP contributes almost as much to fuel poverty as all other measures put together including mCHP. This paradox is explained by the fact that, if homes are well insulated, the reduction in thermal load leads to a reduction in electricity production and hence makes it unlikely that micro CHP would be installed in as many homes: *"Micro CHP can do almost as much for fuel poverty as making all possible energy efficiency improvements, including micro CHP."*

### 3.2 Carbon mitigation

A report by the consultancy Ilex, shows that appropriate emission factors to be used for calculating $CO_2$ displacement for the next 10 years[12] are actually higher than both that of the average generation mix and of current marginal generation emissions. Current government policy is based on 0.43kg/kWh which is the average mix, a somewhat arbitrary and in this case, inappropriate measure. Micro CHP is shown to displace marginal plant and the study, which matches actual generation profiles for installed WhisperGen units against marginal plant, shows a displacement of 0.54 rising to 0.67kg/kWh by 2010. This counter-intuitive result is the consequence of the increasing cost of coal-fired generation which, although it reduces the total amount of coal generation in the overall mix, shifts all coal generation into the margin. The CO2 displaced by Microgeneration is recognised in SAP (Standard Assessment Procedure) based on studies of profiled grid emissions undertaken by Christine Pout[13], which uses a figure of 0.568kg/kWh for all Microgeneration, (regardless of type) conflicting with the assumption of 0.43kg/kWh for consumption (import).

### 3.3 Support of intermittent renewable generation

Further indirect benefits accrue to micro CHP as it has a profile which supports intermittent wind resources and, by nature of its diversity, reduces the need for back-up capacity. The ECI study[14] based on 20 years of wind and consumption data, concludes that only 400MWe back-up capacity would be required if micro CHP were to support 10GWe of wind generation.

### 3.4 Reduction of network costs

The SIAM[15] (System Integration of Additional Microgeneration) study was expected to identify adverse impacts of large-scale implementation of micro CHP on Distribution Networks, potentially requiring significant investment in network upgrades. In fact, the study showed that in only a few extreme cases would integration of micro CHP incur additional short term costs, that in the majority of cases it would have beneficial impacts and the overall benefit to the UK distribution network was substantial; savings in deferred network upgrades and improved operational efficiency were estimated at up to £1.2 billion by 2020 assuming a high penetration level of Microgeneration.

### 3.5 Incremental, low risk investment

A fundamental attribute of Microgeneration is that it will, by definition, be introduced incrementally, avoiding catastrophic financial and technical risks and delivering real carbon and financial savings from day one. Other potential carbon mitigating solutions, such as nuclear, involve step changes in capacity and will not deliver any benefits for as much as a decade; it is a substantial risk to attempt to anticipate what market conditions might pertain in 10 years when it comes on line, still less over the subsequent 40 years or so life of such plant.

### 3.6 High value generation profile

It is, therefore, inappropriate to consider Microgeneration as just another generation option in the same way as central plant alternatives. If we invest in a CCGT plant to replace an existing obsolete plant, that is not the same as incrementally eroding the demand for marginal plant. The former may (as in the case of nuclear) demand to be run as baseload and will thus displace baseload or "must run" plant such as renewable wind; in this context nuclear is displacing zero carbon generation. Microgeneration by contrast (specifically micro CHP which is largely peak-following) will displace marginal plant, with consequently high financial and carbon benefits.

### 3.7 Public engagement and empowerment

Some advocates of Microgeneration cite the benefits of public engagement, and it is clear that householders who invest in Microgeneration do become more conscious of their overall carbon footprint and tend to modify their lifestyles to further reduce their environmental impact. However, there is a limit to how much value should be attributed to this, particularly if the technologies in which they invest are subsequently shown to be significantly less effective than larger scale alternatives. An example of this is the current fad for micro wind which, even at the optimistic cost of £1500 for a 1kWe unit is far less effective than investing a similar amount in a large scale, say 2MWe, product which will have a yield of an order of magnitude higher, even accounting for transmission & distribution losses.

### 3.8 Lower cost to Government

A significant difference between Microgeneration and central generation for the government is that whilst the former is funded from taxed income and will have a positive socialised cost impact (i.e. it will add tax income to the Treasury), central plant investments will result in a reduced tax income (as they are tax deductible), and will have the further impact of being spread across all households in the form of higher energy bills!

# 4 Microgeneration technologies

As mentioned earlier, Microgeneration can be considered to comprise three main types of technology, heat producing, electricity producing and heat and electricity producing. Heat producing technologies have a particularly important role to play as, at the domestic level, 85% of energy consumption for a typical household is for the production of space and water heating. Even allowing for the reduction in space heating demands for new homes, water heating will remain a significant demand; space heating for the existing 24 million homes will also remain.

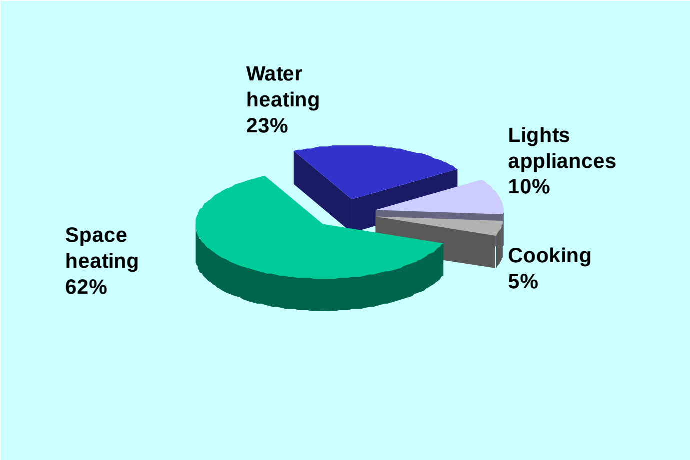


Diagram: Energy use within the home [16]

In general, electricity-only production technologies are discretionary, that is to say that they are an addition to the existing domestic energy system. They are thus penalised by the fact that their entire cost has to be recovered by the energy savings they generate, unlike biomass boilers, heat pumps or micro CHP which only need to recover their marginal cost over that of a conventional oil or gas fired boiler. An additional challenge is that the electricity may not be generated at the time it is required and thus flows naturally onto the network. If an export arrangement has been made with an energy supplier, this has some value. However, the underlying value of each kWh exported is based on wholesale electricity prices, which are roughly half of the retail price, as they do not include network and other charges. This and the transaction costs that the utility incurs for measuring and settling export make it preferable to displace import rather than sell export. No such problems are attached to heat only technologies, the reason that solar thermal systems displacing electric immersion water heating (which can be stored for later use) can paradoxically have a higher value than electricity production from a PV system which cannot be economically stored.

Most micro CHP products under consideration today are fossil fuel fired and although they offer a highly cost effective carbon mitigation solution under current conditions, they will become less effective as fuel prices increase and the carbon intensity of grid electricity decreases. Such technologies thus have a window of opportunity of perhaps 20-30 years before alternatives such as heat pumps using low carbon electricity become more appropriate for domestic applications. There will however remain a niche opportunity for solid biomass micro CHP; already one or two products are under development. Liquid biofuels are unlikely to be available to the domestic heating sector due to limited fuel availability and the more pressing demands of the transport sector.

The following section considers the characteristics of and the role for each Microgeneration technology.

4.1

**Solar PV (Photovoltaic)**

| | |
|---|---|
| 1600 kWh | Energy produced annually per installation (electricity) |
| 0.25 kg/kWh | Specific $CO_2$/kWh power |
| 500 kg | CO2 saving per installation |
| 10 million | Number of suitable homes |
| 5 million tonnes | Total potential CO2 saving |
| 63 years | Payback without subsidy |
| £1,000 | Cost per tonne lifetime CO2 saving |

Assumptions:
2kWp crystalline silicon PV installation in central England
100% of generation is consumed in home (or net metering)

The majority of commercially available PV products comprise roof-mounted panels made up of large numbers of individual solar cells produced from crystalline silicon, together with various essential electronic components. Solar radiation falling on the panels, produces a flow of electrons in the cells. This DC electricity requires power electronics to convert it to 230 volt AC suitable for use in the home.

### *4.1.1 Embodied carbon*

The embodied energy in the production of the silicon cells and the ancillary components is significant; indeed, the electricity produced by a typical UK PV system over its entire life, results in $CO_2$ emissions of between 0.22kg/kWh[17] and 0.25kg/kWh[18], admittedly only half of the current displaced grid mix, but not zero carbon by any stretch of the imagination and not particularly impressive when compared with other Microgeneration technologies.

### *4.1.2 Economics*

The cost of a typical 2kWp PV system, which will deliver around 1600kWh per annum in central England, is in the region of £10,000 without subsidies. Economic paybacks are between 50-100 years (well in excess of the anticipated life of both the panels and the electronic ancillary components) depending on the level of utilisation by the householder of the power produced; even with credit from ROC (Renewable Obligation Certificates) and assuming exported power has a relatively high value, the paybacks are more than 30 years (about the life of the system).

So why has so much attention (and tax payers money) been focussed on PV?

Protagonists would argue that the cost of PV will fall over time if we invest enough to stimulate the market and that the embodied $CO_2$ will also fall as new production techniques are developed; that does not answer the question of why we are still funding what is clearly a sub-optimal technology today. If the new technologies such as thin film and dye-sensitised materials do show promise, we should be focussing our efforts and investment in bringing those to market, rather than subsidising yesterday's technology. Otherwise the cost reductions so far demonstrated are not convincing; the cost of PV would have to fall by a factor of 10 to compete with micro CHP and nobody is claiming that, particularly when cost reduction is also dependent on comparable reductions in installation and ancillary components. Even if the PV panels themselves were free, the total cost would still be around one third of current costs, resulting in an unsubsidised payback of around 20 years!

Other arguments are that building-integrated PV can displace the cost of conventional roofing materials and that, as a prestige cladding material, it is cheaper than polished granite, but that does still not address the central argument that PV is not a cost effective carbon mitigation solution and that there are better ways of investing our finite resources.

Probably the most spurious case is made by individuals who claim it adds value to the house, using their own anecdotal experience as an example. It is notoriously difficult to identify which component of a house most contributes to its value, particularly in periods of rapidly increasing house prices; even if such a value gain were to be demonstrated it would not justify the investment to the UK, but simply reflect the effectiveness of the preferential treatment of PV by current support mechanisms.

Indeed, the case of PV should serve as an example of what happens when well-intentioned, but ill-informed policy makers are swayed by the unsubstantiated arguments of special interest groups.

Those who quote the example of how effective the German FIT (Feed-in-Tariff) has been in delivering significant amounts of PV generation might pause to consider the staggering long term cost to the taxpayer, around £40 billion over the next 20 years for the PV already installed! In fact the German Government introduced the scheme primarily as a boost to the fledgling PV industry in the hope of creating jobs, not as an energy policy measure. Now, when faced with the prospect of a progressively reducing FIT the PV industry objects vociferously, despite their claimed expectations of achieving “grid-parity” within five years. In this context it seems that “grid parity” is a comparison with peak price electricity in a sunny Mediterranean location, when the bulk of the PV is being installed in Germany where solar yields are considerably lower.

#### *4.1.3 Advanced PV technologies*

In contrast to the unimpressive economic and environmental credentials of current (crystalline silicon) PV technologies, there appears to be considerable potential for the next generations of PV, such as thin-film amorphous silicon and more advanced PV such as dye-sensitised and metallic coating technologies. These offer lower production costs and very much lower embodied carbon; however, manufacturers are currently focussing efforts on exploiting markets with favourable support regimes, rather than developing those where the technologies are more suitable. Cynics might question why there is more PV in Germany than the entire Middle East and the continent of Africa.

### 4.2

**Micro & mini wind**

| 1 kWe MICRO WIND TURBINE (HORIZONTAL AXIS) | |
|---|---|
| 700 kWh | Energy produced annually per installation |
| 0.02 kg/kWh | Specific $CO_2$/kWh power |
| 355 kg | CO2 saving per installation |
| 1 million | Number of suitable homes |
| < 500,000 tonnes | Total potential CO2 saving |
| 30 years | Payback without subsidy |
| £280 | Cost per tonne lifetime CO2 saving |

Assumptions:
1kWe free-standing turbine installed in location with average wind speed >5m/s
100% of generation is consumed in home (or net metering)

| 5 kWe MINI WIND TURBINE (HORIZONTAL AXIS) | |
|---|---|
| 10,000 kWh | kWh produced annually per installation |
| 0.005 kg/kWh | Specific $CO_2$/kWh power |
| 5700 kg | CO2 saving per installation |
| 500,000 | Number of suitable installations |
| 3 million tonnes | Total potential CO2 saving |
| 13 years | Payback without subsidy |
| £150 | Cost per tonne lifetime CO2 saving |

Assumptions:
5kWe free-standing turbine installed in location with average wind speed >5m/s
100% of generation is consumed in home (or net metering)

Micro wind turbines can be either mounted on buildings or free-standing and can be either vertical axis (VAWT) or horizontal axis (HAWT). Generally speaking buildings mounted units are cheaper to install as they require no tower, but are more susceptible to the turbulent wind conditions found near buildings which will significantly reduce their output.

VAWT are less influenced by turbulent wind conditions, but tend to be rather larger and considerably more expensive for the same nominal power output, although their actual generation over the course of a year may be higher for the same rated output as a HAWT.

Larger HAWT from 5kWe upwards are usually located away from buildings or other obstructions and have demonstrated effective performance. However, there are limited applications for such products which represent a significant investment, around £18,000 for a 5kWe unit generating electricity worth typically £1350 per year excluding ROCs or other support measures.

The EST study identified micro wind products at the 1kWe level as a major component of their 2050 target for Microgeneration, so when the Windsave 1kWe product was launched by B&Q last year, it seemed that this was a technology whose time had come. However, there are many who are concerned that such products may not deliver the electricity production levels expected for a number of technical reasons, even in locations with theoretically favourable wind conditions.

There is clearly a need to test these micro wind devices in real applications to demonstrate the potential benefits, and the EST has recently initiated a trial of micro wind devices to this end. However, if we assume that they do in fact perform as claimed by the manufacturers, micro wind can deliver $CO_2$ savings far more cost effectively than PV for example.

Recent analysis by the Carbon Trust has concluded that micro wind technologies do provide significant benefits if installed in rural locations where wind speeds are both high and consistent, illustrating again the importance of actually trialling new technologies in a scientifically rigorous way rather than simply accepting manufacturers (or interest groups) wishful claims.

Unfortunately this conclusion means that the assumed performance based on the flawed NOABL wind speed database is invalid and the economically viable application micro wind technology will be confined to limited rural areas, so that market potential is probably an order of magnitude less than the EST and earlier studies suggested.

Some commentators make the simplistic assumption that it does not matter how little power is produced from micro wind (provided that the householder is aware of this when making the investment) as it will still make a small contribution to our energy system. Unfortunately, this assumption ignores both the embodied CO2 involved in the manufacture as well as the continuous losses in the controls and inverters of such equipment which, in many cases exceed the generation, so that they are in fact net consumers of electricity!

**4.3**

**Micro Hydro**

(Due to highly variable costs and performance it is not possible to provide typical data for this technology)

Micro hydro is a niche technology, being confined to locations where a suitable flow of water exists, but offers significant potential benefits particularly for rural applications and does deliver more or less continuous power, unlike most other renewable technologies. Although relatively expensive and requiring bespoke design, it is generally more cost effective than solar technologies in UK!!

Hydro power has been a useful source of power for many centuries and was, with wind, the main power source prior to the industrial revolution. However, the same constraints that limited its application then still apply today, notably the need for access to a suitable flow of water; more often than not, this does not coincide with the location of power demand. One major benefit of this technology compared with other renewable sources, however, is that it produces a much more consistent output, which can be further enhanced by simple energy storage (in the form of water). Indeed, at the micro power level the small proportion of water off-take from a weir etc. is often still well above the minimum flow requirements for the device to maintain its designed power output, so that power output can be continuous.

The two key parameters which determine the power output are the "head" (that is the height difference between water inlet and outlet) and the "flow" (volume of water); power output is directly to proportional to both. In order to achieve an economically viable installation, it is therefore necessary to have either a high head or a high flow or, ideally, both.

The economics are determined by the water resource as well as the local conditions which influence the construction costs of the generation equipment and associated infrastructure. Each site needs to be considered on its own merits, which leads to high implementation costs and it is thus a difficult technology for which to achieve economies of scale. This is not helped by the complex legal and other processes which must be complied with, prior to installation, further adding to the investment risk as significant costs must be incurred with no certainty of a successful outcome.

It can be seen from the above that it is not easy to establish "typical" installation costs, but it is unlikely that paybacks of less than 10 years can be achieved except for the best locations.

Micro hydro is, along with micro wind, a useful niche resource.

**Solar thermal**

| | |
|---|---|
| 2000 kWh | Energy produced annually per installation (hot water) |
| | Specific $CO_2$/kWh heat |
| 540 kg | CO2 saving per installation |
| 10 million | Number of suitable homes |
| 5 million tonnes | Total potential CO2 saving |
| 50 years | Payback without subsidy |
| £370 | Cost per tonne lifetime CO2 saving |

Assumptions:
£5000, 5m2 installation in central England
Displaces 70% efficient gas boiler; comparison with electric heating would give higher value per installation, but much lower number of potential installations
25 year life of system

Solar thermal systems use either a series of evacuated tubes or glazed panels to capture solar radiation and heat hot water. Some evacuated tubes use an intermediate heat exchange medium, but the overall principle is the same. The hot water is then pumped through the lower of two heat exchanger coils in a hot water cylinder to provide domestic hot water; a second coil located above this one is normally connected to the primary heating system to raise the temperature in the cylinder to a suitable level when solar heating alone is insufficient.

### *4.3.1 Economics of solar thermal*

Typically solar thermal systems provide around 50% of a household's needs over the course of a year and can cost between £2-5000, or more for individual retrofit systems. Unlike solar PV which generates valuable electricity, solar thermal generates heat which, depending on the primary fuel being displaced is worth significantly less, generally between £50-150 per year. Likewise the carbon mitigation value is also substantially lower unless the primary fuel is electricity.

### *4.3.2 Solar thermal current market position*

Despite the rather poor economic case, solar thermal is the most popular Microgeneration technology in the UK with more than 80,000 systems installed. In other countries with warmer climates the need for frost protection are absent and relatively simple, thermo-syphon systems with integrated hot water header tanks are common; these systems are considerably cheaper and, combined with their higher output (due to geographic location) can be a cost effective solution to the provision of hot water.

### *4.3.3 Marketing challenges*

The introduction of solar thermal technology to the UK was initially characterised by a cottage industry with more than its fair share of cowboys, and strenuous efforts have since been made by the industry to establish voluntary codes to avoid mis-selling and provide customer confidence. However, whether due to ignorance or for other reasons, even reputable players who have now entered the market, make performance claims which are at best optimistic and misleading and often appear deliberately confusing to prevent proper analysis of benefits. Such claims include some manufacturers' attribution of improved insulation measures being undertaken at the same time as the solar installation contributing a claimed performance enhancement of the solar thermal system, whilst others make irrelevant claims about the "efficiency" of their panels.

#### *4.3.4 Potential for solar thermal technology*

However, solar thermal systems can make demonstrable contributions to domestic hot water demand and, if in the longer term, they can be installed at a significantly lower cost, either by inclusion as part of new-build homes or as a component of a new central heating system in existing homes, then as the technology is relatively simple it could be incorporated in the majority of houses.

As each home in the country has a not insignificant demand for hot water (about 3000kWh per year) throughout the year, it may be able to make a useful contribution to the nation's substantial (70TWh) annual demand for domestic hot water. This could result in around 5 million tonnes annual CO2 savings according to manufacturers' performance claims.

### 4.4

**Heat pumps**

| | |
|---|---|
| 2008 GROUND SOURCE HEAT PUMP | |
| 20,000 kWh | Energy produced annually per installation (heat) |
| 0.162 kg/kWh | Specific $CO_2$/kWh heat |
| 3,000 kg | CO2 saving per installation |
| 1 million | Number of suitable homes |
| 3 million tonnes | Total potential CO2 saving |
| 20 years | Payback without subsidy |
| £44 | Cost per tonne lifetime CO2 saving |

Assumptions:
20,000 kWh total heating demand
Displaces oil boiler; marginal cost £4000
30 year life of GSHP

| | |
|---|---|
| 2020 AIR SOURCE HEAT PUMP | |
| 20,000 kWh | Energy produced annually per installation (heat) |
| 0.13 kg/kWh | Specific $CO_2$/kWh heat |
| 1,700 kg | kg CO2 saving per installation |
| 20 million | Number of suitable homes |
| 34 million tonnes | Total potential CO2 saving |
| 5 years | Payback without subsidy |
| £29 | Cost per tonne lifetime CO2 saving |

Assumptions:
20,000 kWh total annual heating demand
Displaces gas boiler; marginal cost falls to £1,000
Gas price doubles and electricity price increases by 50%
Grid CO2 falls by 20%
ASHP COP increases to 3.5 as technology develops
20 year life of ASHP

It might seem paradoxical that, although heat pumps are categorised as "Microgeneration", they in fact ***consume*** significant amounts of electricity. However, they do generate more useful heat than the electricity they consume; this is in fact true of all heat producing Microgeneration technologies.

The current debate as to whether ASHP (Air Source Heat Pump) technology is "renewable" yet again illustrates the perversity of allowing government (in this case EU) to make spurious classifications based on perception rather then relevance; the notion that, because the COP (Coefficient of Performance)[19] falls below a certain arbitrary threshold, changes it from renewable into non-renewable is absurd. There is after all, no such thing as a "zero carbon" technology; over its life every technology requires some energy (and $CO_2$) input, so it has an effective COP. For example, the COP of solar thermal is the amount of useful heat delivered to the domestic hot water system divided by the electricity consumed by pumps, controls etc., typically a ratio of around 10.

This unhelpful political situation, resulting from persistent, opportunistic lobbying from special interest groups, could cause irreparable damage to one of the most promising technologies for domestic heating.

### *4.4.1 Air to water heat pumps*

There are several different types of heat pumps, but the two main technologies normally considered for Microgeneration are Ground Source (GSHP) and Air

Source (ASHP) heat pumps, both of which produce hot water from ambient sources.

Heat pumps are essentially fridges in reverse, comprising three main components:

- The evaporator, which extracts heat from its surroundings (e.g. outdoor air) by evaporating a refrigerant,
- A condenser which gives off heat to its surroundings (i.e. the house) as the refrigerant condenses,
- A compressor which pumps the refrigerant through the evaporator and compressor.

In a GSHP the evaporator is connected to a pipe which is buried in the ground and extracts heat from it. The pipe can either be installed down a vertical borehole 30-100 metres deep, or horizontally in a shallow trench (space permitting). The condenser is connected to the central heating circuit in the house, to heat radiators and the water in the hot water cylinder, as in a conventional hydronic (wet) central heating system.

In an ASHP, the evaporator takes the form of a fan coil unit, a significantly cheaper solution providing more flexibility as to location, although they do need to be carefully sited to avoid noise problems; the performance of ASHP is lower than GSHP as their heat source is cooler when most heat is required.

The COP is typically between 2.5 to 3.5 over a complete year for ASHP and GSHP respectively. Already today GSHP compares favourably with gas heating in terms of carbon, but is somewhat less economic, due mainly to the high marginal cost, up to £4000 more than a gas boiler. Operating costs are lower for GSHP than gas, but higher for ASHP due to its lower COP. Natural gas today costs around 2.5p/kWh and electricity (standard tariff) around 9p/kWh; thus gas and heat pump systems have similar running costs when the COP is ~3.5. However, if an off peak tariff is used, the COP can be less and still achieve running cost savings; still, when gas is available ASHP cannot compete on economic terms alone. The situation changes substantially, however, where no mains gas is available and the alternatives tend to be LPG, oil or coal; then both capital and operating costs as well as carbon tip in favour of both types of heat pump.

#### *4.4.2 Air to air heat pumps*

Although most observers focus on these two (hydronic) types of heat pump due to the predominance of hydronic heating systems in the UK, there is also considerable potential for air to air heat pumps. These will have a significantly lower capital cost where the existing system being replaced is not hydronic, that is the majority of Economy 7 systems found in electrically central heated homes (primarily small houses and flats). They will also tend to have a higher COP due to the lower temperature required for air heating systems. Therefore, they will have significantly better paybacks and thus will be easier to introduce to the market, particularly for fuel poor, and propositions targeting this sector should be developed as a matter of urgency, possibly within the current CERT framework.

#### *4.4.3 Impact of decarbonised grid*

It is interesting to consider the long term role of heat pumps as the carbon mix of the grid falls in line with UK aspirations to reduce carbon by 60% by 2050. This implies a carbon content of 0.18 kg $CO_2$/kWh, less than the content of natural gas at 0.194kg $CO_2$/kWh. In this case, even electric resistance heating will have a lower carbon footprint than gas central heating; it is also highly likely that gas will increasingly become a premium fuel and, like biodiesel today, uncompetitive for domestic heating applications.

Thus, whilst heat pumps are a viable investment now, (particularly GSHP with an expected life of 50 years for the ground loop) and even though the immediate economics are less attractive than the likely lifetime value, they will become increasingly competitive with gas central heating as gas prices rise, and may eventually displace gas altogether as a domestic heating option. ASHP systems in particular, are likely to become the prominent technology due to their flexibility of installation, particularly for new homes with a higher proportion of DHW than space heating.

**4.5**

**Biomass**

| | |
|---|---|
| 20,000 kWh | Energy produced annually per installation (heat) |
| 0.025 kg/kWh | Specific $CO_2$/kWh heat |
| 5,300 kg | CO2 saving per installation |
| 1 million | Number of suitable homes |
| 5.3 million tonnes | Total potential CO2 saving |
| 45 years | Payback without subsidy |
| £78 | Cost per tonne lifetime CO2 saving |

Assumptions:
Displaces oil boiler; marginal cost £8,000

A biomass boiler is installed with a conventional (radiator) central heating system. It burns biomass, usually wood pellets in place of gas, oil or LPG. It is somewhat larger than a gas or oil fired boiler and requires a substantial fuel store. The wood pellet fuel is stored in a bulk container from where a vacuum tube draws the fuel to a small store next to the boiler itself. The boiler then draws the pellets as required to the boiler where they are first heated to produce combustible gas; this is then burned to heat water as in a conventional boiler to provide space and water heating.

As with heat pumps, economics for biomass are more favourable where there is no natural gas supply, and where a local biomass fuel supply is available. It is an alternative to fuel oil or LPG where no mains gas is available and, like them, requires fuel storage which can be in any dry building near the boiler. The economics depend on the cost of the local fuel supply, but the costs are generally competitive with the other fuels. More importantly, biofuels are less susceptible to the highly volatile price variations in oil and gas prices and should become increasingly competitive.

In environmental terms, biomass can make a very significant reduction in household $CO_2$ emissions, typically between 4-10 tonnes depending on the fuel displaced. As wood absorbs carbon during its growth and releases $CO_2$ when it is burnt, it is considered a “carbon neutral” fuel provided that the fuel source is managed sustainably to make sure it can be continuously harvested. However, some $CO_2$ is also released by processing and transport of the fuel so it is not entirely carbon neutral in practice. Although it is advantageous to source local biomass to minimise the transport emissions, the urban myth that biomass loses its environmental benefits if it has to be transported more than 25km are entirely unfounded; even if shipped to the UK from Siberia, it is still lower carbon content than natural gas.

**4.6**

**Micro CHP**

| | |
|---|---|
| 1kWe STIRLING ENGINE | |
| 3,000 kWh | Energy produced annually per installation (electricity) |
| 0.22 kg/kWh | Specific $CO_2$/kWh electricity |
| 1,000 kg | CO2 saving per installation |
| 12 million | Number of suitable homes |
| 12 million tonnes | Total potential CO2 saving |
| 4 years | Payback without subsidy |
| £40 | Cost per tonne lifetime CO2 saving |

Assumptions:
Displaces 90% efficient gas boiler; marginal cost £600
WhisperGen UK1
21,000 kWh annual thermal demand

| | |
|---|---|
| 1kWe SOLID OXIDE FUEL CELL | |
| 8760 kWh | Energy produced annually per installation (electricity) |
| 0.28 kg/kWh | Specific $CO_2$/kWh heat |
| 2,500 kg | CO2 saving per installation |
| 18 million | Number of suitable homes |
| 45 million tonnes | Total potential CO2 saving |
| 4 years | Payback without subsidy |
| £60 | Cost per tonne lifetime CO2 saving |

Assumptions:
Displaces 90% efficient gas boiler; marginal cost £1500
21,000 kWh annual thermal demand
Current grid carbon intensity displaced
Market potential will displace a proportion of the Stirling engine micro CHP potential

A micro CHP unit replaces the gas boiler in a conventional central heating system. Current products are floor mounted, typically located in a utility room under a worktop; they are the same size as a standard washing machine. It is expected that wall-mounted products will soon become available as well as a range of products to meet the needs of various other market sectors.

Current micro CHP products are engine driven, either ICE (internal Combustion Engine) or Stirling engines. In both cases gas is used to fuel the engine which drives a generator, the waste heat from which is used to heat the primary central heating circuit. They thus heat the home in the same way as a gas boiler, but also generate electricity, most of which is used in the home; any excess is exported to the network and sold back to the supplier.

### *4.6.1 Economics of micro CHP*

A typical micro CHP unit costs around £600 more than a boiler, but offers economic and environmental benefits to the householder. An average home with annual thermal demand of 18,000kWh will generate around 3000kWh of electricity; around 2000kWh will be consumed in the home, with 1000kWh exported to the network. This electricity is typically worth around £150-200, depending on how much is consumed by the householder and how much is sold back to the supplier and at what price. Although it consumes slightly more gas than a modern high efficiency boiler, the net saving is still more than £125 for a family home. In this example, the unit will therefore pay for itself in around 4 years. However, as most commentators have noted, the target market for micro CHP is not the average home, but the homes with *at least* the average consumption, hence the 12 million homes in the target market out of the UK total of 24 million homes.

For the average home, carbon savings of 1 tonne $CO_2$ per year can be achieved; a larger family home could expect to generate 4000kWh or more, providing an economic benefit of up to £300, a carbon saving in excess of 1.5 tonnes annually and a payback of no more than two years.

#### *4.6.2 Micro CHP developments*

Within the next few years, it is expected that a new generation of higher electrical efficiency micro CHP products will be introduced, based on fuel cell technology; already there are more than 2000 such systems operating in Japan. Although current costs are an order of magnitude higher than is required for economic viability, they are already a more cost effective means of carbon mitigation than solar PV. Significant development activity is currently focussed on reducing this high initial capital cost as well as demonstrating the service life and overall performance.

It is most likely that SOFC (Solid Oxide Fuel Cell) technology will emerge as the technology best able to meet cost and performance targets and, equally importantly, have a heat to power ratio making it suitable for the vast majority of UK homes.

#### *4.6.3 Impact of decarbonised grid*

However, the competitive position of all fossil fuel fired technologies will suffer as grid carbon intensity falls and eventually makes even high efficiency products obsolete. There is thus a finite window of opportunity for fossil fuelled micro CHP to contribute to the energy system as a transitional technology, extending the more efficient use of our finite fossil fuel resources.

#### *4.6.4 Micro CHP route to market*

The key attraction of micro CHP compared with large scale community based systems is that it is possible to use existing supply chains, most notably the gas boiler replacement market of over 1.2 million units annually to rapidly introduce a step change technology making use of the existing supply infrastructure. It is also a technology suited to the UK competitive market enabling individuals to invest as they choose based on their own assessment of their needs.

#### *4.6.5 Micro CHP compared to large scale CHP (Community Heating)*

On a technical basis, a community based scheme, with a higher heat to power ratio than current engine based micro CHP, can deliver higher total carbon savings per home, but at a higher specific carbon intensity, due to the lower total system efficiency resulting from heat distribution losses[20]. In this respect CH schemes face a similar challenge to SOFC based micro CHP with higher electrical efficiency, but lower total efficiency than Stirling engine based micro CHP. Paradoxically this means that, as grid carbon intensity falls, and the margin between specific CO2 for CHP and grid is reduced, the lower electrical efficiency (higher total efficiency) micro CHP will eventually deliver a higher absolute saving than CH systems.

The other attraction of CH is that it also offers the potential for utilisation of other fuels such as energy from waste and biofuels which are not suitable for exploitation at an individual house level.

Regardless of the relative technical merits of CH versus micro CHP, there is a clear investment benefit for micro CHP in low density housing areas as heat networks become both extremely expensive and operationally inefficient. There is thus a natural merit order for micro CHP in low density housing and CH for high density housing such that the two technologies complement one another for the provision of heat and power across the UK housing stock.

## 5 Comparison of electrical Microgeneration technologies

The following tables show the relative merits of electricity producing Microgeneration technologies both in carbon mitigation terms of the electricity production and in terms of the overall economic impact of installing the respective technology options in a typical family home. (Note that wind has been assumed to perform in line with manufacturers' claims.)

| Technology | Total $CO_2$ (kg/year) | $CO_2$ saving (kg/year) | Lifetime £/tonne | kg $CO_2$/kWh generated |
|---|---|---|---|---|
| Condensing boiler | 8596 | - | - | - |
| Condensing boiler plus PV | 8088 | 509 | 786 | 0.25 |
| Condensing boiler plus wind | 8342 | 254 | 591 | 0.06 |
| Micro CHP | 7515 | 1081 | 55 | 0.23 |
| Micro CHP (15%) | 7042 | 1555 | 45 | 0.18 |
| Micro CHP (20%) | 6711 | 1885 | 42 | 0.17 |
| Micro CHP (FC) | 6075 | 2521 | 48 | 0.28 |

Table 1: Cost of carbon mitigation with Microgeneration technologies. Total $CO_2$ is for home with thermal demand of 23,000kWh and electrical demand of 6000kWh per year. The cost per tonne of $CO_2$ saved shown here does not take into account the alternative cost of building new capacity in the form of, for example, CCGT central plant as was shown in the EWP 2004 figures, resulting in a negative cost for micro CHP.

| Technology | Marginal cost | Annual saving | Payback (years) |
|---|---|---|---|
| Condensing boiler plus PV | £8000 | £112/£212 | 40 - 70 |
| Condensing boiler plus wind | £1500 | £47/£97 | 15 – 30 |
| Micro CHP | £600 | £151 | 4 |
| Micro CHP (15%) | £700 | £221 | 3 – 4 |
| Micro CHP (20%) | £800 | £267 | 3 |
| Micro CHP (Fuel Cell) | £1200? | £240 | 5 |

Table 2: Economics of Microgeneration technologies. The alternative savings figures depend on whether the value of ROC is recoverable or not; again wind data assumes manufacturers' claimed performance.

## 6 Conclusion

Microgeneration can make a significant contribution to the UK's energy needs. However, it is only possible to develop a sensible energy policy including Microgeneration as a component by undertaking an objective evaluation of individual technologies separately rather than as a homogenous category. There is currently reluctance in Government, perhaps rooted in earlier ill-advised policy attempts, to "pick winners". As this paper has shown, there are clear winners, heat pumps for off-gas and eventually on-gas areas, micro CHP as a transitional solution for on-gas areas and biomass, micro wind and micro hydro in their respective niche markets.

Lumping winners and losers in the same pot is unhelpful, creates confusion in the minds of policy makers and householders alike and can lead to perverse distortions of the market. For example, the so-called "Merton Rule" which seeks to promote Microgeneration by mandating a percentage of Renewable generation on new developments, distorts the market *against* cost-effective low carbon solutions which are not "renewable"; as we have seen there are some renewable generation technologies which have a higher specific $CO_2$ content than others based on fossil fuels.

There is also a danger that the uncritical advocacy of Microgeneration may lead to the implementation of a sub-optimal energy policy and, worse still, create a backlash against all Microgeneration on the basis of those technologies which not only fail to deliver real benefits, but may even cause nuisance to their owners and those nearby.

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However, there is no theoretical limit to the cost of natural gas and as peak oil and gas becomes more apparent, the gap between supply and demand can only be closed by substantial price increases intended to price certain customers out of the market. Who those customers (or nations) will be and what that cost might rise to, are both unknown, but it would be unduly optimistic to assume that gas will remain a viable primary fuel beyond 2050.
At the same time, the decarbonisation of the grid will result in the carbon content of delivered electricity matching, and eventually falling below, that of gas as a primary fuel. In this case micro CHP, even generating at 100% efficiency will become pointless and heat pumps, converting low carbon electricity into greater amounts of useful heat will deliver increasing carbon savings.

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