Micro CHP in rural areas

Introduction

Micro Combined Heat & Power (CHP) has the potential to revolutionise the electricity industry in the UK and much of Western Europe. It is a cost-effective method of generating electricity with an estimated potential capacity of up to 22GW installed in the UK, significantly greater than the entire nuclear industry[1].

Not only is it economically viable for the end-user without any form of subsidy, it also represents the most cost effective carbon[2] mitigation strategy of all technologies at or near market.

However, the current estimates of market potential are invariably based on the assumption that micro CHP units will replace gas-fired boilers in hydronic central heating systems[3]. Whilst this may be true in the early stages of market development, there is a substantial additional potential for installations in rural areas where a natural gas network is not available and the opportunities for network support are considerably greater. Including such installations in the estimates for micro CHP raises the potential by around 10% in the UK, but up to 100% in other EU States, such as France.

Of greater significance, perhaps, is that these installations may also provide the earliest opportunity for the utilisation of liquid bio-fuels, raising carbon mitigation potential to over 50 million tonnes per year in the UK, and demonstrating the longer term role of micro CHP as a carbon-free domestic energy supply option.

Background

CHP has been identified by the UK government as a key component of its CO_2 abatement programme[4] and it also represents the most significant individual measure in achieving the European Union's CO_2 reduction targets (150Mt of a total of 800Mt)[5]. In order to meet their CO_2 emission reduction targets agreed at Kyoto, and to maintain security of supply, the EU aims to double the proportion of power generated by CHP to 18% of total capacity[6].

However, it is now clear that the emerging micro CHP technologies which were not included in this original target may help to make up for the disappointing growth currently being experienced in conventional CHP markets. (Micro CHP is relatively insensitive to the high fuel prices and low electricity prices which have had a detrimental effect on larger scale CHP). Although CHP generally represents a cost effective CO_2 abatement measure, micro CHP is potentially an even more cost effective measure. Perhaps more importantly, it can be readily implemented in the vast majority of existing homes for which relatively few substantial energy efficiency measures can be implemented in a realistic commercial manner.

Until recently, however, studies of the potential for micro CHP have focussed almost entirely on natural gas fired applications. A number of commentators have questioned this approach, as it is widely believed that a substantial additional market for liquid fuels may be available. It is against this background, that EA Technology established a project to examine the economic and environmental aspects of liquid fuels in micro CHP applications and to evaluate potential prime mover technologies. The study examined liquid fossil fuels as well as a range of biofuels. Evaluation of the WhisperTech Stirling engine was carried out using kerosene, fuel oil and recycled vegetable oil.

Environmental issues

Domestic energy consumption represents around one third of all UK CO_2 emissions. Of that total, around 85% is used for space and water heating in a typical existing home. An additional 5% is used for cooking (which may use electricity or fossil fuels) with only 10% for lights and appliances. Similar proportions apply to other European countries. Thus, although it might appear attractive to produce electricity from "zero carbon" technologies, in the domestic sector this can only address up to an absolute maximum of 15% of the typical domestic energy demand. Of course, different proportions and absolute values apply to new homes where space heating can be virtually eliminated, but at the present rate of construction it will take centuries to replace the existing inefficient housing stock, even assuming this were desirable for other reasons.

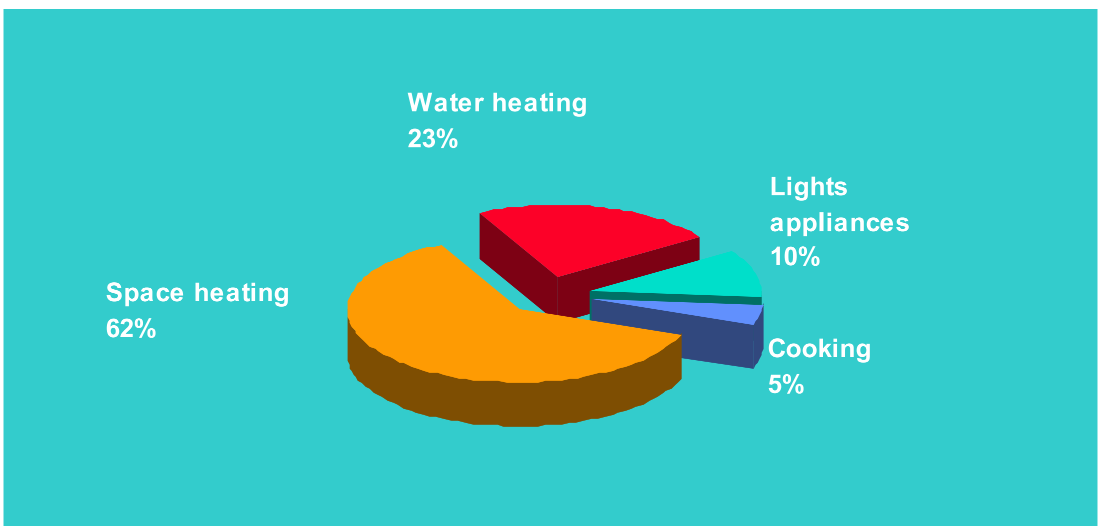

Figure 1: UK domestic energy consumption by application[7]

In other words, if we are to effectively address the key environmental challenge of climate change and carbon mitigation, it is logical to focus efforts on tackling the 85% rather than the 15%!

Of the 23 million existing homes in the UK, around 18 million are provided with gas-fired central heating. Of these, it is estimated that up to 12 million have sufficient energy demands to be economically viable for micro CHP. In addition there are over 1 million homes with oil-fired central heating, most of which could be economically provided with micro CHP. It should also be borne in mind that these homes also emit significantly higher amounts of carbon than those equipped with natural gas-fired systems, both due to the inherent carbon content of oil compared with gas, and the generally more substantial nature of homes equipped with oil-fired heating.

It is often argued that no technology option should be selected which is less efficient than the Best Available Technology (BAT)[8]; however, the definition of what constitutes BAT and, in particular the relevance of BAT in a given application, is highly contentious.

If we consider the options available for heating and electricity supply in a typical home, we need to examine not only the conversion efficiency of any given technology, but also the efficiency of the transmission and distribution system. Thus, in the diagram below (figure 2), we see the "perfect system" with 100% efficient conversion of gas to heat in a perfect boiler, and 100% efficient conversion of gas to electricity and no distribution losses. The current BAT is considered to be a very efficient gas boiler (>90%), with electricity from a Combined Cycle Gas Turbine (CCGT) with a conversion efficiency of ~60%. However, there are two flaws with this concept. Firstly, the losses in transporting electricity to the point of use will reduce this efficiency by at least 10% and, for practical reasons, it is not possible for all power to be provided by baseload CCGT stations running continuously at full load. The reality for current domestic customers is thus represented by the green line, with a maximum of around 40% delivered electrical efficiency and >80% (seasonal efficiency) for heat production.

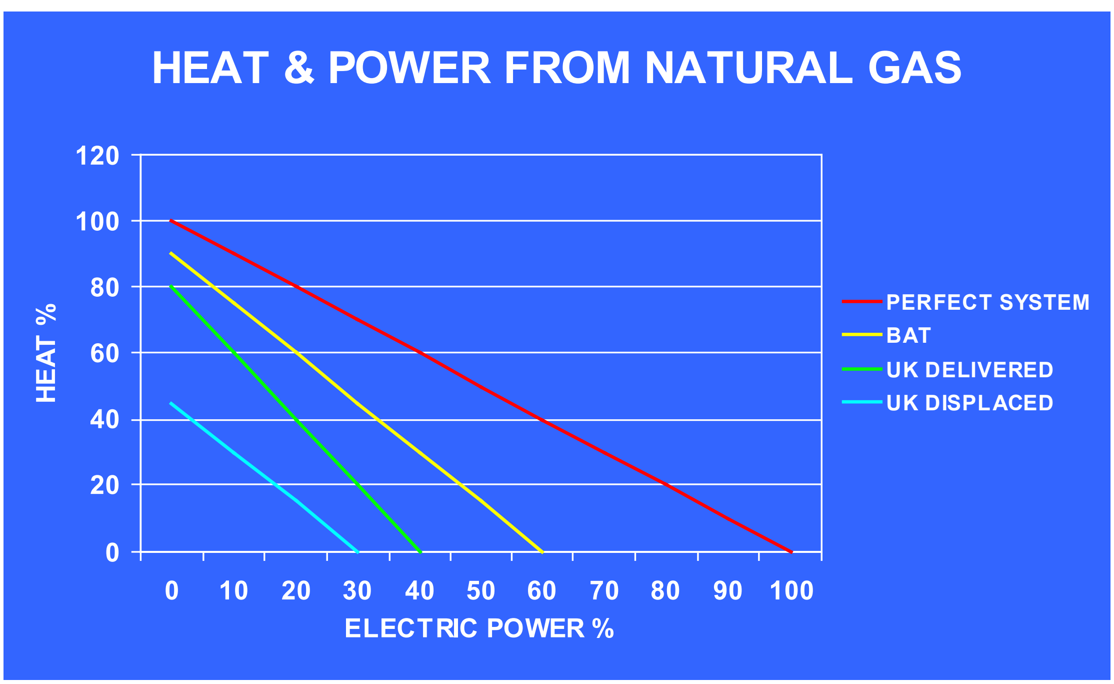

Figure 2: Domestic energy supply options

When considering the potential environmental benefits of micro CHP it is important to consider which generation technology will be displaced. Micro CHP operation follows thermal demand and generates electricity according to that demand profile. Generally, this corresponds with peak network demand, which is largely met by coal-fired plant or open cycle GT technology, represented by the bottom line in the diagram. Both these types of plant produce significantly higher emissions than the average generation mix.

However, even based on a modest (550g/kWh) estimate of displaced carbon dioxide emissions, a typical micro CHP unit (1kWe electrical output) will save 1.7 tonnes CO_2 per year when installed in place of a natural gas fired boiler with the same thermal conversion efficiency. The same CO_2 savings will be achieved with an oil-fired unit as the savings arise from the generation of effectively CO_2 – free electricity, assuming that no additional fuel is consumed compared with a boiler. Clearly, the use of biofuel will reduce the CO_2 emissions further, although it is not necessarily true that biodiesel is a "zero CO_2" fuel, as some fuel input is required to produce and distribute it (unless that fuel input is itself biodiesel). Due to the variability in processes and feedstocks, this "loss" is variously estimated at 15%[9], based on total biomass output for rapeseed crops, 22%[10] for the biodiesel component alone, and 30-50%[11] based on current "worst practice".

Thus, the ultimate CO_2 mitigation potential of micro CHP using natural gas is up to 40 million tonnes per year. An additional savings potential of 5 million tonnes could be achieved if oil fired systems are included, and a total in excess of 50 million tonnes if biofueled systems are installed in place of fossil fuel oil.

It is arguable that, given finite feedstocks for biodiesel, it is more effective to use such fuels in automotive applications, particularly when considering pure plant oils. However, refining waste oils requires significant energy and process material inputs as well as creating waste residues. It is possible that Stirling engine technology may be able to make use of less refined waste vegetable oils at a lower cost and with less environmental impact than oils required for automotive (internal combustion) applications. It is also considered desirable by many to eliminate waste vegetable oil as a feedstock for recycling into animal feed, due to the risk of cannibalistic spread of disease through the food chain.

Other considerations to be taken into account include the localised emissions of carcinogens and odours. Compared with fuel oil, particulate and other odour emissions are reduced, although concerns have been expressed regarding the carcinogenic potential of continuous combustion of rapeseed oil[12]. There are also some who are concerned with the risk of monoculture farming of substantial quantities of rapeseed.

Figure 3, below illustrates the potential environmental benefits that could be achieved by implementing a range of technologies[13] in a typical UK home. On the extreme left of the diagram, the least effective measure is installation of photovoltaic panels (PV) without modification of the gas boiler system. The top portion of the histogram (shown blue) is for the CO_2 originating in the imported grid electricity. The red section in the middle represents the embodied energy consumed in manufacturing the PV panels, and the large lower portion represents the CO_2 resulting from the consumption of gas to provide space and water heating. As was mentioned earlier, this latter portion represents in excess of 80% of domestic energy consumption. The same representation is shown for the installation of a condensing boiler (a much cheaper and more effective measure than PV), both PV and condensing boiler, micro CHP, and finally biofuel fired micro CHP.

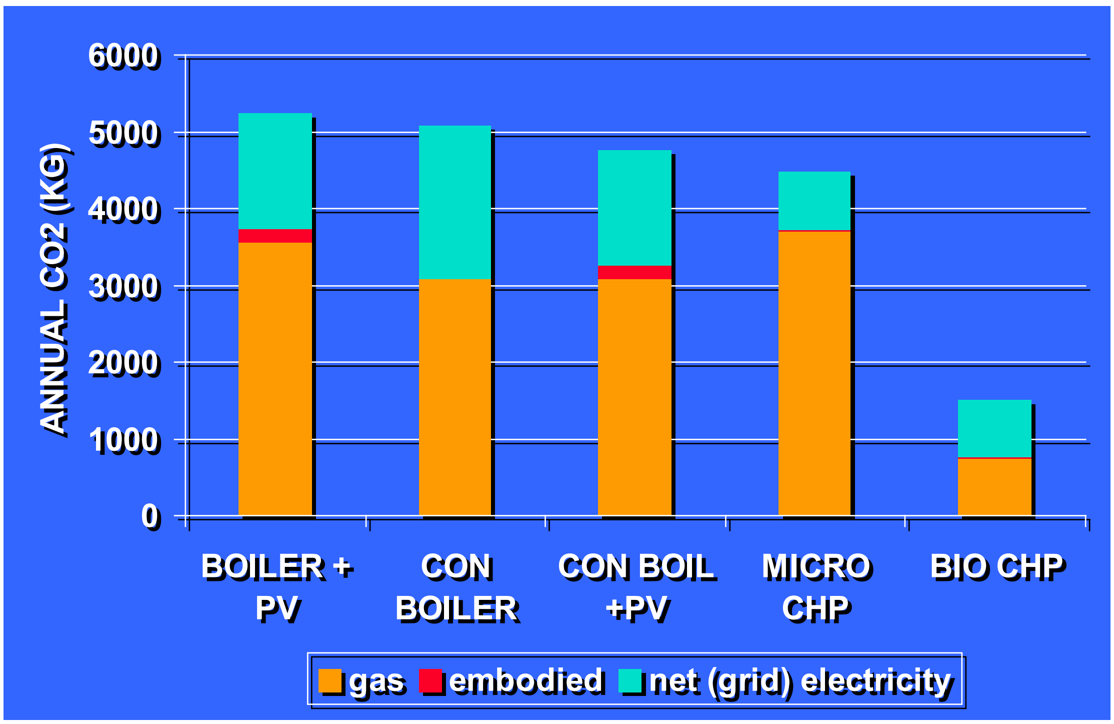

Figure 3: Comparison of micro CHP with other carbon mitigation technologies

Economics

From the above analysis, it is clear that micro CHP, particularly when using biodiesel as a fuel, is a very effective carbon mitigation measure. However, it has also been identified as the most cost-effective measure by the UK Government. Figure 4 below, lists potential carbon mitigation options, illustrating the highly cost-effective nature of micro CHP[14].

However, it is difficult to provide definitive economic comparisons for biofueled CHP as, under the current UK tax regime, pure vegetable oils are clearly uneconomical and the market for reprocessed vegetable oils is still in its infancy. Current costs for domestic fuel oil in the UK, are less than for standard automotive grade biodiesel, but a number of other incentives (such as

Renewable Obligation Certificates) and fossil fuel price volatility, could change this in the near future. In other EU States, where domestic fuel oil is heavily taxed, biodiesel is already competitive with fossil alternatives.

Table 4: Carbon Abatement Costs and Potential Contribution to Carbon Emission Reductions for the Leading Low-Carbon Options

	Carbon abatement cost £/tC (2020)		Potential contribution to carbon emission reduction (MtC)	
	Min.	Max.	2020	2050
Domestic energy efficiency	–300	50	15	30
Service sector energy efficiency	–260	50	4	10
Industrial energy efficiency	–80	30	9	25
Transport energy efficiency	-	-	14	30
Large CHP	–190	110	3	5
Micro CHP	–630	–110	1	5
Onshore wind	–80	50	1	5
Offshore wind	–30	150	8	>20
Marine (wave and tidal)	70	450	small	>20
Energy crops	70	200	3	10
Solar photovoltaics	520	1250	<1	>20
Nuclear	70	200	7	>20
Carbon sequestration	80	280	small	>20

The cost of biodiesel produced from waste vegetable oil comprises two components. The feedstock price is taken as the current price for waste oil supplied for alternative uses, primarily as an ingredient for animal feed. This is currently around 14p/litre in the UK. An additional cost of around 12p/litre is incurred in processing the feedstock into road grade diesel fuel. However, for combustion in a Stirling engine, which is an external combustion device, the processing cost may be significantly reduced, as less refining is required. Initial estimates indicate a reduction in processing costs of 50%[15].

Table 5: Relative fuel costs in EU

Country	Fuel type	Comment	Cost	
			Euro /litre	Eurocent /kWh
France	Fuel oil		0.35	3.32
Germany	Fuel oil		0.34	3.29
Italy	Fuel oil		0.82	7.92
Spain	Fuel oil		0.37	3.55
UK	Fuel oil		0.28	2.72
UK	vegetable oil	new	0.38	3.82
UK	recycled oil	automotive quality; feedstock at current market price (0.22 euro)	0.42	4.22
UK	recycled oil	as above, but minimum refined	0.30	3.02
UK	recycled oil	plus ROC @ "buy out" price (3p/kWh electricity)	0.30	2.52

Regardless of the costs of biofuel, there is only a limited amount of feedstock available at present. The 80 million litres of waste oil currently on the market each year (in the UK) would only be sufficient for around 40,000 homes. Assuming that the upper estimate of 330,000Ha[16] of rapeseed production were entirely dedicated to micro CHP, this would provide sufficient for an additional 200,000 homes. However, there is clearly a need for an improved waste oil collection system if the remaining 750,000 or so homes are to benefit from the potential for biofueled micro CHP.

The EA Technology project

EA Technology has been involved with testing and evaluation of various micro CHP technologies since the late 1980's and has recently successfully completed trials of the natural gas fired version of the WhisperTech Stirling engine unit. Further trials of this unit are planned for the forthcoming heating season with a view to commercial launch in 2004.

Having demonstrated the technology as a grid connected, gas fired unit it seemed appropriate to consider the potential for the remainder of the residential sector, as it had become clear that there remains considerable potential in terms of thermal and electrical loads for rural installations, particularly in other EU countries.

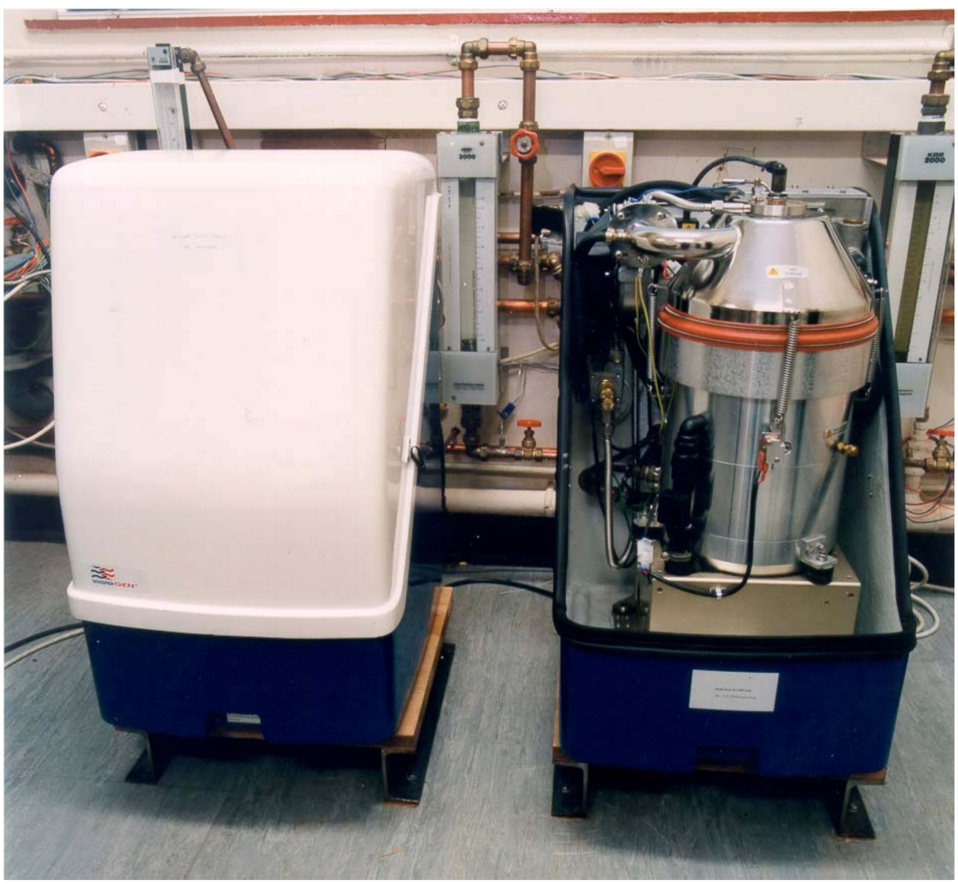

Figure 6: WhisperGen Stirling engine unit under test

The WhisperGen product was selected on the basis that it was a well-proven prime mover technology, as demonstrated in the earlier field trials. Furthermore, it had started life as a diesel fired, DC output unit for marine APU applications and is still commercially available in that configuration. Thus, the initial tests were carried out using the existing diesel burner in conjunction with the same basic engine and an AC induction generator. The attraction of the Stirling engine, being an external combustion device, is that, in theory at least, it can make use of virtually any fuel. It is only the burner which requires modification to take account of the fuel's viscosity and other characteristics, a significantly lesser challenge than redesigning an internal combustion machine. It therefore came as no great surprise that the unit operated satisfactorily on fuel oil and that the substitution of biodiesel for fossil diesel also represented no insurmountable challenges. Indeed, although automotive grade fuel was used in the burner, it is clear that the considerable potential for reducing the cost (both economic and environmental) of the fuel if a less refined fuel is supplied, may well be realised without incurring excessive product development costs.

Indeed, it is likely that the oil-fired version of the WhisperTech unit can be produced at a similar cost to the gas-fired version. Thus, the economics case for oil fired micro CHP is rather attractive and, once the gas fired version of the unit is established in the market, it is expected that the oil-fired version will be introduced. However, for the time being, the distortions in the market for biofuels caused by somewhat perverse tax regimes as well as the limited availability of low cost process stock, will impede the introduction of a biofueled micro CHP product in the UK, although there is considerable potential in other EU countries.

Further work is planned to examine these obstacles and evolve a strategy for market development. To discuss participation in this process or for further information please contact:

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