Options for upgrading residential CHP

"All energy generation options levy environmental costs. Some of these can be mitigated through careful planning and appropriate technology configurations."
Adam Serchuk in *Renewable Energy World July 2000*

There is little doubt that CHP/CH (Combined Heat & Power / Community Heating) is an environmentally superior solution to the separate production of heat and (remote) power. It is widely recognised as a leading CO2 mitigation technology. However, it is not without economic challenges nor is it without some degree of environmental impact. Whilst we might regret the economic and other obstacles, and many believe they are unfair for a range of reasons, they are real. If we hope to overcome these obstacles and improve penetration of CHP in the residential sector, we therefore need to seek optimum solutions rather than indiscriminately applying CH technology. These challenges are particularly severe for new CHP/CH schemes, but they also face those intending to refurbish existing schemes. This paper seeks to evaluate a range of technological solutions for a variety of applications applied to the refurbishment and upgrading of an existing CHP/CH scheme, based on economic and environmental objectives.

The dogmatic pursuit of large scale, Community Heating schemes by some advocates is similar to that employed by advocates of DG (Distributed Generation), particularly in the USA. They argue that DG is good because it avoids the system losses and "empowers" the consumer. Not surprisingly this is popular in USA as a concept at least. But, as pointed out by Simon Minett, in response to a recent Economist article, DG is not per se the best solution; central plant can often achieve better performance despite its distribution handicaps. It is only when use is made of the otherwise wasted heat that DG stacks up as a more environmentally benign solution.

The same logic, albeit at a smaller scale, applies to large scale CHP in conjunction with a distributed heat network. CHP/CH is efficient in its use of fuel, but loses out on the distribution side. Losses from the heat network usually exceed 10% even for good modern systems.

CH is sometimes defended on basis that it is "no worse than other uneconomic measures such as double glazing", ignoring the fact that double glazing and external insulation are applied for other reasons and have significant non-energy benefits. Even though the same may be true of CHP in terms of stand-by capacity, security of supply etc., these are not normally relevant in the context of UK urban power supplies. However, we need to look at those issues if the economics alone do not add up!

If, however, we insist on pursuing large scale DH solutions without considering potentially superior solutions, we run the risk of falling into the same trap as advocates of central plant albeit on a smaller scale - the view from the vested interests that only substantial project engineered solutions are economically or technically viable.

This policy, ignoring the smaller scale options, will inevitably limit the scope of residential CHP and fail to exploit the significant potential which can be met by applying a portfolio of solutions.

Technologies & Options

The case study uses a model representative of the many ageing CH schemes (with or without CHP) and due for replacement. In order to evaluate a range of technologies, it considers a mixed density urban housing scheme with high-rise apartment blocks, terraced houses and maisonettes and some low rise semi-detached homes.

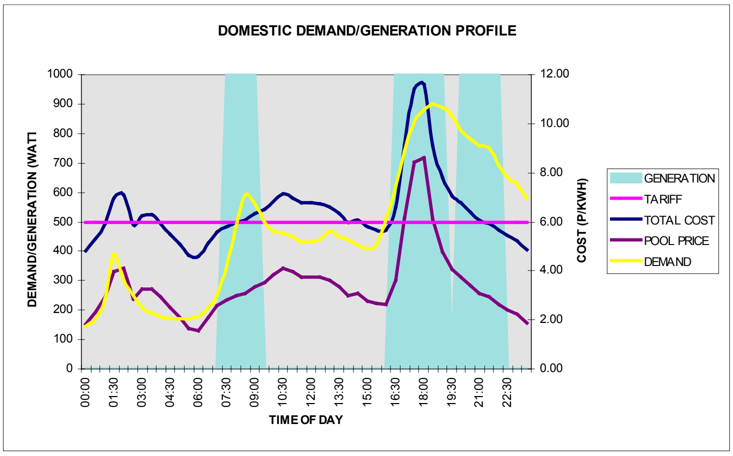
TECHNOLOGY	HEAT/ POWER	ELECTRICAL EFFICIENCY %
coal-fired CHP/CH	1.25	42
gas engine CHP/CH	1	40
gas turbine CHP/CH	0.8	50
gas engine	1.7	35
micro turbine	2.25	20
Stirling engine (1kWe)	6	12
Stirling engine (3kWe)	3	25

TECHNOLOGY OPTIONS
(manufacturers data)

The first issue to address within a competitive energy market is the unit charge for the currently used fuel. It is often possible simply to negotiate a cheaper energy supply contract! However, within the evaluation it is important to assess the true energy costs within the delivery chain. It is false economics to attribute a lower fuel cost to a large central CHP plant as though this were an attribute of the technology. If it is possible to negotiate bulk supply contracts for gas supplied to a central CHP plant, the same could be done for onward supply to a number of individual homes. The only real difference is that in the first case you are metering heat and in the second gas. It is extremely doubtful if the metering and billing costs for heat are noticeably lower than for gas. Indeed it is for this reason that a number of municipalities in the UK are establishing “preferred supplier” arrangements on behalf of their tenants, or establishing “Energy Clubs” for bulk fuel purchase and discounted fuel sales.

Equally, the value of electricity export has to be fairly evaluated, although here the comparison is biased by the rather arbitrary method of attributing DUoS charges to transport of electricity within a restricted area. A typical unit price for retail electricity is 6p/kWh, of which less than half represents the energy cost. The remainder comprises DUoS (Distribution Use of System), TUoS (Transmission) and utility margins. Distribution costs are recovered substantially from a fixed kWh charge, regardless of the distance the electricity is transported. Thus, although it is possible to use the existing network for electricity transport, this results in a higher cost than that actually incurred by the DNO (Distribution Network Operator). It is for this reason that private wire networks are being established to compete with incumbent DNOs within defined urban areas, and to recover the true value of embedded generation.

Variation of electricity cost throughout a typical winter's day shows the value of micro CHP generation. Generation coincides substantially with peak supply cost, as does domestic demand. Demand weighted value of micro CHP is around 3.4 p/kWh over the year compared with an average pool price around 2.5 p/kWh.



Although the case study assumes equal value for export electricity units whether from CHP/CH or micro CHP, the value in practice will be significantly different. As the thermal output from the CH scheme would normally be modulated by use of supplementary boiler plant, the electrical output would be relatively constant. Thus its value would be close to the average pool (wholesale) electricity price, currently around 2.5p/kWh. Micro CHP however, being thermally led, exhibits an output profile which varies largely in accordance with the pool price. That is, most power is generated when pool price is highest. Detailed analysis shows that the demand weighted value of micro CHP generation can be as high as 3.4 p/kWh.

The second step is to evaluate the potential for reduced energy consumption by energy efficiency measures such as insulation. Although often not cost effective as energy efficiency measures alone, it is sometimes necessary in any case to renovate the external shell of concrete high rise blocks. One example of a refurbishment of CHP/CH in Nottingham achieved double the savings from improved thermal performance of the fabric than from replacement of the leaking heat distribution network!

The comparison of different technologies to provide CHP/CH is fraught with difficulties. For example, should the energy production costs and emissions be attributed to heat production with electricity considered an "free" by-product or vice versa?

The rationale applied in this case study is to aim for the implementation of the system which exploits the potential heat demand as fully as possible, with electricity production in capital plant amortisation, operating costs and pollutant emissions having no additional impact. This methodology has been previously applied by some analysts to calculate an upper boundary for the potential CHP market in an entire country. Naturally this leads to an apparently high capital cost per home for high electrical conversion efficiency technologies (e.g. large gas turbines), but this is balanced by the high value in economic and environmental terms of the resulting electricity produced.

Case Study parameters

Although based on a representative mixed housing development, the case study considers for illustrative purposes only a sample of 300 of the total stock, each with an individual annual thermal load of 20,000 kWh. For a number of reasons large scale CH schemes are not designed to meet the entire thermal load of the system from CHP. It would therefore be confusing to compare micro CHP systems (which aim to provide virtually all the heat from CHP at this power level) with a centralised system which only provides a proportion of heat in this way. The assumption is therefore that the centralised system is meeting the entire thermal load of the 300 homes under consideration and that the balancing thermal plant feeds the remaining homes in the system.

It is also recognised that some of the technologies referred to could not realistically be applied at this power level and are included for reference purposes only.

AVEDØRE COAL FIRED CHP

A leading coal-fired CHP plant with an overall efficiency approaching 92%, serves 100,000 Danish homes.

Other options

Before considering any of the more exotic technologies, it is natural to consider the most commonly used form of providing heat and power to homes, namely heat from a conventional gas boiler and electricity from the public supply network. Although it is generally assumed that CHP displaces the most polluting form of generation (coal), as more CCGT (gas) stations are commissioned, the average emissions of the network will reduce. The study therefore evaluates the varying environmental impacts of gas boilers in conjunction with three grid supply options; coal generation, UK average mix (2000) and CCGT.

Environmental impacts are no longer simply of academic interest. It is more than likely that, within the life of a typical CH plant, pollutant emissions will have an economic impact on operators. In recognition of this, a value of $20 per tonne CO2 has been attributed to the overall operating costs of each option. Although this does not significantly alter the ranking of any option in terms of overall operating costs, it does at least illustrate the benefits of adopting an environmentally more benign solution.

As a reference technology, new coal-fired plant is considered, based on one of the world's most efficient plants at Avedøre in Denmark. Although clean coal plants have been sited in urban locations (Copenhagen, Stockholm), the costs of environmental control and fuel and waste handling are significant barriers to further uptake. The economics based on UK fuel prices make such plants unattractive in any case, so it is included only for comparison purposes.

Two other CH schemes, gas engine and gas turbine, provide a more realistic option for high density housing using a distributed heat network. However, smaller gas engines, with significantly different heat/power ratios, are considered for individual apartment blocks or group heating applications and appear to offer one of the most cost-effective options. The same cannot at present be said of micro turbines due to their current high capital costs, although it is anticipated that these will fall from around £1000/kWe to less than half this figure within ten years.

In terms of upgrading the performance of existing CH schemes, the elimination of summer load by providing DHW from alternative sources can significantly improve the overall annual operating efficiency. Already micro CHP technologies such as the Senertec and Ecopower ICE units are available and these could be profitably operated to meet the DHW baseload throughout the year avoiding distribution losses on part system load. One Senertec

ECOPOWER PACKAGED MICRO CHP UNIT
Based on Internal Combustion Engine technology, the Ecopower unit produces up to 5kWe and 15 kWt to provide baseload capacity in apartment blocks.

unit would typically serve a block of 30 apartments in this application.

Of course, distribution losses may be avoided altogether with the advent of micro CHP units with one system in each home. However, even when such units do become commercially available it will not be possible to install them in many high rise buildings for safety reasons (as is already the case for individual gas boilers).

Before considering the cost and direct implications for the technologies, it is perhaps worth mentioning some of the less tangible issues which should be considered. Perhaps the greatest virtue of CHP/CH is its potential for fuelling from a variety of fuels and in particular the potential for waste firing which, under current UK conditions, effectively means fuel with a negative cost. However, in the longer term it would be unwise to promote waste fuel in isolation from a coherent waste management/recycling strategy. The location of heat generating plant clearly raises another issue, that of the localisation of pollution. Regardless of the global impact of the selected system it is arguably of greater importance to minimise the level of emissions adjacent to the generating plant. This is where micro CHP scores highly. There is currently little or no concern arising from air quality impacts of domestic gas heating systems. The combustion of natural gas for simultaneous heat and power production using the same quantity of gas would therefore appear to have a negligible impact at a local level and a reduced impact at a global level.

Both from a fiscal and logistic point of view, the incrementality of development is of significance. Whilst it may take months or even years to replace CH section by section, the implementation of micro CHP can be achieved in a matter of hours. Capital is tied up for less time prior to recovery and the benefits are immediate and obvious. Furthermore the impact in construction is also significantly reduced.

Operating costs

It should come as no surprise that the least capital cost option is the one most commonly implemented in the UK. Installation of conventional gas boilers either in individual homes, or serving flats on a block by block basis is a readily implementable and cost effective solution.

However, in order to evaluate the overall costings, the case study uses a life-cycle costing methodology which amortises CH over a 40 year period and individual boilers over 15 years. Additionally, external costs are internalised in the form of carbon taxation. However, even taking environmental costs into consideration, only the best CH schemes using high efficiency plant options can compete with the conventional gas boiler/grid electricity option. Even then a housing density and the large numbers of homes found only in central urban areas comes anywhere near this solution. In practice the distribution system needs to cost less than £1000 per home to be viable, representing only a few linear metres of heating pipe and implying almost continuous terraced housing.

MINIGEN MICRO TURBINE CHP UNIT

Confusingly the “micro-turbine” is actually significantly larger than micro CHP and is perhaps more appropriately termed “mini CHP” with an electrical output of 30 kW. Currently such units are expensive (around £1000/kWe) and have relatively low electrical efficiencies compared to larger turbines. However, anticipated capital and maintenance costs will enable them to compete effectively with gas engine units.

STIRLING ENGINE MICRO CHP

WhisperTech Stirling engine micro CHP unit with an output of 1kWe, 6 kWt. Currently available in diesel fired DC version for leisure applications. Expected commercial availability of AC version for installation in smaller family homes in 2002 at an installed price of 3000 euro.

Overall, a more cost effective solution than CH appears to be gas engine driven CHP installed in blocks of apartments, although the economics again break down as soon as housing density falls and a heat distribution network is required. Currently, the conventional solution of gas boilers and grid electricity remains the only economically realistic one for low density housing. Note that the study considers suitable technologies for homes with an annual heat demand of 20,000 kWh, so that the required housing density for better insulated homes will be even higher in order to compete economically. Indeed, it may be that, following thermal upgrade of the properties, the economic case for CH is less attractive.

The economic and environmental case for micro CHP is strong, but so far only field trial installations have been implemented. A number of potential technologies have been evaluated in the study, with two representative Stirling engine based units shown using manufacturers production cost and performance data. It should be noted that the Sigma (3kWe) unit compares favourably with lower efficiency units even though it is sized to meet the demands of larger family housing, and it is quite feasible that this unit could be used to provide heat and down as soon as housing density falls power to two or more households in the typical UK semi-detached home configuration. However, this is dependent on the commercial availability of micro CHP anticipated to be in early 2002.

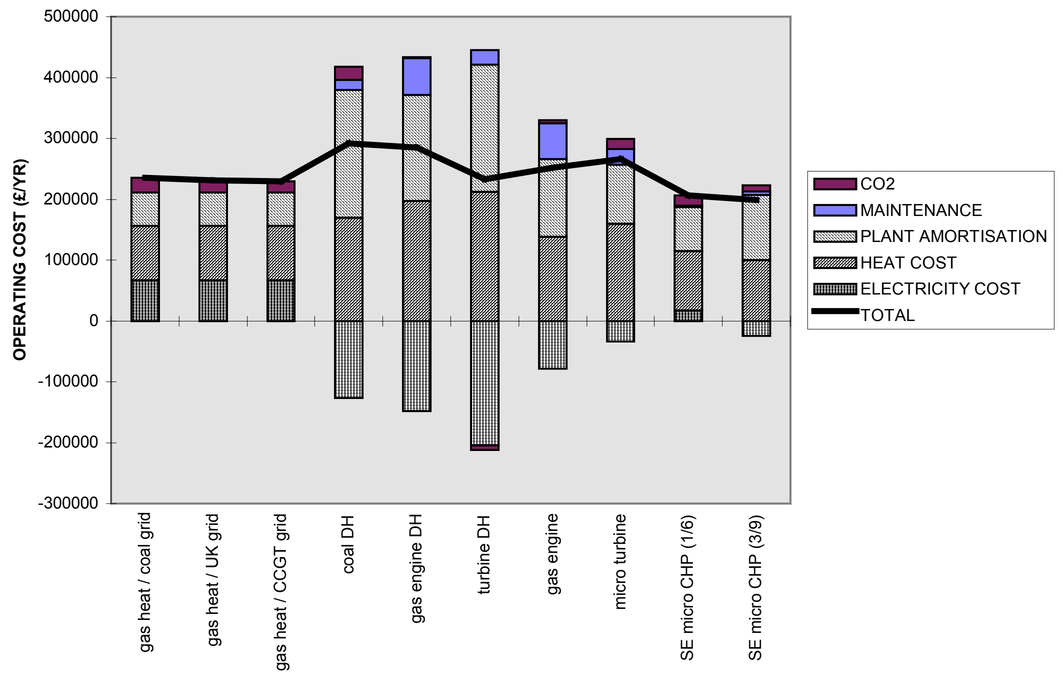
Environmental considerations
Advocates of CH would argue that the economic challenges are more than compensated for by the potential environmental benefits. It is perhaps disappointing that not only is this a debatable contention, but that in some configurations, CH actually results in a worse environmental impact than conventional solutions. The economic scenarios evaluated take account of CO_2 emissions in the form of cost per tonne based on calculated output; still CH is not significantly advantaged to alter the rankings. Indeed, the application of coal-fired CH compares unfavourably with the grid supply scenarios, whether UK average or CCGT. Only when compared with displaced central coal generating plant does it have a marginal benefit. This feature would be even more pronounced in other EU countries with lower average CO_2 in their generation mixes. So, although the conversion of primary fuel to useful energy is more efficient, the CO_2 emissions are actually higher. This raises the interesting question as to whether we should be more concerned with CO_2 or with depletion of finite fossil fuel resources.

Naturally, gas-fired CH schemes result in a lower level of CO_2 emissions, but not to the extent which might be expected. The substantial heat distribution losses (and a small electrical distribution loss), would tend to result in emissions reductions less than is the case for CHP in an individual block. It is only as a consequence of the lower heat to power ratios and the resultant high electrical generation (and therefore grid displacement) that the high efficiency gas turbine CH scheme has an apparently negative CO_2 emission. It is for the same reason (low heat/power ratio) that the 3kWe micro CHP unit results in a lower CO_2 production than the 1kWe unit as it produces significant electricity for export to neighbouring homes.

At the level of carbon tax envisaged in the evaluation, the gas turbine CHP/CH compares fairly evenly with the micro CHP solution in life-cycle economics. It would require significantly higher carbon taxes than currently envisaged to enable it to compete with block by block CHP solutions, particularly as production costs for micro turbines begin to fall.

Conclusion
Although the economics and applicability of technologies will vary considerably from scheme to scheme, in broad terms it can be concluded that CHP in conjunction with a distributed heat network will be limited to very high density housing areas in conjunction with large numbers of connections. Even for existing schemes, if the heat distribution network requires anything more than minor renovation, CH will have difficulty competing with other available technologies. High density, but smaller schemes may however, take advantage of block heating with CHP.

However, CHP will remain unattractive for the majority of UK housing until micro CHP systems become commercially available. At that time, economic and logistic considerations will make this the most cost effective and environmentally benign option for mass housing.



LIFE CYCLE OPERATING COSTS FOR RESIDENTIAL CHP TECHNOLOGIES