FORESIGHTING REPORT

Microgeneration

Investigating the global market for microgeneration and opportunities for Scotland to commercialise related technologies

For Members only

31st March 2006

V1.0

ITI ENERGY EXECUTIVE SUMMARY

In December 2005, ITI Energy decided to undertake a foresighting study into microgeneration. Although microgeneration was not identified as a top priority area in ITI Energy's initial foresighting activity, the decision to perform this study was driven by the fact that:

- ITI Energy had received a number of interesting proposals for investment which required us to take a considered view of the market demand for, and readiness of, microgeneration technologies;
- The need for ITI Energy to focus its portfolio of investments around the emerging clusters.

As such ITI Energy commissioned Delta Energy and Environment, widely respected in the microgeneration industry, to perform an objective study of the potential for technology development in this area. We asked Delta three key questions:

1. Is the scale of the microgeneration technology / market opportunity sufficiently attractive for Scotland to aim to become a leading global player?
2. Is there (scope for) Scottish capability in microgeneration that can compete globally?
3. Is there a role for ITI Energy in the microgeneration sector? In particular, is further technology development a key requirement and, if so, is there a funding gap?

The results of their work is set out in the next chapters. We believe that this report provides a good overview for ITI members that are already active in the sector or that are interested in entering into the microgeneration industry. Indeed with this report we aim to:

- Provide a structured analysis of market needs and technology opportunities
- Present conclusions to ITI members for their review and input
- Catalyse further discussion and development of focused project proposals

ITI Energy has taken on board Delta's analysis and their conclusions and recommendations. After consideration of these and further internal deliberation ITI Energy concludes that:

Overall, microgeneration is not a top priority for ITI Energy to focus its investment attention, relative to other areas like mature oil and gas, energy storage, offshore renewables and power management.

This is mainly because:

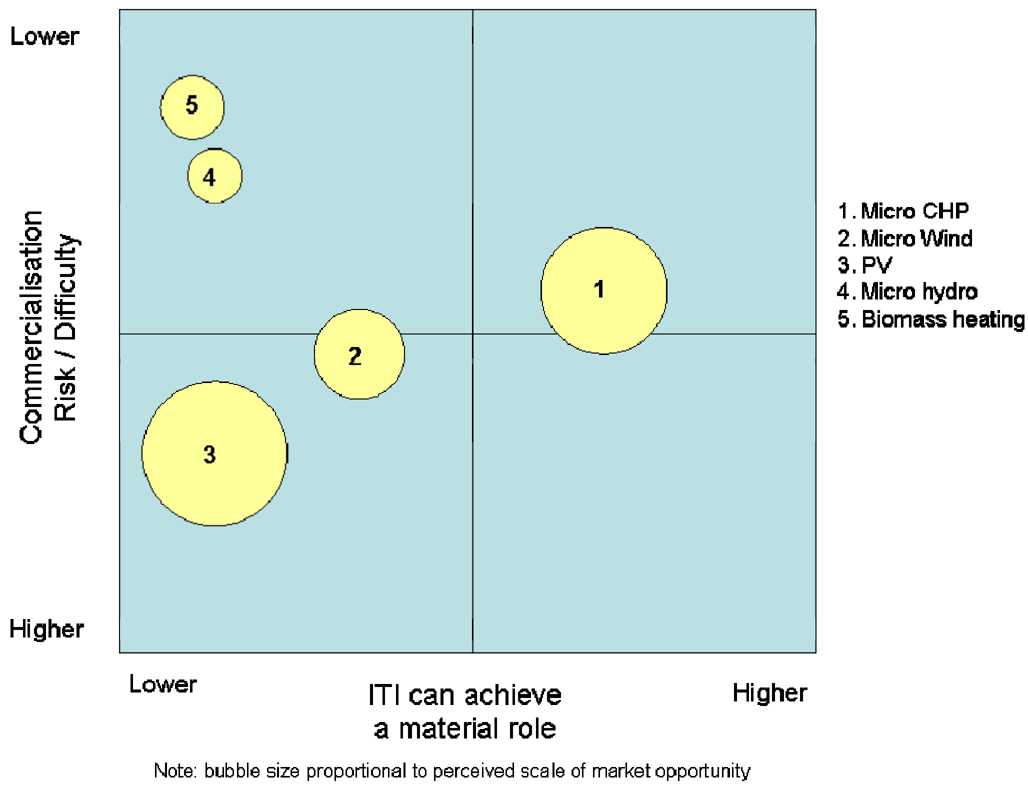
a. Current market scale is small
b. Commercially viable market scale is only expected to be achieved in 10-15 years from now and there are significant barriers that still need to be overcome
c. Microgeneration has to be able to compete directly with existing generation sources, particularly for applications in the home.
d. Scotland does not have the depth of R&D expertise or scale in this area at present from which to develop a globally competitive industry.

However, specific proposals for investment, especially for off-grid applications, can be of interest where:

a. Globally competitive Scottish capability can be found or built, particularly if it can be combined with capability in other clusters (e.g. electro-chemistry), and
b. There is a clear market opportunity in the next 5-10 years, and
c. Technology development is a key enabler for market success.

For each microgeneration technology, ITI Energy's view can be summarised as follows:

- **Micro CHP**: although this is a highly competitive market, with existing products and with new alternatives, there is scope for new technologies, either as niche solutions, or as a significant better alternative, where Scottish capability can be leveraged or built. Selective investment should be considered in fuel cells, engines, or in new technologies.
- **Micro wind**: technology development is not seen as the key enabler for market adoption.
- **PV**: the current market is driven by government grants. Only fundamental technology developments can realise the cost-of-electricity improvements that are required. Therefore, PV is too far away from a commercial market and there is only limited Scottish capability.
- **Micro hydro**: this technology is mature. Applications and market size are limited.
- **Biomass heating**: the base technology is mature, but maybe there are some possibilities for improvements in the fuel supply chain. Scotland would need to build capability to be globally competitive.



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ACKNOWLEDGEMENT

ITI Energy wishes to thank Delta Energy and Environment for their dedication and hard work in conducting this foresighting study and in developing this report.

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DELTA EXECUTIVE SUMMARY

Microgeneration systems provide power to homes and other small energy users. Markets may grow rapidly (possibly very rapidly) over the next fifteen years, albeit from a current very small base. However there are major uncertainties about the rates of growth of these markets and how large they may ultimately become. There are also potential show-stoppers that may prevent mass markets from emerging.

A range of microgeneration technologies, occupying a small number of very niche markets, are currently commercially available and relatively mature. These are micro-hydro systems; photovoltaic systems; (non-building mounted) wind turbines; micro-CHP units designed for multi-family homes and small businesses; and residential biomass heating systems.

There is potential for microgeneration sales to grow rapidly as a new breed of products, being developed for mass-market applications, are commercialised. One of the major uncertainties affecting market growth is the speed (or otherwise) of new product commercialisation. Timelines for commercialisation generally only move in one direction – backwards - and developers often encounter problems and issues they had not anticipated.

Micro-CHP products – covering a number of technologies, including fuel cells - are being developed with the target of penetrating the mass residential boiler and furnace market. Micro-wind products, which can be manufactured at relatively low cost, are being developed to be mounted on buildings, potentially opening up new markets on a very large scale. Continued technology development for photovoltaic systems, together with increasing levels of national support programmes, is likely to ensure continued strong rates of growth in that sector. The high volume opportunity for micro-hydro systems is primarily for locally manufactured low cost units in developing economies.

Market Projections

Under Delta’s strong growth scenarios, annual global market sales in 2020 could be over 2.5 million micro-CHP units, over 0.3 million micro-wind units, and just under 10 million PV systems. Some organisations forecast even stronger growth. This scenario – perfectly plausible but by no means certain - assumes that a range of key factors will work in favour of microgeneration, including positive regulatory and policy developments, utility engagement in developing microgeneration markets, escalating electricity prices and successful product commercialisation, performance and cost reduction. To some degree, there are already emerging indications that most of these developments could take place.

Delta’s moderate growth scenario give 2020 worldwide markets at 0.7 million micro-CHP units and 0.1 million micro-wind units, with PV markets of possibly just a few million units or less a year. This assumes both less and slower progress in the key factors identified above.

If potential show-stoppers – principally the failure (in the case of micro-CHP and micro-wind) to develop reliable low cost products, an unhelpful policy environment, and lack of any significant market push by utilities – manifest themselves, market sizes could be considerably smaller than this. Micro-wind market growth in particular is still subject to some significant uncertainties in performance.

Technology Requirements

Technology development remains a key requirement for photovoltaic mass markets to widely occur, and for a number of micro-CHP technologies including fuel cells, pico-turbines and, to a lesser degree, Stirling engine and Rankine cycle systems. Some micro-wind product developers targeting mass-market (building mounted) applications have not yet commercialised their products, but believe that fundamental technology challenges have been overcome. For some micro-CHP companies, and some micro-wind companies, a critical short term challenge is one of establishing volume production rather than overcoming fundamental technology challenges, although product engineering issues may still need to be addressed.

Whilst technology developments are still expected in the micro-hydro and residential biomass heating sectors, in most cases these are likely to lead to incremental improvements in performance rather than major jumps forward.

Opportunities for ITI Energy

The emergence of microgeneration does offer opportunities for ITI Energy, although due to the uncertain rate of market development and future market size, these opportunities come with notable risks. One advantage for ITI Energy is that the UK may well be – initially at least – one of the fastest growing markets for micro-wind and micro-CHP, giving advantages to technology developers based in the UK.

Micro-wind stands out as one area where Scotland has potentially globally competitive product developers/manufacturers, and opportunities to stake out a global leadership position. However for two of these companies the major challenge is one of product commercialisation and volume manufacturing, rather than fundamental technology development. Most emerging micro-wind product developers are relatively small companies, with a number likely to need investment in order to exploit mass market opportunities. The uncertainties about micro-wind product performance should become far clearer within the next 2-3 years, but is currently an important risk factor.

Micro-CHP brings opportunities through two Scottish fuel cell developers, with technology that may be able to compete globally. However the micro-CHP product development landscape is extremely competitive, both within fuel cell developers and between different micro-CHP technologies. Other opportunities may exist to attract micro-CHP product developers, still with key technologies issues to address, to Scotland. Although micro-CHP markets may grow rapidly in the short-term, the market should be able to absorb new products and technologies that come to market in the future. Opportunities may also exist to bring micro-CHP manufacturing to

Scotland for products that have overcome many of their key technology challenges, provided manufacturing costs are internationally competitive. Developers of micro-CHP technologies and products consist of a range of scales, from multi-nationals through to start-ups that are likely to require investment.

As long as subsidy programmes for PV remain in place and expand as the PV industry expects, then it is likely to continue to represent the largest microgeneration market in the period up to 2020 – possibly by some way.

This market is dominated by some large well-capitalised companies. However given that further technology development is required, opportunities may arise for companies able to compete globally in this area. Whilst there is perhaps only one Scottish organisation that falls into this category, potential may exist to pull such technology development to Scotland. However the ability of Scotland to compete globally in new technology development requires further investigation.

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INTRODUCTION

This report provides an assessment of the microgeneration sector. It specifically aims to address the following questions:

Is the scale of the microgeneration technology / market opportunity sufficiently attractive for Scotland to aim to become a leading global player?

Is there specific Scottish capability in the microgeneration sector that can compete globally; and, if so, how can this be achieved, and with what specific products?

Is there a role for ITI Energy in the microgeneration sector? In particular, is further technology development a key requirement and, if so, is there a funding gap?

Delta would like to thank all organisations and individuals that have shared their time to discuss their views and thoughts with Delta. In particular Delta would like to thank IT Power with regard to their contribution on micro-hydro issues.

1 DEFINITION OF MICROGENERATION

1.1 Mass market potential

The investor appeal of microgeneration relates greatly to its potential for mass market uptake in residential and small commercial markets. It is this criterion that Delta is using as the basis for its definition of microgeneration. For the purposes of this report, therefore, Delta will assume that microgeneration includes power generation systems up to 10 kWe (kilowatt electrical), for mass-market residential and small commercial applications. Beyond this limit, and even arguably in the 5 kWe to 10 kWe range, products are much less relevant for mass markets. Delta's definition excludes heat-only systems.

Microgeneration therefore includes:

- Micro-CHP, with a number of prime mover technologies that include:
- Stirling engines
- Reciprocating engines
- Rankine cycle engines
- SOFC and PEM fuel cells
- Picoturbines.
- Micro-wind systems.
- Photovoltaics.
- Micro-hydro systems.

ITI has also requested that brief information on small (residential-size) wood-based boiler systems are included in this report; however other heat-only technologies (such as heat pumps and solar water heating) are excluded.

The report goes into greater detail for micro-CHP and micro-wind, for which there is less public domain information currently available. Less detail is provided on PV, micro-hydro and wood-based boiler systems.

The geographical focus of the report is Europe, Japan and South Korea, and North America. These are the regions that Delta believes show greatest mass market potential for micro-CHP systems, at least in the period up to 2020, the timeframe addressed by this report. In the longer term developing country markets may provide strong markets for both micro-wind and PV systems, and may well provide near and medium term opportunities for locally manufactured micro-hydro systems. However mass market microgeneration technologies will depend on success in the markets identified above.

1.2 Other definitions

The criteria adopted by Delta, is in general validated by others:

- The Micropower Council, a UK trade association, defines microgeneration as "the production of energy on the smallest of scales, for individual buildings or communities". It includes micro-CHP, micro-wind, two forms of solar power, ground source heat pumps and fuel cells.

- The UK Government, in its June 2005 consultation, defined microgeneration as "the production of heat and/or electricity on a small-scale (homes and small commercial developments / public sector buildings).

- Ofgem, the UK electricity and gas market regulator, which refers to 'domestic-scale microgeneration' regards the definitions in the UK Energy Act of 2004 and the EU Cogeneration Directive, both of which have thresholds of 50 kWe, as inappropriate because "these definitions embrace generating plant too large to be used in a domestic or small-business setting".

- COGEN Europe's Micro-CHP Working Group defines micro-CHP as less than 20 kWe, but it is acknowledged that the mass market is for systems smaller than 5 kWe.

- The CENELEC Draft European Standard on the interconnection of microgeneration to electricity systems, prEN50438, defines microgeneration as less than 16 Amps per phase. This is equivalent to 3.5 kVA (between 3.1 and 3.5 kWe depending on the power factor) for a single phase connection, which is normal for the domestic market.

2 MICROGENERATION TECHNOLOGIES

2.1 Summary

This section reviews and describes the microgeneration technologies, and covers their main applications.

Micro-CHP products, the principal focus of this section, can be broadly categorised into two groups:

Mass-market products, designed to replace boilers for single-family homes. These are typically sized at around 1 kWe.

Products designed for multi-family homes and small commercial buildings. These are typically sized between 5 kWe and 10 kWe electrical output. These are sometimes known as mini-CHP products. The total market opportunity for these products is considerably smaller than for the lower capacity size range.

Of the technologies summarised in this section, pico-hydro systems stand out as having a heavily constrained capability for mass market application in the principal regions assessed for this report, given its requirement for specific hydro resources close to the residential consumer.

With micro-CHP, micro-wind and PV, however, such constraints are relatively insignificant. The growing availability of natural gas and the almost universal availability of wind and light provide these systems with a clear potential to secure mass market take-up.

There are other constraints, however:

In the case of fuel cell-based micro-CHP (with high power-to-heat ratios), the fact that natural gas is a non-renewable resource, subject to significant price uncertainty, is an important issue and is addressed below in the section describing 'Commercial Drivers'. For these products also, the current state of technological development, several years from widespread commercialisation, is also a constraint.

The performance of rooftop-mounted micro-wind technologies in real-life conditions is an uncertainty. Load factors are unlikely to often exceed 20%, and in some cases will be less than 10%. The relative simplicity of micro-wind systems, however, indicates that technological development will not be a constraint on market uptake.

Given the sophisticated nature of the technology PV capital costs remain extremely high and the economic unfavourable, although market growth may be supported by widening policy incentives, or through further technological breakthroughs.

These issues are addressed in later sections of the report and will be reflected in the market projections.

2.2 Micro-CHP - Technology Summary

Table 1 below summarises the main features of the micro-CHP prime mover technologies described in the report. The performance data presented principally represents current proven performance for commercially available units or prototypes as reported by product developers. Data for picoturbines – and for the higher end of the Rankine cycle and Stirling engine ranges – is based on projected rather than current performance.

Several of the technologies are also able to utilise a wide range of fuels, for example Stirling engines. In terms of the potential for mass market application, however, the capability to use natural gas is the key requirement, as indicated in the table.

Table 1 – Micro-CHP technology summary

Micro-CHP technology	Principal fuel	Electrical efficiency (%)	Power/heat ratio	CHP efficiency (%) based on gross calorific value
Stirling engine	Natural gas	10 – 25	1:3 – 1:8	Up to ~90
Rankine cycle	Natural gas	9 – 18	1:4 – 1:9	Up to ~90
Reciprocating engine	Natural gas	20 – 29	1:2 – 1:3	Up to ~90
PEM Fuel cell	Reformed natural gas	27 – 34	1:1 – 1:2	Up to ~85
SOFC Fuel cell	Reformed natural gas	28 – 45	1:1 – 1:2	Up to ~85
Pico-turbine	Natural gas	10 – 20	1:4 – 1:7	Up to ~90

(Delta Energy and Environment)

The ‘pros’ and ‘cons’ of the various technologies are summarised in Table 2 and highlights the advantages and disadvantages relative to each other rather than to other microgeneration technologies.

Table 2 – Advantages & disadvantages of Micro-CHP technologies

Technology	Advantages	Disadvantages
Stirling Engine	Low maintenance (in theory no more than a boiler) due to hermetically sealed unit. Low noise (constant rather than pulsed combustion), although vibrations must be controlled. Low emissions. High overall efficiency. Multi-fuel capability (external heating), including solar and biomass.	High heat-to-power ratio – therefore unsuitable for households with very low heat demands. Length of start up time. High mass as thick walls needed due to higher pressure of working fluid.
Reciprocating Engine	Higher electrical efficiency than Stirling and Rankine Cycle engines. High reliability, mature, well-understood technology.	Relatively high vibrations require support and shielding to reduce acoustic noise. Requirement for periodic oil and component changes increases O&M costs over a boiler. Emissions control adds to cost.
Rankine Cycle Engine	No maintenance costs for some products under development. Typically comprise low cost components, most of which have proven reliability. Low noise and emissions. High overall efficiency.	High heat-to-power ratio – therefore unsuitable for households with very low heat demands. .

Table 2 Continued – Advantages & disadvantages of Micro-CHP technologies

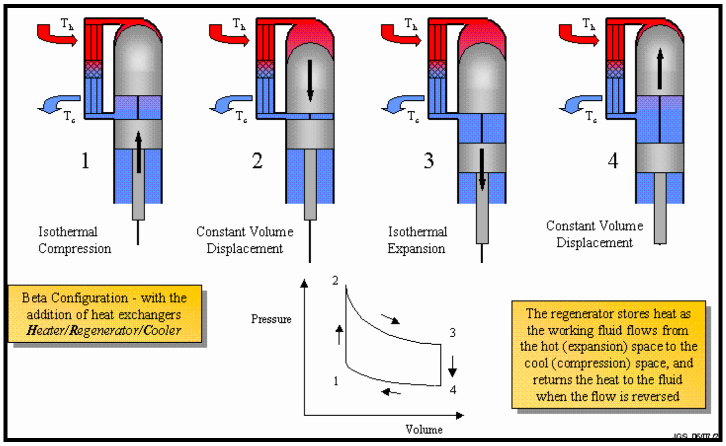
Technology	Advantages	Disadvantages
Fuel Cell	High electrical efficiency (30 to as much as 45%) under varying load. Low emissions Low noise: no moving parts (except fans).	Complexity of design - requirement to reform natural gas (some developers will use internal reforming) and inverters for power conversion. Likely lower overall efficiencies compared to some other micro-CHP technologies. Significant remaining challenges to demonstrate acceptable lifetime, reliability and competitive cost for micro-CHP applications.
Pico-turbine	Relatively straightforward integration into conventional boiler technology (replacing the burner). Lightweight. High overall efficiency.	Relatively low electrical efficiency. Early stages of product development.

(Delta Energy and Environment)

2.3 Micro-CHP - Stirling Engines

The Stirling engine is an external combustion engine allowing, in theory, for a range of fuel sources such as natural gas, biomass or solar energy. This energy source flexibility is one of the underlying advantages of Stirling engines. The heat supplied to the engine causes the working fluid (typically nitrogen, helium or hydrogen) to expand, moving the piston. The fluid is transferred into a cold zone of the engine where it cools, contracts, is recompressed by the working piston, and transferred back to the hot region of the engine and the cycle continues. Figure 1 illustrates the basic structure of the engine.

Figure 1 – Stirling engine schematic



(Source NASA Glenn research)

There are two types of Stirling engine. Linear free-piston engines use the working gas to create linear vibrations of a piston, whereas kinematic Stirling engines drive a crankshaft resulting in a rotating motion. In both cases the motion drives an alternator.

The noise created by a Stirling engine is considerably less than other technologies due to the low number of moving parts and the absence of internal combustion. The Stirling engine unit is typically hermetically sealed for life, and therefore maintenance free.

2.4 Micro-CHP – Reciprocating Engines

The operation of reciprocating engines, a well-established and proven technology, is based on the same principles as petrol and diesel automotive engines. They operate at mid-range electrical efficiencies (when compared to other micro-CHP technologies) and currently account for virtually all sales of CHP units of under 10 kWe.

Figure 2 – Stirling Engine Micro-CHP Systems: Senertec (Left) and Honda/Ecowill (Right)

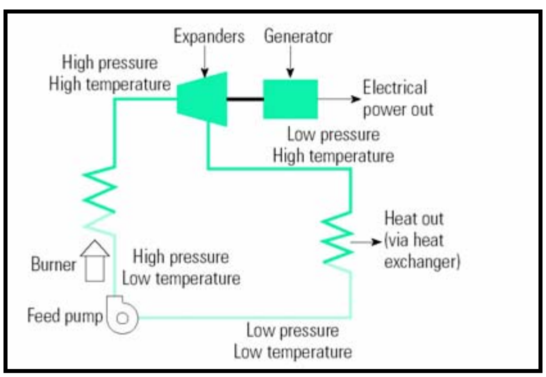
(Source Senertec and Osaka Gas)

These small-scale engines are specifically designed for CHP applications ensuring long running hours between maintenance (3,500 to as long as 10,000 hours), low emissions and improved electrical efficiencies – when compared to non-CHP engines in this size range. Viable engines, both technically and economically, in this smaller range have now become available from a number of manufacturers.

2.5 Micro-CHP - Rankine Cycle Engines

A pressurized working fluid is heated to a high temperature and produces a hot vapour (see Figure 3). This is then passed to an expander, which converts some of the energy in the working fluid to kinetic energy, which is used to drive a generator. During this process, the temperature and pressure of the vapour falls.

Figure 3 – Rankine Cycle Engine



(Source Platts)

The vapour then passes to a condenser and, for micro-CHP applications, a domestic hot water heat exchanger - a simple device that recovers heat and passes it on to the home at the appropriate temperature. The working fluid condenses at this stage and is re-injected - using a feed pump - at relatively high pressure to the hot end. The

Rankine cycle is a closed one - the working fluid is totally recycled, although the fluid changes phase during operation.

Some developers are using a scroll expander to generate mechanical energy. Compared with piston engines, these offer the advantages of low noise, low vibration, and fewer moving parts - for example, no valves are required. Other expanders include a free-piston engine and a reciprocating engine. Working fluids are either water/steam or an organic refrigerant. Some units are planned to be hermetically sealed, whereas others require lubrication and therefore periodic maintenance.

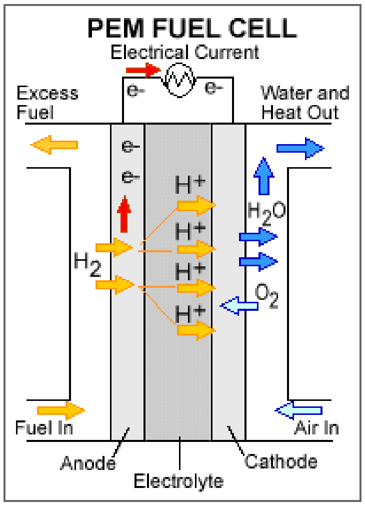
2.6 Micro-CHP – Fuel Cells

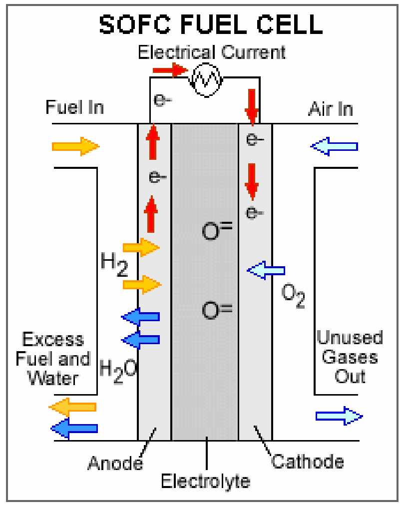
Fuel cells use the chemical energy created upon the oxidation of hydrogen (and in some cases carbon monoxide) to produce heat and electricity with a by-product of water. For natural-gas fuelled micro-CHP applications, a reformer is required to convert natural gas into a usable fuel. Inverters are used to convert the low voltage direct current output into higher voltage alternating current outputs.

Although fuel cells all operate on the same principle, there are many different types distinguished by differing chemical reactions. For micro-CHP applications, proton exchange membrane (PEM) fuel cells and solid oxide fuel cells (SOFCs) are of most relevance. Alkaline fuel cells (AFCs) have been pursued by some developers, but stringent reforming and gas clean-up requirements have led to decreased interest in this technology for micro-CHP applications.

PEM fuel cells and SOFCs can also be distinguished by their operating temperatures and reforming requirements. PEMs operate at less than 100oC (although PEMs which operate at up to 180°C are currently being developed) and require carbon monoxide to be removed from reformed natural gas. SOFCs, on the other hand, operate at temperatures typically between 500°C and above 800°C, but have less stringent natural gas reforming requirements.

Figure 4 – PEM and SOFC Fuel Cell schematics





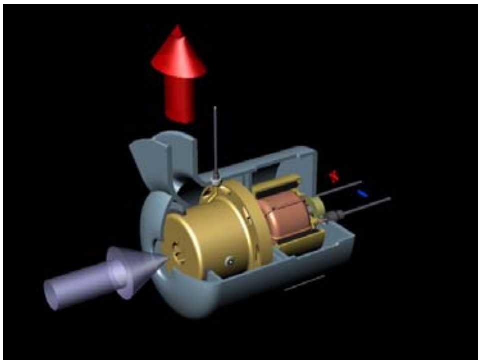
(Source: U.S. Department of Energy)

Low temperature systems have the advantage of rapid start and ability to rapidly modulate output, whereas the high operating temperature of SOFCs typically leads to much longer start-up and shut-down periods. SOFCs have the advantage of higher electrical efficiency than PEM fuel cells.

2.7 Micro-CHP - Picoturbines

A new technology for micro-CHP applications has recently emerged. The MTT picoturbine (not to be confused with microturbines for commercial applications, with typical outputs of 25 – 250 kWe) is aiming for an output range of 0.6 - 3 kWe, and is the sole publicly-disclosed product under development in this micro-CHP technology group. MTT envisages that the picoturbine will become a key component as a burner in residential boiler systems. The three principal components, compressor, combustor and turbine, can be held in the palm of a hand. Figure 5 shows a schematic of the micro-CHP system.

Figure 5 – Picoturbine-based Micro-CHP



(Source MTT BV)

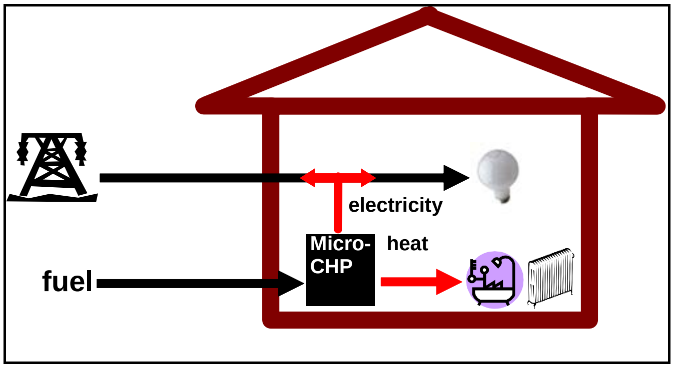
2.8 Micro-CHP – Applications

With its capability of generating useful heat, the key application for micro-CHP is the boiler / furnace replacement market for existing single and multiple unit homes and, to a lesser extent (because of the smaller market opportunity), for installation into new residential buildings.

The operation of a micro-CHP unit is schematically shown below. It provides all of a home's thermal (domestic hot water and space heating) needs, in nearly all cases by including a supplementary burner alongside the micro-CHP unit. Typically between one quarter and half of a household's electrical needs are met by the micro-CHP unit, with a proportion of the electricity generated usually exported back to the grid.

Some types of micro-CHP units will be able to continue to operate when the grid fails (without re-energising the grid), whereas others (some types of reciprocating engines, Stirling engines and Rankine cycle engines – depending on the type of generator used) will not. Importantly, this will enable boilers or furnaces to keep operating, as well as powering a limited number of lights and appliances.

Figure 6 – Applications of Micro-CHP



(Delta Energy and Environment)

An alternative vision for micro-CHP is for it to meet all of a home's electrical needs, eliminating the need for a grid connection. This will involve an electrical storage system due to rapid variations in household electricity demand. For grid-connected homes, the complexities of electricity storage and the very high levels of reliability required mean that such applications are unlikely to be seen within at the least the next ten years and probably much longer.

There is, however, a niche market for off-grid homes for such applications. North America in particular has a large number (in the region of 200,000) of off-grid homes (varying from large ranches in remote areas, to rustic hunting shacks). This is a potential market for micro-CHP systems, and some fuel cell developers are investigating this potential. Micro-CHP will, in these cases, typically compete with diesel generators, PV systems, and small wind turbines.

Providing Back-Up Power

The ability to provide electricity when the grid fails is one potential selling point for microgeneration. Attractive though this feature sounds, in practice providing this capability is not straightforward – for a number of reasons, including:

Mass market microgeneration products are typically sized to produce around 1 kW. Whilst this is sufficient to meet a home's base-load electrical requirements, it will not meet the peaks (several kW or more) that occur when several electrical appliances are on at the same time.

Some microgeneration products typically don't run continuously – micro-wind only produces power when the wind blows and most micro-CHP units only run when the waste heat can be used. There is no guarantee it will be windy when the grid fails, and if micro-CHP units are to run, either a use needs to be found for the waste heat, or the heat must be "dumped".

Some microgeneration products use induction generators, which require external power to start running. When the grid fails, all microgeneration units must stop running and disconnect from the grid. Some will not be able to start without an external power source.

In order not to re-energise the grid, either a transfer switch will be needed to enable household electricity circuits to be powered from the microgeneration unit rather than the grid, or appliances will have to be directly plugged in to microgenerator.

Provision of back-up power is – in many product developers and vendors eyes – not a key market requirement. Some micro-CHP product developers plan to include it as an optional extra, with a key selling point being the ability to provide power to heating systems to enable them to operate during grid-failures in winter.

There are some important differences between the technologies, some of which have implications for their prospects for application on a large-scale, and/or the way in which they will operate. For example a low-electrical efficiency Rankine cycle unit may operate for just 2,000 hours a year in some homes, operating in a very similar manner to a conventional boiler. A high-electrical efficiency solid oxide fuel cell, on the other hand, may run continuously for much of the year, either shutting down in the summer months or modulating its output down and trickle-heating a hot water storage tank.

The main variations between the different technologies that relate to their application are as follows:

- Heat-to-power ratios. This is important since the longer a micro-CHP unit operates, the more electricity it generates and the better its economic performance (although there are some issues about gaining attractive value for electricity exported to the grid). Technologies with higher heat-power ratios (most Stirling engine and Rankine cycle products) will usually run for less time to meet a given thermal demand, resulting in less electricity generated. This is not an issue in homes with medium to high thermal demands, but trends towards greater residential sector thermal efficiency will tend to favour the latter over time, although the replacement cycle of stock of existing poorly insulated homes, particularly in the UK, is very long.

- Output modulation and response time. Some types of solid oxide fuel cell can take several hours to start-up and shut-down. Most other technologies can start-up and shut-down in a matter of minutes, although Stirling engines take a little longer. Some technologies are well suited to modulating their output, enabling them to optimise their operation economically as well as in meeting household energy requirements.

- Maintenance requirements. Stirling engines and some Rankine cycle engines are likely to have – if developers' targets are reached - low, or no, maintenance needs, apart from the burner used to supply the heat to the system. Reciprocating engine – and possibly fuel cell requirements are likely to be higher, adding to overall costs.

In terms of non-stationary applications, PEM fuel cells have major global market potential in the automotive market, though not in the short-term. Niche markets exist (or may be developed) for other technologies. These are not elaborated here – beyond the box below – given the focus on the mass market opportunity for stationary power generation.

Early Market Non-Residential Applications

Although this report focuses on residential mass markets, other markets exist or could be developed for microgeneration technologies. Developers and manufacturers are pursuing different strategies in this regard. Some are focusing purely on the large, high volume mass market opportunities. Others are initially targeting smaller non-residential niche markets, which often have less stringent product requirements and can command higher prices. Some examples follow.

Some PEM fuel cell companies provide an excellent example of this strategy. Companies such as Plug Power, IdaTech, ReliON and Ballard are all likely to ultimately target micro-CHP applications, but have all seen an opportunity in providing back-up power to telecommunications companies for their transmitters. Conventionally, these companies have used batteries as a source of back-up power, but batteries require periodic maintenance. By providing hydrogen cylinders feeding PEM fuel cells, maintenance requirements can be reduced. By using hydrogen and only operating for limited hours, the PEM fuel cells meet requirements for these markets even though they are still a number of years away from cost-effective meeting requirements for micro-CHP applications.

Auxiliary power units (APUs) are another early market opportunity. Whisper Tech, the Stirling engine developer spotted an opportunity in providing power to top-end yachts, where noisy diesel engines where typically used to charge batteries. They started selling units, which are much quieter than diesel engines, into this market long before they had fully developed their unit to meet more stringent micro-CHP applications. Small wind turbine manufacturers have also been selling into this – and the telecommunications market – for a number of years.

Other APU opportunities exist in the leisure vehicles market (caravans), trucks, and aircraft. All of these systems can generate power from the primary engine, but often require power when the engine is switched off for onboard electrical systems. Major automotive components supplier Webasto is developing fuel cell technology specifically for such applications.

Trucks and buses often use heating systems to either supplement the waste heat available from the engine, or to heat the vehicle when the engine is off (or to save idling the engine to heat the truck). This market is being targeted by developers of both fuel cell and pico-turbine technology, and could be as large as hundreds of thousands of units a year.

2.9 Micro-Wind Systems

The principles underlying the micro-wind technology are straightforward. Wind turbines convert the kinetic energy of wind to mechanical energy using a rotor, which is then converted to electrical energy via a generator. Micro-wind turbines can be used to charge batteries in remote off-grid applications or can be grid-connected (using an inverter) to offset electricity consumption. Micro-wind products are available in a wide range of sizes starting at 0.1 kWe.

Figure 7 – Micro-Wind products

(Source Renewable Devices (left) and Proven Energy (right))

The main parts of a wind turbine installation are:

- The mounting system. Micro-wind systems can be fixed either on a stand-alone basis (the pole on which they are mounted is fixed to the ground) or rooftop-mounted (the pole is fixed to the side of a building with brackets and vibration isolators). Rooftop mounted varieties are not suitable for all types of building (for larger systems) given the strength of the fixing required to avoid vibration. Virtually all systems currently installed are stand-alone.

- The turbine. This can be of vertical orientation (in which the turbine spins in a perpendicular orientation to the wind) or of horizontal orientation (parallel to the wind).

- Generator.

- The inverter.

Wind turbines in the range covered in this analysis (up to 10 kWe) produce ‘wild’ AC current (of variable voltage and frequency) that is converted to DC, and then ‘normal’ AC current (in the UK 230V, 50Hz) by inverters, as with PV for grid connection.

The economics of micro-wind turbines are critically dependent upon real-life load factors and the degree and impact of turbulence that occurs over roofs. Research and product testing is ongoing in this area.

Lifetime is still an uncertainty; both the Energy Saving Trust and Renewable Devices suggest around 20 years and some products already on the market (not designed for the mass market) are expected to last for a similar timeframe.

Table 3 – Advantages & disadvantages of Micro-Wind Turbines

Advantages	Disadvantages
Zero carbon emissions. Relatively simple design. Can potentially benefit from renewable energy incentive programmes.	Uncertain load factors. Not all buildings are suitable for rooftop mounting. Planning permission issues may add cost or limit market. Must produce very low noise levels.

(Delta Energy and Environment)

Micro-Wind Applications

Small scale applications range from:

- Individual battery charging systems (less than 600 We) for off-grid applications, recreational use (caravans, boats), remote telecommunications needs and street lighting.
- Grid connected systems for homes (1.5 – 3 kWe) or larger buildings, including schools or community halls (5 – 6 kWe). These can be:
    - Standalone pole mounted, or
    - Building-mounted (the mass market application).

Micro-wind is well-suited to meeting off-grid needs, for which there is more interest in North America than there is in Europe or Japan, and significant activity in China and some other emerging markets. A diesel-wind hybrid arrangement, where the former is used during periods of low wind speed, can give greater all round efficiency and flexibility in such applications.

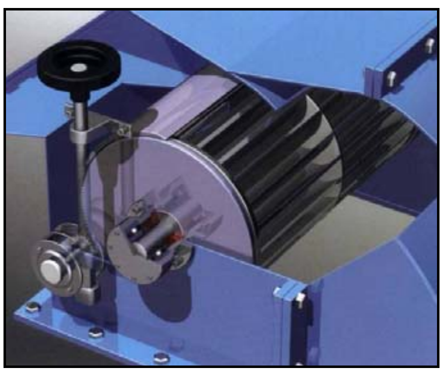
2.10 Micro-Hydro Systems

Micro-hydro schemes are conventionally defined as having outputs of 5 – 100 kWe, while pico-hydro schemes are below 5 kWe. The principle of operation for these, like larger hydro systems, is simple: they convert potential energy stored in water held at height to kinetic energy (or the energy used in movement) to turn a turbine that produces electricity. Improvements in small turbine and generator technology mean that micro and pico-hydro schemes can be an increasingly attractive means of producing electricity in certain situations.

There are various types of turbine, the choice of which will depend mainly on the pressure head available and the design flow for the installation. An impulse turbine converts the kinetic energy of a jet of water in air into movement by striking turbine buckets or blades. The blades of a reaction turbine are totally immersed in the flow of water, and the angular as well as linear momentum of the water is converted into shaft power.

The cross-flow turbine shown below is a reaction turbine, suitable for low-head sites.

Figure 8 – Cross-Flow Pico-Hydro Turbine



(Source IT power)

Table 4 – Advantages & disadvantages of Pico-Micro-Hydro systems

Advantages	Disadvantages
Zero carbon emissions. Can potentially benefit from renewable energy incentive programmes. Long life-times, in excess of 50 years.	Non-standard installations, with cost and performance being highly site specific. Limited to sites with appropriate resource. Potential environmental concerns, for example with fish.

(Delta Energy and Environment)

Micro-Hydro Applications

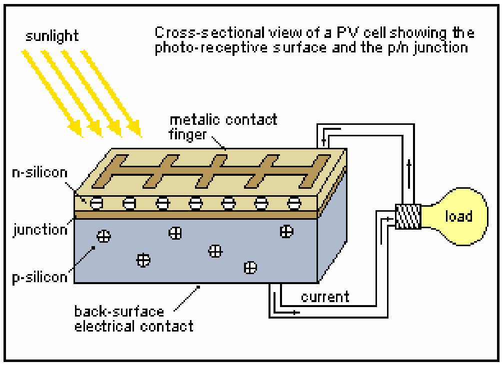
By far the greatest opportunity for pico-hydro systems are in developing countries, particularly those with tropical climates and mountainous terrain such as Nepal. Schemes can provide power for industrial, agricultural and domestic uses through direct mechanical power or by the coupling of the turbine to a generator to produce electricity. The many rural communities in such countries that have no, or insufficient, grid access and a suitable hydro resource represent a good market opportunity for locally produced, lower cost products that can be installed for around $1,000. The primary application is for electricity supply, with battery charging an important secondary need.

In OECD (Organisation for Economic Community Development) countries, with mature and extensive grid systems, the opportunity is marginal and the requirement is for a higher grade of product. There are a very small number of off-grid requirements, particularly in North America and Northern Europe. As electricity prices rise, there is now an emergent interest in small community-based grid-connected pico and micro-hydro systems resulting in a handful of sales, for example in the UK (where there may be no more than 10,000 sites where this scale of hydro is feasible), but the site-specific nature of these schemes prevents any mass market potential. In Japan, the Shinko Electric Company has developed a 0.5 – 1 kWe system for use in upland areas and by farmers with access to irrigation canals. They claim there is a potential demand of 3-4 GWe in Japan alone.

2.11 Photovoltaics

PV systems use cells to convert solar radiation into electricity. The PV cell consists of one or two layers of a semi-conducting material, usually silicon. When light shines on the cell it creates an electric field across the layers, causing electricity to flow. The greater the intensity of the light, the greater the flow of electricity.

Figure 9 – PV diagrammatic



(Source www.buildingsolar.com)

The three main types of solar cells currently available are:

- Thin Film. This is made from a very thin layer of semiconductor atoms deposited on a glass or metal base. This has a typical efficiency of around 7%.
- Polycrystalline. This is made from thin slices cut from a block of silicon crystals. This has a typical efficiency of around 12%.
- Monocrystalline. This is made from thin slices cut from a single crystal of silicon. This has a typical efficiency of around 15%.

Individual PV cells are connected together to form a module. Modules are then linked and sized to meet a particular load.

Figure 10 – Typical Domestic PV Installation

(Source Energy Saving Trust, UK)

Table 5 – Advantages & disadvantages of PV Systems

Advantages	Disadvantages
Zero carbon emissions.	Product efficiency remains low.
Can potentially benefit from renewable energy incentive programmes.	Load factors in many countries can be low, reducing competitiveness.
Silent operation.	Despite year-on-year reductions, costs remain high.
High opportunity for standardised installation.	
Can be used on an extensive range of buildings and integrated in building structures.	

(Delta Energy and Environment)

Photovoltaic Applications

PV can be used for most types of building with a roof (provided it is sufficiently strong to hold the significant weight of the panels) or a wall that faces within 90 degrees of south (in the northern hemisphere), as long as no other buildings or large trees overshadow it. If the roof surface is in shadow for parts of the day, the output of the system decreases and so, in general, the load factors increase in regions that have higher sunshine levels and that are closer to the equator. Given the scope for PV to be used on a wide range of buildings, there is (in principle) a very high potential for PV application, both in OECD countries (both grid connected and, mainly in N. America, off-grid) and developing countries, where there is significant potential for off-grid systems.

More sophisticated, as yet small, applications are also emerging[1]. Rooftop systems are, in essence, modules attached to the roof. Building-integrated modules, however, can also serve other, more aesthetic, functions as, for example, PV facades, roofs, shadowing elements and other parts of the building. In these cases, the module serves not only as a source of electricity but can provide roof sealing, thermal insulation and sound protection.

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[1]Source European Photovoltaic Industry Association. EPIA Roadmap, 2004.

2.12 Biomass- Fuelled Residential Heating Systems

Residential biomass heating systems, fuelled by wood pellets, are rapidly gaining in popularity in parts of central Europe, Scandinavia and Italy. There are essentially two types of systems:

- **Stoves:** these are best described as room heaters. With a glass panel showing an aesthetically pleasing flame, they are typically placed in a home's main living area, and provide warm air (and radiative) heating to that room. Some products have connections for ducts to carry warm air to other rooms. Other products also have heat exchangers which allow for domestic hot water or central heating circuits to be heated by the stove. However stoves do no typically provide sufficient heat for all a home's domestic hot water or central heating needs, and an additional heat source is typically required.

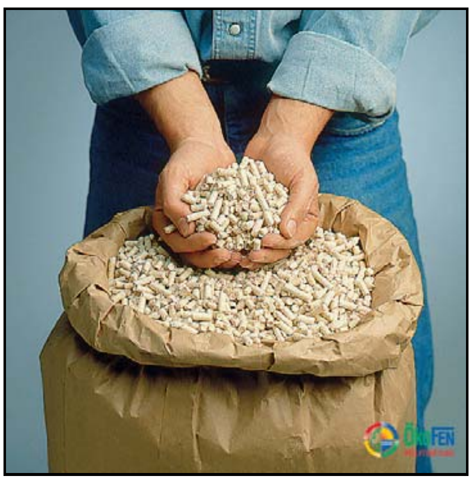
- **Boilers:** these are designed to provide all of a home's domestic hot water and space heating needs (in a similar manner to a conventional natural gas or oil boiler).

Figure 11 – Biomass residential heating systems

Stove (CALIMAX) **Boiler (FROELING)**

Pellets, as shown in Figure 12 below, are the most common type of fuel for the above systems, although log-fuelled products are also available.

Figure 12 – Propellets



(Pellets are widely available in some European markets)

Pellets are easy to handle, and can be delivered either by tanker or in sealed bags. For boilers, there are two main storage methods used. If room is available, the simplest solution is to use a sealed storage unit in a room next to the wall on which the boiler is installed against. An automatic feeder system then carries pellets to boiler. A separate solution is to use an outside store (similar to an oil storage tank for oil heating systems). In this case pellets are "sucked" along pipes to the boiler.

Table 6– Advantages & disadvantages of biomass residential heating systems (Compared to Oil and LPG-fuelled heating systems)

Advantages	Disadvantages
Renewable-fuelled heating system (providing fuel comes from sustainable wood source) Less volatile fuel cost (and currently lower fuel cost) Stoves can supply supplemental heat with an attractive visual appearance	Higher capital cost than oil-fuelled heating systems Requires pellet supply infrastructure

(Delta Energy and Environment)

Biomass Heating Applications

Biomass boilers – providing all of a home's hot water and space heating requirements – are typically installed in homes without access to natural gas supplies. This is because natural gas is a relatively cheap fuel source, no fuel storage is required, and natural gas boilers are – compared to biomass systems – relatively low cost.

Although natural gas availability is high in many countries (such as the UK, Italy and the Netherlands), even in these countries there are significant numbers of households without access to natural gas – typically in rural areas. And in Germany, Scandinavia, Austria, France and other (cold climate) European countries, natural gas availability is much less widespread.

Biomass stoves are typically installed as supplemental heating systems in houses. In some cases the aesthetic appeal of stoves is a key driver for purchase. Stoves are widely used in Italy, and the aesthetic appeal of stoves – together with a strong tradition of wood-burning – explains the high popularity of biomass stoves there.

3 TECHNOLOGY STATUS

Some microgeneration products are already widely available – such as PV systems – but at prices prohibiting development of mass markets unless widely available subsidies are in place. Other products – such as some Stirling engine micro-CHP systems – are being or are about to be introduced to markets at prices that could lead to mass market development. And yet other products – such as fuel cell micro-CHP systems – still have a number of technical and cost challenges to overcome before they are commercialised at prices likely to lead to mass markets.

This section discusses the current status (in terms of the fundamental technology and timing of market introduction) and prospects for each microgeneration technology. Looking forward involves taking account of manufacturers' and product developers' plans, while recognising that commercialisation and market introduction timescales generally only ever move in one direction – backwards.

The commercialisation status of the different technology groups are shown in the table below.

Table 7– Commercialisation status and economics of microgeneration Technologies

Technology	Widely available on commercial basis?	Currently economical for mass markets without grant support	Future developments
Micro-CHP	Japan and Germany	Yes, for multi-family housing.	Mass-market designed products set to be launched from 2007 are likely to be economically attractive.
Micro-wind	Yes	Not currently economical for mass market applications.	Mass-market designed roof mounted products set to be launched in 2007 or 2008; may only be economically attractive for a wide range of applications with grant support.
PV	Yes	No	Cost competitive in near/medium term if incorporated into cladding, otherwise not for 20 years plus without subsidy.
Micro-hydro	Yes	Yes, if low installation cost and good resource.	No change.
Residential biomass heating	Yes	Yes, if compared to oil and electric heating.	Likely to gradually become more economically competitive.

(Delta Energy & Environment)

3.1 Micro-CHP

Product requirements for mass-market micro-CHP applications are stringent. Conventional boilers and furnaces (which micro-CHP units typically replace) are very reliable, quiet, require only annual servicing at most and last for over (sometimes well over) ten years.

This section examines micro-CHP technology status first by segmenting the market into micro-CHP (for single-family homes) and mini-CHP (for multi-family homes and small commercial applications) and secondly by examining the various technologies used inside these systems.

Mini-CHP

Mini-CHP products have been commercially available in Japan and Europe since the late 1990s through commercialisation of 5 kWe (and larger) internal combustion engines, as shown in the table below.

Table 8 – Mini-CHP products currently commercially available

Company	Product	Output (kWe)	Main markets
SenerTec (owned by Baxi)	DACHS	5.5	Germany
Power Plus Technologies (owned by Vaillant)	Ecopower	4.7	Germany
Yanmar	Genelight	5.0 and 9.9	Japan
Sanyo	Genelight	8	Japan
Aisin Seiki	Genelight	6	Japan

(Delta Energy and Environment)

These products are based on mature technology and are generally very reliable. Typical installations are in small commercial applications (for example restaurants and hotels), multi-family buildings and apartment blocks and increasingly (in Germany) in single family homes. However these products are not ideal for single family homes, although SenerTec has sold thousands of units into this market. Their electrical outputs are typically too high (resulting in a high proportion of exported electricity), they are large (in size), and above all their cost is such that paybacks for single family homes are typically greater than ten years.

Annual sales currently stand at just over 3,000 units a year in Europe and less than 1,000 units a year in Japan, with sales growing in the region of 20% or so a year.

Several companies are developing new products for these markets. Apart from one Stirling engine developer, these are exclusively based on fuel cells (PEM and SOFC).

Micro-CHP

Only one micro-CHP product designed for mass-market applications is currently widely available on a true commercial basis. This is the ECOWILL unit, built around Honda's 1 kWe internal combustion engine, of which over 20,000 units have been sold in Japan since the product's launch in 2003.

Globally, over 30 other companies are striving to join them. Selected close contenders are identified in table below. (Note that Climate Energy plans to sell micro-CHP units in the US built around Honda's engine later in 2006, although expectations of initial sales volumes in the next few years are low (no more than a few thousand units a year at most). Delta also expects Honda to be selling – through partners – its product into the European market by 2008).

Table 9 – Selected micro-CHP developers planning to launch products and/or make them widely available by 2008

Company	Technology and fuel	Initial target markets	Commercialisation target and notes
Whisper Tech (New Zealand, owned by utilities and others)	Stirling (natural gas)	UK	E.ON UK commenced sales of limited no. of units (<1,000) in 2004 and has placed an order for 80,000 units. Mass launch planned for 2007 (meeting this is dependent upon imminently securing a manufacturing partner).
OTAG (German start-up)	Rankine (natural gas)	Germany	Commenced commercial sales in 2006 (in Germany, 600 units for the year). High price could limit mass market potential.
Sunmachine (German start-up)	Stirling (biomass)	Germany	Commencing commercial sales in 2006 (Germany, plans for ~3,000 units for year). High price likely to limit mass market potential.
Microgen (subsidiary of UK's BG Group)	Stirling (natural gas)	UK, Netherlands, Germany	Launch planned for 2007. Targeting rapid growth to volume production. Tie-up with Remeha, Europe's 7th largest boiler manufacturer.
ENATEC (main shareholder is ENECO, major Dutch utility)	Stirling	Japan and Europe	Launch expected in 2007 or 2008. Tie up with Japanese gas appliance manufacturer Rinnai. Targeting rapid growth to volume production, dependent on securing agreements with boiler manufacturers.
Several Japanese companies including Toshiba, Matsushita, Ebara Ballard, Sanyo, and Toyota	PEM fuel cell	Japan	Leasing hundreds of products to households in 2005-6. Potentially growing to thousands of units in 2007, with true market introduction and larger volumes planned for 2008 onwards. Dependent on continuing progress to reduce costs and improve durability and reliability.

Baxi	Rankine cycle	UK	Launch expected by 2008 according to 2005 press release, although no product development news since may mean this target is ambitious.

(Delta Energy & Environment)

Internal Combustion Engine - Technology Status

This is a mature technology that has only in the last ten years been developed specifically for micro-CHP applications. Apart from Honda's 1 kWe product, other units are sized between 5 kWe and 10 kWe.

Table 10 – Internal combustion engine micro-CHP technology status

Metric	Status
Cost¥	Honda 1 kWe unit: ~£2,000/kW (marginal cost on boiler). Other products, 5 kWe and larger: ~£2,000/kW (full cost).
Servicing	Service intervals vary from 3,500 to 10,000 hours for natural gas fuelled units.
Noise and vibration	Controlled to low enough levels for installations in utility rooms (not in living space, perhaps except for Honda product).
Lifetime	Over 40,000 hours and higher.
Reliability	High
Emissions	Controlled using catalysts to low enough levels.

(Delta Energy & Environment)

Note: with "Cost" in table 10 through to table 14 is meant the capital cost excluding any installation costs.

These products work, are generally very reliable and, beyond incremental improvements, no breakthroughs or fundamental technology improvements are anticipated or required.

Additional companies may enter the market (possibly for 1 kWe capacity products for the Japanese market), although Delta is aware of a Scottish company with incremental improvements in technology that is seeking investment in this area.

Stirling Engine - Technology Status

The Whisper Tech and Sunmachine products are already being sold in limited numbers. Other products are likely to be commercialised in 2007-8 in Europe (with the Whisper Tech unit likely to manufactured and sold in volumes of several thousand units a year from 2007 if a manufacturing partner is secured). As many as seven products may become commercially available by 2009 if all product developers meet their targets, which is unlikely.

Manufacturers and developers are confident that fundamental technology development issues have been overcome. While minor technology issues are likely to arise, Delta shares this view. The major challenge now is one of refining product engineering issues and serial production.

Table 11 – Stirling engine micro-CHP technology status

Metric	Status
Cost	Most developers targeting ~£650 to ~£1,000/kW marginal cost on a boiler when in serial production.
Servicing	In principle no additional maintenance compared to boiler, although yet to be proven.
Noise	Most developers state noise and vibration levels low enough for installation in living space.
Lifetime	Targeting over 10 years, but not yet proven.
Reliability	Not proven.
Emissions	Similar to boiler if low-emission burner is used.

(Delta Energy & Environment)

Whilst two companies already have manufacturing partners, others are currently seeking or are expected to shortly seek partners.

Although additional fundamental technology development is not required, further investment is likely to be required to develop a market-ready product. At least one company is currently seeking investment for this, and Delta is aware of other companies that may also require investment.

Rankine Cycle Engines - Technology Status

Developers are pursuing different configurations of Rankine Cycle technology. These differ by the type of working fluid (water or organic refrigerant) and type of prime mover (reciprocating engine, free-piston or scroll expander), making it difficult to generalise about the status of this broad technology area and further technology development.

One company, Otag, has commercialised its product, which produces 3 kWe. Over the period to 2008 it is expected to be manufactured in volumes up to a few thousand units a year, with unit costs currently relatively high (compared to boilers) of €11,000. Other developers are targeting commercial launch in 2008 or at a later unspecified date.

The next closest to market is a Baxi Group product, using an organic refrigerant as a working fluid with a scroll expander. Climate Energy has been developing similar technology (but with a water-based working fluid) for a number of years.

A key challenge for these companies is the design of the scroll expander.

Whilst scroll compressors are made in large volumes (millions of units a year) for air-conditioner applications, it is not yet clear whether existing scroll compressors can be used and run in reverse mode as expanders, or whether more fundamental re-design (and therefore time and investment) is required.

Table 12 – Rankine cycle micro-CHP technology status

Metric	Status
Cost	Otag's product currently at ~£1,500/kW marginal cost on boiler for 3 kWe product. Other products may be as low as £400/kW (marginal cost) when in serial production.
Servicing	For some products no additional servicing - in theory - compared to a conventional boiler; others will require periodic servicing.

Noise	Potentially no more than a boiler for some products, other products will have to address higher noise and vibration issues.
Lifetime	Targeting over 10 years, but not yet proven.
Reliability	Not proven
Emissions	Similar to boiler if low-emission burner is used.

(Delta Energy & Environment)

Of the five companies developing product for this market, three may require external investment for full development and to establish serial production capability.

PEM Fuel Cell - Technology Status

To many, PEM fuel cells are the ultimate micro-CHP technology – the core technology is simple and does not include any moving parts. Reasonably high electric efficiencies are achievable and rapid start-up and modulation is possible. Despite these attractions there are significant challenges to commercialise the technology for micro-CHP applications. These are due to:

The need to reform natural gas and extract carbon monoxide and sulphur since they poison the fuel cell stack.

Degradation of the membrane inside the fuel cell stack leading to low lifetimes.

Complex balance of plant (such as requirements to humidify the stack, and associated water management issues).

High costs.

Table 13 – PEM Fuel Cell micro-CHP technology status

Metric	Status
Cost	Currently estimated at >£10,000 for 1 kWe product (in many cases significantly more). Target prices quoted by some at £1,700/kW for a 5 kWe product and £2,500/kW for a 1 kW product.
Servicing	Depends on lifetime of fuel cell stack, which may need to be replaced periodically. Aside from this, some – but not substantial – additional servicing is likely to be required above a conventional boiler.
Noise	Low.
Lifetime	Currently less than 10,000 hours (in many cases substantially less).
Reliability	Currently low – interruptions at best every 350 hours in recent Japanese demonstrations.
Emissions	Very low.

(Delta Energy & Environment)

Large amounts of capital are being invested in both product engineering and fundamental technology development.

The critical technology areas requiring further development include the fuel reformer, de-sulphuriser, decreasing the platinum content of the catalyst, and the membrane electrode assembly (MEA).

One initiative of note is the development of a higher temperature membrane that could eliminate humidification and carbon monoxide removal requirements. This would also lead to higher temperature heat recovery, an advantage over current technology.

For micro-CHP applications Japan is the focus of the majority of commercialisation activity. Hundreds of units have been installed in homes as part of a widespread government-supported trial. Product sales are stated to commence by 2008, by which time thousands of demonstration units may have been installed. The

Japanese government has challenged developers with an aggressive cost target of ¥500,000 (£2,500). In Europe, activity is limited to a handful of product developers and system integrators, with market introduction estimated for the 2010-12 timeframe at the earliest.

The future for PEM fuel cells for micro-CHP applications is therefore far from clear. The technology offers considerable promise, but major challenges still remain to be overcome. Predicting whether and when these will happen is impossible. Delta's view is that 2010-12 is the earliest realistic timeframe for widespread introduction, with 2015 onwards possibly being a more likely timeframe.

Continued investment in terms of fundamental technology development, product engineering and development, and serial production capability is undoubtedly required. While many PEM fuel cell players are well capitalised companies, a number are not and are likely to require external investment.

Solid Oxide Fuel Cell - Technology Status

This technology has recently been gaining increasing attention. Hexis (previously known as Sulzer Hexis), a Swiss-based company, has led the world in placing products in the field, with over 100 field tests units installed between 2001 and 2004. However several other companies have raced to catch up with them.

SOFC technology developers need to demonstrate longer lifetimes than have been demonstrated to date, with low enough levels of degradation. Costs need to be significantly reduced, a key element of which is the materials for the cells. For some developers this is dependent upon high volume ceramics and coatings manufacturing facilities being established.

As there are a variety of approaches to designing SOFC (planar versus tubular, metallic stacks versus ceramic stacks, intermediate temperature against high temperature), it is difficult to generalise about remaining technology challenges.

However, these challenges (not all of which are issues for all SOFC developers) include: include fuel processing (reforming); cell materials (typically ceramics); electrical interconnect materials; and fuel cell stack seals.

Some of these issues are not so much fundamental technology issues, but more materials challenges and engineering and design challenges.

Table 14 – SOFC cell micro-CHP technology status

Metric	Status
Cost	Currently high, several thousand pounds per kW. Target manufacturing prices for the fuel cell stack are as low as £300/kW.
Servicing	Depends on the lifetime of the fuel cell stack, which may need to be replaced periodically. Aside from this, some – but not substantial – additional servicing is likely to be required above a conventional boiler.
Noise	Low.
Lifetime	Not yet demonstrated to be more than 10,000 hours.
Reliability	Not widely known.
Emissions	Low.

(Delta Energy & Environment)

3.2 Micro-Wind - Technology Status

Small wind turbines have been commercially available for many years. Indeed in China over 120,000 (locally made) units with outputs between 0.1 kWe and 0.3 kWe have been sold to off-grid homes, charging batteries which run radios, televisions and lights for example. In developed economies, wind turbines have been used for battery charging for the marine market, in remote applications and for street lighting applications (the later particularly in Japan). Southwest Wind Power claims to have sold 70,000 units since it was founded in 1987, to a wide range of applications.

There is a small market (estimated at no more than a few thousand units a year) for (mainly) pole-mounted grid-connected systems for households and small commercial buildings. Although some of these products have also been installed on rooftops, these are typically for public relations purposes, with the products not suitable for mass-market applications.

A major potential opportunity for micro-wind is to develop new low-cost building mounted systems, although not all wind experts are yet convinced by this potential.

The technical challenges – compared with pole mounted systems and those designed for battery charging – are:

- Minimising noise to acceptable levels
- Minimising transmission of vibration to the building
- Securely mounting the wind turbine to the building
- Achieving low cut-in wind speeds and coping with turbulent airflow often found over buildings
- Designing an efficient inverter for grid-connection
- Understanding exactly where to site the turbine to maximise energy output

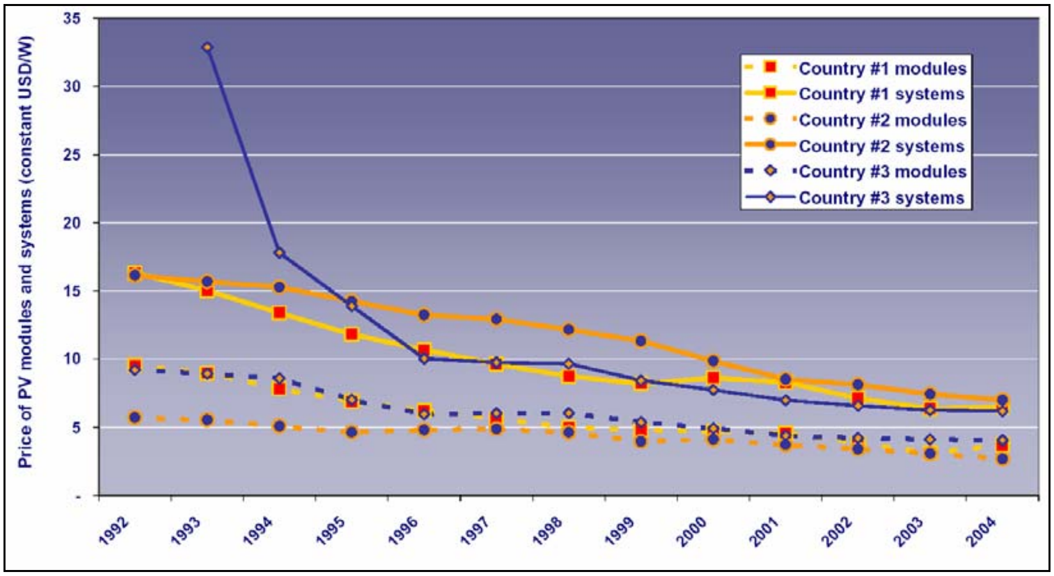
To achieve low cost (possibly as low as £1,000 or even less for a 1 kW unit) the products must be designed for serial production/assembly with low-cost components. A rapidly growing number of companies are developing products suitable for building mounting. A handful of these companies are on the cusp of introducing products to markets – primarily in the UK and Japan. There are a number of developers in the Netherlands – another likely early market for roof-top wind turbines.

Widespread market introduction (thousands of units a year) is possible in the second half of 2006 and – more likely – 2007 onwards. Windsave, Renewable Devices and Zephyr are all planning to manufacture thousands of units a year in this period. All claim to have addressed most of the technology issue noted above (although products have not yet been widely demonstrated).

3.3 Photovoltaics - Technology Status

PV systems have been commercially available for a wide variety of applications – including residential power generation – for several years. These systems are proven and typically come with guarantees of 25 years or more. The market limiter for PV systems is, of course, cost. Current and historic costs for PV modules are shown in Figure 13 below:

Figure 13 – Prices of PV modules and systems over time



(IEA PV Power Systems Programme)

This is not the complete cost to install a PV system; the costs for inverters, PV support structures, cabling and installation must be added. The module itself typically accounts for about 50% of installation costs. Learning rates for PV systems have been around 18% to 20% - meaning that for every doubling in production, prices have fallen by 18% to 20%. Future price decreases are expected to occur from a number of sources:

Lower cost silicon through dedicated solar grade silicon production

Reduction in the materials component of cells (especially for crystalline silicon technology)

Increased efficiency of cells

Lower cost production processes – partly due to economies of scale but also due to improved production processes

Advances in thin film, organic and other emerging PV technology

Meeting these challenges requires further significant investment – expected to come from the major PV cell/module manufacturers themselves as well as from start-up companies and other less-well capitalised companies.

The European Photovoltaic Industry Association estimates that in southern Europe, unsubsidised PV electricity may become competitive with grid-supplied electricity by 2030, but not before 2040 in northern Europe. A recent study by the Energy Saving Trust predicts that, in the UK, PV electricity will only be competitive with grid electricity (for residential consumers) by 2050 if net metering arrangements are in place. Due to the high cost of electricity in Japan, PV electricity may become competitive with grid electricity earlier than in other regions.

3.4 Micro-Hydro - Technology Status

Micro- and pico-hydro systems that generate electricity have been in operation for decades and the technology is now largely mature with little scope for significant reduction in the cost of product manufacture or installation.

However, with two different types of application (impulse and reaction) and with several different product designs for each, together with options for different heads of water, the diversity of products is great. New designs and design improvements are therefore not uncommon, but change tends to be incremental.

3.5 Biomass Residential Heating System - Technology Status

Pellet stoves and boilers use mature technologies that have been developed – mostly in Scandinavia and central Europe – since the 1980s. The products are fully automated and require little more attention than oil-fired heating products. Challenges that have been successfully addressed include:

- Low emissions of carbon monoxide and nitrogen oxides
- High efficiency – reportedly as high as 93%
- Fully automatic operation, including automatic start up and shut down and programmable operation.
- Long maintenance intervals – only once a year servicing, emptying of ash as little as once per year, and filling of pellet storage tanks as little as a few times a year.
- High reliability, reportedly as high as natural gas and oil burners.
- Ability to modulate thermal output.

The best products on the market use computer-controlled combustion processes to meet some of the above challenges.

Emissions of fine particulates are an issue for this technology, with increasing levels of discussion about associated health impacts. The biomass heating industry is currently looking at options to reduce such emissions.

Consistency of composition of wood pellet fuel has also been important. National standards for composition are in place in some countries, with Europe-wide standards being developed.

Europe is the focus of the vast majority of pellet fuelled heating system activity, with very little activity in North America or in East Asia. The most important European markets are Germany, Austria, Italy, Denmark and Sweden. The largest pellet boiler market is Germany at around 14,000 units in 2005, and the largest stove market is Italy with about 100,000 units in 2005. The Austrian Pellet association, proPellets, estimates market growth across Europe at 30-40% in the last 2-3 of years, with sustained growth of 20% for a number of years before that.

Leading manufacturers are found in Austria (boilers and stoves), Italy (stoves), and to a lesser degree in Germany, Denmark and Sweden.

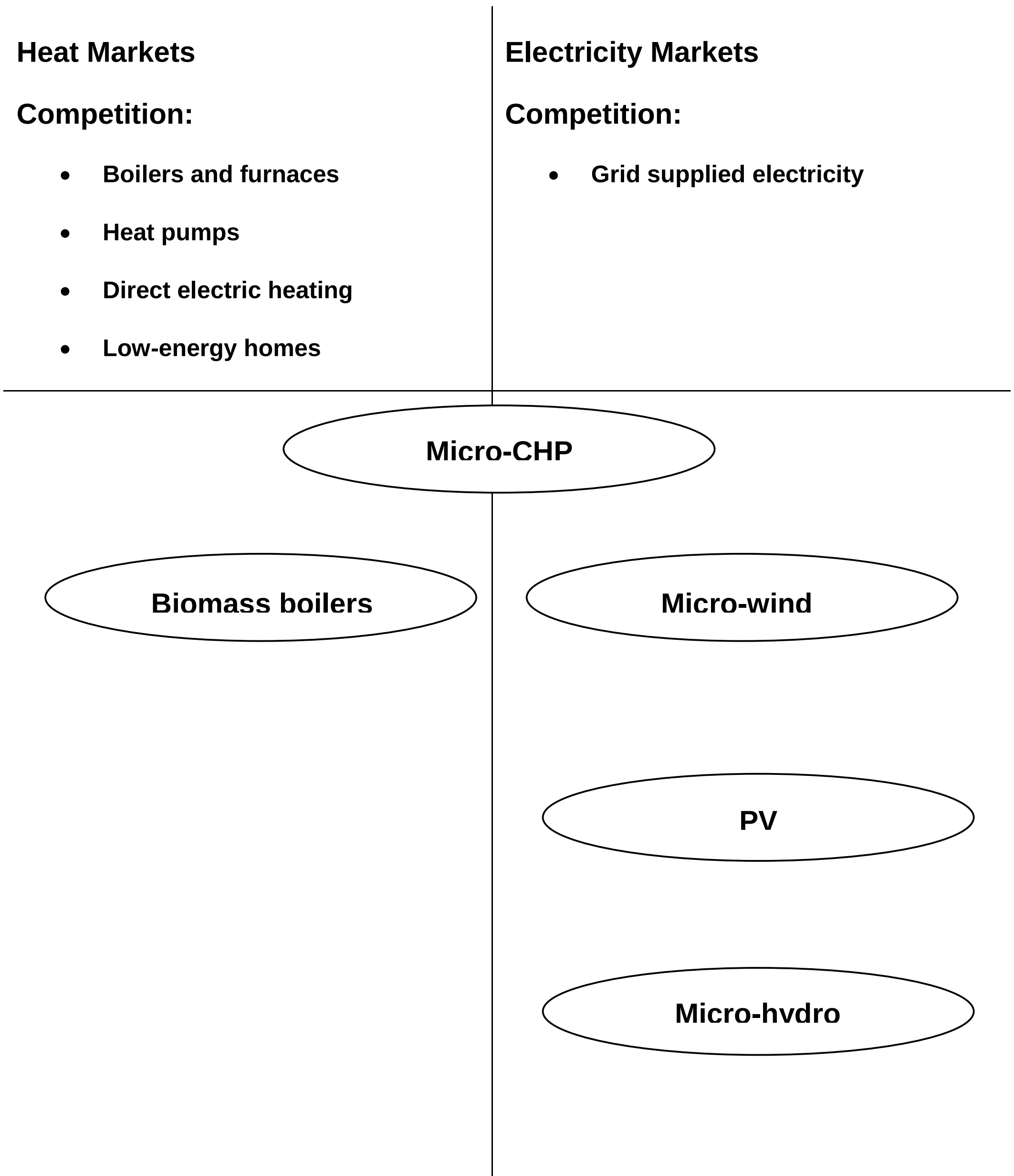
In the main markets for pellet heating systems, prices for stoves are typically in the €2,000 to €3,000 range, with boilers typically costing around the €10,000 mark. These figures include the pellet retrieval systems but do not include installation. For boilers in particular there is significant scope for cost reduction as higher volumes are manufactured, with some estimates of 20% to 30% cost reductions within the next five years if markets continue to grow rapidly.

A pellet supply infrastructure is of course a key requirement for residential biomass heating systems. Such infrastructures have developed in the markets identified above, but are unsurprisingly not well developed where there is little use of biomass heating systems.

4 COMPETING TECHNOLOGIES

The competition for microgeneration technologies is, on the one hand, straightforward and strong: conventional heating products and grid-supplied electricity generally do an excellent job of meeting customer demands. This competition can be separately analysed in terms of competition for heating and competition for electricity.

Figure 14 – Competitive technologies for microgeneration



(Delta Energy & Environment)

4.1 Heating Markets

For mass-market applications, there are two types of heat demand relevant to microgeneration: space heating and domestic hot water. These are typically supplied by the same heating system in Europe, parts of Japan and a few parts of North America. Competition between heating systems is typically a function of a variety of factors, as shown in Table 16 below:

Table 15 – Competitive dimensions for heating products

Factor	Comments
Capital cost	One of the most important factors.
Running cost	A major factor, as a few years of running cost can be equivalent to the capital cost. Running cost is a function of fuel cost, efficiency and maintenance costs.
Comfort and controllability	The system must provide sufficient space heating and hot water, and be fully controllable.
Reliability	The system must be reliable.
Green-ness	Not (currently) a major factor for most purchasers.

(Delta Energy and Environment)

Heating markets differ significantly from country to country and region to region:

- District heating is widespread in some countries – Denmark and Finland - but virtually unknown in others – Belgium and Spain.
- Natural gas is widely available in some countries – UK and the Netherlands – but has limited availability in other countries – including Sweden.
- Heat pumps are commonly used in parts of North America and Japan – they are widely used in some European markets but hardly at all in other parts of Europe.
- One heating system typically serves both hot water and space heating demands in some countries (including UK and the Netherlands), but in other

countries (including US, Canada and parts of Japan) separate water heaters and space heating systems are used.

- The level of heating demand varies from country to country due to climatic, insulation and energy usage patterns.

For micro-CHP and biomass heating systems, the main competitive heating technologies comprise district heating, heat pumps, passive homes, and conventional gas / oil-fired boilers and furnaces.

District heating

District heating is a market limiter (in a small number of countries) rather than a competitive technology for micro-CHP and biomass heating systems. Where district heating is available, it is typically difficult for other heating systems to compete.

Degree of competitive threat: LOW **- limits market significantly in Denmark and Finland and, to a lesser degree, in Germany.**

District heating schemes involve the generation of heat at a large central source with pipes distributing the heat to a neighbourhood or even most parts of a city. Some countries, notably Denmark, Finland and to a lesser degree Germany, Sweden and parts of Eastern Europe, have had policies in place supporting the development of district heating schemes. A few schemes exist in Japan and North America, but they are not widespread.

Where such schemes are in place it is difficult for other heating systems (micro-CHP and biomass) to gain a share of the space heating market. This limits the market for these technologies to a large degree in Denmark (where 50% of all space heating is served by district heating) and Finland, and to a lesser degree in Germany and some parts of Eastern Europe.

There is little current growth in district heating schemes, and Delta expects minimal expansion of existing schemes and the development of new schemes in Europe, East Asia or North America.

Heat Pumps

Heat pumps are a competitive technology for biomass heating systems and non-gas fuelled micro-CHP systems in Europe, and for biomass heating systems and all micro-CHP systems in Japan.

Capital costs are usually similar; running costs are very market dependent (fuel prices, energy consumption patterns and climate); heat pumps are 'green' (the shade depending on electricity generation mix); reliability is high.

Degree of competitive threat: **HIGH in Japan and HIGH for biomass heating systems and non-gas fuelled micro-CHP systems in Europe**.

Heat pumps use compressors (usually electric-powered but in some cases, mainly in Japan, powered by gas-fired internal combustion engines) to take heat from a low-temperature source (the ground, water or air), 'concentrating' this to supply either warm air or hot water to households.

There is a very large market for air-to-air heat pumps (over 20 million units a year, mainly in China and Japan), which mostly run in reverse mode as air-conditioners during summer months and run as heat pumps for limited periods in winter. These are suitable for relatively mild climates and are not further considered here as they will rarely directly compete with micro-CHP or biomass heating systems.

Of more interest are heat pumps designed to produce domestic hot water and/or space heating in relatively cold climates. Markets for more than 10,000 units a year currently exist in the US, Japan, China, Sweden, France, Germany and Switzerland. These heat pumps are typically ground or water source heat pumps, although advanced air-source heat pumps have been developed in Japan.

In all cases, apart from Japan (see below), these heat pumps are typically installed in regions where natural gas is not available. In such regions, households may opt for oil, propane or biomass fuelled heating systems, or indeed direct electric heating. Heat pump popularity in Sweden and Switzerland also stems from the ‘greenness’ of electricity due to their excellent hydropower resources. These systems do present competition for biomass heating systems, but are of limited threat to micro-CHP systems.

In Japan the situation differs, with very strong growth of heat pump water heaters driven by electric utility and gas utility competition for the water heating market (domestic hot water heating demands are typically much larger in Japan than in other markets). Japanese heat pump manufacturers have developed highly efficient air-to-water heat pumps (which can supply either domestic hot water-only or domestic hot water and hydronic heating systems), and have seen market penetration rise – with government support - from less than 10,000 units a year in 2001 to 120,000 units a year in 2004. The degree to which heat pump water heaters successfully secure a share of the domestic hot water could limit the market for micro-CHP systems in Japan.

Passive Homes and Low Energy Homes

Passive and low energy homes will limit the potential for micro-CHP systems with high heat-to-power ratios.

These homes require the same levels of water heating but very low levels of space heating. Thus, the fuel element of running costs are a less important consideration for meeting space heating demands.

Degree of competitive threat: LOW **– will limit potential for some types of micro-CHP systems in a proportion of new-build housing in Europe.**

In central Europe the concept of passive homes, requiring only extremely low levels of space heating (<15 kWh/m2 of floor area per year) has been developed – with about 5,000 such homes built. These homes feature ultra-high levels of insulation and are designed to incorporate passive solar gain. As they need very little space heating they do not need conventional heating systems. Small biomass heating systems (probably stoves) could be used in such homes. Only micro-CHP systems with very low heat-to-power ratios (fuel cells, and in particular solid oxide fuel cells) are likely to be suitable for such homes.

Aside from passive homes, increasingly stringent building regulations for construction of new homes are resulting in lower space heating demands. Over time this may limit the market in new housing for micro-CHP units with higher heat-to-power ratios.

Conventional Gas and Oil Heating Systems

No improvements beyond condensing heating systems are anticipated, therefore no 'new' competition from conventional heating systems.

Conventional heating systems have lower capital costs than micro-CHP and biomass; higher running costs; very high reliability and comfort; but are not especially 'green'.

Degree of competitive threat: **HIGH in that micro-CHP and biomass competes directly against these systems, but NO NEW competitive threat.**

Micro-CHP systems will typically compete directly with natural gas-fuelled systems, with biomass heating systems typically competing against oil heating systems. The introduction of condensing heating systems (both boilers and furnaces) has been the largest change in these technologies in the last twenty years, raising typical efficiencies from the high seventies to around 90% (when heating circuits are designed so that condensing heating systems do actually run in condensing mode).

No further notable improvements in conventional oil and gas heating systems are anticipated.

4.2 Electricity Markets

Microgeneration competes against grid-supplied electricity, except for a very small niche of off-grid homes (probably of most significance in North America, with an estimated 100,000 such homes).

The competition against grid-supplied electricity can be expressed in three dimensions:

- **Price** – a straightforward cost per kWh comparison of grid-supplied electricity and micro-generated electricity. This is the key issue when comparing grid-supplied electricity microgeneration. From a householder point of view, price competition is typically thought of in terms of payback time.

- **Reliability** – only a very minor issue in Japan and Europe, where grid reliability is (currently) very high, but in parts of North America a less reliable grid means that a premium value may be placed in microgeneration if it can supply electricity during grid outages.

- **Green-ness** – effectively the carbon content of grid electricity. The lower the carbon content of grid-supplied electricity, the lower the carbon savings from microgeneration. Green-ness can also be expressed in another dimension: the ability to purchase green electricity from the grid, although these markets have not developed to a significant scale so far in any market.

Likely trends in the competitiveness of grid-supplied electricity to microgeneration are shown in the table below.

Table 16 – Dimensions of competition for grid-supplied electricity and microgeneration

Dimension	Changes in competitiveness of grid-supplied electricity	Explanation
Price	No change / less competitive	No expectations for breakthroughs in generating technology cost. Fuel costs likely to rise rather than fall. Higher environmental burdens, such as the EU Emissions Trading Scheme and the Large Combustion Plant Directive. No expectations for significant reductions in grid costs. No expectations for significant reductions in supply costs – although introduction of competition into some markets may be a downward driver on prices.
Reliability	No change / less competitive	Reliability is typically high across most of Europe and Japan, lower in parts of North America. Privatisation of grid owners could lead to lower investment in grids in Europe, potentially resulting in lower reliability.

Table 16 (continued) – Dimensions of competition for grid-supplied electricity and microgeneration

Dimension	Changes in competitiveness of grid-supplied electricity	Explanation
Green-ness	Variable Unlikely to be a major threat to microgeneration in the short- to medium-term.	Lower carbon content of grid-supplied electricity due to: Increasing penetration of renewable power generation. Increasing share for gas-fired power generation (often displacing coal or oil). This may be mitigated in some European markets by the closure of nuclear power plants, although new nuclear capacity may be built in some European markets and in North America.

(Delta Energy and Environment)

5 POLICY AND COMMERCIAL DRIVERS FOR MICROGENERATION

5.1 Critical Requirements

A conducive policy and regulatory environment is critical for the development of a mass market for microgeneration. This can be characterised by the removal of barriers, for example adverse interconnection conditions, or by the introduction of specific market incentives.

In order to assess the outlook for mass market potential, it is the future policy climate that is of more relevance than the current one. This section therefore briefly summarises the current policy environment for microgeneration and provides some more specific assessment for its future evolution and direction.

Some caution is needed here, however. The opportunity for take-up of microgeneration systems has emerged only in the last 5 – 10 years. The products that can satisfy this market are still under development and only a handful are commercially available today. Consequently, the policy and regulatory responses are only now beginning to emerge. It is therefore too early to be confident about the degree to which they will accelerate the market through the introduction of ad hoc incentives or, over time, through the development of a market framework that is designed to accommodate widespread microgeneration development:

- In the early stages, for the next 5 years or so, the most that can be expected anywhere is the piecemeal implementation of incentive measures designed to promote some types of microgeneration within existing market arrangements. These can be very effective: strong PV market development in Germany and Japan have been as a direct consequence of the grant and feed-in programmes introduced there.

- A market framework that is designed to accommodate and recognise the benefits of very large numbers of small-scale grid-connected generators is likely in some markets but is not inevitable. The earliest it is likely to emerge in any country is in around 5 years or so and may more likely take 10 years or longer.

For the **commercial environment**, electricity prices are key (gas prices also have relevance for gas-fired micro-CHP, particularly high power-to-heat ratio systems). Here also the future outlook is of greater relevance than current conditions. This section therefore provides a general outlook for electricity price evolution on the basis that all the microgeneration technologies described will benefit from increasing price trends.

This section concludes with an assessment of the outlook for the achievement of certain key policy and commercial drivers for microgeneration in each of the main markets (Europe, USA and Japan):

- Clear and transparent interconnection arrangements that enable microgeneration users to be connected to the grid.
- Reasonable and fair value for exported electricity from microgeneration projects.
- Utilities are able to capture full value of microgeneration (for example in reducing demands on the distribution network and reducing peak power demands).
- There are incentives for early market development.

5.2 Policy Drivers - Micro-CHP

Europe - Current

At the EU level, there is little current direct influence that is specific to micro-CHP market development. It is too early for the EU CHP directive to have had any influence (reviewed below).

Policies in national markets are best described as ‘patchwork’, with some incentives in place, but as yet no clear and coherent policy to develop mass markets for micro-CHP. Highlights include:

- **Germany** – there are some helpful incentives in place for micro-CHP in Germany, particularly for larger capacity units that export significant proportions of the electricity they generate to the grid.
    - Some useful support mechanisms for micro-CHP (for example, electricity generated by micro-CHP units (< 50 kWe) and exported to the grid receive a bonus price of €c5.11 / kWh on top of the base-energy price; this benefit will run till 2008, and is useful but only rewards micro-CHP electricity exported to the grid).
    - Fuel used by micro-CHP units is exempt from the Eco-tax, levied on the consumption of fossil fuels.
    - In principle, generating units have the right to connect, under the VDE 1026 guidance, to distribution networks and in many cases micro-CHP units have little difficulty in connecting to the grid, but there can be difficulties in some cases.

- **The UK** – some key supportive measures are in place:
  - The government published, in March 2006, a micro-generation strategy, detailing a series of planned actions to help realise the potential that microgeneration offers.
  - The March 2005 Budget earmarked £50 million to support microgeneration technologies in England and Wales over the next three years. This is additional to the £28.5 million already committed to the Low Carbon Building Programme (over the same period), providing capital grants to microgeneration technologies.
  - Interconnection for microgeneration is covered by the G83/1 Engineering Recommendation that allows for straightforward interconnection for micro-CHP units, provided it meets certain requirements.
  - There is a reduced rate of VAT for most types of microgeneration units of 5% and, under the Energy Efficiency Commitment, micro-CHP can be installed by utilities to secure credits.

The Netherlands. Grid interconnection is relatively straightforward, with residential PV systems having been connected to the grid for several years. However there is no 'right to connect', something that some micro-CHP companies are working to implement.

France. Exported power is limited to 20% of the rated power output for LV connections and there is a requirement to install an external isolation switch. Both of these are limiting market uptake. There is no right to connect to the grid.

Europe – Outlook

At the **EU** level, the outlook is positive. The CHP Directive requires member states to take various steps to encourage all forms of CHP and its requirements for micro-CHP (defined as less than 50 kWe) to qualify for incentive regimes is less stringent than for larger CHP schemes. There are other, more indirect EU measures that are likely to impact market development. The EU Emissions Trading Scheme (ETS), for example, is already creating upward pressure on electricity prices and this trend will probably continue.

In **Germany**, there are no additional specific measures on the immediate horizon. Some take the view that the major and municipal utilities do not wish to see large numbers of micro-CHP units on the market. If this is the case, this suggests only slow movement. In the **UK**, the outlook will be determined significantly by the nature of the government's Microgeneration Strategy and is likely to create a more favourable environment for micro-CHP than exists today. In the **Netherlands**, the outlook is less clear. There is the growing effort by major players, including Gasunie and Essent, to guarantee a 'right to connect and resolve meter change issues, and it is unlikely that they will come away empty-handed from their discussions with government.

USA

Current energy policy, both at federal and state levels, neglects micro-CHP altogether. New projects face interconnection and other requirements that differ on a state-by-state and/or utility-by-utility basis and, generally speaking, are not designed for micro-CHP implementation at all. Regulators have not yet started to consider the issue.

Federal policymakers have, however, taken some first steps and these are reflected in the 2003 Department of Energy Micro-CHP Technologies Roadmap. It outlines a set of actions to be taken by both government and industry. There are three main strategies that comprise the Roadmap:

- Defining the markets and applications.
- Developing the technologies.
- Accelerating acceptance of micro-CHP through, for example, demonstration programmes.

As yet, however, there has been little in the way of specific measures beyond a few relatively small development grant awards. The Bush administration's recent enthusiasm for financing the development of new clean energy technologies may bring some, possibly significant acceleration, to this process.

Japan

The policy environment in Japan is already a positive one for micro-CHP, and is being supported by a significant effort among gas utilities to promote the technology as a response to the power sector strategy of promoting all-electric homes.

Governmental support is centred around the development of fuel cells, for which there is a national capacity target, for PEM cells, of 2.1 GWe by 2010 (and 10 GWe by 2020) – figures that are, however, unlikely to be achieved. The Ministry of Economy, Trade and Industry (METI) has led this push, through its New Energy Foundation, with demonstration projects, R&D programmes and other measures designed to bring unit costs down. In addition a grants programme supports the market for other micro-CHP technologies by providing subsidies for installations.

5.3 Policy Drivers - Micro-Wind

There are no specific incentives for micro-wind in any of the major markets discussed here. To the extent that it is encouraged at all, it is almost always in the context of wider policy to promote renewable energy, or through emerging microgeneration policies (such as in the UK). In some respects, this is potentially a strongly positive factor since renewable energy policy, particularly in Europe, is continuing to strengthen, both at EU and national levels.

In Europe, the two countries of most relevance in this sector are the UK and the Netherlands. There are no specific measures in the Netherlands apart from a reasonably favourable interconnection arrangement. In the UK the interconnection regime is clear (through G83), a reduced rate of VAT applies for micro-wind, a grant support programme is in place, and there is a strong renewable energy regime through the Renewables Obligation. (However, there is as yet no mechanism for small owners to capitalise on this given the low volumes of ROCs generated. A change to the regulatory regime would be required to enable this and consolidators are therefore not offering this opportunity). The forthcoming Microgeneration Strategy is likely to bring forward some more specific measures.

In the USA, renewable policy is determined primarily by state regulatory regimes through, for example, Renewable Portfolio Standards. However, utilities with obligations are generally not interested in very small projects and the emergence of anything more specific for on-grid market development will depend mainly on the advocacy work of micro-wind technology developers themselves, of which there are currently few. In Japan, there is almost no policy interest in micro-wind, less focus on renewable energy than in Europe, and no immediate prospects for change.

Local planning issues are an important potential challenge, given the high visual impact of building-mounted systems. It is too early to assess how planners will respond if the market emerges. Should it become a negative factor, it opens the way for the possibility of offsetting positive policy intervention to override such local objections.

5.4 Policy Drivers – Micro-Hydro, PV and Biomass

Of the other renewable-based systems, PV has been the most significant beneficiary of policy support programmes so far, particularly so in Germany, Japan and, to a lesser degree, the US (mainly in California). There is every likelihood that policy support will continue and accelerate in some major markets. By the end of 2004, 4 GWp (giga-watt peak) had been installed worldwide:

- In Europe, Germany is the market leader, largely through its favourable long-term feed-in tariffs, offered since 2000 under the Renewable Energy Law that guaranteed €c0.5 / kWh for 20 years for solar electricity fed into the grid. This has been coupled with low-cost loans. The feed-in price is reduced by 5% each year for new contracts in order to stimulate further system price reductions. All this has enabled the PV industry move from niche markets to mass production. Other European countries have also had incentive programmes (eg France, Italy, Luxembourg, the Netherlands, Portugal, Spain and the UK) but with much less impact than in Germany. According to the EPIA, 550 MWp is expected to be installed in Germany alone in 2006.

- About half of the world's PV is installed in Japan. Through long-standing and aggressive government subsidies and policies (that started in the 1970s), PV houses are now common in Japan, and Japanese manufacturers dominate the global PV market. By 2005, over 1 GWp had been installed. Measures have included:
  - A subsidy for domestic installations since 1994, originally covering 50% of the installation cost. In 1997, this switched to a fixed sum per kilowatt installed.
  - Many local governments have developed their own PV programmes for providing financial assistance.
- Until 1985, the US was a world leader in support for PV R&D development. Since then, it has fallen behind both Japan and Europe. This may change, with the 'President's Solar America Initiative', announced in January 2006. This proposes a large funding increase for research and aims to decrease costs to be competitive with existing sources of electricity within 10 years. It also aims to deploy 5-10 GWp of PV capacity by 2015. Several states are also active, notably California where the new Solar Initiative aims to bring about 3 GWp of new rooftop installations by 2017 through rebates for installation costs.

Policy support for **pico- and micro-hydro** in OECD countries has been negligible. In Europe, both Norway and Spain have implemented incentives in the past, and the UK Clear Skies programme has provided grants of £1,000 / kWe up to a maximum scheme size of 5 kWe. In contrast, there is significant aid-related support (both bi-lateral and multi-lateral) available for investment in projects in developing countries. This support is usually channelled through in-country or external project and engineering consultants.

For **biomass boiler systems**, the main support programmes exist in Austria and, to a lesser extent, in Sweden (where biomass has benefited through high energy taxes on fossil fuels), Denmark, France and Germany, where such schemes are becoming more common in areas where there is no gas or district heating supply. In Austria especially, where the long-standing tax credit and grant-based incentives have been used to strengthen local manufacturers, the market has grown sharply in recent years. Small incentive programmes exist also in other countries, including France and the UK (where the Clear Skies programme has provided grants of £600 per installation).

There is an emerging prospect of a renewable heat obligation in the UK which may also stimulate the market, together with growing interest among energy supply companies (Northern Ireland Electricity, for example, is involved in a grants programme for pellet-based boilers for use in schools and small businesses).

In the US, the 2005 Energy Policy Act introduced a new tax credit regime for biomass boiler systems for homes and small businesses and a small number of US companies are establishing arrangements for the import of European products. There is no indication of any specific incentive regime in Japan.

5.5 Policy Drivers – Status Summary

Table 17 – Microgeneration policy drivers: status summary

Policy Requirement	Europe	USA	Japan
Clear and straightforward interconnection arrangements.	✓	×	✓
Fair value for exported electricity.	×	×	××
Utilities able to capture full value of microgeneration.	×	××	×
Incentives for early market development.	✓ Mainly for PV	✓ Mainly for PV	✓ Mainly for PV
Overall prospects.	Generally positive but some way to go.	Generally too early; hostile environment.	Generally positive, though electric utilities hostile.
×× - Not existing; × - Emerging only ✓- A few examples; ✓✓ - Widespread			

(Delta Energy and Environment)

5.6 Commercial Drivers

Electricity Prices

By far the most potent commercial driver of microgeneration use in on-grid applications is the price of its main competitor – grid-based electricity. Its impact is explored in detail in section 7, Economics of Microgeneration.

Driven to a great degree by the increasing cost of primary energy resources, electricity prices have been rising, sometimes sharply, in most parts of the world, including Europe, North America and Japan. In most of these regions, there is growing influence exerted by natural gas prices on the overall costs of electricity production given the increasing share of gas-based generation. Natural gas prices have increased dramatically since 2004 in the wake of successive oil price hikes (in Europe) and a rapidly tightening supply / demand balance (in the US).

In the US there is a clear expectation that electricity supply prices will continue to rise. Residential electricity prices rose by 5.5% in 2005. Some of the fastest increases occurred in the Northeast (particularly New England) and were caused, according to the US Department of Energy (DOE), by sharply higher prices for peaking fuels and very high summer demand for those fuels, particularly natural gas. The DOE forecasts further increases in delivered residential prices in many regions through to the end of 2007 at least.

The recent electricity price trends have been similar in Europe. While there are no official projections available from the EU, IEA or member states, general market expectation is that prices will continue to rise for at least the short-term. In Japan, electricity prices have traditionally been much higher than US prices, and higher than most parts of Europe, although there is growing competition in the electricity market that has reduced this differential. While a high nuclear share of generation insulates Japan in part to rising fossil fuel prices, gas, coal and oil have significant secondary market shares. The prices of all three have increased. As in Europe, there are no official price projections available, but it is likely that the higher price regime will be maintained.

Other Drivers

Other drivers include:

- Carbon markets, of which the EU Emissions Trading Scheme is the most important, have a central goal to increase the price of carbon-based energy, including natural gas and fossil-based electricity generation. In the EU, there is already clear evidence that the ETS is having some upward impact on electricity prices. As the ETS develops, and allocation levels become more constrained, it is probable that this impact will grow greatly in significance over the long-term.

- While increasing energy prices have direct impacts on the economics of microgeneration, they can also have an important impact on customer awareness and the motivation of consumers to consider increasing their independence from external supplies over which they feel they have little or no control. It is not easy, however, to assess the significance of this driver until a more active market for microgeneration emerges.

- Supply reliability has the potential to be an important driver for microgeneration if residential customers become concerned about the ability of the grid to provide unbroken supply. There were a number of high profile supply outages in Europe and North America in 2003, and again in the US in 2005 (associated with hurricanes). If these events continue, and when / if residential customers are able to secure a competitive microgeneration alternative, this may become an important driver of customer switch.

Gas Prices

As grid-based electricity supply prices have gone up, in part through their linkages to natural gas prices, the competitiveness of micro-CHP systems has improved. However, gas-fired micro-CHP systems are also seeing their fuel costs rise. This is generally more detrimental to those fuel cell-based micro-CHP systems with high power-to-heat ratios, since the volume of gas consumption will be much higher than for smaller heat-to-power ratio systems in providing a given amount of heat.

Rising gas prices will also be an issue in those countries where the gas and power prices are not closely linked. In this context, micro-CHP economics in parts of the US, Germany and Japan, with lower overall gas shares in generation, are a little more vulnerable to gas price rises than for example in the UK and the Netherlands which have higher shares.

The overall short-term world outlook for gas prices is flat or increasing as demand grows strongly, particularly in emerging markets. In some specific cases, for example the UK, prices may fall as interconnection and LNG infrastructure becomes operational in the next 1-2 years. The longer-term world outlook, however, is more uncertain, but is likely to be linked to demand growth rates in India and China, which are projected by the IEA to be around 7% and 14% / year respectively over the next 20 years. In Japan, for example, while the gas price has not moved up as fast as the oil price and is relatively stable, competition in the region for LNG is certain to become aggressive, with probable upward price impacts.

6 THE ECONOMICS OF MICROGENERATION

6.1 Introduction

Microgeneration economics are expressed in terms of:

- **Simple payback**: the capital cost of the equipment divided by annual revenues from electricity and heat (if any) less the yearly fuel (if any) and maintenance (if any) costs. In the case of micro-CHP, these relevant costs are usually the additional costs to a conventional boiler.

- **Levelised electricity costs**: the cost of electricity production over the lifetime of the unit. These costs are discounted over the lifetime of the unit. The levelised electricity cost effectively enables the cost of electricity generated by microgeneration to be compared with the cost of grid-supplied electricity.

Householder purchasing decisions for microgeneration technologies are governed by a range of diverse factors, which are often not well understood. Householders do not typically undertake detailed economic analysis and may base their decisions on whether they can afford the capital investment. Upfront costs are likely to play a part in market uptake, especially for more visible microgeneration technologies such as micro-wind and PV.

However, an economic assessment based on payback is most appropriate for capital purchases. For utilities and policymakers, the levelised electricity cost also provides a means of assessing these technologies against the costs of grid supply from central power stations via electricity networks.

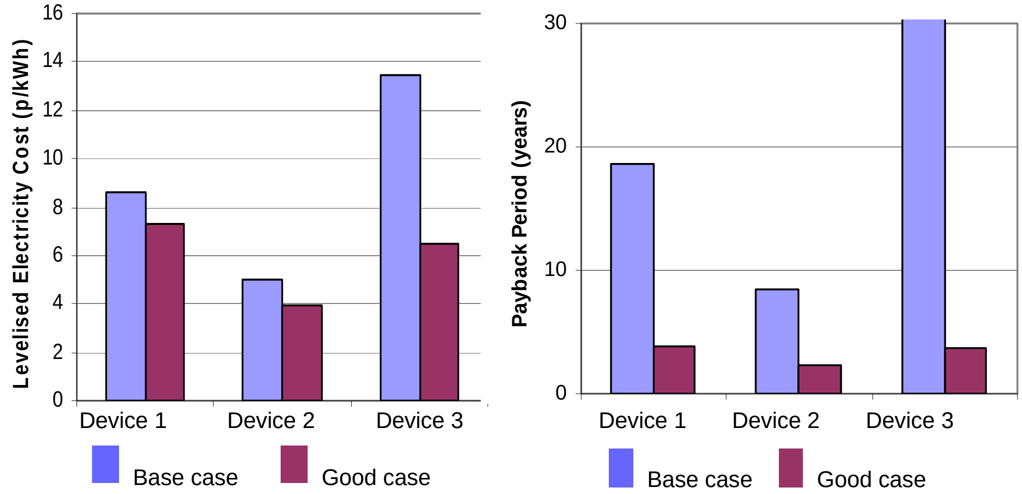
Delta has modelled these economic metrics for a range of micro-CHP and other microgeneration technologies, examining the sensitivities of these metrics to some key variables.

The modelling outputs provide an indicative understanding of the economics of microgeneration. **However, care should be used in using these results, as the economics are in some cases highly sensitive to assumptions that differ significantly both from country-to-country and application-to-application**. For example, the 1 kWe ECOWILL gas engine sells well in Japan and is priced according to that market, but its economics look relatively poor in European markets based on Japanese cost assumptions.

There are also **major uncertainties about the degree to which additional values microgeneration brings will be able to be monetised** (such as reductions in peak household power demand, explained further below, and reductions in carbon emissions). **Further uncertainties exist around possible reductions in equipment costs, maintenance requirements, and product performance**.

The figure below illustrates the impact that these uncertainties can have on microgeneration economics.

Figure 15 – Base case and good case scenarios for selected microgeneration technologies



(Delta Energy and Environment)

Although the differences in levelised electricity cost appear small, they are significant in markets where profit margins in retail electricity supply are typically below 10%, and in some cases below 5%. The differences in payback between the two scenarios are dramatic. The Good Case is a potentially achievable scenario, although certainly not in the short term.

The main features of the two cases are:

- The Base Case - the technologies are assessed without support schemes or payments for network, carbon or other benefits. In addition, the capital costs are based on estimates of prices when products are widely available in markets.
- The Good Case - the technologies benefit from incentive or support schemes (for example based on a renewables obligation, or, for micro-CHP, on an annual payment for the carbon savings and income from avoided utility costs). In addition, the capital costs have been reduced to a level expected that may be achieved a number of years after market introduction.
- Finally, in the Good Case, the electricity prices, both for import and export have been increased from 7p/kWh and 3.2p/kWh respectively to 9p /kWh and 6p/kWh respectively. These prices can already be found in a number of markets.

In both cases the operating regime, the installation environment and all other factors are kept the same. The specifications for each technology are given in the ‘Summary of Inputs' table in the Appendix (high efficiency Stirling engine and high load factor micro-wind turbine).

Key Sensitivities

Key sensitivities affecting economics include:

Capital cost – the outputs presented in this section show payback and levelised electricity costs for a range of capital costs.

Maintenance cost – for many micro-CHP technologies, and for mass market building mounted micro-wind, there is still uncertainty around maintenance costs.

For micro-wind, maintenance costs are a key area of uncertainty. Annual electricity cost savings can be in the £50 to £150 range. Utilities may aim to sell maintenance agreements with micro-wind products, which may be priced in the £50 to £75 range. This dramatically reduces customer savings, therefore dramatically increasing the payback and the cost of electricity. If there are no maintenance costs, the picture for micro-wind improves significantly.

- **Load factors**:
  - For micro-CHP, load factors are dependent upon space heat demand (although less so for high electrical efficiency fuel cells which will primarily serve hot water rather than space heating demands), and will vary according to the thermal demand from house-to-house. Delta has assumed likely load factors based on houses with moderate UK thermal demands.
  - For micro-wind, the amount of wind available over a rooftop will dictate the load factor. There is considerable uncertainty over typical load factors that will be achieved, with estimates ranging from above 20% to less than 6%. Delta has modelled two scenarios for micro-wind, with assumed load factors of 8.5% and 17%.
  - For PV, the amount and strength of sunlight dictates how much electricity is produced. Delta has modelled two scenarios, one for the UK (9% load factor) and one for Spain (21% load factor).
  - For micro-hydro, the costs and economics are extremely site specific. Delta has used typical data for a run-of-river scheme in the UK.
- **Electricity and fuel prices**. The higher the electricity price, the better the economics of microgeneration; for gas-fired micro-CHP, the lower the fuel cost, the better the economics. Electricity and fuel price sensitivity analysis is included below.

- Delta has assumed residential supply prices of 7p/kWh. These are currently a little lower than some UK residential prices, towards the lower end of European electricity prices, significantly lower than Japanese electricity prices, but higher than electricity prices in many parts of North America (except for California and north-eastern US).

- Prices paid for electricity exported to the grid are assumed at 3.23 p/kWh - the UK wholesale price plus 10%, the approximate tariff for embedded benefits. In some countries (such as Germany) feed-in prices are significantly higher, but in other markets it is not possible to get any value for electricity exported to the grid.

- Gas prices of 1.76 p/kWh are assumed, slightly lower than current European gas prices.

Other sensitivities tested include:

- **Subsidies and incentives.** In many markets there are subsidies and incentives available for certain kinds of microgeneration – such as grants to reduce the capital cost. Sensitivity analysis is presented below to illustrate the impact of investment subsidies on the cost of electricity from microgeneration.

- **Utility value streams**. Micro-generation can also bring value to utilities, potentially impacting (in some cases significantly) the economics of microgeneration. Utility values include the following, and **have only been incorporated into the economic analysis in Figure 15 above.**

  - The use of microgeneration to retain or acquire customers in competitive retail electricity and gas markets.

  - The ability of microgeneration to generate electricity during times of peak electrical demand. This can be extremely valuable as it can reduce the need for utilities to purchase (or generate) expensive peak-time electricity. In addition it can reduce the capacity requirements of distribution networks during times of peak demand. Micro-CHP (which typically generates during winter peaks) and PV (which typically generates during summer peaks) bring such value. This value is only included in the Good Case above and is estimated to be around £30 per year. This value is generally not well understood, even by utilities themselves.

  - Microgeneration can help utilities meet energy efficiency or low carbon obligations. For example, UK electricity and gas retailers have energy efficiency targets to improve energy efficiency in their customers' homes. Microgeneration can be used to meet these targets. This value is only included in the Good Case and is estimated to be a one-off payment of £100.

- If a utility owns a microgeneration asset, selling electricity to the home, then there can be value in meeting emissions targets, for example under the EU Emissions Trading Scheme. This will depend on the carbon saving attributed to the installation, and its value. This is valued in the Good Case above and is based on a C02 price of £17 per tonne and a saving in the range of 0.6 to 0.9 tonnes per year depending on the type of microgeneration.

6.2 Model Outputs

The technologies included in the assessment are shown below (further details of the modelling assumptions are shown in the Appendix).:

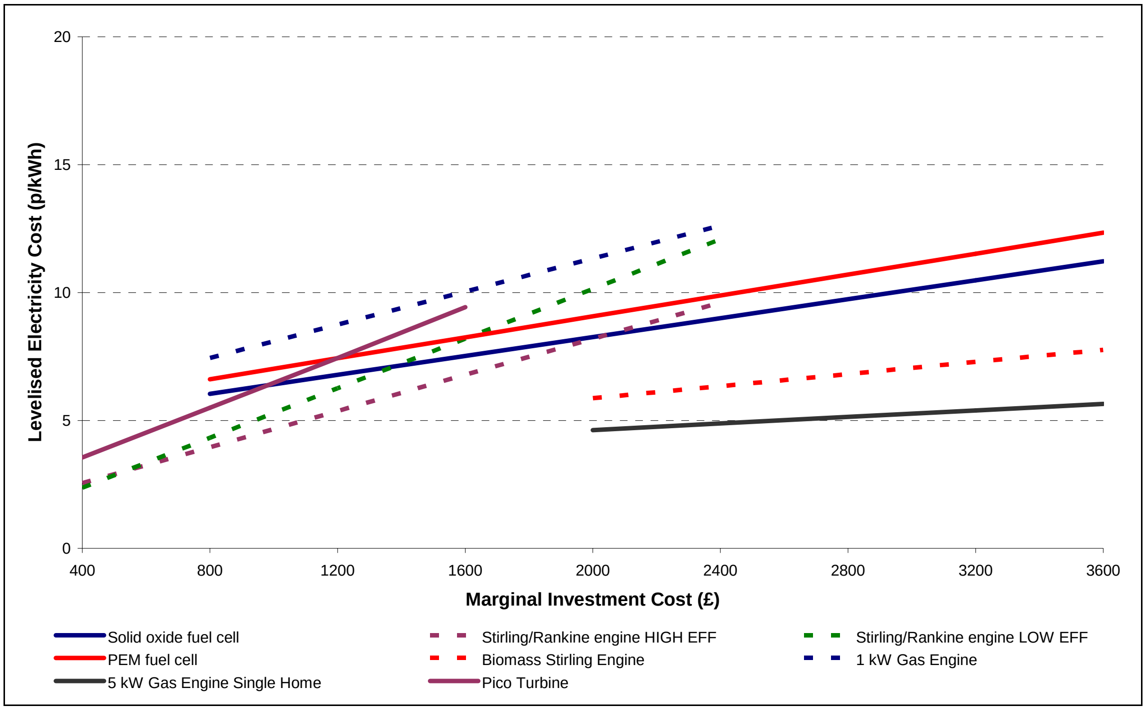
- Micro-CHP using natural gas:
  - 1 kWe Solid Oxide Fuel Cell in a single family house
  - 1 kWe Stirling Engine (or Rankine cycle engine) with low electrical efficiency in a single family house
  - 1 kWe Stirling Engine (or Rankine cycle engine) with high electrical efficiency in a single family house
  - 1 kWe PEM Fuel Cell in a single family house
  - 1 kWe Gas Engine (ICE) in a single family house
  - 1 kWe Pico-Turbine in a single family house
  - 5 kWe Gas Engine for a large single family house
  - 5 kWe Gas Engine for a multi-residential house
- Micro-CHP using biomass:
  - 3 kWe Stirling Engine for a large single family house
- Micro-Wind:
  - 1 kWe Micro-Wind Turbine in a low wind speed area
  - 1 kWe Micro-Wind Turbine in a higher wind speed area
- Photovoltaics:
  - 2 kWp Roof Mounted PV Array in a low solar area (for example the UK)
  - 2 kWp Roof Mounted PV Array in a high solar area (for example Spain)

- Mini-Hydro:
    - o 10 kWe Pico-hydro Turbine in a run of river location supplying an isolated farmhouse.

The figures shown below summarise the levelised cost outputs. The investment cost (for the microgeneration product) is shown on the x-axis. For micro-CHP, this is the investment cost over and above that for a conventional boiler (except for the 5-kW products, as these are not typically installed in place of a boiler). The y-axis shows the levelised electricity cost, which can be compared against the cost of grid-supplied electricity.

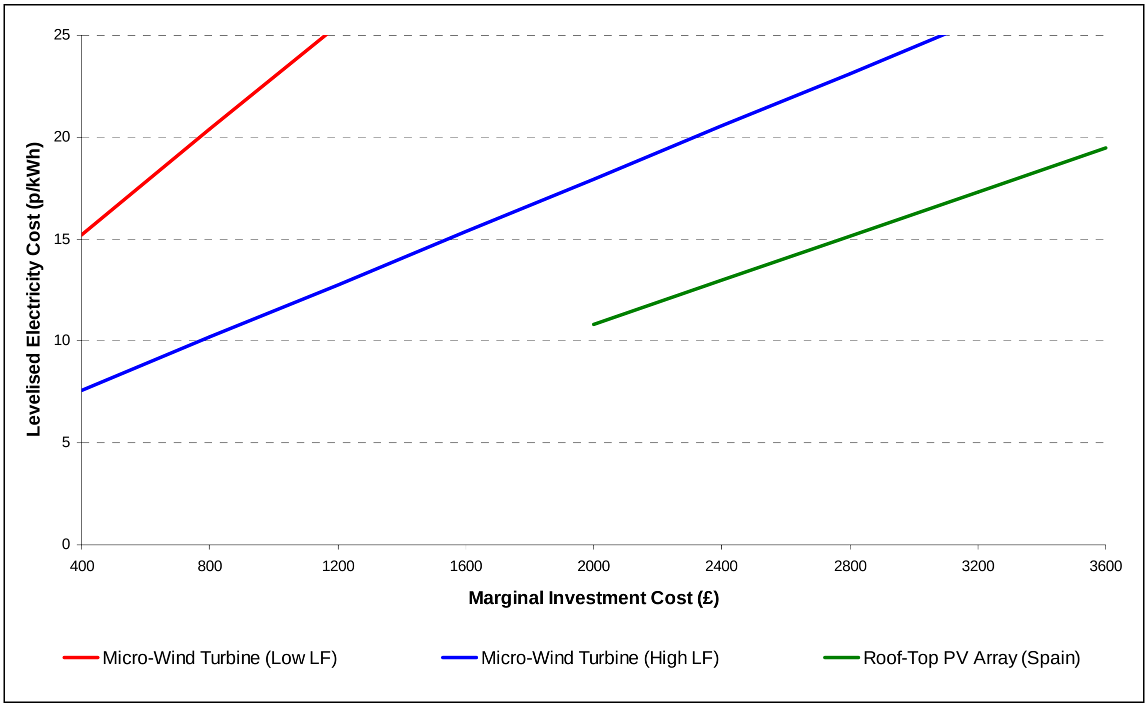
The plots show how the cost of electricity changes for different investment costs. The starting and ending points of each plot illustrate high-end investment costs as well as the potential for future very low investment costs.

Figure 16 – Levelised electricity costs for Micro-CHP technologies with varying investment costs



(Delta Energy and Environment)

Figure 17 – Levelised electricity costs for micro-wind and PV technologies with varying investment costs



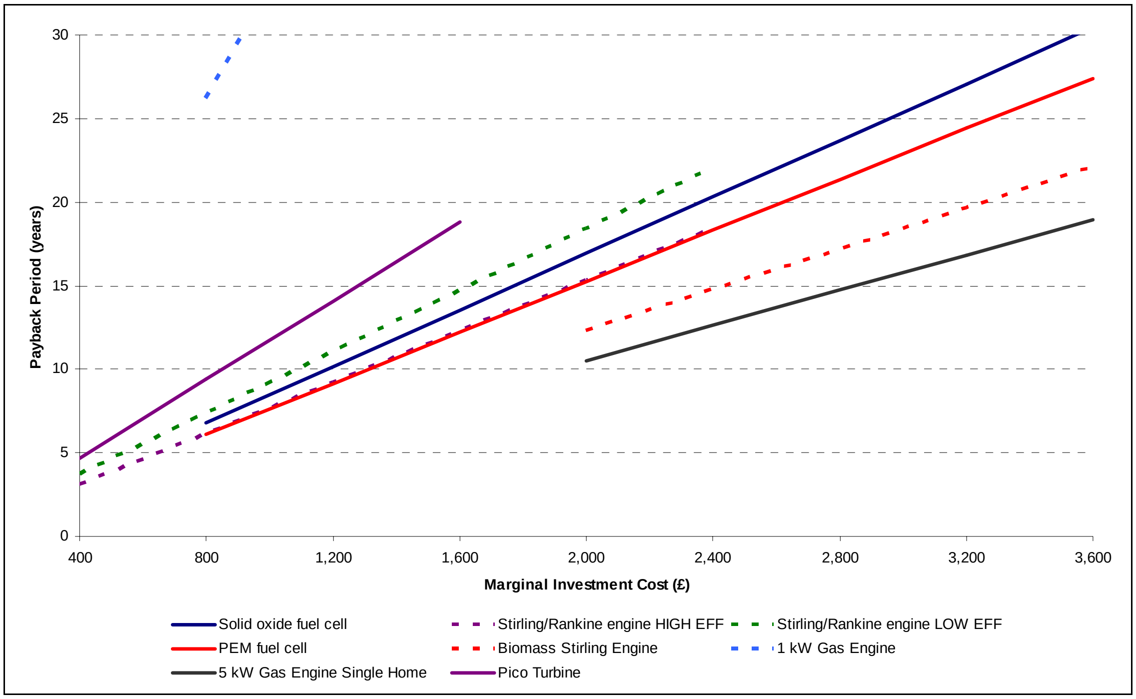
(Delta Energy and Environment)

These results suggest that:

- Micro-CHP technologies become competitive at around £800 - £1,600 / kWe.
- **For micro-wind, parity with grid-supplied electricity is harder to reach**, even for the high load factor scenario, given that even the most aggressive manufacturer's cost targets are £750 - £1,000 / kWe. If the assumed £75 per year maintenance costs are stripped out, the situation improves dramatically. In this case (£1000 / kW installed and no maintenance costs) the levelised electricity cost for micro-wind is 6.5 p/kWh.
- **PV costs need to fall substantially** from current levels to be competitive. Current module/system prices (uninstalled) are around £4,000 per kW.
- **Micro-hydro** is not shown on these graphs since the technology is already mature and the costs are very site-specific. The example used in the modelling, a 10 kW scheme, gives a levelised electricity cost of 5.8 p/kWh (with a range of 4 p/kWh to over 15 p/kWh depending on capital, installation and grid connection costs and turbine load factor).

The figures below summarise the payback outputs.

Figure 18 – Paybacks for Micro-CHP technologies with varying investment costs



(Delta Energy and Environment)

Figure 19 – Paybacks for micro-wind and PV with varying investment costs

(Delta Energy and Environment)

These results suggest that:

- Micro-CHP offers attractive paybacks at less than £800 - £1,000 / kW.
- Micro-wind cannot pay for itself under the low load factor scenario, where the assumed annual maintenance cost is more than the annual savings. For micro-wind in the high load factor scenario, when the installation cost is reduced and there is no maintenance cost, the payback period is reduced to 11 years.

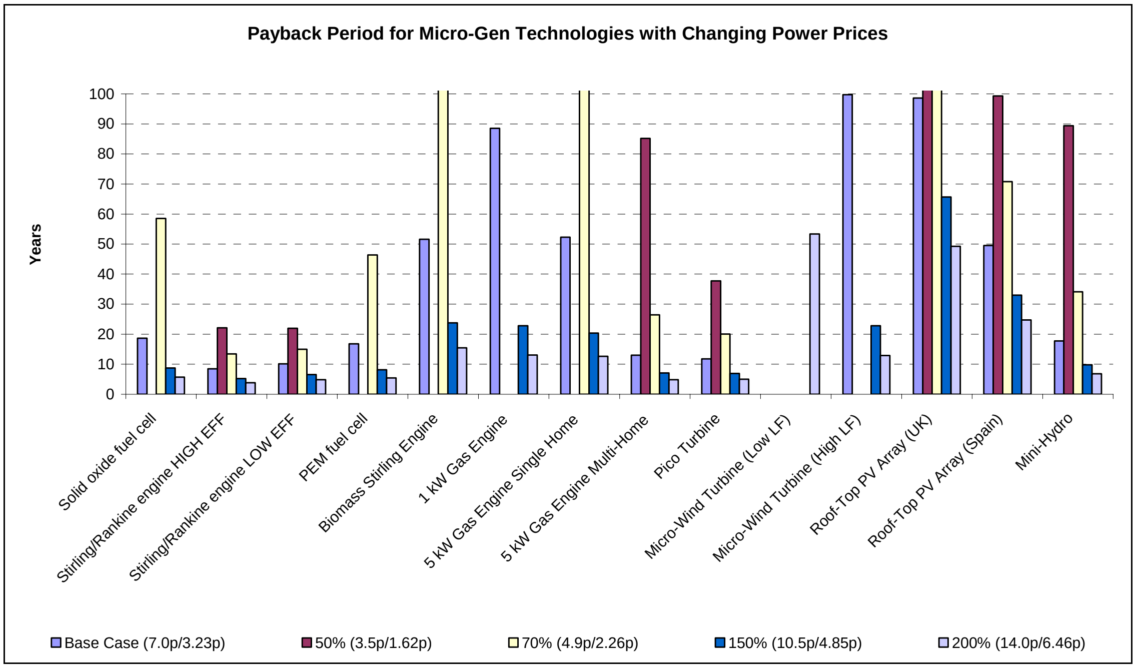
6.3 Sensitivity Analysis

The three key sensitivities that are explored are as follows:

- Electricity Prices
- Fuel Prices
- Investment subsidies.

The figure below shows the impact of variations of **power prices** on the payback periods for each of the technologies (no bar indicates no payback).

Figure 20 – The influence of changes in power prices

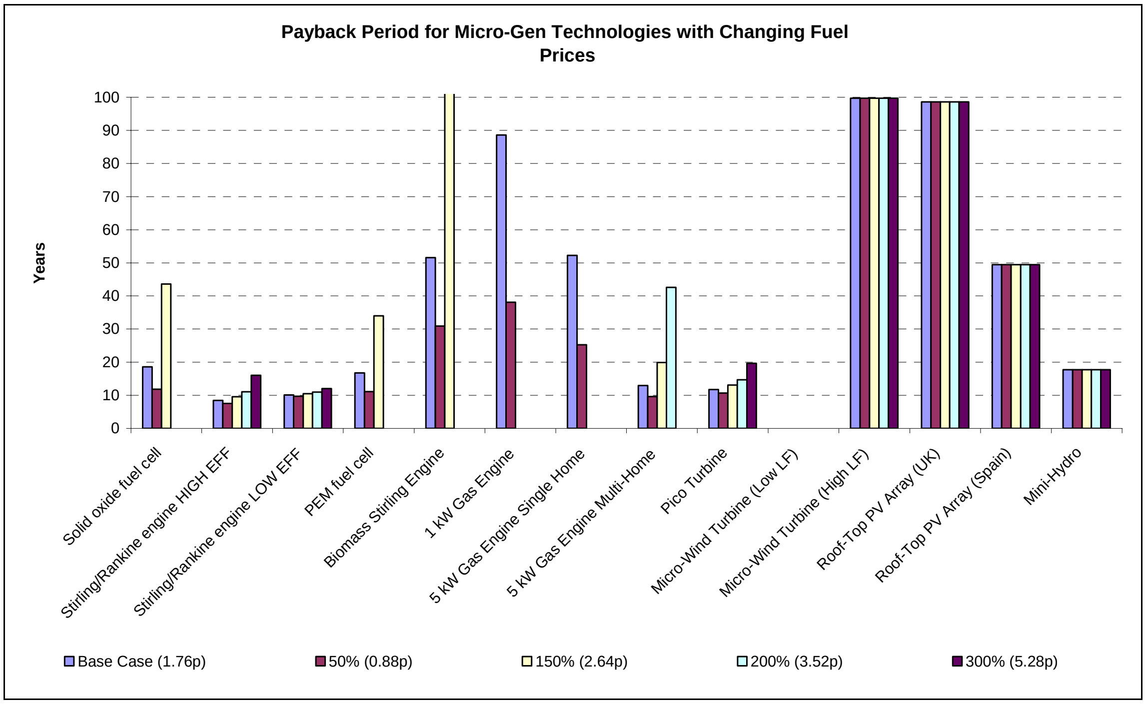


(Delta Energy and Environment)

Power prices are a key influence on the economics of microgeneration and this is especially the case for the renewable energy technologies. Power prices of the level of the mid-west of the US (50% of base case) result in the technologies being much less economic. In Europe and Japan, where prices are generally higher than the base case, suggest that the technologies are increasingly economic.

The figure below shows the impact of changes in **fuel prices** on microgeneration technologies.

Figure 21 – The influence of changes in fuel prices

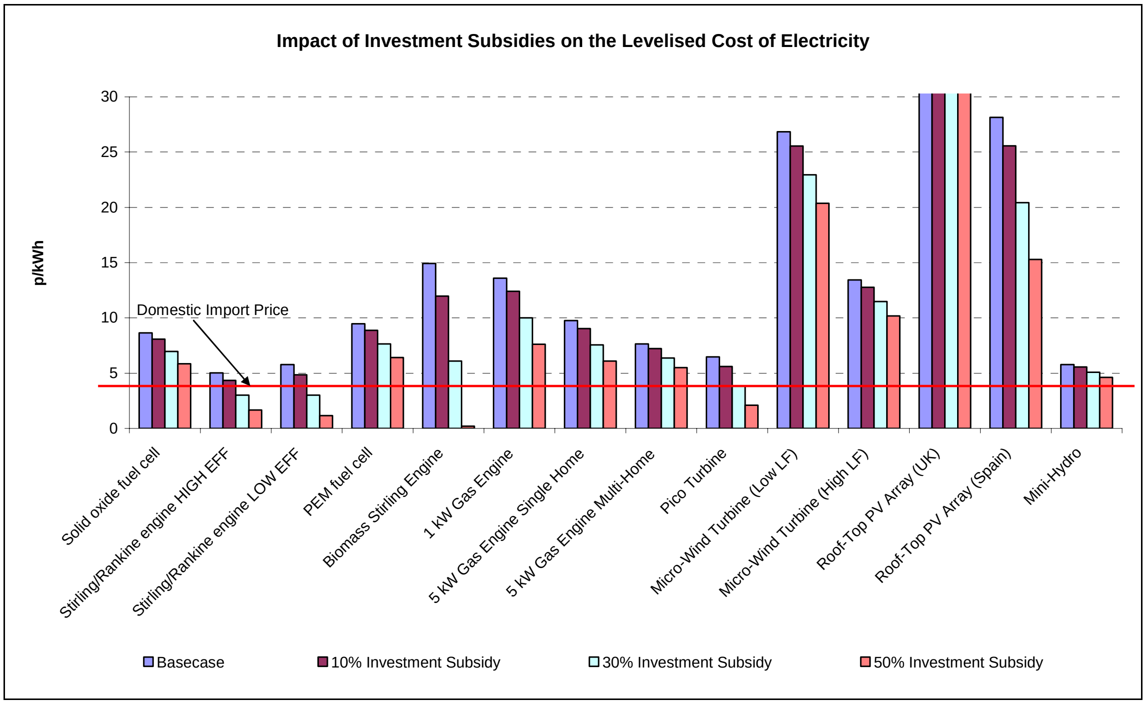


(Delta Energy and Environment)

Fuel prices only influence the technologies that use such fuels. However, rising fuel prices may also influence power prices in the same markets. The fuel for all, but the biomass Stirling engine, is natural gas. The micro-CHP technologies that are most insulated from natural gas price changes are the Stirling Engine, Rankine cycle engine and pico-turbine technologies. This is due to the high heat-to-power ratios of such systems. In contrast, micro-CHP schemes that export a high proportion of the electricity, such as SOFC CHP, or have low overall efficiency are more vulnerable to increases in fuel prices. Note that there is no impact on PV and micro-wind as they do not use any fuel.

The next figure shows the impact of **investment grants**.

Figure 22 – The influence of investment subsidies on the levelised cost of electricity



(Delta Energy and Environment)

The levelised electricity costs for most of the technologies fall below the assumed residential electricity price as the level of grant increases. Such grants have a significant potential for stimulating early market development by reducing the effective installation cost. It is, however, Delta's view that investment subsidies are unlikely to be sustainable beyond the initial market for each option.

7 MARKET SIZES FOR MICROGENERATION

7.1 SWOT Analysis and Potential Show-Stoppers for Microgeneration Technologies

For all microgeneration technologies, the major opportunity is to develop a mass market product that is attractive to customers – primarily by reducing their energy costs. This section preludes the market forecasts with a SWOT analysis for each microgeneration technology.

Micro-CHP

One of the main attractions of micro-CHP is that there is already an existing mass-market for boilers and furnaces, with over 8 million boilers sold in Europe, Japan, South Korea and North America (likely to be the initial markets for micro-CHP), with the figure rising to nearer 12 million units if furnaces in the North American market are also considered.

There is already strong gas utility and boiler company interest in Japan, and growing utility and boiler company interest in Europe. Continued such interest is likely to be crucial for mass micro-CHP markets to develop, at least in the short to medium term.

The degree to which this will happen in Europe is not yet clear. Strong interest is set to continue in Japan, with currently very little interest from utilities or boiler/furnace manufacturers expected in North America in the short to medium term at least.

Product requirements for micro-CHP products are very stringent, and it is not clear how many product developers will fully meet these requirements.

The major potential show-stopper is the ability of mass-market micro-CHP systems to meet the stringent product requirements demonstrated by conventional heating technology – primarily in terms of reliability and lifetime. This will take a number of years of operation to fully demonstrate. Manufacturing product at an acceptable cost premium over boilers/furnaces is another critical show-stopper.

Another threat to micro-CHP is that required regulatory forms will not take place. Straightforward grid interconnection is a make-or-break issue. In other cases reform is required so that all the benefits micro-CHP brings can be monetised.

SWOT Table Key

Bold = of high importance

Normal = of medium importance

Grey = of low importance

Figure 23 – micro-CHP SWOT analysis

Strengths	***Weaknesses***
• **Sells into existing markets for heating systems.** • **Potential for very low incremental cost on conventional boilers.** • **Typically generates power at times of peak demand, bringing significant value to power markets.** • Relatively straightforward to install. • Brings significant carbon reductions. • Growing government support and incentives for micro-CHP.	• **Stringent product requirements and cost targets.** • Some technologies require medium to high heat loads for good economic performance. • Conservative nature of installers. • Mass-production required to access serial production costs. • Product development, for some technologies, still requires large amounts of capital.
Opportunities	***Threats***
• **Growing (but not yet substantial) interest from boiler manufacturers and utilities.** • Rising electricity prices result in shorter paybacks. • Potential for customer pull through micro-CHP/microgeneration brand building. • Power outages could place premium on ability to generate without the grid. • Emerging distributed energy storage technologies could provide synergy with micro-CHP.	• **Boiler manufacturers and utilities do not drive micro-CHP market development.** • **Heat pumps (in Japanese market).** • Requires electricity sector regulatory reform fully capture all benefits. • Development of low energy homes (for all bar fuel cells). • Rising gas prices (mainly for fuel cells with their low heat to power ratio) • Lowering carbon content of grid electricity reduces carbon savings.

(Delta Energy and Environment)

Micro-Wind

Rooftop wind turbines are starting to gain much publicity, primarily in the UK, with two utilities already engaging with product developers in testing and even selling products.

One of the major opportunities for micro-wind is that it is a very visual technology, enabling people to demonstrate their green credentials and 'feel good' about their energy consumption.

This is likely to result in significantly more market pull when compared to a conventional energy efficiency technology such as cavity wall insulation, even though the latter is a much more cost-effective investment.

As with micro-CHP, utility engagement – with their marketing power and customer relationships – is likely to be crucial in developing mass markets.

In the UK, utilities are already engaged with product developers, or else are looking closely at this area. Elsewhere there has been some utility interest in the Netherlands, but little signs of activity elsewhere.

The major show-stopper for micro-wind is the possibility for lower-than anticipated energy outputs, due to lower-than anticipated wind resource over rooftops. Early performance data from installations (hundreds will be needed for reliable data) will provide a firm indication of whether or not this is a show-stopper.

Maintenance is also another critical issue. If annual maintenance is required, the cost of this will eliminate a significant proportion of annual electricity cost savings.

There is also a risk of catastrophic failures of the turbine (blades coming loose or the mounting becoming detached from the building) or for poorly designed or installed products blighting the market.

A final critical issue is the ability to install units without the cost and hassle-factor of seeking planning permission. This is currently an issue in some (but not all) markets.

An important issue for micro-wind is installation infrastructure. The turbines should not be "do-it-yourself" installed, so having a regional or national installation infrastructure is likely to be necessary – at least in the early days of market growth. Some utilities may be able to leverage existing infrastructure.

Figure 24 – micro-wind SWOT analysis

Strengths	*Weaknesses*
• **Extremely visual technology may generate customer excitement and customer pull.** • Potential for low-cost manufacture/assembly.	• **Poor current understanding of wind resource at roof-top level - low outputs will lead to poor economic performance**. • New installation infrastructure required for low cost installation in large numbers. • Certain building types may not be suitable for installing roof-top wind turbines.
Opportunities	***Threats***
• **Utility engagement to develop markets** • Potential to create customer-pull and brand as an aspirational product. • Emerging distributed energy storage technologies could provide synergy with micro-CHP.	• **Utilities do not drive market development** • **Annual maintenance is required, eroding electricity cost savings** • Polarisation on appearance of rooftop wind turbines. • Planning regime not reformed, so cost and complexity added to installations in some markets. • Planning regime may require permission to be granted for individual installations. • Lowering carbon content of grid electricity reduces carbon savings.

(Delta Energy and Environment)

Photovoltaics

PV technology remains many years away from widespread unsupported market introduction for mass-market microgeneration applications. However the sector continues to see rapid market growth and significant investment in manufacturing capability and new technology development.

Potential show-stoppers are reductions in the levels of government support leading to shrinking markets, lack of investor confidence and decreasing investment in new technology development.

Figure 25 – PV SWOT analysis

Strengths • Attracting large investment in new technology development. • Rapidly growing (grant supported) markets. • Visual technology may generate customer excitement and customer pull. • Technology can be integrated into (or displace the need for) building materials (eg tiles and cladding), effectively reducing costs. • Certainty in outputs.	***Weaknesses*** • Widespread, non-grant supported microgeneration applications still tens of years away. • PV is less attractive in high latitudes.
Opportunities • More governments introduce significant support schemes for PV, stimulating markets. • Technology breakthroughs dramatically lower costs. • Market growth leads to significant reductions in installation and balance of plant costs.	***Threats*** • Future cost reductions and technology developments not achieved. • Governments withdraw or do not widen grants and technology development funding.

(Delta Energy and Environment)

Pico-Hydro

The economic returns of pico- and micro-hydro schemes are generally within an acceptable range. However, given the highly site-specific nature of the hydro resource, the scope for anything other than small, or very small, niche markets in OECD markets will be limited. As electricity prices rise, there is some scope for on-grid development, but the number of feasible sites is dwarfed by the much more abundant opportunity for micro-CHP, PV and micro-wind.

Environmental concerns, mainly in the form of fish conservation, are also a persistent challenge. Though there are now new designs, described as 'fish friendly', that may overcome this constraint.

The developing country market is altogether different, with a suitable level of resource in many countries and abundant off-grid requirements. The market here is for low-cost, low-grade systems that can be produced in volume in the home market.

Figure 26 – Pico / micro-hydro SWOT analysis

Strengths • **Reasonable or even strong economic returns are possible, depending on site conditions.** • High, or very high, load factors. • Potential for low-cost manufacture/assembly. • Long project life-times.	***Weaknesses*** • Highly site specific, severely limiting market opportunity. • **Some visual and noise impacts.**
Opportunities • Developing country market opportunity is extensive, for relatively low-grade, low cost products. • **Some scope for community-based projects in OECD.**	***Threats*** • Growing environmental concerns, eg fish conservation and impacts on river flow.

(Delta Energy and Environment)

7.2 Market Size Forecasts for Microgeneration Technologies

Major uncertainties exist in relation to projecting the market sizes for microgeneration technologies. This is especially so for technologies that have not yet, or have only recently been, commercialised – micro-CHP and mass-market micro-wind products.

Micro-CHP market growth is arguably less uncertain than micro-wind market growth in that it the products sell into an existing market – the boiler market. Micro-wind (and PV) vendors have to create new markets for their products.

Given these uncertainties, Delta estimates that with strong (but plausible) market growth, by 2020 over 2.5 million micro-CHP products, over 0.3 million micro-wind products, and just under 10 million PV systems could be sold each year. Under some sets of assumptions growth could be even stronger.

More moderate growth assumptions give 2020 markets at 0.7 million micro-CHP units and 0.1 million micro-wind units a year. PV markets could be less than 2-3 million units a year.

Show-stoppers identified in section 7.1 could see market sizes considerably smaller than this, with sales number in the tens of thousands of units a year. PV market growth could be significantly weaker if subsidy programmes do not continue to be brought forward by governments.

7.3 Micro-CHP

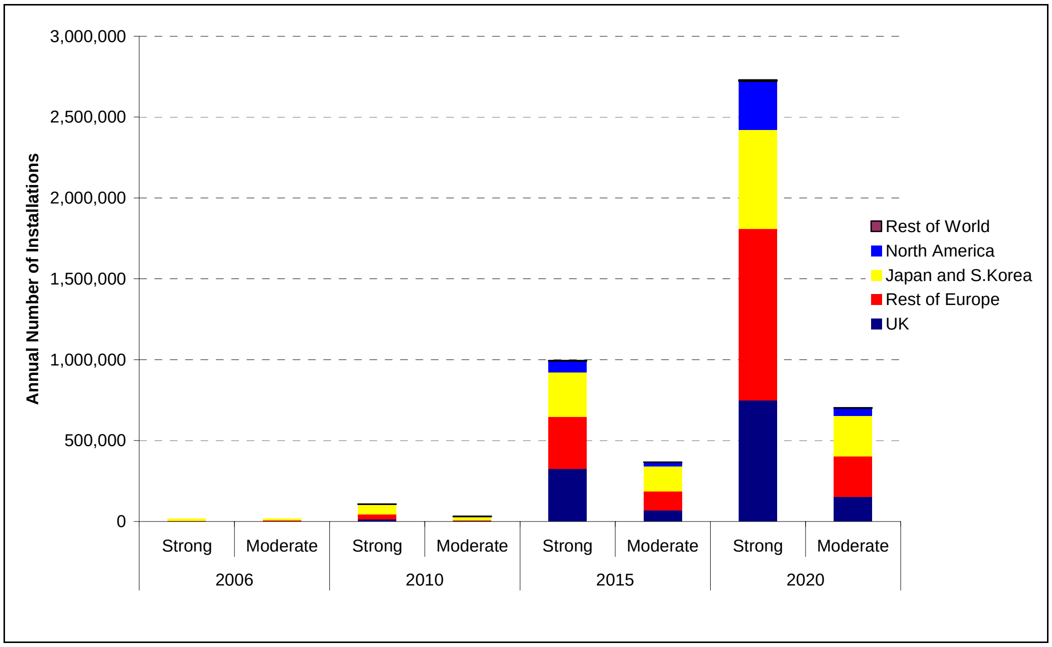
Delta has based its micro-CHP market projections (amalgamating all micro-CHP technologies) on assumptions for its penetration into boiler and furnace markets. This is based on Delta's understanding of market drivers and barriers and the policy, economics and SWOT analyses earlier in this report.

Little growth is expected to occur outside of Europe, Japan, South Korea and North America in the period to 2020. Towards the end of this period, markets in China and other emerging economies may start to develop, but this will only happen if markets first become established elsewhere.

Current boiler and furnace market sizes (in terms of units per year) are 5-6 million in Europe, 2 million in Japan and South Korea, and about 4 million in North America (mainly furnaces, with just under 0.5 million boilers; warm air heating systems served by furnaces are more challenging systems for micro-CHP to work with).

The following figure shows possible market growth scenarios.

Figure 27 – Micro-CHP market projections



(Delta Energy and Environment)

The Strong Growth Scenario represents a very good outlook for micro-CHP (although not the best outlook), but one that Delta believes is achievable under certain circumstances:

- Product developers meet their targets of product commercialisation timescales, and product performance. Fuel cell micro-CHP systems are widely brought to market in the first half of the next decade initially in Japan, and then in Europe and North America.
- Volume production is achieved (involving key players in the boiler industry) enabling manufacturers to offer products at low cost.
- European utilities, initially in the UK and Netherlands, and later on elsewhere, put their weight behind micro-CHP and drive market development. North American utilities, in the second half of the decade, start to push micro-CHP to market.
- Governments support the growth of micro-CHP markets, and regulators and the electricity industry remove key barriers.

The Moderate Growth Scenario is again plausible, but is one with weaker drivers and slower barrier removal for micro-CHP. This scenario may see product developers take longer to commercialise their products than planned, take longer to produce their products in volume and thus drive down costs, less encouraging regulatory and policy environments, and less drive from utilities and boiler companies in pushing products to market.

Market growth may even be much lower than the Moderate Scenario, 'bumping along the bottom' of the graph with sales remaining under, possibly well under, 100,000 units a year throughout the period. This may happen if products do not perform well in the initial stages of commercialisation, reducing market confidence and support from policy makers, boiler manufacturers and utilities show little – or only very tokenistic – support for these products, and no – or possibly negative progress – is made in removing regulatory barriers. Although plausible, Delta considers this scenario less likely.

The Strong Growth Scenario suggests that by 2020, micro-CHP unit sales rise above 2.5 million units a year, comprising just under one quarter of the boiler and furnace market in Europe, Japan and Korea, and North America (penetration becomes just over 30% if the North American furnace market is ignored), meaning that micro-CHP is firmly established as a mainstream and commonly found heating product. The Moderate Growth Scenario suggests that micro-CHP will only penetrate about 6% of the market – meaning that it may be fairly widespread in a few markets, but does not meaningfully penetrate many markets.

Market projections from other institutions are set out below. These demonstrate that although there is significant (and in some cases very significant) variation between forecasts, Delta's forecasts are within a plausible range.

- The Society of British Gas Industries projects micro-CHP market sizes for Great Britain of 117,000 (2010), 540,000 (2015) and 938,000 (2020) units per year.

- The Japanese Government and the Japan Gas Association predict that 200,000 to 250,000 ECOWILL micro-CHP systems will be installed (cumulatively) by 2010. This translates to over 40,000 units a year being sold by 2010.

- The Japanese Government has a target of 2,100 MW of stationary PEM fuel cells to be installed by 2010, expected to largely comprise of micro-CHP systems, and equivalent to 2.1 million such systems. Whilst this target is expected to be (significantly) undershot, it does demonstrate the scale of ambition in Japan. The South Korean government has also recently started giving increased attention to fuel cell adoption.

- In a recent study for the UK Government, the Energy Saving Trust predicted that by 2020 less than 50,000 (cumulatively) units will have been installed.

- At Delta Energy & Environment's 'Micro-CHP in Europe Summit: 2006' (held in February 2006), a group of 30 of Europe's leading utilities, boiler manufacturers and micro-CHP product developers gave their personal projections for the size of the European market in 2011. The mean projection was for 123,000 unit sales a year. Half the projections were for 50,000 units a year or less, whilst a quarter were for 200,000 units a year or more.

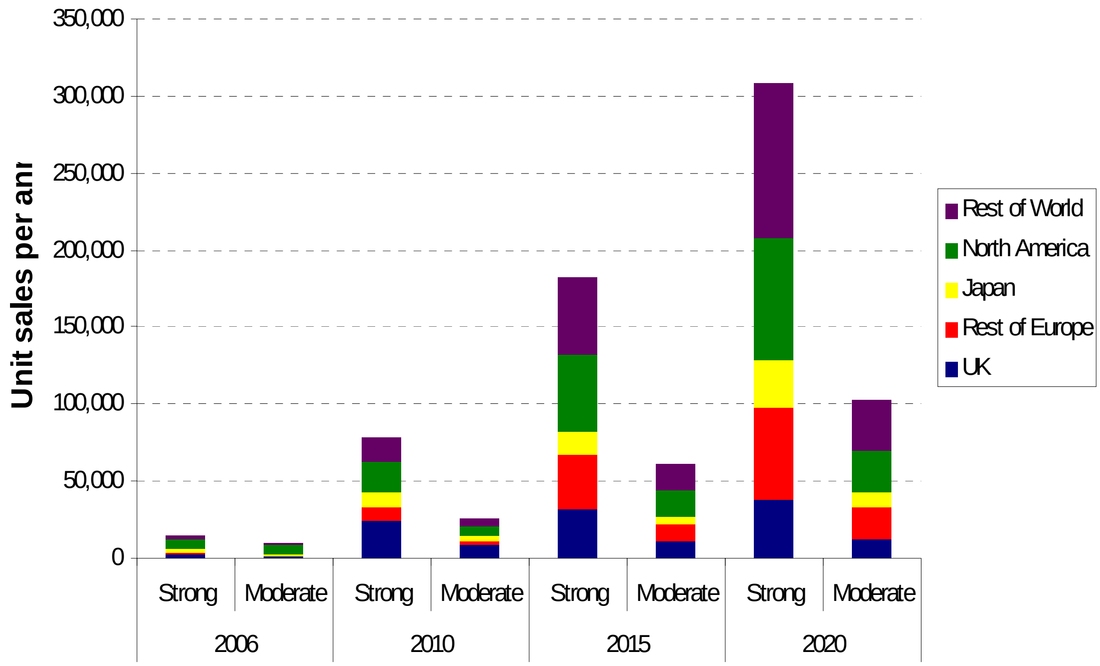
- A study for the UK Government on the network impacts of microgeneration assumed that by 2020 over 2,000 MW of micro-CHP capacity will have been installed in the UK, representing some 2 million 1 kW units.

7.4 Micro-Wind

Micro-wind market growth is perhaps the hardest to forecast amongst microgeneration technologies. Although small markets have existed for some time for relatively expensive non-building mounted products, markets for building-mounted products designed for mass markets have not started to develop. As noted in this report, considerable uncertainties around installed costs (targeted as low as £1,000 per kW for 1 kW capacity products, but currently much higher), load factors and energy produced, maintenance requirements and costs, and utility engagement affect market growth.

The only independent global market data publicly available is from a study published by the American Wind Energy Association in 2005. This predicts that nearly 13,000 small wind turbine systems were expected to be sold by US manufacturers in 2005, with the global market estimated at twice this size. Their definition of small wind covers products sized up to 100 kW, much larger than the 10 kW threshold used in this report. However the average size of the small wind turbines included in their study is 1 kW, meaning that a significant number of these units are less than 10 kW in size. These are used for a wide range of applications of which residential/small businesses are only one, and hardly any of the products are of the building mounted variety – where the mass market opportunity lies. In Japan the current market for micro-wind products (which are mainly used in street lighting and demonstration projects) is estimated at a few thousand units a year, as illustrated in the following figure.

Figure 28– Micro-wind market growth projections



(Delta Energy & Environment)

Sales of thousands of mass-market micro-wind products are planned, by developers, to commence in 2006. Delta's Strong Growth Scenario shows global sales rising to over 80,000 units in 2010 and more than 300,000 units by 2020. This is dependent upon mass-market products proving themselves (with respect to low cost, excellent performance, acceptably high energy production, and zero or extremely low maintenance requirements) in the UK and Japan initially, and then penetrating several other major markets including North America. This is likely to require significant utility engagement and market push, as well as favourable government policies and regulatory reform in a number of major markets.

One UK developer expects to launch their product in May 2006 and sell over 20,000 units in the first 12 months of sales. Another UK developer expects to reach sales of 10,000 units a year in the first few years of sales and believes that they will be selling more than ten times this number worldwide. If these developer expectations are realised then markets may grow more rapidly than in the Strong Growth Scenario.

Delta's Moderate Growth Scenario represents one third of the Strong Growth Scenario. Again products designed for mass-markets will have to prove themselves (as described above), but under this scenario utilities do not give the same push to these products and markets are harder to develop, with perhaps less supportive policies and less progress on regulatory reform in some markets.

If mass-market designed products do not prove themselves (with respect to cost, performance, energy production, or maintenance requirements), then market growth may be significantly less than the Moderate Growth Scenario. In this case, market growth may be limited to steady growth of products already commercialised (not generally designed for mounting on buildings), with sales of less than around 30,000 units a year worldwide by 2020.

Two other sets of forecasts have been made for the UK:

A recent study carried out by the Energy Saving Trust for the UK Government predicted that, without subsidies, between 13,000 and 50,000 (1.5 kW capacity) units would be installed (cumulatively) by 2020. With subsidies, this number rose to over 75,000 units – less than Delta's Moderate Growth Scenario predicts.

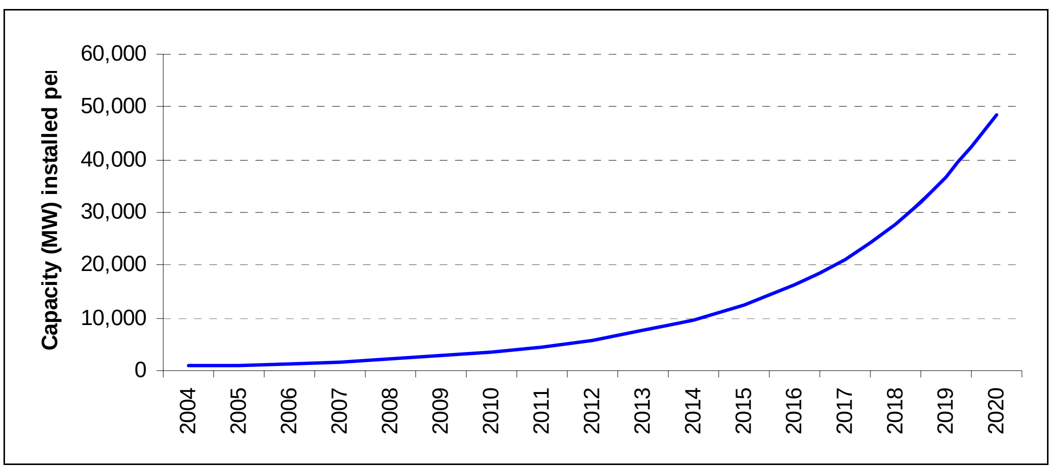
A study for the UK Government on the network impacts of microgeneration assumed that by 2020, over 140 to 270 MW (medium and high scenarios) of micro-wind capacity will have been installed (cumulatively) in the UK, representing some 93,000 to 180,000 1.5 kW units.

7.5 Photovoltaics

Future market growth will be highly dependent on large government subsidy programmes. Whilst there is a risk that governments may withdraw such support and that no new programmes will be introduced, Delta's view is that more rather than less subsidy programmes are likely in the future.

The European Photovoltaic Industry Association estimates future market growth at 28% per year (such growth rates have been seen in recent years) through to 2010, and 35% thereafter. This gives around 0.75 million units a year in 2010 and just under 10 million units a year in 2020 (assuming an average unit size of 5 kWp).

Figure 29 – PV market growth



(Delta Energy & Environment; data from European Photovoltaics Industry Association)

8 KEY SCOTTISH AND GLOBAL PLAYERS

Can Scotland become a leading or significant player in the growing microgeneration sector? This section examines the principal companies and institutions involved in the microgeneration sector, focusing on product development, manufacturing and significant areas of research expertise (rather than covering all research activity, component supply and sales and servicing of microgeneration equipment, which are outside the scope of this work).

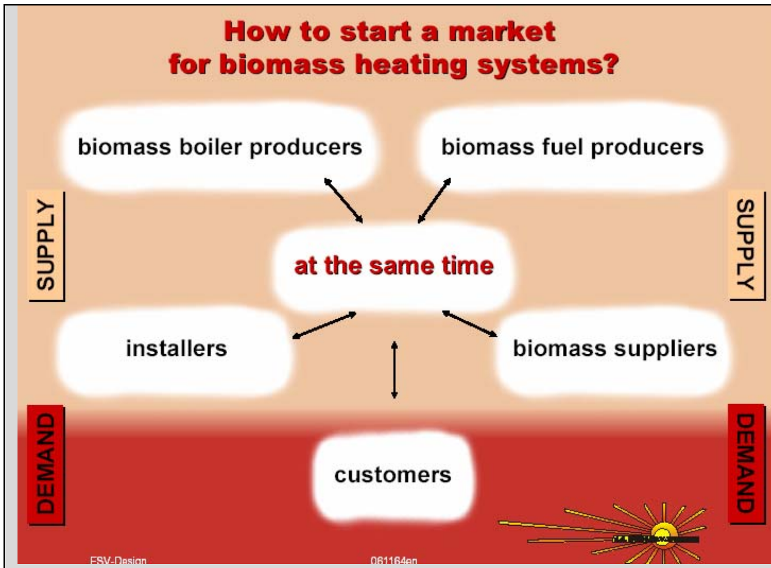
Micro-wind stands out as the sector where Scotland has the clear potential to compete globally. Scottish companies are amongst the leading developers of products with the potential for mass-market applications.

It could also be possible to stimulate the development of fuel cell technology in Scotland for micro-CHP applications, although global competition in this area is intense. Opportunities may also exist to attract micro-CHP production facilities to Scotland, benefiting from what may be rapid growth in the UK and other European micro-CHP markets. However picking winners amongst a wide-range of technology developers brings a large slice of risk.

For photovoltaics, micro-hydro and biomass boilers it is not clear that Scotland is capable of becoming a global leader in these areas. For PV, there are clearly new technology developments required, there is already some research capability in Scottish universities, although possibly only that at Heriot Watt could be described as globally competitive research. Possibilities could exist to attract technology research from other markets to Scotland, possibly using Scotland's semiconductor and electronics capability. However this possibility requires further investigation.

Biomass Heating Cluster in Upper Austria

The region of Upper Austria, centred around the town of Linz, is one of Europe's leading regions for biomass utilisation for residential heating. With an excellent local biomass resource, and a high reliance on oil fuelled heating systems, the regional government's Energy Plans have put a high priority on increasing biomass fuel sources together with other forms of renewable energy. They realised that they must both create demand for biomass heating systems, as well as building supply chain capability, as shown below.



UPPER AUSTRIAN ENERGY SAVING AGENCY

A variety of techniques were used to build demand, including financial support, energy advice, an energy hotline and publications and events. To meet demand, research and development was supported, together with training and education work. The Oekoenergie-Cluster was formed, which now consists of a network of 140 renewable energy companies comprising a turnover of €390 million (export share of >50%) and employing almost 2,800 people.

This concerted effort to build a domestic market for biomass technology has resulted in world-leading biomass heating technology companies developing in Upper Austria with substantial export opportunities.

8.1 Micro-wind

Scottish players

Scotland is home to one of the world's leading micro-wind manufacturers (Proven) and two companies (Windsave and Renewable Devices) developing building mounted wind turbines that appear to be, globally, in the leading group of companies developing products for this market.

Table 18 – Scottish micro-wind companies

Company	Website	Summary
Product developers/manufacturers		
Windsave		Developing a 1 kW building mounted wind turbine, plans for mass launch from mid 2006 and sales of 20,000 units in following 12 months.
Renewable Devices		Developed a 1.5 kW building mounted wind turbine (and developing a 1 kW product); an order from Scottish & Southern for 2,000 units in 2006.
Proven		Established manufacturer of 0.6 kW to 15 kW wind turbines (typically not building mounted), selling about 150 units a year and seeing strong growth in sales. Also developing concept for rooftop wind turbine.
Others		
NEL		Have a wind test facility (mainly for larger wind turbines) and behind the development of Scottish Enterprise's Energy Technology Centre which includes wind turbine test facilities. Specific NEL capabilities include testing, certification and engineering development.
Strathclyde University		Has developed a ducted rooftop wind turbine systems, with a prototype installed. Future development is unclear.

(Delta Energy and Environment)

Renewable Devices, based in Edinburgh, started developing a rooftop wind turbine in 2002, and in 2004 announced an order for 2,000 from Scottish & Southern Energy. To date, about 60 units have been installed, with a further 2,000 units planned to be installed over the next 12 months. Virtually all of the materials and components are sourced from within the UK. Renewable Devices say that about 50% of the value of the product is from components sourced from outside of Scotland, with the remaining 50% (much of which is machining) within Scotland. Production (or elements of production) may move overseas after 3-4 years.

Windsave, based in Glasgow, was formed at about the same time to develop a mass-market building mounted wind turbine. About 130 units have currently been installed, with the company planning a mass launch in May 2006 and projecting sales of about 20,000 units in the following twelve months. Windsave secured some components (blades, generator, inverter) internationally with the product being 'marshalled' in Scotland. They estimate that around 35% of the product value is within Scotland.

Proven, based in Ayrshire, manufacture 0.6 kW to 15 kW wind turbines, and have sold over 1,000 units since they were formed about 25 years ago. Last year they sold about 150 units, and see sales increasing at about 50% a year. Although only a handful of their products have been installed on buildings, they are also investigating the possibility of developing units specifically designed for buildings which may be suitable for mass-markets. They estimate that about three quarters of the value of each sale is Scottish-based.

Global Players

The current market for (non-building mounted) micro-wind products is relatively diverse, although four North American companies, according to the American Wind Energy Association, have about half the market. Numerous other manufacturers are located around the world.

There is a rapidly growing list of companies developing building-mounted wind turbines. One developer estimates there are over 60 companies worldwide. Delta's research supports this estimate. A selection of these companies – in Delta's view, those that are relatively advanced in either manufacturing product for non-building mounted applications and those which are advanced in developing product for the building-mounted market – are shown below.

Table 19 – Selected global micro-wind product developers and manufacturers

Company	Country	Summary
Zephyr	Japan	Developed a 1 kW building mounted wind turbine, plan to sell 5,000 in 2005-6 in Japan.
Ecofys	Netherlands	Testing prototype 1 kW systems in 2006 – hope to sell (via distributors) hundreds of units in 2007.
Bergey	US	Claim to be the world's leading supplier of small wind turbines, they supply 1 kW and 10 kW machines (not-building mounted), with units installed in over 90 countries.
Southwest Windpower	US	Report sales of more than 70,000 turbines in the 0.4 to 3 kW size range, with (typically not building-mounted) installations in a wide range of applications.
Eclectic Energy	UK	Developed 0.6 kW system for marine and off-grid market, and currently testing systems for grid-connected mass-market (building mounted) applications.

(Delta Energy and Environment)

8.2 Micro-CHP

Scottish Players

There are relatively few Scottish players in the micro-CHP arena, as shown in the table below.

Table 20 – Scottish Micro-CHP companies

Company	Summary
Technology Developers	
Fuel Cells (Scotland)	Developing solid oxide fuel cell technology. A proof of concept stack has been built with over 4,000 running hours.
St. Andrews Fuel Cells	Spin off from St. Andrews University – now with venture capital funding to commercialise novel solid oxide fuel cell technology (target within five years).
Kelvin Micro-CHP	Developed unique reciprocating engine technology that could be developed for micro-CHP applications. Currently in R&D/prototype stage of development.
Others	
NEL	Behind the development of Scottish Enterprise's Energy Technology Centre. Specific NEL capabilities include testing, certification and engineering development – covering product development activity.
SiGEN	Not a technology developer, but an applications engineer and systems developer. Partnerships with leading fuel cell product developers and with fuel cell end users.
Strathclyde University	UK partner for the International Energy Agency's Annex 42 work on microgeneration, looking specifically at micro-CHP system performance. Also working on other areas including PEM fuel cells and internal combustion engine micro-CHP.

(Delta Energy and Environment)

Both Fuel Cells (Scotland) and St. Andrews Fuel Cells are developing innovative SOFC technology. Fuel Cells (Scotland) key technology advantage is their seal-less fuel cell stack technology, and they have currently built two prototypes and are now building full-scale stacks. St. Andrews Fuel Cells hope to have prototypes up and running in about one year's time, and are using a hybrid planar-tubular concept. Both companies believe they have significant cost advantages compared to other SOFC fuel cell developers.

Kelvin Micro-CHP has developed an innovative reciprocating engine technology able to yield higher efficiencies than conventional technology. A prototype engine has been developed.

Global Players

Delta tracks over thirty companies developing products for the micro-CHP market. Selected developers, together with those already having commercialised their product, are detailed below.

Table 21 – Selected global micro-CHP product developers and manufacturers

Company and location	Country	Summary
Stirling Engine		
Sunmachine	Germany	A start-up company, commercialising in 2006 a biomass (pellet) fuelled Stirling engine in the German market, with a sales target of 3,000 units in 2006.
Microgen	UK	Subsidiary of BG Group, over £60M investment; commercialisation of product planned in 2007 for UK and Netherlands with Germany shortly to follow.
ENATEC	Netherlands	Dutch utility ENECO is the major shareholder. ENATEC has partnered with Japanese gas appliance manufacturer Rinnai and European boiler manufacturers. Targeting product launch in 2007-8.
Fuel Cells		
Ebara-Ballard	Japan/Canada	Joint venture between fuel cell technology developer Ballard and system developer Ebara. Targeting market launch in Japan from 2008, working with gas and oil suppliers. Current widespread field tests.
Kyocera	Japan	Kyocera are a major ceramics company and are field testing a high-electrical efficiency unit with Osaka Gas.
Toshiba	Japan	Targeting market launch in Japan from 2008, working with gas and oil suppliers. Current widespread field tests.

Table 21 (continued) – Selected global micro-CHP product developers and manufacturers

Company and location	Country	Summary
Fuel Cells (continued)		
Ceramic Fuel Cells Ltd	Australia/UK	Australian technology company looking to commercialise their technology in Europe. A UK office and set to list on AIM market and establish European ceramics manufacturing capability.
Vaillant-Webasto	Germany	Partnership between Europe's number 2 boiler manufacturer and €1bn automotive components supplier to develop and commercialise fuel cell product.
Ceres Power	UK	Developing innovative fuel cell technology and has partnership with Centrica.
European Fuel Cell	Germany	Subsidiary of Baxi Group, a top five European boiler manufacturer. Currently field testing prototypes in UK and Germany - market introduction from 2010-12
Internal Combustion Engines		
Honda	Japan	Established manufacturing capability of 50,000 units per year. Currently selling more than 10,000 units a year in Japan, launching in the US in 2006 and investigating European opportunities.
Yanmar	Japan	Active in the Japanese market for a few years, selling hundreds of units a year through gas utilities.

Company and location	Country	Summary
SenerTec	Germany	Owned by Europe's number 3 or 4 boiler manufacturer Baxi, active in the German market since 1997, and have sold more than 10,000 units.
Rankine Cycle		
Baxi	UK	Europe's number 3 or 4 boiler manufacturer, developing low-cost micro-CHP product. Prototype unveiled and targeting market launch by 2008.
Otag	Germany	Start-up company, have developed and launched product for single-family homes in Germany. Expect 600 units to be sold in 2006.
Pico-Turbine		
MTT	Netherlands	Dutch start-up, established partnerships with a number of other organisations to develop and commercialise (target: 2009) gas turbine that will substitute burners in boilers.

(Delta Energy and Environment)

8.3 Photovoltaics

The market for PV cell/module production is relatively disparate – the top eight companies, shown in the table below, account for 65% of the global market (2004 data).

Table 22 – Selected global PV cell and module component manufacturers

Company	2004 Production (MWp)	Manufacturing sites
Sharp	324	Japan
Kyocera	105	Japan
BP Solar	85	Australia, Spain, US, India and elsewhere
Mitsubishi	75	Japan
Q-Cells	75	Germany
Shell Solar	72	US, Germany
Sanyo	65	Japan
RWE Schott	63	Germany and US

(Delta Energy & Environment, from Renewable Energy World)

The above companies are, with the exception of Q-Cells, large, well capitalised multi-national corporations. Although the PV market is growing rapidly and there are a large number of other PV manufacturers, the opportunity for Scotland to become a major PV cell/module manufacturer is not clear.

Whilst there is PV research activity ongoing in Scottish Universities (Strathclyde University, Glasgow University, The Robert Gordon University, St. Andrews, Napier University, Dundee University and Heriot Watt University, according to Universities Scotland submissions to the Scottish Executive's Renewable Energy in Scotland Inquiry, February 2004), there does not appear to be any immediate potential for spin-off activity with the ability to compete globally in the PV cell/module market. One possible exception is the thin film PV research ongoing at Heriot Watt University.

Given there is certainly substantial further technology development required in the PV industry, there is also potential to attract technology developers from overseas to

Scotland if there is a relevant skills base in Scotland. This area requires further investigation.

8.4 Micro-Hydro

There is no clear evidence of Scottish manufacturing capability in the micro- or pico-hydro field, although there are a small number of service and installation companies. The major players in the sector, producing systems for use in OECD markets, are based elsewhere in the UK and continental Europe, or in the USA.

The manufacturers of products that were accredited by the UK Clear Skies programme (with a bias towards UK companies) included:

UK companies: Valley Hydro, Derwent Hydro, NHT Engineering, Greenearth Energy, Hydro Generation and Energy Systems and Design. None of these companies are located in Scotland.

German companies: Ossberger, Ritz-Atro, Wasserkraft Volk and Hydrowatt.

North American companies: Nautilus Water Turbine and Powerpal.

The Scottish potential appears therefore to be minimal, although there will continue to be capability in project development. There is therefore little sign of a role for ITI Energy in this sector.

8.5 Biomass-Fuelled Residential Heating Systems

Major manufacturers of biomass heating systems are primarily located in a few European countries, with Austrian companies currently dominating the market for biomass boilers, and Austrian and Italian companies dominating the market for biomass stoves. Other manufacturers exist in Germany, Sweden and Denmark in particular.

There is no manufacture or technology development of residential biomass heating systems in Scotland to Delta's knowledge. It is not clear what would enable Scotland to compete with the current leading biomass boiler and stove manufacturers.

9 POSITIONING FOR ITI ENERGY IN MICROGENERATION

9.1 Conclusions made by Delta Energy and Environment

9.1.1 Micro-wind

There is potential for Scotland to consolidate its leading position in the micro-wind area, specifically through Windsave, Renewable Devices, and Proven Energy. These companies appear to be global leaders in micro-wind (and small-wind) applications, and are supported by capability at NEL and Scottish Enterprise's Energy Technology Centre.

There is scope for both continued technology development (although Renewable Devices and Windsave report they have overcome fundamental technology and product engineering challenges) and in particular mass-manufacturing capability – although there is a risk that companies may move manufacturer overseas to access lower costs (for some companies, key components – blades and inverters for example – are already sourced internationally).

Continued and further incentives for rooftop wind turbine markets in Scotland and the rest of the UK should be put in place to ensure that these companies can continue to grow through a strong home market as well as exporting their products to other markets. Although this is not a role for ITI Energy, securing a strong domestic market – together with investment in micro-wind product developers (for technology development if necessary and manufacturing capability) could lead to Scotland replicating the success of Austria with biomass heating, or Denmark with larger wind turbines.

Critically, however, it is not yet clear that micro-wind will indeed develop into a mass market. Key issues include energy output from roof-top wind turbines, customer attitudes, and the amount of 'utility push'. Investment in this sector, at this stage, would be taking the risk that mass markets do not develop.

Delta recommends that further investigation is necessary to determine whether these companies are seeking investment, and whether this investment is required for technology development or for mass manufacturing capability. Further investigation of the potential for micro-wind mass markets to develop may also be required, depending on the degree of risk ITI Energy is willing to accept.

9.1.2 Micro-CHP

ITI Energy could stimulate the development of Scottish-based technology – for example Fuel Cells (Scotland), St. Andrews Fuel Cells and Kelvin Micro-CHP. The opportunities in the micro-CHP market are large, but the competition is numerous and strong. For fuel cells, companies in Germany, Japan, the US and Canada in particular benefit from strong government (local and/or federal support) which has leveraged in large private sector investments in developing fuel cell technology and products. Scottish-based fuel cell technology companies will require significant funding to enable them to compete on a global scale.

Kelvin Micro-CHP has developed novel reciprocating engine technology that could have attractive features for micro-CHP applications, although reciprocating engine micro-CHP (for mass-markets) faces strong competition from other emerging micro-CHP technologies.

ITI Energy could also attract investment in manufacturing capability from micro-CHP product developers outside of Scotland, or to attract technology developers from overseas to Scotland as a base to develop their technology. This would require more detailed assessment of Scotland's capabilities with regard to specific skills. Scotland is an attractive location in that the UK is likely to be Europe's leading micro-CHP market within the next few years. The Scottish Hydrogen and Fuel Cell Association is actively encouraging such inward investment from global fuel cells technology developers.

There is little sign of a role for ITI Energy in biomass, PV and micro-hydro, further investigation is required across these areas.

9.2 Conclusions made by ITI Energy

ITI Energy has taken on board Delta's analysis and their conclusions and recommendations. After consideration of these and further internal deliberation ITI Energy concludes that:

Overall, microgeneration is not a top priority for ITI Energy to focus its investment attention, relative to other areas like mature oil and gas, energy storage, offshore renewables and power management.

This is mainly because:

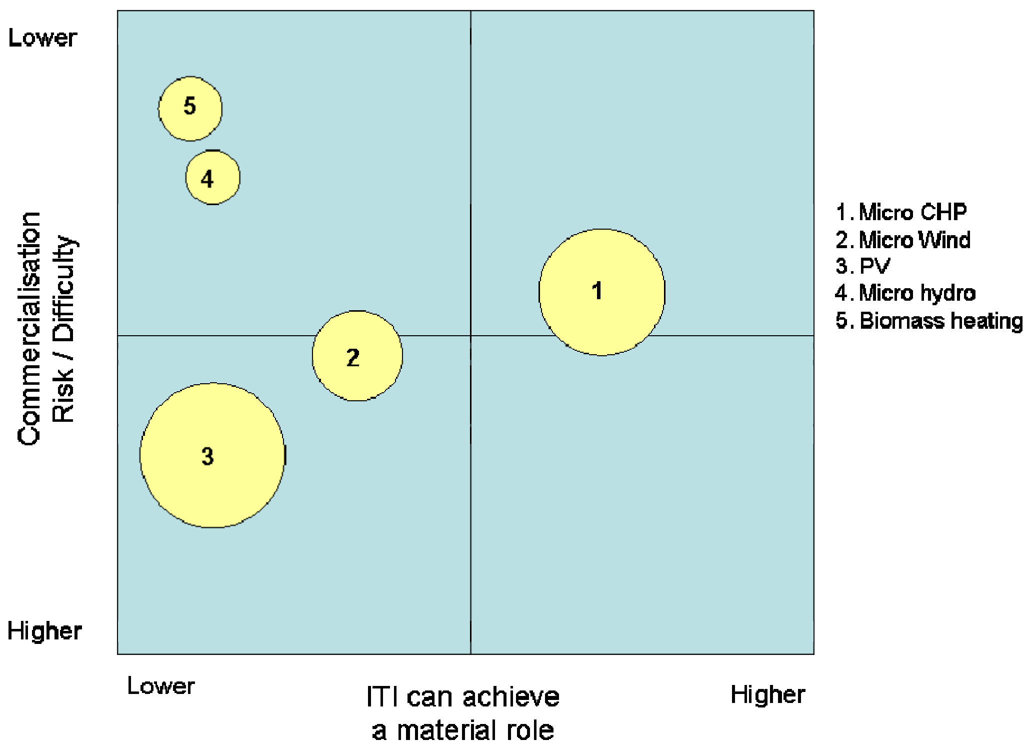
- Current market scale is small
- Commercially viable market scale is only expected to be achieved in 10-15 years from now and there are significant barriers that still need to be overcome
- Microgeneration has to be able to compete directly with existing generation sources, particularly for applications in the home.
- Scotland does not have the depth of R&D expertise or scale in this area at present from which to develop a globally competitive industry.

However, specific proposals for investment, especially for off-grid applications, can be of interest where:

- Globally competitive Scottish capability can be found or built, particularly if it can be combined with capability in other clusters (e.g. electro-chemistry), and
- There is a clear market opportunity in the next 5-10 years, and
- Technology development is a key enabler for market success

For each microgeneration technology, ITI Energy's view can be summarised as follows:

- **Micro CHP**: although this is a highly competitive market, with existing products and with new alternatives, there is scope for new technologies, either as niche solutions, or as a significant better alternative, where Scottish capability can be leveraged or built. Selective investment should be considered in fuel cells, engines, or in new technologies.
- **Micro wind**: technology development is not seen as the key enabler for market adoption.
- **PV**: the current market is driven by government grants. Only fundamental technology developments can realise the cost-of-electricity improvements that are required. Therefore, PV is too far away from a commercial market and there is only limited Scottish capability.
- **Micro hydro**: this technology is mature. Applications and market size are limited.
- **Biomass heating**: the base technology is mature, but maybe there are some possibilities for improvements in the fuel supply chain. Scotland would need to build capability to be globally competitive.



Note: bubble size proportional to perceived scale of market opportunity

For further information on this study and ITI Energy, please contact Chris DeGoey, Acting Technology & Markets Director on Tel +44 (0)1224 701207 or email chris.degoey@itienergy.com.

