New Technologies for CHP Applications

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SUMMARY REPORT

1. Introduction

More than ever before, there are now a range of small-scale generation technologies that can be applied as high efficiency CHP systems in a range of applications. These new options lie at various stages of development and approach commercialisation at different rates. For the developers of all of these systems, the key to achieving commercial breakthrough will be the degree to which they can secure the benefit of economies of scale through mass production. To achieve this will require a combination of effective technological development, attractive market conditions and a strong competitive position.

2. Summary of Emerging Technologies - Prime Movers for CHP

2.1 Microturbines

Microturbines are small high-speed generator plants with an electric output range from 25-250 kW. They are predominately fuelled by natural gas, but diesel, petrol or biogas can be used. They produce very high power density relative to weight and also a high quality of electricity suitable for sensitive applications.

The recovered heat that is produced by a microturbine can be used to produce low-pressure steam or hot water for on-site requirements and is well suited to provide heat and electricity to small commercial applications such as restaurants, hotels and offices. With heat recovery, overall efficiencies of up to 85% can be achieved; without, the electrical efficiency of 23-30% will normally be too low to compete with grid supply.

Manufacturers, the leading one being Capstone Turbines, have not yet been able to achieve sufficient mass production of standardised units to reduce costs to full competitive levels. If this can be done, there is no reason why microturbines could not achieve more common usage in Ireland (there are already several).

2.2 Stirling Engines

The Stirling engine is a low noise external combustion engine allowing, in theory, for a range of fuel sources such as combustible gas or solar energy. The major challenge facing developers of Stirling engines is overcoming the lead in mass production and thus cost reduction enjoyed by reciprocating engines, which enjoy very high volume production for transportation applications.

With a size range of 1kW (or less) to 25kW (and in the future up to 100 kW), and with a low power-to-heat ratio, Stirling engines are suitable for residential or portable applications using natural gas and a wide variety of other fuels (US-based DTE is developing a 25 kWe engine that can be use renewable fuels).

Cost and reliability remain uncertain as products are slowly introduced to the market. If these first moves in the UK and elsewhere are successful, the potential in Ireland could be significant in the domestic market as a boiler replacement.

2.3 Fuel Cells

Fuel cells use the chemical energy created upon the oxidation of hydrogen to produce heat and electricity with a by-product of water. Although fuel cells all operate on the same principle, the operating temperature has important implications for balance of system, system design and application fit. Specifically, low temperature fuel cells require more complex fuel processing (i.e. a separate reformer) since they can only convert hydrogen to electricity. These fuel cell types are also more sensitive to carbon monoxide (CO) poisoning. High temperature fuel cells are able to directly convert hydrogen and CO to electricity and can internally reform simple hydrocarbon molecules into these compounds.

Low temperature systems have the advantage of rapid start, but the disadvantage of low efficiency. Of these, the phosphoric acid fuel cell has been in commercial use for over 35 years and has well proven reliability, but with high first costs and low efficiency. This probably represents a technological dead-end. Another low temperature technology, the Proton Exchange Membrane (PEM) fuel cell, can be used in CHP mode to produce hot water at 80°C, ideal for space or water heating. With low operating temperature, PEM fuel cells are easier to start up and are able to adjust to variable power demands. Both Baxi and Vaillant are developing PEM fuel cell technologies for CHP operation.

The molten carbonate and solid oxide fuel cells both operate at high temperature and are especially well suited for stationary power and it is with these systems that the best commercial prospects for CHP lie, with both commercial and industrial applications. There are, however, some important caveats. In particular, these fuel cells are not yet fully commercially viable and the technology is unproven on a large-scale basis. To achieve significant market penetration outside of high cost niche applications, installed costs will need to fall significantly.

2.4 Small Reciprocating Engines

Reciprocating engines are based on the same principles as petrol and diesel automotive engines, but are specifically designed for the stationary power market. Senertec, owned by Baxi, is the leading producer of small gas engine CHP systems with its 5.5 kWe engine. At this size range, small gas engines can supply heating and hot water to small commercial buildings and apartment blocks. Other producers include Honda (1 kWe) and Ecopower, owned by Vaillant, (4.5 kWe) with the former having scope for use in individual residential units.

Senertec has now sold over 9,000 units, mostly in Germany, and is marketing actively in other European countries, including the UK where there is interest from the public housing sector. This engine is probably now close to full commercialisation.

2.5 Organic-Rankine Engines

These are relatively recent entrants to the field of domestic CHP technology development. At present, two suppliers are developing products for the domestic market, Energetix (owned by Baxi) and Cogen Microsystems with sizes of 1.1 kWe and 2.5 kWe respectively. These machines use standard components that are used, for example, in fridges. The basis of the technology is a scroll expander linked to an alternator using an organic fluid.

The manufacturers are not currently able to indicate when their products will come to the market. However, it is likely that this could be at around the same time as Stirling engines, in late 2004 or 2005.

3. Technology Matrix

Table 1 summarises the results of the research and analysis undertaken for the assignment, and includes the full range of projections for costs and installed capacities by technology type.

Table 1: New CHP Technology Matrix

		Stirling Engine	Micro-turbine recuperated	Fuel Cell Molten Carbonate	Fuel Cell PEM	Fuel Cell Solid Oxide	Small Gas Engine	Organic-Rankine Engine
Fuel input		G	G, LG, Di	G, H	G, H, Pr, Di	G, H, LG, FO	G	G
Electrical output range (kWe)	2004	1 – 25	25 – 250	200 – 300	3 – 50	1 – 100	1 – 15	1 – 2.5
	2010 / 2020	1 – 100	20 – 400	150 – >500	1 - 250	1 - >1,000	1 - 15	1 – 15
Electrical efficiency (%)	2004	12 – 25	23 – 30	-	-	-	25 – 30	12 – 20
	2010	12 – 27	24 – 33	40 – 45	30 – 45	40 – 50	27 – 32	12 – 22
	2020	14 - 28	25 – 35	45 – 55	35 – 45	45 – 55	30 - 34	12 – 22
Power/ heat ratio	2004	1:3 – 1:6	1:1.6 – 1:3	-	-	-	1:1 – 1:2.2	1:4 – 1:6
	2010	1:3 – 1:6	1:1.7 – 1:2.8	1:1 – 1.5:1	1:2 – 1:1	1:1 – 2:1	1:1 – 1:2.2	1:4 – 1:6
	2020	1:3 – 1:6	1:1.6 – 1:2.5	1:1 – 2:1	1:1.5 – 1:1	1:1 – 2:1	1:1 – 1:2.2	1:4 – 1:6
CHP efficiency (%) based on gross calorific value	2004	Up to 90	Up to 85	-	-	-	Up to 90	Up to 90
	2010 / 2020	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90
NOx emissions (ppm)	2004	3 – 50	<20	-	-	-	10 – 200	3 – 40
	2010	3 – 30	<20	< 5	< 1	< 1	10 – 100	3 – 30
	2020	3 – 25	<20	< 5	< 1	< 1	10 – 50	3 – 20
Heat temperature (°C)		85	120 – 350	350	80	1000	85 – 100	85
Application market		D / C	C/ I	C / I	D / C	D / C / I	D / C	D / C
Capital cost (€000 / kWe)	2004	1.8 - 4	1 – 1.8	-	-	-	2	1.2 – 2.5
	2010	0.8 – 2.5	0.5 – 1.3	4.7 – 5.5	2.5 – 3	4	1.5 – 2	1 – 2
	2020	0.7 – 1.5	0.4 – 0.9	1.2 – 2	0.65 – 0.9	0.9 – 2	1.3 – 1.8	1 – 1.5
Installed cost (€000 / kWe)	2004	2 – 5	1.3 – 2.1	-	-	-	2.5	1.4 – 3
	2010	1 – 3	0.6 – 1.5	5 - 6	2.75 – 3.5	4.5	1.8 – 2.3	1.2 – 2.2
	2020	0.8 – 2	0.5 – 1	1.5 – 2.5	0.85 – 1.1	1.0 – 1.5	1.5 – 2	1.1 – 1.7
Operation and maintenance costs (€c / kWh)	2004	1 – 3.5	0.5 – 1.0	-	-	-	1.2 - 2.4	1 – 3.5
	2010	0.5 – 2	0.2 – 0.7	1.5 – 2.5	1.5 – 2.0	1.5 – 2.5	1 – 2	0.5 – 2
	2020	0.3 – 1.5	0.2 – 0.6	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.6 – 1.5	0.3 – 1.5
Delivered electricity cost (€c / kWh)	2004	10.25	7.70	-	-	-	9.24	8.03
	2010	6.84	5.74	15.98	12.36	11.99	7.54	6.01
	2020	3.37	5.00	8.11	5.31	4.77	5.53	4.30
Lifetime (000 hours)		30	40	40	80	40	80	30
Maintenance interval (hrs)		4,000	2,500	4,000 (target)	4,000 (target)	4,000 (target)	5,000	4,000
Projected installed capacity (MWe)	2010	8.0	10.2	0	1.0	0	2.5	2.5
	2020	53.5	35.0	35.0	50.0	40.0	15.5	25.0
Likely year of commercial availability / Europe		2004/05 UK, NL	1999 Several	2010 D	2009 D, NL, UK	2010 D, NL, UK	1998 D	2005 UK
Likely availability Ireland		2005/06	Now	2012	2012	2012	Now	2006/07

SOURCE: DELTA ENERGY & ENVIRONMENT, 2004. KEY: G – NATURAL GAS; LG – LANDFILL GAS; H – HYDROGEN; PR – PROPANE; DI – DIESEL OIL; FO – FUEL OIL; D – DOMESTIC; C – COMMERCIAL; I – INDUSTRIAL; NL – THE NETHERLANDS; D – GERMANY

4. Uncertainties and Unknowns

There are two important variables that present uncertainty to the projections relating to commercialisation of the technologies summarised in the report:

1. Much of the information that circulates about projected commercialisation is derived from the technology developers and manufacturers themselves. Over the past few years, such projections have been notoriously optimistic. The fuel cell developers have been particularly prone to this. Consequently, the projections given here are relatively conservative.
2. The price of fuel, in particular natural gas, and electricity are two factors that strongly influence the overall market conditions for CHP. Generally speaking, the lower the fuel price and the higher the power price, then the better will be the market conditions for CHP, including those based on new technologies. In Ireland, the outlook for both is for an increase, perhaps greater for electricity than for gas. This would be expected to favour CHP. Nonetheless, circumstances can change and if there are significant shifts in either of these parameters then this would certainly change the projections.

5. Energy System Issues

The issues facing the development of these smaller-scale CHP technologies include:

- The penetration of small-scale generation into medium and low voltage electricity networks may require consideration on the share that can be incorporated without network redesign, though the levels estimated in this study are unlikely to cause any major problems over the next 15 years.
- The electrical network connection is crucial for simple and cost-effective installation of very small generators. The UK has developed a good standard for domestic CHP, G83/1, and it is recommended that Ireland looks at this. At a European level a similar standard is being developed by CENELEC and this should be completed in 2005. In addition, the EU Cogeneration Directive requires Member States to simplify their grid connection procedures.
- The valuation of the benefits of embedded generation need to be considered. The current prices paid for exported power do not justify the design of plant to export. The currently levels are below the true value of this export and it is recommended that Ireland investigate and implement an improved pricing structure. Without changes CHP will still be installed to satisfy internal requirements but this will limit the scale of uptake.
- The impacts on the natural gas markets are less severe, with only limited increases in gas consumption and no extra network issues foreseen. However, the spark-spread between gas and electricity prices is a major factor for CHP and if gas prices rise, narrowing the spread, then the economics will deteriorate and the uptake will be less. This is less of an issue for CHP installed in the domestic sector, where the replacement of old inefficient boilers by CHP will result in no or very minor increases in gas consumption.

6. Projections and Targets

Projections for installed capacity for each of the technologies are summarised in Table 2 below:

Table 2: Installed capacity projections, 2010, 2020

		Stirling Engine	Micro-turbine recuperated	Fuel Cell Molten Carbonate	Fuel Cell PEM	Fuel Cell Solid Oxide	Small Gas Engine	Organic-Rankine Engine	Total
Projections for installed capacity (MWe) Low CHP Scenario	2010 D	0.7	0	0	0	0	0.05	0.25	1.0
	2010 C/I	0.8	8	0	0.8	0	1.6	0	11.2
	2020 D	10	0	0	3	1	1	5	20.0
	2020C/I	1.1	11	11	11	11	3.3	0	48.4
Projections for installed capacity (MWe) High CHP Scenario	2010 D	17.5	0	0	0	0	1.25	6.25	25.0
	2010 C/I	1.8	18	0	1.8	0	3.6	0	25.2
	2020 D	50	0	0	15	5	5	25	100.0
	2020 C/I	3.5	35	35	35	35	10.5	0	154.0
NCCS Scenario: Contribution to NCCS objective - 2010 (commercial and small industrial only)		1.0	10	0	1.0	0	2.0	0	14.3
NCCS Scenario: Additional contribution from domestic CHP									10

DELTA ENERGY & ENVIRONMENT, 2004. KEY: D – DOMESTIC SECTOR; C – COMMERCIAL SECTOR; I - SMALL INDUSTRIAL SECTOR; NCCS – NATIONAL CLIMATE CHANGE STRATEGY

The 2010 projections in the NCCS Scenario fall between the Low and High Scenarios. These projections therefore appear reasonable as a basis for separate technology targets for 2010, while the High Scenario projections for 2020 can serve as a basis for targets for that year.

7. Recommendations for Policy in Ireland

Ireland is unlikely to be a first mover country in the implementation of CHP technologies that are not yet fully commercialised. In addition, there is little or no Ireland-based technology lead that needs to be reinforced or defended in order to secure a strong foundation for international growth. For these reasons, the market side promotion of CHP will be the most important issue for policymakers to secure sound market conditions for the new technologies.

In addition, Ireland, being a small country, causes market entry issues. For a supplier to enter the Irish market, sufficient early potential must exist to cover the establishment of a network for maintenance and spares. This has proved to be a problem in the past with some reciprocating engine CHP suppliers being reluctant to travel. The policy options therefore need to ensure, as far as possible, that this barrier does not occur for these emerging technologies.

Ireland has already recognised the merits of establishing a national CHP growth target, a measure that has been shown in many countries to provide an important focus for policy action. The type of additional policy support required will depend on the relative stage of development of the various technologies. Small reciprocating engines and microturbines have virtually broken through to market, though mass production has not yet been achieved. Stirling engines and Organic-Rankine engines are relatively close to market, while fuel cells remain some distance away.

1. For the small reciprocating engines, microturbines, Organic-Rankine engines and Stirling engines, any policy that aims to provide incentives for CHP in general should also apply to these systems:
   a. With agreement of the EU Cogeneration Directive, a means of assessing the efficiency of CHP has been defined and associated with this is the option to target incentive policies at CHP systems that achieve a threshold efficiency.
   b. Equally, the EU Directive obliges Member States to assess barriers to CHP, especially in respect of network access and interconnection. If there exist any specific regulatory, fiscal or institutional barriers to the implementation of these systems that are constraining market entry, these should be removed by policymakers.
   c. The revision of the building codes, in line with the EU Directive on the Energy Performance of Buildings, to recognise the benefits of CHP and to encourage its adoption as the principal energy supply. This measure is especially important for the technologies under discussion here.

2. Fuel cells remain some way from mainstream market commercialisation and, while the approaches summarised above should apply, different policy measures are more likely to have impact. With many corporate and government-funded research programmes on fuel cells now going on around the world, there is probably little point in Ireland creating any new such effort. Much more value could perhaps be gained by assessing what sectoral applications of fuel cells are best suited to the Irish market, and targeting support at these fertile niche opportunities. This can be done perhaps most effectively by supporting the development of one or more demonstration projects.

Main Annex

1. Introduction

This Annex provides an assessment of the new and emerging generation technologies for CHP – Stirling engines, fuel cells, microturbines, small reciprocating engines and Organic-Rankine engines. Many of these generate electricity and heat at much smaller scales, including residential applications, than conventional systems. This promises to open up completely new markets and applications for CHP, and the associated opportunity for increasing the share of CHP in the electricity mix.

There are a number of important factors that will determine the extent to which some or all of these new technologies can be successfully commercialised. The most important of these is the overall installed costs of the CHP package and the speed with which manufacturers can reduce these to acceptable levels is crucial. Manufacturers' assertions on the likely time-scale for price reductions are notoriously optimistic, and the projections provided in this Annex reflect a more cautious approach.

Among other important factors affecting the overall development of the markets for the new technologies is the policy and regulatory environment. There now exists a significant amount of worldwide experience in respect of CHP promotion, the impact of various barriers and the role of effective strategic approaches to CHP market development. The experience is summarised in this Annex, and conclusions are drawn on how policy in Ireland can be used to provide suitably fertile market environments for new CHP technologies.

2. The Technologies

2.1 Microturbines

The Technology

Microturbines are small high-speed generator plants with an electric output range from 25-250 kW. They have evolved from automotive and truck turbochargers, auxiliary power units for airplanes and small jet engines. Systems may be either simple cycle, where no heat is recovered from the exhaust for preheating of the combustion gases, or recuperated. Recuperation typically doubles the electrical efficiency of the unit whilst reducing the amount of recoverable heat from the boiler.

Microturbines consist of a single shaft connecting a turbine, compressor and generator. In the recuperated process, air is drawn in through a compressor into a recuperation unit that has been heated by the exhaust gases. The air flows into a combustion chamber where it is mixed with the fuel and burned. The hot gas is expanded through the turbine creating mechanical energy. The exhaust gases pass out through the recuperation unit to capture some of the remaining heat. Microturbines are predominately fuelled by natural gas, but diesel, petrol or biogas can be used. Some turbines use air bearings eliminating the need for lubricating oil, while the use of air as a cooling source removes the need for more complex cooling systems.

Several microturbines in production today gain the efficiency of very high speed power turbines, directly connected to a high-speed generator and producing extremely high frequency alternating current – up to 100,000 Hertz. This enables very high power density relative to weight, but produces current that is of no use to existing power systems without solid-state transformation.

To solve this problem, the high frequency AC is sent to a rectifier that converts the energy into direct current. Solid state devices then convert the direct current into alternating current with a shaped profile of local power, either 50 or 60 cycle alternating current. This approach increases the capital cost, due to the solid state inverter cost, but produces very clean power, particularly suitable for sensitive applications, and these systems are inherently simpler to parallel with utility grids.

Microturbine manufacturers are aiming for significant mass production of standardised units relative to all other decentralised generation technologies, which would lower the cost and enhance competitiveness of these devices in cogeneration applications.

Table 1: Advantages and disadvantages of Microturbines for cogeneration

Advantages	Disadvantages
Low maintenance Long life Low unit cost Variable output and recuperation Black start capability Relatively high noise Not suitable for repeated stop/start	Relatively low electrical efficiency

Applications

The heat produced by a microturbine can be used to produce low-pressure steam or hot water for on-site requirements. Thus microturbines are well suited to provide heat and electricity to small commercial applications such as restaurants, hotels, small factories and offices. Direct heating CHP applications can include glass-house heating, desiccant regeneration, process drying and supplementing boiler combustion air. There are also CHP cooling (trigeneration) options using recovered exhaust heat for absorption chillers. Future applications are likely to remain with these categories.

Microturbines have been applied commercially since 1999 and there is now reasonable international coverage, particularly in Europe, including Ireland, and North America. However, a mass sales market has not yet been achieved. At present each sale of a microturbine CHP at 100 kWe is almost as protracted as a sale for a 1 MWe system. Thus the transaction costs are high and time-consuming and in effect prevent the move to the mass market. This problem has caused both Turbec and Bowman Power Systems to withdraw recently from the market, before re-emerging under changed ownership. Solving the issue is therefore a key factor in establishing a successful market for microturbines.

2.2 Stirling Engines

The Technology

The Stirling engine is an external combustion engine allowing, in theory, for a range of fuel sources such as natural gas or solar energy. The heat supplied to the engine causes the working fluid to expand, moving the piston. The fluid is transferred into a cold zone of the engine where it is recompressed by the working piston, and transferred back to the hot region of the engine and the cycle continues. 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. One potential advantage of Stirling technology is its ability to extract energy from any fuel or waste heat stream, regardless of the corrosive properties.

The concept has been around for nearly 200 years, but significant development was prevented by challenging technical problems, such as effective seals for the chamber of the working fluid. These problems are now mostly solved and products are starting to appear in the market. Now, however, the major challenge facing developers of Stirling engines is overcoming the change from bespoke manufacture to mass production, and thus cost reduction, enjoyed by reciprocating engines, which enjoy very high volume production for transportation applications.

Table 2: Advantages and disadvantages of Stirling Engines for CHP

Advantages	Disadvantages
Low power-to-heat ratio – therefore suitable for domestic applications Low maintenance and long life (few moving parts) Low noise (constant rather than pulsed combustion) Low emissions Multi-fuel capability (external heating) Length of start up time Power input requirement to start unit Low electrical efficiency of current models, especially at the micro-scale	Limited ability to modulate output

Applications

With a size range of 1kW (or less) to 25kW (and in the future up to 100 kW), Stirling engines are highly suitable for residential and portable applications. The small size and quiet operation mean that they can integrate well into a domestic environment. There is also the possibility of using a solar dish to heat the Stirling engine eradicating the need for combustion of a fuel. Future CHP applications will almost certainly remain in the domestic and small commercial markets.

The most immediate prospects for application are in Europe, where commercial launch is expected later in 2004. The UK and the Netherlands will be the first markets, with Ireland expected to follow in 2005 or 2006.

Once again, the key to success for Stirling engine CHP will be the ability to access the mass market. For residential applications, this will entail replacing the household heating boiler at the end of its life. Thus, vital to its success will be very low transaction costs for network integration and permitting. The UK, which leads in this respect in Europe, will allow a "fit and inform" process, with almost no administrative burdens that may apply equally to other micro-generation technologies described below.

2.3 Fuel Cells

The Technology

Fuel cells use the chemical energy created in the oxidation of hydrogen to produce heat and electricity with a by-product of water. The voltage produced by a single fuel cell is small. However, fuel cells can be organised into stacks to provide the required power. The main technology characteristic that distinguishes one fuel cell type from another is the electrolyte. The five principal types are:

- Proton exchange membrane (PEM)
- Alkaline fuel cells (AFC)
- Phosphoric acid fuel cells (PAFC)
- Solid oxide fuel cells (SOFC)
- Molten carbonate fuel cells (MCFC).

A wide variety of technical approaches are used. PEM, AFC and PAFCs use low temperatures and have the advantage of rapid start, but the disadvantage of low efficiency. They all require hydrogen for fuel, necessitating a fuel reformer that converts commercial fossil fuel to hydrogen and CO2.

The other two approaches – MCFC and SOFC – both operate at temperatures of several hundred degrees centigrade and can require up to 8 hours from cold start to full power, making them undesirable for transportation motive power. However, they have several advantages that are especially apparent for stationary power generation:

- They reform fuel internally, avoiding a separate reformer and enabling them to use most commercial liquid and gaseous fuels.
- They achieve up to 50% fuel-to-electricity efficiency today with theoretical future possibilities of another 10 percentage points.
- The by-product heat is 260 to 370ºC, suitable for most thermal uses.

Table 3: Advantages and Disadvantages of Fuel Cell CHP Application

Advantages	Disadvantages
Potentially high electrical efficiency (30 to 50%) under varying load Low emissions (virtually no NOx, SOx or particulates) Rapid modulation of output between full and zero electrical output (additional flexibility to heat supply) Can provide heat for a wide range of applications Low noise: no moving parts (except fans) Complexity of design Relatively high noise No existing infrastructure for large-scale supply of hydrogen (only impacts low temperature FCs) Size and weight, especially at larger capacities	Not yet commercially viable - high capital costs

Applications

These are summarised as follows:

- PEMFC - Can be used in cogeneration mode to produce hot water at 80°C. Ideal for space or water heating.
- AFC - With an operating temperature of 80°C, AFCs could be ideal for use in stationary applications and in desalination plants.
- PAFC - An operating temperature of 200°C allows recovered heat to be used for space or water heating, often suiting district heating systems
- SOFC - An operating temperature of 1000°C allows recovered heat to be used for industrial processes.
- MCFC - An operating temperature of 650°C allows recovered heat to be used for commercial buildings such as hospitals and hotels and for combined cycle applications.

The PAFC has been in commercial use for over 35 years and has well proven reliability, but with high first costs and low efficiency. PAFC costs cannot be reduced much further and so it does not have realistic commercial prospects and has been abandoned by the manufacturers as a long term option. There is also little current development of AFC. For the remaining fuel cell types, future applications are likely to remain unchanged for the foreseeable future.

SOFC and MCFC are the most promising options for CHP, the latter more so for larger applications, though it remains unproven for long-term operation. Both are expected to become commercially available by 2010 or so. PEM FC is currently under intensive development for the residential and small commercial markets, led by Europe's major domestic boiler suppliers. Commercialisation is also likely by around 2010. SOFC may also find a market in the domestic sector, with one developer producing a 1 kWe system. The first countries of application in Europe are likely to be Germany, the Netherlands or the UK. Application in Ireland could follow one or two years afterwards.

2.4 Small Reciprocating Engines

The Technology

Reciprocating engines are based on the same principles as petrol and diesel automotive engines. They enjoy high volume mass production and are often the lowest capital cost per kW of capacity. They operate at relatively high electrical efficiencies (up to 45%) and are well suited to standby, peaking or medium scale CHP systems. Reciprocating engines currently account for the majority of

CHP units of under 5 MWe. Their main disadvantage in cogeneration applications is the difficulty of recycling the multiple and relatively low-grade heat streams. Up to a third of the fuel energy is available in the exhaust at temperatures from 370-540°C, but the other rejected heat is low temperature, often too low for most processes (jacket cooling water at 80 to 95°C, lube oil cooling at 70°C and intercooler heat rejection at 60°C, all difficult to use in CHP). Like automotive engines, reciprocating engines can be split into two categories: compression ignition (diesel cycle) engines and spark ignition (Otto cycle) engines.

Reciprocating engines represent a well-established and proven technology and there are a large number of manufacturers offering products for cogeneration applications in the range 35 kWe to 1 MWe or so (e.g. Perkins, MAN, Caterpillar). Below around 35 kWe, however the efficiency of conventional reciprocating engines decreases and maintenance costs increase.
Thus it has been necessary for a radical redesign of the package. The small scale engines are designed especially for CHP applications ensuring long running hours between maintenance and improved electrical efficiencies. Viable engines, both technically and economically, in this smaller range have now become available from a number of manufacturers.

Senertec is the leading producer of small gas engine CHP systems with its 5.5 kWe engine. At this size range, the engines can supply heating and hot water to small commercial buildings and apartment blocks. Other producers include Honda (1 kWe) and Ecopower (4.5 kWe) with the former having scope for use in individual residential units.

Senertec has now sold over 9,000 of its spark ignition units, mostly in Germany, and is marketing actively in other European countries, including the UK where there is interest from the public housing sector. The small gas engine is probably now close to full commercialisation, though the 1 kWe engine has yet to reach the European market (it has been trialled in Japan).

Table 4: Advantages and Disadvantages of Small Reciprocating Engines

Advantages	Disadvantages
High efficiencies at part load, giving a flexible power source and a range of different applications Short start-up times to full loads (10-15 seconds) High reliability. Large number of moving parts increases O&M costs, offsetting fuel efficiency advantages Full use of the varied heat sources is difficult	Relatively high vibrations require support and shielding to reduce acoustic noise

Applications

Depending on size, reciprocating engines can be used to produce up to 15 bar of steam from the exhaust gases with independent production of hot water at 85-90°C from the cooling system. If the heat from the exhaust gases and cooling systems are combined it is possible to produce water at 100°C and steam at higher temperatures. The new generation of small reciprocating engine CHP is therefore typically applied in single or multiple residential buildings, commercial and small industrial applications.

The Senertec unit first became available in Germany in 1998 and is now becoming widespread in Europe. None of the suppliers have yet to establish references in Ireland, though Senertec is expected to achieve this within the year.

2.5 Organic Rankine Engines

The Technology

The Organic Rankine engine is an integrated system to provide both heat and electric power. The system operates with an organic working fluid that circulates in a Rankine-type cycle, where the organic working fluid is superheated by a heat source, expanded through an involute spiral wrap (scroll) expander such that the organic working fluid remains superheated through the expander, cooled in a condenser, and pressurized by a pump. Heat exchange loops within the system define hot water production capability for use in space heating and domestic hot water, while the generator is coupled to the scroll expander to generate electricity.

The components are all relatively simple and are in effect those used in a refrigerator, only operating in reverse. Thus the technology should be relatively cheap to build as all the parts are mass produced.

Two companies are developing this technology. Energetix, which has recently sold this technology to the Baxi Group, has developed a 1 kWe unit; this development is based in the UK. The second is Cogen Microsystems, an Australian company, which is developing a 2.5 kWe system. Much secrecy surrounds both of these in terms of performance and costs. However, it appears that the performance is quite similar to that of the Stirling engine and some commentators believe they will be direct competitors. The electrical efficiency of the units is likely to around 12-15%, with overall efficiencies up to 90%.

Unlike the Stirling engine, the Organic Rankine engine has much less scope for technical improvement. The Organic Rankine engine will be fuelled with natural gas.

Table 5: Advantages and Disadvantages of Organic Rankine Engines

Advantages	Disadvantages
Low cost components and proven reliability of these components	
Short development time and rapid route to market are likely	
Suitable for houses with high thermal loads	
Low noise and NOx levels	Low electrical efficiency and little scope for long term improvement

Applications

With a size of 1 kWe to 2.5 kWe this technology is suitable for the residential market. It will compete head on with Stirling engines and may be more competitive due to low capital costs in the short term. They have similar size, noise and external appearance to the Stirling engines and so will integrate well with the domestic environment.

The manufacturers are not currently able to indicate when their products will come to the market. However, it is likely that this could be at around the same time as Stirling engines, in late 2004 or 2005. The initial market again is likely to be the UK and possibly the Netherlands, with Ireland following a year or so later.

3. Energy System Issues to 2020

The key issues to face in respect of the main energy networks are the integration of the smaller scale generation technologies into electricity grid, the issue of gas grid strength and the fuel availability.

3.1 Penetration of Small Scale Generation

A high penetration of small-scale CHP into low and medium voltage networks, which have been designed for little or no embedded generation, is a cause of much discussion presently. Some European utilities are of the view that almost no small scale generation can be accepted without safety and controllability problems (EdF in France and the PPC in Greece). On the other side of the debate are the Dutch utilities and the distribution companies of the UK who believe there will be little problem until at least 30% of the load is reached. There are major programmes of research ongoing at the European level on this and Ireland should follow this work. These research programmes include DISPOWER, ENIRDGnet, EU DEEP, DG FACTS and others.

At the level of penetration predicted in this study, it is unlikely that Ireland will reach any serious problems before 2020. However, there may be locations where a number of generators are concentrated and here network reinforcement may be necessary.

3.2 Electricity Grid Interconnection

In the range of technologies considered here, the interconnection to the electricity distribution system is highly important. Ease of access and simple procedures that are transparent and fair to both generator and network operator are necessary. The UK last year published Engineering Recommendation G83/1 for the connection of domestic CHP to the electrical system. This is a very progressive approach and overcomes all the barriers to micro-CHP below 16 Amps per phase (3.5 kWe on single phase and 11.2 on 3-phase systems). The basis of this standard is a "fit and inform" approach based on standardised protection settings for the unit. This allows the domestic CHP to be installed in the case where a boiler has to be replaced urgently due to failure. A similar standard is being developed by CENELEC TC8x WG2, under the chairmanship of COGEN Europe. This will take about another year to complete.

In addition, the EU Cogeneration Directive requires interconnection arrangements to be transparent, cost reflective and fair. This will have an impact on the Irish network company(s) over the next 15 years and should benefit the introduction of these new technologies.

3.3 Valuation of Electricity System Benefits

Currently in Ireland exported power is rewarded with very low prices, €c2.5-3 / kWh. This is not sufficient to encourage the installation of CHP plants where the thermal load would allow a significant level of power export. In the economic modelling for this study, a price of €c4 / kWh was used. This figure is still quite low if the generator displaces most of the network losses (10% on average in Ireland) and helps strengthen the grid. The valuation of system benefits is a controversial topic and there is as yet no agreement on what should be included in the box, how to price these items and what the obligations on each party are. Again DISPOWER and EU DEEP are working on these issues currently and a recently completed project – DG-FER – is worth consulting for the views of the industry.

Nevertheless, it can be stated that if the current export price remains broadly unchanged the scope for the introduction of these new technologies in Ireland will be less than if the price moves towards a price more reflective of the macro-economic benefits.

3.4 Gas Network Issues

Most of the technologies considered are fuelled on natural gas and this is likely to remain the case in the next 15 years. In the longer term it may be possible to supply hydrogen as the fue, especially to the fuel cells and the microturbines.
For Ireland the availability of gas is a key question. This availability covers two aspects: geographical scope and import supplies. Over the period in question the gas network is foreseen to be extended to the west of Ireland, especially with the exploitation of the Porcupine Basin. This would open up a greater share of the domestic market to the use of gas. The import of natural gas from the UK and increasingly from continental sources may cover the long term demand. The question is then one of price. The economics of CHP is primarily dependent up on the spark spread between the input fuel and the displaced electricity. Interestingly, the domestic CHP plants, based on Stirling engines and Organic Rankine engines, are rather insulated from this problem. It appears that the gas consumed by the boiler that was replaced by the CHP was about the same as the gas consumed by the CHP unit itself. Thus these installations may be unaffected by gas price.

The increase in gas demand caused by the adoption of these new technologies may also be modest. Firstly the penetration in the next 15 years is not that rapid and secondly, especially in the domestic sector, the gas burn may be about the same as now.

4 Guidance on Policy Options

4.1 Review of Policy Options

The encouragement of new and emerging technologies can present something of a challenge to policymakers. Increasingly, national governments have a tendency to rely on private industry and 'the market' to ensure that technologies can be fostered. Such a laissez-faire approach can work but it is unlikely to achieve the scale of sales required to bring production prices down with sufficient speed. On the other hand, if other countries are investing hard in the development of new technology winners, then there may be little to gain from Ireland adopting the same approach.

Equally, unless the technologies can achieve mass markets outside Ireland, there is little that can be done at the national level to achieve this. It will therefore be important that Ireland creates a fertile market environment for these technologies that do achieve mass market breakthrough elsewhere.

In Ireland's case, there are therefore two main options for promoting the new technologies; they are by no means exclusive:

- Market side promotion, involving the establishment of secure market, regulatory and fiscal conditions for the relevant CHP sectors. This will ensure that the technologies, once commercialised, have the opportunity to flourish. Some of the options that can be included in an effective national CHP policy, or strategy, are summarised below under 'Successful international experience'.
- Supply side promotion, involving support for demonstration projects and information programmes for pre-commercial systems that appear to have best prospects for mass sales in the world's major markets.

For all countries, the first of these options is essential. The second option is desirable, particularly for those countries that have indigenous companies and technologies that can build international success on a favoured domestic market environment. For the majority of these new CHP technologies, mass market access is a necessity and thus policies that can accelerate this will be important.

4.2 Successful International Experience

For market side promotion, an analysis of successful international experience suggests that there are certain important features for the development of an effective policy strategy to develop CHP:

1. The government ministry responsible for a CHP strategy should ideally have responsibility for overall electricity and gas market regulation and should have the commitment to intervene in energy markets in order to revise regulatory issues that adversely affect CHP.
2. A CHP growth target.
3. A long-term CHP perspective that sets out a robust vision, ideally over 10-12 years. This can create the opportunity for the development of policies that have time to take real effect and for both government and industry stakeholders to review and revise policies through the time period.
4. A comprehensive review of barriers to CHP in order to provide the basis for ensuring that new policies are devised to remove those barriers.
5. Scope for the development of policies that deliver a significant financial benefit to CHP projects, including:
    - Tax breaks or incentives;
    - Fuel price benefits;
    - Electricity price benefits for electricity exported to the grid;
    - Simple permitting and positive encouragement through building codes;
    - Emissions trading or a CHP obligation on electricity suppliers.
6. Scope for the development of policies that tackle grid access and interconnection issues, including:
    - The imposition of standard rules, transparency and unbureacratic procedures;
    - Ensuring that the grid company can recover its costs and so will not act to block CHP;
    - Ensuring that CHP operators are charged appropriately for the grid services they use, taking into account any services or benefits that CHP in turn provides to the grid.
7. Actions to address each CHP sector (eg industrial, district energy, commercial, micro-CHP).
8. A commonly agreed and acceptable means of assessing the 'quality' of CHP projects and for calculating the energy/emission benefits that arise from them. This enables policymakers to target incentive policies and to counter any doubts as to the benefits that CHP can bring.

A number of these measures already apply to Ireland. The incentives that such a strategy will bring for new technologies can be reinforced by a supply side programme, which need not be extensive in scope, by providing a catalytic role in securing the development of a small number of demonstration projects, particularly for fuel cells.

4.3 Relevance and value of CHP targets

A critical condition is the setting of a CHP growth target, perhaps combined with a series of staged targets. While, in itself, it provides no assurance that the target will be delivered, international experience suggests that the countries that have been most successful in promoting CHP have established some form of market development target.
There are three main issues that relate to the setting of targets:

- A target must be set at a level that is thought to be achievable on the basis of both bottom-up and top-down market analyses.
- The target must be realistic in terms of assessing what can be achieved in each CHP sector and in terms of the feasibility of the policies that will be required to deliver a target.
- A target can be set to achieve a certain amount of emission reductions or energy savings and can thus form a part of wider environmental or energy efficiency policies.

The application of Ireland's target for CHP, the installed capacity should reach 370 MWe by 2010, in order to fulfil its part of the National Climate Change Strategy, and its impact on new CHP technologies can be assessed in the light of this experience.

4.4 Recommendations for policy in Ireland

Ireland is unlikely to be a first mover country in the implementation of CHP technologies that are not yet fully commercialised. In addition, there is little or no Ireland-based technology lead that needs to be reinforced or defended in order to secure a strong foundation for international growth. For these reasons, the market side promotion of CHP will be the most important issue for policymakers to secure sound market conditions for the new technologies.

In addition, Ireland, being a small country, causes market entry issues. For a supplier to enter the Irish market, sufficient early potential must exist to cover the establishment of a network for maintenance and spares. This has proved to be a problem in the past with some reciprocating engine CHP suppliers being reluctant to travel. The policy options therefore need to ensure, as far as possible, that this barrier does not occur for these emerging technologies.

Ireland has already recognised the merits of establishing a national CHP growth target, a measure that has been shown in many countries to provide an important focus for policy action. The type of additional policy support required will depend on the relative stage of development of the various technologies. Small reciprocating engines and microturbines have virtually broken through to market, though mass production has not yet been achieved. Stirling engines and Organic-Rankine engines are relatively close to market, while fuel cells remain some distance away.

1. For the small reciprocating engines, microturbines, Organic-Rankine engines and Stirling engines, any policy that aims to provide incentives for CHP in general should also apply to these systems:
    a. With agreement of the EU Cogeneration Directive, a means of assessing the efficiency of CHP has been defined and associated with this is the option to target incentive policies at CHP systems that achieve a threshold efficiency.
    b. Equally, the EU Directive obliges Member States to assess barriers to CHP, especially in respect of network access and interconnection. If there exist any specific regulatory, fiscal or institutional barriers to the implementation of these systems that are constraining market entry, these should be removed by policymakers.
    c. The revision of the building codes, in line with the EU Directive on the Energy Performance of Buildings, to recognise the benefits of CHP and to encourage its adoption as the principal energy supply. This measure is especially important for the technologies under discussion here.
2. Fuel cells remain some way from mainstream market commercialisation and, while the approaches summarised above should apply, different policy measures are more likely to have impact. With many corporate and government-funded research programmes on fuel cells now going on around the world, there is probably little point in Ireland creating any new such effort. Much more value could perhaps be gained by assessing what sectoral applications of fuel cells are best suited to the Irish market, and targeting support at these fertile niche opportunities. This can be done perhaps most effectively by supporting the development of one or more demonstration projects.

5 Market Projections, 2010 and 2020

5.1 Review of assumptions

Projections for the installed capacity of the technologies are given in Table 7, with three scenarios having been provided (High, Low and a scenario associated with the achievement of the 370 MWe commitment within the National Climate Change Strategy (NCCS). The assumptions underlying these figures are as follows:

- A 2002 installed CHP capacity of 131.5 MWe.
- 1.2 million houses in Ireland, of which 700,000 would be suitable for domestic CHP (and assuming the gas network is extended to the west of Ireland).
- Economic potential for CHP in commercial and small industrial sectors is as summarised by Therese Murphy in a presentation given on 24 May 2004.
- Low and High Scenario assessments of installed capacities for small-scale and micro-CHP are based on the outputs of the EU studies: Future Cogen and MicroMap.
- Market shares for the domestic and commercial / small industrial sectors as follows :

Table 6: Assumptions for Technology Market Shares (%), 2010 and 2020

	Stirling Engine		Micro-turbine recuperated		Fuel Cell Molten Carbonate		Fuel Cell PEM		Fuel Cell Solid Oxide		Small Gas Engine		Organic-Rankine Engine	
	D	C/I	D	C/I	D	C/I	D	C/I	D	C/I	D	C/I	D	C/I
2010	70	1	0	10	0	0	0	1	0	0	5	2	25	0
2020	50	1	0	10	0	10	15	10	5	10	5	3	25	0

KEY: D – DOMESTIC SECTOR; C – COMMERCIAL SECTOR; I - SMALL INDUSTRIAL SECTOR

- For the NCCS scenario, achievement of the 370 MWe CHP objective assumes a 41% share of new capacity arising from commercial / small industrial installations, and 59% from larger plants (also an assumption made by Future Cogen). On this basis, 102 MWe of the growth required to achieve the target will be met by the former group; the installed capacity for each of the new technologies in this group is based on a straight line derivation between the Low Scenario (80 MWe) and High Scenario (180 MWe) for the group as a whole.
- If overall market conditions are such that the 370 MWe target is achieved by 2010, a figure of 10 MWe appears realistic for the domestic CHP market (though not included in the target).

5.2. Installed capacity projections, 2010 and 2020

Table 7: Installed Capacity Projections, 2010, 2020

		Stirling Engine	Micro-turbine recuperated	Fuel Cell Molten Carbonate	Fuel Cell PEM	Fuel Cell Solid Oxide	Small Gas Engine	Organic-Rankine Engine	Total
Projections for installed capacity (MWe) Low CHP Scenario	2010 D	0.7	0	0	0	0	0.05	0.25	1.0
	2010 C/I	0.8	8	0	0.8	0	1.6	0	11.2
	2020 D	10	0	0	3	1	1	5	20.0
	2020C/I	1.1	11	11	11	11	3.3	0	48.4
Projections for installed capacity (MWe) High CHP Scenario	2010 D	17.5	0	0	0	0	1.25	6.25	25.0
	2010 C/I	1.8	18	0	1.8	0	3.6	0	25.2
	2020 D	50	0	0	15	5	5	25	100.0
	2020 C/I	3.5	35	35	35	35	10.5	0	154.0
NCCS Scenario: Contribution to NCCS objective - 2010 (commercial and small industrial only)		1.0	10	0	1.0	0	2.0	0	14.3
NCCS Scenario: Additional contribution from domestic CHP									10

DELTA ENERGY & ENVIRONMENT, 2004. KEY: D – DOMESTIC SECTOR; C – COMMERCIAL SECTOR; I - SMALL INDUSTRIAL SECTOR; NCCS – NATIONAL CLIMATE CHANGE STRATEGY

The 2010 projections in the NCCS Scenario fall between the Low and High Scenarios. These projections therefore appear reasonable as a basis for separate technology targets for 2010, while the High Scenario projections for 2020 can serve as a basis for targets for that year.

5.3 Impact on Carbon Dioxide and Other Emissions

Table 7 above provides projections for the installed capacity of new technologies required to achieve the National Climate Change Strategy CHP objective. This is 14.3 MWe. Under the Low CHP Scenario, 11.2 MWe is projected while under the High Scenario, 25.2 MWe is projected for 2010 .

Under the more pessimistic Scenario, there is a deficit of around 3 MWe. Given that the NCCS objective is 370 MWe, and recognising that there is a margin for error in the scenarios, this is not a critical issue. Under the High Scenario, there is a surplus of around 11 MWe. This is more significant, but the achievement of the 370 MWe target is nonetheless overwhelmingly dependent on the growth of the conventional CHP market rather than that for new technologies. After 2010, however, the development of CHP will be much more dependent on these new technologies.

Most of the technologies are low NOx emitters, typically in the range 50 ppm and lower – frequently much lower. The exception to this is the reciprocating engine, with up to 200 ppm NOx today. The suppliers expect a rapid improvement in NOx emissions over the next few years. It is likely that NOx emissions will fall to 50 ppm or lower and thus will be comparable to competing technologies.

In relation to SOx emissions, all the technologies under review are expected to most often be fuelled by natural gas or other gases and so to have zero or near zero emissions. In relation to carbon monoxide (CO) emissions, there is an approximate inverse relationship with NOx emissions. Consequently, with emissions of the latter being driven down on an ongoing basis, CO emissions are tending to rise, though not to levels in any of the systems that are deemed to be excessive, and certainly will be in the same range or lower than conventional CHP technologies.

6 Technology Matrix

Table 8 summarises the results of the research and analysis undertaken for the assignment, and includes the full range of projections for costs and installed capacities by technology type.

		Stirling Engine	Micro-turbine recuperated	Fuel Cell Molten Carbonate	Fuel Cell PEM	Fuel Cell Solid Oxide	Small Gas Engine	Organic-Rankine Engine
Fuel input		G	G, LG, Di	G, H	G, H, Pr, Di	G, H, LG, FO	G	G
Electrical output range (kWe)	2004	1 – 25	25 – 250	200 – 300	3 – 50	1 – 100	1 – 15	1 – 2.5
	2010 / 2020	1 – 100	20 – 400	150 – >500	1 - 250	1 - >1,000	1 - 15	1 – 15
Electrical efficiency (%)	2004	12 – 25	23 – 30	-	-	-	25 – 30	12 – 20
	2010	12 – 27	24 – 33	40 – 45	30 – 45	40 – 50	27 – 32	12 – 22
	2020	14 - 28	25 – 35	45 – 55	35 – 45	45 – 55	30 - 34	12 – 22
Power/ heat ratio	2004	1:3 – 1:6	1:1.6 – 1:3	-	-	-	1:1 – 1:2.2	1:4 – 1:6
	2010	1:3 – 1:6	1:1.7 – 1:2.8	1:1 – 1.5:1	1:2 – 1:1	1:1 – 2:1	1:1 – 1:2.2	1:4 – 1:6
	2020	1:3 – 1:6	1:1.6 – 1:2.5	1:1 – 2:1	1:1.5 – 1:1	1:1 – 2:1	1:1 – 1:2.2	1:4 – 1:6
CHP efficiency (%) based on gross calorific value	2004	Up to 90	Up to 85	-	-	-	Up to 90	Up to 90
	2010 / 2020	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90	Up to 90
NOx emissions (ppm)	2004	3 – 50	<20	-	-	-	10 – 200	3 – 40
	2010	3 – 30	<20	< 5	< 1	< 1	10 – 100	3 – 30
	2020	3 – 25	<20	< 5	< 1	< 1	10 – 50	3 – 20
Heat temperature (°C)		85	120 – 350	350	80	1000	85 – 100	85
Application market		D / C	C/ I	C / I	D / C	D / C / I	D / C	D / C
Capital cost (€000 / kWe)	2004	1.8 - 4	1 – 1.8	-	-	-	2	1.2 – 2.5
	2010	0.8 – 2.5	0.5 – 1.3	4.7 – 5.5	2.5 – 3	4	1.5 – 2	1 – 2
	2020	0.7 – 1.5	0.4 – 0.9	1.2 – 2	0.65 – 0.9	0.9 – 2	1.3 – 1.8	1 – 1.5
Installed cost (€000 / kWe)	2004	2 – 5	1.3 – 2.1	-	-	-	2.5	1.4 – 3
	2010	1 – 3	0.6 – 1.5	5 - 6	2.75 – 3.5	4.5	1.8 – 2.3	1.2 – 2.2
	2020	0.8 – 2	0.5 – 1	1.5 – 2.5	0.85 – 1.1	1.0 – 1.5	1.5 – 2	1.1 – 1.7
Operation and maintenance costs (€c / kWh)	2004	1 – 3.5	0.5 – 1.0	-	-	-	1.2 - 2.4	1 – 3.5
	2010	0.5 – 2	0.2 – 0.7	1.5 – 2.5	1.5 – 2.0	1.5 – 2.5	1 – 2	0.5 – 2
	2020	0.3 – 1.5	0.2 – 0.6	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.6 – 1.5	0.3 – 1.5
Delivered electricity cost (€c / kWh)	2004	10.25	7.70	-	-	-	9.24	8.03
	2010	6.84	5.74	15.98	12.36	11.99	7.54	6.01
	2020	3.37	5.00	8.11	5.31	4.77	5.53	4.30
Lifetime (000 hours)		30	40	40	80	40	80	30
Maintenance interval (hrs)		4,000	2,500	4,000 (target)	4,000 (target)	4,000 (target)	5,000	4,000
Projected installed capacity (MWe)	2010	8.0	10.2	0	1.0	0	2.5	2.5
	2020	53.5	35.0	35.0	50.0	40.0	15.5	25.0
Likely year of commercial availability / Europe		2004/05 UK, NL	1999 Several	2010 D	2009 D, NL, UK	2010 D, NL, UK	1998 D	2005 UK
Likely availability Ireland		2005/06	Now	2012	2012	2012	Now	2006/07

DELTA ENERGY & ENVIRONMENT, 2004.
KEY: G – NATURAL GAS; LG – LANDFILL GAS; H – HYDROGEN; PR – PROPANE; DI – DIESEL OIL; FO – FUEL OIL; D – DOMESTIC; C – COMMERCIAL; I – INDUSTRIAL; NL – THE NETHERLANDS; D – GERMANY.

APPENDIX – Electricity Cost Model

This appendix provides an example of the model used to assess the current and future economics of the new technologies analysed in the study. The results are incorporated into Table 8. The example given on the following page is for a 1 kWe Stirling Engine CHP plant in a domestic application and with current market conditions. The assumptions used include the following:

- Gas and electricity prices are based on Eurostat data for July 2003 and are dependent on the volume purchased.
- Load factors are taken as 3500 hours for residential and 5000 hours for non-residential applications.
- The investment in CHP is based on avoiding an investment in a similar capacity boiler for the heat demand. Thus the capital cost of the CHP plant is balanced against the costs that would have been incurred for the boiler.
- The fuel consumption and costs for the CHP plant are corrected for the fuel that would have been consumed by a boiler for the same heat output. The same is true for maintenance.
- All efficiencies and fuel are on a Lower Heating Value Basis.
- The displaced boiler efficiency is 85%.
- The discount rate applied is 6%.
- The amount of exported electricity is 20% of the total electricity produced by the CHP plant and this receives €c4 / kWh. This is above the current rate paid in Ireland for spill electricity, which is between €c2.5-3 / kWh.
- No subsidies are included.
- All other data is based on research from the manufacturers either done through this study or taken from other work such as the EU MicroMap study.

DELTA TECHNOLOGY ASSESSMENT MODEL

Technology: **Stirling Engine 2004**

INPUTS

Technical Specifications

Electrical Output	kWe	1
Thermal Output	kWt	6,5
Electrical Efficiency	%	12%
Heat Efficiency	%	78%
Total Efficiency	%	90%
Fuel Input	kWf	8,33

Capital Investment CHP

Total Cost of Equipment	€	3400
Installation Fixed Cost	€	600
Installation Variable Cost	€/kWe	0
Total Installation Cost	€	4000
Marginal Equipment Cost	€	2200
Marginal Installation Cost	€	150
Marginal Total Cost	€	2350

Capital Investment Boiler

New Boiler Costs	€	1200
Installation Costs	€	450
Total Avioded Boiler Costs	€	1650

Other Inputs

Operating Hours	hrs/yr	3500
Gas Price	€c/kWh	3,24
Discount Rate	%	6%
Electricity Import Price	€c/kWh	11,79
Electricity Export Price	€c/kWh	4
Self Consumption %	%	80%
Boiler Efficiency	%	85%

Operational Performance

Variable O&M	€c/kWh	0
Variable O&M	€/a	0
Fixed O&M	€/a	180
Total O&M	€/a	180
Boiler O&M costs	€/a	180
CHP Gas Consumption	kWh	29167
Boiler Gas Consumption	kWh	26765
Net Consumption	kWh	2402
Heat Output	kWh	22750
Electricity Output	kWh	3500
Exported Electricity	kWh	700
Electricity Used On-Site	kWh	2800

OUTPUTS

Year		Total	0	1	2	3	4	5
Marginal Costs								
Capital cost	€	-2200	-2200					
Installation cost	€	-150	-150					
O&M	€	0	0	0	0	0	0	0
Fuel input	€	-856	-78	-78	-78	-78	-78	-78
Total cost	€	-3206	-2428	-78	-78	-78	-78	-78
Discounted	€	-3001	-2428	-73	-69	-65	-62	-58
Production								
Electricity	kWh	38500	3500	3500	3500	3500	3500	3500
Electricity discounted	kWh	29260	3500	3302	3115	2939	2772	2615
Revenue								
Electricity revenue	€	3939	358	358	358	358	358	358
Discounted revenue	€	2994	358	338	319	301	284	268
Net Cost/Income (not discounted)	€	733	-2070	280	280	280	280	280
Net Cost/Income (discounted)	€	-7	-2070	264	249	235	222	209

Economic Summary before subsidies		
Levelised Electricity Cost	€c/kWh	10,25
Net Present Value	€	-€6
Internal Rate of Return	%	6%
Simple Payback Period	years	8,38