Micro-CHP Technology Assessment and Benchmarking

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Technical Update, September 2009

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Delta Energy & Environment

Electric Power Research Institute (EPRI)

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CITATIONS

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This document describes research sponsored by (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

Micro-CHP Technology Assessment and Benchmarking. EPRI, Palo Alto, CA: 2009. 1018977.

PRODUCT DESCRIPTION

Significant public and private R&D investments continue to be made in the area of high-efficiency distributed fossil generation. Micro generation in combined heat and power (micro-CHP) applications is part of the portfolio mix, with a focus on residential and small commercial market segments. Such systems offer a potentially attractive cost of electricity, low greenhouse gas emissions, and smaller capital investments and shorter lead times than large central generation facilities. As part of a smart grid, such customer-based generation could be a significant component to the use of natural gas for power generation. This report benchmarks the current development status of micro-CHP and describes six micro-CHP technologies:

- Internal combustion engines (ICEs)
- Stirling engine
- Organic Rankine cycle
- Pico turbines
- Proton exchange membrane fuel cells (PEMs)
- Solid oxide fuel cells [SOFCs]

In addition to the status of these technologies, recent developments in Europe, Japan, and North America are also covered.

Results and Findings

Micro-CHP is a potentially disruptive technology providing opportunities and threats to U.S. utilities. Although many activities are under way in Japan and Europe, there are three major challenges for micro-CHP in North America:

- There is a lack of U.S. utility, policy, and heating industry engagement, compared to that in Europe and Japan.
- European and Japanese micro-CHP products must be adapted to warm air heating instead of hot water systems, leading to longer timelines for adaptation and production costs.
- The cost of electricity from micro-CHP products is currently higher when compared to the average U.S. grid retail rates.

Challenges and Objectives

The objectives of the research are the following:

- Assess and summarize the current landscape in micro-CHP technology and the leading vendors
- Benchmark the micro-CHP options in terms of key performance, operational, cost, and timing characteristics
- Summarize different approaches that European and Japanese utilities are adopting toward micro-CHP

Applications, Value, and Use

Electric utility strategic planners, smart grid planners, customer technology managers, and R&D managers can use the results of this work to understand the timelines and feasibility of micro-CHP systems. Results can be used in smart grid plans, community initiatives, new service offerings, and strategies for lowering greenhouse gas emissions.

EPRI Perspective

Fossil-fuel-based distributed generation is part of the Electric Power Research Institute (EPRI) Energy Storage and Distributed Energy Resources research program. This study benchmarked potentially disruptive technologies that are currently incubating and finding niche markets and applications in international markets. The deployment of systems in these markets will help drive down capital costs and enable derivative systems to be configured for the U.S. market. All-electric advanced, micro-generation systems are in development and testing, which could be quite competitive with future U.S. retail rates particularly in lower natural gas fuel price scenarios. Such systems, if proven to be reliable and cost effective, should be one part of a full portfolio of high-efficient natural-gas-based power generation options, helping reduce the electric sector's carbon footprint and future generation capital investments.

Approach

A worldwide assessment and benchmarking effort was conducted in the area of micro-CHP systems. Background expertise was developed and extensive discussions with several utilities, micro-CHP developers, and manufacturers took place. Modeling of leveled electricity costs and U.S. market requirements served as a metric for U.S. retail competitiveness.

Keywords

Micro-generation
Micro-CHP
PEM fuel cells
Stirling engines
Internal combustion engines (ICE)
Organic Rankine cycle
Solid oxide fuel cells (SOFC)

EXECUTIVE SUMMARY

Introduction

Significant public and private R&D investments continue in the area of high efficiency distributed fossil fuel generation. Micro generation configured in combined heat and power (Micro-CHP) applications is part of the portfolio mix with a focus on residential and small commercial market segments. Such systems offer potentially attractive cost of electricity, low green house gas emissions, smaller capital investments and shorter lead times than large central generation facilities. As part of a smart grid, such customer based generation systems could potentially be a significant component in the use of natural gas for power generation. This report benchmarks the current development status of six different micro-CHP technologies (internal combustion engines, Stirling engine, organic Rankine cycle, pico turbines, proton exchange membrane and solid oxide fuel cells) and recent developments in Europe, Japan and North America.

The objectives of the research were to:

1) Assess and summarize the current landscape in micro-CHP technology and benchmark the leading vendors of these systems.
2) Benchmark micro-CHP options in terms of key performance, operational, cost and timing characteristics.
3) Summarize different approaches that European and Japanese utilities are adopting towards micro-CHP adoption and commercialization.
4) Benchmark the retail cost effectiveness of these systems in the United States.

Key Findings

Key Players and Commercialization efforts

Micro-combined heat and power (micro-CHP) technology has been commercially available since the late 1990s, but has only made limited market-inroads to date. But a plethora of new products and technologies, together with policy support, is opening up a potential mass market opportunity in Europe and Japan for residential applications.

Some of the leading micro-CHP developers are shown below (Figure ES-1) – these companies are amongst the leading technology developers and have established strategic partnerships and market channels.

Figure ES- 2 shows the contenders in this market as well as the ‘wild cards’ which have the potential to become significant players in the market.

Technology	Micro-CHP Developer	Headline Plans
ICE	HONDA The Power of Dreams; MARATHON ENGINE SYSTEMS; BAXI; YANMAR	Reliable commercial products and expanding their global market outreach
Stirling Engine	microgen engine corporation; eHe efficient home energy, s.l.	Setting up the production facilities for mass market (30,000 units per year) in 2009/2010
Organic Rankine Cycle	energetix genlec	Developing a low cost micro-CHP system and commercialization expected within the next three years
PEM Fuel Cell	ENEOS; Panasonic; TOSHIBA	Commercialization in Japan in 2009. Next steps to lower costs and improve reliability further.
SOFC	Ceramic Fuel Cells Limited (Clean power for your home); KYOCERA; CeresPower	Companies with closest SOFC products to market by 2012

Figure ES-1
Leading Vendors in Product Development

Technology	Contenders	Wild Cards
ICE	AISIN	
Stirling Engine	DISENCO; ENATEC MICRO-COGEN B.V.	DEKA
Organic Rankine Cycle	Climate Energy	OTAG
PEM Fuel Cell	plug power; Serenergy; BAXI INNOTECH; ClearEdge POWER; IRD Fuel Cell Technology	Korean Fuel Cell developers
SOFC	TOPSOE FUEL CELL; Acumentrics; HEXIS; TOTO	Bloomenergy Honda SOFC? Versa Power Systems

Figure ES-2
Wild Cards / Contenders

Figure ES-3 below illustrates sales figures for products currently available on the market. Key points relating to each product:

- Honda ECOWILL – 1 kWe, Japan, Internal Combustion Engine. Large support from gas utilities to deliver product to market and customers to compete with growing share of all electric homes. Commercialization since 2003.
- Vaillant – 5 kWe, 90% sales in Germany, Marathon Engine (US), packaged by Vaillant, International Combustion Engine. Commercialization since 1999.
- Baxi SenerTec – 5 kWe, mainly in Germany, Internal Combustion Engine. Sales fell in 2007 as customers were waiting for CHP incentives starting in 2009. Commercialization since 1997.
- WhisperGen – 1 kWe, mostly field trial units across Europe, Stirling Engine. Aiming for first volume production of 3,000 units in 2009. Commercialization since 2003.
- OTAG – 3 kWe, sales mostly in Germany, Rankine Cycle. Technical challenges in the product to be improved, only 100 sales per year since 2006.
- Sunmachine – 3 kWe, focusing on German market but considering other market, Stirling Engine. Unit runs on wood pellets. Building product confidence and reliability. Commercialization in 2008.
- Yanmar – 5 kWe, Japanese market, Internal Combustion Engine. 400 units sold per year, looking at opportunities in the North American and likely to be available in Europe in 2010. Commercialization since 2002.

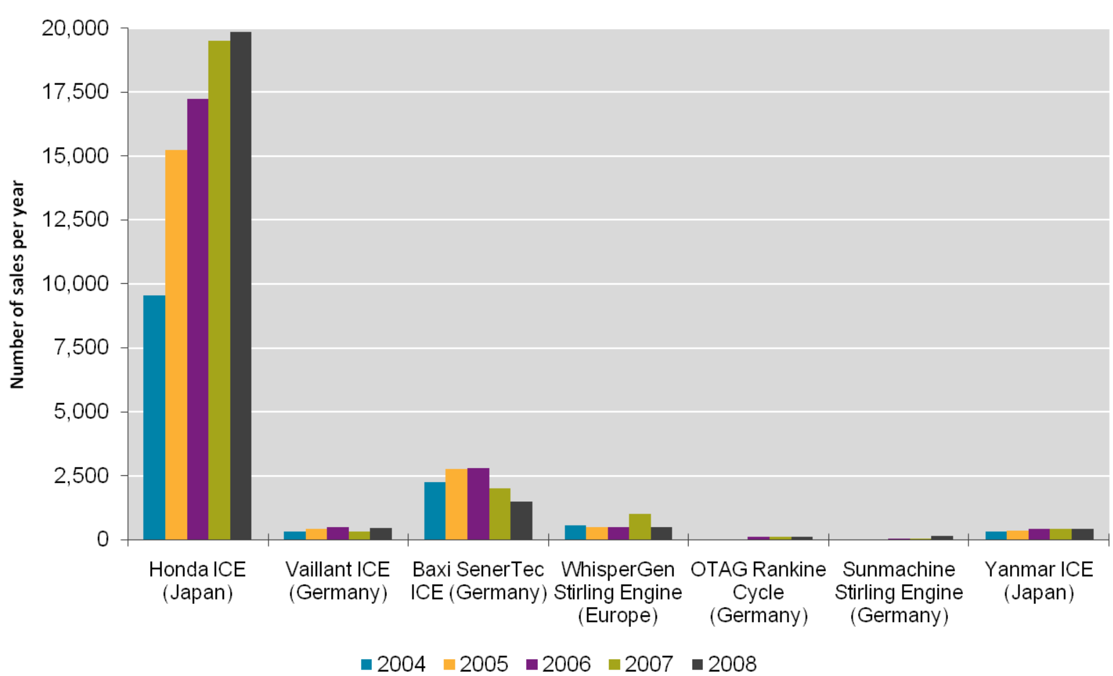

Figure ES-3
Commercial Products Currently Available on the Market

Technology Status and Market Readiness

In North America, Internal Combustion Engine (ICE) and Stirling engine technologies have the potential to dominate the micro-CHP market in the next few years. Only after 2012 is it likely that a relatively affordable and reliable fuel cell micro-CHP will be available in the U.S. market, with the timing more likely to be closer to 2015. Figures ES-4 and ES-5 summarize / illustrate the status of each technology and examples of field trial currently underway to develop market ready products.

- The ICE is a reliable and mature technology, with products available to customers in Japan, Europe and North America.
- Stirling engines are in the early stages of commercialization with Whisper Tech (through a Spanish joint venture) and Microgen Engine Corporation establishing volume production facilities (tens of thousands of units a year) in 2009.
- Energetix, a UK ORC developer is assembling a low-cost micro-CHP system and commercialization is expected within the next three years in Europe.
- PEM fuel cells are, as of 2009, being commercialized in Japan, with major developers such as Panasonic, Toshiba and Eneos aiming to achieve lower production costs over the next five years.
- Kyocera, Ceramic Fuel Cells Limited, Honda and Ceres Power are on track to offer commercial Solid Oxide Fuel Cell (SOFC) products by around 2012 (initially in Europe and Japan). Field trials and strong partnerships are aiding in further product development and results so far are promising. Wild card companies like DEKA, Bloom Energy and others should be followed and monitored.

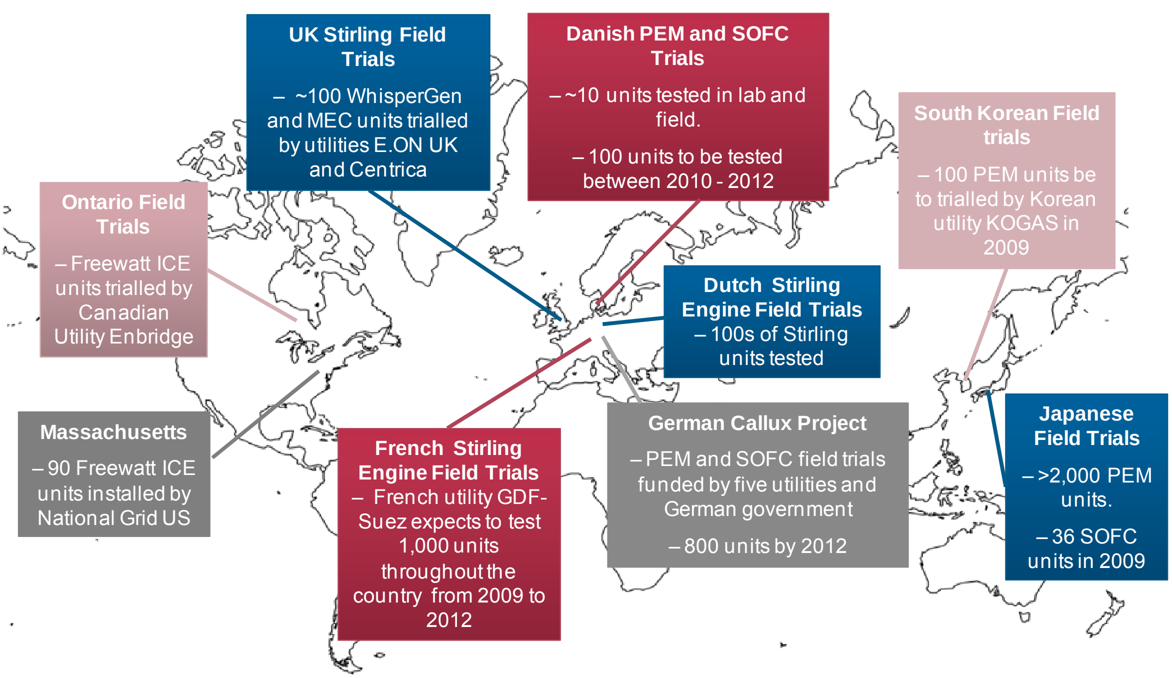

Figure ES-4
Global Effort: Micro-CHP Field Trials

Technology	Status
ICE  	• Mature and reliable • Lifetime of max. 15 years • Servicing required every 4,000 – 10,000 hours • Two products adapted to US Market
Stirling Engine  	• Finalizing product for volume production • Expected lower maintenance costs than ICE • No products adapted to the US market
Organic Rankine Cycle 	• Lab and field trials • Packaged for European market • Potentially maintenance costs as low as furnace • No products adapted to the US market
PEM Fuel Cells  	• Commercialization in Japan • Focus on cost reduction • Currently, fuel stack needs replacement every 5 to 10 years • No products adapted to the US market except ClearEdge Power
SOFC  	• Under development • Performance, durability and reliability challenges • Initial field trials in Japan and Europe • No products adapted to the US market

Figure ES-5
Technology Status and Market Readiness

Adaptation to the U.S. Market – Micro-CHP to Step Up to the Challenge

Micro-CHP produces waste heat while generating electricity (ORC produces ~8 units of heat for each unit of electricity; SOFC: 1 or less units of heat for each unit of electricity). The waste-heat is typically utilized for space heating. Other modes of operation are possible, including:

- Water heating – the waste heat is recovered for residential hot water use.
- Space heating and water heating - the only mode of operation in Europe and Japan, where hydronic heating predominates.
- Electricity only - dumping the waste heat (unlikely to be attractive as it brings no environmental benefits)

Given space heating is the most likely application for micro-CHP, we explore this below, but include some economic analysis of other operation modes in this report.

In North America, micro-CHP has to compete with electric heat-pump water heaters and furnaces for warm air heating. Despite micro-CHP products being ready for market in Europe and Japan, so far, only Climate Energy and Marathon Engine Systems have adapted their units to supply warm air. This adaptation requires substantial product development effort and time.

North American customers typically spend less than US$6,000 on equipment and installation of a normal furnace. Annual maintenance costs are typically US$50 or less, and furnaces are expected to last well beyond 10 years. Currently, micro-CHP technologies cannot compete with these three requirements – the marginal costs above a furnace (product cost and maintenance) are far too high, and 10 year lifetimes are in many cases unproven.

However, micro-CHP can deliver several benefits to both customers and utilities (these are expanded on in the next section), including the primary benefit of lower electric and energy bills.

Heating demand is also a key factor, as micro-CHP only operates when there is a demand for heat. North-Eastern U.S. States and Ontario, which have high heating hours combined with high electricity prices, are therefore ideal micro-CHP markets.

Analysis of Retail Competitiveness

The analysis was carried out using a model that calculated the leveled cost of electricity from micro-CHP up to 2015. Both conservative and aggressive scenarios were considered. The aggressive scenario assumes that micro-CHPcosts (capital, installation and maintenance) are significantly reduced for all technologies.

The modeling was based on assumptions relating to:

Product Characteristics: The capital costs assumed micro-CHP units (capacities between 0.7 – 1.2 kWe) are adapted to the North American market. For the "displaced" furnace, total installation costs of US$6,000 and maintenance costs of US$50 per year.

Operation: In the conservative case, Micro-CHP system operates for only 4,000 hours per year – typical heating season in North-Eastern U.S. states and all heat is used when producing electricity. Comparison was made with a furnace with 95% overall efficiency.

Energy Prices and Electricity Export: net metering was assumed with the same import/export costs of 15c/kWh for 2009, 2012 and 2015. A gas price of $12/MMBtu was assumed for 2009, 2012 and 2015.

Discount Rates: Assumed discount rate of 15%.

Figures ES- 6 and ES-7 below illustrate the outputs from the model. When comparing leveled electricity costs from a micro-CHP unit with average US residential electricity costs, it is only likely that micro-CHP can beat the grid after 2015. More aggressive scenarios and different operation mode assumptions may bring micro-CHP electricity costs down more quickly as shown by Figure ES-7.

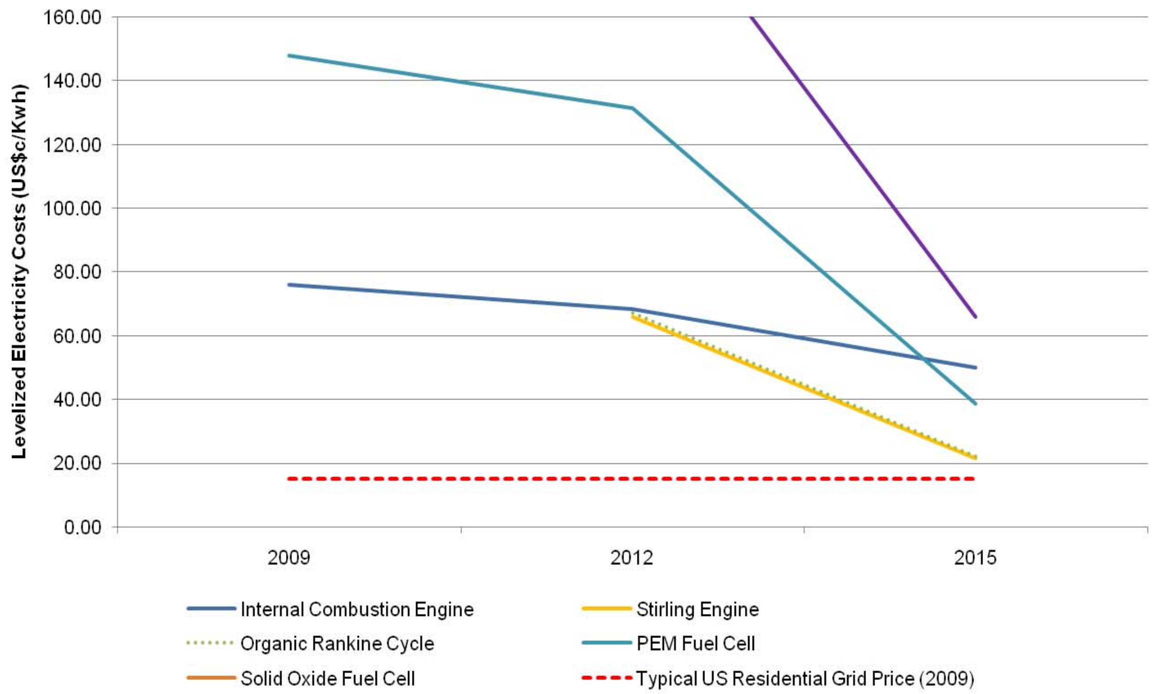

Figure ES-6
Leveled Electricity Costs for 1 kWe Micro-CHP Unit - Conservative Scenario

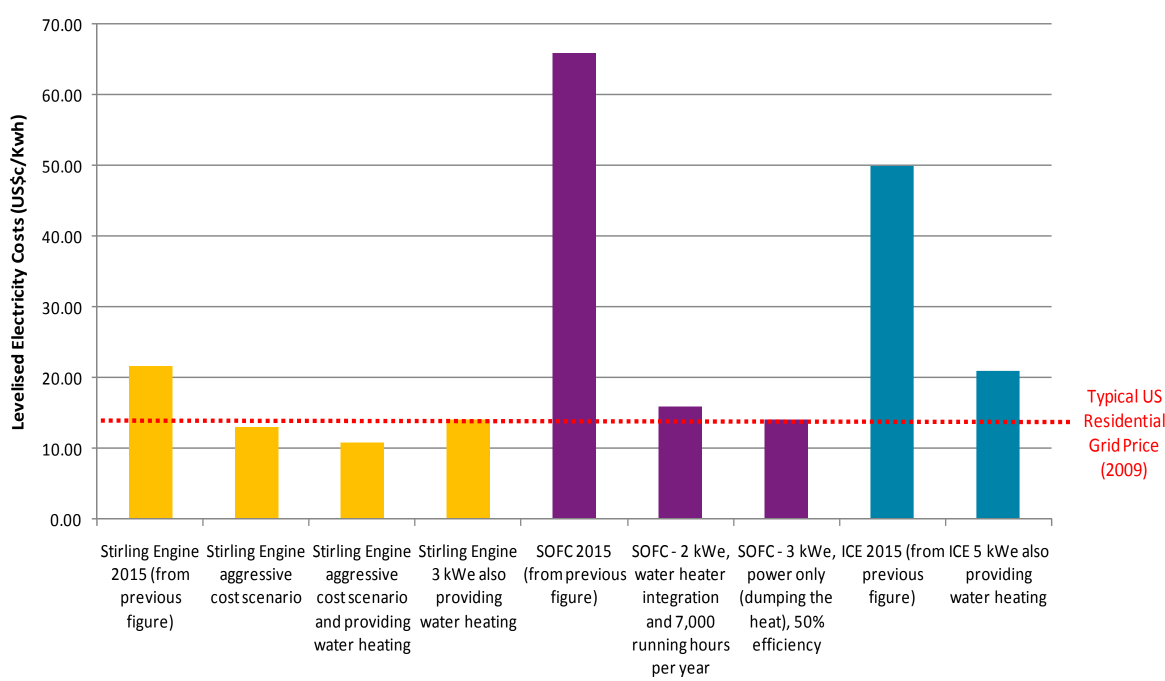

Figure ES-7
Leveled Electricity Costs for 1 kWe Micro-CHP Unit - Aggressive Scenario

Why are Utilities Engaging with Micro-CHP Globally?

Micro-CHP is a potentially disruptive technology for utilities as it can potentially be a lower cost source of electricity supply than the grid and lead to a reduction in grid electricity sales. On one hand this makes it a threat for electric utilities. But several European and Japanese utilities (generally electric and gas, or just gas utilities) are engaging with micro-CHP to bring it closer to market and believe micro-CHP can deliver several benefits, including:

1) Sustainable customer solutions: part of portfolio of low carbon products for their residential customers – with micro-CHP potentially offering the best mass market opportunity.
2) A way to deepen customer relationships, resulting in stickier customers in competitive markets.
3) A cost effective way to meet carbon / efficiency targets.
4) Shaping the customer demand curve by influencing / controlling when micro-CHP units run.
5) Potentially owning micro-CHP assets, selling the electricity to customers.

Global retail gas suppliers see micro-CHP as a key hope for securing customers and gas sales in the face of falling gas competition from efficiency improvements and growth in renewable heating.

In the North American market, only Enbridge in Canada and National Grid in the US have so far stepped up to the micro-CHP plate.

Conclusions

Micro-CHP is a potentially disruptive technology providing both opportunities and threats to US utilities in the near future. The potential threat is a decrease in grid electricity sales and coping with export power back onto the grid. Opportunities for utilities include:

- Sustainable customer solutions: part of portfolio of low carbon products and solutions for their residential customers – with micro-CHP potentially offering mass market supply side energy efficiency and a grid support opportunity.
- A way to leverage smart grid initiatives with customers.
- A cost effective way to meet carbon / efficiency targets.
- Shaping the customer demand curve by influencing / controlling when the micro-CHP units run.
- Potentially providing lower cost electricity than the grid, if high efficient systems prove to be reliable.

Micro-CHP has not yet taken-off in North America as it has in Japan and Europe. There are four major challenges for micro-CHP in North America:

- There is a lack of US utility, policy maker and heating industry engagement, compared to initiatives and policies in Europe and Japan.

European and Japanese micro-CHP products have to be adapted to warm air heating instead of hot water leading to longer timelines for adaptation and production costs. At the moment, only Climate Energy (Freewatt) and Marathon Engine Systems have a micro-CHP product fully adapted to the US market and warm air heating;

- Micro-CHP products are currently expensive – as volume production increase and prices fall, the leveled electricity costs could fall below grid electricity prices in 2015-2020, although these estimates come with large uncertainties.
- If micro-CHP provides warm air heating in place of a furnace, the low cost, long lifetime and low maintenance requirements of furnaces is a challenging yardstick for micro-CHP.

All electric, high efficient (50%) solid oxide fuel cell systems are in the early stage of field trials and demonstration. Except for modest power electronics and interconnection / protection changes, such systems would not have to be modified to meet US markets.

Recommendations

Given micro-CHP's environmental credentials and potential customer appeal, micro-CHP is expected to emerge in North America over the next few years. While on one hand a threat to utilities, there are several opportunities that can be exploited. Forward-thinking utilities have opportunities to help shape micro-CHP products to their own market conditions, gaining early insight into how they can benefit from micro-CHP's emergence.

For those utilities intending to capitalize on this market, action now will enable them to exploit opportunities in 2015 and beyond. In preparation, utilities should consider:

- Developing partnerships with manufacturers (e.g. like E.ON UK) and actively participating in product development. The near-term focus should be to engage with those companies developing high efficient all electric systems.
- Engaging the customer and promoting micro-generation to raise awareness ensuring that there will be significant demand when products become available.
- Engaging in pre-commercial testing and evaluations
- Continuing to monitor and track product development, market penetration and cost and performance features of top tier companies.
- Ensuring that micro-generation systems are inter-operable with smart grid initiatives and implement and tests such systems in smart grid pilots.

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1
TECHNOLOGY STATUS AND PROSPECTS

This section provides some reader background on the six different types of micro-CHP technologies:

- *Internal Combustion Engine (ICE)*
- *Stirling Engines*
- *Organic Rankine Cycle (ORC)*
- *Proton Membrane Exchange Fuel Cells (PEMFC)*
- *Solid Oxide Fuel Cells (SOFC)*
- *Pico Turbines*

Each is addressed in turn in this section.

Internal Combustion on Engine – Reliable and Mature Technology

ICEs for micro-CHP applications are based on specially designed long-life engines and achieve electrical efficiencies of 20% to 30%. These specialized engines have long maintenance intervals (a few to ten thousand hours) and are quiet enough to be installed inside a building.

Honda has been producing a 1 kWe engine for micro-CHP applications since 2003, and three companies have been manufacturing 5 kWe engines for several years.

Source: Honda, 2009; Freewatt, 2009

Figure 1-1
Similarities between the Honda ECOWILL (left) and Honda Freewatt unit (right)

The Japanese unit includes a water storage tank and supplementary burner, while the US version includes a furnace for warm air heating.

Stirling Engine – Edging Closer to Volume Production

Stirling engines are external combustion engines. A working fluid, usually nitrogen, hydrogen or helium, is enclosed within a hermetically sealed pressure vessel meaning no valves are required and any heat source can be used. Electrical efficiencies of micro-CHP Stirling engines are typically between 10 and 20%. The engines in principle require no maintenance, and promise to be quiet enough to be installed in a kitchen.

Several European and US companies are developing Stirling engine micro-CHP products ranging from 0.45 kWe to 3 kWe (Figure 1-2). Some developers are working on wall hung designs (despite product weight typically above 90kg), meaning Stirling engine micro-CHP units could directly replace a significant proportion of gas boilers in Europe.

Leading developers have announced ambitious commercialization plans since 2002, but progress from demonstration units to commercial sales has been much slower than expected. In 2009 two companies, Microgen Engine Corporation and Whisper Tech, established volume production facilities.

Source: Whisper Tech, 2008, Eneco, 2008, Remeha, 2009

Figure 1-2:
WhisperGen's (left), ENATEC's (center) and Remeha's (right) 1kWe Stirling Engines.

The differences in size are due to different stages of development, with ENATEC unit requiring further development to ensure optimal size for average European households. The Remeha micro-CHP system is the only wall hung unit.

Organic Rankine Cycle Engines – Cheap but Low Electrical Efficiency

ORC engines are also external combustion engines, using an external heat source to heat a working fluid - water (steam) or a refrigerant - in a closed loop cycle. Rankine cycles units are quiet in operation and efficiencies are typically low compared to other micro-CHP technologies – around 10% or below, with limited potential for substantial improvements above this. However, manufacturers project low production costs. Some designs have a low mass compared to other micro-CHP technologies, and can be incorporated in a wall-hung unit.

Only two European companies are actively developing Rankine cycle micro-CHP units, with electrical output from 1 to 3 kWe. Since 2006, German developer OTAG sells a few hundred units per year, while UK developer Energetix has partnered with Dutch boiler manufacturer Daalderop to sell an ambitious 30,000 micro-CHP units by 2012 (Figure 1-3).

Source: Energetix, 2008, OTAG,2008

Figure 1-3
Energetix's Genlec 1 kWe unit (left) and OTAG's Lion 2 kWe unit (right)

At the moment, Energetix is one of the few ORC developers with capacity and partnerships in place to enable a reliable product. However, there are still several challenges before bringing it to market.

PEM Fuel Cells – Edging Closer to Mass Market

The Proton Exchange Membrane or Polymer Electrolyte Membrane (PEM) fuel cells have received substantial attention as potential micro-CHP generators since the late nineties. Electrical efficiencies of 30% or more are typical, with overall efficiency around 80% at lower heating values. Operating temperatures are low compared to SOFCs and the recovery of heat at low temperature is a challenge for system design, although the emergence of high temperature PEM technology offers promise for micro-CHP applications. PEM micro-CHP market activity has slowed to some extent as many companies developing core PEM technologies are now concentrating on other markets e.g. backup power supplies or powering forklift trucks.

The biggest micro-CHP commercialization efforts have been in Japan, where more than 3,000 units have run in demonstration programs and units such as that shown in Figure 1-4 are now available to customers. In Europe and North America, several other companies are also developing product (such as Baxi Innotech, also shown in Figure 1-4 below).

Source: Osaka Gas, 2009; Baxi Innotech, 2009

Figure 1-4
Osaka Gas 1 kWE ENE-FARM system with water storage tank (left and Baxi Innotech's 1kWE PEM unit (right)

The ENE-FARM is the general brand given to PEM micro-CHP systems in Japan in order to raise awareness irrespective of the developer or installer. The Baxi Innotech unit includes a fuel cell from Ballard, a leading PEM fuel cell developer.

Solid Oxide Fuel Cells – Product Development Underway in Europe and Japan

SOFCs operate at a significantly higher temperature than PEMs (typically 500-1000 degrees Celsius) meaning waste heat can be used more effectively in the home. High electrical efficiencies are also possible. Ceramic Fuel Cell Ltd has surpassed the 50% milestone, reaching 60% electrical efficiency in lab (including inverter, parasitic and reforming losses). Kyocera has prototype system which has demonstrated an electrical efficiency of 50 % at lower heating values and Honda currently has a 50% LHV efficient under development.

Several SOFC technology developers have installed small numbers of trial units in Japan and Europe, in partnership with boiler manufacturers and utilities (Figure 1-5). Most units are installed in Japan, but no manufacturer has more than a few tens of units installed. The one exception is Swiss-based Hexis, which installed one hundred units between 2001 and 2004, mainly in Germany before realizing it needed to retreat to develop its core technology further.

Source: Ceres Power, 2008; CFCL, 2008; Hexis, 2008; Kyocera,2008

Figure 1-5
SOFC micro-systems developed by Ceres Power (left), Ceramic Fuel Cell Ltd (left-center), Hexis (right-center) and Kyocera (right - with water storage)

These four companies are at the forefront of SOFC development in Europe and Japan with tens of field trials so far. All are aiming at having a commercially viable product by 2012.All units developed are to be floor-mounted except for the Ceres Power unit.

Pico-turbines

Micro Turbine Technology (MTT) in the Netherlands is developing a coffee-cup sized gas turbine for micro-CHP applications. The turbine incorporates an innovative design, whereby the compressor and turbine are integrated into a single unit. The turbine powers a permanent magnet generator, which is in turn connected to an inverter. It is intended that the hot exhaust from the turbine will replace the burner in a boiler / furnace.

The initial electrical efficiency target is 11%. The turbine has a high power density, and is expected to be of relatively low thermal mass. MTT is aiming to produce a number of units with different capacities ranging from 600 W to 3 kW. Commercialization is not expected until after 2011 at the earliest.

2
MICRO-CHP COMMERCIALIZATION EFFORTS – A GLOBAL OVERVIEW

Micro-CHP is edging-closer to commercialization and shows plenty of potential to play a key and disruptive role in heating and energy markets. It has the potential of meeting all the heating requirements of a household and at the same time provide at least half of household's electricity requirements. This section looks at the commercialization efforts from several micro-CHP developers and the move to mass production of micro-CHP products (< 5 kWe). Market developments in Europe, Japan and North America are also discussed.

Introduction – Edging Towards Mass Market

Internal combustion engine (ICE) and Stirling engine micro-CHP developers are progressing steadily to deliver a reliable and affordable product to end-customers. The scene is set for the next three years to be pivotal in micro-CHP's future as a plethora of new products comes to market.

However, looking back at 2008, there has been little change in annual commercial sales with annual installed capacity of 33.5 MWe. Approximately 22,700 units were sold in 2008, bringing cumulative micro-CHP sales through the 100,000 unit mark (Table 2-1). The vast majority of these are the Honda 1 kWe ICE based systems in Japan.

Manufacturer	Product and capacity (kWe)	Technology	First commercial sale	Cumulative sales to date	Primary markets
Honda and partners	ECOWILL, 1	ICE	2003	86,300	Japan
OTAG	Lion, 3	RC	2006	310	Germany
PowerPlus Technology	Ecopower, 4.7	ICE	1999	2,350	Germany
SenerTec	DACHS, 5.5	ICE	1997	19,500	Germany
Sunmachine	Sunmachine Pellet, 3	SE	2008	150	Germany
Whisper Tech / Efficient Home Energy	WhisperGen, 1.2	SE	2003	3,050	Germany, Netherlands, UK
Yanmar	Genelight, 5	ICE	2002	2,150 (estimate)	Japan

Source: Delta Energy and Environment, 2009

Table 2-1:
Micro-CHP Products Available in European, Japanese and North American Markets

The Honda, OTAG, Sumachine and WhisperGen products are designed for single famiy homes – the rest are generally installed in multi-family home and small business applications.

Note: ICE – Internal combustion engine, RC –Rankine cycle, SE – Stirling engine.

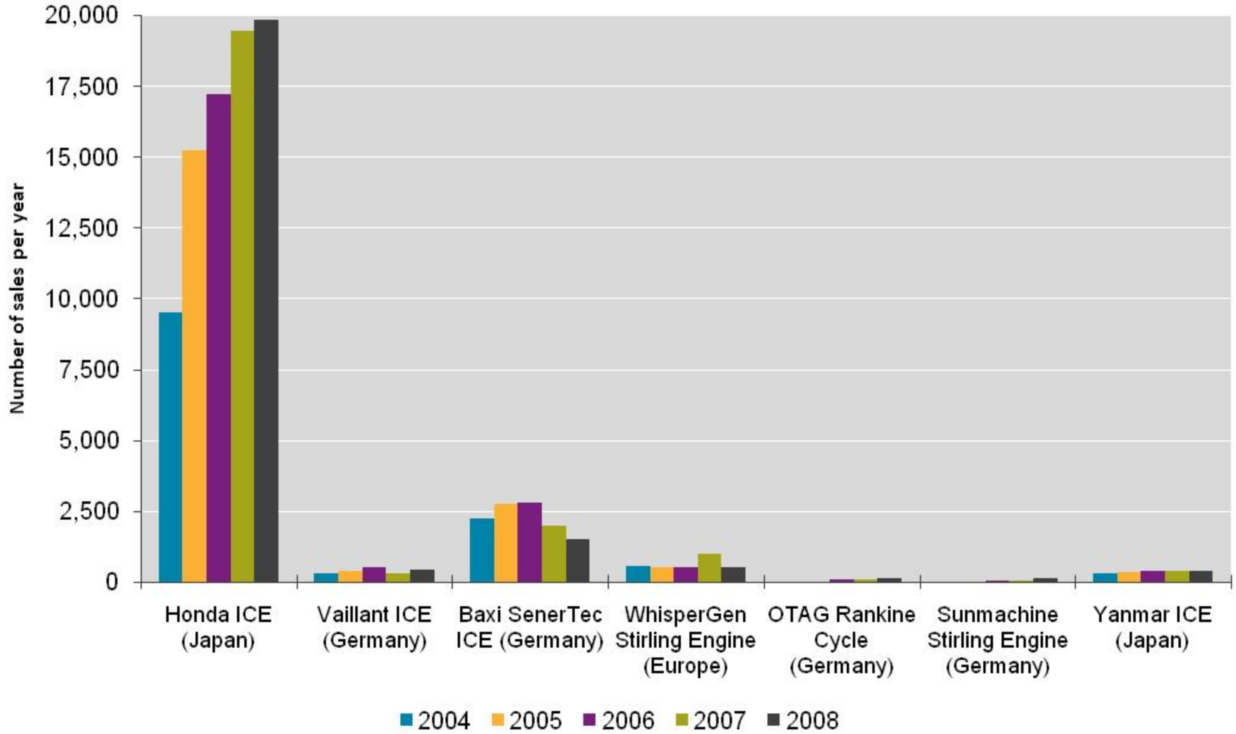


Figure 2-1:
Sales of Products Currently Available in the Market

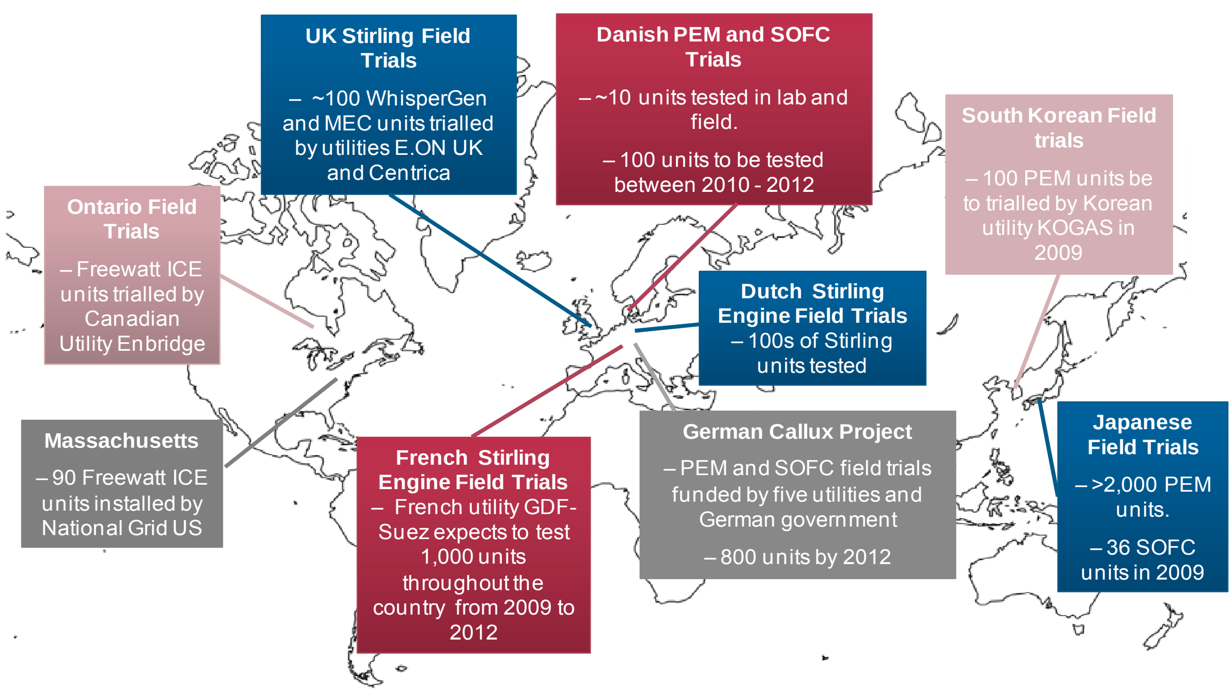


Figure 2-2:
Global Effort: Micro-CHP Field Trials

Europe – Internal Combustion and Stirling Engines Lead the Way

As shown by Table 2-1, in Europe the 5 kWe ICE micro-CHP units have been commercially available since the late 90s in Germany. However, their larger capacity limits the overall opportunity (a niche, not mass market product in Europe). Hence, greater interest for smaller 1-2 kWe units with mass market potential.

Two Stirling engine manufacturers offering 1 kWe units (Whisper Tech / Efficient Home Energy and Microgen Engine Corporation) are establishing volume production facilities capable of producing 30,000 units per year, with product demonstrations and market introduction towards the end of 2009 (Figure 2-3). If all goes smoothly, sales of each product could reach tens of thousands of units a year within the next couple of years. Several other micro-CHP developers, such as Energetix, ENATEC and Disenco hope to join them.

Source: Microgen Engine Corporation, 2008

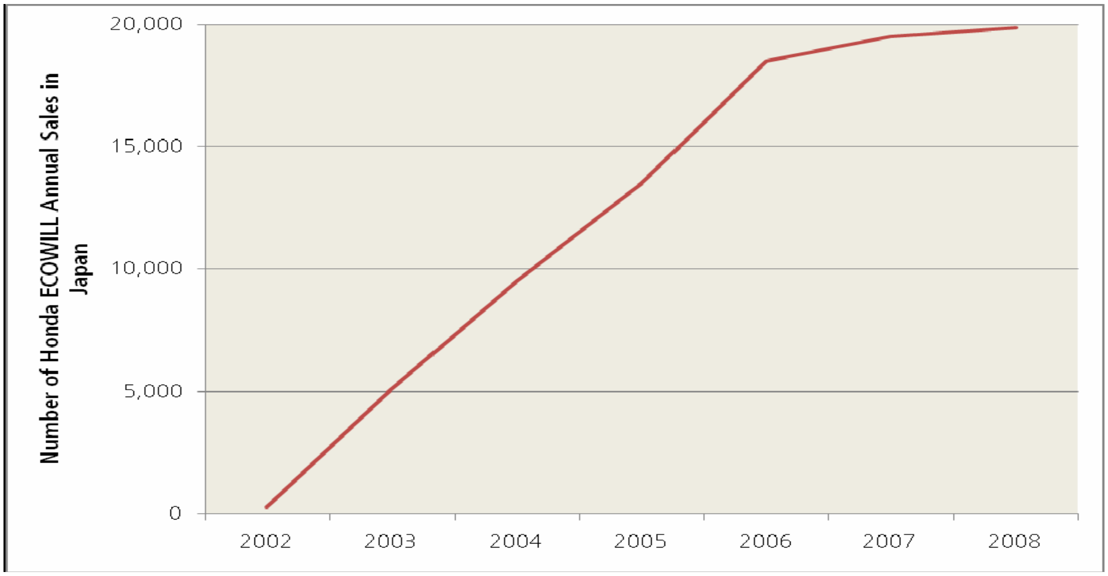
Figure 2-3:
Microgen Engine Corporation Production Facilities in China

On the left building housing a low volume production line built by Microgen Engine Corporation to manufacture its free-piston Stirling engine. On the right, the building containing its high volume production facilities (each line will be capable of producing 250 units per shift per week)

Japan – The Model and Leading Micro-CHP Market

Japan is the leading market for micro-CHP in terms of sales of ICEs and for commercializing PEM and solid oxide fuel cells (SOFC). The Japanese policy and government initiatives, gas utility and kerosene suppliers are all very supportive of micro-CHP technologies, providing incentives for customer engagement and heavily supporting development of affordable and reliable products. Gas utilities and kerosene suppliers are eager to use micro-CHP to battle the growing trend of all-electric homes. This alliance between government, micro-CHP developers and utilities leads to a unique and strong push for micro-CHP deployment, which has been a success and seen as the model to follow.

The most sold micro-CHP unit is the Honda ICE-based ECOWILL with 20,000 units sold a year, (Figure 2-4). This product is mature and has been sold in Japan since 2003 at competitive prices with customer paybacks typically below six years.



Source: Delta Energy & Environment, 2009

Figure 2-4:
Honda ECOWILL Sales in Japan since 2002

Currently reaching a plateau in annual sales in the last two years due to growing competition from heat pumps, the Honda 1 kWe ICE ECOWILL system continues to dominate global micro-CHP sales. All major Japanese gas and LPG retailers offer the product, which is bought by end-customers attracted by the ~6 year pay back.

Japanese PEM fuel cells have moved out of the demonstration phase and into market introduction in 2009 with average costs of US$35,000. Japanese utilities plan to sell at least 5,000 PEM fuel cell units in 2009. Major companies such as Eneos CellTech (Nippon Oil), Panasonic and Toshiba have established production facilities to manufacture thousands of units per year. Their main target will be to bring costs down considerably in the next five years to a challenging target of $5,500 in 2015.

SOFC technology continues to make steady progress under the Japanese Government's field trials with 36 units being tested in 2009. SOFC technology is showing average electrical efficiencies 5% above PEM fuel cells in the field, with mid 40% electrical efficiency (lower heating value) reached in the laboratory.

The Kyocera's early micro-CHP prototype systems (at 50 % steady-state efficiency) shows potential promise especially after the company partnered with Toyota, CHP packager Aisin Seiki and Japanese utility Osaka Gas. This strong partnership is expected to accelerate SOFC development in Japan.

North America – Still Not Managing to Break the Ice

North America has been a slow market for micro-CHP deployments with limited awareness and interest from utilities and government. This is likely to change with an increasing number of energy efficiency and low carbon policies from the Obama administration and State governments. Furthermore, changes are expected with increases in residential utility rates due to a confluence of high cost of new central generation, increased costs due to T&D infrastructure investments and the impact of renewable portfolio standards.

At the moment only two micro-CHP products are properly adapted to the US market for warm-air heating and available to the end-customer – The Honda Freewatt system and the Marathon Engine System, both of these systems are built around ICEs currently used in Japan and Europe. The Honda unit has been installed in the low hundreds in the North-Eastern US States, and a few tens of Marathon systems have been installed.

The 1 kWe Freewatt system has been developed by Climate Energy, a joint venture between boiler and furnace manufacturer ECR International, and heating engineering company Yankee Scientific. ECR is now establishing a distributor network and hopes to sell thousands of units a year, building on the hundreds already installed. Engagement from utilities such as National Grid US and Canadian utility Enbridge will help. New product variants, including backup power and remote dispatch for demand response programs, will help to raise interest.

Marathon Engine Systems, the US company that manufacturers the 5 kWe engine at the heart of the Ecopower micro-CHP system in Europe, has adapted the packaged system for the North American market. The company launched its product (mainly targeting North Eastern States) in late 2007. By the end of 2008, Marathon had sold 18 units and is on track to sell at least 70 units in 2009.

ClearEdge Power, a high temperature PEM fuel cell system developer, is deploying 5 kWe micro-CHP units in California in small commercial end-use establishments and high end homes. They are forecasting sales of over 700 units by end of 2010. This depends on the success of their early pre-production field trials as well as state and tax incentives. ClearEdge has an aggressive timescale for commercialization when compared to Japanese PEM products which have trialed hundreds of units over three years to get to a reliable product.

3

WILL-MICRO CHP MEET MARKET REQUIREMENTS

The North American heating market is fundamentally different from the European and Japanese markets, in terms of heating requirements and heating system design. In most European and Japanese homes, a boiler provides hot water and hydronic heating, while in the North America a furnace provides warm air heating and a separate water heater delivers hot water.

As most micro-CHP units are being developed for the European and Japanese market, it will be necessary to adapt these systems to the US market. In this section, the current technology status, and challenges are discussed as well as the need to adapt systems for the North American market. Leveled electricity costs from micro-CHP in 2015 are also calculated.

Developing a Product for the North American Market

At present, only ECR International and Marathon Engine Systems are offering warm-air micro-CHP systems adapted to the US market.

Companies bringing micro-CHP technology to the US market face a significant challenge. However great the technology, it will likely take at least two to three years to develop and trial a product compatible with a warm air heating system.

Backup generation is another challenge for product developers. Most European and Japanese consumers have little interest in such a feature, and most products do not offer it. ECR's FreeWatt product will have this from 2010, but this capability again incurs significant development effort.

Capital Product Costs – A Significant Challenge

The FreeWatt system from ECR costs around US$20,000 to US$30,000 (including installation) to the homeowner. This cost difference is only likely to drop when these companies start selling tens of thousands of units a year, but even then we do not anticipate a price reduction of several thousand dollars.

Other products are being commercialized in Europe and Japan, but costs in these markets are high while volumes are low. 1 kWe Stirling engine micro-CHP systems are currently on offer to utilities for close to US$15,000. PEM fuel cells in Japan are retailing for US$35,000. It will take a few years before volumes may reach a few tens of thousands of units per year, and costs are significantly reduced in these markets. And we do not see such technology being adapted for North America and on the market before 2012-13. In the year or two after this, costs will likely remain high with initially low volumes in the North American market.

Scenarios exist where cost falls more quickly than this more conservative scenario. With concerted effort, it may be possible to take a technology and package it for the North American market in two years, and riding on the back of increasing production volumes in Europe and Japan could see product costs well under double that of a US$6,000 furnace by 2015.

Another factor which could reduce the capital cost barrier is financing – if utilities invest and own micro-CHP assets (as they do with larger power plants, and now PV in some cases), this would reduce the customer investment required.

Maintenance and Lifetime – Furnaces Lay Down a Challenging Yardstick

A typical furnace will have maintenance costs below US$50 per year and a lifetime as long as 20 years. Currently, the maintenance costs of Climate Energy and Marathon Engine Systems are above US$200 per year, and lifetimes more like 10 rather than 20 years.

While Stirling engines and ORC engines are potentially maintenance free, ICEs and fuel cell maintenance costs are in the hundreds of dollars a year range and will struggle to fall substantially below this. Lifetimes is another major challenge – a ten year lifetime is the target most micro-CHP companies are working towards (upwards of 40,000 hours), but the emerging technologies will take a number of years to build confidence that they have reached this.

Utility Micro-CHP Economics – Do They Stack Up?

Leveled electricity costs were used as a metric to examine utility micro-CHP economics. These were calculated using a model based on a ten year operating life and a 15% discount rate. The base-case scenario has a ~1 kWe micro-CHP unit providing space heating, installed in place of a new furnace. The investment cost (and ongoing maintenance cost) is taken to be the marginal cost above that of a condensing furnace. The fuel cost is calculated as the marginal fuel consumption above that of a condensing furnace to produce the equivalent amount of heat.

Net-metering for micro-CHP is assumed, and as such the modeling is not dependent upon the proportion of electricity used in the home and the proportion exported to the grid.

The more aggressive scenario examines the cost for different capacities for micro-CHP, and for different modes of operation (e.g. water heating, combined space heating and water heating, power-only). Where micro-CHP is used instead of a heating appliance, the investment and operating cost is always taken as the marginal cost above that of a conventional heating appliance.

Figure 3-1 shows that micro-CHP in 2012 is far from competitive with the grid. But, as shown in Figure 3-2, under more aggressive assumptions micro-CHP can beat grid electricity prices.

The more conservative assumptions (detailed in the Appendix to this report), used in Figure 3-1, are based upon products developed for the North American market, providing warm air heating and being installed instead of a furnace (i.e. when a furnace needs to be replaced or in new homes). Developing products for the North American market and manufacturing them in volume in this timeframe will be a very tough task. Hence product costs are expected to remain high in the near term.

By 2015, the potential for higher volumes, and better product adaptation for the North American market could lead to potentially lower costs, with Stirling and ORC engines appearing particularly promising. The uncertainties around these assumptions are high – based on projecting forward six years for technologies that are, in the main, only on the cusp of commercialization today. Also by 2015, several high efficient (50%) all electric solid oxide fuel cell systems (configured as micro-generators) could emerge in the US after deployments in Japan and Europe emerge. Such systems could potentially compete very well with retail electric rates even in high natural gas price scenarios.

Given these uncertainties, a much more aggressive scenario was also considered – with potentially achievable assumptions (detailed in Appendix A), with electricity costs shown in Figure 4-2. We also included different operating modes for micro-CHP, including an electricity only mode with all the heat being dumped. Under these assumptions, micro-CHP beats grid electricity costs in a number of cases and will be an extremely cost effective way to reduce carbon emissions. Investment tax credits and State incentives could also help to reduce capital cost (through subsidies, and helping to drive higher volumes) down towards the assumptions in this aggressive scenario.

This analysis is simplistic in that it does not take into account any of the benefits micro-CHP brings to utilities and consumers, for example:

- Value of carbon savings.
- Dispatch-ability to shape the customer load curve / operate as part of a smart-grid.
- Value of backup power.
- Demand response or T&D values.
- 20-30 year (rate-based) financing available to electric utilities.

The key to lower cost micro-CHP electricity is achieving high production volumes. Two factors will drive volume:

- Production volumes of the core technology – which will be driven by Europe and Japan, at least for the next few years.
- Production of the balance of plant appliance – which will depend upon volumes in the North American market.

For the core technology, a number of Stirling, ORC and fuel cell manufacturers are hopeful (but by no means certain) of each manufacturing tens of thousands of units a year by 2012. This should put them well on track to driving down costs towards some of the more aggressive assumptions used in Figure 4-2 by 2015. The Honda ICE is already manufactured in such volumes, but we do not see costs of the packaged appliance falling dramatically by 2015.

Volume production of the balance of plant for a product for the North American market is harder to read. We certainly do not see tens of thousands of units a year by 2012, but depending on how hard utilities and others drive the market forward such volumes could be reached by 2015.

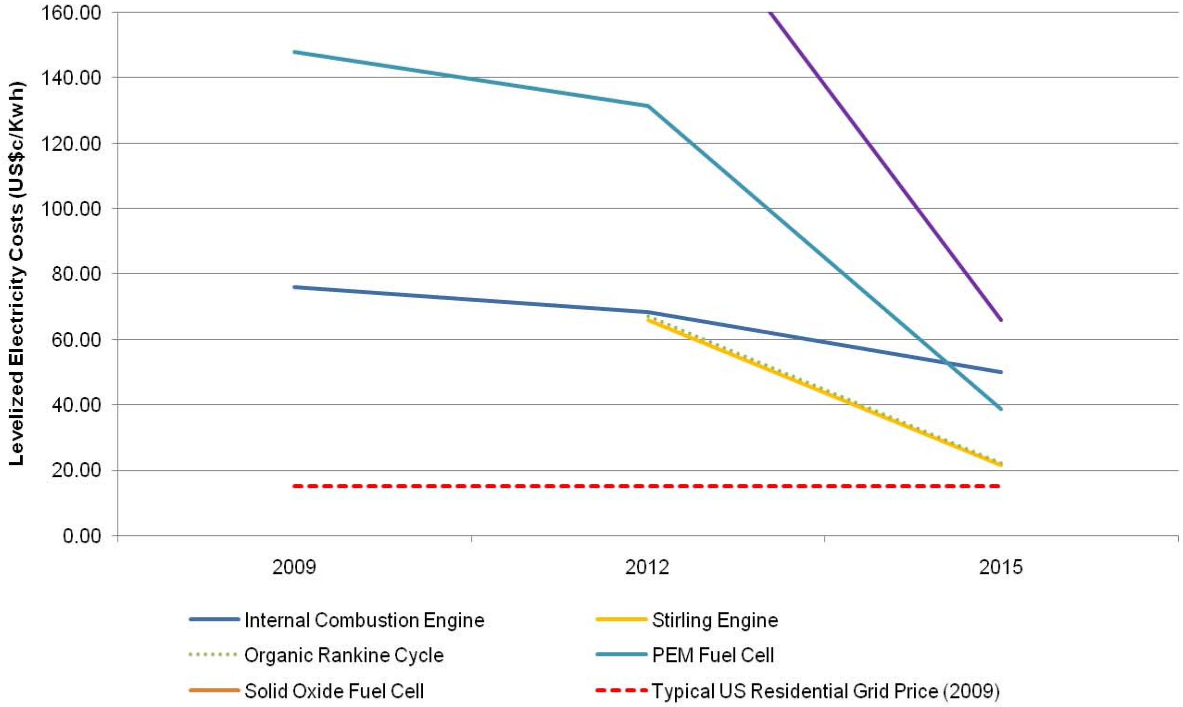


Figure 3-1:
Leveled Electricity Costs for 1 kWe Micro – CHP Units in North America – Based on Conservative Assumptions with the Micro-CHP Unit Providing Space Heating

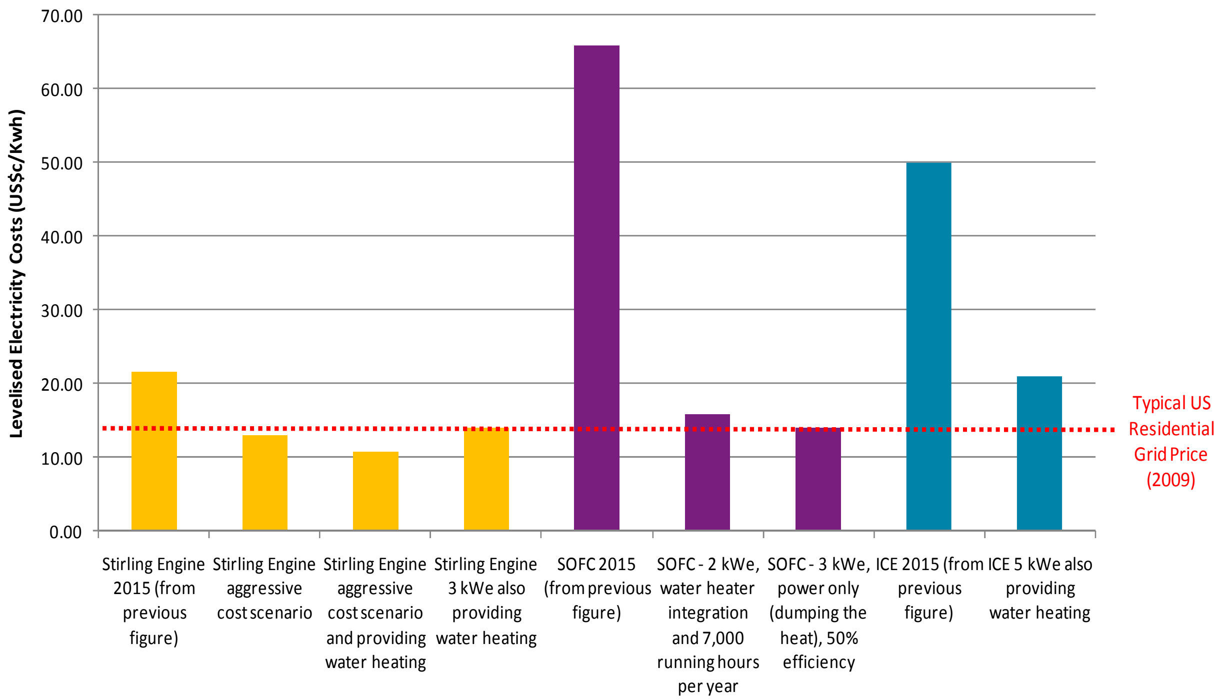


Figure 3-2:
Leveled Electricity Costs for 1 kWe Micro-CHP Units in North America based on Aggressive Assumptions and Various Modes of Operation

4
LEADING UTILITY MICRO-CHP ENGAGEMENT

Globally, some utilities are taking the plunge into micro-CHP waters. Centrica and E.ON UK stand out in the UK, Eneco in the Netherlands, together with Japanese fuel suppliers Osaka Gas, Tokyo Gas and Nippon Oil. In the North American market, only Enbridge in Canada and National Grid in the US are dipping their toes in the micro-CHP water.

What is Driving Utility Micro-CHP Engagement?

Utility engagement can be grouped into two categories: from fuel suppliers, and from electric utilities (which in many cases sell both electricity and gas).

Globally, fuel suppliers (gas, LPG and heating oil) are latching on to micro-CHP to increase fuel sales, and help secure markets for their product in the face of growing competition from renewables and electrically driven heating. Japanese gas companies see natural gas micro-CHP as their trump to secure customers in a very tough battle with electric heat pumps.

In competitive retail markets such as the UK, the Netherlands, and Alberta, electric and gas utilities see micro-CHP delivering multiple benefits:

1) Sustainable customer solutions: part of portfolio of low carbon products and solutions for their residential customers – with micro-CHP potentially offering the best mass market opportunity.

2) A way to deepen customer relationships, resulting in stickier customers.

3) A cost effective way to meet carbon / efficiency targets.

4) Shaping the customer demand curve by influencing / controlling when the micro-CHP units run.

5) Potentially providing lower cost electricity than the grid.

Companies that stand out in these markets include ENMAX (Alberta), E.ON and Centrica (UK) and the three major Dutch energy suppliers (Nuon, Essent and Eneco). Some of these companies have taken the view that micro-CHP will emerge – and if they watch from the sidelines then micro-CHP will be a threat to their businesses. But if they engage with this technology, there are ways to benefit from it, turning it into an opportunity.

Examples of Utility Approaches

Utilities are adopting a variety of approaches to effectively bring micro-CHP to market and customers. Examples of these approaches are briefly outlined below.

German EWE's Fuel Cell Ownership Model

Utility EWE, which runs electricity and gas network and retail operations in North-Western Germany, has a novel approach to owning micro-CHP assets. It is already entering into long term heat supply agreements with customers based on installing boilers. It hopes to be offering heat and electricity contracts based on fuel cell micro-CHP in the future. A big driver for this is to effectively shape the customer demand curve – to meet winter peaks and cope with a high penetration of wind on EWE's network. And if fuel cell production costs fall to sufficient levels, EWE will be able to supply electricity at a lower cost than grid electricity. Access to the carbon savings is another plus point for EWE.

Eneco – Investor in Micro-CHP Technology and Pushing Product to Market

Eneco, one of the three major Dutch electricity and gas utilities, is the major shareholder in Stirling engine developer ENATEC, which is the micro-CHP partner of leading European boiler manufacturers Bosch and Ariston Thermo Group, and Rinnai in Japan. Eneco has supported Stirling manufacturer ENATEC throughout its development and as a shareholder will benefit from sales of Bosch, Ariston and Rinnai micro-CHP products.

Eneco is also trialling other types of micro-CHP products, and has already run prime-time TV adverts for micro-CHP. It already has a business selling heating products and services, and sees micro-CHP as potentially a key part of this business and a key tool to supporting the sustainable brand it is building.

E.ON UK – Spreading Their Technology Bets

E.ON UK, a major electricity company and gas supplier in the UK (and subsidiary of E.ON), is rolling up its sleeves and working with three different technology developers to bring micro-CHP product to market: Whisper Tech (Stirling engine), Energetix (ORC) and Ceramic Fuel Cells Ltd (SOFC). It sees different technologies being suitable for different homes / market segments, and its multiple bets also help cover uncertainties in time to market and technology risk.

The utility has developed a home services business in the last few years, installing and servicing heating products in homes. It believes micro-CHP has mass market potential, and understands how micro-CHP can bring value to their business – through all of the five ways identified on the previous page.

Centrica – Access to Leading Technologies

Centrica sells more than 100,000 boilers a year in the UK. Centrica has established a new business unit “British Gas New Energy”, with a mandate to offer low carbon services to UK customers. As part of this business Centrica has given a strong push to UK SOFC developer Ceres Power by committing to purchase 37,500 units over a four-year period, dependent on certain milestones being reached. It has also invested 26 million in UK SOFC developer Ceres Power. Furthermore Centrica has been involved in trials with micro-CHP developers Disenco and Baxi.

For Centrica this is more about access to what they believe are leading technologies. Centrica has also acknowledged the need to create customer “excitement” about micro-CHP. Despite the partnerships with Baxi and Ceres Power, so far, Centrica has done very little to create micro-CHP brand awareness or excitement amongst UK customers.

Osaka Gas – A Micro-CHP Front-Runner

Japanese utility Osaka Gas has invested very heavily in supporting micro-CHP product development and in developing a micro-CHP brand (Figure 5-1). It has sold well over 50,000 micro-CHP products (based on Honda’s gas engine), and is launching a PEM fuel cell based system this year with Toshiba and Eneos. With a growing share of Japanese homes becoming all electrical, Osaka Gas sees natural gas micro-CHP as a key technology in their battle with all-electric homes, which are grabbing a worrying share of the residential water heating market. Osaka Gas sells, installs and services the micro-CHP units offering their lowest gas tariff and a yearly maintenance contract worth approximately US$60 per year for the Honda-based unit.

Source: Osaka Gas, 2009

Figure 4-1:
Publicity of the 1 kWe Honda ECOWILL unit in the Japanese market

A
LEVELIZED ELECTRICITY COST ASSUMPTIONS

A leveled electricity cost model for micro-CHP in the US was created based on several conversations with micro-developers for each technology. The base assumptions for the conservative scenario (shown in Figures 4-1) and more aggressive scenario (Figure 4-2) are as follows:

Product characteristics

Detailed product characteristics are shown in Tables B-1 and B-2 below.

- The capital costs assumed micro-CHP units are adapted to the North American market. For example, the Japanese ECOWILL target price for less than US$10,000 was said to be too challenging for the North American market by 2015 according to Climate Energy.
- Each technology for the is based on an existing micro-CHP product between 0.7 – 1.2 kWe.
- For the “displaced” furnace, total installation costs of US$6,000 and maintenance costs of US$50 per year.

Operation

- Micro-CHP runs for 4,000 hours per year – typical heating season in North Eastern US states. Although with a SOFC unit it would be possible for it to run for 7,000 hours (reflected in one scenario in Figure 4-2, detailed in Table B-2 below).
- Furnace efficiency of 95%.
- Assumed that when producing electricity, all heat is used (not dumped).

Energy prices and electricity export

- Assumed net metering (electricity import price = electricity export price).
- Assumed same electricity import/export costs of 15c/kWh for 2009, 2012 and 2015.
- Assumed same gas price of $12 / MMBtu for 2009, 2012 and 2015.

Discount rate

- Assumed discount rate of 15%.

	ICE	Stirling	ORC	PEMFC	SOFC
Electrical Output (kWe)	1.2	1.2	1.0	1.0	0.7
Thermal Output (kWth)	2.8	6.0	8.0	4.7	1.3
Electrical Efficiency, LHV (%)	23	19	10	32	45
2009					
Capital Cost (US$)	20,000	-	-	34,000	-
Installation Cost (US$)	5,000	-	-	5,000	-
Maintenance Costs (US$)	250	-	-	300	-
2012					
Capital Cost (US$)	18,000	18,000	15,000	30,000	34,000
Installation Cost (US$)	5,000	5,000	5,000	5,000	5,000
Maintenance Costs (US$)	250	150	150	300	300
2015					
Capital Cost (US$)	15,000	8,000	7,000	10,000	12,000
Installation Cost (US$)	3,000	2,500	2,500	3,000	3,000
Maintenance Costs (US$)	200	100	100	250	250

Table A-1:
Model inputs for Figures 4-1, Delta's conservative scenario

	Stirling Engine aggressive cost scenario	Stirling Engine aggressive cost scenario and providing water heating	SOFC - 2 kWe, water heater integration and 7,000 running hours per year	SOFC - 3 kWe, power only (dumping the heat), 50% efficiency	ICE - 5 kWe also providing water heating	Stirling Engine - 3 kWe also providing water heating
Capital Cost (US$)	6,500	6,500	6,500	7,000	22,000	10,000
Installation Cost (US$)	1,500	1,500	1,500	1,000	3,000	2,500
Maintenance Costs (US$)	100	100	100	100	300	200
mCHP Hours Operation per Year	4,000	5,500	7,000	8,000	4,500	4,500

Table A-2:
Model inputs for the more aggressive scenario (Figure 4-2)

B

MICRO-CHP DEVELOPERS – STATUS, RECENT DEVELOPMENTS AND FUTURE PLANS

Stirling Engines									
Manufacturer	**Output**	**Electric Efficiency (LHV)**	**Overall Efficiency (LHV)**	**Fuel Source**	**Technology Status**	**Commercialisation / Manufacturing Status**	**Key Performance Characteristics**	**Costs**	**Market Coverage**
Microgen Engine Corporation	1 kWe, 6 kWth	19%	92%	Natural Gas	- 100s of demonstration field trials in Europe - Commercialization expected in 2010	- Engine production facilities established in China – capable of manufacturing10,000s units a year - Commercialization by European boiler manufacturers within next year - Adapting first units in 2009 for warm air heating to target US market by 2012	- Free-piston Stirling Engine designed by US-based Sunpower. - Packaged as wall-mounted appliance with a supplementary burner - Ability to modulate down to 0.1 kWe and 3 kWth	Current in the region of $15,000 to utility partners	Europe, (US - likely soon)
ENATEC / Rinnai	1 kWe, 7 kWth	12% (1st generation unit)	95% (1st generation unit)	Natural Gas	- Sheltered field trials only - Developing second-generation product	- Rinnai manufacturing Stirling engine in Japan - European boiler partners expect to install 1,000 micro-CHP systems in Europe between 2008 and 2010.	- Free-piston Stirling-engine system based on technology developed by US-based INFINIA. - Floor mounted and includes thermal storage	-	In Europe, with boiler manufacturers Ariston and Bosch. Rinnai has licence for North America
Whisper Tech / Efficient Home Energy (EHE)	1 kWe, 14 kWth	12%	90%	Natural Gas	- 100s of demonstration field trials in Europe. - Commercialization expected at the end of 2009, beginning of 2010	- EHE holds the licence for the Whispergen product in Europe - Expect to produce 2,000 units at the end of 2009. Site able to manufacture 30,000 units per year.	- Uses a novel, proprietary "wobble-yoke" kinematic system	- US$21,000 including installation costs. - Short term target price is US$10,000	Europe, some trials in North America
Disenco	3 kWe, 12 kWth	15%	92%	Natural Gas, Biogas	10s of sheltered trials in Europe	- Trials in Europe and North America (National Grid) - Large manufacturing partner established (Autokfraft) - Expect to produce 1,000 units in the first year of production – aimed at 2010	- Single-cylinder kinematic Stirling engine technology originally developed by Norwegian-based Sigma. - Aiming a niche market with their 3 kWe unit unlike other 1 kWe Stirling competitors.	- Field trial units sold for US$30,000. - Long-term target price is US$4,500	Europe and North America

Stirling Engines									
Manufacturer	**Output**	**Electric Efficiency (LHV)**	**Overall Efficiency (LHV)**	**Fuel Source**	**Technology Status**	**Commercialisation / Manufacturing Status**	**Key Performance Characteristics**	**Costs**	**Market Coverage**
Honda (Freewatt in the US)	1.2 kWe, 3.5 kWth	22%	86%	Natural Gas, (Propane unit in development)	Commercialization in US and Japan	• The Japanese version (ECOWILL) has reached more than 85,000 sales Japan since 2003. • In March 2009, Honda partnered with Vaillant (large European boiler manufacturer) to target the European market. • 1.8 kWe Freewatt unit with backup power system and remote dispatch underdevelopment. • At least 100 units installed in the State of Massachusetts through National Grid US.	• Maintenance required every 10,000 hours for the engine. Every 6,000 hours for the whole system. • Inverter based • Internet-based control & monitoring • Honda engine coupled with a warm-air furnace (Honda engine is air-cooled). The Freewatt system provides space heating, with the system running throughout the winter months. • Freewatt has five year parts and labor warranty. • Energy Star Appliance.	US$20,000	Europe, Japan, Canada, US (North Eastern States)
Marathon Engine Systems	4.7 kWe, 12.5 kWth	25%)	90%	Natural Gas, Propane	Commercialization in US and Europe	• Over 2,500 units packaged by Vaillant (large European boiler manufacturer) installed in Europe. • Marathon Engine Systems on track to sell 70 units in 2009.	• Ability to modulate down to 28% of full output • Inverter based • Marathon also offers a unit for grid-independent applications. • Design lifetime of 40,000 hours between overhauls, with servicing intervals of 4,000 hours. • The European micro-CHP unit can run on biogas.	$35,000 to $40,000 including installation (North American price)	Europe and North America
Baxi SenerTec	5.5 kWe, 12.5 kWth	27%	90%	Natural Gas, LPG, Fuel Oil, Biodiesel	Commercialization in Europe	• Baxi SenerTec aims at selling 2,000 units in Germany in 2009. • More than 20,000 units sold since 1997.	• Maintenance is required every 3,500 hours. • Longest-running units are reported to have run for more than 80,000 hours. • Asynchronous generator, but optional off-grid package with inverter • No modulation • Modem capability for remote monitoring (including maintenance) and control called DachsWeb.	The natural gas unit sells for US$23,500 in the German market	Europe
Honda (Freewatt in the US)	1.2 kWe, 3.5 kWth	22%	86%	Natural Gas, (Propane unit in development)	Commercialization in US and Japan	- The Japanese version (ECOWILL) has reached more than 85,000 sales Japan since 2003. - In March 2009, Honda partnered with Vaillant (large European boiler manufacturer) to target the European market. - 1.8 kWe Freewatt unit with backup power system and remote dispatch underdevelopment. - At least 100 units installed in the State of Massachusetts through National Grid US.			

Organic Rankine Cycle

Manufacturer	Output	Electric Efficiency	Overall Efficiency	Fuel Source	Technology Status	Commercialization / Manufacturing Status	Key Performance Characteristics	Costs	Market Coverage
Energetix	1 kWe, 8 kWth	10%	90%	Natural Gas	- 10s of sheltered field trials - Commercialization likely in the next three years	- Daalderop, Dutch boiler manufacturer and packager, aims to sell 30,000 units by 2012.	- Lightweight, compact, relatively straightforward to integrate into a boiler - Fast start-up and response time	Target price of US$4,500	Europe

PEM Fuel Cells

Manufacturer	Output	Electric Efficiency	Overall Efficiency	Fuel Source	Technology Status	Commercialization / Manufacturing Status	Key Performance Characteristics	Costs	Market Coverage
Toshiba	0.7 kWe, 0.9 kWth	34%)	85%)	Natural Gas, LPG	Commercialization	- Units sold by Osaka Gas and other gas utilities as ENE-FARM starting from June 2009. - At least 550 units installed for field trials as of March 2008.	- The fuel processor has verified performance for 3,000 start-stop cycles although designed to be a non-stop unit. - Durability of the system estimated in 10 years and cell stack in 5 years. - Regular inspections required at least every two years.	Currently US$34,000 without installation.	Japan
ENEOS Celltech	0.7 kWe, 0.9 kWth	34%	85%	Natural Gas, LPG	Commercialization	- Units sold by Osaka Gas and Nippon Oil as ENE-FARM starting from September 2009. - At least 750 units installed for field trials as of March 2008.			Japan
Ballard	1 kWe, 1.3 kWth	37% - 2nd generation unit	89% - 2nd generation unit	Natural Gas, Kerosene	- Commercialization in Japan ceased - Sheltered field trials in Germany	- At least 550 units installed for field trials as of March 2008 in Japan. - In May 2009, Ebara-Ballard joint venture in Japan was terminated mainly for cash flow reasons. - Ballard now focusing on fuel cell stacks for micro-CHP developers and packagers. - Early field trials with German micro-CHP developer Baxi Innotech	- Designed for start and stop and fuel stack durability estimated at 10 years. - The units installed in 2005 in Japan have been running on average for 12,000 - 18,000 hours.	In Japan, US$40,000 (without installation costs)	Japan and Germany
Panasonic	1 kWe, 1.9 kWth	32%	93%	Natural Gas	Commercialization	- At least 550 units installed for field trials as of March 2008. - Tokyo Gas (Japanese Gas utility) aims to sell 1,500 units in 2009	- Designed for start and stop and fuel stack durability estimated at 10 years. - Fuel stack durability estimated in 10 years and operates with start and stop.	In Japan, US$40,000 (without installation costs)	Japan

PEM Fuel Cells									
Manufacturer	**Output**	**Electric Efficiency**	**Overall Efficiency**	**Fuel Source**	**Technology Status**	**Commercialization / Manufacturing Status**	**Key Performance Characteristics**	**Costs**	**Market Coverage**
Plug Power (GenSys - high temperature PEM)	4.6 kWe, 11 kWth	30%	85%	Natural Gas	Sheltered and proof of concept field trials	- Working with several utilities in an effort to develop a commercially viable product by 2011/2012. - In 2009, Plug Power will be supplying prototype systems to Korea, Germany and US as well as initiating field trials with utility partners by the end of the year.	- Demonstrated a life-time of 20,000 hour lifetime (8,000 hour lifetime for stacks). The target is to develop a unit with lifetime of 40,000 hours. - Works with radiant, forced air or baseboard hot water.	-	Europe, US, South Korea
ClearEdge Power (High Temperature PEM)	5 kWe, 6 kWth	38-40% (LHV)	85% (LHV)	Natural Gas, LPG	Field Trials	- Commercialization expected in 2009/2010. - Pre-production fields trials of 25 trials in 2009.	- Suitable for both indoor and outdoor. - Five year warranty covering installation, parts (inc. fuel stack) and maintenance. - According to ClearEdge, mechanical and electrical balance-of-plant components have already been tested for hundreds of thousands of cycles to prove adequate endurance. - Base-load machine, designed to operate 24h so the customer can benefit from net-metering. - ClearEdge will be responsible for production, installation and maintenance of units to ensure equipment performs to a high standard.	-	California

Solid Oxide Fuel Cells									
Manufacturer	**Output**	**Electric Efficiency**	**Overall Efficiency**	**Fuel Source**	**Technology Status**	**Commercialization / Manufacturing Status**	**Key Performance Characteristics**	**Costs**	**Market Coverage**
Kyocera	0.7 kWe, 0.9 kWth	50%	85	Natural Gas	Under development	- In May 2009, Osaka Gas, Kyocera, Toyota and Aisin decided to join forces to develop SOFC micro-CHP. - Development to be completed by 2010. - 30 units field trialled in 2008.	- Start-up time below 100 min. - Durability of 10 years and maintenance intervals of 24months still under development - Ability to modulate down to 10 Watts	Osaka Gas price target of US$5,000 – US$6,000 for the whole system	Japan

Solid Oxide Fuel Cells									
Manufacturer	**Output**	**Electric Efficiency**	**Overall Efficiency**	**Fuel Source**	**Technology Status**	**Commercialization / Manufacturing Status**	**Key Performance Characteristics**	**Costs**	**Market Coverage**
Ceramic Fuel Cells Ltd	1 kWe, 1.4 kWth	50%	Above 80%	Natural Gas	Under development	- Field trials and further development are now being carried out in Europe with the utilities - 2 kWe Blue GEN micro-CHP unit to be commercially available in 2010 for the Australian market.	- Targeting a stack lifetime of 80,000 hours. - No start-stop option, continuous operation only. - Long-term stack trials are being carried out with 6,000 hours racked up so far, although with some degradation in the first few thousand hours of operation.	-	Europe, Australia
Ceres Power	1 kWe, ~1 kWth	na	75-80%	Natural Gas, LPG	Under development	- Commercialization expected in 2012. - Field trials milestones with UK utility British Gas have been achieved with success in 2008 and 2009	- Daily start – stop possible - Wall Mounted unit	-	Europe
Hexis	1 kWe, 2 kWth	25-30% (LHV)	90% (LHV)	Natural Gas	Under development	- Hexis expects to field trial 15 units in 2009 and another 20 units in 2010 – Planning for commercially viable unit by 2012	- Target electrical efficiency of 35-40%. - A stack life of over 10.000 hours was achieved in 2008.	-	Europe
Acumentrics	1 kWe, 1 kWth	na	90%	Natural gas, propane, ethanol, methanol, and hydrogen	Under development	- Partnership with Ariston Thermo Group - an Italian boiler manufacturer – to target the European micro-CHP market and complete development by 2012. - Consortium comprising five European and North American utilities to have access to lab results and participate in field trials. The objective is to increase utility confidence in the process.	- Acumentrics' measurements of cell degradation rates give the company confidence that it can achieve a 10-year lifetime for the unit. - Start-up time is currently 30 - 60 minutes, although Acumentrics believes it can reduce this to 10 to 15 minutes. - The 1 kWe unit has been tested for over 10,000 hours.	Targeting a manufacturing cost of US$400/kW for the fuel cell stack by 2012	Europe
Honda	1 kWe	50%		Natural Gas	Under development	- Testing underway in Japan - Exploring markets in the US and role of fuel cells in Smart Grid initiatives.	-		

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