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Networks and Niches for Microturbine Technology in Europe and U.S.

- A Strategic Niche Management Analysis of Microturbines

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Executive summary

Microturbine technology is an emerging technology aiming for small scale, on-site power and heat generation applications. Producers realize they have a technology with high performance potential but have difficulties in finding users that values the advantages that microturbines can offer. Therefore the purpose of this thesis is to analyze the microturbine networks and niches in Europe and the U.S., and discuss future niche strategies. A niche is defined as a protected space where the selection criterias of users and producers are different from established markets. The following research questions are answered:

- What do the present microturbine networks look like, in terms of technological, institutional, user, and producer relational dimensions?
    - How are networks and niches functioning and developing and what factors influence the development?
- What are the visions, expectations, and strategies of actors in the networks?
    - From a niche management perspective, are microturbine actors using effective strategies?

The review highlights that regulatory forces favour large scale, combined heat and power alternatives in general. Energy institutions and several energy organisations are promoting internal combustion engines for general small scale heat and power generation, but envision microturbines as a promising alternative in waste utilisation applications. Microturbine producers in general have small, volatile and narrowly focused networks. The main competition, reciprocating engine producers have well established and diversified networks, aiming at the same niches as microturbines. There are some diversified actors, such as General Electric, being present in all small scale, on site niches with several alternative technologies to microturbines as well as reciprocating engines.

The analysis of the networks highlights some general factors influencing the development of the microturbine networks and niches. The main blocking factors are found in utility rates and prices set by current energy utility providers, as well as volatility and general increase in natural gas prices. Another blocking factor comes from the lack of interconnection standards and infrastructural issues for providing the fuel needed for the small scale units.

The niche management evaluation in the analysis highlights the following issues;

- Producer networks are weak and diverse, with only one actor having extensive linkages in both distribution and development.
- Producer- institutional (state) linkages are strong in the U.S., but focus is mainly on R&D.
- User- producer linkages are weak, and most potential users need much education about benefits and values.
- Partnerships and information sharing organisations play a key role in spreading outcomes and insights to a wider community, which is an active practice in the U.S., but not in Europe.
- For most applications, microturbine producers need to ally with complementary technologies and system integrators, since the actual microturbine unit often only account for a small part of the total system installation cost.
- Microturbine producers initially formed unbalance between expectations and actual potentials and benefits.
- In order for microturbine producers to bring more focus to current niches, they must listen to their users. Current articulations are voiced by producers without potential users participating. Developments should integrate insights between producers and users, to shape more precise and accurate value proposals in the future.

The discussion of future niche strategies state that the niche of utilising waste biogases at landfills, sewage sites and farms should be the primary target for microturbine technology. In this niche, the values of the technology have the greatest chance to become acknowledged by all actors, such as users, producers, and institutional and regulatory organisations. Furthermore, microturbines can get the highest protection against competition, constituted by reciprocating engines and large scale combined heat and power technologies.

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1 Introduction

In this chapter the background to the thesis and an introduction to the current situation for microtubines in Europe and the U.S. will be described. This is followed by a description of the purpose of the thesis and the research questions that are to be answered.

1.1 Background

On site, small scale power and heat generating technologies are currently trying to penetrate the energy markets. Among the competing, emerging technologies are microturbines fueled by natural gas or biogas. Microturbines as a power and heat generating technology has been practiced since the late 90s, with producers targeting several different types of users, where the technology holds specific value advantages relative established, centralized energy structures.

Microturbines experiences competition from small gas engines as well as new, large scale combined heat and power plants. Gas engine technology has roots in the transportation industry and is mature and established as a power and heat generating alternative, initially aimed as backup power source. New large scale combined heat and power plants have regulatory alignments and have been widely practiced at targeted areas, where biomass can be used instead of fossil fuels.

The users that have been targeted by the microturbine actors are industrial, commercial, and residential customers with high needs of heat. Other opportunities targeted by the producers are sites that generate biogas wastes that can be used to run the microturbine.

Actors, such as producers promoting microturbines have been shaping different users and external actors for several years. The functioning and structure of these networks and niches vary between different areas and regions in Europe and the U.S. The visions and strategies of actors in the networks are diverse and shifting in character.

Microturbines as a technology have potential values that have been articulated by actors targeting different types of user. The different values have experienced diverse acknowledgements in different niches and networks. Microturbine producers as well as other network actors do not have shared views, expectations or market approach. Therefore, the purpose of this thesis is to;

1.2 Purpose

- *Analyse the networks and niches for microturbine technology in Europe and the U.S., and discuss future niche strategies.*

To perform such an analysis, an analytical framework based on the theoretical perspective of "Strategic niche management" will be used.

1.3 Research questions

The review and analysis of the microturbine networks and niches will answer the following research questions;

- What do the present microturbine networks look like, in terms of technological, institutional, user, and producer relational dimensions?
- How are networks and niches functioning and developing and what factors influence the development?
- What are the visions, expectations, and strategies of actors in the networks?
- From a niche management perspective, are microturbine actors using effective strategies?

In order to answer these research questions and fulfill the purpose, the structure of the report will start with a description of the analytical framework and the method that is used. To create an understanding of the technology behind the microtubine and its complementary and competing technologies a technological background will be presented which is followed by a description of the markets and niches that are of interest. The review of the present network will give an understanding of the actors involved and demonstrate some data from current markets and local practices. This is followed by an analysis from a perspective described in the analytical framework and a discussion of possible future strategies which ends up in some overall conclusions.

1.4 Delimitations

The concept of distributed generation involves different technologies and aspects depending on what organization or who is defining the concept. This thesis will only discuss the technologies and aspects that we find are relevant to microturbines in terms of technologies aiming at the same niches. Because of time and resource limitation the case studies comprising user surveys and installation descriptions that are presented in the thesis relay on the work of U.S. and European energy institutions and organizations. The time and resources had been focused on interviews with actors regarding strategic issues and network linkages.

Marketing and business strategy concepts and literature for individual producers and actors are not used, since:

- Microturbine technology as a power source is in an emerging stage.
- No clear market or strategic context is known, thus such context are instead mapped out and analyzed as potential business context.
- The purpose is to review and analyze the technology network, not individual markets or individual actor businesses.

2 Analytical framework

In line with the purpose of the thesis, analysing the networks and niches for microturbine technology, parts of the theoretical perspective "Strategic niche management" (SNM) will constitute the analytical frame. The derived analytical framework formed from that theoretical perspective will emphasize niche creation and development (creation of protective market spaces) as a method for actors promoting new technology to overcome barriers from established technology structures.

The SNM literature states that introduction of a new technology is a complex and uncertain process with high likelihood of failure; even though the innovation might have some superior performance attributes relative established technologies (Schot & Geels 2007). The SNM literature see creation and development of a protected space (defined as a space where the selection criterias of users and producers are different from established markets), called a niche, as a method for overcoming barriers that new technologies face. The barriers exist because technologies in general are part of large social networks, called regimes, which influence user preferences, regulatory visions as well as technical developments. The framework will present methods for creating and developing niches when introducing new technology, which can result in technologies with robust designs and competitive price/ performance ratios relative to established technologies. From that dynamic procedure the new technology may eventually compete and interact on established markets. (Raven & Geels 2006; Schot et al. 1994; Kemp et al. 1998; Raven 2005).

The framework presentation will first of all explain how technologies are part of large, social networks, called regimes. The large, social networks embedded with established technologies form barriers for new technologies. Those barriers and their impact will be explained. Following this, the SNM management methods of niche creation and development, aiming at overcoming barriers for the new technology will be presented.

2.1 Technologies and regimes

Technologies are parts of a larger social system called sociotechnical regime, which consist of interacting technological and social dimensions (Schot & Geels 2007). Those dimensions can be divided into:

- A network of actors and social groups, which develops over time. Such a network is shown in figure 2.1.
- A set of formal and informal rules that guide the activities of actors.
- The technical elements of the embedded technologies.

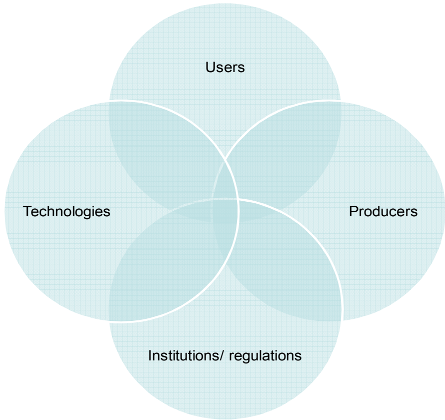


Figure 2.1 Elements of a network

The networks hold linkages between different actors. Actors are producers, users, market formation organisations, interest organisations, and regulatory institutions. Networks carry different vision, strategies, and actions linked to different competing technologies aiming at the same users.

Through co-evolution, the incumbent technologies are well aligned with an established regime and can form large barriers for new technologies to get acknowledged by users (Raven & Geels 2006). Therefore, to overcome the barriers for new technologies, an approach is needed that emphasises not merely technical and economical aspects, but also social, ethical, political and regulatory dimensions.

The sociotechnical regimes that influence and interact with niches and new technologies have rule-sets which are embodied in engineering practices, ways of defining problems, user preferences, product characteristics, as well as standards and regulatory frameworks. Thus, regimes carry and store the rules for how to produce, use and regulate specific products, which influence the preferences and acknowledgements of users.

The technical elements of established technologies have been developed in the social networks. Therefore, the technical performance attributes are well aligned with the demands of users and the visions of different social groups. Thus, the technical performance attributes that new technology is put up against when trying to reach users are embedded in social and cultural preferences.

Dominant actors linked to established technologies are front figures in an established regime and they constitute the largest barriers for new technologies to get acknowledged. The barriers can come from large market shares, superior technology performance or government support through regulations, subsidies and likewise. In addition social commitments and acknowledgements of users and social groups are often strongly aligned with the dominant actors' technologies and ways of developing performance attributes of products and services.

In conclusion, new technologies should not try to go for mainstream, established markets since the social preferences in the networks and in user groups will make judgement of the new technology an unfair process. The specific advantages and values of the new technology might not even get acknowledged, in favour of a screening of the attributes that established technologies historically are strong at. Thus, actors promoting new technology should seek for spaces in the networks where the specific advantages can get acknowledged, and in that space general attributes, needed for penetration of mainstream markets can get developed.

2.2 The concept of niches

The first task when creating a niche is to locate a space, for example a specific application that is connected to users and social groups that demand and therefore can acknowledge the specific advantageous attributes of the new technology (Kemp et al. 1998). To exemplify, some user groups value efficiency and attractive design in favour of price and reliability. Established technologies in the social networks might not offer such products, explained by technical development paths that have been guided by similar social rules. Thus, such a space of users acknowledging the new technology attributes hold potential protection from established markets and technologies. One can view the space as a niche, developing along different stages.

There are two basic types of niches. The first type, a technological niche is a protective space created by subsidies or expectations of future markets, often driven by innovators or producers pushing a new technology. In this space, the technology developments are not driven by users acknowledging the values of the technology, instead acknowledgements are pushed by producers (Schot et al. 1994). The protection enables practices to be performed without economic competition from established technologies. When no clear selection environment where users acknowledge the value of the new technology is to be found, technological niches can work as "proto-markets", allowing interactions between producers and users in protective spaces. Learning and developments in this space may result in articulation of clear demand, which can be acknowledged by users.

Through articulation of a clear demand a technological niche can develop into a second type of niche, a market niche. Market niches are clear selection environments where users acknowledge value advantages of the technology offered. Through feedback loops and development actions, the technological niche practices may become economically competitive and eventually develop into market niches, which are application domains in which a new technology has advantages in terms of performance and value over the established technology, with both producers and users acknowledging that fact (Raven 2005). This concept is illustrated in figure 2.2.

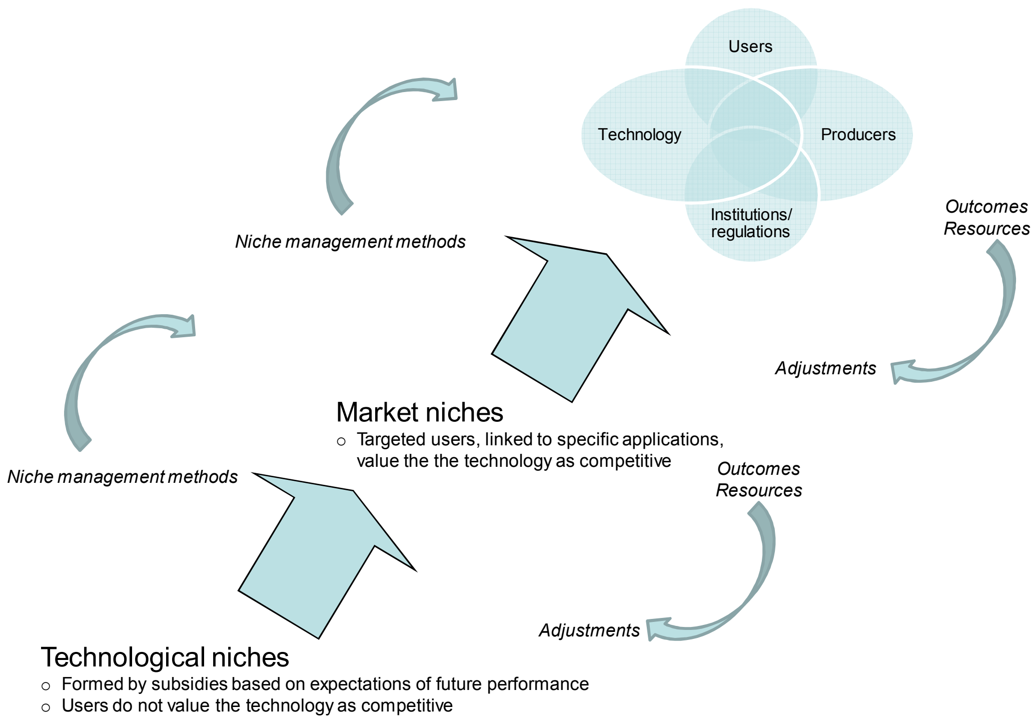


Figure 2.2 Niche creation and development

Because very different selection pressures operate in the market niche, technology development might lead to an adoption process in new divergent directions. The technology might also diffuse into other market niches, eventually leading to the development of a new sociotechnical regime, seen as a network of social and technical elements. This regime can compete with the existing one or become part of it.

From these development theories, the Thesis embraces in line with SNM theories that; there is sometimes a lack of an application space where users as well as producers acknowledge the value of a new technology, explained by social and technical barriers. Therefore niches needs to be shaped and developed by actors, since that can create a space where there is social acceptance and user acknowledgement for the technology.

2.3 Niche management methods

Given that an actor(s) promoting a new technology experience protection either from subsidies (technological niche) or from users acknowledging specific attributes not offered by established technologies, individual and collective groups of actors should perform actions along certain methods to reach competitiveness in the long run (Kemp et al. 1998). These key management methods that need to be performed by actors shaping and developing niches are learning, aggregation activities, articulation, network formation, and voicing and shaping of expectations.

The "directions of search" and "action agenda", which are seen as social visions and perceptions among actors of what to develop and produce, for new technology projects are initially fuzzy, unclear and unstable. Therefore, projects on local level need to elaborate, test and iterate alternative practices, ideas and designs, to create a learning process. Learning is one of the most central processes to handle in niche formation. The SNM literature makes particular emphasis on a learning process called "experiential learning" (Raven & Geels 2007). This process is learning through experimentation, which is most relevant in exploration and pioneering of new technology. In relative terms, "experiential learning" is more crucial than economical learning processes such as "increasing returns", when the emerging technology does not have a market. Projects at local level in small scale constitute good opportunities for such learning. Sequential projects may lead to changes in the content of knowledge, ideas, and perceptions. Cycles of actions and experiences that leads to feedback form and set directions for the shared perceptions of a technology. This leads to a selection of data in the next cycle. Furthermore, experiments lead to interaction between users, firms, regulatory actors, and social actors, which can give integration and later a shared view on design selection.

To be able to transform local outcomes and experiences, a process of "aggregation activities" (Raven & Geels 2007) needs to be performed. Such activities comprise standardization, codification, model building, formulation of best practices and likewise. If the different learning processes in several local projects are aggregated and linked together by such activities, the rules and guiding at community, industry or global level can become clear, stable, shared and articulated.

The next niche process, articulation of demand is in close connection to experimental activities and learning processes. Articulation of user preferences is central, since new technology is unknown to users. Articulation is taking place at local level between users and producers, which can later be aggregated by above mentioned activities, to global level where articulation through regulatory activities also will take part.

Another niche process that needs to be performed in niche formation and development is network formation. Since diffusion processes are of collective art and learning insights need to be shared and aggregated, niche creation often requires cooperating actor networks. The composition of these networks is important, and active changes such as expansions or divestments may need to be performed depending on the stage of development of the niches and the technology.

In close connection with learning processes, network formation, and articulation of demand are voicing and shaping of expectations, which is another central process in niche formation, since they form direction for learning processes and technical developments in local projects. Expectations are strategically formed by actors to draw attention and resources to their projects during emerging stages. Moreover, expectations are cyclical in the way that projects are evaluated and new expectations are shaped. From this, actors embedded in networks have a rationale to invest resources in projects only if the project's expectations and guiding rules are shared on a higher level, preferably embedded in a niche. If there are shared visions, expectations and guiding rules, the local projects can use this as a direction for their learning processes. The dynamics end up as feedback loops, when outcomes from the local project can be aggregated into generic lessons and rules, which transform local learning into community, industry or global learning via networks and actors.

2.4 Summary of analytical framework

To visualize the analytical framework, figure 2.3 describes an emerging technological niche that can be developed into a market niche through actors performing the niche management methods.

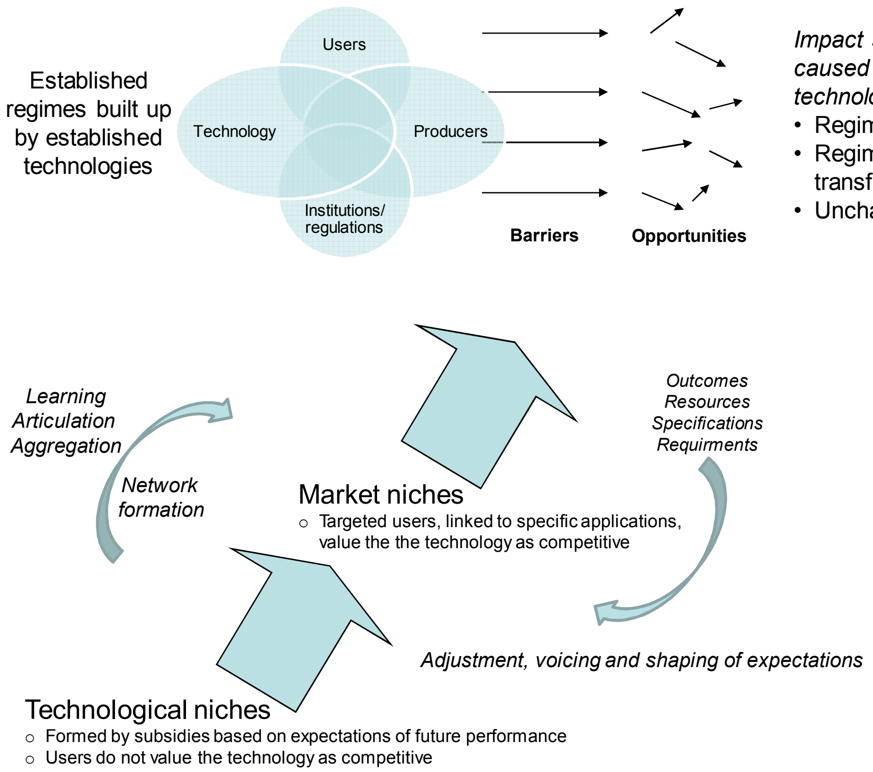


Figure 2.3 Visualization of the analytical framework

Actors creating and developing niches should follow the guidelines of the management methods; learning, aggregation, articulation, network formation, and voicing and shaping of expectations. Outcomes from feedback loops come both as technical specifications and requirements as well as financial returns. The established regime is seen as a large social network with embedded technologies and users. The network and the regime constitute barriers, but also hold opportunities for a new technology. Some summarizing comments about the analytical framework are:

- Technologies are connected to a larger system called regimes, which are formed of social, economic, and technical elements.

- Regimes which are shaped and based on established technologies hold barriers for new technologies to reach users and customers. Such barriers are:
    - Social and cultural preferences.
    - Superior technology performance.
    - Large market shares.
    - Regulatory alignment.
- Formation and development of niches is a way of seeking protection from competition with established technologies, which are embedded in regimes and therefore hold barriers.
- Initial niches, called technological niches can through certain management methods develop into market niches, which is a space were users start to acknowledge the values of the new technology.
- Market as well as technological niches interacts with established technologies and the regimes they are embedded in. Certain management methods can help to create and develop a niche to push the new technology to a level where it becomes an established element in a regime, or an element that forms a new regime. Both outcomes focus on overcoming barriers or forcing them to adjust.

3 Method

In this section a description of the methodology, the data collection as well as a discussion of the composition of sources will be outlined.

3.1 Methodology

The methodology that will be used is influenced by a method named "Socrobust". Socrobust is an analytical tool derived from SNM theories that have been used in a number of assessments of new energy technologies and methods in Europe (Laredo et al. 2002; Kets & Burger 2003). The objectives and motives behind the Socrobust creation came from empirical evidence that new energy technologies face particularly large barriers, explained by strongly linked social, cultural and political perceptions in the established energy networks. Those conditions fit well to the context that microturbine technology has been facing.

The analytical framework guides the composition of elements in the networks and the parameters and factors being analyzed. The analytical framework also provides a structure for the analytical conclusions being derived as an evaluation of how well the microturbine actors have used the niche management methods. Figure 3.1 gives an overview of the different dimensions and methods that will be discussed.

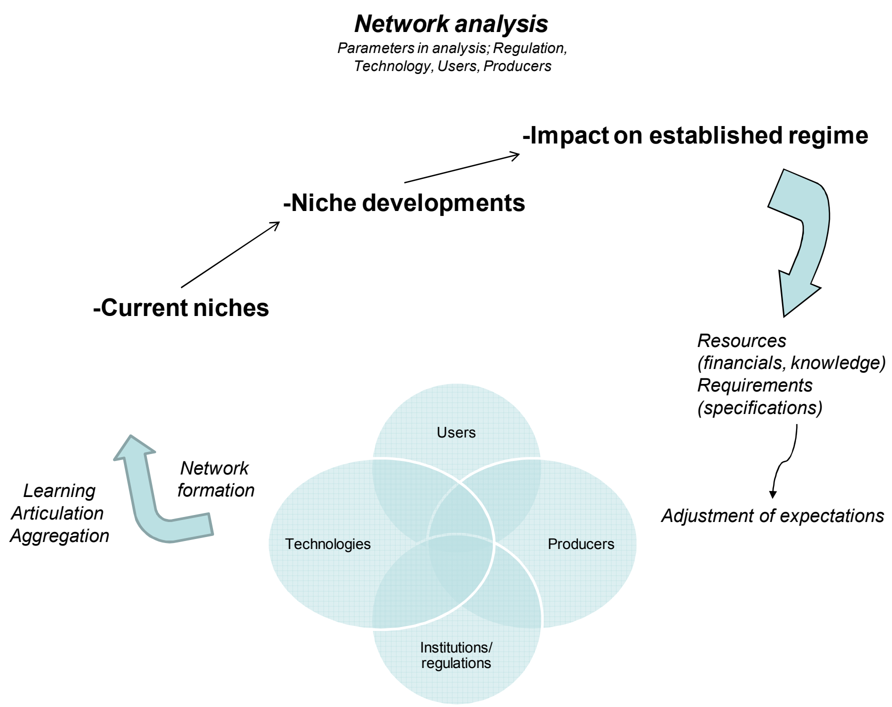


Figure 3.1 Elements of the network analysis

The analysis that will be performed takes four dimensions into account: regulation, technology, users and producers. The management methods that will be evaluated for the microturbine actors are learning, articulation, aggregation activity, network formation, and adjustment and shaping of expectations.

From the discussed methodology this report can be described as having three steps; review, analysis and discussion of future networks. To these different steps a number of actions are connected as shown in figure 3.2.

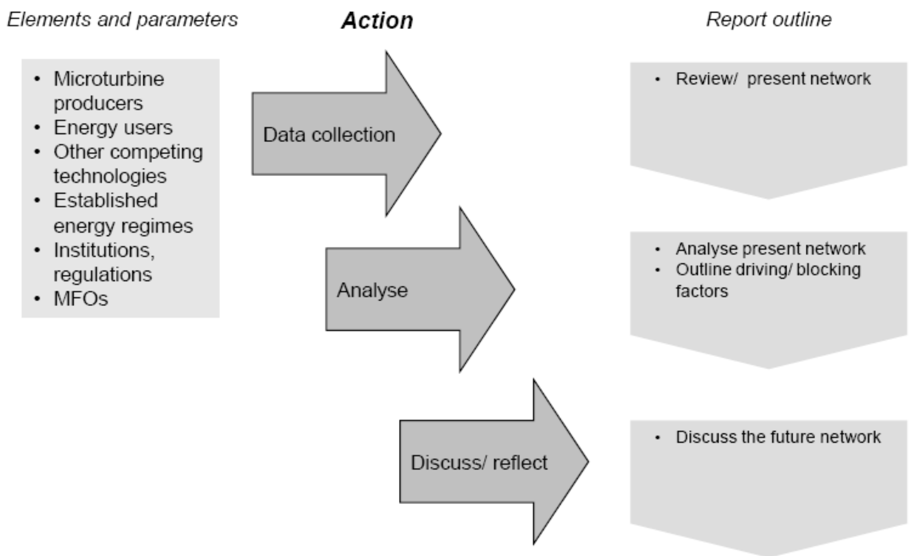


Figure 3.2 The different steps of the report

3.2 Data collection

The data collection performed comprise interviews, visiting websites, acquiring local practice material, and assessing technology and market reports from market formation organizations and energy institution. These activities are distributed on the different network elements as shown in figure 3.3.

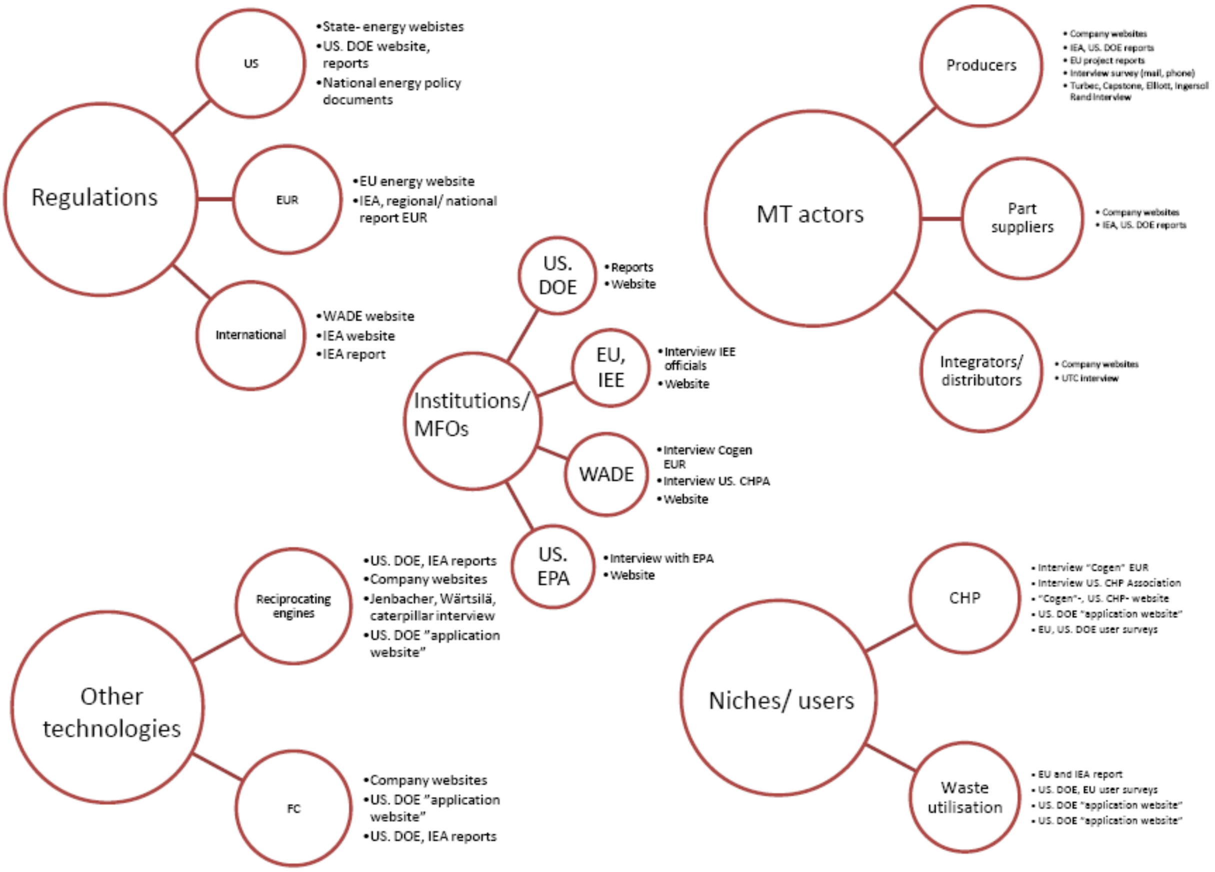


Figure 3.3 Data collection areas

3.3 Composition of sources

The composition of sources can be divided into interviews with actors representing the different elements in the networks, actor websites and official portfolios and report material from MFOs and energy institutions.

Interviews are performed using interview templates and formulas, created for the different actor groups. The questions handle the different elements composing the networks, which are derived from the analytical framework. See Appendix A for detailed interview formulas. The interview results are used as data for actor visions, strategies and expectations. The actors being interviewed are the key microturbine actors, the key competing technology actors, the key MFOs and energy institutions, as well as U.S. and European energy departments. Actor websites and official portfolio materials are used as a complement and guiding for interviews.

The report material from MFOs and energy institutions about energy technology and its opportunities are used as guiding material for the network structures, linkages and functioning.

The objective of using a composition of actor interviews (representing all technologies), actor websites, and non market organization and energy institution reports is to catch all different perspectives in the network review.

4 Technological background

This chapter will give a description of the concept of distributed generation, the different embedded technologies and the values and applications connected to them. To determine the values of microturbine technology and its competing technologies, the following outline will be used:

- Description of the concept of distributed generation (DG)
- Technology descriptions
  - Microturbines
  - Fuel cells
  - Fuel cell hybrids
  - Reciprocating engines
- Complementary technologies
  - Recuperators
  - Heat exchangers
  - Absorption chillers
  - Interconnection systems
- Comparison of the different DG technologies

4.1 Distributed generation

There is no internationally recognized and adopted definition of distributed generation. Therefore a definition is chosen, stated by the International Energy Agency which describes it in a way that is suitable for this report.

"Distributed generation is generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages. The technologies generally include engines, small (and micro) turbines, fuel cells, and photovoltaic systems. It generally excludes wind power, since that is mostly produced on wind farms than for on-site power requirements" (*Distributed generation in liberalised electricity markets* 2002).

The concept of DG is to produce electricity, and in some cases heat, to a small facility close to the end-user. One argument for this is to raise the efficiency of power production and minimize the waste of power because of long distance transportation and transmission losses in today's centralized power production system (*Advanced microturbine system: market* *assessment* 2003). In some regions increased reliability is also a value provided by the DG technologies along with more control over cost of energy. Arguments against DG are higher installation costs per kW for small units and lack of interconnection standards. Figure 4.1 shows a schematic sketch of how a central grid can work together with a network of different DG technologies.

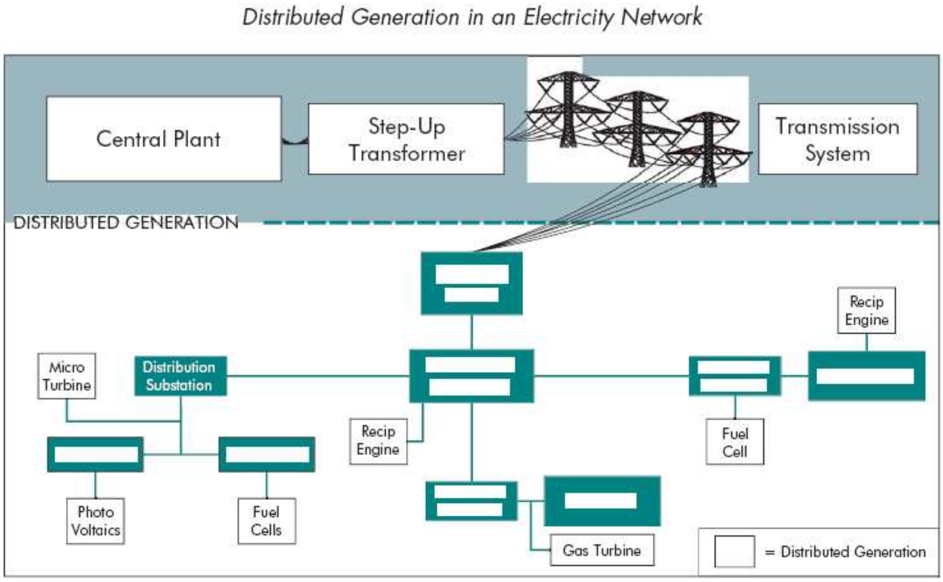
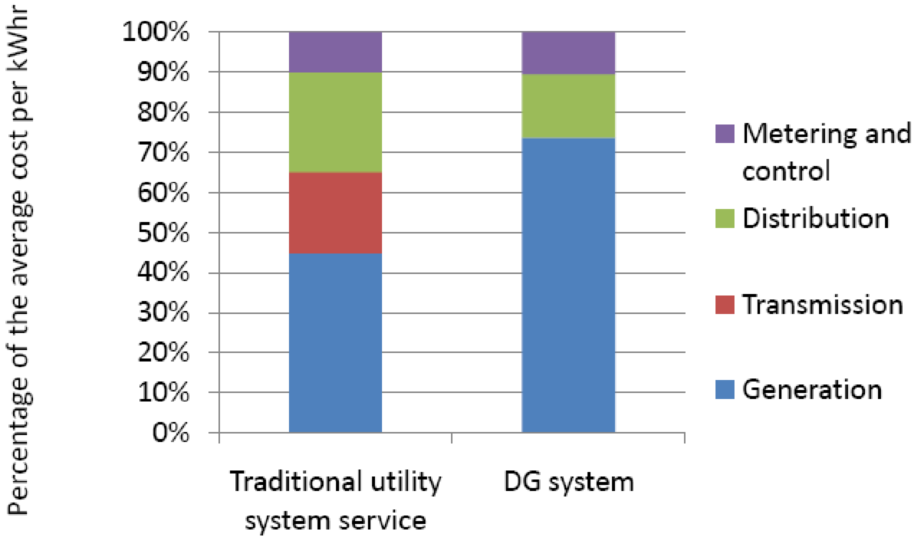


Figure 4.1 A schematic of distributed generation. Source: Distributed generation in liberalized electricity markets 2002

DG is often seen as complementary to the expansion of the grid. It's important to declare that DG technologies not always are more fuel efficient than centralized alternatives, but often are more cost effective because of the elimination or reduction of transmission losses and distribution costs. This is shown in an illustrative example in figure 4.2.



Calculated from the cost per kilowatt for 3000 hours of service to a ranch. DG can prove to be more efficient, not because its generation cost is lower, but because it can be more cost-effective, since the transmission costs are avoided and distribution cost are lower relative the overall costs.

Figure 4.2 Cost distributions for traditional utility and DG systems. Source: Willis & Scott 2000.

From the perspective of viewing DG as an alternative or a supplement to today's energy supply structures, some overall economic advantages are (*Distributed generation in liberalized electricity markets* 2002; Brown & Casten 2004; Liebich and Vivarelli 2004; Joerss et al 2002):

- On-site production avoids transmission and distribution costs, which otherwise amount about 30 % of the cost of delivered electricity, or 6.8% of electricity produced by a central plant.
- On-site power production by fossil fuels, such as natural gas generates waste heat that can be used by the consumer.
- DG may be better positioned to utilize inexpensive, waste fuels such as landfill gas.
- DG can improve the liability of electricity supply and also serve growing consumer demand for higher quality electricity.

The status of DG differs in each country and region, depending on economics, government policy, electricity prices, gas prices and regulative barriers. Traditionally, most DG capacity is generated by reciprocating engines through backup power and not for continues power production.

Since beginning of 2000, DG has been attracting increasing interest and policy attention. There are six major factors behind this; electricity market liberalization, developments in DG technologies, constrains on the construction of new transmission lines, increased customer demand for highly reliable electricity, improving energy efficiency through CHP plants, and concerns about climate change. The regions comprised in this report, Europe and the U.S., have the following attributes that have been influencing DG (*Distributed generation in liberalized electricity markets* 2002; *Advanced microturbine system: market assessment* 2003; Brown & Casten 2004; *Renewable energy- market and policy trends in IEA countries* 2006; Joerss et al 2002):

- Electricity prices
- Gas prices
- Varied pace of electricity market liberalization
- Lack of international interconnection standards
- Environmental regulations
- Ownership and administrative regulations

There are big differences regarding regulations and electricity markets in the different countries and states. In most countries the liberalization of the electricity market has resulted in lower electricity prices, which in combination with rising gas prices has resulted in difficulties for the DG technologies to penetrate the market.

4.2 Microturbines

A microturbine is a small combustion turbine usually in the range between 20 to 300 kW (Walsh & Fletcher 2004; *Advanced microturbine system: market assessment* 2003). The typical configuration is a high speed turbine driving a high speed generator that produces electricity with approximately 30 percent electrical efficiency when a heat exchanger (recuperator) that preheats the compressed air is used. In cogeneration applications, where the waste heat is used to heat buildings or processes, overall efficiencies of up to 80 percent can be achieved. Figure 4.3 shows a schematic of a typical recuperated turbine.

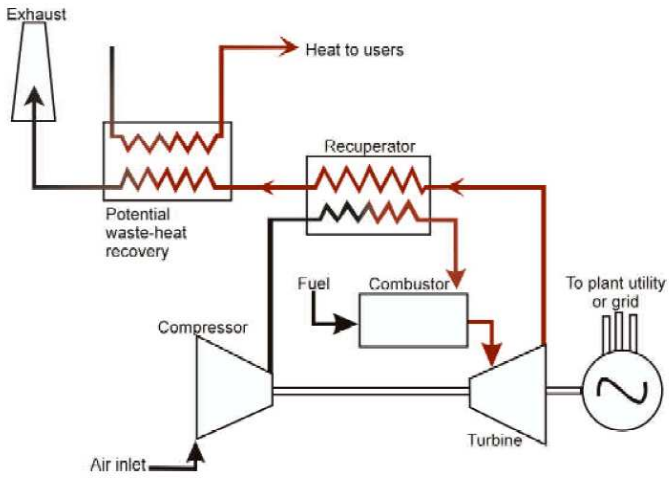


Figure 4.3 Schematic sketch of a recuperated microturbine system. Source: Advanced Microturbine Systems 2000

Air is drawn through the compressor which increases the pressure of the air from ambient conditions to approximately 500 kPa, and forces the air into the recuperator. In the recuperator, exhaust heat from the turbine is used to preheat the pressurized inlet air before it enters the combustion chamber where the heated air is mixed with fuel and burned. The hot gases than expand through the turbine that drives the compressor and the generator. The reason for having a recuperator is to increase the electrical efficiency by reducing the fuel required. An unrecuperated microturbine has an efficiency of 17 – 20% while a recuperated one can reach efficiencies of over 30%.

There are some characteristics that differs one microturbine from another. These are (*Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications* 2000):

- The number of shafts in the design
- The type of bearings used
- If the system has a recuperator or not
- The type of materials used in the hot section

The most common configuration is a recuperated, single shaft, metal turbine with air bearings.

Microturbines primary application areas are combined heat and power generation using natural gas or waste biogases. An advantage with microturbines in comparison to competing alternatives is that they can run on many different fuels which make them very flexible (K Crossman 2007, interview, 30/8). Typical fuels are: natural gas, biogas, butane gas, propane gas, and diesel. They also require little maintenance in comparison to the main competing technology, reciprocating engines (M Jarheim 2007, interview, 30/8).

4.3 Fuel cells

Fuel cells, like ordinary batteries, have an anode and a cathode separated by an electrolyte. Fuel (often hydrogen) diffuses through the anode and reacts with the oxygen ions, creating water and heat, and at the same time releases electrons (Pålsson 2002). The electrons pass through an external circuit to the cathode, producing electrical power. In the cathode the free electrons are absorbed by the oxygen, creating oxygen ions. These ions are transported through the electrolyte, closing the electrical circuit. Figure 4.4 shows the principle of a solid oxide fuel cell (SOFC).

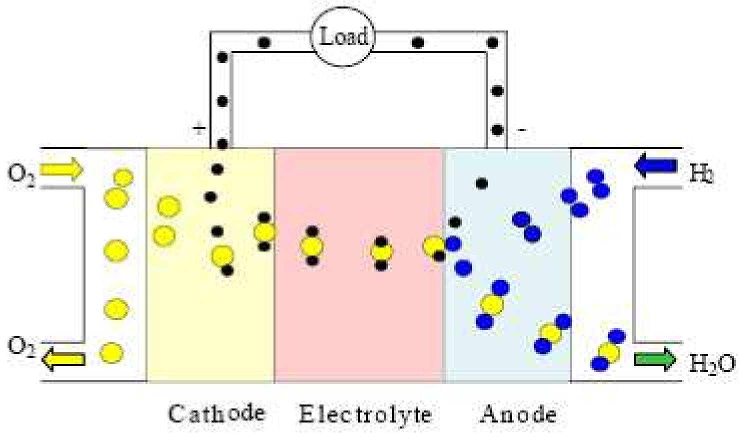


Figure 4.4 The principle of a SOFC. Source: Pålsson 2002

The main difference between different types of fuel cells is the electrolyte. The five principles are: alkaline (AFC), proton exchange membrane (PEMFC), phosphoric acid (PAFC), molten carbonate (MCFC), and solid oxide (SOFC). The operating temperature, which ranges from less than 100°C to 1000°C, is determined by the type of electrolyte. These fuel cells fall into two different categories, high-temperature and low-temperature fuel cells, where MCFC and SOFC are high-temperature while the rest are low temperature.

A big advantage with the high-temperature operations, in comparison with low-temperature, is that it is not as fuel dependent and can run on ordinary natural gas. In the low-temperature operations a fuel processor often must be used, depending on what the primary fuel consists of.

4.4 Fuel cell hybrids

A fuel cell hybrid is a combination of a fuel cell and a gas turbine. Gas turbines produces relatively low cost electricity with low emissions but the efficiency is thermodynamically limited because of the combustion process. Fuel cells have high efficiency and close to no emissions but are very expensive (Pålsson 2002; *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications* 2000). The combination of these two result in electricity efficiency higher than either technology alone (up to 70%), at a capital costs per kW that has the potential to fall between the two. For this system to work a high temperature fuel cell must be used so that the fuel cell can function as a combustor to the gas turbine. The air and the natural gas are preheated in the recuperator before going in to the fuel cell. The high temperature of the fuel cell heats up the gas which is expanded through the turbine. The exhaust air from the turbine then heats up the air and gas going in to the fuel cell. Figure 4.5 shows a schematic of a Solid oxide fuel cell hybrid (SOFC hybrid).

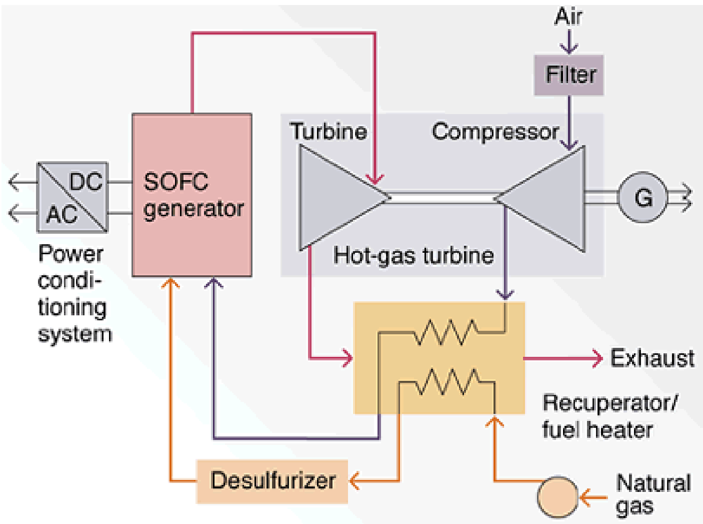


Figure 4.5 SOFC hybrid cycle diagram. Source: Siemens Power Generation

A configuration with a MCFC is also possible but because of the lower operating temperature a combustor is needed in addition to the fuel cell to run the turbine.

4.5 Reciprocating engines

Reciprocating engines, also known as internal combustion engines, are by far the most common applications when mechanical or electrical power is needed (Willis & Scott 2000). Reciprocating engines can be categorized into two different groups: spark ignition, which is used in traditional gasoline or gaseous-fueled engines; and compression ignition, which is used in Diesel-cycle engines. Figure 4.6 is showing the principles for a four stroke, spark ignition cycle.

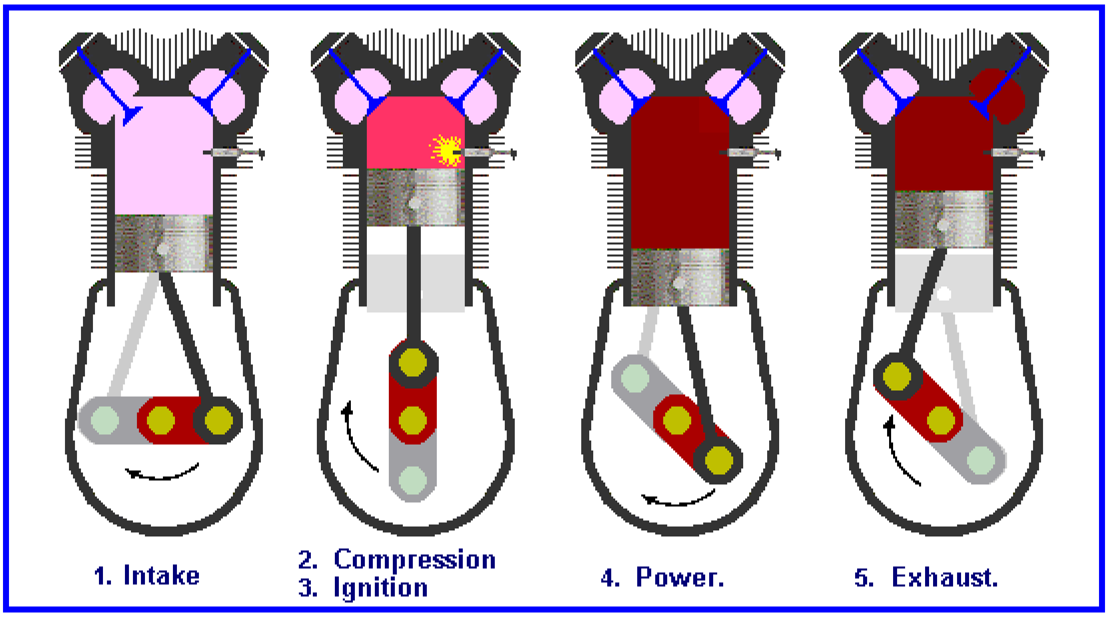


Figure 4.6 Principles for a four stroke, spark ignition cycle. Source: Troop 509

Reciprocating engines ranges from a couple of kW up to several MW (M Jarheim 2007, interview, 30/8) but the thesis will focus on the engines that are considered to compete with microturbines, which are the ones under 1 MW.

4.6 Complementary technologies

Many of the technologies described above would not work satisfyingly as power and heat generation devices without complementary technologies raising the efficiency, handling the waste heat, distributing the exhaust heat, and connecting the total system to a grid. Some of the most critical complementary components will be described below.

4.6.1 Recuperators

A recuperator is a heat exchanger which uses the exhaust heat from an operation that generates heat (Kuppan 2000). In microturbines, a gas/gas recuperator is used to preheat the inlet air before going into the combustor through using the heat from the exhaust gases. This raises the electricity efficiency dramatically through less fuel consumption. Microturbine system designers and developers state that efficiency levels are raised by 30 - 50% (M Xie 2007, interview, 1/6; J Rehn 2007, interview, 1/6). Figure 4.7 shows a typical compact gas/gas recuperator used in microturbine systems.

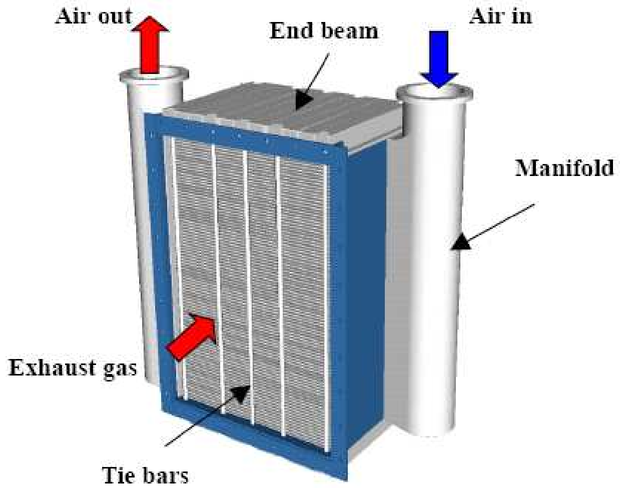


Figure 4.7 A schematic sketch of a recuperator. Source: Lagerström & Xie 2002

4.6.2 Heat exchangers for hot water distribution

To make use of the remaining waste heat from the recuperator, another heat exchanger is often used to heat water (Kuppan 2000; Kaminski & Jensen 2005). This hot water can be used to heat up a facility. A typical example from microturbines is that the exhaust gas from the turbine enters the recuperator at a temperature of around 650°C to heat the inlet air to the turbine. This is a gas/gas operation and the exhaust gas exit the recuperator at a temperature of 200°C. This gas enters another heat exchanger with the purpose of heating up water, which is a gas/liquid operation. The water is being heated to a temperature of 90°C which can be used in the facility. When using the waste heat to generate hot water, called combined heat and power (CHP), the overall efficiency of the system can get as high as 80%, compared to 30 % with power only generation (*Advanced microturbine system: market assessment* 2003).

4.6.3 Absorption chillers

An absorption chiller use thermal energy to provide cooling. Instead of mechanically compressing a refrigerant gas, as in the familiar vapour compression process, the absorption chiller uses a thermo-chemical process.

There are two kinds of absorption chillers commercially available, single-effect and double-effect (*Process applications for small absorption chillers*). Double-effect machines are about 40% more efficient but requires higher grade of thermal input. Because of the high thermal output from a microturbine, the double-effect absorption chiller is the most suitable for this application.

4.6.4 Interconnection systems

One big problem for DG technologies today is the ability to connect them to the centralized grid (Willis & Scott 2000). The reason for a DG unit to be connected to the grid is to support the grid with electricity when a surplus of power is produced and to purchase electricity from the grid when the user needs more power than the unit can produce. Another reason is to use the grid as backup power when repair or maintenance work is needed for the unit. The DG technologies are facing problems in this area because of the lack of an internationally practiced interconnection standard.

4.7 Comparison of the DG technologies

Today, reciprocating engines are the most common alternative when it comes to DG. The technology has been known for over 100 years and a lot of know-how and research has been built up over the years. Both microturbines and fuel cells have been known for several decades but never had the commercial breakthrough because of the hard competition from the reciprocating alternatives. In some application areas though, the microturbines can be compatible because their fuel flexibility and relatively low maintenance costs. Table 4.1 shows a list of key numbers about the different technologies is given below:

Table 4.1 Key data on the different DG technologies. Source: Distributed Generation; Technology data for electricity and heat generating plants 2004; Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications 2000

Technology	**Recip Engine: Diesel**	**Recip Engine: Natural gas**	**Microturbine: Natural gas**	**Fuel Cell**	**Fuel cell hybrids**
Size	30kW - 6+MW	30kW - 6+MW	30kW -400kW	100kW-3000kW	200kW - 6+MW
Installed Cost ($/kW)[1]	600-1,000	700-1,200	1,200-1,700	4,000-5,000	N/A
Elec. Efficiency (LHV)	30-43%	30-42%	14-30%	36-50%	55-75%
Overall Efficiency[2]	~80-85%	~80-85%	~80-85%	~80-85%	~85-95%
Total Maintenance Costs[3] **($/kWh)**	0.005 - 0.015	0.007-0.020	0.008-0.015	0.0019-0.0153	N/A
Emissions (gm / bhp-hr)	NO_x: 7-9 CO: 0.3-0.7	NO_x: 0.7-13 CO: 1-2	NO_x: 0.15-0.9 CO: 0.1-0.55	NO_x: <0.02 CO: <0.01	N/A

As seen in table 4.1 the reciprocating engines have higher electrical efficiencies compared to microturbines but the same level of overall efficiency. The maintenance costs for microturbines are less volatile when running on fuels with different energy content.

4.8 Summary of technological background

In general, DG technologies provide the users with certain values compared with a centralized grid structure. These values are often similar for the different technologies. The general values of microturbines can be summarised as follows (Willis & Scott 2000; *Microturbine system: market assessment* 2003);

- Generate power where it is used.
- Boost total capacity and utility costs and delays.
- Ensure high level of power quality (low emissions and low noise).
- Ensure high level of power reliability.
- Give end users energy cost control.
- Increase energy efficiency (currently with use of CHP).
- Multi fuel flexibility.
- Modularity, flexible usage and fast installation.
- Low emission levels.

Microturbines compete with established central energy structures as well as other DG technologies; especially the most practiced one, reciprocating engines.

All DG technologies aim at replacing or complementing central power structure. The value of replacing or complementing lies in utilizing the heat on-site as well as avoiding transmission and distribution costs and losses. Those values vary between different regions depending on energy prices, grid infrastructure shape, availability and price of natural gas, availability of unutilized waste biogases, and type of central plant (coal, hydro, nuclear etc.)

When comparing microturbines with reciprocating engines, microturbines have higher installation cost but lower maintenance costs. In terms of applications, microturbines can run on a more diverse set of fuels such as waste biogas with lower modification costs compared to reciprocating engines.

5 Description of Markets and Niches

From the different values that microturbine technology provides that was described in chapter four, the application areas linked to different compositions of values will be presented in this chapter. Microturbine technology is suitable for a number of small-scale, on-site applications, such as power only generation using natural gas, stand by power, power and heat generation using waste gas fuels, and combined heat and power using natural gas.

From the value proposition, several niches and markets have been explored, shaped or tested by actors. According to interviews, the key niches that are being targeted, shaped, and practiced currently are:

- Combined heat and power generation (CHP).
    - Traditional CHP
    - Direct CHP
    - Combined cooling, heating and power - CCHP
- Power generation using waste gas fuels

The most common fuel used in CHP installation is natural gas, but the use of renewables like sewage gas and other biogases are increasing in this niche (see Table C.4 in Appendix C). Different values can be seen in the different niches which will be outlined in the coming sections.

5.1 Combined heat and power – CHP

Combined heat and power (or co-generation) refers to an installation that produces both electricity and heat in the same process. The key factor for doing so is that the overall efficiency increases dramatically, typically from 30-45% to 80-90%. The system uses the energy released from the fuel to heat a fluid which is used for an external process or facility heating. The most common CHP units are (Bosch et al, 2007):

- Combined-cycle gas turbine – steam turbine with simultaneous heat recovery
- Steam backpressure turbine
- Steam condensing extraction turbine
- Gas turbine with heat recovery

- Internal combustion engine with heat recovery

CHP systems vary a lot in size and range from a couple of kW up to 50MW. The niche is therefore not a niche only for small scale units but for all units that generates waste heat. The problem though, is that the infrastructure for distributing thermal heat is very expensive which result in problems of distributing waste heat to sparsely populated areas. Table 5.1 givens an example of how the CHP installations spread over different size groups in the UK.

Table 5.1 CHP installations divided by unit size in the UK, end of 2005. Source: Combined heat and power association

Electrical capacity size range	Number of installations	Share of total (Per cent)	Total electricity capacity (MWe)	Share of total (Per cent)
Less than 100 kWe	**581**	**37.9**	**35**	**0.6**
100kWe - 999 kWe	**682**	**44.4**	**171**	**3.0**
1 MWe - 9.9 MWe	**196**	**12.8**	**772**	**13.3**
Greater than 10 MWe	**75**	**4.9**	**4,814**	**83.1**
Total	**1,534**	**100.0**	**5,792**	**100.0**

As shown in the table, over 80% of the CHP units installed were under 1MW but they stand for less than 4% of the electricity capacity.

For microturbine actors, the CHP niche is the most successful in terms of number of installations. In 2003, 98 % of the European microturbine units were CHP systems (J Holbrook 2007, interview, 29/8). The microturbine CHP systems can provide most value for customers currently using grid connections, since the microturbine systems can provide both heat and power on site with higher efficiency ratios. The relative extensive actor focus and overall positive developments of the niche is also explained by a combination of the high overall efficiency ratios in the microturbine CHP systems relative simple generation using other microturbine systems, which has been of increasing importance since the rise in natural gas price relative electricity prices.

Microturbine actors are offering output levels of 20- 200 kWe (electricity), which corresponds to 50- 400kW (heat). One household demands 10- 20 kW of heat, and one apartment demands 5- 10 kW, while other commercial and residential facilities require 50kW – 5+MW. The most suitable targets, and the targets that have been most successful for actors, are commercial and residential groups such as: schools, apartment buildings or attached houses, residential homes, office buildings, sports centres, swimming pools, hospitals, hotels and resorts, supermarkets, and shopping centres (table C.3 in Appendix C). The offered output levels have also found targets in industrial applications such as food processing, chemical processing and other small sized industrial sites with suitable heat demands (table C.2 in Appendix C). However, microturbine actors are seeing potential in using modular product offerings where several small units can be linked together with respect to the demand of output levels. That overcomes the potential output barrier in several industrial applications, where the demand levels are higher than 20- 200 kW electricity and 50- 400 kW heat.

CHP applications can be divided into three different categories:

- Traditional CHP where exhaust heat is transfered as low pressure steam or hot water to a boiler, which in turn distributes heat to a facility.
- Direct CHP, where exhaust heat is transfered directly as steam to another process that uses the heat.
- Combined cooling, heating, and power (CCHP) is a system that can use the thermal energy from the heating source for heating and cooling. The cooling process uses an absorption chiller to create the cold air or water.

5.1.1 Traditional CHP

Traditional CHP is a niche that in most geographical areas is occupied by the central power plants operating over the grid and an additional heating alternative, often run on oil or gas. Prior to the commercialisation of microturbines, only a cumulative number of 1000 sites in the U.S. had installed on-site traditional CHP systems (hot water systems) with capacities less than 1MW. Thus, the niche has demanded extensive shaping and formation activities from microturbine actors.

Compared with the main established systems, formed by the central power plant and a water heater, for a given output of 60kW usable heat and 25kW usable electricity, total efficiency for microturbine CHP system is 85 % and 57 % for the established power plant and boiler combination (Bronson & Theiss 2006). The potential value proposed by microturbine producers are currently simplicity, compactness, modularity, low emission levels, low maintenance and fuel flexibility (natural gas, biogas, diesel, gasoline, liquid biofuels). The stated value proposal articulated by the microturbine market leader Capstone shown in figure 5.1.

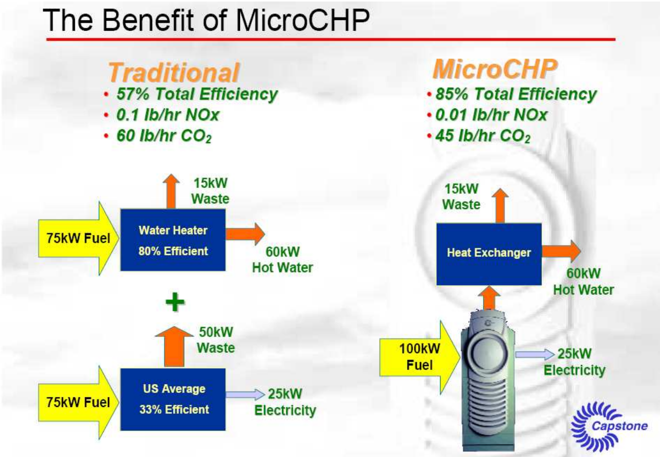


Figure 5.1 Value proposal from Capstone. Source: Capstone

In general, microturbine CHP units have experienced the highest efficiency ratios and most economic value in applications with high, steady electricity loads and steady, relatively high heat loads. In the commercial sector, applications such as hotels, hospitals, water parks and laundries have been penetrated by microturbine CHP systems, fulfilling suitable high electrical demands and steady heat requirements. In the commercial niches, most heat demands are in the form of hot water. In industrial applications, industries that require low temperature heating, such as for wash water heating or space heating or cooling have been targeted by microturbine actors. The largest number of industrial microturbine CHP systems are in chemicals, paper, lumber and miscellanous manufacturing processes. The commercial and industrial CHP targets identified by microturbine actors can be summarized with the following data in table 5.2 and 5.3, provided by the U.S. Department of Energy in 2003:

Table 5.2 CHP target applications – commercial. Source: Advanced microturbine system: market assessment 2003

Application	CHP System Size	Thermal Demand
Hotels/Motels	100 kW- 1+ MW	Domestic hot water, space heating, pools
Nursing Homes	100 – 500 kW	Domestic hot water, space heating, laundry
Hospitals	100 kW – 5+ MW	Domestic hot water, space heating, laundry
Schools	50 – 500 kW	Domestic hot water, space heating, pools
Colleges/Universities	300 kW – 30 MW	Centralized space heating, domestic hot water
Commercial Laundries	100 – 800 kW	Hot water
Car Washes	100 – 500 kW	Hot water
Health Clubs/Spas	50 – 500 kW	Domestic hot water, space heating, pools
Country/Golf Clubs	100 kW – 1 MW	Domestic hot water, space heating, pools
Museums	100 kW – 1+ MW	Space heating, domestic hot water
Correctional Facilities	300 kW – 5 MW	Space heating, domestic hot water
Water Treatment/Sanitary	100 kW – 1 MW	Process heating
Large Office Buildings*	100 kW – 1+ MW	Space heating, domestic hot water
Apartment Buildings	50 kW – 1+ MW	Domestic hot water, space heating

* > 100, 000 square feet

Table 5.3 CHP target applications – industrial. Source: Advanced microturbine system: market assessment 2003

Application	E/T Ratio	Thermal Demand
Food Processing	0.4-1.0	Hot water, low pressure steam
Textiles	0.5-1.5	Hot water, low pressure steam
Lumber/Wood	2.0-5.0	Low pressure steam, direct heat
Furniture	1.5-3.0	Low pressure steam, direct heat
Paper Products	0.8-2.0	Medium - high pressure steam
Chemicals	0.4-1.0	Low - high pressure steam
Rubber/Plastic Products	1.0-3.0	Low pressure steam, direct heat
Primary Metals	0.5-4.0	Medium-high pressure steam
Fabricated Metals	0.75-3.0	Low pressure steam, direct heat
Machinery	2.0-4.0	Hot water, low pressure steam
Transportation Equipment	1.2-2.2	Hot water, low pressure steam
Instruments	1.0-2.5	Hot water, low pressure steam
Misc Manufacturing	2.0-4.0	Hot water, low pressure steam

The E/T ratio is a measure of the electricity need divided by the thermal need. The most suitable industries for microturbines are therefore the ones with low E/T ratios because of the high thermal output of such system.

5.1.2 Direct CHP

Exhaust gas from microturbines have several characteristics that are suitable for direct use in processes, boilers or process air preheat. The characteristics are low levels of criteria pollutants, no hazardous chemicals, no lube oil, and high oxygen content. Using microturbine systems can avoid the use of a boiler, or reduce the effective net power cost for an industrial user. In addition, the direct use of heat can displace the use of fuels for heating air from ambient.

There are a limited number of industries that demand low temperature heat in line with exhausts from microturbine systems. The most suitable industrial applications are vegetable and fruit drying or cooking, plastics drying (warm air or warm directly or for desiccant regeneration for resin drying), textiles drying, wood drying kilns, paper drying, and chemical processes (*Advanced microturbine system: market assessment* 2003). Commercial targets for direct CHP systems have been very limited in niche practices, since demand profiles suitable should have the need of heat with very high thermal content, which is not common for hotels, resorts and likewise.

The total market potential and size for direct CHP is not as large as for traditional CHP, since the E/T ratios and low temperature heat demands are not present at too many locations. However, the economic outcomes from direct CHP are more competitive, since higher efficiencies and lower waste levels can be achieved from direct use of the heat, making potential niches promising (K Crossman 2007, interview, 30/8).

Direct CHP, with supply of direct process heat is a niche area that is targeting industrial processes where the heat and power needs are fairly levelled (in terms of output size). The ideal application would be large drying ovens, where the amount of electricity and heat needs are equal, and the heat requirements are in a temperature interval that suits the temperature of the microturbine system's exhaust gas, extracting from the recuperator, which is often medium temperature gas (*Advanced microturbine system: market assessment* 2003). If the temperature requirements are higher, it would be more suitable to apply a microturbine system without a recuperator, since that configuration extracts higher quality steam with higher temperature. Another application in the direct CHP is air heating and chilling and absorption chilling where heat, or heat transfer (chilling), (and in some applications electricity) is generated in direct connection with the process that has heating or chilling needs. Such applications are often associated with a levelled, high demand for heat and power which suites the low maintenance, and high availability and reliability values of microturbine systems.

5.1.3 Combined cooling, heating and power – CCHP

The thermal energy produced by a microturbine not always fit the demanded heat from the potential buyer of a CHP system. In many cases the buyer are in need of heat during the wintertime and cooling during the summertime. By connecting a microturbine, or another device that generates waste heat, to an absorption chiller both heat and cool can be produced, whatever is needed.

A CCHP system can fit in a variety of different areas. Residential and commercial buildings in regions with high summer temperatures often uses air-conditioning systems to produce cool while some industries are using cool in production processes. As for traditional CHP, this niche is mainly occupied by electricity from a centralized plant, heat from an on-site boiler, and cool from a vapour compression device running on some kind of fuel or electricity. The advantage of a CCHP is therefore the ability to produce cool, heat, and power with one system.

5.2 Power generation using waste gas fuels

Microturbines can be fuelled by biogas, and are often in that niche functioning as a CHP system. Biogas production is a growing market both in Europe and in the U.S., initially driven by regulation policy requiring landfill operators to control methane emissions. Other industries that release methane emissions have also realized the potentials in utilizing this gas to produce valuable fuels to produce heat and electricity or refine it to sell it as vehicle fuel (see figures D.1 and D.2 in Appendix D). To exemplify, EU energy policy aims at forcing all landfills in the EU area to collect and refine their waste gases in the future (T Elmqvist 2007, interview, 5/9). From a bio-turbine workshop in 2004 it was concluded that bio fuel driven microturbines are in line with EU goals for the energy sector, which comprise (Liebich & Vivarelli 2004):

- Improvement of energy efficiency (CHP)
- Guarantee of security of supply
- Environmentally friendly production of power

Currently, specific regions have large economic drive towards landfill owners selling their refined gases to the transportation industry. The process to produce vehicle fuel is more complex than the one for producing the fuel needed for electricity and heat production. The delivery decision for a landfill owner is dependent on local gas pipe infrastructure, local regulations and incentives, and gas demand from transportation industry. The figure below illustrates how the methane emissions are spread over different industries (for emissions by country see figure D.3, D.4 and table D.1 in Appendix D).

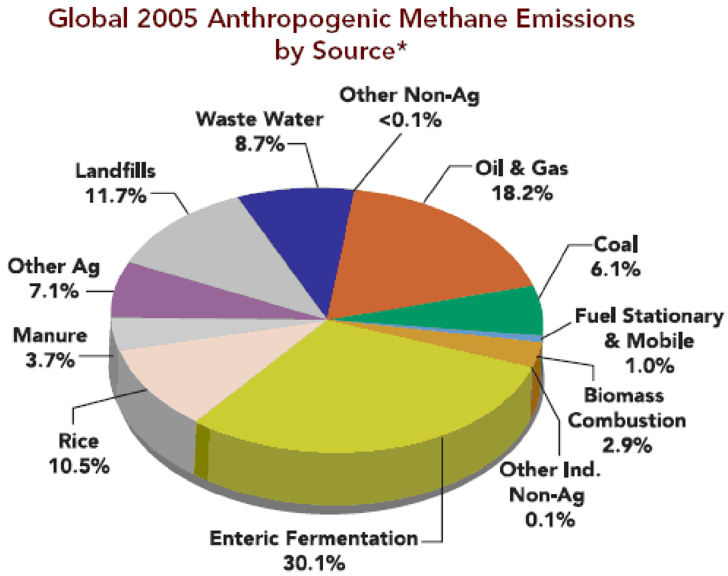


Figure 5.2 Methane emissions divided by source. Source: "Energy Sector Methane Recovery and Use Initiative"

The microturbine systems are strong competitors in this niche because of their fuel flexibility and the ability to work as a CHP system. The established and competing technologies and methods for utilising waste methane gases are; burning of the fuel to operate a boiler, use the gas to run a reciprocating engine that produces electricity (and sometimes heat), or transporting the waste material to a centralized plant that produces electricity (and sometimes heat). Values articulated by microturbine and reciprocating actors comprises eliminating or reducing electricity costs, which make these products very competitive relative grid power in targeted applications. Applications practiced currently are different landfill sites, waste water treatment plants, oil and gas fields, and farms utilizing the gas produced from manure. The waste fuel on these sites has a limited economic value for sale or collection and is of poor quality, demanding a steady burning process with high flexibility. It is indeed the flexibility value that differentiates the microturbine systems from current reciprocating engines (T Rainbow 2007, interview, 29/8). In addition, if heat is to be produced, the CHP system for reciprocating engines is far more complex and expensive compared to the CHP system connected to a microturbine. The current power structure for remote waste fuel sites is mostly dominated by either central plants with grid connection, or rural electric cooperatives using coal based plants.

5.3 Summary of markets and niches

Microturbine producers are currently targeting two different niches, CHP and waste gas recovery. The concept of CHP is to produce heat, power and in some cases cool for residential, commercial, and industrial users using natural gas as fuel. In the waste gas niche, landfills, wastewater treatment plants, oil and gas fields, and farms are targeted. These will use existing gas emissions to fuel the microturbine to generate the heat and power needed for their processes. The different actors have different focus in their strategies towards the two niches which will be discussed in the following chapter.

6 Review of present network

In this section, a review of the present network and niches comprised by microturbines and its competing technologies will be presented. The different actors and actions involved in the networks and niches will be described comprising producers, users, non-market institutions, and regulatory institutions. The general values that can potentially be offered by microturbine technology determine the key niches and networks. These niches and networks are built up by elements that induce, counteract or work in parallel with microturbine technology. The elements and the forces are embedded in networks of producers, users, institutional and regulatory elements. The links and objectives of the different elements will be described along the following outline:

- The value of microturbines
- Producers
  - Microturbine producers
  - Fuel cell and fuel cell hybrid producers
  - Reciprocating engine producers
  - System integrators and part suppliers
- Users
  - Customer needs
  - Customer perceptions
  - Industrial users
  - Commercial users
  - Residential users
- Institutional and regulatory elements
- Niche practises in Europe and the U.S.
  - Key programs
  - Market data and local practices

6.1 The value of Microturbines

Microturbines are currently aligned with the regime of distributed power generation (DG). DG niches in general have been striving for transformation of power and heat supply towards a decentralized structure, where utility is produced close to the end user (Willis & Scott 2000). The proposed value by actors in DG niches is increased energy efficiency and in the long run, less emission. Other values proposed and articulated by actors are increased reliability and quality of power compared to today's monopolistic and centralized supply. A more targeted value that has been used lies in giving certain industries and other large power and heat consumers, cost and supply control of their energy needs. In addition, the low noise level and potentially low maintenance requirements of microturbines compared to today's reciprocating engines is being articulated to some user segments as well. Thus, the outspoken value proposition of microturbines can be concluded as follows (*Distributed generation in liberalised electricity markets* 2002; Fraser 2002);

- Generate power where it is used.
- Boost total capacity and utility costs and delays.
- Ensure high level of power quality (low emissions and low noise).
- Ensure high level of power reliability.
- Give end users energy cost control.
- Increase energy efficiency (currently with use of CHP).
- Multi fuel flexibility.
- Modularity, flexible usage and fast installation.
- Low emission levels.

Around these values, a network comprising markets and niches, users, producers, technologies, and institutional and regulatory elements has been formed. In the network several key niches have been shaped, some markets have been established, and a number of actors can be seen as being market shapers or key actors, whereas some actors can be seen as technological shapers. Against the network development, the established regime of centralized power plant suppliers are acting, and against the development of the specific technology of microturbines, the established technology of reciprocating engines is acting, as well as the emerging fuel cell technology. Furthermore, the networks and niches are also influenced by institutional and regulatory elements such as regulation laws and decentralization fees.

6.2 The producers

Around the value proposition of microturbines, there has been a development of a small number of key producers, aiming at a large number of users. General explanations for this composition are the complexity of the microturbine technology, and the lack of a large market for the products. The small number of producers can be differentiated as market shapers or market followers. General issues about the producer's actions and relations can be stated as follows:

- On-site generation is still not considered part of most users' core business or priority, and is therefore subject to higher investment hurdles relative internal alternatives.
- Microturbine system technologies have improved significantly since the early 1990s and are gaining greater market acceptance. Most users however, remain unaware of the particular cost and performance benefits that are available.
- Customer and user requirements have not yet been fully understood by microturbine system developers.

These issues will be highlighted through detailed reviews of producers acting in the niches and markets. This section will describe the different producers that are active in the markets of microturbines, fuel cells and fuel cell hybrids, reciprocating engines, system integrators and part suppliers.

6.2.1 Microturbine Producers

The four largest producers of microturbines have shipped a number of approximately 5100, in as a cumulative volume. Figure 6.1 shows a graph of how the units are divided over the different actors.

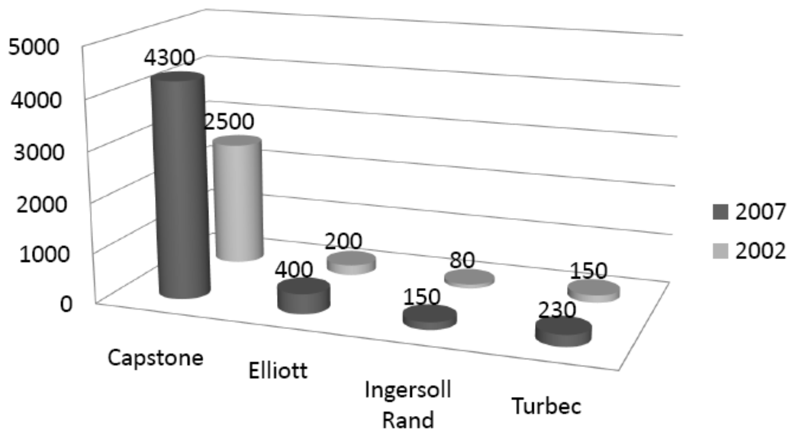


Figure 6.1 Cumulative number of units shipped in 2002 and 2007 (the number for Ingersoll Rand in 2007 is estimated). Source: Interviews with T Rainbow, M Greer, J Holbrook, and M Svensson.

The producers of microturbines are relatively few and most of them are operating from the U.S. In early 1990s when microturbine systems became commercially available for power generation, some traditional turbine manufacturers aligned with aero industry or direct mechanical drive of industrial processes got attracted by a vision of a large microturbine market, and started to develop microturbine capabilities. When the expectations didn't get fulfilled most of these established turbine specialists divested their microturbine projects. In parallel there had been a formation of some microturbine specialists, who had more of market shaping roles. Such market shapers are the ones that currently hold the strongest products and have formed the strongest network linkages. The microturbine actors' general strategies can be summarized as follows;

- Multiple product and technology paths.
- Some strategic marketing and distribution alliances with major power systems providers, such as GE, UTC, and Siemens.
- Some strategic alliances with major energy companies, especially in the U.S.
- Emerging international synergies between Europe and the U.S.
- Large portion of resources linked to government funded R&D programs and product acquisitions.

Today the key producers of microturbines for power generation are Capstone, Elliot, Turbec, and Ingersoll Rand. These companies will be described below. A short description will also be given of other actors that are, or have been connected to the microturbine market. To give a brief overview of the key microturbine producers, table 6.1 presents key attributes linked to the technology practices within the companies.

Table 6.1 Key producer attributes (installation costs are based on numbers from 2001). Source: Steeley 2001; company websites, and interviews with T Rainbow, M Greer, J Holbrook, and J Rehn.

	Output	Efficiency	Cost	Cost/ kW	Learning effects
Capstone	30, 60 kW	26+-2%	30kW: 39 500 $ 60kW: 63 500 $	30kW: 1300 $ 60kW: 1050 $	4 300
Turbec	100 kW	29+- 1%	138 000 $	1 380 $	230
Elliott	100 kW	29+-1%	100 000 $	1 000 $	400
Ingersoll	70 kW	29+-1%	80 000 $	1 200 $	150

This data shows that the product performance as well as the product price is about the same for all producers. What differentiates them is the learning effects, measured in cumulative number of units shipped, where Capstone is by far the strongest.

6.2.1.1 Capstone

Background

Capstone was formed by the first visionary person of microturbines for power generation. This company has established many network linkages with actors such as U.S. Department of Energy (U.S. DOE), United Technology Corporation (a distributor and service company for many energy technologies, including microturbine systems), “green profiled” and energy concerned hotels and residential building owners and landfill owners in Texas. Capstone has acted as a market shaper with strong presence and currently holds the largest number of microturbine systems sold in the industry. However, the company was established through venture capital and went public limited in the late 1990s, which constitutes a problem up until today since the expectations from investors and shareholders have not been in line with the size of the niche opportunities.

Operations

Capstone has two different microturbines, 30 kW and 60 kW, that can be connected together to generate a large range of capacity outputs. Their market share is currently around 80 % and they have a cumulated number of units sold of 4300 (T Rainbow 2007, interview, 29/8). Around 20% of Capstone's units are traditional CHP systems that rely heavily on the gas/electricity price ratio, while the rest of the installations are systems that run on waste gas. The big advantage of microturbine in comparison with reciprocating engines, according to T Rainbow, is the compact, modular design. By connecting many small units together, the fluctuation of energy output is easier to manage.

Strategy

Their strategy is to continue to be the largest actor on the U.S. microturbine market through concentrating on the smaller waste gas segments. Capsone are currently trying to penetrate Europe as well as Asia, through establishing sales units and partnerships with local distributors. The emerging market of installations on oil and gas fields is the strongest growing segment currently, according to T. Rainbow.

6.2.1.2 Elliot

Background

While many of the other producers' microturbines came from the auto-motive or aerospace industry, Elliot's microturbine already from the beginning was developed to function as a power generation unit for facilities and small industries. Elliot is today the second largest actor in the world but in contrast to Capstone the majority of the products are sold in Europe (J Holbrook 2007, interview, 29/8). In 1999, Elliot was bought by a Japanese company and is today a part of the Ebara Group which gives them a unique opportunity to explore the Asian market. In the U.S., the diversified DG actor General Electric is currently acting as a distributor of the Elliot microturbine systems, which also gives them a great opportunity to grow in the U.S.

Operations

Elliot's microturbine is a 100 kW unit which most of the times is connected to a CHP system. In the end of 2007 they approximate their total sales over the years to around 400 units, 80%

of these in Europe (J Holbrook 2007, interview, 29/8). In comparison with reciprocating engines, J Holbrook sees a couple of advantages with microturbines:

- The maintenance costs are significantly lower
- The system for recovering the heat (CHP system) is less complex for microturbines than for reciprocating engines
- The possibility to run on gas with lower methane content

Strategy

Elliot's strategy is to keep focusing on the European market because of the more favourable conditions compared to the U.S. market. According to J Holbrook, the attitude towards decentralized energy is more open in Europe and the electricity, compared to the U.S., is more expensive. Another objective is to work on the interconnection systems which make it easier for the end-user to connect the microturbine to work as a complement or a support to the grid.

6.2.1.3 Turbec

Background

Turbec is the strongest European microturbine producer, with strong technology but less extensive R&D and market networks compared to Capstone. Turbec acted much as a soul market shaper in Europe before 2003, when divestment was performed due to lack of micropower market opportunities. However, Turbec got bought by a large Italian company involved in vehicle testing equipment in late 2003.

Operations

Turbec is currently focusing on bio gas fuels aiming at landfills and sewage sites in Europe. The majority of the installations have been on demonstration level but API Com is trying to increase the commercial value of Turbec's technology.

Strategy

Turbec's main focus is on the European market and especially in the bio fuel segment. To increase market penetration, they collaborate with European environmental biogas projects and state financed developing programs. They show current indications of diversifying into the U.S. market because of the low market potentials.

6.2.1.4 Ingersoll Rand

Background

Ingersoll Rand's microturbine division was founded by the Carlifonia gas industry as a reaction to the buzz around distributed generation and decentralized energy in the end of 1990s. Ingersoll offers two different microturbine systems, 70 kW and 250 kW and their microturbines are based on a less complicated technology, compared with other microturbine producers. With a dual shaft turbine and a low speed generator their microturbine has some similarities to reciprocating engines. This makes Ingersoll's microturbines more suitable when yearly sales are small. According to M Greer, Ingersoll's microturbine division would be in big trouble if the yearly sales of microturbines in the world rose to 10000 units. In 2003 Ingersoll Rand had around 3 % market share, and had 80 units as a cumulated number of units sold.

Operations

From the perspective of the whole Ingersoll Rand business, microturbine is viewed as a niche product in their wide product portfolio. Operational capacity has been adjusted for today's small volumes, and expectations are still remaining fairly low in terms of scale and potential market size.

Strategy

Ingersoll's initial objective of serving the Carlifonia gas utility companies with more reliable and efficient alternatives as a technology experiment is limiting today's strategic visions to remain in west coast U.S. Ingersoll currently views resource recovery in gas and oil fields on the west coast as the focus market for their microturbines.

6.2.1.5 Other microturbine producers

Bowman, with origin from a UK based heat exchanger company sourced Elliot's microturbine technology for some while during the early 2000s and performed selling and service of microturbine units in the U.S. About two years ago, Bowman got into IP infringement issues with Elliott and one of its key suppliers, and current information state that Bowman is not selling microturbine units anymore, instead they perform service functions on prior installations (interview John Holbrook).

Honeywell, which is diversified energy technology company, had an microturbine division up until 2002/ 2003, when the large, diversified parent company decided to divest from the microturbine market (T Rainbow 2007, interview, 28/9). The initial expectations were high and R&D investments were substantial in the early 2000s. Honeywell sold around 100- 200 units at the U.S. coasts, and demonstrations has up until recently showed high technology levels in several state funded R&D projects linked to both microturbines and FC hybrids (Yinger 2001; *Advanced Microturbine Systems* 2000).

6.2.2 Fuel cell and fuel cell hybrid producers

The two major FC (fuel cell) producers, FuelCellEnergy and Ballard, have performed IPO's (initial public offerings) in the U.S., with high expectations and large venture capital interest. However, current stock levels are indeed low, and pressure of getting products to the market and increasing the market and overall sales is large presently. Ballard is responding to this pressure by aligning with reciprocating engine products, where they are launching an engine together with Ford Power Products (Ballard). Both FuelCell Energy and Ballard are aligned with the automotive industry in some ways, providing their technology and receiving R&D resources that can well be used in DG linked products.

SiemensWestinghouse is another market and technology shaping FC actor. The large resources in the parent company of Siemens have not been invested in FC products, mainly since the market expectations does not satisfy such a large corporation and its associated investors. However, technology wise they are strong and are promising offerings of a microturbine/ SOFC hybrid in 2011, which has at least 20 % greater efficiency ratios compared to current microturbine systems (C Forbes 2007, interview, 4/9).

The diversified U.S. marketing, distributor, and R&D actor United Technologies Corporation (UTC), acted as a distributor for the first commercially available FC for power generation in DG applications in 2003. The cumulative number of units shipped was 200 in 2003 (UTC Power). UTC is currently a major customer to Capstone, as a distributor, marketer, and module assembler of microturbine systems.

In general FC companies have been the most active niche shapers and have been most active in looking for new applications and networks when comparing wih all DG technologies and actors. The reason for this is the general high expectations on FC as a clean, efficient and future superior power resource. What remains the problem for this relatively mature technology is the high costs.

6.2.3 Reciprocating Engine producers

Two of the largest companies producing reciprocating engines for use in DG applications and niches are Caterpillar and Cummins (*Case No COMP/M.3113 – GE/Jenbacher* 2003). Both actors have long experience of power generation applications for industries in general (mainly standby or remote power duties). However, the DG alignment has emerged during the last couple of years. To be able o form and participate in emerging niches within DG both Caterpillar and Cummins have used their large resources to acquire capabilities in alternative fuel generation and increased efficiency ratios. They have also formed alliances with niche actors such as institutions and producers aiming for DG niches. Current product offerings comprise engines in the range of 20 kW- 5 MW, running on diesel or natural gas fuel. In addition, Caterpillar, Cummins and a major European actor Wartsilä, all have shown interest in investing and learning of FC technology, manufacturing and distribution. Aligned projects are to some extent linked to institutional support. Table 6.2 displays the number of reciprocating engines that were sold in the U.S. in 1997.

Table 6.2 Reciprocating units sold in the U.S. in 1997 (SI includes natural gas and LPG but not gasoline). Source: Advanced microturbine system: market assessment 2003.

Output	Total Market*		SI Market**		Diesel Market**		SI Share
kW Range	MW	Units	MW	Units	MW	Units	%
<100	969	25,990	101	1,898	868	24,092	10.4%
101-300	2,080	12,186	234	1,491	1,846	10,695	11.3%
301-500	1,133	2,672	85	229	1,048	2,443	7.5%
501—800	909	1,425	120	198	789	1,227	13.2%
801-1200	1,493	1,478	241	293	1,252	1,185	16.1%
1201-2000	1,517	1,046	82	49	1,435	997	5.4%
2001-5000	322	115	81	31	241	84	25.2%
5001-10000	155	25	12	2	143	23	7.7%
Total	8,578	44,937	956	4,191	7,622	40,746	11.1%

Jenbacher, a part of General Electric, is a reciprocating engine manufacturer who is specialised in engines running on waste fuel gas. Their CHP installations show an overall efficiency of around 90% and an electrical efficiency of 40% which is significantly better than any microturbine alternative. According to Kristian Jarheim, Jenbacher has sold around 2000 installations worldwide that are running on waste fuel gas and he can see that the market for small applications running on waste gas, such as landfills and wastewater sites is getting bigger.

6.2.4 System integrators and part suppliers

There are many components that are integrated in the microturbine systems. Some examples are recuperators, absorption chillers, heat exchangers, power electronics, and interconnection devices. Depending on which application the microturbine performs in, different components have to be integrated to fulfil the purpose. Thus, there are specialized component producers and system integrators acting in the same network as the microturbine producers.

6.2.4.1 Recuperator producers

There is only one external producer offering recuperators to microturbine manufacturers at this time, which is RSAB. RSAB's recuperator was developed in alliance with Turbec to suite their T100 microturbine (J Rehn 2007, interview, 1/6). All the other microturbine producers manufacture their own recuperator where Capstone's recuperator is based on a technology licensed out by Solar Turbines (Shah 2005). Because of the quantities of microturbines sold by Capstone and Ingersoll Rand together, their recuperator technology is by far the most tested.

In addition to producers mentioned above, one key producer, which recently commercialised its ceramic, rotating technology, is WilsonTurboPower, formed by an MIT Professor with patent rights on revolutionary, high temperature and high efficient compact heat exchangers. The company is currently starting to deliver the first products. In addition to aiming at microturbine systems, Wilson will try to reach widespread diffusion in high temperature industrial and chemical process duties. The patented technology will be superior, if demonstrations and further tests show positive results (L Sundin 2007, interview, 1/6). The company will act as an active market shaper for compact heat exchanger niches in industrial and chemical process applications. Furthermore, they will also try to get into several microturbine niches, through current development of an own high efficient, high temperature microturbine, also based on ceramic material. However, the finished microturbine product is scheduled to be commercialised in 2009 or 2010 (Wilson TurboPower).

6.2.4.2 Distributors, assemblers, and integrators

There are two types of system integrators, one that supplies microturbine systems with absorption chillers, power electronics and interconnection devices, heat exchangers for facility heating and anther type that act as distributors, assemblers or marketers of finished microturbine solutions.

- **Unifin** is a focused heat exchanger supplier for microturbine CHP systems based in the U.S. It has alliances with microturbine producers such as Capstone, Ingersoll Rand and Honeywell.
- **UTC** is currently the largest system integrator with operations in the U.S. They supply absorption chillers to microturbine CHP systems, assemble final microturbine systems through sourcing of microturbines from Capstone and acts as a final distributor, marketer, and service company for small scale power generation products in general. In addition to the microturbine related system, they also design and produce fuel cell systems for distributed generation.
- **General Electric** is currently developing interconnection to grid devices for distributed generation technologies in general. They will in the future act as a supplier of such devices. In addition, they are currently the main distributor and service function for Honeywell's microturbine products.
- **PowerWorks** is a U.S. based supplier of power electronics for DG technologies, with special focus on microturbine systems. They have official alliance with Ingesoll Rand.
- **Simmax Energy Group** owns and operates 14 DG sites in south-west U.S. They act as an operator and distributor of energy, not equipment. They have alliances with Bowman, Ingersoll Rand and Turbec.
- Some European and U.S. based **gas utility companies** source microturbine systems from the microturbine producers and additional parts from part suppliers, and act as a distributor and service company for final microturbine solutions.

6.3 *The users*

In this section the users of microturbine systems, their needs, issues, actions, and experiences will be presented.

6.3.1 Customer needs

Some general customer needs linked to power distribution can be summarized in the following way, according to a U.S. DOE investigation (*Advanced microturbine system: market assessment* 2003);

- Electric capacity; Customers need to have the ability to meet the highest electric load.
- Electric energy; Different customers have different load profiles, and they all demand electricity according to the individual profiles.
- Power quality; Some customers are sensitive to fluctuations in the band of voltage, requiring a very "clean" signal.
- Reliability; Customers expect service without interruptions, some customers have very high outage costs.
- Cost certainty; Customers want to be protected from price pikes and uncontrolled price excursions

These needs determine how current DG technologies and applications are valued in different applications.

6.3.2 Customer perceptions

A number of issues can be sited to conclude the customer criteria for choosing on-site, DG generation alternatives. The key issues collected from surveys performed by the organization "on-site" (*Advanced microturbine system: market assessment* 2003), with extensive experience in on-site generation products and operations in the U.S. are as follows;

- Economics
    - Economic attractiveness is paramount for customers evaluating on-site, DG alternatives.

- The current utility or main electricity provider has a powerful economic role. An example is found in California where recent utility changes are threatening to erode the economics of earlier introduced microturbine and FC systems.
- Avoiding costs of outages is central to certain users like high tech manufacturing sites, data centres and hospitals.
- Many users do not want price volatility in their energy expenditures.

- Restructuring
  - On-site generation is seen as a way to provide operational flexibility and as a way to preserve reliability, compared to a centralised grid structure.
  - Some users see deregulation and restructuring of the power structure as an opportunity to sell and distribute power in mini- grids.
  - There is generally a "wait and see" attitude in on-site investments from users.

- Product requirements
  - Most customers would like a single point of contact when going for DG alternatives, such as a "design- to- build" offering.
  - Control systems and operations should be easy to manage, requiring no additional staff resources.
  - Reliability and maintenance requirements are central attributes when choosing a DG product.

- Administrative, regulatory factors
  - Getting approval for grid interconnection of a microturbine system is complicated and difficult.
  - Excessive paperwork for ownership, testing and approvals when installing a microturbine unit is articulated as a problem by users.
  - Users with past experience with reciprocating engines, perceives DG units as requiring extensive maintenance.

Current users comprised by the niche opportunities discussed above can be divided into industrial, commercial, residential and households. Demands, actions and experiences differ between the different user segments, therefore separate discussions will be outlined below.

6.3.3 Industrial users

Some general attributes make industrial niches suitable for microturbine systems. These are; first, industries in general have by far most experience in on- site power generation through usage of steam and gas turbines for direct power supply to targeted processes (*Advanced microturbine system: market assessment* 2003; *Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications* 2000). However, those turbines are currently well established and are operating in selected niches which will not compete with the microturbine systems' initial niches (> 10MW). Second, several industry sites have relatively high thermal- to- electric ratios and load factors, which makes them suitable for combined heat and power microturbine systems. And third, in some specific industries (forest products, chemicals, petrochemicals and integrated steel mills), power generation using combustible waste fuels have been practiced for some time, and is acknowledged since it increases the operating cost for the targeted site.

Although the scale and technology of such boilers and burners differ from that of microturbine systems, the experience of on-site power generation can be valuable for microturbines' niches development. The current niche for microturbine systems to generate power from waste oil and gas fuels at industrial sites fits well with the users' demands, values and experiences, and the niche is also protected from the established technology of reciprocating engines, since they are currently less fuel flexible. In addition, some industries, which should be targeted by microturbine actors, have governmental and regulatory incentives to improve energy efficiency and reduce emissions, which therefore are important values. Industries also hold a strong willingness to undergo alliances and partnerships for demonstration projects and likewise, relative other user segments.

Thus, the current lack of cost competitiveness of microturbines has the largest potential relative other user segments, to be outweighed by other values. One important remark lies in the fact that different industries' values of reliability and availability are currently fulfilled by reciprocating engines in backup or standby applications, which limits the scope of niche targets for microturbines.

Some attributes of industries will constitute barriers for microturbine systems. One such attribute lies in the fact that industries currently enjoy relatively low heat and electricity prices, since they constitute a large amount of the total energy demand, and therefore enjoy large bargaining power. Another barrier comes from the established and widely practiced reciprocating engine technology, which will improve and try to diversify even further from its strong niche of resource recovery duties (backup, stand by), mainly through improvements in fuel flexibility, emissions and efficiency. The microturbine systems' value of reliable and available power for industries will currently have trouble to overcome the current acknowledged reliability and cost competitiveness of reciprocating engines.

One important remark is that targeting within niches has primarily been small to medium sized industries, with suitable load profiles of heat and power, and with alternative source being the centralised power plants and heating plants. In addition, some industries such as gas and oil sites have limited access to grid distributed power, which make them well suited for flexible, on- site installations of microturbines.

6.3.4 Commercial users

Commercial buildings and sites, such as hotels, hospitals and restaurants have some suitable attributes for microturbine system (Liebich & Vivarelli 2004). First, electricity and heat load factors are often high and energy costs have a strong relative importance. Second, targeted air-conditioning or heating duties combined with power generation on- site goes in line with some hotels' and supermarkets' willingness to reach energy cost control.

The attributes and experiences that constitute barriers are; some sites like offices and retail stores have relatively low load factors, which make them more suitable for grid connection. Most users have no experience in on- site generation and interconnection possibilities to form small grids is currently not available.

6.3.5 Residential users

A number of issues and attributes make residential users a limited niche target for microturbine systems. First, Residential users have little experience in on-site power generation, and acting as producers instead of users. Second, their current load factors for electricity and heat are relatively low compared to industries. Third, the scale of output required (< 10kW) for single households is relatively low, which will limit the utilisation possibilities for microturbine technology. Larger scales are only demanded when interconnecting a number of households, which constitutes a barrier currently.

The non traditional on-site structure will require new approaches for ownership and operations, in terms of responsibilities and regulations. Furthermore, interconnection standards and possibilities will be an important issue to solve if the small scale microturbine systems want to reach successful penetration in the residential segment. In addition, in the heating generation segment, several technologies have already penetrated niches and reached widespread diffusion in targeted application areas, which have taught households and residential site owners cost awareness, which makes an alternative like microturbine systems less attractive in most applications.

Some attributes make residential users well suited for targeted niches. First, in some countries and regions, the relative price of grid distributed electricity for residential buildings and facilities is high, since they do not enjoy the same bargaining power as large industries. Only if deregulation takes place and a distributed power generation structure gains ground, household owner's awareness and willingness to value emissions and efficiency more than initial installation price (probably through governmental subsidies) is likely, but than it is a large market which can bring scale and widespread diffusion of microturbine systems (*Advanced microturbine system: market assessment* 2003). Thus, most attributes that make residential users a suitable target are dependent on institutional and regulatory influences.

6.4 Institutional and regulatory elements

For distributed generation (<1MW) technologies in general, some regulatory factors have major effects on the overall market development. Some of the factors are aligned with monopolistic or state allianced utility providers, such as large nationally state owned energy companies controlling centralised plants and the grids. These factors are:

- Regulation of the energy market actors
- Government incentives
- Fees for distributed power to interconnect with the grid
- Additional fees for installation of on- site power generators
- Forcing distributed power generator owners to act as resource recovery for current grid
- Government R&D funding

- Emission laws and regulations
- Ownership rules
- Spark spread ratios (electricity price/ natural gas price)

In addition to the factors above, there are some aspects on global level that have effects on the market development for microturbines:

- Electricity rates, variable (depending on the utility demand) and overall prices
- Fuel prices, such as natural gas prices relative to electricity prices
- Fuel availability
- Fuel supply infrastructure
- Global environmental concern, and global energy agenda
- Promotion of decentralisation of the energy market, to induce the use of renewables

To give some examples of how regulatory forces are handling the above mentioned factors some overall comments will be given (Joerss et al. 2002); in 2003, EU decided to apply concrete evaluation measures and to set up a framework for national policies favouring cogeneration. For example, in Portugal, cogeneration actors get state incentives equal to the savings the state makes in not having to expand the grid and the centralized plants. Another example is when the European Commission in 2003 forced the monopoly energy utility in France to repay taxes because of unfair treatment.

There are some key institutions, state departments and market formation organisations (MFOs) that have been aligned with the formation of a decentralised power generation structure, and has acted with specific support for microturbine systems. The key actors are shown in figure 6.2 and their actions are described in the following sections.

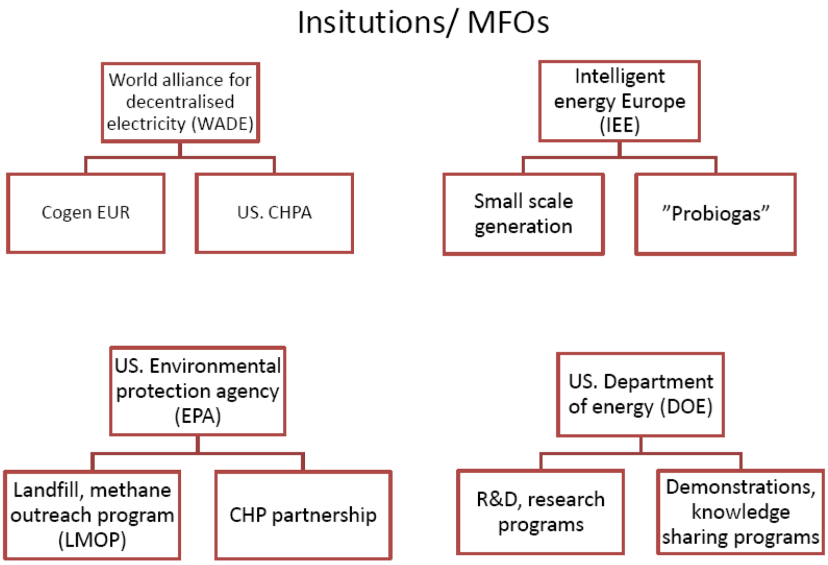


Figure 6.2 Map of institutions and MFOs

6.4.1 U.S. Department of Energy – U.S.DOE

U.S. Department of Energy supports a variety of programs aiming at improving the resource efficiency and productivity of energy and waste intensive industries. The projects are often formed with partners in the industries and have a general goal of improving energy efficiency with 25 % in 2010, and 35 % in 2020 (U.S. Department of Energy).

One project is the "Advanced Microturbine Program", which was planned to last between 2000- 2006. Five microturbine actors were involved, including today's key microturbine producers, Ingersoll Rand and Capstone. One of the aims was to develop an microturbine system with efficiency ratio over 40 %, and reduce overall system cost to 500 $US/ kW. In this program there is an ongoing project with the aim to increase electrical efficiency to 40%, keep the NOx-levels under 0,15 grams/kWh, have a pay-back time of under 4 years and have a total efficiency of over 70% is also in operation (*Advanced Microturbine Systems* 2000).

Following the U.S. energy crisis in 2000/2001 (K Crossman 2007, interview, 30/8), U.S. DOE started a program called "Distributed Energy Program", with objectives of increasing reliability in national electricity supply, lower emissions and increase the overall efficiency in the national energy structure through promoting distributed energy technologies, with focus on CHP applications. Their mission is to develop the "next generation" of clean and efficient technologies and to state national and international standards for infrastructure and institutional and regulatory needs. The base technologies included in the program are gas-fired reciprocation engines, industrial gas turbines, microturbines, absorption chillers, heat exchangers for CHP and CCHP applications, fuel processing devices and power electronics. Thus, their aim is to develop and promote whole DG systems, not only technology components, to replace and support today's centralized energy system. The program's budget for 2006 was M$ 56.6. As a comment, microturbine technology received 16% of the total budget.

6.4.2 U.S. Environmental Protection Agency – EPA

EPA's mission is to protect human health and the environment. They do so by (U.S. Environmental Protection Agency):

- Develop and enforce regulations
- Offer financial assistance
- Perform environmental research
- Sponsor voluntary partnerships and programs
- Further environmental education
- Publish information

Combined Heat and Power Partnership is a part of EPA and provides opportunities for their partners to share knowledge, showcase their CHP projects and educate others. This is possible to do through conferences and newsletters provided by the CHP Partnership. The program is technology and fuel neutral which means that their partners come from many different areas, from equipment manufacturers to end users. Some examples of partners are: Capstone, Elliot, Ingersoll Rand, Caterpillar, and FuelCell Energy. Also some universities and utilities are partners of this program (Combined Heat and Power Partnership). According to Kim Crossman, representative for the U.S. CHP Partnership, the reciprocating engines are in most cases the preferred alternative when it comes to CHP installations. The reason for people choosing a microturbine system is in most cases the illusion of it to be a "cleaner" alternative. Kim argues that peoples "clean microturbine technology" perceptions have helped the microturbine producers to find early adopters.

6.4.3 Intelligent Energy Europe – IEE

IEE is a committee working under the EU energy framework on national energy department levels. There is one central ruling committee including one representative from each EU country, trying to spread "best practice" information to nations about energy efficient alternatives. The committee is technology neutral, and DG is not a specific focus for the information sharing work (L Lundmark 2007, interview, 30/8; Intelligent Energy Europe)

6.4.4 World Alliance for Decentralised Electricity – WADE

WADE is a non-profit research, promotion and advocacy organisation. They represent companies as well as industry and environmental groups in the work to accelerate the adoption of decentralized electricity (World Alliance for Decentralized Energy). Two partners of WADE, U.S. Clean Heat & Power Association and COGEN Europe, will be discussed below.

6.4.4.1 U.S. Clean Heat & Power Association - USCHPA

USCHPA is a private, non profit association formed in 1999 that promotes the growth of clean and efficient CHP in the U.S. Their vision is to create an energy system that is more efficient, less pollutant and more reliable, trough promotion of clean, local generation technologies. Their action plan is to create a regulatory system to promote clean and efficient local energy production. One specific goal is to double today's use of CHP in the U.S. USCHPA is a key element in the "National Energy Policy Plan" carried out in 2001 by the Bush administration, since CHP activities is viewed as an opportunity for increasing the use of DG in place of expensive central station generating facilities (U.S. Clean Heat and Power Association).

6.4.4.2 COGEN - Europe

Within Europe there is an organisation called Cogen Europe that is supported by the European commission in collaboration with International Energy Association (IEA). COGEN Europe's vision is in line with the European policy to have 20% of the electricity produced in 2020 coming from renewable sources, 20% reduction of emissions by 2020 and raise the efficiency of the power produced with 20% by year 2020 (COGEN Europe; T Bouquet 2007, interview, 29/8). The general aim is to increase generation flexibility in EU's energy market, give customers more choices, and by this, induce future opportunities for renewable alternatives. Short term actions in the program include DG systems certifications, electrical interconnection standardisation, industrial user partnerships and incentives and financing.

6.4.5 Financial institutions

Investors and actors in financial markets are getting more interested and attracted by "energy technology", and the amount of venture capital in energy ventures is rising currently. "Energy technology" encompasses microturbines, software or trading technology for electricity management in general. The visions and expectations among investors can be highlighted by quotes from venture capital actors as follows; "The companies and VCs are made possible by electricity deregulation" (Energy Venture Fair), said Todd Klein, managing director of Kinetic Ventures, a Chevy Chase, Md.-based Venture Capital firm. "We have been following these technologies 10 years, and they never were anything more than science experiments" (Energy Venture Fair), said Jeff Miller of Boston's Beacon Group, which manages $1.6 billion in two energy Venture Capital funds. He continues; "Now you've got the demand coming from the marketplace and very serious managers with very focused business plans" (Energy Venture Fair).

Many investments aligned with future regulatory and state visions are favouring renewable energy technologies. In fact, alternative energy firms raised $2 billion in 2007 from IPOs and VCs, according to Clean Edge (Clean Edge), a research firm that tracks "green" investment. But renewable energy requires deep pockets and patience, and tends to be backed by big power companies which, if they can make alternative energy work, will have the infrastructure in place to connect it to the grid, which indicates that the established energy regime has visions of integrating technologies such as microturbines and future FC hybrids as support and complement to the centralised plants and grids. As an example of this, many big power companies ensure they get the needed technology by backing start-ups themselves. Houston-based conglomerate Enron, for instance, has invested $90 million in 12 companies it sees as strategic partners, two of which have gone public.

Big declines in the shares of publicly traded FC and microturbine companies have been the case during 2000- 2006. While many of the stocks surged following initial offerings, investors moved on after it became apparent that sales and profits are years away. Plug Power Inc., a fuel-cell maker that peaked at $156.50 in January 2000, now trades for less than $21. Ballard Power

Systems Inc. of Canada, which reached \$121.50 as recently as September, is at about \$47. Capstone Turbine Corp., a microturbine maker that climbed to \$98.50 in August, is now around \$22. This indicates that the expectations have changed during these years.

6.5 Niche practices in Europe and the U.S.

In this section a number of key programs that support and promote testing and implementation of DG technologies in general and microturbines in specific will be described. Following this, the current market for small power units will be presented along with some practice examples, being representative for microturbine application targets in general. The examples will outline the key information from the different projects to give an overall perspective of the practices performed. The projects will be divided into the different niches and technology focuses.

6.5.1 Key programs

The current programs having the strongest influence on microturbine practices and the network formations in Europe and the U.S. will be described below.

6.5.1.1 GENDIS

This project focuses on general implementation obstacles with installing small scale power and heat units (GENDIS). Technologies being practiced are photovoltaics, small hydro, microturbines and reciprocating engines. The articulated objectives of the project are to identify and map current distributed generator technologies in Europe. To determine the size and characteristics of the potential market and identify legislative obstacles. Local practices are carried out to test the effects of installing distributed generators. Finally, the local tests and the mapping procedures will be summed up as guidelines for European electricity companies. The main problem area highlighted so far is the actual interconnection procedures to grid structures. To solve this problem, a prototype grid model has been set up for future test procedures.

6.5.1.2 Distributed generation- Future energy resources (DG-FER)

This is a finished project that focused on developing a roadmap for future distributed energy in Europe (*Roadmapping of the paths for the introduction of distributed generation in Europe* 2004). In detail the aim was to bring together the various elements comprising all technologies that make up distributed generation, in order to understand the links between "resource recovery", "CHP", and "power only" projects. Finally, the project processes tried to incorporate the insights with the current and future needs of improvements in the energy infrastructure in Europe. Highlights state that commission incentives are working only on general "resource recovery" and "CHP" implementation, with a lack of focused incentives for small scale DG alternatives.

6.5.1.3 Cogen challenge

This project is carried out by COGEN Europe under the organization of "Intelligent energy Europe". The project wants to achieve enhancement in regional and local energy capacity by implementing small scale DG units (<1MW) (Cogen Challenge). Support the transition of Europe's energy system, in line with the energy commission visions, towards higher efficiency and lower emissions by facilitating the development of a significant number of DG installations. Transfer best practices and know how between local and regional energy agencies. Finally, an overall improvement of service in the energy market and an understanding of the small scale CHP market barriers should be reached within the project.

6.5.1.4 European local electricity production - ELEP

This programme is running under the European Energy Commission and is a sequel of DG-FER, with narrative focus on accomplishing improvements in the areas located as barriers in the DG-FER work (ELEP). Current ELEP work focus on the barriers of interconnection standardization, general commercial and policy issues, building directive issues, certification and authorization.

6.5.1.5 Landfill Methane Outreach Program

LMOP is a program under EPA as part of the United States' commitment to reduce greenhouse gas emissions under the United Nations Framework Convention on Climate Change. Aims comprise overcoming barriers of using waste landfill gas as an energy resource (Landfill Methane Outreach Program (A)). The program forms partnerships between communities, landfill owners, utility providers and DG manufacturers. Procedures involve assessments of DG technology feasibility and help with finding financing to different installations. Technology focus for CHP installations are reciprocating engines, large turbines and microturbines. The program is currently administrating 450 landfill installations, where approximately 200 are CHP installations.

6.5.1.6 Methane to Markets Partnership

This partnership is a voluntary framework for international cooperation to advance the use of methane as a clean energy source. The partnership was founded in 2004 when 14 governments sign up as partners with the objective to minimize the methane emissions from key sources. Currently the main focuses are on (Methane to Markets Partnership):

- Agricultural (animal waste management)
- Coal mines
- Landfills
- Oil and gas systems

The partnership consists of private companies, the research community, development banks, and other governmental and non-governmental organisations.

6.5.1.7 HEGEL

This project goes under the 6th EU energy framework, and aims at developing, demonstrating and compare small scale tri-generation applications for the industry segment in Europe (HEGEL). Three demonstration installations have been carried out. Technology designs in these demonstrations are; one CHP reciprocating engine coupled with a cooling system, one microturbine units coupled with absorption chillers, and one steam engine using the waste heat from a reciprocating engine.

6.5.2 Market data and local practices

To give an overview of the current markets for microturbines, market data from the different niches will be presented. Some examples of microturbine and reciprocating engine installations carried out by actors in networks will also be described in detail, giving some key details regarding actual practices and outcomes in the niches. Most of the case descriptions can be found on the U.S.DOE, “Energy Efficiency and Renewable Energy’s” webpage.

6.5.2.1 Traditional and direct CHP

Small-scale traditional CHP units have mostly been adopted by schools, apartment buildings, hotels, and likewise to fit their environmentally friendly profile and to better manage their energy costs. These installations are most common to find in the U.S. Many manufacturing processes use big amounts of heat which makes it favourable to use the heat produced by the microturbine directly. In 2003 the CHP units less than 1 MW in the U.S. was divided between different sectors as shown in figure 6.3.

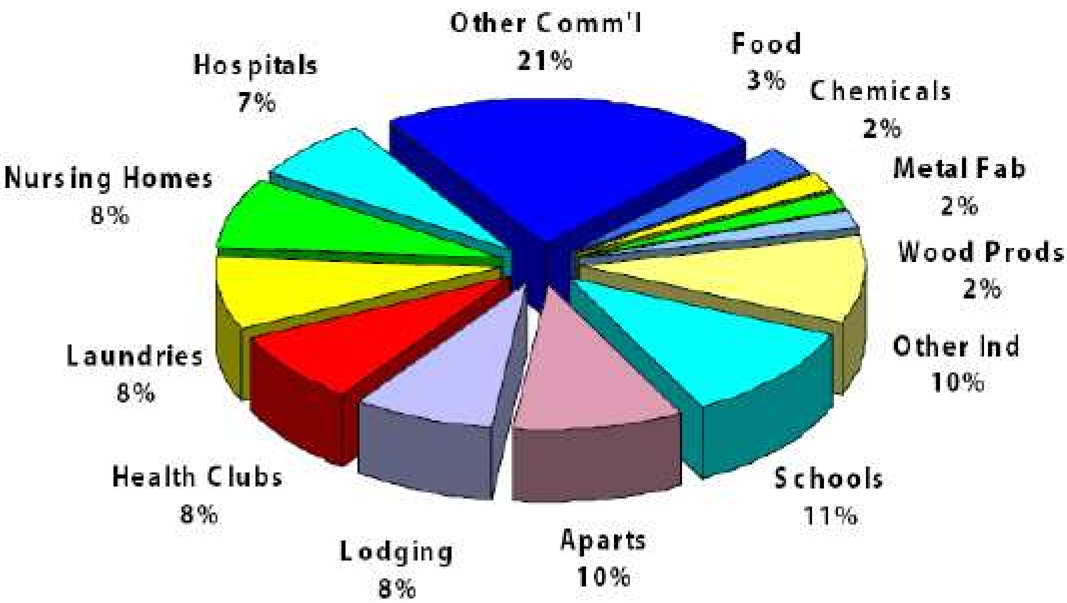


Figure 6.3 Small CHP (<1MW) installations divided by user in the U.S. Source: Hedman &. Darrow 2002

A number of local practices have been performed by microturbines in the CHP niche. Most of them are traditional CHP units but some direct CHP units have also been installed. Below are some examples on practices on local level and the economic outcome of some of these projects.

Apartment building in Danbury
An example of a CHP installation in the residential area is an apartment building in Danbury, Connecticut. The building experienced substantial transmission problems with the centralized grid that was used. The region also had problems regarding power capacity during electricity demand peaks and also has a high electricity price over natural gas price ratio. As a solution to the problems the building installed a 60 kW Tecogen reciprocating engine system running on natural gas. The building already had a connection to the gas grid which provided the fuel to the engine. The installation now provides 70% of the electricity need in the building. The rest of the electricity is provided from the grid, which also function as a back-up resource. The system also provides 100% of the heat water and 50% of the facility heating. The total outcome resulted in a 50% energy cost reduction.

Hotel in California
Holiday Inn Hotel in California installed an 80 kW Bowman microturbine in 2004 with aim of reducing energy costs and increased stability in energy spendings. The operating responsibility is provided by Simmax Group, acting as an independent energy supplier. The system satisfies the hotel with all electricity and hot water needed. Simmax Group has collected the following cost structure for the installation:

- *Engineering costs $9,700*
- *Permitting costs $300*
- *Microturbine $80,000*
- *Fluid cooler $5,000*
- *Construction cost $70,000*
- *Electrical interconnection cost $500*
- *Gas interconnection cost $5,200*
- *Heat exchanger $16,000*
- *Misc costs $27,300*
- ***Total cost** $214,000*

The actual microturbine unit was 40% of total installation cost, mainly explained by expensive correcting design expenses and other on site adjustments.

Natural gas storage plant
In 2002 a natural gas storage plant decided to invest in a 30 kW microturbine from Capstone. The reason for this was to reduce peaking electricity cost during a high energy consuming process when gas is cooled and pressurized for storage. Because of that the company was a gas storage plant, they had easy access to the fuel to run the microturbine and resulted in a payback time in 2.5 years. The heat produced by the microturbine was used for facility heating. In 2003, another microturbine system was installed, a Capstone 60 kW, to replace a 40 year old backup reciprocating engine. To support the refrigeration process, plans are being made in adding an absorption chiller to the later invested microturbine.

Metall plate manufacturer in California
*As new emission regulations were constituted in California in 2001 regarding heat boilers, a metal plate manufacture had to replace his old boiler with a new one. The manufacturer experienced high variation in electricity prices and wanted better manage of the energy costs. The manufacturer replaced his old boiler with 4*30 kW Capstone microturbine system. The exhaust heat from the microturbine system was used to directly heat the tanks that were used to heat the plates in the manufacturing process. The system has an overall efficiency of 72% and provides 100% of the heat needed and 50% of the electricity which result in an annual cost saving of $ 55000*

Paint process in Indiana
A paint process in Indiana wanted to reduce fuel consumption and emissions from their heat process. They contacted a company called NiSource Energy Technologies that develops and applies DG technologies. The result was the installation of a 70 kW Ingersoll Rand microturbine with direct use of the exhaust gas to heat the oven and power production to base load electricity. The State of Indiana sponsored the project with $ 30000 and the result was an overall efficiency of 76% and a 21% saving of fuel compared to the old system.

Grocery store in NY State
*A grocery store in NY State recently replaced their old power and heating system, consisting of grid power and an on site boiler, with a 4*60 kW Capstone microturbine system combined with an absorption chiller. "By providing both hot and cold water, the buildings thermal energy, and the microturbine systems thermal output is utilized year around" (CEO of Mt. Kisco Grocery Store). The outcome was an overall efficiency of 80%, annual savings of $44000 in electricity cost and annual savings of $85000 in heating costs.*

Source: Energy Efficiency and Renewable Energy

These cases of microturbine CHP installations carried out at sites with suitable heat profiles show positive results on energy savings but large economic investment requirements.

6.5.2.2 Combined cooling, heating and power generation (CCHP)

Following similar attributes as traditional CHP systems, with enlarged suitability for energy demand profiles, requiring heat and cool in large amounts, some microturbine installations has been made for space and process cooling and heating. These systems have mostly been adopted by office buildings and grocery stores but applications are to be found in a variety of user segments that are in need of both heat and cool. Some examples of installations are:

Natural gas storage plant	**Grocery store in NY State**	**Educational campus in NY**
In 2002 a natural gas storage plant decided to invest in a 30 kW microturbine from Capstone. The reason for this was to reduce peaking electricity cost during a high energy consuming process when gas is cooled and pressurized for storage. Because of that the company was gas storage plant they had easy access to the fuel to run the microturbine and resulted in a payback time in 2.5 years. The heat produced by the microturbine was used for facility heating. In 2003, another microturbine system was installed, a Capstone 60 kW, to replace a 40 year old backup reciprocating engine. To support the refrigeration process, plans are being made in adding an absorption chiller to the later invested microturbine.	*A grocery store in NY State recently replaced their old power and heating system, consisting of grid power and an on site boiler, with a 4*60 kW Capstone microturbine system combined with an absorption chiller. "By providing both hot and cold water, the buildings thermal energy, and the microturbine systems thermal output is utilized year around" (CEO of Mt. Kisco Grocery Store). The outcome was an overall efficiency of 80%, annual savings of $44000 in electricity cost and annual savings of $85000 in heating costs.*	*One ongoing project in an educational campus in NY State is currently installing a 3*27 kW microturbine system combined with an absorption chiller which is expected to save $100000 in energy costs. The system provides the campus with electricity, heat in the winter and cooling in the summer and has an expected overall efficiency of 70%.*

Source: Energy Efficiency and Renewable Energy

These CCHP installations show similar energy savings as the CHP practices but are often requiring larger investments and higher level of technical expertise in the installation process, since there are additional duct work and refinements to be made with the additional absorption chiller.

6.5.2.3 Waste gas fuel from manure

In the U.S. around 180 of 5700 feasible farms use digesters to produce biogas currently (see figure 6.4). For a farm to be feasible for installation of a CHP unit there has to be over 500 cows or 2000 swines to produce enough gas to run a microturbine.

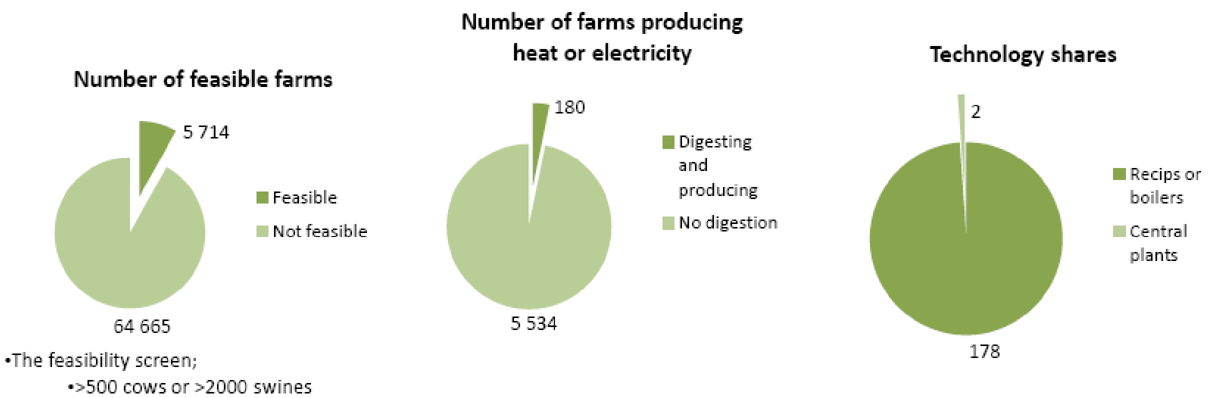


Figure 6.4 Utilization of biogas from farms in the U.S. Source: Lymberopoulos 2004

These statistics reveal a large potential for an increase in gas collection and refinement comprised by the 5534 farms with feasible gas quality and quantity, which are today not collecting these gases. A large share of those sites could benefit from on-site heat and electricity production by using a microturbine, a reciprocating engine or get connected to larger scale biogas plants. Below is a description two microturbine installations in the U.S.:

Hog farm in North Carolina
Smithfield Foods at Kenansville, North Carolina is a hog farm that feed up pigs. The installation of a 30 kW Capstone microturbine is considered a demonstration project to learn more about how well a CHP system can be integrated with an existing anaerobic digester. Smithfield handles approximately 60000 liters per day of manure witch equals a collection of 1300 cubic meters of biogas per day. Prior to the CHP installation the biogas was used in a boiler to keep the digester at a specific temperature. The installation is considered to be successful with annual savings on $ 46250 per year and a payback in 2.6 years.

Manure utilization
Two installations with similar background and objectives are operating in US currently. In Lamar, Colorado an animal feeding operation supplies an 85 kW Caterpillar reciprocating engine, and one 30 kW Capstone microturbine with biogas from hog manure. Outcomes state 3500$ in electricity savings per month, relative the former use of the centralised grid. The rationale for using a microturbine in parallel with a reciprocating engine, was to evaluate the feasibility for future usage of microturbines in these kind of contexts. In Wester Weber, Utah a 150kW Caterpillar reciprocating engine was installed in 2004, using biogas from 1200 cows diary manure, to provide heat and electricity for the site. Outcomes state a 10 year payback period, with annual energy savings of 50 000$ for the site owner, relative the former use of the centralised grid.

Source: Energy Efficiency and Renewable Energy

These cases reveal relatively short payback periods for the high installation costs. It also reveals that microturbines can complement or support other power generating devices such as reciprocating engines, which gives the user the flexibility and easy maintenance of the microturbine and the cost efficiency of the reciprocating engine.

6.5.2.4 Waste gas fuel from waste water treatment plants and sewages

In the U.S., following the energy crises in 2000, several wastewater treatment plants have applied microturbines and reciprocating engines to treat own waste water anaerobically, to recover biogas for microturbines. Typical examples of waste water treatment plants are food processing sites, generating large amounts of waste processed water and sewage sites located in and around cities. In figure 6.5 the wastewater treatment sites are segmented into sites that are processing more than 19 000 m3 of wastewater per day and sites that are processing less than 19 000 m3 per day. This limit equals enough gas production to run a 100 kW unit.

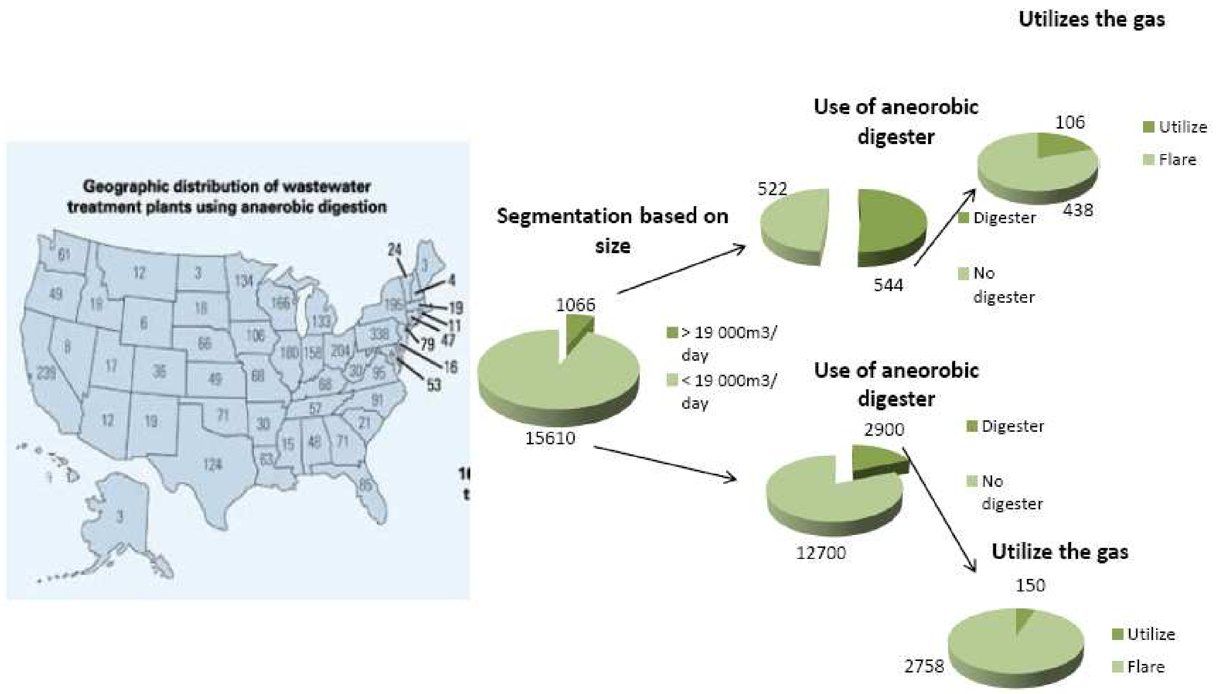


Figure 6.5 Utilization of biogas from wastewater treatment plants in the U.S. Source: Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities 2006

Two examples of practices with power producing units on wastewater treatment sites are shown below.

Waste water treatment sites	***Sewage site in NY***
In Shafter and San Luis, CA, two waste water treatment sites have installed 3 30kW and 8*30kW Capstone microturbines, to generate heat for the digester tanks and provide electricity for the site and neighbouring facilities. Both these projects have been financed by the local states, and current outcomes state successful operations. Another microturbine producer, Ingersoll Rand has installed a 4*70kW microturbine system in Santa Maria recently, to use digester gas from a sewage plant to generate electricity and heat on site. This project is currently under construction. In Gresham, Oregon, a 400kW Caterpillar reciprocating engine was installed in 2005, to generate heat for the site's digester tanks and electricity and heat for the neighbouring buildings. Another Caterpillar 200kW reciprocating engine was installed in Birlingham, CA in 2006, providing the treatment plant with heat and electricity. Outcomes from the Caterpillar projects are positive, staying within projected pay back times.*	*The New York state initiated a program in 2004, comprising installation of 8*200kW UTC fuel cells (PEMFC) at four different sewage sites. The background to this project was major blackout problems in 2001, where sewage and waste water had to be thrown out in rivers, since no power was available. The fuel cells are operating successfully, providing electricity to pumps and additional heat to surrounding buildings through hot water heating or AC configurations.*

Source: Energy Efficiency and Renewable Energy

These cases do not state information about quantitative economic outcomes but reveal positive operational results. The cases show that different small scale technologies can complement each other on the same sites.

6.5.2.5 Waste gas fuel from landfills

Landfill sites as a general on-site power generation niche has been growing 15 % a year, since the year of 2000 (Liebich & Vivarelli 2004). The main reason for this is that the sites have incentives and rules to encourage use of renewable fuels. The strongest incentive placed in many areas is that central power plant owners (utilities) has been forced to purchase the output power produced form waste fuels at landfill sites. In addition, "The clean air act" brought out in 1996, forces many large landfills to collect and combust or use their waste methane gases. In the U.S., the "Environmental protection agency" was involved in 300 waste fuels to energy projects (not only microturbines) in 2003, and currently an estimated number of 800 projects are underway (*Advanced microturbine system: market assessment* 2003).

As shown in figure 6.6 microturbines has a 4% total market share in the landfill niche while they have a 20% market share in the landfill sites that are smaller then 800 000 ton of wastes.

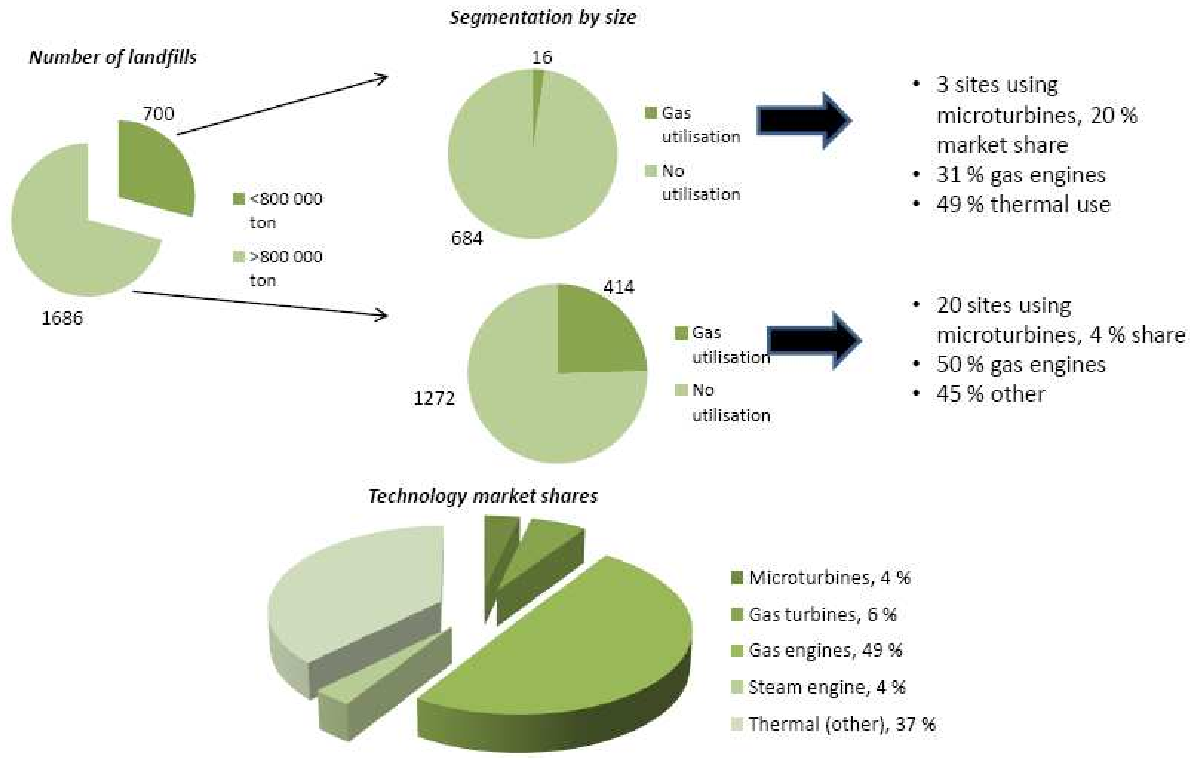


Figure 6.6 Utilization of biogas from landfills in the U.S. Source: Landfill Methane Outreach Program (B)

Three examples of practices on landfill sites are shown below.

Landfill sites in the U.S.	Educational landfill site in Illinois / Landfill in France
Landfill sites in the U.S. *In Spring Valley, CA, a 3*70kW Ingersoll Rand microturbine system was installed in 2002 with aim of reducing energy costs for the landfill site, and increase overall energy efficiency, through utilising wastes. Current outcomes state that 100 % of the electricity and heat demand for the landfill site is fulfilled by the system, and maintenance requirements and overall availability are favourable, according to the landfill owner. At another landfill site outside LA, CA, a 6*70kW Ingersoll Rand microturbine system is operating with positive results since 2004. Overall availability measures are 98%, and required maintenance intervals are 8000 hours, according to the landfill owner and Ingersoll Rand's project manager. The objective to this installation came from the landfill owner experiencing approximately 450 000$ increase in his energy bills in 2001.*	***Educational landfill site in Illinois*** *In Antioch, Illinois, an interesting installation involving a 12*30kW Capstone microturbine system using local landfill wastes to generate electricity and heat for the local school was initiated by the school's board and principle in 2003. Part of the objective for the installation involved educational purposes for the school. Nearby the school, a landfill site is connected through a gas pipeline to provide fuel for the microturbine system. Outcomes state annual energy savings of 165 000$ and a 8,5 year payback period.* ***Landfill in France*** *Thieulloy l'Abbaye landfill plant in France installed 8*30 kW Capstone microturbine system in 2004. At the moment the biogas flow is insufficient, only 3 microturbines are currently running. Economics of the project are stated below.* •*Equipment $836,580* •*Grid connection $48,820* •*Biogas collection network extension $68,760* •*Miscellaneous $19,310* •***Total*** ***$****973,470*

Source: Energy Efficiency and Renewable Energy

These cases show large investment requirements but positive operating results and in the long term positive economic outcomes.

6.5.2.6 Oil and gas fields

In the oil and gas field niches, on-site generation units, such as microturbine units are used to provide remote power from unprocessed, waste gas that would traditionally be flared or emitted to the atmosphere, since the fuel quality is to low for pipeline collection and distribution. Thus, the microturbine systems can perform a value of increased energy efficiency, reduced grid electricity demand, as well as lower emissions of greenhouse gases. On-site power demand for a gas or oil well is between 60- 400 kW. An example of an installation is shown bellow.

Oil and gas producer in California
*An independent oil and gas producer operating 7 oilfields in Ventura, CA, faced new gas standards in 2003. The new standards, forbidding flare of gas, made the company aware of the method of compressing the gas and using it to produce electricity through a micrturbine. They had thoughts of using reciprocating technology but they needed catalytic converter, other expensive equipment and required more maintenance. In addition California state provided a 42% DG-incentive for microturbine-technology. The resulting installation was a 5*70 kW microturbine system from Ingesoll Rand placed on 4 oilfields, with an additional 250 kW microturbine placed close to the gas plant facility. The heat from the microturbine system is used by the processing plants on the fields, which all together resulted in $ 250000 savings per year for the entire project.*

Source: Energy Efficiency and Renewable Energy

This case show a key difference between microturbines and reciprocating engines in that the reciprocating engine sometimes need additional converters and refiners to use the waste gas, whereas the more expensive microturbine can run on the more unrefined waste gas.

6.5.2.7 Key findings from niche practices

The different local practices performed in Europe and the U.S. have some similar and differentiative attributes. To describe that, the applications' backgrounds, operations and outcomes will be summarized.

Backgrounds;

- Most U.S. CHP applications are driven by prior energy price volatility, energy blackouts and regional emission regulations.
- Industrial CCHP applications are characterized by prior energy consuming chillers and heating systems operating in contexts where large amounts of heat or cool are required.
- Some U.S. CHP applications are setup through industry alliances, linked to state incentives, aiming at improving regional and national energy efficiency.
- Some CHP applications are setup by gas utility companies, diversifying their services into energy distribution.
- Farm applications, using manure as fuel, are characterized by prior energy consuming digester handling methods.
- European landfill demonstrations indicate microturbine advantage over reciprocating engines, where low quality fuel is supplied.

- U.S. regulations on waste gas flaring have driven oil and gas field owners to apply microturbines.
- Generally, most European applications have demonstration objectives, while U.S. applications have more commercial natures, supported by state incentives.

Operations;

- The total installation cost for a microturbine system, has been unpredictable, depending on local regulations, availability of spare parts, cost of complementary components, and availability of gas fuel.
- Some distribution, service, and operating actors have taken a role of offering energy reliability, independency and flexibility for industrial companies, through sourcing microturbines.
- Efficiency levels stated by producers are based on natural gas fuel, which is therefore not fulfilled in waste gas applications.
- Overall efficiencies for CHP and CCHP systems are dependent on other components besides microturbines. Mainly traditional boilers, complementing heat exchangers and chillers.
- Most microturbine systems operate in parallel with the grid, with the grid acting as a backup source.
- In general, microturbine systems supply 100 % of the heat and around 50 % of the electricity demanded.
- microturbines are often coupled in severals, which increases the flexibility and adjustability of the systems offered.
- User driven objectives for installing an microturbine system are often the need for a new and more efficient heat source. The installed microturbine system provides the heat needed plus some of the electricity.

Outcomes;

- U.S. CHP installations show positive economic outcomes, with increased efficiency ratios and following payback periods (based on present grid electricity costs and traditional heating alternatives), through incentive and tax support.
- Manufacturing site owners in the U.S., with prior price and reliability volatility, have experienced more managerial energy costs.
- “Energy savings”, including both electricity and heat, have been positive in certain regions, supported by incentives and prior poor efficiencies.

- Fuels with low heat value, such as landfill and digester gases favour microturbines over reciprocating engines, since efficiency ratios are higher and maintenance requirments are lower.
- microturbines can successfully be coupled in severals to adjust to the availability of fuel in a waste utilisation application.

In the waste gas niche, the microturbines are experiencing competition with reciprocating engines in potential installations. This competition was assessed in an EU project a couple of years ago (see table D.2 in appendix D). The assessment shows that reciprocating engines are cheaper in terms of installation cost, but microturbines have the ability to run on more "dirty" fuel without having an increase in maintenance or additional refinement equipment costs. Microturbines also showed higher efficiency ratios when running on the dirty, low methane content gases.

6.6 Summary of present network

Based on the information in this chapter a visualization of the present network is shown in figure 6.7 with the existing linkages between the different actors. A more detailed network can be found in Appendix E. Some overall comments about the network are:

- Regulatory and policy forces favour centralized structure, but envision an increase in CHP.
- Institutes and MFOs are promoting reciprocating engines for CHP applications and both microturbines and reciprocating engines for waste utilization applications.
- Capstone is the only microturbine producer with diversified marketing and distribution channels.
- Diversified DG companies, such as General Electrics, practising FC, microturbine as well as reciprocating engine technology are trying the same niche as focused microturbine actors, which goes in line with the finding that different DG technologies can complement each other as well as complementing a central grid structure.
- Reciprocating engine actors have networks, alliances and channels aiming at the same targets as microturbine actors.

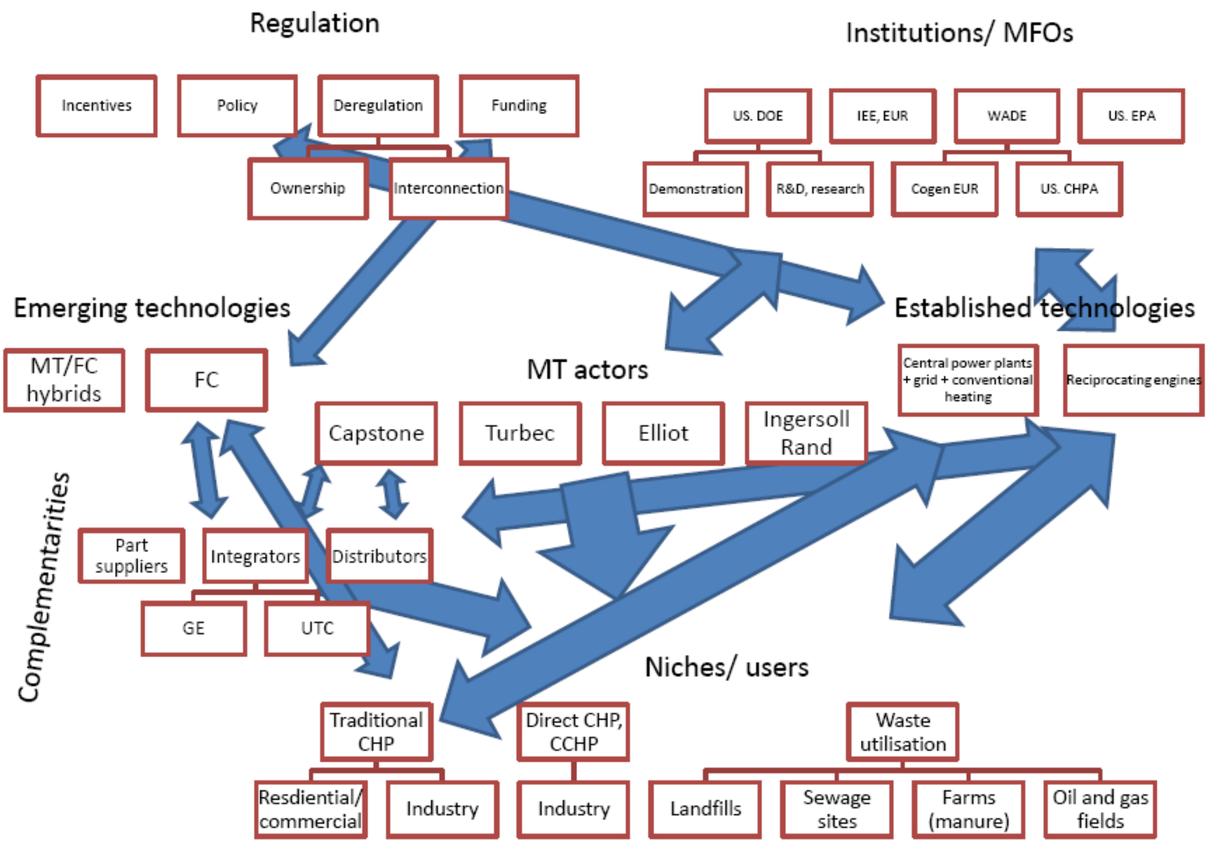


Figure 6.7 Visualization of present network

The microturbine producers have been focusing on industry CHP and commercial buildings CHP, promoting microturbine systems as flexible and efficient. This focus have not given the expected volume sales because of the competition from the more efficient and less costly reciprocating engines and regulatory energy visions of larger scale CHP. An emerging change in the microturbine network is the focus on waste gas applications where there is more regulatory support, less competition from reciprocating engines since they can't run as flexible and reliable on fuels with low heat value in comparison with microturbines.

7 Analysis of present network

The analysis of present network will discuss the strategic issues that actors face in the networks, followed by an assessment on how they resolve and try to overcome these issues. From these perspectives a summary of the key driving and blocking factors for microturbine technology will be presented. The chapter will be structured as follows:

- Strategic issues
  - User issues
  - Competition
  - Producer issues
  - Institutional and regulatory issues
- Strategic niche management assessment
  - Protection
  - Network formation
  - Niche enlargement and development
  - Development strategies
- Key driving and blocking factors

7.1 Strategic issues

The key strategic issues inflencing microturbine actors and products will be discussed. The key issues influencing microturbine networks are divided into separate groups of actors and areas of strategic impacts.

7.1.1 User issues

The value of microturbine products measured in terms of user preferences is dependent on local incentives, regulations and policy, existing heat and electricity source, fuel availability and prices as well as the heat and electricity demand profile.

Policies in the U.S. and Europe acknowledge DG as a way to increase energy efficiency and reinforce utilisation of renewables. In parallel, policies and regulatory frameworks embrace CHP generation in general. Institutions and policymakers initially viewed microturbines as a low emission, high efficiency alternative in DG, but developments of reciprocating engines and a raise in natural gas prices have somewhat changed that view. Microturbines are currently viewed as a niche alternative, with value of modularity and flexibility in CHP applications for industry or residential and commercial users. Energy departments and institutions see largest potential for microturbines in the niche of utilising waste fuels at landfills, sewage sites, farms (manure), and oil and gas fields. Thus, biogas is the fuel that policy forces want to align microturbines with. In Europe, more CHP plants have been installed compared to the U.S. In addition, the U.S. has experienced far worse blackout periods in the early 2000s, reinforcing a decentralisation of supply in certain regions.

Another element of local regulations and policies are found in ownership and approval administration of microturbines. Experiences from U.S. and Europe states that administrative hassles can constitute a barrier for microturbines compared to the more established and "accepted" reciprocating engines.

The nature of the existing electricity and heat structure differ heavily between nations and regions. The existing structures that see the largest drive for replacement with microturbines, reciprocating engines or medium and large CHP plants are centralised coal or oil fired plants, since emissions are high and efficiencies are lower compared to microturbines and other DG technologies in CHP mode.

Electricity prices in the U.S. have traditionally been low, compared to regions within Europe. The same is found for natural gas prices (see figure B.1 and B.2 Appendix B). Although, following the U.S. energy crisis in 2000/ 2001, energy prices in general rose, and became highly volatile. The fact that natural gas prices doubled during a week, meant that the promised value of microturbines got questioned and future expectations got more pessimistic. On the other hand, the energy crisis meant that energy supply and existing energy structures got questioned, since unreliability and cost volatility got aligned as attributes. In Europe, energy prices in general have risen during the past years, in parallel with greater awareness of energy efficiency improvements and CHP installations. In both Europe and the U.S., microturbines can "avoid" dependency of fuel and electricity prices through waste utilisation of biogases. In some areas in northern Europe, waste biogases are used for vehicle fuelling, therefore being a competitive alternative to microturbine installations on site.

The user's heat and electricity demand profile determines the economic value of a potential microturbine installation. Ultimately, microturbines generate large amounts of heat, relative electricity, implying that users must have a need for large and levelled amount of heat.

However, the use of absorption chillers in parallel with heat exchangers connected to a microturbine can direct and level the heat demand, making microturbines more applicable. But in those installations, microturbines account for no more than 50 % of the installed cost, indicating that the potential value is determined by factors outside the microturbine technology. In the niche of waste utilisation applications, economics are valued differently since the fuel is cheaper compared to general CHP installations, since many waste site owners want to distribute heat and electricity to other facilities in the neighbouring area.

7.1.2 Competition

Microturbines are currently facing head to head competition with other power distribution alternatives in the niches of CHP and waste utilisation. Strategic issues of key competition areas for microturbines will be discussed.

7.1.2.1 Microturbines versus reciprocating engines

The performance attributes subject to competition between reciprocating engines and microturbines in the niches of CHP for industries and waste fuel utilisation are; efficiency, installed cost, maintenance requirements, fuel flexibility, emissions, and O&M costs. Some of these performance attributes are shown in table 7.1 for microturbines and gas engines.

Table 7.1 Key data on microturbines vs. gas engines. Source: www.distributed-generation.com/technologies.htm 4/9 2007; Technology data for electricity and heat generating plants 2004; Opportunities for Micropower and Fuel Cell/Gas Turbine Hybrid Systems in Industrial Applications

	Microturbines	Gas engines
Capacity	30- 400 kW	30 kW- 6 MW
Installed cost ($/kW)	1200- 1700	700- 1200
El. Efficiency	14- 30 %	30- 42 %
Overall efficiency	80- 85 %	80- 85 %
Total maintanance cost ($/kWh)	0.008- 0.015	0.007- 0.02
Emissions (gm/bhp-hr)	NOX: 0,15- 0,9 CO: 0,1- 0,55	NOX: 0,7- 13 CO: 1- 2

The electrical efficiency ratios of reciprocating engines are generally higher compared to microturbines. Microturbines have not developed as fast as projected and articulated in its emergence. Reciprocating engines have relative matureness as a technology and have been aimed for development during a long period of time by the large transport industry.

The total installed cost for a reciprocating engine is smaller relative microturbines. Aspects such as larger scale of production and longer product life cycles play a key role. Reciprocating engines have parts and components that are used outside the small scale power industry, which increases scale and level of commodity. A different aspect of installed cost lies in the dependency of complementary components, such as chillers and heat exchangers, where reciprocating engines have more experience of integration with these units. When installing a small scale power unit, redesign, installation service expertise and availability of spare parts are influencing the total cost as well.

Maintenance requirements and O&M costs are determined by the time interval between maintenance activities for the system and the amount of resources required each time. Microturbines have an advantage in this attribute in applications where the fuel has low heat value and is dirty, while reciprocating engines have about the same maintenance costs and requirements in applications where natural gas is used as fuel.

The attribute of fuel flexibility is about being able to use natural gas and different heat valued biogases. When microturbines emerged, they had advantage in the sense that reciprocating engines had not developed biogas capabilities, but that has changed. Currently, microturbines have a small advantage in that when the biogas fuel is dirty and of low heat value, the maintenance requirements do not increase, while for reciprocating engines, the time interval between maintenance activities decreases with lower quality biogas fuel.

Some important aspects of the competition between microturbines and reciprocating engines are specific for the niche of landfill, digester and sewage sites. In these applications actors and institutions are embracing the "free fuel" attribute, since using wastes for power generation. The extent of this attribute is highly dependent on the O&M costs. When looking at low heat valued biogases, reciprocating engines have higher O&M costs over the long term, since cleaning and component replacing requirements are larger relative microturbine units. At some landfill and digester sites the availability of fuel is varying over time, demanding variation in output capacity of the small scale power unit. Where variations are large, decoupling and modularity abilities giving flexibility in capacity of microturbines indicate an advantage over fixed capacity reciprocating engines.

7.1.2.2 Microturbines versus central power

From the perspective of microturbines replacing the central plants and grids in targeted applications, the existing distribution and transmission cost is central. Depending on user location and demand size, the costs can vary between 30- 40 % of the total cost of electricity. On the other hand, the installation cost per kW is larger for small scale technologies such as microturbines compared to large central plants and the cost of fuel delivered to microturbines is larger than large scale conventional plants, with waste biogas fuel applications being an exception.

The flexibility and expandability of microturbines are advantages relative central power plants. This implies that microturbines can more quickly respond to local peak demands compared to central plants. Expandability and adjustability in installations can also be an advantage in some installations compared to central plants, but outcomes from local practices with microturbines state that the promised delivery time comprised by weeks, have in reality been comprised by 1- 4 years with all complementary equipment taken into account. (K Crossman 2007, interview, 30/8). The ownership and energy supply control can also be an advantage for high consuming, energy sensitive users that place a high value on low price volatility and/ or high reliability.

Looking at CHP in general, most CHP installations today are large scale, out competing small scale alternatives such as microturbines, since capital cost per kW is lower (see Table C.1 in Appendix C). Current installations are often aligned with heavy energy load industries or large, dense city areas, which implies that microturbines only protective space in CHP applications would be rural areas with high electricity prices.

As an alternative to competition with the central power structure, regulatory and energy actor forces like to view microturbines as a complement to central power plants, providing flexibility, relief of grid infrastructure overload, waste utilisation and quick response to demand at targeted applications with suitable demand profiles.

7.1.3 Producer issues

The analysis of producer issues is divided into four aspects; resources and expectations, perceptions and strategies, actor networks, and aggregation and learning.

7.1.3.1 Resources and expectations

Financial resources from investors and owners linked to microturbine producers have been low since 2001/ 2002, following the raise in natural gas prices. Development resources for microturbine producers have been scarce, limited by the low market penetration. Since microturbine is an advanced, expensive technology to develop, the resource requirements in producers' R&D labs have not been fulfilled during the past years. Instead, most developments in designs, components and materials have been performed in state labs in the U.S., with microturbine producers providing their products for the labs. In synthesize, microturbine producers require larger resources than currently being present.

There is a link between resources and expectations comprising a priority between high or low volume microturbine product designs. Focused microturbine actors have chosen designs and technical manufacturing equipment requiring large scale of volumes to get cost competitive in the market, explained by their initial high expectations about market volumes. Furthermore, current R&D focus indicate that actors are looking for higher efficiencies in their microturbine components, instead of reducing costs through using common materials and technologies in the systems. Such focus indicate that microturbine focused actors want to out compete superior reciprocating engines in targeted segments.

Expectations can be divided into internal and external for microturbine technology. Internal expectations among key actors such as Capstone and Turbec were high in the late 90's and early 2000's, articulating a potential future of high volumes, further deregulation of the energy markets, low emission profiles and general social awareness of energy efficiency and small scale CHP benefits. These expectations were too diverse and too large in scope, not taking into account competition from other technologies, natural gas price volatility or regulatory adjustments. As a consequence, Turbec divested its production of microturbines in 2002, and Capstone being public offered on the stock market fell dramatically in stock value during 2001- 2006. Producers in general, overestimated the potential volumes of the market and the potential production costs. One producer, Ingersoll Rand acknowledged microturbines as a small scale niche product from the start, not articulating as low potential costs as Capstone and Turbec.

Another aspect of internal expectations is found in the ownership structure of producers. Producers belonging to large, diversified companies have articulated lower expectations compared to small focused microturbine companies. Interviews state that this can be explained by larger companies' high demands on actual market potentials rather than fictional and visionary scenario based market potentials, articulated by a focused actor such as Capstone.

Determining the current internal expectations of microturbines are outcomes from the local practises of microturbines, which state that efficiency and cost levels in general CHP installations for industry and residential and commercial users are not as positive as initially articulated by microturbine producers. This and other outcomes have forced microturbine actors to revise focus into primarily articulating competitiveness in the waste utilisation niches. As a consequence, volume, performance and cost expectations are lower today compared to early 2000. Interviews with Turbec and Elliott highlight the fact that they see their products as a “middle path” (in terms of efficiency, emissions and cost) in general CHP installations, when competing with reciprocating engines and large CHP plants in replacing coal and oil based electricity plants with grids.

External expectations of microturbine products can be divided on regulatory and state institutions, non-profit organisations and financial investors. States and policy makers have low volume expectations on microturbines, viewing it as a small scale, flexible alternative in some waste utilisation applications. In waste utilisation applications and some general CHP applications using biogas, states and policy makers view larger scale structures such as large turbines and other large CHP plants as the main alternative, with microturbines being too small and not economically competitive.

Energy associations and non market organisations generally place microturbines as less economic competitive than reciprocating engines in all applications, including the waste utilisation applications, where microturbine actors see their product as superior in handling low heat valued biogas with fluctuating fuel availability.

Financial investors have low expectations on microturbines as a commercial success, generating returns. Instead, their focus currently is with fuel cells and other renewable generation sources, fulfilling the same purposes in general CHP applications as microturbines.

7.1.3.2 Perceptions and strategies

Interviews state that the four key microturbine producers are all focusing on two separate segments; CHP and waste fuel utilisation. They all view biogas waste fuels as the most promising niche, articulating the flexibility in capacity installed and low maintenance requirements relative reciprocating engines. In addition, the producers want to align with the regulatory frameworks, which aim at substantial increase in the waste biogas utilisation at landfills, farms (digester) and sewage sites.

The U.S. producers are targeting Europe as a more mature waste fuel utilisation market relative the U.S., mainly explained by producers viewing Europe as more developed in biogas energy awareness in society and regulation. In the U.S., one specific waste fuel utilisation application not present in Europe is oil and gas fields, which U.S. producers are focusing on, backed up by regional incentives and laws for utilising waste gas.

Capstone and Turbec, two of the largest producers have similar backgrounds, being initially aligned with transportation, diversifying into power generation. Ingersoll Rand on the other hand had initial resources and objectives coming from the regional gas companies, wanting a technology that could efficiently generate power, using their fuel resources. Ingersoll Rand has remained with low market expectations throughout the 2000s, while Capstone and to some extent Turbec have both had an expectation-"boom" in the early 2000s, articulating high efficiency improvements to customers, and large economic potentials for investors.

After the market stagnation in 2001/ 2002, refinement and adjustment of strategies and perceptions have led to more shared views among microturbine producers in today's microturbine industry. All producers currently promote microturbine as a "middle path" DG product in the CHP applications in industry, residential and commercial contexts, with relatively high efficiency ratio and relatively low emissions. The main issue in the CHP segment is cost, in lack of scale in production and in some instances lack of manufacturable designs. In the waste fuel utilisation niches, producers' visions and expectations are more diverse, with the U.S. niches being focused on wastewater treatment, sewage and oil or gas fields, whilst in Europe focus is on landfills and farms. The relative diversity is explained by regional and national differences in regulation, incentives and social awareness in energy efficiency.

7.1.3.3 Actor Networks

The networks shaped by microturbine actors differ a lot between the different producers. Alliances and collaborations between producers have been non-existing. Some non market organisations have been formed, currently collecting and sharing information of local microturbine practices.

Capstone is the most active in network forming, having a network of several owned distribution companies focused on microturbines as well as some other distribution partners with diverse DG technology focus. Capstone also has extensive linkages to non market organisations promoting microturbines, state energy institutions, advocacy coalitions, and lobbying groups. One key in Capstone's network is receiving of state funding for technology development and marketing resources. Capstone is the only microturbine producer that actively enrols more actors in their practicing networks, both microturbine focused and DG diversified organisations.

Turbec, being one of the largest microturbine producers has a limited, focused network. The key of their network is collaboration with EU funded microturbine programs with focus on bio fuels in waste utilisation niches. Turbec's network has looked the same in terms of number and direction of linkages since their commercialisation.

The microturbine network in general is highly dependent on the information gathering and information sharing of the non market organisations promoting general CHP applications or waste utilisation applications. All microturbine producers are somewhat aligned with the key organisations performing such activities. The reciprocating engine producers focusing on biogas waste utilisation at landfills, sewage sites, and farms are aligned with the very same organisations. Interviews with those reciprocating engine actors highlight that they are not experiencing head to head competition from microturbines, and they view their established products as the main alternative in the small scale niche.

7.1.3.4 Aggregation and learning

Local practices and outcomes performed by microturbine producers have led to adjustments in actor strategies and focus, but feedback loops and insights tend to remain local over time.

There has been a lack of aggregation of experiences between different regions and local practices. Learning insights have not been shared between different microturbine producers; instead each producer has used its own feedback loops for developments. The only functions currently working to share outcomes on national and global level through information spreading are the non market organisations promoting small scale CHP or biogas waste utilisation.

Focuses and insights derived from outcomes of microturbine practices performed differ substantially between different regions and nations. Some regions in the U.S. focus merely on small CHP for industrial and commercial installations, driven by the local energy volatility in price and quality, while some regions in Europe focus merely on biogas waste utilisation installations, driven by prior state funded demonstration projects.

Looking at product design, user targets and following outcomes and insights differ in different regions. U.S. producers have been focusing on CHP and CCHP installations, primarily targeting industries with large and levelled heat demands. Interviews with information sharing CHP organisations state that values and benefits for microturbines in such installations are not economically competitive, nor giving public benefits through increased energy efficiency. Such outcomes indicate that targets ought to be biogas waste applications rather than general CHP and CCHP applications. In Europe, design and targets shifted from CHP and CCHP to biogas waste utilisation much earlier compared to the U.S., driven by a larger social awareness of biogas utilisation in general.

Continuing on product design and targeting, interviews with organisations that share information about CHP highlight the fact that the actual microturbine accounts for no more than 50 % of the total installation cost in a small CHP or CCHP installation. Furthermore, system integration duct systems and other complementary components in those installations limit the efficiency ratio more than the actual microturbine unit. Such insights should have been aggregated and shared at a higher level at an early stage, to prohibit some producers of still targeting these spaces, where the value of the product is low relative other alternatives.

Information and insights of fuel flexibility competition between microturbines and biogas fuelled reciprocating engines are diverse and fuzzy among actors in the networks, according to interviews. One of the key microturbine producers, Turbec views its products as superior in handling low heat valued biogases relative reciprocating engines, while the key reciprocating engine producer focusing on biogas engines state that they have never experienced any sharp competition in their application spaces from microturbines. Concluding that reciprocating engines can handle approximately the same heat value levels of biogas wastes, the competition comes down to maintenance, where outcomes state that microturbines have an advantage. One way to approach the competition for a microturbine producer would be to form an alliance with a reciprocating engine producers, with aim of giving users the optimal alternative for a given application duty.

7.1.4 Institutional and regulatory issues

Policy issues of DG technologies in general and microturbines in particular can be divided into economic efficiency, deregulation and energy security.

Economic efficiency issues include connection of DG technologies to distribution grids and networks to enlarge the initial niche markets for today's small scale alternatives. In the next stage, pricing of DG generated electricity becomes an issue of how to incorporate potential public benefits in the tariffs. One example of this is found at landfills and farms in Europe, where site owners are given incentives to install power generating equipment to utilise their biogas wastes, instead of buying electricity from the central grid.

Issues of deregulation involves permitting today's users to generate own power, and in the next stage distribute some power to neighbouring areas. In today's regulatory frameworks the aim seems to be an increase of competition and diversity of technologies in the energy market. Small scale DG are given the same regulatory environment as large scale CHP or other large power plants comprising; laws of forecasting all exact output levels generated for a grid in advance, purchase all excess power (energy demand not covered by the microturbine unit on site) to a higher tariff price, and pay the same fees and transaction cost as the conventional large power plant owners and operators. Thus, to summarize the general status of deregulation, one can say that incentives and rules are making small scale alternatives less competitive relative large scale. In addition, current energy utility providers operating and / or owning large scale power plants (sometimes aligned with local states) have the competitive response power of discounting prices for targeted microturbine customers, lowering microturbines economic competitiveness.

7.2 Strategic niche management assessment

To evaluate how the actors are resolving and trying to overcome the strategic issues in the networks an analytic evaluation of the elements: protection, network formation, niche enlargement, development, and development strategies, will be outlined. These elements are derived directly from the strategic niche management framework.

7.2.1 Protection

One first step in niche management of technology such as microturbine, is about finding an appropriate protected space, where the technology can develop in the networks of actors. The initial space for microturbines was backup or electrical support resource in the U.S. during the volatile periods of 2000/ 2001, when number of outages and level of utility and “peak” prices rose significantly. The protection lied in increased reliability and easy setup with low maintenance. That protection eroded through a significant increase in natural gas prices and developments and market penetration by reciprocating engine actors.

Microturbine’s protection in the general CHP application space came from high efficiency, potentially low cost and low maintenance value articulation by microturbine actors. That protection has been lowered through experiences showing that complementary components and general technical and administrative problems during installation and setup periods set limits for realized efficiency levels and costs. In parallel, energy organizations see larger potential in large scale CHP, since they show higher efficiency and more benefits for the energy structure on society level. The general CHP application space has also been struck by the volatility and general increase in natural gas prices, which has lowered the potential value benefits for microturbine systems.

The most recent application space, waste gas utilization applications held an initial protection in fuel flexibility, since the main competing technology of gas engines have been viewed as not being competitive with microturbines on low heat value gas, such as landfill and sewage gas. However, gas engines have proven competitive in most spaces using waste gases, and have up to today penetrated a dominant part of the market spaces that microturbine actors view as appropriate.

The protection attribute currently being focused in the waste gas space is capacity flexibility and low maintenance relative gas engines. That protection focus is still in emerging stages but holds large potentials for targeted landfills, sewage sites and farms. There is a regulatory vision of large scale waste gas utilization, but that is simply not possible for all sites, indicating that microturbines can benefit from protection in parallel with state funded large scale penetration.

7.2.2 Network formation

- Producer networks are weak and diverse, with Capstone being the only actor with extensive linkages in both distribution and development.
- Distribution systems are narrow and focused, especially in Europe.

- Producer- institutional (state) linkages are strong in the U.S., but focus is mainly on R&D.
- User- producer linkages are weak, and most potential users need to be educated about benefits and values.
- Partnerships and information sharing organisations play a key role in spreading outcomes and insights to a wider community.
- For most applications, microturbine producers need to ally with complementary technologies and system integrators, since the actual microturbine unit is not the bottleneck for efficiency ratios.

7.2.3 Niche enlargement and development

- Given that the primary target should be waste biogas utilisation at landfills, sewage sites and farms, these users need to be educated much more actively by microturbine producers.
- Regarding marketing and promotion activities, Capstone being the main actor exaggerated product benefits and performance in the early 2000s, which gave an unbalance between expectations and actual potentials and benefits.
- Feedback from experiments is being shared only through information organisations or energy departments, indicating a lack of dialogue between microturbine producers and component, or complementary product suppliers.
- The deregulation of the electricity market and the outspoken regulatory visions of a "distributed generation" can give further targets and application possibilities for microturbines, but the relative position of microturbines in DG is not being articulated or acknowledged currently.

7.2.4 Development strategies

- The three main microturbine producers, Capstone, Elliott and Turbec, sharing the attribute of merely focusing on microturbine products, have been forced reactively to large adjustments in strategies and expectations, explained by too narrow views of their technologies in combination with individual marketing, distribution, and strategic plans, with a lack of collective partnerships, sharing forums and channels.
- Current voicing and shaping of expectations about microturbine as a technology is rather diverse and fuzzy. There is a need to voice expectations about benefits in small

scale biogas waste applications, especially in the U.S. where biogas utilisation in general is lower compared to Europe.

- In order for microturbines to enlarge current niches, further user acknowledgements must take place. Current articulations and value acknowledgements are voiced by producers without potential users participating. Developments should integrate insights between producers and users, to shape more precise and accurate value proposals in the future.

7.3 Key driving and blocking factors

Based on the network review and the analytic conclusions, the key driving and blocking factors for microturbine technology will be derived.

7.3.1 Blocking factors

- High gas prices and low electricity prices, especially in the U.S.
- Lack of customer experience compared to centralized power and small scale reciprocating engines.
- Lack of shared value targets among microturbine actors.
- No universal interconnection standard.
- Lack of social awareness about waste biogas utilisation potentials, and competition from the automotive industry promoting biogas.
- Lack of network linkages and formation for microturbine producers in distribution and marketing.
- Improvements and developments in alternative on-site, small scale power generation technologies, such as reciprocating engines.

7.3.2 Driving factors

- Combined heat and power generation improving overall energy efficiency, even though regulatory drivers are aiming at larger scale.
- Social will and incentives to reduce emissions, comprising a replacement of fossil fuel based energy sources.
- Reduced fuel consumption in buildings and factories using microturbine CHP systems.
- Burn waste and gas in landfills, oil and gas fields, and sewage sites.
- Increased reliability and availability for energy sensitive applications.

- Low maintenance, flexible and fast installation
- Current electricity price volatility for industry sites.
- Further grid energy distribution volatility, like in California blackouts.

8 Future strategies

From the analysis of the present network and the driving and blocking factors that have been presented, this chapter will give alternative future strategies for microturbine actors. This proposition will focus on the two niches, CHP and waste gas utilisation, and give some guidelines of what a microturbine actor should focus on.

8.1 CHP niche strategy

CHP applications involving direct heat use or cool use through transformation in absorption chillers will be highly dependent on natural gas/ electricity price ratio, gas infrastructure availability, incentives and regulations, state of grid infrastructure, and availability and performance level of complementary components.

The natural gas price varies between different regions. The price is lower in the U.S. compared to Europe. In parallel, the electricity price in the U.S. is lower compared to Europe, resulting in a fairly level natural gas/ electricity price ratio in both regions. There are specific countries in Europe and specific states in the U.S. where the ratio is much lower than the average country ratio. Such regions are primary targets for microturbine systems. Examples, referring to figure B.4 in Appendix B are; Hungary, Luxemburg, Italy, Slovakia, Estonia and Belgium in Europe, and specific central states in the U.S. These regions have ratios below 0,3. Given that microturbines have electrical efficiencies of 30 %, and the gas to electrical price ratios are 0,3, gives a cost for a given amount of electricity that is equal for microturbines relative central power. In addition to the equal cost of electricity, the microturbine system can also offer supply of heat to the user. However, this potential value of microturbines will face head to head competition with reciprocating engines, since they are able to deliver even higher value with electrical efficiencies of 40 %. An example from Elliot is given in figure 8.1 of when it is economical to install a microturbine.

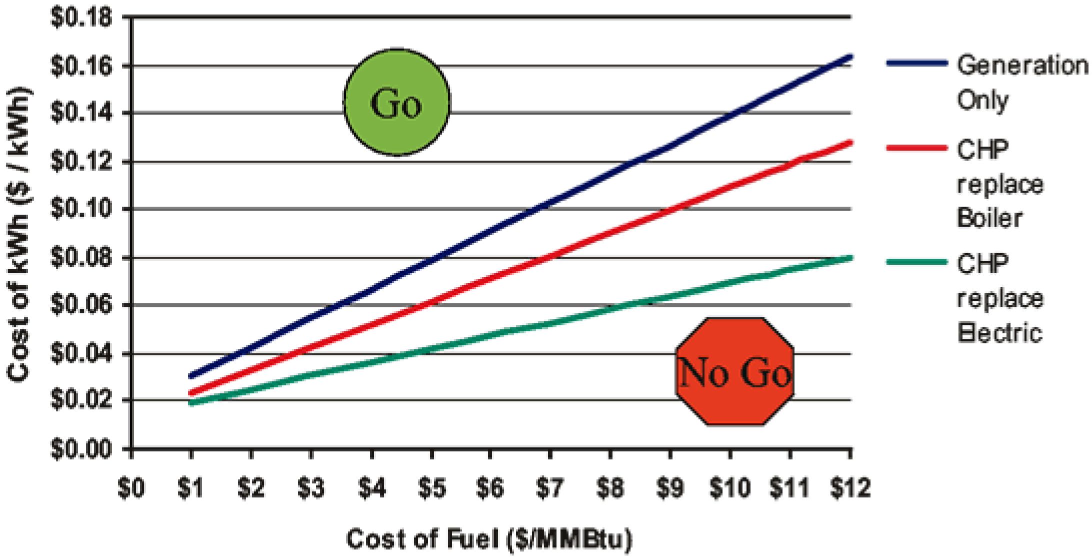


Figure 8.1 When is it economical to install a microturbine system? Source: Elliot Microturbines

To be able to run a microturbine system for power and heat supply with competitive cost attributes, there must be easy access to natural gas supply. The density, scope and capacity of the natural gas infrastructure are more developed in the U.S. compared to Europe, with some regional variances.

Unsuitable gas/ electricity ratios can be compensated by tax and other installation incentives. In some regions, incentives, such as a 10- 20 % tax relief when installing a microturbine unit instead of a new heat boiler, can overcome the barrier of poor gas/ electricity ratios. The decision by an industry or a commercial facility to install a microturbine unit should have the preference of being forced to upgrade the current heat boiler, in order for the microturbine product to be economically competitive.

The state of the current grid infrastructure varies between different regions as well as the user demand for reliability and capacity and scope expansion. microturbine systems can be competitive in cases where the infrastructure expansion is expensive or in cases where the demand location can't be reached by a grid infrastructure. From the perspective of viewing microturbines as an alternative to grid expansion and upgrading, the most favourable context for microturbine systems is where power is supplied from a coal based plant and the grid gives transmission losses up to 10 %.

When coupling microturbine units with absorption chillers and/ or heat exchangers for space heating and cooling duties, the duct work installation and operating performance, as well as the efficiency levels of the absorption chillers often have larger impacts on the total economic and efficiency benefits compared to the actual microturbine unit.

8.2 Waste gas niche strategy

Waste gas applications will be driven by size and number of waste gas sites, regulations on methane emissions, biogas demand in the transportation industry, and developments in reciprocating engine technology.

The capacity scale of microturbines will limit its penetration capability in all waste gas segments; landfills, sewage sites, farms and oil & gas fields. However, in some applications, the availability of waste gases varies in time and quality, which demands flexibility and easy set up that can be fulfilled by microturbines to greater extent relative reciprocating engines or large scale methods.

Regulations on current methane emissions will intensify in the future, especially in Europe, where the EU is currently trying to force all landfills to utilise large portion of the waste gases. The U.S. regulations will continue to vary heavily between the different states. Farm owners constituting methane emissions through digester gases, are already practicing methods to utilise the gas for heating duties at small scale on site, therefore that group need to acknowledge economic advantages with microturbine power and heat production in the role of becoming small scale suppliers of power.

Biogas demand from the transportation industry is much stronger compared to the average drivers for site owners to produce power and heat from their gases. The transportation industry demand will vary between different countries and regions. To be able to distribute biogas for further usage, the current methods and technologies indicate that economic feasibility can only be considered within a 10 mile radius of the waste gas site. Specific sites with suitable sizes and energy demands will in the future see economic as well as energy efficiency advantages in the alternative of producing heat and power on-site with and microturbine unit or a reciprocating engine unit.

Reciprocating engines running on waste biogases are much more established compared to microturbines. The main reciprocating engine actor in this niche, Jenbacher currently holds 2000 - 3000 installations running on waste gases, whilst microturbine units are still in demonstration projects with some feasibility and reliability issues yet to solve. However, when looking at low heat value methane waste gas, the microturbine products hold advantages in lower maintenance and more levelled efficiency ratios relative reciprocating engines. The barrier although, remains to be cost.

8.3 Summary of future strategies

Microturbine actors should focus on areas where their product can provide the highest value for the user, relative competing alternatives. These values are different for the CHP niche and the waste gas niche and therefore two separate strategies should be formulated. In general the waste gas niche holds greater value than the CHP niche; therefore a bigger focus and more resources should be invested on the waste gas niche compared to the CHP niche. When targeting the CHP niche the actors should focus on geographic areas where:

- Natural gas/ electricity price ratio are low.
- Gas infrastructure availability is high.
- Incentives and regulations favour small scale alternatives.
- State of grid infrastructure is pour.
- Availability and performance level of complementary components

When targeting the waste gas niche, the factors that need to be taken into account are:

- Size and number of waste gas sites
- Regulations on methane emissions
- Demand and price of biogas
- Developments in reciprocating engine technology

9 Conclusion

With a background of diverse and unfocused visions among actors promoting new small scale, on-site power and heat generating technology the purpose of the thesis got formed. The thesis purpose of *Analysing the networks and niches for microturbine technology in Europe and the U.S., and discuss future niche strategies* have been fulfilled through a review of the microturbine networks and niches, followed by an analysis of the networks and actor actions, ending up in niche management conclusions and a discussion of future niche strategies.

The review of the microturbine networks and niches answered the research questions of; What do the present microturbine networks look like, in terms of technological, institutional, user, and producer relational dimensions? How are networks and niches functioning and developing and what factors influence the development? The review highlights that regulatory forces favour large scale alternatives and combined heat and power alternatives in general. Energy institutions and MFOs are promoting reciprocating engines for general small scale heat and power generation, but vision microturbines as a promising alternative in waste utilisation applications. There is only one microturbine producer having and actively developing a diversified, established network. Other microturbine producers have small, volatile and narrowly focused networks. The main competition, reciprocating engine producers have well established and diversified networks, aiming at the same niches as microturbines. There are diversified “distributed generation” actors, such as General Electric, being present in all small scale, on-site niches with several alternative technologies.

The analysis of the networks highlights some general driving and blocking factors influencing the development of the microturbine networks and niches; the main blocking factors are found in utility rates and prices set by current energy utility providers, as well as volatility and general increase in natural gas prices. Another blocking force comes from interconnection and infrastructural issues for small scale units installed to support, replace or complement the current, centralized energy structure. Improvements and developments in fuel flexibility of established gas engines constitute a barrier for microturbine market penetration. The specific application opportunity of utilising waste biogases at sites such as landfills, sometimes see competition from the transportation industry, placing increased value on refining and utilising the waste biogases. In general, biogas waste providers, as well as high heat demanding industries in general are not informed on the values of microturbine systems.

The main external driving force for microturbines comes from social awareness and regulatory and energy institutional promotion of combined heat and power as a substitute to central power plants and on-site heat boilers. Although the combined heat and power visions promote large scale plants, there are several local acknowledgements of the values of small gas engines, microturbines, and future fuel cells. Another institutional drive is found in promotions, incentives, and programs of waste biogas utilisation in general, on site as well as connection of several sites to a central combined heat and power plant. One specific attribute driving on site power and heat supply for industrial sites are local and regional electricity price volatility, which is currently complicating industrial energy management.

The analysis of the networks and niches, focusing on actor visions, strategies and expectations answered the research questions of; what are the visions, expectations, and strategies of actors in the networks? From a niche management perspective, are microturbine actors using effective strategies? The analysis answered the research questions through the following conclusions:

- Producer networks are weak and diverse, with only one actor having extensive linkages in both distribution and development.
- Producer- institutional (state) linkages are strong in the U.S., but focus is mainly on R&D.
- User- producer linkages are weak, and most potential users need much education about benefits and values.
- Partnerships and information sharing organisations play a key role in spreading outcomes and insights to a wider community, which is an active practice in the U.S., but not in Europe.
- For most applications, microturbine producers need to ally with complementary technologies and system integrators, since the actual microturbine unit often is not the bottleneck for efficiency ratios.
- Regarding marketing and promotion activities, the initial main actor exaggerated product benefits and performance in the early 2000s, which gave an unbalance between expectations and actual potentials and benefits.

- Feedback from experiments is being shared only through information organisations or energy departments, indicating a lack of dialogue between microturbine producers and component, or complementary product suppliers.
- The three main microturbine producers, sharing the attribute of merely focusing on microturbine products, have been forced reactively to large adjustments in strategies and expectations, explained by too narrow views of their technologies in combination with individual marketing, distribution, and strategic plans, with a lack of collective partnerships, sharing forums and channels.
- Current voicing and shaping of expectations about microturbine as a technology is rather diverse and fuzzy. There is a need to voice expectations about benefits in small scale biogas waste applications, especially in the U.S. where biogas utilisation in general is lower compared to Europe.
- In order for microturbines to enlarge current niches, further user acknowledgements must take place. Current articulations and value acknowledgements are voiced by producers without potential users participating. Developments should integrate insights between producers and users, to shape more precise and accurate value proposals in the future.

The discussion of future niche strategies state that the niche of utilising waste biogases at landfills, sewage sites, farms, and oil and gas fields should be the primary target for microturbine technology. In this niche, the values of the technology have the greatest chance to get acknowledged by all actors, such as users, producers, and institutional and regulatory organisations. Furthermore, microturbines can get the highest protection against competition, constituted by reciprocating engines and large scale combined heat and power technologies.

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10.3 Interviews

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11 Appendix A – Interview formulas

11.1 Interview formula for DG companies

Small scale (<1 MW), power generation survey

- What was your initial motivation to align with small scale power generation?
    - Was the technology acquired or did emerge "in- house"?
- What expectations did the organization and the investors/ owners have during the first product commercialization?
    - How have the expectations changed during your time in small scale power generation?
    - What are your expectations for your technologies today in general?
    - What technology development priorities are you focusing on?
- Which attributes and values do you strive to articulate in your product/ service offerings?
- Have you formed or participated in any alliances aligned with small scale power generation?
    - Number of R&D alliances/ partnerships?
    - Number and type of marketing/ distribution/ production alliances/ partnerships?
    - In general, have you been an active initiator to partnership/ alliance formations?
- Do you see potentials of large scale/ low cost in your products and technologies?
- Do you receive any funding from state institutions?
- Would you say that your targeted users and customers are well informed and aware of potential benefits with small scale, on- site power generation?

- Which power generation technologies is your company focusing on, currently and in the past?
- Which are the key competing technologies, targeting the same markets and applications as your products?
- In general, what is the largest external barrier for your technologies?
    - Established technologies?
    - Energy companies?
    - States and regulatory institutions?
    - Other emerging technologies?
- What do you/ your company view as the largest barrier for interconnection (to the central grid) possibilities of your on site generation products?
- What key regulations and laws have influenced the utilization of your products and how?
    - For example; approval, installation fees and administrative hassles?
- How do your local regulative/ institutional/ legislative organs view your technology?
    - Do they vision a deregulated, distributed generation transformation of energy supply where your product is "central", or do they view your technology as a small niche alternative?
- Are you participating in any lobbying activities towards shaping local policies and visions?

11.2 Interview formula for institutions and MFOs

Description of organization

- Aims? Objectives?
- Resources? Financial sources?
- Participants/ alliances?
- DG projects/ programs? DG technologies?
- Microturbine/ FC hybrid projects/ programs?

Microturbine and FC hybrid visions

- How do you vision today's DG technologies, as part of a complement/ supplemental energy structure or a replacing energy structure?
- How do you vision microturbine technology in the energy structure? Key values?
    - Current key application areas? Future?
    - What market impact are you expecting for microturbines?
- How do you vision future FC hybrid technology in the energy structure?
    - Current key application areas? Future? Key values?
    - What market impact are you expecting for FC hybrids?

Niche strategy

- Who do you see as the main microturbine actors?
    - What strategies do they have? Key network linkages?
- Who do you see as the main FC hybrid actors?
    - What strategies do they have? Key network linkages?

Niche practices

- Can you describe any commercial microturbine CHP applications?
    - User drivers? Other drivers?
    - Outcomes? Results?
- Can you describe any commercial microturbine waste "utilization" applications, such as landfill, sewage, or gas field?
    - User drivers? Other drivers?
    - Outcomes? Results?
- Can you describe any FC hybrid projects/ demonstrations?
    - Status?

Barriers/ drivers

- What are the key barriers for microturbine technology currently?
- What are the key drivers for microturbine technology currently?
- What drivers/ barriers do FC hybrids face?

Microturbine actor evaluation

- Do you see any problems with microturbine producers' strategies?
    - Are the key microturbine actors aiming at the "right" niches?
    - Do microturbine actors have the appropriate expectations?
- Do you see any problems with FC hybrid producers' strategies?

12 Appendix B – Gas & electricity prices

Table B.1 Electricity prices for industrial customers in the world. Source: Energy Information Administration (A)

Electricity Prices for Industry			(U.S. Dollars per Kilowatthour)						
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Argentina	NA	NA	NA	NA	NA	NA	0,033	NA	NA
Australia	0,047	0,050	0,045	0,044	0,049	0,054	0,061	NA	NA
Austria	0,078	0,057	0,038	NA	NA	NA	0,096	0,102	0,109
Barbados	NA	NA	NA	NA	NA	NA	0,197	NA	NA
Belgium	0,061	0,056	0,048	NA	NA	NA	NA	NA	NA
Bolivia	NA	NA	NA	NA	NA	NA	0,051	NA	NA
Brazil	NA	NA	NA	NA	NA	NA	0,047	NA	NA
Canada	0,038	0,038	0,039	0,042	0,039	0,047	0,049	NA	NA
Chile	NA	NA	NA	NA	NA	NA	0,057	NA	NA
China	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chinese Taipei (Taiwan)	0,058	0,059	0,061	0,056	0,053	0,053	0,055	0,057	0,056
Colombia	NA	NA	NA	NA	NA	NA	0,081	NA	NA
Costa Rica	NA	NA	NA	NA	NA	NA	0,069	NA	NA
Cuba	NA	NA	NA	NA	NA	NA	0,078	NA	NA
Cyprus	0,072	0,074	0,087	0,079	0,082	0,104	0,107	0,125	0,167
Czech Republic	0,052	0,048	0,043	0,043	0,049	0,056	0,066	0,081	0,094
Denmark	0,068	0,066	0,058	0,060	0,070	0,092	0,096	NA	NA
Dominican Republic	NA	NA	NA	NA	NA	NA	0,120	NA	NA
Ecuador	NA	NA	NA	NA	NA	NA	0,089	NA	NA
El Salvador	NA	NA	NA	NA	NA	NA	0,120	NA	NA
Finland	0,050	0,046	0,039	0,038	0,043	0,065	0,072	0,070	NA
France	0,047	0,044	0,036	0,035	0,037	0,045	0,050	0,050	0,051
Germany	0,067	0,057	0,041	0,044	0,049	0,065	0,077	0,084	NA
Greece	0,050	0,050	0,042	0,043	0,046	0,056	0,063	0,067	NA
Grenada	NA	NA	NA	NA	NA	NA	0,188	NA	NA
Guatemala	NA	NA	NA	NA	NA	NA	0,116	NA	NA
Guyana	NA	NA	NA	NA	NA	NA	0,078	NA	NA
Haiti	NA	NA	NA	NA	NA	NA	0,085	NA	NA
Honduras	NA	NA	NA	NA	NA	NA	0,035	NA	NA
Hungary	0,056	0,055	0,049	0,051	0,059	0,078	0,093	0,096	0,105
India	0,082	0,081	0,080	NA	NA	NA	NA	NA	NA
Indonesia	0,025	0,029	0,040	NA	NA	NA	NA	NA	NA
Ireland	0,060	0,057	0,049	0,060	0,075	0,094	0,096	0,099	0,122
Italy	0,095	0,086	0,089	0,107	0,113	0,147	0,162	0,174	NA
Jamaica	NA	NA	NA	NA	NA	NA	0,130	NA	NA
Japan	0,128	0,143	0,143	0,127	0,115	0,122	0,127	0,121	NA
Kazakhstan	0,030	0,018	0,013	0,014	0,014	0,015	0,018	0,020	0,024
Korea, South	0,039	0,046	0,052	0,048	0,047	0,051	0,053	0,059	0,065
Mexico	0,038	0,042	0,051	0,053	0,056	0,063	0,078	0,088	0,099
Netherlands	0,062	0,061	0,057	0,059	C	C	C	C	C
New Zealand	0,038	0,033	0,028	0,028	0,033	0,046	0,051	0,055	0,053

Nicaragua	NA	NA	NA	NA	NA	NA	0,128	NA	NA
Norway	NA	NA	0,019	0,025	0,031	0,046	0,043	0,043	0,055
Panama	NA	NA	NA	NA	NA	NA	0,099	NA	NA
Paraguay	NA	NA	NA	NA	NA	NA	0,039	NA	NA
Peru	NA	NA	NA	NA	NA	NA	0,079	NA	NA
Poland	0,037	0,037	0,037	0,045	0,049	0,056	0,060	0,070	0,073
Portugal	0,090	0,078	0,067	0,066	0,068	0,083	0,093	0,098	0,110
Romania	0,045	0,037	0,044	0,042	0,053	0,067	0,071	0,096	NA
Russia	NA	NA	NA	0,021	0,024	0,029	NA	NA	NA
Slovak Republic (Slovakia)	0,049	0,041	0,042	0,043	0,047	0,070	0,083	0,086	0,098
South Africa	0,020	0,017	0,017	0,013	0,012	0,019	NA	NA	NA
Spain	0,057	0,049	0,043	0,041	0,048	0,054	0,060	0,083	0,091
Suriname	NA	NA	NA	NA	NA	NA	0,123	NA	NA
Sweden	NA	NA	NA	NA	NA	NA	NA	NA	NA
Switzerland	0,101	0,090	0,069	0,069	0,073	0,081	0,085	0,083	0,080
Thailand	0,053	0,054	0,057	0,056	0,057	0,060	0,063	NA	NA
Trinidad and Tobago	NA	NA	NA	NA	NA	NA	0,037	NA	NA
Turkey	0,075	0,079	0,080	0,079	0,094	0,099	0,100	0,107	0,100
United Kingdom	0,065	0,064	0,055	0,051	0,052	0,055	0,067	0,087	NA
United States	0,045	0,044	0,046	0,051	0,049	0,051	0,053	0,057	0,061
Uruguay	NA	NA	NA	NA	NA	NA	0,055	NA	NA
Venezuela	NA	NA	NA	NA	NA	NA	0,032	NA	NA

Table B.2 Natural gas prices for industrial customers in the world. Source: Energy Information Administration (B)

Natural Gas Prices for Electricity Generation (U.S. Dollars per 10^7 Kilocalories - Gross Calorific Value)

Country	1998	1999	2000	2001	2002	2003	2004	2005	2006
Argentina	NA	NA	NA	NA	NA	NA	NA	NA	NA
Austria	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barbados	NA	NA	NA	NA	NA	NA	NA	NA	NA
Belgium	C	C	C	C	C	C	C	C	C
Bolivia	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brazil	NA	NA	NA	NA	NA	NA	NA	NA	NA
Canada	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chile	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chinese Taipei (Taiwan)	218,90	201,67	246,17	244,70	252,10	258,57	281,03	329,14	345,22
Colombia	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cuba	NA	NA	NA	NA	NA	NA	NA	NA	NA
Czech Republic	159,8	142,8	146,2	151,7	168,7	197,8	NA	NA	NA
Denmark	C	C	C	C	C	C	C	C	C
Finland	119,9	107,7	113,2	109,0	109,0	136,2	145,6	165,4	223,0
France	NA	NA	NA	NA	NA	NA	NA	NA	NA
Germany	147,3	139,4	153,4	NA	NA	NA	NA	NA	NA
Greece	C	C	C	C	C	C	C	C	C
Hungary	124,9	134,4	99,9	155,5	189,2	216,8	251,4	285,9	391,9

Indonesia	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ireland	103,7	101,1	99,1	127,0	150,6	168,3	NA	NA	NA
Italy	C	C	C	C	C	C	C	C	C
Japan	NA	NA	NA	NA	NA	NA	NA	NA	NA
Kazakhstan	NA	NA	NA	NA	NA	NA	NA	NA	NA
Korea, South	NA	NA	NA	NA	NA	NA	292,9	367,0	477,0
Luxembourg	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mexico	81,4	88,3	150,0	163,4	122,7	205,3	275,0	363,8	339,6
Netherlands	121,7	NA	NA	NA	NA	NA	NA	NA	NA
New Zealand	C	C	C	C	C	C	C	C	C
Norway	NA	NA	NA	NA	NA	NA	NA	NA	NA
Peru	NA	NA	NA	NA	NA	NA	NA	NA	NA
Poland	NA	NA	NA	NA	NA	NA	NA	NA	NA
Portugal	NA	NA	NA	NA	NA	194,1	242,0	291,8	355,1
Romania	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russia	NA	NA	NA	20,02	23,74	31,59	NA	NA	NA
Slovak Republic (Slovakia)	124,6	106,6	101,4	106,3	131,8	220,6	243,0	287,4	378,9
South Africa	- -	- -	- -	- -	- -	- -	- -	- -	- -
Spain	128,2	119,8	165,0	NA	NA	NA	NA	NA	NA
Switzerland	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thailand	NA	NA	NA	NA	NA	NA	NA	NA	NA
Turkey	165,6	158,3	168,5	197,1	214,4	222,9	227,9	301,5	349,3
United Kingdom	126,3	114,7	104,0	111,1	106,2	129,6	162,1	214,6	NA
United States	94,3	102,1	172,9	176,3	140,5	213,1	235,7	325,9	281,8
Venezuela	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table B.3 Electricity price for industrial customers in Europe. Source: *Eurostat (A)*

Electricity prices charged to final industrial consumers. Prices are given in Euro (without taxes) per kWh corresponding to prices applicable on 1 January each year.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EU (27 countries)	:	:	:	:	:	:	:	:	:	0.0672	0.0752	0.0822
EU (25 countries)	:	:	:	:	:	:	:	:	0.0623	0.0672	0.0755	0.0825
EU (15 countries)	0,0689	0,0679	0,0663	0,0636	0,0625	0,0644	0,062	0,0648	0,0634	0,0682	0,0766	0,0839
Euro area	:	:	:	:	:	:	:	:	:	:	:	:
Euro area (12 countries)	:	:	:	:	:	:	:	:	0.0667	0.0713	0.0774	0.0839
Belgium	0.0775	0.0746	0.0746	0.0739	0.0734	0.0752	0.0760	0.0764	0.0755	0.0695	0.0830	0.0880
Bulgaria	:	:	:	:	:	:	:	:	0.0409	0.0429	0.0460	0.0465
Czech Republic	:	:	:	:	0.0467	0.0473	0.0518	0.0499	0.0492	0.0601	0.0731	0.0783
Denmark	0.0473	0.0467	0.0512	0.0485	0.0504	0.0558	0.0639	0.0697	0.0631	0.0646	0.0724	0.0638
Germany	0.0906	0.0845	0.0830	0.0791	0.0675	0.0669	0.0685	0.0697	0.0740	0.0780	0.0871	0.0946
Estonia	:	:	:	:	:	:	0.0465	0.0455	0.0455	0.0472	0.0511	0.0534
Ireland	0.0615	0.0691	0.0662	0.0662	0.0662	0.0662	0.0768	0.0762	0.0787	0.0896	0.0998	0.1125
Greece	0.0571	0.0580	0.0588	0.0583	0.0571	0.0571	0.0590	0.0614	0.0630	0.0645	0.0668	0.0698
Spain	0.0756	0.0703	0.0620	0.0624	0.0636	0.0550	0.0520	0.0528	0.0538	0.0686	0.0721	0.0810
France	0.0650	0.0635	0.0596	0.0583	0.0567	0.0557	0.0562	0.0529	0.0533	0.0533	0.0533	0.0541
Italy	0.0638	0.0713	0.0721	0.0646	0.0693	0.0919	0.0776	0.0826	0.0790	0.0843	0.0934	0.1027
Cyprus	:	:	:	0.0602	0.0878	0.1050	0.0903	0.0962	0.0818	0.0787	0.1114	0.1048
Latvia	:	:	:	:	:	:	:	:	0.0431	0.0409	0.0409	0.0443
Lithuania	:	:	:	:	:	:	:	0.0550	0.0513	0.0498	0.0498	0.0548
Luxembourg	0.0747	0.0737	0.0725	0.0736	0.0709	0.0632	0.0645	0.0675	0.0690	0.0752	0.0845	0.0963
Hungary	0.0341	0.0456	0.0500	0.0506	0.0510	0.0520	0.0595	0.0604	0.0654	0.0701	0.0753	0.0812
Malta	0.0578	0.0596	0.0650	0.0635	0.0675	0.0683	0.0698	0.0636	0.0620	0.0706	0.0711	0.0897
Netherlands	0.0608	0.0570	0.0566	0.0576	0.0669	0.0640	:	:	:	0.0806	0.0855	0.0920
Austria	0.0814	0.0765	0.0755	0.0763	:	:	:	:	0.0553	0.0621	0.0653	0.0786
Poland	:	:	:	:	:	0.0492	0.0585	0.0566	0.0446	0.0506	0.0543	0.0541
Portugal	0.0756	0.0749	0.0712	0.0646	0.0643	0.0651	0.0665	0.0673	0.0684	0.0713	0.0817	0.0860
Romania	:	:	:	:	:	:	:	0.0405	0.0468	0.0769	0.0773	0.0842
Slovenia	0.0533	0.0565	0.0668	0.0679	0.0604	0.0603	0.0599	0.0582	0.0609	0.0611	0.0651	0.0750
Slovakia	:	:	:	:	:	:	:	:	0.0683	0.0703	0.0773	0.0932
Finland	0.0481	0.0414	0.0401	0.0389	0.0377	0.0372	0.0401	0.0566	0.0543	0.0527	0.0517	0.0542
Sweden	0.0413	0.0430	0.0392	0.0348	0.0375	0.0313	0.0310	0.0666	0.0520	0.0462	0.0587	0.0626
United Kingdom	0.0544	0.0604	0.0627	0.0619	0.0664	0.0661	0.0614	0.0539	0.0478	0.0570	0.0799	0.0950
Croatia	:	:	:	:	:	:	:	:	:	0.0556	0.0596	0.0597
Turkey	:	:	:	:	:	:	:	:	:	:	:	:
Iceland	:	:	:	:	:	:	:	:	:	:	:	:
Norway	0.0322	0.0442	0.0375	0.0344	0.0356	0.0344	0.0433	0.0560	0.0542	0.0528	0.0520	0.0724

Table B.4 Natural gas prices for industrial customers in Europe. Source: *Eurostat (B)*

Natural gas prices charged to final industrial consumers. Prices are given in Euro (without taxes) per GJ corresponding to prices applicable on 1 January each year.												
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EU (27 countries)	:	:	:	:	:	:	:	:	:	6.01	8.11	8.89
EU (25 countries)	:	:	:	:	:	:	:	:	5.35	6.13	8.22	8.99
EU (15 countries)	3,6	4,03	4,03	3,49	4,22	6,12	5,75	5,56	5,44	6,23	8,34	9,14
Euro area	:	:	:	:	:	:	:	:	:	:	:	:
Euro area (12 countries)	:	:	:	:	:	:	:	:	5.55	6.27	8.25	8.94
Belgium	3.97	4.16	4.25	3.46	4.42	6.32	5.25	5.42	5.28	5.27	7.06	6.89
Bulgaria	:	:	:	:	:	:	:	:	3.50	3.78	4.50	5.22
Czech Republic	:	:	:	:	3.01	3.88	4.68	4.14	4.20	5.11	7.34	6.56
Denmark	3.42	4.03	3.59	2.65	4.59	5.99	4.49	5.26	4.61	6.01	6.17	5.77
Germany	4.41	4.96	4.98	4.21	4.78	7.76	7.28	6.73	6.39	7.76	10.47	12.15
Estonia	:	:	:	:	:	:	:	2.91	2.91	2.75	2.84	3.69
Ireland	2.93	3.83	2.96	3.09	3.59	4.65	4.88	4.94	:	:	:	:
Greece	:	:	:	:	:	:	:	:	:	:	:	:
Spain	3.14	3.73	3.67	2.84	4.05	5.54	4.34	4.81	4.41	4.68	7.24	7.07
France	3.39	3.58	3.70	3.39	4.29	5.94	4.93	5.46	5.16	6.22	8.06	7.63
Italy	3.58	4.42	4.23	3.48	4.14	6.58	5.87	5.38	5.60	6.09	7.04	8.46
Cyprus	:	:	:	:	:	:	:	:	:	:	:	:
Latvia	:	:	:	:	:	:	:	:	3.47	3.48	4.05	5.29
Lithuania	:	:	:	:	:	:	:	4.21	3.83	3.61	4.45	6.02
Luxemboburg	4.86	5.01	5.03	4.69	4.94	6.89	5.90	6.17	5.94	6.95	9.01	9.85
Hungary	2.25	2.88	3.30	2.91	2.74	4.09	4.91	5.20	5.41	5.81	7.95	9.48
Malta	:	:	:	:	:	:	:	:	:	:	:	:
Netherlands	3.38	3.72	3.72	3.09	4.06	5.40	:	:	5.89	6.39	8.14	8.40
Austria	4.84	4.59	4.23	4.23	3.53	5.53	5.62	5.46	5.57	6.14	8.34	8.91
Poland	:	:	:	:	:	5.60	6.15	5.59	4.26	5.30	6.77	7.54
Portugal	:	:	:	:	:	6.88	6.26	6.39	5.68	6.03	7.63	7.76
Romania	:	:	:	:	:	:	:	2.29	2.83	3.68	6.23	7.32
Slovenia	3.47	3.45	5.36	3.89	4.78	7.66	6.41	4.46	4.00	5.10	7.17	7.33
Slovakia	:	:	:	:	:	:	:	:	5.33	5.08	7.65	8.00
Finland	3.15	3.98	3.62	2.51	4.53	7.08	6.18	6.37	6.25	6.43	7.32	7.61
Sweden	:	4.86	4.59	3.37	5.07	9.53	5.93	6.80	6.40	8.08	11.15	11.06
United Kingdom	2.60	2.89	3.18	3.15	3.53	4.01	5.42	4.87	4.70	5.81	8.92	10.55
Croatia	:	:	:	:	:	:	:	:	:	6.42	6.57	6.58

Table B.5 Comparison between natural gas prices and electricity prices in Europe and the U.S.

Electricity price for industrial customers (€/kWh). Exchange rate of 3/9 2007: 1$=0,73€												
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EU-15	0,0689	0,0679	0,0663	0,0636	0,0625	0,0644	0,062	0,0648	0,0634	0,0682	0,0766	0,0839
U.S.			0,032704	0,032339	0,033872	0,036865	0,035624	0,037303	0,038325	0,041829	0,044457	
Gas price for industrial customers (€/kWh). Exchange rate of 3/9 2007: 1$=0,73€, 10^7 kcal=11630 kWh, 1GJ=277,8 kWh												
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EU-15	0,012958963	0,014507	0,014506839	0,012563	0,015191	0,02203	0,020698	0,020014	0,019582	0,022426	0,030022	0,032901
U.S.			0,005920972	0,006408	0,01085	0,011067	0,008818	0,013377	0,014796	0,020456	0,017686	
Gas price/Electricity price												
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
EU-15	0,188083647	0,21365	0,218806025	0,197531	0,243053	0,342084	0,333844	0,308864	0,308871	0,32883	0,391927	0,39215
U.S.			0,181047322	0,198153	0,320329	0,300197	0,247523	0,358603	0,386058	0,489034	0,397823	

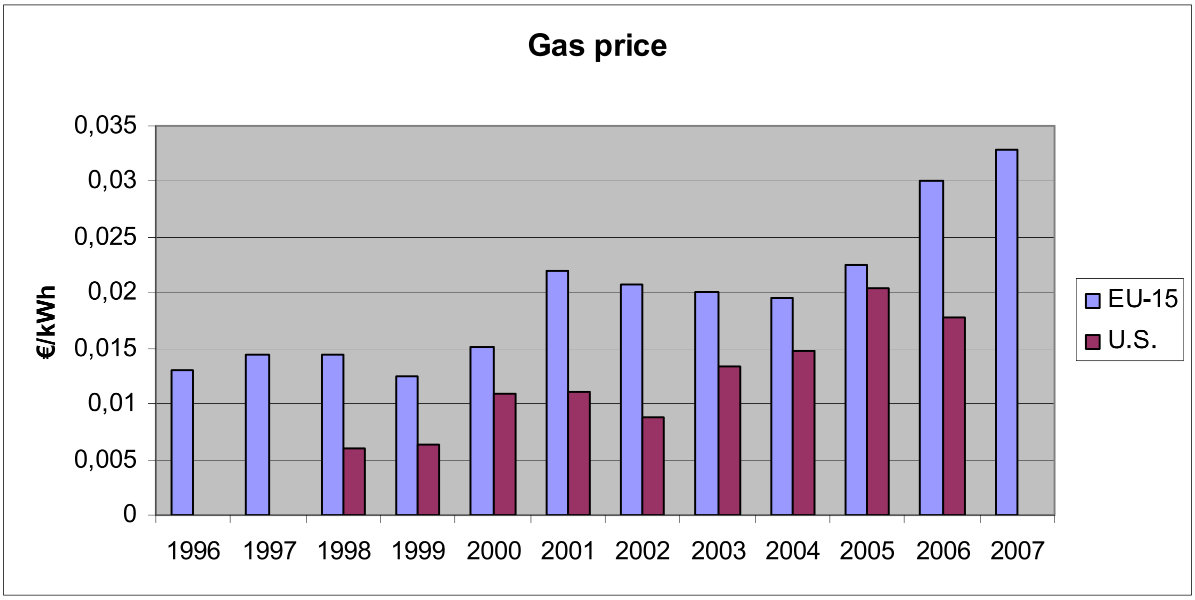

Figure B.1 Gas prices in EU-15 and the U.S.

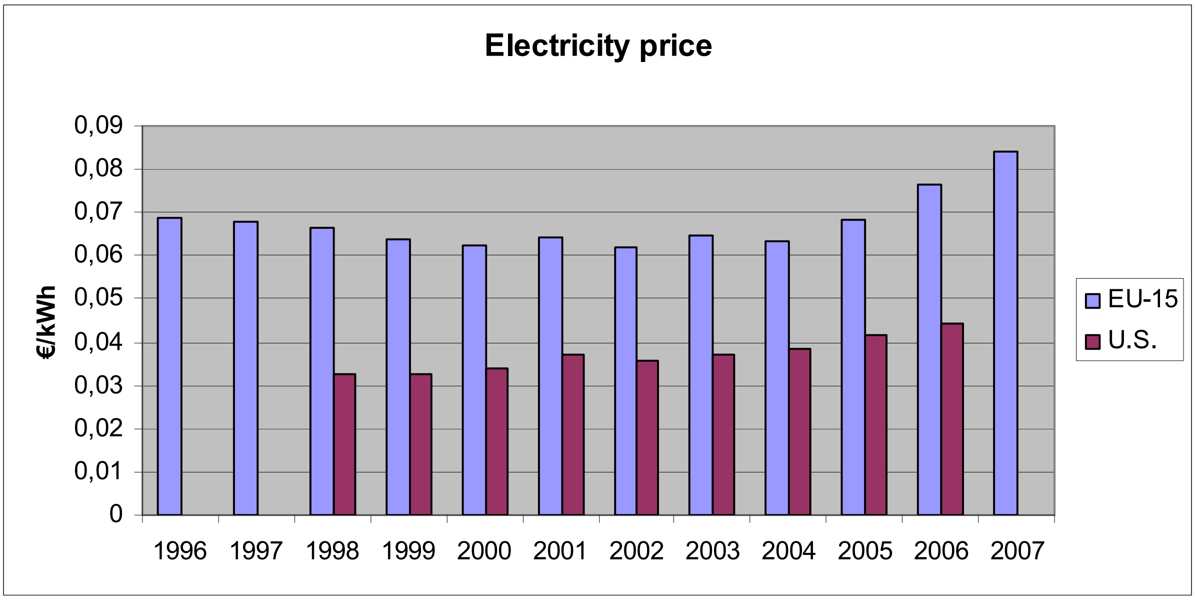

Figure B.2 Electricity prices in EU-15 and the U.S.

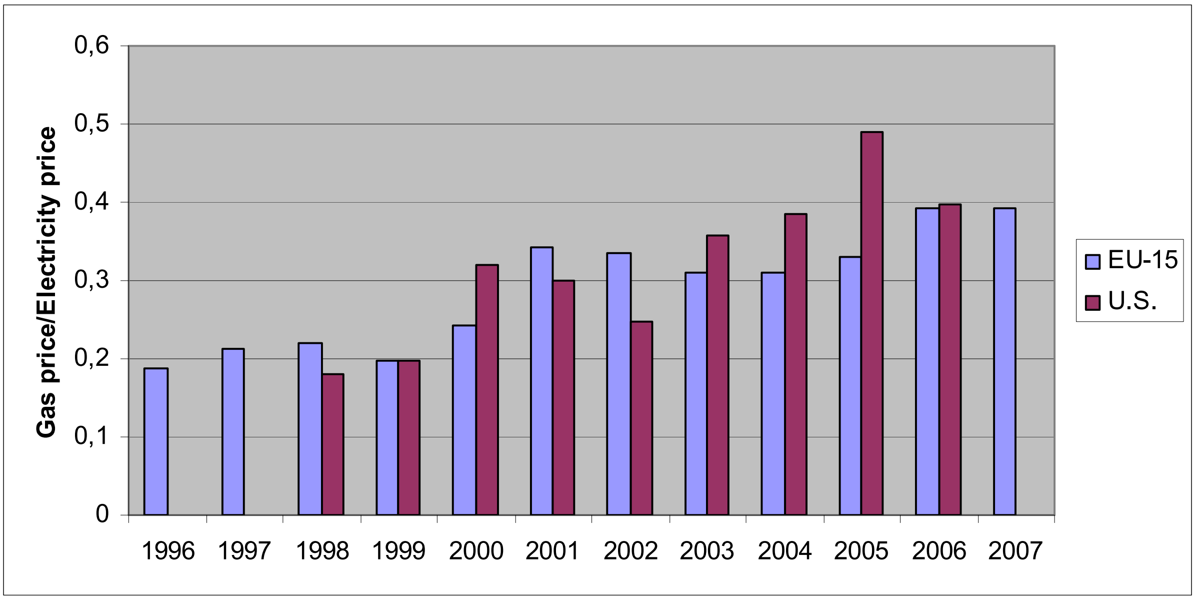

Figure B.3 Gas price/electricity price ratio in EU-15 and the U.S.

Table B.6 Electricity and gas prices for households in Europe. Source: Goerten & Clement 2007a & b

All prices are for households in jan 2007 with annual consumption of 3500 kWh/ 83,7 GJ (prices include all taxes) 1 GJ = 277,8 kWh				
Country	Electricity prices in €/100 kWh	Gas prices converted into €/100 kWh	Gas price/Electricity price	
EU-27	15,28	5,38	0,352094241	
Belgium	15,81	4,64	0,293485136	
Bulgaria	6,58	3,17	0,481762918	
Czech rep.	10,67	3,4	0,318650422	
Denmark	25,8	11,11	0,430620155	
Germany	19,49	6,64	0,340687532	
Estonia	7,5	2,12	0,282666667	
Ireland	16,62	6,02	0,3622142	
Greece	7,2	N/A	N/A	
Spain	12,25	5,12	0,417959184	
France	12,11	4,85	0,400495458	
Italy	23,29	6,6	0,283383426	
Cyprus	13,72	N/A	N/A	
Latvia	6,86	2,69	0,39212828	
Lithuania	7,77	2,54	0,326898327	
Luxembourg	16,84	4,15	0,246437055	
Hungary	12,22	2,58	0,211129296	
Malta	9,86	N/A	N/A	
Netherlands	21,8	6,63	0,30412844	
Austria	15,45	5,76	0,372815534	
Poland	11,84	3,85	0,325168919	
Portugal	15	5	0,333333333	
Romania	10,18	3,26	0,320235756	
Slovenia	10,64	4,99	0,468984962	
Slovakia	15,37	4,11	0,267404034	
Finland	11,6	N/A	N/A	
Sweden	17,14	9,57	0,558343057	
United Kingdom	13,23	4,25	0,321239607	
Croatia	9,23	2,95	0,319609967	
Norway	18,55	N/A	N/A	

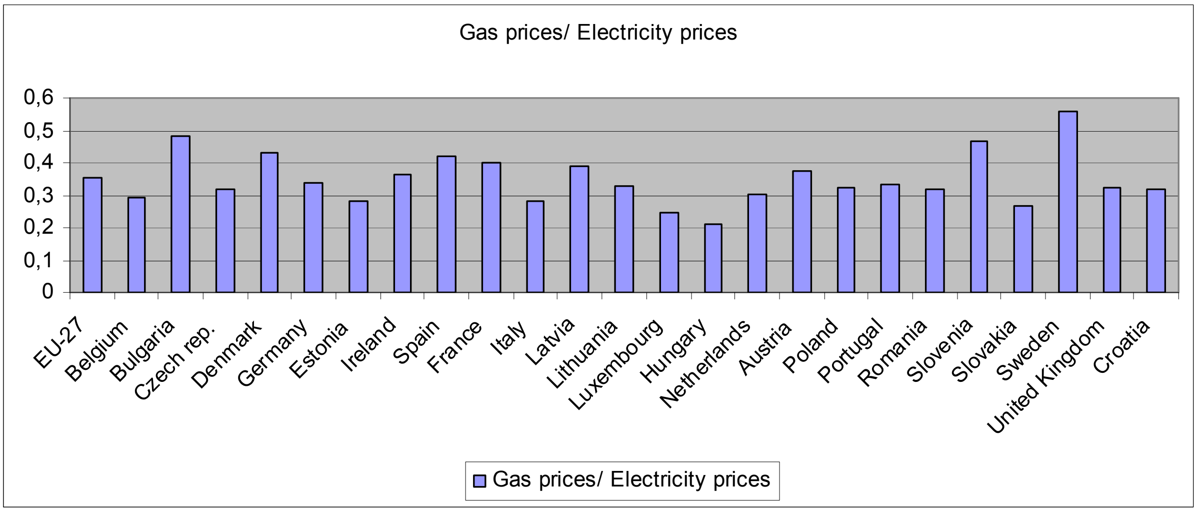

Figure B.4 Gas prices/electricity prices for households in Europe.

13 Appendix C – CHP data

Table C.1 Capital costs and efficiencies for different CHP installations. Source: Advanced microturbine system: market assessment 2003

Type	Size (MW)	Installed Cost (USD/kW)	Electrical Efficiency	Overall Efficiency
Micro-CHP (Stirling Engine)	< 0.015	2 700	15-25%	85-95%
Microturbine	0.1	1 970	28.7%	59%
Engine	0.1	1 380	28.1%	75%
Fuel Cell	0.2	3 764	36.0%	73%
Engine	0.8	975	30.9%	65%
Engine	3	850	33.6%	62%
Turbine	1	1 600	21.9%	72%
Turbine	5	1 075	27.6%	73%
Turbine	10	965	29.0%	74%
Turbine	25	770	34.3%	78%
Turbine	40	700	37.0%	78%

Table C.2 Small existing CHP installations in the industrial sector in the U.S. Source: Advanced microturbine system: market assessment 2003

Category	Active Sites <2 MW	Description
Food and Kindred Products	54	Wide range of food industries, especially dairy, canning, frozen fruits and vegetables
Chemicals and Allied Products	30	Higher value, small production chemicals
Lumber and Wood Products	24	Many applications within the industry
Fabricated Metal Products	23	Tools, stampings, electroplating, and other small parts
Paper and Allied Products	19	Variety of paper and paperboard applications
Oil and Gas Extraction	18	Oil and gas field applications
Misc. Manf. Industries	17	Not defined by use
Agricultural Production -Crops	11	High value agricultural products and greenhouse operations
Industrial Machinery and Equipment	11	Widespread
Primary Metal Industries	8	Small production operations
Other	51	Furniture, refining, clay products, textile mills, plastics, product fabrication industries
Total	266	

Table C.3 Small existing CHP installations in the commercial sector in the U.S. Source: Advanced microturbine system: market assessment 2003

Category	Active Sites <2 MW	Description
Health Services	169	Smaller general hospitals, nursing homes, and specialty clinics
Educational Services	156	Secondary schools and some smaller colleges and technical schools
Real Estate	123	Mostly apartment buildings with some nonresidential buildings included
Hotels, Rooming Houses, etc.	82	Small hotels and motels
Personal Services	77	Power laundries, coin-op laundries, linen supply, industrial laundries
Amusement and Recreational Services	76	Health clubs, sport clubs, water parks
Private Households	34	Use not defined
Electric, Gas, and Sanitary Services	31	Natural gas, water, sewer, and refuse
Eating and Drinking Places	13	Full service and fast food restaurants
Exec., Leg., and General Government	13	Use not defined, probably office buildings
Food Stores	11	Grocery stores
Social Services	10	Use not defined, probably office buildings
Miscellaneous Services	10	Use not defined
Justice, Public Order, and Safety	9	Courthouses and prisons
Other	62	Retail and wholesale trade, warehouses, offices, automotive dealers, transportation and arboreta (probably greenhouse)
C&I Total	876	

Table C.4 Fuel used to generate electricity and heat in CHP installations in the UK. Source: Department for Business, Enterprise & Regulatory Reform

6.2 Fuel used to generate electricity and heat in CHP installations

GWh

	1998	1999	2000	2001	2002	2003	2004	2005	2006
Fuel used to generate electricity *(1)*									
Coal *(2)*	3 343r	2 248r	1 372r	2 261r	2 152r	2 221r	1 719r	1 582r	1 507
Fuel oil	4 055r	4 077r	2 779r	2 589r	2 009r	1 832r	1 888r	1 617r	1 496
Natural gas	22 847r	27 059r	37 529r	35 107r	39 543r	40 922r	44 255r	47 677r	45 687
Renewable fuels *(3)*	1 081r	1 181r	1 037r	1 070r	1 078r	1 198r	1 268r	1 420r	1 719
Other fuels *(4)*	6 872r	6 494r	7 570r	6 779r	7 048r	6 552r	9 290r	10 435r	10 611
Total all fuels	**38 197r**	**41 059r**	**50 288r**	**47 806r**	**51 830r**	**52 725r**	**58 420r**	**62 731r**	**61 020**
Fuel used to generate heat									
Coal *(2)*	9 552r	6 575r	3 391r	4 371r	4 308r	4 222r	3 070r	2 844r	2 768
Fuel oil	8 628r	8 467r	3 050r	5 046r	3 012r	2 587r	2 763r	2 150r	1 944
Natural gas	31 199r	31 087r	37 488r	38 369r	41 142r	40 159r	40 789r	41 323r	39 201
Renewable fuels *(3)*	977r	1 044r	1 074r	1 083r	1 176r	1 412r	1 424r	1 440r	1 283
Other fuels *(4)*	12 337r	12 332r	11 562r	13 256r	11 795r	12 572r	14 294r	14 859r	14 373
Total all fuels	**62 693r**	**59 504r**	**56 564r**	**62 125r**	**61 433r**	**60 952r**	**62 339r**	**62 616r**	**59 569**
Overall fuel use									
Coal *(2)*	12 895r	8 823r	4 763r	6 631r	6 459r	6 443r	4 788r	4 426r	4 275
Fuel oil	12 683r	12 544r	5 829r	7 635r	5 021r	4 419r	4 651r	3 767r	3 440
Natural gas	54 045r	58 146r	75 017r	73 476r	80 685r	81 081r	85 043r	88 999r	84 888
Renewable fuels *(3)*	2 057r	2 225r	2 111r	2 154r	2 254r	2 610r	2 692r	2 860r	3 003
Other fuels *(4)*	19 210r	18 826r	19 132r	20 035r	18 843r	19 124r	23 584r	25 294r	24 983
Total all fuels	**100 890r**	**100 564r**	**106 852r**	**109 931r**	**113 263r**	**113 676r**	**120 759r**	**125 347r**	**120 589**

(1) See paragraphs 6.34 to 6.36 for an explanation of the method used to allocate fuel use between heat generation and electricity generation.
(2) Includes coke and semi-coke.
(3) Renewable fuels include: sewage gas; other biogases; municipal waste and refuse derived fuels.
(4) Other fuels include: process by-products, coke oven gas, blast furnace gas, gas oil and uranium.

14 Appendix D – Waste gas fuel data

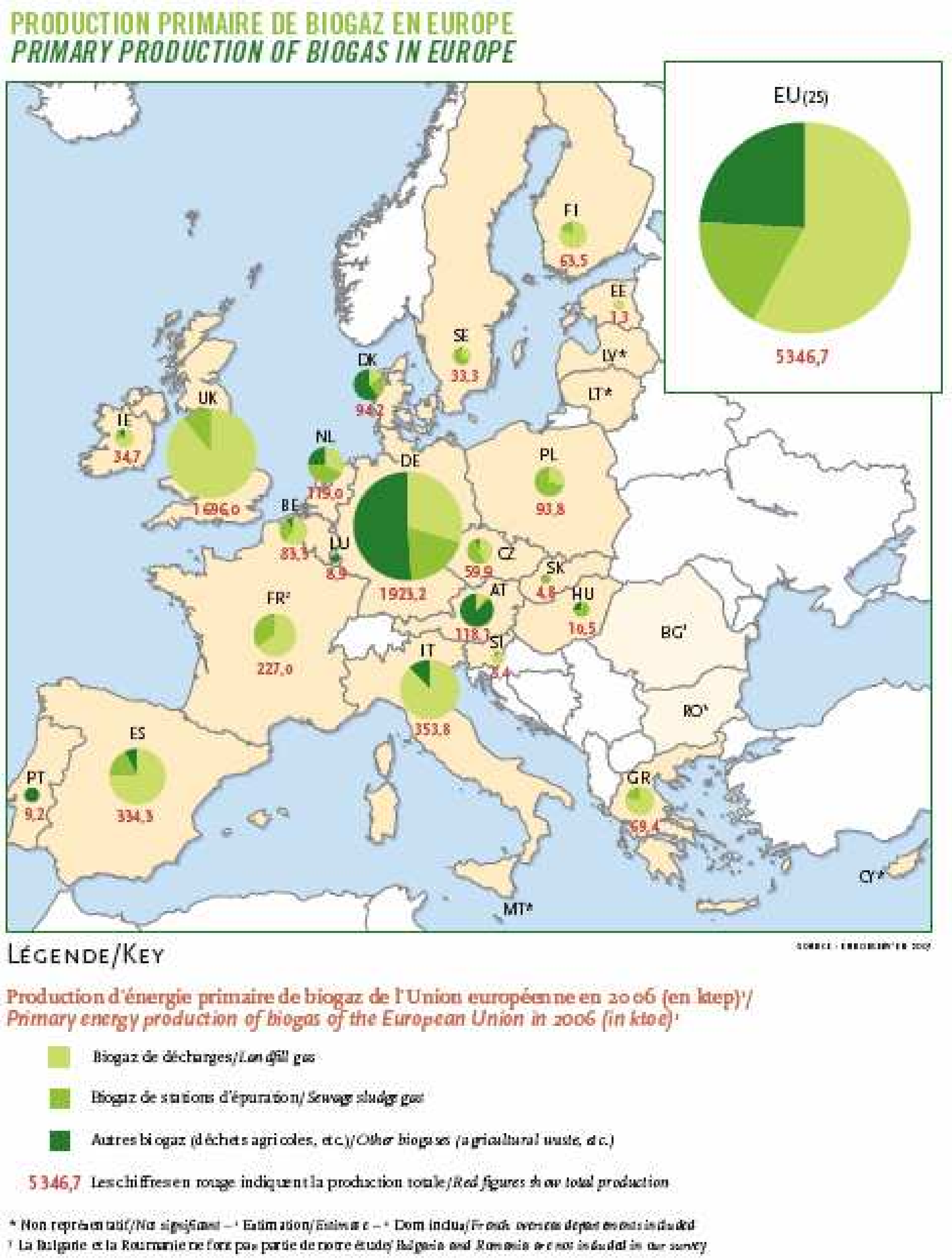

Figure D.1 Production of biogas in Europe. Source: Biogas Barometer 2007

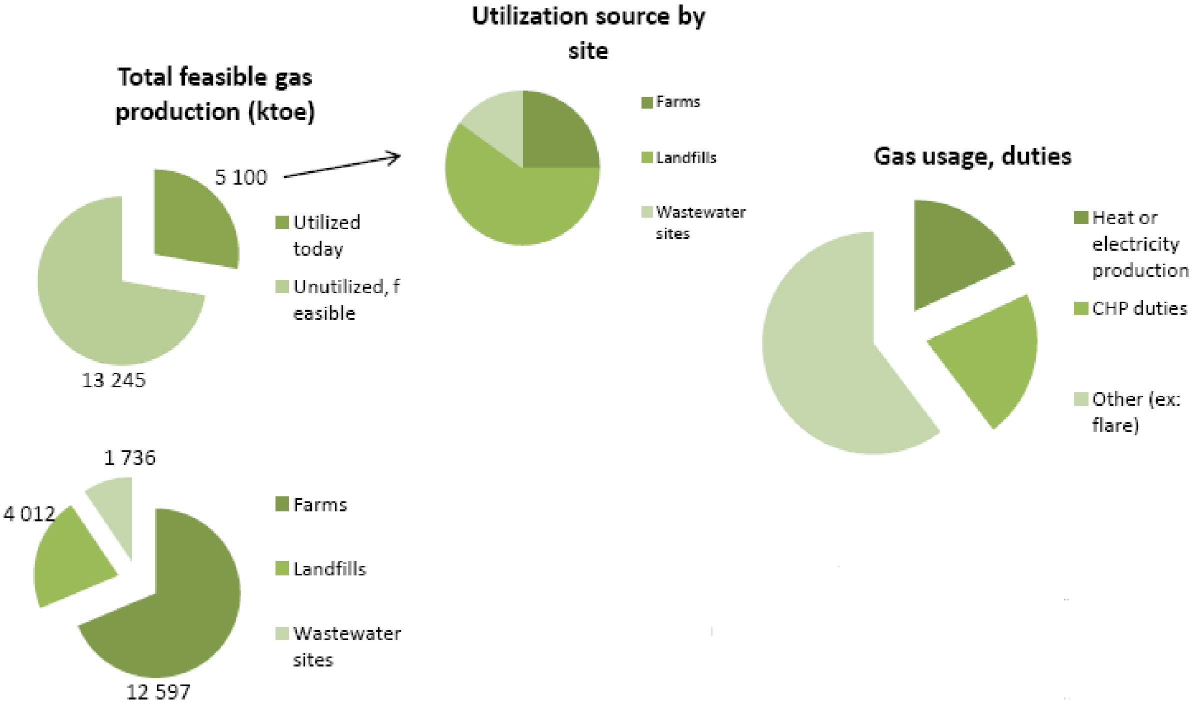

Figure D.2 Biogas production and emissions in EU-15 in 2006. Source: EurObserver 2007

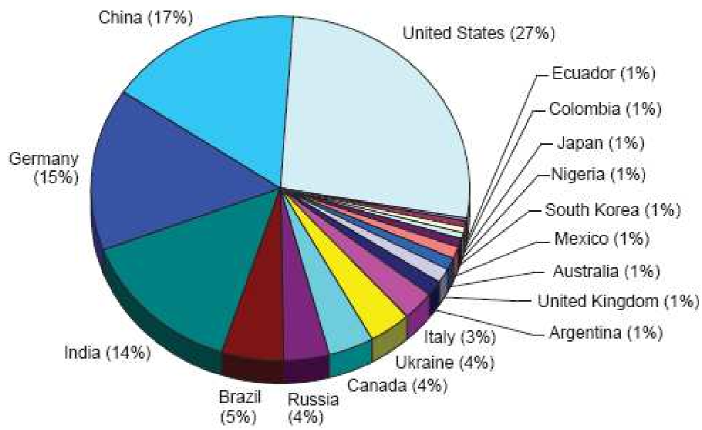

Figure D.3 Global methane emissions from livestock manure management in 2005. Source: Methane to Markets Partnership

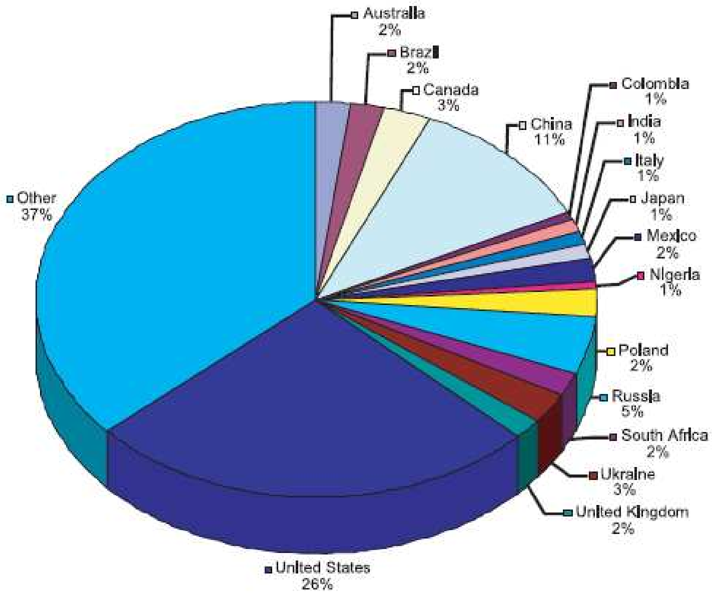

Figure D.4 Global methane emissions from landfills in 2000. Source: Methane to Markets Partnership

Table D.1 Global methane emissions from gas and oil infrastructure. Source: Methane to Markets Partnership

Figure 1: International methane emissions from natural gas and oil infrastructure.

Country	Methane Emissions (MMTCE)		
	1990	2000	2010 (projected)
Russia	91.6	69.1	74.7
United States	40.3	37.8	39.6
Ukraine	19.6	16.4	10.8
Venezuela	11.0	14.3	18.6
Uzbekistan	7.4	9.2	11.7
India	3.5	6.7	15.0
Canada	4.7	6.4	6.5
Mexico	3.0	4.2	6.0
Argentina	2.2	3.7	8.3
Thailand	0.8	2.3	4.3
China	0.2	0.4	1.3

Table D.2 Microturbine vs. Reciprocating engine. Source: Lombard 2005

Demonstration project: Microturbine vs. Reciprocating engine

A demonstration project performed by Verdesis, a European distribution partner to Capstone, with support from the European Energy Commission, started in the beginning of 2000. The aim of the project was to compare a Capstone 30 kW microturbine with a reciprocating engine and also investigate the opportunities for the microturbine to run on waste water treatment and landfill gas. Some lessons learned from the comparison between the engine and the microturbine are stated below:

Engine

- *The efficiency is dramatically decreasing when $CH_4<50\%$*
- *Maintenance cost is fix (even at part load)*
- *Auxiliary losses remain practically constant, which penalizes the economic at part load*
- *Operator had to restart manually the engine*
- *The starting procedure is vary sensitive to the methane content*

Microturbines

- *Easy to install/ easy to move to another site*
- *The ability to run with low methane content: $CH_4>35\%$*
- *Efficiency does not decrease with low methane content*
- *Several microturbines to follow the biogas generation curve*

15 Appendix E – Detailed presentation of present network

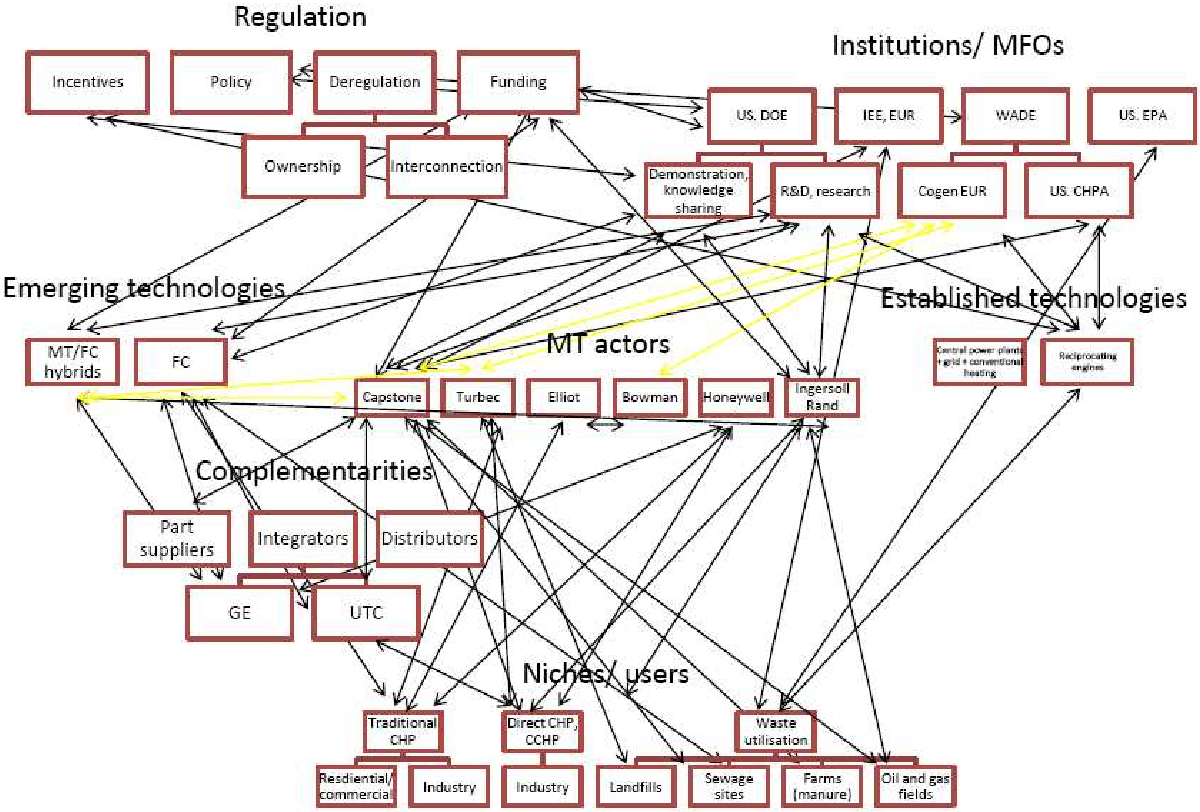

Figure E.1 Detailed presentation of present network.