IEA Bioenergy Agreement

Task 33: Thermal Gasification of Biomass (2001-2003)

Subtask: REVIEW OF ENERGY CONVERSION DEVICES

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INTRODUCTION AND BACKGROUND

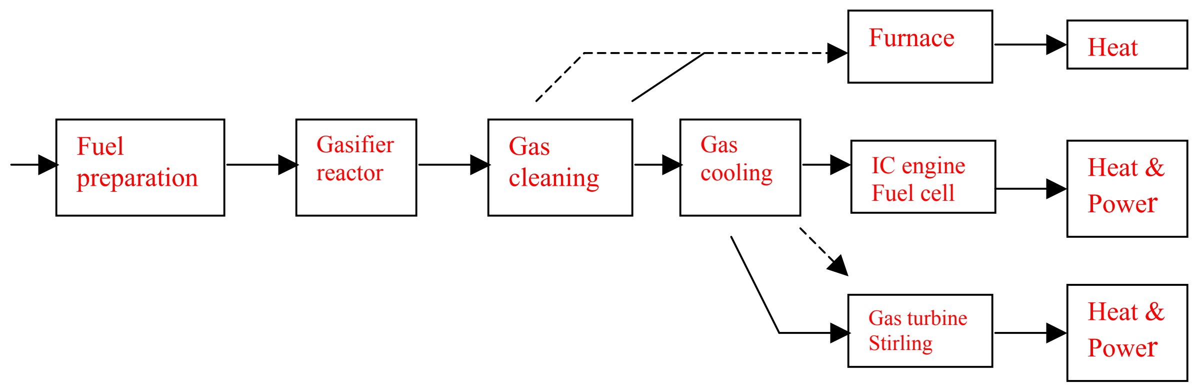
Gasification has been developed to commercial scale of operation very quickly, and more or less widely implemented throughout the world, both in the developed countries and in the developing ones. Generally processes have been fuelled with wood feedstock which is currently a premium fuel in many parts of the world, while relatively little attention has been dedicated to waste (residues) as feed even if it is shown to be potentially much more attractive economically.

So far there are few systems being offered commercially and few systems operating successfully.

The technology is still needful of a robust program of research and development in order to provide a gasification system that is reliable and can meet performance specifications, in particular those needed by the energy conversion devices to which is coupled.

Recent interest in the gasification technology for power production is mainly due to the policy focused at reduction of CO_2 and its associated global warming effect.

The objectives of the present work are to establish the current state of the art and identify areas where development is needed, regarding the technologies that use the gas from biomass gasifiers to generate electricity:



Reciprocating Engines (natural aspiration, turbocharged);
Stirling Engines;
Micro-Turbines;
Fuel Cells.

In particular the work will focus on three main technical issues facing the technology:

- technical performances of the devices operating on producer gas. This includes the extent of capacity de-rating, efficiency loss etc;
- operational problems, such as increased maintenance and failure modes;
- required gas quality at the inlet to the device. This includes the acceptable limits for tar and dust contamination, the impact of the gas composition and variability, gas characteristics (temperature, heating value, etc.).

Economic aspects will be also taken into consideration in terms of investment costs of the prime mover (incl. catalyst, generator, control device, connection to the grid)/generator isle for commercial application now and in the future.
For completion, a short note of history on each prime mover type is given as introduction of the energy generating device.

Reciprocating Engines

Some experiments with an internal-combustion engine started at the end of the 17th century (a Dutch physicist Christian Huygens), but a real gasoline-powered engine was developed only in the second half of the 19th century, by the French engineer J. J. Étienne Lenoir who built a double-acting, spark-ignition engine that could be operated continuously. Following, in the same period, a French scientist Alphonse Beau de Rochas, patented without building a four-stroke engine; only a few years later Nikolaus A. Otto realised with success a four-stroke engine, which, since then, it was known as the "Otto cycle." In the same year (1878) Sir Dougald Clerk built with success a two-stroke engine, still in use today after some modifications made by Joseph Day in 1891. The prototype of the modern gas engine was realised by Gottlieb Daimler in 1885, it was small and fast, characterised by a vertical cylinder, and it was gasoline fuelled injected through a carburettor. Few years later, in 1889, Daimler realised a four-stroke engine with mushroom-shaped valves and two cylinders arranged in a V. Daimler's engines, with just some e exceptions, could be considered the father of all modern gasoline engines.

Pistons moving up and down inside the cylinders

(1) http://www.howstuffworks.com/

At the "Industrial Revolution" dawn, on the beginning of 1800 the fuel essentially used was coal and only about 30 years later also gas was used. In the following years gas substituted coal for city and home lighting, then for cooking and finally for electricity production. This new condition was evident, in fact the presence of gasometres as high metallic structures, changed the landscape of many cities in the world.

The reciprocating engine fuelled by wood gas was designed and realised at the turn of the 19^{th} century for evident shortage of gasoline due to the political situation that generated the well known world wars.

(Rome, Italy - Gasometres in the city skyline, year 2003)

Only a few years later things changed when natural gas was preferred as producer gas substitute, even though, during World War II over a million gasifiers were built and used for household sector while gasoline was used in the military sector.

Now, many years later, many reasons (world oil supplies are being depleted, global warming is perceived as a threat to our environment), there is renewed interest in the gas from biomass.

Depending upon the ignition source, the reciprocating engines generally fall into two categories: 1) spark-ignited engines, typically fuelled by gasoline or natural gas, or 2) compression-ignited engines, typically fuelled by diesel oil fuel. Our interest falls upon the first category.

During World War II over a million gasifiers were built for the civilian sector while the military used up all the gasoline. Here, below, a few interesting pictures are shown.

(2) *http//www.woodgas.com/images/NAS*

(2a) *http://www2.whidbey.net/lighthook/woodgas.htm*

Stirling Engines

It was Henry Wood in 1759 who first envisioned the possibility to produce power by exploiting the changing of the volume of air at temperature changing, in an engine chamber.

His idea consisted in pumping heated air into a large cylinder, cool the air, and let the atmosphere do the work on the inward stroke of the piston.

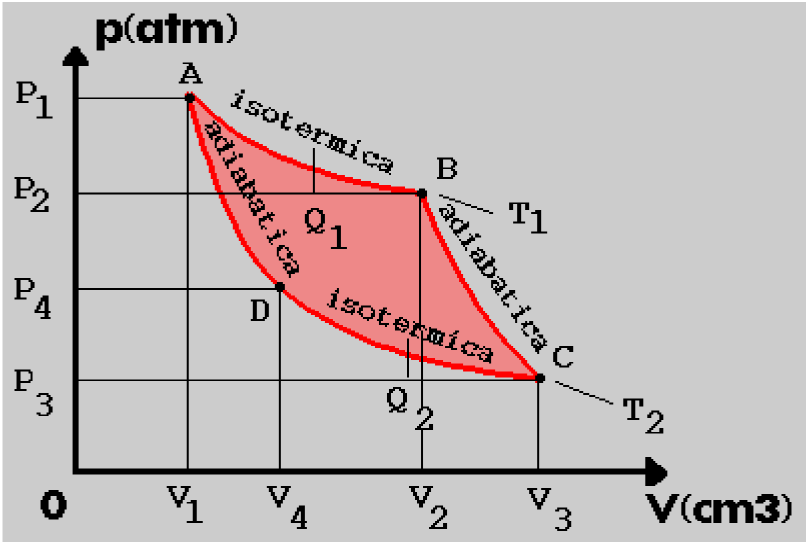
Sir George Cayley in 1807 built a functioning model based on Wood's idea. Following an improved design by Cayley was produced by the Caloric Engine Company in England and the Roper Caloric Engine Company in the USA.

Rev. Robert Stirling, a Scottish minister in 1816 made further technological advancements and became the "inventor" of the hot air or "Stirling" engine. At that time, Stirling engines were recognized as a safe engine that could not explode like steam engines of that era often did.

The theory behind the performance of the Stirling engine is based on the thermodynamic principle of the Carnot Cycle. The following figure shows a P-V diagram of an ideal Stirling cycle. Where a fixed quantity of gas is subjected to the four steps as foreseen by an ideal gas Carnot cycle, shown below:

1. Step 1 from P1-V1 to P2-V2 is an isothermal (constant temperature) expansion at temperature T_{Hot}. The volume increases, the pressure falls, and a quantity of heat Q_h is absorbed by the working fluid from the heat source.
2. Step 2 from P2-V2 to P3-V3 is a reversible adiabatic expansion where heat Q_c is rejected and the pressure drops.
3. Step 3 from P3-V3 to P4-V4 is an isothermal compression at temperature T_{Cold}, with more heat Qc rejected to a heat sink at the same temperature. The pressure rises and the volume decreases.
4. Step 4 from P4-V4 to P1-V1, reversible adiabatic compression, more heat is added at a constant volume thus increasing the pressure to its initial value, as the temperature rises T_{cold} to T_{hot}, at which point the cycle can be repeated.

The amount of work produced is represented by the integration of the area between the higher and lower temperatures.



Ideal Carnot Cycle (*hppt//www.bdp.it)*

The system has returned to its initial state and an amount of work, *W*, has been done to the system. By the conservation of energy,

$$W = Qh - Qc$$

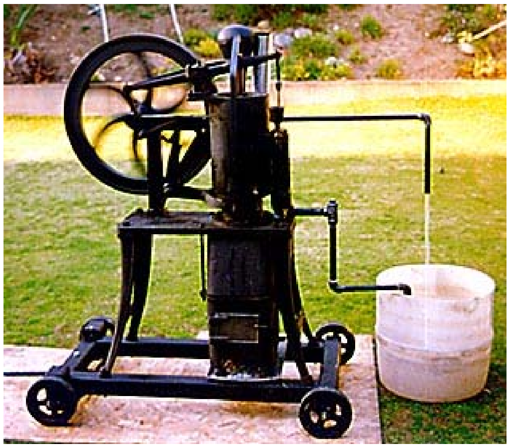
The source of heat can be wood, fuel oil, sunlight, or geothermal sources. Cooling can be achieved from water, air, or even ice cubes.

Stirling engines have two pistons that create a 90 degree phase angle and two different temperature spaces. The working gas in the engine is perfectly sealed, and doesn't go in and out to the atmosphere.

Stirlings are usually classified into three categories named Alpha, Beta and Gamma:

- Alpha, consisting of two cylinders each containing a piston. One cylinder is kept hot while the other is cooled. A Displacer Piston attached to the end of each power piston continuously pushes the air back and forth between the hot and cold cylinders. The regenerator is located in the passage between the two cylinders.
- Beta, which is arranged in a long tube with the power piston at one end. Air is continuously pushed from a heated section of the tube to a cooled area by a displacer piston. The regenerator is located between the hot and cold areas of the tube.
- Gamma, that is similar to a Beta except for the power piston which is located in its own cylinder. The two cylinders are connected by a short passage. The regenerator is located

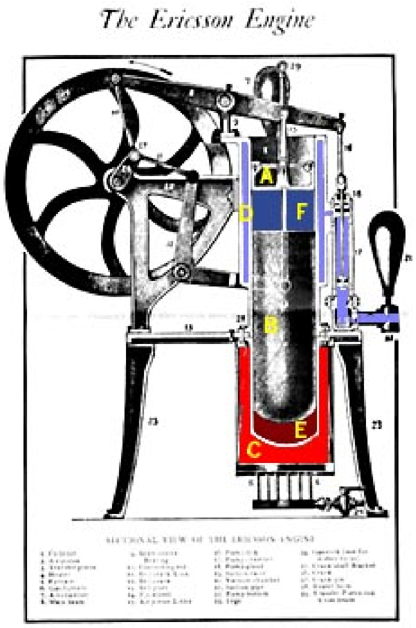
between the hot and cold ends of the main vessel. Gamma engines are usually less efficient and powerful than a similar Beta but they are much simpler mechanically.



(3) http://www.sesusa.org/

John Ericsson, builder of the ironclad U.S.S. Monitor, developed many different hot air engine designs, beginning with his 1826 British Patent.

Ericsson engines were used strictly to pump water; the smaller engines were used in households and small businesses. The water was pumped from a well or cistern into an overhead tank where it was stored for later usage.



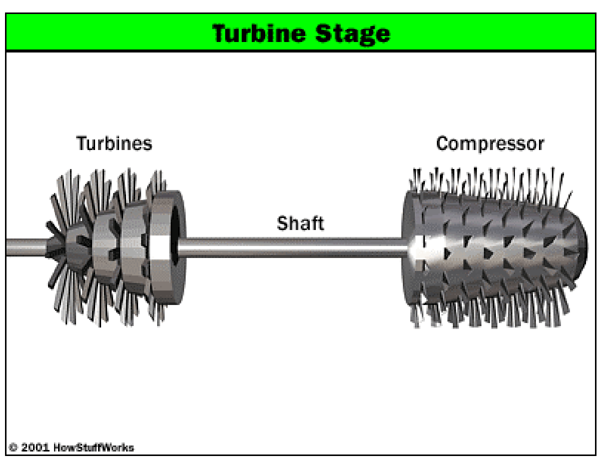
(4) *http://www.rustyiron.com/engines/stable/ericsson.html*

Taking into consideration the colored diagram of the figure above, the following parts are indicated:

- "A" is the power piston; it moves up and down as the air in the cylinder is respectively heated and cooled. The piston diameter is 6 inches and the stroke is 2 7/8 inches.
- "B" is the displacer which is about 1/4 inch smaller than the cylinder diameter. The displacer acts moving the air from the hot side of the cylinder to the cold side and vice versa.
- "C" is the firebox where fuels as wood, natural gas, or other.
- "D" is the water jacket. Water is first sent into the water jacket to provide cooling and then pumped by the engine .

Micro turbines

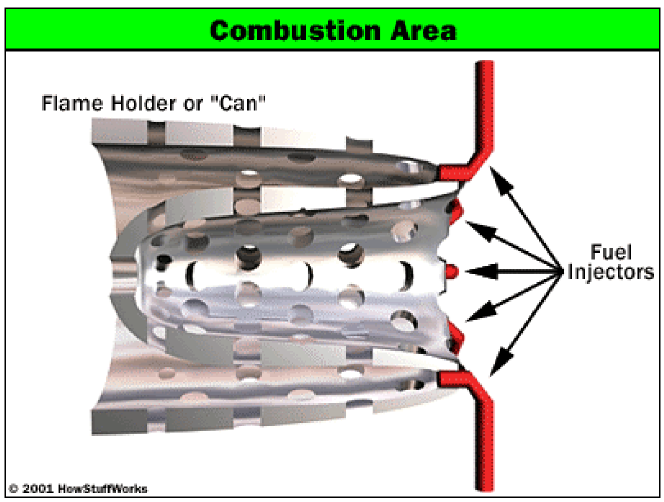
The micro-turbine is a power generation system that is based on a combination of a small gas turbine and a directly driven high-speed generator. In all modern gas turbine engines, the engine produces its own pressurized gas (for spinning the turbine), and it does this by burning fuels like propane, natural gas, producer gas, kerosene or jet fuel. The heat that comes from burning the fuel expands air, and the high-speed rush of this hot air spins the turbine. The level of harmful emissions is very low. Generally, the gas turbine is provided with an exhaust gas recuperator that improves the efficiency of the system (the gas recuperator heats the combustion air by extracting the excess heat in the exhaust gases, increasing the efficiency of the micro turbine). The electricity created by the high-speed generator is converted into useful voltage and frequency by a power converter that is also include in the system. Inspired by developments in the automotive industry, the ingenious design of the micro turbine is the key to its reliability.



(1) *http://www.howstuffworks.com/*

One very important application is stationary power generation where the system is used for continuous power production. The micro turbine is suitable for many applications where electricity is needed as well as combined heat and power production (hot gases leaving the micro turbine are used to heat water or air, to produce steam or for cooling purposes).

In micro turbines air sucked in by the compressor, generally a cone-shaped cylinder with small fan blades fixed in rows, is forced through the compression stage and its pressure rises significantly entering the combustion area. Fuel is injected in this area and burns continuously by means of the "flame holder" or “can,” a device consisting of a hollow perforated piece of heavy metal. Half of the flame holder in cross-section is shown below:



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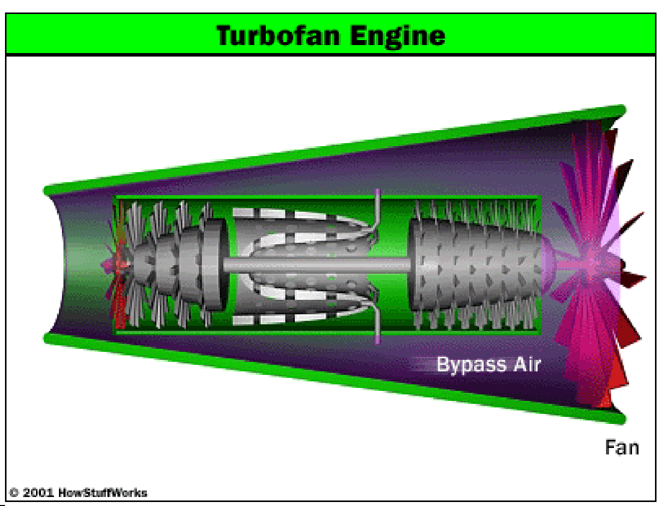

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Fuel Cells*

Fuel cells are electrochemical systems capable of converting the fuel chemical energy (generally hydrogen) directly to electric energy, without the intermediate intervention of a thermal cycle, featuring therefore higher conversion yields than the conventional thermal devices.

Fuel cells birth goes back to the year 1839, when the English William Grove reported the results of an experiment in which he succeeded to generate electric energy in a cell containing sulphuric acid, where two electrodes had been submerged, consisting of thin platinum layers, where hydrogen and oxygen respectively arrived.

A fuel cell works exactly as a battery, in fact it produces electric energy through an electrochemical process, nevertheless unlike the battery the cell consumes substances coming from outside and therefore it is able to work in continuous, until fuel (hydrogen) and oxidising (oxygen or air) are supplied to the system.

The cell is composed by two electrodes in porous material, separated by an electrolyte. Electrodes act as catalytic sites for the cell reactions that consume basically hydrogen and oxygen, with production of water and electric flow passage into the external circuit.

The electrolyte has the task of bringing ions produced by a reaction and consumed by the others, closing the electric circuit in the cell.

The electrochemical transformation is accompanied by heat production, that it is necessary to extract for keeping steady the functioning temperature of the cell.

A single cell produces normally a tension of about 0.7 V and current comprised between 300 and 800 mA/cm^2, therefore in order to obtain the desired power and voltage various cells are disposed in series, by means of bi-polar plates, to form the so-called “stack”. Therefore, in order to obtain the required power generation, stacks are assembled as modules.

So far, various types of cells technologies are available, with different characteristics and different development degree. Generally cells are classified on the basis of the electrolyte used (alkaline cells, polymer electrolyte, phosphoric acid, molten carbonate, solid oxides) or by the operational temperature (cells at low and high temperature).

The electrolyte strongly determines and conditions:

- •the operational temperature range;
- •the type of ions and the direction toward the direct through the cell;
- •the construction material nature;

- •the reacting gases composition;
- •the modality of the reaction products storage;
- •the characteristics of mechanical resistance and utilisation:
- •The cell life.

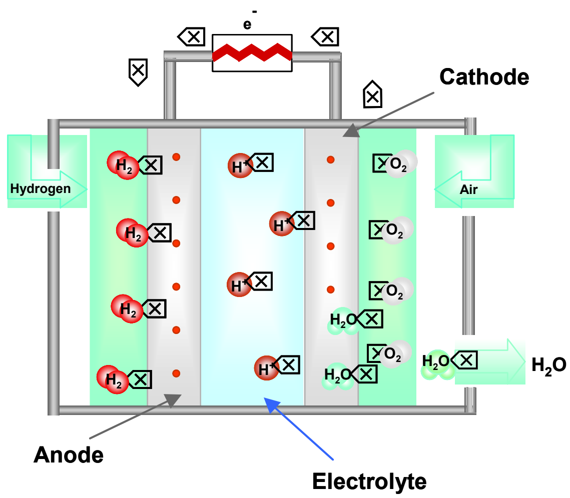
Fuel Cells Characteristics

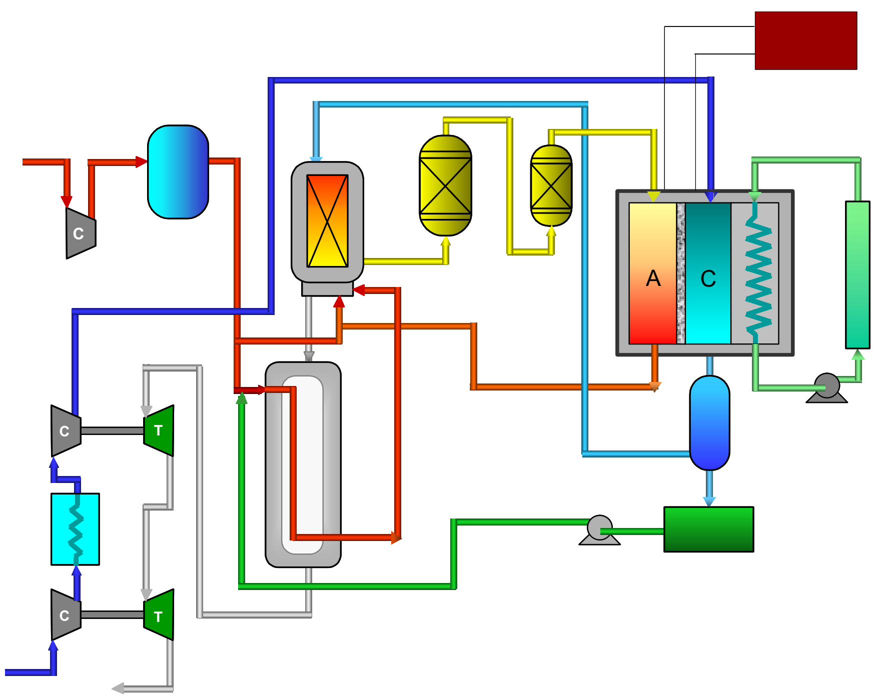
Fuel Cells represent interesting devices for the production of electric energy thanks to their energetic and environmental characteristics. Main fuel cells characteristics are:

- high electric efficiency, the values are around 40-48% (referred to the fuel LHV) for plants which operate at low temperature, up to over 60% for those which operate at high temperature used in combined cycles;
- possibility to use a wide range of fuels such as methane, methanol, natural gas, syngas (derived from liquid fuels), gasification of coal, biomass);
- modularity, which allows to increase the installed power when the electric energy demand grows up, with economic savings and reduced construction time;
- efficiency independent by the load and size of the plants. The cell's efficiency is not influenced by the electric load variations as the conventional plants. In practice a single cell can operate between 30 and 100% of the load, without consistent loss of efficiency. Furthermore, the efficiency is independent by the installed power in a wide range of power, while in the traditional plants the efficiency decreases along with the plant size;
- very reduced environmental impact, both from the point of view of the gaseous and acoustic emissions, this characteristic allows the plants installation also in residential areas, then suitable for distributed electric energy production;
- cogeneration possibility. the heat co-generated can be available at various temperatures, as steam or hot water, and used for sanitary applications, rooms conditioning, etc..

Principal types of cell:

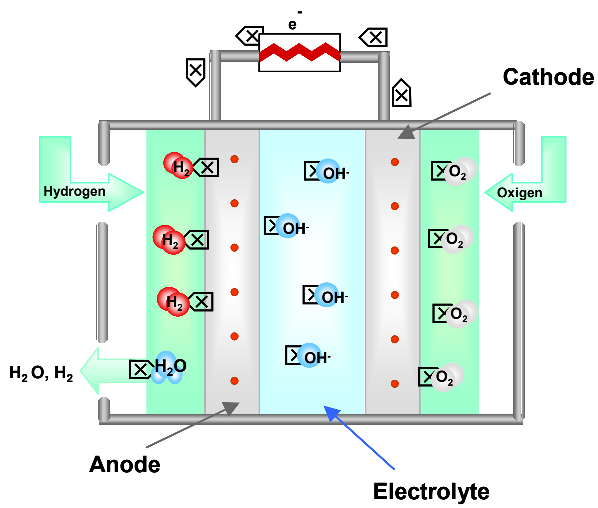
PEFC, Polymer Electrolyte Fuel Cell. These cells use as electrolyte a polymeric membrane at elevated Proton conductibility and operate at temperature between 70 and 100 °C.



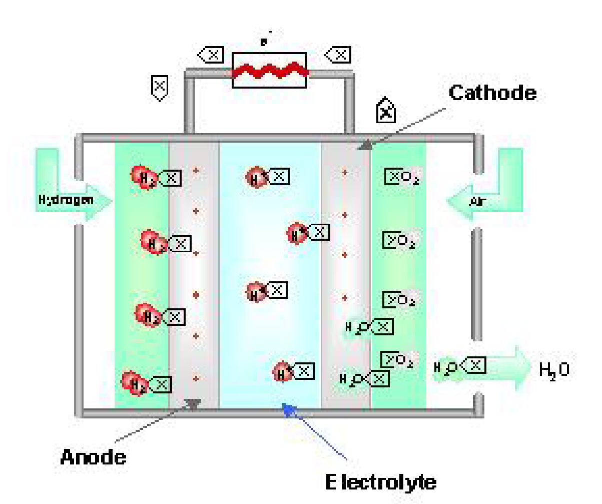


Process scheme of a PEFC fuelled by natural gas (with steam reforming)

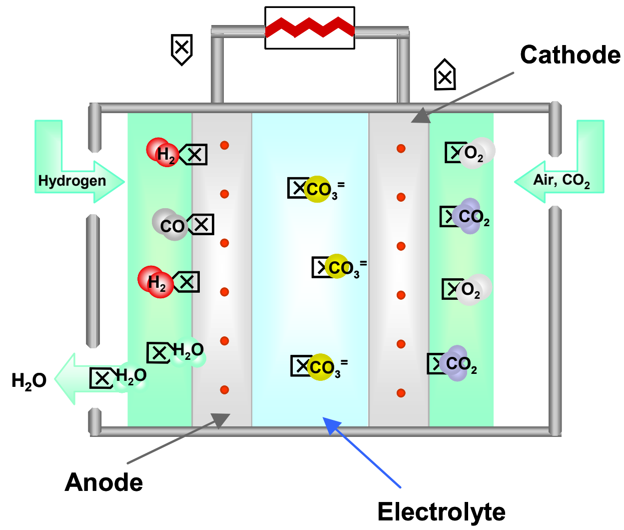
AFC, Alkaline Fuel Cell. They use as electrolyte Potassium Hydroxide and operate at about 120 C. The advantages presented by this cell are the electric efficiency (up to 65%), components cost not elevated, long lifetime (10,000-15,000 hours have been demonstrated).



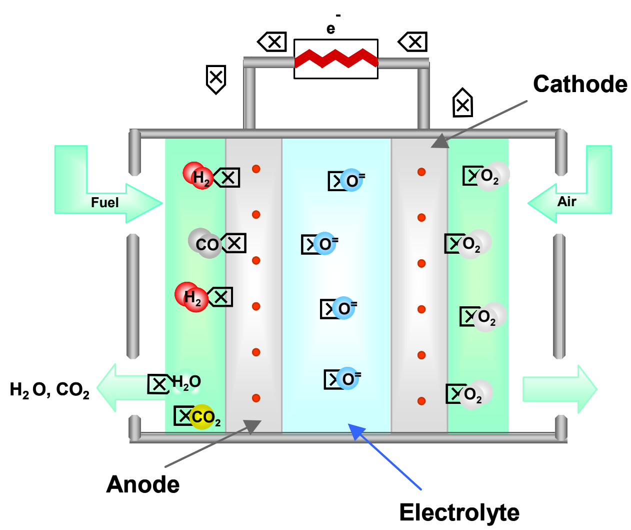
PAFC, Phosphoric Acid Fuel Cell. These cells use as electrolyte a concentrated solution of phosphoric acid and operate at about 200 C.



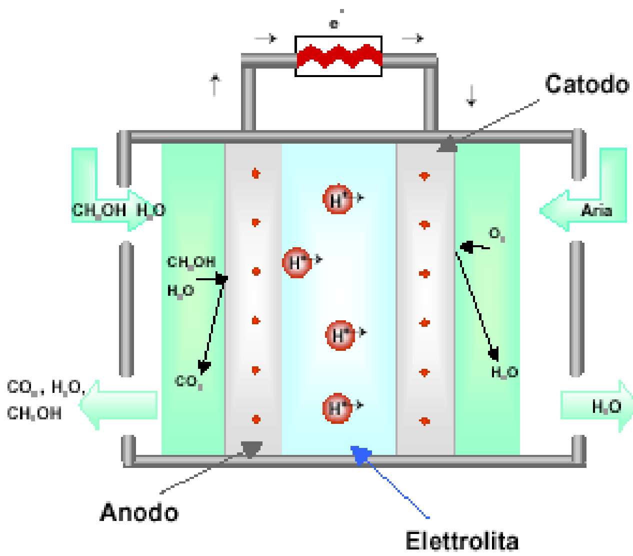
MCFC, Molten Carbonate Fuel Cell. These cells use as electrolyte a solution of molten alkaline carbonate at the cell operational temperature (650 C) that is contained in a porous ceramic matrix and nickel based electrodes (Ni-Cr at the anode and Ni oxide with Li at the cathode).



SOFC, Solid Oxide Fuel Cell. These kind of cells operate at high temperature (about 900-1000 °C) in order to assure a sufficient conductibility to the electrolyte, consisting of a ceramic material (zircon oxide mixed with yttrium oxide); like the carbonate cells , they are promising above all for the generation of electric energy and cogeneration from some kW to some tenth of MW.



DMFC, Direct Methanol Fuel Cell. Temperature of operation is between 70 and 120 °C as PEFCs and utilise a polymeric membrane as electrolyte.



ENERGY DEVICES: STATE OF THE ART

Reciprocating Engine

Commercially available reciprocating engines for power generation range from 0.5 kW to 6.5 MW. Reciprocating engines can be used in a variety of applications due to their relatively small size, low unit costs, and useful thermal output.

They offer low capital cost, easy start-up, proven reliability, good load-following characteristics and heat recovery potential.

Possible applications for reciprocating engines in power generation include continuous or prime power generation, peak shaving, back-up power, premium power, remote power, standby power and mechanical drive use.

When properly treated, the engines can run on fuel generated by waste treatment (methane) and other bio-fuels (biomass gasification).

Reciprocating engines also make up a large portion of the combined heat and power (CHP), or cogeneration, market. Currently cogeneration accounts approximately for six percent (200 MW) of the electricity annually produced worldwide.

Below some reciprocating engines examples, worldwide available, are presented (performances and characteristics are supplied, on the respective internet site, by manufacturers).

Gas engines Jenbacher Energy system

Jenbacher is developing and producing gas engine for an optimised power and heat generation for more than 40 years. The IC engines are produced in the 0.3 – 3 Megawatt range (Type 2, Type 3, Type 4 and Type 6 engines) and are designed for stationary non-intermittent operation.

Model	Power kW	Cylinders
Type 2	300-600	8 - 12
Type 3	600-1100	12 - 16 - 20
Type 4	1500	20
Type 6	3000	12 - 16 - 20

Besides natural gas, the engines can be operated using a broad spectrum of different gases. Here below are shown Type 2 and Type 6 engines.

Gas engines Jenbacher – Type 2 (300-500 kW)

Gas engines Jenbacher – Type 6 (1.7-3 MW)

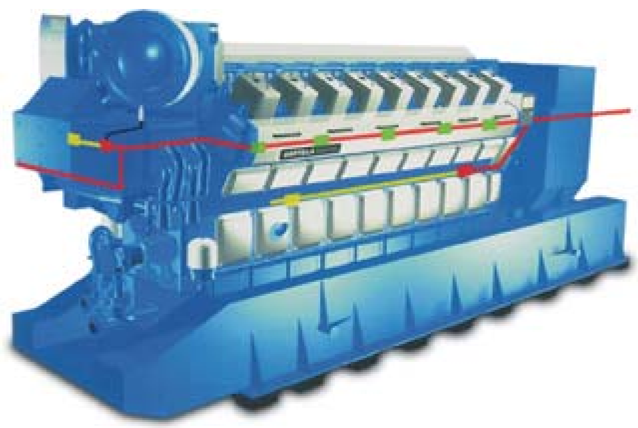
(5) http://www.jenbacher.com/

Gas engine Wärtsilä

Wärtsilä designs, manufactures, licenses, sells and services Wärtsilä and Sulzer engines. The engines can be run on heavy fuel oil, light fuel oil and gas. The gas fuelled engine models offered by Wärtsilä are depicted in the following table:

Model	**220SG**	**34SG**
50 Hz 12 cylinders	2100 kW	3995 kW
50 Hz 18 cylinders	3200 kW	5993 kW
50 Hz 20 cylinders	--	7744 kW
60 Hz 12 cylinders	1860 kW	3821 kW
60 Hz 18 cylinders	2800 kW	5732 kW
60 Hz 20 cylinders	--	7434 kW

Here below the two engines models are shown:



Gas engines Wärtsilä 220SG

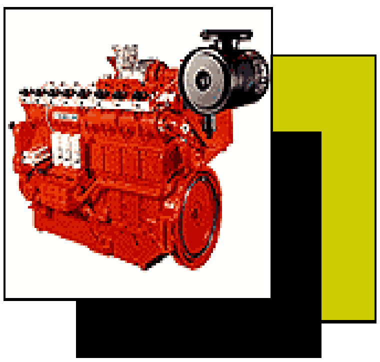
Gas engines Wärtsilä 34 SG

(6) *http://www.wartsila.com*

Guascor Group

The gas-biogas engines and gensets manufactured are designed directly by Guascor, here below in the table are depicted the engine and genset models available on the market:

Model	**6 Cylinders**	**8 Cylinders**	**12 Cylinders**
Gas bio-gas engines	150-314	200-419	520-985
Gas bio-gas gensets	144-301	193-405	503-952



Guascor Gas Bio-gas Engines

Guascor Gas Bio-gas Gensets

(7) *http://www.guascor.com*

Tessari Energia S.r.l

By the year 1950 the Tessari society is present as leader in the sector of the gensets gaining a long experience on research of alternative fuels to produce energy.

The following pictures show some examples of application of Diesel engines converted to Otto cycle and then fuelled with gas and bio-gas.

Tessari's cogeneration-sets with 8-cycle engine fuelled with biogas.
Electric continuous total power 450 kW a power factor 0.8 and thermal power 780 kW.

(8)

325 kW electric power generating-set with 8-cycle engine fuelled with biogas

(8) http://www.tessarienergia.it/ing/index.htm

Caterpillar Gas Package Generator Sets

At 50 Hz the gas packages are rated 156-450 kVA continuous. At 60 Hz the packages are rated 150-450 kWe standby and 150-375 kWe continuous.

This new product combines the already proven Caterpillar gas engines, time-tested SR4B generators and EMCP II controls for improved performance and reliability.

The package claims for a low emissions by the gas engines that meets most emission regulations for continuous operation and provides customers with a low emissions alternative for electric power applications.

Caterpillar engine

(9) *http://www.cat-electricpower.com*

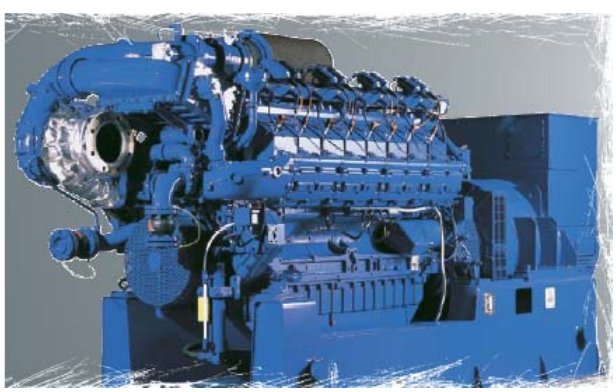
DEUTZ gas engines

DEUTZ is one of the world's leading independent manufacturers of diesel and gas engines used in construction machinery, compressors, commercial vehicles, agricultural vehicles, power generators, drive units, materials handling equipment, and in ships.

Products range from individual gas engines with electronic control units to power units and block heat-and-power stations and even complete systems for decentralized energy supply.

DEUTZ gas-engines cover the range from 323 to 3,620 kW:

50 Hz	**60Hz**
TBG – 616 (323 – 700 kW)	TBG – 616 (350 – 700 kW)
TBG – 620 (970 – 1875 kW)	TBG – 620 (1050 – 1400 kW)
TBG – 632 (3000 – 3620 kW)	TBG – 632 (2700 – 3260 kW)



Deutz 8 - 12- and 16-cylinder V-gas-engines.

(10) *http://www.deutz.de/index4.htm*

Stirling Engine

So far, there are many companies developing Stirling engine plants for a specific nitch market, (in particular, as cogeneration units and power generation using alternative fuels).

The state of the art of modern engines have come very far from the old configuration in terms of total volume, weight, material used, technology, manufacturing accuracy and, above all, in terms of efficiency and reliability (if operated at best conditions).

Stirlings that operate with a gas at atmospheric pressure do not produce much power because the density of the gas is low. If a compact powerful engine is needed the working gas must be pressurized inside the engine.

This necessitates that the engine be well sealed and strong. Some Stirlings, such as ones for vehicles, are pressurized at up to 3000 psi.

Another problem with Stirlings is that they are inefficient and slow if air is used as the working gas. If a lighter gas is used, such as hydrogen or helium, the engine's power increases and the efficiency soars.

Some Stirling engines can attain an efficiency of over 30%.

Below, a short list of organisations and companies involved in the Stirling engines manufacturing is presented with their respective products:

D. Viebach Design

A small power Stirling engine was developed in Germany on a design by D. Viebach, who developed an engine with a shaft power of 500 Watt.

In the case of the prototype that can run on natural gas, liquid gas or biogas, the efficiency is about 30 percent, and this is to be optimised to achieve 35 percent.

D. Viebach Design

(11) *http://www.stirlingengines.org.uk/manufact/manf/germany/new8.html*

Sunmachine

The Sunmachine prototype has a thermal output of 6 kW, whereby the integrated burner can, in future, deliver a thermal output of up to 20 kW. An additional peak load burner is therefore unnecessary.

The input of thermal energy into the Stirling engine from outside enables the use of a wide variety of different heat sources.

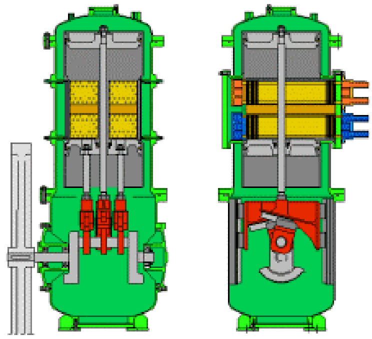
6 kW thermal output Sunmachine

(12) *http://www.stirlingmotor.com/sunmachine.html*

Suction Gas company

The Suction Gas company are developing a 1 kW low temperature differential engine.

In this engine, Alpha type construction is adopted with a phase angle of 150 deg between the pistons which are constructed in line. The compression ratio of the engine is higher than conventional gamma type low temperature difference engines, and friction losses are reduced significantly. Suction in collaboration with Japan Society of Mechanical Engineering, RC Committee 127 developed successfully a small type Stirling engine (100 W). This Stirling engine is applied for a portable prime mover or generator using many kind of fuels.

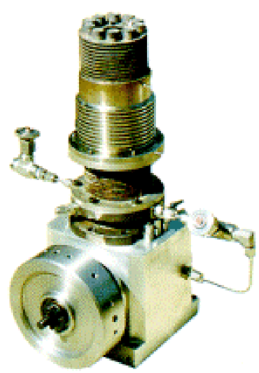


Suction Gas company

(13) *http://www.stirlingengines.org.uk/manufact/manf/misc/jap.html*

Whisper Tech

Whisper Tech of Christchurch, New Zealand, are developing a small co-generation unit, with an electrical output of 800 W at 12-15 Volts. The Stirling engine is fitted with a wobble-yoke drive which the designers claim overcomes previous Stirling engine problems. The engine is water cooled giving 6 kW of water heating via heat exchangers.



Whisper Tech (14) *http://www.whispergen.com/#*

Stirling Thermal Motors Power Inc.

The STM 4-120 Stirling Engine is the result of 15 years of Stirling engine development at Stirling Thermal Motors Inc. (STM) in Ann Arbor, Michigan, USA. The four cylinder, double acting STM 4-120 engine (4 cylinders each with a displacement of 120 cm^3) is designed to meet industrial as well as automotive specifications.

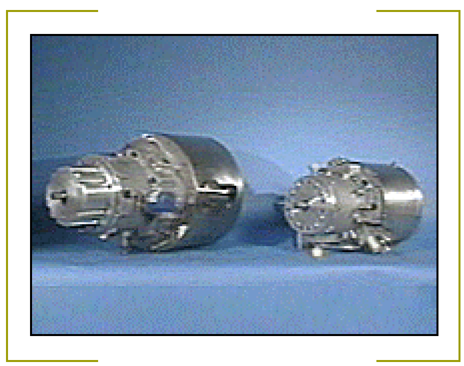
The designers claim a fuel efficiency equivalent to a Diesel engine, with ultra-low emissions and up to 90% less noise than a Diesel engine. The ST 4-120 uses a variable swash plate to change the stroke, and so in turn change the power at constant working gas pressure.

Stirling Thermal Motors has recently been renamed as STM Power Inc which is a developer of on-site, electricity and cogen systems using a proprietary four-cylinder adaptation of external heat (Stirling-cycle) engine technology. A 25 kW PowerUnit, which is based on the STM 4-120 engine, began testing in December 1999. A renewable DG product, the SunDish Solar system, has already been installed in five test facilities.

Another product will be the 10 kW PowerUnit, based on the STM 4-70 engine, which is being developed as an adaptation of the engine that was built in conjunction with General Motors Corporation for use in GM's hybrid electric car.

Re-configured as a PowerUnit, it will be designed to deliver a rated capacity of 10 kW of electricity and 66,000 Btu per hour of heat.

The 10 kW PowerUnit will measure approximately 3ft by 3ft by 2ft (about the size of a small residential air conditioning unit).



The STM Power Inc 10 kW PowerUnit

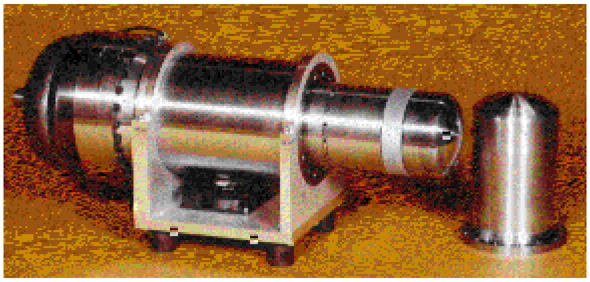
(15) *http://www.stmpower.com/*

Stirling Technology Co.

Stirling Technology Company (STC) has been developing long-life and maintenance-free, free-piston Stirling coolers and engines since 1985.

Stirling Technology Company (STC) has developed a product line of Stirling cycle generator sets (Stirling engine with integral linear alternator) known as RemoteGen™.

STC's engines have demonstrated tens of thousands of hours of maintenance-free, degradation-free operation, combining the efficiency of dynamic systems with the reliability of static systems.



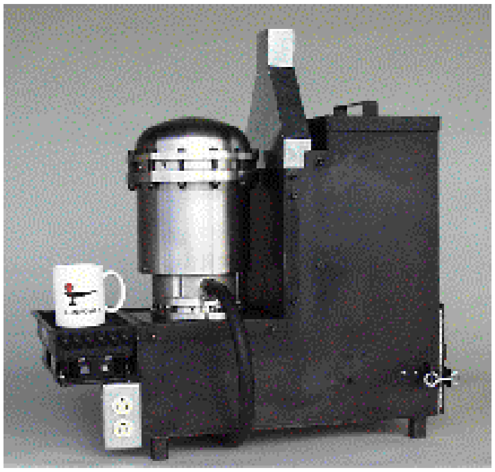
Stirling Technology Co.

(16) *http://stirlingtech.com/about/index.shtml*

Sunpower, Inc., and Wood-Mizer Products, Inc.

are developing BIOWATT^{TM}, a line of electric generators with a free-piston Stirling engine heated by burning biomass.

These products convert various biomass fuels (e.g., wood, wood pellets, sawdust, chips, biomass waste) to power and useful heat (cogeneration, or combined heat and power). BIOWATT^{TM} systems generating 500 W to 10 kW of electrical power have been designed to meet the need for electricity and heat in residential, small commercial, and agricultural applications.



Sunpower, Inc.

(17) *http://www.sunpower.com/*

Kockums (Sweden)

The main feature of Kockums Air Independent Propulsion (AIP) System is the use of Stirling engines burning pure oxygen and diesel fuel in a pressurized combustion chamber.

The combustion pressure is higher than the surrounding sea water pressure, thereby allowing the exhaust products, dissolved in seawater, to be discharged overboard without using a compressor. Oxygen is stored in liquid form (LOX) in cryogenic tanks.

Kockums Air Independent Propulsion (AIP) System

(18) *http://www.kockums.se/Products/kockumsstirlinggm.html*

Sigma Elektroteknisk A.S

Sigma Elektroteknisk A.S of Hølen, Norway is currently working on industrialising the PCP (Personal Combustion Powerplant), a micro energy converter utilizing a Stirling engine as the prime mover.

The PCP 1-130 is an energy converter based on a Stirling engine designed in Sweden to be used in micro CHP applications.

The engine is a single cylinder, beta type Stirling engine with a bore 65 mm, stroke 40 mm, swept volume 133 cm. the working fluid is helium at 8 MPa nominal charge pressure.

Sigma Elektroteknisk A.S

(19) *http://www.sigma-el.com/*

Solo Kleinmotoren

Solo started its involvement in 1990 with Stirling technology with the construction of Solar Engines for metal skinned parabolic mirror dishes from Schlaich Bergmann und Partner (SOLO acquired the license from SBP for the most advanced Stirling engine SPS V160 with regard to life expectancy and reliability).

Solo is developing Stirling Engines developing 10 kW power which have been tested for use with natural gas and solar Dish/Stirling systems.

Solo Kleinmotoren

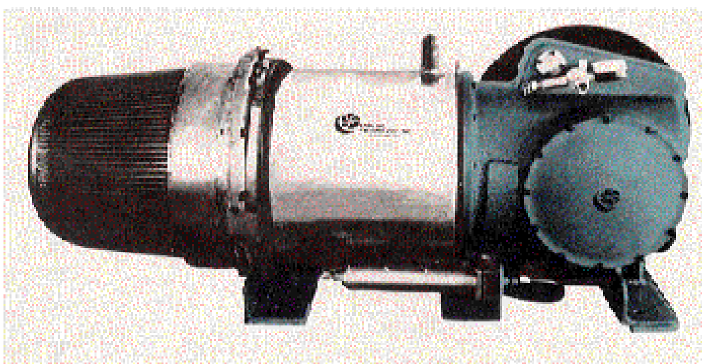
(20) *http://www.solo-germany.com/english/frames/frame_stirlingengine2.html*

Stirling Technology Inc.

The ST-5 is built by Stirling Technology of Athens, Ohio USA. This engine operates with pressurized air at 5 bar and has been designed for long periods of stationary use for residential and small-scale agricultural and industrial purposes.

The engine is rated at 5 hp and can run off impure natural gas, crude oil or bio-mass.

A small scale rice milling system could use part of the waste husk as fuel and small scale milk condensing plants, utilize the heat from the engine as well as the mechanical power.
By the use of simple heat exchangers, waste heat can be used for space heating of house, dairy or greenhouse as well as supplying domestic hot water needs.
At full output, the engine produces over 25kW of recoverable heat.
The ST-5 is no longer produced in the U.S. Information about the ST-5 can be obtained by the Stirling Engine Company in Japan at n-tezuka@net.ksp.or.jp.



Stirling Technology Inc. – ST-5

(21) *http://www.stirling-tech.com/ (http://www.stirling-tech.com/stk/SECback.htm)*

Joanneum Research, Graz, Austria.

This Institute realized a 3 kW alpha type Stirling model that has been successfully tested. One of the advantages of this Stirling type is that it can be constructed with standard industrial parts, in this case a Ducati 500cm^3 motor cycle cankcase.
At present Joanneum Research is developing a small Stirling engine CHP production plant with an electric output of 30-100 kW that meets the criteria for series production.

Joanneum Research Stirling engine CHP (30-100 kW)

(22) *http://www.joanneum.ac.at/*

<u>Micro Turbine</u>

Research is progressing on using lower grade, lower energy fuels such as gas produced from biomass to power the micro turbines.

With opportune modifications, micro turbines are able to utilize low pressure fuels with a lower energy content than traditional fuels. Biogases typically have between 10 and 20 percent of the heating value of fossil fuels.

Improvement options for gas turbine.

This overview summarises information on the most important future developments of the gas turbine technology, that is:

- increase of capacity
- increase inlet temperatures
- options for the gas turbine cycle
- improve performance of industrial gas turbines through use of advanced materials;
- low Emissions Technology – target < 5 ppm NOx
- consideration for transition to back- up fuels
- durable for at least 8000 hours

- no more than 10% cost add- on
- no negative impacts on gas turbine performance.

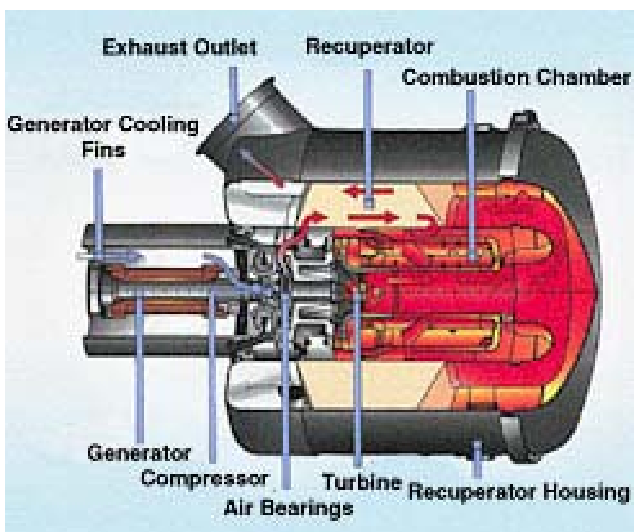
Capstone Micro Turbine

The Capstone MicroTurbine system is a compact, ultra-low-emission generator providing up to 30 kW of power and 85 kW of heat for combined heat and power applications.

Automatic grid/stand-alone switching, the system incorporates a compressor, recuperator, combustor, turbine and permanent magnet generator.

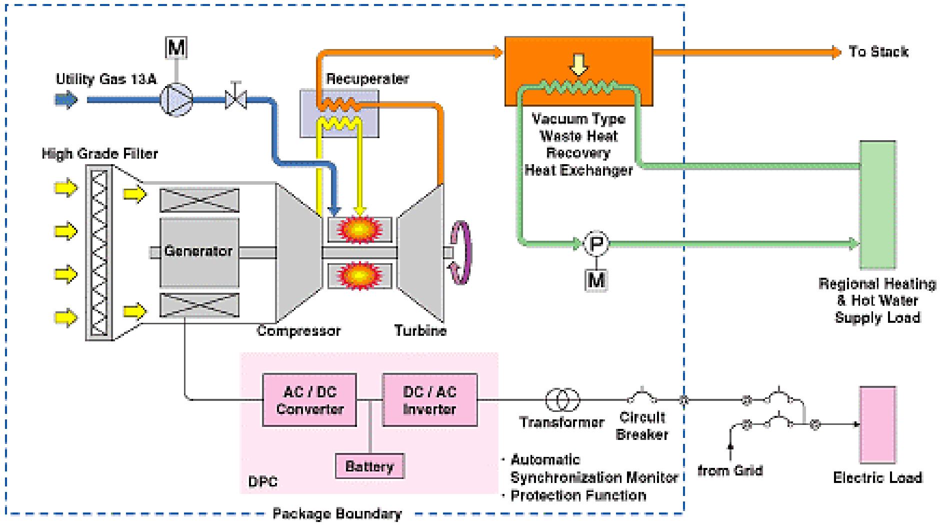
The rotating components are mounted on a single shaft, supported by air bearings, that spins at up to 96,000 rpm. This is the only moving part of the microturbine.

A natural gas fuelled 60-kW of power and 150 kW of heat for combined heat and power applications model and other 30-kW models are also available.



(23a)

Capstone MicroTurbine



(23b)

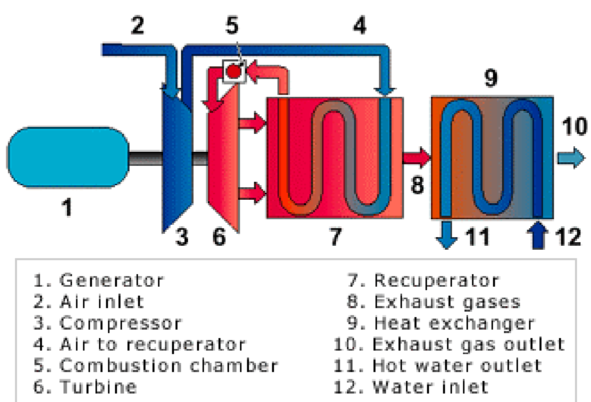
Capstone-Tacuma TCP-30 System Flow Sheet (uses waste heat for heating water)

Turbec

The Turbec T100 CHP produces electricity and heat, the main components are:

- Gas turbine and recuperator
- Electrical system
- Exhaust gas heat exchanger
- Supervision and control system
- Gas compressor

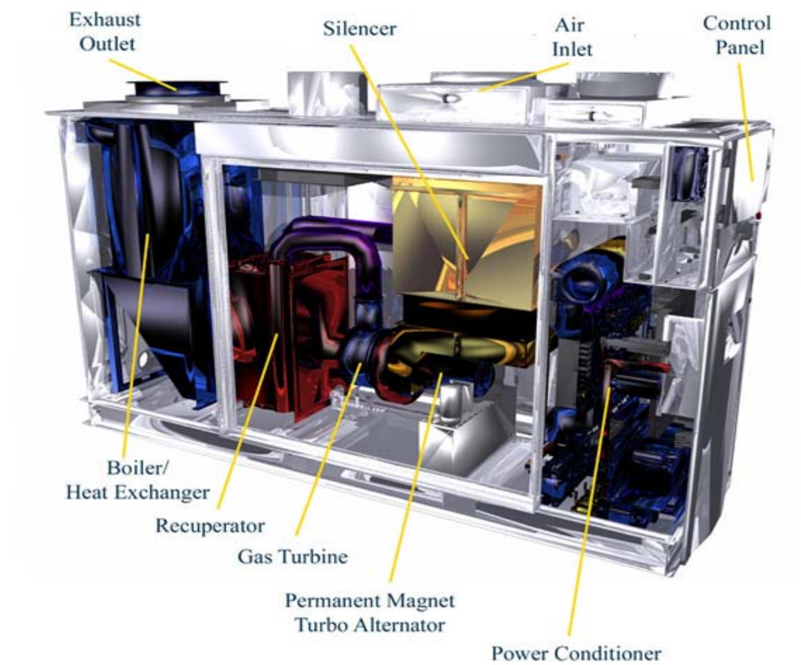
The T100 CHP (fuelled by natural gas) uses a turbine mounted on the same shaft as the compressor and a high-speed generator rotor. Hot gases leaving the micro turbine are used to heat water or air, to produce steam or for cooling purposes).



(24) ***Turbec T-100 Combined heat and power production***

Bowman Power Systems (BPS),

Bowman Power Systems (BPS), has developed the TurbogenTM family of small scale compact power generation systems ranging from 25 kWe to 80 kWe, for distributed power generation and for mobile power applications.



(25)

80 kWe BPS Cogeneration (CHP) Systems (Bowman)

Ingersoll Rand

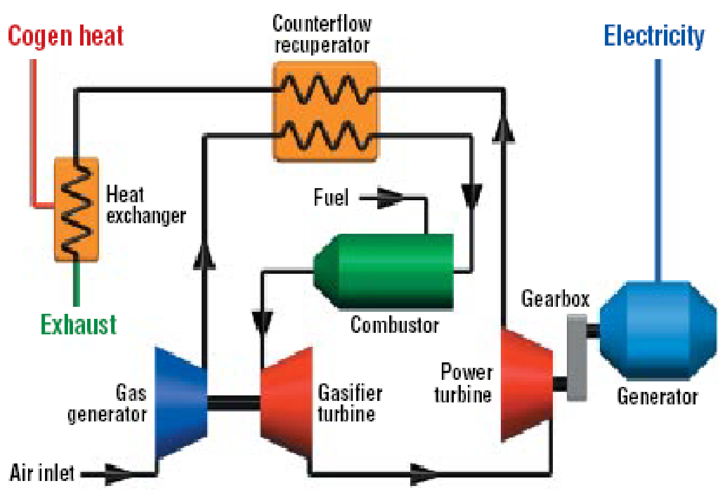
The Ingersoll Rand produces two systems both all-in-one unit micro turbine with output of 70 and 250 kW of electricity.

Each unit has an integral gas booster and thermal fluid heat exchanger which give up to 180 deg. F. hot water and up to 30 GPM flow rates.

This unit is suitable for household and small enterprises which need hot water or process heat.

Ingersoll Rand IR 70 kW Microturbine

(25a) *http//www.globalmicroturbine.com*



(25a)

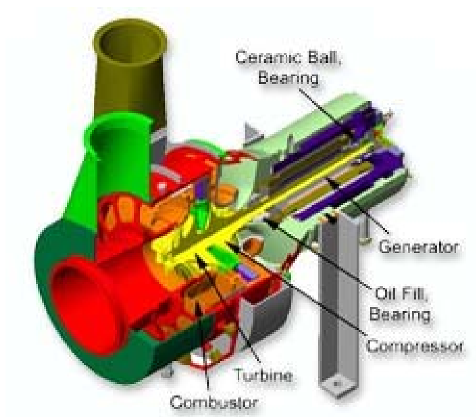
IR 70 kW Powerworks Cycle

Elliott Energy Systems Inc. (EESI)

is a fully owned subsidiary company of Ebara Corporation of Tokyo, Japan.

Formerly known as Universal Turbine Energy Systems, the company was founded in 1993 to develop and manufacture microturbine generators. The micro turbine TA 100R is capable of producine 100 kW of electrical power and 172 kWth of exhaust power.

Model TA 100R CHP 100 kW Turbo Alternator$_{tn}$



Fuel Cell

GE MicroGEn, society formed in February 1999 by the fusion of the General Electric Power Systems and the Plug Power. GE MicroGEn's activities foresee a program of development and commercialisation of power units up to 35 kW, for residential and commercial uses.

The society is at present developing PEFC systems with power of 7 kW (HomeGen 7000) fuelled with natural gas.

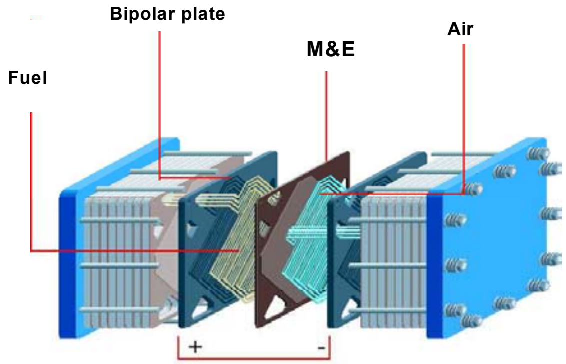
Joh. Vaillant GmbH Co. (Remscheid, Germany),
one of the principal manufacturers of heating plants in Europe, has signed an agreement with Plug Power, in order to supply and sell on the European market systems fuelled with natural gas (4.5 kW power) for residential applications.

MicroGen with Kubota Corp. (Osaka),
is testing 7 kW power units. Besides collaborations are ongoing with Soroof Trading Developing Company and with Rahim Afrooz for the distribution and selling of GE MicroGen products, respectively in Saudi Arabia and Bangladesh.

Nuvera Fuel Cells, formed in April 2000 by the fusion of De Nora Fuel Cells SpA (Milano, I), division of the society De Nora that since 1990 is involved in the development of PEFC systems and Epyx Corp. (Cambridge, Massachussets US), Arthur D. Little group, active since 1992 in the development of systems for fuel treatment.
On May 2001 Nuvera formed a joint venture with RWE Plus (Germany) for the development, production and commercialisation of residential plants with size up to 50 kW for the European market. Nuvera has also signed an agreement with Air Liquide (France) for the development of Hydrogen units and a memorandum of understanding with Mitsui & Co., Ltd., with the aim of exploring the fuel cells development possibilities in Japan.

Fuel Cell Energy (Danbury, CT)
works in the sector of molten carbonate fuel cells by the middle ‘70s and arrived to demonstrate stacks and plants of MCFC at different power.

Ansaldo Fuel Cells SpA
The plant of “SERIE 500” represents the last step in the development of the MCFC technology studied by Ansaldo Fuel Cells (AFCo) since the early ’80s.



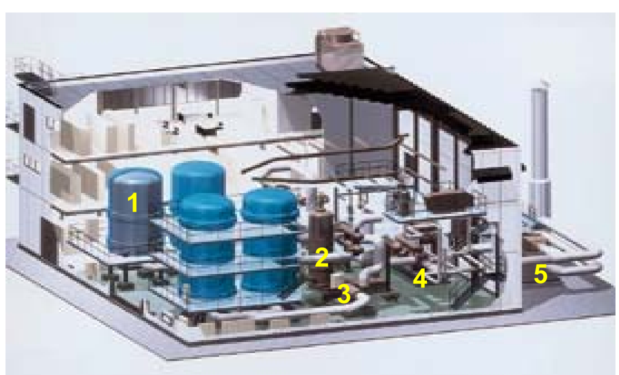
(26)

Polymer electrolyte cell stack (Ballard Power System)

(27) ***Vaillant Prototype /Plug Power - 4,5 kWe***

1 MW Fuel Cell Project, US Post Office, Anchorage, Alaska

1.8 MW MCFC plant - S. Clara (CA, US)

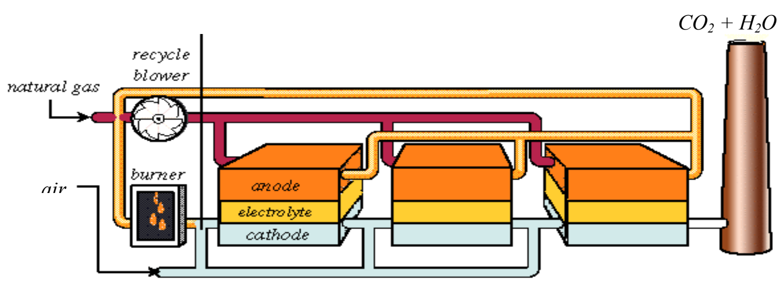


1MW demonstrative plant scheme at Kawagoe

1. *250 kW Stack*
2. *Reformer*
3. *Blower*
4. *Compressor*
5. *Steam Generator*

***100 kW modules for MCFC plants
(Ansaldo Ricerche laboratories)***

(28)



SMARTER system Scheme

***PEP Iberdrola station test at S. Augustin
de Guadalix (Madrid, E)***

TECHNICAL AND NON-TECHNICAL BARRIERS

Reciprocating Engines

The feeding of the producer gas to the engine needs a deep purification with the elimination of the following pollutants:

•Dust (< 10-20 mg/m^3)

•Tar (< 100 mg/m^3 in suction engines)

•Acids (< 20 mg/m^3 in turbo-compressed engines)

Dust can obstruct the device that controls the fuel rate in function of the requested power. In this way it is kept steady the rotating speed independently by the load conditions. Furthermore, when the particles reach the combustion chamber can provoke some damage to the pistons sealing, to the inner surface of the cylinders and to the valves.

In order to prevent these problems, the gas produced by the gasifier must be opportunely treated. To this purpose before the engine a cooling system is installed which lowers the gas temperature to about 0°C, once more the gas is condensed; following an electric resistance heats the gas up to 40 °C required for a good combustion into the engine. In this way the gas which is obtained presents a humidity degree almost null.

Stirling Engines

The primary disadvantage is undoubtedly manufacturing cost. It appears that will be difficult to produce a Stirling engine that costs less than twice the price of diesel engine of equivalent power. The high manufacturing cost is mostly due to the expense to manufacture the heat exchanger.

The engine thermal efficiency is highly dependent on the maximum cycle temperatures so to sustain a reasonable level (30%) of efficiency it is necessary to use relatively expensive materials for the hot parts - stainless steel or high temperature alloys.

Although the Stirling engine is inherently more efficient than the internal combustion engine, in practice even the best Stirling engines can only achieve thermal efficiencies similar to those routinely achieved in modern diesel engines (35%). Another contribution to increased cost is that Stirling engines require a cooling system having a thermal capacity approximately twice that of the internal combustion engine of comparable power output.

There is a further important consideration. Whereas the efficiency of a diesel engine increases as the coolant temperature increases the Stirling engine operates less efficiently. For an air-cooled radiator to function properly the temperature of the liquid engine coolant must, of course, be higher than the ambient air temperature.

Micro Turbine

Operation and maintenance costs have a key role to determine the development of these devices in the turbine market. Both the primary operational and maintenance costs are relatively low, in fact the former deals only with the fuel costs which vary from country to country, the latter deals with the replacement of consumables. What affects the total operation and maintenance costs is the recuperator considered the critical component in terms of durability as well.

Fuel Cells

So far the principal obstacles to the market penetration and arrive to a concorrential condition with the traditional technologies, are necessary costs reduction from 3 to 5 times.

The introduction of fuel cells requires, beyond the development of a favourable context to the distributed energy generation/cogeneration, that users take confidence with the technology, overcoming the preoccupations connected with the novelty in terms of safety (i.e. presence of hydrogen), modalities and management costs, reliability, maintenance, etc., and feel themselves guaranteed by the continuity and quality of the plant operations. To this aim a significant importance have the demonstration programs that are carried out in close collaboration with users, both in the development phase and in that pre-commercial:

RECENT/NEW DEVELOPMENTS

Reciprocating Engines

The wide power range and operating flexibility make reciprocating engines suitable for substations and small municipalities plus commercial, industrial, institutional, and even residential applications.

Reciprocating engines are the fastest-selling, lowest-cost distributed generation technology in the world today.

So far industry has developed gas engines which can utilise an unmatched range of different gases such as biogas, pyrolysis gas and almost any other combustible gas. The heating value of gases that can be turned into electricity at an efficiency of up to 40% lies between 0.5 kWh/m^3 and 34 kWh/m^3.

Stirling Engine

Here below some recent applications are depicted. The aims of these applications deal mostly with the costs reduction, efficiency improvement and the environment saving.

Norway: Sigma Elektroteknisk A.S of Hølen,

Norway is currently working on industrialising the PCP (Personal Combustion Power-plant), a micro energy converter utilizing a Stirling engine as the prime mover. The PCP 1-130 is an energy converter based on a Stirling engine designed in Sweden to be used in micro CHP (Combined Heat and Power) applications.

The engine is a single cylinder, beta type Stirling engine with a bore 65mm, stroke 40mm, swept volume 133cm. the Working fluid is helium at 8MPa nominal charge pressure.

New Zealand: Whisper Tech of Christchurch,

New Zealand, are developing a small co-generation unit, with an electrical output of 800W at 12-15 Volts. The Stirling engine is fitted with a wobble-yoke drive which the designers claim overcomes previous Stirling engine problems.

The engine is water cooled giving 6kW of water heating via heat exchangers.

Sweden: Kockums Air Independent Propulsion (AIP) System

the main feature is the use of Stirling engines burning pure oxygen and diesel fuel in a pressurized combustion chamber.

The combustion pressure is higher than the surrounding sea water pressure, thereby allowing the exhaust products, dissolved in seawater, to be discharged overboard without using a compressor. Oxygen is stored in liquid form (LOX) in cryogenic tanks.

Japan: The Suction Gas Company

are developing a 1kW low temperature differential engine.

In this engine, Alpha type construction is adopted with a phase angle of 150 deg between the pistons which are constructed in line. The compression ratio of the engine is higher than conventional gamma type low temperature difference engines, and friction losses are reduced significantly.

Suction in collaboration with Japan Society of Mechanical Engineering, RC Committee 127 developed successfully a small type Stirling engine (100 W). This Stirling engine is applied for a portable prime mover or generator using many kind of fuels.

USA: Sunpower, Stirling Technology Co.

Sunpower, Inc., and Wood-Mizer Products, Inc., are developing BIOWATT^{TM}, a line of electric generators (500 W to 10 kW) with a free-piston Stirling engine heated by burning biomass. These can convert various biomass fuels (e.g., wood, wood pellets, sawdust, chips, biomass waste) to electricity and useful heat (cogeneration, or combined heat and power).

USA: STM Power Inc. Omachron

is a developer of on-site, electricity and cogeneration systems using a proprietary four-cylinder adaptation of external heat (Stirling-cycle) engine technology.

The Company refers to its products as Power Units. The Company believes that electricity and heat produced by its Power Units are expected to be more economical than other energy conversion technologies (fuel cells, micro turbines and photovoltaic systems) competing in the distributed generation ("DG") market.

Micro Turbines

Improvement options:

Below some information have been summarised on the most important future developments of the gas turbine technology, that is:

- increase of capacity
- increase inlet temperatures
- options for the gas turbine cycle
- Improve performance of industrial gas turbines through use of advanced materials;

- Low Emissions Technology – target < 5 ppm NOx
- Consideration for transition to back- up fuels
- Durable for at least 8000 hours
- No more than 10% cost add- on
- No negative impacts on gas turbine performance

<u>Fuel Cell</u>

DOE/USA Program

Project VISION 21 (Clean energy plants for the 21st Century), carried out in the USA by the Department of Energy and by the National Energy Technology Laboratory (NETL).

The aim of this project is to dispose in 2015 of electricity generation systems that, even though they continue to use fossil fuels, are able to guarantee an environmental impact nearly null.

In this frame, a key role have the systems that have been developed by the 21st Century Fuel Cell Program, whose objective is to develop systems that utilise fuel cells of new generation.

These cells are offered at installation costs of 400 $/kW (<90 $/kW for the stack), efficiency > 80%, emission "close to zero".

EU Program

The European Union finances research, development and demonstration activities on fuel cells and on connected technologies, in the frame of the V Framework Program (1998-2002), Subprogram "Energy".

For stationary applications the program supports the development of:

- fuel cell cogeneration plants for residential and commercial uses with power 10-100 kW;
- high temperature fuel cells (100 kW-11 MW) for electricity production, included hybrid systems with gas-turbines;
- portable gensets with power 500 We-3 kWe.

PRINCIPAL TECHNOLOGY DEVELOPERS CONTACT DETAILS

Reciprocating Engines

GRUPO GUASCOR
Arkaute 5, P.O.Box: 768
01080 Vitoria (Spain)
TEL: 34945 27 98 77
FAX: 34945 27 84 37
Email: amartinezda@gr.guascor.com

DOE-DER Program Contact
Merrill Smith
Program Manager
EE/Office of Distributed Energy Resources
U.S. Department of Energy
Tel: (202) 586-3646
E-Mail: merrill.smith@ee.doe.gov

JENBACHER ENERGY SYSTEM
Achenseestraße 1-3,
A-6200 Jenbach
e-mail: contact@jenbacher.com
Phone: +43 5244 600 2135.

NAT GAS GENERATOR SETS
Corporate Main Office Phone - 1-661-589-2870
Corporate Fax - 1-661-589-1165
Address: 6615 Rosedale Hwy Bakersfield, CA 93308
United States
Mailing Address: P.O.Box 1934 Bakersfield, CA 93301
Electronic mail
General Information: Sales: Rod Headley sales@gensets.com

TESSARI ENERGIA S.r.l
Via Venezia 69
35100 Padova - Italy –
Tel. ++49-8076233
Fax. ++49-8071618
info@tessarienergia.it

WÄRTSILÄ CORPORATION, Helsinki
John Stenbergin ranta2

00530 Helsinki
P.O. Box 196
00531
Finland
Tel. +358 10 709 00 00
Fax +358 10 709 57 00

Stirling Engines

Engines manufacturers are listed alphabetically by country of origin: Canada, Germany, Japan, New Zealand, Norway, Pakistan, Sweden, USA.

Canada:

FREE BREEZE
Gerry Gascho / Sales Rep: Myron Gascho
P.O. BOX 451, Tavistock, Ontario, Canada N0B 2R0
e-Mail - gerry@orc.ca
Phone: 519-655-3100 ~ FAX: 519-655-9954

Germany:

SOLO *Kleinmotoren GmbH*
Postfach 60 01 52
D-71050 Sindelfingen
Stuttgarter Straße 41
D-71069 Sindelfingen
Telefon: (0 70 31) 3 01-0
Telefax: (0 70 31) 3 01-202
info@solo-germany.com

D. VIEBACH,
Contact Herr Dieter Viebach at:
Entwicklungsburo
Dieter Viebach,
Spielhanstr. 17
D-83059 Kolbermoor -Germany.

SUNMACHINE,
Gesellschaft für Stirling-Technologien mbH
Am Laufer Schlagturm 6 · D-90403 Nürnberg
Tel: +49(0)911 / 62388-0 · Fax: +49(0)911 / 62388-10
e-mail: stirling@sunmachine.de

Japan:

SUCTION GAS ENGINE MFG. Co., LTD
6-10-4 HIGASHI SUNA, KOTO-KU, TOKYO,136-0074
TEL: 03(3646)5131
FAX: 03(3646)5357

New Zealand:

WHISPER TECH Ltd
224 Armagh Street
Christchurch 8031
New Zealand
Phone: +64 (3) 363 9293
Fax: +64 (3) 363 9294

Norway:

SIGMA ELEKTROTENISK A.S of Hølen.
P.O.Box 34, Brandstadveien,
N-1550 Hølen, Norway
Phone: +47 / 64 98 24 00
Fax: +47 / 64 98 24 01

Sweden:

KOCKUMS
Lars Larsson
Head of Stirling Department
Kockums AB
SE-205 55 Malmö
Tel. +46 40 348 438
lars.a.larsson@kockums.se

USA:

SUNPOWER,
Mailing address:
Sunpower, Inc.
182 Mill Street
Athens, OH 45701 USA
Phone: 740-594-2221
Fax: 740-593-7531
e-mail: info@sunpower.com

STIRLING TECHNOLOGY Co.
4208 West Clearwater Ave
Kennewick WA 99336-2626, USA

Tel: 509/735-4700 Ext. 112
Fax: 509/736-3660
E-mail: info@stirlingtech.com

STIRLING TECHNOLOGY Inc.
The ST-5 is no longer produced in the U.S.. For further information about ST-5, contact Stirling Engine Company in Japan at n-tezuka@net.ksp.or.jp.

S T M POWER Inc., Omachron
Sales & Marketing:
1655 North Fort Myer Drive, Suite 825
Arlington, Virginia 22209
Phone 703-248-0454
Fax 703-248-8124
Contact: John J. McKenna
mckenna.john@stmpower.com

Micro Turbines

USA:
CAPSTONE Turbine Corporation
21211 Nordhoff Street
Chatsworth, CA 91311
PH. 818.734.5300
FX. 818.734.5320

ALLISON Advanced Development Company
P.O. Box 7162
Indianapolis, Indiana
46206-7162 USA
Since 1995, Indianapolis, Indiana-based Allison Engine Company has become part of Rolls-Royce plc. Information on the engines designed and manufactured at the Indiana operations of Rolls-Royce, can be accessed through the Rolls-Royce at the following address and web site:

ROLLS-ROYCE Corporation
Post Office Box 420 Indianapolis, IN
46206 USA
Tel: (317) 230-2000
Fax: (317) 230-4020
www.rolls-royce.com

HONEYWELL:
World Headquarters
Honeywell
101 Columbia Road
Morristown, NJ 07962

Phone: (973) 455-2000
Fax: (973) 455-4807

TURBEC AB
Turbec is an independent company established by ABB and Volvo Aero. Turbec has its own network of suppliers and customers.
Regnvattengatan 1
200 21 Malmö Sweden
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Fax: +46 40 680 00 01

BOWMAN POWER SYSTEMS Inc
(Tony Hynes, Director of Sales and Marketing, North and South America)
20501 Ventura Boulevard
Suite 295 Woodlands Hills
CA 91364 USA
Tel +1 (818) 999 6709
Fax +1 (818) 884 0991

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SUBTASK COORDINATOR CONCLUDING COMMENTS

Reciprocating Engine

One of the advantage of the biomass gasification is represented by the possibility to produce power without the use of steam turbines. Turbines efficiency results to be competitive for power over 5 MWe, in fact, for power from some kWe up to few hundreds of kWe, reciprocating engines are suitable and giving efficiency around 25-30%.

The typical power range and operating flexibility make reciprocating engines suitable for substations and small municipalities plus commercial, industrial, institutional, and even residential applications.

Reciprocating engines could be the fastest-selling, lowest-cost distributed generation technology in the world today.

On the other side the use of syngas in the reciprocating engines is almost limited, in particular in engines provided with turbo-feeding compressor, by the low heating value of the gas (LHV). In fact, the output is lower than a fossil fuelled engine but the efficiency only marginally reduced.

Stirling Engines

In the previous pages the main characteristics of the Stirling engine have been fully detailed, so in this section they are summarised:

Low weight, low noise, low vibrations, almost no emissions hence it is good for the environment, clean, due to the engine's continuous external combustion. It can use multiple fuels without modifications such as fossil fuel as well as renewable.

Stirling engines are reliable (low maintenance) because of the simple mechanism arrangements: no valves, no ignition timing and it can be constructed with standard industrial component (commercial cycle crankcases).

Different considerations must be made regarding the power generation and the efficiency of the system that are related and both affect the economics. Simple construction with air used as working gas, at low pressure is chipper and the efficiency is close to 10%.

More accurate construction with the engine well sealed, strong and compact; using lighter gas such as Hydrogen or Helium as working gas at higher pressure is more expensive and the efficiency can overcome 30%.

Micro Turbine

Durable heat exchangers of high effectiveness and low cost are needed to increase the efficiency of gas turbines to the levels needed to compete with reciprocating engine based power generation systems. Their function is to preheat the air used in the combustion process and thereby reduce the amount of fuel used to reach operating temperature.

Present state of the technology require almost extensive pre-treatment for successful operation; additional studies are necessary on moisture and H_2S impact. High CO emission levels can be reduced by modifying the fuel injection system.

Fuel cells

Fuel cells result particularly suitable to the generation of distributed power, the development of their market, however, depends strongly by the ongoing evolution with the liberalisation of the electric system and, more in general, of the energetic system, and by the times and methods with which this liberalisation will be carried out.

Already today in the whole world the tendency is that to lessen the medium size of the generation plants. In the USA, for example, the medium plant size was 600 MW before 1992, then 100 MW and 100 at the end of the '90s. In Italy in the same period the medium plant size was below 50 MW.

Therefore it is expected a growing space for the small-medium size generation technologies with limited environmental impact and elevated efficiency as the fuel cells.

The emission of the fuel cells plants are below 10% of those of an equivalent conventional plant. NOx and CO content is practically negligible, because they are emitted directly during the combustion phase. Also compounds as particles and SOx are negligible, in fact every fuel cell plant foresee the conversion and/or elimination of SOx before the cell inlet.

A fuel cell plant presents an energetic efficiency sensibly higher than that of conventional systems, also in their most advanced configurations. As a result of this high efficiency a reduced quantity of CO_2 is emitted, at equal heat or electric energy produced.

Taking as an example a 200 kW plant (CO_2 emissions equal to 190 kg/MWh), it is estimated that fuel cells utilisation, assuming an efficiency around 40%, it gives, if compared to a gas engine of the same size (30% efficiency), to a CO2 saving of about 1,000 t/a, considering a medium utilisation of 7000 h/a.

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Reciprocating Engine

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Note: