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DIDSOLIT-PB: Development and implementation of decentralised solar-energy-related innovative technologies for public buildings in the Mediterranean Basin countries.

Coordinating Institution: BEG-INCERS Research Group – Universitat Autònoma de Barcelona (UAB)

Report 1

Technical assessment and viability study of scale-down Dish Stirling (DS) technology for power generation in the Mediterranean Regions

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CONTENT

INTRODUCTION

This report summarizes the state of the art and the main principles and components of the Dish Stirling (DS) technology, andgathers the results of our assessment of the technical & commercial viability of small scale, market available, systems.

The small scale Dish Stirling CSP (Concentrated Solar Power) systems are mainly driven to electricity and thermal generation, and are suitable for both, ground and roof mounted applications.

As a result of a preliminary research and benchmark analysis, the report presents some of the most suitable systems available in the market, and includes a Conceptual design of a scale down prototype.

This document is the final result of an innovation-study process, which 1) started witha first overall research and documentation workconducted by the UAB-EsE Technical Team, which in turn allowed us to 2) specify and commission two Technological Centres (CITCEA and CDEI, associated to Universitat Politècnica de Catalunya) with a technical assessment and design for a specific DS pilot unit to be placed in public buildings.

The research work has been rounded off by 3) installing a functional prototype, assessed by the referred Technological Centres. The procurement, installation, commissioning and O&M stages have been an extremely valuable source of practical knowledge from a technological and economical point of view.

The above mentioned Technological Centres, the DIDSOLIT-PB Technical Team and the installation company of the Pilot have been intensely involved, through internal meetings, trainings and open conferences.

As a result of this process, the referred Centres have produced and delivered three reports to us: *"DS viability study"*, "*DS Executive project*" and "*DS Pilot*". [1]

Then, building on them, we have prepared an operative document that is suitable for our Project applications: **DS Conceptual design** (our ref. T4.2.3.2 DS)[2]. This document aims at being a synthesis of all this exhaustive material.

1. A compact version,prepared by us,of these two reports made by the technological centres ("*Dish Stirling's technical assessment and designing of scaled down systems, for in-building integration*", ref. TechC_1_DS) may be available upon request.

2. Which may also be made available upon request

1. CONCENTRATED SOLAR TECHNOLOGIES

In recent years, increasing global electricity needs, fossil fuel shortage and awareness of global warming have made solar energy an attractive energy source. The solar energy industry is now entering a commercial ramp-up phase.

There are two main approaches to generate power from sun radiation [1]:

- **Photovoltaic** (PV) or **Concentrated Photovoltaic** (CPV) technologies are a method of generating electric power by converting solar radiation into direct current electricity, using semiconductors that evidence photovoltaic effect[1].
- **Concentrated Solar Power** (CSP) technology is a method for generating electric power by concentrating solar thermal energy onto a receiver in order to heat a fluid, which circulates inside the receiver. The fluid drives, directly or indirectly, a heat engine, subject to a thermodynamic cycle, which converts solar thermal energy into kinetic energy, and finally, into electricity through an electric generator [1][2][3][4].

1.1. Technologies options and classification

Based on the electric generation capacity, CSP technologies can be divided into four groups, defining as large-scale everything over 1 MW, medium-scale everything under 1 MW, small-scale everything under 500 kW, and finally, micro-scale for everything under 20 kW [5].

Concentrated Solar Power technologies can be divided into two groups, based on whether solar collectors concentrate the sun rays along a focal line or on a single focal point [2][3][4][6]:

- **Line-focusing systems** track the Sun along a single axis and focus irradiance on a linear receiver, which makes tracking simpler. Line systems concentrate radiation about 100 times, and achieve working temperatures of up to 550°C. Parabolic Trough (PT) and Linear Fresnel Reflector (LFR) systems are line-focusing systems.
- **Point-focusing systems** track the Sun along two axes and focus irradiance at a single point receiver, which allows higher temperatures. Point systems can concentrate far more than 1,000 times and achieve working temperatures of more than 1,000°C. The following systems, Solar Dish (SD), which may be referred to as Dish Stirling (DS) or Parabolic Dish, and Solar Tower (ST), which may be referred to as Central Receiver, are point-focusing systems.

Moreover, the solar receiver can be divided into two types, based on whether the receiver is fixed or mobile [2][3][4][5][6]:

- **Fixed receivers** are stationary devices that remain independent from the plant's focusing device. This eases the transportation of collected heat to the power block.
- **Mobile receivers** move together with the focusing device. In both lines, focus and point focus designs, mobile receivers collect more energy.

So, there are four main CSP technology families, which can be categorized by the way they focus sun rays and the technology used to receive solar energy. Four main elements are required: a concentrator, a receiver, some form of transport media or storage, and power conversion. The Fossil-fired Back-up system is an alternative component of CSP plants [2][4][6].

In Figure 1, the scheme of concentrating solar collector and concentrating solar thermal power plant is presented.

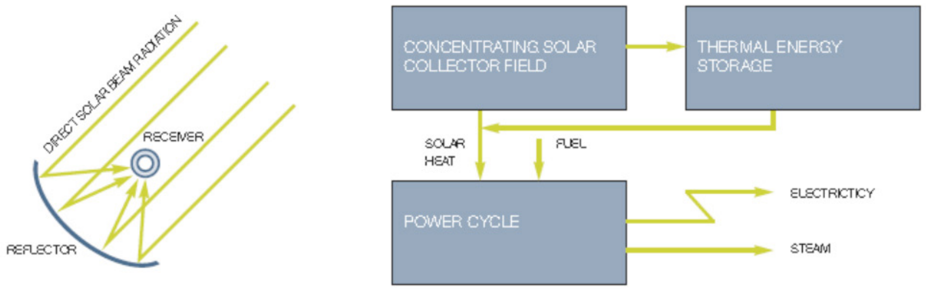


Figure 1 Scheme of concentrating solar collector and CSP plant. Source: [4]

- **Parabolic Trough (PT)**

Parabolic trough-shaped mirror reflectors are used to concentrate sunlight onto thermally efficient receiver tubes, which may be fixed or mobile, placed in the trough's focal line. The troughs are usually designed to track the Sun along one axis, predominantly north–south. A heat-transfer medium that circulates inside the receiver absorbs the highly concentrated radiation reflected by the parabolic trough-shaped mirrors converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine, an organic Rankine cycle turbine or a Stirling engine. To date, the heat transfer media demonstrated include water/steam, mineral and synthetic oils and molten salts. The Hybrid operation and thermal storage are possible[2][3][4].

- **Solar Tower or Central Receiver (ST)**

A circular array of heliostats (mirrors with sun tracking motion) concentrates sunlight onto a fixed central receiver mounted on the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by heliostats and converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine, a gas turbine or a gas and steam combined cycle. To date, the heat transfer media demonstrated include water/steam, molten salts and air. The Hybrid operation and thermal storage are possible[2][3][4].

- **Dish Stirling, Solar Dish or Parabolic Dish (DS)**

A parabolic dish-shaped reflector concentrates sunlight onto a mobile receiver located at the focal point of the dish. The mirrors are usually designed to track the Sun along two axes. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas (air) which is then used to generate electricity in a small piston or Stirling engine or a micro turbine, attached to the receiver. The Hybrid operation and thermal storage are under research and development. [2][3][4].

- **Fresnel Linear Reflector (FLR)**

An array of nearly-flat reflectors concentrates solar radiation onto elevated inverted linear receivers. The mirrors are usually designed to track the Sun along one axis, predominantly north–south. A heat-transfer medium that circulates inside the receiver absorbs the concentrated radiation reflected by the mirrors and converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine. To date, the heat transfer media demonstrated is water. The Hybrid operation and thermal storage are possible [2][3][4]. This system is similar to Parabolic Trough.

Figure 2 shows the four main Concentrated Solar Power technologies families.

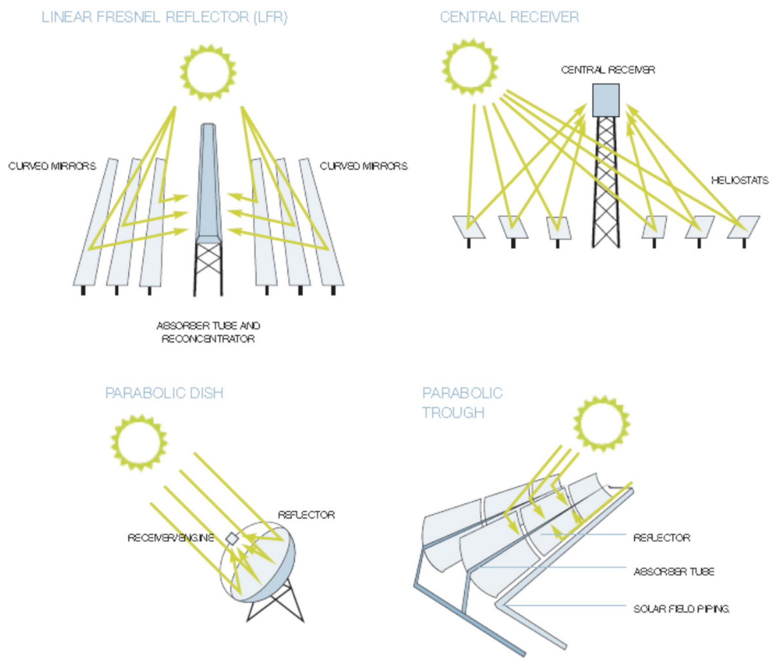


Figure 2 Concentrated Solar Power technology families. Source: [4]

2. DISH STIRLING TECHNOLOGY

The Dish Stirling Technology (DST) is the oldest technique to obtain electricity from solar energy. At the beginning, it was used together with a Rankine cycle, but it was also tried with a Stirling engine. Up until the 1970's, however, there had been poor development, so the technology that we know nowadays started then.

The Dish Stirling Technology is characterized by its modularity and high efficiency for small power (in the order of some kW) compared with other concentrated solar power technologies [7]. DST efficiencies usually range between 14% and 32% [8]. In addition,DST can achieve temperatures of 1500 to 2000ºC.

However, the usual working temperatures are between 600-800ºC [9]. Dish Stirling systems are the most efficient solar energy systems, having sizes that typically range from 5 to 15 m in diameter or 5 to 25 kW per dish [10].

The principle of operation of a DST is to concentrate solar radiation, through a parabolic dish reflector to a receiver. The receiver absorbs solar radiation and converts this into thermal energy. Then this energy is transformed into mechanical energy through the Stirling engine, and it is finally transformed into electric energy through an electric generator.

2.1. Dish Stirling system

A Dish Stirling System (DSS), shown in Figure 3, is a point-focus solar collector that tracks the Sun in two axes through a solar tracking system, concentrating solar energy onto a receiver located at the focal point of the dish. The dish structure must track the Sun fully to reflect the beam into the thermal receiver. In addition, the dish structure and support has to bear the system during normal operations and adverse weather conditions.

The Power Conversion Unit (PCU) absorbs the radiant solar energy through the receiver, and then the Stirling engine converts thermal energy into mechanical energy. Finally, mechanical energy can be either converted into electricity using an electric generator, or again into thermal energy, using the heat losses of the engine. Sometimes, it is also necessary to condition the output power extracted from the electric generator. Finally, the PCU also contains a cooling system that is used to evacuate excess thermal energy, which can be used for cogeneration systems.

As shown in Figure 3, the Stirling dish is composed of different parts. A basic overview of the main components will be seen later in this document.

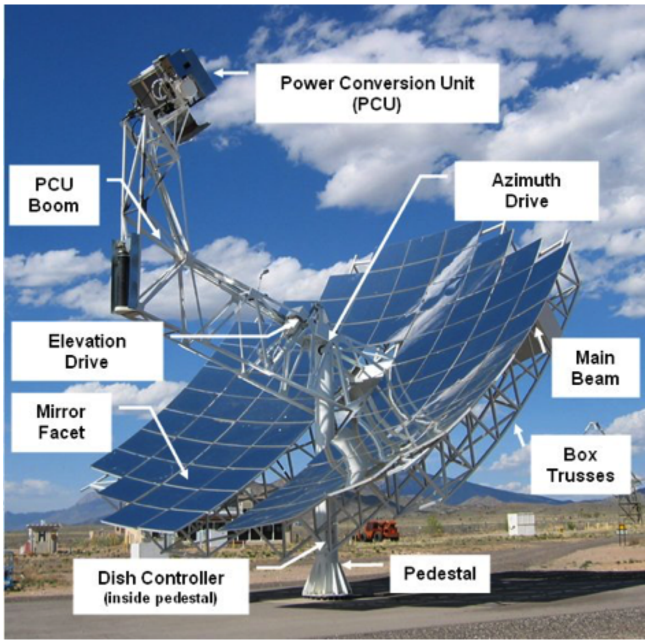


Figure 3. Dish Stirling System. Source [11]

2.1.1. Solar field

- **Solar collector**

The solar collector or concentrator is the part of the Dish Stirling that receives solar irradiance and, as its name suggests, it concentrates it in a very specific spot, the focal point. It has a parabolic shape, as it is the only shape that ensures that it does not matter where sun rays come from, they will end up being reflected into the focal point. Depending on costs and capabilities of the manufacturer, this parabolic shape can be achieved with a single parabolic mirror, hundreds of small round pieces, several trapezoidal panels, etc.

They are made of reflective surface materials in order to be able to reflect as much light as possible to the concentration focus. The materials are still under development and can go from a glass and silver combination, similar to normal mirrors, to polymeric materials capable of reflecting sunlight.

Nowadays, depending on the materials used, cleanliness... the solar reflectance yield of the concentrators varies between 90% and 94% [12].

Depending on the size of the dish and on its quality, the concentration ratio of solar energy can reach 3000 [10]. This ratio is one of the ways we have to evaluate a dish system, as it is equal to solar incidence in the focal point divided by direct normal solar incidence. It means to what extension the dish is able to concentrate sun rays.

The diameter of the dish will depend on how much energy is needed to produce, and it can vary from 3 m to 20-25 m [9].

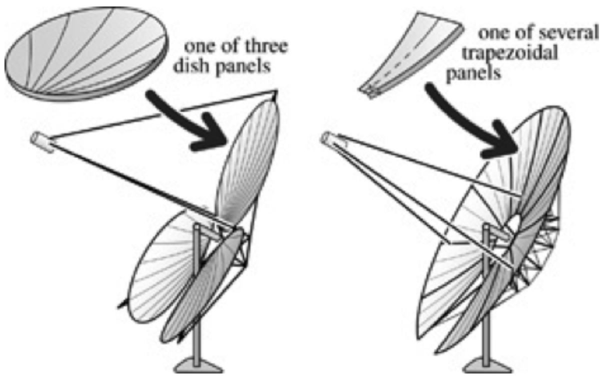


Figure 4. Example of one-shape parabolic reflector or multiple spherically-shaped reflectors. Source [13]

- **The receiver**

The receiver is located exactly on the focal point of the parabolic dish. Its purpose is to gather all the concentrated radiation and transfer it, as thermal energy, to the Stirling engine working fluid.

There are two different kinds of receivers, the externals and the cavity ones. The externals are spherical and use radiation coming from every direction. Its shape ensures more solar rays arriving, but it has more thermal losses. The cavity ones receive sun rays internally. There are less thermal losses, but not all of the solar energy arrives into it. The cavity receivers are used more frequently as far as the receiving surface can be bigger than the other one, because light passes through the focal point (minimum area) and reaches the receiving surface (bigger area of energy exchange), reducing the thermal stress of the materials. In the external receiver, this combination is harder to achieve. Moreover, the cavity system helps to prevent the receiver from getting some dirt.

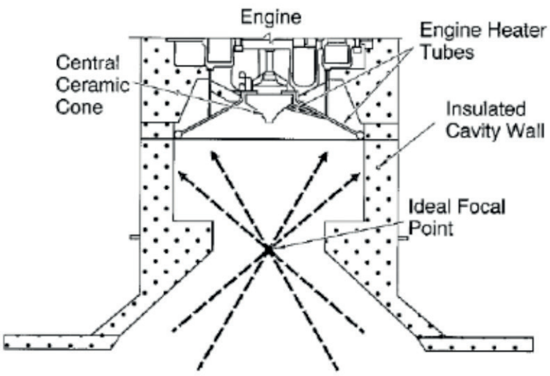


Figure 5 Cavity receiver. Source [9]

There are other receivers for parabolic concentrators like for example hybrid receivers, which combine heat from solar collectors and heat generated by burning a combustible; and volumetric receivers, which are designed to heat a gas and drive a turbine, but this document does not focus on them [14].

After receiving the energy, it must be transferred to the engine. It can be done through a direct insulation receiver, which works directly heating the engine working fluid, or through the reflux receiver, which has an intermediate gas and a heat exchanger in between.

It is important to choose the materials properly in this part of the Dish Stirling, as it is the part that will suffer more thermal fatigue out of all the components of the system.

- **Structure and support system**

The structure and support must bear the system during normal operations and adverse weather conditions and it must also track the sun fully. Most current designs fall into the three categories described below [9]:

Structural optical surface: this system uses the reflectors themselves as the main structural part of the whole dish. Every mirror gore or small honeycomb mirrors are bolt with each other, making a structure that can suffer structural inefficiencies and warpage. This kind of structure is not very common.

Space frame: this option separates the optical elements from the structure. This structure is robust and efficient. In addition, this is recommendable for high power DSS and it is usually composed of several mirrors.

Figure 6 Space frame. Source: [15]

Membrane frame, this system uses a concave membrane to do a reflective surface which is very light. This enables producing a reflective dish composed by just one piece. It is structurally better and easier to maintain, but its production is more difficult.

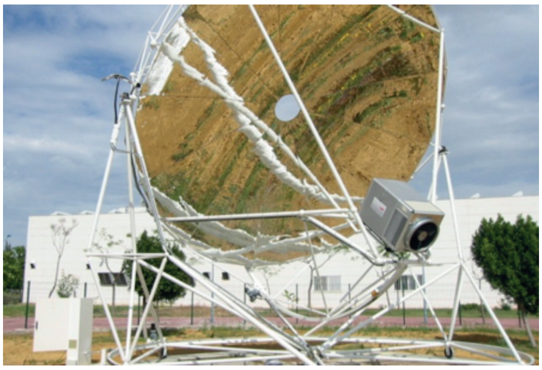


Figure 7. Membrane frame. Source: [16]

- **Solar tracking system**

A solar tracker is a device that positions the Dish Stirling System in the Sun's direction. The tracking systems have the following characteristics [17]:

- Single column structure or a parallel console type
- One or two moving motors
- Light sensing device
- Autonomous or auxiliary energy supply
- Light following or moving according to the calendar
- Continuous or step-wise movement
- Positioning adjustment with/without the tilt angel adjustment

In order to properly follow the Sun, the system must have two different movement axes. It can be done with the following combinations [9]:

- **Azimuth-elevation tracking.**The dish rotates in a plane parallel to the Earth (azimuth) and in another plane perpendicular thereto (elevation).
- **Polar tracking method.**The collector rotates about an axis parallel to the Earth's axis of rotation. The collector rotates at a constant rate of 15 degrees per hour, the same rotation rate as the Earth's. The other axis of rotation, the declination axis, is perpendicular to the polar axis. Movement about this axis occurs slowly and varies by ± 23 degrees and 27 minutes over a year.

2.1.2. Stirling engine

The Stirling engine is the engine which converts heat into mechanical power, which is the main difference with a conventional combustion engine. Thermal energy must be transferred into and out of a Stirling engine via heat exchangers at the hot and cold focuses. The Stirling engine relies on an external source for heat input, the cycle itself operating as a closed system since the working fluid is contained within the cylinders and not vented to the atmosphere like exhaust gases from internal combustion engines.

In theory, the Stirling engine is the most efficient device to convert heat into mechanical work. However, it requires high temperatures. The concentrating solar collectors can produce the high temperatures required for efficient power production, therefore the Solar Dish with a Stirling engine is a good match for the production of solar electricity [9]. Additionally, the system can produce domestic hot water using the residual thermal energy. In addition, it has been shown that the ideal Stirling engine also has the maximal mechanical efficiency within a fair comparison class of reciprocating engines [18].

In the ideal Stirling cycle, the working gas is alternately heated and cooled by two constant-temperature and two constant-volume processes. Moreover, Stirling engines usually incorporate an efficiency enhancing regenerator that captures heat during constant-volume cooling and replaces it when the gas is heated at constant-volume. Figure 8 shows the ideal and real PV diagram for a Stirling engine [19].

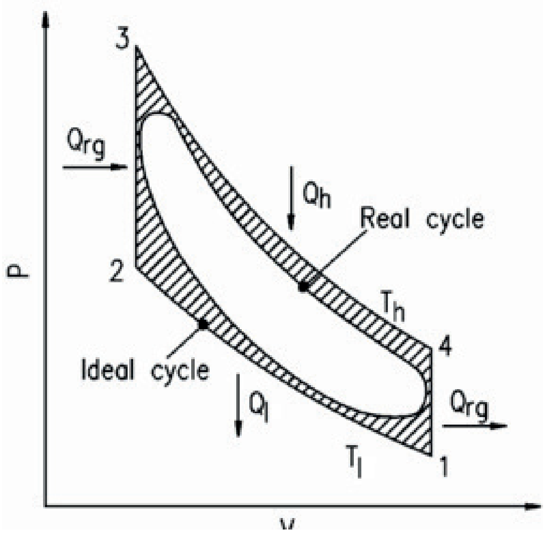


Figure 8. PV diagram for Stirling engine. Source: [20]

Stirling engines operate at the thermal limits of the materials used for their construction. The typical temperatures range from 650ºC to 800ºC, resulting in engine conversion efficiencies about 30% to 40% [9].

Advantages of Stirling Engines

- Maximum potential efficiency for a heat engine operating in the same temperature range.
- Flexible fuel usage such as biomass, solar, geothermal, waste heat, and fossil fuels.
- Lower nitrogen oxides compared to internal combustion engines.
- Quiet and minimal vibration.
- Free-piston Stirling engines are highly reliable.
- Stirling engines allow for operations such as a refrigerator or a heat pump.
- They have the highest specific work output for any closed regenerative cycle.

Disadvantages of Stirling Engines

- Stirling engines often have a slow response to a load increase or decrease.
- Lower specific power output, so added weight and volume would be less practical for automotive purposes.
- Hydrogen or helium seals can be problematic for kinematic Stirling engines.

Stirling engine classifications:

There three typologies of Stirling Dishes; alpha, beta and gamma:

- **Alpha Stirling:** Alpha engines have two separate power pistons in separate cylinders which are connected by a heater, a regenerator and a cooler. The cold focus, as the hot focus, is formed by a cylinder and a power piston. As it has power pistons in both focuses, cold and hot, it has problems with the seals of the hot focus. There is high temperature in the hot focus, and it is complicated to properly seal the used gases, basically Hydrogen or Helium, at those temperatures.

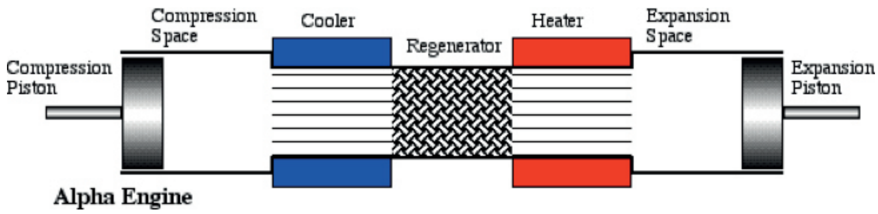


Figure 9 Alpha Stirling scheme. Source: [21]

- **Beta Stirling:** The beta engines were the first Stirling engines to be discovered in the 19th century. Itsr main particularities is that it has just one cylinder and instead of having two power pistons; it has one power piston and one displacer piston. The use of the displacer piston is to move the working fluid from the hot focus to the cold focus and vice versa. The displacer does not help the power piston in extracting energy from the cycle, but its moving role is fundamental in the operation of the Stirling engine. As it only has one power piston and it is in the cold focus, it is much simpler to seal the system properly, avoiding gas leakages and durability problems.

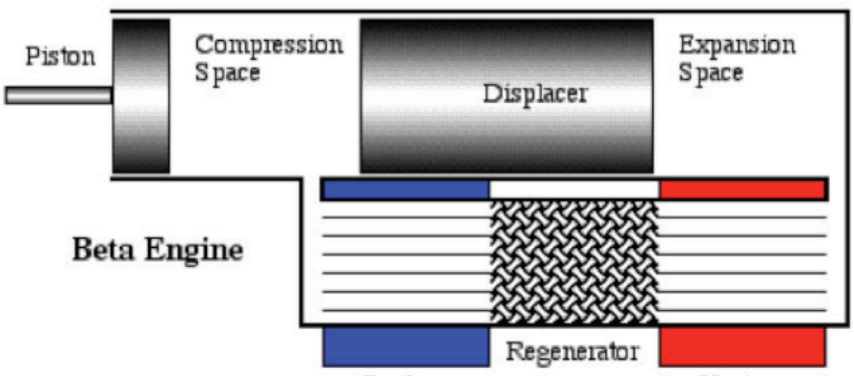


Figure 10 Beta Stirling scheme. Source: [21]

- **Gamma Stirling:** Gamma engines are very similar to the beta ones. Their only difference is that the power piston is build inside another piston which is physically connected to the displacer piston. The gas flows freely between both cylinders. This configuration produces a lower compression ratio than the others, but it is mechanically simpler, so it is often used in multi-cylinder Stirling engines, to have some equilibrium between power and mechanical complexity.

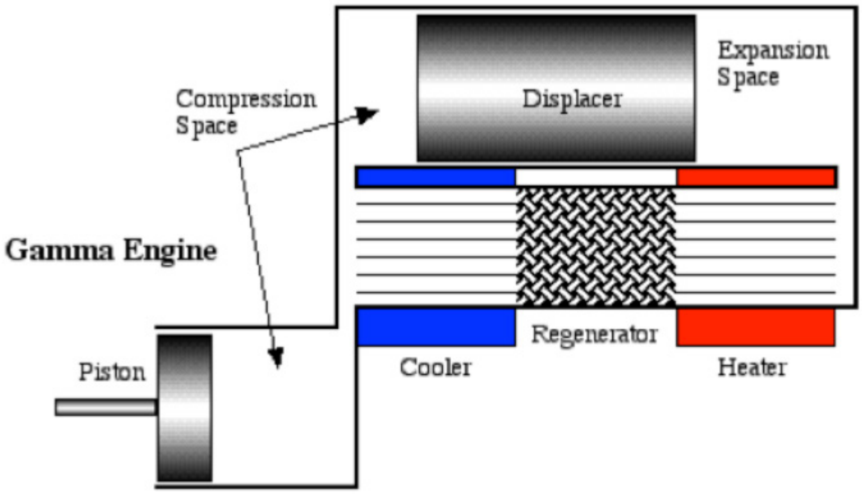


Figure 11. Gamma Stirling scheme. Source: [21]

These three kinds of Stirling engines are divided in turn into another two groups, depending on how the piston and displacer are physically connected to the system:

- **Kinematic**: The power piston of a kinematic Stirling engine is mechanically connected to a rotating output shaft. If there is a separate gas displacer piston, it is also mechanically connected to the output shaft. This facilitates the control of the rotation speed of the system, a very important factor related to generation frequency.

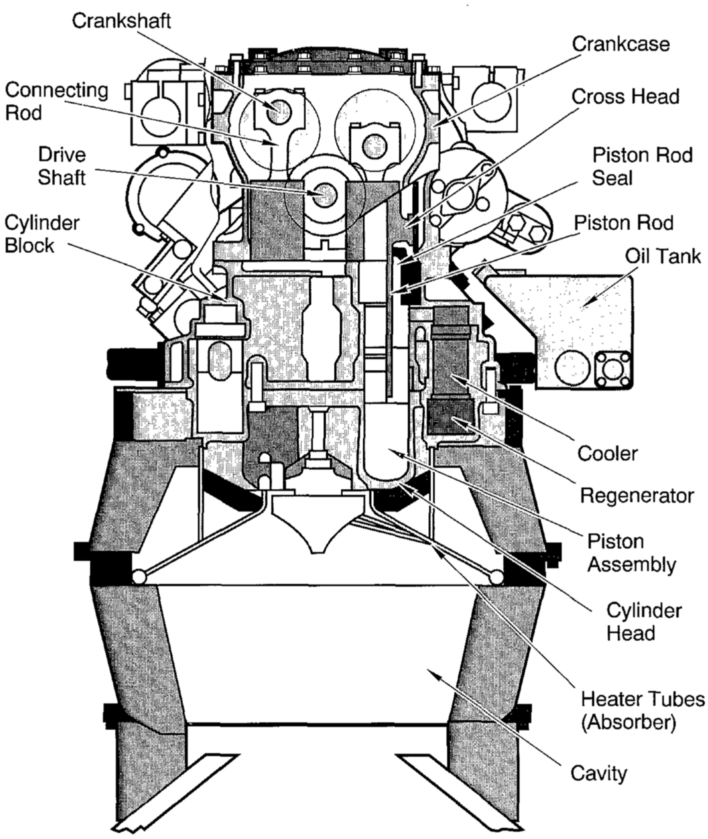


Figure 12 Kinematic Stirling engine. Source [9]

- : The power piston is not mechanically connected to an output shaft. It bounces alternately between the space containing the working gas and a spring. The bouncing frequency is determined by the spring and system mass. A magnet is attached to the power piston to be able to extract electric energy. It is simpler, cheaper and more durable, but harder to control as it moves freely, so the design must be very accurate.

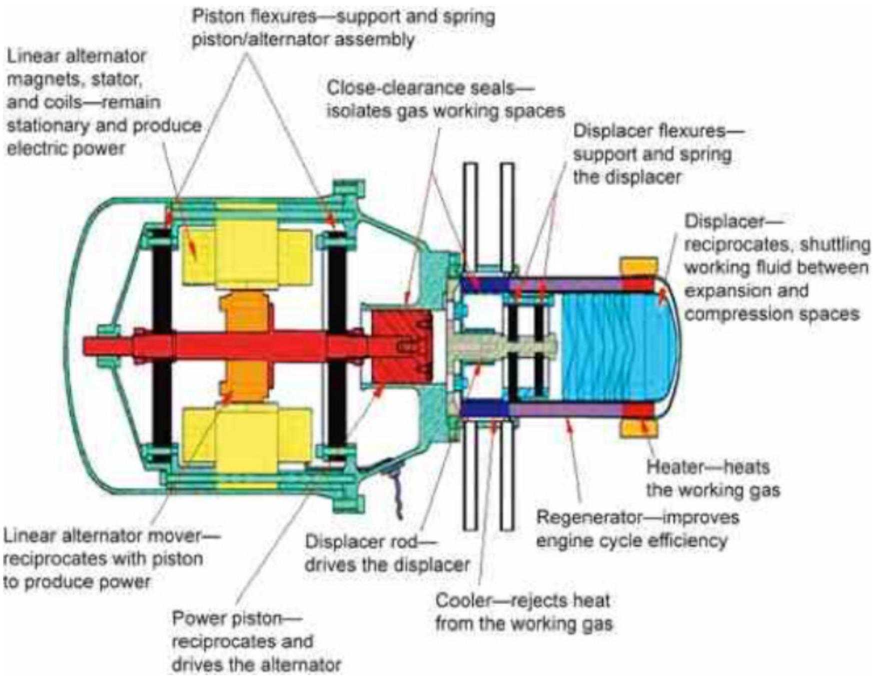


Figure 13 Free-piston engine. Source [22]

The choice of working fluid is also important, as it provides some of the main parameters and characteristics of the thermodynamic cycle. Four main aspects must be taken into account when choosing the working gas:

- Heat capacity: It is the factor which will determine the shape of the thermodynamic cycle and its properties. The higher it is the better, as it will have a faster and better capacity of exchange energy between the cold and hot focus.
- Security: There are some gases that can explode when they mix with air, so if the case, it will be very important to ensure that nothing can ever scape from the sealed Stirling, as it could become dangerous.
- Economics: The costs of the different working fluids can vary significantly, so it will be another important factor when deciding about the working fluid.
- Chemical reactivity: It is important that the gas used does not interfere with the materials of the system, as the reliability of the system would be affected.

Taking into account only the first factor, Hydrogen would be the chosen gas, as it has the best heat capacity out of all gases. The problem with this gas arises with safety and its chemical reactivity. Hydrogen is very explosive in almost every mixture with air, so any small leakage would be very dangerous. Moreover, as it is the one with the smallest molecule and given its high chemical reactivity, it can flow through the materials and react with most of the components of the Stirling engine, mainly metals.

The second gas with the highest heat capacity is Helium. It is the cheapest of the noble gases, which are characterized by not being reactive with almost any chemical compound. Moreover, as it is not reactive, it would not be dangerous if there was a leakage problem, thus solving the safety issue.

Other gases that would be cheaper than Helium are air and Nitrogen (very similar to air). Anyway, their heat capacity is so small compared to that of Helium that they would never be chosen to build a Stirling engine.

To finalise, Helium is the best choice in general to build a new Stirling engine, as far as it is the second gas with the highest heat capacity and being there no other negative factor that would make us disregard it.

The power of Stirling engines can be controlled by altering the temperature, pressure, stroke, angle, phase, dead volume, speed or load. Each methodology has its own advantages and disadvantages. Note that regulating the speed of the Stirling engine is required to extract maximum power. In case of constant speed engines, the efficiency is lower than variable speed engines. However, the efficiency can be improved by varying load conditions [18].

2.1.3. Electric Generator

The electric generator is responsible for transforming the mechanical energy into electric energy. There are many types of electric generators, the most common being asynchronous machines, although there are also synchronous, brushless or DC machines. In general, asynchronous machines are cheaper and can also start at the network frequency. In addition, asynchronous machines can be used like a generator or an engine, and in the case of Dish Stirling, they are used to start the Stirling engine. Synchronous, brushless or DC machines, which need to condition their waveforms, are more expensive, more complex and more uncommon in Dish Stirling applications. Moreover, the machines can be rotating or lineal depending on the typology of the Stirling engine, i.e. if it is a kinematic or free-piston engine. Figure 14 shows the conversion from a rotating machine to a lineal machine.

Figure 14. Conversion of a rotating machine to a lineal machine. Source [23]

In addition, many types of generators produce reactive power with low associated operation cost. However, for small generators, the major drawback of generators based on power factor correction options is a relatively higher initial equipment cost. Using synchronous generators, doubly feed induction generators or DC generators, also requires redesigning other parts of the system. This is why induction generators will usually be used in these systems [24].

The main problem of using asynchronous generators is that there is not control over the reactive power consumed. Since the requirement is to provide the power factor at the point of interconnection, a small amount of Vars will be needed. Capacitors must therefore provide reactive power to offset this reactive power consumption [24].

2.1.4. Power conditioning

Power conditioning is not basic in all DSS, only the most complex DSS has it. Power conditioning is responsible for adapting the output power system. In general, it adapts the reactive power. However, there are some aspects that are more important such as the waveform of the supply voltage. It is known that the performance of Stirling engine depends on engine speed. Therefore, if the electric generator speed can vary the Stirling engine, performance improves and more power is obtained. To vary the speed, it is necessary to change the width or frequency of the supply.

In addition, it is necessary to know the performance curves of the Stirling engine to implement the control which will find the optimum operating point. It is necessary to note that, in this case, the system includes another step which represents an increase in cost, volume and weight, being there also a power lost in the converter.

2.1.5. Cooling system

In order to be able to achieve the correct temperatures in the different parts of the Stirling engine,we need to have thermal exchangers; cooling and heating fluids. Their main purpose is to get the cold focus at the correct low temperature to maintain the Stirling engine working properly.

Initially, most DSS shave only been conceived to generate electricity and the cooling system was designed like Figure 15. However, DSS can be a source of heat which warms water and enables the use of waste heat as something valuable. Some types of DSS have a cooling system like Figure 16.

In this second configuration, the radiator and fan are only used as an auxiliary system to cool the refrigerating liquid, if there is not enough hot water consumption to dissipate all the produced heat. In this case, the main dissipation system is the water heat exchanger, from where it is possible to obtain thermal energy by using the hot water.

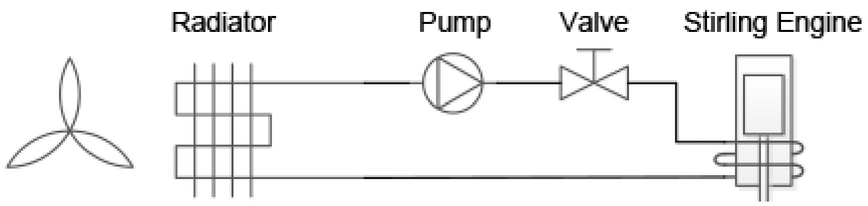


Figure 15 Cooling system

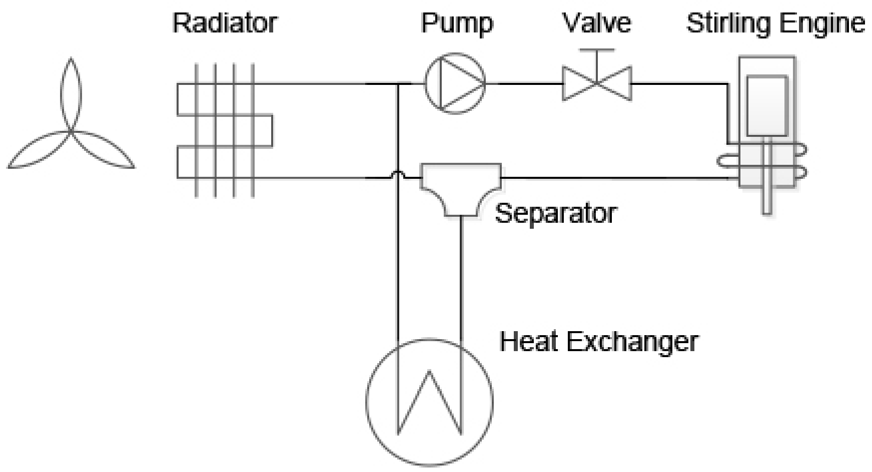


Figure 16. Cooling system with thermal energy use

Usually, every DSS uses a fan and plate-finned radiator to reject the thermal load from the cooler into the atmosphere using a cooling fluid loop. The fan typically consumes the greatest fraction of the parasitic power. A water pump is used in the cooling fluid loop to pump the cooling fluid through the cooler and/or radiator. If the DSS uses thermal energy, a valve separator is used to separate the cooling fluid between the radiator with fan and the heat exchanger depending on the temperature of the heat exchanger.

Finally, note that the piping provides the path to transport the fluid in the system. The piping must be compatible with system temperatures, pressures and other components. Most systems use copper piping because of its durability, resistance to corrosion and ability to withstand very high temperatures. Also, piping usually has insulation to reduce thermal loss. Copper, brass and bronze are normally the only materials used in active direct solar systems using potable water. In cases where galvanized piping already exists, it should either be replaced, or dielectric unions should be used to isolate the different metals.

2.1.6. Storage

As the DSS is a cogeneration system, it is possible to have two kinds of energy storage:

On the one hand, it is possible to store thermal energy by having a water heating deposit, where hot water arrives and from where the cold fluid is taken to be entered again into the Stirling engine. When needed, it is possible to obtain this stored thermal energy through the use of the accumulated hot water.

On the other hand, it is possible to store the electricity generated through the use of batteries, which will take the electricity when generated and it will release it when it is needed, independently from the amount of sun there is in that precise moment in the sky. Although this can be done, it causes greater problems than thermal storage, given that stored electricity is much harder to control than stored heat.

2.2. State of the art

CSP technologies have been mainly implemented at medium and large scale, looking for the optimization of the construction and operation costs of these highly technical systems.

The following table shows the main Dish Stirling System applications in the world (until 2013).

Table 1 Facilities

Company	Project	Location	Total Power	Nº of units	Building year	Comments	Ref.
Innova	Trinum	Monteodorisio, Italy	2 kWe	2	2011	Similar trials in other Italian cities.	[25]
Infinia		Kirtland Air Force Base, in New Mexico, USA	21 MWe	6	-	Shared with Stirling Engine Systems and Sandia National Laboratories	[26]
Infinia	Helios Power	Cyprus	50 MWe		-	This project is in development	[27]
Infinia	Maximus	Greece	75 MWe	16,920	-	This project is indevelopment	[27]

Company	Project	Location	Total Power	Nº of units	Building year	Comments	Ref.
United Sun Systems		Maricopa Park, Arizona, USA	1,5 MWe	25,160	2010	It was initially from Stirling Engine Systems	[28]
Ripasso Energy		Upington, Republic of South Africa	60 kWe	60	2012	Solar yield record: 32%.	[8]
Cleanergy		Ordos desert, Mongolia	100 kWe		2012		[29]
	Megha	India	50 MWe	2	-	This plant is under construction	[30]
	Gujarat Solar One	India	25 MWe		-	This plant is under construction	[30]
	MNRE R&D Project	India	1 MWe	10	-	This plant is under construction	[30]
	Indian Institute of Technology CSP Project	India	3. MWe	-		This plant is operational	[30]
	ABhijeet (Corporate Ispat Alloys)	India	50 MWe	-	-	This plant is under construction	[30]
	Godawari	India	50 MWe	-	-	This plant is under construction	[30]
	Lanco Solar	India	100 MWe			This plant is under construction	[30]
	Rajasthan Solar One	India	10 MWe	-		This plant is under construction	[30]
	KaXu Solar One	South Africa	100 MWe	-	-	This plant is under construction	[30]
	Bokpoort	South Africa	50 MWe		-	This plant is in development	[30]
	Fort Irwin	USA	500 MWe		-	This plant is in development	[30]
	Genesis Solar 1	USA	125 MWe	-	-	This plant is under construction	[30]
	Genesis Solar 2	USA	125 MWe	-	-	This plant is under construction	[30]
	Holaniku at Keyhole Point	USA	2 MWe	-	-	This plant is operational	[30]
	Keahole Solar Power	USA	5 MWe	-	-	This plant is under construction	[30]

Company	Project	Location	Total Power	Nº of units	Building year	Comments	Ref.
	Martin Next Generation Solar Energy Center	USA	75 MWe	-	-	This plant is operational	[30]
	Mojave Solar Project	USA	280 MWe	-	-	This plant is under construction	[30]
	Nevada Solar One	USA	64 MWe	-	-	This plant is operational	[30]
	Palmdale Hybrid Gas-solar Project	USA	50 MWe	-	-	This plant is in development	[30]
	Saguaro Power Plant	USA	1.16 MWe	-	-	This plant is operational	[30]
	SEGS I	USA	14 MWe	-	-	This plant is operational	[30]
	SEGS II	USA	33 MWe	-	-	This plant is operational	[30]
	SEGS IV	USA	33 MWe	-	-	This plant is operational	[30]
	SEGS V	USA	33 MWe	-	-	This plant is operational	[30]
	SEGS VI	USA	33 MWe	-	-	This plant is operational	[30]
	SEGS VII	USA	33 MWe	-	-	This plant is operational	[30]
	SEGS VIII	USA	89 MWe	-	-	This plant is operational	[30]
	SEGS IX	USA	89 MWe	-	-	This plant is operational	[30]
	Solana	USA	280 MWe	-	-	This plant is under construction	[30]
	Victorville 2 Hybrid Power Project	USA	50 MWe	-	-	This plant is in development	[30]
	CSP Pilot Plant	China	10 MWe	-	-	This plant is under construction	[30]
	Erdos Project	China	50 MWe	-	-	This plant is under construction	[30]
	Gansu, Jinta	China	50 MWe	-	-	This plant is in development	[30]
	Ningxia ISCC	China	92.5 MWe	-	-	This plant is under construction	[30]
	Qinghai	China	50 MWe	-	-	This plant is in development	[30]
	Ain-Beni-Mathar ISCC	Morroco	20 MWe	-	-	This plant is operational	[30]

Company	Project	Location	Total Power	Nº of units	Building year	Comments	Ref.
	Ouarzazate	Morroco	160 MWe	-	-	This plant is in development	[30]
	Solar Oasis	Australia	43.5 MWe	-	-	This plant is in development	[30]
	PSA	Spain	56 kW	-	1992-97	This plant is operational	[31]

2.3. Market availability

The DIDSOLIT-PB project has focussed its research on small scale innovative solar systems, that can be integrated into public buildings, either ground or roof mounted.

Small scale Dish Stirling units are a small market niche, and, nowadays, few manufacturers and suppliers prioritize them in their business model.

An intensive benchmark has been conducted in order to identify the most suitable, technically mature and market available options.

The following benchmark summary includes both medium and small scale Dish Stirling manufacturers.

2.3.1. Innova Solar Energy

Innova Solar is an Italian company which develops new solar technologies, searching for concentration alternatives to what we already have today [25].

Innova has already launched its Dish Stirling based on electric and thermal cogenerates with peak power of 1 kWe and 3 kWt. The Dish Stirling is called Trinum, and has a 3.75m diameter dish. Trinum uses a small free piston Stirling to be able to develop the needed thermodynamic cycle [32].

It is a completely automatic system which is able to track the Sun, generate electricity and thermal energy and even goes into safety mode in case of strong winds, rains or overheating of the system.

The overall conversion efficiency of the system is 55.2%, composed by a 13.8% electric and 41.4% thermal yields [32].

They have trial facilities composed by one or two dishes in some Italian cities such as Lettomanoppello (Pescara), Monteodorisio (Chieti), Torino di Sangro (Chieti), Roccamontepiano (Chieti), etc. [25]

Table 2. Characteristics of Trinum by Innova [32]

Company	Product name	Electric Power/Unit	Thermal Power/Unit	Diameter	Weight	Working fluid	Performance
Innova	Trinum	1 kWe	3 kWt	3.75 m	600 kg	Helium	13.8%el 41.4%th

Figure 17. Trinum by Innova. Source [25]

2.3.2. Energon

Energon is a Mexican company thatwas founded in 2008 and developed an investigation of theDish Stirling prototype. They assure they have designed a system which is capable of producing 1.5 kWe and 4.5 kWt with a 3.75m diameter dish [33]. The assumed yields,when reaching such good productions, to be 20% electric and 55% thermal efficiencies.

Table 3. Product by Energon characteristics [33]

Company	Product name	Electric Power/ Unit	Thermal Power/ Unit	Diameter	Weight	Working fluid	Performance	Others
Innova	Not defined	1.5 kWe	4.5 kWt	3.75 m	450 kg	Not defined	≈20%el ≈55%th	It is a prototype

Figure 18. Prototype Stirling Dish by Energon Industries. Source [33]

2.3.3. Stirling Engine Systems

It is a USA company that has worked for the aerospace and defense department of their government.

They produced a 25 kWe dish which has been developed during the last 40 years. They had a trial facility at the Kirtland Air Force Base and also a 1.5 MW power plant, composed of 60 SunCatcher systems in Arizona, called Maricopa Park [34].

They went bankrupt in 2011.

2.3.4. Infinia Solar

It is a company from the United States of America. They have been developing the Dish Stirling technology for some years now [35]. Firstly, they tried to develop small scale systems for small scale productions, but lately, they decided to change their project and use small scale products to feed big scale projects. This is the reason why they produce Stirling dishes of 3.5 kWe but they sell them in 64 unit packs.

In this case, the dish has a 7 m diameter. Another particularity of this product is that it does not do heat recuperation to produce thermal energy. It is completely focused on producing electricity. Anyway, it is necessary to have a heat dissipation system.

They have a trial DSS facility at the Kirtland Air Force Base, in New Mexico, USA. Six of their Stirling dishes are being tested in one of the sunniest zones of the USA together with other DSS from Stirling Engine Systems and Sandia National Laboratories [36].

Table 4.Characteristics of PowerDish by Infina [37]

Company	Product name	Electric Power/Unit	Diameter	Weight	Working fluid	Performance	Other
Infinia	PowerDish	3.5 kWe	6 m	1,525 kg	Helium	≈30%	It is not available individually, the minimum pack is composed of 64 units

Figure 19. PowerDish by Infinia. Source: [37]

2.3.5. United Sun Systems

United Sun Systems is a company born in Sweden and the United Kingdom [28].

They produce solar dishes aimed at the mid or big scale. Their Stirling dishes are able to produce 25 kWe. It is a much bigger construction which needs a higher level of design, but it becomes cheaper as it requires building less units to achieve the desired power supply.

They bought the Maricopa Park, in Arizona, after Stirling Engine Systems went bankrupt.

Table 5. Product characteristics by United Sun Systems [28]

Company	Product name	Electric Power/Unit	Diameter	Weight	Working fluid	Performance
United Sun Systems	Not specified	25-30 kWe	11.73 m	6800 kg	Hydrogen	≈30%

Figure 20. Product by United Sun Systems. Source: [28]

2.3.6. Ripasso Energy

Ripasso Energy is a private company which was founded in 2008.

It is a Swedish manufacturer which also produces big Stirling dishes in order for each unit to be able to generate around 30 kWe [38].

To achieve this power production, the dishes must have a very considerable diameter, but there is no information about this. In these cases, it would be impossible to adapt these dishes to a building, as they must necessarily be installed on the ground.

They have the Dish Stirling world efficiency record, and they are located in South Africa. It reached a 32% [8] solar yield in electricity production, compared with PV, which reached between 10% and 20%. It is a big improvement.

Table 6. Product characteristics by Ripasso [38]

Company	Product name	Electric Power/Unit	Diameter	Weight	Working fluid	Performance	Other
Ripasso Energy	Dish Solar	30 kWe	Not specified	Not specified	Hydrogen	≈30%	No more information

Figure 21. Dish Solar by Ripasso Energy. Source [38]

2.3.7. Cleanergy

Cleanergy is also a Swedish company which has developed a 11 kWe Dish Stirling [29].

The information provided is very scarce and they only sell the system in packs of a considerable amount of units. They have some demonstration parks in Asia, as the one they have in the Ordos desert, in Mongolia [29].

Table 7. Product characteristics by Cleanergy [29]

Company	Product name	Electric Power/Unit	Diameter	Weight	Working fluid	Performance	Others
Cleanergy	Not specified	11 kWe	Not specified	Not specified	Not specified	Not specified	No more information

Figure 22. Product by Cleanergy. Source: [29]

2.3.8. El.Ma

El.Ma. is an Italian company which is specialized in the design and manufacture of custom machines to solve specific industrial and production needs [39].

They have developed a small Dish Stirling System which is capable of generating 0.5 kW. They are also developing bigger prototypes, until 2 kW, but they are still not able to sell them.

Table 8. Product characteristics by El.Ma [39]

Company	Product name	Electric Power/Unit	Diameter	Weight	Working fluid	Performance	Others
El.Ma.	Not specified	0.5 kW	2.4 m	600 kg	Not specified	Not specified	It is a prototype

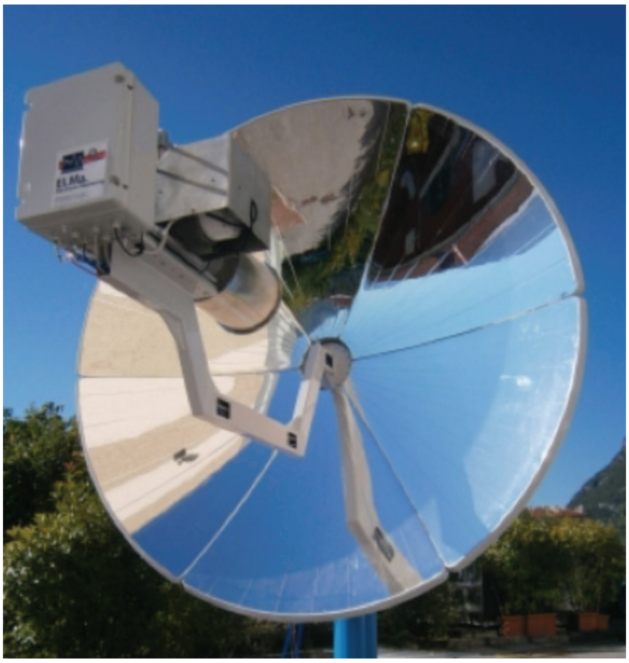


Figure 7. Dish Solar by El.Ma. Source: [39]

2.4. Technical viability study

This section summarizes the technical viability study conducted by the DIDSOLIT-PB project, based on small-scale and limited short units.

The table below shows the different options available in the market nowadays.

Table 9. Different options on the market

Company	Power/Unit	Diameter	Weight	Performance	Others
Innova (Trinum)	1 kWe 3 kWt	3.75 m	600 kg	13.8%el 41.4%th	-
Energon	1.5 kWe 4.5 kWt	3.75 m	450 kg	≈20 %el ≈55 %th	It is not available

Company	Power/Unit	Diameter	Weight	Performance	Others
Infinia	3.2 kWe	6 m	1,525 kg	≈ 30% el	It is not available individually.
United Sun Systems	25-30 kWe	11.73 m	6800 kg	≈ 30% el	-
Ripasso Energy	30 kWe	Not specified	Not specified	≈ 30 %el	System is far too big for the project.
Cleanergy	11 kWe	Not specified	Not specified	Not specified	It is not available individually.
El.Ma.	0.5 kW	2.4 m	600 kg	Not specified	-

Considering all the technical, commercial and economic facts, the Project Technical Team decided to focus on the Trinum System by INNOVA.

It is considered to be the one that better fulfils the Project requirements due to: a solar concentrator with a smaller diameter; a good production/weight relationship and finally, a dual energy output(1 kW electric / 3 kW thermal), that takes full advantage of the possibilities of the system and makes it more versatile to the demands of the building.

Its stronger points are the following:

- **It can produce electric and thermal energy:** Although it was not one of the scopes of the project, it is very useful to be able to cogenerate, as it can supply the different needs of a building by itself.
- **Small scale:** It is small enough to be ground and roof mounted, although ground mounted solutions revert on cost optimization. Static loads (weight) and dynamic loads (wind) are significantly lower than in larger size units.
- **Modularity:** As it is a small scale Dish Stirling, it can be installed together with others, and choosing how many dishes will be installed will depend on the energy needs of the whole system.
- **Economy:** Being this a system in its initial development phase it is obvious that it will have a higher cost than the more mature technologies, such as photovoltaic.
- **Automatism:** Its completely automatic operation is a very important point. Nothing has to be done for its normal operation, as it is capable of switching itself on, tracking the Sun, producing by itself and going into a safety position in case of rough external conditions or O&M operations.
- **Low maintenance:** It is a completely automatic system and its maintenance is very low. It is important to clean the mirrors once a month, and to introduce grease into the tracking motors, but nothing else should be needed in a normal operation, at least on a regular basis.
- **Marketable product:** It is the only small scale Dish Stirling which is already developed and marketed.

3. SCALED-DoWNDish Stirling System

All that follows is referred to the results of our assessment of the technical & commercial viability and estimate of energy-yield of scale-down models of the Dish Stirling technology for power generation, which could be installed in buildings' flat roofs or annexed ground plots. The approach of the following synthesis is to provide what is essential of the technical design and specification for such scale-down system; i.e., a **Conceptual design.**

As stated at the beginning, the following pages are the final result of an innovation-study process, which has entailed specifying and commissioning two Technological Centres, CITCEA and CDEI, associated to Universitat Politècnica de Catalunya, conducting the technical assessment and designing of a scaled down system of DS technology for electricity generation to be placed in public buildings, and finally, to install a prototype that has been assessed by the referred Technological Centres. Such commissioning implied an interactive process with and the participation of our technical 'Barcelona team' through working meetings.

In section 3 and section 4, we build mainly on the contributions, as it occurs in the first two reports on the scaling-down DS technology delivered by the referred Centres. And the last section 5 is devoted to gathering the essential outcomes of the assessment of the Pilot scaled-down DS system.

This section breaks down the commercial solution chosen for Dish Stirling technology, which is capable of cogenerating electricity and thermal energy. Its parabolic concentrator uses the solar thermal heat to warm up the hot focus of a Stirling engine, which is integrated into the same structure, to pump a piston and generate electricity. The thermal energy extracted from the cold focus, cooled down with a mixture of water and propylene glycol, is the useful thermal energy produced. This installation is capable of producing 1 kWe and 3 kWt. The global efficiency of solar energy conversion into thermal and electric energy is 55.2%, composed of a 13.8% electric and 41.4% thermal.

The following figure shows the main parts of the installation. Note that the red marks show the parts which are not included in the marketable product, so they must be dimensioned by the engineering company in charge of the installation. Most of the parts of the system can be installed outdoors, except for the solar tank and the control board. An extra pump will be needed if the considered pipe is larger than 20 m.

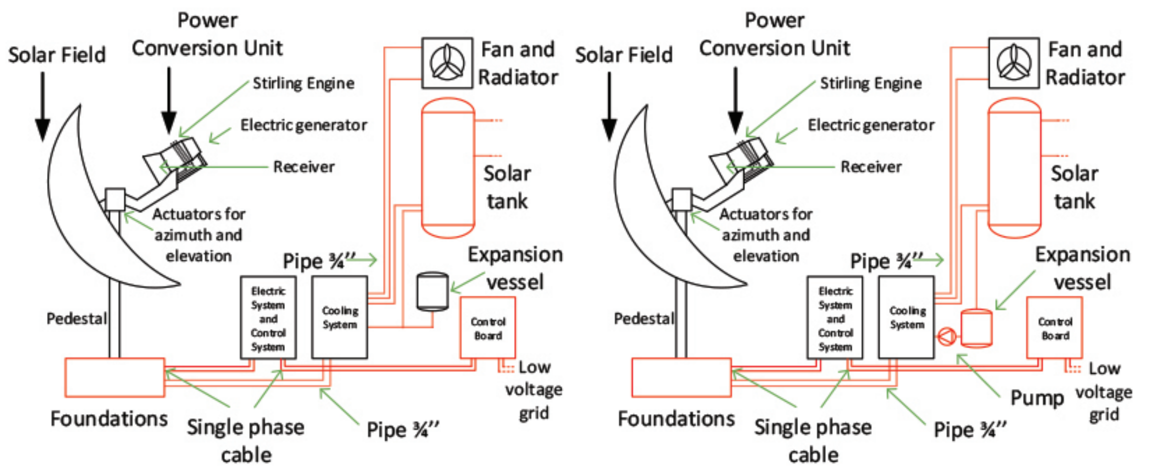


Figure 23.Diagram of dish Stirling with piping distance shorter than 20 m (left) and larger than 20m (right)

To be able to install this cogeneration system, the building must have a free space area of approximately 7x7m. It also needs a metallic net to secure the area and a small room to install the hydraulic and electric auxiliary systems.

In order to maximize energy performance, the building will also need to have a hot water consumption rate above 3 kWt, which is about 86 l of 30 ºC heated water per each hour of nominal use of the system. It will also need to have a monophasic connection of 4 mm^2 of the section, with the capacity to accept 1 kW of power.

3.1. Solar Field

The solar field is composed mainly of a parabolic solar collector, the solar tracking engines, which move the system into the azimuth and elevation axis, and the structure and pedestal.

3.1.1. Solar collector

The solar collector must have a 3,75m diameter. The total area of the solar collector is about 11 m^2, although its useful area is 9.58 m^2. The solar collector can concentrate about 7.3 thermal kW. The capturing surface is an orthogonal parabolic area that reflects the sunlight to the receiver and is composed of 11 individual mirrors of highly reflective aluminium.

Also, the performance curve for thermal production of the solar collector is:

$$\eta = \eta_0 - a_1 \cdot \frac{T_m - T_e}{G} - a_2 \cdot \frac{(T_m - T_e)^2}{G}$$

Where the η_0 is the initial performance and its value is 0.769, the coefficient a_1 is 0.66 W/m^2K and coefficient a_2 is 0.008 W/m^2K^2, the T_m is the mean temperature, T_e is the environment temperature and G is the radiation.

The following Figure 24 shows the individual mirrors, the metal framework, the focal support and the metal trunk support.

This system can be easily assembled by smaller parts. The system is lifted out from its packaging with the aid of a forklift or a crane. Once it is elevated, it is vertically fixed to the plinth using M16 bolts. The centre hub is fixed to the inner side of the arm. Then, the long and short braces, which will hold the mirrors, are assembled using 48 M8x25 bolts (4 for each brace). Later on, in the short braces, the supports will be installed and the eleven mirrors assembled. The 11 mirrors are immobilized by caps fixed by self-tapping screws.

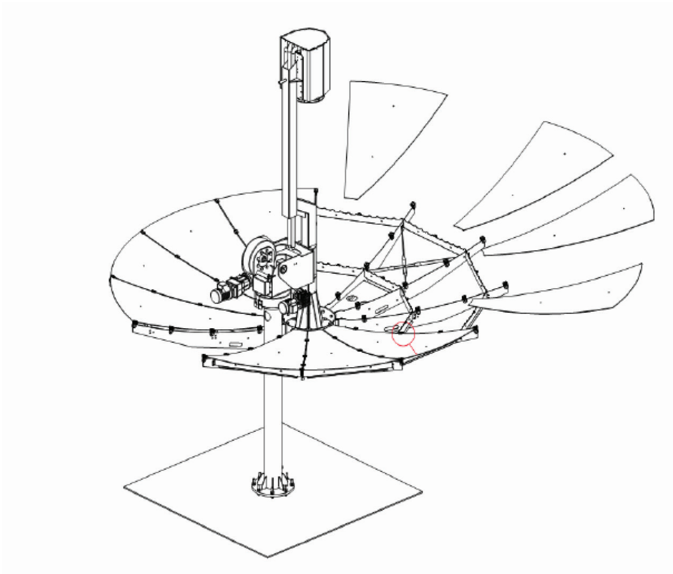


Figure 24. Parts of the solar collector. Source [43]

3.1.2. Solar tracking system

The solar field must include a solar tracking with the biaxial technology, the azimuth range being between -110° and +110° and the elevation range being between -90° and +90°. The following figures show the azimuth range and elevation range of the solar collector. The solar tracking must concentrate the radiation into the heat point of the Stirling engine, which is placed into the receiver of the power unit conversion. The system follows the sun position through a calendar algorithm that determines the azimuth and elevation degree through the GPS coordinates, which is integrated in the marketed product. There are two integrated brushless engines, one for each axis, which can move the dish in every direction to track the Sun properly. The tracking system has to adjust its position every few seconds to ensure optimum concentration of solar energy.

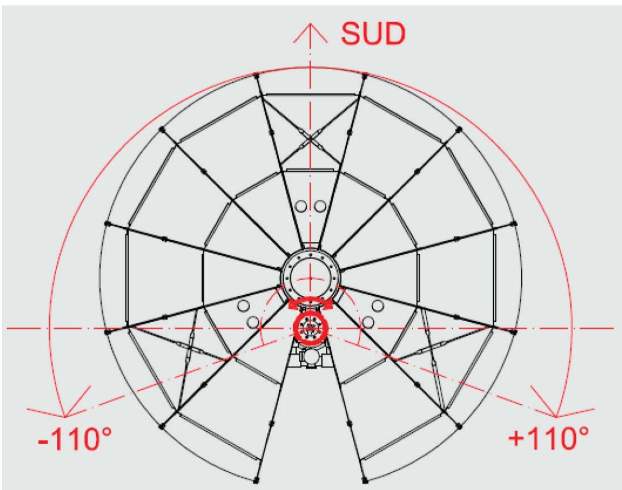


Figure 25. Azimuth movement of solar collector. Source: [44]

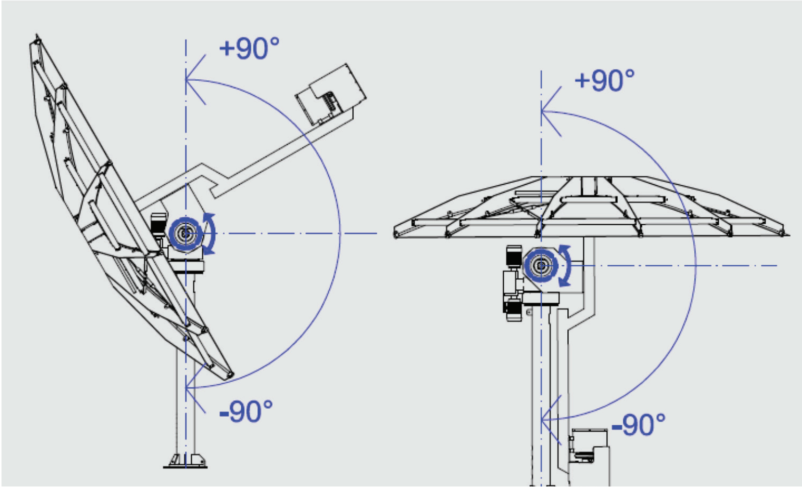


Figure 26. Elevation movement of solar collector. Source: [44]

To ensure the solar tracking system is properly controlled, the following wires will be needed so that every part is connected with the control board:

Table 10 Wires needed for the solar tracking system

Device to be connected	Cable Type	Minimum Quantity	Notes
Motors	FROR 300/500V 7 x 1.5 mm²	6	6 poles cable + yellow/green
Encoder	FROR 300/500V 8 x 0.5 mm²	6	Screened cable
Limit switch	FROR 300/500V 12 x 0.5 mm²	6	Screened cable

3.1.3. Structure

This system is held in place through a metallic foot. This is made up of recyclable materials and the solar system has a CE certificate. This system can be installed on the ground. In addition, the system occupies an operating area of about 23 m^2 that must be obstacle free. The access into this area will be restricted by a security fence of at least 49m^2.

Metal carpentry, which makes up the system framework, includes the metal base that holds the optics, the focal support for Stirling engine and the metal trunk support. Every part is made of stainless steel.

The overall weight of the set is about 650 kg. The height of the system is about 4.6 m when functioning and less than 3 m in safety mode. The Dish Stirling goes automatically into the safety mode whenever the wind blows over 50 km/h, or when it rains, or if there is any electric or hydraulic control problem. In addition, it has an automatic anemometer, rain sensor and protective systems. The maximum wind that it can withstand is about 162 km/h in safety mode.

The metallic elements are hollow in order to let the cables pass through. All the hydraulic and electric circuits related to signal and power will be connected inside these elements. The structure is provided with connection units to make it easier to install and maintain the device. The wired plumbing circuit is equipped with an air valve.

The structure has a rust protection layer because it will be installed outdoors and thus has to be resistant to harsh weather conditions.

3.2. Power Conversion Block

The power conversion unit is composed of the receiver, the Stirling engine and the electric generator, which are shown in the following figure. The system produces electric energy, which can be streamed straight into the consume grid and thermal energy that can be accumulated and used anytime during the day.

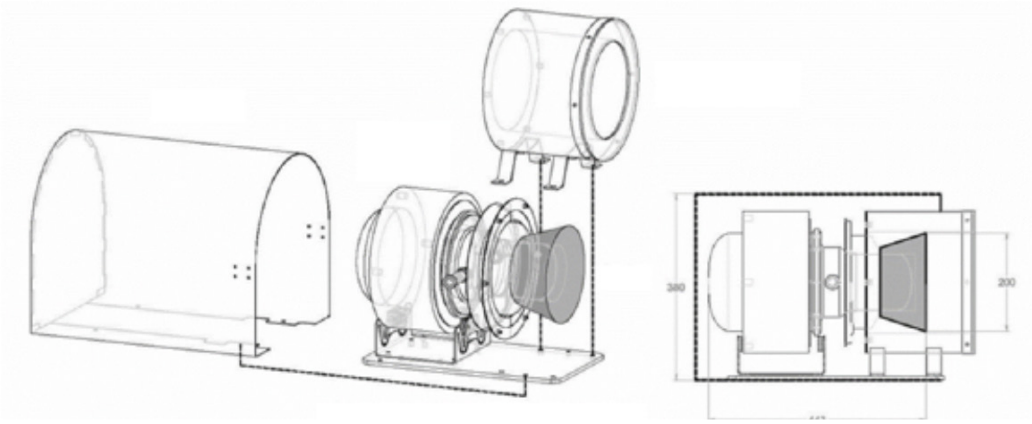


Figure 27. Parts of power unit conversion. Source: [45]

3.2.1. Receiver

The power conversion unit is composed of the receiver, the Stirling engine and the electric generator. The system produces electric energy, which can be streamed straight into the consumption grid, as well as thermal energy, which can be accumulated and used anytime during the day.

The receiver is a small 10 cm radius circle that receives all the concentrated solar energy from the 9.58m^2 area of the parabolic dish. Its main function is transferring the thermal energy to the engine's hot focus.

The head of the Stirling engine, which is metallic, is therefore treated against rust following three steps: first, by sanding the stainless steel; next, by treating it with fluoride at 500 °C; and last, by covering it with nickel on the lateral surfaces.

3.2.2. Stirling engine

The Stirling engine is a free-piston engine designed for cogeneration, which can generate electricity and hot water. The Stirling engine operates using helium at around 450 ºC, and the pressure inside the engine is about 28 bar. The engine turns on automatically when the temperature in the hot focus reaches 190 ºC, which is when production begins. However, the nominal power is produced when the Stirling engine head reaches 400 ºC. The Stirling engine is noted for its efficiency compared with other thermal engines, which are about 22%.

To cool down the cold focus, there is a thermal exchanger that allows the system to operate with the proper temperature difference between the hot and cold focuses. The cogeneration ratio is 3:1, meaning 3 kW thermal and 1 kW electric. Therefore, the system can satisfy the needs of small entities that need thermal supply and a small amount of electricity.

3.2.3. Electric generator

The thermal energy received is converted into mechanical energy by the Stirling engine. Later on, this mechanical energy is converted into electricity by the lineal synchronous generator which is located in the Stirling engine. The group, meaning the alternator and Stirling engine, works at 50 Hz (3000 rpm) and does not need any inverter to be connected directly to a single phase network because its tension output is 230 V.

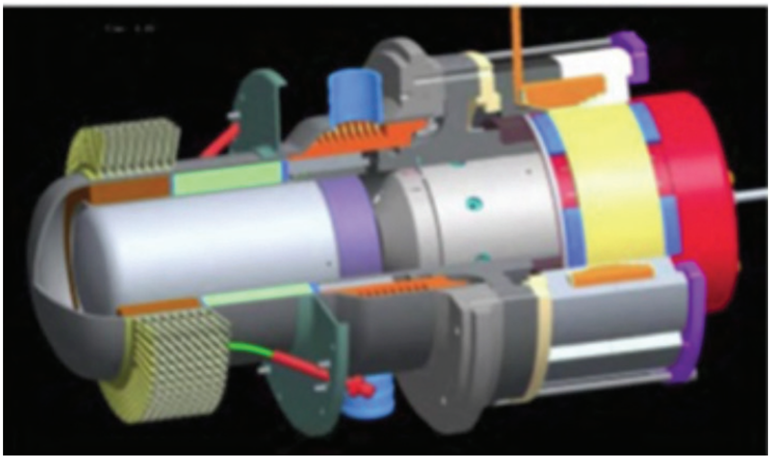


Figure 28. Stirling engine and electric lineal generator. Source: [46]

As with the solar tracking system, it is necessary to connect the different parts of the engine with the following wires:

Table 11. Wired required for the generation system

WDevice to be connected	Cable Type	Minimum Quantity	Notes
Da/OT	FROR 300/500V 2 x 0,5 -1 mm²	6	6 poles cable + yellow/green
Stirling	FROR 450/750V 3 x 2,5 mm²	6	Screened cable
Thermocouples	Thermocouple K RS: 611 - 7895	6	Screened cable

3.3. Power Block / Cooling System

The cooling system is composed of a hydraulic control unit with sensors and valves, the piping, the cooling fluid, the hydraulic pump and the auxiliary pump (if needed), the expansion vessel, and the thermo fan. To maintain the correct temperatures in the different parts of the system, thermal exchangers and cooling fluids need to be used. Their main purpose is to hold the cold focus at the correct low temperature in order to keep the Stirling engine working properly. Figure 29 shows the cooling system and its main parts.

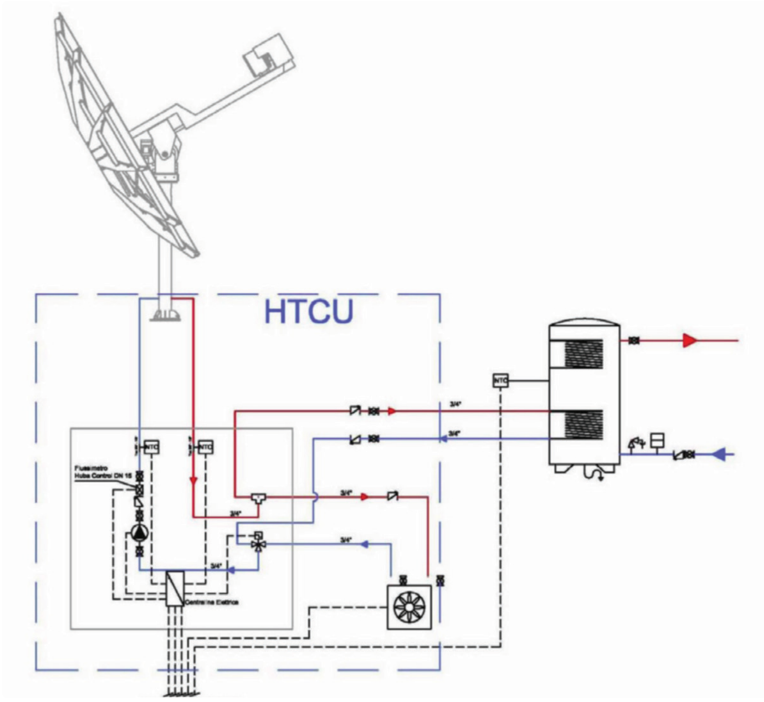


Figure 29 Cooling system scheme. Source: [45]

3.3.1. Solar hydraulic circuit

All the piping will be copper, with a diameter of ¾ inches (20/22 mm). The accessories and valves can be put together with pipes, either threaded, welded or bridled. All piping should be insulated, fixations being required every 50 cm.

With the aim of avoiding thermal losses, the total longitude of the pipes must be minimized in sofar as possible, i.e. to reduce the possibility of pipe turns and load losses in general. To help towards this point, the horizontal parts of the piping should have a 1% inclination in direction of the flow.

The insulating materials of the exterior plumbing have to ensure the durability of the system despite the harshness of weather conditions. Possible materials could be asphaltic paints, fibreglass reinforced polyesters or acrylic paints. The insulating materials will not leave any part of the plumbing exposed, except for those parts that need to be manipulated for the correct operation of the system.

The minimum insulating thickness of the system pipes and accessories, which transport warm fluids in interior pipes, taking into account an approximate maximum temperature of 100 ºC, and less than 35 mm of exterior diameter pipe, which is 25 mm. For exterior pipes and accessories, the correct isolation will have to be 35 mm. The chosen insulation material is a white polyolefin copolymer.

3.3.2. Cooling fluid

It is important that the Stirling engine heat is absorbed by an antifreeze fluid made of water and propylene glycol, the latter having been selected specifically because of three reasons: its capability to mix with water; its low proportions needed to drop significantly the freezing point; and most of all, because of its almost zero toxicity, a major problem in most other antifreeze fluids.

The flow of cooling fluid is about 15 l/min and its working temperature is between 6 ºC and 60 ºC, although its maximum temperatures can be around 90ºC. Its operating pressure is around 3 bars and the safety maximum pressure is 7 bars.

For example, with the proportion of 10 parts water to one part antifreeze, the cooling fluid can reduce the freezing point to -3 °C. The choice of what proportion of propylene glycol to use will depend on the exact location of the system, and this would normally take into account the minimum historical temperature of the site. For example, in Barcelona it would be required to use a mixture of around 24% of propylene glycol, because the lowest temperature ever recorded in Barcelona is -10ºC. As a reference, the following chart shows the needed proportions of propylene glycol to achieve varying freezing points.

Table 12. Water solution freezing points and boiling points. Source: [47]

Propylene Glycol in solution [%]	Temperature at freezing point [ºC]	Temperature at boiling point [ºC]
0	0	100
10	-3	100
20	-8	101
30	-14	102
40	-22	104
50	-34	106
60	-48	108

3.3.3. Exchange system

The exchange system is composed of a hot water accumulator and a heat exchanger inside it. This kind of solar tank is called internal exchanger. Another kind of heat exchanger is called external exchanger, which is composed of only a heat transference system that introduces thermal energy directly into the grid, with or without accumulation.

For this case study, given that we want to maintain a degree of control over hot water consumption, we need to choose an internal accumulator for the system that can regulate itself when the energy is consumed, regardless of when it is generated. This thermal tank will be installed in the technical room near the Dish Stirling System.

The selected solar tank for the designed installation will have a volume of 500 l with an exchange surface of 2 m^2. The size of the solar tank will be 770 mm wide and 1690 mm high.

The tank should be made of vitrified steel to ensure the healthiness of the water for human consumption, which is compulsory for sanitary hot water systems. It must also be insulated, in this case through rigid mould-injected polyurethane foam without CFC.

The main characteristics of the tank are the following:

- Primary or solar circuit (exchange surface):
  - 25 bar maximum pressure
  - 200ºC maximum temperature
  - 2 m^2 exchange surface
- Secondary or consumption circuit (accumulation):
  - 10 bar maximum pressure
  - 90ºC maximum temperature

There must be visual control of temperature and pressure inside the tank, in addition to a cathodic protection. The selected tank has a control unit with a thermometer and a magnesium anode with a charge gauge for the cathodic protection of the solar tank. In addition, it should allow access for maintenance for cleaning and repairing when needed.

The exchange system or solar tank needs a filling/emptying system for maintenance tasks, which will include a non-insulated copper pipe, a brass ball valve and a retention valve. The entire system is connected to the cold water grid.

Figure 30 shows the selected solar tank, including details on the main hydraulic connections:

A: Width → 77 cm
B: Height → 169 cm
kw/e: Water intake Drain→ 1 in
ww: How water output → 1 in
z: Recirculation → 1 in
kv: Entrance solar circuit → 1 in
Kr: Return solar circuit → 1 in
eh: Lateral connection → 1 in
tm: Sensor temperature
pc: Cathodic protection

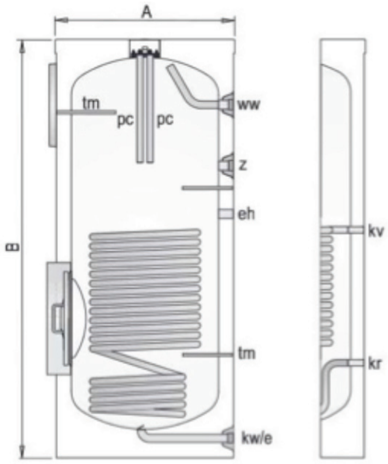


Figure 30 Solar tank. Source: [40]

3.3.4. Support hydraulic system

- **Pumps**

The cooling system makes the fluid circulate with a flow rate of approximately 15 l/min. If the circuit exceeds a total longitude of 20 m, a supplementary pump will be needed to give the system enough pressure and movement to work. The system includes a 70 W pump, which provides pressure for the liquid to move inside the system.

In our case, the dish Stirling system is 50 m long. Therefore, it needs an auxiliary pump, which results in losses equivalent to 5.51 m and 80 W of power.

In compliance with European legislation, the pump will be electrically powered by a frequency converter, which will be controlled by the hydraulic control unit.The auxiliary pump is activated when the primary pump is turned on and when the thermo fan is shut off. This is why it is necessary to install current relays both on the primary pump and the thermo fan.

If possible, the auxiliary pump should be installed in the colder zones of the circuit, assuming there are no problems with cavitation and the rotation axis is in a horizontal position.

- **Expansion tank**

The hydraulic system has auxiliary pipes because it is farther than 20 m away from the dish system, and it should therefore be protected from dilatation and increase in volume.

It should be dimensioned in a way that when, despite an interruption of electricity and the solar radiation is at its maximum values, it will be able to absorb the increased volume of the cooling fluid caused by the temperature increase, taking into account that a part of the liquid can be transformed into gas. Preferably, the expansion vessel should be connected to the pump suction.

In this study case, the volume of the expansion vessel is 8 litres.

Figure 31. Expansion tank. Source: [41]

In these systems, a manual or automatic filling system capable of maintaining the systems' pressure within the correct rangeis compulsory.

If there is any risk of freezing, the relation between the quantity of water and the amount of propylene glycol must be kept in the correct ranges, as this could result in leakage.

3.4. Control and Management

This section is divided into 4 subsections: Electric Control Unit, Hydraulic Control Unit, Electric Control Board and Monitoring System.

The Electric Control Unit section includes the general control of the system, which manages the hydraulic control unit and the power conversion block. The Hydraulic Control Unit manages the thermal operation and restrictions systems. These last two are included in the marketed product. Later, the Electric Control Board shows the main protection and network requirements. Finally, the Monitoring System describes the monitoring system design for the cogeneration system.

3.4.1. Electric Control Unit

The system control board includes the Stirling engine control board, the mother board for connecting all of the different components, which can gather data from the environmental sensors and from the Stirling electronic control generator. This board can be controlled remotely through Modbus RTU. The system control function is to track the Sun using an algorithm set on the astronomic watch and GPS coordinates. This board, together with the hydraulic control unit, must be installed at least two meters away from the dish, preferably in front of it, to avoid any physical contact between them.

Due to the high temperature of the Stirling, about 600 °C, the focal group must be monitored by both thermocouples located on the Stirling head. The head of the Stirling engine is bound by the maximum operating temperature of 525 °C and the maximum temperature in terms of safety of 585 °C. Moreover, temperature sensors in the hydraulic circuit are also necessary, because the cooling hydraulic circuit is bound by the limit of 70 °C in terms of the maximum temperature for the engine's safety.

If this temperature is exceeded, the system goes into self-protection mode through the control system. The engine switches off, the cooling circuit is activated, the dish Stirling moves away from the focal point and closes itself into safety mode. Any temperature anomaly is read by the system as a breakdown, which activates the safety mode. In addition, if the wind reaches speeds of more than 50 km/h, or if it rains, a sensor is activated and the dish Stirling closes itself into safety mode.

Below is a list of the Electric Control Unit components:

- Dish Stirling control board, that manages all system and verifies that all conditions are fulfilled.
- Display, which allows visualizing the main parameters and variables of the system.
- A GPRS antenna, which allows determining the position of Dish Stirling and calculating the angles for the tracking system.
- The tracking system control, which governs the movements in azimuth and elevation angles.
- The battery regulator, which guarantees that the battery has sufficient charge to feed the system in case of there being a problem with the feeding grid.
- Grounding system together with other protection, to guarantee the safety of the system.
- Relays, which activate the circuit breaker in case an anomaly appears in the system.
- Fuses, to protect the system from the different electric components.
- Differential switch, which detects current leakages.
- MCB switch (circuit breaker), which protects the distribution network and installation fromover-current, over-voltage, and short circuit problems.

- Transformer, which isolates the system from the grid.
- A capacitor, to compensate the reactive power generated.
- Resistances, which allow for consuming the excess of energy in case of there being an anomaly in the network system.

Furthermore, the system has to include a fuse-breaker or circuit breaker to protect the individual devices such as the pump, the fan-radiator, and the dc-brushless. If the auxiliary pump, monitoring devices or other devices required are not included in the marketed product, the auxiliary system must include a circuit breaker for each device in the auxiliary system box near the electric control unit. There must be two circuit breakers type C 0.5 A in the Electric Control Board. This is connected through a 1P+1N cable to the network.

3.4.2. Hydraulic Control Unit

The hydraulic control unit allows for the management of thermal energy produced and for the safety mode. The switchboard contains the hydraulic pump, flow meter, temperature sensors and the three-way motor valve and heat dissipater. It is also included in the marketed product. All the hydraulic devices that control the thermal system are included.

It is important for the hydraulic control unit to be placed at a minimum distance of 2 m from the dish Stirling to avoid any impact problem with the parabolic dish. The cooling fluid is a mixture of water and antifreeze propylene glycol. The optimal working temperature range of the cooling fluid to the entrance should be between 6ºC and 60ºC and the cooling fluid flow should be about 15 l/min. Note that at cooling, the circuit can withstand a maximum pressure of 7 bar and a maximum temperature of around 90ºC.

The hydraulic system has an associated consumption of about 70 W because of the hydraulic pump, which moves the cooling fluid. In case a new pump is needed, its consumption should also be added. When the thermal energy produced cannot be consumed or the cooling fluid temperature reaches 70 ºC, the heat dissipater is switched on, and it would consume another 80 W to dissipate this thermal energy to the environment. The heat dissipater has capacity to dissipate thermal energy up to 3 kWt.

The control system will ensure that the temperature of the liquids of the system do not reach any temperature that could damage the holding materials, components and treatments of the circuits. The maximum security temperature that the system can reach before shutting down and going into protection mode is between 70-90 ºC.

To be able to control all the devices of the hydraulic system, the management control system will be connected to the devices through the following wires:

Table 13. The wires needed for the hydraulic control unit:

Device to be connected	Cable Type	Minimum Quality	Notes
Dissipater	FROR 300/500V 3 x 1,5 mm^2	Based on the distance between the dissipater and the H.C.U.	-
NTC/ Boiler/Thermostat	FROR 300/500V 2 x 0,5 -1 mm^2	Based on the distance between the E.Switchboard and the H.C.U.	If NTC 10kOhm and distance from the sensor=>10m=>2x1.5 mm^2

Device to be connected	Cable Type	Minimum Quality	Notes
Signals H.C.U -> E.Switchboard	FROR 300/500V 9 x 0,5 mm²	Based on the distance between the E.Switchboard and the H.C.U.	-
Network H.C.U - > E.Switchboard	FROR 300/500V 8 x 1 mm²	Based on the distance between the E.Switchboard and the H.C.U.	7 poles cable + yellow/green

3.4.3. Electric Control Boards

The system must be electrically protected with over-current breakers or fuses and a residual-current device, strictly following each country's own guidelines. This will be installed inside a fuse box.

The electricity runs along a monophasic line connected between the general protection and measurement box and an auxiliary electric box. In the case, the cable section must be 4 mm^2 because of at least three factors: the power generated, the tension, and the distance of 50 m.

The supply modality is by self-consumption. In this case, the consumer has installed a generation system that is fully designed for self-consumption and is not registered as a production installation in the official registers. There is only one subject, the consumer, which is not able to supply energy to the grid.

The designed installation corresponds to the interconnected generation facility which usually works in parallel with the public distribution network and is located near the general control board.

The connection point does not necessarily concur with the point at which the energy measurement is performed. However, at this point, the first element (seen from the network) of the general protections is installed.

The interconnection point must be accessible to the distributor control and measurement devices. A circuit-breaker where the protections will act should also necessarily be installed. The protections and the circuit breaker must be sealed but allow for access to the breaker. These must be approved and should be fully verified and a have seal of approval from a recognized laboratory. In any outdoor installations not covered by the technical building code, it is important to take into account external protection systems against lightning, depending on the kind of building. The choice of the switchgear, system installation and its features is based on the minimum level of protection, which for outdoor installations is IPX4.

To guard against indirect contact, a differential protection can be integrated into an electric box. This must also correspond to an approved type and should also be fully verified and have seal of approval from a recognized laboratory. Any deviations would imply a danger of electrocution. The sensitivity of the circuit breaker must be 30 mA to obey the Spanish law. All the metallic parts of the system must be grounded to prevent electrocution.

Finally, protections must be able to ensure system safety in case of lightning over-voltages, due to switching, etc. These devices can be a gas arrester, zinc oxide varistors, suppressor diodes, spark gaps, etc. For installations in buildings with external lightning protection systems, an over-voltage protection system for atmospheric phenomena is recommended.

- **General Protections and measurements box**

In this board, the general protections and the global measurements can be found. The circuit breaker must be able to work with a rated current 5.52 A. Working with standard values, the correct circuit breaker to be used must have a rated current 7.5 A. The differential breaker must be able to work until 7.5 A, which will protect it against electric derivations to the ground. In addition, a bidirectional single phase meter 10 (60) A, and a power analyser single phase 230 V 50 Hz 32 A with Modbus/RTU RS-485 communications must be integrated into the general protections and measurements box.

The following table shows the main characteristic of the network.

Table 14.Electric and physical characteristics of network and coupling mode

Device	Characteristics
Overcurrent circuit breaker	7.5 A Type B
Differential circuit breaker	7.5 A - 30 mA
Bidirectional single phase meter	230 V 10 (60) A
Power analyser single phase	230 V 50 Hz 32 A Modbus/RTU RS-485

- **Auxiliary electric box**

In this board, the auxiliary elements that are not included in the marketable product are found, such as the protections and contactors for the auxiliary pump and the monitoring and management devices. The circuit breakers from both the auxiliary pump and monitoring system must be able to work with a 0.35 A and 0.035 A, respectively. Working with standard values, the correct circuit breaker to be used must be type C and the rated current 0.5 A in both cases.

The auxiliary pump is activated when the primary pump is turned on and when the thermo fan is shut off. This is why a current relay on primary pump and a current relay on the thermo fan must be installed. Note also that the auxiliary electric box is located near the solar tank inside the facility.

The following table details the main characteristic of the network:

Table 15. Electric and physical characteristics of network and coupling mode

Device	Characteristics
Pump overcurrent circuit breaker	0.5 A Type C
Pump monitoring and management overcurrent circuit breaker	0.5 A Type C

Device	Characteristics
Contactor	230 V 8.5 (25) A
Management system	230 V Ethernet 10Base TX Modbus/RTU RS-485

3.4.4. Monitoring system

There is a monitoring system within the Electric Control Unit whose purpose is to guarantee correct operations by managing different variables, which can be remotely monitored. These variables are listed below:

- Data (dd/mm/yyyy)
- Time (hh:mm:ss)
- Electricity Energy produced (kWh)
- Wind Speed (km/h)
- Head temperature set point (ºC)
- Temperature Stirling head (Cº)
- Temperature entry cooling fluid (ºC)
- Temperature exit cooling fluid (ºC)
- Cooling fluid flow (l/min)
- Environment temperature (ºC)
- Boiler water temperature (ºC)
- Voltage (V)
- Current delivered (A)
- Power (W)
- Frequency (Hz)

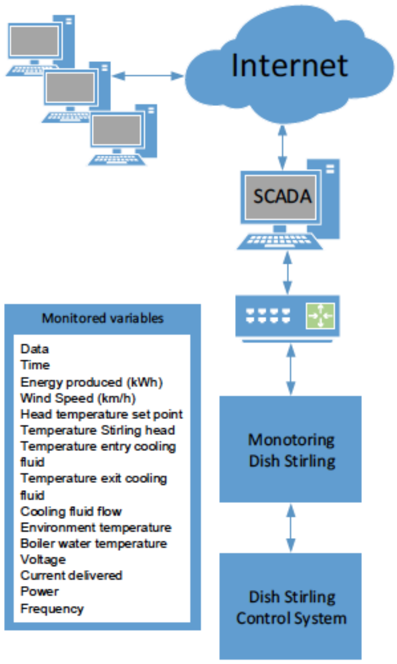


Figure 3.2. Monitoring and control system

The monitoring system will have a Modbus RTU, connected with a net manager, in order to be able to log the data or send it to a computer for analysis. This net manager must be able to act over the system in terms of starting up, or shutting down, for example.

To complement this system, another external monitoring system has been selected, It will be detailed in the following section. This system will enable owners or technicians to a) obtain more information about the consumption and production profiles of electricity and thermal energy, plus b) know more about the power quality parameters of the electricity generated.

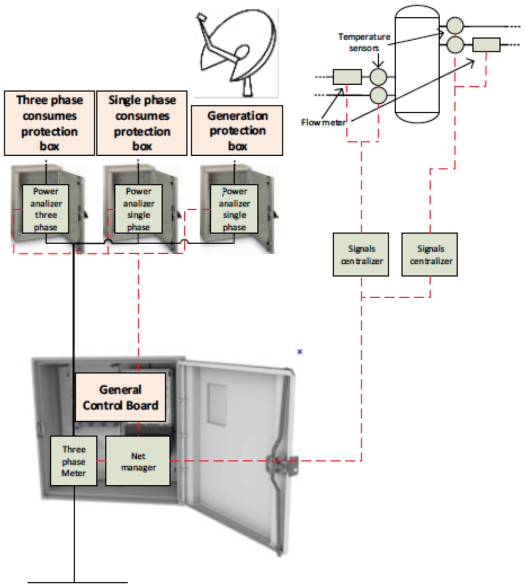


Figure 33 External Monitoring System scheme

Below are described the highlights of the main features of the required elements of the external monitoring system.

- **Net manager**

The energy manager is equipped with embedded software and a built-in web and XML server, which enables users to query any electric variable by connecting the metering equipment to its RS-485 bus without having to install any software. Thanks to the RS-485 expansion bus, users can view any variable from the units connected to the bus and can even display real time information in table or graphic format (data logger). There are 8 voltage-free digital inputs and 6 programmable relay digital outputs.

This manager can be used to control partial consumptions of the different single-phase and three-phase loads during productive and non-productive periods. The system can also control the consumption of installations 24 hours/365 days a year and can a) locate residual consumption during non-production periods, b) check the power level contracted in the installation, c) supervise the level of harmonics and the reactive load of your installation, d) warn through alarms of any consumption anomalies or incidents in the electric network.

It automatically provides information on the bill before the consumer receives it. Moreover, in the case of load distribution (or remote installations), it can control the individual consumption of each of the installations and centralize them into a single one. Finally, the device can produce energy reports per consumption zone or site.

- **Power analyser single phase**

The single-phase circuits analyser can work up to 32 A and has an LCD display with a rotating screen system, showing a total of 24 instantaneous, maximum and minimum electric variables. It has been designed in an enclosure with only 1 DIN module (18 mm), and the size of the analyser allows it to be installed in any electric panel. The unit has the Modbus/RTU (RS-485) protocol and is compatible with energy management software.

- **Electric meter**

The meter is a three phase indirect connection meter. It has a RS 485 communications system, and has to work at 3x230/400 V and the nominal current of installation. The meter must be robust and competitive, in addition to being in full compliance with the new European Directive MID (EN 50470) and all the relevant IEC's.

- **Power analyser three phase**

A three-phase power analyser (balanced and unbalanced) for its assembly on DIN rails with very small dimensions, which can take measures in 4 quadrants, which also has RS 485 communications.

- **Analogical signals centralizer**

The digital signals centralizer is assembled in 4 DIN modules. The unit has 2 relay outputs, and centralizes 4 analogue inputs from 0 to 20 mA, 2 voltage free digital inputs. The unit includes an RS-485 communications bus with a Modbus/RTU protocol, which allows real time control through communications. The unit is compatible with the software and energy manager. It can read any impulse-emitting device (up to 4 units).

- **Temperature sensors**

The temperature sensors are based on a PT100 or PT1000 resistor. The measured temperature value corresponds to a change in resistance and is converted into an electric analogue signal. A microprocessor controls the evaluation of the electric signal.

A complete temperature measurement system usually consists of several components. The temperature is detected by a sensor and is converted into a measured electric signal. The mechanical design and the dimensions of the sensors must vary to enable their use for different media and measuring points. The analogical output is from 4 to 20 mA and the measuring range is from -50 to 300ºC.

- **Flow meter**

Electronic flow sensors operate with different measurement technologies. They meet all requirements from a simple monitoring function to the exact detection of flow volumes. Harmonized operating menus ensure that operators who use different flow sensors can quickly and precisely carry out settings on the sensors. Some flow sensors feature an integrated temperature monitoring which makes an additional measuring point unnecessary. This enables the control of processes being in the optimum operating status, especially regarding energy savings. Analogue, binary and pulse outputs offer various possibilities to process the measured data. The main characteristics are the following: process connection Rp ¾ '', analogue output from 4 to 20mA, a measuring range between 2 to 50 l/min, and a temperature range from -10 to 85 ºC.

- **Monitoring electric box**

If the monitoring electric box is going to be installed outdoors, it shall have a protection index of 55-60, in order to protect the inner system from rain and harsh weather. If the box is going to be installed indoors, the protection index shall be of around 40. For the correct installation of the different protection systems, the box must have DIN rails to fix the protections. Depending on the protection device chosen, and the space available given other already installed boxes, the required box dimensions will change, but as a point of reference, these canbe in the region of 351x305x112 mm.

3.5. Support system

The structure can be installed in or on the ground through a reinforced concrete plinth, whose size should be about 2x2x0.5m. It must ensure that the system will be stable and safe when there are winds of 50 km/h in operation and 162 km/h in safety mode. To do so, a concrete plinth of about 4000 kg must be ready for the arrival and installation of the dish.

The system will be anchored to the concrete plinth through a metallic platform and M16 bolts, which will be able to ensure that the system stands still together with the concrete plinth provided that the climatological conditions are not worse.

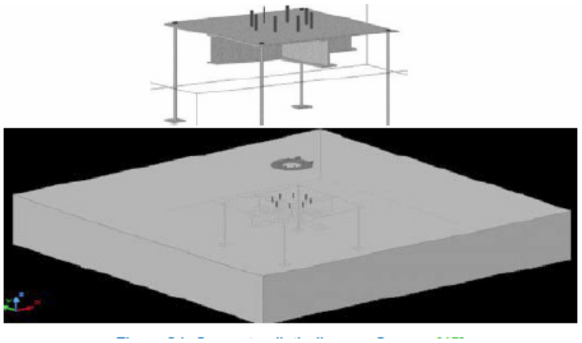


Figure 34. Concrete plinth diagram Source: [45]

3.6. Building Interaction

As shown in Figure 35, the area needed to secure the installation of the system is around 7x7 m = 49m^2.

The electric and hydraulic control units can be installed in the security space around the systems, separated at least by 2.32 m from the centre of the dish, as this is the minimum obstacle-free distance to ensure there is no problem with the solar collector system. The accumulator and the auxiliary components should be installed in a technical room, which must measure at least 2 x 2 x 3 m to be able to accommodate all the systems.

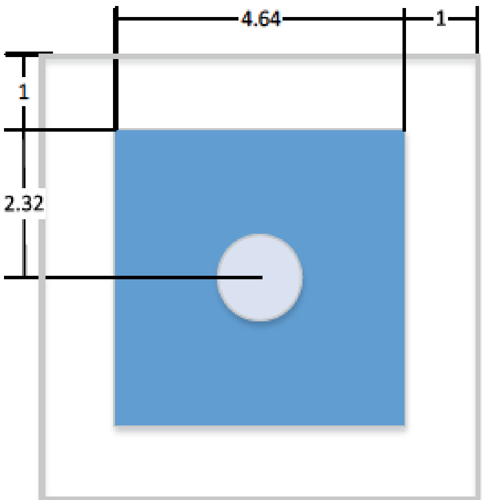


Figure 35. Security area of system

3.7. Maintenance

A good maintenance plan should analyse any possible failure just from the design, and it should be developed and updated regularly.

The dish Stirling system needs a very low maintenance. However, it must be visually checked in intervals that vary depending on the different type of environments the system operates in (aggressive weather, presence of dust or sand, etc.). The aim is to determine whether there is any abnormality, broken parts or damages that might affect the integrity of the system. Ancillary or additional equipment must be taken into account, since an undetected failure can cause serious damage to other equipment.

Its normal use and exterior conditions could damage any part of the system; water leakages, rust, motor problems, etc. In any case, these would be occasional problems which should have a solution incoordination with the supplier.

Maintenance is divided into preventive maintenance and corrective maintenance. Procedures and planning for the first one are detailed. Some ideas for corrective maintenance are finally presented.

- **Preventive maintenance planning**

Main maintenance tasks are carried out yearly or every 6 months. These activities can be grouped into two yearly inspections. It is recommended to schedule these maintenance inspections at spring and autumn.

Preventive maintenance operations are shown in Table 16.

Table 16. Maintenance tasks

Component or installation	Task description	Frequency
Support and fixing structure	Visual inspection: • Check the integrity of components. • Verify the absence of folds. • Check the uniformity of galvanised layer and the absence of rust stains.	Yearly
	Tightening control: • Ensure the proper tightening of bolted mechanical connections.	Yearly
Mirrors	Cleaning mirrors: • Clean the collector modules' surface from impurities (using water)	Every 6 months (or in case of obvious dirt)
Electric board	Visual inspection: • Verify the integrity of the electric board in relation to enclosures damage, protection against direct contact, water ingress and condensation, dirt. • Check (with proof of slipping) terminal tightening.	Yearly
Switching and protection devices	Visual inspection: • Check the good condition of switching and protection devices.	Yearly
	Electric control: • Check the calibration and electric characteristics of automatic switches. • Check the efficiency of switching and protection devices (RCD, disconnectors, circuit breakers, relays, surge arresters)	Yearly

Component or installation	Task description	Frequency
Electric connections (wiring)	Visual inspection: • Checking of status of power cables and communication buses and connections.	Every 6 months
	• Verify the integrity of electric cables (when positioned at sight) in relation to damage, burns, abrasions, deterioration of insulation. • Check the status of the contacts and terminal tightening.	Yearly
Grounding	Visual inspection: • Check the system's integrity. • Check the tightness of connections at accessible points. • Replace the parts that show signs of corrosion or oxidation.	Yearly
	Electric controls: • Equipotential and continuity test. • Check cable insulation.	Yearly
Mechanical parts	• Lubricate mechanical parts, mainly the two tracking systems. • Check if there is movement impediment.	Biyearly
Measurement devices	• Check if the system goes into safe position in case of strong winds or rain. • Clean system sensors.	Every 6 months (or when the system does not go into safe position)
	• Data collection of operating conditions and comparison with the nominal design values.	Every 2 Months
Battery	• Check if it has enough energy to lead the dish Stirling to the safe position.	Every 6 months
Hydraulic circuit	• Check that the system pressure remains constant and that there are no leaks in each circuit.	Every 6 months
	• Check that the pump is operating in the presence of sunlight.	Every 6 months
	• Check that there is no noise in the water pipes, caused by the presence of air inside.	Every 6 months
	• Check the antifreeze concentration in the primary circuit. Biyearly	Biyearly
	• Check the pH of the mixture of water and glycol in the primary circuit. It must be replaced if pH falls below 6.6.	Biyearly
	• Check condition, functionality and actuation of each valve: isolation, regulation and retention. Replace or repair, if applicable.	Biyearly
	• Check condition of mechanical seals and packing of the stem valves. Check tightness and correct leaks, if applicable.	Every 6 months
	• Check correct positioning of each valve in normal operating condition. Correct, if applicable.	Every 6 months
Thermal insulation	• Check condition of thermal insulation: status, absence of degradation, absence of moisture. Repair or replace, if applicable.	Yearly
	• Check condition of external protection of the insulation. Repair, if applicable.	Yearly

Component or installation	Task description	Frequency
Solar tank	• Outer inspection: tightness, absence of leaks, status of gaskets and connections	Yearly
	• Inner inspection: tightness between primary and secondary circuits, absence of leaks	Yearly
	• Outer inspection of casings and thermal insulation: status, absence of degradation, absence of moisture. Repair or replace, if necessary	Yearly
	• Control the anode corrosion in the hot water tank[3].	Yearly
	• Inner inspection of tubes/plates: status, absence of deformation, bulges, corrosion, erosion and fouling. Correction, if applicable.	Yearly
	• Inner inspection of casings: status, absence of corrosion, fouling and scale. Cleaning and descaling of heads.	Yearly
Control device	• Check hydraulic parameters.	Yearly
	• Check mobility of the dish Stirling.	Yearly
	• Check Stirling connections.	Yearly
	• Check auxiliary connections.	Yearly

- **Corrective maintenance**

If there is a good preventive maintenance, there should be no problem with the system, but as it happens in every technological device, unexpected things can happen that affect the proper operation of the system. In the dish Stirling, there are mainly four parts that could be broken because of its normal usage:

- The piping: Some leaks can appear and consequently there would be an energy loss and a pressure drop that would affect the good operation of the hydraulic system, being that a problem for the motor refrigeration process. To solve this, the leakage must be found and fixed by changing the broken parts or fixing them.

- The tracking engines: These could also break because of a movement impediment or something else. In this case, the engine should be changed or fixed by a mechanic one, if possible.

- The mirrors: They can get damaged by dirtiness or by a collision. Cleaning is important to avoid the first kind of damage, and the second kind should be fixed by changing only the damaged triangular mirror.

- Electric components: It can happen that some parts of the electric system get burned because of an overcharge or something similar. First of all, the problem must be spotted, in order to know where and which is the broken part, and then change it.

Another part that seems to be provably the most potentially problematic is the Stirling engine. However, it is completely sealed and ready to work for approximately 15 years without any need of predictive or reparation maintenance.

3. A yearly revision is needed only if a magnesium anode is used. If an electronic control is used to prevent corrosion, no maintenance is needed.

4. ENERGY STUDY

This section intends to break down and analyse the main parameter that affect the energy performance of the system.

4.1. Solar collector

The Solar collector is responsible for concentrating sun rays at a point. Usually, the collector shape is a parabolic reflector or a multiple spherically-shaped mirrors. The solar energy available on the receiver depends on the following factors:

- The **reflectance of the solar collector**, around 90% [12][9].
- Reflectance is influenced by **cleanliness of the dish**. If mirror cleaning is not done once a month, reflectance decreases to an approximate value of 75% [48].
- High accuracy is required for the **tracking system**. If not, the solar tracking system, the surface irregularities or receiver alignment with focal point can adversely affect the solar collector's efficiency. If we assume that the solar radiation is parallel to the axes of the dish, the intercept factor is between 95% and 99% [49]. A sun-tracker system's electric consumption in a year is about 5% of the energy generated [50] and this has to be deducted from the electric power output of the generator.

The global efficiency considered for this block is 89%.

4.2. Receiver

The receiver is the interface between the concentrator and the engine where the Sun's rays impact and are transformed into thermal energy. This then transfers the maximum thermal energy to Stirling engine. The thermal energy available in the Stirling engine depends on the following factors:

- If the receiver reaches high temperatures, thermal losses are significant. These losses increase as **the temperature of the receiver** rises.
- Convective losses, which can be due to natural convection if there is no wind speed or due to forced convection, i.e. the environmental **conditions**. There are two main types of receptors, flat and cavity-each with different thermal dynamics.
- Radiation losses. Note that the **proprieties of receiver materials** which are strong absorbers at a given wavelength are also strong emitters at that wavelength and vice versa. Normally, the conduction losses are not taken into account (i.e. the surface of the receiver is perfectly adiabatic).

The global efficiency considered for this block is 90%.

4.3. Stirling engine

The Stirling engine is responsible for converting the thermal energy that is concentrated in the receiver into kinetic energy, and for then feeding the generator with this energy.

The ideal Stirling thermodynamic cycle can be as efficient as Carnot's cycle, provided there is a perfect regeneration (i.e. during constant volume stages no heat leaves or enters the system). However, in practice, Stirling engines' efficiencies are much lower, because they lose play in an important role [51].

The main losses that undermine its efficiency are when [19]:

- The **regenerator** has a finite heat transfer capacity and thermal losses.
- **Expansion and compression** are not perfectly isothermal.
- The **working gas** passing through the regenerator leads to a pressure loss.
- The **piston movement** causes pressure losses.
- There are **dead volumes** in the engine that consume heat but don't do work.

Although all Stirling engines follow the same thermodynamic cycle, there is a wide variety when it comes to mechanical implementation. Cylinder coupling, piston coupling and regenerator design can present significant differences between engines.

The global efficiency considered for this block is between 20% and 40%, strongly depending on the temperature of the working fluid. Note that the efficiency of this free-piston engine is about 22%.

4.4. Electric generator

The electric generator is responsible for transforming mechanical energy into electric energy. Although the efficiency of electric machines varies slightly depending on its load, temperature, lubrication, etc. efficiency can be considered as a constant because these parameters are almost constant. This global efficiency can be divided into several terms, even though the two main terms are the mechanical part and the electric part.

- In the mechanical part, the losses mainly correspond to friction losses which depend on **speed**.
- In the electric part, the losses correspond to Joule losses which depend on **voltage or intensity.**

A value from 85% to 95% can be used for the global efficiency of an electric generator. Note that the efficiency of this lineal electric generator is about 86%.

4.5. Thermal system

The thermal exchange system is responsible for recovering the thermal energy from Stirling. The efficiency of this system is usually high. However, this depends on various factors affecting **heat recovery** efficiency, such as: insulation, exchanging surface, the inlet temperature, and the physical characteristics of the cooling fluid.

The global efficiency considered for the thermal exchange system is between 70% and 90% and strongly depends on the temperature of the outside environment. Note that the heat recovery efficiency is about 93% and the piping system and solar tank efficiency is about 81%. As a result, the global efficiency of the system is 75%.

4.6. Energy system performance

The overall system with its key factors and losses is shown in Figure 36. The power transmitted in each stage per unit is written in blue.

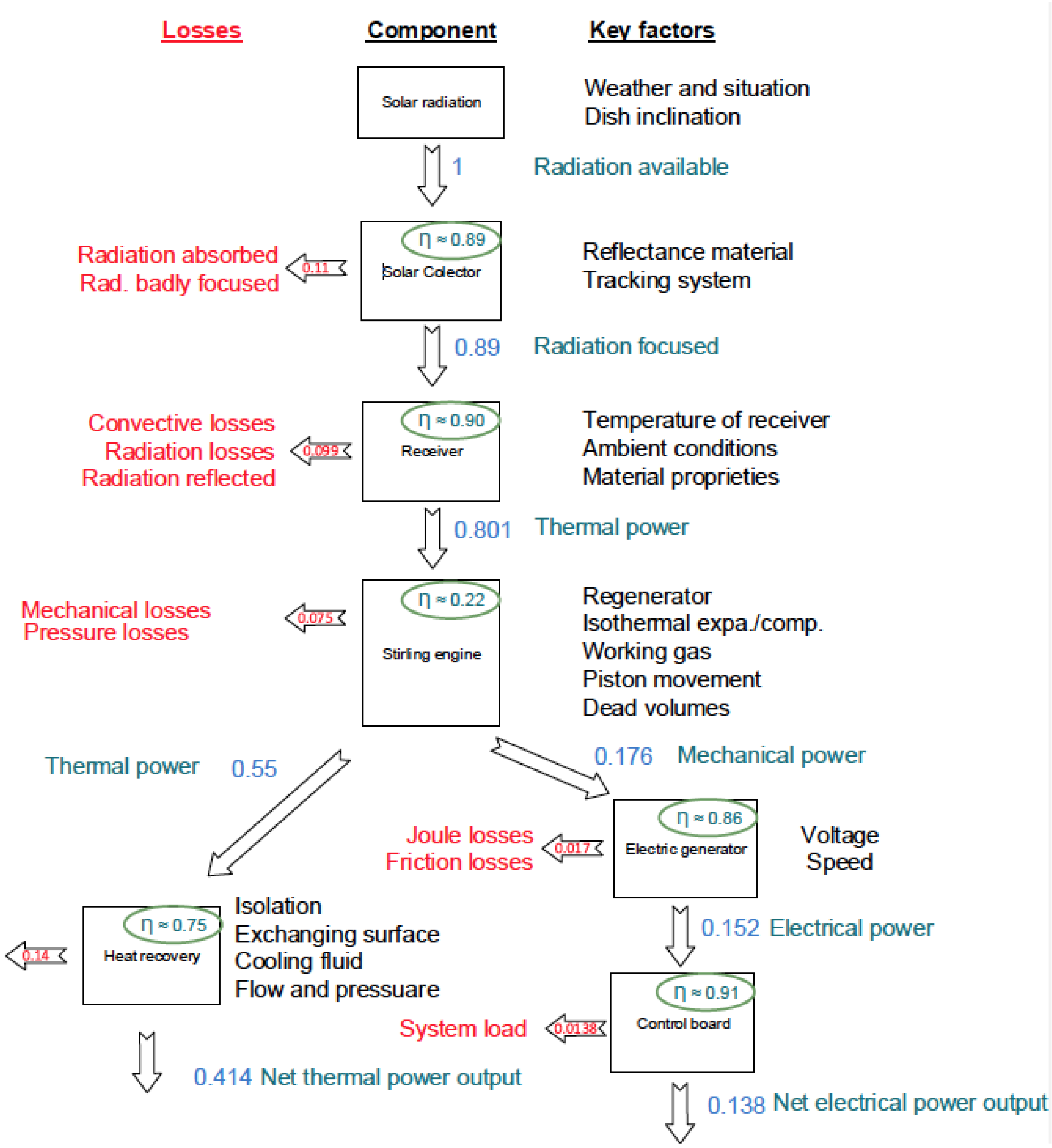


Figure 36. Dish Stirling System model overview

As the figure shows, the most critical step of the process is the Stirling engine. In this case, the electric performance is lower than some available products or models because a conservative value has been chosen. This is because a significant part of the energy performance output is due to thermal losses, which, in turn, warms the water and turns into thermal energy.

4.7. Energy production

In order to calculate the electricity and thermal production estimation of the Dish Stirling, an internal Spreadshee thas been developed by the Technical Team.

You will find below the information sources used to feed the calculation tool:

- DNI and temperature data have been taken from the PVGIS database. The data is taken for each 15 minutes from 5:22 in to 18:52. The information taken is monthly averaged for each moment of the day. The PVGIS database takes the data from a simulation map, so there is not experimental data used in this study. It is given in W/m².
- Electric production data have been calculated through the linear regression method provided by the manufacturer of the marketable product used to transform the incidence of irradiation into produced energy as follows:

$$E_{elec} = 0.1247 G_{DNI} * Area - 1.2156$$

Once the power has been obtained for every 15 minutes of the day, a sum up is done in order to obtain the whole production of energy for a complete day of every month of the year. It is important to divide by four this sum up, because the data obtained is given every 15 minutes, in order to be able to give the results in Wh/day.

Finally, a new sum up of the production for every month has been calculated in order to obtain the global energy production for all the year.

- Thermal production data have been calculated through the polynomial regression method provided by the manufacturer of the marketable product used to transform the incidence of irradiation into produced energy is as follows:

$$\rho_{th} = 0.55\left(0.769 - 0.66\frac{(T_m - T_e)}{G_{DNI}} - 0.008\frac{(T_m - T_e)^2}{G_{DNI}}\right)$$

$$E_{Th} = \rho_{th} A_c G_{DNI}$$

The 0.55 factor which changes all the regression given by the manufacturer is used because this regression is designed for a system which only produces thermal energy, not electricity, so the thermal yield is reduced by a 0.55 ratio in the cogeneration scenario.

Once the power has been obtained for every 15 minutes of the day, a sum up is calculated in order to obtain the whole production of energy for a complete day of every month of the year. It is important to divide this sum up by four, because the data obtained is given every 15 minutes, in order to be able to give the results in Wh/day.

Finally, a new sum up of the production for every month has been calculated in order to obtain the global energy production for the whole year, and it is given in kWh/y.

The summary of the electricity and thermal energy productions for the different installation sites of the project is shown as follows:

Table 17. Energy production summary

Country	Latitude	Length	DNI [kWh/m²y]	Electric prod. [kWh·y/kWp]	Thermal prod. [kWh·y/kWp]	Electric prod. [kWh·y/kWp]	Thermal prod. [kWh·y/kWp]
Patras, Greece	38.25	21.73	1977	2352	2365	2235	2247
Crete, Greece	35.53	24.15	2165	2309	2334	2193	2217
Matrouh, Egypt	31.33	27.22	1974	2350	2364	2232	2246
Alexandria, Egypt	31.19	29.91	2094	2493	2566	2368	2438
Salt, Jodan	31.97	35.99	1846	2197	2219	2087	2108
Barcelona, Spain	41.33	02.14	1943	2315	2326	2199	2210

In the two columns on the right, the calculations take into account approximately 5% less production due to dust losses on the concentrator, given that several facilities will be located in areas near a desert.

5. ECONOMIC DATA

This section breaks down the system components and costs of a Dish Stirling pilot unit.

Some assumptions have been taken into account:

- The system is installed in Barcelona: using its climatological data and its legal framework for electric protections.
- The Electric Control Unit and Hydraulic Control Unit are installed close to the dish Stirling concentrator (Trinum).
- The DSS is installed on the ground.
- The distance between the dish Stirling concentrator and the exchange system (solar tank) is larger than 20m. Therefore, an extra pump is needed, see right drawing in Figure 23.

The tables below show the measurements' list and the cost break down of the DS pilot system.

N	Ua	Measurements	Un
1.1.		**Dish Stirling system**	
	u	DISH STIRLING System: Modular cogeneration system with a nominal power of 1 kW electric and 3 kW thermal. The cooling system of the Stirling engine is a heat exchange system to support the use of a hot water system. Solar collector based on a cylindrical parabolic collector of 3.75 meters in diameter, supported by a pedestal or base. The overall optical performance should be at least 0.89%. Heat transfer system based on a compact set comprising a Stirling engine and an alternator unit. The Stirling engine architecture shall have a free piston, and the working fluid will be He and shall work at high temperatures (550-600 °C). The alternator shall be single phase with alternating current voltage of 230V and a frequency of 50Hz. An electric control system, control panel and regulation of the power system with all the necessary electronic components. It shall have a display panel for data such as: the electricity and heat generated, input and output temperatures of the working fluid, temperature of the fluid entering and leaving the cooling system, cooling flow, etc...an emergency disconnection switch, a manual switch, a biaxial tracking system (azimuth and elevation) through GPS system, a control system of the Stirling engine, a battery booster system. It shall also have an anemometer and a rain sensor. Hydraulic control system, control panel and the regulation of the hydraulic part with all the necessary components. It shall have a pump system, an expansion system (expansion vessel with a 3-litre capacity), safety valve, security valve, pressure gauge and thermometer, a flow meter and two temperature sensors for the input and output fluid cooling system. In addition to a three-way solenoid valve that diverts cooling fluids to a heat sink, a 3 kW heater shall also be included in the system.	1
1.2.		**BOS - Balance Of System**	
1.		**Power Block - Hydraulic Thermal System**	
	1.	**Primary hydraulic system**	
m.l.		Primary solar circuit formed by 20/22mm diameter copper pipes and exterior thermal isolation with a thickness of about 35 mm and coated with a white polyolefin copolymer. It includes the proportional part coming from the accessories as fixations, connections and pressure trials.	13.2
	u	Primary solar circuit formed by 20/22mm diameter copper pipes and interior thermal isolation with a thickness of about 25 mm and coated with a white polyolefin copolymer. It includes the proportional part coming from the accessories as fixations, connections and pressure trials.	32.8
	u	Brass ball valve with 3/4" Teflon rings. Maximum temperature 100 °C, PN 10 and ISO-9001 Certificate/AENOR. Keys for the internal exchanger system.	4
	u	Brass ball valve with 3/4" Teflon rings. Minimum temperature 100 °C, PN 10 and ISO-9001 Certificate/AENOR. Keys for the hydraulic control system.	2
	u	Brass ball valve with 3/4" Teflon rings. Temperature 100 °C, PN 10 and ISO-9001Certificate/AENOR. Keys for the heat sink system.	2
	u	Emptying valve, brass packing and closing top with 1/2" screw	1
	u	Air separator, vent and bottle of 3/4", suitable for use at high temperatures (130 °C minimum) and glycolate fluid. It shall be located at the highest point of the primary or solar circuit.	1

N	Ua	Measurements	Un
2.		**Heat transfer fluid**	
	u	Container with a 25-litre capacity composed of a mixture of distilled water and 1-2 propylene and corrosion inhibitors with a freezing point of approximately - 25oC	1
3.		**Exchange system - Thermal tank with internal exchanger**	
	u	Tank for the production and accumulation of hot water with a 500-litre capacity, in a vertical installation on the floor, made of enamelled steel according to DIN4753. The tank shall incorporate a coil with a minimum exchanger surface area of 2 m2, a lateral mouth for inspection with a 400 mm diameter. It shall incorporate a standard control panel with a thermometer and a magnesium anode with load meter for cathode protection of the deposit. The tank shall be insulated with rigid polyurethane foam injected into the mould, free of CFC's and exterior finish with removable quilted lining polypropylene, with covers included.	1
	u	Brass ball valve with 3/4" Teflon rings. Maximum temperature 100°C, PN 10 and ISO-9001 Certificate /AENOR. It shall include keys to insulate the consumption system accumulator.	2
	u	Automatic trap buoy column with password included. It shall be located at the top of the tank.	1
	u	Brass safety valve (10 bar) and rubber (1/2'' screw)	1
	u	Emptying valve and brass packing and closing top with 1/2" screw	1
	u	Glycerine gauge with 1/4'' screw with back connection, the scale of 0 to 10 bar. Includes pod and fittings required for installation (manometer).	1
	u	Thermometer with pod having 1/2'' screw with connection in the back, the scale of 0 to 120°C. Includes the required accessories for installation.	1
4.		**Filling system**	
	l.m.	Filling circuit for all the circuits, primary and secondary, made of copper pipes of 16/18 mm diameter and insulation. It shall include the proportionate part of accessories for fixing, connections and pressure tests.	6
	u	Brass ball valve with Teflon rings 3/4". Temperature 100°C, PN 25 and ISO- 9001 Certificate/ AENOR	2
	u	Brass Retention Valve 3/4" screw. Maximum temperature 90°C, PN 16 and ISO-9001 Certificate/AENOR.	1
5.		**Support Primary hydraulic system**	
	u	Expansion vessel with a minimum 8-litre capacity with replaceable membrane.	1
	u	Low-consumption pump (80W), pressure-regulated. The working temperature range is between 2oC and 110oC, it is feed by a 230 V single-phase voltage at 50 Hz. The hydraulic connector is 1. Nominal flow: 900l/h and 5.51 mH20 of load losses.	1
	u	Brass ball valve with 3/4" Teflon rings. Maximum temperature 100oC, PN 25 and ISO-9001 Certificate/AENOR. Keys to isolate the pumping system.	2
	u	Balanced flow valve without emptying (3/4"). Range of regulation between 3-12l/min. Maximum temperature 100ºC, PN 25 and ISO-9001 Certificate/AENOR.	1
	u	Anti-vibration sleeves 3/4" screw. EPDM body with nylon reinforcement. Maximum temperature 100ºC, PN 10 and ISO-9001 Certificate/AENOR.	2
	u	Retention valve 3/4" screw. Maximum temperature 90ºC, PN 16 and ISO-9001 Certificate/ AENOR.	1
	u	Brass filter strainer 3/4" screw. Maximum temperature 110ºC, PN 16 and ISO-9001 Certificate/AENOR.	1
	u	Glycerine Gauge 1/4" screw, with vertical connection, scale of 0 to 10 bar. Includes pod and fittings required for installation.	2

N	Ua	Measurements	Un
	u	Thermometer pod 1/2” screw with connection in the back, the scale of 0 to 120°C. Includes the accessories required for installation.	1
	m.l.	Primary solar circuit formed by 20/22mm diameter copper pipes and interior thermal isolation with a thickness of about 25 mm and coated with a white polyolefin copolymer. It includes the proportional part coming from the accessories as fixations, connections and pressure trials.	54
2.		**Electric Control Board**	
	u	Safety box protection of the electric system to current regulations (PMGB)	1
	u	Bidirectional monophasic (single phase) meter	1
	u	Breaker type B 7,5 A (PMGB)	1
	u	Differential switch 30 mA (PMGB)	1
	u	Safety box protection of the electric system to current regulations (Auxiliary Electric Box and Monitoring Box)	1
	u	Breaker type C 0,5 A (Auxiliary pump and Monitoring system)	2
	u	Pump relay	2
	u	Pump contactor	2
	l.m.	Wires and accessories	100
3.		**Support system**	
	u	Support system of the Stirling Dish and all its components. It will be based on a concrete plinth or a metallic structure which shall be strong enough to secure all the components against meteorological harshness such as wind or rain. The best option will be determined depending of the installation site.	1
	u	Metallic support for hydraulic and electric boxes	1
4.		**Transport**	
	u	System transport	1
1.3.		**Installation**	
	u	Installation and mounting for global Dish Stirling System, includingall small accessories for a good execution and operation of the system.	1
1.4.		**Monitoring System**	
	u	Net manager	1
	u	Analogic signals centraliser	2
	u	Monophasic analyser	2
	u	Flow meter	2
	u	Temperature sensors	4
	u	Three phase electric meter	1
	u	Three phase power analyser	1

N	Ua	Measurements	Un
	u	Circuit breaker	1
	u	Differential switch	1
	u	Fuses	1
	u	Commissioning (1-day programming)	1
1.5.		**Project**	
	u	Elaboration Projects: Executive and Safety-Health	1
	u	Permits and licences' administrative legalisation	1
	u	Commissioning	1
	u	Final Legalisation	1
1.6.		**O&M**	
	u	Preventive and corrective maintenance (product warranties)	1

DISH STIRLING COST ESTIMATION	€/Wp	KWe	KWt	kWeq total
	9,40	1	3	4
	kWh/kWp y	2100	2133	
	Annual output of the system kWh	2100	6399	
Dish Stirling System	51%			19.000 €
Cogeneration modular system, it generates 1 kWe-3kWt It includes the following components:				19.000 €
Solar field - Parabolic reflective concentrator - Solar tracking system - Structure (metal framework, focal support and metal trunk support)				
Power Block - Receiver - Stirling engine - Exchange chamber - Alternator (AC monophase)				
Electric Control Unit - Stirling engine control board (ECU) - Solar tracking control board (GPS coordinates - TCU) - Grid Protection board				

DISH STIRLING COST ESTIMATION	€/Wp	KWe	KWt	kWeq total
	9,40	1	3	4
Hydraulic Control System - Management of thermal energy produced - Control safety mode - Radiator				
Balance Of System (BOS)	30%			11.170 €
Power block / Cooling System - Solar hydraulic circuit - Cooling fluid - Exchange system - Thermal tank with internal exchanger - Filling system - Support primary hydraulic system* *In this case it is necessary, when the exchange system is placed farther away than 20 metres of DSS.				4.120 €
Control and Management - Electric Control Board				**1.900 €**
Support system components - Ground structure - concrete foundations				1.000 €
Building interaction / site preparation - Technical chamber conditioning				-
Storage				-
Transport				**1.000 €**
Installation / mounting - Mounting - Piping system - Electric system				**3.150 €**
Monitoring System	13%			4.800 €
Control and Management - Monitoring system				
Project	7%			2.640 €
Project, legalisation & administrative process				
Capital Cost	9,40			37.610 €
O&M (Operation and Maintenance) (€/year)	0,08			320 €

6. ANEXES

A.1. Trinum model

Co-generation
Trinum is a cogenerating system able to produce on the same time 1 kW of electric energy 230 V AC 50 Hz and 3 kW of thermal energy (warm water for heating and sanitary use). Trinum is in compliance with the EU directive 2009/28CE and with machine directive.

Efficiency
The overall conversion efficiency of the solar energy (DNI 725 W/m²) in thermal and electric energy is 55,2%, with 13,8% of electrical efficiency and 41,4% of thermal efficiency.

Electric Energy
Trinum is able to generate 1 kW of electric power. In one year Trinum produces 2100* kWh of electric energy.

Thermal Energy
Trinum is able to generate 3 kW of thermal power. In one year Trinum produces 6400* kWh of thermal energy.

Recyclable
Trinum is 100% recyclable.

Stirling Engine
Trinum is the only system in the world equipped with a free piston Stirling engine with an electrical power of 1 kW named LFPEG (Linear Free Piston Engine Generator) class EM1 produced by MEC, Microgen Engine Corporation.

Self Protection
Trinum can close on itself protecting the whole system from bad weather conditions. Trinum is equipped with an automatic solar tracking system and with digital data transmission devices for remote control.

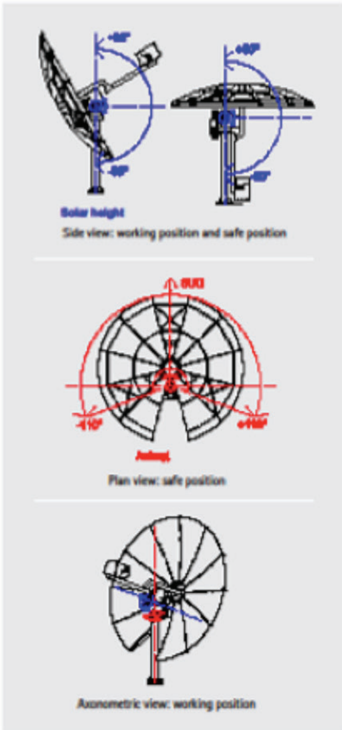
Operating Space
With the same production of electric and thermal energy, Trinum makes use of an area that is about the half of the one used by traditional protovoltaic and thermal panels (the occupied area is about 20 m², equivalent to a circumference with a diameter of about 5,00 m).

Economics
With the same installed power rating, Trinum generates up to 40% more of electric energy than a normal photovoltaic panel.

Plug & Play
Trinum generates alternate electric energy that can be input directly into the electric grid. Trinum needs no INVERTER.

* Estimate based on solar radiation of Rende (CS - Italy) (DNI source ENEA)

Generale	
Gross collector area	11,04 m²
Collector area	9,6 m²
Optical efficiency	89,00 %
Sun tracking	Dual axis
Temperature protection	Automatic system
Electric	
Peak electric power	1 kWp
Power supply	230/50 V/Hz
Yearly average electric energy*	2.100 kWh
Termico	
Peak thermal power	3 kWp
Yearly average thermal energy*	6.400 kWh
Heat transfer fluid	Water / Propylene glycol-water solution
Flow Rate	7-19 L/min
Hot water production @ 45 °C	80 L/h
Max IN temperature for Stirling engine of heat transfer fluid	60° C°
Min IN temperature for Stirling engine of heat transfer fluid	6° C°
Max heat transfer fluid pressure inside Stirling engine	7 Bar
Piping connection for cooling circuit	3/4 inches
Materials	
Reflector	Multilaminar Aluminium Mirrors
Structure	Galvanized steel / Inox steel
Environmental Performance, dimension and weight	
Maximum wind speed in operating conditions	50 km/h
Maximum wind speed in operating conditions	162 km/h
Weight	600 kg
Reflector diameter	3,75 m
Maximum overall dimensions	d. 5,00 m x h. 4,60 m
Height in safe position	3,00 m
Maximum height in working position	4,60 m
Warranty	2



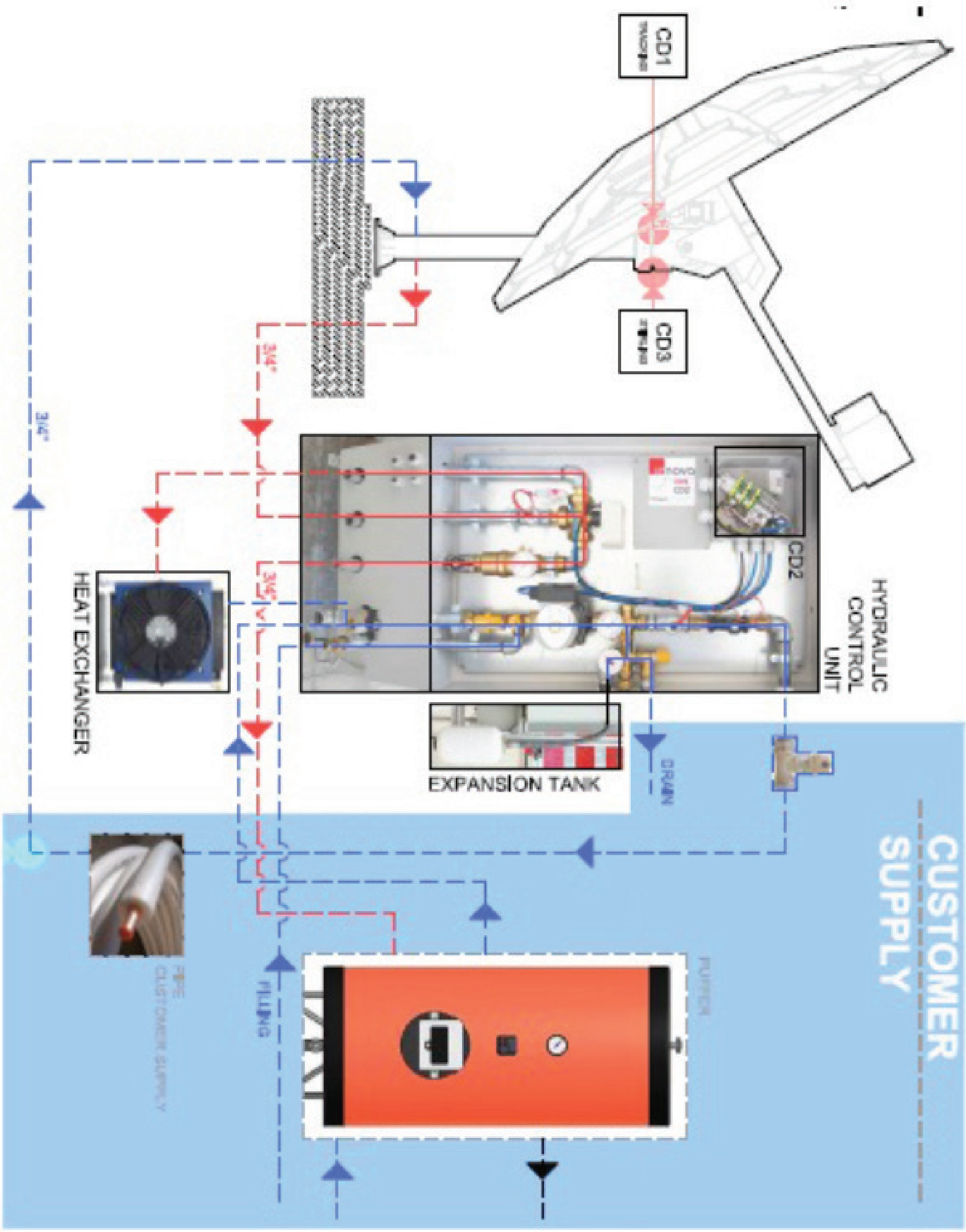
Trinum

CE Certified Product by IMQ from 01/12/2011.
Approved Component by Enea as Technical Report no. RT. 2012.COL.172.1

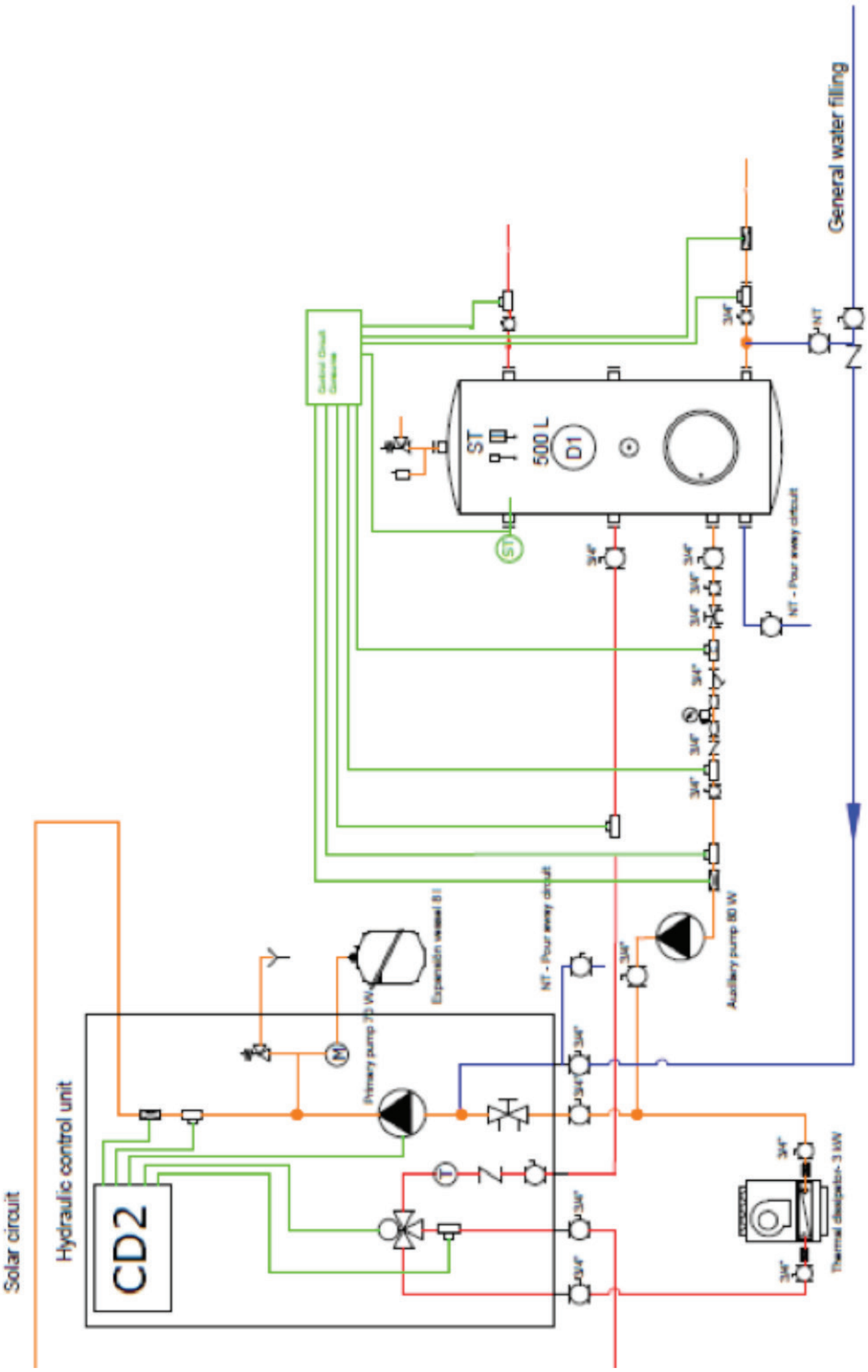
R&D e Production
Via Pedro Alvares Cabral C.da Lecco
Zona Industriale – 87036 Rende (CS) – Italy
Phone +39.0984.482602

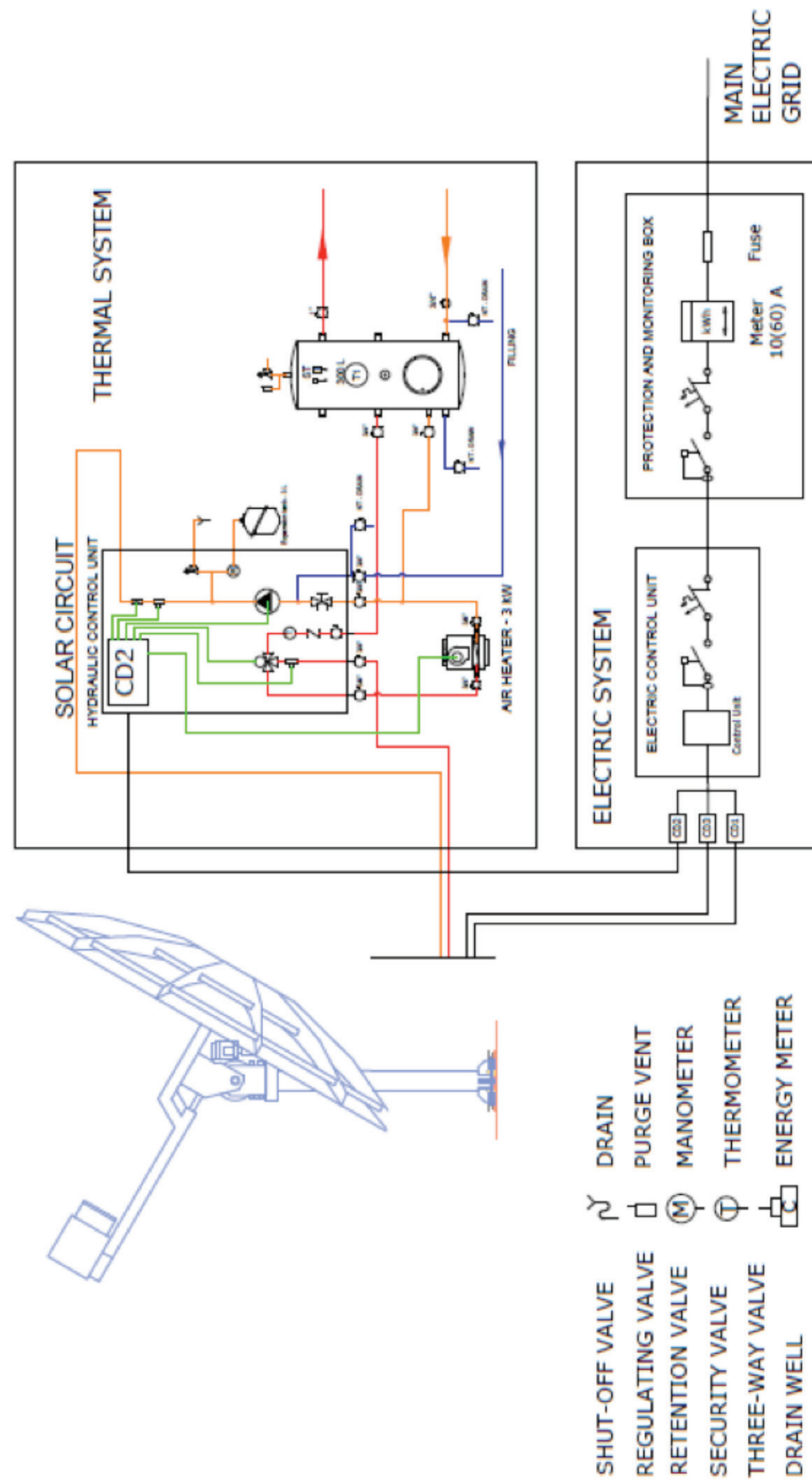
Sales Office
Via Raffaello, 23
65124 Pescara
Phone +39.085.7998300

Innova APPLIED BRILLIANCE


CD1
CD3
3/4"
3/4"
CD2
HYDRAULIC
CONTROL
UNIT
HEAT EXCHANGER
3/4"
EXPANSION TANK
DRAIN
CUSTOMER
SUPPLY
FILLING

A.2. Diagram


General water filling
Solar circuit
Hydraulic control unit
CD2
ST
500 L
D1


THERMAL SYSTEM
SOLAR CIRCUIT
HYDRAULIC CONTROL UNIT
CD2
AIR HEATER - 3 kW
FILLING
ELECTRIC SYSTEM
ELECTRIC CONTROL UNIT
Control Unit
PROTECTION AND MONITORING BOX
Meter
10(60) A
Fuse
kWh
CD2
CD3
CD1
MAIN
ELECTRIC
GRID
SHUT-OFF VALVE
REGULATING VALVE
RETENTION VALVE
SECURITY VALVE
THREE-WAY VALVE
DRAIN WELL
DRAIN
PURGE VENT
MANOMETER
THERMOMETER
ENERGY METER

A.3. Images

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General statement on the European Union

Project funded by the
EUROPEAN UNION

The European Union is made up of 27 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.

بيان عام عن الاتحاد الأوروبي
يتكوّن الإتحاد الاوروبي من ال 27 الدول الأعضاء الذين قرروا معاً ربط خبراتهم والموارد ومصائرها. معاً، وخلال فترة 50 عاماً من التوسع، تم بناء منطقة من الإستقرار، الديمقراطية والتنمية المستدامة مع الحفاظ على التنوع الثقافي، التسامح والحريات الفردية. يلتزم الإتحاد الأوروبي في تقاسم إنجازاته وقيمه مع الدول والشعوب خارج حدوده.

General statement on the European Union (Greek)

Η Ευρωπαϊκή Ένωση αποτελείται από 27 Κράτη Μέλη που έχουν αποφασίσει να συνδέσουν σταδιακά την τεχνογνωσία, τους πόρους και το μέλλον τους. Κατά τη διάρκεια μιας περιόδου διεύρυνσης 50 ετών, έχουν δημιουργήσει μαζί μια ζώνη σταθερότητας, δημοκρατίας και αειφόρου ανάπτυξης διατηρώντας παράλληλα την πολιτιστική πολυμορφία, τη διαφορετικότητα και τις ατομικές τους ελευθερίες. Η Ευρωπαϊκή Ένωση έχει δεσμευθεί να μοιράζεται τα επιτεύγματα και τις αξίες της με χώρες και λαούς που βρίσκονται εκτός των συνόρων της.

Statement about the Programme

ENPI CBCMED
CROSS-BORDER COOPERATION IN THE MEDITERRANEAN

The 2007-2013 ENPI CBC Mediterranean Sea Basin Programme is a multilateral Cross-Border Cooperation initiative funded by the European Neighbourhood and Partnership Instrument (ENPI). The Programme objective is to promote the sustainable and harmonious cooperation process at the Mediterranean Basin level by dealing with the common challenges and enhancing its endogenous potential. It finances cooperation projects as a contribution to the economic, social, environmental and cultural development of the Mediterranean region. The following 14 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestinian Authority, Portugal, Spain, Syria, Tunisia. The Joint Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French.

بيان حول البرنامج
هو برنامج للتعاون المشترك عبر الحدود لحوض البحر الأبيض المتوسط، هو جزء من سياسة الجوار والشراكة 2013 – 2007 NPI CBC MedEإن برنامج
الأوروبية ومن آلياتها التمويلية. يهدف هذا البرنامج إلى تعزيز ودعم عملية التعاون المستدام والمنسجم على مستوى حوض البحر الأبيض المتوسط وذلك من خلال معالجة التحديات المشتركة وتعزيز الإمكانات الذاتية. يموّل البرنامج مشاريع التعاون كمساهمة في التنمية الإقتصادية، الإجتماعية، البيئية والثقافية لمنطقة البحر الأبيض المتوسط. إن قبرص، مصر، فرنسا، اليونان، إسرائيل، إيطاليا، الأردن، لبنان، مالطا، السلطة الفلسطينية، البرتغال، إسبانيا، سوريّا، الدول ال 14 التالية هي الدول المشاركة في البرنامج: هي منطقة الحكم الذاتي لمقاطعة سردينيا (إيطاليا). إن اللغات الرسمية للبرنامج هي : العربية ، الإنجليزية والفرنسية. JMAتونس. إن سلطة الإدارة المشتركة

Statement about the Programme

Το Πρόγραμμα Διασυνοριακής Συνεργασίας Μεσογειακής Λεκάνης (ENPICBCMediterranean SeaBasin) 2007-2013 είναι μια πολυμερής πρωτοβουλία Διασυνοριακής Συνεργασίας η οποία χρηματοδοτείται από το Ευρωπαϊκό Μέσο Γειτονίας και Εταιρικής Σχέσης (ENPI). Το Πρόγραμμα έχει σαν στόχο να συμβάλει στην προώθηση της βιώσιμης και αρμονικής συνεργασίας στην περιοχή της Μεσογειακής Λεκάνης αξιοποιώντας πλήρως τις ενδογενείς δυνατότητες της περιοχής και αντιμετωπίζοντας τις κοινές προκλήσεις. Χρηματοδοτεί έργα συνεργασίας τα οποία συμβάλλουν στην οικονομική, κοινωνική, περιβαλλοντική και πολιτιστική ανάπτυξη της Μεσογείου. Στο Πρόγραμμα συμμετέχουν οι ακόλουθες 14 χώρες: Κύπρος, Αίγυπτος, Γαλλία, Ελλάδα, Ισραήλ, Ιταλία, Ιορδανία, Λίβανος, Μάλτα, Παλαιστινιακή Αρχή, Πορτογαλία, Ισπανία, Συρία, Τυνησία. Η Κοινή Διαχειριστική Αρχή (ΚΔΑ) του Προγράμματος, είναι η Αυτόνομη Περιφέρεια της Σαρδηνίας (Ιταλία). Επίσημες γλώσσες του Προγράμματος είναι τα Αραβικά, Αγγλικά και Γαλλικά.

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تنبيه
. إن محتويات ENPI CBC Med" لقد تم إعداد هذه النشرة بمساعدة مالية من الإتحاد الأوروبي في إطار برنامج التعاون المشترك عبر الحدود لحوض البحر الأبيض المتوسط
هذه الوثيقة من مسؤولية ولا تعكس تحت أي ظرف من الظروف رأي الإتحاد الأوروبي أو الهياكل الداخلية للبرنامج. "

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