NOVEL m–CHP GENERATION FROM SMALL SCALE CONCENTRATED SOLAR POWER

L. Crema[1], F. Alberti[1], A. Bozzoli[1], E. Wackelgard[2], B. Rivolta[3], S. Hesse[4], M. Luminari[5], D. Hislop[6], B. Restall[7]

[1] Renewable Energies and Environmental Technologies, Fondazione Bruno Kessler, Povo-Trento, Italy

[2] Department of Engineering Sciences, Uppsala University, Uppsala, Sweden

[3] Department of Mechanics, Politecnico di Milano, Milano, Italy

[4] Narva Lichtquellen GmbH + CO; Brand-Erbisdorf, Germany

[5] El.Ma. Electronic Machining srl, Riva del Garda (TN), Italy

[6] Sustainable Engine Systems Ltd, London, UK

[7] Projects in Motion Ltd., Triq il-Minfah, Malta

1. Introduction

The paper describes the realization of a modular 1-3 kW_e, 3-9 kW_{th} micro Combined Heat and Power (m-CHP) system based on innovative Concentrated Solar Power (CSP) and Stirling engine technology. This CSP m-CHP will provide electrical power, heating and cooling for single and multiple domestic dwellings and other small buildings.

The cogeneration of energy at distributed level is one of leading argument in large part of energy policies related to renewable energy resources and systems. The actual marketable solar systems for domestic and distributed applications (PV and Solar thermal) suffer of notable limitation: i) the low overall (electrical) efficiency of PV systems create a small collected energy from available space, sometimes restricted in surface to few square meters, ii) the stagnation temperatures on solar thermal collectors actually limiting the diffusion of solar thermal systems, iii) fixed and not retrofittable systems may generate energy in intermittent way not aligned with the auto consumption profile of domestic spaces.

The development of a new cogeneration system, based on a compact concentrated solar power is therefore highly required, realized compatibly with the market levelised energy cost (LEC).

Such system (see Fig. 1) integrates small scale concentrator optics with moving and tracking components, solar absorbers in the form of evacuated tube collectors, a heat transfer fluid, a Stirling engine with generator, and heating and/or cooling systems; it incorporates them into buildings in an architecturally acceptable manner, with low visual impact. Four main themes have led to the development of this proposal:

- improvements in glass technology allow the adaptation of large parabolic trough solar concentrator technology for much smaller scale systems, down to the single domestic dwelling;
- recent studies on ceramic-metal (Cer.Met.) coatings suggest that they can provide improved optical behaviour and material durability for absorbers inside evacuated tube collectors, at higher temperatures than previously possible, leading to lower emittance and higher efficiencies, with very low costs at high production volumes;
- modified Stirling cycles and new compact heat exchanger technology can improve the costs and performance of small heat engines, so that they can operate with higher proportions of Carnot efficiency on the intermediate temperatures (~ 320 °C) from the new CSP collectors;
- the high cost and low power efficiency of gas-fuelled m-CHP systems, combined with increases in natural gas prices, both absolute and relative to electricity prices, can undermine the financial viability of gas-fuelled m-CHP. There is an urgent need for alternative m-CHP systems, of which solar m-CHP , whether separately or as a hybrid, is an option with high potential.

This paper will describe the first phases of development of such m-CHP solar technology, which integrates a cooperation between seven main partners distributed along five European countries. The work is part of a European Funded project (DiGeSPo, 2011) in the CALL ENERGY-2009-1.

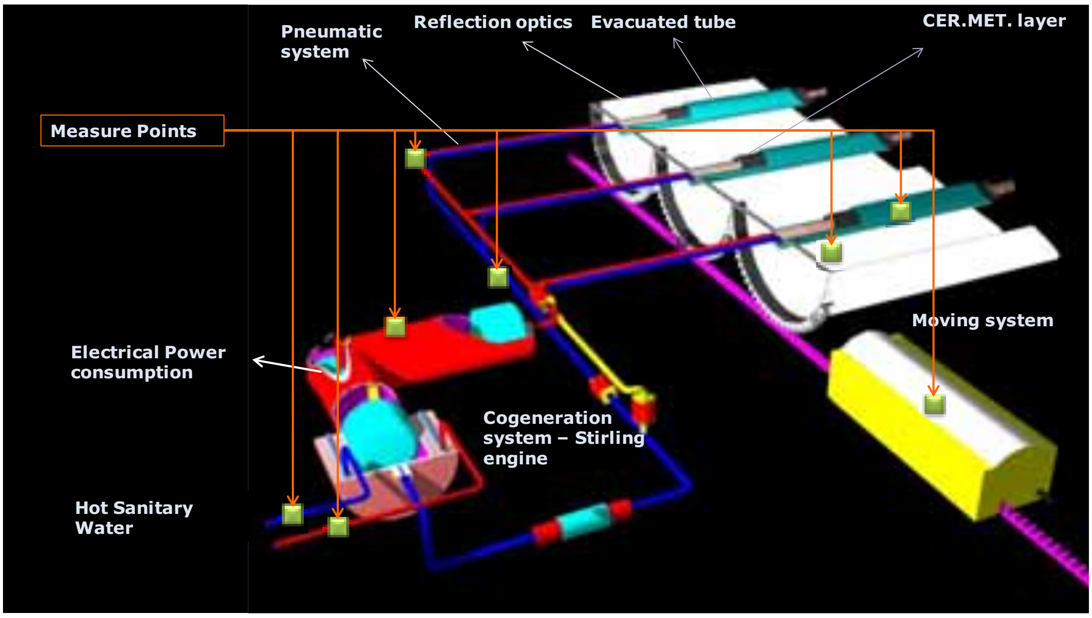

Fig. 1: Schematic picture of the m-CHP system under development within DiGeSPo project

2. Methodology

2.1. Multidisciplinary approach

The CSP m-CHP technology under development requires a multidisciplinary approach and regards a series of themes below described on the main objectives for the related research.

Selective absorber (Cer.Met. coating): R&D on an innovative coating for the solar absorber inside the evacuated tube collector. A new nano-technology-based Cer.Met. layer (ceramic-metal) will be used to minimise solar re-radiation back to atmosphere and increase the conversion efficiency of solar radiation to heat energy in the thermal vector fluid at temperatures up to 250-350°C. The general efficiency target is to have an absorbance greater than 0,93 and an emittance smaller than 0,06.

Concentration optics and tracking system: modelling and development of the optical sub-system. It comprises a very high efficiency, low profile parabolic trough reflector using new, chemically treated, flexible and low cost thin glass mirrors, with concentration ratio of 12:1, a tracking system (both mechanical and electronic control components). The efficiency target is a reflectance higher than 0,93 (averaged on solar spectrum) and an impact factor higher than 0,93.

Thermal fluid: R&D on a suitable single or two phase fluid that maximises heat transfer efficiency from the Cer.Met. layer to the Stirling engine; reducing the NTU deficit, Number of Transferred Units (of heat), to a minimum. The thermal fluid must adapt at the defined heat engine cycle and must be compatible with the hydraulic circuit of the evacuated solar collector.

Full solar collector: Modelling and optimisation of an existing evacuated tube collector It uses a low iron, glass tube with a nanoparticle-based anti-reflective coating (actual certified transmittance of the glass: 0,96), an absorber with the improved, new high temperature Cer.Met. layer; integration of the complete collector system to the input/output of the thermal vector fluid. The overall efficiency target is 80% (heat to fluid/radiation to concentrator).

Heat engine: modeling, development and assessment of two novel engine options that will provide higher efficiencies than existing engines at the target temperatures. One is a high energy density Stirling engine, based on a pre-engineering realized by Fondazione Bruno Kessler; the second is a rotary, modified Stirling cycle engine based on scroll compressor technology. Both will use novel, extremely compact heat exchangers based on new manufacturing technology, offering higher efficiency and lower cost. Both will be matched to the low/medium temperatures and different cycle conditions, with a target power conversion efficiency for the engine/generator of 20-22%, with air-cooling if required.

2.2. System integration and Demonstration of the technology

sub-components are integrated into complete formats suitable for initial prototype characterization, and compliant with later large scale industrial production, commercial impact on the market and prescribed standards. A test bench has been equipped with sensors to measure performance parameters. The final prototype will integrate sensors with the control system, to provide feedback and to control all security options. All the sensors have been chosen in order to meet the precision requirement defined by the UNE EN 12975-22006 standard, which is the guideline for efficiency testing and certification of solar collectors.

A thermoregulation unit, also referred as “Centralina”, is the system designed to decouple the testing for the solar collector and the engine (see Fig. 2). It’s capable to set a fixed temperature in the system, thanks to a PID controller, which regulate the rejection or insertion of heat power in the system. The main components are a water heat exchanger (FT-H), which is used to extract power during solar collector’s efficiency testing, and an electrical heater (RRE), which will be used for Stirling engine performance characterization and preheating purpose. The thermoregulation loop is driven by a magnetic seal pump (PRC-1), while the flow delivered to the system is set by a secondary pump (PRC-2), which rotation velocity is controlled with an inverter. This configuration allows a better control on the response of the system and avoid the risk of oil degradation.

To avoid the contact of hot oil with atmospheric air, which can lead to oxidation of the fluid starting at 70 °C, an open expansion tank is located upon the unit . The connecting leg act as a thermal insulator and the system is open to atmosphere and not pressurized. Temperature in the expansion tank is further controlled with a secondary water heat exchanger (FT-C), which is automatically activated if a temperature sensor is triggered. Total power is 14 kW for electrical heater and 25 kW for the cooler heat exchanger.

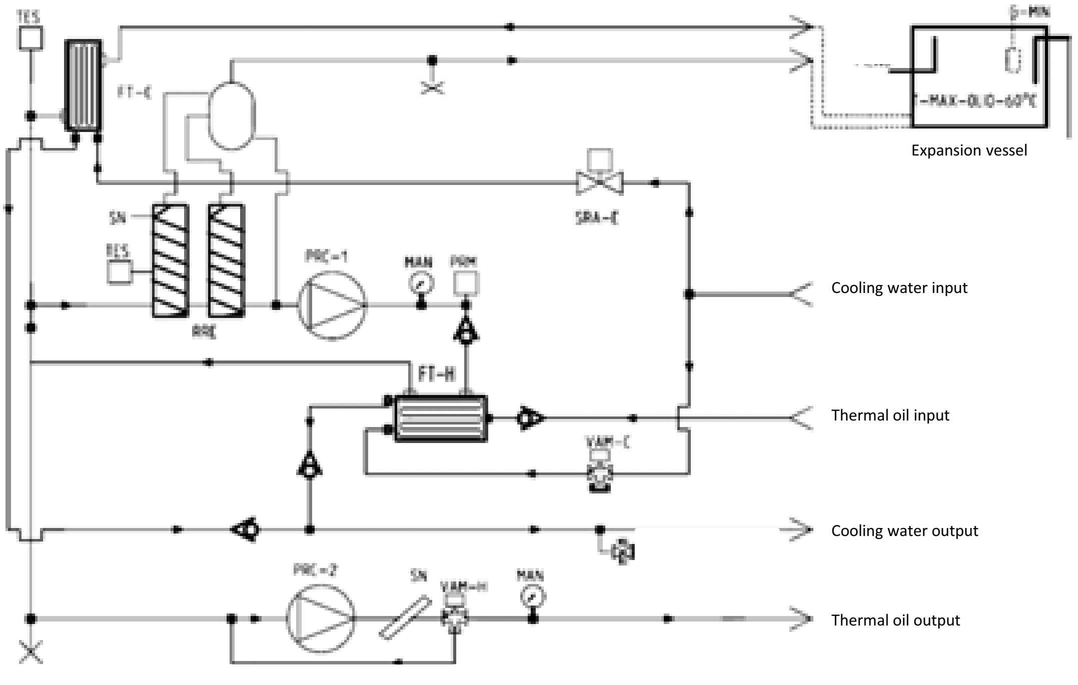

Fig. 2: thermoregulation unit layout (“Centralina”). The system is designed to test solar collector efficiency and engine performance up to 320 °C

The demonstration of the technology will be located in a high impact and visibility location in the middle of the Mediterranean area (ArrowPharma Ltd. in Malta).

2.3. System modelling and qualification, energy balance and overall efficiency

The proposed technology is able to convert direct solar radiation into electrical and thermal energy. The energy flow has been characterized and the different energy conversions / transfers have been partly verified and partly theoretically confirmed.

The overall efficiency, for a parabolic trough collector, is given by Eq. 1.

$$\eta = F_R\left[\eta_0 - U_L\left(\frac{T_i - T_a}{G_B C}\right)\right]$$ (eq. 1)

Where F_R is the heat removal factor, η_0 is the collector optical efficiency, U_L is the solar collector overall heat loss [W/m^2·K], T_i is the collector input temperature [K] and T_a is the ambient temperature [K], G_B is beam radiation and C is the collector concentration ratio.

The fluid dynamic of the overall system has been modelled and tested. The mass nominal flow rate for the pump is calculated in relation to the maximum thermal power at the input of the system. The solar field is composed by 4 unit, each with four parabolas with dimensions 2 x 0,4 m. The data used in the calculation are:

I = 850 W/m^2 (maximum direct solar radiation); A = 2 · 0,4 m = 0,8 m^2 (parabola area); n = 16 (total number of parabolas); η_{OptiTh} ≈ 0,8 (maximum thermal efficiency expected for the solar collector @ 300 °C and 850 W/m^2).

During calculations the oil is assumed at 300 °C, with a density of 809 kg/m^3 and specific heat capacity (C_p) of 2,51 kJ/kg·K. Maximum power transmitted to the fluid is calculate in a on conservative way, by assuming a perfect thermal efficiency for solar collectors, as indicated in Eq. 2:

$$P_S = \eta_{OptiTh} \cdot I \cdot A \cdot n = 10{,}8\ kW \approx 11\ kW$$ (Eq. 2)

This value can be used to select pump size, which must provide sufficient flow in order to control temperature rise inside the collectors. It is assumed that the flow is equally distributed on solar field, which is composed by 16 tube in parallel. Simulation on heat transfer phenomena shown that maximum bulk (345 °C) and film temperature (375 °C) is avoided (Solutia Inc., 2010) when a velocity of at least 0,4 m/s is imposed inside the collector tube (Fig. 7). This value correspond to a flow rate as from Eq. 3:

$$\dot{m}_1 = \pi\left(\frac{D_i}{2}\right)^2 \cdot v \cdot \rho \cdot n = 0{,}212\ kg/s = 15{,}8\ l/min$$ (Eq. 3)

Temperature rise is calculate as reported in Eq. 4:

$$\Delta T = \frac{P_S}{\dot{m}_1 \cdot C_p} = \frac{11}{0{,}212 \cdot 2{,}57} = 20\ °C$$ (Eq. 4)

Under such flow regime the oil in the solar field is heated from 300 °C to 320 °C. See Fig. 3 for temperature distribution in function of the inlet velocity and inlet temperature.

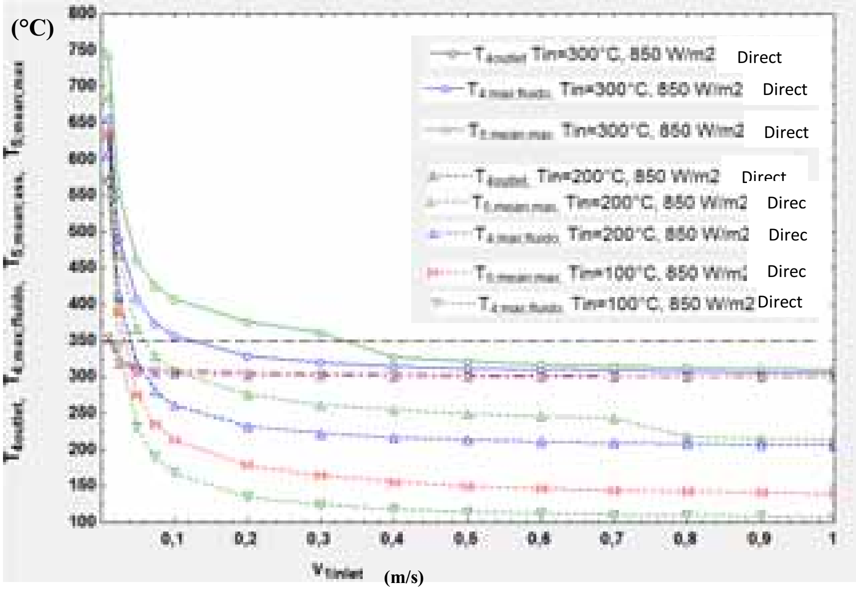

Fig. 3: Maximum bulk (blue dot) and film temperature (green dot) for the fluid in the solar collector, as a function of flow rate, solar irradiation and inlet temperature

A lower temperature rise and film temperature can be achieved by increasing the flow rate. A flow rate of 32 l/min can reduce outlet temperature to 305 °C (see Eq. 5).

$$\dot{m}_2 = \frac{P_S}{\Delta T \cdot C_p} = \frac{11}{10 \cdot 2,5} = 0,44\ kg/s = 32\ l/min \qquad \text{(Eq. 5)}$$

Simulation show that a minimum velocity should always be imposed inside the collector, in order to avoid losses in thermal efficiency for the solar collector (Fig. 4). The efficiency is reduced when velocity is below 0,1 m/s, which correspond to a flow rate of about 4,2 l/min (see Eq. 6).

$$\dot{m}_{MIN} = \pi \left(\frac{D_i}{2}\right)^2 \cdot v \cdot \rho \cdot n = 0,0556\ kg/s = 4,13\ l/min \qquad \text{(Eq. 6)}$$

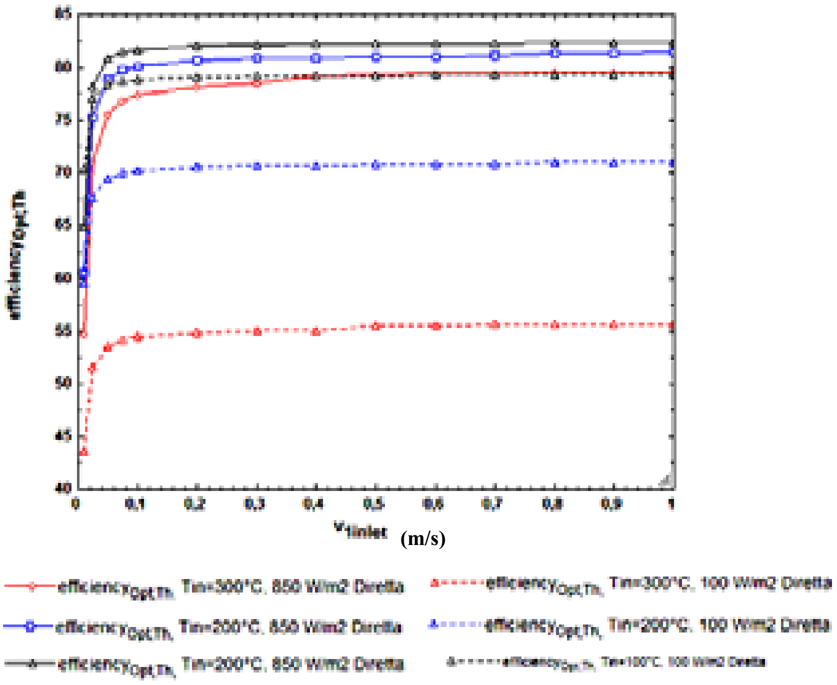

Fig. 4: thermal efficiency for the solar collector is function of solar irradiation and fluid velocity. Below 0,1 m/s thermal efficiency is lost under every irradiation level

An important element for the overall efficiency of the system is the solar receiver in form of evacuated solar tube. To understand and design the trough, receiver and system components, specific software tools have been developed (Alberti A., Crema L. 2010).

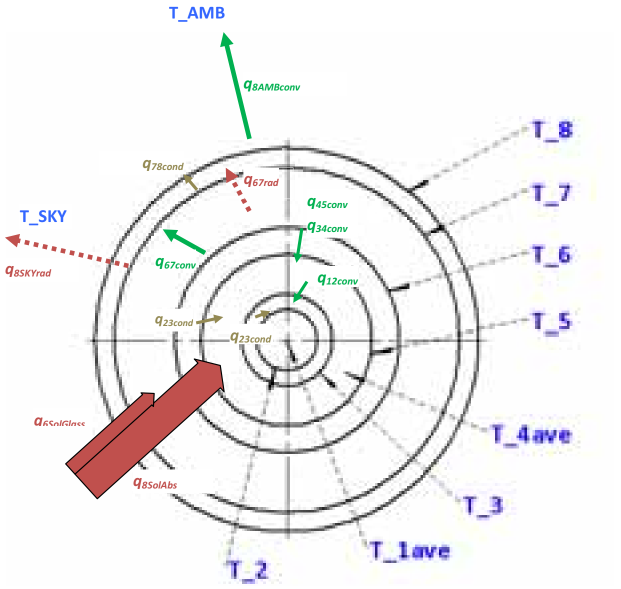

Fig. 5: : Defined temperatures, thermal resistance and heat fluxes on a collector cross-section of the receiver

The simulation program enable the analysis and prediction of the thermal behaviour of coaxial vacuum tubes under different working conditions. The software algorithms allow the realization of parametric studies, where various input variable (such as temperature fluid at inlet, solar irradiation, outside temperature and wind conditions) can be varied, in order to calculate the efficiency and find the optimal operational configuration. An example of the parameters taken in consideration is presented in Fig. 5.

On the extreme end of the hydraulic circuit, thermal energy enters a heat engine for energy cogeneration. The thermodynamic design of the cycle for the heat engine has used different tools in order to find the optimal parameters for main components of the engine, including pistons, the regenerator and heat exchanger. The starting point has been Schmidt analysis and the Beale number, from which qualitative parameters can be extracted. Since the beginning, the Beale number takes in evidence that an high density power, which means reducing the swept volume, can be achieved by increasing the charge pressure or the working frequency.

$$B_n = \frac{Wo}{PVF} \quad \text{(Eq. 7)}$$

Where B_n is the Beale number, W_o is the power output of the engine [W], P is the mean average gas pressure [Bar], V is swept volume of the expansion space [m^3], F is the engine cycle frequency [Hz].

Increasing the cycle efficiency has the disadvantages of increasing mechanical losses from friction, and leaves with the option of increasing instead the pressure. Other engine realized for medium temperature application show that the design of a low speed engine is the way to follow (Cool Energy, Boulder CO), in order to achieve good efficiency and reduce mechanical losses. A low speed engine can also operate more quietly and with less noises. From the beginning the results was the selection for a low speed high charged pressure concept, and the initials parameters derived from the Beale number have been used to perform the iterative simulations. The simulation tools used are the one developed by Urieli and Berchowitz (Urieli and Berchovitz, 1984). Those method results in sinusoidal varying temperatures in the working spaces, temperature drop between the compression space and cooler, temperature drop between the heater and the expansion space, non-constant working fluid temperatures over the cycle, and pressure losses across the cooler, regenerator, and heater, as shown in Fig. 6. An accurate correlation for heat transfer is very important in order to predict correctly the cycle performance, and weakness of quasi-steady-flow correlations. A specific tool has been used to find and optimize the thermodynamic cycle in a iterative way, while the code from Urieli have been used to check the results and for secondary analysis.

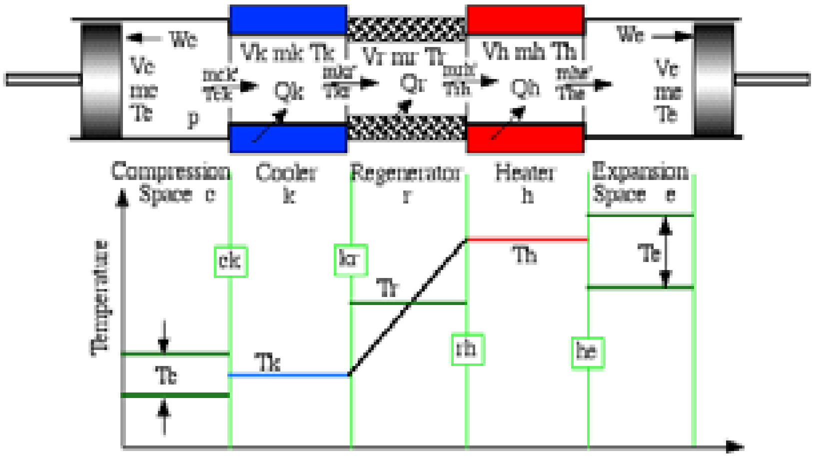

Fig. 6: components and parameters model (Urieli and Berchowitz, 1984)

The energy flow, including all sub-components, from direct solar radiation to thermal and electrical energy generation, is reported in Fig. 7. Main conversions / energy transfers have already been confirmed experimentally.

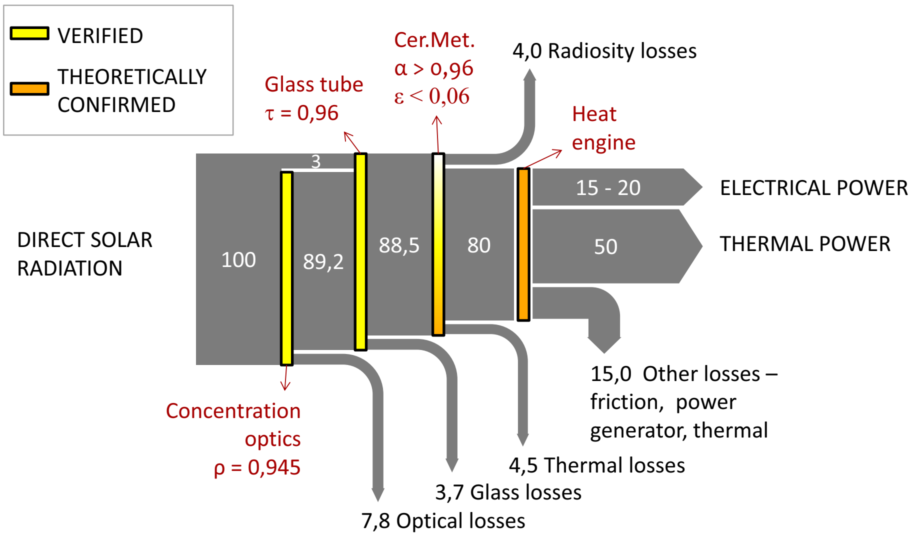

Fig. 7: Energy flow and efficiency loss / gain through the CSP modules and the thermodynamic cycle

2.4. Methodological approach to the technological development

The technology under development addresses directly the above issues with the intention to make available solar cogeneration systems for the distributed scale, by respecting specific contents/scopes, as follows.

- improving the efficiency of key components: the efficiency of the following sub-systems will be improved: small scale parabolic trough concentrators, solar absorbers inside evacuated tube collectors, heat transfer to the prime mover, and the prime mover (modified Stirling engine) itself;
- improving CSP's environmental profile by: vastly increasing its potential market and the CO2 savings that result; locating the CSP plant on roof-tops to eliminate the need for extra land; and reducing or even eliminating the use of water for cooling: final heat rejected by engine is used for heating and/or cooling the building, because the high efficiency of the engine, together with the use of highly compact heat exchangers, particularly the cooler, allows significant reductions in the temperature of reject heat, compared with existing Stirling engines;
- employing new coatings and nano-technology: self-cleaning nano-surfaces on the concentration mirrors reduce maintenance costs and increase reflective efficiency; Cer.Met coatings on the absorber increase energy conversion efficiency;
- providing large reductions in both capital and maintenance costs: approaching the EU's target of 6-9 cent€/kWh$_e$ by 2020 [2] is one of the main project drivers. It will be achieved by innovation in component and sub-system design ; by later mass production; by eliminating land and water costs; by the use of reject heat for heating and/or cooling on-site; and by almost eliminating transmission costs;
- hybridization with other fuels can be achieved in several ways. Most attractive is integration with gas-fuelled m-CHP, for which there are several options;
- reliability and durability will be ensured by the small scale, low profile design, by transferring lessons learnt in the large scale sector to the small scale sector and by the use of proven evacuated tube technology.

3. Results

On the starting development phases related to the project, some good results have already been achieved. Some details are yet under modelling and development. Indeed some results are presented on the main technological issues.

3.1 Selective absorber (Cer.Met. coating) and evacuated solar tube

A theoretical modelling on sample candidates has been performed at Angstrom Laboratories in Uppsala

University. The modelled results have provided indications on the best candidates (Wackelgard et Al., 2010).

From theoretical calculations using the commercial software SCOUT, it has been modelled a number of coatings. It has been used a Cer.Met. structure of three layers (two Cer.Met. and one antireflection) using the oxide matrix TiO_2, SiO_2, ZrO_2 and Fe, Co, Ni, Y, Nb, Mo, W, Pt, Ce, Sm, Tb, Dy, Er, Tm, Yb as metal component. Also Al_2O_3 was modelled with Mo, W and Ni and Ta_2O_5 with W, Pt and Ta.

One clear result is that the 4f-element Cer.Met. (i.e. specifically Dy) showed in general a lower absorbance (for about the same emittance) compared to the 3 d – element Cer.Met.. Another systematic result is that TiO_2 as matrix gives a lower absorbance than SiO_2 and ZrO_2. However the differences are small, the best result for in the titanium oxide group (Ce-TiO2) has absorbance/emittance 0.955/0.097 compared to the best result (0.964/0.096 for Y-ZrO_2 or 0.963/0.091 for Ta-SiO_2). The worst result of all modelled is 0.907/0.097 for Dy-ZrO_2. The limitation here has been a little higher in the emittance than set by the delivery condition. Lowering the emittance to the delivery of 0.06 gives a lower absorbance by 0.02 to 0.03 units. Two Cer.Met. have been modelled for the lower emittance than for W-Al_2O_3 0.937/0.06 and for W-Al_2O_3 0.935/0.05.

The candidates from the modelled group are: W-Al_2O_3, W-SiO_2 since W is proved to be relatively stable in temperature.

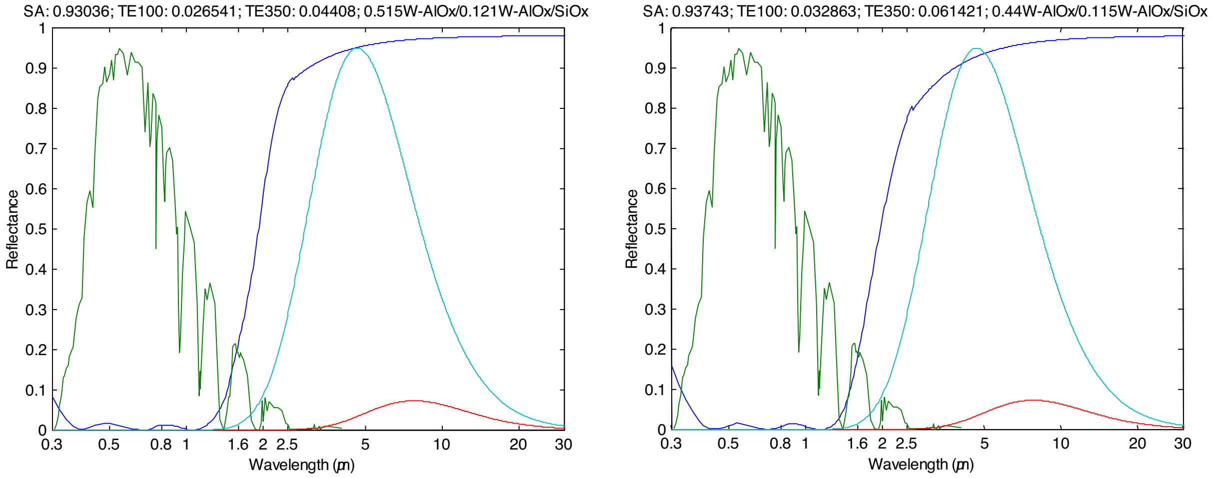

Fig. 8: Two spectra of best Cer.Met. candidates from theoretical modelling (W-AlOx/SiOx)

Numerous solutions for the absorption pipes studied are possible since the absorption pipe is a compromise between achieving different operational requirements. Mathematics models have been used to find a good compromise since they provide the possibility to calculate the essential output parameters in relation to the input parameters. The first prototype will be a 12 mm (external diameter) coaxial coated tube, which will use a commercial absorption layer developed by ALMECO-TINOX (Figures 9 and Figure 10 below). The objective for the final prototype is to realize an absorber pipe made from stainless steel, with a molybdenum protection layer, coated with the best Cer.Met identified and developed by above indicated analysis.

Fig. 9: First series of coated tube from Tinox

A proposed technology has been designed and realized for a first series of tests. Some of the main conclusions achieved include:

- Market analysis has shown a lack of products for concentrated receivers in the small - mid size range. The solution available on the market (glass tube without vacuum isolation or the Sydney type) cannot reach good efficiencies at the indicated working conditions;

Fig. 10: Details from the first series of tube. The coating has been deposited directly on the stainless steel tube

- The potential problem arising from thermal stress dilation and glass cracks has been resolved by the use of a coaxial tube (Mientkewitz G., Schaffrath W., 2010);
- A fundamental parameter for collector efficiency is the vacuum quality. Line losses arising from convection and conduction are greatly reduced with a level of vacuum below 0.02 Pa. This feature has been experimentally tested and proven;
- For the first prototype a Cer.Met layer from ALMECO-TINOX is used. The second series of test tubes will have a molybdenum layer which will further limit the emissivity of the coating and the target value is equal to 0.06 @ 350°C;
- The actual concentration ratio has been based on similar values obtained by similar medium to large scale technologies, so a scale factor has been applied both to the dimension of the optics and that of the receiver;
- The first tube will have a diameter of 12 mm.

3.2 Concentration optics

The system will be provided of a concentration ratio 12:1, and a single module will be 200 cm long, 40 cm wide and 20-25 cm high. Two or more modules can be combined. The evacuated solar tube, located on the focus, will have the selective absorber on a tube of 12 mm in diameter. A very thin glass mirror have been developed (< 1 mm), chemically treated to provide flexibility at ambient temperature, with a multi-layered structure of silver for reflection and protective coatings. The overall mirror reflectivity has been measured, the verified value is 0,954. In Fig. 11 are evidenced the 4 optical modules after manufacturing by a project partner (ELMA).

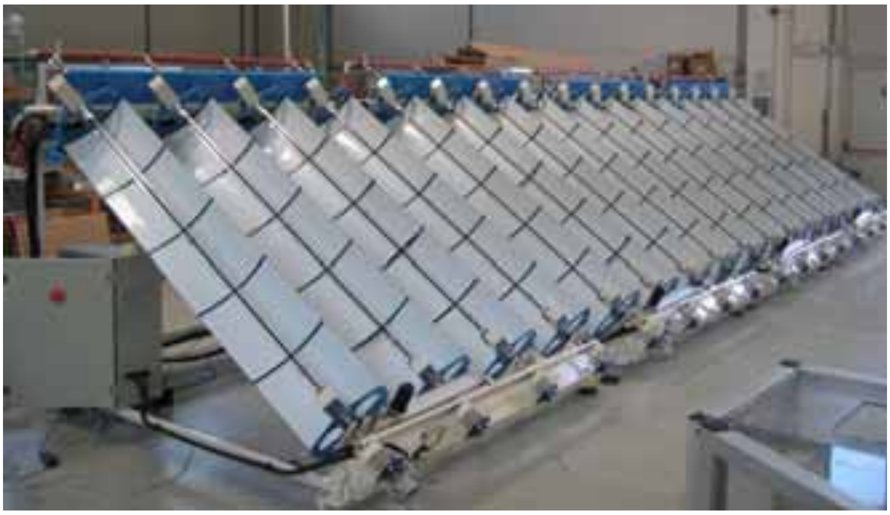

Fig. 11: first prototypal realization of the optical system

3.3 Heat engines

Research will focus on solutions to the technical and cost problems that are delaying commercialisation of the Stirling engine, whether in m-CHP or other applications. The development phase will includes two separate engine solutions, and one solution to the heat exchanger problems, that will be used for both engines.

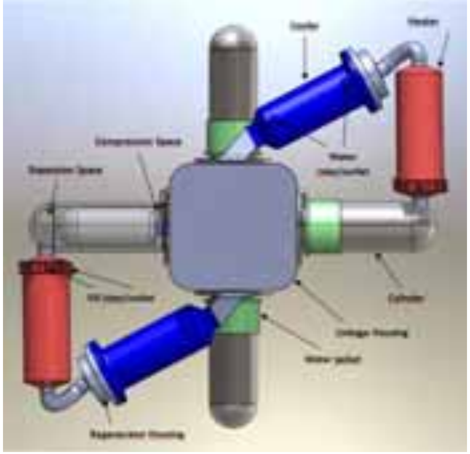

Fig. 12: Engineering of a high energy density Stirling engine

Fig. 13: Compact heat exchanger realized through SLM process

The first investigated solution in a new ***Stirling engine*** (Fig. 12), improved of latest available materials and technologies and with overall objective of realizing a high energy density, light weight, efficient engine. The thermodynamic cycle has been investigated and defined theoretically respect some border conditions set for the engine itself. The engine configures as a high pressure double acting Stirling. Peak power from the current solar field under realization is estimated to be 10 kW. The target efficiency for the cogeneration unit is 20 % in electrical conversion and 65 % in the overall efficiency (including thermal), which is recuperated as hot sanitary water for heating and domestic consumption. The load profile for a solar energy application has a typical non-constant curve, which should be followed by the engine. The heat power extracted by the engine should be adjustable, otherwise the fluid in the collectors is cooled/heated, and the source temperature is perturbed. The power can be reduced or increased by a factor of 2-3 by acting on the engine speed. Due to technological constrain, both on materials and fluid, the maximum temperature has been imposed to 320 °C. The cold sink is water for heating purpose, at temperatures in the range from 40 °C to 60 °C. The target mechanical output is 3 kW. The engine is required to be adjustable to lower nominal power, down to 1 kW, in order to be scalable with the input source, which is a function of the solar field dimensions. The nominal output power for the engine can be increased or reduced by a factor of 10 by managing the charge pressure. The heat exchangers has been optimized through a entropy minimization analytical model (Bejan A., 1996).

Another development will regard a new and compact ***scroll engine***. In contrast to the Stirling engine, a heat engine based on mass-produced orbiting scroll compressor technology will have uni-directional, near-steady state charge gas flow. This addresses issue (a): heat exchangers can be specified optimally for most of the cycle, and the anomalous heating and cooling can be eliminated. Issue (b) is addressed by new manufacturing techniques for compact heat exchangers, that provide complete freedom of 3-D design and "build to shape" manufacture of complex, thin-walled, voided components (see Fig. 13 for example). These allow the manufacture of very compact heat exchangers, with surface area densities of 20,000 $\mathrm{m}_2/\mathrm{m}_3$ or more (the Stirling heater is normally <1000 $\mathrm{m}^2/\mathrm{m}^3$), pure counter flow heat transfer, surface enhancement and varying duct cross-section, in high performance materials. Several functions (i.e. combustion air pre-heat, combustion, heating) can be incorporated in a single component. This helps to overcome the heat transfer imbalance across the heater tube walls, reduces costs, size, weight and materials use, and increases thermodynamic efficiency.

3.4 Variable speed control

The Stirling (or Scroll) engine is provided and instrumented with all necessary on-boars sensors for the monitoring of performances, fault detection, identification and solution in real-time during operability. At the same time they're required for the engine characterization and verification of the overall system efficiency, measure of the energy and mass balance through the engine itself. Main sensors included in the Stirling are pressure and temperature, mainly used for the characterization of the thermal cycle. Sensors are sampled through an A/D board, included of an encoder connected to the drive control (DS2000 by MOOG Industries), in feedback loop with the measures themselves. The engine provides also a three-phases power line from the integrated generator. The generator is a 48-pole, 3-phase alternator using permanent magnet (PM) excitation, nominally designed to operate at 480rpm, but rated for operation until 600 rpm. The electric power at the output has 500 VDC in open circuit, and 420 VDC at 7.15 A at full load, generating 3000W of nominal power. The drive control is used for the engine start-up, speed regulation and electrical power regeneration.

The Overspeed Protection Box is an additional and independent device included in the overall control system. The box is an additional safety tool in case of fault of the main drive DS2000, and for extreme faults out of the potential direct control of DS2000. It's an electromechanical protection that brakes the engine and slow it down preventing major damages in case of load loss contemporarily to a fault status of DS2000. The objective of the Protection Box will be to maintain the engine below its maximum speed of 600 RPM.

DC load/Inverter has the purpose of conversion of direct voltage in alternate and deliver it to the grid. During the engine characterization the load for the Stirling engine is composed of a programmable electronic device, while during demonstration activities it will be replaced by an inverter for on-grid electrical generation.

During the monitoring, the control system will sample input information from the hot sided of the thermo – fluidic system until the power generation. The measure of the thermal energy transferred by the thermal oil to the Stirling is in direct relationship with the rated output power from the Stirling engine itself. Specific temperature and flow sensors are included in the side of the thermal oil for the quantification of the energy balance. Similarly, on the cold side, the transferred heat is monitored to account the amount of energy from the Stirling (Scroll) engine to the hot water storage tank.

The PC/PLC control unit is used for the acquisition of the sensor measures and for the activation of relative commands, together with their elaboration and handling. The unit will be equipped with a PC user interface for interpretation of the measured values and for implementation of controls in automatic o in manual mode. All the measures are saved in a data logger for a post processing of sampled values. A complete description of the system is illustrated in Fig. 14.

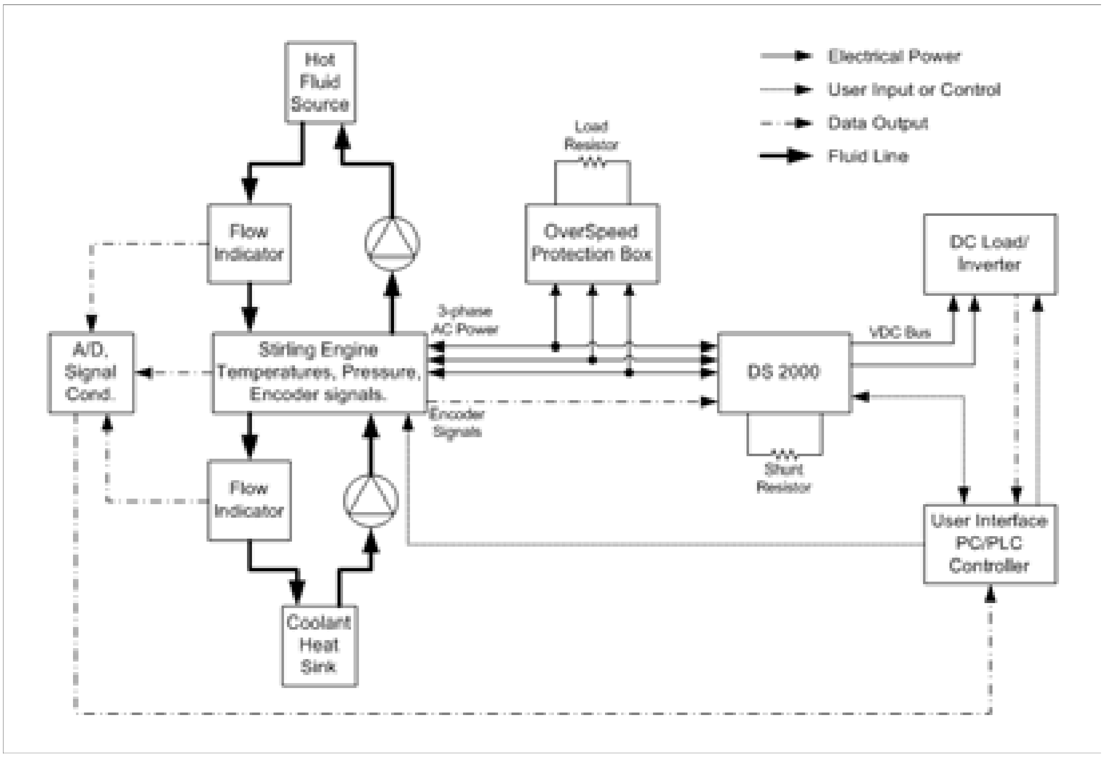

Fig. 14: Architecture for the variable speed control of the engines

4. Conclusions

The presented work will has started first tests and demonstration activities. On the next months full characterization of the proposed technology will be completed. Other developments will regards an enhanced thermal fluid, possibly realized integrating metal oxide nano particles and thermal oil used in the hydraulic circuit. The evacuated tubes will be integrated of a more performing Cer.Met. coating. The engines will be manufactured and characterized by the half of 2012.

The actual work is part of a European Funded project, the best valued within the specific topic of CSP in the call FP-Energy-2009-1.

The impact strategy for such technology is addressed in four main issues: *First* is the contribution to "improvements in the optical and thermal efficiency of the solar components, power generation efficiency (including hybridization with other fuels), and operational reliability". *Second* is the scope for hybridization with other fuels. *Third* is a large reduction in capital and maintenance costs. *Fourth* is improvements in the environmental profile of CSP.

There are three additional impacts. *First* is the creation of a new and extremely large market for small scale CSP systems, down to the size of the individual household. *Second* is the application of the innovations, particularly in the engine, to other solar CSP applications. *Third* is the application of the engine innovations to non-solar carbon saving applications.

Finally ***DiGeSPo*** project will provide a new technology system, with the potential for an extremely high impact in the field of energy production from renewable sources.

5. References

Alberti A., Crema L. (2010). "Heat Transfer Analysis and Modeling fort the Coaxial Solar Collector". Fondazione Bruno Kessler, Internal Report, 09/2010;

Bejan A. , (1996), "Entropy generation minimization: The new thermodynamics of finite-size devices and finite-time processes". J. Appl. Phys. 79 (3), 1191 – 1218;

Cool Energy Inc. (Boulder, CO), http://www.coolenergyinc.com/ , last accessed 12.08.11;

DiGeSPo project (2011) "Distributed generation from a small size concentrated solar power". http://www.digespo.eu/ , last accessed 10.08.11;

Israel U., Berchowitz D. (1984). "Stirling Cycle Engine Analysis". First ed. Bristol: Adam Hilger Ltd, 1984;

Mientkewitz, G. Schaffrath, W., NARVA (2010). Solarabsorberrohr. Patentanmeldung, 21.10.10;

Solutia Inc. (2010), "Therminol 66 Fluid Proprieties". Group Provoc T.B.S 10-7 (2010) E. Solutia. <http://twt.mpei.ac.ru/MCS/Worksheets/HEDH/.\..\..\..\TTHB\HEDH\HTF-66.PDF>, last accessed 10.08.11;

Wackelgard at al, (2010). "New development of spectrality selective Solar absorbing coating for low and intermediate temperature applications". World Renewable Energy Congress 11, September 2010, Abu Dhabi