1. Description of main S & T results/foregrounds

Please provide a description of the main S & T results/foregrounds. The length of this part cannot exceed 25 pages.

1.1 Introduction to the present section

The 9 S&T objectives presented in the earlier section were pursued via the implementation of the foreseen Work Packages.
More specifically:

- S&T objectives 1 & 2 were pursued within WP 2
- S&T objectives 3 & 4 were pursued within WP 3
- S&T objectives 5 & 6 were pursued within WP 4
- S&T objectives 7 was pursued within WP 5
- S&T objective 8 was pursued within WP 6
- S&T objective 9 was pursued within WP 7

In the following pages of this section we show how the different S&T objectives were pursued and achieved across the different WPs

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1.2 Work package no. 2: Receiver

WP2 was dedicated to research and manufacturing activities related to the receiver tube, with particular reference to the development of sol-gel coatings solutions that are capable of being implemented in the new coater machine design targeted in WP4. WP2 targeted scientific objectives 1 & 2, i.e:

- Sol Gel Anti-reflection coatings (ARC) for 96% transmittance for the glass envelope
- Sol Gel selective absorptance coatings for 95% absorptance and 7% emittance at 250oC for the absorber tube.

These objectives were pursued in two different ways.

Cranfield identified and produced ARC coatings whose properties were in line with the project objectives, as shown by the results reported in the figure below.

Sol Age(No. of days after Reflux stage)	1	53	168
Transmittance/%	95.72	95.73	95.61
SPF MEASURED	95.6	95.7	95.5

Fig. 1.1: Transmission characteristics of TEOS sols produced via a Stober process, measured at both CU and SPF. Coating thickness is around 350-400nm.

In particular, transmittance of produced ARC samples was measured by two different partners (Cranfield and HRS) for a cross validation of the measures.

Regarding the absorber coating, the work performed by Cranfield identified the main challenges of producing an absorber coating via a sol route i.e.:

- Achieve a stable suspension of the relatively dense Nickel particles within sol.
- Maintain metallic nature of Nickel within sol, and after deposition.
- Achieve a high loading of Nickel within the final film.

Additionally, manufacturing challenges with the process were identified and these included:

- Thicknesses below 100nm are difficult to realize via a sol gel process route and more importantly,
- An ideal solution according to the model is very sensitive to variations in layer thickness.

Nevertheless, CU developed sols that met the project objectives, which due to the challenges of having an ease-of-manufacturing solution has put the project behind schedule. Also, the modelling revealed that films with thicknesses of around 100nm would be required, in reality this would be difficult to achieve since the final solutions are very sensitive to variations in layer thicknesses.

An opportunity to put the project back on schedule has been undertaken and involved accessing sol gel coatings developed by CIEMAT for both ARC and absorber coatings.

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These new SolGel coatings were successfully introduced in the project activities and were included in the relevant test of performance and durability in WP6. Results were in line with the project targets, which were therefore achieved.

Unfortunately, unexpected issues with the hazardous properties of the coating mixes (e.g. with reference to Health and Safety and fire hazard), revealed a challenge that will be addressed by Soltigua and Ciemat during the first year after the completion of the FRESH NRG project.

Besides the coating development, WP 2 included also Task 2.3, dedicated to "Receiver thermal and optical modelling", which contributed to the achievement of S&T objective #3, as shown in the next paragraph.

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1.3 Work package no. 3: Collector

WP3 was dedicated to the activities related to the collector development, with particular reference to the development of new design and innovative and competitive engineering. WP3 overall targets were:

- Optimized collector design to reach 60% efficiency at 250°C
- Engineering of modular "clip-on" secondary mirror and key "plug-in" components

These objectives were achieved via simulations tasks performed mainly by partner ISE and by engineering tasks performed mainly by partner Soltigua.

The collector design optimization included the set-up of a detailed model of the collector during project Period 1.

The model was then used in Period 2 to check several different possible improvements to the collector design and engineering.
The following table provides a list of several optical loss mechanisms considered during Period 2.

1	All optical losses	All optical losses listed below and cosine losses are considered.
2	Shading from Secondary mirror	Case 1: Only the Receiver Housing is omitted from the simulation.
3	Shading from Receiver/Housing	Case 2: No shading from the Receiver structure occurs.
4	Shading and blocking losses	Mirrors shading a neighboring mirror from the incoming light, preventing reflection. Reflected light is blocked by a neighboring mirror on its way to the receiver. The efficiency of the collector not considering these losses is achieved from simulating the mirrors individually.
5	Astigmatism (focal length)	The simulation is run for the case where the primary mirrors are always focused perfectly in the transversal plane. The aiming point of the primary mirrors is shifted to the center of the absorber tube and it is assumed that the mirrors are tracked individually.
6	Primary reflectance	Reflectance of the primary mirrors is set to 100%.
7	Primary mirror error / tracking quality	Primary mirror total optical error (sigma) is set to 0.0 mrad.
8	Transmittance	Glass sleeve or glass cover nominal transmittance is set to 1.0 at perpendicular incidence (still considering incidence angle dependency).
9	Secondary reflectance	The reflectance of the secondary mirror is set to 100%.
10	Absorbtance	Absorber tube absorbtance is set to 1.0 (still considering incidence angle dependency).

Fig.1.2 List of analyses of several loss mechanisms considered in the project

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Furthermore, in Period 3, in order to assess the influence of all the necessary engineered components implemented in the actual construction of the LP, a more detailed modelling was performed. This detailed model was also implemented in ray tracing simulation tools at ISE to derive a more accurate incidence angle modifier curves (IAM curves) as input to the data evaluation algorithm for the thermal characterization.

Results from raytracing simulations of the detailed model has helped to point out the relative influence on optical losses and room for further improvements connected to engineering details provided and implemented by Soltigua.

The feasibility or additional benefit in terms of increased annual mean optical efficiency of alterations to the current design has been shown through variation from the current engineering and design.

A choice of components to be modelled was made based on their possible interaction with the sun rays' path towards the receiver. Minor objects such as screw and other connection devises/parts were not considered. This choice was made in coordination and agreement between ISE and SOLTIGUA.

Some new features for the ISE in-house raytracing software Raytrace3D had to be programmed in the implementation process. The new features were furthermore implemented in an updated version of the optical simulation package.

A set of components/substructures were defined based on the geometry of the collector. The largest substructure is a collector module (of which there were two installed in the prototype installed in Freiburg – in the following called "Lab prototype" / "LP"). A representation of the geometries implemented in the raytracing studies is depicted in Fig. *1*.3. The major components implemented and their names can read from Fig. 1.3 as well.

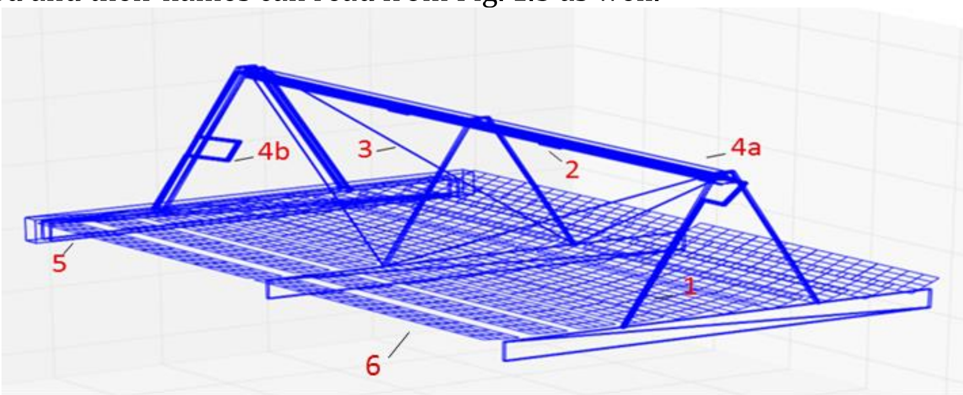

Fig. 1.3Geometrical model of the collector for the ray tracing simulation with major components: 1. Struts, 2. Receiver, 3. structural Cables, 4a. Piping on southern end, 4b. Piping on northern end, 5. Gearbox, 6. Primary mirrors.

Thanks to this very detailed collector model, to identify those parts of the structure that are responsible for most optical losses, a detailed analysis of the LP was performed. All potentially shading objects described before (see Figure of collector model) were "turned off" individually

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and a simulation was performed. The following scenarios were simulated: LP without struts, LP without front piping, LP without back piping, back piping rotated (the shading part lies in the longitudinal plane), LP without cables, LP without trolley, LP without trolley but with support cylinder at absorber connections, LP without support cylinders. (The simulations were performed with Raytrace3D for incidence angles in the longitudinal and transversal plane in 5° resolution using the detailed model of the LP.) Using the derived IAM functions, annual optical simulations were performed to derive the mean annual optical efficiency for each scenario.

The reduction in annual mean optical efficiency caused by the struts (through shading of the primary mirrors) was identified as a factor which might be reduced through an alteration in design. The other components were all deemed as necessary (or potential effects of changes considered as minor, or design changes considered too difficult and/or connected with high efforts, respectively) and thus kept fix "as is".
An alternative single-pillar strut design was considered and annual simulations of the two configurations were compared.

The simulations described above were performed in parallel with the engineering of the collector components, of which we provide in the following some examples.

1. *Design of ultra light panels for primary mirrors*

A great effort was spent on the design and manufacturing process of the substrate (metal beams) of the primary mirrors so that it does not deform the mirror's shape. This is very important in order to meet the target "reflected ray" precision, which was assumed during the overall collector geometrical design and optimization and which directly influences the collector's efficiency.
The design also further optimized the beam shape, reducing its weight compared to former Soltigua's Fresnel collector substrate. In order to do so, more advance design tools were adopted such as FEM, and several reiteration were required. The weight reduction of the primary mirror beams (mirror + substrate) was 23 %, as shown in the following figure.

Description	Weight (kg)	Mirror surface (m^2)	Specific weight (kg/m^2)	Relative weight reduction
Original Soltigua mirror beams	94.1	3.74	27.08	0%
FRESH-NRG mirror beams	77.5	3.70	20.73	-23%

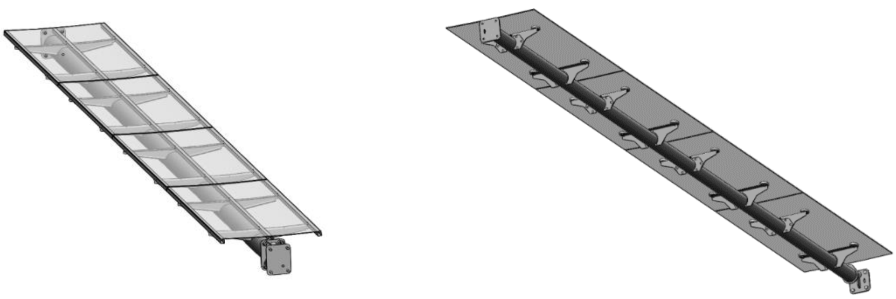

Fig.1.4 Comparison between original Soltigua mirror beams (left) and the Fresh-NRG beams (light). The metal structure weight optimization which was possible thanks to extensive FEM simulations is clearly visible.

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The manufacturing process is based on welding, but it is divided into a 2-step process and a new welding technique, which avoids shape changes due to welding heat deformations. Fraunhofer ISE tested prototypes of such a solution in their FRT lab. Small samples were tested in their lab, whereas full scale components were tested on the prototype assembled at Soltigua's premises. The results (See Task 6.2 2nd periodic report) show that the connection to the substrate does not deform the mirror significantly more than its original accuracy.

2. *Couple drive*

In the couple drive: the design of components proportions and the introduction of CNC manufacturing components ensured that each mirror line is within ±0.1-0.15° from its ideal position. In the field the mirror beams can therefore just be connected to the preassembled drive.

Fig.1.5 FRESH NRG prototype drive ready to be shipped to Fraunhofer ISE for the lab prototype test. The connections of the mirror beams are visible in the front.

3. *Collector structural and mechanical engineering*

The engineering of the collector was detailed particularly during the second year of the project. A whole collector model was developed in a FEM simulation environment, so that the interaction between all components could be evaluated under external loads. Earthquake loads were also added to the possible external loads (in additions to wind and snow). This more accurate model implied to change some components, which in turn lead to several simulation reiterations.

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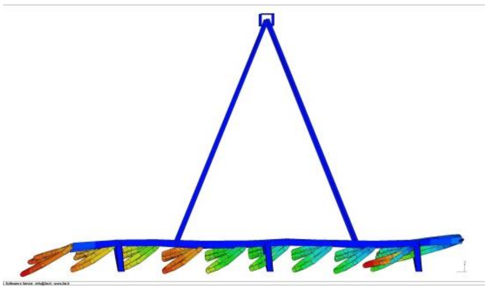

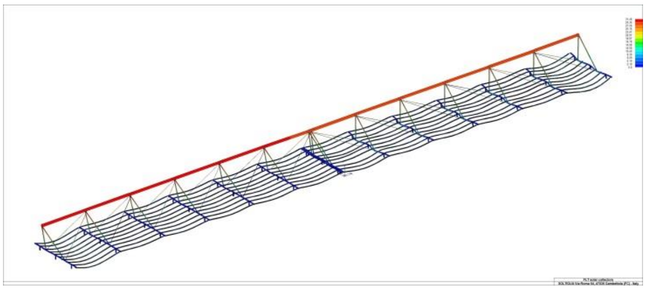

Figure 1.6: Example of FEM simulation of solar collector under external loads: side wind (left) and seism (right)

Based on the FEM results, it was decided to classify different versions of the collectors:

- low wind
- standard
- high wind

All of them have the same overall geometry and use the same core components (receiver, primary mirrors) but the metal structure is optimized according to the loads (mainly wind force) they have to bear. The right version for each installation location will be proposed.

From the basic dimensions defined in year one, several collector models were defined, with different lengths to adapt to different available areas for installation: 36, 48, 60 and 72 m.

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1.4 Work package no. 4: Manufacturing

WP4 overall targets were:

- Lean manufacturing process for Sol-Gel coatings and receiver assembly
- Engineering of scalable manufacturing process

First WP4 objective

The first of these two objectives was pursued in Task 4.1.
In this Task, using findings from the design of multiple full scale Prototype Coating System concepts, the process of the full scale Prototype Coating System was finalized (Figure 1.7).

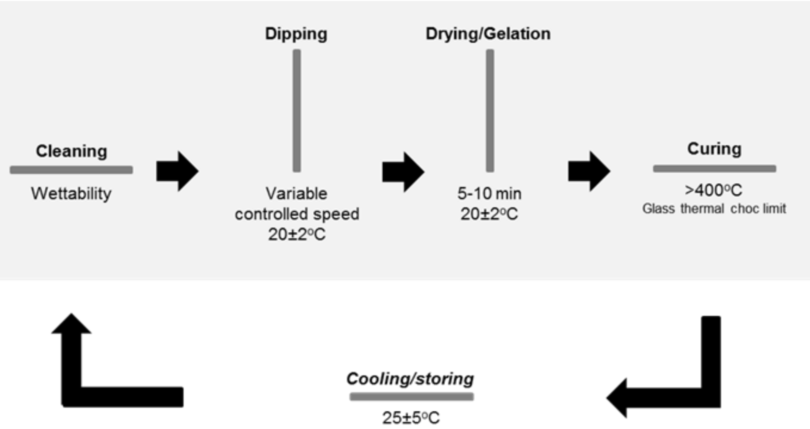

Fig. 1.7 Coating process chain - Borosilicate glass tubes (1 layer coating) and Stainless steel tubes (2 layers coating)

The machine design was finalized to have a batch production system. Main activities performed were to design to handle two tubes for dipping system and multi-tubes curing oven. A budget breakdown (reported in D4.2) was carried out in order to select best technologies combination for cleaning, dipping and curing stations.
To obtain an adequate process through-put, with high manufacturing flexibility, for different sol-gel solutions and deposition rates, a manufacturing process simulation was developed. Different scenarios were modelled and simulated using Witness software. The simulation results outlined several optimised manufacturing process chains based on specific batches sizes using multiple dipping tanks to supply enough tubes to the oven. A built-in drying and curing capability can be used to increase the daily manufacturing process through-put. In addition, once cured, receiver tubes could be stored before the next coating procedure. Based on these findings, a layout was developed (Figure 1.8), with an indication of the location of the different stations (cleaning, loading dipping and curing/cooling).

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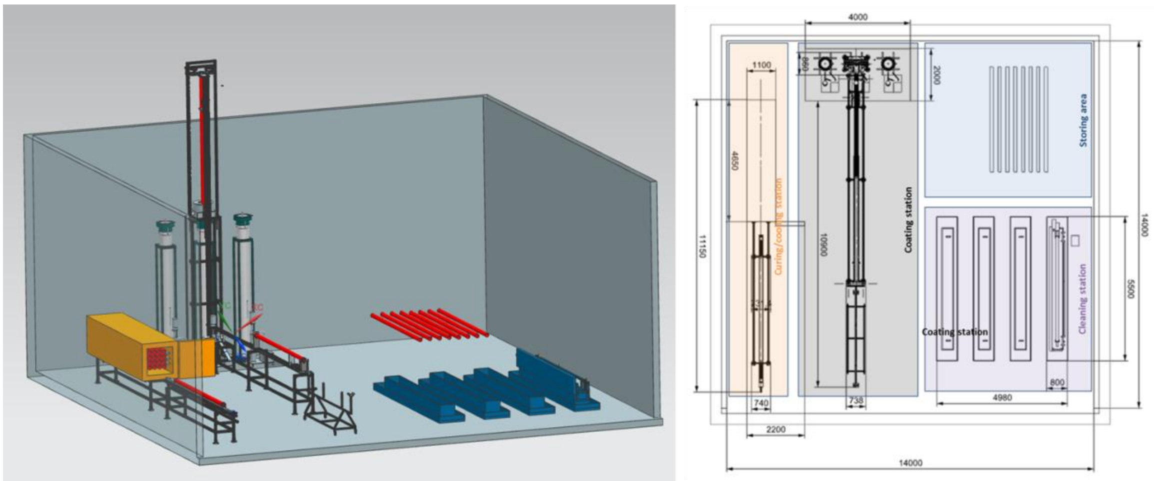

Figure 1.8 Coating production hall layout

A maximum area of approximately 14m by 14m was defined to build a “white box” of 4-7m of height. A hole in the area of the dipping machine was considered to accommodate the machine additional height during loading and dipping. This area would need to comply with all relevant European health and safety regulations, including ATEX.
In parallel, challenges to prepare the production hall and implement the process within Soltigua laboratory (Italy) were investigated. The oven system was highly modified based on the requirements of the CIEMAT solgel. The requirements for a high level of temperature control 500 ± 10°C for such a large heated volume increase drastically envisaged oven cost. In addition, in order to produce batches, an additional large temperature controlled drying chamber was necessary.
Finally, implementing process within Soltigua facility meant that large quantities of solgel solution had to be handled safely by employees. Following consultations with Italian experts about ATEX and safety regulations, it was decided that Soltigua production hall could not be built within project budget and timescale.

The coating system described was developed as a dip coating based machine with particular emphasis on built-in flexibility. This system is a more agile and flexible machine than existing large production plants. For example, both anti-reflective and selective coatings can be deposited on different tubes diameters, lengths and materials using the same machine. Each dipping tank is optimised to reduce the amount of solgel required. A multiple tank configuration allows different solgel solutions to be employed and minimizes the amount of coating solution unused. While experimental dip coating machines could process large tubes in a laboratory control environment, the handling, cleaning and curing stations had to be specifically designed. It is expected that the machine would be used to develop novel and cost-competitive thin film coatings for optical surfaces on CSP receiver tubes for mid-temperature applications, able to compete with existing but more expensive technology that uses large evacuated PVD chambers.

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Second WP4 objective

The engineering of scalable manufacturing process was pursued via 3 tasks:

- Task 4.2 Receiver tube assembly
- Task 4.3 Plug-in components manufacturing
- Task 4.4 Manufacturing of collector prototypes

Task 4.2 developed a prototype receiver tube assembly area which has developed further Soltigua's former concept and which is shown in Fig.1.9

Figure 1.9: receiver tube assembly area.

The first position from the right is used to weld together metallic absorber tubes to reach the required length for one module of the collector. In this position one flange is also welded to the metallic tube.
The second position form the right is used to complete the assembly of the not evacuated receiver tube with the outer glass tube, the second flange and the other connections and fittings between the absorber and the glass tubes.
The third position from the right is used to test the pressure resistance of the produced tubes.
The fourth position from the right is dedicated to store the produced tubes in wood boxes, ready to be shipped.

The work of Task 4.3 implied the development of several processes and procedures to guarantee the quality of the produced collectors

Special care was devoted to the implementation of systems for the control of optical accuracy of the collectors.

The following picture shows the pilot line developed to check the production tolerances of the supporting beams of the primary mirrors

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Fig. 1.10 Pilot line for beams for primary mirrors

Both Task 4.2 and 4.3 focused on creating systems and procedures that can be easily scaled up after the end of the project.

Task 4.4 tested the developed production systems by manufacturing 3 different collector prototypes which were installed in Freiburg, Gambettola and Mutah, as shown in the following photos.

Fig.1.11 Photo of Freiburg collector prototype

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Fig.1.12 Photo of Gambettola collector prototype

Fig.1.13 Photo of Mutah collector prototype installed on Mutah Univeristy (left) and installation team (right)

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1.5 Work package no. 5: Application

WP5 targeted scientific objective 7, i.e. the improvement of the suitability of the new collector for industrial applications.

As other Work Packages aimed at designing a more efficient Frensel Collector this work package (WP 5) aimed at making the FRSH NRG collector more suitable to industrial applications.
As such it intended to have a pilot built and tested in the field.
The chosen field was the Tri-Generation system built at the roof of Mutah University. This was chosen for an innovative and award winning system demonstrating various uses of CSP and Fresnel collectors. The Tri-Generation system in Mutah Generates Electricity, Distilled water, and Cooling/Heating. The system operates at the same range of temperature that the FRSH NRG collector is designed to.

Task 5.1 of this WP learnt lessons from installing the FRSH NRG collector in the field at Mutah so that better future design and system set-up processes can be developed to speed up the installation process and to reduce cost.
We provide below a short summary of the lessons learnt, which focused around 3 main areas.

1. *Documentations for customs*

It is very important to have the correct documentation for importing the FRSH NRG device.
Usually solar energy devices has tax exemption (like it is the case in Jordan) but since this device is not commonly known among custom duty officers some difficulties were faced during the import process. Since Mutah is a public University solving this problem was a relatively easy task. However, if a private company is to import the FRESH NRG collector, considerable difficulties may occur. As such, the following was proposed to make the documentation presented to the customs a more facilitating ones:

- (ideally) obtain for the FRESH NRG collector a dedicated international custom code as a solar system, which can then be included in the shipping documents.
- (alternatively), create a full explanatory catalog of the FRESH NRG collector with explicit mentioning that it is a solar energy device including photos of the full system and the packages.

2. *Preparation and infra structure for system connectivity*

The coordination between Mutah and Soltigua to prepare the infrastructure of the system was of great help and time saving. In this stage that Soltigua was acting only as the supplier of the device and was not responsible for other aspects of the installation.
A learnt lesson is on the importance of vendor's technical support and expert advices on connectivity and foundation layout of the system. Some examples of foundations for example could be provided with the product catalogue.

3. *Design optimization for small roof-top applications*

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By shipping, handling, and assembling the FRSH NRG collectors many lessons were learned on some design modifications for faster and easier installation. Some of the most important are as follows:

a) The main driver beam is a 10 meters 800 kg single part. For installations on rooftops which can't withstand the weight of a crane or a fork lift, handling such a heavy weight single piece is problematic. One option may be to re-design this beam so that it is made of two, three, or four components that can be assembled on sight reducing handling issues.
b) In cases when Soltigua is not supervising the installation directly, a full step by step installation manual with illustrations in English should be provided with all needed tools and needed man power.
c) The installation should be done with easily available equipment rather with some un common equipment in the third world. For example in the list of equipment it is mentioned that an automatic leveling station should be available, but later on it is mentioned that it should be laser automatic leveling station which is not readily available in Jordan for example and cannot be rented. Is it crucial to have the laser leveling device? Can the system be installed using the traditional one? It is advisable that the installation of the modified design is done based on as commonly available tools as possible.

It should be mentioned, however, that the collector can be installed in countries like Jordan without much problems even with its current design.

Task 5.2 of this WP investigated the possible applications and markets for the new FRESH NRG collector in the Mediterranean region. Such application included solar cooling and industrial steam generation.

The specific objective of Task 5.2 was to evaluate the possible applications and markets for the new FRESH NRG collector in the Mediterranean region. This activity started in the first project period and ended with the Deliverable D5.2 at the end of the second project period in Month 24.

In the second project period the Deliverable D5.2 was finalized. Therefore, 24 identified potential industrial users have been identified and interviewed and their processes have been analysed to collect useful inputs. MUTAH and Soltigua have then performed a high level assessment of these 24 cases: 13 in Italy, 7 in Jordan, 1 in Turkey and 3 in Chile. Therefore, the Jordanian and the Italian industrial sectors are the ones, which have been investigated in more detail, since 20 cases over the 24 concerned these areas.
Parallel to gathering useful input for the collector development, this activity has explored the application potential of the new FRESH NRG collector across the entire spectrum of its possible applications and has therefore covered process heat, cooling and electrical power generation.

Further to this high level assessment the application potential of the new FRESH NRG collector was explored by JER as final input for the Deliverable D5.2. Therefore, three detailed application studies specific to the FRESH NRG collector were carried out for Italy, Chile and Jordan. The 3 detailed studies addressed the applications with the highest industrial potential as identified by analysing their inherent economic convenience for the final user. Investigations therefore

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covered solar cooling, solar process heat generation and poly-generation applications in order to prove the full potential of the new FRESH NRG collector.

The results of Deliverable "D.5.2 Report on industrial potential inclusive of three detailed application" including the high-level assessments and the three detailed application studies showed clearly that the new FRESH NRG collector has a high market potential against already existing solar concentrator products like other parabolic trough and Fresnel collectors.

In general, there were three key findings for the new FRESH NRG collector:

- Price list reduction of -15% between existing parabolic trough collector (PTMx) and FRESH NRG collector, with that the FRESH NRG collector achieve the price target set in the DOW of less than 300 €/m^2.
- Depending on the application and with that the required collector aperture area the preliminary system design shows area reductions for the FRESH NRG collector against the other investigated solar concentrator collectors is 7-15% for the real collector area as well as 12-34% for the gross installation area. This is because of the much better collector performance of the FRESH NRG collector
- The preliminary system costing shows that for the solar cooling application lower system costs up to 31-42% or specific costs of 1,132 EUR/kW can be achieved with the FRESH NRG collector. The investigated solar process heat systems show up to 32-38% cost reduction or specific costs of 412 EUR/m2 for process heat applications

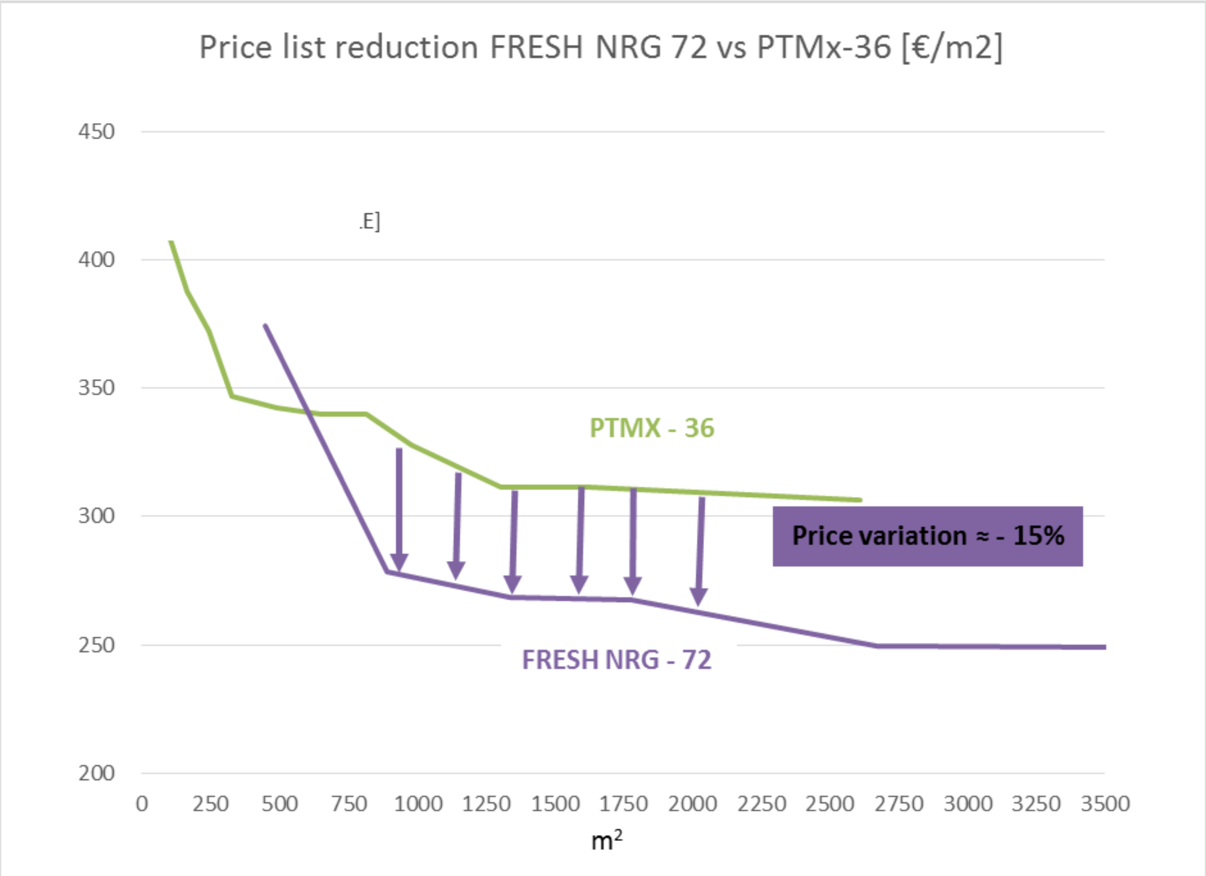

Fig.1.14 Collector ex-work price in €/m2 for PTMx and FRESH NRG as function of system net collecting surface in m2. To ensure comparability, for each collector type, the analysis is based on the largest available size of individual collector models (Source: Soltigua)

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1.6 Work package no. 6: Testing

WP6 targeted scientific objective 8, i.e. test of receiver and complete collector in the 100-250°C temperature range.

More specifically, WP6 is dedicated to the testing activities pursuing the following three WP-specific targets:

- Detailed characterization of components during the development phases (Tasks 6.1 to Task 6.3)
- Complete test of whole collector in the 100-250°C temperature range (Task 6.4)
- Characterization of collector installation, collector and collector field performance with a 120 kW installation in Jordan, operated under real application conditions (Task 6.5).

Task specific objectives were:

Task 6.1: Tasting optical properties, durability and lifetime tests on the Sol-Gel coatings including:

- damp-heat test and abrasion test of the ar-coated glass tubes
- accelerated lifetime test of the absorber coating

Task 6.2: Tests of the secondary mirror developed in WP 3 with regards to its spectral and geometrical optical properties and its accuracy by means of Fringe Reflection.

Task 6.3: Tests of the primary mirror developed in WP 3 with regards to its optical and mechanical properties (accuracy) and hail resistance

Task 6.4: Collector laboratory test: Finalizing the high temperature measurements on the laboratory collector prototype. Final results have been achieved and are reported here.

Task 6.5: Installation of a collector field including a monitoring system at Mutah. Due to unexpected delays in the shipping of the collector it was expected that the results from the monitoring will come too late for being evaluated thoroughly within the time of the project. Thus, a collector field of similar size was installed and monitored at Gambettola additionally.

Task 6.6: Comparison and evaluation of the test results from the component tests, the collector lab test and the field test at Gambettola.

In the following we report the main results regarding the collector testing. Other results were reported in the project periodic reports.

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Task 6.4: Collector laboratory test

After the collector was delivered by Soltigua in February 2015, the following were the main work items before putting the test loop into operation:

- Final design and installation of collector piping and hydraulic components
- Calibration and installation of sensors
- Set up of measurement network
- Installation, programming and testing of test loop controls and safety features
- Preparation of evaluation methodology


Figure 1.15 : Collector in focus at ISE.


Figure 1.16 Hydraulics of test loop.

In July 2015 the test loop was put into regular operation and measurements were started immediately. As, for the sake of a minimum measurement uncertainty, water was chosen as HTF, the required pressure ratings for temperatures of 250°C exceeded the available investment funds in the project. Subsequently the hydraulic loop was designed for maximum temperatures of 230°C. According to EN ISO 9806 (2013) Annex A an extrapolation of measurement results is acceptable up to a maximum of 30°C beyond the highest measured temperature level. Thus, the efficiency objective at 250°C can still be validated according to standard procedures.

Until November 2015, measurement sequences in the range of 20-125°C could be realized and evaluated; high temperature sequences were delayed due to leakages in the collector piping and difficulties in the temperature control of the test loop. With data at high temperature still pending, deliverable D6.3 was submitted in February 2015 with preliminary results based on the assumption of typical heat loss coefficients for evacuated receiver tubes.

The temperature controls of the test loop were improved during the winter months and the collector was reactivated in March 2016. The improvements allowed test sequences with temperatures of almost 230°C. Figure 1.3.16 shows an exemplary measurement sequence with an inlet temperature of 175°C under clear sky condition from May 5th 2016.

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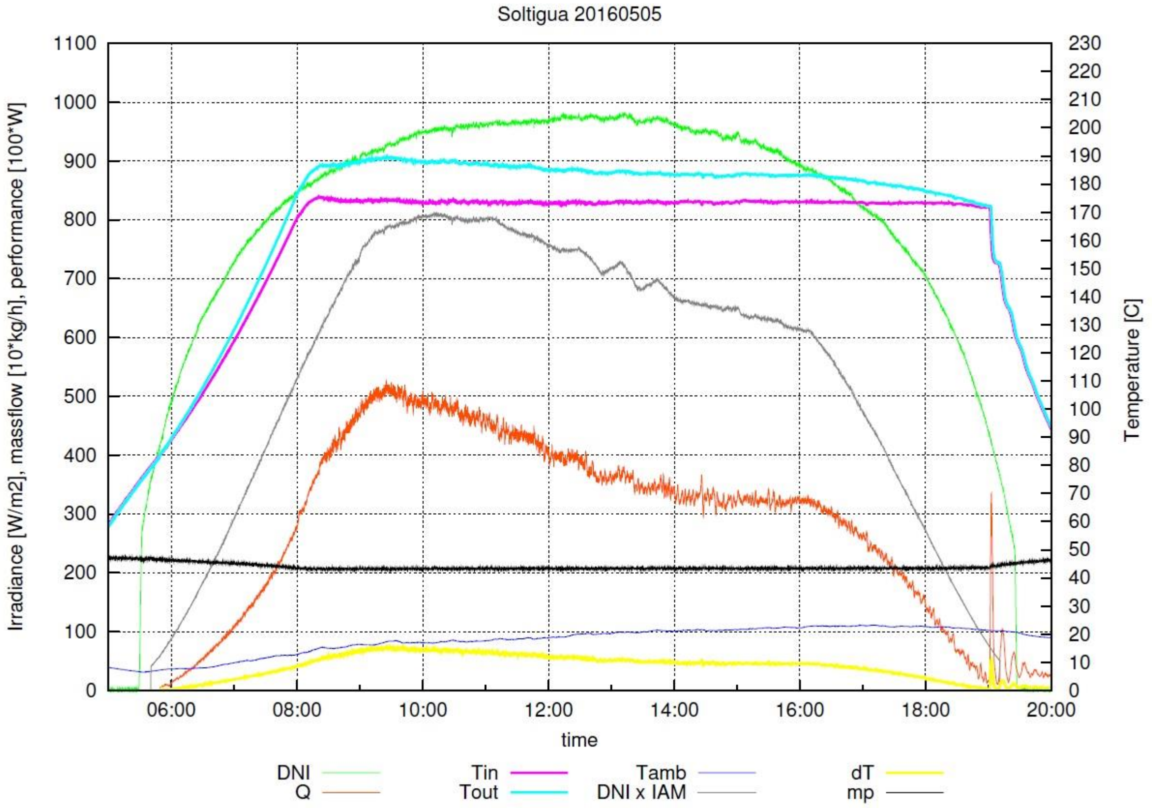

Fig. 1.17 Exemplary measurement sequence, inlet temperature of 175°C under clear sky condition measured May 5th, 2016

The analysis of the test data shows, that enough data could be gained to successfully characterize the collector. Cross-validation of different evaluation methods (QDT (Quasi-Dynamic-Test) and DT (Dynamic-Test)) has been performed and compared with raytracing results. Additional validation sequences have also been evaluated with the parameters derived from the QDT-measurement.

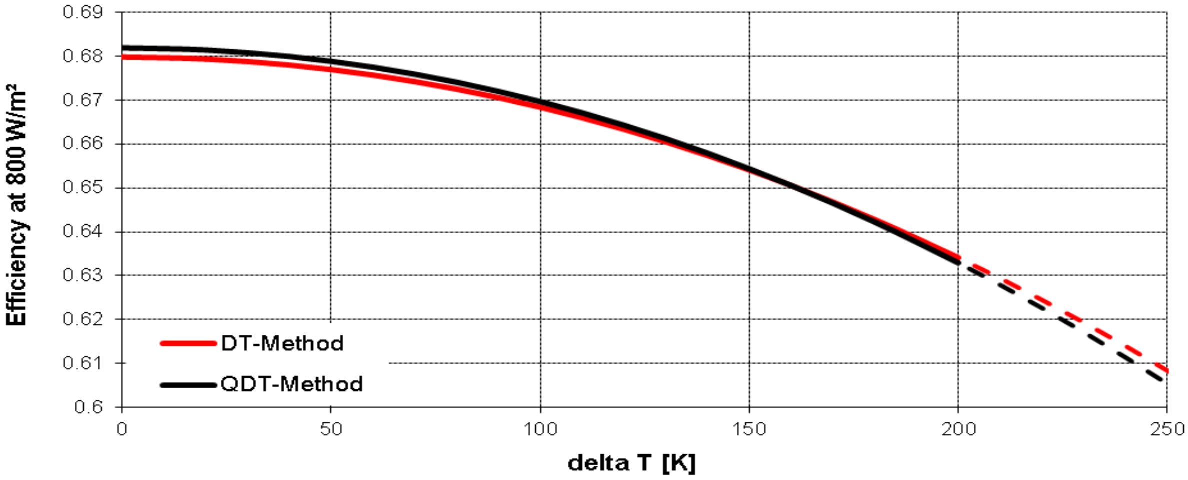

Figure 1.18 Efficiency curves determined with QDT-/DT-method (for 100% beam radiation)[1].

[1] These values are not directly comparable with data from a SolarKeymark data sheet.

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The QDT-evaluation gives an $\eta_{opt,0}$-value of 0.682 and a second order heat loss coefficient of 0.00098 W/m^2K^2 related to the collector aperture area of 74,25m^2.
The project targeted an efficiency of 0.6 at 250°C. Assuming an ambient air temperature of 30°C the temperature difference between fluid and ambient air is 220K. The efficiency curves in Figure 18 show that at this point the development target can be outperformed.

Task 6.5: Collector field test

As indicated during the GA amendment process, the installation of the collector field in Mutah was delayed. For this reason, also the monitoring will be delayed. As documented in Deliverable D5.3, the collector was successfully installed on the rooftop of Mutah University. Currently it can be assumed that the monitoring system will be taken into operation shortly after the end of the FRESH NRG project. Nevertheless, the consortium agreed that Mutah University will record data for at least 30 days of operation after the end of the project and transfer the data to HSR-SPF who will do the evaluation.

Due to this delay, it was decided to do measurements within the time of the FRESH NRG project on a collector field installed at the Laterizi Gambettola. For this purpose, a new monitoring concept was worked out and realized:

- a new set of Pt100 4-wire sensors were calibrated at HSR-SPF and installed at the inlet and outlet of the collector field (at the outlet with a turbulator)
- the pyrheliometer, which was existing at this location, was cross-checked on-site versus a calibrated pyrheliometer from HSR-SPF
- a new Vortex flow sensor was installed in the collector field loop
- sensors for measuring ambient temperature and wind speed were installed close to the collector field
- for the signal recording all sensors were connected to the data logger of the collector and the data were transferred regularly to HSR-SPF

Fig. 1.19 The collector field installation in Soltigua's industrial site Laterizi Gambettola in Italy. The framed area indicates the monitored collector field, which is also shown in the inset picture.

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The specifications of the ground-installed prototype collector field are given in Fig. 1.20. During the monitoring period the collector was cleaned at least once a week. Due to its position close to the ground, cleaning was important due to soiling, especially after rainfall.

Collector field	
Aperture area	222.75 m²
Orientation	East-West (azimuth =78°)
Heat transfer medium	Thermo-oil (Therminol SP)
Temperature range	70°C-280°C
Flow rate range	150 l/min – 200 l/min

Fig. 1.20 Parameters of the collector field in Gambettola

The performance of the collector field in Gambettola is monitored and evaluated for days with stable weather conditions during June and July 2016. The collectors are connected to a heat removal system that can stabilize the temperature in a range of ± 10 K.

The evaluation of the collector field test has shown a good performance of the collector field. Although the measurement period was limited, several good measurement days with clear sky conditions allowed the detailed investigation of the collector field performance at dT (difference ambient temperature and medium fluid temperature) ranging from 70°C up to 260°C. The overall efficiency of the complete collector field system (collector and piping) is approximately 40% including all losses, such as shading, endlosses and IAM. Furthermore, the IAM model calculated by ISE has proven to correspond well with the determined thermal output of the collector. Further monitoring of the system would be advisable to obtain more statistical data.

Task 6.6: Test result comparison and evaluation

The challenge of this task is to compare the efficiency of a single collector and of the respective collector field, both operating under very different conditions, as shown in Table 5. The single collector was installed on the rooftop of a building in Freiburg im Breisgau and used water as heat transfer medium. The collector field on the other hand was a ground-installation in Gambettola, Italy and used thermo-oil for heat transfer. Here, the results from the laboratory test of task 6.4 and from the field test monitoring of task 6.5 are compared.

Figure 1.21: Collector at Fraunhofer ISE (left) and collector field at Gambettola (right).

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Collector field	Gambettola	Freiburg
Aperture area	222.75 m^2	74.25 m^2
Orientation	East-West (azimuth =78°)	SSW (azimuth +20°)
Heat transfer medium	Thermo-oil (Therminol SP)	Water
Temperature range	70°C-280°C	100°C-230°C
Flow rate range	150 l/min – 200 l/min	

Fig. 1.22 Comparison of the working parameters of the collector Field in Gambettola and the single collector at ISE.

For the determination of the following quasi steady-state efficiency curve, stable ambient conditions are needed. Therefore, only data sets around solar noon (±15 min) with stable DNI at 800 W/m^2 and stable flow rate are evaluated. Figure 1.22 shows the measured data, which fulfill the above mentioned conditions over the temperature difference between the medium fluid temperature and the ambient air temperature. The lowest temperature difference measured was 72°C and the highest was 253°C, with a typical ambient temperature around 30°C.

The measured data points with the trend line are compared in Fig. 1.23 with the efficiency curves determined by ISE (black curve) and by HSR-SPF (red curve) for a stable DNI = 800W/m^2 as a function of the temperature difference. The collector efficiency curve by ISE is based on an empirical determination of the heat losses and η_0 was determined to be 0.682. Due to the quasi-dynamic approach based on the EN ISO 9806 standard K_d and c_5 were also determined, but not in the case of the quasi steady-state test by HSR-SPF. All the parameters are summarized in Table 6.

For the determination of the efficiency curve (red curve in Figure 1.23) by HSR-SPF, the heat loss parameters where obtained from heat loss measurements performed at the HSR-SPF facility (see deliverable D6.2) and are listed also in Fig.1.24.. In the heat loss measurement four evacuated receiver tubes, connected in series, were tested with water as heat transfer medium. The maximum temperature reached was 200°C.

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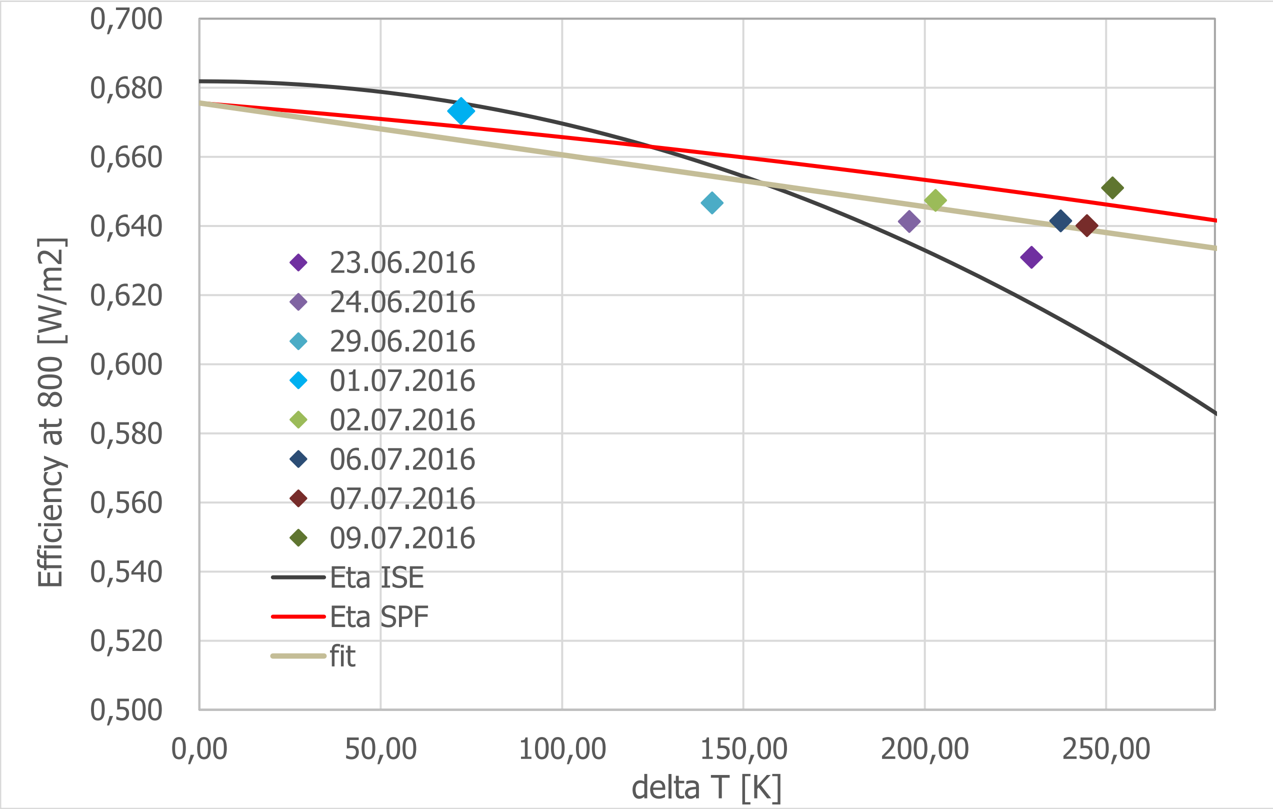

Figure 1.23 Comparison of the data measured data with the efficiency curves obtained theoretically by HSR-SPF and by EN ISO 9806 measurements at ISE.

	SPF	ISE
η_0	0.6752	0.682
c_1 [W/(m²K)]	0.069	0
c_2 [W/(m²K²)]	0.0001	0.000978
c_5 [J/m² K]	-	3589
K_d	-	0.078

Fig. 1.24 Overview of parameters for the efficiency curve based on the quasi steady-state (HSR-SPF) and on the quasi dynamic test method (ISE), respectively.

In general the trend of the measurement is resembled well by both efficiency curves. However, the efficiency is over estimated with a deviation of 3% by the approach of HSR-SPF. For this, HSR-SPF has based the efficiency function on heat loss coefficient obtained during the measurements performed at deliverable D6.2. The efficiency curve from ISE shows a deviation up to -7% and underestimates the efficiency for delta T >200°C. However, it was anticipated that the efficiency curve does not overlap perfectly with the data points since the determination of the heat loss were done on a different systems. In fact, it is rather remarkable that the efficiency curve is in very good agreement with the data.
The objective of the project was to achieve 60% efficiency at 250°C and our measurements show that this target is safely achieved.

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1.7 Work package no. 7: Dissemination and Exploitation

WP7 targeted scientific objective 9, i.e. update of high impact plan for scientific and technical exploitation in the Mediterranean region.

To avoid repetition, we report the activities of WP7 in the following section 1.4, which addresses the same topic.

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