Integrating National Research Agendas on Solar Heat for Industrial Processes

Project Deliverable 6.4:

D 6.4 – Final report on exchange of personnel within the Researchers Mobility Scheme.		
WP	**6**	
Due date:	**M48**	
Submitted	**M50**	
Partner responsible	**CIEMAT**	
Person responsible	**Ricardo Sanchez**	
Reviewed/supervised by:	**Peter Nitz, Josephine Stemmer (Fraunhofer)**	
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R	**X**	
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Author	Date	Comments
Ricardo Sánchez		INITIAL CONSOLIDATED VERSION

Contents

1. Content of deliverable

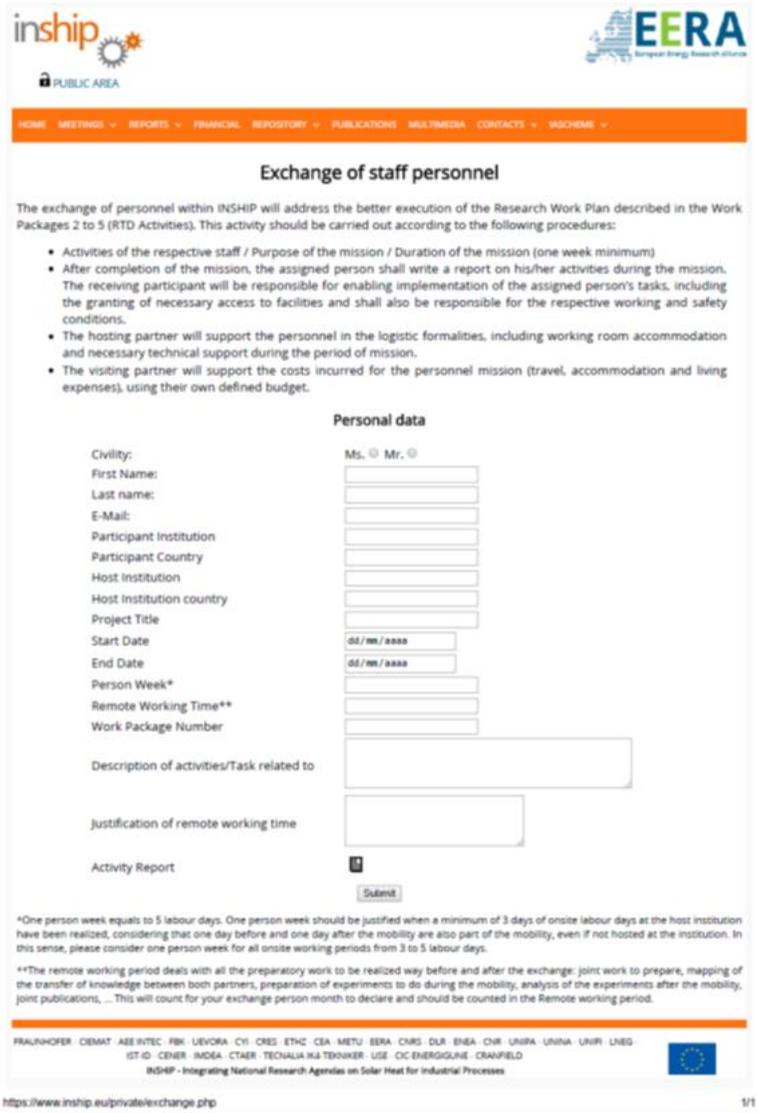
In this document we have tried to compile all the activity related to the Exchange of Personnel (EoP) that has been carried out in the framework of WP6 of the INSHIP project, the aim of which was none other than to support the implementation of the research activities included in the work plan of work packages 2 to 5.

The procedure established for the application, approval, and implementation of projects under this EoP programme has been described, or reference has been made to the document containing it in some cases. This report has attempted to establish the extent to which the partners have complied with the grant agreement and, finally, the impact of the exchanges on the research activities included in the work plan of work packages 2 to 5 has been described.

2. Staff exchange synthesis report

To manage the Research Mobility Scheme (RMScheme), INSHIP has provided a dedicated application template as well as a clear set of eligibility criteria for applicants. These have been described in detail in deliverable D6.3. Both the application template as well as the eligibility criteria have been published on the INSHIP website[1] and have been circulated by email among project partners.

In general, the application procedure aimed to be clear, simple, and hurdle-free requiring only a minimal set of information about the planned activities of an EoP. The application template (**Figure 1**) had to be filled with some general information of the staff to be exchanged as well as about the sending and hosting institutions and their relation to the involved RIs.


PUBLIC AREA

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Exchange of staff personnel

The exchange of personnel within INSHIP will address the better execution of the Research Work Plan described in the Work Packages 2 to 5 (RTD Activities). This activity should be carried out according to the following procedures:

- Activities of the respective staff / Purpose of the mission / Duration of the mission (one week minimum)
- After completion of the mission, the assigned person shall write a report on his/her activities during the mission. The receiving participant will be responsible for enabling implementation of the assigned person's tasks, including the granting of necessary access to facilities and shall also be responsible for the respective working and safety conditions.
- The hosting partner will support the personnel in the logistic formalities, including working room accommodation and necessary technical support during the period of mission.
- The visiting partner will support the costs incurred for the personnel mission (travel, accommodation and living expenses), using their own defined budget.

Personal data

Civility: Ms. Mr.
First Name:
Last name:
E-Mail:
Participant Institution
Participant Country
Host Institution
Host Institution country
Project Title
Start Date dd/mm/aaaa
End Date dd/mm/aaaa
Person Week*
Remote Working Time**
Work Package Number
Description of activities/Task related to
Justification of remote working time
Activity Report

Submit

*One person week equals to 5 labour days. One person week should be justified when a minimum of 3 days of onsite labour days at the host institution have been realized, considering that one day before and one day after the mobility are also part of the mobility, even if not hosted at the institution. In this sense, please consider one person week for all onsite working periods from 3 to 5 labour days.

**The remote working period deals with all the preparatory work to be realized way before and after the exchange: joint work to prepare, mapping of the transfer of knowledge between both partners, preparation of experiments to do during the mobility, analysis of the experiments after the mobility, joint publications, ... This will count for your exchange person month to declare and should be counted in the Remote working period.

FRAUNHOFER · CIEMAT · AEE INTEC · FBK · UEVORA · CYI · CRES · ETHZ · CEA · METU · EERA · CNRS · DLR · ENEA · CNR · UNIPA · UNINA · UNIPI · LNEG · IST-ID · CENER · IMDEA · CTAER · TECNALIA IK4-TEKNIKER · USE · CIC ENERGIGUNE · CRANFIELD

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https://www.inship.eu/private/exchange.php 1/1

Figure 1. A sample of the application form for the RMScheme.

[1] https://inship.psa.es/private/exchange.php

As can be seen in this figure, the request is sent electronically through the INSHIP project's website and it arrives directly to the WP6 leader.

It is only necessary to request these mobilities for those new exchanges that have not already been agreed by the partners and included in the amendment of Annex 1 of the INSHIP project (AMD-731287-19), and which are listed in Table 1. In no case is it necessary for any evaluation board to assess the application, beyond the WP6 leader ensuring that the task to be carried out certainly corresponds to one of those described in Annex 1 of the INSHIP project (AMD-731287-19).

Table 1. List of exchange and mobility of research staff

Partner name	Partner to be visited	Number of weeks	Activities to be performed	Specific Task
FISE	CIEMAT	2	Development of cost-effective concepts for solar steam integration layout: definition of implementation and experimental demonstration	Task 3.1
	AEE INTEC	2	Development of process integration method linking simulation software on EE measures and heat storages with solar simulation software	Tasks 5.3 / 5.5
	CIEMAT	1	Definition of suitable ageing tests for industrial environment conditions	Task 3.3
	CEA	1	Heat storage integration and simulation	Task 5.1
CIEMAT	FBK	2	Tracking system based on SMA definition of possible application	Task 3.4
	ETHZ	1	Solar fuels / Solar thermochemical production of syngas assessment (WP4)	Task 4.3
	CEA	2	Heat storage integration and simulation (WP5)	Task 5.1
	INTEC	1	Development of methodologies for the calculation of inter-dependencies between the different RES technologies (WP5)	Task 5.3
AEE INTEC	FISE	2	Development of concepts for industrial parks (WP5)	Task 5.4
	ETHZ	1	Solar Fuels / Solar thermochemical production of syngas assessment (WP4)	Task 4.3
	ETHZ	1	Solar Metallurgy (WP4)	Task 4.1
	CMT	1	Solar driven steam generation (WP3)	Task 3.1
	FISE	1	Balance of plant concepts (WP3)	Task 3.2
FBK	CIEMAT	24	Testing and validation of innovative concepts of volumetric solar receivers for process heat in metallurgy (WP4)	Task 4.4
	UEVORA	1	Application of SMA for quasi-static solar collector (WP2)	Task2.3
FBK or CRES	METU	1	Design of a new receiver direct flow (WP2)	Task 2.1
UEVORA	FISE	1	Solar driven steam generation (WP3)	Task 3.1
	CIEMAT	1	Thermal Energy Storage systems and storage management (WP5)	Task 5.1
CYI	CEA	3	Heat storage integration and simulation	Task 5.1
	CIEMAT	3	High-concentration optics for high-temperature solar reactors	Task 4.4
CRES	CIEMAT	2	Direct steam generation for industrial applications using Parabolic trough and Fresnel type collectors (WP3)	Tasks 3.1 / 3.3
	AEE INTEC	1	Study on methodologies and modeling on solar cooling with low temperature collectors (WP2)	Task 2.1
	AEE INTEC	1	Study on methodologies and modeling on solar cooling with medium temperature collectors (WP3)	Task 3.1
	CYI	2	Development of methodologies for solar desalination for Mediterranean regions (WP5)	Tasks 5.3 / 5.5

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Table 1. List of exchange and mobility of research staff

Partner name	Partner to be visited	Number of weeks	Activities to be performed	Specific Task
ETHZ	CIEMAT	1	Assessment of solar fuels / solar thermochemical production of syngas (WP4)	Task 4.3
	UEVORA	1	Assessment of solar fuels / solar thermochemical production of syngas (WP4)	Task 4.3
CEA	FISE	1	Collaboration in durability and reliability tests	Task 3.3
	AEE INTEC	1	Process integration and storage management activities	Task 5.1
METU	ETHZ	2	Solar Metallurgy (WP4)	Task 4.1
	ETHZ	2	Solar Lime (WP4)	Task 4.2
	FISE	1	Industry parks and heat distribution networks (WP5)	Task 5.4
	CIEMAT	1	Activity based on drying processes	Task 2.2

As expected, during the implementation of the INSHIP project several of these mobilities were redefined, and some new ones were scheduled. As a result, the RMScheme can be considered a success.

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3. Degree of progress

After all these changes agreed between the partners and with the consent of the WP6 leader, a total of 29 mobilities have been carried out, for a total of 40 person-weeks.

Mobility no.	Project month	Project Title	Home Institution	Host institution	WP/Task related	Start date	End date	Onsite working time[a]	Remote working time[a]
36	M9	Operation and measurements of Linear Fresnel Collector facility	CRES	CYI	WP3, Task 3.4	11/09/2017	22/09/2017	2	12
35	M14	Solar steam for industry (SSI)	CIEMAT	CRES	WP3, Task 3.2	03/12/2018	07/12/2018	1	2
34	M26	Cross cutting activity – New Receiver	METU	FBK	WP2, Task 2.2.1	28/01/2019	01/02/2019	1	4
38	M26	Knowledge exchange on particle technologies for high temperature SHIP	METU	DLR	WP4: Task4.1 & 4.2	28/01/2019	01/02/2019	1	4
38	M26	Knowledge exchange on particle technologies for high temperature SHIP	METU	DLR	WP4: Task 4.1 & 4.3	28/01/2019	01/02/2019	1	4
40	M30	SETC - Design of new receiver direct flow	FBK	CRES	WP2	03/06/2019	07/06/2019	1	0
34	M30	Cross cutting activity – New Receiver	METU	FBK	WP2, Task 2.1.1	17/06/2019	21/06/2019	1	4
28	M30-M31	Study of mirrors specular reflectance on V-LABS	CEA	FISE	WP3	24/06/2019	05/07/2019	2	4
15	M31-M32	SMA	FBK	UEVORA	WP2, Task 2.3	29/07/2019	02/08/2019	1	0
49	M34	Conceptual design of high-concentration optics for scale-up of ceramic cavity air receiver	UEVORA	ETHZ	WP4, Task 4.4	21/10/2019	25/10/2019	1	1
19	M35	Thermal Energy Storage systems and storage management	UEVORA	CIEMAT	WP5, Task 5.1	20/11/2019	22/11/2019	1	0
47	M38	Wetting mechanisms in MD at low driving forces	AEE INTEC	CIEMAT	WP5	03/02/2020	18/02/2020	2	2

Mobility no.	Project month	Project Title	Home Institution	Host institution	WP/Task related	Start date	End date	Onsite working time[a]	Remote working time[a]
2	M38	Development of process integration method linking simulation software on EE measures and heat storages with solar simulation software	FISE	AEE INTEC	WP5, Task 5.3 & 5.5	17/02/2020	28/02/2020	2	2
51	M43	HEAT PIPE PCM	FBK	UEVORA	WP2, Task 2.1.1	20/07/2020	31/07/2020	2	3
52	M43	LowSHIP - Development of a radiative heat transfer model of the ETC collector with internal reflectors	CRES	METU	WP2, Task 2.1	21/07/2020	24/07/2020	1	2
41	M45-M46	Comparison of the modelling technics for linear Fresnel collectors for heat processing in the real environment	CYI	FISE	WP3, Task 3.4	09/09/2020	05/10/2020	1	1
53	M45	LowSHIP2 - Development of a radiative heat transfer model of the ETC collector with internal reflectors	CRES	METU	WP2, Task 2.1	30/09/2020	02/10/2020	1	3
4	M47	Exchange on Thermal Energy Storage	FISE	CEA	WP4, Tasks 4.1, 4.2 & 4.3 WP5, Tasks 5.1, 5.3 & 5.4	02/11/2020	13/11/2020	2	2
43	M47-M48	Development of interface for ray tracing on GPU in Tonatiuh	CYI	FISE	WP4, Task 4.4	23/11/2020	04/12/2020	2	2
48	M47-M48	Flux characteristics of the solar tower at IMDEA Energy	ETHZ	IMDEA	WP4, Task 4.3 & 4.4	27/11/2020	10/12/2020	1	0
37	M47-M48	Knowledge exchange on modeling tools for high-flux solar optics and solar receivers	ETHZ	UEVORA	WP4, Task 4.4	24/11/2020	10/12/2020	1	0
31	M47-M48	Knowledge exchange on high temperature heat transfer media for SHIP, including solid particles and air	METU	ETHZ	WP4, Task 4.2	30/11/2020	09/12/2020	2	3
42	M47-M48	Development of optical layout of heliostat field for the specific high-temperature thermochemical processes	CYI	UEVORA	WP4, Task 4.4	30/11/2020	04/12/2020	1	1

Mobility no.	Project month	Project Title	Home Institution	Host institution	WP/Task related	Start date	End date	Onsite working time[a]	Remote working time[a]
54	M48	DISHVR	FBK	CYI	WP4, Task 4.3	03/12/2020	10/12/2020	1	1
55	M48	GreekSHIPs - Performance assessment of a SHIP simulation study in Greece	CRES	AEE-INTEC	WP3, Task 3.2	07/12/2020	18/12/2020	2	3
3	M48	Definition of suitable ageing tests for industrial environment conditions	FISE	CIEMAT	WP3, Task 3.3	11/12/2020	17/12/2020	1	0
3	M48	Definition of suitable ageing tests for industrial environment conditions	FISE	CIEMAT	WP3, Task 3.3	11/12/2020	17/12/2020	1	0
	M47-M48	Business Models, Economic Assessment, Solar Payback (SPB) Online Calculator	AEE INTEC	FISE	WP5, Tasks 5.3 & 5.4	15/11/2020	22/12/2020	2	2
56	M47	Comparison of two reactor configurations for carbonate mineral calcination	CIEMAT	UEVORA	WP4, Task 4.4	15/11/2020	30/11/2020	2	1

[a] in person-week(s)

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4. Impact on the project

In general, the staff exchange programme can be regarded as highly beneficial for involved RIs. It was successfully launched and was able to motivate a large number of RI staff to engage, travel and share their knowledge within the SHIP community.

4.1. A brief overview on staff exchanges activities

4.1.1. In the framework of WP2

4.1.1.1. Cross cutting activity – New Receiver (mobility number 34)

METU participated in this mobility, and worked closely with **FBK** with the following objectives:

- To exchange fundamental and cross-cutting knowledge on solar receiver applications to benefit METU-GÜNAM and FBK.
- To more fully explore solar receiver design and applications with the help of experience and instruments available in FBK. Improvement and re-verification of current theoretical model using alternative software and/or experimentation.
- To more fully involve INSHIP networking partners in research activities.

The knowledge gained from the activity have increased the METU-GÜNAM's scientific excellence in the following tasks:

- Task 2.1 modelling, simulation and performance estimation of the ETC/PTC collector fields operating at low temperatures (80-150°C) and with no phase-change. combined with a waste-water sludge dryer or with different loads.
- Task 2.1 / Task 2.2 combining the collector field with a storage element and a load such as a waste-water sludge dryer. Control system and flow circuitry design of solar thermal power plants for SHIP applications.

4.1.1.2. SETC (mobility number 40)

A key element to facilitate the use of evacuated tube solar collectors in the industrial processes is the use back reflectors to enhance the temperature and improve efficiency. The optical design of those reflectors inserted in the evacuated tube can have an impact in terms of the collector performance (annual energy yield and efficiency at operation temperature), cost (materials and manufacturing), and occupied space. Extensive work has been done by CRES on the use of CPC collector in an evacuated tube, using computational analysis and optical simulations. In this mobility, **FBK** adapts the computational protocol developed by **CRES** to explore the efficiency of a collector based on simplified geometry and estimate the effect of the degradation of the mirror reflectance on the efficiency of the collector. FBK developed and studied simplified mirror profiles to increase efficiency and reduce production cost.

The results of the mobility reveal that just inserting an angular mirror with an angle 90 on the semi-circular reflector and beneath the collector receiver increase in sensible mode the efficiency of the evacuated tube with semi-circular mirror (widely diffuse) obtaining performance quite similar to the CPC mirror. The innovation looks easy to embed under the optical point of view on a wide range of geometry of the evacuated tube. Therefore, the hybrid geometry looks more comfortable to be tested inside the subtask 2.1.1. Moreover, the flexibility of this geometry can be a great advantage

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in terms of the modularity of the collector subtask 2.3.2. The computational activity on the effect of the ageing of the performance of the reflector (dust) demonstrates the mirror embedded in the evacuated tube is the best way to keep constant the efficiency of the collector in the time (durability).

4.1.1.3. Shape Memory Alloys, SMA (mobility number 15)

An important issue with stationary high-performance collectors is the stagnation temperature that can go up to a few hundred degrees. This can generate internal pressures higher than the rating pressure of the hydraulic circuit when water is used, temperatures higher than the thermal oils working temperature limits, or even higher than the survival temperature of the tubes. Also, the collector components can be damaged if submitted to these temperatures over an extended period. In the case of a no-flow or low-flow condition, an overheating protection strategy must act. For this reason, the main target of this exchange is the use of Shape Memory Alloys (SMA) as actuators of the solar reflector is to avoid the risk of stagnation condition, automatic defocusing the reflector from the receiver.

The mobility action has been dedicated to the study of the reflector for direct flow evacuated tubular collector of subtask 2.3.1 of INSHIP project. The research of **FBK** has been performed in collaboration with **UEVORA** to design and find a solution to use these SMAs as actuators of CPC reflector. The mobility activity allowed the demonstration that SMA material with a proper set up can be used as actuators for anti-stagnation. This has been proved in the laboratory and also under sun irradiation in the PECS installation located at Universidade de Évora.

4.1.1.4. HEAT PIPE PCM (mobility number 51)

The solar collector for low temperature is the more diffused collectors in solar thermal applications. Unfortunately, solar energy is an intermittent source of energy and this is a technological barrier for the implementation of solar thermal energy in several industrial processes. Three key elements are necessary to facilitate the use of evacuated tubular collectors in the industrial field one is the providing of heat with a stable temperature, the second is the improvement of the efficiency of the whole system and the last identify new applications for SHIP technology. For this reason, in this mobility, **FBK** collaborates with **UEVORA** to study the solar collector system based on the evacuated tube (ET) developed to sterilize the mask tissue used against Coronavirus. To improve the efficiency, the stability and the managing of the solar system, the researchers embedded in a standard ETC collector, a swirler device, PCM materials (functional energy storage), and a low cost of irradiance sensor (using CPM sensors).

The results of mobility reveal that the carnauba was can fully melt by the heat of a solar collector at the temperature of 83-85°C. This allows the storage of energy by latent heat. Therefore, inserting a bag of carnauba wax in the evacuated tube is possible to increase the energy storage of solar collector. We estimate that constant time for ETC without PCM is $7.5 \cdot 10^4$ and with PCM $9 \cdot 10^4$ indicating that PCM act as energy storage. Moreover, the solar system with and without PCM can heat the air of sterilizer at a temperature higher of 55°C indicating that the system can be used to for sterilization (in terms of temperature) of the mask tissue against Coronavirus.

4.1.1.5. LowSHIP and LowSHIP2 (mobility number 52 and 53)

This activity focussed on assisting the development and validation of a radiative heat transfer model of an ETC collector with internal reflectors, of various geometries; and defining the structure and the detailed steps of the model development, the model verification, and the parametric analysis.

The novel research work that has been implemented during WP2, Task 2.1 was taken one step further by this mobility action in which **METU** developed a radiative heat transfer model using COMSOL software, without taking into consideration the reflectors' emissivity. Since this model uses the same initial conditions and assumptions with Tonatiuh software, it is compared with the model developed in Tonatiuh. In this way, the radiative heat transfer model that has been developed by METU in COMSOL software will be compared towards the Tonatiuh model developed by **CRES**. At a first glance, these two software produce similar results without any substantial deviation between them. This should be expected and shows that both models are reliable.

4.1.2. In the framework of WP3

4.1.2.1. Operation and measurements of Linear Fresnel Collector facility (mobility number 36)

The activities of the exchange aimed at:

- Operating a Linear Fresnel Collector under real environment conditions
- Performing an evaluation of the LFC and a thermal performance characterization
- Comparing the optical models
- Checking the theoretical models by comparing the results with the measurements

The technology of the Concentrating Solar Collector lies in the operational range of 150-400°C and the investigated Linear Fresnel Collector is installed in a building roof. The validation of theoretical models, the performance evaluation of the LFC installed on the roof of a public building (the KEPA School building) in Nicosia (Cyprus), and the exchange of know-how between **CRES** and **CYI** personnel are the main achievements of this exchange. As a result, the use of the exchange results and experience gained can contribute to the Task 3.4 objectives and on potential improvements of the LFC facility.

4.1.2.2. Solar steam for industry, SSI (mobility number 35)

The objective of the exchange was to review, complete and validate a software tool for dimensioning solar thermal energy supply systems in industrial processes within the temperature range 90°C to 300°C. **CRES** is in charge of the main activity as responsible of Task 3.2 (to be completed in Month 24) and **CIEMAT** is one of the partners involved in this task, which is supporting CRES in the preparation of this software tool.

The completion of the tool, which has been prepared in an Excel format, is one of the activities committed in the Task 3.2 of the project. The tool will be useful for the pre-dimensioning of solar systems for industrial process heat applications in the medium temperature range, considering actual and reliable data of parabolic troughs available in the market and available heat transfer fluids to be used in the solar field.

4.1.2.3. Study of mirrors specular reflectance on V-LABS (mobility number 28)

The main objectives of the exchange were to use the V-LABS (very-low-angle beam spread) equipment. This equipment is an experimental setup to measure/assess the specular reflectance for reflector materials and soiled reflectors, regarding their specular reflectance properties and the estimation of the amount of radiant flux reaching a given target area. Most important, this setup can measure the specular reflectance peak distribution with an accuracy of 0.03 mrad. We have used this setup with different degraded mirror (low and high natural dust, different sand and particles impacts, etc.). The aim was to study the specular reflectance peak for these samples, to conclude if

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standard measurement methods actually used at CEA are pertinent. These results give estimations for the suitability of different mirror materials as candidates for CSP/CPV primary optics.

The main scientific advances achieved are mostly focused on the solar mirrors characterization methods. **CEA** improved the knowledge on the measurement of spectral and specular reflectance form solar mirrors of several type (glassed, polymeric, silvered or aluminized etc.) using a CCD camera. As example, CEA has now a better knowledge of the impact of bright pictures, black pictures, and temperature control of the CDD camera. All these parameters affect the digital noise, which impact the measurement quality too. As example, the numerical treatment wrote during this exchange, with the help of researchers working at **FISE**, improved of two log (10-1 to 10-3) the camera sensitivity by taking into account the parameters cited above. At the same time, the results obtain with this exchange, improve CEA's knowledge of the spectral effect of the dust and corrosion deposited on solar mirrors.

4.1.2.4. Comparison of the modelling technics for linear Fresnel collectors for heat processing in the real environment (mobility number 41)

The main objective of the remote mobility is to refine the quasi-dynamic modelling of the Fresnel collectors exposed in real environment based on the ISO9806. Methodologies from **FISE** and **CYI** were compared in order to consider the aspect of soiling, tracking efficiency and asymmetric behaviours. New variables have been added to the equation in order to better fit to the outlet temperature based on a registered data sample every 15s or 30s. More than 50 days of experiments were used involving the off-line ray tracing modelling (Incident Angle Modifiers) and HTF properties. The real time data enclosed the flow rate of the HTF loop, inlet and outlet temperatures. A weather station provided the ambient temperature and a pyrheliometer, the DNI. The data sets were compiled altogether on a same time base to improve the ISO9806 modelling.

The main achievement was the decrease of the RMS on predicted outlet temperature compared to the real one of the collector for the recorded days. It started from a rough application of ISO9806 RMS varies between 1.97°C and 2.24°C, without considering reflectometry nor tracking errors. The IAMs are not corrected either but considered as a result of the ray-tracing modelling. Applying the methodologies from both Institute, the RMS decreases to 0.99°C (RealTrackEff for The Cyprus Institute) and 1.48°C (ParaID from Fraunhofer ISE). The methodologies in force undoubtedly help to improve the modelling of Fresnel collectors in real environment, notably for controls and power prediction purpose. This work shall thus enhance the reliability of the small collectors for heat-processing (150°C-400°C). It takes also into account the issue of soiling that is part of the scope of the WP3, Task 3.4.

4.1.2.5. Performance assessment of a SHIP simulation study in Greece, GreekSHIPs (mobility number 55)

This mobility action was focussed on:

- discussing the development process of a Polysun simulation model regarding a real SHIP case study in Greece,
- refining the input parameters of the simulation model,
- qualitatively assessing the results of the simulation model, and
- discussing the next steps of the energy performance simulation, i.e., the cost efficiency of the system.

The impact of this mobility action, apart from the close collaboration of **CRES**, **FISE**, **AEE INTEC** and **CYI**, is that the model was screened from 3 other scientists that spotted some points that needed clarification / justification. As a result, the model is now refined and optimized, and its results are more reliable and closer to reality.

4.1.2.6. Definition of suitable ageing tests for industrial environment conditions (mobility number 3)

In this mobility involving **FISE** and **CIEMAT** the main objective was the discussion of scientific results, difficulties, and questions of the current and completed work of both partners on corrosion and soiling remaining, and of qualitative and quantitative measuring methods, mechanism and suitable aging test. As a result of the exchange, both partners agreed to work together on issues such as reflectance measurements; monitoring corrosion and erosion by optical methods as microscopy, AFM, roughness, transportable devices for measurements on test sites; and detection methods to monitor corrosion or erosion and accelerated stress test (correlation of test results indoor/outdoor).

4.1.3. In the framework of WP4

4.1.3.1. Knowledge exchange on particle technologies for high temperature SHIP (mobility number 38)

The main goals of this mobility action were to exchange fundamental and cross-cutting knowledge on particle technologies, i.e., numerical modelling and experimental knowledge, for high-temperature SHIP applications to benefit **METU** and **DLR**. This fundamental knowledge supports T4.1 (particle technologies for the metallurgical industry), T4.2 (particle technologies for the Cement Industry), T5.1 (particle technologies for storage), and T5.2 (particle-based solar receivers), and to further explore the research synergies that motivated the exchange and develop and implement strategies to exploit these synergies after the onsite working. The knowledge gained by METU-GÜNAM's will increase the Scientific Excellence in these tasks.

4.1.3.2. Conceptual design of high-concentration optics for scale-up of ceramic cavity air receiver (mobility number 49)

The objectives of this exchange were: (1) to present the main results of optical conceptual developments done within Task 4.4 of WP4; (2) To acquire knowledge about the work done in ETH about solar thermal cavities/solar fuel production; (3) To link this knowledge with the future developments within WP4, namely the study of the optical and thermal performance of solar tower systems with beam-down approach; (4) Set the conditions and boundaries for the collaboration between UEVORA and ETH within INSHIP activities and (5) Definition of future joint collaboration between UEVORA and ETH regarding publications, mobilities and future projects.

The main achievement was the success of the link between the optical developments done in **UEVORA** and the research on thermal cavity/solar fuel production in **ETH**. Indeed, there is almost a perfect match between these two topics as the solar fuel production requires the use of high concentration optics, seeking maximum efficiency conversion. The methodologies of optical design were presented to the group and, as a first task, it was even possible to replicate ETH's solar dish system. A quick prediction of the solar dish optical performance was presented, using raytracing technique and etendue-conservation method, along with some blueprints of how it can be eventually improved in the future. Furthermore, the inputs received from ETH about the solar cavities used have provided the necessary inputs to link the optical designs with a concrete practical solution, seeking the final modelling of the annual performance of a solar tower system for solar metallurgy/lime/fuel production.

4.1.3.3. Exchange on Thermal Energy Storage (mobility number 4)

In this mobility action involving **FISE** and **CEA**, the main objective was the open discussion of scientific results, difficulties, and questions of the current and completed work of both partners. The focus was on experimental and numerical work on thermocline energy storage with and without fillers in the high temperature range and was supplemented by content on latent heat storages.

Both parties gave a tour of their experimental facilities, to existing prototypes and to existing test benches. Evaluation methods of prototypes were discussed as well as material selection and testing routines. Discussion on concepts and their advantages and drawbacks of different storage technologies and the integration of thermal energy storage for 24/7 continuous operation in CSP plants, industrial application as well as for solar driven industrial processes took place. Existing models developed by the two parties for the simulation of TES (bed, hydraulic, thermal, phase change, distribution etc…) where presented as well as previous work on system simulation with Integration of TES model. During the exchange the parties identified several fields of interest for further collaboration between FISE and CEA.

4.1.3.4. Development of interface for ray tracing on GPU in Tonatiuh (mobility number 43)

The main objective of this mobility exchange was to investigate the advantages of ray tracing on a GPU card (a GeForce GTX 1070 by Nvidia) for the numerical simulation of CST power plants. The performance of ray tracing in the test case exceeds all expectations. It was possible to render a CST power plant with more than 1 million heliostats at 60 FPS (vsync) in 4K on a mid-range laptop with GeForce GTX 1070. A big advantage of OptiX library is that it can run even on pre-RTX cards by using CUDA cores. The shadows and multiple reflections of rays (coming from the camera) are still rendered correctly. The ability to have such a tool for a real-time control of big heliostat fields is very valuable. It helps to check quickly which parts of heliostat field have a performance issue and provide a clue on how to fix that.

The ray tracing was also used to compute the flux distribution on the receiver. In this simulation, the rays were cast from the sun rather from the camera, and the number of rays was significantly increased to cover a field with 10K heliostats. Once again, the performance exceeded the expectations, and it was possible to trace more than 300M rays per second. For comparison, the ray tracing on CPU is typically limited to 10M rays per second.

The source code developed during the exchange has been added to a repository with version control and is ready to be published on GitHub. The tool mostly serves as a proof-of-concept (PoC), but some additional efforts are necessary to make it suitable for a general-purpose use as a ray tracing interface in Tonatiuh.

4.1.3.5. DISHVR (mobility number 54)

The research mobility was dedicated to the study on the optical coupling between solar dishes in the context of subtask 4.4.1, and the metallic volumetric receiver with a hierarchical structure developed by **FBK** and studied in subtask 4.3.3. The optical study was perfumed using the last innovative version of software dedicate to the Monte Carlo ray tracing called Tonatiuh++. In particular, the irradiation map on the target composed by a mosaic composed by several hexagonal HVR was studied. A comparison with direct coupling and the use of CEC secondary optics was also studied. This modelling based on Tonatiuh++ clearly indicates that the positioning of CEC is strategic to optimize the solar propagation on the target.

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4.1.3.6. Flux characteristics of the solar tower at IMDEA Energy (mobility number 48)

This mobility was aimed at knowledge transfer from **IMDEA** to **ETHZ** on the flux characteristics of the solar tower at IMDEA Energy to assist in the long-term vision of designing a scaled-up prototype of ETHZ's lab-scale solar air cavity-receiver and testing it at the solar tower.

Experimentally measured flux maps were shared by IMDEA Energy for two days of the year: one close to the summer solstice and the other close to the autumn equinox. The flux maps, in the form of a data matrix, were successfully processed by ETHZ using Matlab to obtain the mean flux density (in kW/m2) and radiative power (in kW) as a function of the diameter of a circle centred around the geometrical centre of the flux map. The circle represents the aperture of the envisioned cavity-receiver. This spatial distribution of the radiative flux on the focal plane of the solar tower is expected to assist ETHZ further in the design of a scaled-up cavity-receiver.

Under INSHIP Task 4.3 ("Solar fuel production for the transportation sector"), an experimental proof-of-concept of ETHZ's solar air receiver was successfully demonstrated (TRL 3). The current exchange established the first step towards pushing this technology towards validation in a relevant environment (TRL 4/5) as part of future research efforts.

4.1.3.7. Knowledge exchange on modeling tools for high-flux solar optics and solar receivers (mobility number 37)

This mobility was aimed at knowledge transfer between **UEVORA** and **ETHZ** on modelling tools for high-flux solar optics and solar receivers to support future joint studies on scaling-up a solar air receiver.

The main achievements of this mobility were:

- The transfer of knowledge from UEVORA to ETHZ on the typical workflow of designing solar concentrators, including the use of Python for design of a concentrator geometry and its export to the ray-tracing software Tonatiuh for optical performance assessment.
- The transfer of knowledge from ETHZ to UEVORA on a typical solar receiver modelling workflow, including solution of radiation heat transfer using Monte Carlo ray tracing, followed by export of radiation solution to a CFD software to solve for fluid flow and temperatures.
- Potential configurations of large-scale implementation of the solar receiver on top of a solar tower were also discussed.

4.1.3.8. Knowledge exchange on high temperature heat transfer media for SHIP, including solid particles and air (mobility number 31)

The specific objectives of this mobility were:

- To share the details of the open-source Monte Carlo Ray Tracing software developed at **METU** for particle systems in beds of thousands of particles. Discussions included modelling methods, assumptions, applicability, and software usage.
- To describe a new open-source software for modelling heat transfer in dense granular flows, which can be used to simulate particle and heat flow in many solar receivers and heat exchangers. Details of the model and example outputs are demonstrated.
- To share modelling techniques for multi-phase radiative problems, relevant to the work of both METU and ETHZ. Modelling approaches (Monte Carlo, particle-scale, pore-scale, and

continuum approaches) are discussed. Applicability of programming languages to different simulation applications discussed, comparing Matlab, Julia, C++, and Fortran.

- To share of recent experimental and modelling results for non-pressurized air receivers by **ETHZ**.
- To discuss the potential overlaps of air receiver technologies and particles systems for industrial applications.

ETHZ and METU have identified several areas of expertise which overlap and could complement each other in the future. The deep knowledge of radiation in air receivers at ETHZ alongside the solid particle heat transfer expertise of METU may provide a synergetic relationship where both technologies are used in a SHIP system. This may include the non-pressurized air receivers for process heat applications, with thermal storage in particles being a method to store excess heat for later use or in a secondary process.

4.1.3.9. Development of optical layout of heliostat field for the specific high-temperature thermochemical processes (mobility number 42)

The main objective of this collaboration was to further enhance the modelling and optimization of the beam down concept proposed by **UEVORA** and explored by CYI in a previous collaboration.

The main achievement of the mobility was the design of the facility in Tonatiuh++, which is an advanced Monte-Carlo Ray-Tracer (MCRT) currently in active development by **CYI** and it is considered as the evolution of Tonatiuh which is the de-facto standard of open source MCRT's for the modelling of solar concentrating systems. The results obtained within the framework of this mobility have undoubtedly helped towards getting a deep understanding related to the etendue-matched LCCS of the proposed concept. A clear roadmap to keep progressing, refining and fine tuning of the concept has been established between UEVORA and CYI.

4.1.3.10. Comparison of two reactor configurations for carbonate mineral calcination (mobility number 56)

The aim of this collaboration between **CIEMAT** and **UEVORA** was to make a comparison between the option of using or not using a secondary concentrator to see which configuration gives better optical efficiency of the reactor installed in the CRS installation located at PSA.

In this collaboration UEVORA designed the geometry of a secondary mirror for the particular scenario of the heliostat field in the CRS installation. Furthermore, a comparison between the results of the system with and without the chosen CPC concentrator (secondary concentrator) was carried out at UEVORA, where the Tracepro software was employed to perform these simulations. From the results it was observed that the CPC increases both the optical efficiency and concentration factor in both of the two scenarios considered: 1) ideal materials and collimated rays; 2) realist material reflectivity of 92% and solar angular profile considered.

From the results obtained it can be concluded that for high concentration factors (small receivers), the inclusion of CPC and/or non-imaging optics as secondary mirrors might be very important to increase the performance of such systems, as well as it shows the feasibility to use them to perform different processes related to the processing of the lime from limestone such as carbonate mineral calcination.

4.1.4. In the framework of WP5

4.1.4.1. Thermal Energy Storage systems and storage management (mobility number 19)

The main target of this mobility was to share knowledge and good practices with **CIEMAT**'s team, regarding thermal energy storage modelling and simulation skills, as well as procedures for testing thermal energy storage systems, since **UEVORA** developed a simplified storage model for a real phase change material (PCM) storage medium, deployed in a solar heat to industrial processes (SHIP) installation project in Portugal. After obtaining experimental data from the installed system the model was adapted to be validated. These results also help to predict storage system behaviour and improve energy management strategies of the whole system, to deliver solar process heat both to continuous and batch type processes.

Good practices concerning procedures for testing thermal energy storage prototypes/systems were collected and discussed. This will help to better characterize experimentally the storage system, which in turn will help to further validate the model with experimental data. Another point of interest is that probably different geometries can be modelled in the future in order to predict adequate storage systems that are suitable for SHIP after a well conducted system sizing.

4.1.4.2. Wetting mechanisms in MD at low driving forces (mobility number 47)

In this mobility action involving **AEE INTEC** and **CIEMAT** the main objectives were MD experimentation at PSA facilities, and exchange on MD experiences at low temperature between the two institutions, in line with the activities being developed in Task 5.3.

These results confirm a limitation in the MD technology that needs to be avoided. It would be very interesting to make a more detailed study as there are still some unanswered questions about the characteristics of the membrane or the characteristics of the solution that trigger this behaviour, whether it is salt-induced wetting or whether it is an osmotic phenomenon that is always present.

4.1.4.3. Development of process integration method linking simulation software on EE measures and heat storages with solar simulation software (mobility number 2)

In this mobility action involving **FISE** and **AEE INTEC** the main objectives were the exchange on models and methods developed at both institutes, the identification of further cooperation, the visit of local test facilities as well as an operating SHIP plant and the refinement of project related open tasks.

In several sessions an intensive exchange on programming, modelling & simulation took place with different contact persons: FISE has expertise, among others, on simulation of SHIP and CSP and other heat supply systems, e.g., heat pump integration in industrial processes. AEE INTEC presented several tools for energy efficiency analysis and shared some of their profound knowledge on how to gather and process the necessary data. Energy efficiency analysis is an essential part of feasibility studies for SHIP integration. Besides this, AEE INTEC gave insights into detailed process side models.

These actions serve the better understanding of the methodology and the potential of the models and thus broaden the view for niches, possible linking of models and further development.

4.1.4.4. Business Models, Economic Assessment, Solar Payback (SPB) Online Calculator (mobility number)

In this mobility action involving **AEE INTEC** and **FISE** the main objectives were to jointly work on general methodology on the optimized integration of SHIP, to discuss main work steps, to understand the selected methodology, to compare it with other approaches and thus identifying strengths and weaknesses, and finally to apply it for a selected case study. As a result, a detailed understanding of three different business models (EPC-Sales Model, EPC-Rental Model, ESCO Model) used in SHIP systems was established, and an online exercise session was conducted on the use of solar payback calculator, which led to a good understanding for different challenges, demands and needs, that will further influence the development of the presented pathway.

4.2. Scientific output of the exchange of personnel

No.	Type[a]	Title	Authors	Title of the Journal/Proc./Book	Number, date or freq. of the Journal/Proc./Book	Is Peer-reviewed? (Yes/No)	Is Open Access? (Yes/No)	DOI
1	Paper in Proceeding of Conferences/Workshops	Comparison of Advanced Parameter Identification Methods for Linear Fresnel Collectors in Application to Measurement Data	Peter Schöttl, Alaric C. Montenon, Costas Papanicolas, Stephen Perry and Anna Heimsath	Proceedings of the 26th SolarPACES International Conference (SolarPACES 2020)	-	Yes	Yes	Under review
2	Paper in Proceeding of Conferences/Workshops	Etendue-Matched Solar Tower Beam-Down System for High-Temperature Industrial Processes	Diogo Canavarro, Gonçalo Delgado, Vikas Patil, Manuel Blanco and Pedro Horta	Proceedings of the 26th SolarPACES International Conference (SolarPACES 2020)	-	Yes	Yes	Under review
3	Paper in Proceeding of Conferences/Workshops	Dimensioning tool for the balance of plant of solar heat for industrial processes systems	R. Christodoulaki, M. Biencinto, L. González, V. Drosou, L. Valenzuela	13th International Conference on Solar Energy for Buildings and Industry (Eurosun 2020),	Athens, Greece, 1-4 September, 2020	Y	Y	Under review
4	Paper in Proceeding of Conferences/Workshops	Solar Heat for Industrial Processes Systems; a	Christodoulaki R., Tsekouras P., Drosou V., Fluch J.	13th International Conference on Solar Energy for Buildings and	Athens, Greece, 1-4 September, 2020	Y	Y	Under review

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No.	Type[a]	Title	Authors	Title of the Journal/Proc./Book	Number, date or freq. of the Journal/Proc./Book	Is Peer-reviewed? (Yes/No)	Is Open Access? (Yes/No)	DOI
		case study in Greece		Industry (Eurosun 2020),				
5	Paper in Proceeding of Conferences/Workshops	Optical analysis of an evacuated tube collector with built-in compound parabolic concentrator for process heat applications	R. Christodoulaki, P. Tsekouras, V. Drosou	SBE 19 Sustainability in the built environment for climate change mitigation	Thessaloniki, 23-25 October 2019	Y	Y	https://doi.org/10.1088/1755-1315/410/1/012040

[a] Peer reviewed publication, Paper in Proceeding of Conferences/Workshops, Article/Section in an edited book series.