Call: HORIZON-CL5-2022-D3-03

(Sustainable, secure and competitive energy supply)

Topic: HORIZON-CL5-2022-D3-03-01

Type of Action: HORIZON-IA

Proposal number: 101122231

Proposal acronym: ASTERIx-CAESar

Type of Model Grant Agreement: HORIZON Action Grant Budget-Based

Table of contents

1 - General information

Fields marked * are mandatory to fill.

Topic	HORIZON-CL5-2022-D3-03-01	Type of Action	HORIZON-IA
Call	HORIZON-CL5-2022-D3-03	Type of Model Grant Agreement	HORIZON-AG

Acronym: ASTERIx-CAESar

Proposal title: AIR-BASED SOLAR THERMAL ELECTRICITY FOR EFFICIENT RENEWABLE ENERGY INTEGRATION & COMPRESSED AIR ENERGY STORAGE

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months: 48

Fixed keyword 1: Renewable electricity

Free keywords: *Electricity storage; Concentrated solar power; Compressed air energy storage; Volumetric solar receiver; CAES; CSP*

Abstract *

Highly efficient energy conversion of solar power and storage will play a vital role in a future sustainable energy system. Thus, this project focuses on the development of a novel high-efficiency solar thermal power plant concept with an integrated electricity storage solution. The project combines air-based central receiver Concentrated Solar Power (CSP) and Compressed Air Energy Storage (CAES) to maximize conversion efficiency and power grid energy management, enabling a new operation strategy and business models. The hybrid concept initiates a futuristic era with adaptive renewable power plants, producing both electrical and thermal energy, including process heat supply and reverse osmosis desalination. Because cheap off-peak electricity is used to provide the air compression work of the topping Brayton cycle, the overall peak solar-to-electric energy conversion efficiency of the proposed power plant may reach up to 40% efficiency, which roughly doubles the peak efficiency with respect to state-of-the-art CSP technology. The project's activity will cover the techno-economic-environmental optimisation of the innovative CSP-CAES plant using representative boundary conditions, provided by grid operators and specialised partners, as well as the development and extensive testing of key components needed for its implementation. The main development will cover: (i) an advanced high-efficiency solar receiver, (ii) optical sensors and AI-based control, (iii) optimized CAES with heat exchangers and compressor/expander detailed designs and (iv) innovative integration of desalination. The proposed technology is set forth by an interdisciplinary partnership spanning the entire CSP value chain. Targeting a TRL of 6-7, the ASTERIx-CAESar concept will be validated with a demonstration scale of 480 kWth prototype in a relevant environment.

Remaining characters 142

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under any EU programme, including the current call? ◉ Yes ○ No

Please give the proposal reference or contract number.
101083607

Administrative forms

Proposal ID **101122231**

Acronym **ASTERIx-CAESar**

Declarations

Field(s) marked * are mandatory to fill.

Declaration	
1) We declare to have the explicit consent of all applicants on their participation and on the content of this proposal. *	☒
2) We confirm that the information contained in this proposal is correct and complete and that none of the project activities have started before the proposal was submitted (unless explicitly authorised in the call conditions). *	☒
3) We declare: - to be fully compliant with the eligibility criteria set out in the call - not to be subject to any exclusion grounds under the EU Financial Regulation 2018/1046 - to have the financial and operational capacity to carry out the proposed project. *	☒
4) We acknowledge that all communication will be made through the Funding & Tenders Portal electronic exchange system and that access and use of this system is subject to the Funding & Tenders Portal Terms and Conditions. *	☒
5) We have read, understood and accepted the Funding & Tenders Portal Terms & Conditions and Privacy Statement that set out the conditions of use of the Portal and the scope, purposes, retention periods, etc. for the processing of personal data of all data subjects whose data we communicate for the purpose of the application, evaluation, award and subsequent management of our grant, prizes and contracts (including financial transactions and audits). *	☒
6) We declare that the proposal complies with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity, as well as applicable international and national law, including the Charter of Fundamental Rights of the European Union and the European Convention on Human Rights and its Supplementary Protocols. Appropriate procedures, policies and structures are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct. *	☒
7) We declare that the proposal has an exclusive focus on civil applications (activities intended to be used in military application or aiming to serve military purposes cannot be funded). If the project involves dual-use items in the sense of Regulation 2021/821, or other items for which authorisation is required, we confirm that we will comply with the applicable regulatory framework (e.g. obtain export/import licences before these items are used). *	☒
8) We confirm that the activities proposed do not - aim at human cloning for reproductive purposes; - intend to modify the genetic heritage of human beings which could make such changes heritable (with the exception of research relating to cancer treatment of the gonads, which may be financed), or - intend to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer. - lead to the destruction of human embryos (for example, for obtaining stem cells) These activities are excluded from funding. *	☒
9) We confirm that for activities carried out outside the Union, the same activities would have been allowed in at least one EU Member State. *	☒

The coordinator is only responsible for the information relating to their own organisation. Each applicant remains responsible for the information declared for their organisation. If the proposal is retained for EU funding, they will all be required to sign a declaration of honour.

False statements or incorrect information may lead to administrative sanctions under the EU Financial Regulation.

2 - Participants

List of participating organisations

#	Participating Organisation Legal Name	Country	Role	Action
1	FUNDACION CENER	Spain	Coordinator	
2	CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMB	Spain	Partner	
3	UNIVERSIDAD DE SEVILLA	Spain	Partner	
4	BLUEBOX ENERGY LTD	UK	Partner	
5	DOOSAN SKODA POWER SRO	CZ	Partner	
6	UNIVERSITA DEGLI STUDI ROMA TRE	Italy	Partner	
7	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANG	Germany	Partner	
8	CLANCY HAUSSLER RITA	AT	Partner	
9	AALBORG CSP AS	DK	Partner	
10	EUROPEAN TURBINE NETWORK	BE	Partner	
11	Fundacion IMDEA Energia	ES	Partner	
12	SOFTINWAY SWITZERLAND LLC	Switzerland	Associated	
13	Innovation Therm Technologies, S.L.	ES	Partner	
14	Walter E.C. Pritzkow Spezialkeramik	DE	Partner	
15	DIACHEIRISTIS ELLINIKOU DIKTYOU DIANOMIS ELEKTRIKIS	EL	Partner	
16	engionic Femto Gratings GmbH	Germany	Partner	
17	APRIA SYSTEMS SL	Spain	Partner	

Organisation data

PIC	**Legal name**
999745342	*FUNDACION CENER*

Short name: CENER

Address

Street	AVENIDA CIUDAD DE LA INNOVACION 7
Town	SARRIGUREN
Postcode	31621
Country	Spain
Webpage	www.cener.com

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	31/12/2017 - no
SME self-assessment	31/12/2017 - no
SME validation	08/09/2008 - yes

Departments carrying out the proposed work

Department 1

Department name	Department of Solar Energy Technologies and Storage	☐ not applicable
	☒ Same as proposing organisation's address	
Street	AVENIDA CIUDAD DE LA INNOVACION 7	
Town	SARRIGUREN	
Postcode	31621	
Country	Spain	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Dr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Fritz**

Last name*: **Zaversky**

E-Mail*: **fzaversky@cener.com**

Position in org.: Research Engineer – Head of thermal simulation

Department: Department of Solar Energy Technologies and Storage

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: AVENIDA CIUDAD DE LA INNOVACION 7

Town: SARRIGUREN

Post code: 31621

Country: Spain

Website: www.cener.com

Phone: +34 948 252 800

Phone 2: +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Eduardo	Fernández	efernandez@cener.com	+34 948 252 800
Javier	Baigorri	jbaigorri@cener.com	+34 948 252 800
Jana	Santamaría	jsantamaria@cener.com	+34 948 252 800
Elena	Arbizu	earbizu@cener.com	+34 948 252 800

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Marcelino	Sánchez	Man	Spain	msanchez@cener.com	Category A Top grade re	Leading	0000-0001-8690-2539	Orcid ID
Dr	Fritz	Zaversky	Man	Spain	fzaversky@cener.com	Category B Senior resea	Leading	0000-0001-6905-3811	Orcid ID
Mr	Javier	Baigorri	Man	Spain	jbaigorri@cener.com	Category B Senior resea	Team member	0000-0002-2994-8458	Orcid ID
Mr	Francisco	Cabello	Man	Spain	fcabello@cener.com	Category B Senior resea	Team member	0000-0002-4005-5802	Orcid ID
Ms	Ana	Bernardos	Woman	Spain	abernardos@cener.com	Category A Top grade re	Team member	0000-0002-6670-353X	Orcid ID
Mr	Xabier	Rández	Man	Spain	xrandez@cener.com	Category C Recognised	Team member	0000-0001-7720-1474	Orcid ID
Ms	Amaia	Mutuberria	Woman	Spain	amutuberria@cener.com	Category B Senior resea	Team member	0000-0002-2799-029X	Orcid ID
Ms	Olaia	Itoiz	Woman	Spain	oitoiz@cener.com	Category B Senior resea	Team member	0000-0003-4863-6932	Orcid ID

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☒
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*X. Rández, F. Zaversky, D. Astrain, A novel active volumetric rotating disks solar receiver for concentrated solar power generation, Applied Thermal Engineering, 206 (2022) 118114*
Publication	*X. Rández, F. Zaversky, D. Astrain, M.A. Garrido-Maneiro, S. Tortuero, A. Rico, P. Poza, Thermomechanical study of a novel rotating disk volumetric receiver, Solar Energy, 223 (2021) 302-317*
Publication	*F. Zaversky, I. Les, P. Sorbet, M. Sánchez, B. Valentin, F. Siros, J.-F. Brau, J. McGuire, F. Berard, CAPTure Concept Specification and Optimization (Deliverable 1.4), European Commission, https://cordis.europa.eu/project/id/640905/results, 2020*
Publication	*F. Zaversky, F. Cabello Núñez, A. Bernardos, M. Sánchez, A Novel High-Efficiency Solar Thermal Power Plant Featuring Electricity Storage - Ideal for the Future Power Grid with High Shares of Renewables, SolarPACES, AIP Conference Proceedings - SolarPACES 2020, 2022*
Publication	*F. Zaversky, L. Aldaz, M. Sánchez, A.L. Ávila-Marín, M.I. Roldán, J. Fernández-Reche, A. Füssel, W. Beckert, J. Adler, Numerical and experimental evaluation and optimization of ceramic foam as solar absorber – Single-layer vs multi-layer configurations, Applied Energy, 210 (2018) 351-375*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
H2020 CAPTURE	*The global objective of this project is to increase plant efficiencies and reduce levelized cost of electricity (LCOE) by developing all relevant components that allow implementing an innovative plant configuration. This plant configuration is based on a multi-tower decoupled advanced solar combined cycle approach that not only increases cycle efficiencies but also avoids frequent transients and inefficient partial loads, thus maximizing overall efficiency, reliability and dispatchability*
H2020 RESTORE	*The main objective of RESTORE - an H2020 project led by CENER 2021-2025 - is to develop a technical solution able to overcome the current technological barriers that limit the penetration of RES in the DHC sector by the Pumped Thermal Storage (PTS) concept, which is based on the combination of two innovative technologies: a Thermo-Chemical Energy Storage (TCES) and a nonconventional power system based on Heat Pumps and Organic Rankine Cycles (HP/ORC)*
H2020 MOSAIC	*The main objective of this project is to design, manufacturing and validation in a “relevant environment” of an innovative CSP concept based on a fixed hemispheric semi-Fresnel solar field and a high temperature mobile receiver with low implementation and O&M costs at the highest plant efficiencies, thus reducing the LCOE.*
FP7 - STAGE-STE	*Scientific and technological alliance for guaranteeing the European excellence in CSTE - The main objective of this project was to promote coordination and support actions between institutions in the field of solar thermal energy. Promotion of the realization of coordinated projects covering the full spectrum of current research topics concentrating solar energy to provide the highest EU added value and filling gaps between national programs.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
High concentration solar simulator	*High concentration solar simulator with instrumented thermal air loop for testing of ceramic and metallic samples of volumetric absorbers. This facility allows to measure thermal performance and temperatures of volumetric absorber samples in a wide range of air flows and concentration ratios*

Solar components testing laboratory	*CENER solar laboratories are accredited at international level to perform tests on wide range of solar components and systems, including PV components, low and medium temperature solar thermal collectors and components of high temperature solar thermal applications such as mirrors*
Laboratory for characterization of materials	*The laboratory is fully equiped with some instruments such as spectral response analysis, Atomic Force Microscopy (AFM), Deep Level Transient Spectroscopy (DLTS), Scanning Electron Microscopy (SEM), Lock-in Thermography, abrasion tests, soiling tests, among others.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	Legal name
999614877	*CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT*

Short name: CIEMAT

Address

Street	Avenida Complutense 40
Town	MADRID
Postcode	28040
Country	Spain
Webpage	http://www.ciemat.es

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	30/12/2019 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Energy – Plataforma Solar de Almeria – Point Focus Unit	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Ctra. Senés km. 4,5	
Town	Tabernas – Almería	
Postcode	04200	
Country	Spain	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Dr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Antonio**

Last name*: **Avila-Marin**

E-Mail*: **antonio.avila@ciemat.es**

Position in org.: Senior Researcher

Department: Energy – Plataforma Solar de Almería

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: Avenida Complutense 40

Town: MADRID

Post code: 28040

Country: Spain

Website: www.ciemat.es

Phone: 0034-91-346-6629

Phone 2: +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Jesús	Fernández-Reche	jesus.fernandez@psa.es	950387903

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Antonio	Avila-Marin	Man	Spain	antonio.avila@ciemat.es	Category B Senior resea	Leading	0000-0002-9523-9705	Orcid ID
Dr	Jesus	Fernandez Reche	Man	Spain	jesus.fernandez@psa.es	Category B Senior resea	Team member	0000-0003-1967-7823	Orcid ID
Dr	Jesus	Ballestrin	Man	Spain	jballestrin@psa.es	Category B Senior resea	Team member	0000-0002-1800-7273	Orcid ID
Mr	Rafael	Monterreal	Man	Spain	rmonterreal@psa.es	Category B Senior resea	Team member	0000-0001-7903-0082	Orcid ID
Mr	Jose	Rodriguez	Man	Spain	jrodriguez@psa.es	Category C Recognised	Team member	0000-0001-7153-7743	Orcid ID
Mr	Raul	Enrique	Man	Spain	renrique@psa.es	Category C Recognised	Team member	0000-0002-0960-6362	Orcid ID
Dr	Jose Antonio	Carballo	Man	Spain	joseantonio.carballo@psa.es	Category C Recognised	Team member	0000-0003-0529-5672	Orcid ID
Mrs	Noelia	Estremera	Woman	Spain	noelia.estremera@psa.es	Category D First stage r	Team member	0000-0001-6884-7804	Orcid ID
Mr	Daniel	Sanchez-Señoran	Man	Spain	Daniel.Sanchez@ciemat.es	Category D First stage r	Team member	0000-0002-9891-5545	Orcid ID
Dr	Yolanda	Lechon	Woman	Spain	yolanda.lechon@ciemat.es	Category A Top grade re	Team member	0000-0003-4101-1788	Orcid ID
Dr	Daniel	Garrain	Man	Spain	daniel.garrain@ciemat.es	Category B Senior resea	Team member	0000-0003-3219-0139	Orcid ID
Dr	Ana Rosa	Gamarra	Woman	Spain	AnaRosa.Gamarra@ciemat.es	Category C Recognised	Team member	0000-0002-7233-8524	Orcid ID
Dr	Patricia	Palenzuela	Woman	Spain	patricia.palenzuela@psa.es	Category B Senior resea	Team member	0000-0001-8044-969X	Orcid ID
Dr	Javier	Bonilla	Man	Spain	javier.bonilla@psa.es	Category B Senior resea	Team member	0000-0002-2322-2867	Orcid ID
Dr	Bartolome	Ortega-Delgado	Man	Spain	bortega@psa.es	Category C Recognised	Team member	0000-0003-3924-4697	Orcid ID

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*A.L. Avila-Marin, J. Fernandez-Reche, A. Martinez-Tarifa. Modelling strategies for porous structures as solar receivers in central receiver systems: A review. Renewable and Sustainable Energy Reviews. Volume 111, September 2019, Pages 15-33. https://doi.org/10.1016/ j.rser.2019.03.059*
Publication	*A.L. Avila-Marin, J. Fernandez-Reche, S. Gianella, L. Ferrari, D. Sanchez-Señoran. Experimental study of innovative periodic cellular structures as air volumetric absorbers. Renewable Energy. Volume 184, January 2022, Pages 391-404. https://doi.org/10.1016/j.renene.2021.11.02*
Publication	*J.A. Carballo, J. Bonilla, M. Berenguel, J. Fernandez-Reche, G. Garcia. New approach for solar tracking systems based on computer vision, low cost hardware and deep learning. Renewable Energy. Volume 133, April 2019, Pages 1158-1166. https://doi.org/10.1016/ j.renene.2018.08.101*
Publication	*A.R. Gamarra, S. Banacloche, Y. Lechón, P. del Río. Assessing the sustainability impacts of concentrated solar power deployment in Europe in the context of global value chains. Renewable and Sustainable Energy Reviews, Volume 171, January 2023, 113004. https:// doi.org/10.1016/j.rser.2022.113004*
Publication	*P. Palenzuela, B. Ortega-Delgado, D.C. Alarcón-Padilla. Comparative assessment of the annual electricity and water production by concentrating solar power and desalination plants: A case study. Applied Thermal Engineering 177 (2020) 115485. https://doi.org/10.1016/ j.applthermaleng.2020.115485*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
LEIA	*CSP EraNET project that aims to contribute to the market deployment of the next generation of innovative, reliable, and smart Concentrated Solar Power (CSP) plants. To achieve it different techniques will be implemented in Cerro Dominador CSP plant, including: a) Smart heliostat field control to automate calibration and characterization; b) Smart receiver control to measure temperature and irradiance distribution; c) Solar field O&M strategies (soiling inspection and energy management system).*
NEXTOWER	*H2020 project that aims at demonstrating high-performance durable materials for the next generation of concentrated solar power air-based tower systems, making them commercially competitive in the energy market beyond 2020. Moreover, the exploitation of the hotter air (up to 800°C) is then crucially tied to the development of a high-temperature thermal storage based on liquid lead by means of new corrosion resistant steels.*
COMPASsCO2	*H2020 project focused on the integration of two innovative processes, a CSP solid particles system coupled to a highly efficient supercritical CO2 (sCO2) Brayton power cycle for electricity production. For this purpose, the project aim is to research on tailored particles and alloy combinations that will be produced and tested to withstand the extreme operating conditions in terms of temperature, pressure and abrasion to validate a particle/sCO2 heat exchanger.*
SFERA-III	*Funded by the European Commission under the H2020 program, this project aims to engage all major European Solar Research Institutes into an integrated structure, operating a unique set of Concentrating Solar Thermal Research infrastructures to promote innovative researches, to improve services offered by CST research infrastructures and to train researchers and engineers on the CST technologies. In this project, both academia and industry users are targeted.*

STAGE-STE	*This Integrated Research Programme engages all major European research institutes with relevant and recognized activities on solar thermal electricity (STE) and related technologies, in an integrated research structure plus relevant industrial and international organizations. The main objectives are to convert the consortium into a reference for STE research, accelerate knowledge transfer to the industry, reinforce current European leadership, promote cooperation beyond EU borders, etc.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**
SF-40 Solar Furnace	*It consists of an 8.5 m diameter parabolic-dish, with a focal distance of 4.5 m. It is able to reach peak concentrations of 5,000 suns and powers of 40 kW.*
SF-60 Solar Furnace	*It consists in a 120 m2 flat heliostat that reflects the solar beam onto a 100 m2 parabolic concentrator which concentrates the rays on the focus of the parabola, where the tested specimens are placed. The radiation is regulated with a shutter placed between the heliostat and the concentrator.*
SSPS-CRS	*It is able to provide 2.5 MWth in nominal conditions, consisting of a solar field with 91 heliostats and 43 m tower. It's a flexible facility for testing different components such as heliostats, solar receivers, solarized gas turbines, control systems and measurement instrumentation.*
CAPTure facility	*CAPTure prototype composed of a solar receiver with a nominal power of about 300 kWth, a regenerative heat exchange system including valves and a small-scale Brayton cycle with a bespoke turbo-charger technology. This facility will be extended with the ASTERIx-CAESar system.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	Legal name
999862518	*UNIVERSIDAD DE SEVILLA*

Short name: UNIVERSIDAD DE SEVILLA

Address

Street	CALLE S. FERNANDO 4
Town	SEVILLA
Postcode	41004
Country	Spain
Webpage	www.us.es

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	05/04/1988 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Energy Engineering	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Camino de los descubrimientos s/n	
Town	Seville	
Postcode	41092	
Country	Spain	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Prof.

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **David**

Last name*: **Sanchez Martinez**

E-Mail*: **ds@us.es**

Position in org.: Professor of Energy Engineering

Department: Energy Engineering

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Camino de los descubrimientos s/n

Town: Seville

Post code: 41092

Country: Spain

Website: https://investigacion.us.es/sisius/sis_showpub.php?idpers=7139

Phone: +34639721497

Phone 2: +xxx xxxxxxxxx

Other contact persons

First Name	Last Name	E-mail	Phone
Alejandro	Carballar	carballar@us.es	+xxx xxxxxxxxx

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	David	Sánchez	Man	Spain	ds@us.es	Category A Top grade re	Leading	0000-0002-2464-7365	Orcid ID
Prof	Lourdes	García	Woman	Spain	mgarcia17@us.es	Category A Top grade re	Team member	0000-0003-1357-9085	Orcid ID
Prof	Miguel	Torres	Man	Spain	migueltorres@us.es	Category A Top grade re	Team member	0000-0002-2268-8251	Orcid ID

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*A.L. Facci, D. Sánchez, E. Jannelli, S. Ubertini, 2015, Trigenerative micro compressed air energy storage: Concept and thermodynamic assessment, Applied Energy (158) pp.243–254*
Publication	*B. Monje, D. Sánchez, M. Savill, P. Pilidis, T. Sánchez, 2014, A design strategy for supercritical CO2 compressors, Proceedings of ASME Turbo Expo, June 16-20, Dusseldorf*
Publication	*S. Semprini, D. Sánchez, A. De Pascale, 2016, Performance analysis of a micro gas turbine and solar dish integrated system under different solar-only and hybrid operating conditions, Solar Energy (132) pp.279–293*
Publication	*M. Martín, D. Sánchez, 2018, A detailed techno-economic analysis of gas turbines applied to concentrated solar power plants with central receiver, Journal of Engineering for Gas Turbines and Power (141) pp.4040844*
Publication	*G. Gavagnin, S. Rech, D. Sánchez, A. Lazzaretto, 2018, Optimum design and performance of a solar dish microturbine using tailored component characteristics, Applied Energy (231) pp.660–676*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
OMSoP	*Optimised Microturbine Solar Power Generators OMSoP, 2013-2017. Funded by the 7th R&D Framework Programme of the European Commission. Call ENERGY.2012.1. Grant ID: 308952. Project aimed at the integration of a micro gas turbine engine into a parabolic dish collector to develop a low-cost CSP power generation system*
NextMGT	*Next Generation of Micro Gas Turbines for High Efficiency, Low Emissions and Fuel Flexibility NextMGT, 2020-2023. Funded by the H2020 R&D Programme of the European Commission (MSCA-ITN). Call H2020-MSCA-ITN-2019. Grant ID: 861079 MSCA action aimed at the development of micro gas turbine technology beyond the current state of the art. The scope of the project covers component development and system development*
SOLMIDEFF	*Solar Micro Gas Turbine - driven Desalination for Environmental Off-Grid Applications. Funded by the National R&D Programme of the Government of Spain. Grant ID: RTI2018-102196-B-I00. The project includes the design of micro gas turbine engines tailored to Concentrated Solar Power applications for polygeneration of power, heat and freshwater. This includes the design of dedicated components (turbomachinery and heat exchangers)*
SCARABEUS	*Supercritical Carbon Dioxide/Alternative Fluids Blends for Efficiency Upgrade of Solar Power Plants SCARABEUS, 2019-2023. Funded by the H2020 Programme of the European Commission. Call H2020-LC-SC3-2018-RES. Grant ID: 814985 The project aims at the development of power cycles operating on mixtures of carbon dioxide and secondary dopants to boost the efficiency of CSP plants. The scope of the project includes the development of dedicated turbomachinery and heat exchangers.*
Personal activities in R&D and industry	*Prof. David Sánchez has been involved in the gas turbine industry through the following activities:* *- Associate Editor of the ASME Journal of Engineering for Gas Turbines and Power, the leading international journal for gas turbine systems and components. Since 2016.* *- Chair of the Cycle Innovations Committee of the International Gas Turbine Institute of ASME. 2017-2019.* *- Member of the Project Board of the European Turbine Network (gas turbine manfacturer and user community). Since 2020.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Micro gas turbine lab	*Laboratory to carry out research on micro turbomachinery. The lab is comprised of a 3 kWe micro gas turbine arranged in two shafts and it is currently in the process to acquire a second unit for micro CHP, rated at 3 kWe but in a single-shaft arrangement and fully automated/ instrumented.*
Software - proprietary	*Codes for the design and assessment of turbomachinery: compressor/turbine, axial/radial, ideal/real gas.*
Software - commercial	*Thermoflex SUITE. The research team includes users of this software (specific to power generation systems) with more than twenty year experience.*
Computing facilities	*High-performance computing facilities will be made available to researchers.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
942303106	*BLUEBOX ENERGY LTD*

Short name: Blue

Address

Street	49 ANGLESEY ARMS RD ALVERSTOKE
Town	GOSPORT
Postcode	PO12 2DG
Country	United Kingdom
Webpage	www.blueboxis.co.uk

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	30/11/2018 - yes
SME self-assessment	30/11/2018 - yes
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Engineering	☐ not applicable
	☒ Same as proposing organisation's address	
Street	49 ANGLESEY ARMS RD ALVERSTOKE	
Town	GOSPORT	
Postcode	PO12 2DG	
Country	United Kingdom	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Mr

Gender ◯ Woman ◉ Man ◯ Non Binary

First name* **Jonathon**

Last name* **McGuire**

E-Mail* **jon@blueboxis.co.uk**

Position in org. Director

Department Engineering

☐ Same as organisation name

☒ Same as proposing organisation's address

Street 49 ANGLESEY ARMS RD ALVERSTOKE

Town GOSPORT

Post code PO12 2DG

Country United Kingdom

Website www.bluebox.energy

Phone +44 7795 527901

Phone 2 +44 239216 2020

Other contact persons

First Name	Last Name	E-mail	Phone
Flavien	Berard	flavien@blueboxis.co.uk	+44 7584 075394

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Mr	Jonathon	McGuire	Man	United Kingdom	jon@blueboxis.co.uk	Category A Top grade re	Leading		
Mr	Flavien	Berard	Man	France	Flavien@blueboxis.co.uk	Category A Top grade re	Team member		
Mr	Oliver	Baroni-Harrisson	Man	United Kingdom	Oliver@blueboxis.co.uk	Category D First stage r	Team member		
Mr	Jorge	Perfect	Man	United Kingdom	Jorge@blueboxis.co.uk	Category D First stage r	Team member		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☒
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Techno-Economic Optimization and Benchmarking of a Solar-Only Powered Combined Cycle with High-Temperature TES Upstream the Gas Turbine - DOI: 10.5772/intechopen.90410*
Good	*Supply of hot air turbine heat to electricity modules in the range 50kWe – 330kWe.*
Service	*Consulting assistance in the development of low-carbon energy production.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
CAPTure (EU Sponsored)	*Work package leader for WP4 – Solar driven brayton cycle. Designed, manufactured and commissioned a custom two stage 50kWe Brayton cycle to couple to an innovative concentrated solar power production facility.*
Dudingen HLT-100 hot air turbine	*Designed, manufactured and commissioned a 100kW hot air turbine to couple to a biomass heating system.*
Fehraltorf CPP-800 hot air turbine	*Designed, manufactured and commissioned a 50kW hot air turbine to couple to a biochar production facility.*
Innowill hot air turbine	*Designed, manufactured and commissioned an 80kW hot air turbine as a proof of concept to improve the efficiency of steel production*
BIOCCUS design study (UK BEIS sponsored	*Designed the power cycle that is integrated with a Biochar production plant and innovative CO2 capture process.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Control software development environment	*A full hardware & software control software development environment (based on Siemens ET200SP PLC).*
CAPTure hot air turbine	*A two stage hot air turbine coupled to a solar capture system presently located at PSA.*
TOAST	*In-house developed 1D thermodynamic simulation and test data analysis environment.*
Hot air turbine Modelica model	*Dynamic 1D simulation model of hot air turbines in the range 50kW – 330kWe (including the model presently located at PSA).*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
968566438	*DOOSAN SKODA POWER SRO*

Short name: DSPW

Address

Street	TYLOVA 1 57
Town	PLZEN
Postcode	301 28
Country	Czechia
Webpage	

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	01/07/1993 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Business Drivers	☐ not applicable
	☒ Same as proposing organisation's address	
Street	TYLOVA 1 57	
Town	PLZEN	
Postcode	301 28	
Country	Czechia	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Stepan**

Last name*: **Smida**

E-Mail*: **stepan.smida@doosan.com**

Position in org.: Head of Business Drivers

Department: Business Drivers

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: TYLOVA 1 57

Town: PLZEN

Post code: 301 28

Country: Czechia

Website: www.doosanskodapower.com

Phone: +420 705 656 647

Phone 2: *+xxx xxxxxxxxx*

Other contact persons

First Name	Last Name	E-mail	Phone
Petr	Mestanek	petr.mestanek@doosan.com	+420 371 435 511

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☒
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Slama, V, Rudas, B, Simurda, D, Hala, J, & Luxa, M. "Pressure Losses Analysis in Two High-Pressure Steam Turbine Control Valves Situated in One Valve Chamber." Proceedings of the ASME Turbo Expo 2022: Turbomachinery Technical Conference and Exposition. Volume 2: Coal, Biomass, Hydrogen, and Alternative Fuels; Controls, Diagnostics, and Instrumentation; Steam Turbine. Rotterdam, Netherlands. June 13–17, 2022. V002T20A002. ASME. https://doi.org/10.1115/GT2022-78969*
Publication	*Hoznedl, M, Sedlák, K, Mrózek, L, Dadáková, T, Kubín, Z, & Gregor, K. "Experimental and Numerical Study of Flow and Dynamics on LSB at 34 MW Steam Turbine." Proceedings of the ASME Turbo Expo 2020: Turbomachinery Technical Conference and Exposition. Volume 9: Oil and Gas Applications; Organic Rankine Cycle Power Systems; Steam Turbine. Virtual, Online. September 21–25, 2020. V009T23A003. ASME. https://doi.org/10.1115/GT2020-14280*
Publication	*Slama, V, Rudas, B, Ira, J, Macalka, A, Eret, P, & Tsymbalyuk, V. "Subsonic Stall Flutter of a Linear Turbine Blade Cascade Using Experimental and CFD Analysis." Proceedings of the ASME 2020 International Mechanical Engineering Congress and Exposition. Volume 7A: Dynamics, Vibration, and Control. Virtual, Online. November 16–19, 2020. V07AT07A026. ASME. https://doi.org/10.1115/IMECE2020-23356*
Publication	*Hoznedl, M. "Experimental steam turbine T10MW cold end cooling by water spraying." MATEC Web Conf. 345 00010 (2021). DOI: 10.1051/matecconf/202134500010*
Publication	*Nemec, M, Jelinek, T, Uher, J, & Milcak, P. "Effect of Stage Reaction and Shaft Labyrinth Seal in a Stage of an Axial Steam Turbine." Proceedings of the ASME Turbo Expo 2020: Turbomachinery Technical Conference and Exposition. Volume 9: Oil and Gas Applications; Organic Rankine Cycle Power Systems; Steam Turbine. Virtual, Online. September 21–25, 2020. V009T23A014. ASME. https://doi.org/10.1115/GT2020-14741*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
TURBO-REFLEX	*TURBOmachinery REtrofits enabling FLEXible back-up capacity for the transition of the European energy system.*
FLEXTURBINE	*Flexible Fossil Power Plants for the Future Energy Market through new and advanced Turbine Technologies*
AMCOR	*Additive Manufacturing for Wear and Corrosion Applications*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
999866107	*UNIVERSITA DEGLI STUDI ROMA TRE*

Short name: ROMA3

Address

Street	VIA OSTIENSE 133
Town	ROMA
Postcode	00154
Country	Italy
Webpage	www.uniroma3.it

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	29/10/1991 - no
SME self-assessment	29/10/1991 - no
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Dipartimento di Ingegneria Industriale, Elettronica e Meccanica	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Via della Vasca Navale 79	
Town	Roma	
Postcode	00149	
Country	Italy	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Prof.

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Coriolano**

Last name*: **Salvini**

E-Mail*: **coriolano.salvini@uniroma3.it**

Position in org.: Member

Department: Dipartimento di Ingegneria Industriale, Elettronica e Meccanica

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Via della Vasca Navale 79

Town: Roma

Post code: 00149

Country: Italy

Website: www.uniroma3.it

Phone: +39 06 57333249

Phone 2: +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Salvatore	Tricoli	salvatore.tricoli@uniroma3.it	+39 06 57332590

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	Coriolano	Salvini	Man	Italy	Coriolano.salvini@uniroma3.it	Category B Senior resea	Leading	0000-0002-9632-4696	Orcid ID
Prof	Antonio Casimiro	Caputo	Man	Italy	Antoniocasimiro.caputo@uniroma3.it	Category A Top grade re	Team member	0000-0001-9837-1616	Orcid ID
Prof	Ambra	Giovannelli	Woman	Italy	Ambra.giovannelli@uniroma3.it	Category B Senior resea	Team member	0000-0003-4991-173X	Orcid ID

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☐
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Salvini C., Giovannelli A., Farhat H., 2022. On the possibility of using an industrial steam turbine as an air expander in a Compressed Air Energy Storage plant.J. of Energy Storage, Volume 55, 105453. https://doi.org/10.1016/j.est.2022.105453*
Publication	*Salvini C., Giovannelli A., 2022. Techno-Economic Comparison of Utility-Scale Compressed Air and Electro-Chemical Storage Systems. Energies, Volume 15, Issue 18. September 2022, 6644.*
Publication	*Salvini C., Giovannelli A., Sabatello D., 2021. Analysis of diabatic compressed air energy storage systems with artificial reservoir using the levelized cost of storage method. Int. J. of Energy Research., Volume 45, Issue 1, Pages 254 – 268, January 2021. https://doi.org/10.1002/er.5325*
Publication	*Bashir M. A., Giovannelli A., 2019. Design optimization of the phase change material integrated solar receiver: A numerical parametric study. Applied Thermal Engineering, Volume 160, September 2019, 114008. https://doi.org/10.1016/j.applthermaleng.2019.114008*
Publication	*Salvini C., 2018. Performance Analysis of Small Size Compressed Air Energy Storage Systems for Power Augmentation: Air Injection and Air Injection/Expander Schemes. Heat Transfer Engineering, Volume 39, Issue 3, Pages 304 - 3157 February 2018. https://doi.org/10.1080/01457632.2017.1295746*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
EU, Grant agreement ID: 101022831 - CO2OLHEAT	*The project (2021-2025) is aimed at demonstrating the use of supercritical CO2 power cycles in operational environments locally valorising industrial waste heat. The ROMA TRE Research Group of Fluid Machinery and Energy Conversion Systems is involved in the techno-economic optimization of sCO2 plants fed by waste heat available from different kinds of industrial activities.*
MISE, sCO2 cycles integrated with storage system	*The project (2019-2021) IS funded by MISE (Italian Ministry for the Economic Development) in the framework of the National Electric System Research Project. The ROMA TRE Research Group of Fluid Machinery and Energy Conversion Systems is involved in the design of turbomachinery equipping innovative sCO2 cycle integrated with energy storage systems and in off-design analyses of selected plant configurations.*
MISE, Design of power-blocks for sCO2 plants	*The project (2013-2017) was aimed at assessing the feasibility of Optimized Microturbine Solar Power System. The ROMA TRE Research Group of Fluid Machinery and Energy Conversion Systems was involved in in the design of turbomachinery constituting the power block and in the off-design analysis of the overall system*
EU, FP7-308952, OMSoP	*The project (2013-2017) was aimed at assessing the feasibility of Optimized Microturbine Solar Power System. The ROMA TRE Research Group of Fluid Machinery and Energy Conversion Systems was involved in in the design of turbomachinery constituting the power block and in the off-design analysis of the overall system.*
EU, FP7-239349, H2-IGCC	*The project (2009-2013) was addressed at the optimization of IGCC plants with CO2 separation and to the assessment of gas turbine operations with hydrogen –rich syngas. The ROMA TRE Research Group of Fluid Machinery and Energy Conversion Systems was involved in in the design of power plant components and in the off-design analysis of the overall system.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (●) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - o work-life balance and organisational culture;
    - o gender balance in leadership and decision-making;
    - o gender equality in recruitment and career progression;
    - o integration of the gender dimension into research and teaching content;
    - o measures against gender-based violence including sexual harassment.

Administrative forms

PIC	Legal name
999984059	*FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV*

Short name: FHG

Address

Street	HANSASTRASSE 27C
Town	MUNCHEN
Postcode	80686
Country	Germany
Webpage	www.fraunhofer.de

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	12/01/2022 - no
SME self-assessment	unknown
SME validation	15/09/2008 - no

Departments carrying out the proposed work

Department 1

Department name	Fraunhofer Institute for Ceramic Technologies and Systems IKTS	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Winterbergstrasse 28	
Town	Dresden	
Postcode	01277	
Country	Germany	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Dr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Alexander**

Last name*: **Fuessel**

E-Mail*: **alexander.fuessel@ikts.fraunhofer.de**

Position in org.: Research associate

Department: Carbide and filter ceramics

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Winterbergstrasse 28

Town: Dresden

Post code: 01277

Country: Germany

Website: www.fraunhofer.de

Phone: +49 351 2553 7714

Phone 2: +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Joerg	Adler	joerg.adler@ikts.fraunhofer.de	+49 351 2553 7515
Daniela	Haase	daniela.haase@ikts.fraunhofer.de	+49 351 2553 7748
Steffen	Kunze	steffen.kunze@ikts.fraunhofer.de	+49 351 2553 7820

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Alexander	Fuessel	Man	Germany	Alexander.fuessel@ikts.fraunhofer.de	Category C Recognised	Leading	0000-0002-4693-5181	Orcid ID
Dr	Daniela	Haase	Woman	Germany	Daniela.haase@ikts.fraunhofer.de	Category C Recognised	Team member	0000-0002-6508-2241	Orcid ID
Dr	Steffen	Kunze	Man	Germany	Steffen.Kunze@ikts.fraunhofer.de	Category C Recognised	Team member	0000-0003-2390-8102	Orcid ID
Mr	Joerg	Adler	Man	Germany	Joerg.adler@ikts.fraunhofer.de	Category B Senior resea	Team member	0000-0002-5533-4345	Orcid ID
Dr	Wieland	Beckert	Man	Germany	Wieland.beckert@ikts.fraunhofer.de	Category B Senior resea	Team member	0000-0002-7496-4166	Orcid ID
Mr	Christian	Freytag	Man	Germany	Chrisitan.Freytag@ikts.fraunhofer.de	Category C Recognised	Team member	0000-0003-2791-0306	Orcid ID

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Numerical and experimental evaluation and optimization of ceramic foam as solar absorber – Single-layer vs multi-layer configurations. DOI: 10.1016/j.apenergy.2017.11.003*
Publication	*Experimental evaluation of volumetric solar absorbers – Ceramic foam vs. an innovative rotary disc absorber concept. DOI: 10.1063/1.5067080*
Publication	*Cellular Ceramics in Combustion Environments. DOI: 10.1002/adem.201100020*
Publication	*Characterization of a silicon nitride ceramic material for ceramic springs. DOI: 10.1016/ j.jeurceramsoc.2020.03.046*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
CAPTure - Grant agreement ID: 640905	*European project focussing the efficiency and competitiveness of concentrated solar power, wherein main components for the power generation have been investigated. Focus of IKTS was the development of a solar absorber structures made of silicon carbide foam regarding its composition, preparation technique and the optimal design for highest efficiency, supported by simulation work.*
EndurSpring	*IGF-Project No. 19125 BG "EndurSpring"; Development platform for design and technology/ manufactoring of ceramic springs for use under high temperature and corrrosive conditions: relevant for the current project due to the development of a reliability evaluation workflow/ tool for mechanical components under thermo-mechanical load*
SOLPOR	*financed by German strategic fund "renewable energy", FKZ 01SF0055-57, 2000-2003. IKTS contribution: development of cellular ceramics for simulation and characterization purposes to prevent unstable flow behaviour*
CoMETHy	*"Compact Multifuel-Energy To Hydrogen converter" 2011 – 2014. IKTS contribution: development of cellular SiC ceramic with catalytic coating for the reformer. Relevant due to the developed knowledge about the possibilities of shaping the foam material and subsequent coating.*
Cellular ceramic components for CSP test receiver	*in US and Spain (industry partners). 2011, 2013 and 2018. IKTS contribution: development and manufacturing of cellular SiC components for large test receivers*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
laboratory (preparation of open-celled structures	*Equipment for preparation and characterization of open-celled ceramic structures (oxides and non-oxides) including replication technique (rollers, centrifuge), rheometer, microscopy etc.*
Thermal treatment	*Furnaces for Debinding and sintering (up to 2.300 °C, volume 40-240 litres) as well as pre-oxidation and/or oxidation tests in air and/or combustion environment for accelerated ageing*
Finish workshop and characterization	*Equipment for machining of ceramic foams (cutting, grinding, drilling) and characterization (cell size measurement, optical and electron microscopes, pressure drop measurement, etc.)*
FE-modelling platform ANSYS +HPC-Workstation	*commercial FE-Multiphysics-License (including Fluent), hardware platform: Xeon E5-2968 processor2x20 kernels, 512 GByte RAM, Geodict License*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (●) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
  - work-life balance and organisational culture;
  - gender balance in leadership and decision-making;
  - gender equality in recruitment and career progression;
  - integration of the gender dimension into research and teaching content;
  - measures against gender-based violence including sexual harassment.

PIC	Legal name
951130203	*CLANCY HAUSSLER RITA*

Short name: EURIDA

Address

Street	Trins 46
Town	Trins
Postcode	6152
Country	Austria
Webpage	www.eurida-research.com

Specific Legal Statuses

Legal person	no
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	31/12/2019 - yes
SME self-assessment	31/12/2019 - yes
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name	*Name of the department/institute carrying out the work.*	☒ not applicable
	☐ Same as proposing organisation's address	
Street	*Please enter street name and number.*	
Town	*Please enter the name of the town.*	
Postcode	*Area code.*	
Country	*Please select a country*	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mrs

Gender: (●) Woman ( ) Man ( ) Non Binary

First name*: **Rita**

Last name*: **Clancy**

E-Mail*: **r.clancy@eurida-research.com**

Position in org.: Sole proprietor

Department: CLANCY HAUSSLER RITA

☒ Same as organisation name

☒ Same as proposing organisation's address

Street: Trins 46

Town: Trins

Post code: 6152

Country: Austria

Website: www.eurida-research.com

Phone: +43 663 0324 4114

Phone 2: +XXX XXXXXXXXX

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Mrs	Rita	Clancy	Woman	Germany	r.clancy@eurida-research.com	Category A Top grade re	Leading		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☐
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☒
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*R. Clancy: Future sustainable seaweed industries in Europe - Social and regional aspects. December 2019. (Policy Brief as part of the H2020 MacroFuels project) https://www.macrofuels.eu/policy-briefs*
Publication	*V. Wabitsch, A. Uslu, T. Christensen, C. Khawaja, R. Janssen, R. Clancy: Renewable Fuels – Advancing European Market Uptake. In: REVOLVE – Quarterly Insights into a Changing World, No. 33, Fall 2019. http://www.advancefuel.eu/contents/files/190923-market-uptake-articlerevolve.pdf*
Publication	*R. Clancy, B. Groenendaal, A. Bruhn, A. Macleod: "Seaweed as sustainable biomass for a European bioenergy sector." July 2018 (Policy Brief as part of the H2020 MacroFuels project) https://www.macrofuels.eu/policy-briefs*
Publication	*R. Clancy, S. Saighi: Event-based vision systems and their possible role in the EU Green Deal. August 2021. (Policy Brief as part of the H2020 ULPEC project) https://ulpecproject.eu/publications/fact-sheet-2/*
Publication	*A.v. Zomeren, R. Clancy: UNRAVEL – A concept for a cascading, mild organosolv lignocellulosic biorefinery. December 2021 (Fact Sheet as part of the BBI JU UNRAVEL project).*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
MUSIC (Horizon Europe, 2023-2026, GA No.101092080)	*A 4-year project funded by Horizon Europe (GA in preparation), aiming to develop materials for sustainable sodium ion capacitors responding to the need of a new energy storage technology that has energy density comparable to that of power batteries, but still recharges within few seconds and offers long cycle life with minimum efficiency loss over time. Coordinator: CICe/Spain, Eurida's role: Consortium Partner, Communication & Exploitation Officer, WP leader 'Dissemination, Communication an*
MacroFuels (H2020, 2016-2019, GA No. 654010	*4-year R&I project funded by Horizon 2020, the EU Framework Programme for Research and Innovation (2016-2019, GA No. 654010), aiming to develop macroalgae based biofuels for the transportation sector. The project focused on improving seaweed cultivation and conversion processes for 3rd generation biofuels. Coordinator: DTI/Denmark, Eurida's role: Consortium Partner, Dissemination Officer, WP leader 'Dissemination, Communication and Exploitation', Partner for social impact assessment.*
UNRAVEL (BBI JU, 2018-2022, GA No. 792004)	*A 4-year R&I project funded by BBI JU (2018-2022, GA No. 792004), aiming to develop a novel mild organosolv lignocellulosic biorefinery for high quality lignin and hemicellulose as compounds for bio-based construction materials, green chemicals and other high value applications. Coordinator: TNO/Netherlands, Eurida's role: Consortium Partner, Communication & Exploitation Officer, WP leader 'Dissemination, Communication and Exploitation'*
ULPEC (H2020, 2017-2021, GA No. 732642)	*A 50-month research project funded by Horizon 2020 (2017-2021, GA No. 732642). ULPEC developed advanced computer vision applications (event-based sensor) with ultra-low power requirements and ultra-low latency for the application areas such as autonomous driving, surveillance/monitoring and smart agriculture. Coordinator: University of Bordeaux (IMS laboratory)/France, Eurida's role: Consortium Partner, Communication & Exploitation Officer, WP leader 'Dissemination, Communication and Exploit*
RadioSpin H2020 'FET Proactive' (2021-2025)	*A 4-year research project funded by Horizon 2020 'FET Proactive' (2021-2025, GA No. 101017098). The goal of RadioSpin is to build a hardware neural network that computes using neural dynamics as in the brain, has a deep layered architecture as in the neocortex, but runs and learns faster, by seven orders of magnitude. Coordinator: University of Bordeaux (IMS laboratory)/France, Eurida's role: Consortium Partner, Communication & Exploitation Officer, WP leader 'Dissemination, Communication an*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Software	*Eurida owns licenses for standard graphics software (e.g. Corel Draw Graphics Suite) and software packages for logo development and other graphics/visuals which will be used to create the project's materials for industry and citizen engagement.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	**Legal name**
951229143	*AALBORG CSP AS*

Short name: AALBORG CSP AS

Address

Street	HJULMAGERVEJ 55
Town	AALBORG
Postcode	9000
Country	Denmark
Webpage	www.aalborgcsp.com

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	15/01/2013 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Integrated Energy Systems - IES	☐ not applicable
	☒ Same as proposing organisation's address	
Street	HJULMAGERVEJ 55	
Town	AALBORG	
Postcode	9000	
Country	Denmark	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Mr

Gender ◯ Woman ◉ Man ◯ Non Binary

First name* **Miguel** Last name* **Herrador Moreno**

E-Mail* **mhm@aalborgcsp.com**

Position in org. Senior Sales - R&D Manager

Department Integrated Energy Systems - IES

☐ Same as organisation name

☐ Same as proposing organisation's address

Street C/ Leonardo da Vinci, 30

Town San José de La Rinconada, Sevilla

Post code 41300

Country Spain

Website www.aalborgcsp.com

Phone +34 625 174 010

Phone 2 +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Peter Badstue	Jensen	pbj@aalborgcsp.com	+45 21 60 87 03
Hammam	Soliman	has@aalborgcsp.com	+45 21 60 87 03
Jens Jørgen	Falsig	jtf@aalborgcsp.com	+45 29 68 22 67
Rasmus	Junker	rju@aalborgcsp.com	+45 28 30 46 16
Line	Justesen Pløger	ljp@aalborgcsp.com	+45 88 16 88 36

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Hammam	Soliman	Man	Denmark	has@aalborgcsp.com	Category B Senior resea	Team member	56704541100	Researcher ID

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*SolarPaces 2015. “The impact of fouling factor on ASME standard steam generator component size and cost”. Jens Taggart Pelle, Jelica Matoricz, Palle Wendelboe and Svante Bundgaard.*
Publication	*CSP Plaza 2017. “Development experience of industrial-scale tower plants: desert-farming project in Australia”. Jan Kragbæk.*
Publication	*FORESIGHT Technical Magazine. March 2017.P40-41. “Desert Farming with Next Era Solar”. Sofie Buch Hoyer.*
Publication	*FutureEnergy Technical Magazine. March 2015. “A Simple Key to Reduce Capex by 35% in CSP Steam Generator Design”.*
Publication	*FutureEnergy Technical Magazine. November 2015. “New Configuration of Steam Generation Systems Optimised for Molten Salt CSP Plants”*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
Integrated Energy System for Sundrop Farms, Austra	*In December 2014, Aalborg CSP was selected to design and deliver the world's first Integrated Energy System based on CSP for the sustainable operation of Sundrop Farms' new greenhouse facilities -operational since October 2016.*
CSP for combined heat and power generation, Denmar	*In February 2016, Aalborg CSP was selected to design and deliver a CSP system to be integrated with a biomass-organic rankine cycle (ORC) plant for combined heat and power generation in Denmark - operational since the end of 2016.*
20MWe solar tower receiver, Spain.	*In 2008, Aalborg CSP designed and supplied a complete solar tower receiver system for production of saturated steam. The core design features of the solar tower receiver system are the natural circulation inside the boiler, the high steam purity, the high efficiency and neglectable electricity consumption.*
5x50MWe steam generators for CSP power plant, Spai	*Between 2009 and 2011 Aalborg CSP developed and supplied 5 x 50MWe steam generating systems for concentrated solar powered parabolic trough plants in Spain.*
MOSAIC - MOdular high concentration SolAr Config.	*H2020. The project aims to develop a new CSP modular configuration which will be based on a fixed hemispheric semi-Fresnel solar field and a high temperature mobile receiver. The approach is to implement 3D solar concentration units with fixed mirrors of high solar concentration ratios with actuated receivers, comprising several of these concentrator units in a modular plant of high efficiency.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Infrastructure	*Aalborg CSP A/S has local facilities in San Jose de la Rinconada (Spain) as follows:* *1) Engineering office (130 m2).* *2) Workshop for prefabrication of piping and small steel structures (400m2).* *3) Covered storage place (140m2).*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	**Legal name**
998080822	*EUROPEAN TURBINE NETWORK*

Short name: ETN

Address

Street	CHAUSSEE DE CHARLEROI 146-148
Town	BRUXELLES
Postcode	1060
Country	Belgium
Webpage	www.etn.global

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	08/08/2005 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name *Name of the department/institute carrying out the work.*

☒ not applicable

☐ Same as proposing organisation's address

Street *Please enter street name and number.*

Town *Please enter the name of the town.*

Postcode *Area code.*

Country *Please select a country*

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Christer**

Last name*: **Björkqvist**

E-Mail*: **cb@etn.global**

Position in org.: Managing Director

Department: EUROPEAN TURBINE NETWORK

☒ Same as organisation name

☒ Same as proposing organisation's address

Street: CHAUSSEE DE CHARLEROI 146-148

Town: BRUXELLES

Post code: 1060

Country: Belgium

Website: www.etn.global

Phone: +32 (0) 2 646 15 17

Phone 2: +XXX XXXXXXXXX

Other contact persons

First Name	Last Name	E-mail	Phone
Jitka	Spolcova	js@etn.global	+32 (0) 2 646 15 17
Rene	Vijgen	rv@etn.global	+32 (0) 2 646 15 17
Nicolo	Cairo	nc@etn.global	+32 (0) 2 646 15 17

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☐
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*ETN R&D Recommendation Report 2021, ETN Global, 2021* *This report was prepared by the ETN Project Board, which provides an independent support to new initiatives or issues brought to the ETN platform. The report includes recommendations on key research topics of gas turbine development based on the current market outlook and the users' requirements. It undergoes periodical updates; the next one is planned for 2023.*
Other achievement	*International Gas Turbine Conference (IGTC)* *IGTC is a well-established and renowned biennial conference, organised by ETN, representing the whole gas turbine community, to raise the awareness of GT and turbomachinery technology development needs and to explore and exchange ideas with GT experts from the whole value chain attending from all continents. RThe IGTC also provides the opportunity to meet and discuss with policymakers the role of gas turbines in future energy scenarios.*
Other achievement	*ETN's High-Level User Meeting* *ETN's annual High-Level User Meeting (HLUM) is an excellent occasion to exchange views and experiences with senior-level users from the oil & gas, utility and industry sectors, and to bring forward short- and long-term turbomachinery development needs that will have an important impact on the profitability of your operations and the fulfilment of your long-term strategy*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
OMSOP – GA 308952 FP7	*The overall objective of this project was to provide and demonstrate technical solutions for the use of state-of-the-art concentrated solar power system (CSP) coupled to micro-gas turbines (MGT) to produce electricity.* *ETN led the Communication and Dissemination activities.*
CO2OLHEAT - GA 101022831 H2020	*CO2OLHEAT aims at demonstrating at TRL 7 the operation of a 2 MW Waste-Heat-to-Power (WH2P) system, with a first-of-a-kind waste heat-sCO2 plant installed in a cement manufacturing plant. ETN is CO2OLHEAT's project coordinator and leader of Dissemination, Communication and Exploitation, supporting replication potential in Extra-EU analysis*
ROBINSON – GA 957752 H2020	*ROBINSON aims to help decarbonise islands through different technologies.* *ETN is ROBINSON's project coordinator. ETN is also the leader of WP7 – Dissemination, Communication and Exploitation. ETN is in charge of dissemination and communication activities and it supports the activities on stakeholders engagement and market analysis.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
998683192	*Fundacion IMDEA Energia*

Short name: IME

Address

Street	AVENIDA RAMON DE LA SAGRA 3
Town	MOSTOLES MADRID
Postcode	28935
Country	Spain
Webpage	http://www.energia.imdea.org/

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	19/08/2008 - no
SME self-assessment	unknown
SME validation	19/08/2008 - no

Departments carrying out the proposed work

Department 1

Department name	High Temperature Processes Unit	☐ not applicable
	☒ Same as proposing organisation's address	
Street	AVENIDA RAMON DE LA SAGRA 3	
Town	MOSTOLES MADRID	
Postcode	28935	
Country	Spain	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr

Gender ◯ Woman ◉ Man ◯ Non Binary

First name* **José** Last name* **González Aguilar**

E-Mail* **jose.gonzalez@imdea.org**

Position in org. Senior Researcher

Department High Temperature Processes Unit ☐ Same as organisation name

☒ Same as proposing organisation's address

Street AVENIDA RAMON DE LA SAGRA 3

Town MOSTOLES MADRID Post code 28935

Country Spain

Website *Please enter website*

Phone +34 917 37 11 36 *Phone 2* *+XXX XXXXXXXXX*

Other contact persons

First Name	Last Name	E-mail	Phone
Ángela	García de Arana	angela.garcia@imdea.org	+34 91 737 11 48
Manuel	Romero Álvarez	manuel.romero@imdea.org	+34 917 37 11 23
International Projects Offi	IMDEA Energy	projects.energy@imdea.org	+34 91 737 11 48

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier	
Dr	José	González-Aguilar	Man	Spain	jose.gonzalez@imdea.org	Category A Top grade re	Leading	57217224588	Other ID	SCOPUS
Dr	Manuel	Romero Álvarez	Man	Spain	manuel.romero@imdea.org	Category A Top grade re	Team member	55506446500	Other ID	SCOPUS
Dr	Ricardo	Carrao da Conceiçao	Man	Portugal	ricardo.conceicao@imdea.org	Category C Recognised	Team member	55506446500	Other ID	SCOPUS

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Zoller S., Koepf E., Nizamian D., Stephan M., Patané A., Haueter Ph., Romero M., González-Aguilar J., Lieftink D., de Wit E., Brendelberger S., Sizmann A., Steinfeld A. A solar tower fuel plant for the thermochemical production of kerosene from H2O and CO2, Joule, 2022, 6(7), pp. 1606–1616. DOI: 10.1016/j.joule.2022.06.012. Description of the high-concentration solar tower at IMDEA Energy including main performances and capabilities for high-temperature applications.*
Publication	*Martínez-Hernández A., Gonzalo I.B., Romero M., González-Aguilar J. Drift analysis in tilt-roll heliostats. Solar Energy (Open Access) Volume 211, Pages 1170 - 118315 November 2020. DOI: 10.1016/j.solener.2020.10.057. Detailed description of heliostats in the high high-concentration solar tower at IMDEA Energy*
Publication	*Rodríguez-Garrido R., Carballar A., Vera J., González-Aguilar J., Altamirano A., Loureiro A., Pereira D. High-Temperature Monitoring in Central Receiver Concentrating Solar Power Plants with Femtosecond-Laser Inscribed FBG. Sensors 21 (11), 3762. DOI: 10.3390/s21113762. Application of femtosecond-laser-inscribed fiber Bragg gratings (FsFBGs) for monitoring the internal high-temperature surface distribution (HTSD) in solar receivers of concentrating solar power (CSP) plants.*
Publication	*Luque S., Menéndez G., Roccabruna M., González-Aguilar J., Crema L., Romero M. Exploiting volumetric effects in novel additively manufactured open solar receivers. Solar Energy 174, 342-351. 10.1016/j.solener.2018.09.030. Description of full aerothermal assessment of four novel hierarchically-layered fractal-like volumetric absorbers, designed to be employed in high temperature concentrating solar power applications.*
Publication	*Gomez-Garcia, F., González-Aguilar, J., Olalde, G., Romero, M. Thermal and hydrodynamic behavior of ceramic volumetric absorbers for central receiver solar power plants: A review. Renewable and Sustainable Energy Reviews, 2016, 57, pp. 648–658. DOI: 10.1016/ j.rser.2015.12.106. Extensive review of the thermal and hydrodynamic behavior of conventional ceramic volumetric absorbers, i.e. monolithic honeycombs and open-cell foams.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
EU H2020 SFERA-III, 2019-2022	*In SFERA III: "Solar Facilities for the European Research Area - Third Phase", IME contributes to the development and application of enhanced SCADA (Supervisory Control And Data Acquisition) systems and control algorithms for flexible and fast-response operation of heliostat fields and increase the quality of services for optical characterization of point-focusing concentrators among others.*
EU H2020 SUN-TO-LIQUID Project, 2016-2019	*Experimental validation of the integrated fuel production chain (from solar, CO2 and water to liquid fuels) at a pre-commercial scale and high energy conversion efficiency. Key innovations were achieved: advanced high-flux ultra-modular solar heliostat field, 50 kW solar reactor, and optimized redox materials to produce synthesis gas. IME took over the design, construction and commissioning of the solar field, host the experimental facilities and conducted the experimental tests.*
EU H2020 INSHIP Project, 2017-2020	*In INSHIP: "Integrating National Research Agendas on Solar Heat for Industrial Processes", IME participated on actions related to high-temperature heat for industrial processes. These includes experimental test bed design & commissioning as well as performing the aerothermal characterization of 3D-printed volumetric absorbers.*
EU FP7 STAGE-STE Project, 2014-2018	*In STAGE-STE "Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar", IME contributed to solar receiver developments based on atmospheric volumetric absorbers and system integration on solarized Brayton cycles.*

Comunidad de Madrid ACES2030-CM (S2018/EMT-4319) “	*ACES2030 is a project funded with regional and EU structural funds and coordinated by IME. Different concentrating solar technologies are assessed including solar towers and solar receivers. IME participates in the development of volumetric and pressurized receivers as well as fast characterization techniques of solar fields.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Very-high concentration solar tower (VHCST)	*Unique infrastructure for testing components and devices under very high solar fluxes. Customized 250kWth heliostat field (169 heliostats) that makes use of the most recent developments on small size heliostats (1.9 m x 1.6 m) and a tower with reduced optical height (15 m) to minimize visual impact.*
Computational Design Lab (CDL-HTPU)	*Specific hardware and software tools for characterizing, designing and modelling solar thermochemical and high temperature processes*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
914828341	*SOFTINWAY SWITZERLAND LLC*

Short name: SOFTINWAY

Address

Street	BAARERSTRASSE 2
Town	ZUG
Postcode	6300
Country	Switzerland
Webpage	www.softinway.com

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	30/08/2011 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name	*Name of the department/institute carrying out the work.*	☒ not applicable
	☐ Same as proposing organisation's address	
Street	*Please enter street name and number.*	
Town	*Please enter the name of the town.*	
Postcode	*Area code.*	
Country	*Please select a country*	

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Mr	Eugenio	Rossi	Man	Italy	Eugenio.Rossi@softinwayswitzerland.ch	Category A Top grade re	Leading		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	**Short description (Max 500 characters)**
Publication	*Steam Turbine Rotor Transient Thermo-Structural Analysis And Lifetime Prediction. This study performs transient thermal and structural analyses of a 30 MW steam turbine for a combined High and Intermediate pressures (HPIP) rotor during a full cold start cycle with special attention to initial start-up phase with 'condensation' thermal boundary conditions. https://www.softinway.com/wp-content/uploads/2016/07/Steam-Turbine-Rotor-Transient-Thermo-Structural-Analysis-and-Lifetime-Prediction.pdf*
Publication	*Evaluation for Scalability of a Combined Cycle Using Gas and Bottoming sCO2 Turbines. This paper presents both the qualitative and quantitative advantages of combined cycles for scalability using machines ranging from small to several hundred MW gas turbines to determine which configurations of S-CO2 bottoming cycles are best for pure electricity production. https://www.softinway.com/wp-content/uploads/2015/08/ASME-PowerEnergy-2015-49439.pdf*
Publication	*A New Concept to Designing a Combined Cycle Cogeneration Power Plant. This paper considers a new concept for combined heat and power generation: the combination of Rankine Steam and Brayton Supercritical CO2(S-C02) cycles. The principles and features of combined Steam/S-CO2 cycles are presented and performances at different ratios of cogeneration are studied. https://www.softinway.com/wp-content/uploads/2014/12/A-New-Concept-to-Designing-a-Combined-Cycle-Cogeneration-Power-Plant-Article.pdf*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	**Short description (Max 500 characters)**
Anax Turbo Expander Development	*Responsible for technical management of 500kW turboexpander (including preheater, interheater, hydraulics and turbomachinery integration) that harnesses wasted energy in natural gas regulating stations to generate clean electricity*
sCO2 TurboCompressor Design	*Turbocompressor conceptual design and mechanical layout for sCO2 cycle integrating thermodynamic cycle, turbomachinery, and heat exchanger optimization*
Various Steam Turbine Designs	*Several activities covering anything from conceptual design to detail design of steam turbines ranging from kW up to tens of MW.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**
AxSTREAM Platforms	*AxSTREAM is an in-house developed software platform with several capabilities including system heat balance modelling, turbomachinery generative & detailed design, rotordynamics & bearings, heat exchanger & hydraulics modelling, co-simulation environment for digital twin development*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (●) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
884591016	*Innovation Therm Technologies, S.L.*

Short name: NTT

Address

Street	Avda. Garcia Lorca s/n, Edificio Innova
Town	Benalmadena Costa
Postcode	29630
Country	Spain
Webpage	http://novathermtech.com/

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	19/10/2022 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	R&D Department	☐ not applicable
	☒ Same as proposing organisation's address	
Street	Avda. Garcia Lorca s/n, Edificio Innova	
Town	Benalmadena Costa	
Postcode	29630	
Country	Spain	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Jesús**

Last name*: **Reyes Delgado**

E-Mail*: **jesus.reyes@novathermtech.com**

Position in org.: R&D Manager

Department: R&D Department

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: Avda. Garcia Lorca s/n, Edificio Innova

Town: Benalmadena Costa

Post code: 29630

Country: Spain

Website: http://novathermtech.com/

Phone: +34663821937

Phone 2: +xxx xxxxxxxxx

Other contact persons

First Name	Last Name	E-mail	Phone
Antonio	Ruano Povedano	antonio.ruano@novathermtech.com	+34660986933

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Mr	Jesus	Reyes	Man	Spain	jesus.reyes@novathermtech.com	Category B Senior resea	Leading		
Mr	Antonio	Ruano	Man	Spain	antonio.ruano@novathermtech.com	Category B Senior resea	Team member		
Mr	Daniel	Merino	Man	Spain	daniel.merino@novathermtech.com	Category B Senior resea	Team member		
Mr	Tomas	Delestal	Man	Spain	tomas.delestal@novathermtech.com	Category B Senior resea	Team member		
Mr	Daniel	Diaz	Man	Spain	daniel.diaz@novathermtech.com	Category B Senior resea	Team member		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Good	*Key NTT's researchers have design and develop high thermal insulation systems and heat shields for most of the commercial CSP plants built around the world and are considered as key elements in these systems research.* *Further, they have been involved in the manufacturing and installation of those systems.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
LMS-Tank	*Experimental development of novel constructive approaches to molten salt tanks.*
Avanza2	*Advanced refractory materials for the lining of furnaces and hydraulic systems in solar thermal plants. Validation of thermal insulation and mechanical resistance with fluids at very high temperature.*
Cersol	*High temperature and pressure ceramic receptor for hybrid solar systems with gas turbine and combined cycle.*
CSTR Shield	*Novel insulating shield for concentrating solar tower receivers based on space thermal protection system technologies.*
Solera	*Novel insulation system for the foundation of molten salt storage tanks.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
  - work-life balance and organisational culture;
  - gender balance in leadership and decision-making;
  - gender equality in recruitment and career progression;
  - integration of the gender dimension into research and teaching content;
  - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	Legal name
884087683	*Walter E.C. Pritzkow Spezialkeramik*

Short name: WPS

Address

Street	Adam Opel Str. 6
Town	Filderstadt
Postcode	70794
Country	Germany
Webpage	www.keramikblech.com

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	14/12/2022 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name	*Name of the department/institute carrying out the work.*	☒ not applicable
	☐ Same as proposing organisation's address	
Street	*Please enter street name and number.*	
Town	*Please enter the name of the town.*	
Postcode	*Area code.*	
Country	*Please select a country*	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Walter**

Last name*: **Pritzkow**

E-Mail*: **pritzkow-wps@keramikblech.com**

Position in org.: CEO

Department: Walter E.C. Pritzkow Spezialkeramik

☒ Same as organisation name

☒ Same as proposing organisation's address

Street: Adam Opel Str. 6

Town: Filderstadt

Post code: 70794

Country: Germany

Website: www.keramikblech.com

Phone: +4971589157090

Phone 2: +XXX XXXXXXXXX

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Mr	Walter	Pritzkow	Man	Germany	pritzkow-wps@keramikblech.com	Category B Senior resea	Leading		
Mr	Frank	Wehner	Man	Germany	Wehner-wps@keramikblech.com	Category B Senior resea	Team member		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	Legal name
953032082	*DIACHEIRISTIS ELLINIKOU DIKTYOU DIANOMIS ELEKTRIKIS ENERGEIAS AE*

Short name: HELLENIC ELECTRICITY DISTRIBUTION NETWORK OPERATOR (DEDDIE/HEDNO)

Address

Street	PERRAIVOU 20 KALLIRROIS ODOS 5
Town	ATHINA
Postcode	117 43
Country	Greece
Webpage	www.deddie.gr

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	05/07/2012 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Research and Innovation Dpt.	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Lagoumitzi 24	
Town	Kalithea	
Postcode	17671	
Country	Greece	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Mr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Sotiris** Last name*: **Christopoulos**

E-Mail*: **s.christopoulos@deddie.gr**

Position in org.: Researcher

Department: DIACHEIRISTIS ELLINIKOU DIKTYOU DIANOMIS ELEKTRIKIS ENERGEIAS AE ☒ Same as organisation name

☐ Same as proposing organisation's address

Street: Lagoumitzi 24

Town: Kallithea Post code: 17671

Country: Greece

Website: *Please enter website*

Phone: *+xxx xxxxxxxxx* Phone 2: *+xxx xxxxxxxxx*

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Georgios	Loukos	Man	Greece	g.loukos@deddie.gr	Category A Top grade re	Leading		
Mr	Sotiris	Christopoulos	Man	Greece	s.christopoulos@deddie.gr	Category D First stage r	Team member		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☐
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*N. Hatziargyriou,, V. Kleftakis, F. Palaiogiannis, A. Dimeas, I. Vlachos, C. Katsanos, A. Zafeirakis, A. Tzevelekos, "Towards the modernisation of the supervisory control and data acquisition systems of the Hellenic electricity distribution network operator: considerations and steps forward.", CIRED - Open Access Proceedings Journal (Volume: 2017, Issue: 1, 10 2017),*
Publication	*P Ch. Papadimitriou, G. Messinis, D. Vranis, S. Politopoulou, N. Hatziargyriou, "Non-technical losses: detection methods and regulatory aspects overview", CIRED - Open Access Proceedings Journal (Volume: 2017 , Issue: 1 , 10 2017)*
Publication	*P. Pediaditis, D. Papadaskalopoulos, A. Papavasiliou and N. Hatziargyriou, "Bilevel Optimization Model for the Design of Distribution Use-of-System Tariffs," in IEEE Access, vol. 9, pp. 132928-132939, 2021, doi: 10.1109/ACCESS.2021.3114768.*
Publication	*P. Pediaditis, C. Ziras, D. Papadaskalopoulos and N. Hatziargyriou, "Synergies between Distribution Use-of-System Tariffs and Local Flexibility Markets," 2022 International Conference on Smart Energy Systems and Technologies (SEST), 2022, pp. 1-6, doi: 10.1109/ SEST53650.2022.9898437*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
SYNERGY (GA ID:872734)	*It introduces a novel framework and references big data architecture that leverages data, primary or secondarily related to the electricity domain, coming from diverse sources to help the electricity value chain stakeholders to enhance their data reach, improve their internal intelligence on electricity-related optimization functions while getting involved in novel sharing/trading models of data sources and intelligence, to gain better insights and increase collective decision-making.*
X-FLEX (GA ID:863927)	*It will design, develop and demonstrate a set of tools to integrate the emerging decentralized ecosystems into the existing European energy system, in an efficient and cost-effective manner, to create more stable and sustainable smart grid, with special attention to extreme weather conditions. HEDNO leads the activities for the Greek pilot for the evaluation and testing of the technical solutions, while also providing critical impact on the design and implementation phase.*
PLATONE (GA ID:864300)	*It will provide a seamless integration of operation and market simplifying the life of customers, distribution grid operator and aggregators, thanks to a multilayer platform architecture collecting data on the edge and delivering secure information both to Distribution Management Systems and to an open Marketplace for service provision by utilizing IoT & blockchains technology frameworks. HEDNO leads the activities for the Greek pilot for the evaluation and testing of the technical solutions.*
PARITY (GA ID: 864319)	*It delivers a unique local flexibility market platform through the seamless integration of IoT and blockchain technologies. By delivering a market for automated flexibility exchange based on smart contracts & blockchain, it will facilitate transparent local flexibility transactions and reward flexibility provision.* *HEDNO has an advisory role based on its experience from running a large distribution grid and retail/market operations on many small local energy systems*
SHAR-Q (GA ID: 731285)	*The objective is to optimize the storage capacities deployed in the grid with the help of a peer-to-peer interoperability network that connects neighbourhooding RES+Storage ecosystems into a collaboration framework. An open interoperability gateway with semantic interface descriptors will be provided that will be based on the most adopted standards in the field. The users will be provided with an ability to manage their contribution in a way that resembles the well-known social web portals.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
SCADA	*Supervision of the HV/MV substations. The system has the ability to supervise the protection relays of the MV subsystems by the use of the communication protocol IEC 870-5-103. Critical data are aggregated for the sustainable operation of the HV/MV substations: event, fault alarms and metering data.*
Smart metering infrastructure	*In Greece, currently, smart meters have already been installed at all MV customers and major LV customers (between 55 kVA and 250 kVA).*
AMI	*HEDNO has set up two telemetering centres, one to collect remotely meter readings from MV customers and RES producers, and the other to collect remotely meter readings from major LV customers (> 55 kVA) including photovoltaics (PV).*
GIS	*The geographic information system is designed to capture, analyse, manage and present the spatial or geographical network data. It is a flexible system that collaborate with other systems and technologies concerning the network functions and management operations, such as DMS-SCADA, SAP, CIS, etc...*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
  - o work-life balance and organisational culture;
  - o gender balance in leadership and decision-making;
  - o gender equality in recruitment and career progression;
  - o integration of the gender dimension into research and teaching content;
  - o measures against gender-based violence including sexual harassment.

PIC	**Legal name**
884218536	*engionic Femto Gratings GmbH*

Short name: engionic

Address

Street	Am Stollen 19
Town	Goslar
Postcode	38640
Country	Germany
Webpage	https://engionic-femto-gratings.de/de/home

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	25/11/2022 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	R&D	☐ not applicable
	☒ Same as proposing organisation's address	
Street	Am Stollen 19	
Town	Goslar	
Postcode	38640	
Country	Germany	

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Dr

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Andreas**

Last name*: **Pohlkötter**

E-Mail*: **pohlkoetter@engionic.de**

Position in org.: Head of R&D

Department: R&D

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: Am Stollen 19

Town: Goslar

Post code: 38640

Country: Germany

Website: https://www.engionic-femto-gratings.de/de/home

Phone: +49 (0)5321 39 58709

Phone 2: +49 (0)30 62 88 730

Other contact persons

First Name	Last Name	E-mail	Phone
Margarethe	Kampling	kampling@engionic.de	+49 (30) 62 88 73 16
Britta	Koch	koch@engionic.de	+49 (30) 62 88 73 23

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Andreas	Pohlkötter	Man	Germany	pohlkoetter@engionic.de	Category B Senior resea	Leading		
Dr	Hatem	Dachraoui	Man	Germany	dachraoui@engionic.de	Category B Senior resea	Team member		
Dr	Felix	Leyssner	Man	Germany	leyssner@engionic.de	Category B Senior resea	Team member		

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☐
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Good	*Commercial FBG-glass fibre probes from FemtoFiberTec (now: engionic Femto Gratings) were successfully used in the predecessor project to the present project application for the monitoring of high temperature surface distribution in solar receivers of concentrating solar power (CSP) plants. Areal temperature profiles up to 566 °C were monitored and fiber optic sensors were shown to be a viable and reliable alternative to thermocouples (until now the benchmark sensor for this application)*
Publication	*"High-Temperature Monitoring in Central Receiver Concentrating Solar Power Plants with Femtosecond-Laser Inscribed FBG" [Sensors (Basel). 2021 May 28;21(11):3762. DOI: 10.3390/ s21113762]*
Good	*Standard fibre optic temperature sensors as single sensors or temperature lances, -30°C - 700 °C* *https://engionic-fiber-optics.de/en/products/fiber-bragg-sensors/products/temperature-sensors* *FBG-inscibed optical fibres for sensor assembly enabling the development of standard products for high-temperature measurements. Typical applications are in the areas of process control, borehole and pipeline monitoring, fire protection, power plant monitoring, engine monitoring and others.*
Publication	*"Second generation fs-laser-written fibre Bragg gratings for high accuracy temperature measurement in harsh environments" [Proc. SPIE 10654, Fiber Optic Sensors and Applications XV, 106541L (05/ 2018). DOI: https://doi.org/10.1117/12.2315507]* *Isotropic femtosecond point -by-point written FBGs with especially favourable properties resulting in extremely precise static measurements required for accurate temperature monitoring and allowing flexible sensor arrangements.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
FBGs for Temperature Sensing	*engionic Femto Gratings has developed point-by-point fs inscribed FBGs in glass optical fibers that are capable of sensing strain and temperature at 700°C. This has been achieved through the continuous developments of the company's production and research team.*
Prototype FBGs in Saphire Fiber	*For a university research application FBGs in multimode Sapphire fibres were inscribed as a proof of principle. No characterisation or measurements were done with these fibres. Known obstacles are problems with coupling light into the fibres, problems with multimode FBGs and unreliable FBGs parameters*
ACHIEF (Horizon 2020)	*Goal: Improving process performance and energy efficiency in energy intensive industries by developing more durable high-performance materials/components and equipment* *Contribution: Within the engionic group of companies our sister company engionic Fiber Optic is part of an EU-wide consortium and develops fiber optic high-temperature and strain sensors for embedding in novel coating materials. The protected sensors are tested for temperature monitoring in energy-intensive metallurgical processes*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
fs laser writing station	*Four production lines for femtosecond point-by-point FBG Inscription in optical fibres with two high power femtosecond Laser systems. This can be used to inscribe FBGs in a wide range of optical fibres including specially fibres. Single FBGs and FBG Arrays can be inscribed through the coating of the*

FBG Characterisation Equipment	*FBGs inscribed in fibres can be characterised spectrally with various instruments. The spectral detection is possible inhouse over a rage from 800 to 2000 nm. Lightsources are available from 125 nm to 1680 nm and around 800 nm. Different standard FBG interrogators are available to test FBGs sensing*
FBG Sensor Development	*Several high temperature calibration ovens are available, some through our partner companies, that can be used to develop and characterise FBG temperature sensors*
Optical fibre assembly	*All standard equipment for optical fibre and FBG sensor assembly is available (i.e., splicing, connector, etc.) Assembly of FBG sensors can be done at our partner company if required.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ○ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
939080184	*APRIA SYSTEMS SL*

Short name: APRIA

Address

Street	POLIG PARQUE EMPRESARIAL DE MORERO S/N, P
Town	ASTILLERO (EL)
Postcode	39611
Country	Spain
Webpage	www.apriasystems.es

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	31/12/2019 - yes
SME self-assessment	31/12/2019 - yes
SME validation	31/12/2013 - yes

Departments carrying out the proposed work

Department 1

Department name	R&D	☐ not applicable
	☒ Same as proposing organisation's address	
Street	POLIG PARQUE EMPRESARIAL DE MORERO S/N,	
Town	ASTILLERO (EL)	
Postcode	39611	
Country	Spain	

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr

Gender ◯ Woman ◉ Man ◯ Non Binary

First name* **Javier**

Last name* **Pinedo**

E-Mail* **javier.pinedo@apriasystems.es**

Position in org. CTO

Department APRIA SYSTEMS SL

☒ Same as organisation name

☒ Same as proposing organisation's address

Street POLIG PARQUE EMPRESARIAL DE MORERO S/N, PARCELA 2. NAVE 1-5 GUARN

Town ASTILLERO (EL)

Post code 39611

Country Spain

Website https://apriasystems.es/

Phone +34 942078147

Phone 2 *+XXX XXXXXXXXX*

Other contact persons

First Name	Last Name	E-mail	Phone
Álvaro	Soriano	alvaro.soriano@apriasystems.es	+34 942078147
Ana	Hernández	ana.hernandez@apriasystems.es	+34 942078147

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Javier	Pinedo	Man	Spain	javier.pinedo@apriasystems.es	Category B Senior resea	Leading	0000-0003-2036-9246	Orcid ID
Dr	Álvaro	Soriano	Man	Spain	alvaro.soriano@apriasystems.es	Category B Senior resea	Team member	0000-0001-6689-8595	Orcid ID
Dr	Ana	Hernández	Woman	Spain	ana.hernandez@apriasystems.es	Category B Senior resea	Team member	0000-0003-2004-9453	Orcid ID
Dr	Axel	Arruti	Man	Spain	axel.arruti@apriasystems.es	Category B Senior resea	Team member	0000-0001-9379-9621	Orcid ID
Dr	Andrés	del Castillo	Man	Spain	andres.delcastillo@apriasystems.es	Category B Senior resea	Team member		
Dr	Sara	Dominguez	Woman	Spain	sara.dominguez@apriasystems.es	Category B Senior resea	Team member		
Mr	Ricardo	Moran	Man	Spain	ricardo.moran@apriasystems.es	Category C Recognised	Team member		
Dr	Esther	Santos	Woman	Spain	esther.santos@apriasystems.es	Category B Senior resea	Team member	0000-0001-9370-141X	Orcid ID

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*Santos, E., Rodríguez-Fernández, E., Casado-Coterillo, C., Irabien A. Hybrid Ionic Liquid-Chitosan Membranes for CO2 Separation: Mechanical and Thermal Behavior. International Journal of Chemical Reactor Engineering, 14 (3), 713 - 718, 2015.*
Publication	*Del Castillo, A., Alvarez-Guerra M., Solla-Gullón J., Sáez, A., Montiel V., Irabien, A. Sn nanoparticles on gas diffusion electrodes: Synthesis, characterization and use for continuous CO2 electroreduction to formate. Journal of CO2 Utilization, 18, 222 - 228, 2017*
Publication	*Santos, E., Albo, J., Irabien A. Acetate based Supported Ionic Liquid Membranes (SILMs) for CO2 separation: Influence of the temperature. Journal of Membrane Science, 452, 277–283, 2014*
Publication	*Santos E., Albo J., Rosatella A., Afonso C., Irabien A. Synthesis and characterization of Magnetic Ionic Liquids (MILs) for CO2 separation. Journal of Chemical Technology & Biotechnology, 89, 866-871, 2014.*
Publication	*Pérez-González, A., Ibáñez, R., Gómez, P., Urtiaga, A.M., Ortiz, I., Irabien, J.A. Desal., 2015, 473, 16-27.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
DSWAP	*https://www.dswap-prima.eu/* *DSWAP (PRIMA-med programme). The role of APRIA was the integration of forward osmosis and nanofiltration for the effective water recovery from secondary waste streams for irrigation purposes.*
LIFE-4-Fgases	*https://life4fgases.eu/* *LIFE-4-Fgases applies membrane technology for the selective recovery of fluorinated gases. In this ongoing project APRIA is responsable for the construction and start-up of an innovative hybrid system, the so called HAMSYS (Hybrid Adsorption and Membrane Systems), which integrates membrane technology and adsorption processes.*
LIFE INDESAL	*https://indesal.revolve.media/* *LIFE INDESAL aims to develop and demonstrate an integrated and circular seawater desalination scheme, with a lower carbon footprint than conventional desalination process, that recovers energy and raw materials from the process. The role of APRIA in this project is the design, construction and integration of a novel reverse electrodyalisis (RED) unitary process.*
LIFE-3E	*https://life3e.eu/* *LIFE programme project, where APRIA coordinated the design, construction and integration of a novel reverse electrodyalisis (RED) pilot plant aiming at the recovery of the saline gradient energy for its use in the reclamation of urban wastewaters for urban, irrigation or industrial processes.*
HYSOLCHEM	*www.hysolchem.eu* *Funded under FETPROACT programme, HYSOLCHEM aims to develop a hybrid reactor for solar CO2 and N2 conversion coupled to wastewater treatment. The role of APRIA is the design and construction a photo-reactor prototype based on advanced separation processes for the conversion and storage of renewable energy.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Project office	*Project office. A complete set of laptops, software for modelling & simulation (Aspen) as well as for design (SolidWorks, AUTOCAD), patent and research databases (Scopus, Patentscope), and equipment for R&D activities.*

Construction equipment	*Specialized equipment and tools for engineering and construction of bench and pilot plant setups (i.e. 3D SLS and FDM printers, mitre saw, digital multimetre, multifunction tools, etc.).*
Bench and pilot plant setups	*Specialized equipment and tools for engineering and construction of bench and pilot plant setups (i.e. mitre saw, digital multimetre, multifunction tools, etc.).*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ○ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Proposal ID **101122231**

Acronym **ASTERIx-CAESar**

3 - Budget

No.	Name of beneficiary	Country	Role	Personnel costs/€	Subcontracting costs/€	Purchase costs - Travel and substistence /€	Purchase costs - Equipment/€	Purchase costs - Other goods, works and services/€	Internally invoiced goods and services/€ (Unit costs- usual accounting practices)	Indirect costs/€	Total eligible costs	Funding rate	Maximum EU contribution to eligible costs	Requested EU contribution to eligible costs/€	Max grant amount	Income generated by the action	Financial contributions	Own resources	Total estimated income
1	Fundacion Cener	ES	Coordinator	639 710	0	15 000	0	167 000	0	205 427.50	1 027 137.50	100	1 027 137.50	1 027 137.50	1 027 137.50	0.00	0.00	0.00	1 027 137.50
2	Centro De Investigaciones Energeticas,	ES	Partner	461 825	0	36 500	0	173 500	0	167 956.25	839 781.25	100	839 781.25	839 781.25	839 781.25	0.00	0.00	0.00	839 781.25
3	Universidad De Sevilla	ES	Partner	266 400	0	15 000	0	94 250	0	93 912.50	469 562.50	100	469 562.50	469 562.50	469 562.50	0.00	0.00	0.00	469 562.50
4	Bluebox Energy Ltd	UK	Partner	245 000	0	15 000	0	0	0	65 000.00	325 000.00	70	227 500.00	227 500.00	227 500.00	0.00	0.00	0.00	227 500.00
5	Doosan Skoda Power Sro	CZ	Partner	181 050	0	15 000	0	35 000	0	57 762.50	288 812.50	70	202 168.75	202 168.75	202 168.75	0.00	0.00	0.00	202 168.75
6	Universita Degli Studi Roma Tre	IT	Partner	273 000	0	15 000	0	108 000	0	99 000.00	495 000.00	100	495 000.00	495 000.00	495 000.00	0.00	0.00	0.00	495 000.00
7	Fraunhofer Gesellschaft Zur Forderung	DE	Partner	238 203	0	8 000	0	89 500	0	83 925.75	419 628.75	100	419 628.75	419 628.75	419 628.75	0.00	0.00	0.00	419 628.75
8	Clancy Haussler Rita	AT	Partner	129 601	0	18 000	0	22 500	0	42 525.25	212 626.25	70	148 838.38	148 838.38	148 838.38	0.00	0.00	0.00	148 838.38
9	Aalborg Csp As	DK	Partner	320 418	0	15 000	1 200	12 500	0	87 279.50	436 397.50	70	305 478.25	305 478.25	305 478.25	0.00	0.00	0.00	305 478.25

10	European Turbine Network	BE	Partner	141 950	0	12 000	0	48 000	0	50 487.50	252 437.50	100	252 437.50	252 437.50	252 437.50	0.00	0.00	0.00	252 437.50
11	Fundacion Imdea Energia	ES	Partner	214 781		13 000	0	35 000		65 695.25	328 476.25	100	328 476.25	328 476.25	328 476.25		0.00	0.00	328 476.25
12	Softinway Switzerland Llc	CH	Associated	0	0	0	0	0	0	0.00	0.00	70	0.00	0.00	0.00	0.00	700 656.00	300 281.00	1 000 937.00
13	Innovation Therm Technologies,	ES	Partner	180 000	0	7 500	0	0	0	46 875.00	234 375.00	70	164 062.50	164 062.50	164 062.50	0.00	0.00	0.00	164 062.50
14	Walter E.c. Pritzkow Spezialkeramik	DE	Partner	132 290	0	9 000	0	20 000	0	40 322.50	201 612.50	70	141 128.75	141 128.75	141 128.75	0.00	0.00	0.00	141 128.75
15	Diacheiristis Ellinikou Diktyou	EL	Partner	195 000	0	15 000	0	0	0	52 500.00	262 500.00	70	183 750.00	183 750.00	183 750.00	0.00	0.00	0.00	183 750.00
16	Engionic Femto Gratings	DE	Partner	198 000	0	12 000	0	15 000	0	56 250.00	281 250.00	70	196 875.00	196 875.00	196 875.00	0.00	0.00	0.00	196 875.00
17	Apria Systems Sl	ES	Partner	56 400	0	10 000	0	44 000	0	27 600.00	138 000.00	70	96 600.00	96 600.00	96 600.00	0.00	0.00	0.00	96 600.00
	TOTAL			3 873 628	0	231 000	1 200	864 250	0	1 242 519.50	6 212 597.50		5 498 425.38	5 498 425.38	5 498 425.38	0.00	700 656.00	300 281.00	6 499 362.38

Administrative forms

Proposal ID **101122231**

Acronym **ASTERIx-CAESar**

4 - Ethics & security

Ethics Issues Table

1. Human Embryonic Stem Cells and Human Embryos		Page
Does this activity involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does this activity involve the use of human embryos?	◯ Yes ◉ No	
2. Humans		**Page**
Does this activity involve human participants?	◯ Yes ◉ No	
Does this activity involve interventions (physical also including imaging technology, behavioural treatments, etc.) on the study participants?	◯ Yes ◉ No	
Does this activity involve conducting a clinical study as defined by the Clinical Trial Regulation (EU 536/2014)? (using pharmaceuticals, biologicals, radiopharmaceuticals, or advanced therapy medicinal products)	◯ Yes ◉ No	
3. Human Cells / Tissues (not covered by section 1)		**Page**
Does this activity involve the use of human cells or tissues?	◯ Yes ◉ No	
4. Personal Data		**Page**
Does this activity involve processing of personal data?	◯ Yes ◉ No	
Does this activity involve further processing of previously collected personal data (including use of preexisting data sets or sources, merging existing data sets)?	◯ Yes ◉ No	
Is it planned to export personal data from the EU to non-EU countries? Specify the type of personal data and countries involved	◯ Yes ◉ No	
Is it planned to import personal data from non-EU countries into the EU or from a non-EU country to another non-EU country? Specify the type of personal data and countries involved	◯ Yes ◉ No	
Does this activity involve the processing of personal data related to criminal convictions or offences?	◯ Yes ◉ No	
5. Animals		**Page**
Does this activity involve animals?	◯ Yes ◉ No	
6. Non-EU Countries		**Page**
Will some of the activities be carried out in non-EU countries?	◉ Yes ◯ No	55
Partner Bluebox Energy is from the United Kingdom. Thus, part of the activity of WP4 (described on page 55) will be carried out in its facilities in the UK. Partner SoftInWay Switzerland GmbH is from Switzerland. They are mainly involved in WP4 and part of the activities of that WP will be carried out in their facilities in Switzerland.		
In case non-EU countries are involved, do the activities undertaken in these countries raise potential ethics issues?	◯ Yes ◉ No	
It is planned to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	◯ Yes ◉ No	
Is it planned to import any material (other than data) from non-EU countries into the EU or from a non-EU country to another non-EU country? For data imports, see section 4.	◯ Yes ◉ No	

Is it planned to export any material (other than data) from the EU to non-EU countries? For data exports, see section 4.	◯ Yes	◉ No	
Does this activity involve low and/or lower middle income countries, (if yes, detail the benefit-sharing actions planned in the self-assessment)	◯ Yes	◉ No	
Could the situation in the country put the individuals taking part in the activity at risk?	◯ Yes	◉ No	
7. Environment, Health and Safety			**Page**
Does this activity involve the use of substances or processes that may cause harm to the environment, to animals or plants.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	◯ Yes	◉ No	
Does this activity deal with endangered fauna and/or flora / protected areas?	◯ Yes	◉ No	
Does this activity involve the use of substances or processes that may cause harm to humans, including those performing the activity.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	◯ Yes	◉ No	
8. Artificial Intelligence			**Page**
Does this activity involve the development, deployment and/or use of Artificial Intelligence? (if yes, detail in the self-assessment whether that could raise ethical concerns related to human rights and values and detail how this will be addressed).	◯ Yes	◉ No	
9. Other Ethics Issues			**Page**
Are there any other ethics issues that should be taken into consideration?	◯ Yes	◉ No	

I confirm that I have taken into account all ethics issues above and that, if any ethics issues apply, I will complete the ethics self-assessment as described in the guidelines How to Complete your Ethics Self-Assessment ☒

Administrative forms

Proposal ID **101122231**

Acronym **ASTERIx-CAESar**

Ethics Self-Assessment

Ethical dimension of the objectives, methodology and likely impact

Partner Bluebox Energy is from the United Kingdom. Thus, part of the activity of WP4 will be carried out in its facilities in the UK. In order to justify risk-benefits it should be pointed out that Bluebox Energy is a key company that took part in the previous H2020 project CAPTure, providing an essential contribution. It is the partner who designed and installed the two stage hot air turbine coupled to the CSP prototype located at PSA that will be extended by the ASTERIx-CAESar project.
Partner SoftInWay Switzerland GmbH is from Switzerland. They are mainly involved in WP4 and part of the activities of that WP will be carried out in their facilities in Switzerland. SIW is a global R&D engineering company specialized in the development of efficient turbomachinery components and reliable systems for different applications such as power generation. They have led various projects that focused on system integration from full micro gas turbine development to the design of complete waste heat recovery systems and zero-emission power plants. Their expertise rely in design, modelling and optimization of power generation equipment (gas and steam turbines, boilers, heat exchangers, combustors etc.) and their participation is key in the design and development of a critical component in the proposed ASTERIx-CAESar system which is the CAES expander.

Remaining characters 3640

Compliance with ethical principles and relevant legislations

Both the UK partner (Bluebox Energy) and the Swiss partner (SoftInWay Switzerland GmbH) fully commits to complying with all EU Ethics standards for all research, technology development and exploitation activities as part of the project, including any measures to avoid non-civil applications of the technology. Therefore, according to legislation, there are no relevant issues. All the activities or tasks that are going to be carried out in the UK and Switzerland are compliant with the EU/ national EU-countries legal and ethical requirements.

Remaining characters 4455

Administrative forms

Proposal ID **101122231**

Acronym **ASTERIx-CAESar**

Security issues table

1. EU Classified Information (EUCI)[2]		Page
Does this activity involve information and/or materials requiring protection against unauthorised disclosure (EUCI)?	◯ Yes ◉ No	
Does this activity involve non-EU countries which need to have access to EUCI?	◯ Yes ◉ No	

2. Misuse		Page
Does this activity have the potential for misuse of results?	◯ Yes ◉ No	

3. Other Security Issues		Page
Does this activity involve information and/or materials subject to national security restrictions? If yes, please specify: (Maximum number of characters allowed: 1000)	◯ Yes ◉ No	
Are there any other security issues that should be taken into consideration? If yes, please specify: (Maximum number of characters allowed: 1000)	◯ Yes ◉ No	

Security self-assessment

Please specify: (Maximum number of characters allowed: 5000)

Remaining characters 5000

[2]According to the Commission Decision (EU, Euratom) 2015/444 of 13 March 2015 on the security rules for protecting EU classified information, “European Union classified information (EUCI) means any information or material designated by an EU security classification, the unauthorised disclosure of which could cause varying degrees of prejudice to the interests of the European Union or of one or more of the Member States”.

[3]Classified background information is information that is already classified by a country and/or international organisation and/or the EU and is going to be used by the project. In this case, the project must have in advance the authorisation from the originator of the classified information, which is the entity (EU institution, EU Member State, third state or international organisation) under whose authority the classified information has been generated.

[4]EU classified foreground information is information (documents/deliverables/materials) planned to be generated by the project and that needs to be protected from unauthorised disclosure. The originator of the EUCI generated by the project is the European Commission.

5 - Other questions

ASTERIx - CAESar

- AIR-BASED SOLAR THERMAL ELECTRICITY FOR EFFICIENT RENEWABLE ENERGY INTEGRATION & COMPRESSED AIR ENERGY STORAGE

List of participants

Participant No. *	Participant organisation name	Short name	Country
1 (Coordinator)	Fundación CENER	CEN	ES
2	CIEMAT O.A, M.P.	PSA	ES
3	Universidad de Sevilla	USE	ES
4	Bluebox Energy Ltd.	BLUE	UK
5	DOOSAN Škoda Power S.R.O.	DSPW	CZ
6	Università degli studi Roma Tre	ROMA3	IT
7	FRAUNHOFER-Gesellschaft zur Förderung der angewandten Forschung e. V. (IKTS)	IKTS	DE
8	Eurida Research	EURIDA	AT
9	Aalborg CSP A/S	AAL	DK
10	European Turbine Network (ETN Global)	ETN	BE
11	Fundación IMDEA ENERGÍA	IME	ES
12	SoftInWay Switzerland GmbH	SIW-S	CH
13	Innovation Therm Technologies, S.L.	NTT	ES
14	Walter E.C. Pritzkow Spezialkeramik	WPS	DE
15	Hellenic Electricity Distribution Network Operator S.A.	HEDNO	GR
16	engionic Femto Gratings GmbH	EFG	DE
17	APRIA Systems	APRIA	ES

1 Excellence

Like Asterix & Obelix, who needed the magic potion to continuously defeat the powerful Roman Empire,

the Renewable Energy Sector also needs its "magic potion", massive Energy Storage in order to succeed!

Nomenclature:

CAES – Compressed Air Energy Storage
CC - Combined Cycle (Topping Brayton + Bottoming Rankine)
CSP – Concentrated Solar Power
ERD – Energy Recovery Device (reverse osmosis desalination)
HEX - Heat Exchanger (H-HEX/L-HEX: High/Low-temperature)
HRSG - Heat Recovery Steam Generator
H-TES - High-temperature TES
HTF - Heat Transfer Fluid
KPI – Key Performance Indicator
LCOE – Levelized Cost of Electricity
LCOS – Levelized Cost of Storage
L-TES - Low-temperature TES
OCMC - all-oxide ceramic matrix composite
OVAR - Open Volumetric Air Receiver
P2H2P - Power to Heat to Power
PV – Photovoltaic
RE – Renewable Energy
RTE – electricity storage Round Trip Efficiency
TES – Thermal Energy Storage
TIT - Turbine Inlet Temperature

1.1 Objectives and ambition

The ongoing renewable energy revolution, i.e. the ever rising fraction of non-dispatchable renewable power generation, is dramatically changing the way of power generation. Coming from a centralised system of power production, where mainly large-scale fossil fired or nuclear power plants provide stable and firm supply, we are moving towards a 100% renewable energy system where power is produced in highly decentralised and uncontrolled manner, i.e. power is produced where and when the wind is blowing, or the sun is shining. **Thus, a key requirement for the efficient operation of the future energy system is massive energy storage on the one hand, and highly flexible power generation on the other**. It is clear that the future's ideal power plant needs to provide "adaptive" power generation, being able to generate power, when required by the grid, and also to store energy efficiently, when electricity demand is low, but renewable energy is available in excess (e.g. from PV, or wind). **Therefore, it is mandatory that future CSP plants implement efficient electrical energy storage, in addition to, or in combination with thermal energy storage (TES) in order to stabilize the power grid**. Future "adaptive" CSP plants must store energy during periods of high renewable output and low demand (low price periods), in order to dispatch electricity during hours of high demand (high price periods), **representing the crucial "magic potion" in order implement a future 100% renewable energy system**.

Furthermore, the CSP plant of the future must be **optimally integrated into the energy system**, not only considering the electricity grid, but the energy system in general. This means that the CSP plant of the future must be able to **efficiently interact with the industry for process heat supply as well as with desalination units**. Desalination is expected to become a key technology for human life in many locations around the world, in particular in high solar resource areas (with low water availability), which are relevant for CSP. There is currently a lack in available technology to cover 24/7 renewable power supply for desalination plants.

The ASTERIx-CAESar project focuses on a **novel solution, an innovative hybrid CSP – Compressed Air Energy Storage (CAES) combined cycle power plant configuration** that provides **very competitive electrical energy storage technology ("the magic potion")** and a **break-through in solar-to-electric energy conversion efficiency**. A sophisticated set of features of both technologies make the approach highly attractive, compared to state-of-the-art CSP solutions. ► Today, oil-based parabolic trough plants and molten salt towers are the dominating commercial solutions. Their solar-to-electric efficiency is very low (not higher than 21% peak efficiency – see Figure 2 - and about 16% on annual basis). This is mainly due to the low conversion efficiency of the power cycle (steam Rankine with about 30% annual mean thermal-to-electric conversion efficiency due to high ambient temperature) and the low optical efficiency of large-size heliostat fields. ►Therefore, in order to increase conversion efficiency, the operating temperature of the receiver must be increased so that advanced high-efficiency power cycles can be applied (e.g. the combined cycle – GT & Rankine steam cycle). A second positive effect of higher operating temperatures is that the sensible TES becomes cheaper (per kWh of energy stored) since the usable temperature difference is higher.

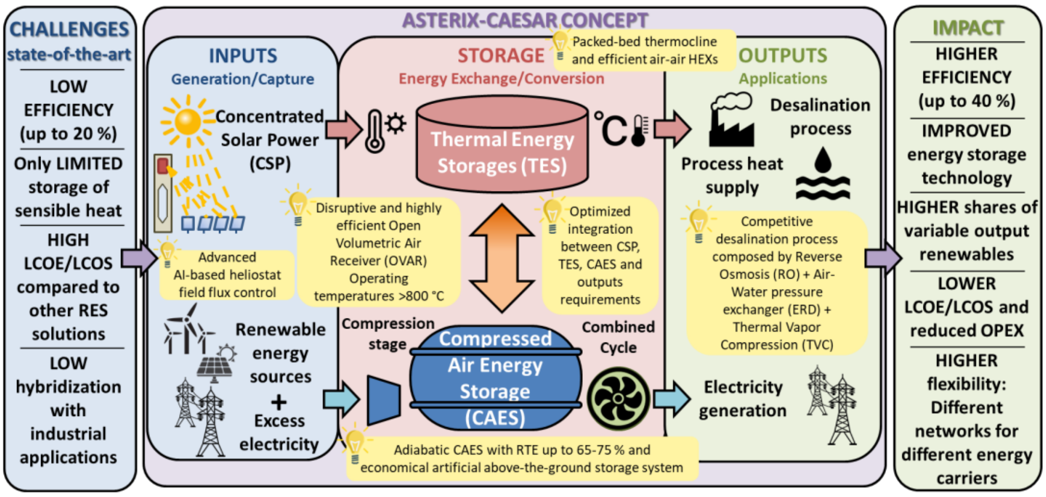


Figure 1: ASTERIx-CAESar concept overview – Graphical Abstract

The ASTERIx-CAESar project even goes one step further and **achieves a crucial conversion efficiency boost** by **using low-value excess renewable energy from the electricity grid – a clever trick that removes the compressor work from the topping Brayton cycle, and results in a very high "expansion" efficiency of the combined cycle** (see Figure 2). This break-through approach lowers the necessary maximum power cycle temperature (TIT) to about 800 ºC (compared to the classical combined cycle TIT of over 1000 ºC – see Figure 2), adds efficient electrical energy storage (CAES) to the plant, and **increases the peak solar-to-electric conversion efficiency to about 40%** [2]. Figure 2 shows the benchmarking of CSP technologies and its great efficiency potential of the novel approach.

Main objective 1: Develop a **novel high-efficiency adaptive power plant concept combining air-based central receiver CSP with compressed air energy storage (CAES)**, providing a **highly competitive LCOE/LCOS**, and optimise its **integration in the energy system of the future** (electrically as well as thermally, including process heat supply and desalination). Main KPIs:

- Due to the combination of CSP and CAES, **the peak solar-to-electric energy conversion efficiency is doubled (>40%) w.r.t. state-of-the-art technology (≈20%).**
- Very competitive electrical energy storage round-trip efficiency (RTE) of > 60%, at very low LCOS of < 10 - 15 c€/kWh.

Project results: The optimised overall concept for a wide range of nominal power (from small-scale ≈1 MWe up to ≈ 150 MWe) for 11 different locations around the world. The numerical modelling and simulation will be validated with data obtained at a validation-scale research prototype. An open-source Modelica model library ready to simulate and a user-friendly interactive online simulation environment.

In order to complete objective 1, <u>a set of innovative key components and sub-systems is needed to implement the novel CSP plant (see Table 1)</u>

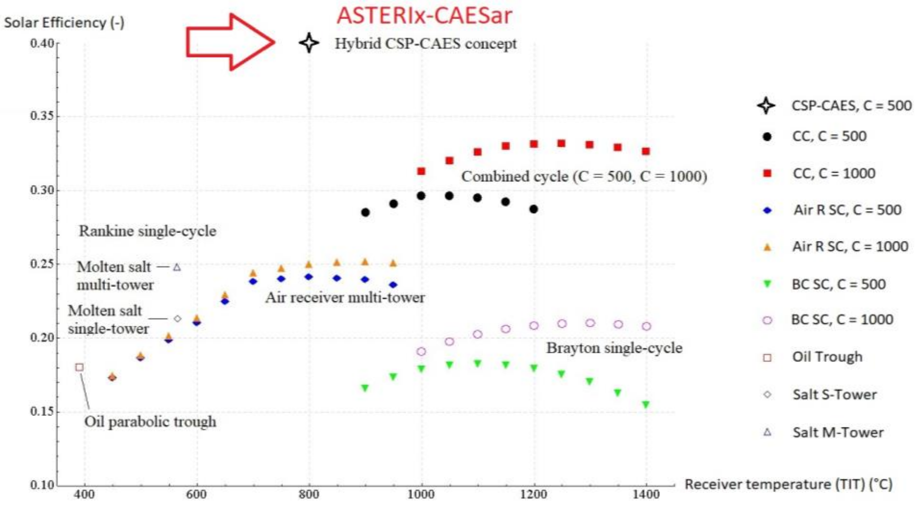


Figure 2: Solar-to-electric efficiencies as function of operating temperature and technology (CC=Combined cycle; SC=Single cycle; R = Rankine; BC= Brayton cycle) [1]

The CSP plant is in its basic concept a combination of 2 energy conversion systems: (1) a **high-temperature solar collector (solar field + receiver: key subsystem #1)** and (2) a **thermodynamic power cycle (key subsystem #2)**. Therefore, the conversion efficiency of CSP technology fundamentally depends on two factors, (i) the solar-to-thermal (solar collector), and (ii) the thermal-to-electric energy conversion process in the power cycle [3]; the first being mainly a function of solar field size, optical concentration ratio and solar receiver operating temperature; the latter being a function of the power cycle layout of choice, and the maximum (≈ solar receiver operating temperature) and minimum (heat rejection) temperature (according to Carnot's theorem). **In order to maximize the overall solar-to-electric conversion efficiency, the optical concentration ratio C and the solar receiver operating temperature need to be as high as possible in order to enable a high solar receiver efficiency (>85%) and high thermal efficiency of the power cycle at the same time (> 50% [4])**, ideally applying advanced power cycles, such as the combined cycle, comprised of a topping gas turbine (Brayton cycle) and bottoming steam turbine (steam Rankine cycle).

Table 1: ASTERIx-CAESar key sub-systems and components and corresponding implementation results

Key R&D sub-systems	Technological challenges	Key components	ASTERIx-CAESar results
Key subsystem #1 - **Solar energy conversion system**	#1.1- High radiation absorption	High flux density volumetric solar receiver	► 480 kWth receiver **demonstrated** at TRL 6-7 ► Commercial scale receiver **design**
	#1.2 - Accuracy in solar flux on the surface of the receiver	AI-based heliostat field/solar flux control unit	► AI-based heliostat control unit **demonstrated** at TRL 6-7
		Optical sensor for monitoring high-concentration solar thermal systems	►Novel fibre optic sensors **demonstrated** at TRL 6-7
Key subsystem #2 - **Energy conversion system for electricity generation and energy storage**	#2.1 - Demonstrated and optimized CAES	CAES compressors and expanders	► Optimum turbo machinery **design** for the small scale and large-scale application ► 100 kW small scale air expander train **demonstrated** in a solar powered CAES system at TRL 6-7.
		Innovative low-cost artificial compressed air storage vessel for small-scale CAES	► Optimum storage vessel **design** for the small-scale CAES application ► Air storage vessel **demonstrated** in a solar powered CAES system at TRL 6-7
		Low-temperature air-air heat exchanger – L-HEX (reuse of heat of compression – storage mode)	► Optimum heat exchanger **design** for small scale and large scale application
		High-temperature air-air heat exchanger – H-HEX (heat input in power cycle – generation mode)	► Optimum heat exchanger **design** for small scale and large scale application ► 480 kWth heat exchanger **demonstrated** together with a small-scale solar powered CAES system at TRL 6-7
	#2.2 - Integration of desalination process with CAES	Innovative gas-liquid pressure exchanger (ERD) for integration of desalination	► Optimum **design** of the gas-liquid pressure exchanger for small-scale and large-scale commercial application ► Small scale prototype **demonstrated** together with a small-scale solar powered CAES system at TRL 6-7

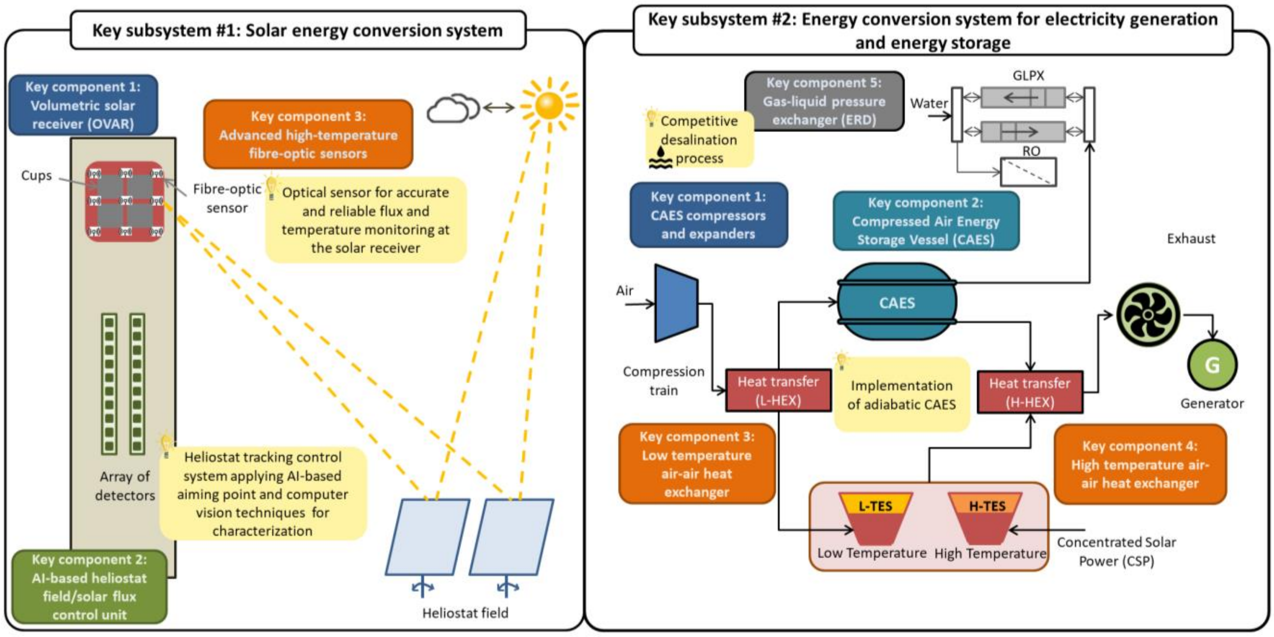


Figure 3: ASTERIx-CAESar key sub-systems and components

Today, allowable peak flux densities in molten salt receivers may reach values above 1 MW/m^2 [5], with a typical mean flux at the receiver aperture area of about 500 kW/m^2, i.e. mean concentration ratios of about C = 500 (500 suns). Today's state-of-the-art molten salt receivers are tube-panel designs, **where the salt (HTF) is heated inside expensive high-performance alloy metal tubes**. The thermal conductivity of the tubes is typically low and high temperature gradients inside tube wall limit the efficiency (maximum temperature is always on the outer tube surface causing high radiative losses – see Figure 4).

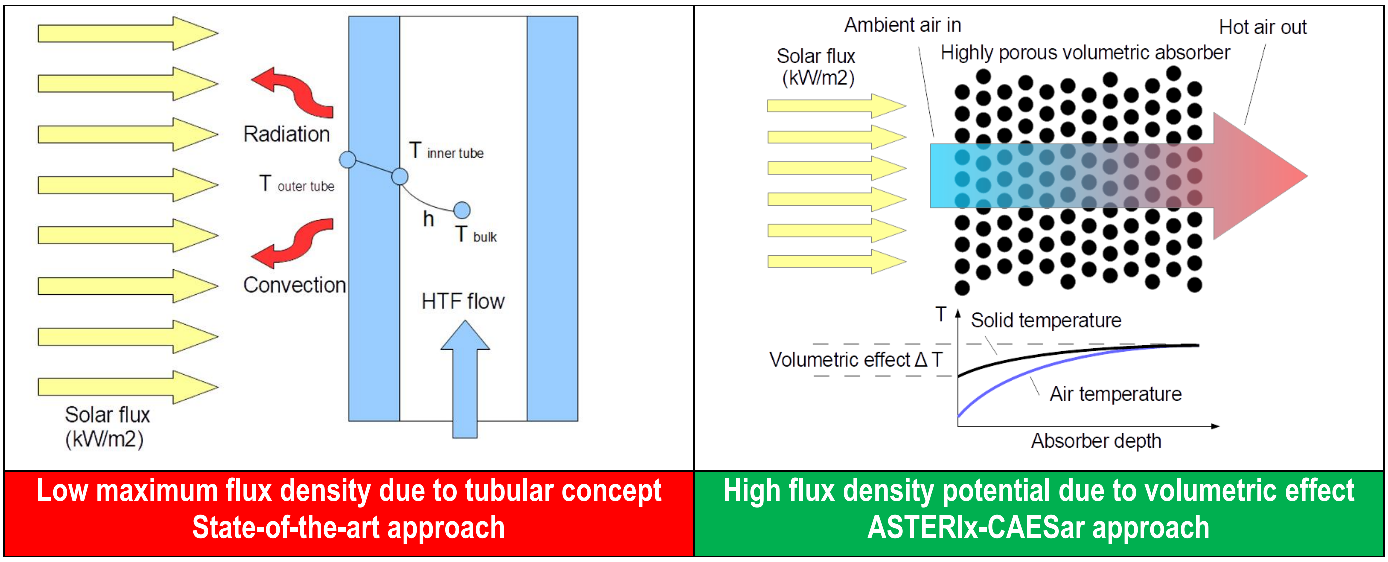


Figure 4: Tubular receiver concept (left) with low maximum solar flux density versus high flux density volumetric receiver concept (right)

The ASTERIx-CAESar project will focus on an advanced **cost effective high-flux Open Volumetric Air Receiver (OVAR) concept**, pushing mean concentration ratios C to above 700 – 800 suns, and receiver operating temperatures above 800ºC, ideally suited for the here presented break-through application. **The volumetric effect offers high thermal efficiency also at elevated outlet temperatures (see Figure 4).** Additionally, by using air as HTF, there are no environmental concerns, no leakage hazards, higher operating temperatures and no freezing issue of the HTF circuit in case of black outs, compared to molten salt systems.

Volumetric solar receivers [6] have been investigated since the 1980's and have shown to be a promising alternative to tubular receivers, due to higher solar flux density limits and the so-called "volumetric effect" [3], which leads to efficiency advantages. The "volumetric effect" is a steady state heat transfer phenomenon, where the frontal part of the solar absorber, facing the incoming solar flux, has a lower temperature than the rear part of the absorber at the air outlet (see Figure 4 - right). This characteristic temperature profile is caused by dominating radiative (heat loss to ambient) and convective (air flow) cooling of the absorber within the absorbing volume, despite very high incident solar flux densities.

Technological answer 1.1: Develop a novel high-efficiency (>85%) and cost effective receiver concept based on volumetric absorbers (0.7-0.8 MW_{th}/m^2 mean flux; 1.5 MW_{th}/m^2 peak flux), maximizing concentration ratio C and solar-to-thermal conversion efficiency.

Project result: A 480 kWth solar receiver prototype demonstrated in the relevant environment with at least 6 months of operation (TRL 6-7).

Additionally, in order to reduce OPEX and enhance plant operation, the ASTERIx-CAESar project will target the implementation of an **advanced Artificial Intelligence (AI) high precision aiming strategy generation method, heliostat field calibration and flux monitoring system.**

Maintaining the optimum solar flux distribution on the receiver aperture (as function of solar position and DNI variation) is a very difficult task and is so far not automated and depends on a highly experienced plant operator team **that additionally has to rely on little available measurement data**. High-temperature monitoring under high fluxes (ordinary working conditions in central receiver CSP plants) is extremely challenging due to the harsh environment in terms of temperature and high solar radiation. Current temperature measurement systems are classified in direct, indirect and combined methods. Direct measurement systems are composed of thermocouple type sensors distributed in the aperture plane of the receiver surface. Thus, temperature maps are created by spatial interpolation of the measured points. Indirect measurement can be done by the use of infrared cameras, which however implies a high uncertainty. Today, a combination of infrared cameras and thermocouple sensors are used in commercial plants. However, thermocouples have limited life time, require troublesome assembly, have a slow response and can cause false measurements and false alarms. These disadvantages make thermocouples cost prohibitive if they are deployed in a large number [7]. Additionally, there is currently no commercially available reference solution for solar flux monitoring at central receiver plants. Typically, a very limited number of water-cooled Gardon gauges are installed and additional optical methods with CCD cameras are used to monitor the flux distribution on the receiver .[8]

Hence, there is currently a clear lack in suitable temperature and flux monitoring equipment. However, it is of upmost importance to introduce the highest degree of automated and monitored plant operation, in order to guarantee safe and efficient plant operation (to keep operation close to allowed limits with appropriate safety margins), as well as to reduce operating cost. **Therefore, the ASTERIx-CAESar project targets the development of a break-through solar receiver monitoring system based on advanced fibre-optic sensors.** Fibre-optic sensors have intrinsic advantages, such as passive nature, flexible structure, high sensitivity, high resolution, lightweight, low loss, small size, fast sensor time response, non-affected by external electromagnetic fields [9] and capability to operate in harsh environments with long life time [10].

Technological answer 1.2: Develop a fast, dynamic, accurate, adaptive AI-based heliostat field/solar flux control and monitoring system for CSP central receiver plants to guarantee a stable solar flux distribution on the receiver and reduce O&M effort.

Project results: Demonstration of the advanced flux control and monitoring system at IME (experimental tower) as well as at CIEMAT-PSA (experimental tower); An innovative fibre optic sensor for improved flux and temperature monitoring demonstrated at TRL 6-7.

Recent research (H2020 project CAPTure) [1, 11] has shown that the application of the combined cycle (CC) together with optimised volumetric air receiver technology [6], has the potential to raise the peak solar-to-electric efficiency to about 30% [1]. However, the required high operating temperatures (≈1000ºC) of the solar receiver and the externally heated Brayton cycle require the application of very expensive high-temperature materials (air-air HEX, piping and valves), which make the CC technology too expensive and commercially not viable for CSP [11, 12].

Considering this**, novel power cycle architectures are mandatory for CSP that reduce the maximum operating temperature of the cycle (turbine inlet temperature - TIT), while maintaining or improving the thermal-to-electric conversion efficiency w.r.t. the conventional combined cycle benchmark (≈ 50% at TIT of 1000ºC [1, 13])**.

A further issue of current CSP technology, in particular the central receiver technology, is the techno-economic trade-off between optical conversion efficiency (heliostat field) and the thermal efficiency and specific cost (€/kWe) of the power cycle, that limits their economic viability: **Small heliostat fields have higher optical efficiencies than large ones; small power cycles however have lower efficiencies and additionally much higher specific investment costs (€/kWe).** Thus, small CSP plants, while having high solar-to-thermal conversion efficiency, are **so far** economically not feasible because of the constraint of conventional power cycles. **Therefore, compact power cycles (< 50 MW_e) are sought that achieve outstanding conversion efficiencies, having still**

competitive specific costs.

Due to the innovative combination of CSP and CAES, **the ASTERIx-CAESar project introduces a highly attractive power cycle for CSP (key subsystem #2), addressing both abovementioned issues**. The project develops a highly efficient (60-70% thermal efficiency) and optimally sized power cycle for the CSP application with maximum operating temperatures between 750 and 800ºC, allowing excellent solar energy conversion efficiencies.

Main objective 2: Develop a **highly efficient** (60-70% thermal efficiency - roughly doubling that of state-of-the-art cycles)[1] and **optimally sized power cycle** for the CSP application with maximum operating temperatures between 750 and 800ºC (for very efficient receiver operation and reasonable material costs) and **flexible/adaptive operation (easy and quick start-up, shutdown and load variation)**; for large-scale (up to ≈150 MWe) and distributed small-scale applications (as low as ≈1 MWe).

*Project result: The optimised power cycle design (**key subsystem #2**) for a wide range of nominal power, as defined by the virtual use cases. Optimum heat exchanger design for power cycle heat input.*

Most importantly, this novel power cycle concept integrates efficient electrical energy storage via Adiabatic Compressed Air Energy Storage (A-CAES). By improving the state-of-the-art diabatic CAES technology (according to Huntorf and McIntosh plants [14]), **the combination of an advanced adiabatic CAES approach together with renewable solar heat input** (instead of natural gas firing), will lead to **highest electricity storage round-trip efficiency (RTE) of > 60%**. Most importantly, in order **to achieve geography-independent application, the optimization of cost-effective artificial air storage volumes will be treated**.

Technological answer 2.1: Optimize the concept of **adiabatic CAES for the competitive application in air-based CSP central receiver plants** (optimised turbomachinery, air storage, TES, heat exchangers, and their control), in particular focusing on the **cost-effective design and integration of the artificial compressed air storage vessels**.

Project results: The optimised adiabatic CAES parameters for the ASTERIx-CAESar plant concept (objective 1) and the optimised heat exchanger configuration for charging and discharging of the CAES.

Besides the conventional application for stand-alone CSP plants for power generation and storage, the ASTERIx-CAESar project will also address the **optimum integration into the energy system**, to **efficiently interact with the industry for process heat supply as well as with desalination units** (24/7 renewable energy supply). The dominating desalination technology is today reverse osmosis (RO). During the day, these plants (with mainly electric consumption from the high pressure water pump) can be powered by PV arrays, however grid operators cannot implement high fractions of PV supply due to grid stability issues (typically no storage available). Hence 24/7 renewable energy supply is difficult to achieve. The unique feature of the ASTERIx-CAESar concept is that the pressure energy is stored in the form of compressed air. This stored pressure energy can be used for desalination, applying a so-called pressure exchanger or energy recovery device (ERD) to cover energy supply when PV or wind output is not available.

Technological answer 2.2: Optimum integration of ASTERIx-CAESar with different industry sectors for process heat supply and desalination technology to cover 24/7 renewable power supply for desalination plants.

Project results: The optimised overall concept of ASTERIx-CAESar for specific use cases (objective 1); A dedicated pressure exchanger (ERD) to couple the CAES plant with reverse osmosis (RO) units. ERD demonstrated at TRL 6-7 at the modified CAPTure prototype.

The combination of all abovementioned attractive features leads to a **highest solar-to-electric conversion efficiency as well as reduced O&M cost**, at the same time providing very **competitive electrical energy storage**. **In order to optimise the operation of the novel ASTERIx-CAESar plant, the energy system as a whole needs to be analysed, especially considering the highly variable output of photovoltaic (PV) and wind power.**

Rather than evaluating the LCOE of CSP, the true value of CSP for grid operation, i.e. its "magic potion" cheap energy storage [15], is indispensable when considering an increasing fraction of not dispatchable renewables. Solar thermal electricity is not to be seen as competitor of photovoltaic, in fact, it will be the enabler of a 100% renewable energy system. **The ASTERIx-CAESar project provides THE missing puzzle piece to implement the renewable revolution.**

---

[1] **This high efficiency level (≈ ideal Carnot cycle) is achieved by assuming off-peak electrical energy not as effort, a clever trick, to boost CSP performance by using low-value surplus renewable generation.**

The LCOE of photovoltaic (PV) power generation has fallen dramatically in recent years (to 2-3 €c/kWh) [16] seriously outperforming current commercial CSP technology (in the range of 7 – 12 €c/kWh), oil-based parabolic trough power plants or molten salt central receivers. Considering this immense price difference, the unique and very valuable advantage of CSP providing cheap thermal energy storage – TES – (thus providing dispatchable operation) is not sufficient to be competitive any more, a CSP technology breakthrough is needed. There is no point in operating CSP plants during the day, when PV is running at full capacity and electricity prices are low (so called "**duck curve**" [17, 18]). CSP needs to provide peak supply [19] in high-price **periods (morning, evening) or at night to guarantee high revenue and the "magic potion" for the power grid.** Therefore, **LCOE is not the correct metric for CSP plants when taking into account the global picture**. Besides LCOE, other additional figures of merit will be discussed within the project.

The ASTERIx-CAESar project will therefore **propose new and specifically optimised operating strategies and business models** in order to **maximize not only economic revenues for the CSP-CAES plant**, but also to **maximize the integration of variable output renewables in the energy system**, applying its **"magic potion", energy storage**, **thus minimizing the overall cost of Renewable Energy (RE).**

Main objective 3: Establish a new operation strategy and business model to make this new concept of adaptive CSP-CAES power plant economically competitive by providing the electrical grid with an efficient storage capacity.

Project result: Optimised operation strategy based on annual performance simulations using representative boundary conditions for 11 different locations and corresponding electricity markets, among them the case of Greece and South Africa.

In order to make a solid argument, other competing electricity storage technologies need to be listed **in order to clearly show the project's unique potential and ambition**:

Table 2: Advantages of ASTERIx-CAESar concept against other current electricity storage technologies

Advantages of ASTERIx-CAESar concept against other current electricity storage technologies	
Pumped hydro-energy storage (PHS) is the most widely deployed, mature and economical technology. It has a high round-trip efficiency (RTE) in the range of 70-84 %. However, the main limitation of this energy storage system is due to geographical restrictions. Pumped hydropower achieves a LCOS between 15 c€/kWh and 20 c€/kWh [20], for short term storage in daily cycling.	The ASTERIx-CAESar project proposes a power plant concept with compressed air energy storage (CAES) using an economical above-the-ground storage system. **This fact removes the geographical restriction of conventional systems**. The approach of artificial storage vessels is viable for the nominal power levels that are of interest for CSP. The objective of the project is to achieve highly competitive LCOS of < 10 - 15 c€/kWh.
Diabatic Compressed air energy storage (D-CAES) would be another state-of-the-art technology and it has been installed and optimised since the 1970s. It uses compressed air to store energy to time shift power generation. The air needs to be heated before expansion in the turbine, applying natural gas burners. The RTE is in the range of 46-48 % [21], when having gas turbine inlet temperatures of ≈ 850ºC in expansion mode.	In the ASTERIx-CAESar concept the integration of an **adiabatic CAES** is targeted. The waste heat is reduced because the heat of compression is stored in a Thermal Energy Storage (TES) system and later reused for pre-heating the air before the expansion phase, which increases the RTE up to the range of 65-75 % [22] Additionally, **the combination with Concentrated Solar Power (CSP) – to increase air temperature – increases power output and enables electrical energy storage with zero emissions**.
Electrochemical storage (battery technology) is very promising due to high RTE up to 90 % and easy integration with renewable energy technologies such as PV or wind energy. Nevertheless, most of the progress so far has been done in the laboratory and the main challenge is related to its short life cycle [23], which leads to a significant increase in LCOS 30-40 c€/kWh [24, 25]. Also the **environmental impact and recyclability** is currently a matter of discussion.	The ASTERIx-CAESar energy storage approach is based on turbo machinery, thermal energy storage as well as the storage of pressurised air. **It has very long life time (>25 years) with highest degree of recycling potential and no environmental harm.** It provides **reactive power and frequency regulation**, which can be performed even when the plant is neither charging nor discharging by opening both clutches. Furthermore, it can be **integrated with thermal processes within a flexible and smart grid**.
Power-to-Heat-to-Power – P2H2P - (Joule Heating Effect) is a simple idea with high TRL that uses the Joule Heating Effect by electric heaters. In the charging process, this system transforms excess electrical energy directly into heat that is stored efficiently. In the discharging process, heat is transformed again into electricity by a thermodynamic cycle – usually Rankine cycle - when it is desired. The main drawback is that the RTE is equal to the Rankine cycle efficiency (35-40 %). The P2H2P concept is now under	It seems that electricity storage based on storage of thermal energy and thermodynamic processes involving heavy duty turbomachinery is the most interesting alternative for massive grid-scale storage with long life time and low cost. Hence, knowing that CSP plants feature efficient TES technology and heavy-duty turbomachinery, ASTERIx-CAESar proposes a combination with CAES that boosts the competitiveness of this novel technology and raises the efficiency. **The achievable RTE is above 60%, clearly outmatching the**

major development by all big players in the energy sector and numerous start-up companies have emerged lately. **However, P2H2P can be seen as a "thermodynamic crime", as pure exergy is transformed into heat.**	**Joule P2H2P approach, making sense thermodynamically as well as economically**.

Last but not least, the ASTERIx-CAESar project has the objective to validate the novel CSP-CAES plant operation at an already existing research prototype installed at CIEMAT-PSA in the south of Spain. The 300 kWth prototype (see Figure 33 and Figure 34) has been developed and installed in the framework of the H2020 research project CAPTure [26], which lasted from May 2015 to July 2020 and focused on an innovative central receiver CSP plant configuration, investigating the application of an open volumetric air receiver (OVAR) for heat generation at highest temperature in order to power a combined cycle (CC) – topping Brayton, plus bottoming steam Rankine cycle – for efficient and competitive renewable power generation.

In order to be able to validate the novel approach of combining air-based CSP with CAES, **the CAPTure prototype needs to be slightly adapted, modifying the receiver and adding an air compressor, an artificial compressed air storage vessel, as well as additional piping and valves to the existing prototype**.

Main objective 4: To leverage synergies with the finished H2020 project CAPTure and optimally reuse EU research funds, by extending and adapting the existing research prototype of the CAPTure project (6 M€ budget). The existing small-scale solar powered hot air turbine will be extended by a CAES system, being able to validate the most relevant components and their operation experimentally (solar receiver, high-temperature heat exchanger, 3 stage compressed air expander).

Project result: Extended research prototype and demonstration in the relevant environment at TRL 6-7. At least 500 hours of operation.

The ASTERIx-CAESar project has the following specific objectives:

Table 3: ASTERIx-CAESar Specific Objectives and Target Key Performance Indicators (KPI)

#	Specific Objectives	Target (KPIs) and Verification
1	An optimised novel high-efficiency adaptive power plant concept combining air-based CSP with compressed air energy storage (CAES)	• Double solar-to-electric peak efficiency w.r.t. state of the art (>40%) • Highly competitive LCOS of < 10 - 15 c€/kWh electric • Very competitive electricity storage round trip efficiency (RTE) of > 60% • Long life time of power plant (> 25 years) + minimum environmental impact.
2	A novel cost-effective approach for open volumetric air receivers based on large-module **fixed ceramic foam** absorbers suitable for high-flux operation	• Mean concentration ratio > 700 - 800 suns • Peak flux > 1.5 MW_{th}/m^2. • Mean flux > 800 kW_{th}/m^2. • Receiver efficiency > 85% at operating temperatures of 800ºC. • Demonstrated at TRL 6-7 (experimental tower – CAPTure prototype) at 480 kW thermal. • Specific receiver cost of below 25 k€/ m2 of aperture.
3	AI-based heliostat field/solar flux control and monitoring system	• Fully automated heliostat field control • Flux maps at receiver always close to nominal flux density (mean and peak value) ± < 5% target 1% of accuracy. • Fibre optic sensor suitable for temperature and flux measurement at above 800ºC and solar-flux > 1.5 MW/m2.
4	A highly efficient and optimally sized power cycle for the CSP application with maximum operating temperatures between 750 and 800ºC (for very efficient receiver operation); for large-scale and distributed small-scale applications.	• Thermal power cycle efficiency between 60 and 70% • Maximum cycle temperature between (750 and 800ºC) • Nominal electric power up to ≈ 150 MW_e for large-scale application • Nominal electric power as low as ≈ 1 MW_e for small-scale application
5	An optimised concept of adiabatic CAES, tailored for the application in the proposed hybrid CSP-CAES plant	• Very competitive electricity storage round trip efficiency (RTE) of > 60%
6	Optimised and efficient air-air low and high-temperature heat exchangers	• High heat exchange effectiveness (>85%) • Competitive costs (< 60 k€ per kg/s of air flow) [12, 27]
7	Very cost competitive design of an artificial compressed air energy storage volume partly or fully integrated in	• Maximum pressure of ≈ 150 bar (energy storage density >15 kWh/m^3, due to higher pressure and higher TIT)

	the CSP tower with high storage density.	• LCOS target of below < 10 - 15 c€/kWh electric • Air storage vessel CAPEX < 35 € /kWh of exergy storage capacity [28]
8	Optimum integration of desalination in the ASTERIx-CAESar concept	• 24/7 energy supply to reverse osmosis units (via pressure energy storage) • Gas-liquid ERD efficiency (>80%) • Demonstrated at TRL 6-7 at experimental tower (adapted CAPTure prototype) > 6 months operation • Optimized integration for specific use cases
9	Establish a new operation strategy and business model to make this new concept of adaptive CSP-CAES power plant economically highly attractive.	• New revenue-based operation strategy leveraging market price differences in the future energy grid with high share of variable output renewables. Minimum amortization time < 10 years (small-scale ASTERIx-CAESar); < 20 years (large-scale ASTERIx-CAESar).
10	Validation of the CSP-CAES operation by extending an already existing research prototype.	• At least 500 hours of experimental solar powered operation at about 480 kW thermal.

1.1.1 From Idea to Application – Technology Readiness Levels (TRL)

The ASTERIx-CAESar project combines two technology concepts (CSP and CAES) in order to provide a break-through solution that enables the renewable energy revolution. Although commercially operating plants exist of both technology concepts (CSP and CAES), the ASTERIx-CAESar project addresses innovative solutions for both areas, targeting a final TRL level between 6 and 7 at the end of the project.

Regarding CSP: Today, commercial-scale CSP technology is based on parabolic trough as well as central receiver molten salt and steam plants. These plants have very low conversion efficiency and are economically not competitive against PV. Also, operation is complex and the operation is not yet automated and thus expensive. Therefore, novel high-efficiency plant concepts and low-cost components as well as smart autonomous operation are required. **The ASTERIx-CAESar project targets this issue via developing key components reaching TRL 6-7 at the end of the project (solar receiver, AI-based heliostat control).**

Regarding CAES: The project proposes an advanced **adiabatic CAES** approach (heat of compression is fully recovered) **with additional high-temperature solar heat input to increase power output and conversion efficiency**. Although CAES technology is already commercially available (operating plants in Germany, US and China), the adiabatic CAES technology is still in development stage, due to challenges of heat storage, heat recovery and turbomachinery operation. **The ASTERIx-CAESar project investigates all necessary key components in order to implement the novel combined CSP-CAES plant.** The key components include advanced heat exchangers (recuperative and regenerative concept) as well as turbo-machinery, where feasibility and flexibility to operate on variable pressure ratios and operating temperatures need to be optimised for the innovative plant concept. As the application of CAES involves very high pressures (up to 150 bar) and also high temperatures (750-800ºC), the main challenges are related to high-temperature solar heat supply, heat exchanger and turbo-machinery design and cycle architecture. Overall, TRL 6-7 will be achieved at the end of the project.

Key subsystem #1 - Solar energy conversion system:

Solar Receiver: The air receiver technology is very promising due to high operating temperatures, compatibility with low-cost TES, high efficiency potential and minimum environmental impact. Therefore, the project development targets a high-flux density and cost-effective open volumetric air receiver capitalizing on the results obtained in the H2020 research project CAPTure [11]. It is a novel solution based on a simple modular stackable design approach. During the CAPTure project this receiver technology has been tested successfully at TRL 5. The ASTERIx-CAESar project will continue the development line stressing maximum permitted solar flux density (to increase efficiency) and optimizing module design to reduce cost. The technology will be brought to TRL 6-7 at the end of the project and demonstrated at 480 kWth at CIEMAT-PSA.

Smart AI-based flux control and monitoring via fibre optical sensors: In order to reduce O&M costs, the challenging task of solar flux control (heliostat aiming point optimization) needs to be automated. Currently a team of highly experienced plant operators is necessary to guarantee safe plant operation. The ASTERIx-CAESar project will develop and demonstrate an artificial intelligence (AI) heliostat control capitalizing on the work done in CAPTure [29], HELIOSUN project [30], H2020 SFERA-III as well as additional know-how within the consortium. The technology will be brought from TRL 4-5 to 6-7 at the end of the project. Additionally, the application range of fibre optic sensors will be extended to above 800ºC and flux densities of over 1.5 MW/m^2, based on the promising results gained in the predecessor EFECTO project (ITC-20161223, FEDER INTERCONNECTA 2016) [7].

Key subsystem #2: Energy conversion system for electricity generation and energy storage:

Compressors and expanders: The ASTERIx-CAESar CAES concept can be based on available turbo machinery.

Regarding compressors, standard air compressor equipment can be used since the operating temperatures are modest (low to medium temperature adiabatic CAES) with compressor stage outlet temperatures of about 200ºC. Nevertheless, challenges are related to control. There is a risk of hitting the choke limit of the performance map in the initial phases of the charging process and then getting very close to the surge limit when the storage vessel is close to its maximum capacity. This must be addressed with control elements such as variable inlet guide vanes for example. In summary, it is an implementation challenge, rather than a technological challenge. **There are similar aspects concerning the turbo expanders**. High-pressure air expanders can be obtained by applying modified steam turbines or gas turbines depending on maximum operating pressure and temperature. The implementation challenge is related to the appropriate combination of turbine stages in order to have a good efficiency over a wide range of pressure ratio (storage vessel pressure decrease during discharge). The ASTRIx-CAESar project will apply multiple turbine stages, where specific stages can be by-passed as the storage pressure decreases.

High- and low-temperature heat exchangers: The ASTERIx-CAESar concept allows the implementation of a "low-temperature" combined cycle (CC), where the maximum turbine inlet temperature (TIT) is reduced to about 800ºC (in contrast to conventional fossil fired CC technology, reaching TIT of up to 1500ºC). This means that high TRL air/air heat exchanger equipment can be used, typically based on shell-and-tube layouts applying available high-temperature metallic alloys as pipe material. Alternatively, the ASTERIx-CAESar project proposes a regenerative heat exchanger concept that is promising for small-scale application. It has been successfully implemented and tested in the finished CAPTure project. The heat exchanger development is also an implementation challenge, rather than a technological one. The challenges are mainly related to correct sizing (pressure drop limits) and process control.

Low-cost artificial compressed air storage vessel for small-scale CAES: Artificial above-ground pressure vessels for small-scale CAES application have been proposed by several authors [21, 28]. The concept is typcially based on interconnection of large-diameter steel pipes. In order to reduce costs, the well-known wire-winding technique (applied in industry for conventional pressure vessels) is very promising in order to reduce the needed wall thickness. Also here, it is a high TRL solution and challenges are related to the suitable implementation.

Air-water pressure exchanger for reverse osmosis coupling: So-called energy recovery devices (ERDs) are used in state-of-the art reverse osmosis (RO) plants in order to recover pressure energy and reduce water pumping power. ERDs are pressure exchangers, which exchange pressure energy between two fluid streams (water-water) and are based on rotary-type or valve-type technology [31]. For the application in the ASTERIx-CAESar concept, one fluid is compressed air, the other water. Only valve-type ERDs are suitable and need to be slightly modified to efficiently exchange pressure energy between air and water. Also here, the component is a high TRL solution. The project will demonstrate the technology at small scale (about 1 m3/h clean water production).

1.2 Methodology

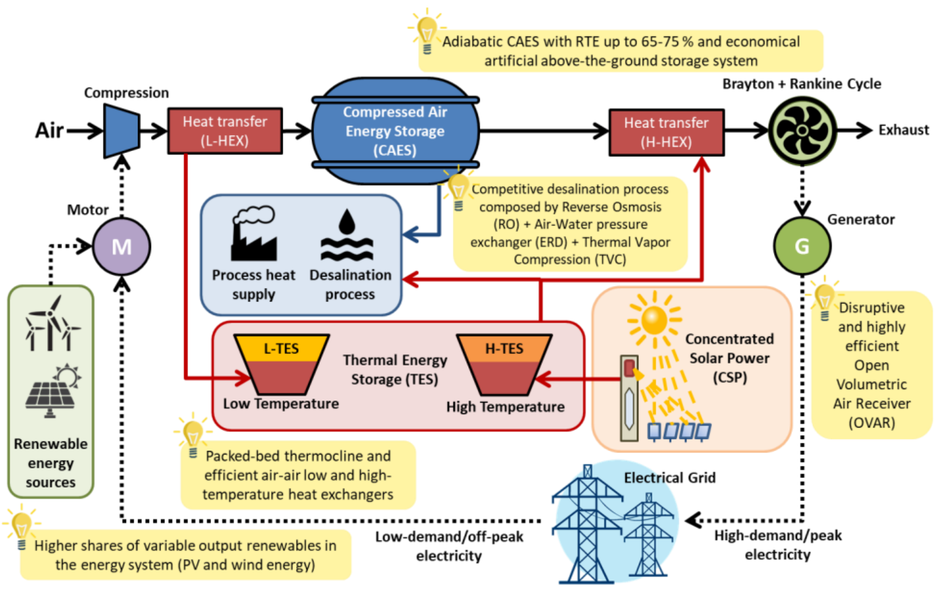


Figure 5: ASTERIx-CAESar overall concept.

Core of the project is the afore-mentioned innovative power plant concept combing air-based CSP and compressed air energy storage (CAES). Figure 5 displays the overall concept. The CSP section transforms solar energy to high-temperature heat that is stored (H-TES). In parallel, cheap excess electricity is used to compress air that is stored in a CAES vessel. The heat of compression is recovered and stored (L-TES). The stored heat (H-TES and L-TES) is reused to raise the temperature of the stored compressed air before the expansion in the power cycle. **This flexible system very efficiently stores cheap off-peak electricity generated by other renewable energies like PV or wind energy, and generates electricity during peak hours, and can provide industrial process heat or desalination plants with heat and pressure supply (air-water ERD plus reverse osmosis).**

In conventional CAES systems, before the expansion in the gas turbine (also air expander), the compressed air is heated to the turbine inlet temperature applying conventional natural-gas-powered combustion chambers [14]. Therefore, several authors proposed the integration of solar thermal energy in order to make this storage technology CO_2-neutral [32, 33]. The ASTERIx-CAESar project proposes a power plant concept according to this line but based on the **central receiver technology** applying **air as heat transfer fluid (HTF)** using a **highly efficient open volumetric air receiver (OVAR) and combined cycle (topping Brayton hot air turbine and bottoming Rankine cycle) technology**, capitalizing on the experiences obtained within the 5 year CAPTure H2020 project [11].

The proposed innovation is to dramatically improve the combined cycle's thermal to electric conversion efficiency, while at the same time adding electrical energy storage to the plant. Adding the CAES technology to the combined cycle CSP plant, **introduces the possibility to provide the compression work of the topping gas turbine from the excess of electricity of the electrical grid**. As function of electricity prices in the grid (which can even be negative at certain times, e.g. at high wind energy output), the plant is even being paid for receiving compression work that can be later on used in the combined cycle when power is demanded by the grid. **By not considering the work needed to compress air as thermodynamic effort, the thermal-to-electric conversion efficiency may be increased to the 60-70% range, at relatively low turbine inlet temperatures (≈700- 800ºC) that are very interesting for central receiver plants, because the receiver's efficiency can be kept high.** This feature suddenly makes combined cycle CSP plants feasible with very competitive specific power cycle costs (as power output is increased).

The power plant concept is displayed in Figure 6 and Figure 7 [2]. During the charging phase (Figure 6), solar energy is stored in the form of high-temperature heat in a thermocline TES (right-hand side of the figure) at about 800-850ºC. The CAES system is charged when low-price electricity from the grid powers a multi-stage inter-cooled air compressor train (left-hand side of the figure). The low-temperature heat coming from the inter-coolers is stored in a low-temperature thermocline TES, with maximum charging temperature of about 200ºC (depending on pressure ratio of compressor stages). The compressed air is stored in a pressure vessel. Note that the optimum number of compression stages and the temperature of the low-temperature TES (L-TES) system is not yet defined; it will be subject to optimization during the project's development. There may be different optimums for small-scale and large-scale application, depending on the turbomachinery parameters.

The heat of compression is stored (adiabatic CAES): It should be stressed that the proposed plant configuration is a special case of a medium-to-low-temperature adiabatic CAES system [14] with additional solar heat input at high temperature to increase discharging efficiency and power output. One could argue that there is already enough heat in the system, since the low-temperature heat of compression can be reused to heat the air before expansion – however only low-value low-temperature heat. **The additional thermodynamic high-value high-temperature heat of the CSP plant is used to raise expander stage inlet temperature and increase power output and conversion efficiency of the cycle.**

The ASTERIx-CAESar project will optimise the temperature level of the low-temperature TES, thus finding the ideal number of compression stages and associated pressure ratios. Note that as the temperature level increases, the more heat is recuperated and the less solar heat input is needed in the first high-temperature (H) HEX during power generation mode. It may thus make sense to also recirculate the return air stream of the first H HEX train to the bottoming Rankine cycle (see Figure 7 (#)), as further described in the following.

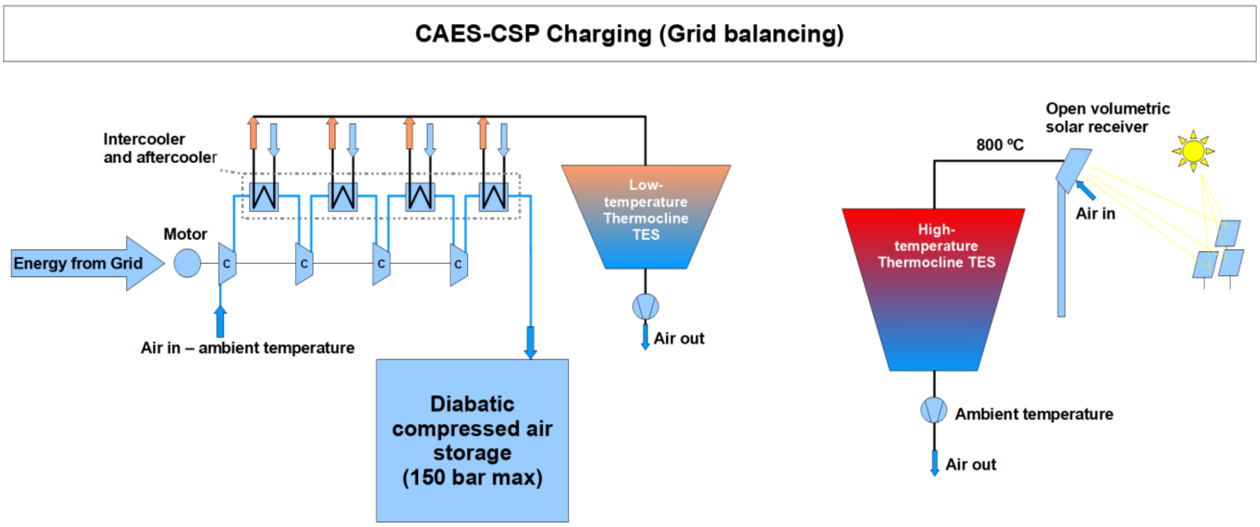


Figure 6: CAES-CSP plant during charging

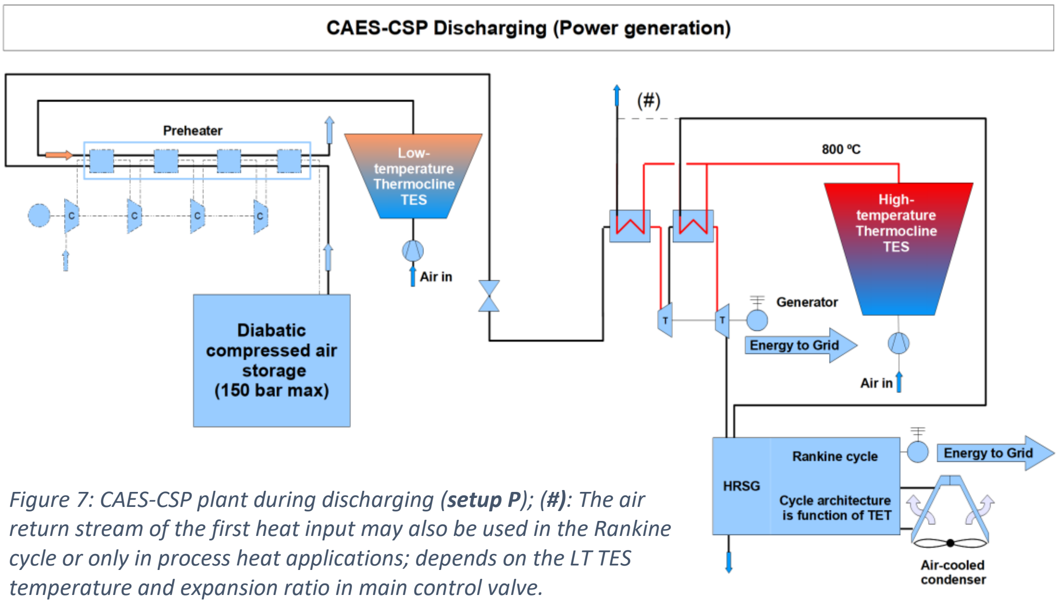


*Figure 7: CAES-CSP plant during discharging (**setup P**); (**#**): The air return stream of the first heat input may also be used in the Rankine cycle or only in process heat applications; depends on the LT TES temperature and expansion ratio in main control valve.*

During the discharging phase (Figure 7), i.e. electricity production, **a modified combined cycle is applied**, where the topping two-stage turbo generator (1 reheat) is followed by a bottoming Rankine steam cycle. The introduced modification is that this bottoming steam cycle is fed by two gas streams, (i) by the turbo generator exhaust stream (like in conventional combined cycle plants), and (ii) by the air return stream of the reheater (added feature) and optionally the first heater (Figure 7 (#)). This additional HRSG feed stream is available because there is a second heat exchanger train for reheating, and furthermore **the expansion ratio of the first turbine stage is chosen such that the exit temperature of the first turbine stage is very similar to the exit temperature of the second stage** (by exploring variable geometry turbine designs and arrangements). If this additional air return stream was not used, the return air would have to be wasted by rejection to the ambient. The positive effect of the reuse of the reheat air return stream is that the power output and overall energy conversion ratio (ratio of energy discharged to energy charged [21]) of the system is increased. Also, the rated power output of the bottoming cycle is increased (roughly doubled), which increases Rankine cycle efficiency due to the effect of scale (larger turbine). By doing so, the obtained power cycle is not a true combined cycle, as part of the heat is actually supplied in a parallel manner. Thus, the obtained power-cycle conversion efficiency will be diluted, when compared with the true combined cycle efficiency.

Start-up and load variation capabilities: By applying air expanders which are very similar in its operation to conventional gas turbines, quickest start-up times with the important additional feature of black-start capability is achieved. The general approach of ASTERIx-CAESar power plant start-up is that the topping air expander stages provide quick start-up, and during the first minutes of operation, the bottoming cycle is preheated to start-up temperature. In order to avoid frequent cool downs during longer idle periods, heat from the thermal energy storage (TES) is used to keep component temperatures (HRSG and steam turbine) at sufficient level. In summary, quickest start-up is guaranteed within a few minutes, compared to at least 0.5-1 hour at state-of-the-art CSP plants. Highly flexible load following capability is achieved as the topping cycle (air expanders) can be fully modulated, maintaining at the same time the bottoming cycle power by feeding missing air stream from the TES. Thus, the bottoming cycle can remain at constant load (in contrast to conventional combined cycle technology). Last but not least, the ASTERIx-CAESar concept provides reactive power and frequency regulation, which can be performed even when the plant is neither charging nor discharging by opening both clutches (both, compressor train and expander train are connected to the motor/generator unit).

The ASTERIx-CAESar project focuses on (1) the overall definition and optimization of the novel power plant concept (as described above), and (2) on the development and validation of its key components necessary for the future implementation. The development will be devoted to distinct R&D areas:

1.2.1 High efficiency open volumetric solar receiver

The key performance indicator of the solar receiver is its conversion efficiency, i.e. the fraction of incident solar power that is transformed into heat and transferred to the heat transfer fluid. At the targeted operating temperature of 800 to 850ºC the suitable receiver technologies and heat transfer fluid options are high-temperature gas receivers (tubular, opaque heat exchanger type or volumetric), particle receivers or liquid metal receivers [5].

Besides high receiver efficiency, the second fundamental requirement is the compatibility with cheap TES, as solar heat must be stored during the day (when PV output is high and electricity price low). Liquid metal receivers and pressurised gas receivers have both difficulties with cheap and simple TES integration. The only two viable options are therefore, (i) open volumetric air receiver (OVAR) technology to be combined with atmospheric thermocline TES [34], and (ii) particle receivers. **The ASTERIx-CAESar project focuses on the OVAR technology due to several reasons related to power cycle architecture, cheapest TES integration, easy and**

simple long-term operability, lowest environmental impact as well as recycling potential.

Regarding receiver efficiency, the governing loss mechanism at high operating temperatures is thermal radiation. Therefore, the aperture area of the solar receiver must be kept at the minimum, **which means that the incoming solar flux density, i.e. the solar concentration ratio must be as high as possible**. At current commercial receivers (tubular design using molten salt) the maximum allowable peak flux density is at around 1 MW_{th}/m^2 [5] and complex heliostat aiming point strategies are required in order to guarantee a suitable flux distribution at all times. **It is clear that for next generation high-efficiency central receiver technology, the allowable incoming solar flux density must be pushed to the limit.** Based on the experience within the consortium, the **peak flux may be pushed up to above 1.5 MW_{th}/m^2**, reaching a **mean flux densities above 0.7 to 0.8 MW_{th}/m^2**, which requires a highly optimized aiming point strategy that can be achieved with the help of artificial intelligence – AI – methods – see section 1.2.2.

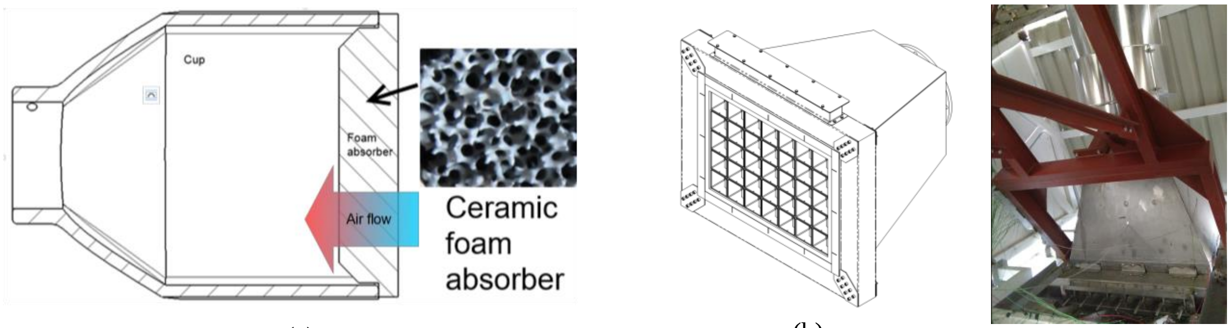
The ASTERIx-CAESar project will capitalize on the experience obtained during the 5 year research project CAPTure [26] where a novel OVAR concept was tested at TRL 5.

The novel OVAR technology is a simplified version of that developed in previous OVAR research projects [35-37]. The key modification is that no return-air stream is implemented due to a different power cycle architecture. The receiver design is also modular, based on individual absorber modules (cups), using ceramic foam of porous sSiC (pressureless sintered Silicon Carbide) as solar absorber material (Figure 8 and Figure 10), in contrast to honeycomb-type ceramic solar absorbers used previously [35-37]. Each cup contains the solar absorber matrix. The modular design is required for two reasons:

- Ideally, the solar absorber should be exposed to uniform solar flux in order to avoid local overheating and thermal stress that could lead to absorber failure; the modular design approximates uniform flux conditions at absorber module scale.
- The modular design is required to adjust the mass flow locally (different air outlet geometry for each cup) according to the given solar flux map. Zones with higher incident flux density need higher air flows, thus lower flow resistance (e.g. larger outlet orifice diameter or variable foam thickness). The aim is to achieve the same air outlet temperature for all absorber modules.

The novel approach of the ASTERIx-CAESar receiver is that the design is considerably simplified compared to previous research projects [35], where a very complex metallic double membrane structure was used to serve as absorber module mounting structure. Ideally, the whole receiver and absorber structure should be of ceramic material in order to reduce complexity of thermal insulation and costs. **The ASTERIx-CAESar design applies the novel concept of "*free floating*" absorber modules. The idea is that the ceramic absorber modules themselves, in stacked configuration, form the receiver structure only exposed to compression loading in the vertical walls.** Ceramic materials are most resistant to compression loading, while bending stress and ductile stress should be avoided. At the same time, the compression loading must be kept within limits, such that thermal expansion does not introduce additional stress to the existing compression stress due to the weight of the absorbers. Therefore, thermal expansion must be taken into account, and all absorber modules of the receiver must be able to expand freely according to their specific temperature distribution and heat load. **The design concept is based on stackable, "*free-floating*" ceramic modules that are arranged in vertical columns. Each column is able to expand upwards according to its specific temperature distribution (**see Figure 8 and Figure 9**). .** A key issue during solar receiver design is the thermal expansion of the ceramic material (SiSiC), which is about 1 mm per module when being heated up to 900°C. Additionally, the free gap between each column is the space needed for free thermal expansion in horizontal direction. The vertical movement and the correct horizontal position of each column is guaranteed by a set of guiding elements, which are in this specific implementation proposal, ceramic tubes (Fig. 3). **This design has not only advantages with respect to simplicity of design, but also regarding reduced thermal stress loading of individual absorber modules, reducing the risk of failure. A target cost of below 25 k€ per m^2 of receiver aperture is envisaged.**

In order to easily replicate the receiver at different nominal power classes, the proposed up-scaled receiver design is modular as well. The complete receiver is composed of an even number of sub-modules until the corresponding nominal power is achieved. The size of one sub-module is defined by the maximum number of cups that can be stacked on top of each other (compression strength limit). A reasonable size would be a maximum stacking height of about 3 meters, also taking into account the assembly process where at least two operators need to install the receiver cup columns inside the receiver aperture. In this case, ceramic tubes of about 3.5 meters length would be needed. When having a maximum height of 3 meters, the maximum width of the sub-module would be defined by structural limitations of the horizontal beams of the receiver main frame (see Figure 12). A sub-module width of up to 6 meters seems reasonable at the first sight. In any case, these maximum dimensions may be varied according to the specific total nominal solar power and is thus project specific. Therefore, a typical size of one sub-module would be about 18 m^2 (6 m x 3 m), falling approximately into the 5 MW_{th} power class. The final receiver would then be composed of several identical 5 MW_{th} units. Figure 12 displays the concept having two receiver sub-modules placed on top of each other.



(a) (b) (c)

Figure 8: Absorber cup and foam cross section (a) – CAPTure receiver 3D view, cups only (b) – CAPTure receiver in tower test room (c)

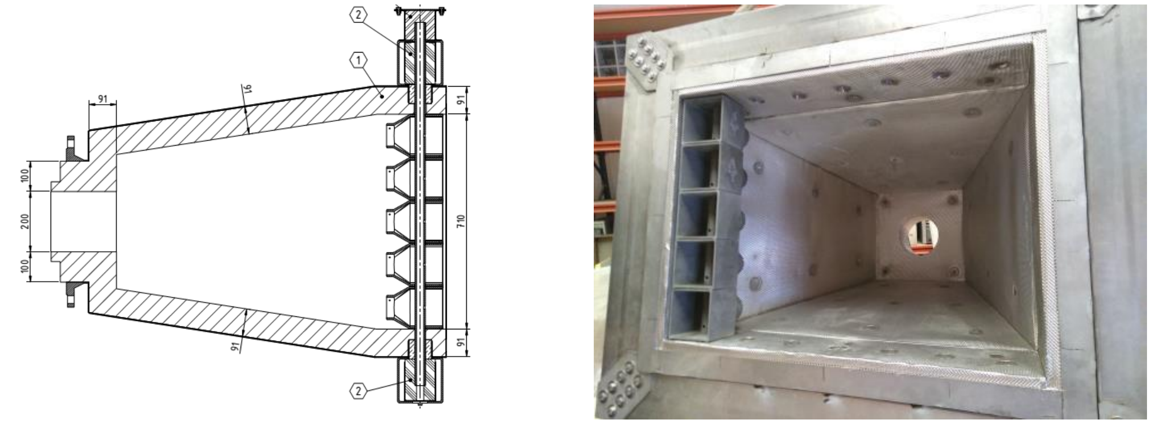


Figure 9: CAPTure receiver prototype drawing (left) and partly assembled prototype (right) with only one column of absorber modules

Figure 10: CAPTure solar receiver prototype cups (left) and installation procedure at CIEMAT-PSA experimental tower (center and right)

Within the CAPTure project this design approach has been evaluated at TRL 5, implementing and testing a 300 kWth prototype at CIEMAT-PSA in the south of Spain (see Figure 8, Figure 9 and Figure 10) at the end of the project.

Each cup size (rectangular aperture area) is about 14 cm x 14 cm in the CAPTure receiver. **The ASTERIx-CAESar project will continue the development line, stressing the structural development of the ceramic modules in order to allow larger module sizes, moving to 20 x 20 cm or even larger sizes (30 x 30 cm), which would dramatically reduce CAPEX and will further reduce complexity**. In particular, the ceramic material of the absorber cups will be optimized, introducing the **all-oxide ceramic matrix composite (OCMC) technology [38]** (see Figure 11). This new material will reduce weight and will allow cost reductions, compared to the conventional approach. **OCMC is a novel type of "sheet ceramic" that is an oxide fibre reinforced oxide ceramic**, a part of the material group called ceramic matrix composites. This material is an advanced technical ceramic for developers, designers and users, who want to design thin walled, thermal shock resistant and oxidation resistant ceramic components for continuous service temperature of up to 1300°C. This advanced material replaces thermal and mechanical highly loaded sheet metal components, which should not be distorted or should not be oxidized. OCMC material has unique features that are highly interesting for solar receivers: • long term operation up to 1300°C; • high strength at high temperatures; • high mechanical load by the use of the textile ceramic composite; • pseudo elastic behaviour; • very good thermal shock resistance; • very good oxidation resistance at high temperatures; • good corrosion resistance at high temperatures; • good hardness • low thermal expansion –

about 50% of stainless steel. **In short, OCMC material is the excellent choice for the ASTERIx-CAESar ceramic receiver structure. It will be used for the improved large-size absorber module (absorber cup) design, the vertical guiding tubes, orifices for passive air flow control, as well as for air flow dampers in the receiver main casing (see** Figure 12**).**

Figure 11: Examples of all-oxide ceramic matrix composite (OCMC) technology provided by Walter E.C. Pritzkow Spezialkeramik

Besides the enlarged design of absorber modules, the second development aim of the ASTERIx-CAESar project is to further improve the local air flow adjustment in order to reach homogenous absorber outlet temperature across the receiver. **The aim is to apply passive (orifices or specific modular cup shape) and active air flow adjustment (dampers) inside the receiver casing** (see Figure 12). Also, the ceramic foam's oxidation resistance need to be improved and manufacturing process needs to be further developed to achieve long-term stability at high operating temperatures.

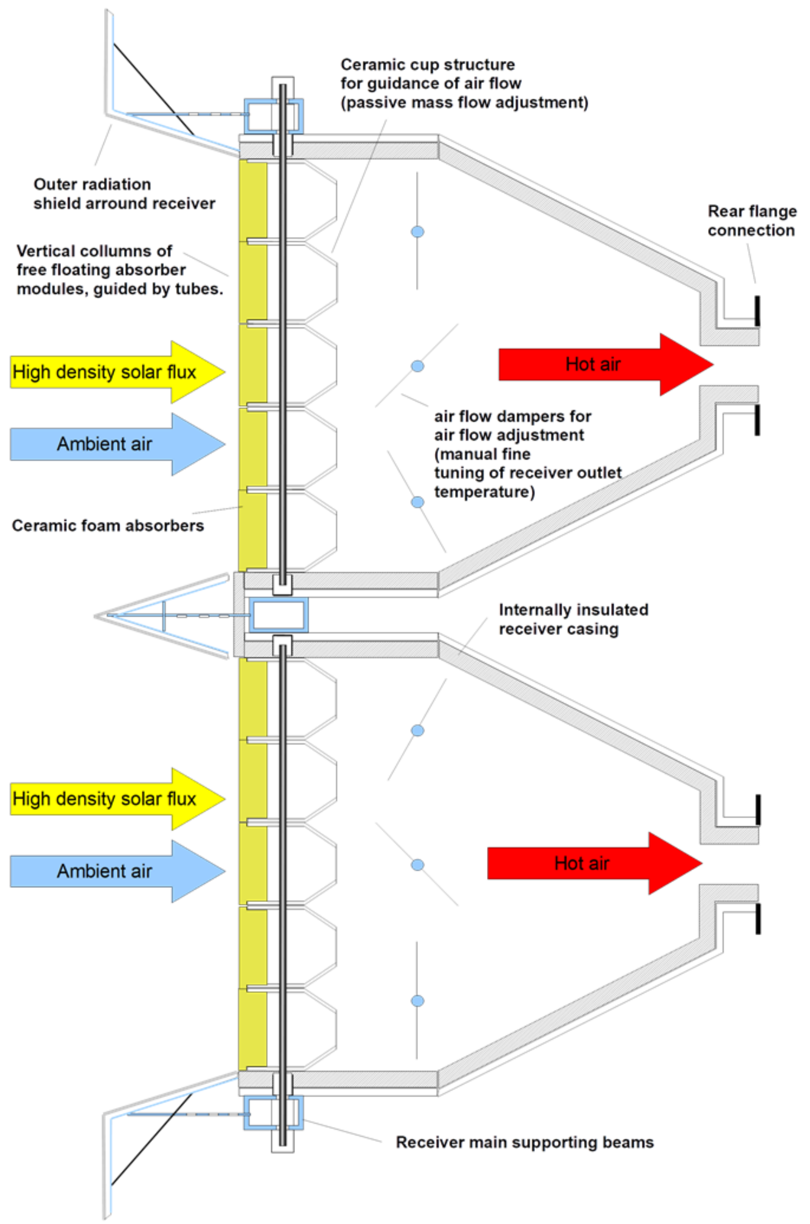


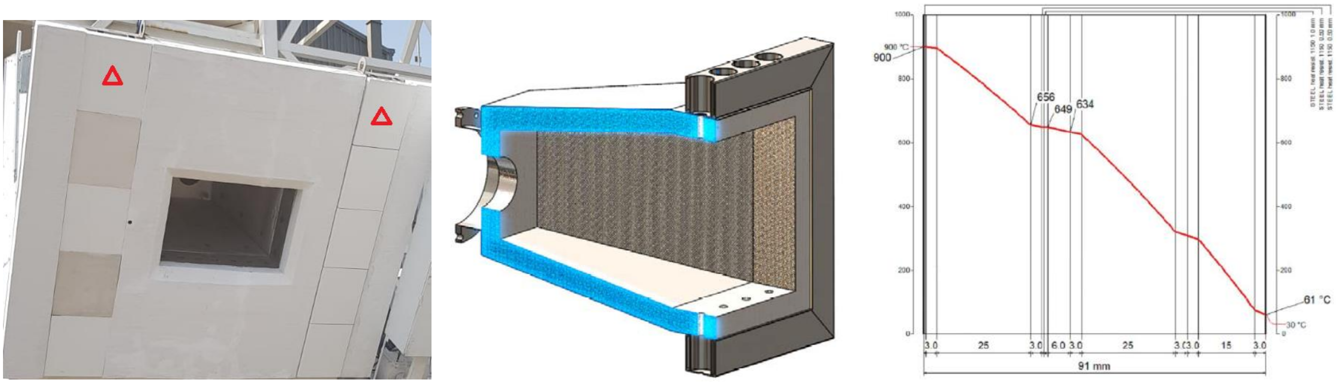
Figure 12: Receiver concept with free floating absorber modules in up-scaled configuration (prelaminar up-scaled design proposal); Side view of two 5 MWth receiver modules on top of each other.

The ASTERIx-CAESar project will completely validate this receiver technology at TRL 6-7 at a thermal power of 480 kWth reutilizing and modifying the existing CAPTure prototype, by replacing the existing cup modules by newly developed ones. Figure 9 displays the CAPTure prototype receiver casing design and pre-assembled prototype before installation at the experimental tower at CIEMAT-PSA. Figure 10 (left) shows the CAPTure absorber modules (14 x 14 cm) and the receiver installation process at the tower.

The ASTERIx-CAESar project will reuse the existing receiver casing and will install the new large-size OCMC material modules, guiding tubes as well as additional air flow guidance components for demonstration of the technology at CIEMAT-PSA tower.

<u>As a next step, the receiver's radiation shield and internal thermal insulation</u> will be optimized for future commercial size up-scaling and replication. State-of-the-art radiation shields rely on a solid thick composite structure of reflective refractory material, typically mounted parallel to the receiver aperture area (normal to incident solar flux). While no mayor improvements are foreseen related to materials available to improve heat shields or insulation systems, how current materials are used through the manufacturing process is a development area with great potential. Further, novel designs tendencies aim for higher fluxes within smaller areas of spillage, requiring more efficient heat shields.

Related to thermal shields, there are three mayor layers to work on. For the metallic structure (layer 1), which acts as support, standardization and integration within tower main structure is a must. For the internal insulation layer (layer 2), the use of high-performance insulation materials is required to withstand higher fluxes, while this type of materials need to be encapsulated to withstand environmental conditions. The encapsulation of this materials and how they are integrated and assembled are key aspects to improve. As for the final layer (layer 3) that has to withstand the radiation, mayor areas of improvements comes from the **application of reflective layers** and their curing through automatic means and by experimenting with alternative materials that may be used as alternatives to current ones. Additionally, the ASTERIx-CAESar project will **analyse tilted and reflective heat shield layouts (see Figure 12), such that the "spilled" radiation is reflected back on the receiver aperture, maximizing the usage of incoming solar flux.** Figure 13 shows the CAPTure prototype radiation shield with vertical test zones (indicated with red triangles). In this zones, the novel heat shield materials will be tested and demonstrated in the relevant environment. **Regarding the internal insulation of the receiver box**, a trade of needs to be found between insulation thickness and material cost. For the high-temperature application, high-performance micro-porous insulation material [39] exists. The main components of such high-performance thermal insulation material are typically SiO_2 and SiC [39, 40]. Thermal conductivity depends on the prevailing operating temperatures, ranging from 0.022 W/(m K) at 200 °C to about 0.033 at 800 °C [39, 40]. However, cheaper high-temperature insulation material has a significantly higher thermal conductivity. For example, high-temperature wool with Al_2O_3 and SiO_2 as main components, features thermal conductivity values between 0.11 W/(m K) at 400 °C, and 0.31 W/(m K) at 1000 °C [41]. **The ASTERIx-CAESar project will optimize the internal insulation composition in order to minimize costs.** Figure 13 (c) shows an example temperature profile and insulation layers as applied in the CAPTure prototype.



(a) (b) (c)

Figure 13: (a) CAPTure prototype radiation shield provided by NTT (red triangles indicate material testing zones- vertical columns with tiles); (b) Internal insulation cross section indicated in blue; (c) Temperature profile across internal insulation of receiver box

1.2.1.1 High-temperature and high-flux validation of ASTERIx-CAESar volumetric absorber modules at PSA and IME

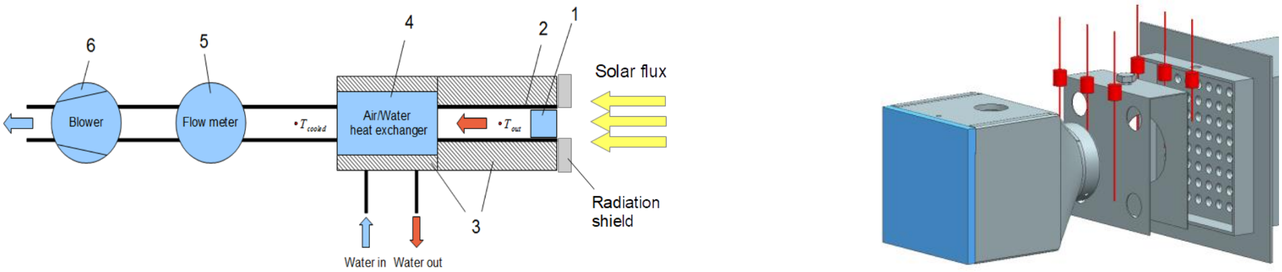
High flux validation at PSA's solar furnace (10 kWth)

CIEMAT has an OVAR thermal test loop (similar to Figure 15 – (a)) that can be used in SF-60 or SF-40 solar furnaces of the PSA (Figure 14), which reach a peak concentration over 7000 suns. The optical axis is horizontal, and is of the "on-axis" type, that is heliostat, parabolic concentrator and focus are aligned on the optical axis of the parabola. It basically consists of a flat heliostat with 100 m^2 reflecting surface, a parabolic concentrator with 56.5 m^2 projecting area, slats shutter or attenuator, and test table with three axis movement. This project will experimentally test and evaluate optimised foam parameters to guide the consortium towards the most suitable absorber foam for installation in the CRS tower. The OVAR thermal test loop will be placed in the focal plane of the solar furnace and the input thermal power and the maximum solar flux will be regulated by a shutter. Simultaneously, a blower will force the movement of the ambient air through the new absorber foams. Behind the device where the foams are placed, an air-water heat exchanger is used for a proper and detailed thermal analysis. The entire system is equipped with temperature sensors that are monitored online. The system is ready to use and allows a thorough thermal characterisation of absorber samples.

Figure 14: SF60 solar furnace; Detail view of the secondary concentrator and the OVAR test loop (left); outside view and heliostat (right)

Single module high-flux validation at IME tower (20 kWth)

A **tailored transportable thermal loop** for absorber module testing (see Figure 15 and Figure 16) will be used to test advanced ceramic foam modules at the IME experimental tower (at slightly larger scale than at the solar furnace). A simple scheme of the test loop is shown in Figure 15 (a). The volumetric absorber module (1) is mounted at the inlet of the air duct/receiver pipe (2). The ambient air is forced through the experimental circuit by a blower (6). In particular, the air is forced through the absorber module (1), the receiver pipe (2), the air/water heat exchanger (4) and the flow meter (5). The absorber sample (1) will be irradiated by concentrated light of IME's heliostat field (see Figure 18). The heat exchanger and the receiver unit are insulated (3) in order to keep thermal losses negligible. The air temperature is measured in a plane right after the absorber module outlet (3 K-type class 1 thermocouples in diagonal staggered configuration) and after a following double membrane air mixer (also 3 K-type class 1 thermocouples in diagonal staggered configuration – see Figure 15 (right) and Figure 16 (right)). The air mixer is of orifice type [42] and is needed in order to achieve a homogeneous mixing temperature of the air flow for correct representative air temperature measurement. The air temperature is also measured at the heat exchanger exit (cold end) with a single K-type class 1 thermocouple. The air/water heat exchanger is a simple shell and tube design, having the water flow on the shell side and the air flow on the tube side. Both, the heat exchanger outer shell and the receiver inlet air duct are thermally insulated externally with layers of micro porous high-performance insulation material [43]. Thermal losses to the ambient are therefore negligible.



(a) (b)

Figure 15: Simplified scheme of the transportable test loop (a); Absorber module, thermocouple placement and air mixer before the inlet tube sheet of the heat exchanger (b)

(a) (b) (c)

Figure 16: Test loop installed at the Synlight facility (a); Absorber and radiation shield after testing (b); Detailed view of the receiver air channel with mounted absorber module (c).

The air flow is measured via two ways, (i) directly via a vortex flow meter located in the air flow circuit right after the heat exchanger outlet, and (ii), indirectly via measuring the cooling water flow of the heat exchanger and cooling water temperature difference (with two Pt100 class A sensors) and calculating the air flow via the energy balance across the heat exchanger (neglecting thermal losses). This redundancy is very helpful as accurate air mass flow measurement is typically very challenging.

1.2.2 Automatization and improved plant operation and monitoring via AI methods and innovative fiber-optic sensors

The ASTERIx-CAESar project will **address in this context 3 activities that in combination result in an advanced AI-based automated heliostat-field control and monitoring system.** (i) The first activity covers the development of an AI-based aiming point generation method, which is able to quickly provide the best aiming point configuration as function of solar position, DNI level and solar receiver operating point. In order to do so, it is crucial to correctly characterize all involved heliostats to capture individual mirror shape errors and reflecting behavior in general. A new approach will be used for characterization of heliostats, which is based on an array of variable-gain detectors mounted on a static vertical pole, allowing the characterization of heliostats with a higher precision than other techniques. (ii) The second activity will cover the development of a smart AI-based heliostat tracking system, using low-cost components, computer vision, open hardware and deep learning. Thanks to smart tracking control, a precise installation process or periodic offset calibration is not required. (iii) The third activity will cover the development of advanced high-temperature fibre-optic sensors for accurate and reliable long-term flux and temperature monitoring at the solar receiver. An array of sensors will deliver valuable measurement data in order to fine tune AI algorithms, as well as to safely monitor solar receiver operation. **All three activities will be outlined in the following**:

(i) AI-based aiming point generation and heliostat characterization: Maintaining the optimum solar flux distribution on the receiver aperture (as function of solar position and DNI variation) is a very difficult task and is so far not automated and depends on a highly experienced plant operator team. It is of upmost importance to introduce the highest degree of automated plant operation, in order to guarantee safe and efficient plant operation (keep operation close to allowed limits with appropriate safety margins), as well as to reduce operating cost. Therefore, the project will develop an enhanced high-precision aiming point generation strategy based on AI methods. AI is needed to solve the aiming point strategy optimization problem, where a large number of heliostats need to get assigned the correct aiming point on the receiver aperture as function of current sun position, DNI level and cloud movement. **Note that the cloud movement will be captured via AI-based visual "now casting" methods developed in point (ii) below**. In order to so, a dedicated AI algorithm [29] will have access to a large dataset of heliostat image quality characterization (i.e. each or at least a representative number of heliostats of the solar plant need to be optically well characterized) and will need to model the expected solar flux distribution on the receiver as function of assigned aiming points, and as a next step, optimize it. One crucial feature of the method is the adequate modelling of the optical image of each heliostat. By combining computational-intensive approaches, based on ray tracing (e.g. Tonatiuh software, see Figure 18 - right), with simpler methods, based on flux profile generation by e.g. using convolution of Gaussian functions, a good trade-off between accuracy and computational effort will be achieved. The final flux map estimation is obtained by superimposing all individual images. The aiming point strategy development will capitalize on the developments done in the finished CAPTure project [29], which are based on a method applying a combination of Dijkstra's and Nelder-Mead algorithm.

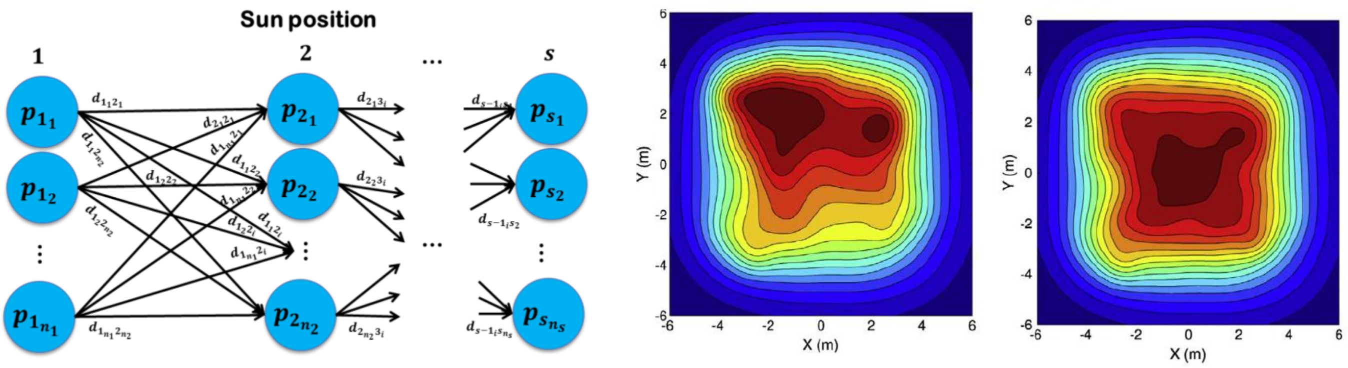


Figure 17: Aiming points and distances in a weighted graph (left); Flux distribution before and after optimization (right)

Dijkstra's algorithm contains two main elements: nodes and weights/distances, and its extension to aiming strategy is as follow: The allowed aiming points in each sun position represent the list of nodes; Every node belongs to a sun position and is linked with every node of the next sun position; The weights/distances are calculated as function of the positions of the linked aiming points and the current flux in those positions. It means that the weights/distances of an aiming point in a sun position are the flux density values of the aiming points in the next sun position. These values are also subject to the relative movement between aiming points for all heliostats in a specific sun position. The idea behind this constraint is to secure that the aiming point movement of two or more heliostats do not cross at any time and that the flux density does not overpass the threshold, in which case the weight would go to the upper boundary, i.e. infinity. Figure 17 (left) represents the aiming points and distances in a weighted graph. The algorithm finds the shortest path, this means the aiming points (for an individual heliostat) where, globally, the flux is optimized. If the resultant flux density distributions surpasses the maximum flux value, the needed heliostats will be defocused until an admissible maximum flux is achieved. The defocus will start from the heliostats furthest from the tower and just will be effective in the sun position where the flux is not correct.

The heliostat characterization data base will be obtained by applying a novel method. The optical quality of heliostats is crucial and describes how well the heliostat concentrates the light on the receiver, and is usually given in terms of slope deviation. It is a measure about how much the actual shape of the mirrors of the heliostat is deviated from their design shape, both locally and their orientation in relation to the structure of the heliostat (canting). Hereafter, measuring this deviation is simply called heliostat characterization. The ASTERIx-CAESar characterization system is an optoelectronic device whose configuration mainly consists of an array of sensors distributed along a vertical pole that can be as long as required, being its final longitude determined by a trade-off between the reflected beam sizes, the time per measurement and the cost. With this configuration, the system is portable, versatile and easy to integrate in the existing commercial power towers by attaching it to the tower structure (Figure 19 (a)) or being placed elsewhere on a simple pole (Figure 19 (b)), in order to be used as quality control system during heliostat manufacturing and assembling. Figure 19 (d) shows a test pole installed at CENER.

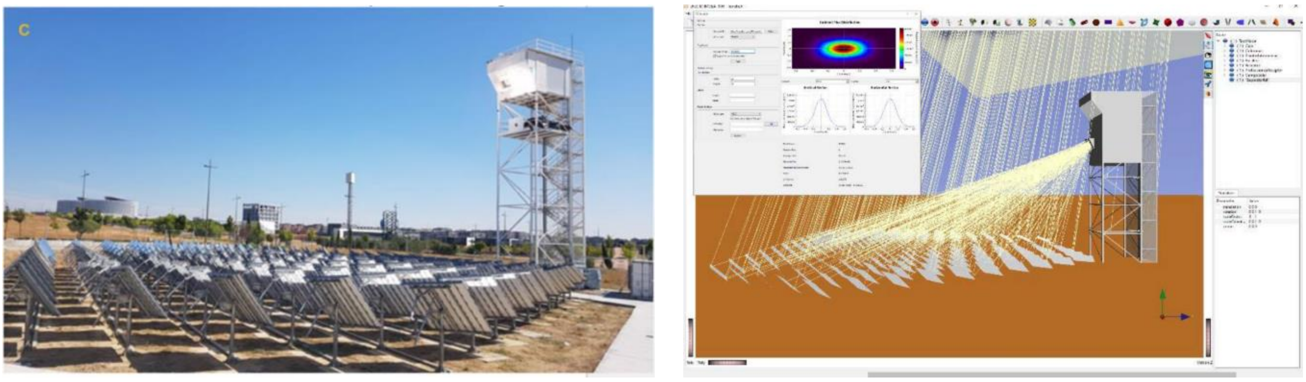


Figure 18: Experimental tower at IME (left); Detailed optical ray tracing model of the IME tower in Tonatiuh (right)

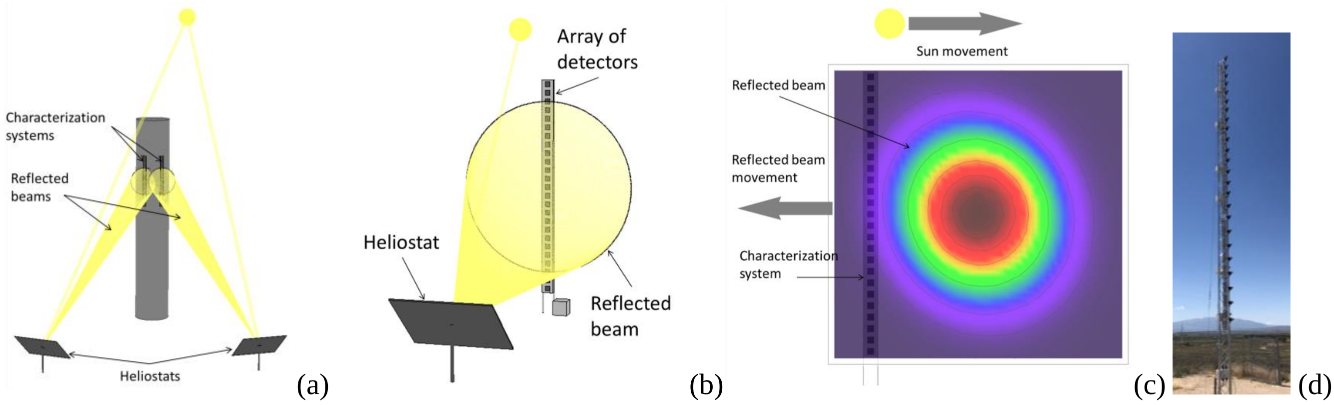


Figure 19. ASTERIx-CAESar heliostat characterization method based on optical sensors mounted on a vertical fixed pole

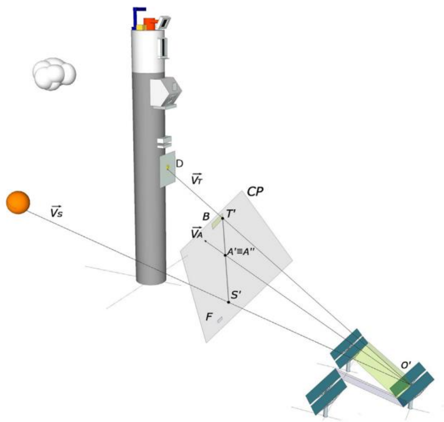


Figure 20: Heliostat tracking vectors

(ii) AI-based heliostat tracking control system for low-cost operation: The smart heliostat (Hel IoT) is a concept that arises from applying artificial intelligence and computer vision techniques, mainly the machine learning technique for object detection, to the traditional heliostat to increase its efficiency and reduce costs. The new approach is based on low cost, computer vision open hardware and deep learning [44]. Besides accurate control, the proposed approach can provide key variables for the sun tracking system control **like cloud movements prediction**, blocking and shadow detection, atmospheric attenuation or measures of concentrated solar radiation, which are used as input for the aiming point generation algorithm (see above section) and improves the control strategies of the system and therefore the system performance.

For a correct sun tracking, the tracking system needs to know the relative sun position in the sky, the receiver position and the heliostat aiming point. Each of these three points together with the point on the heliostat surface closest to the rotation axis (O’), form respectively the solar vector ($\vec{V}_S$), the reflected or target vector ($\vec{V}_T$) and the aiming vector ($\vec{V}_A$) – see Figure 20. Traditionally, these three vectors are usually computed by solar equations, which is a functional method but has several limitations such as time and location dependence, on the other hand, electro optical sensors are only able to obtain the solar vector, limiting the range of application of the traditional method. The novel ASTERIx-CAESar approach eliminates these limitations by installing a camera, placed in O' and whose optical axis is arranged parallel to the optical axis of the heliostat. By taking pictures enables detecting S', A' and T', which represent the intersection between the camera plane (CP) and $\vec{V}_S$, $\vec{V}_A$, and $\vec{V}_T$, respectively. With this arrangement, for a correct heliostat alignment, the vector $\vec{V}_A$ should intersect the middle point (A'') of the segment formed by S' and T' in the CP. The differences between A' and A'' are known as tracking error and it is employed as the main input for the heliostat tracking control system [44].

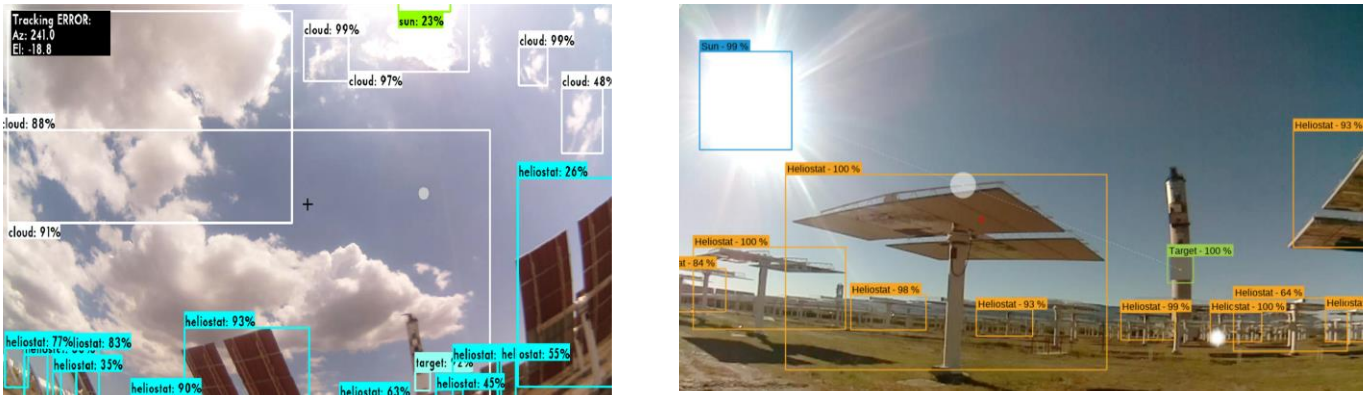


Figure 21: Augmented reality images processed on a mobile device at CESA solar field at CIEMAT-PSA.

The new approach is based on computer vision, specifically on deep Convolutional Neural Networks (CNNs) for objects localization and detection due to the large number of advantages that it presents. Neural networks models transform the input through a series of hidden stages (layers), composed by a set of neurons (small and simple processing unit). Each neuron is connected to many others neurons creating a massively parallel processing model. Neurons have learnable parameters (weights and biases), that modify the individual output. Weights and biases and other general configuration parameters (such as the learning rate, number of epochs, etc.) must be adjusted in a iterative process called learning or training. The training is an optimization problem, where some parameters are set to minimize a loss function on a training dataset. The loss function expresses the discrepancy between the ground truth and the neural network prediction. In the specific application, the tracking error is minimized.

Additionally, the novel approach simplifies the control system and reduce the number of components. A low-cost hardware platform such as Raspberry Pi can be employed. This reduces the fixed cost associated to the heliostat field control hardware ranging from $ 290 to less than $ 75 approximately, removing costs in electronic devices such as limit switches, GPS or encoders that are not needed. Communication wire costs can be removed as well, due to the great connectivity offered by this type of platforms, in this case Wifi and Bluetooth. Also, the new hardware can be powered with a small PV cell and a battery [44].

The ASTERIx-CAESar project will demonstrate this novel heliostat tracking system at the CRS tower at CIEMAT-PSA at TRL 6.

(iii) High-temperature (>800ºC) fibre-optic sensors for accurate and reliable long-term temperature and solar flux monitoring:

Solar flux monitoring at the receiver is a very challenging task that is currently done applying Gardon type heat flux sensors which are very expensive, require water cooling and have sensor diameters at around 15 to 20 mm. Hence, the installation and operation (water cooling) of such sensors is complex and they are too big to be installed in large numbers across the receiver aperture. There is not enough space between absorber modules (volumetric receiver) or tubes (classical tubular receivers) and operation with water cooling and regular maintenance is not viable. **The ASTERIx-CAESar project proposes here a break-through solution by applying optical fibres that guide the incoming solar flux from the receiver aperture (i.e. from the high-temperature and high flux environment) towards the light sensor module that can be installed in safe distance from the harsh receiver operating conditions.** Optical fibres can be designed very thin (< 1 mm) such that the absorbed heat can be withstood without cooling and they are thin enough to be placed in small spaces between absorber modules (volumetric receivers) and also receiver tubes, in case of classical tubular receivers. Hence, an array of temperature resistant optical fibre cables can be installed across the receiver aperture and the flux map can be measured and monitored with sufficient resolution at acceptable cost. **At the cold end of the optical fibre, a photodiode (a light-sensitive semiconductor diode) is placed that can register light in stable, linear and low-cost manner,**

with almost instantaneous reaction times. This breakthrough solar flux sensor concept is currently being patented by partner USE (patent application process is ongoing at the moment of submission).

Fibre optics can be also applied for temperature measurement: Fiber Gragg Gratings (FBGs) are optical gratings inscribed in optical waveguides, normally telecom grade glass fibers. According to the Bragg formula these gratings reflect a narrow spectral peak of light of Bragg wavelength when the grating period multiplied with the index of refraction equals the wavelength of the light. Therefore, the position of the reflected wavelength changes when the grating period or the index of refraction changes. Therefore, a change in temperature via the temperature-dependence of the refractive index and the elongation/shortening of the glass fiber results in a detectable shift of the Bragg wavelength. With this technique, the temperature can be measured over a wide temperature range with a resolution of approx. 0.1 °C. Main advantages compared to traditionally used electronic sensors (e.g. thermocouples) are the immunity to electrical noise and the ease of building small sensing cables with multiple sensors without extensive wiring. Optical gratings are regular, (sub-)microperiodic refractive index changes that are normally inscribed by modifying the glass of the fiber with high power laser light. The laser light gets absorbed by the glass and gives rise to localized changes in the index of refraction. The most common technique to achieve the micropatterning is to write through a phase mask with UV light. **At engionic Femto Gratings, an innovative technology for producing FBGs has been developed, the so-called point-by-point inscription with femtosecond (fs) Lasers at 800 nm wavelength.** Due to low IR absorption and low laser intensity away from the fiber core it is possible to write through most fiber coatings and therefore circumvent cumbersome stripping- and recoating steps. The refractive index changes thus manufactured are much more temperature stable than UV written FBGs that do not survive prolonged exposures to temperatures above 350 °C. **In addition, with femtosecond pulses FBGs can also be written in other materials than glass, e.g. sapphire.** Sapphire exhibits even better temperature resistance than glass and is a viable option for fiber materials when glass fibers no longer provide satisfactory results.

1.2.3 Efficient and cost competitive heat exchangers

Two separate heat exchanger trains are needed to implement the innovative power plant concept, i.e. **(A)** the so-called low-temperature heat exchanger – L-HEX – (intercoolers and aftercooler) needed for the adiabatic CAES (connected to the low-temperature TES), and **(B)** the so-called high-temperature heat exchanger train (H-HEX) needed to heat and reheat the air before expansion across the turbines. In principle, both heat exchangers need to exchange heat between two air streams with significant pressure differences, which is a cumbersome design task due to significant density differences, especially at high temperature, that also poses mechanical integrity challenges. **Nevertheless, the appropriate heat exchanger design is more an implementation than a technological challenge, i.e. the necessary equipment can be obtained by combining available high-TRL solutions.**

For both heat exchanger trains, two different design approaches will be addressed and evaluated in parallel in order to find the optimum solution. The ASTERIx-CAESar project will address **the conceptual and detailed design approach,** targeting main issues like thermal design optimization, thermal cycling, fluid dynamics and mechanical integrity.

(A) Low-temperature (adiabatic CAES) heat exchanger (L-HEX) design options:

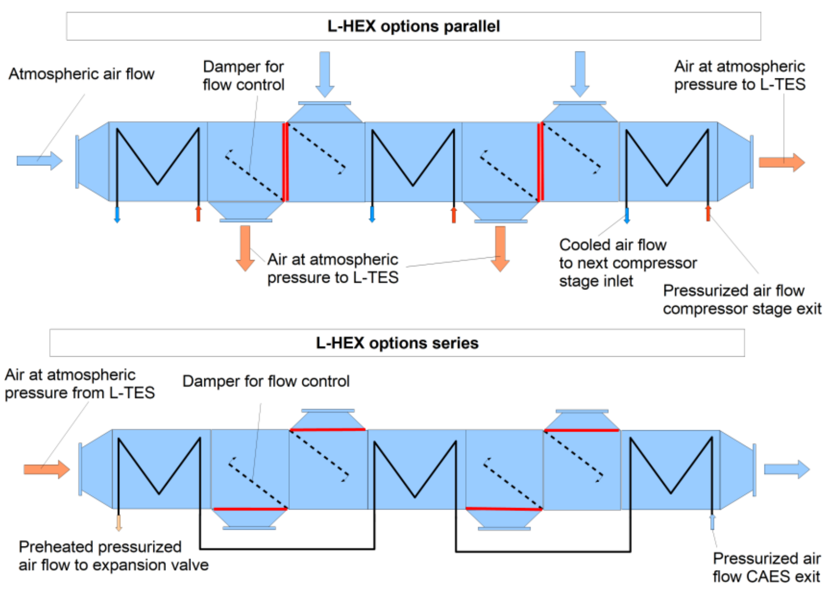


Figure 22: Dual use of air-air heat exchanger – Intercooler/aftercooler – Preheater

The first design option is based on conventional indirect recuperative heat exchangers (e.g. shell-and-tube layout, or advanced primary surface layouts also based on a main shell for the atmospheric air flow). **The crucial aspect in order to reduce CAPEX is to use the same components for intercooling/ aftercooling (charging) and air heating before expansion (discharging).** The typical layout of this heat exchanger would be of shell-and-tube type, where the atmospheric air (for cooling or heating) flows on the shell side, and the compressed air flows on the tube side (Figure 22 gives a detailed view of the dual use of the heat exchanger; parallel flow for air cooling after compression;

serial flow for air heating before expansion). The heat removed by intercoolers and aftercooler is stored in a low-temperature packed-bed thermocline TES (see Figure 6). The generated heat during compression can be reused for preheating the compressed air before throttling to expander inlet pressure.

The second design approach will be the integration of low-temperature thermal energy storage (L-TES) and heat exchanger (L-HEX) in the same component, by applying a direct contact regenerative heat exchanger concept, in order to reduce size and cost. **Regenerators are well known for high specific heat transfer areas and very high heat exchange effectiveness [45].** Also, when ceramic material is used as regenerator matrix, substantial cost savings can be achieved with respect to conventional shell-and-tube heat exchangers of similar power rating. **For example, cordierite ceramic honeycomb structures (as widely applied in catalytic converters and high temperature gas filtration, etc.) are orders of magnitude cheaper than metal alloys that would be needed for the shell-and-tube heat exchanger design**.

A key design requirement is **the internal insulation of the regenerator pressure vessels as the regenerator shell must support very high pressures and must therefore be kept at low temperatures (<50°C)**.

The idea is to apply a network of parallel high-pressure pipe lines that are internally insulated and filled with suitable material in order to obtain a packed-bed thermocline heat storage concept. Thus, between each compressor stage a packed-bed TES pipe network fulfils the task of air intercooling (aftercooling) as well as heat storage (see Figure 23). During charging state, the regenerative pipe-networks are connected in series. During discharge operation, the regenerative networks are used in parallel, preheating the compressed air upstream the expander train (see Figure 24).

It is crucial to correctly design flow cross section, i.e. number of parallel pipes (only 3 are shown in Figure 23 and Figure 24), such that the pressure drop between compressor stages is acceptable.

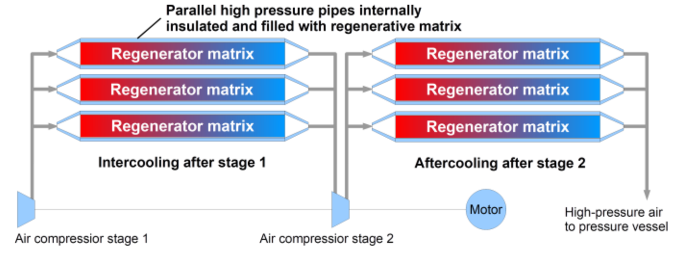


*Figure 23: Low-temperature (adiabatic CAES) heat exchanger (L-HEX) and thermal energy storage (L-TES) as regenerative system (**in charging state**)*

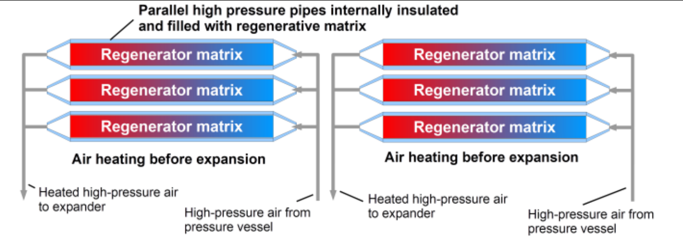


*Figure 24: Low-temperature (adiabatic CAES) heat exchanger (L-HEX) and thermal energy storage (L-TES) as regenerative system (**in discharging state**)*

(B) High-temperature (solar heat input) heat exchanger (H-HEX) design options:

One of the most critical components of the proposed power plant concept (see Figure 7) is the needed high-temperature gas-gas heat exchanger in order to heat the air before the expander stages externally. As the heat transfer coefficient on the atmospheric air side is very limited, the design of such a heat exchanger is expected to be very bulky, since a large heat transfer area is needed.

Within the project, similar to the previous section, 2 design options will be analysed, (i) **a conventional indirect recuperative heat exchangers (shell-and-tube layout)**, and (ii) **a regenerative heat exchanger design**.

Concerning option (i), the shell-and-tube type heat exchanger design would have the pressurised air stream coming from the pressure vessel on the tube side, and the heating air stream at ambient pressure (coming from the high-temperature TES) on the shell side. This type of heat exchanger could be similar to a heat recovery steam generator, but using metal alloys with higher temperature and oxidation resistance, which would mean relatively high CAPEX.

Design option (ii), will treat a regenerative heat exchange system (atmospheric heating, pressurised cooling) in order to reduce size and cost of the air-air heat exchanger. **Cordierite ceramic honeycomb structures are orders of magnitude cheaper than metal alloys that would be needed for the shell-and-tube heat exchanger design**. This regenerative heat exchanger design approach has been investigated within the H2020 project CAPTure [11] in order to power a Brayton hot-air cycle externally (see Figure 25). When looking at the specific application of heat exchange between two air streams at different pressures, there are important design considerations. First, the vessel size of this regenerative heat exchange system is limited due to the pressurization process (the higher the vessel volume, the longer the time needed for pressurization), which requires several two-vessel subunits (such as shown in Figure 25) in parallel, depending on the power rating and cycling period duration. The second reason for several two-vessel subunits in parallel is the requirement for continuous thermal power transfer (while one system is pressurised/depressurised, the parallel systems need to take over). Thus, one disadvantage w.r.t. conventional heat exchangers is the higher complexity, as besides several parallel systems also high-temperature valves and piping are required for managing the pressurization/de-pressurization process.

Furthermore, the pressurization process requires a certain amount of work, i.e. represents an additional parasitic consumption. Additionally, the cross sectional area of the atmospheric ducts is considerably larger than that of the pressurised circuit, which complicates the design. Clearly, these disadvantages need to be offset by higher heat exchanger effectiveness and reduced heat exchanger size and cost (with respect to the conventional shell-and-tube layout). **It is crucial to correctly address the regenerator vessel, piping and valve selection**, as besides very high pressure differences, also high differences in density of the working fluid occur. **According to the results of the H2020 CAPTure project, such a regenerative heat exchange system is only viable for small-scale implementation (< 5 MWe [11]), due to the limitation of commercially available high-pressure ball or poppet valves**. Also, the needed piping and connection effort of needed vessels imposes upscaling limits. Nevertheless, at small-scale (< 5 MWe), the application seems promising and will be analysed in the ASTERIx-CAESar project, benchmarking it against the classical approach of indirect recuperative heat exchangers.

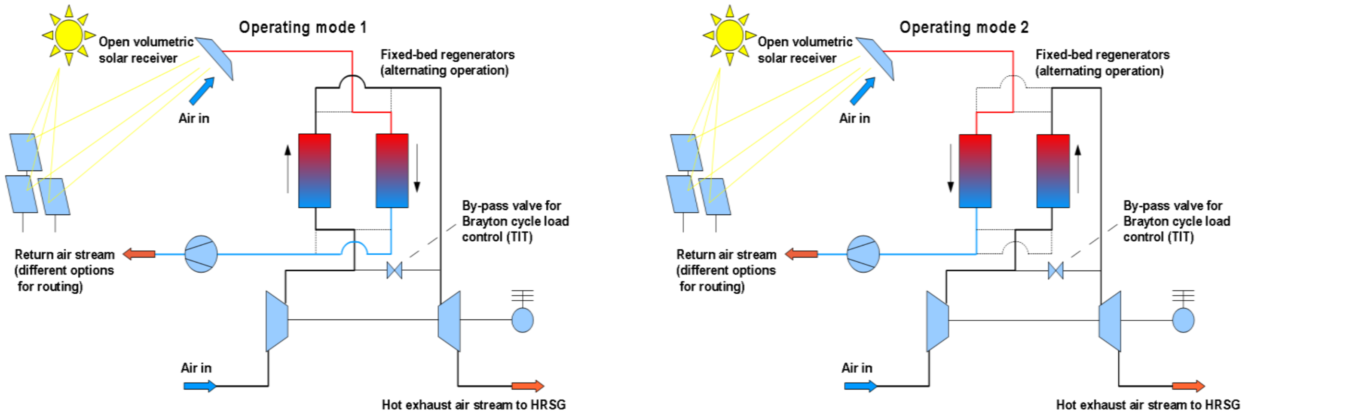


Figure 25: CAPTure concept scheme of alternating operation of fixed-bed regenerators in order to exchange heat between atmospheric (receiver) and pressurised air stream (Brayton cycle) [1, 11]

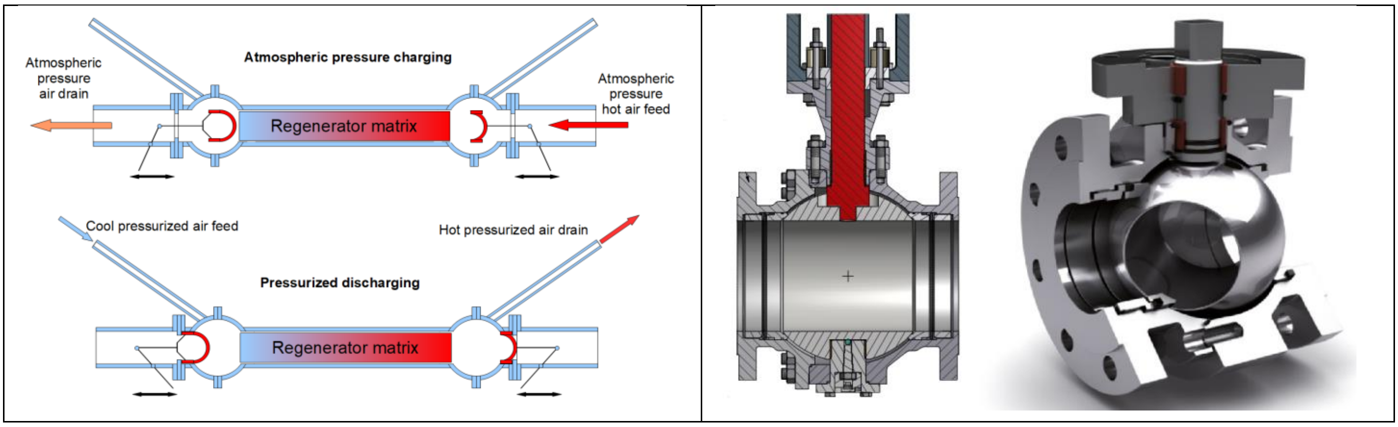


Figure 26: (left) High-temperature regenerative heat exchanger design concept (conceptual drawing from CAPTure project); (right) Commercial metallic ball valve example for real implementation based on existing components (www.cerasystem.de).

The regenerative system's design concept is shown in Figure 26 (left). In order to support very high working pressures, the regenerator vessel must consist of cylindrical and spherical sub-volumes (see *Figure 26*) fulfilling industrial pressure vessel design codes. Another key design requirement is **the internal insulation of the regenerator pressure vessel as the regenerator shell must support very high pressures and must therefore be kept at low temperatures (<50°C)**. In the development process of the finished Horizon 2020 CAPTure project, poppet-type valves (self-sealing inlet and outlet dome) were proposed in the conceptual design phase, ideally designed for high working pressures and low pressure drop under atmospheric charging of the system (Figure 26 – left side). However, the commercial implementation will need to apply commercially available components to reduce development costs. High-pressure ball valves or poppet valves are the most suitable options. Figure 26 (right) shows the example of ball valves, which could be applied up to DN400 approximately (small-scale application only). In both cases (ball or poppet valves), due to the high operating temperatures, valve cooling and temperature monitoring is required. **The valves need to have sufficient distance to the hot regenerative bed, in order to reduce cooling needs and heat losses when valves are closed. The ASTERIx-CAESar project will address the optimization of the regenerative heat exchange system for the CSP-CAES application (vessel sizing, pipe dimensions and valve selection), as well as the detailed design** targeting main issues like thermal cycling, fluid dynamics and mechanical integrity. As stated above, the main challenge is the system integration based on available high TRL technology.

1.2.4 Specific compressor/expander design for small-scale and large-scale application

Turbomachinery is a key enabler technology for CAES systems for a number of reasons. The typical operating conditions of CAES pose numerous challenges to the efficient design and performance of compressors and turbines, setting the need to find compromise solutions balancing trade-offs between efficiency, reliability, costs and economics. Some of the most salient follow.

Compressors: Air storage pressures are very high, up to ≈ 150 bar. There are **three approaches** to the compression train of a CAES system as proposed in this project: (1) Multi-stage, intercooling reciprocating compressors, (2) Multi-stage, intercooled (barrel) centrifugal compressor. (3) Multi-stage, adiabatic axial compressor followed by single or multi-stage centrifugal compressors. While reciprocating compressors make use of valves actuated by the pressure difference between the cylinder and the inlet/outlet ducts, turbocompressors do not have valves. They deliver air continuously but are also exposed to flow reversal problems in the event of unexpectedly high pressures (surge). Controlling the operation of a reciprocating compressor through shaft speed is hence safer whereas turbo compressors must make use of built-in features (variable inlet guide vanes) in addition to shaft speed variations or even recirculation valves (increasing compression work). The adaptability of reciprocating compressors to variable operating conditions in the proposed systems is higher but, at the same time, the scale is limited economically and mechanically. For CAES, whilst pressure ratio (PR) is not a challenge in itself, operability of the compression train is a concern given that the pressure ratio is largely variable during the charging process (**variable pressure operation due to constant volume pressure vessel**). This means that there is a risk of hitting the choke limit of the performance map in the initial phases of the charging process and then getting very close to the surge limit when the storage vessel is close to its maximum capacity. Two research areas stem from this: a) implementing the control elements (Variable Inlet Guide Vanes, Variable Diffuser Vanes, Variable Speed Drives, Suction Throttle Vales, Recirculation, pressure relief valves, cooling duty of the intercoolers) that enable safe operation of the compressor train; and b) defining the operating strategies enabling not only safe operation but also the highest possible efficiency during excursions from the rated operating conditions of the compressor. **In short, the compressor selection imposes tradeoffs that must be studied carefully when optimizing the system.** This is why ASTERIx-CAESar will look into three system scales, characteristics of volumetric machines and radial and axial-radial turbocompressors, since this will yield different performances, control strategies and economic KPIs. For the region where two technologies are possible, a techno-economic-environmental optimization will be carried out to determine which type of compressor enables higher system performance globally.

Expanders: The same problem with variable pressure ratio applies to expanders/turbines though, in this case, there is an additional degree of complexity brought about by the high inlet (storage) pressure. This adds up to the variable pressure ratio problem. Large expansion ratios imply strong cooling across the turbine and this poses a risk of ice forming in the main flow path and across the end shaft seals of the turbine. To avoid this, either inlet temperature is raised substantially or pressure ratio is reduced. The former implies being able to achieve these high temperatures but it also has the benefit of increasing enthalpy drop and, therefore, specific output: higher output from the same amount of heat stored or longer storage capacity (and more compact, less costly machine). The latter implies performance losses brought about by the exergy loss of inlet throttling that reduces the amount of electric power that can be produced from a given mass of air stored; this is uneconomic. A clear solution to compensate for the variable pressure ratio, ensuring safe operation and maximizing performance is not available. This will be studied in the project through the incorporation of control elements -variable inlet nozzle vanes, variable speed operation, **series/parallel arrangement of multistage expanders**, variable turbine inlet temperature (reheater duty) **- to yield an adaptive operating strategy accommodating a decreasing expansion ratio**.

Akin to the compressor case, axial and radial expanders will be considered. Radial expanders adapt well to variable pressure operation though their turbine inlet temperature is limited due to the lack of internal cooling. Axial turbines achieve much higher temperatures when thermal barrier coatings and blade cooling are used as in gas turbines operating at >1500ºC inlet temperature, but these solutions have never been applied to high pressure (>50 bar) machines. Steam turbines achieve much higher pressures (>300bar) but their operating temperature is limited to some 625ºC. This is nevertheless not due to technical constraints but to economic reasons, as recently proved by the operation of a multistage supercritical Carbon Dioxide turbine operating at 300bar and 1100ºC, adapted from an existing ultra-supercritical steam turbine [46]. **ASTERIx-CAESar project will explore parallel routes for the turbines: 1) adapting existing equipment; and 2) developing turbines specific to the CAES concept proposed.**

Bottoming Rankine Cycle: During the discharge phase, turbine exhaust gases are still at a high temperature and there is an opportunity to recover this heat to produce additional electricity through a bottoming power system. The novel power cycle proposed by the ASTERIx-CAESar project is a modified combined cycle, where a topping gas expander train is followed by a bottoming Rankine cycle aiming to achieve the highest thermal-to-electric conversion efficiency possible. Two options will be studied: steam Rankine cycles and Organic Rankine Cycles (ORC). Steam cycles perform better at high (gas) turbine exhaust temperatures and larger scales while performance deteriorates quickly as temperatures decrease and the system gets smaller. The features of ORC are exactly opposite and they outperform steam cycles when waste heat is available at lower temperature and the power output is moderate to low. Since the temperature at the exhaust from the turbine depends on storage pressure (vessel) and turbine inlet temperature, techno-economic trade-offs between considering higher gas turbine inlet temperatures in combination with steam cycles or lower turbine inlet temperatures in combination with ORC must be studied carefully. It is expected that the very strong impact of scale on performance and, therefore, economics yields different optimum solutions across the range of possible system scales.

The ASTERIx-CAESar project will investigate a wide power range for the power cycle, starting as low as ≈ 1 MW for the smallest configuration (radial expanders + ORC as bottoming cycle) going until ≈ 150 MW_e (axial expanders + bottoming steam Rankine cycle). Whilst small-scale plants suit remote locations and grid islands, large-scale implementations achieve even lower cost targets mainly due to the lower specific cost of turbomachinery, grid connection, control systems and project management / site engineering costs. **The big advantage of the ASTERIx-CAESar concept is that the small-scale application for distributed generation is economically viable because of excellent conversion efficiency, not seen so far**. The **outcome of the project will be a theoretical design study** indicating all key turbomachinery parameters and needed modifications if based on existing machines.

1.2.5 Desalination with 24/7 renewable energy coverage

An added value in this proposal is the combination of the ASTERIx-CAESar power plant concept with desalination by reverse osmosis (RO) [47, 48]. During the day, the RO plant will be powered by the PV array, recovering the energy contained in the concentrated brine that leaves the membranes by a conventional Energy Recovery Device (ERD) [31], such as a liquid-liquid pressure exchanger (LL-PX) (see Figure 27 – left). As can be seen, the main high-pressure pump is backed up by a booster pump, which reuses part of the energy of the discharge brine. **After sunset, a dedicated multi-stage pressure exchanger (a gas/liquid pressure exchanger - GL-PX) that uses the energy stored in the compressed air vessel, will power the RO desalination unit** (see Figure 27 - right). Figure 28 shows the integration of the desalination unit in the ASTERIx-CAESar power plant. The use of low-temperature excess heat (from L-TES and H-HEX return streams) to drive a thermal desalination unit through a Heat Recovery Steam Generator (HRSG) will be also considered. The treatment of rejected brine to achieve Zero Liquid Discharge (ZLD) processes is particularly relevant in the case of plants located in regions far from the coast. Thermal desalination plants are less sensitive to high salinity than RO and thus are more suitable to concentrate brines. Therefore, it is proposed to analyze (from a theoretical point of view) the combination of a thermal technology such as Multi-Effect Distillation (MED), with and without thermal vapor compression steam ejector (MED-TVC and LT-MED, respectively), for the treatment of the brine exiting the reverse osmosis process. These thermal technologies are proposed as the most advantageous option, from a techno-economic point of view, to recover a substantial amount of the exergy content of the residual high-temperature air streams released from the CSP-CAES plant.

The ASTERIx-CAESar project will develop the optimum **design** of the needed key component, **the GL-PX**, for small-scale and large-scale commercial application, and will **demonstrate it at TRL 6-7 at PSA together with the solar powered CAES plant.** Only the operation of the RO+GL-PX powered by the compressed air from the CAES will be tested at pilot scale, since the coupling of the RO with PV is already available at commercial scale.

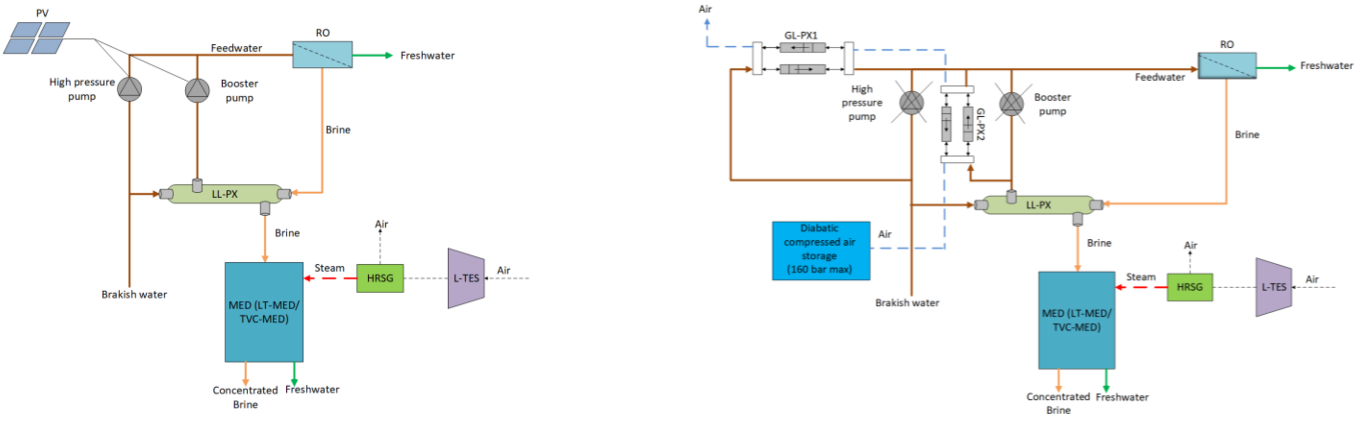


Figure 27: Conventional RO-MED during the day (left); Compressed air powered RO-MED after the sunset (right)

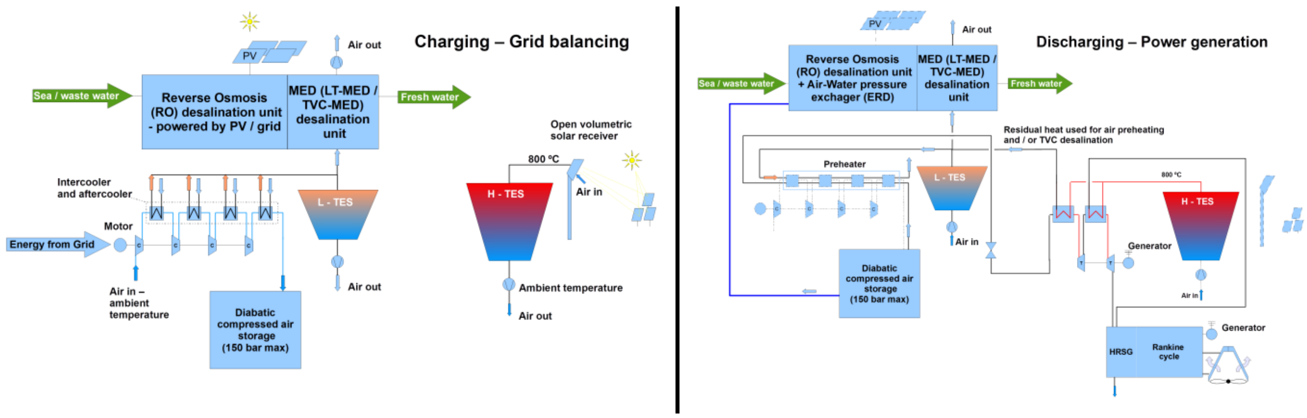


*Figure 28: Advanced CSP-PV-CAES power plant configuration with RO-MED (LT-MED/TVC-MED) desalination unit (**setup D**)*

1.2.6 Optimization of the power plant concept at small and large scale with relevant electricity grid boundary conditions, also considering integration with process heat and desalination

In ASTERIx-CAESar (WP1), the overall power plant configuration will be optimised for different power classes and locations, also considering integration with process heat and desalination. As already mentioned above, a key requirement for the ASTERIx-CAESar concept is very cost effective storage of compressed air. Compressed air can be stored either at constant volume (isochoric) or at constant pressure (isobaric). The isochoric approach is the most common (steel vessel or salt cavern). Here the pressure varies and thus indicates the state of charge [14]. The ASTERIx-CAESar project focuses on the classic isochoric approach and several isochoric storage concepts will be analysed and compared. On the one hand, the project targets the application of **artificial above-ground air storage volumes**, partially or totally integrated within the structure of the CSP tower, as well as the **consideration of unused/recycled gas pipelines as storage volume** [49]. On the other hand, the project will consider the classical approach **storing compressed air underground in solution-mined salt caverns, gas fields or abandoned mines**.

Artificial above-ground compressed air storage for small-scale application:

Artificial storage vessels [28] are crucial in order to overcome any restriction regarding plant location. The novel key concept of ASTERIx-CAESar is **that the air storage volume will be formed partially by the CSP tower's structure itself, consisting of several large diameter steel pipes (about 1 m in diameter) used to build gas pipelines for example.** According to Ref. [50], the application of an array of large diameter steel pipes represents the most cost-effective solution for storage pressures up to 150 bar. By inter-connecting the pipes by smaller diameter piping, a large air storage volume is obtained. **Additionally, further cost reduction can be achieved by applying the well-known wire winding technique**, where reinforced thin-walled pipes or vessels can be made suitable for high-pressure operation. These type of aboveground pressure vessels are formed by winding mono-filament steel wire around a cylindrical (or possibly spherical) container such that the steel wire withstands the pressure instead of the container's wall [28]. This approach can provide artificial storage vessels for lower than \$35 per kWh of exergy storage capacity (CAPEX per kWh storage capacity) [28]. **The ASTERIx-CAESar project will demonstrate this vessel design at small scale at the modified H2020 CAPTure prototype (see Figure 34).**

Besides the consideration of conventional underground CAES storage volumes, the ASTERIx-CAESar project will in particular focus on the cost-effective integration of artificial storage vessels, ideally suited for the small-scale application for distributed energy storage and power generation. The air storage volume may be part of the CSP tower structure to reduce costs.

For example, when taking a relatively small CSP tower of about 50 MW_{th} nominal solar power, having a tower height of about 100 m, the air storage volume potential would be about 2200 m^3. Assuming a multi-tower approach (3 towers), the air storage volume would then be 6600 m^3, which would allow about 5 hours of discharge using a 20 MW_e expander train. This should demonstrate that the orders of magnitude are coherent, but optimum combinations of rated solar power and discharge power need to be optimised for each location and electricity grid boundary conditions (to be done in WP1).

Underground compressed air storage – the conventional approach

Concerning underground storage, solution-mined salt caverns are the best choice [14], but the application is of course limited according to the geographical distribution of underground salt formations. Three of the many areas of salt structures in the world are representative of all; these are the Gulf of Mexico region of North America, the North German–North Sea area of Europe, and the Iraq–Iran–Arabian Peninsula of the Middle East. **Additionally, the locations of underground salt formations must be within high DNI resource areas, a must for CSP**.

Recently, due to the emerging concept of large-scale power-to-gas and hydrogen storage, suitable salt formations have been re-evaluated and mapped [51-55]. Figure 29 indicates the locations of suitable salt formations within high DNI resource areas [51-59]; the most interesting locations would be Australia, Middle East (Iraq, Iran, UAE, Oman), Turkey, Morocco, Algeria, Tunisia, southern areas of Spain, southern areas of the USA, northern Chile, southern Peru and southern Angola.

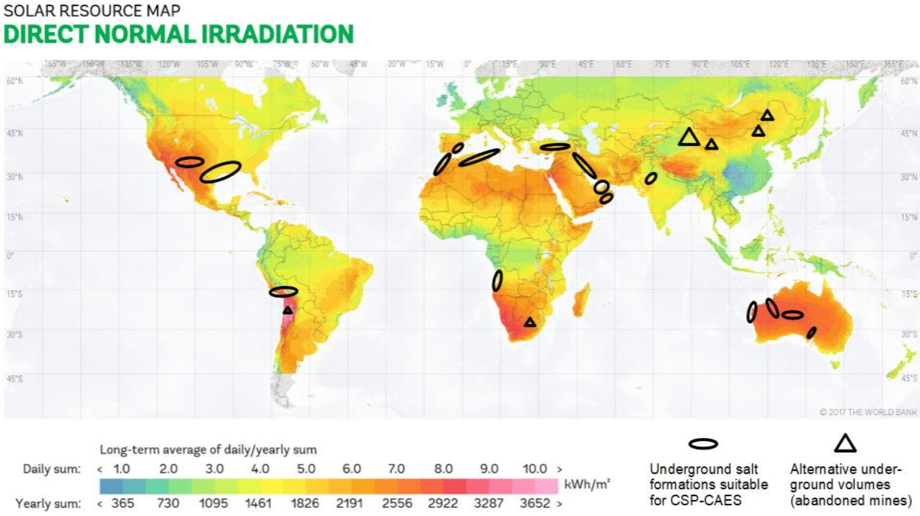


Figure 29: Direct Normal Irradiation (DNI) resource map and suitable underground salt formations

A viable alternative would be abandoned underground mines to be used as air storage volume [56, 60, 61], for example coal mines in China [ref] or gold mines in South Africa [ref]. Mine shafts would need to be sealed and made ready for the storage of high pressure air. The related cost is however small, compared to the cost of excavating an artificial new underground volume. A positive side effect would be the control and limitation of polluting acid mine drainage (AMD) [62]. AMD is a serious problem occurring at closed mines where acidic and heavy metal enriched water decants from flooded mine workings and pollutes the surrounding land and water ways [62]. The installation and operation of a CAES plant in old mine shafts would limit the seeping and decanting of water because used mine volumes would need to be made air tight. Furthermore, as the site remains active, the pumping and treatment of seeping water can be continued, controlling AMD and limiting environmental harm.

Low-cost thermal energy storage - TES

Today, molten salt is the reference technology, however corrosion and freezing issues are severe disadvantages that need to be correctly addressed. The cost of molten salt TES is currently between 25 and 30 $/kWh and may be reduced to about 15 $/kWh [63] until 2030. Possible options for cost reduction are thermoclines [64] and novel storage tank designs that avoid the expensive stainless steel shell (e.g. concrete designs [65]).

The ASTRIx-CAESar approach focuses on air as HTF, with the objective to increase the maximum operating temperature of the TES system and to avoid the freezing issue of salts, air-based thermocline packed-bed storage technology [66, 67] is proposed. It is highly attractive because of simplicity and very low cost (< 20 $/kWh today [67, 68]), with targets of below 10 $/kWh using advanced filler materials (solid-solid phase change materials (e.g. [69]). **The techno-economic optimization will consider air thermocline TES for both the ASTERIx-CAESar L-TES and H-TES units**. In principle, the air-based TES technology applied in the ASTERIx-CAESar project is already at an advanced development stage and a high TRL solution. The concept is based on packed beds of crushed rocks or other more advanced filler materials placed in large subterranean volumes (see Figure 30) [34, 66]. Within the project, besides the classical filler materials [70], also more advanced solid-solid phase change materials (e.g. [69]) will be analysed in the techno-economic optimization study at system level.

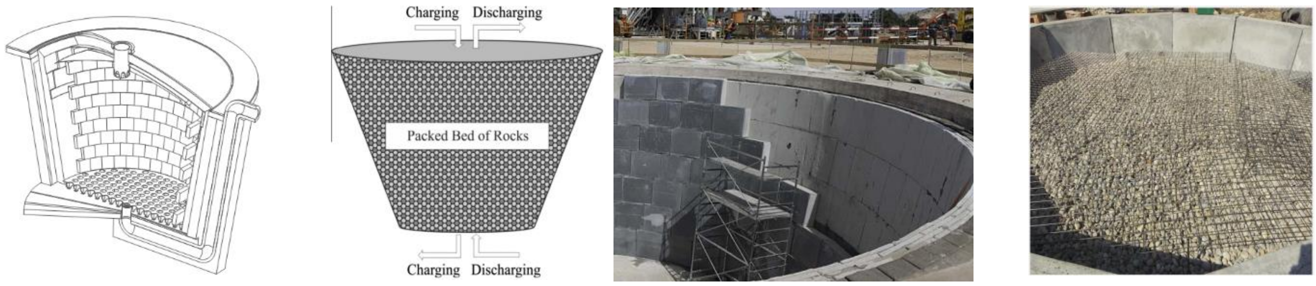


Figure 30: Atmospheric air thermocline TES concept according to Refs. [34, 66, 68]

Hybridization with PV and integration of desalination and process heat for industry:

Additionally, the techno-economic optimization study will consider the direct integration of a photovoltaic (PV) array, resulting in an advanced CSP-PV-CAES power plant. Thus, besides cheap off-peak electricity, also on-site PV output will be used during the day to compress air. **This concept would be particularly interesting for combination with a reverse osmosis (RO) desalination plant**. Here, the key idea is that the RO desalination unit

[47] is powered by the PV array during the day, and after sunset a **dedicated pressure exchanger (a so-called energy recovery device – ERD [31] – gas/liquid pressure exchanger) uses the energy stored in the compressed air to power the RO desalination unit** (see Section 1.2.5 and Figure 28). Thus, for this particular application, the air storage vessel size must be optimised for desalination and power generation. In this way, the low-temperature excess heat (from L-TES or H-HEX return) of the process can be used to drive a thermal vapour compression (TVC) desalination unit. The treatment of reject brine is a particularly relevant aspect in the case of plants located in regions far from the coast.

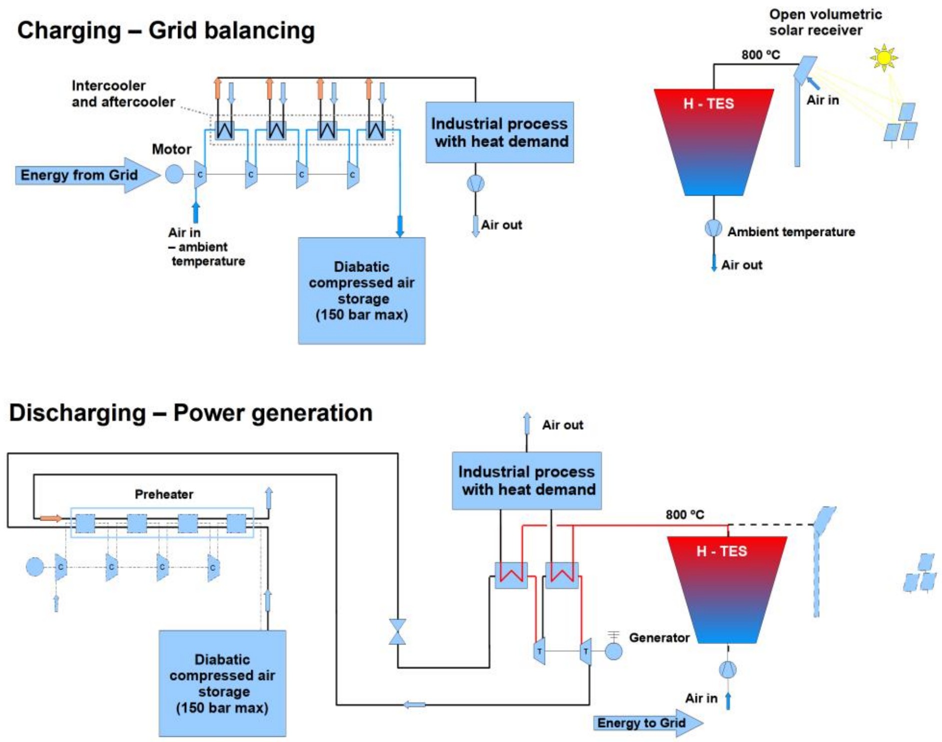


*Figure 31: ASTERIx-CAESar plant for process heat supply (**setup H**)*

Last but not least, for the case of other types of industrial process heat supply (≈ 200 ºC), the ASTERIx-CAESar plant can be simplified, considering only the CAES expander as power cycle and removing the L-TES (see Figure 31). The CAES air expander exhaust stream would then be used to preheat compressed air prior to expansion, according to the conventional CAES approach.

The ASTERIx-CAESar project considers the following reference cases for the techno-economic optimization study **at 9 different locations world-wide in 3 different setups (P = Power generation only -** Figure 7**; D = with desalination -** Figure 28**; H = with process heat integration -** Figure 31 **-** taking into account the main energy-intensive industries of each country**). A set of open-source simulation models will be developed in Modelica language. These models will be online available and also ready to be simulated on the project's website with a simple graphical user interface for any user.**

1.2.7 ASTERIx-CAESar virtual use cases worldwide – Interactive online Modelica environment and public model library

Figure 32: Virtual use cases graphical user interface on project website

The ASTERIx-CAESar project will create a Modelica library of fast simulation models in order to perform the techno-economic optimisation for **specific use cases** (see Table 4) **within Task T1.5**. Modelica is a multi-purpose physical system modeling language and has been developed in an international effort in order to unify already existing similar modeling approaches and enable developed models and model libraries to be easily exchanged. The concept is based on non-causal models featuring true ordinary differential and algebraic equations, i.e. differential-algebraic equation (DAE) systems [71]. Developed models and model libraries are exchangeable, i.e. can be read and simulated using different Modelica tools. Today, commercial, as well as open-source Modelica tools are available [72]. The Modelica tool generates the numerical simulation code, which uses a state-of-the-art differential-algebraic system solver (e.g. DASSL [73]). **The ASTERIx-CAESar project plans to apply the open source tool OpenModelica** [72] since the developed models can be run by anybody without license costs. It is foreseen that the annual yield simulation should be accomplished within minutes in order to run a parametric optimisation with acceptable computational time. The developed Modelica model library will be open source (available for download on the project website, as well as Zonedo for long-term access). In addition, the developed model for each use case will be available online on the project website and ready for interactive simulation by any visitor. **Figure 32 shows a screen shot example of the online graphical user interface.** The ASTERIx-CAESar use cases are presented in Table 4 below, and will serve as world-wide demonstration of the project's potential via specific techno economic optimization studies (see T1.5).

Table 4: ASTERIx-CAESar Reference Use Cases Worldwide

<table>
<tr><th colspan="2">Use case #1 – Location: Greece, Crete Island with main grid connection – Leader: HEDNO</th></tr>
<tr><td>
</td><td>Nominal power class: Intermediate-scale (20 to 50 MWe)
Air storage technology: Artifical above ground.
Process heat usage: Desalination, setup D (Figure 28) / None, setup P (Figure 7).
Short description: The southernmost Greek islands have the highest solar resource of the country (above 2045 kWh/m^2 and year), which makes them an ideal location for solar power generation. Recently (July 2021), Crete has been connected to the mainland electricity grid with an undersea power connection (longest AC cable connection in the world). A second connection to the mainland (Attica) is in construction (500kV DC cables, the total transmission capacity of which is 1000 MW). The peak demand of Crete in 2020 was 754MW in 2020. Besides 3 conventional generation stations, there are 40 Wind Farms with a total capacity of 200.3 MW, 1047 PV Stations with a total capacity of 78.3 MW (not including rooftop PV) as well as 1 Small Hydroelectric Station (SHP) with a capacity of 0.3 MW. The ASTERIx-CAESar project will consider a solar plant complex in the south-east of the island, close to the existing steam power plant at Atherinolakkos where good grid connection can be achieved. The number of towers and nominal electric power will be optimized for the specific power grid conditions.</td></tr>
<tr><th colspan="2">Use case #2 – Location: Greece, Rhodes Island – Leader: HEDNO</th></tr>
<tr><td>
</td><td>Nominal power class: Intermediate-scale (20 to 50 MWe)
Air storage technology: Artifical above ground.
Process heat usage: Desalination, setup D (Figure 28) / None, setup P (Figure 7).
Short description: In the autonomous electricity system of Rhodes there are two Conventional Generating Plants, the Steam-Electric Power Plant Soronis and the Thermal Power Plant of South Rhodes. Also, 5 wind farms, with a total capacity of 49.15 MW and 216 PV stations, with a total capacity of 18.2 MW (not including rooftop PV) are in operation today (December 2022). The peak electricity demand for 2022 was 237 MW. Rhodes has excellent solar resource conditions (among the highest of Greece, above 2045 kWh/m^2 and year). The ASTERIx-CAESar project will consider a solar plant complex located close to the existing South Rhodes Power Plant with good grid connection. The number of towers and nominal electric power will be optimized for the specific power grid conditions on Rhodes island.</td></tr>
<tr><th colspan="2">Use case #3 – Location: South of Spain (Villena) , main grid – Leader: CENER</th></tr>
<tr><td>
</td><td>Nominal power class: Large-scale (> 100 MWe)
Air storage technology: Underground in salt formation [51]
Process heat usage: None, power plant setup P (Figure 7).
Short description: Available underground saline formations and good solar resource make Villena a very good location. An existing CSP plant ensures grid connection.</td></tr>
<tr><th colspan="2">Use case #4 – Location: South Africa (Witwatersrand Basin), main grid – Leader: CENER (ESKOM)</th></tr>
<tr><td>
</td><td>Nominal power class: Small-scale (< 10 MWe)
Air storage technology: Underground in abandoned gold mines [56]
Process heat usage: None, power plant setup P (Figure 7)
Short description: South Africa has excellent solar resource and many deep level goldmines that are currently abandoned and cause environmental problems due to acid mine drainage. The usage as underground air storage volume can mitigate this issue as the volume must be made air tight. The project's industrial stakeholder board member ESKOM will provide the required information of grid boundary conditions.</td></tr>
<tr><th colspan="2">Use case #5 – Location: South Africa (Northern Cape province), main grid – Leader: CENER (ESKOM)</th></tr>
<tr><td>
</td><td>Nominal power class: Intermediate-scale (20 to 50 MWe)
Air storage technology: Artifical above ground.
Process heat usage: None, power plant setup P (Figure 7)
Short description: The north west of South Africa has one of the highest solar resource conditions in the World (>3000 kWh/m^{2}a) making it a must for energy harvesting. The project's industrial stakeholder board member ESKOM will provide the required information of grid boundary conditions. The ASTERIx-CAESar project will consider a solar plant complex located at the existing Redstone CSP project.</td></tr>
</table>

Use case #6 – Location: Chile (Antofagasta), main grid – Leader: CENER	
	**Nominal power class:** Intermediate-scale (20 to 50 MWe) **Air storage technology**: Artifical under ground in unused piplines [49] **Process heat usage**: Copper mining, power plant **setup H**, (Figure 31) **Short description**: Chile (Antofagasta region) has the highest solar resource available on planet Earth. Furthermore, unused pipelines can be used as air storage volume [49]. Additionally, copper mining requires process heat supply.
Use case #7 – Location: Australia (Port Augusta), main grid – Leader: AAL	
	**Nominal power class:** Small-scale (< 10 MWe) **Air storage technology**: Undergorund storage in salt deposits [54] **Process heat usage**: Desalination, power plant **setup D** (Figure 28) **Short description**: Working with a hostile climate and poor soils, agriculture consumes around 70% of Australia's water footprint. Thus, AAL has already developed an Integrated Energy System (heating, electricity and desalinated water) based on CSP for horticultural activities (36 MWth) [74]. The high direct normal irradiation (>2500 kWh/m2 year) and the extensive available salt deposits in the zone makes Port Augusta an ideal place for ASTERIx-CAESar concept.
Use case #8 – Location: United Arab Emirates (Al Ain), main grid – Leader: ROMA3	
	**Nominal power class:** Small-scale (< 10 MWe) **Air storage technology**: Artifical above ground and underground. **Process heat usage**: Concrete factory, power plant **setup P and H** (Figure 31) **Short description**: UAE (Al Ain region) has excellent solar resource (near 2000 kWh/m^2 year), the highest of the region near a big city with industrial heat demand, making it an ideal location. Additionally, concrete factories in the region require process heat supply that can be provided by this technology [75].
Use case #9 – Location: China (Three North Region), main grid – Leader: CENER	
	**Nominal power class:** Large-scale (> 100 MWe) **Air storage technology**: Underground storage in abandoned cole mines [57] **Process heat usage**: None, power plant **setup P** (Figure 7) **Short description**: The Three North Region in China simultaneously owns wind and solar power, grid capacity and underground space, ideal for a solar powered CAES plant. Abandoned underground coal mines can be used as storage volume for large-scale CAES application [57].
Use case #10 – Location: Morocco (Anti-Atlas Region), main grid – Leader: ROMA3	
	**Nominal power class:** Intermediate-scale (20 to 50 MWe) **Air storage technology**: Underground storage in abandoned old mines **Process heat usage**: None, power plant **setup P** **Short description**: (i) Excellent solar resource (>2500kWh/m^2), (ii) several old mine sites in Anti-Atlas region that have been abandoned without the implementation of proper closure plans and (iii) the Noor Power Station (I, II, III and IV) - (>500 MWe) already installed in Ouarzazate – that provides the required resilient power grid for implementing ASTERIx-CAESar.
Use case #11 – Location: USA (New Mexico), main grid – Leader: ROMA3	
	**Nominal power class:** Small-scale (< 10 MWe) **Air storage technology**: Underground storage in abandoned precious metal and molybdenum mines, as well as underground salt fromations. **Process heat usage**: None, power plant **setup P** (Figure 7) **Short description**: South-west of USA has excellent solar resource (>2500kWh/m^2 year) and many precious metals mines that are abandoned. This underground space can be used as air storage volume for CAES.

1.2.8 Demonstration at TRL 6-7 by extending an existing research prototype in the south of Spain

The ASTERIx-CAESar project will **make maximum use of valuable EU-funds** by extending an already existing research prototype that was developed within the H2020 project CAPTure (see Figure 33). The aim is to prove receiver operation as well as solar heat input in the novel power cycle at TRL 6-7 at small scale. **The new prototype components to be added are marked in green in Figure 34.**

The 3 main components of the existing CAPTure prototype, described in the following, are (i) the solar receiver, (ii) the regenerative heat exchange system including valves, and (iii) the small-scale Brayton cycle (hot air turbine). These main components are connected via atmospheric and pressurised circuit piping (Figure 33, left).

The CAPTure receiver has an aperture area of 0.706 m^2. **The internally insulated existing receiver (Figure 8, c) casing will be reused, only the absorber and ceramic mounting structure will be replaced by the new ASTERIx-CAESaer developments**. The receiver will have a nominal thermal power of about 480 kW. The incident solar flux coming from the solar field will be measured applying a Lambertian moving bar and a fixed Gardon radiometer installed right next to the receiver aperture [8].

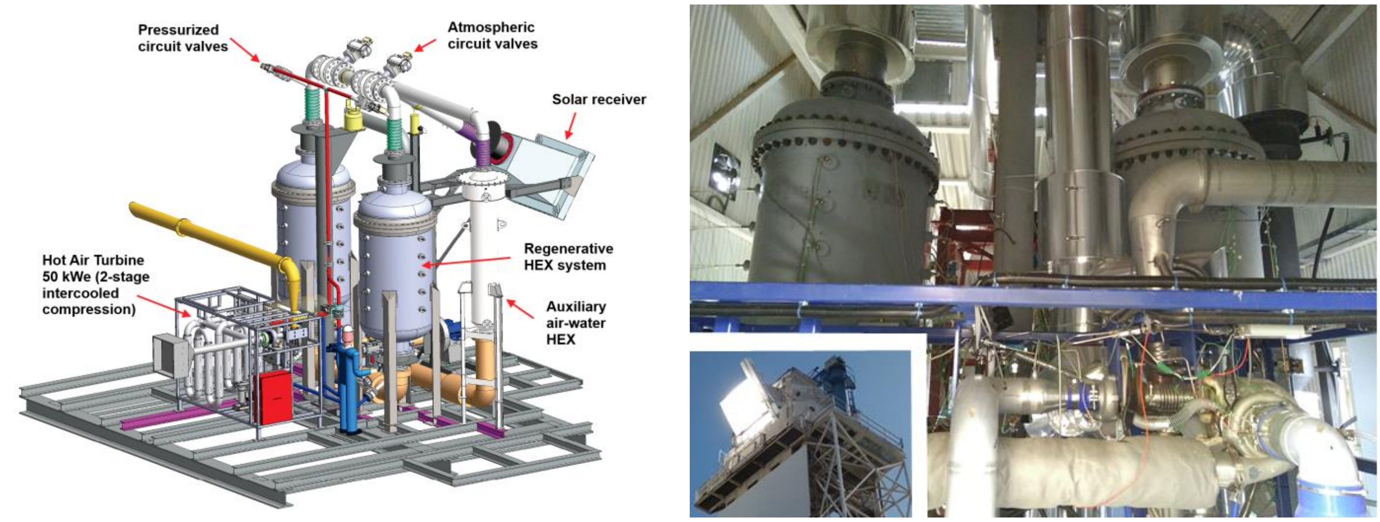


Figure 33: CAPTure validation prototype 3-D view (left); Receiver during on sun testing and internal view of testing room (right)

The regenerative heat exchange vessels are shown in Figure 33. They are internally insulated pressure vessels, containing a matrix of cordierite ceramic honeycomb bricks. The height of the vessels from top to bottom flange is about 3 m. The free internal diameter is roughly 1 m. The internally insulated design allows the application of standard carbon steel for the pressure vessel, since the maximum temperature of the vessel can be kept at about 50ºC, while the internal volume is designed for 900ºC operating temperature. Besides the two identical regenerator vessels, the regenerative heat exchange systems also includes 8 valves (4 large diameter – DN200 – atmospheric valves, and 4 small diameter – DN50 - pressurised circuit valves) that allow the individual charging, discharging and switching operation between operating states. The valves are of ball valve type and use ceramic balls on the high-temperature side (regenerator top: receiver outlet and turbine inlet) and metallic balls on the low temperature side (regenerator bottom: blower inlet and turbo charger outlet).

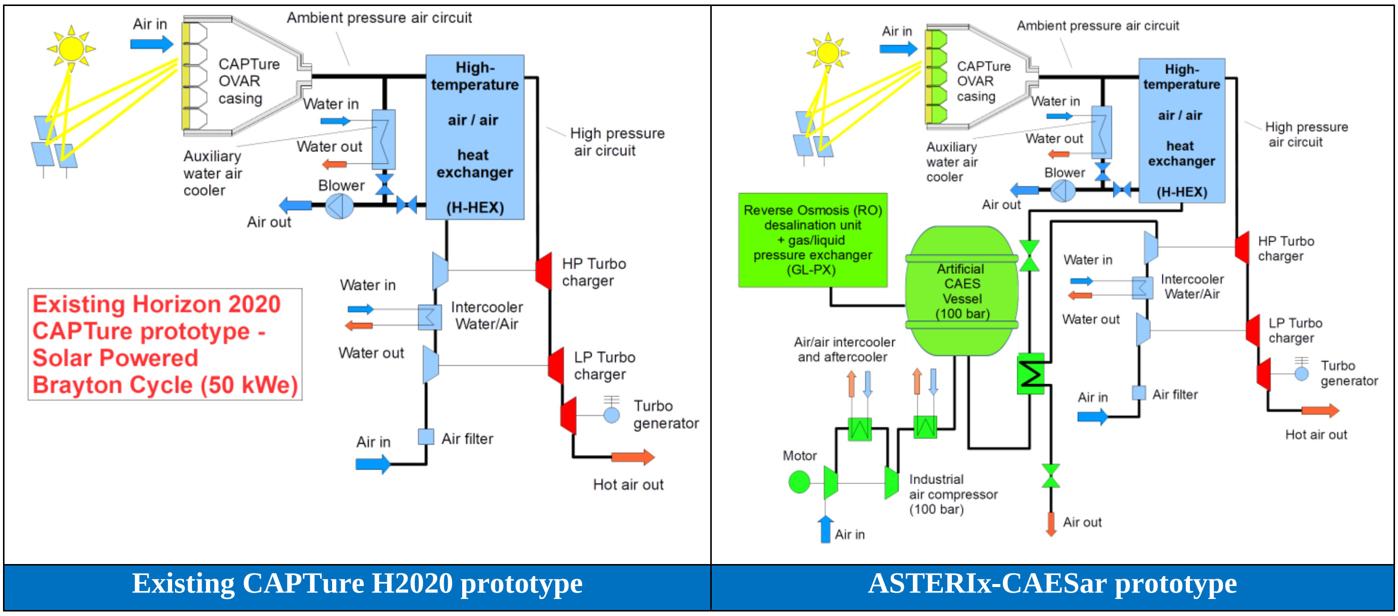


Figure 34: Left: Existing CAPTure prototype; Right: ASTERIx-CAESar extended prototype (new components marked in green: New receiver modules, CAES vessel, air compressor, air preheater, expansion control valve, existing CAPTure hot air turbine compressor outlet valve, RO desalination unit with GL-PX).

The CAPTure small-scale hot air turbine for power generation is a bespoke design based on heavy duty turbo-charger technology applying radial turbomachinery (designed by partner BLUE). It consists of a low pressure turbocharger unit, a high pressure turbo charger unit, an intercooler between the two compression stages, and a power turbine (see Figure 34, showing the prototype scheme). All hot air turbine components, including the inter cooler, were mounted on a metal frame as shown in Figure 33. The small-scale hot air turbine unit has a nominal power output of roughly 50 kW. The maximum turbine inlet temperature for short-term testing is 850ºC, and 750ºC for long-term operation. The pressure ratios of low pressure and high pressure compressor stages are about 3. The nominal air mass flow rate is about 0.4 kg/s. **The existing CAPTure hot air turbine will be reused in the ASTERIx-CAESar project, in order to demonstrate CAES expander operation at small scale,** driven by compressed air that is heated by solar energy, i.e. the volumetric receiver heats air to high temperature and the heat exchange system exchanges heat between atmospheric air and compressed air.

The existing CAPTure prototype will be newly equipped with an artificial pressurised air storage tank for 2 to 3 hours of nominal turbine operation, a reciprocating air compressor, an air expansion control valve and an adapted monitoring and control system. In the prototype, the heat of compression will not be stored to reduce budget. Therefore, an additional gas-gas HEX will preheat the air prior to expansion using the exit stream of the existing hot air turbine compression stages (**all new components are marked in green in Figure 34**). **It must be emphasized that this particular prototype configuration intents to maximize demonstration with the least possible budget effort.** It will therefore **not represent** the exact configuration for future application at small scale, since the two first expansion stages do not power a generator, instead they are still connected to the radial compressor stages, **which are used as "mechanical brakes"**.

1.2.9 Maximizing the project impact

To maximise the outcomes and impacts of the project, and to effectively exploit project outputs, a threefold strategy is used**: i) communicate project results** and directly connect with industries, end users and society at large to foster a two-way flow of information between the project and a wide range of stakeholders; **ii) Disseminate and communicate with the scientific community**, relevant projects and networks (national and international) to boost the advancement and uptake of scientific breakthroughs to maximise the transformative effects of ASTERIx-CAESar in Europe and **iii) build a business case and exploitation roadmap for the CSP-CAES technology** and **identify individual key exploitable results, business models and exploitation and commercialisation pathways for effective follow-up and market uptake**. ASTERIx-CAESar has already identified a wide variety of stakeholder groups and target sectors, i.e. turbo machinery providers (**DOOSAN Skoda Power, Bluebox Energy**), industrial end-users of CSP-CAES (**HEDNO, EDF, ESKOM**), suppliers/EPC (**Aalborg CSP, TSK-Flagsol**), the scientific community, investors, policy makers, regulators, standardisation bodies, the civil society and citizens. These will be targeted via systematic dialogues and formats, deploying the principles of Open Science (see Section 1.2.12) based on a sound dissemination, communication and exploitation strategy (as opposed to ad hoc communication). Activities are based on the principles of Responsible Research and Innovation (RRI) by engaging the civil society in Research and Innovation activities and making know-how openly accessible to wide user groups. Deploying the principle of Open Science, we will focus on understanding the needs, market interests and concerns of end users and consumers by engaging with two key stakeholder representative groups: the Industrial End-User Panel and the Citizen Panel, through regular and systematic forms of dialogue, i.e. meetings and a technology demonstration round at the end of the project (PSA). While the Industry Panel will maximise the market feasibility and technology integration at industry scale, the Citizen Panel aims to increase the public acceptance of the CSP-CAES concept and will allow to learn about citizens' concerns and expectations towards sustainable energy solutions. **A thorough stakeholder analysis will provide the basis for all activities** intended to maximise the impact and serves as the foundation for the Dissemination and Exploitation Plan.

1.2.10 Compliance with "do no significant harm" principles

ASTERIx-CAESar project will fully comply to the criteria for environmentally sustainable economic activities as set out by the EU Taxonomy regulation (2020/852 of 18 June 2020). The project concept contributes substantially to both climate related environmental objectives ("climate change mitigation" and "climate change adaptation") as well as "the transition to a circular economy" objective, and does not significantly harm any other environmental objective. The reference is made to the Climate Delegated Act (2021/2139 of June 2021), in particular to the following activities listed in its Annex I: 3.1 Manufacture of renewable energy technologies, 4.2 Electricity generation using concentrated solar power (CSP) technology, and 4.7 Electricity generation from renewable non-fossil gaseous and liquid fuels, and 4.10 Storage of electricity. As the project aims at bringing a marketable product by 2028-2029, it also fully complies to the EU Taxonomy Complementary Delegated Act. It will recognise as sustainable only those activities, which will perform a full switch towards renewable or low-carbon fuels by 2035.

1.2.11 Gender Analysis

It is considered that the technical tasks of the project do not directly affect women or men. Therefore, no complex gender analysis is required. Nonetheless, **the project dissemination and engagement activities will be gender-balanced** and encourage more significant participation of women in technology. In relation to the dissemination materials – website, poster, conferences, etc. – special effort will be made for connecting successfully with both female and male audience and display a balance of female/male imagery. All engagement formats and Panels will strive for gender parity. Moreover, ASTERIx-CAESar will implement measures to eradicate gender-based disparities and promote gender equality along all its development activities, in accordance with the EU Gender Equality Strategy 2020-2025. **From a wider perspective, it is considered that the project neither contributes to social inequality; quite the contrary. The new technology will be spread around the world, improving access to electricity and RE coverage everywhere (main grid & remote).**

1.2.12 Open Science

Open science will be considered as an integral part of the methodology. All of the techno-scientific publications will be made available as Open Access, for maximizing the spreading of the results and producing knowledge during the project. Results, including measurement data, and deliverables will be published throughout the project on the website, Zonedo, and social media – by the specialist partner ETN - in order to **increase the audience and ensure the reproducibility of the work**. Additionally, the objective is to encourage the researching interaction and information exchange with other similar ongoing projects and lines of investigation. **Therefore, specific workshops organised by project partners (academic and industrial) will ensure this objective**. Finally, a social and market impact is ensured by identifying industrial stakeholders for the project results like TSK, EDF or ESKOM which are members of the external industrial stakeholders board – see Section 2.2).

1.2.13 Data management and management of other research outputs

ASTERIx-CAESar will develop an initial Data Management Plan in month 6 of the project (DMP, WP6), which will be updated and used as living working document during the entire project. The DMP will detail how newly generated data will be made available and curated and how the project will organise the re-use of existing data. The DMP will be developed by the coordinator, in coordination with all those partners who generate or re-use data. It will follow the guidelines and standards for data protection and management as set by the European regulations and be based on the DMP template for Horizon Europe projects. ASTERIx-CAESar is committed to ensuring full data transparency and to give full access to non-sensitive data and project results that are not IP protected. In all data and results management activities, we will follow the FAIR principles as explained next.

● **Types of data/research outputs generated by ASTERIx-CAESar:** numerical, experimental, plots/figures of numerical results/experimental results and measurement data with and estimated size of up to 500 GB.

● **Accessibility of data/research outputs:** To comply with the principles of FAIR data, the ASTERIx-CAESar consortium will use Zenodo (https://zenodo.org) as the main repository for making the project's research data and other outputs, such as scientific publications, fact sheets and other info materials widely available in accordance with the requirements towards open data as stated in the Grant Agreement and the Horizon Europe Open Data principles. We will create a project community in the Zenodo repository, so all open datasets, public deliverables, publications and other public outputs can be uploaded in this community by all consortium partners. Through Zenodo, all uploads will be linked to OpenAire (https://www.openaire.eu/). This will ensure maximum visibility of RadioSpin data and results among the European scientific and expert community and make data findable via the Zenodo metadata standards.

● **Findability of data/research outputs:** The following principles are used by Zenodo to make research data findable. Those principles also apply for all open datasets shared by ASTERIx-CAESar via Zenodo:

- (Meta)data are assigned a globally unique and persistent identifier; a DOI is issued to every published record.
- (Meta)data are richly described with a plurality of accurate and relevant attributes; each record contains a minimum of DataCite's mandatory terms, with optionally additional DataCite recommended terms and Zenodo's enrichments, compliant with DataCite's Metadata Schema terms and additional features.
- (Meta)data are registered or indexed in a searchable resource (Zenodo, DataCite).

Metadata associated with each data set that will be published by RadioSpin in Zenodo will by default include: Digital Object Identifiers, version numbers, bibliographic information, keywords, abstract/description, associated project and community, associated publications and reports, grant information, access and licensing info, language. Project name and Grant Agreement number represent standard details as part of the grant information.

2 Impact

2.1 Project's pathways towards impact

The project proposes a paradigm shift in CSP systems with a revolutionary concept that seeks to transform this sector, aimed to achieve **a realistic target of 40% solar-to-electric efficiency of CSP systems, which literally doubles the current values.**

Moreover, the project will largely contribute to the global energy sector by providing a very cost effective and long-term grid-scale energy storage solution. This way, **the ASTERIx-CAESar CSP-CAES plant is the enabler – the magic potion – to achieve a 100% renewable future energy scenario**. Thus, the potential impact of this project is enormous.

These objectives are very ambitious. To achieve them, the project will develop, combine and advance different technologies in materials, components and control systems for the solar collectors to allow (1) the system to operate with air (with all the advantages this entails in terms of the environment, maintenance, affordability and simplicity of the system) and (2) to allow the CSP system to operate at temperatures of around 800 ºC. Besides, the innovative combination of CAES together with CSP (thus using renewable solar heat input instead of natural gas firing) will require relevant innovations in the main components of CAES which, at the same time, will enable to use a mixed energy conversion system that combines Brayton and Rankine cycles.

All this joint effort at technology level combining different systems and technologies is a big challenge, but it is also a huge opportunity to put the European entities at the forefront of this sector while opening the door to innovative applications. An important aspect to highlight is the wide range of targeted CSP plants (from small-scale ≈1 MWe up to ≈ 150 MWe) covered by the project, which makes the ASTERIx-CAESar solution a very promising alternative at worldwide level, in a very positive context with two-digit CAAGR market growth expected for CSP in the coming years [76].

This way, ASTERIx-CAESar project results are fully aligned with the key outcomes specific in the call topic that will be taken up by key stakeholders, maximizing project's impact. The following section will layout these impacts in more detail, in particular: how the key results of the project convert into outcomes and their potential impact, the broad groups we will target to achieve the described impacts, the barriers that the project results may face, the potential market and business model that the project results could focus on, how project results will need to be protected and how we disseminate and communicate with various groups.

2.1.1 Contributions to outcomes as specified in the work programme

Impact #1: Higher shares of variable output renewables in the energy system: Nowadays, producing renewable electricity is associated with PV and wind turbines. Although these technologies are very cost competitive, they are unreliable since they strongly depend on the weather. Therefore, a **significant increment in storage capacity of the energy system is mandatory** in order to obtain higher shares of variable output renewables. The ASTERIx-CAESar concept solves this problem by providing a CSP plant with TES and a CAES system. This not only increases the power dispatchability and efficiency of the CSP plant, but also allows storing electricity from PV/wind at a very interesting round trip efficiency (RTE > 60 %) when demand and prices are low. Additionally, the transition to renewable energy cannot only focus on electricity; it must cover the energy system as a whole, including power and heat. In this context, ASTERIx-CAESar has been designed in order to be easily integrated with industrial process heat supply and desalination. The combination of desalination plants with the proposed ASTERIx-CAESar concept is interesting, because ideal locations for CSP plants are typically areas with low water availability. There is currently a lack in available technology to cover 24/7 renewable power supply for desalination plants. Furthermore, grid instability issues are emerging with increasing fraction of non-dispatchable renewables. Many rural/remote locations that depend on water supply from desalination plants have very weak electricity grids that must guarantee 24/7 operation of the desalination plants, but cannot handle highly fluctuating output of non-dispatchable renewables. Grid operators avoid the connection of large-scale variable output renewables to such fragile grids. **The ASTERIx-CAESar approach is able to provide grid stability (the "magic potion") by guaranteeing 24/7 renewable energy coverage for remote as well as main-grid areas**. Future energy networks will have to exploit synergies between electricity, heat networks, fresh water generation, digital infrastructure, etc. This will be essential for enabling the smart, integrated, flexible, eco-friendly and sustainable operation of the relevant infrastructures**. The ASTERIx-CAESar CSP-CAES plant is the enabler – the magic potion – to achieve a 100% renewable future energy scenario**.

Additionally, the ASTERIx-CAESar concept **provides the CSP sector with a highly efficient power cycle with thermal-to-electric efficiencies beyond 60%, which additionally improves performance regarding start-up, shut-down and load variation**. By applying air expanders which are very similar in its operation to conventional gas turbines, **quickest start-up times with the important additional feature of black-start capability is achieved.** The general approach of ASTERIx-CAESar power plant start-up is that the topping air expander stages provide quick start-up, and during the first minutes of operation, the bottoming cycle is preheated to start-up temperature. In order to avoid frequent cool downs during longer idle periods, heat from the thermal energy storage (TES) is used to keep component temperatures (HRSG and steam turbine) at sufficient level. **In summary, quickest start-up is guaranteed within a few minutes**, compared to at least 0.5-1 hour at state-of-the-art CSP plants. **Highly flexible load following capability is achieved as the topping cycle (air expanders) can be fully modulated, maintaining at the same time the bottoming cycle power by feeding missing air stream from the TES**. Thus, the bottoming cycle can remain at constant load (in contrast to conventional combined cycle technology). Even, once the topping cycle (air expanders) is completely shut down, the bottoming cycle can power the air compressor if no power can be fed into the grid. This particular feature also provides a break-through in shut-down speed of the plant (i.e. its isolation from the grid). **TES + CAES is the key**! Last but not least, the

ASTERIx-CAESar concept provides **reactive power and frequency regulation**, which can be performed even when the plant is neither charging nor discharging by opening both clutches (both, compressor train and expander train are connected to the motor/generator unit).

Impact #2: Higher efficiency of concentrated solar power (CSP) plants and/or concentrating solar thermal installations: The current state-of-the-art peak solar-to-electric conversion efficiency is between 18 and 21% [77]. The solar receiver is a key component whose conversion efficiency strongly determines the overall conversion efficiency. The novel volumetric high-flux density receiver approach significantly reduces the receiver size (i.e. receiver cost), while increasing concentration ratio C (the conversion efficiency). Additionally, the high-flux density approach significantly reduces the complexity of the aiming point strategy, reducing auxiliary consumptions and operational effort. The target is to move to the simplest possible aiming strategy where all heliostats point on a single location (for small-scale receivers), and a few selected spots for large-scale implementation. For instance, considering compact north fields of 6, 17 and 51 MW_{th} nominal solar power, the receiver aperture size could be reduced to 6, 17 and ≈ 56 m^2, respectively (≈ 1 to 0.9 MW_{th}/m^2 mean flux density). A receiver efficiency of >85% at 800ºC is possible. Today's molten salt receivers have the same efficiency, however at 565ºC of operating temperature.

By using cheap or even negative priced off-peak electricity to provide the compression work of the topping Brayton cycle, the conversion efficiency of the ASTERIx-CAESar power cycle is significantly increased (to above 60%). Furthermore, by integrating compressed air energy storage, the conversion efficiency depends most on the achieved expansion ratio (maximum air expander inlet pressure) and less on the maximum temperature of heat supply, therefore achieving highly attractive conversion efficiencies at temperatures of 750 and 800ºC. The ASTERIx-CAESar approach improves the power cycle performance by ≈50% with respect to state-of-the-art Rankine cycle conversion efficiency. **The overall peak solar-to-electric conversion efficiency is therefore pushed above 40%, which doubles the performance compared to the state of the art.**

Impact #3: Reduced operation and maintenance costs of CSP plants and/or concentrating solar thermal installations: One of the most relevant advances proposed in the project is the use of air instead of molten salts or pressurized synthetic oils as HTF. Apart from obvious environmental benefits, this is a key advance in terms of O&M of CSP plants, since it avoids the leakage problems that are quite frequent and problematic in current systems used today. The leakage appears mostly in ball-joints being a problem that requires regular ocular inspections and exhaustive periodic detection interventions, where detection methods currently available are very costly and also detect the leaks too late, when they already pose a significant risk. These problems currently unresolved will be eliminated. At the same time, the use of air eliminates corrosion problems related to high corrosive environment generated by the molten salts at 565°C. Another problem associated to CSP is freezing of the HTF. To avoid freezing of the HTF, molten-salt CSP plants are equipped with large heat tracing systems that consume electricity to maintain the salts at high temperature during night. The use of air also eliminates freezing issues of the HTF circuit and part of heat tracing consumption in case of black outs.

Last but not least, a large percentage of the operating cost of CSP plant is related to human resources dedicated to monitoring and control the semi-automatic heliostat control system in order to prevent overheating in the receiver due to problems with operation strategies and aiming control. With the AI-based heliostat control the human resources for the operation of the plant will be reduced to a few people in short-term. Developing this system, in the long term, the plant will even be able to operate without onsite supervision (in remote surveillance only) reducing considerably the operation costs. Moreover, the AI-based heliostat control will provide a more accurate aiming system that prevent overheating in the receiver increasing lifetime of the components and reducing maintenance costs of the plant. This, coupled with the use of air as HTF, also facilitates the operation of the CSP plants, making possible an instantaneous shutdown in an extreme case without risk for the plant components.

By using air as HTF and with the AI-based heliostat control, the ASTERIx-CAESar concept reduces the O&M costs of a CSP plant or concentrating thermal installations by 40%.

Impact #4: Achievement of the targets of the SET Plan Initiative for Global Leadership in CSP: The current official SET plan initiative for global leadership in CSP delivered in November 2017 establishes two main strategic targets by 2020. An updated version of the implementation plan is under preparation (last draft from December 2022). The ASTERIx-CAESar project contributes to both main targets, which are:

► ***Short-term: 40% cost reduction by 2020 (by 2030 in the updated implementation plan) translating into cost of electricity provided below 10 c€/kWh (for specific given conditions***): In terms of LCOE, currently CSP (already in the range of 7 – 12 c€/kWh) plants are not competitive in comparison with other renewable technologies like PV (2-3 c€/kWh). Although ASTERIx-CAESar aims at reducing LCOE of CSP, we believe that – at least in the short-term – it is not realistic that CSP could surpass PV with regard to LCOE alone. **Therefore, we suggest a new operating strategy in which CSP does not solely compete against PV in terms of LCOE, but in which CSP should primarily boost the advantage of cheap energy storage.** ASTERIx-CAESar will provide the enabling technology to achieve 100% renewable energy supply. Although the investigated technologies (especially the high-flux density OVARs) aim at reducing the LCOE, this project's main focus will be on the levelized cost of storage (LCOS), as well as on the revenue maximization via a game changing CSP business model. ASTERIx-CAESar provides highly competitive electricity storage to the power grid with realistic LCOS targets below 10 - 15 c€/kWh (which competes with hydro storage). The revenue maximization will be achieved by selectively selling electricity primarily during high-price periods. Business cases will be optimised for different market boundary conditions. On top of that, using air as heat transfer fluid at high working temperatures allows the application of very cost effective thermal energy technology (packed-bed thermocline), where the cost of the TES unit can be as low as 15 €/kWh thermal, depending on the filler material. This is significantly cheaper than the state-of-the-art approach of using molten salts, additionally avoiding the operational problems related to salt freezing and heat tracing. **In total, the reduction in CAPEX and OPEX may reduce LCOE by 10 to 15%.** This also holds for classical air-based CSP, where the ASTERIx-CAESar developments can be applied as well.

► ***Longer-term: develop next generation of CSP/STE technology, with the aim to achieve additional cost reductions and opening new business opportunities***: As explained above, the project is fully aligned with this target: ASTERIx-CAESar proposes a very innovative concept that aims to revolutionize the CSP sector with improved efficiency and very cheap energy storage. The solution can be the next generation technology as it is suitable for low- to large-scale CSP plants and for many different applications as it can store and provide both electric and thermal energy, enabling new business opportunities.

Other than these two main targets, CSP heat for industrial processes is defined in SET Plan as a main tender design for the CSP in the future. The industrial sector is responsible for 32% of global energy consumption and 74% of this energy is heat. Today, most of this energy is obtained from **natural gas, which has become very expensive (20 c€/kWh)**. **The ASTERIx-CAESar solar receiver can provide solar heat for lower than 5 c€/kWh, i.e. can have a very high impact on the energy independence of the EU.**

Impacts	Today / State-of-the-art	ASTERIx-CAESar future vision
Impact #1a: Shares of variable output renewables (worldwide electricity)	10 % (variable RE) 27% (total RE)	Short-term: 18 % (variable RE), 37% (total RE) [78] Long-term: 60 % (variable RE), 100% (total RE)
Impact #1b: Start-up, shutdown and load variation	Limited load variation. Start-up ½ - 1 hour.	Advanced load variation performance. Start-up ≈ few minutes (< 10 min), Fast shut down (grid isolation) + reactive power and frequency regulation
Impact #2: Peak solar-to-electric conversion efficiency	18-21 % [77]	40 % [2]
Impact #3: Reduced O&M	50 ($/kW-yr) [79]	Reduction of 40% of O&M costs
Impact #4a: LCOE	7 – 12 c€/kWh (function of solar resource, financing conditions and technology)	6 – 10 c€/kWh (function of solar resource and financing conditions, nominal power)
Impact #4b: LCOS	Pumped hydro storage ≈ 15 – 20 c€/kWh [20], CAES ≈ 20 - 24 c€/kWh [25] Battery electric storage: ≈ 40 c€/kWh [25]	< 10 - 15 c€/kWh (function of solar resource, financing, CAES volume, nominal power)

2.1.2 Destination wider impacts

These promising results shows that ASTERIx-CAESar will make the difference in terms of impact and its results will contribute to **Destination 3 wider impacts** in long term. The project will contribute to fostering the European global leadership in affordable, secure and sustainable renewable energy technologies and to ensure cost-effective uninterrupted and affordable supply of energy to households and industries in a scenario of high penetration of variable renewables, including:

► **Cost reduction and improved efficiency of renewable energy technologies and their value chains**: as explained, the project contributes to reduced costs and improved efficiencies of CSP plants. But additionally, it paves the way to innovative applications thus enlarging the value chain of CSP. Besides, the project enables the seamless combination with other renewable energies such as wind or PV that can operate during more time, even when there is an excess of demand as the energy can be easily stored, and therefore increasing their yield.

► **Better integration of renewable energy in energy consuming sectors**. The use of air-based receivers together with CAES facilitates a combined Brayton-Rankine cycle. This opens the door to the use of these systems in industrial applications requiring electricity and/or thermal energy, but also others like desalination.

► **Reinforced European scientific basis and European export potential for renewable energy technologies through international collaboration**: ASTERIx-CAESar will open new research lines joining different disciplines and combining different technologies. The research will generate new high quality FAIR data of key importance in current and future renewable energy transition. All of the techno-scientific publications planned will be made available as Open Access, for maximizing the spreading of the results and producing knowledge during the project.

Furthermore, specific workshops organised by project partners (academic and industrial) will ensure the deep involvement of key actors. The project will seek to establish a new operation strategy and business model to make this new concept of adaptive CSP-CAES power plant economically competitive. The results obtained will support European leadership for global CSP energy market facilitating their entrance to new markets where CSP is growing rapidly such as South Africa, Morocco and China. Specific market watch and business analysis will be performed during the project in the framework of WP7. The primary exploitation route of the ASTERIx-CAESar developments will be via the consortium partner AAL. AAL is a highly experienced provider of solar thermal technology, CSP plants and TES. AAL will act as main license holder of the ASTERIx-CAESar concept for worldwide replication. However, also alternative routes of exploitation exist. E.g. partner BLUE (as SME) can exploit small-scale compressor/expander components also in other ways (exhaust heat recuperation, CHP, other CAES systems, etc.). USE may license turbomachinery modifications to key industrial stakeholders (e.g. DOOSAN Skoda). Priority will be given to European industry.

► **Enhanced sustainability of renewable energy value chains, taking fully into account social, economic and environmental aspects in line with the European Green Deal priorities**: The ASTERIx-CAESar project develops a disruptive renewable technology that will make a high contribution to the replacement of fossil-based energy technologies by 2050. The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement. In consequence, the ASTERIx-CAESar concept will strongly contribute to achieve this objective. By 2050, this technology will have been exploited and commercialised for at least two decades by European stakeholders. Many renewable energy technologies have a high ecological footprint, e.g. their manufacturing processes emit greenhouse gases and cause environmental pollution. For instance, state-of-the-art CSP plants typically use heat transfer fluids with ecological consequences. ASTERIx-CEASar ***reduces the environmental impact of CSP:*** ASTERIx-CAESar approach proposes air as HTF and working fluid, making CSP a more environmentally friendly technology reducing its environmental impact. Additionally, underground CAES systems in abandoned mines would be advantageous for the control and limitation of polluting acid mine drainage (AMD) [62]. **The ASTERIx-CAESar approach is 100% based on highly recyclable components and materials. Most importantly, air is used as heat transfer fluid which is obviously non-toxic for human kind and nature.** A detailed environmental assessment through Life Cycle Analysis and recyclability potential will be carried out during the project and guidelines will be established for future commercialization. The highly attractive environmental profile of the ASTERIx-CAESar plants is ensured due to several reasons: the use of air as heat transfer fluid does not cause environmental problems due to leakages; Thermal Energy Storage systems are based on atmospheric air thermoclines that could be filled with crushed rocks or recycled materials; the assessment of recycled gas pipelines as compressed air storage volume; industrial wastewater can be treated by integrated desalination process; the circular economy is promoted through long-life and recyclability solution. Therefore, ASTERIx-CAESar technology is expected to have a very important impact on sustainability and reducing emission of greenhouse gases. Thus, using the proposed solution will allow the upscaling of the greenhouse gas emissions reduction, improve **environmental** performance, reduction in material usage and environmental impact throughout the lifecycle. It will also scale up the **economic** impact thanks to improved efficiency, reduced costs and O&M cost reductions of CSP plants.

► **In relation to social terms, the ASTERIx-CAESar project will lead to a social acceptance of new energy technologies by showing an eco-friendly appearance and demonstrating that consortium is concerned about the European strategy plan**. The impact of the **social** innovation will be measured by job creation and the engagement and empowering of citizens, increasing the relevance, acceptance, and uptake of the innovation. During the project, a comprehensive assessment study will be performed considering sustainability, circularity and recyclability potential and social impact assessment (D1.4 and D1.5). It is estimated that the large-scale and decentralised deployment of CSP-CAES plants will create more jobs than conventional centralised fossil fuel plants.

► **Increased resilience of the energy system based on improved and/or new technologies to control the system and maintain system stability under difficult circumstances**: ASTERIx-CAESar aims to become the enabler – the magic potion – to maintain the system stability thanks to the storage capacity it provides, which is increasingly relevant in the current context of decentralization of energy production.

► **Improved energy storage technologies, in particular heat storage but also mechanical and electrical**. The ASTERIx-CAESar solution combining CAES with CSP allows to achieve highly competitive LCOS, enabling electrical energy storage with zero emissions. The integration of a flexible storage system with a sufficiently flexible power unit will significantly increase shares of renewables in the energy system as well as the fast start-up, shutdown and load variation.

► **Target stakeholders** The project will only have an impact if the results of the project are taken up by the targeted users. Therefore, it is essential that the project has clearly identified all key exploitable results (KERs) as well as target groups and potential exploitation pathways. **The ASTERIx-CAESar strategy is shown in Table 7.**

2.1.3 Framework conditions and potential barriers for full impacts

In order to achieve full impact, the electricity market needs to fulfil certain conditions. **Curtailment subsidies need to be removed**: Currently wind parks and PV farms in most of the regions of the world are subsidised for curtailment, meaning that they are paid the electricity price even if the grid operator orders them to shut down the plant due to over-production. These curtailment costs (**370 Mio. € in Germany in 2016 alone, 420 Mio € in UK in last five years**) are subsidised by the tax payers and create a strong lack of incentive for energy companies to invest in energy storage [80]. Additionally, at the end of the ASTERIx-CAEsar project, the technology is not fully proven yet, **hindering traditional investment vehicles to invest in the technology**. This could create a deadlock situation for the commercialization. Therefore, in order to become commercial, either government funds or visionary wealthy private investors are necessary to finance a first semi-commercial demonstration plant.

2.2 Measures to maximise impact - Dissemination, exploitation and communication

Achieving the above impacts requires an integrated approach to exploitation, dissemination and communication, taking place within a clear framework for IPR management. Such approach maximises innovation potential and market uptake, but also delivers Open Knowledge to the EU research and innovation community and progressively engages the public, builds awareness, participation and support for innovation through targeted communication. ► This chapter gives a comprehensive overview of all measures to maximise impact planned by the project and the corresponding stakeholder groups addressed. Impact measures are organised in three main categories. ► In addition, CEN will take advantage of its participation in a HORIZON Europe project called "ABraytCSPfuture" (Nov. 2022-2026) that has a similar concept of using air-based CSP with a regenerative heat exchanger design, but with thermochemical energy storage. CEN is contributing in the optimization of the overall process and is leading the dissemination, exploitation and communication work package. Thus, a maximum synergy of both projects is ensured and it will boost the impact of both projects.

2.2.1 Dissemination and exploitation strategy

Dissemination and Exploitation activities have been co-designed to match to the context of required project TRL: starting overall at TRL5 and reaching TRL6-7 at project end. A complete range of activities organized in WP7 will support long-term project impacts described above. ASTERIx-CAESar partners will contribute to leveraging the project impact by participating in dissemination activities and committing to development and implementation of the IPR and exploitation strategy. This section describes the draft plan for disseminating and exploiting the project results, based on principles consistent with TRL target 6-7 at project end. It is anticipated that within ASTERIx-CAESar, the dissemination of results to industrial and policy maker stakeholders will be given particular emphasis to facilitate its market uptake. It is therefore essential that ASTERIx-CAESar closely collaborates with other on-going research initiatives, considers the already identified lessons learned, exchanges on the recent developments of the state-of-the-art with the international research community and monitors and influences the European political agreements.

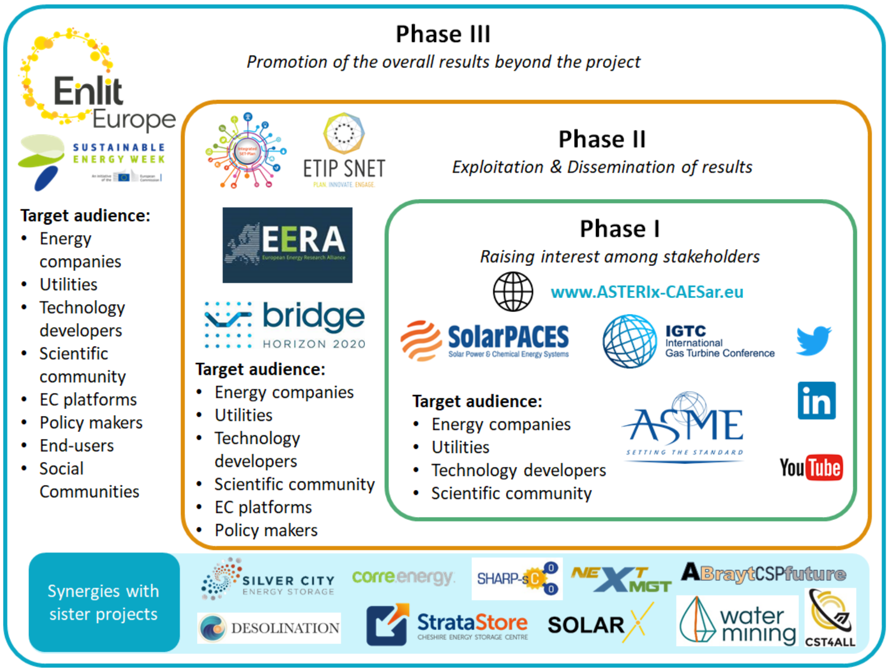


Figure 35: Dissemination strategy phases

Dissemination and exploitation activities will be carried out throughout the project with different aims:

1. **Raising awareness**: In the early phase of ASTERIx-CAESar, activities will mainly focus on communication to raise general awareness of the project existence based on the project objectives and

expected results.

2. **Securing the future**: All along the increasing maturity routes from TRL 5 to TRL 6-7 (during project deployment), and after project formal completion (path to commercialisation by 2028-2029) a first guiding principle consists in preserving multiple implementation options for product(s) development, while being continuously in 'market pull thinking'. This implies simultaneously to activate anticipation (e.g., early detection of future market needs) and defence (IPR management strategy; risk plan of non- or low performance exploitation).
3. **Providing a reference route toward exploitation:** The technology, which will be commercially exploited, constitutes the backbone of the IPR strategy and exploitation plan and will regularly evolve, with a reinforcement of the activities in the final years: this will be subject to market and social acceptance, technical, and regulatory features.
4. **Ensuring stakeholders' acceptance and attraction of end-users:** Mindset preparation to 'next gen technologies' that are developed for a 24/7 RE coverage is clearly a critical success factor. Social surveys on perception and adoption of high techs innovation in a massive deployment will reduce resistance and acceptation barriers or the 'too early for the market' syndrome. Dissemination campaigns and early involvement of stakeholders will be foreseen and scheduled in exploitation plan with increasing intensity after project completion.

Provisional Dissemination, Communication and Exploitation Plan

A detailed Dissemination, Communication and Exploitation Plan (DEP) will be elaborated within WP7 and issued shortly after the beginning of the project in order to serve as an internal practical guide for the consortium partners for engaging with dissemination activities through coordinated actions (D7.2, M6). Its strategy is presented hereinafter, consisting of three main phases (see Figure 35):

► **Phase I (Raising awareness among stakeholders):** create visibility and raise interest among stakeholders about the project and its expected outcomes. The project will be introduced during ETN IGTC Conference in 2023.

► **Phase II (Exploitation & Dissemination of results):** clearly shows the benefits that the new technology can provide. The demonstration of the technology will strongly contribute to a wider exploitation-oriented dissemination.

► **Phase III (Promotion of the overall results beyond the project):** disseminating the complete project results, stimulating replication of the concept and the engagement of potential clients. The results of the project will be presented during ETN Conferences in 2025-2027 in order to engage GT OEMs and Energy Utilities associated to ETN.

ASTERIx-CAESar will develop, disseminate and communicate personalised messages for each target group through the most suitable means and channels adapted during the project life.

Table 5: ASTERIx-CAESar dissemination channels

Target audience	Key message	Channels
EC & Policy makers: DG ENER, RTD, CLIMA, ENV (green growth), GROW, EMPL (for safety) ITRE & ENVI Parliament Committees, as well as national and local policy makers	ASTERIx-CAESar contributes to the implementation of the SET-Plan and the energy transition strategies. More funding and collaborative projects are needed to pursue the quest for development of systems enabling higher shares of RES in the energy system, as a key enabler for decarbonisation.	White papers, position papers, recommendations, reports, events and conferences organised by the EU
Energy companies/ Utilities: Energy companies in Europe and beyond, associations of TSOs and DSOs (ENTSO-E, ENTSOG)	Increased share of RES in the energy mix will require massive storage solutions. With ASTERIx-CAESar system, the power can be loaded to the grid to fill gaps, whereby operators avoid levies for undelivered power.	Scientific publications, conferences, partners' participation, public reports and white papers
Industries/ technology developers: End users for CSP-CAES technology, RE companies, manufacturers, energy-intense industries, desalination units	ASTERIx-CAESar will develop an "adaptive" power plant concept converting solar energy at highest efficiency, providing 24/7 RE coverage. The power cycle will be characterised by fast start-up, easy load variation and fast grid disconnection.	International fairs/conferences, participation in industrial interest groups through partners networks, Industrial End User Board for intense dialogues and feedback on market barriers and end user needs towards CSP-CAES.

Scientific community Research organisations, scientists and expert groups active in energy system transformation, power generation, environmental science, circular economy, climate research, socio-economics etc.	Due to combination of CSP and CAES, the peak solar-to-electricity energy conversion efficiency is doubled (>40%), comparing to state-of-the-art technology. A set of innovative key components and sub-systems is needed in order to implement the novel CSP plant.	Peer-reviewed papers, technical/scientific publications, conference papers/presentations and posters, webinars, website and social media, post-graduate teaching material
Regulatory and standardisation agencies: ISO, CEN, CENELEC	Novel technologies developed in ASTERIx-CAESar require attention from the regulatory and standardisation perspective and upgrade of existing standards through data provided by the project.	Publications, white papers, dedicated events, attendance of relevant technical committees' meetings
General public, local & citizen partnerships & cooperatives: society at large, esp. communities in geographical regions with high CSP potential, civil society & citizen networks & energy cooperatives, environmental NGOs, communities with lacked access to electricity	The EU dedicates significant funding to decarbonisation with the aim to ensure greener energy and better air quality for its citizens. The ASTERIx-CAESar system is safe and non-toxic, fully considering the needs of local communities, and the fragile ecosystem and therefore socially acceptable.	ASTERIx-CAESar communication tools – website, press releases, open access articles, leaflets, social and mass media
Publications in journals		
Solar Energy, Renewable Energy, Energy Storage, Turbomachinery International Magazine, Applied Energy, Energy, Energy Conversion and Management. Open-access publications will be prioritized *Target: 10 publications in journals (includes scientific contributions to conferences)*		
Participation in events, fairs and conferences		
SolarPACES, International Gas Turbine Conference, ASME Turbo Expo, ENLIT Europe, EUSEW, NEXTURBINE, POWER-GEN, Renewable Energy World Europe Conference & Exhibition, etc. ASTERIx-CAESar partners will make sure to participate in the following European workshops: ETIP-SNET Regional Workshops, BRIDGE workshops, SET-Plan Workshops/Conference. *Target: Participation in at least 12 international events*		
Collaboration with relevant projects and initiatives		
The CAES + CSP system developed in ASTERIx-CAESar is not evolving in a closed environment but should collaborate with all previously and future projects funded under the similar topics to exchange on good practices, especially through Horizon Results Booster initiative (Sister projects: Silver City Energy Storage, Corre Energy, SharpSCO2, NextMGT, ABraytCSPFuture, StrataStore, SolarX, Desolination, WaterMining). The following initiatives, platforms and association will be associated: BRIDGE, ETIP-SNET, SET-Plan, EERA Joint Programmes, ETN Global, RESCoop.eu, COGEN Europe. *Target: Participation in at least 10 clustering activities*		

The main focus of all communication activities within the ASTERIx-CAESar project is to increase the economic impact of innovation actions undertaken within the project by facilitating the spread of developed technologies/products/services, towards new customers, countries, regions, sectors, markets and organisations. As such, communication activities will be aimed at promoting the project to various audiences, including groups beyond the project's internal communities to wider audiences, comprising the media and the general public, and at raising awareness on the addressed topics and findings. Table 6 summarizes the draft for the communication plan incl. the main relevant measures, objectives, target audience and KPIs.

Table 6: ASTERIx-CAESar draft for the communication plan

Communication channel and objectives	Target audience	KPI
ASTERIx-CAESar visual identity & communication package (logo, templates, infographics poster, leaflet, roll-up): Make the project information attractive, eye-catching and professional. Share the main results	ALL*	1 initial version of leaflet and poster + updates
ASTERIx-CAESar public website Dedicated project website compiling all project information, reports, publications and outputs, web articles, news and events sections. **A virtual pilot via a simulation and modelling tool will be also made accessible to potential end users**: A set of open-source simulation models (in Modelica language) will be shared openly via the project website, also allowing the direct simulation of selected use cases online via a simple user interface (simulate, plot results), especially for industrial end users.	ALL	7.500 visits, 250 downloads per PU deliverable 1 year after the project end

Media and Social networks (YouTube, Twitter, LinkedIn) Promote the project, change mindsets, and raise awareness.	ALL	50 LinkedIn posts and 50 Twitter tweets/year
Biannual newsletters Disseminate the project's main achievements, breakthroughs and events	Research & Academia, industry, policy makers, gov. institutions, local authorities, post-graduate students	8 releases (sent to newsletter subscribers + disseminated by social media & ETN network)
Promotional videos Promote the project and its findings in an attractive manner (one video at the project's first year and one towards the end)	Local communities and end-users and well as general public on EU level, post-graduate students	1.000 views per video in 12 months from release
ASTERIx-CAESar Public Workshop & Final conference Bring recognised speakers from the scientific community, industries, local organisations, authorities, and stakeholders active in the sector of energy transition.	Research & Academia, industry, policy makers, gov. institutions, local authorities, post-graduate students	1 public workshop and 1 final conference
External communication and Press Releases Partners will use their networks of contacts and the press on local and European level for broader publications of the project results.	ALL	> 100 communications (> 2 per partner and project year)

*ALL refers to the EC & Policy makers, Energy companies/Utilities, Industries/technology developers, Scientific community, Regulatory and standardisation agencies, General public (incl. local & citizen partnerships & cooperatives)

2.2.2 Exploitation of results (incl. knowledge exploitation)

ASTERIx-CAESar will focus on developing novel concepts and credible exploitation pathways for the targeted CSP-CAES technology and innovative concepts and components that could be of interest for future commercialisation, scale-up and other exploitation pathways. Novel business models will consider the inclusion of energy storage and potential societal/socio-environmental benefits, including the contribution to climate change mitigation strategies by boosting the shares of renewable energy, by providing sustainable solutions for energy-intensive industries and by realising a technology that can deliver 24/7 energy supply for example in remote and energy-poor areas. However, for a successful market introduction of the combined CSP-CAES technology, there are still some challenges that need to be addressed. The main barriers are already mentioned in Section 2.1.3. ► IPR protection activities are managed under task T7.4. Depending on its nature, IP generated within the project will be protected mainly by copyrights, patents or secrecy, and its management will be regulated in compliance with the final consortium agreement and the intellectual property agreement among the partners. The consortium has identified three levels of Foreground (Results) IP which will be created in the course of the project, defining the main criteria adopted to distinguish among them in the Data Management Plan (D8.2): (i) Individual and joint IP, which belongs to individual partners or is jointly owned by partners and is restricted to those partners; (ii) Generic IP, which can be used by all partners of the consortium and that can be made more widely available. (iii) Publicly available IP published in Open Access academic journals, at conferences, on the public website and made available with no restrictions including in data repositories according to Open Data FAIR principles. Individual, Joint and Generic IP will be the subject of exploitation planning whilst Open Knowledge will feed into Dissemination and Communication activities.

Access rights and exploitation: The general principles for Intellectual Property Aspects set out by the EC for Horizon Europe projects will apply in ASTERIx-CAESar. Existing know how (background or pre-existing intellectual property) of a specific partner shall be made available on transfer conditions to the Partner(s) within the consortium. The use of such existing know-how is strictly limited for use to the achievement of the project goals and for the duration of the project. An overview of the existing know how will be included as an annex to the consortium agreement that will clarify access rights to background. Foreground shall be owned by the partner(s) who developed these results. IP created in the consortium will be monitored and all possible conflicts will be mitigated. The consortium will assure that all agreements on use of IP inside of the consortium will be performed on fair basis. In order to help the partners in development of IP, a Technology and IPR monitoring report will be prepared and included in the Exploitation Road Map (D7.5, D7.6). It will contain an overview of existing patents related to the ASTERIx-CAESar technologies, analysis of key players and main competitors, press releases and description of related regional, European and international project and initiatives. Depending on the partner needs, deeper analysis around selected patents, products and key players can also be performed in order to avoid any possible infringement of patenting activities. The IP management provides the basis of maximizing the impact of expected key exploitable results - KERs (see Table 7).

ASTERIx-CAESar - Exploitation strategy: A comprehensive Exploitation Plan and individual partner business models will be established in ASTERIx-CAESar (Task 7.4), focusing on how the project technology and individual components or services can be exploited and further used in the future. The development of the plan will be

coordinated by the Exploitation Manager (Rita Clancy, EURIDA) in close cooperation with all consortium partners, contributing their expert knowledge, entrepreneurship, innovation management and marketing expertise to ensure the best strategic positioning across the whole value chain. An initial exploitation strategy and prospects for individual business opportunities can already be outlined at this stage. The ASTERIx-CAESar overall Exploitation Roadmap is depicted in Figure 36. This initial exploitation plan further features the overall project exploitation strategy and the individual Key Exploitable Results (KERs, Table 7) foreseeable at this stage.

The foreseen results and outcomes of ASTERIx-CAESar research and development can be of significant value for a diverse set of stakeholders.. The results that are relevant for exploitation can be classified in five types as summarised in Figure 36 and outlined below:

► (I) **the overall CSP-CAES plant concept,** which will be deployed and demonstrated as plant prototype in an industrial setting by the project end (TRL 6-7). Exploitation is envisaged via technology scale-up and optimisation (internally with publicly funded programs or externally based on contracts signed with clients).

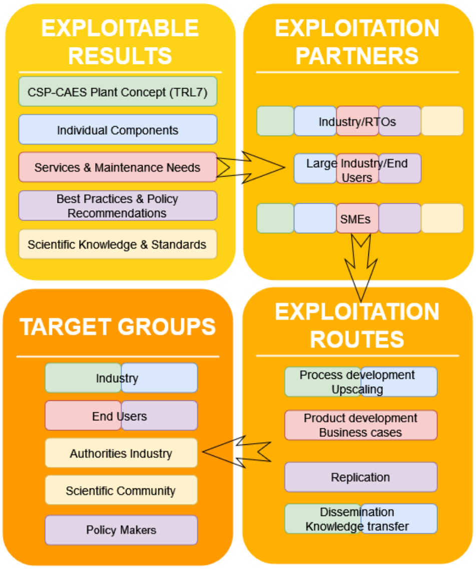


Figure 36: ASTERIx-CAESar overall Exploitation Road Map

► (II) **the individual components of the CSP-CAES technology** that potential future end users will be able to use and integrate autonomous from the CSP-CAES plant. Those will be exploited as novel product, service, or process offerings for the target markets by the respective IP owners in ASTERIx-CAESar. Further IP commercialisation will be assessed and planned for example through assignments, licensing, joint ventures and spin offs, especially in cases where IP owners are RTOs or public bodies for whom direct sales of products or service offerings are unsuited exploitation scenarios.

► (III) the **services** that result from specific features and **maintenance** needs of the CSP-CAES plant.

► (IV) the **best practices** that will emerge from the plant prototype, the **policy recommendations** that are based on the prototyping and demonstration of the ASTERIx-CAESar outputs and the techno-economic assessment (TEA) and life-cycle assessment (LCA) of an fully industrial technology concept.

► (V) **the scientific knowledge** that will be generated through the R&D and demonstration activities. Knowledge exploitation is of particular relevance for standard setting and Best Available Technologies (BAT). Other scenarios for knowledge exploitation are further described in the dissemination and communication activities.

The above set of results show clear exploitation benefits for both the consortium members of ASTERIx-CAESar and external stakeholders who are part of the energy community in the widest sense.

On the one hand, exploitation targets key actors in the fields of CSP and energy storage systems, on the other hand exploitation addresses end users of the novel CSP-CAES technology, such as grid operators, utility companies and the energy-intensive industry (high-temperature process heat).

Besides the specific DEC partners, the ASTERIx-CAESar consortium includes RTOs, large industry and SMEs who represent the supplier, innovation developer and end user sides who are relevant for the exploitation diversity that is required to achieve maximum impact for the project. The final TRL level that will be reached for the majority of results will reach TRL6-7, so the final scale-up in a follow-up action and the take up of solutions by the market and by actors outside the project consortium is pivotal for the success and sustainability of concepts and results. Channels and formats for reaching external key exploitation partners and end users include the project's 'Industrial End User Board' in order to engage all the relevant stakeholders.

External Advisory and Industrial End-user Board (EAIB) / Stakeholder Board (EASB): The planned panel aims to be a consultative body consisting of key industrial end users to identify and discuss priorities, concerns, market needs and barriers for the final scale-up and market introduction of the CSP-CAES technology. The Industrial End-User Panel will further be a crucial part of the risk contingency plan and will allow us to collect more comprehensive data for the techno-economic and overall sustainability assessment (performed in WP1). Confirmed Panel members are **Dr. Mark Schmitz / TSK Flagsol, Dr. Mansour Ahmed / KISR**, **Mr. Benôit Valentin / EDF R&D and Mr Darryl Chapman / RT&D ESKOM** (letters of support are attached to the proposal). Additional members will be added to the Panel selected from customer and client networks of the ASTERIx-CAESar consortium. To facilitate the participation of panel members we will offer flexible ways of communication (e.g. virtual meetings). **A full technology demonstration round of the CSP-CAES plant at CIEMAT-PSA is planned at the end of the project for the Panel members**.

ASTERIx-CAESar will show the great potential of the novel integrated CSP-CAES technology for a range of market segments, among them renewable energy/grid, turbo-machinery, electricity grid operators, EPC and desalination. As a result, the exploitation and business planning of ASTERIx-CAESar is based on a 'road-map' that outlines the different paths of future exploitation and industrialization of the project during its development cycle. The overall ASTERIx-CAESar Exploitation Road Map as described in detail here foresees different routes for exploiting the different result categories, respectively. The exploitation paths are:

(I) Process development, optimisation and upscaling of the ASTERIx-CAESar plant concept: The key outcome of ASTERIx-CAESar, its integrated CSP-CAES plant prototype, and the individual components of the technology will be optimised for the integration of the fully qualified system for industrial use and its competitive manufacturing for the market introduction. Scale-up and system qualification activities will be mapped as a first step for the ASTERIx-CAESar mid-term, refined during the final project year and outlined in detail in the midterm and final exploitation roadmaps (D7.5 & D7.6). Financing and partnership needs will be further assessed. For a successful scale-up and industrial integration large industry partners will be pivotal, therefore process development and scale-up plans will include networking and teaming activities with promising partners from the industry, especially in the targeted application sectors. ► The exploitation responsibilities will mainly lie with the private sector of the ASTERIx-CAESar consortium (AAL, BLUE, DSPW, SIW-S, NTT, WPS and EFG). While AAL can act as EPC company replicating the power plant concept worldwide, all other industrial partners will exploit their individual products also in other markets, not necessarily CSP related. ► Underlying knowledge will be brought to the project by RTOs and academia. Project coordinator CEN is the inventor of the here presented CSP-CAES approach and main developer (together with IKTS and AAL) of the ASTERIx-CAESar solar receiver, both to be exploited by the industry via licensing.

(II) Individual product development & business cases: ASTERIx-CAESar will result in products and services that can be directly exploited by the producers of the results within or beyond the CSP-CAES plant and the applications targeted in this project. All key exploitable results that can be foreseen at this stage are briefly summarised in Table 7. Thorough screening of results for their innovation and exploitation potential and necessary IP protection measures during the entire term of the project will assure that so far unforeseen exploitable results will be detected and appropriate exploitation strategies planned. Led by partner EURIDA, individual business models for each individual partner will be developed and optimized.

Preconditions for the successful technology optimization, scale-up and industrialization will be the enhancement of product robustness, to secure industrial integrators, securing end users and to secure financing avenues.

Product robustness: Inconsistencies in performance of CSP-CAES plants can be introduced by not flexible enough power plant operation (too slow start-up and shut down and limited load following capability) and inadequate energy storage potential and too high electricity costs. By combining CSP with CAES technology and operating different networks for different energy carriers simultaneously in a coordinated manner, the ASTERIx-CAESar approach, all this before mentioned shortcomings can be addressed, creating a very robust product.

Securing industrial integrator and end-users: This is addressed via the collaboration with the **Industrial End-user Board and Stakeholder Board** as well as other dissemination activities (ETN conferences with all relevant Turbomachinery OEMs, etc.) with the industrial sector. End users will be able to provide insight in industry needs (specifications, performance, price) for process and product optimisation, will attend demonstration rounds to showcase the CSP-CAES plant prototype resulting from ASTERIx-CAESar, in order to become partners in final scale-up projects and, eventually, with the prospect to becoming clients for the target products and services.

Securing financing avenues: Financing avenues for final scale-up and industrialization of ASTERIx-CAESar plants target a robust mix of public and private funds and include the following: **Public funding** (i.e. for innovation and business acceleration to mature technology readiness levels to TRL8-9) including for example European funding programmes & initiatives like EIC Accelerator fund or Just Transition Fund. **Private investors:** Usage of the invest EU portal that matches EU based projects with worldwide investors; Implication of traditional investors such as Energy Technology Ventures and Equinox ventures; Addressing industrial corporations investing in energy storage like Iberdrola or Engie.

The ASTERIx-CAESar consortium has the capacity to deliver industrial-scale CSP-CAES plants. Within the consortium the presence of AAL, BLUE, DSPW, SIW-S, NTT, WPS, EFG and APRIA ensures the realisation of the CSP-CAES plant at industry scale. Market introduction can be realistically expected by 2028-2029. Market assessments will be carried out by AAL throughout the project to identify target markets for directing the exploitation strategy. These target markets will be identified based on geography and customer segments and selected according to the expertise and/or business portfolios of consortium partners and the nature and innovation potential of identified KERs. **Table 7 includes the KERs so far identified by ASTERIx-CAESar partners.**

Table 7: ASTERIx-CAESar Key Exploitable Results (KER)

Key exploitable result (KER)	Partner	Exploitation potential	Target Group	Exploitation Pathway
ASTERIx-CAESar concept - small/large scale	Whole consortium	ASTERIx-CAESar concept worldwide replication	EPC, Turbomachinery companies, Utility companies (EDF, IBERDROLA, ENEL, ESKOM)	Sign an exploitation agreement with key companies and industrial stakeholders, license patents, AAL could act as primary license holder of replicating the concept worldwide.
Capacity building / professional training	CEN / ROMA3/ USE	ASTERIx-CAESar concept worldwide replication	EPC, Utility companies (EDF, IBERDROLA, ENEL, ESKOM)	ASTERIx-CAESar implementation case optimization training (application of Modelica model library)
High efficiency /cost effective solar receiver	CEN / IKTS / AAL / WPS / PSA	ASTERIx-CAESar concept, conventional CSP, process heat	EPC companies	Sign an exploitation agreement with key EPC companies, license patents
High efficiency / cost effective HEX	CEN / ROMA3 / AAL / PSA	ASTERIx-CAESar concept, CSP, CAES, SHIP,any industrial process	EPC companies	Sign an exploitation agreement with key EPC companies, license patents
High efficiency / cost effective compressor/ expander technology at small/large-scale	BLUE / USE / SIW-S/ DSPW	ASTERIx-CAESar concept, conventional CSP, CHP, CAES	EPC, Turbomachinery companies	Sign an exploitation agreement with key EPC / Turbomachinery companies (e.g. DSPW, Atlas Copco), license patents
High efficiency Rankine cycle for CAES	DSPW	ASTERIx-CAESar concept, conventional CSP, CHP, CAES	EPC	Sign an exploitation agreement with key EPC companies, license patents
Fiber optic sensor for high-temperature monitoring	EFG	ASTERIx-CAESar concept, conventional CSP, conventional power generation, high-temperature industry	High-temperature sensor market in general, Power generation industry, High-temperature process industry	Sale of sensors worldwide.
AI-based solar field control and flux monitoring unit	CEN, IME, EFG, PSA, USE	ASTERIx-CAESar concept worldwide replication, CSP tower plants in general	EPC companies, CSP power plant operators	Sign an exploitation agreement with key EPC or power plant operator companies, license patents
Heat shield and high temperature thermal insulation technology	NTT	ASTERIx-CAESar concept worldwide replication, CSP tower plants in general	EPC companies	Design and installation of heat shields / thermal insulation in commercial CSP power plants
Cost-effective design of artificial pressure vessel	CEN, AAL, ROMA3	ASTERIx-CAESar concept worldwide replication, conventional CAES, storage of gases in general	EPC companies, gas industry in general	Sign an exploitation agreement with key companies and industrial stakeholders, license patents, AAL could act as primary license holder of replicating the concept worldwide.
Application of ASTERIx-CAESar concept in power grid for stable operation and firm and reliable power supply and maximum revenues via stable grid operation	HEDNO	ASTERIx-CAESar concept worldwide replication	EPC companies, grid operators	Sign an exploitation agreement with grid operators and industrial stakeholders, to share the knowledge acquired during the project for the operation of the concept on the power grid
Innovative gas-liquid pressure exchanger	APRIA, PSA	ASTERIx-CAESar concept worldwide replication	EPC companies	Sale of pressure exchanger for implementation of ASTERIx-CAESar plants worldwide

ASTERIx-CAESar - Business Model and Business Plan for the power plant concept.

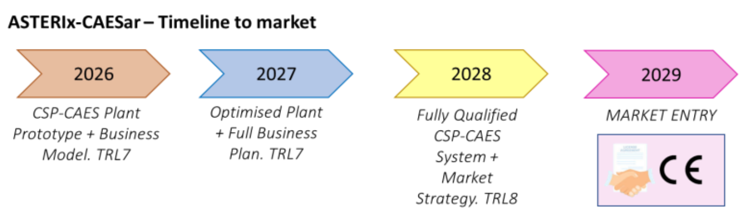


Figure 37: ASTERIx-CAESar time to market strategy

To understand the potential to reach the market, an incipient business case assessment has been performed for the project's main outcome, the power plant concept with the results showing in Table 8 by means of a preliminary Business Model Canvas designed by the consortium.

The Business Model will be further refined during the execution of WP7 together with the detailed Exploitation Roadmap to facilitate additional opportunities among consortium partners for maximizing revenues. Figure 37 shows the envisaged time-to-market for the CSP-CAES technology.

Table 8: ASTERIx-CAESar oncept Business Canvas from the point of view of a possible power plant developer or developing consortium

ASTERIx-CAESar Business Model Canvas

Key Partners

Solar receiver and tower:

► Manufacturer of ceramic foam at industrial scale (Saint Gobain Norpro / Lanik / Haldenwanger/ FCT) -> IKTS would license the industrial-scale SiC foam production

► WPS can scale production of ceramic receiver modules

► CEN would license the receiver casing manufacturing to a company expert in steel structure manufacturing.

► AAL would act as EPC company of the receiver solar receiver and tower construction

Thermal energy storage:

► Civil engineering company for large pits and lining with thermal insulation material (refractory lining) and outer concrete layers

► NTT would provide refractory lining technology

► AAL would actas EPC for TES full implementation

CAES Power/Storage cycle:

► Industrial compressor manufacturer (small/large scale – e.g. Sauer/Atlas Copco

► BLUE would provide small scale expander

► DSPW would provide large-scale expander

► Rankine cycle provider (DSPW/Turboden)

► AAL would act as EPC

Key Activities

► Power plant engineering, procurement and construction

► Solar receiver design upscaling and licensing to key producers

► Solar field engineering, procurement and construction

► CAES storage and power cycle engineering and implementation

Key Resources

► Human resources (power plant engineers)

► Supply of key components like turbo machinery, heat exchangers, thermal energy storage, piping, balance of plant, solar field, solar receiver, tower

► Financial resources and/or financial guarantees for power plant implementation

Value Propositions

► Competitive grid-scale energy storage

► Long life time of power plant with lowest environmental impact

► Higher shares of variable output renewables in the energy system.

► Higher efficiency of concentrated solar power

► Reduced operation and maintenance costs of CSP plants

► Competitive LCOS and LCOE

► Excellent performance regarding plant start-up, shut down and load following

► Black-start capability

► Power grid ancillary services (active power, frequency and reactive power control)

► 100% sustainable technology without resource limitations when upscaling

► Small-scale power plants for distributed generation

► Cheap low- to high-temperature process heat (**independentfrom fossil fuel prices**)

Customer Relationships

► Long-term relationship is established between the developer and the customer(e.g. electric utility). The developer interacts with the customer on arecurring basis *to* maximize power plant implementation

Channels

► Presence at utility and power generationconferences like "PowerGen"

► Direct contact withutilities and CSP EPC companies via the Industrial Stakeholder Board (EDF,ENEL, ESKOM, TSK Flagsol, SENER)

► Dissemination of virtual use-cases extended to additional sites after the project

► Existing partner or client relations of the projectpartners, especially AAL

Customer Segments

► The ASTERIx-CAEsar conceptis limited to high solar resource areas

► Electric utility companies

► CSP Power plant owners and operators

► Power grid operators

► Remote communities that would like to invest in firm renewable distributed small-scale power generation

► High-temperature process industry (metallurgy, glass, cement)

► Low-to-Medium temperature process industry (laundries, breweries, chemical industry)

► Specific examples: Electricite de France, Enel, Iberdrola, Engie, Fortum Corp, RWE, Energias de Protugal, ESKOM, HEDNO

Cost/Financing Structure

► Renewable energy generators require an up-front investment, which may be spread over the duration of the construction.

► The developer acquires lease and land rights, permits, interconnection agreements, power purchase agreements and any renewable certificates or feed-in-tariffs.

► The developer sells the developed project to a strategic investor and receives a development fee from the investor.

► The strategic investor (possibly a utility company) constructs the project on its balance sheet or arranges bridge finance for the construction. The strategic investor owns and operates the plant. The developer's risk is limited to thedevelopment capital.

Revenue Streams

► The most significant revenue stream comes from selling electricity to the grid, either at a fixed price (guaranteed feed-in tariff) or market price. If the installations is not grid-connected, the savings from not having to purchase electricity from other sources improve net income in the same way.

► The project creates revenues from electric energy arbitrage(energy storage).

► The project may also be hable to generate and sell renewable energy certificates or carbon emission reduction certificates, depending on the country.

Summary

SPECIFIC NEEDS	EXPECTED RESULTS	D & E & C MEASURES
1. Adaptive power generation, able to generate power when required by the grid, and to store energy when energy is available in excess, but electricity demand is low. → To maximize RE share! The increased share of non-dispatchable RE (PV, wind) cause grid instability issues and impose a limit of RE share growth. → **Energy storage is mandatory!** **2. Current CSP technology** (LCOE 7-12c€/kWh) **is not competitive against PV and wind energy** (2-5 c€/kWh). **LCOE is not the correct metric for CSP**. Due to the ability of dispatchable generation, CSP is the enabling technology for the RE revolution (energy storage). The overall cost of RE generation needs to be considered! **3.** Solar-to-electric conversion efficiency of CSP is at ≈ 21% peak at best -> similar to PV! -> **A break-through is needed for CSP to be competitive!** **4.** CSP's optical conversion, especially for central receiver technology, is more efficient at smaller power classes, but so far no small-scale competitive power cycle has been available to allow small-scale distributed CSP plants. -> **There is a need for an efficient and cost-effective power cycle from ≈1 MW_e up to ≈150 MW_e.** **5. Solar field operation at central receiver plants is complex** due to flux limits imposed by conventional tubular receivers. Higher flux density operation is needed to increase efficiency and reduce operational complexity. 6. Limited recyclability of CSP plant components 7. Limited conversion efficiency of **diabatic CAES**.	**1. An optimised novel "adaptive" power plant concept (CSP+CAES)** that can store electricity and convert solar energy into electricity at highest efficiency (**> 60% RTE, ≈40% solar-to-electric efficiency**). Besides normal power generation, the plant concept can also be efficiently combined with **process heat supply** and **desalination technology in order to provide 24/7 RE coverage** **2. A new operation strategy and business model of CSP**, which maximizes on the one hand revenue and enables highest shares of variable RE generation (PV, wind), **by providing energy storage, the magic potion!** Highly competitive LCOS of $< 10 - 15\ c€/kWh_e$, **3.** Increased **solar-to-electric peak efficiency up to 40%** due to the innovative power cycle, the high-efficient novel OVAR designs, and optimised air-air HEX. **4. A highly efficient power cycle with fast start-up, easy load variation and fast grid disconnection**, which is able to **maintain efficiency and cost effectiveness over a very wide power range (≈1 MW_e - ≈150 MW_e).** **5. Cost effective and efficient high-flux density open volumetric solar receivers** for small-scale (active absorber type) and large-scale (fixed foam type) application with reduced operational effort (reduced heliostat aiming complexity). **6. Longest life-time** of the power plants **> 25 years** with lowest environmental impact by using recyclable, non-toxic (air as heat transfer fluid) materials. **7.** Optimised concept of **adiabatic CAES**, tailored for the application in hybrid CSP-CAES plants with electricity storage **RTE of > 60%.** **8. Specific Open-source Modelica model library with use cases to be simulated online on website**.	**<u>Processes & Technology: Exploitation</u>** **A. Market entry after 1 to 2 years after project end** and commercial exploitation of the CSP-CAES technology by the project's private sector partners (AAL, DSPW, BLUE, WPS, NTT, EFG, APRIA, HEDNO), based on an **overall Exploitation Roadmap**; **B.** IP protection and exploitation of the **Key Exploitable Results (KERs)** by the project partners (see KER Table 7), **C.** Develop innovation management strategies & individual business models/plans for each project private sector partner. **<u>Communication, Stakeholder Engagement & Open Science – Knowledge Exploitation:</u>** **A.** Involvement of an **Industrial Stakeholder Board** (incl. international end users) for end-user feedback and concept adaptation to specific user needs; **B.** Provision of a **virtual pilot** via a simulation and modelling tool made accessible to end users on the project website; **C.** Policy input via **Policy Briefs** and targeted policy sessions at events; **D. Knowledge and data transfer** towards the energy community (incl. Mission Innovation countries), entrepreneurs, civil society & citizens via Fact Sheets, videos, webinars & workshops on the topics of CSP, CAES, system integration, environmental & social impacts; **E. Participation in at least 2 EU level events** (e.g. EU R&I Days and EUSEW). **<u>Communication & Dissemination – All results</u>** **A. Raise awareness** and diffuse results via the project website, targeted social media campaigns, media; **B.** Share results & data via **Open Access** peer-review publications; **C.** Communicate project concepts, impacts and novel products to the **wider public** via videos, visuals and easy-to-understand materials.

TARGET GROUPS	OUTCOMES	IMPACTS
1. Industry: End users for CSP-CAES technology, renewable energy companies, turbomachinery providers (BLUE, DSPW), power grid operators (EDF, ENEL, HEDNO, ESKOM), energy-intense industry sectors, desalination units. **2. General public, local & citizen partnerships & cooperatives:** Society at large; special opportunities for **communities in geographic regions with high CSP potential** (rural; Southern Europe, Africa, Asia); Civil society & Citizen networks & energy cooperatives (e.g. e.g. REScoop.eu); environmental NGOs; **communities with lacked access to electricity.** **3. Public bodies:** Local, regional, **national authorities in EU**, assoc. & third countries, public energy authorities & grid operators, policy makers. **4. Research and Innovation:** 'Energy' **scientific community**, **EU stakeholder platforms** (e.g. EIT InnoEnergy). Environmental science, circular economy; Climate research; Socio-economics **Collaboration with the Sustainable Desalination Living Lab at CIEMAT-PSA:** The ASTERIx-CAESar project will take advantage of the activities of the EU-project **Watermining** (https://watermining.eu): A Sustainable Desalination Living Lab is being established, where the ASTERIx-CAESar demonstration prototype will be part of as well, in order to maximize impact.	**1.** Uptake of renewable energy technologies by power grid operators and industry end users based on higher shares of RES (e.g. PV or wind) that are made possible by novel competitive energy storage concept, **ensuring higher storage capacity** than state-of-the-art molten salts TES applications in CSP plants. **2. Cost effective OVAR receiver and AI-based heliostat field aiming strategy will improve efficiency** due to the increase in allowable flux density and flux monitoring. Besides, designed turbomachinery will lead to an **adaptive operation** of the CSP-CAES plants. **3. Integration of CSP-CAES concepts in EU policies and future strategies** for renewable energies, such as the EU Green Deal, the Renewable Energy Directive, A Clean Planet for All, UN SDGs, EU Strategy for Energy System Integration etc. **4.** Web-Platform and open-source models will encourage the implantation of ASTERIx-CAESar **demonstrators in relevant locations worldwide.** **5. Upgraded business and growth strategies** of European enterprises as technology providers for CSP-CAES systems, incl. exports to Africa, Asia etc. where CSP technology is part of regional/national smart energy strategies (e.g. Saudi Arabia, UAE, Morocco, China) and other Mission Innovation countries. **6. Improved environmental profiles** for energy-intense target industries, such as cement or metal industry and special operations like desalination units requiring stable 24/7 power in often remote areas with instable grids.	**1. Wider scientific impacts:** **A.** An **increased electricity grid reliability** with high shares of renewable energy via a cost-effective and scalable storage system allowing CSP-CAES plants to store off-peak cheap electricity and discharge it when prices are high, making a **high contribution to the replacement of fossil-based energy** technologies in 2050; **B.** Support of a **CSP-CAES 'ecosystem'** to further improve and exploit the innovation potential of the technology **2. Socio-economic impacts:** CSP flexibility and storage capacity enable the **creation of new services and business models** for the management and transformation of the electricity grid, with economic and societal benefits, i.e. economic growth, EU competitiveness, job creation, reactive power compensation system, energy security. **3. Socio-environmental impacts:** **A. Improved overall CSP ecological footprint** by using only recyclable components and materials, air is used as heat transfer fluid (non-toxic); **B. High social acceptance** of new energy technologies by demonstrating an eco-friendly solution and allowing participation of consumers in energy markets; **C. Large-scale and decentralised deployment** of CSP-CAES plants will create more and 'greener' jobs than conventional centralised fossil fuel plants; **D.** CSP-CAES will strongly **contribute to EU Green Deal and RED targets** by boosting RES in grid and industry applications; it is expected to be market ready by 2028-2029.

3 Quality and efficiency of the implementation

3.1 Work plan and resources

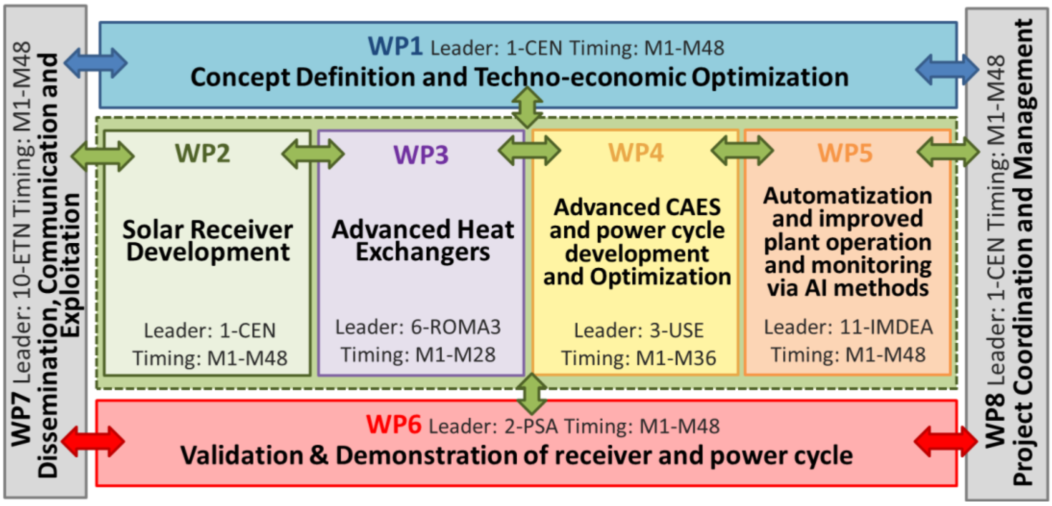


Figure 39: WP interrelation

ASTERIx-CAESar's work plan comprises 8 work packages. Figure 39 illustrates the structure of the WPs and their interrelations. ► WP1 is responsible for the overall concept specification, the definition of requirements related to WP2, WP3 and WP4, the specification of ASTERIx-CAESar prototypes, simulation models and techno-economic assessment of virtual use-cases. WP1 also deals with KPIs and risk management, as well as the project assessment in terms of environmental (LCA) and social and economic sustainability as well as social impact and acceptance. ► WP2 is responsible for the development of the solar receiver. It includes computational simulation, optimization of designs and manufacturing of absorber module prototypes for validation and demonstration. ► WP3 is focused on simulating, analysing and optimizing different technologies of low-temperature and high-temperature heat exchanger needed for the ASTERIx-CAESar concept. Besides it will be necessary to identify process control challenges and provide suitable methods. ► WP4 is responsible for the advanced CAES power cycle optimizing compressor train and expander train configuration (from small-scale ≈1 MWe up to ≈ 150 MWe), including the optimized architecture of bottoming cycles (water or organic Rankine cycles), as well as control challenges. ►WP5 focuses on automatization and improved plant operation and monitoring via AI methods. It demonstrates the developed AI heliostat control system and optical sensors at TRL 6-7 at IME tower and PSA-CRS tower facility. ► WP6 is focused on the demonstration of ASTERIx-CAESar receiver and power cycle concept (combined with a RO-desalination unit) and it is strongly related to the previous WPs results. It involves solar receiver testing at the solar furnace at PSA as well as IME tower. The solar receiver technology will be brought from TRL 5 to demonstration level in a relevant environment (TRL 6-7). WP6 also considers the integration of ASTERIx-CAESar concept in the existing H2020 research prototype of the CAPTure project (see Figure 38 regarding scales). ► WP7 caters for highly efficient communication & dissemination channels and activities. Besides, this WP is focused on KERs' exploitation, IP management and business models and management of the stakeholders group. ► Finally, WP8 is responsible for ensuring an efficient project coordination and management. Figure 40 displays the Gantt chart.

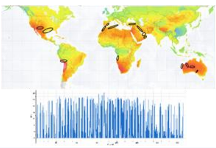
Small scale Solar-furnace Experiments (**PSA** facilities)	• Single absorber cup under representative conditions. (> 800 kW/m² mean flux)	**~10 kW_{th}**	
Demonstration scale (TRL 6-7) in relevant environment (***IMDEA*** facilities)	• Single absorber cup (tailored transportable thermal loop) • AI heliostat control system and optical sensors	**~20 kW_{th}**	
Demonstration scale (TRL 6-7) in relevant environment (***H2020 CAPTure*** prototype extension) (**PSA** facilities)	• Fixed foam receiver (1 prototype, *CAPTure* receiver adapted) • Regenerative HEX (*CAPTure* HEX system) • Air expander train (adapted *CAPTure* turbine system) • RO+GL-PX prototype powered by CAES • AI heliostat control system and optical sensors	**~480 kW_{th}**	
Commercial-scale Techno-economic Optimization	• Virtual Use-cases (at 11 relevant locations) • Open-source model library • Models on Project website ready to simulate	**~1 MW_e to ~150 MW_e**	

Figure 38: ASTERIx-CAESar scales overview

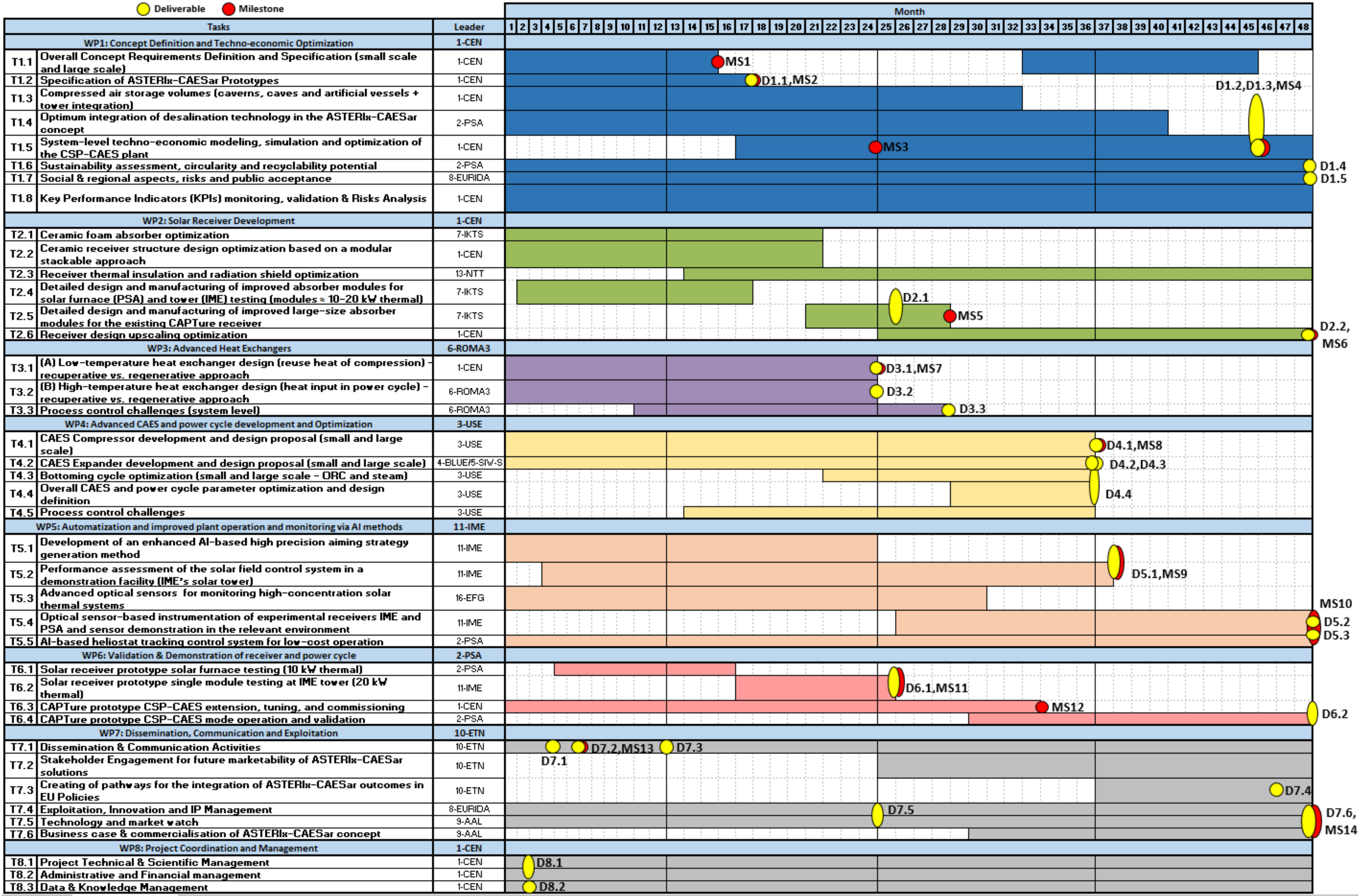


Figure 40: Gantt chart

Table 3.1a

WP number	WP Title	Lead beneficiary	Person-months	Start month	End month
WP1	Concept Definition and Techno-economic Optimization	1-CEN	111	M1	M48
WP2	Solar Receiver Development	1-CEN	104.8	M1	M48
WP3	Advanced Heat Exchangers	6-ROMA3	110	M1	M28
WP4	Advanced CAES and Power Cycle Development and Optimization	3-USE	168	M1	M36
WP5	Automatization and improved plant operation and monitoring via AI methods	11-IME	101	M1	M48
WP6	Validation & Demonstration of receiver and power cycle	2-PSA	117.5	M1	M48
WP7	Dissemination, Communication and Exploitation	10-ETN	91	M1	M48
WP8	Project Coordination and Management	1-CEN	54	M1	M48
		Total	857.3		

Table 3.1b: Work package description

Work package number	1	Lead beneficiary	1-CEN
Work package title	**Concept Definition and Techno-economic Optimization**		

Objectives

● To define requirements, specifications and possible barriers of the ASTERIx-CAESar overall concept; ● To define specifications of the experimental prototypes and validation activities to address TRL-6/7; ● Evaluation of different compressed air storage solutions (aboveground and underground) to identify the most efficient and cost-effective options; ● Techno-economic optimization of ASTERIx-CAESar concept taking into account different use-cases (also considering integration with desalination and process heat); ● To assess the environmental sustainability through Life Cycle Analysis and recyclability potential; ● To assess the socio-economic sustainability and social impact; ● Define and monitor KPIs for project development, validation, and perform the risk analysis and mitigation.

Description of work

T1.1: Overall Concept Requirements Definition and Specification (small scale and large scale) [Leader: CEN; Contr.: All, **M1-M15 & M33-M45]**

This task will define the requirements and specifications for the small scale and large scale concept of the ASTERIx-CAESar approach for its application and adaptation to a wide variety of boundary conditions and scenarios. Requirements as temperature levels, thermal outputs and storage capacities, among others, will be defined in order to optimise its integration – electrically as well as thermally - in the energy system of the future. The task is divided into two stages:

Initial concept requirements definition and specification

The first stage, from M1 to M15, will determine the overall barriers and earliest requirements that must be considered during the development of the ASTERIx-CAESar technologies and being input for other WPs (especially WP2, WP3, WP4, and WP5). The task's result is D1.1.

Second stage of requirements definition and specification

The second stage, from M33 to M45, will receive the inputs from the other WPs related to possible technological limitations or experimental results, adapting the final specifications of the ASTERIx-CAESar concept (D1.2). It will target its exploitation beyond the duration of the project and will support further research (D1.2).

T1.2: Specification of ASTERIx-CAESar Prototypes [Leader: CEN; Contr.: All**, M1-M17]**

Taking into account the first conclusions from T1.1, this task will be focused on the definition of the technical specifications that must be considered for the testing and validation of the experimental prototypes. This will include the design of the prototypes as well as the activities related with the experimental campaigns. Therefore, the conclusions of this task will be strongly taken into consideration in WP5. Nevertheless, specifications will not only be defined for an optimum design, performance, and to reach the validation at TRL 6/7 – for solar receiver prototypes and integration of CAES to CSP – but also it will be considered other important issues as can be security, transport issues and the constraints related to the modification of the already existing H2020 CAPTure facility at PSA.

T1.3: Compressed air storage volumes (caverns, caves and artificial vessels + tower integration) [Leader: CEN; Contr.: ROMA3, AAL, HEDNO**, M1-M32]**

A key requirement for the ASTERIx-CAESar concept is very cost effective storage volume for compressed air. Therefore, taking into account the first requirements from T1.1, this task will analyse different alternatives in order to determine the most favourable option for the ASTERIx-CAESar concept, focusing on the isochoric approach. On the one hand, artificial above-ground air storage volumes will be evaluated, including its integration with the structure of the CSP tower and the reuse of recycled gas pipelines as storage volume. This task will analyse the vessel design approach, taking into account existing pressure vessel and construction codes. If necessary, structural calculations will be done of key components or critical zones. The design of the air storage vessel and its possible integration in the CSP tower will be defined, identifying all key design constraints and requirements, paving the way for future commercial-scale implementation. On the other hand, this task will search for the most promising locations of classical underground solutions such as solution-mined salt caverns, gas fields or abandoned mines within high DNI resource areas in order to allow cost-effective air storage for the large-scale approach. A detailed techno-economic evaluation will be carried out and results will be input to the use-cases of task T1.5.

T1.4: Optimum integration of desalination technology in the ASTERIx-CAESar concept [Leader: PSA, Contr.: APRIA, CEN, AAL**, M1-M40]**

In this task, needed specifications modifications of existing liquid-liquid ERDs will be analysed, and a prototype of a gas-liquid pressure exchanger (GL-PX) will be designed (D1.2) and implemented by partner APRIA to be installed (together with a small-scale reverse osmosis system) into the adapted CAPTure facility at PSA for demonstration at TRL 6-7. In parallel, the application of the developed pressure exchanger will be evaluated theoretically for small- and large-scale future commercial usage (PSA, APRIA). Furthermore, the potential of thermal desalination (powered by the low-temperature waste heat) to achieve Zero Liquid Discharge (ZLD) by treating the brine from the reverse osmosis system will be evaluated theoretically (PSA, CEN). ZLD processes are only possible with thermal desalination technologies (less sensitive to high salinity than reverse osmosis) and they allow to obtain added value products from the brine, which lead to circular economy.

T1.5: System-level techno-economic modelling, simulation and optimization of the CSP-CAES plant [Leader: CEN; Contr.: ROMA3, HEDNO, AAL, USE, BLUE**, M17- M48]**

Considering the ongoing change of the energy system from centralised to de-centralised power generation, the crucial task of the project is to find the optimum power rating for the innovative hybrid CSP-CAES plant. Important questions that need to be answered are: What is the optimum solar multiple? What is the optimum power rating of compressor and expander train? What is the best bottoming cycle configuration (steam or ORC)? What is the optimum combination of storage capacity between compressed air storage and thermal energy storage (LT and HT)? What is the optimum solar field size and CSP tower height (considering optical performance as well as the needed air storage capacity in the CSP tower)? What is the best overall integration in the energy system considering process heat interfaces as well as desalination? Clearly, all these questions need to be answered by doing annual performance simulations under a variety of boundary conditions such as solar resource, electricity market, as well as process heat demand. Therefore, an exhaustive techno-economic optimization study will be done, considering different power plant locations, energy market boundary conditions as well as the integration in the energy system (industrial process heat supply and integration of desalination processes). Several use-cases (11) around the world will be analysed and results will shed light on how to optimise the ASTERIx-CAESar concept and increase its social and market impact in different scenarios. For example, two reference use cases (see Table 4) will be implemented for Greece, where partner HEDNO will provide detailed information regarding power grid operation. A dedicated open-source Modelica model library will be developed and all studied use-cases will be available to the public, ready to simulate (on project website in interactive manner and with public Modelica model library in any Modelica tool after download) (D1.3).

T1.6: Sustainability assessment, circularity and recyclability potential [Leader: PSA; Contr.: CEN, EURIDA**, M1-M48]**

An environmental sustainability assessment will be carried out, through the use of the Life Cycle Assessment (LCA) methodology. LCA will be carried out to quantify, in a scientific manner, the environmental impacts (environmental burden) of the considered system "from cradle to grave", according to standards, that will define the direct and indirect impacts of the proposed solutions through a detailed data collection. Data collection envisages the strict cooperation with partners to enter in each specific task with particular regard to WP2, WP3, WP4 and WP5. Also, the environmental impact on the use-cases will be studied. The LCA will cover the following four stages: Determination of the goal, scope and system boundary; Life Cycle Inventory (LCI) analysis of inputs and output; Assessment of environmental impact; Interpretation of results with proposals for improvement. LCI will be based on the material and energy balances derived from both industrial and experimental data, as well as modelling activities within the project. Various environmental KPI will be calculated and compared within this task. Specific LCA tools, such as SimaPro or Gabi, and databases, such as Ecoinvent, will be used for that purpose. As an impact assessment the Environmental Footprint method, harmonized by the European Commission, will be used. The environmental performances of the ASTERIx-CAESar concept will be compared to the state of the art in the field.

Complementing the environmental assessment, this task will also conduct a socioeconomic assessment of the ASTERIx-CAESar solution. The potential socioeconomic impacts of the investments needed will be studied, considering the outputs of the techno-economic modelling T1.5 of the ASTERIx-CAESar solution and simulations and optimization of each use-case. This assessment holds a key role in evaluating the potential impacts of a new

renewable de-centralised power generation system in value added and employment creation. Using multiregional input- output analysis (MRIO), this task will estimate where (in which countries and sectors) impacts take place. The multi-regional Input-Output Table EXIOBASE (https://www.exiobase.eu/) will be used for this task.
In addition, besides the environmental and socioeconomic impact assessment, this task also analyses in detail the recyclability potential of all applied materials and components in order to minimize the environmental footprint. This approach allows the assessment of circularity by the use of the Material Circularity Indicator (MCI), developed by the Ellen MacArthur Foundation. Thanks to the availability of primary data and the use of specialised software, the value and robustness of the analysis will be very high. The task is active from the beginning of the project and interactive with all development tasks (especially with those mentioned). (D1.4).

Task 1.7: Social & regional aspects, risks and public acceptance [Leader: EURIDA; Contr.: All**, M1-M48]**

This task will assess social sustainability aspects of the systems defined in previous tasks. It will be based on the UNEP guidelines (2020) for social LCA and add complementary methods from social impact assessment (SIA) if/where needed. A SWOT workshop on social aspects with all project partners will be conducted around M24 to capture existing expert knowledge. Among the effects investigated are more common aspects such as employment, income (based on inputs from task 1.5), rural development, inclusiveness, labour rights, health and safety, human rights, competition about resources etc. Social risks will be assessed using available data from the Social Hotspot Database (SHD), the ecoinvent database and similar sources. Task 1.7 will further cover an in-depth social acceptance assessment. This will be an iterative process (following the design thinking methodology). to provide feedback from end users and civil society on the project concept and prototypes. Assessments will be based on concept/value proposition ideas, images, videos or the physical prototypes, depending on the stage of development. The methodology consists of a case study with qualitative interviews (40 in 1 EU country), complemented by quantitative techniques (electronic interviews, 10 EU countries; KPI: 400 interviews per country). For the case study, the participants will be selected from partners' client databases and extended networks, using a stratified sampling method to assure the balance in gender, age, cultural, economic and rural-urban backgrounds. Goal of the study is to provide qualitative or semi-quantitative information for partners and stakeholders in terms of: Value proposition comprehension, likeability, value perception, price perception, main barriers, buying intention, competitors' analysis (comparison with reference concepts available in the market) and marketing/communication strategies. The results will be included in D1.5.

T1.8: Key Performance Indicators (KPIs) monitoring, validation & Risks Analysis [Leader: CEN; Contr.: All**, M1-M48]**

In this task, CEN will manage the ASTERIx-CAESar Project's KPIs, in order to control and monitor the results of the development, validation of the project and the risks that may arise during the project execution in order to apply for contingency plans, when necessary. Additionally, this task will include the evaluation of risks related to further exploitation of this technology such as specific business needs (investments, technological feasibility, etc.), market trends, environmental issues or standards and regulations.

Work package number	2	Lead beneficiary	1-CEN
Work package title	**Solar Receiver Development**		

Objectives

● Optimizing the ASTERIx-CAESar solar receiver based on the developments done in the finished H2020 project CAPTure; ● Optimize the ceramic foam solar absorber to maximize life time for high-flux-density commercial operation; ● Optimize the ceramic receiver structure (stackable free floating modules); ● Optimize the ceramic receiver air flow guiding elements (orifices, dampers); ● Optimize the high-performance thermal insulation and radiation shields; ●Perform an iterative optimization procedure combining numerical as well as experimental evaluation at module (10-20 kW thermal) as well as validation/demonstration scale (480 kW thermal); ● Design and manufacture receiver prototypes in order to be tested experimentally at module and validation scale; ● Optimize material utilization taking into account cost, manufacturing as well as environmental impact.

This work package develops the ASTERIx-CAESar solar receiver, based on the open-volumetric ceramic foam technology, introducing a modular stackable free floating receiver structure to optimize cost and durability. The design will be evaluated at small-scale/module level (solar furnace, ≈10 kW thermal; experimental tower, ≈20 kW thermal), as well as at validation/demonstration scale (modified CAPTure solar receiver prototype, ≈ 480 kW thermal).
The development activity will start from the experience obtained within the 5 year research project CAPTure. The first objective is to move to larger module sizes (e.g. 20 x 20 cm, maybe up to 30 x 30 cm) in order to reduce the cost of the ceramic receiver structure, which supports the ceramic foam tiles (see Figure 10). The second objective is to increase oxidation resistance and mechanical strength of the foam absorber in order to maximize life time under high-flux commercial operation.

T2.1: Ceramic foam absorber optimization [Leader: IKTS, Contr.: CEN, PSA, AAL, WPS, NTT**, M1-M21]**

Foam oxidation resistance improvement and manufacturing cost reduction:
Requirement for a long-term stable receiver foam is the oxidation resistance of the ceramic material, which depends on the density of the microstructure. Within the mentioned CAPTure project, a significant increase of the oxidation and mechanical stability of the pressure-less sintered silicon carbide receiver foam tiles was achieved, but only enabled by a complex manufacturing technique. Aim of the task is to simplify the preparation technique of the foams to reduce costs and simultaneously keep or even increase the oxidation resistance and mechanical stability. For this purpose, a slurry development will be performed to improve the coating quality of foam struts. Additionally, the heat treatment needs to be optimised in order to reach a crack-free sintering process, despite an expected linear shrinkage of up to 20%. This development is mandatory to increase the tile size up to 20 x 20 cm or even larger, without additional preparative effort and, thereby, decrease receiver costs by reducing the number of necessary components.

Thermomechanical simulation and analysis
Based on the successfully tested CAPTure receiver prototype and already developed FEM and CFD models, CEN and IKTS will revise the modelling approach and apply it to a set of design proposals increasing the individual absorber foam module size. For each geometry alternative, the detailed 3-D temperature and resulting stress field needs to be resolved, including steady-state as well as transient analysis (thermal shock). Detailed CFD modelling will be done in ANSYS Fluent (CEN) with a subsequent FEM thermomechanical analysis in ANSYS mechanical (CEN and IKTS). Thermal CFD models will be validated with experimental data obtained from single-module testing (T6.1, T6.2). The design approach will be iterative, i.e. after a first experimental feedback from solar furnace (PSA – T6.1) and tower (IME – T6.2) testing, the final improved absorber foam absorber module design will be elaborated in order to implement the testing at 480 kW_{th}.

T2.2: Ceramic receiver structure design optimization based on a modular stackable approach [Leader: CEN, Contr.: WPS, IKTS, PSA, AAL, NTT**,** IME, **M1-M21]**
In this task, the already successfully tested CAPTure receiver concept (TRL 5) based on stackable free floating absorber modules (cups) will be further optimized in two ways: (i) by increasing module size, and (ii) by improving the ceramic material, introducing the all-oxide ceramic matrix composite (OCMC) technology (partner WPS) [38]. This new material will reduce weight and will allow cost reductions, compared to the conventional approach. Besides optimizing the ceramic module (cup) geometry and material, also the remaining structural components (guiding tubes) as well as elements for air flow adjustment need to be improved and optimized in this task. Similar to T2.1, an iterative optimization procedure will be applied combining numerical as well as experimental evaluation at module scale (20 kW thermal (T6.2)).

T2.3: Receiver thermal insulation and radiation shield optimization [Leader: NTT, Contr.: CEN, PSA, AAL**, M14-M48]** The receiver ceramic structure (stacked modules and foam absorbers) is contained in an internally insulated stainless steel box (see Figure 13). The weight of this box and the ceramic receiver structure needs to be supported by steel beams forming the main frame of the receiver (see Figure 12). This task will optimize the internal insulation with the objective to find the best compromise between total insulation thickness, complexity of insulation layers, material and installation costs and thermal performance. An iterative procedure will be applied based on numerical simulations as well as selected experiments and assembly tests at small-scale in the workshop of NTT. Besides the internal thermal insulation of the receiver housing, the radiation shields that protect the receiver main frame (supporting beams) needs to be designed and optimized for the commercial up-scaled replication. Also here, an iterative procedure will be applied based on numerical simulations, selected experiments and assembly tests. Within the existing CAPTure receiver radiation shield, some zones are prepared so that different specimens may be interchanged in order to further validate and demonstrate promising high-temperature materials (see Figure 13).

T2.4 Detailed design and manufacturing of improved absorber modules for solar furnace (PSA) and tower (IME) testing (modules ≈ 10-20 kW thermal) [Leader: IKTS, Contr.: WPS, CEN, IME, PSA, AAL, NTT**, M2-M17]** At the beginning of the project (M2), this task starts with a small-scale detailed design and manufacturing of an absorber module (cup) that fits for the solar furnace testing. Due to the small focal spot of the furnace, the aperture size of the module will be at the maximum 10 cm x 10 cm. The first testing round at the solar furnace will target thermal evaluation at high solar flux density (> 1.5 MW_{th}/m^2) and temperatures up to 800ºC. Several small ceramic foam absorber samples will be provided in order to evaluate the impact of varying foam parameters on efficiency and oxidation resistance under high-flux conditions. In parallel, after the first thermomechanical study of improved large-size module geometries via simulations (T2.1.2), the most promising ones will be chosen and a detailed design of one module will be elaborated, taking into account the interfaces required by the IME tower experimental setup. The manufacturing will be led by IKTS and WPS. Besides thermal behavior at the highest possible flux density, the experimental activity (T6.1, T6.2) at single-module level will also cover the evaluation of different orifice configurations in order to confirm correct air flow distribution for the up-scaled receiver design.

T2.5 Detailed design and manufacturing of improved large-size absorber modules for the existing CAPTure receiver [Leader: IKTS, Contr.: WPS, CEN, PSA, AAL, NTT**, M21-M28]**

Based on the results of the single module testing activity at IME, the detailed design of the optimised large-size ASTERIx-CAESar absorber modules will be done (D2.1), with the objective to reuse the existing CAPTure experimental receiver casing and replace the smaller CAPTure modules by the larger and optimised ASTERIx-CAESar modules. Besides structural improvements, targeting life time extension and cost reduction, another crucial point will be the optimization of the passive air flow control in order to obtain a homogenous air outlet temperature. The manufacturing will be led by IKTS and WPS.

T2.6 Receiver design up-scaling optimization [Leader: CEN, Contr.: IKTS, WPS, PSA, IME, AAL, NTT**, M25-M48]** Based on T2.5 and the experimental results (WP6), the receiver concept upscaling will be analysed with support of numerical simulations. A possible design solution is already depicted in Figure 12. The design proposal needs to address the conceptual design of the receiver casing, the internal thermal insulation, the radiation shield, as well as absorber module mounting and fixation. Another important factor is to numerically confirm (CFD study) correct air flow distribution for the up-scaled receiver design, taking into account realistic solar flux boundary conditions. A series of specific orifices and adjustable air flow dampers in the rear volume of the receiver will be analysed. The final up-scaled receiver design proposal of the fixed absorber concept will be reported in D2.2. A crucial part of the upscaling activity will be the consideration of recyclability and sustainability and must be evaluated coherently in collaboration with Task T1.6 (WP1).

Work package number	3	**Lead beneficiary**	6-ROMA3
Work package title	**Advanced Heat Exchangers**		

Objectives

● Identify the optimum heat exchanger configuration for low and high temperature exchangers (complete design study on paper); ● Perform a detailed parametric design study applying 1-D Modelica models; ● Feed/fine-tune the Modelica code with heat transfer and pressure drop parameters coming from CFD modelling and experiments; ● Benchmark the classic indirect recuperative heat exchanger concept against regenerative heat exchangers; ● Optimum material selection considering cost, performance as well as environmental impact and recyclability; ● Identify process control challenges and provide suitable methods

Description of work

Two separate heat exchanger trains are needed for the ASTERIx-CAESar concept, i.e. **(A)** the so-called low-temperature heat exchanger (intercoolers / preheater) needed for the adiabatic CAES (connected to the low-temperature TES), and **(B)** the so-called high-temperature heat exchanger train needed to heat and reheat the air before expansion in the expander stages. Both heat exchangers need to exchange heat between two air streams with very high pressure differences (up to 150 bar), which is a cumbersome design task due to significant density differences, especially at high temperature. Nevertheless, the appropriate heat exchanger design is an implementation challenge, rather than a technological one, i.e. the necessary equipment can be obtained by combining available high-TRL solutions.

T3.1: (A) Low-temperature heat exchanger design (reuse heat of compression) - recuperative vs. regenerative approach [Leader: CEN; Contr.: AAL, ROMA3, IKTS, NTT, USE, PSA**, M1-M24]**

The crucial aspect in order to reduce CAPEX is to use the same components for intercooling/aftercooling (charging) and air heating before expansion (discharging). Two different approaches will be covered: (i) the classical indirect recuperative approach, where the two air streams are separate from each other and heat transfer happens through duct walls; and (ii) where air is heated and cooled in one single duct or vessel while passing through porous heat storage media. Both approaches will be analysed in detail numerically and a fair benchmarking will be done based on the extensive heat exchanger design experience within the consortium (CENER, AAL, ROMA3, PSA). Detailed 1-D distributed parameter heat exchanger models will be created using Modelica modelling language. The modelling procedure will be based on existing Modelica model libraries (e.g. [81]) as well as on in-house developments [70]. The developed 1-D Modelica code will be fed and fine-tuned with convective heat transfer and pressure drop performance obtained from literature or (if needed) specific 3-D CFD simulations in ANSYS Fluent or lab-scale experiments at CIEMAT-PSA. Regarding design approach (i), only tubular heat exchanger geometries are viable because of the very high pressure difference of up to 150 bar between the air streams. The classical shell-and-tube heat exchanger design will therefore be the base case, which will be benchmarked with variants including passive heat transfer enhancement methods. Very promising is the application of corrugated tubes (even double corrugated tubes) that have the potential to enhance the performance by up to 25% [82]. Furthermore, other types of tubular primary surface geometries that are viable for high pressure differences will be considered. Considering design approach (ii), also dedicated Modelica distributed parameter models will be developed (partly assisted by CFD simulations for heat transfer and pressure drop, if necessary), being able to simulate tubular regenerator-type heat exchanger configurations. Besides geometric optimization (regenerator bed length and diameter), also advanced filler materials (e.g. PCM [69]) will be analysed. For both approaches, (i) and (ii), an extensive parametric sizing and optimization will be performed. The outcome will be the optimum heat exchanger configuration, which may be dependent on nominal power. Besides heat exchanger specifications, this task will also tackle the dimensioning of connected air piping and valves. Additionally, all involved project partners will review and select the most appropriate materials for the heat exchanger designs analysed within this work package. The selection process must cover material cost considerations, operating temperature limitations, high-temperature oxidation resistance, as well as manufacturing possibilities. Also recyclability and sustainability are important and must be evaluated coherently in collaboration with Task T1.6 (WP1).

T3.2: (B) High-temperature heat exchanger design (heat input in power cycle) - recuperative vs. regenerative approach [Leader: ROMA3; Contr.: CEN, AAL, USE, PSA, NTT, SIW-S**, M1-M24]**

The activity of this task will be equivalent to the previous one, but focusing on the high temperature application for heating pressurised air to high temperature (up to about 800ºC) prior to expansion in the expander stages. The design study will start based on experience obtained in the process industry working with similar pressures and temperatures. Due to the high pressure difference between fluid streams, tubular heat exchanger geometry will be the only design choice for option (i) – recuperative heat exchangers. The activities regarding regenerative heat exchangers (option (ii)) will continue the developments of the CAPTure project, tailoring the design to the CAES application. Since the pressurization process before regenerator discharging is much simpler (CAES application) than in the case of an externally heated Brayton cycle, the requirements for controllability of the large-diameter atmospheric valves is not needed, i.e. poppet type "check valves" or on/off ball valves (see Figure 26) can be applied. The upscaling is however limited by size limitations of available high-pressure valves, which makes the regenerative concept only suitable for the small-scale application. For both approaches, (i) and (ii), an extensive parametric sizing and optimization will be performed based on detailed distributed parameter models in Modelica. Apart from specific CFD simulations regarding heat transfer and pressure drop, also FEM structural modelling may be required of some critical sections in order to check viability of design. The outcome will be the optimum heat exchanger configuration, which may be dependent on nominal power. Besides heat exchanger specifications, this task will also tackle the dimensioning of connected air piping and valves.

T3.3: Process control challenges (system level) [Leader: ROMA3; Contr.: USE, CEN, AAL**, M11-M28]**

The ASTERIx-CAESar system operation imposes control challenges that will need to be correctly addressed. The difficulties are related to the heat exchange processes (transient behaviour of the temperature distribution - thermocline) within the regenerative matrix, as well as the operation under greatly varying pressures between charging and discharging mode. The control design challenges will be targeted for the best heat exchanger configuration of tasks T3.1 and T3.2. Additionally, the heat exchanger (L-HEX and H-HEX) operation is closely linked with compressor, expander operation (inlet temperatures) and pressure vessel charge/discharge control, which must be taken into account as well. Realistic boundary conditions for all components will be assumed based on vast experience within the consortium. Rather than providing an optimised control design for a specific configuration, this task should identify control issues and shall propose possible solutions or methods, i.e. pave the way towards future commercial scale implementation.

Work package number	4	**Lead beneficiary**	3-USE
Work package title	**Advanced CAES and power cycle development and Optimization**		

Objectives

● Provide optimized layouts of compressor and expander trains for small-scale (≈1 MWe) as well as for large-scale implementation (up to about 150 MWe); ● Propose design modifications based on available turbomachinery; ● Establish reliable turbomachinery performance maps and cost data for the techno-economic optimization study in WP1; ● Address turbo-machinery specific control issues; ● Design and optimization of the bottoming cycle architecture (steam or organic working fluid Rankine cycle); ● Overall parameter optimization and definition of the novel energy storage and combined cycle power generation unit; ● Establish overall performance and cost data for the techno-economic optimization study in WP1.

Description of work

The ASTERIx-CAESar concept is appropriate for both small and large scales, but the power range of interest has a very strong influence on the choice of the appropriate compressor / expander technology. The analysis is furthermore different for compressors and expanders. For compressors, reciprocating and turbocompressors can be used, most likely in multi-stage, intercooled arrangements. Moreover, for turbocompressors, multi-stage centrifugal or multistage axial followed by single or multistage centrifugal is also possible. Whichever the case, different layouts and control features have to be explored in order to reunite flexibility, cost and performance. For expanders, radial inflow or axial turbines are the technologies of choice. Boundary conditions used throughout WP4 are determined by WP1 and WP3 (inlet temperature to the expanders) and the results from WP4 feed back into WP1 and WP3. Therefore, strong interaction with these WPs is foreseen. For each of the power bands being investigated, a set of appropriate operating parameters will be developed and fed into the overall techno-economic optimization study in WP1.

T4.1: CAES Compressor development and design proposal (small and large scale) [**Leader: USE**, Contr.:

ROMA3, CEN , BLUE, **M1-M36]**
The CAES charge rate is expected to be significantly lower than the discharge rate, which means that the compressor train's nominal power will be lower than that of the expander. The activity will cover a thorough review of existing industrial air compressor stages, compiling available pressure ratios as well as other relevant performance parameters (efficiency, inlet/outlet temperatures, flow range, etc.). This activity will be led by partner USE, with inputs from ROMA3 and CEN regarding intercooler (L-HEX) parameters. Viable combinations of compressor stages and pressure ratios will be determined. Depending on restrictions of available compressor stages, design modifications will be proposed based on the significant experience within the consortium. Led by partner USE, detailed performance characteristics of the chosen combinations of compressor stages (and design modifications) will be developed (compressor performance maps, flow range, efficiency, speed, etc.) together with reliable cost data, covering a wide flow/power range. This will form the input for the techno-economic optimization study in WP1. An important aspect is the actual power demand by the compressor train as function of pressure build-up in the air storage vessel. This relationship needs to be well established through detailed analysis of the control features built into the compressor (variable speed, variable guide and/or stator vanes and surge-prevention measures) and also the operating strategies throughout the charging process. This information will be used in the techno-economic optimization study (grid boundary condition) in WP1. Regarding intercooler design and sizing, a relevant interface exists with WP3. Heat exchanger pressure drops and intercooling temperatures will be defined in close collaboration between WP3 and WP4.

T4.2: CAES Expander development and design proposal (small and large scale) [M1-M36]

T4.2.1: Radial expanders – small-scale application [Leader BLUE*, Contr.: USE, CEN, ROMA3]:* A multistage expander with the capability to operate in series/parallel depending on vessel pressure will be proposed in order to achieve a wide inlet pressure range. At the start of the discharge cycle, all stages are active. As the storage vessel pressure drops, the high-pressure stage will be bypassed, only the low pressure stage(s) remaining active. Additionally, the utilization of variable nozzle guide vanes for enhanced flexibility will be explored. Viable combinations of expander stages and pressure ratios will be determined and modelled to determine the actual generated power as function of pressure drop in the air storage vessel. This relationship needs to be well established and is input for the techno-economic optimization study (grid boundary condition) in WP1. Regarding air heater and re-heater design and dimensioning, a relevant interface exists with WP3. Related pressure drops and reheat temperatures will be defined in close collaboration between WP3 and WP4. Depending on restrictions of available expander stages, viable design modifications will be proposed based on the experience within the consortium (BLUE, USE). Led by partner BLUE, detailed performance characteristic of the best combination of expander stages will be elaborated (turbine performance maps, flow range, efficiency, speed, etc.) together with reliable cost data, covering a wide flow/power range. This will form the input to the techno-economic optimization study in WP1.

T4.2.2: Axial expanders – large-scale application [Leader: SIW-S*, Contr.: DSPW, USE, CEN, ROMA3]:* The work related to the large-scale expander train will be equivalent to T4.2.1, but applied to large machines. Axial expanders will be considered in this case for more compact, higher efficiency, multistage turbomachinery. A configuration based on proven technology will be considered: the high-pressure casing will be based on steam turbine technology (with lower inlet temperature, TIT < 600ºC), while the low-pressure casing will be based on gas turbine technology (TIT ≈ 700-800ºC). Partner DSPW will lead the high pressure stage development. The targeted air turbine segment will consist of 3 model packages in the range 20 MW - 100 MW, represented by three models 20 MW, 50 MW and 100 MW. Partner SIW-S will lead the low-pressure stage development, deriving design parameters from existing externally fired gas turbines, with inlet temperature up to 800ºC. For both, high-pressure and low-pressure stages, the design work includes heat balance calculations, design drawings with layout and dimensions, data sheets and specifications, functional diagrams, as well as pricing data together with a description of the associated operating envelope and scope of application. Regarding air heater and re-heater design and dimensioning, a relevant interface exists with WP3 (CEN, ROMA3). Related pressure drops and reheat temperatures will be defined in close collaboration between WP3 and WP4. Led by partner SIW-S, detailed performance characteristic of the best combination of expander stages will be elaborated (turbine performance maps, flow range, efficiency, speed, etc.) together with reliable cost data, covering a wide flow/power range. This will form the input to the techno-economic optimization study in WP1.

T4.3: Bottoming cycle optimization (small and large scale - ORC and steam) [Leader: USE, Contr.: CEN, DSPW, SIW-S, ROMA3**, M22-M36]**
The architecture of the bottoming cycle depends on the air exit temperature of the topping air expander stage, i.e. the inlet temperature of the heat recovery steam generator (HRSG). In order to define the optimum expander exit temperature (EET), several air-cooled Rankine cycles will be designed for a wide range of EET (starting from ≈ 200°C for ORC application, until about ≈ 500°C for steam cycles). The Rankine cycle simulations will be performed using a state-of-the-art power cycle simulation software (IPSEpro, Thermoflow, or similar in-house codes), which allows the design and steady-state simulation of HRSGs, taking into account industrial standards.

The HRSG is aimed at recovering as much heat as possible from the Brayton cycle exhaust (which is best performed by using low-pressure steam), while enabling a good Rankine cycle conversion efficiency (best achieved at high steam pressures). For every EET, a case study needs to be performed, optimizing steam generator pressure levels to maximize heat recovery and power output. The design proposal needs to be done for different flow ranges taking into account realistic isentropic efficiencies of turbine stages. The output of this task will be a performance table, giving bottoming cycle efficiency as function of EET, HRSG air flow and ambient temperature, as well as related cost data [1].

T4.4: Overall CAES and power cycle parameter optimization and design definition [Leader: USE, Contr.: CEN, SIW-S, ROMA3, DSPW, BLUE**, M29-M36]**

This task will compile all performance parameters of above described tasks and will define and optimize the overall performance of the proposed innovative thermodynamic cycle (CAES + power cycle). For each of the power bands being investigated, a set of appropriate operating parameters will be developed and fed into the overall techno-economic optimization study in WP1.

T4.5: Process control challenges [Leader: USE, Contr.: BLUE, SIW-S**, M14-M36]**

Compressor and expander stages need an active control system actuating on the control elements featured (e.g. speed, Variable Inlet Guide Vanes, Variable Diffuser Vanes, etc.), also considering series/parallel configuration. Realistic boundary conditions for all components will be assumed based on vast experience within the consortium. Equivalent to T3.3, rather than providing an optimised control design for a specific configuration, this task should identify control issues and shall propose possible solutions or methods, i.e. in order to pave the way towards the future industrialisation of the technology at different scales.

Work package number	5	**Lead beneficiary**	11-IME
Work package title	**Automatization and improved plant operation and monitoring via AI methods**		

Objectives

● Develop a fast, dynamic, accurate, adaptive, and predictive AI-based heliostat control system for CSP central receiver plants to ensure a well-defined and stable solar flux distribution; ● Develop a reliable fibre-optic based sensor measurement system for the concentrated solar flux and temperature distributions on central receivers; ● Demonstrate the AI-based heliostat control system during at least 6 months of operation at IME and PSA CRS experimental tower in relevant environment.

Description of work

T5.1: Development of an enhanced AI-based high-accuracy high-precision aiming strategy generation method [Leader: IME, Contr.: CEN, USE, PSA**, M1-M24]**

This task will develop a high-accuracy high-precision aiming point strategy generation applying AI methods, which capitalises the developments from the CAPTure H2020 project [29] as well as existing know-how within the consortium (CEN, IME, USE, PSA). The CAPTure aiming point strategy optimization lies in a method that combines Dijkstra's and Nelder-Mead algorithms and needs to be further improved and automated for general application by means of applying AI techniques. AI allows for solving the aiming point strategy optimization problem, which requires the individual aiming point of a large number of heliostats be properly assigned on the receiver aperture as function of solar position, DNI level and cloud movement (input from vision-based AI "now casting" developed in T5.5).

The aiming point strategy generation algorithm will be developed and validated using optical modelling of the IME's solar field (Figure 18), which is retained as reference case (numerically in T5.1 and experimentally in T5.2). Firstly, a database gathering the available heliostat optical features will be generated by IME. This database will be used as input for the dedicated AI algorithm as well as the numerical tool for optical modelling of the solar field (i.e. Tonatiuh). In parallel, IME, CEN, USE and PSA will establish an experimental plan that contains all available options met in the routine operation of the IME's solar field. The corresponding flux distributions computed by the numerical tools will become the database to train the AI-based algorithm.

One crucial feature of the method is the adequate modelling of the optical image of each heliostat. By combining computational-intensive approaches, based on ray tracing, with simpler methods, based on flux profile generation by e.g. using convolution of Gaussian functions, a good trade-off between accuracy and computational effort will be achieved. The final flux map estimation is obtained by superimposing all individual images.

An additional analysis will be performed in order to assess the minimum number of cases from the experimental plan to obtain a suitable aiming strategy generation method and the goodness of the training as a function of the number and type of selected cases. This action will help to establish the actual experimental plan to be carried out in T5.2.

T5.2: Performance assessment of the solar field control system in a demonstration facility (IME's solar tower) [Leader: IME, Contr.: CEN, USE**, M4-M37]**

The aiming point generation method developed in T5.1 will be demonstrated using the existing research infrastructure at IME in Madrid (experimental tower see Figure 18). A new and accurate optical characterization of individual heliostats will be performed using a new heliostat characterisation pole (see Figure 19), which will be installed in the IME's solar field. The resulting experimental information will be used to create a detailed characterization database that will feed as input the AI algorithm. The aiming point generation software (from T5.1) will be connected to the SCADA (System Control and Data Acquisition) of the IME's solar tower and further trained with real flux measurements monitored and analysed by conventional indirect methods (CCD camera and moving bar with installed flux sensor for camera calibration). The developed and implemented AI flux generation method will be trained, tested and demonstrated for at least 6 months of operation at the IME experimental tower.

T5.3: Advanced optical sensors for monitoring high-concentration solar thermal systems [Leader: EFG, Contr.: USE, CEN, IME **, M1-M30]**

This task addresses the design and development of new fibre-optic sensors capable of solar flux and temperature monitoring in high-temperature environments (> 800 °C). The proposed objective is the measurement of concentrated solar-flux above 1.5 MW/m2 and temperatures above 800 °C for long periods of operation. Several challenges need to be addressed related to temperature resistant optical fibre sensors (appropriate light acceptance angle, appropriate choice of light detecting photodiodes, low-cost manufacturing, calibration as well as long-term operation). Typical solar receiver service conditions approach the softening temperature of standard glass types (845 °C) at which the operation of fibre optic sensors becomes challenging. To ensure satisfactory sensor specifications, careful optimization of sensor components (like the fibre material and its doping with impurity atoms or the protective tubing) is necessary, as well as the development of favourable pre- and post-treatment procedures. Promising options are pure core fibres with a core of pure silica glass that has a softening point of > 1000 °C, or Sapphire fibres. While pure core fibres may still be troublesome because of the lower softening point of the cladding glass and known issues with drift, they are much easier to assemble i.e. connectorizing and splicing. In addition, the fibre material costs only a few €/m. In contrast to that, Sapphire fibres cost several hundred €/m and assembly is difficult and adds extra costs. For this reason different types of both Sapphire and pure core fibres will be evaluated both theoretically and experimentally, to find the best solution for the application. Temperature sensors in the selected fibre will then be optimised and characterised for the specific requirements of the application. Calibration routines are to be defined to take into account inevitable fiber optic sensor drift over time. Furthermore, the actual FBG-temperature sensors to be used must be well designed to avoid overlap of the indicative reflected wavelengths of the fibre Bragg gratings.

T5.4: Optical sensor-based instrumentation of experimental receivers at IME and PSA and sensor demonstration in the relevant environment [Leader: IME, Contr.: USE, EFG, CEN, PSA**, M26-M48]**

The IME experimental tower has a very busy testing schedule, so that flux sensors can be tested during sufficient time taking advantage of different research projects' testing activities. Thus, in this task, experimental receivers at IME will be equipped with prototypes of the ASTERIx-CAESar optical sensors and the operation of the sensors will be demonstrated under realistic conditions during at least 6 months of operation. Additionally, the 480 kWth ASTERIx-CAESar solar receiver at the PSA's CRS tower will be equipped with a set of sensor prototypes in order to gain additional testing time and improved receiver characterisation. The obtained measurement data will be compared and validated against conventional flux and temperature measurements (CCD camera plus moving bar, Gardon sensor, thermocouples). Additionally, the obtained measurement data will be used to further train and validate the AI-based aiming point generation software developed in T5.1.

T5.5: AI-based heliostat tracking control system for low-cost operation [Leader: PSA, Contr.: CEN, IME, USE**, M1-M48]** Due to the current solar tracking system limitations regarding costs and operational problems, a new approach based on low cost, computer vision, open hardware and deep learning has been developed by PSA [44]. The main goals of this new smart low-cost control system are to reduce costs and improve the performance of existing systems. Furthermore, new control system extends the capabilities of traditional heliostats, for example, smart control gives information about shadows, blockages, cloud tracking and prediction of cloud transients (vision-based AI "now casting"). In addition to the cost reduction due to the use of low cost hardware, the smart control system reduces costs compared to traditional systems because it requires less hardware (no GPS, no encoders, etc.) and smart control does not require a precise installation process or periodic offset calibration, among other cost reduction sources. Tests have been performed at PSA, revealing the great potential and showing the new approach as a good alternative to traditional systems [44]. However, this system must be tested and trained and validated under a rigorous long-term performance evaluation process in the relevant environment. In order to do so, the ASTERIx-CAESar project will further continue AI algorithm training by data collection during at least one year (image taken every 15 min) and evaluation at PSA CRS tower (CAPTure prototype tower). Next, the novel tracking system will be tested, validated and demonstrated during an additional year of operation, fully integrated in the ASTERIx-CAESar smart aiming point generation software developed in T5.1 during the demonstration period of the CAPTure CSP-CAES prototype at PSA (T6.4).

Work package number	6	**Lead beneficiary**	2-PSA
Work package title	**Validation & Demonstration of receiver and power cycle**		

Objectives

● Experimentally evaluate the thermal behavior of the ASTERIx-CAESar solar absorbers at module-scale (10-20 kWth) and validation/validation scale (480 kWth); ● Adapt the existing CAPTure prototype to allow the demonstration of the key components of the ASTERIx-CAESar concept in the relevant environment; ● Operate a demonstration-scale (TRL 6/7) solar powered CAES plant in the in relevant environment, in combination with a small-scale RO desalination unit coupled by a gas-liquid pressure exchanger.

Description of work

The ASTERIx-CAESar project will test prototypes at different scales (see Figure 38), taking advantage of the existing (300 kW thermal) H2020 research prototype of the CAPTure project. On the one hand, the ASTERIx-CAESar project will cover small-scale (≈ 20 kW thermal) and validation-scale (≈ 480 kW thermal, TRL 6/7) testing of the advanced fixed foam solar receiver. On the other hand, coupled with the 480 kW solar receiver prototype, a solar powered demonstration-scale hot air expander train will be operated, also validating the performance of a solar powered CAES plant, operated in a relevant environment (at CIEMAT-PSA).

T6.1: Solar receiver prototype solar furnace testing (10 kW thermal) [Leader: PSA; Contr.: CEN**, M5-M16]**
The novel solar absorber prototypes as described in WP2 will be experimentally evaluated at the solar furnace at CIEMT-PSA for at least 6 months. It is aim to obtain experimental data at high temperature (800-900ºC) and highest flux densities (> 800 kW/m2 mean flux, > 1.5 MWth/m2 peak flux) to collect sufficient data for absorber life-time confirmation.

T6.2: Solar receiver prototype single module testing at IME tower (≈ 20 kW thermal) [Leader: IME; Contr.: CEN, EFG, **M17-M25]** Equivalent to T6.1, single absorber modules will be tested at the 250 kW experimental tower at IME in a transportable thermal test loop (see Figure 15 and Figure 16). There, a larger focal spot can be achieved and the absorber can be tested at real working conditions also together with aiming strategies (optimizing the flux distribution with IA methods, coming from WP5). Taking advantage of two experimental setups, the solar furnace at PSA and tower at IME, the testing time at high flux and relevant temperatures can be maximized, obtaining important data for long-term absorber oxidation estimation.

T6.3: CAPTure prototype CSP-CAES extension, tuning, and commissioning [Leader: CEN; Contr.: PSA, AAL, BLUE**,** APRIA, EFG, NTT, IKTS, ROMA3, USE, IME **M1-M33]**
This task will cover the extension and adaption of the existing CAPTure prototype in order to be able to demonstrate the ASTERIx-CAESar fixed foam solar receiver as well as the solar powered air expander train and the novel combination of RO desalination with a gas-liquid pressure exchanger in the relevant environment. As a first step, the existing CAPTure receiver casing will be reused, only replacing the absorber tiles and cups. A small air pressure vessel (array of pipes reinforced by wire winding) and air compressor will be installed and connected to the existing circuit (see Figure 34). All existing prototype components will be checked and tested for correct operation. In the case of the CAPTure regenerative system, it may be the case that the air valves show limited operability due to the long down-time of the prototype. Additionally, the correct sealing at high air pressure need to be re-confirmed (valves and vessel gaskets). In the case the consortium considers the regenerative system prototype in bad shape and not suitable for 12 months continuous operation, the replacement by a bespoke shell-tube heat exchanger will be considered, ensuring continuous operability. In addition, the small-scale RO desalination unit will be installed and coupled with the CAES system via the gas-liquid pressure exchanger. Last but not least, the control system of the CAPTure prototype needs to be adapted, also integrating the additional operating modes in the top level control system and operator interface. The added operating features will be checked individually for correct operation and control loops will be tuned in order to start experimental operation.

T6.4: CAPTure prototype CSP-CAES mode operation and validation [Leader: PSA; Contr.: CEN, BLUE, AAL, EFG, NTT, IKTS, ROMA3, USE, IME **M30-M48]** Once the extended validation-scale prototype has been successfully commissioned, one year of experimental testing is foreseen. The air storage vessel will be designed for 2 to 3 hours of nominal turbine operation, charging the storage vessel preferably during night time. Before beginning the test of the whole prototype (solar receiver, heat exchange system and air expander train), the solar receiver will be thoroughly characterized, cooling the hot outlet air with the auxiliary air/water heat exchanger. Once, the receiver is characterized and the corresponding control loops tuned, the air/air heat exchanger and expander train will be operated, demonstrating the operation of a small-scale solar powered CAES system (+ RO deslination unit) in the relevant environment. All temperature, mass flow and pressure measurements will be thoroughly evaluated and post processed in order to assess the performance of the system and experimentally validate numerical models of sub-components that will feed the techno-economic evaluation of the concept in WP1.

Work package number	7	Lead beneficiary	10-ETN
Work package title	**Dissemination, Communication and Exploitation**		

Objectives

● Develop and implement a targeted dissemination and communication strategy for maximum project visibility and impact in relevant areas at local, national and international levels; ● Design tools and materials for dissemination and communication that target a variety of stakeholders, incl. the scientific community, industry, policy makers, and the wider public; ● Coordinate the exploitation of results, manage project innovation and IP and develop a preliminary Exploitation Roadmap and follow-up strategies to secure the future uptake of project results; ● Coordinate knowledge exchange and dialogues with key stakeholders to maximize the impact of ASTERIx-CAESar, while minimizing risks that could hamper the uptake of project results; ● The continuous update of the project's context to anticipate the changes in the market´s trends by efficient innovation management; ● Consolidating synergies with other EU-funded projects and EC cluster and initiatives.

T7.1: Dissemination & Communication Activities [Leader: ETN; Contr.: All**, M1-M48]**
The aim of this task is to develop exhaustive and creative internal and external communication and dissemination strategies. A detailed Dissemination, Communication and Exploitation Plan – DEP (**D7.2**) will be submitted in M6 and then periodically re-assessed. The external communication campaign will target all stakeholder groups as identified in Section 2.2, and will also be linked to the exploitation strategy in WP7. ► The following instruments will be used: i) Creation, set up and maintenance of a public project website (**D7.1**), ii) Newsletters, iii) Press releases, iv) Social Medias, v) ASTERIx-CAESar brochures, vi) ASTERIx-CAESar public presentations, posters– updated when the need and purpose arrives, vii) ASTERIx-CAESar videos (**D7.3**) – one teaser at the early stage and one at the end of the project. ► The dissemination activities will be conducted by all the partners with the objective to increase awareness, understanding, visibility and acceptance of ASTERIx-CAESar concept. ► Key activities will include: i) Workshops and conferences: dissemination of project's results will be done through the participation of partners to thematic workshops and events, ii) ASTERIx-CAESar Final Conference that will bring together recognised speakers from the scientific community and other stakeholders active in the energy transition sector, thus ensuring the event's attractiveness, maximizing exchanges between the consortium and stakeholders, and fostering the creation of new research and future opportunities, iii) Scientific publications: the publication of peer reviewed open access papers in journals and/or peer reviewed conference in line with the data management plan.

T7.2: Stakeholder Engagement for future marketability of ASTERIx-CAESar solutions [Leader: ETN; Contr.: All**, M25-M48]**
The aim of this task is to focus on event-based activities both at local and international level with the objective to provide to the partners the opportunity to connect with experts, stakeholders and local communities at European and International level. ►This task will reinforce stakeholder's engagement by involving:
• ETN Working Groups (WGs): project's results will be presented and discussed within relevant ETN WGs and forums, bringing together relevant stakeholders of the turbine's supply chain (i.e. manufacturers, end-users, suppliers, academia). This will pave the way forward for the deployment of the technology, while timely addressing any potential barriers.
• Engagement, as appropriate, with research platforms at EU and international scale: the project partners commit to collaborate with several research platforms (BRIDGE, ETIP-SNET, SET-PLAN) and other EU or international stakeholders (e.g. ASME) to increase and maximise engagement and interest into ASTERIx-CAESar objectives.
• The project partners further commit to collaborate with other relevant EU-funded projects to generate synergies and complementarities with ASTERIx-CAESar project (Horizon Europe Booster).
"Dissemination Activities Tracker", listing all the activities relevant to this task, will be regularly updated and constitute part of the periodic reporting towards the EC.

Task 7.3 Creating of pathways for the integration of ASTERIx-CAESar outcomes in EU Policies [Leader: ETN; Contr.: All**, M37-M48]**
This task will focus on the contribution of ASTERIx-CAESar to EU policies and EU transformation towards decarbonisation in close link with Task 7.2. Developments and outcomes of the project will be brought to the attention of relevant initiatives at EU level with the aim to improve mutual added value regarding several aspects, in particular: policy relevant issues such as R&D needs, regulatory framework, business models, safety aspects, social acceptance as well as other obstacles to market uptake and innovation. The Consortium will redact a position paper in relation to these issues with the aim to influence future policy development (D7.4).

T7.4 Exploitation, Innovation and IP Management – [Leader: EURIDA; Contr.: All**, M1-M48]**
In T7.4 all partners under the lead of EURIDA will develop a plan for exploiting the individual results achieved during the project (i.e. solar receiver, flux sensor, heliostat control system, etc.). Activities cover: **i**) analysing all results generated by the project; **ii**) designing valorization pathways for the outputs tailored for the business strategies of the involved partners, and **iii**) IPR management. The task goal is a comprehensive exploitation and innovation road map complemented by exploitation pathways for Key Exploitable Results (KER) by partner and

individual business models for each KER. It will provide Asterix-CEAsar with an exploitation strategy that complements the overall business case for the Asterix-CEAsar plant to be developed in T7.6 and will be performed in close cooperation with T7.6. Further, T7.4 will comprise the IP management of the project. The Innovation and Exploitation Manager (Rita Clancy from EURIDA) will: **i**) monitor the consortium background IPR, as reported in the CA; **ii**) screen the IPR as developed during the project activities; **iii**) identify potential for new IPR and their protection (e.g via patents); and **iv**) report the final IPR status in the final project report.

T7.5: Technology and market watch [Leader: AAL; Contr.: All**, M1-M48]**

This part will give a clear view of the development of technologies potentially in competition with KERs developed in ASTERIx-CAESar. Only solar technologies with comparable or higher maturity will be considered. It will include technology based on alternative HTFs such as molten salt, liquid sodium, particles as well as air-based towers and other CSP technologies with appropriate TRL. Of course, also photovoltaic and hybrid systems will be covered. Based on public information and with the contribution of all partners, a comparative study will be made addressing economic, technologic, market and maturity aspects. These activities will be summarized and documented in the form of reports every 12 months during project execution (in EC reporting documents) and included in D7.6 at the end of the project. The reports will be elaborated among industrial partners (AAL, HEDNO) as well as non-profit research centres and universities (CEN, IME, IKTS, ROMA3, PSA). The results will of course feed into the risk analysis in WP 7.

T7.6 Business case & commercialisation of ASTERIx-CAESar concept – [Leader: AAL; Contr.: EURIDA, All**, M30-M48]**. This task covers the business case for the ASTERIx-CAESar power plant concept in different electricity markets around the world and designs the commercialisation strategy for the final scale-up and market introduction (envisaged for 2028-2029). Using the ASTERIx-CAESar use cases, electricity markets around the world will be analysed in order to elaborate the best operation strategy and business model of the ASTERIx-CAESar plant at different implementation scales (from about 1MW$_e$ to 150 MW$_e$, remote island and main grid operation). Revenue will be maximized assuming realistic market boundary conditions as performance model input. This task will collaborate very closely with the techno-economic analysis performed within WP1.

Work package number	8	**Lead beneficiary**	1-CEN
Work package title	**Project Coordination and Management**		

Objectives

● Reliable interface to the EC services; ● The project management which includes: i) Coordination of the project WPs (through WP leaders) according to the work plan, ensuring the high quality of the project outcomes; ii) Efficient and high-quality communication between all the partners; iii) Coordination of financial reporting; iv) Distribution of the financial support received from the Commission to the partners; v) Considering relevant gender issues.

Description of work

T8.1: Project Technical & Scientific Management [Leader: CEN, Contr.: all**, M1-M48]**

CENER will lead this task and will be responsible for the following activities: ● To monitor the tasks developed by all the members of the consortium and facilitate the coordination between them, ensuring the fulfilment of the objectives stated in the Grant Agreement in time; ● To be the interlocutor between the European Commission (PO) and the consortium; ● To call the General Assembly and Steering Committee to hold management and technical meetings in order to revise the progress and minimize the deviations; ● To assure the quality of outcomes.

T8.2: Administrative and Financial management [Leader: CEN, Contr.: all**, M1-M48]**

This task will involve the following activities: ● Supervising administrative and financial matters of the project; ● Supporting the preparation and observance of the CA; ● Tracking partners' consumption of person-months and budget in order to manage the resources allocated to the project; ● Supervising partners with the correct preparation and submission of deliverables, periodic reporting (Technical Progress Reports and Financial Reports) and cost statements in line with the requirements set by the EC; ● Distribution of project payments to partners. ; ● Coordinating the activities between the consortium and the EAB members.

T8.3: Data & Knowledge Management [Leader: CEN, Contr.: all**, M1-M48]**

In order to improve and maximise access and re-use of data generated by ASTERIx-CAESar, CEN will elaborate a detailed Data Management Plan (DMP). The project's management team will outline how the different project data will be collected and how these will be handled during and after the project focusing on the data collection methodology and data sharing issues. The DMP will focus on: (a) Data set reference and name (Types of data produced); (b) Data set description (What data will be collected, how many different data formats); (c) Data sharing (Access to data, and data sharing practices and policies); (d) Confidentiality (By data set, to enable successful exploitation of the technology); (e) Standards and metadata; (f) Plans for archiving & preservation (Including storage and backup); and (g) Data Dissemination & Policies for Data Sharing and Public Access (Policies and provisions for re-use, redistribution and production of derivatives).

List of deliverables (Table 3.1c)						
Nº	**Name**	**Short description**	**Lead beneficiary**	**Type**	**Dissemination level**	**Due Date**
D1.1	Specifications of the ASTERIx-CAESar prototypes	Summarize results of T1.2	1-CEN	R	PU	M17
D1.2	Techno-economic optimization and specification of the ASTERIx-CAESar plant concept for distinct use cases	Detailed presentation of results, models (T1.5), optimum integration of desalination (T1.4), and CAES vessel design (T1.3)	1-CEN	R	PU	M45
D1.3	Open-source Modelica model library with use-case models ready to simulate	ASTERIx-CAESar Modelica library published and use-case models integrated in website.	1-CEN	OTHER	PU	M45
D1.4	Sustainability assessment, circularity and recyclability potential of ASTERIx-CAESar	Detailed report of T1.6	2-PSA	R	PU	M48
D1.5	Social impact assessment of the ASTERIx-CAESar concept	Detailed report of T1.7	8-EURIDA	R	PU	M48
D2.1	Final design of the improved large-size absorber modules for demonstration	Design criteria and results of T2.5 and T2.4	1-CEN	R	SEN	M25
D2.2	Final optimized upscaled solar receiver design (absorber, modules, casing and radiation shields)	Design criteria and results of T2.6 and T2.3	1-CEN	R	SEN	M48
D3.1	Optimum low-temperature heat exchanger design (reuse heat of compression)	Design criteria and results of T3.1	1-CEN	R	PU	M24
D3.2	Optimum high-temperature heat exchanger design (solar heat input in power cycle)	Design criteria and results of T3.2	5-ROMA3	R	PU	M24
D3.3	Process control challenges and recommended methods	System level process control challenges. Results of T3.3	1-CEN	R	PU	M28
D4.1	Compressor design, performance and control (small and large scale)	Results of compressor train from T4.1 and T4.5	3-USE	R	SEN	M36
D4.2	Expander design, performance and control (small scale)	Results of expander train from T4.2.1and T4.5.	4-BLUE/ 3-USE	R	SEN	M36
D4.3	Expander design, performance and control (large scale)	Results of expander train from T4.2.2 and T4.5.	12-SIW-S/ 3-USE	R	SEN	M36
D4.4	Overall CAES and power cycle design definition for small and large scale	Overall design criteria and results of T4.2, T4.3, T4.4.	3-USE/1-CEN	R	PU	M36
D5.1	Advanced aiming strategy generation method and demonstration results	Results of T5.1 and T5.2	1-IME	R	PU	M37
D5.2	Fibre-optic sensor designs and demonstration results	Results of T5.3 and T5.4	16-EFG	R	SEN	M48
D5.3	Smart heliostat tracking system demonstration results	Results of T5.5	2-PSA	R	PU	M48
D6.1	Small-scale experimental evaluation results of advanced volumetric absorber modules	Small-scale (10-20 kWth) experimental results of both T6.1 and T6.2	2-PSA	R	PU	M25
D6.2	Demonstration-scale evaluation results of a solar powered hot air CAES expander train – Demonstrating the key components of the ASTERIx-CAESar concept in the relevant environment	Detailed report of the testing at demonstration-scale and validation results of receiver, CAES, AI control and desalination unit.	2-PSA	R	PU	M48
D7.1	ASTERIx-CAESar public website and communication materials (logo, leaflet, poster, roll-up)	Initial dissemination and communication activities.	10-ETN	DEC	PU	M4
D7.2	Dissemination, Communication and Exploitation Plan (DEP)	Advanced DEP report with workplans per partner for each project year.	10-ETN	R	SEN	M6
D7.3	ASTERIx-CAESar project video	Project video for maximizing project impact.	10-ETN	DEC	PU	M12
D7.4	Pathways for the integration of ASTERIx-CAESar outcomes in EU Policies	Contribution of ASTERIx-CAESar to EU policies in line with T7.3	8-ETN	R	PU	M46

D7.5	Initial Exploitation Road Map (ERM) and follow-up strategy	Mid-term strategy paper outlining the overall exploitation strategy and partner business pathways	8-EURIDA	R	SEN	M24
D7.6	Final Exploitation Roadmap, incl. Optimized plant operating strategies and business models	Final overall ERM and partner business pathways; Technology and market watch results.	9-AAL/1-CEN/ 8-EURIDA	R	SEN	M48
D8.1	Project Management plan	Detailed management plan	1-CEN	R	SEN	M2
D8.2	Data Management plan	Detailed data management plan associated to task T8.3 – To be updated during project	1-CEN	DMP	SEN	M2

List of milestones (Table 3.1d)

Nº	WP	Milestone title	Lead beneficiary	Due Date	Means of verification
MS1	**WP1**	Overall concept specifications	1-CEN	M15	Initial requirements specifications of overall concept completed
MS2	**WP1**	ASTERIx-CAESar prototypes specified	1-CEN	M17	All ASTERIx-CAESar prototypes specified with optimum design and aiming at TRL 6-7. It will be verifiable by D1.1
MS3	**WP1**	ASTERIx-CAESar simulation methodology and use-cases defined	1-CEN	M24	At this point in the project the simulation methodology as well as the virtual use-cases need to be fully defined.
MS4	**WP1**	ASTERIx-CAESar use cases optimised and online available	1-CEN	M45	At this point in the project, the plant concept is optimised for all locations. RTE of >60% and LCOS < 10 - 15 c€/kWh must be shown.
MS5	**WP2**	Development and production of ceramic foam receiver for validation finished	1-CEN	M28	Solar receiver modules for demonstration-scale must be designed, manufactured.
MS6	**WP2**	Up-scaled solar receiver design optimized	1.CEN	M48	The solar receiver upscaling design study is completed.
MS7	**WP3**	Optimum HEX configuration for low and high temperature identified	1-CEN/ 6-ROMA3	M24	Optimum design for the ASTERIx-CAESar HEXs. Target KPI of high heat exchange effectiveness (>85%) and specific cost target (<60 k€ per kg/s of air flow) will verify this milestone.
MS8	**WP4**	Optimised overall ASTERIx-CAESar power cycle performance as input for WP1.	3-USE/1-CEN	M36	D4.4 provides ASTERIx-CAESar power cycle overall performance parameters for small and large scale.
MS9	**WP5**	Advanced aiming strategy generation method demonstrated	11-IME	M37	Aiming strategy generation method demonstrated with conventional flux monitoring system (camera / moving bar method) - D5.1.
MS10	**WP5**	Complete ASTERIx-CAESar flux control and monitoring system demonstrated.	11-IME	M48	Complete system demonstrated including fibre optic sensors and smart AI tracking system.
MS11	**WP6**	Solar receiver module small-scale testing (20 kW) finished.	2-PSA / 11-IME	M25	The solar receiver small-scale solar furnace (PSA) and tower (IME) testing needs to be finished.
MS12	**WP6**	ASTERIx-CAESar plant concept demonstration starts	2-PSA	M33	At month 32, the existing CAPTure prototype must be extended, ready for testing activity.
MS13	**WP7**	Advanced DEP defined	10-ETN	M6	Approval of the Advanced DEP by the GA
MS14	**WP8**	Exploitation road-map and follow-up strategies in place	8-EURIDA	M48	Road Map agreed by GA; positive feedback from End User Panel

Critical risks for implementation (Table 3.1e)

Nº	Description of risk	Likelihood	Severity	WP number	Proposed risk-mitigation measures
		(Low/Medium/ High)			
1	Partner default	Low	High	All	In case of partner default, the consortium will seek a substitution, first internally and then, if needed, externally, utilizing the participants' extensive cooperation networks.
2	Difficulties of project execution due to COVID-19	Medium	Low	All	All partners are aware and will ensure compliance with measures to reduce the risk of exposure to COVID-19. The consortium counts on online tools and has previous experience dealing with COVID-19.
3	Failure to implement sufficiently accurate models in T1.4	Low	Medium	WP1	Models will be validated and actualized according to the tests results and data generated during the project, assuring that final models are accurate.

4	OVAR designs cannot reach the target efficiencies estimated	Low	High	WP2	An already proven receiver design will be considered within ASTERIx-CAESar project. Additional detailed thermomechanical optimization and high flux experiments will assess performance. Further foam structural optimization will ensure efficiency.
5	Proposed designs are not easily/cheap manufactured.	Low	Medium	WP1, WP2, WP3,WP4 WP5	There are imporant partners with experience in the industrial sectors within the consortium that will evaluate all decisions and results. Design will be actualized according to the experience in manufacturing.
6	Oxidation resistance of the absorbers is not high enough	Low	High	WP2	Foam structure must be improved by advanced manufacturing techniques. IKTS has key know-how to be applied.
7	Heat exchanger designs cannot meet target performance (efficiency/cost)	Medium	High	WP3	Alternative designs will be analysed by the consortium. CEN, ROMA3, AAL and SIW-S have key know-how on high-temperature HEX design.
8	Low efficiency of air/water pressure exchanger (energy recovery device - ERD)	Low	High	WP1	Energy recovery devices (liquid-liquid pressure exchangers) are available components. Modifications are needed for gas-liquid operation. Best design concept to be selected (piston/valve based).
9	Commercial compressor technology does not meet specifications	Low	High	WP4	Scope of work redefined from selection of commercial technology to design of bespoken designs for the ASTERIX-CAESAR concept.
10	Global control of complex turbomachinery arrangement does not work	Medium	Low	WP4	Multiple compressor/expander trains are operated in parallel in spite of suboptimal round trip efficiency.
11	Fibre optic thermal resistance is not high enough to reach 800°C	Low	Medium	WP5	High-temperature fibre optical sensor designs will be considered within ASTERIx-CAESar project. USE and EFG have key know-how in designing of high temperature fibre optic sensors in order to meet targets. The application of high-temperature Sapphire fibres are an alternative.
12	Delay of the integration for testing activities in WP6 because of a delay in a previous WP.	Medium	Medium	WP5, WP6	The project leader will analyse the possibility of ensuring the fulfilment of the timing by rescheduling other activities.
13	Prototypes are not able to reach the TRL estimated.	Low	Medium	WP1, WP2, WP5	The Project Work Plan defines a detailed pathway with different stages (small-scale and validation-scale for demonstration in the relevant environment) and involved partners have high expertise in all technological areas to cope with difficulties.
14	Estimated budget for the experimental activity is too low.	Low	High	WP5, WP6	Budget has been estimated based on previous experience and offers. However, cost of materials has increased recently. Therefore, the nominal power of the prototypes may have to be slightly reduced.
15	Delay to perform the tests in time due to delays in the manufacturing of components	Medium	Low	WP5, WP6	Manufacturing periods has been estimated based on previous experience and offers. However, some material shortages in different industries have been occurred recently. Testing periods would be extended if possible. Otherwise, the test will be shortened. As the planned testing periods are sufficiently long, results would be still valid.

Table 3.1f: Summary of staff effort

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	Total PM per partner
1-CEN	19	19	19	8	17	25	8	27	142
2-PSA	23	9	4	0	8	54	2	1.5	101.5
3-USE	4	0	4	41	16	3	3	3	74
4-BLUE	4	0	0	21	0	5	3	2	35
5-DSPW	1	0	0	48	0	0	1	1	51
6-ROMA3	8	0	51	2	0	2	1	1	65
7-IKTS	1	23.8	2	0	0	3.5	2	1.5	33.8
8-EURIDA	11	0	0	0	0	0	12	1	24
9-AAL	8	7	13	0	0	3	9	2	42
10-ETN	0.5	0	0	0	0	0	23.5	1	25
11-IME	1.5	4	0	0	28	10	3	3	49.5
12-SIW-S	1	0	10	48	0	0	1	1	61
13-NTT	2	23	7	0	0	7	4	2	45
14-WPS	0.5	19	0	0	0	0	1	1	21.5
15-HEDNO	20	0	0	0	0	0	16	3	39
16-EFG	1.5	0	0	0	32	1	0.5	1	36
17-APRIA	5	0	0	0	0	4	1	2	12
Total PM	111	104.8	110	168	101	117.5	91	54	857.3

3.2 Capacity of participants and consortium as a whole

The ASTERIx-CAESar consortium, led by CEN, represents a multi-disciplinary group that involves 17 partners spread over 10 countries in the EU, 1 partner from the UK, and 1 partner from Switzerland (see Figure 41). They form an ideal team to succeed in the proposed challenges, with a well-balanced participation between universities, RTD centres and companies offering the complete set of interdisciplinary skills required by the project and covering all critical elements of the value chain, a good pre-requisite for successful cooperative project.

Figure 41: Map of Europe - Consortium as a whole

It has to be highlighted that the coordinator has created a consortium limited to the key partners contributing to the critical development tasks. Complementarities between partners have been carefully considered when building the consortium in order to ensure the excellence in the solutions developed in the project, the work to be implemented and the future exploitation of results. Each partner therefore has a well-defined key role in the project and there are no duplicates in the distribution of tasks, as shown in Table 9 below:

Table 9. Consortium partners

PARTNER DESCRIPTION AND MAIN ROLE IN THE PROJECT	
CEN	The **Spanish National Renewable Energy Centre** is a technological centre with a recognized prestige that develops applied research in renewable energies and provides technological support to energy companies and institutions. CENERs main activities are the **development of R&D&I projects**, the **provision of quality testing** and **component certification services**, as well as the **technical assistance and reporting** on several renewable technologies. Important track record in European projects as leader **(coordinator of the CAPTure project)** and as participant. It is the **inventor of the ASTERIx-CAESar concept** and its Department of Solar Energy Technologies & Storage has key expertise on solar receiver, concentrating optics, heat exchanger and power cycle design. Thus, besides the coordination tasks, CEN will be actively involved in the **modelling, optimization and techno-economical evaluation of the ASTERIx-CAESar concept and sub-systems.**
PSA	PSA (CIEMAT) is a **Spanish Public Research Institution** that develops and leads R&D&i projects in the fields of Energy, Environment and Technology. It is **owner of the Plataforma Solar de Almería (PSA).** It is actively participating in several EU projects. PSA will be involved in the **solar receiver development**, in the **development of the AI heliostat control tracking system** and it will be the **responsible of all the testing and prototype evaluation**. It will contribute to **modelling CSP-PV-CAES plant plus desalination** as well as to the design and experimental evaluation of the reverse osmosis powered by the CAES system. Finally, the organization also will carry out the **LCA and Multiregional Input-Output analysis.**
USE	Two departments of the **University of Seville** will be active in the project. The department for turbomachinery (leader of WP4) with deep technical know-how regarding **optimization, operation and control of turbo-compressors and expanders** for small-scale as well as for large-scale application (with a very wide industrial network and deep involvement in professional associations on this topics). On the other hand, the team of the electronics department will lead the **optical sensor development in close collaboration with EFG**.
BLUE	BLUE develops **ultra-low carbon combined heat and power solutions** for business parks, communities, industrial and farming processes **using its own hot air small-scale radial turbomachinery** that discharges waste heat at a high temperature to use it in novel applications. BLUE will (i) **develop the <1MW compressor**, (ii) participate in the development of the **<1MW turbine expander**, (iii) collaborate with the **techno-economic models** and (iv) work to **modify the existing equipment** of the CAPTure prototype.
DSPW	DSPW is a **traditional European manufacturer and supplier of power generation equipment**, with about 950 internal employees. The portfolio includes steam turbines in the range of performances from 4 up to 1200 MW in applications such as CSP power production. DSPW provides full EP/EPC services. It has a significant position in the international market being active in waste heat recovery, energy storage and O&G business. It will be responsible for **the design of high pressure air turbines of 20-50-100 MW** with operating temperatures up to 600 °C and, marginally, DSPW will **contribute to the overall CAES and power cycle**

	parameter design.
ROMA3	The **research group of Fluid Machinery and Energy Conversion System** is expert in optimization of design and operation of advanced energy conversion systems, energy storage systems (CAES equipped with artificial air storage (5-20 MW)) and **design** of components such as **turbomachinery or heat exchangers using 3D CFD models**. It will participate in the **techno-economic modelling** and optimization of the overall system, using their own developed models, the part load analysis and the optimization of CAES systems. ROMA3 will coordinate the optimization of **low and high-temperature heat exchanger network configurations.**
IKTS	The IKTS conducts applied research on high-performance ceramics and is **Europe's largest R&D institute dedicated to the study of ceramics**. IKTS develops advanced high-performance ceramic materials, industrial manufacturing processes as well as prototype components and systems in complete production lines up to the pilot-plant scale **(it is the provider of the CAPTure foam solar receiver)**. There is also a long experience in the modelling of ceramic components. Thus, IKTS is focus on the **solar receiver development and optimization in WP2**. The technological devices and the know-how necessary for the development and the manufacturing of such absorber structures are ensured by IKTS.
EURIDA	Sole proprietorship enterprise EURIDA has a proven track record in **research management and impact maximisation for European collaborative projects**. Core expertise and activities cover **social impact assessment, exploitation strategies, communication, dissemination (Open Science) and stakeholder engagement** of several European projects (six projects since 2016). It will lead the tasks of **exploitation (WP7) and social impact assessment (WP1)** and it will further organize the Industry and Citizen Panels.
AAL	AAL is a **leading developer and supplier of innovative renewable technologies** relying on extensive experience from some of the most efficient CSP projects. It is an engineering provider/supplier of essential key components in integrated energy systems: such as solar receivers, steam generators, HEX and TES. AAL will take part in HEX design (WP3), the **techno-economic optimization study** (WP1) and it will elaborate a **market analysis and business models** based on the best operation strategy and business model for different scenarios (WP7). **AAL** is exploitation leader, and could act as primary license holder of replicating the ASTERIx-CAESar concept worldwide as EPC company.
ETN	ETN is a **non-profit membership association** (with more than 120 members) bringing together the entire value chain of the **gas turbine technology**. ETN offers **wide experience with EU-funded projects** and it is able to successfully consolidate synergies with these projects as well as with numerous EC initiatives Moreover, **ETN is an organiser of numerous events and it is an ASME member**. It is able to reach the widest possible audience of many relevant stakeholders as well as regulatory bodies, thus, ETN will be **responsible for the project's communication and dissemination activities (WP7)**, acting towards stakeholders' engagement in ASTERIx-CAESar, as well as the project results' future marketability.
IMDEA	IME is a **research centre** that operates as a **non-profit foundation** developing world-class R&D in the field of renewable energy. The High Temperature Processes Unit (HTPU) is leader in the field of CSP technologies, mostly focused on **high-temperature applications like electricity generation** by Brayton cycles and **high-temperature heat in industrial processes**. IME will contribute to taking over the **testing at the experimental tower** (20 kW) and it will coordinate the improved operation and monitoring of its solar field via **AI methods (WP5).**
SIW-S	SIW-S is a **global R&D engineering company** specialized in the development of **efficient turbomachinery components** and reliable systems for a wide range of applications. It is staffed with **experts in design, modelling and optimization** of **power generation equipment**, process equipment and other system flow/stress scenarios including both clean sheet designs and **upscaling technologies**. SIW-S will be **responsible for the detailed modelling and design of the large scale air expanders.**
NTT	NTT is a **private owned service company** specified in the **design, maintenance and renovation of the refractory and insulating coatings** of different applications and it is considered one of the world leading companies regarding the heat shields of CSP plants. NTT will be involved in all the **activities related to the insulation of high-temperature components**, improving the efficiency and cost-effectiveness**.**
WPS	WPS is since 1994 **producer of Oxide Ceramic Matrix Composites** and parts out of this material mainly for industrial applications. WPS will take part in **developing thin walled, lightweight and thermal shock resistant structures** made of Oxide ceramic matrix composites to carry sSiC foams for the OVAR. Carrying structures (baskets) for the segmented foam dome of OVAR is considered one specialty of the organization.
HEDNO	HEDNO is the Hellenic Distribution System Operator (DSO) and is responsible for the development, operation and maintenance of the electricity distribution network all over Greece including mainland and the interconnected islands of Greece and transmission and distribution in the non-interconnected islands. HEDNO will be main responsible **for two virtual use cases in WP1** and will collaborate in WP7 regarding business model optimization in order to **maximize revenue by electricity market arbitrage**.
EF	EFG focuses on the **design and production of fiber optic components/sensors** and the production of high-

G	quality precision CNC parts, from prototyping to volume production. It was the world's first commercial supplier of **femtosecond (fs) laser-written fiber Bragg gratings**, which already exhibit an extreme temperature stability up to 700 °C. Within the project, EFG is responsible for the development and fabrication of **suitably assembled fiber optic sensors for high temperature** (up to 900 °C) measurements that will be installed on the solar receiver, taking iterative improvement steps to ensure most suitable sensor setup.
APRIA	APRIA is a **technology-based company** that focuses on **innovation** to provide sustainable advanced solutions through cutting-edge technologies based on **advanced oxidation processes and membrane technologies**. It has proven important track record in EU funded projects related to **improving water treatment and reuse**. APRIA will be **in charge of the design, construction & start-up of the ERD+RO pilot at PSA**. Carrying out the process flow diagram, system layout, construction, O&M manual, installation, support for the operation and evaluation of the results

Table 3.1h: ‘Purchase costs’ items (travel and subsistence, equipment and other goods, works and services)

1. CEN		
	Cost (€)	**Justification**
Travel and subsistence	15 000	1 conference per project year - two persons (4 x 2.000), 2 personal project meetings per year (8 x 875)
Equipment		
Other goods, works and services	167 000	Solar receiver module matrials and thermal loop adaption for IME tower: 46.000; External advisory board: 12.000; Open Access: 6.000; Software maintenance: 10.000; Audit: 3.000; Prototype CAES vessel integration (array of pipes, welding, flanges, wire winding, valves and control): 90.000
Total	182 000	
2. PSA		
	Cost (€)	**Justification**
Travel and subsistence	36 500	Periodic meetings per year x 3 people - there are 3 different Units of CIEMAT working on the project - (18.000 €) , Assistance to 8 international meetings/conferences (12.000 €), International stay (6.500 €)
Equipment		
Other goods, works and services	173 500	Audits (3.000 €); Spare components for air tests at the solar furnace and CRS tower (thermocouples, PT100 for calorimetry loop, solar flux measurement adaptation) (15.000 €); Solar furnace testing bed adaptation for 10 kWth prototype testing (10.000 €); STAR-CCM+ CFD software licenses (18.000 €); Raspberry Pi 4 and lenses to perform Artificial Intelligence tests (6.000 €); Open Access publications (5.000 €); Instrumentation related to desalination setup (temperature, pressure, level and flow monitoring and acquisition data cards, among others) (7.500 €); Purchase of specific LCA software licenses (SimaPro and/or GaBi) and the updating of LCSA databases (ecoinvent, Social Hotspot database,) is considered. (9.000 €); CAPTure prototype repairs (e.g. valves, piping, blower) (35.000 €); CAPTure prototype DCS update (20.000 €); CRS tower prototype integration work (45.000 €)
Total	210 000	
3. USE		
	Cost (€)	**Justification**
Travel and subsistence	15 000	1 conference per project year - two persons (4 x 2.000), 2 personal project meetings per year (8 x 875)
Equipment		
Other goods, works and services	94 250	'Open Access publication (6000 €); IP protection, patent files (6000 €); CFX Annual fee for three years (50% share on the project): 3 x 3500 x 0.5 (5250 €); Thermoflex Annual fee for four years (50% share on the project): 4 x 8000 x 0.5 (16 000 €); prototype air compressor (23.000€); spare parts of prototype air expanders (15.000 €); optical fibers and other sensor materials (20.000 €); audit (3.000 €)
Total	109 250	
5. DSPW		
	Cost (€)	**Justification**
Travel and subsistence	15 000	1 conference per project year - two persons (4 x 2.000), 2 personal project meetings per year (8 x 875)
Equipment		
Other goods, works and services	35 000	Customization of the internal HBD and turbine design software (Power-Cycle 2) for ASTERIx-CAESar project incl. consultations on thermodynamic properties of expanding air and REFPROP licence and customization (16.500 €). Supporting CFD services for internal DSPWs CFD team - mainly providing meshing services of complex geometries and computational HW capacity for DSPW's CFD analyses that would be defined by and evaluated internally in DSPW (17.000 €) Conference fees (1.500 €)
Total	50 000	
6. ROMA3		
	Cost (€)	**Justification**
Travel and subsistence	15 000	Travel to project meetings (8000), conferences (7000)
Equipment		
Other goods, works and services	108 000	CAPTure prototype heat exchanger modifications (80.000 €), Ansys Academic licenses (CFD+FEM) (20.000 €), Open access publication (5.000€); Audit (3.000€)
Total	123 000	
7. IKTS		
	Cost (€)	**Justification**
Travel and subsistence	8000	1 yearly personal project meeting (4 * 1000 €), 2 conferences (2 x 2000 €)
Equipment		
Other goods, works and services	89 500	Foam templates (6.500 €), ceramic powders and auxiliaries (20.000 €), kiln furniture (10.000 €), Capture prototype receiver modifications (50.000 €), audit (3.000€)

Total	97 500	
8-EURIDA		
	Cost (€)	**Justification**
Travel and subsistence	18 000	1 conference/workshop per project year - two persons (4 x 2.750), 2 personal project meetings per year (8 x 875)
Equipment		
Other goods, works and services	22 500	3.500 € - WP1, service license Social Hotspot Database for social impact assessment, 2.000 € - WP1, social risk mapping tool (license fee for 2 years); 17.000 € - WP1, Social impact & Acceptance Workshop costs (lump sum: 2 events at 8.500 € each, incl. travel for 20 external attendees each, event costs and materials)
Total	40 500	
10. ETN		
	Cost (€)	**Justification**
Travel and subsistence	12 000	8 General Assemblies planned, at least 2 persons per GA with 750 euros for travel expenses (transportation, hotels, meeting organisation)
Equipment		
Other goods, works and services	48 000	1 final projects event (4,5k), website (6,6k), website maintenance (1,7k), 2 videos (13,5k), printed communication materials (2,8k), updates of the printed communication materials (1,7k), 8 dissemination conferences provided (10,6k), 4 tradeshows at external conferences (6,6k)
Total	60 000	
11. IME		
	Cost (€)	**Justification**
Travel and subsistence	13 000	Consortium meetings (4 meetings, 2 people): 5.000 €, Participation in international conferences (SolarPACES, SWC): 8.000 €
Equipment		
Other goods, works and services	35 000	Consumable for testing in ST (Thermal shielding, isolation materials...): 20.000 € Consumable for testing in ST (sensors, cabling, metallic structures...): 15:000 €
Total	48 000	
12. SIW-S		
	Cost (€)	**Justification**
Travel and subsistence	10 000	Consortium meetings (4 meetings, 1 person): 4.000 € Participation in international conferences (ASME TurboExpo): 6.000 €
Equipment	135 000	Software licenses (commercial turbomachinery design software licenses for corresponding project periods).
Other goods, works and services		
Total	145 000	
14. WPS		
	Cost (€)	**Justification**
Travel and subsistence	9 000	6 trips x 1.500 € each.
Equipment		
Other goods, works and services	20 000	Mould making, materials for prototyping and small components and materials
Total	29 000	
17. APRIA		
	Cost (€)	**Justification**
Travel and subsistence	10 000	5 coordinating meetings (KOM, 3 PMs & FM) (1-2 persons/2 days) (3.000 €); Installation and start-up of the system (2 persons/3 days) (2.500 €); Travel to follow-up and adjust PU performance and operation (2 persons/3 days) (2.500 €); Attendance to EU industrial fairs (1 person/4 days); (2.000 €)
Equipment		
Other goods, works and services	44 000	GLPX+RO system materials, including hydraulics, control systems, sensoring, skid, flow meters, dosing pumps, electrical connections, additive manufacturing material, electrical cabinet, RO, module, stained steel structure and license for system layout, among others.
Total	54 000	

4 References

[1] F. Zaversky, I. Les, P. Sorbet, M. Sanchez, B. Valentin, J.-F. Brau, and F. Siros, "The challenge of solar powered combined cycles - providing dispatchability and increasing efficiency by integrating the open volumetric air receiver technology," *Energy*, vol. 194, p. 116796, 2020.

[2] F. Zaversky, F. Cabello Núñez, A. Bernardos, and M. Sánchez, "A Novel High-Efficiency Solar Thermal Power Plant Featuring Electricity Storage - Ideal for the Future Power Grid with High Shares of Renewables," 2022.

[3] M. Romero-Alvarez, E. Zarza, F. Kreith, and D. Y. Goswami, *Handbook of Energy Efficiency and Renewable Energy*. Boca Raton, USA: CRC Press Taylor and Francis Group, 2007.

[4] W. H. Stein and R. Buck, "Advanced power cycles for concentrated solar power," *Solar Energy*, vol. 152, pp. 91-105, 2017.

[5] C. K. Ho, "Advances in central receivers for concentrating solar applications," *Solar Energy*, vol. 152, pp. 38-56, 2017.

[6] A. L. Ávila-Marín, "Volumetric receivers in Solar Thermal Power Plants with Central Receiver System technology: A review," *Solar Energy*, vol. 85, pp. 891-910, 2011.

[7] R. Rodríguez-Garrido, A. Carballar, J. Vera, J. González-Aguilar, A. Altamirano, A. Loureiro, and D. Pereira, "High-Temperature Monitoring in Central Receiver Concentrating Solar Power Plants with Femtosecond-Laser Inscribed FBG," *Sensors*, vol. 21, p. 3762, 2021.

[8] M. Casanova, J. Ballestrín, R. Monterreal, J. Fernández-Reche, R. Enrique, and A. Ávila-Marín, "Improvements in the measurement of high solar irradiance on a 300 kWth volumetric receiver," *Renewable Energy*, vol. 201, pp. 441-449, 2022/12/01/ 2022.

[9] E. Udd and W. B. Spillman, *Fiber Optic Sensors. An Introduction for Engineers and Scientifics*. USA: Wiley, 2011.

[10] S. Ma, Y. Xu, Y. Pang, X. Zhao, Y. Li, Z. Qin, Z. Liu, P. Lu, and X. Bao, "Optical Fiber Sensors for High-Temperature Monitoring: A Review," *Sensors*, vol. 22, p. 5722, 2022.

[11] F. Zaversky, I. Les, P. Sorbet, M. Sánchez, B. Valentin, F. Siros, J.-F. Brau, J. McGuire, and F. Berard, "CAPTure Concept Specification and Optimization (Deliverable 1.4)," ed. https://cordis.europa.eu/project/id/640905/results: European Commission, 2020.

[12] F. Zaversky, I. Les, M. Sánchez, B. Valentin, J.-F. Brau, F. Siros, J. McGuire, and F. Berard, "Techno-Economic Optimization and Benchmarking of a Solar-Only Powered Combined Cycle with High-Temperature TES Upstream the Gas Turbine," in *Green Energy and Environment*, ed London, UK: IntechOpen, 2019.

[13] F. Siros and G. Fernández Campos, "Optimisation of a Low-TIT Combined Cycle Gas Turbine With Application to New Generation Solar Thermal Power Plants," presented at the ASME Turbo Expo 2017, Charlotte, NC, USA, 2017.

[14] M. Budt, D. Wolf, R. Span, and J. Yan, "A review on compressed air energy storage: Basic principles, past milestones and recent developments," *Applied Energy*, vol. 170, pp. 250-268, 2016/05/15/ 2016.

[15] ESTELA, "The Value of Solar Thermal Electricity - Cost vs. Value Approach," ed. Brussels, Belgium: ESTELA - European Solar Thermal Electricity Association, 2016.

[16] A. Chatzipanagi, A. Jaeger-Waldau, and C. Cleret de Langavant, "Clean Energy Technology Observatory: Photovoltaics in the European Union – 2022," ed: European Commission, 2022.
[17] F. P. Sioshansi, "California's 'Duck Curve' Arrives Well Ahead of Schedule," *The Electricity Journal*, vol. 29, pp. 71-72, 2016/07/01/ 2016.
[18] S. Wilkinson, M. J. Maticka, Y. Liu, and M. John, "The duck curve in a drying pond: The impact of rooftop PV on the Western Australian electricity market transition," *Utilities Policy*, vol. 71, p. 101232, 2021/08/01/ 2021.
[19] F. Siros, B. Valentin, B. Liu, J. Baeyens, and G. Flamant, "Next-CSP concept with particle receiver applied to a 150 MWe solar tower," *AIP Conference Proceedings*, vol. 2445, p. 060006, 2022/05/12 2022.
[20] M. Rogner, N. Troja, D. Samuel, and S. Law, "The world's water battery: Pumped hydropower storage and the clean energy transition," ed. London, UK: IHA - International Hydropower Association, 2018.
[21] C. Salvini, A. Giovannelli, and D. Sabatello, "Techno-Economic Analysis of Diabatic CAES Systems with Above-Ground Artificial Storage," presented at the 4th International Conference on Smart and Sustainable Technologies (SpliTech), Split, Croatia, 2019.
[22] A. G. Olabi, T. Wilberforce, M. Ramadan, M. A. Abdelkareem, and A. H. Alami, "Compressed air energy storage systems: Components and operating parameters – A review," *Journal of Energy Storage*, vol. 34, p. 102000, 2021/02/01/ 2021.
[23] A. Benato and A. Stoppato, "Pumped Thermal Electricity Storage: A technology overview," *Thermal Science and Engineering Progress*, vol. 6, pp. 301-315, 2018/06/01/ 2018.
[24] IRENA, "Electricity Storage and Renewables: Costs and Markets to 2030," ed. Abu Dhabi: International Renewable Energy Agency, 2017.
[25] O. Schmidt, S. Melchior, A. Hawkes, and I. Staffell, "Projecting the Future Levelized Cost of Electricity Storage Technologies," *Joule*, vol. 3, pp. 81-100, 2019/01/16/ 2019.
[26] F. Zaversky, J. Fernández-Reche, M. Casanova, R. Monterreal, R. Enrique, A. L. Avila-Marin, S. Martínez, M. Schmitz, A. Castellanos, R. Mallo, S. Herrero, S. López, I. Mesonero, I. Pérez, J. McGuire, and F. Berard, "Experimental Testing of a 300 kWth Open Volumetric Air Receiver (OVAR) Coupled with a Small-Scale Brayton Cycle. Operating Experience and Lessons Learnt," 2022.
[27] T. Ilett and C. J. Lawn, "Thermodynamic and Economic Analysis of Advanced and Externally Fired Gas Turbine Cycles," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol. 224, pp. 901-915, 2010.
[28] B. Cárdenas, A. Hoskin, J. Rouse, and S. D. Garvey, "Wire-wound pressure vessels for small scale CAES," *Journal of Energy Storage*, vol. 26, p. 100909, 2019/12/01/ 2019.
[29] I. Les, "D 5.7 – Report on ray-tracing algorithm, model development and dynamic aiming strategies," ed. https://cordis.europa.eu/project/id/640905/results, 2017.
[30] J. A. Carballo, "Hel-IoT Web Server: A Smart Heliostat Development Platform," ed. SolarPACES, 2022.
[31] M. J. Guirguis, "Energy Recover y Devices in Seawater Reverse Osmosis Desalination Plants with Emphasis on Efficiency and Economical Analysis of Isobaric versus Centrifugal Devices - Master Thesis," ed: University of South Florida, 2011.
[32] J. B. Garrison and M. E. Webber, "An integrated energy storage scheme for a dispatchable solar and wind powered energy system," *Journal of Renewable and Sustainable Energy*, vol. 3, p. 043101, 2011.
[33] S. Wu, C. Zhou, E. Doroodchi, and B. Moghtaderi, "Thermodynamic analysis of a novel hybrid thermochemical-compressed air energy storage system powered by wind, solar and/or off-peak electricity," *Energy Conversion and Management*, vol. 180, pp. 1268-1280, 2019/01/15/ 2019.
[34] G. Zanganeh, A. Pedretti, A. Haselbacher, and A. Steinfeld, "Design of packed bed thermal energy storage systems for high-temperature industrial process heat," *Applied Energy*, vol. 137, pp. 812-822, 2015.
[35] B. Hoffschmidt, F. M. Téllez, A. Valverde, J. Fernández, and V. Fernández, "Performance Evaluation of the 200-kWth HiTRec-II Open Volumetric Air Receiver," *Journal of Solar Energy Engineering*, vol. 125, pp. 87-94, 2003.
[36] K. Hennecke, B. Hoffschmidt, G. Koll, P. Schwarzbözl, J. Göttsche, M. Beuter, and T. Hartz, "The solar power tower Jülich - A solar thermal power plant for test and demonstration of air receiver technology," presented at the ISES World Congress, Beijing, China, 2007.
[37] F. Téllez, "Thermal performance evaluation of the 200kWth "SolAir" volumetric solar receiver," ed. Madrid, Spain: CIEMAT-PSA, 2003.
[38] W. E. C. Pritzkow, R. S. M. Almeida, L. B. Mateus, K. Tushtev, and K. Rezwan, "All-oxide ceramic matrix composites (OCMC) based on low cost 3M Nextel™ 610 fabrics," *Journal of the European Ceramic Society*, vol. 41, pp. 3177-3187, 2021/05/01/ 2021.
[39] Morgan-Advanced-Materials-plc, "WDS® NextraShell™ Data Sheet," ed. http://www.morganthermalceramics.com/media/7560/wds-nextra-shell_eng.pdf (07.01.2020): Morgan Advanced Materials - Thermal Ceramics, 2019.
[40] Morgan-Advanced-Materials-plc, "WDS® Nextra™ Board Data Sheet," ed. http://www.morganthermalceramics.com/media/7558/wds-nextra-board_eng.pdf (07.01.2020): Morgen Advanced Materials - Thermal Ceramics, 2019.
[41] Rath-Group, "High Temperature Wool - Alsitra Mat 1300 - Data Sheet," ed. https://www.rath-group.com/: Rath AG, 2019.
[42] M. Ahmed, H. Park, C. K. Bach, and O. San, "Numerical investigation of air mixer for HVAC testing applications (ASHRAE RP-1733)," *Science and Technology for the Built Environment*, vol. 26, pp. 1252-1273, 2020/10/20 2020.
[43] Siltherm-Europe-Limited, "Siltherm Board - Rigid Microporous Insulation," ed. Sandyford Business Park, Dublin, Ireland, 2019.
[44] J. A. Carballo, J. Bonilla, M. Berenguel, J. Fernández-Reche, and G. García, "New approach for solar tracking systems based on computer vision, low cost hardware and deep learning," *Renewable Energy*, vol. 133, pp. 1158-1166, 2019/04/01/ 2019.
[45] R. K. Shah and D. P. Sekulic, *Fundamentals of Heat Exchanger Design*. Hoboken, New Jersey, USA: John Wiley and Sons, Inc., 2003.
[46] M. T. White, G. Bianchi, L. Chai, S. A. Tassou, and A. I. Sayma, "Review of supercritical CO2 technologies and systems for power generation," *Applied Thermal Engineering*, vol. 185, p. 116447, 2021/02/25/ 2021.
[47] E. Jones, M. Qadir, M. T. H. van Vliet, V. Smakhtin, and S.-m. Kang, "The state of desalination and brine production: A global outlook," *Science of The Total Environment*, vol. 657, pp. 1343-1356, 2019/03/20/ 2019.
[48] J. Kim, K. Park, D. R. Yang, and S. Hong, "A comprehensive review of energy consumption of seawater reverse osmosis desalination plants," *Applied Energy*, vol. 254, p. 113652, 2019/11/15/ 2019.
[49] P. Valdivia, R. Barraza, D. Saldivia, L. Gacitúa, A. Barrueto, and D. Estay, "Assessment of a Compressed Air Energy Storage System using gas pipelines as storage devices in Chile," *Renewable Energy*, vol. 147, pp. 1251-1265, 2020/03/01/ 2020.
[50] J. Liu, X. Zhang, Y. Xu, Z. Chen, H. Chen, and C. Tan, "Economic analysis of using above ground gas storage devices for compressed air energy storage system," *Journal of Thermal Science*, vol. 23, pp. 535-543, December 01 2014.
[51] H. Blanco and A. Faaij, "A review at the role of storage in energy systems with a focus on Power to Gas and long-term storage," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 1049-1086, 2018/01/01/ 2018.
[52] A. Ozarslan, "Large-scale hydrogen energy storage in salt caverns," *International Journal of Hydrogen Energy*, vol. 37, pp. 14265-14277, 2012/10/01/ 2012.
[53] R. J. Thomas, R. A. Ellison, K. M. Goodenough, N. M. W. Roberts, and P. A. Allen, "Salt domes of the UAE and Oman: Probing eastern Arabia," *Precambrian Research*, vol. 256, pp. 1-16, 2015/01/01/ 2015.
[54] J. Ennis-King, K. Michael, J. Strand, R. Sander, and C. Green, "Underground storage of hydrogen: mapping out the options for Australia," in *Future Fuels CRC*, ed: Australian Government, 2021.
[55] D. G. Caglayan, N. Weber, H. U. Heinrichs, J. Linßen, M. Robinius, P. A. Kukla, and D. Stolten, "Technical potential of salt caverns for hydrogen storage in Europe," *International Journal of Hydrogen Energy*, vol. 45, pp. 6793-6805, 2020/02/28/ 2020.
[56] R. Luke, "Compressed Air Storage for Electricity Generation in South Africa," ed. Cape Town: University of Cape Town, 1996.
[57] J. Chen, W. Liu, D. Jiang, J. Zhang, S. Ren, L. Li, X. Li, and X. Shi, "Preliminary investigation on the feasibility of a clean CAES system coupled with wind and solar energy in China," *Energy*, vol. 127, pp. 462-478, 2017/05/15/ 2017.
[58] M. King, A. Jain, R. Bhakar, J. Mathur, and J. Wang, "Overview of current compressed air energy storage projects and analysis of the potential underground storage capacity in India and the UK," *Renewable and Sustainable Energy Reviews*, vol. 139, p. 110705, 2021/04/01/ 2021.
[59] Solargis-s.r.o., "Global Solar Atlas 2.0," ed. https://globalsolaratlas.info 2022.
[60] Ł. Bartela, J. Ochmann, S. Waniczek, M. Lutyński, G. Smolnik, and S. Rulik, "Evaluation of the energy potential of an adiabatic compressed air energy storage system based on a novel thermal energy storage system in a post mining shaft," *Journal of Energy Storage*, vol. 54, p. 105282, 2022/10/01/ 2022.
[61] C. Saigustia and S. Robak, "Review of Potential Energy Storage in Abandoned Mines in Poland," *Energies*, vol. 14, p. 6272, 2021.
[62] T. McCarthy, "The impact of acid mine drainage in South Africa," *South African Journal of Science*, vol. 107, p. 7 pages, 2011.
[63] IRENA, "Innovation Outlook - Thermal Energy Storage," ed. Abu Dhabi: International Renewable Energy Agency, 2020.
[64] J. López Sanz, F. Cabello Nuñez, and F. Zaversky, "Benchmarking analysis of a novel thermocline hybrid thermal energy storage system using steelmaking slag pebbles as packed-bed filler material for central receiver applications," *Solar Energy*, vol. 188, pp. 644-654, 2019/08/01/ 2019.
[65] C. Prieto, A. G. Fernández, D. Pérez-Osorio, and L. F. Cabeza, "Thermal and mechanical degradation assessment in refractory concrete as thermal energy storage container material in concentrated solar plants," *Journal of Energy Storage*, vol. 40, p. 102790, 2021/08/01/ 2021.
[66] G. Zanganeh, A. Pedretti, S. Zavattoni, M. Barbato, and A. Steinfeld, "Packed-bed thermal storage for concentrated solar power – Pilot-scale demonstration and industrial-scale design," *Solar Energy*, vol. 86, pp. 3084-3098, 2012.
[67] K. Allen, T. von Backström, E. Joubert, and P. Gauché, "Rock bed thermal storage: Concepts and costs," *AIP Conference Proceedings*, vol. 1734, p. 050003, 2016/05/31 2016.
[68] ALACAES-SA, "ALACAES - Creating Sustainable Energy Solutions for a Brighter Future - https://alacaes.com/," ed. Lugano, Switzerland, 2017.
[69] I. Mahroug, S. Doppiu, J.-L. Dauvergne, M. Echeverria, J. Toutain, and E. Palomo del Barrio, "Study of peritectic compound Li4(OH)3Br for high temperature thermal energy storage in solar power applications," *Solar Energy Materials and Solar Cells*, vol. 230, p. 111259, 2021/09/15/ 2021.
[70] F. Cabello Núñez, J. López Sanz, and F. Zaversky, "Analysis of steel making slag pebbles as filler material for thermocline tanks in a hybrid thermal energy storage system," *Solar Energy*, vol. 188, pp. 1221-1231, 2019/08/01/ 2019.
[71] H. Elmqvist and S. E. Mattsson, "Modelica - The next generation modeling language - An international design effort," presented at the Proceedings of the 1st World Congress on System Simulation, Singapore, 1997.
[72] Open-Source-Modelica-Consortium, "OpenModelica - An open-source Modelica-based modeling and simulation environment," ed. http://www.openmodelica.org (accessed 8.1.2013): Open Source Modelica Consortium (OSMC), 2013.
[73] L. R. Petzold, "A description of DASSL: A differential/algebraic system solver," ed. Albuquerque, New Mexico, USA: Sandia National Laboratories, 1982.
[74] Aalborg-CSP, "Aalborg CSP's tomato growing CSP plant goes online in the Australian desert," ed. https://www.aalborgcsp.com, 2016.
[75] A. Meier, E. Bonaldi, G. M. Cella, W. Lipinski, and D. Wuillemin, "Solar chemical reactor technology for industrial production of lime," *Solar Energy*, vol. 80, pp. 1355-1362, 2006/10/01/ 2006.
[76] IEA, "World Energy Outlook 2022," ed. https://www.iea.org/reports/world-energy-outlook-2022, 2022.
[77] M. T. Islam, N. Huda, A. B. Abdullah, and R. Saidur, "A comprehensive review of state-of-the-art concentrating solar power (CSP) technologies: Current status and research trends," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 987-1018, 2018/08/01/ 2018.
[78] IEA, "Renewables 2021 - Analysis and forecasts to 2026," ed. www.iea.org: International Energy Agency, 2021.
[79] C. Turchi, M. Mehos, C. Ho, and G. J. Kolb, "Current and Future Costs for Parabolic Trough and Power Tower Systems in the US Market," ed. SolarPACES, 2010.
[80] M. Barbato, D. Montorfano, F. Contestabile, J. Roncolato, A. Haselbacher, G. Zanganeh, P. Jenny, E. Jacquemoud, and M. Scholtysik, "Advanced Adiabatic Compressed Air Energy Storage grid-to-grid performance modeling," in *Final report 2019*, ed. www.bfe.admin.ch: Swiss Federal Office of Energy SFOE, 2019.
[81] F. Casella, "ThermoPower 3.1 - Open library for thermal power plant simulation," ed. https://casella.github.io/ThermoPower: Politecnico di Milano, 2014.
[82] K. Navickaitė, M. Penzel, C. R. H. Bahl, and K. Engelbrecht, "Performance Assessment of Double Corrugated Tubes in a Tube-In-Shell Heat Exchanger," *Energies*, vol. 14, p. 1343, 2021.

5 Letters of Support

TSK FLAGSOL

TSK FLAGSOL Engineering GmbH
Anna-Schneider-Steig 10 · 50678 Köln · Germany

Dr. Marcelino Sanchez
Director, Dept Solar Energy Technologies & Storage
FUNDACIÓN CENER
Ciudad de la Innovación 7,
31621 Sarriguren (Navarra), Spain

Date: November 22nd, 2022
Reference: N/A
Contact person: Dr. Mark Schmitz
Direct tel: +49 221 925 970 97
Direct fax: -
Email: mark.schmitz@flagsol.de

In relation to the ASTERIx-CAESar project.
Confirmation of participation in the External Advisory and Industrial End-user Board (EAIB) of the research project ASTERIx-CAESar.

I, Dr. Mark Schmitz, representative of the company TSK Flagsol, hereby express our firm interest in supporting actively the **ASTERIx-CAESar** project within the EU HORIZON EUROPE call HORIZON-CL5-2022-D3-03-01 "Innovative components and/or sub-systems for CSP plants and/or concentrating solar thermal installations".

The **ASTERIx-CAESar** project focuses on an innovative hybrid CSP – Compressed Air Energy Storage (CAES) combined cycle power plant configuration that provides very competitive electricity storage technology and a break-through in solar-to-electric conversion efficiency. The concept initiates a new era of adaptive renewable power plants for optimum power grid management, enabling highest shares of renewables in the future power grid. Due to the fact that cheap off-peak electricity is used to provide the air compression work of the topping Brayton cycle, the overall peak solar-to-electric energy conversion efficiency of the proposed power plant may reach 40%, which roughly doubles the peak efficiency with respect to state-of-the-art CSP technology. The project activity will cover the techno-economic optimization of the innovative CSP-CAES plant, as well as the development of key components needed for its implementation. The three main development lines will cover advanced solar receiver, heat exchanger and turbo machinery design.

Modus operandi: The development activity of the project will be advised by an external independent body, the EAIB, composed of experts in the area of CSP, power grid operation, turbomachinery, thermodynamics and heat transfer. The EAIB will assembly at least once per project year (online) and the development activity will be presented by the consortium. Each EAIB member is expected to give constructive feedback regarding the presented activities.

I hereby confirm that we are very interested in joining the project's EAIB and will actively participate in the yearly EAIB assemblies, as organized by the project coordinator CENER. The **ASTERIx-CAESar** project is proposing a highly attractive approach that could lead to an important break-through in CSP technology.

Yours sincerely,

i.V. Dr.-Ing. Mark Schmitz
Technology Director, Head of R&D

Kuwait Institute for Scientific Research — معهد الكويت للابحاث العلمية
Office of the Director General — مكتب المدير العام

Date : 23 February 2022 — التاريخ :
Ref. No.: DG/19/63/37 — مرجع رقم :

Dr. Marcelino Sanchez, Ph.D.
Director
Department of Solar Energy
Technologies and Storage
CENER-National Renewable Energy Centre
C/Ciudad de la Innovacion 7
31621 Sarriguen Navarra
SPAIN

Dear Dr. Sanchez,

Subject: Official Invitation to form part of the External Advisory/ Stakeholder Board (EASB) of the Research project ASTERIx-CAESar-Air- Based Solar Thermal Electricity for Efficient Renewable Energy Integration & Compressed Air Energy Storage

With reference to your letter regarding the above mentioned subject, please note that the Kuwait Institute for Scientific Research (KISR) has agreed to the participation of **Dr. Mansour Ahmed**, Program Manager of the Water Desalination Technologies Program at the Water Research Center to be a member of the External Advisory Stakeholder Board (EASB) for the research project **"ASTERIx-CAESar-Air-Based Solar Thermal Electricity of Efficient Renewable Energy Integration and Compressed Air Energy Storage"**. KISR considers this invitation as a great honor and an excellent opportunity to foster the ties between the two organizations in the quest to boost the desalination industry using renewable energy and would extend any helping hand within its capacity in this regard.

We look forward to a fruitful cooperation between KISR and your esteemed organization in this endeavor and in any future scientific collaboration effort.

Best Regards

Dr. Mane Alsudairawi
Acting Director General

Dr. Marcelino Sanchez
Director, Department of Solar Energy Technologies & Storage
FUNDACIÓN CENER
Ciudad de la Innovación 7,
31621 Sarriguen (Navarra), Spain

In relation to the ASTERIx-CAESar project.

Confirmation of participation in the External Advisory / Stakeholder Board (EASB) of the research project ASTERIx-CAESar.

I, Mr. Benoît Valentin, Research Engineer at EDF – R&D (Fluid Mechanics, Energy and Environment), hereby express my firm interest in supporting actively the **ASTERIx-CAESar** project within the EU HORIZON EUROPE call HORIZON-CL5-2022-D3-03-01 "Innovative components and/or sub-systems for CSP plants and/or concentrating solar thermal installations".

The **ASTERIx-CAESar** project focuses on an innovative hybrid CSP – Compressed Air Energy Storage (CAES) combined cycle power plant configuration that provides very competitive electricity storage technology and a break-through in solar-to-electric conversion efficiency. The concept initiates a new era of adaptive renewable power plants for optimum power grid management, enabling highest shares of renewables in the future power grid. Due to the fact that cheap off-peak electricity is used to provide the air compression work of the topping Brayton cycle, the overall peak solar-to-electric energy conversion efficiency of the proposed power plant may reach 40%, which roughly doubles the peak efficiency with respect to state-of-the-art CSP technology. The project activity will cover the techno-economic optimization of the innovative CSP-CAES plant, as well as the development of key components needed for its implementation. The three main development lines will cover advanced solar receiver, heat exchanger and turbo machinery design.

Modus operandi: The development activity of the project will be advised by an external independent body, the EASB, composed of experts in the area of CSP, power grid operation, turbomachinery, thermodynamics and heat transfer. The EASB will assembly at least once per project year (online) and the development activity will be presented by the consortium. Each EASB member is expected to give constructive feedback regarding the presented activities.

I hereby confirm that I am very interested in joining the project's EASB and will actively participate in the yearly assemblies, as organized by the project coordinator CENER.

The **ASTERIx-CAESar** project is proposing a highly attractive approach that could lead to an important break-through in concentrated solar power technology.

Yours sincerely,

Mr. Benoît Valentin,
Research Engineer
EDF – R&D

EDF

Dr. Marcelino Sanchez
Director, Department of Solar Energy Technologies & Storage
FUNDACIÓN CENER
Ciudad de la Innovación 7,
31621 Sarriguren (Navarra), Spain

In relation to the ASTERIx-CAESar project.

Confirmation of participation in the External Advisory / Stakeholder Board (EASB) of the research project ASTERIx-CAESar.

I, Ms Ramaesela Prudence Madiba, General Manager, Eskom Research Test & Development, hereby express our firm interest in supporting actively the **ASTERIx-CAESar** project within the EU HORIZON EUROPE call HORIZON-CL5-2022-D3-03-01 "Innovative components and/or sub-systems for CSP plants and/or concentrating solar thermal installations".

The **ASTERIx-CAESar** project focuses on an innovative hybrid CSP – Compressed Air Energy Storage (CAES) combined cycle power plant configuration that provides very competitive electricity storage technology and a break-through in solar-to-electric conversion efficiency. The concept initiates a new era of adaptive renewable power plants for optimum power grid management, enabling highest shares of renewables in the future power grid. Due to the fact that cheap off-peak electricity is used to provide the air compression work of the topping Brayton cycle, the overall peak solar-to-electric energy conversion efficiency of the proposed power plant may reach 40%, which roughly doubles the peak efficiency with respect to state-of-the-art CSP technology. The project activity will cover the techno-economic optimization of the innovative CSP-CAES plant, as well as the development of key components needed for its implementation. The three main development lines will cover advanced solar receiver, heat exchanger and turbo machinery design.

Modus operandi: The development activity of the project will be advised by an external independent body, the EASB, composed of experts in the area of CSP, power grid operation and energy storage. The EASB will assembly at least once per project year (online) and the development activity will be presented by the consortium. Each EASB member is expected to give constructive feedback regarding the presented activities. At the end of the project, a technology demonstration round of the CSP-CAES plant at CIEMAT-PSA in Spain is planned.

I hereby confirm that I am very interested in joining the project's EASB and will actively participate in the yearly assemblies, as organized by the project coordinator CENER.

I delegate responsibility for the colaborative interaction to **Mr Darryl Chapman** (Chief Engineer, RT&D). Darryl Chapman will maintain the interaction between both parites as it pertains to the **ASTERIx-CAESar** project

Yours sincerely,

Ms Ramaesela Prudence Madiba
General Manager
Eskom Research Test & Development

Eskom

Digitally sealed by the European Commission
Date: 2023.01.10 10:30:21 CET
Reason: Acknowledgement of Receipt

This electronic receipt is a digitally signed version of the document submitted by your organisation. Both the content of the document and a set of metadata have been digitally sealed.

This digital signature mechanism, using a public-private key pair mechanism, uniquely binds this eReceipt to the modules of the Funding & Tenders Portal of the European Commission, to the transaction for which it was generated and ensures its full integrity. Therefore a complete digitally signed trail of the transaction is available both for your organisation and for the issuer of the eReceipt.

Any attempt to modify the content will lead to a break of the integrity of the electronic signature, which can be verified at any time by clicking on the eReceipt validation symbol.

More info about eReceipts can be found in the FAQ page of the Funding & Tenders Portal.

(https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/support/faq)