Air-based Solar Thermal Electricity for Efficient Renewable Energy Integration & Compressed Air Energy Storage

ASTERIx-CAESar project overview

Funded by
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UK participant in Horizon Europe Project ASTERIx-CAESar is supported by UKRI grant number 10097908 (Bluebox Energy).

This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

Solar power sector background: PV is less costly than CSP

- **Photovoltaic**
  The global weighted average LCOE* for utility-scale projects fell by 89% between 2010 and 2022, from 0.445 $/kWh to **0.049 $/kWh**. Over 1047 GW installed by 2022.
- **Concentrated Solar Power (CSP)**
  The weighted average LCOE of CSP plants fell by 69% between 2010 and 2022, from 0.38 $/kWh to **0.12 $/kWh**. Over 6.5 GW installed by 2022.
- **New concept of CSP is needed to be competitive**

Source: IRENA, 2022
* Levelised Cost of Electricity

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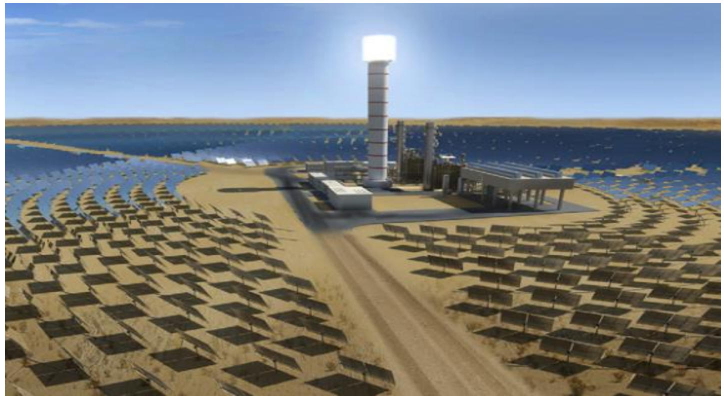
CSP sector background: Low efficiency

- Current **CSP technology** has solar-to-electric conversion **efficiencies 14-16%** on an annual basis
- **Power block efficiencies** vary **between 30 and 40%** (Rankine steam cycle)
- **State-of-the-art technologies**:
    - Parabolic trough (thermal oil as heat transfer fluid [HTF] → 390°C max. operating temperature)
    - Central receiver (molten salt as HTF → 565°C max. operating temperature)
    - LCOE ≈ 7-11 $c/kWh (depending on country – solar resource and financing conditions)



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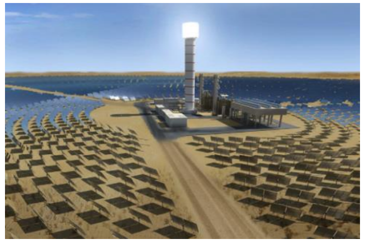
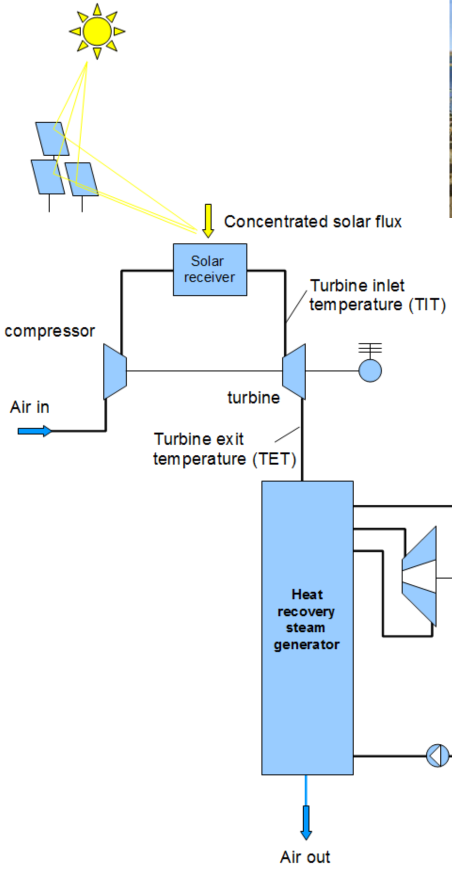
What is the best CSP technology? [1/2]

Is the central receiver technology the most interesting in terms of conversion efficiency potential and cost reduction?

- High concentration ratios allow high receiver operating temperatures (700-1000°C)
- These temperatures are suitable for advanced power cycles (e.g. the **combined cycle: GT + Rankine**) to reach high solar-to-electric conversion efficiencies (**up to 30% peak and 22% on annual basis**)
- The combined cycle is unfortunately not economically viable (CAPTure H2020 project result)
- A **cost-effective** and **efficient** power cycle is needed to **exploit the full potential** of the central receiver technology





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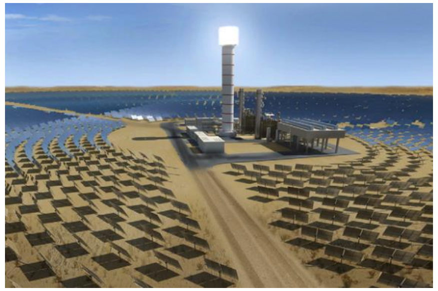
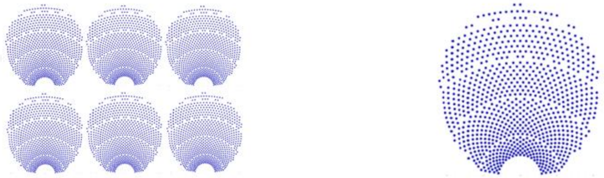
What is the best CSP technology? [2/2]

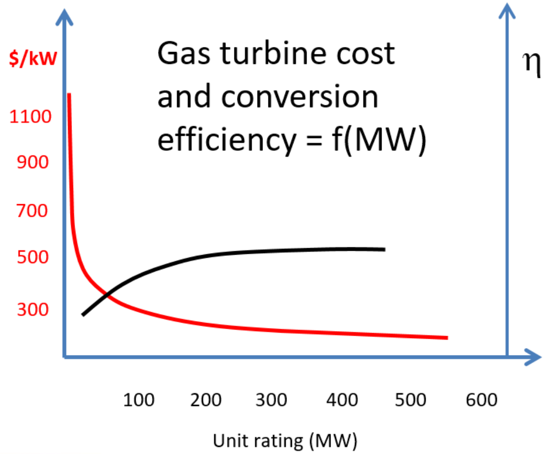


The central receiver technology seems to be the most interesting one in terms of conversion efficiency potential and cost reduction

- There is a performance trade-off heliostat field – receiver – power cycle
- Optical conversion requires small nominal power
- Thermal conversion requires high nominal power
- **ASTERIx-CAESar cost-effective, efficient** and **correctly sized (< 50 MW)** power cycle will be developed to take full advantage of this technology potential



$$\eta_{\ small\, field} > \eta_{\ large\, field}$$



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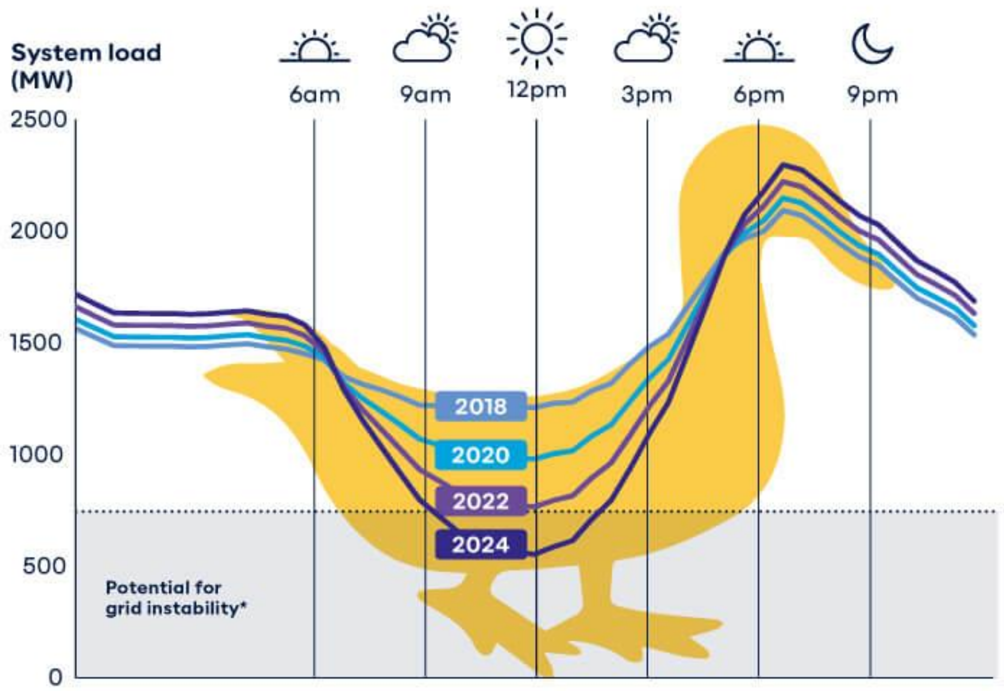
CSP plants need to provide flexibility to the grid

- With increased installation of PV, **value of production of CSP during daylight hours diminishes**
- There is a **need for adaptive power plants**: electricity storage & generation!



Source: www.synergy.net.au

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ASTERIx-CAESar objectives are defined by the current CSP sector's needs

- **Competitive electrical energy storage round-trip efficiency (RTE) of > 60%, at very low LCOS** of < 10-15 c€/kWh → adaptive operation in peak periods!
- **Optimally sized power cycle for the CSP application** with maximum operating temperatures between 750 and 800°C (for very efficient receiver operation and reasonable material costs) and **flexible/adaptive operation** (easy and quick start-up, shutdown and load variation)
- Propose a **new operating strategy for CSP**, capitalising on efficient energy storage, allowing **highest shares of renewables** in the electricity grid.

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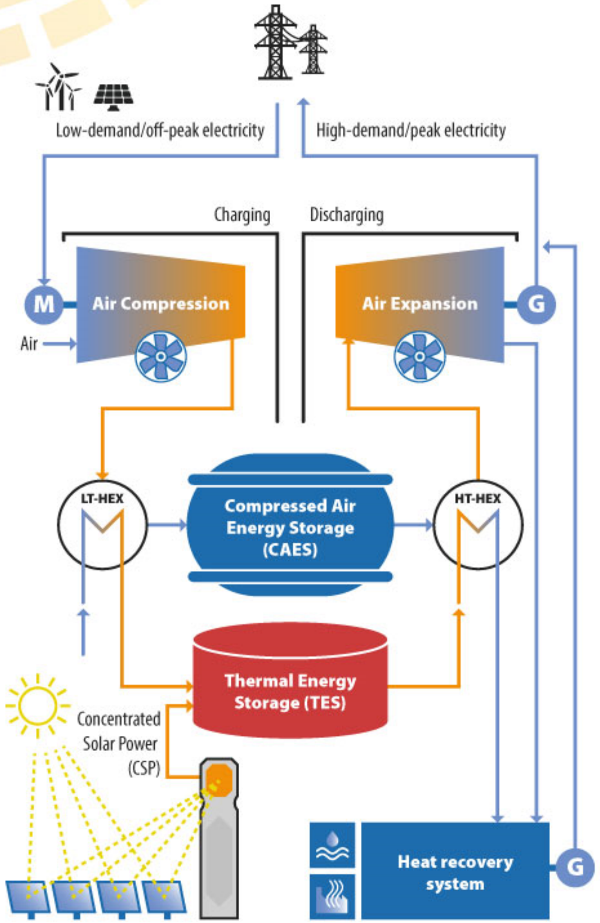
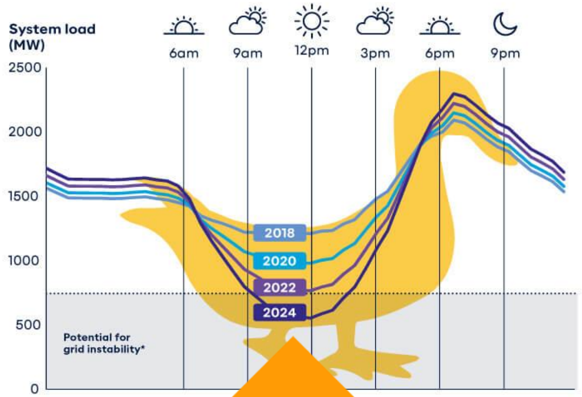
The project concept:
CSP-CAES innovative & adaptive power plant [1/2]



- **Compressed air energy storage** (CAES) technology is **combined with CSP**
- **Off-peak low-price electricity is used to drive a compressor train** – compressed air is stored – heat of compression is also stored (adiabatic CAES)
- **Solar energy is stored** in the form of high-temperature heat (800°C)



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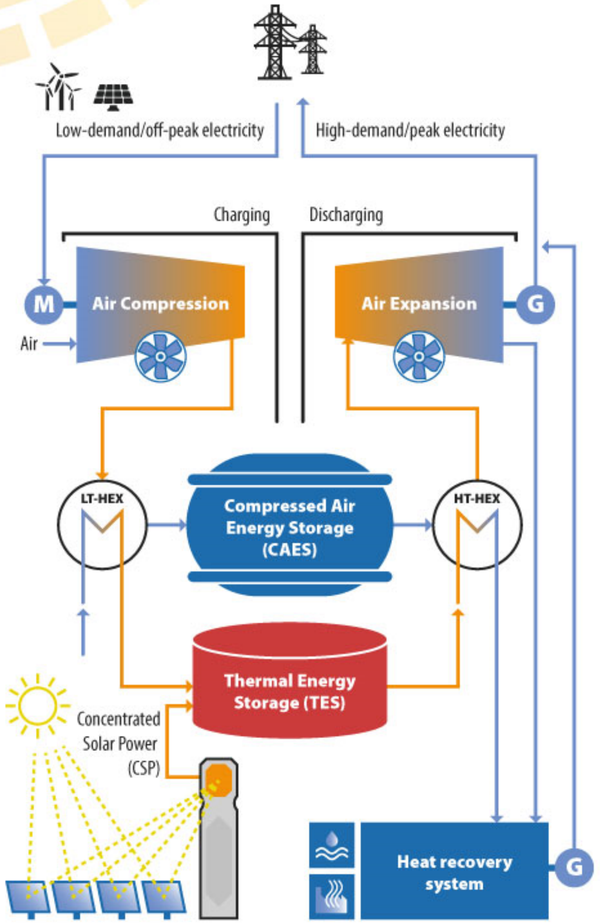
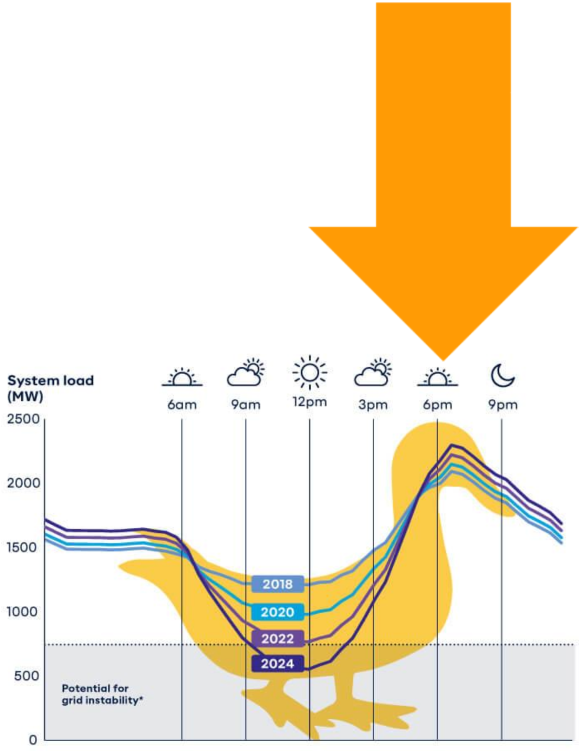
The project concept: CSP-CAES innovative & adaptive power plant [2/2]



- During **peak-hours**, the plant produces electricity via **combined cycle power generation system**
- The **compressed air** is used to **substitute the compression work** of the topping gas turbine
- A **very high** solar-to-electric **conversion efficiency** is achieved (40% peak)
- **This doubles the state-of-the-art efficiency**



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The project breaks down into eight interconnected work packages

- **WP1**: Concept Definition and Techno-economic Optimisation
- **WP2**: Solar Receiver Development
- **WP3**: Advanced Heat Exchangers
- **WP4**: Advanced CAES and power cycle development and Optimisation
- **WP5**: Automatisation and improved plant operation and monitoring via AI methods
- **WP6**: Validation & Demonstration of receiver and power cycle
- **WP7**: Dissemination, Communication and Exploitation
- **WP8**: Project Coordination and Management

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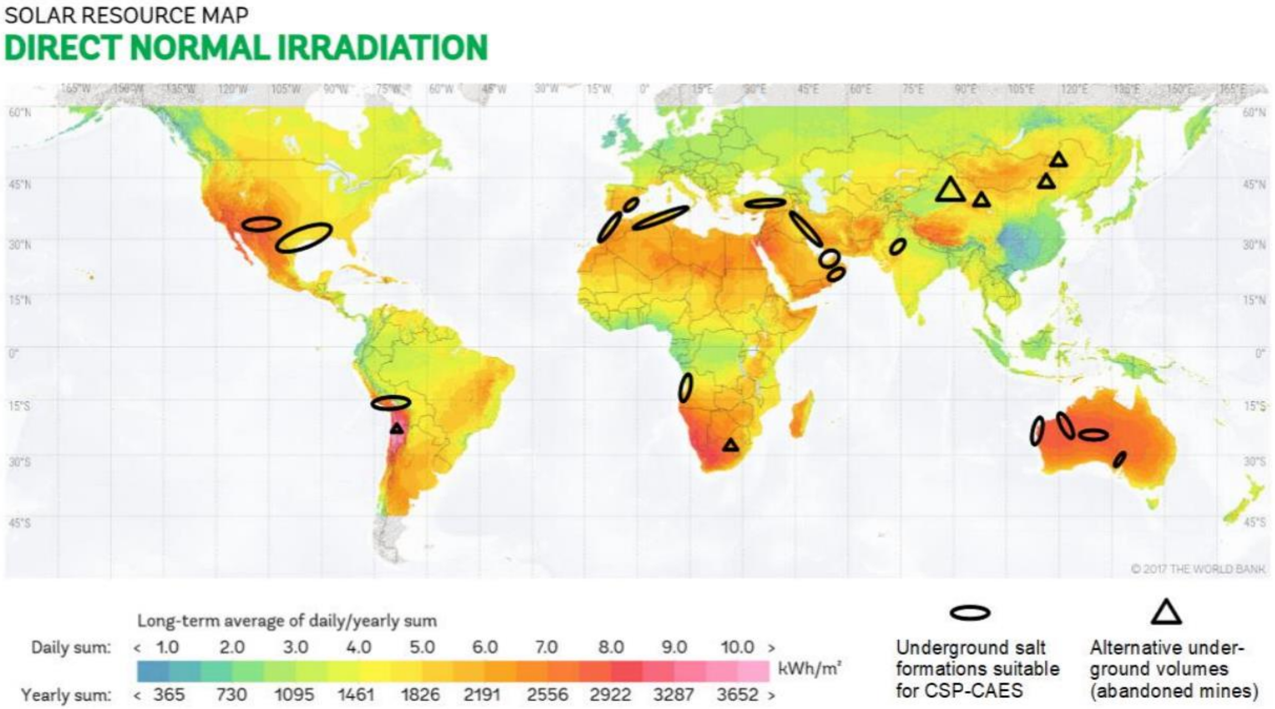
Two options exist for compressed air storage volumes

- **Evaluation** of different **compressed air storage solutions** (aboveground and underground)
    - **Artificial vessels for small scale** (cost effective pressure vessels – e.g. array of connected pipes)
    - **Conventional underground caverns** in salt formations or adapted closed mines within high DNI resource areas (a must for CSP) – large scale application



Information about suitable locations for compressed air underground storage as well as solar resources has been obtained from references listed under this link.

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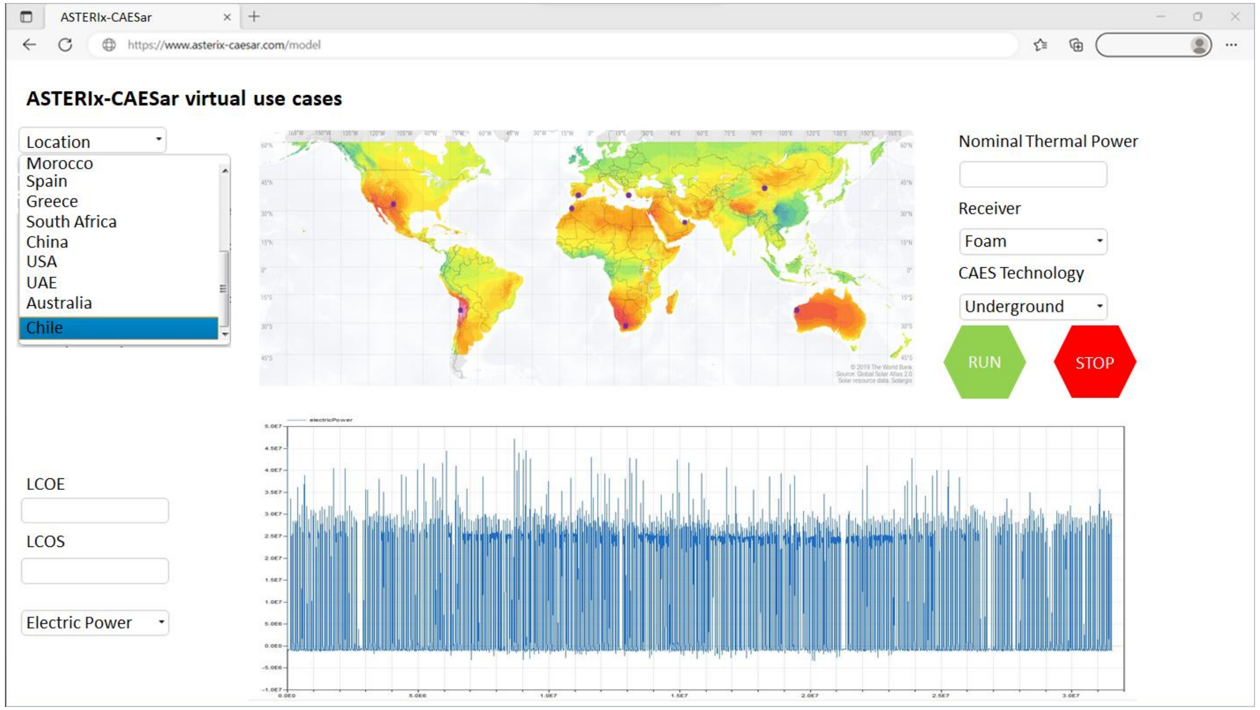
Modelica library allows for techno-economic optimisation

Techno-economic optimisation of ASTERIx-CAESar concept **considers use-cases worldwide**

- 11 use-case locations worldwide
- Integration with desalination
- Integration with process heat
- Open-source public Modelica library
- Online simulation of use-cases will be available on project website in the final project phase



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Questions? Let us know!

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