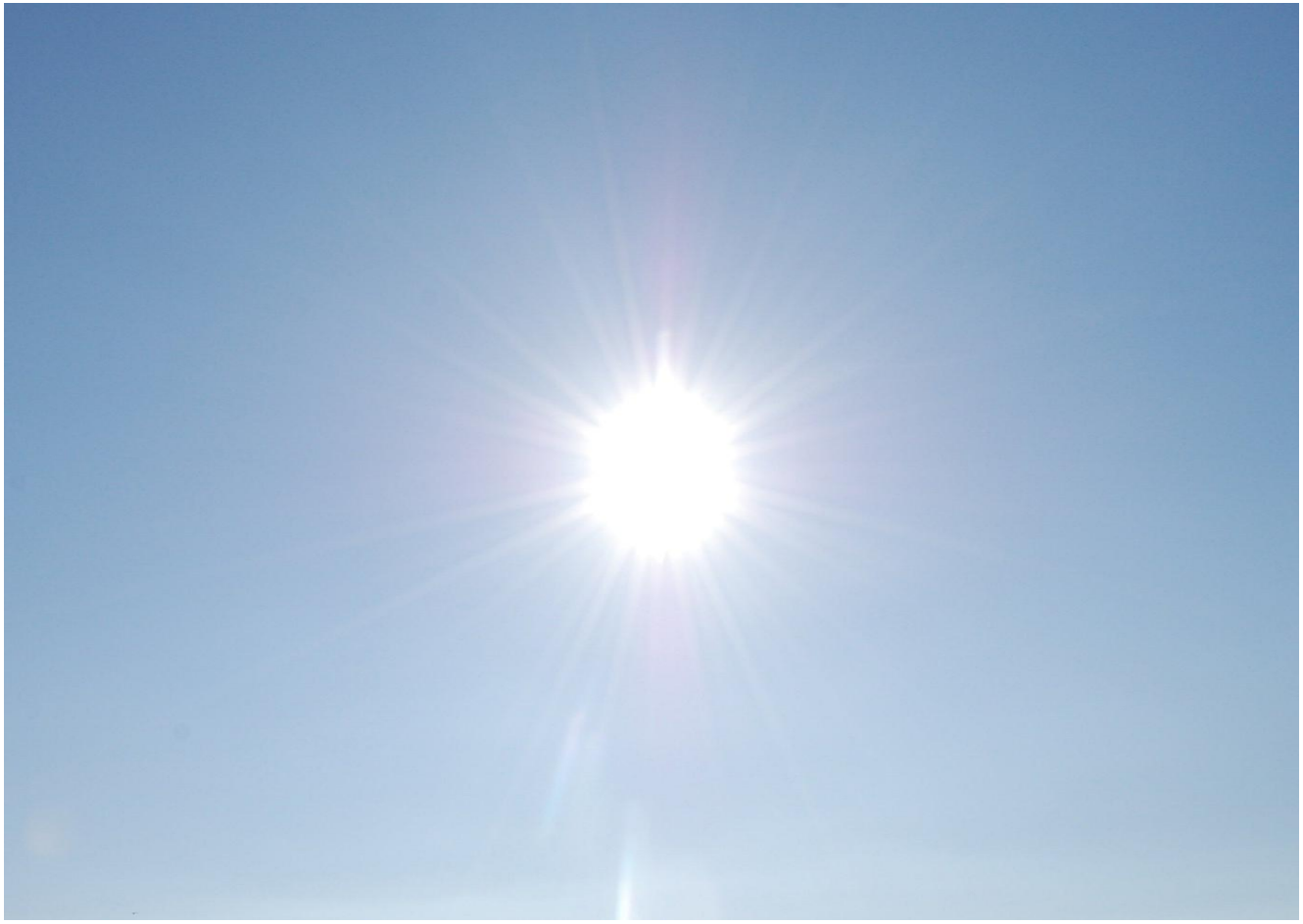

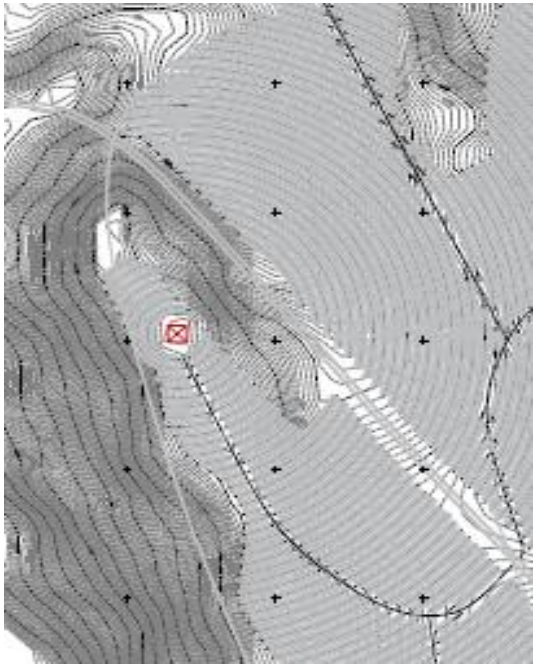

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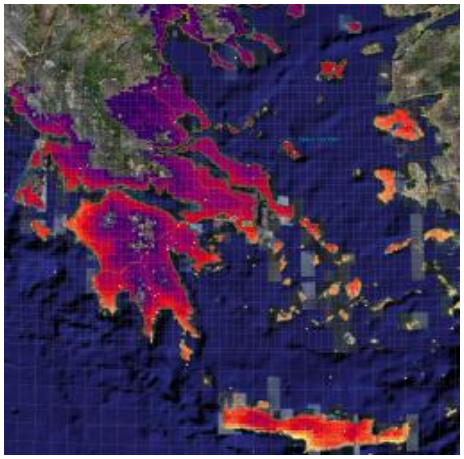
Flexibility in Solar Thermal Power generation: storage, co-firing, hydrogen

Concentrated Solar Power ("CSP") Technologies



Trough

- Most installed capacity
- Lower efficiency
- High water consumption due to water cooling

Power Tower

- 2nd Generation technology
- Superheat steam (550C, 150bar) / higher efficiency
- Lower cost
- Low water requirements due to dry cooling

Linear Fresnel

- New technology
- Lower efficiency and fewer MWh/MW
- Very limited operational experience

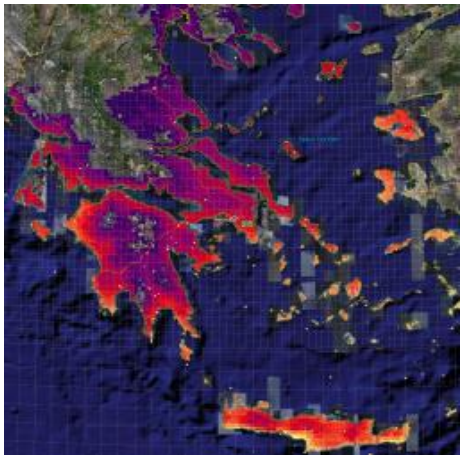
Stirling Engine

- Higher efficiency
- No commercial application to date
- Impractical to adapt a system to prevent intermittency

Common features of all CSP technologies

- Mirrors reflecting and concentrating direct sun rays on a solar receiver
- Conventional thermoelectrical power generation based on steam turbines
- Large-scale installations (10MW to 200MW)
- Direct sunlight required –sunshine under hazy or cloudy skies not cannot be utilized

Most CSP technologies require large & flat sites



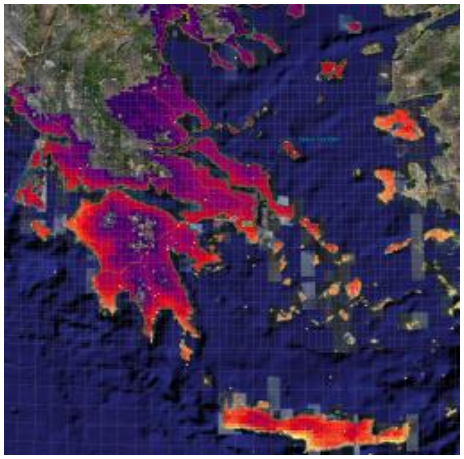
Troughs (aerial view of Andasol plant under construction)

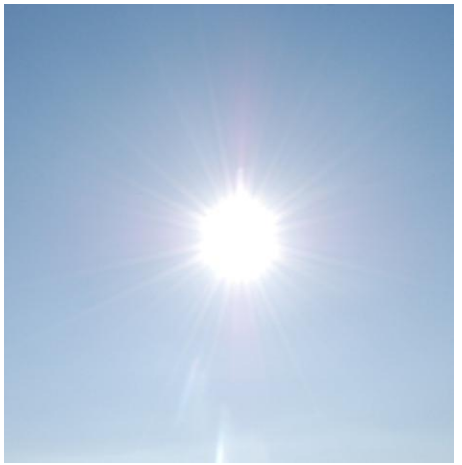
Linear Fresnel

Troughs (close up)

Modular tower

Central Tower CSP





Central Tower with DSG technology offers several advantages over the rest of the CSP technologies

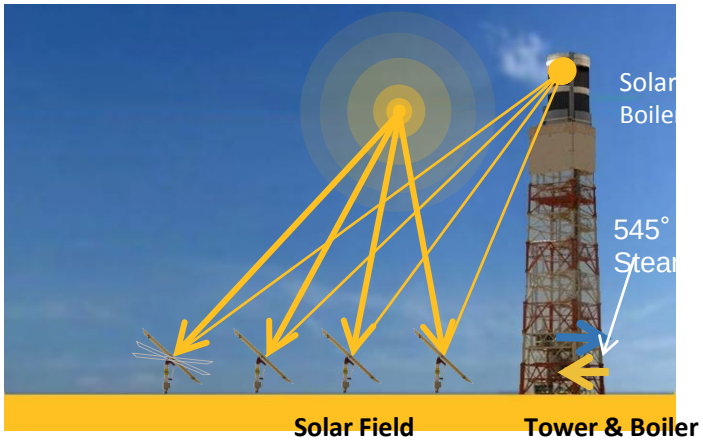
Can be applied on rugged, non-rectangular, and uneven terrain

Higher efficiency due to higher temperature allows air cooling (therefore 90% reduction on water consumption)

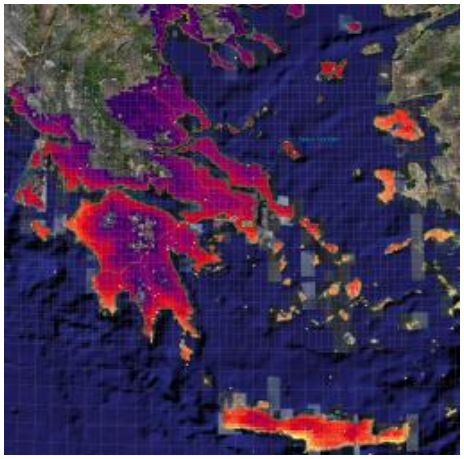
Direct steam generation, no thermal fluids hence no environmental risk

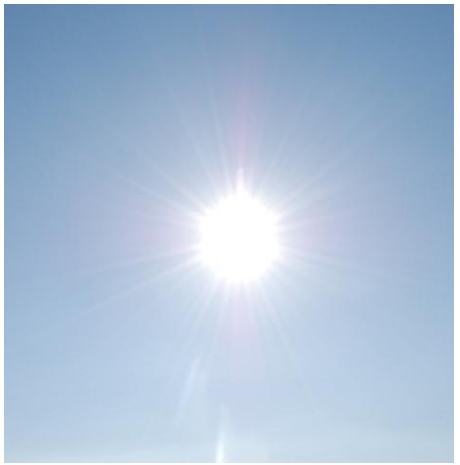
More stable daily power profile across the whole year

Lower parasitic losses



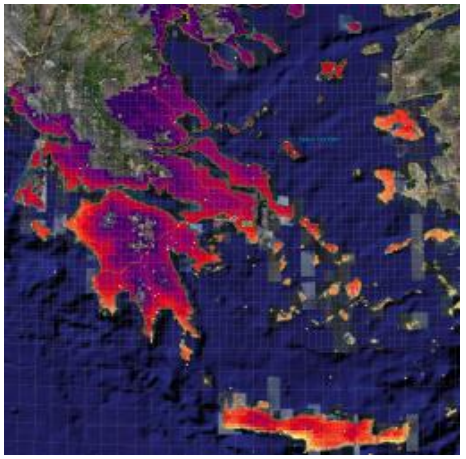
Central Tower CSP also minimizes environmental impact

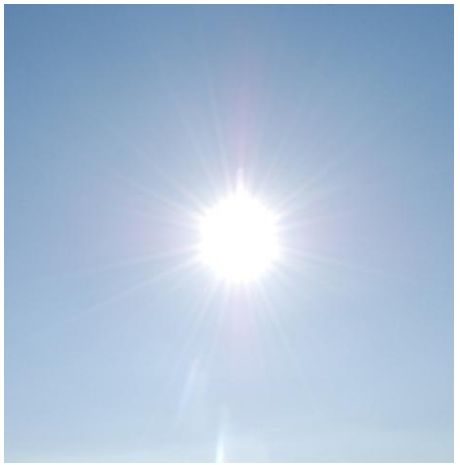




- Small heliostats with minimal foundations
- Harmonization with the natural habitat
- Reduction of earthworks
- Reversible impact on landscape

CSP Development in Greece

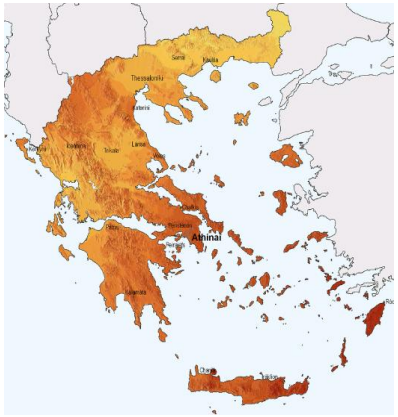


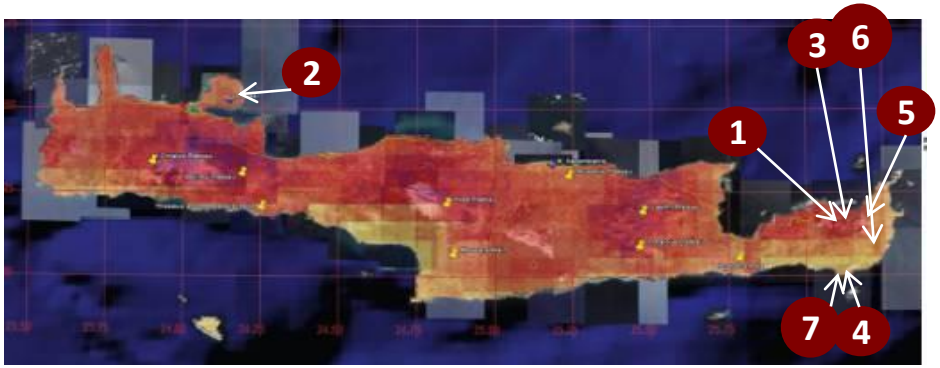


Hellenic National Action Plan set CSP target of 250MW by 2020.

Advantages of CSP technology recognized by Grid Operator and policy makers in the off-grid island systems, where RES penetration is currently saturated.

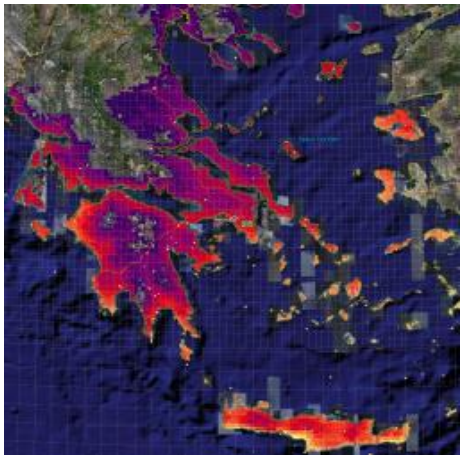
Under the recently passed Law 3851/2010 CSP feed-in tariff is 264,85 €/MWh for plants with co-firing only and 284,85 €/MWh for plants that are also equipped with thermal storage. Use of fossil fuel (diesel, biodiesel, LGP or natural gas) is allowed up to 15% of total energy produced.

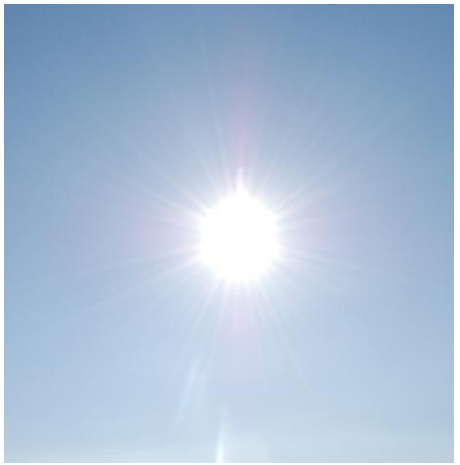


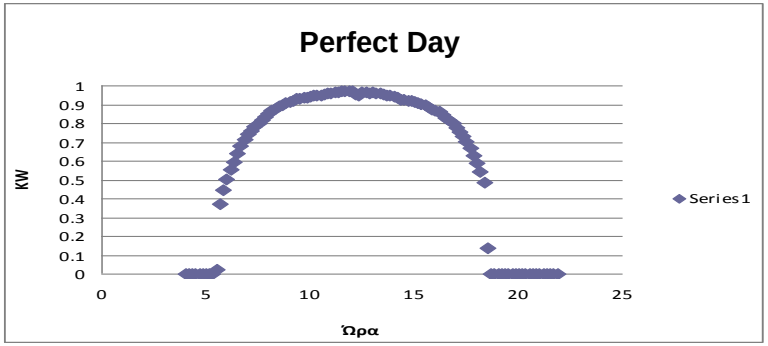


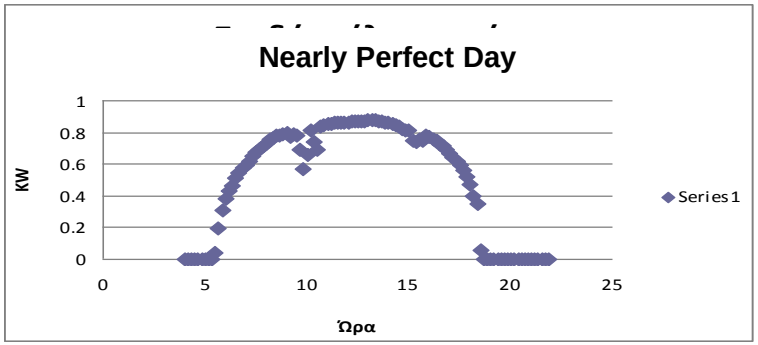
Regulatory Authority of Energy requires:
"The CSP plant must notify the Grid Operator for any change in power output at least 2h in advance"

Transient phenomena dictate CSP operation mode

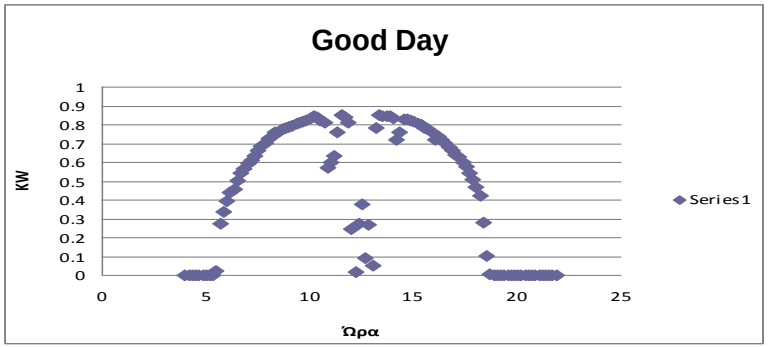


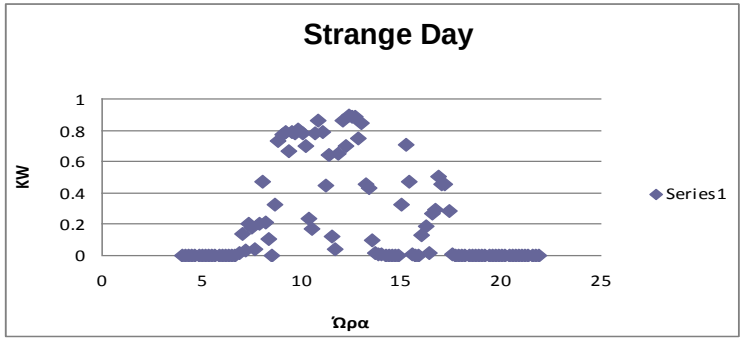




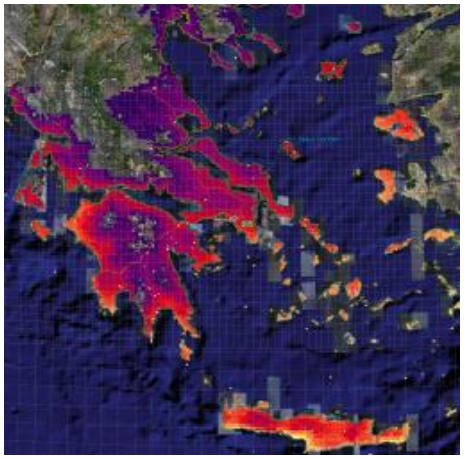


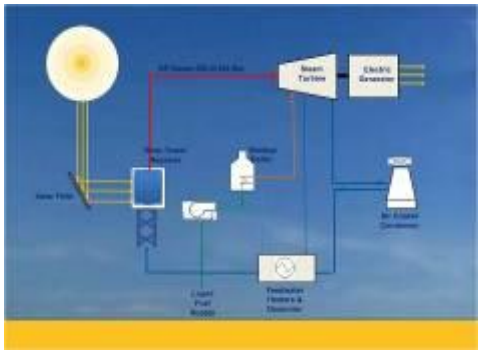
Operational constraints, grid curtailments and line regulation necessitate a solution against the inherent intermittency





Three ways to provide non-intermittent output





Co-firing with a conventional back-up boiler

- Complementary burning of fuel to top up solar steam during transient phenomena

- Known solution, manageable integration, fully reliable

-On an off-grid island system, no additional carbon emissions

- Cannot make use of dumped energy

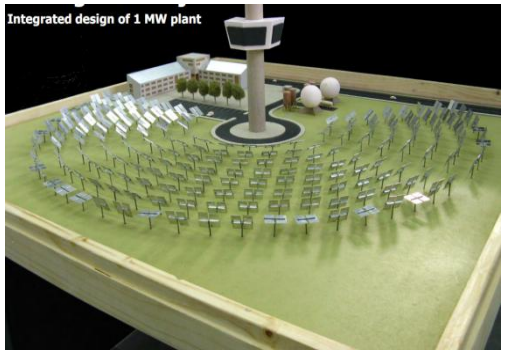
Thermal Storage

- Thermal Storage in molten salt tanks (either direct solar heat uptake or indirect through heat exchanger)

- Commercialised in Spain

- Drop in efficiency, but make use of dumped energy

- Safety concerns and high costs



Hydrosol Technology

- Reach higher temperatures and make use of dumped energy

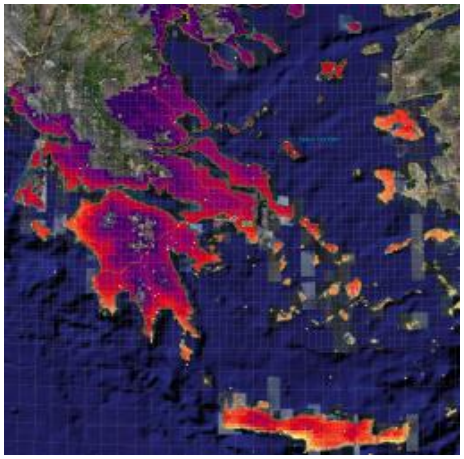
- Use heat for chemical reactions

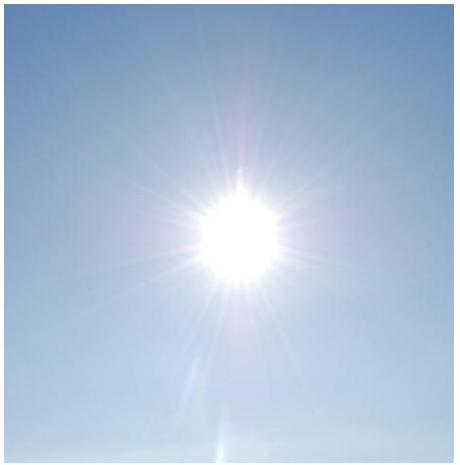
- Produce Hydrogen or synthetic fuels and raise net efficiency

- Combust or use in fuel cells

- Novel, but promising solution

Option 1: Co-firing with fossil fuel





✓**Well known solution**

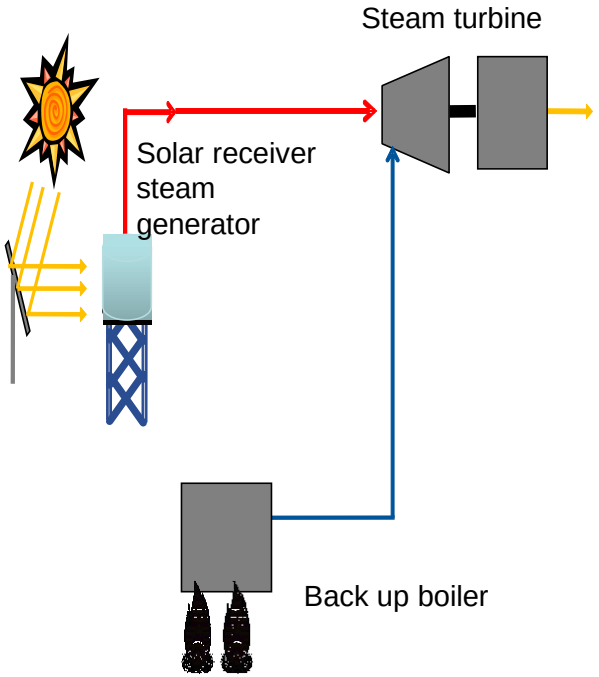
✓**Carries zero technology risk (boilers have been manufactured for more than 100 years)**

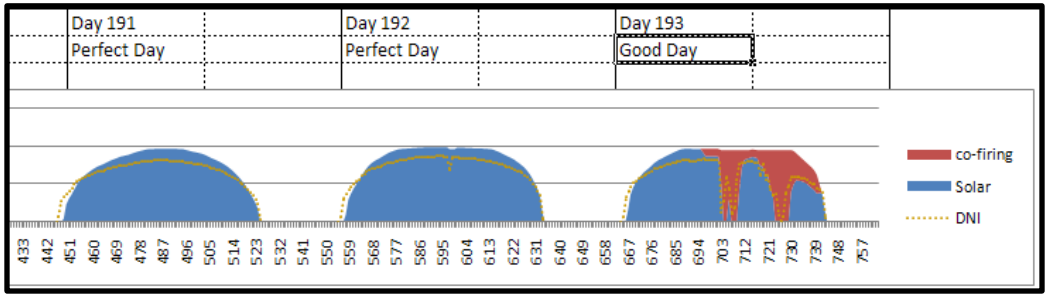
✓**Full hybrid system, one solar and one conventional boiler in parallel**

✓**Most efficient (highest operating temperature and pressure of steam cycle)**

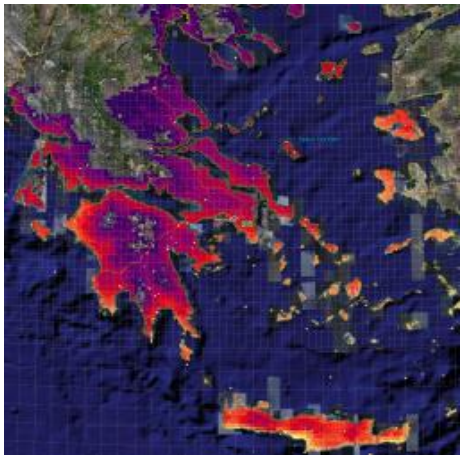
✓**Minimise losses (no heat transfers)**

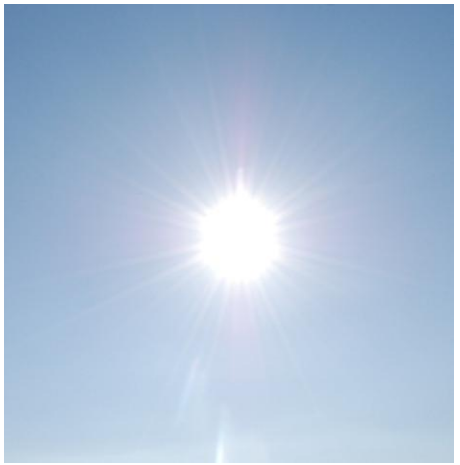
✓**Can operate like fully conventional system during the night or during large periods of cloudy weather**





Option 2: Thermal Storage





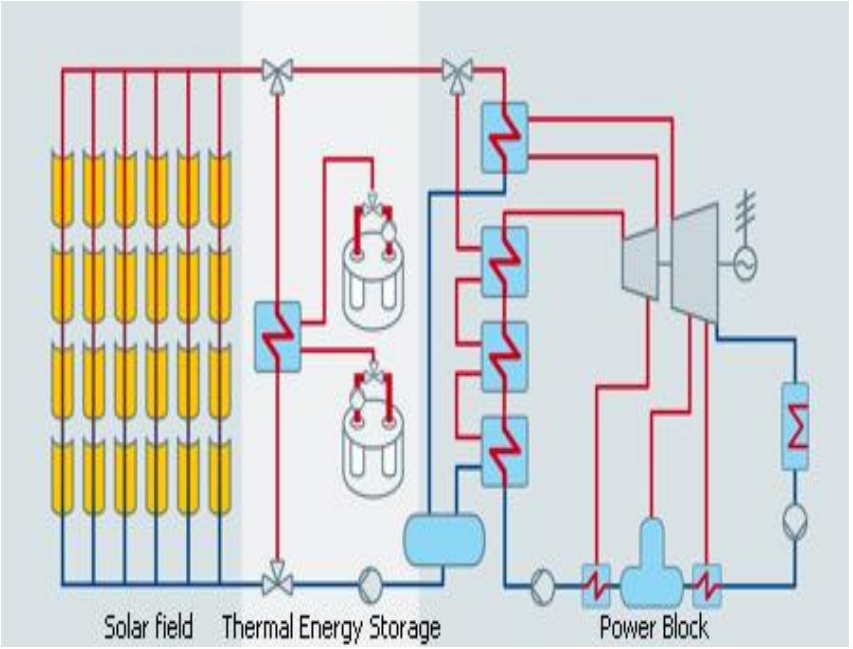
✓**Technology has gained market experience in Spain recently**

✓**Low losses compared to other storage solutions (e.g. batteries / fly-wheels / pumped storage)**

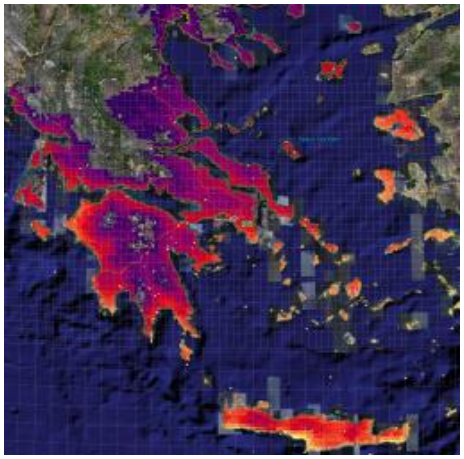
✓**Can shift generation to post-sunset hours**

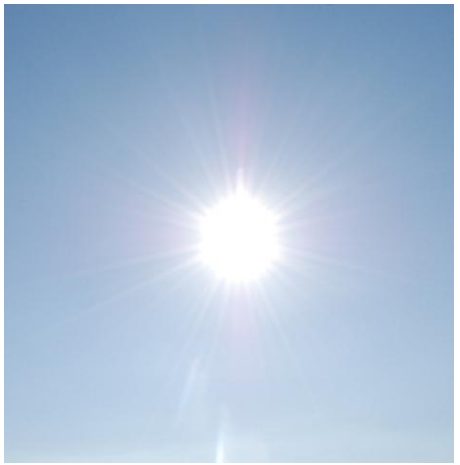
✓**Most common solution:**

- **Two tanks of molten salts**
- **Solar Energy heats the salts from 270ºC to 380ºC**
- **Whenever energy is needed the hot salts are used to generate steam through a heat exchanger**
- **Usual storage capacity about 6hours**



Option 3: Hydrosol technology





✓**Only available on tower technology**

✓**'Air' receiver can reach 1000°C**

✓**Use solar heat for thermochemical splitting:**

$2H_2O$ +  => $2H_2 + O_2$

$4H_2 + CO_2$ + => $CH_4 + 2H_2O$ (Methane)

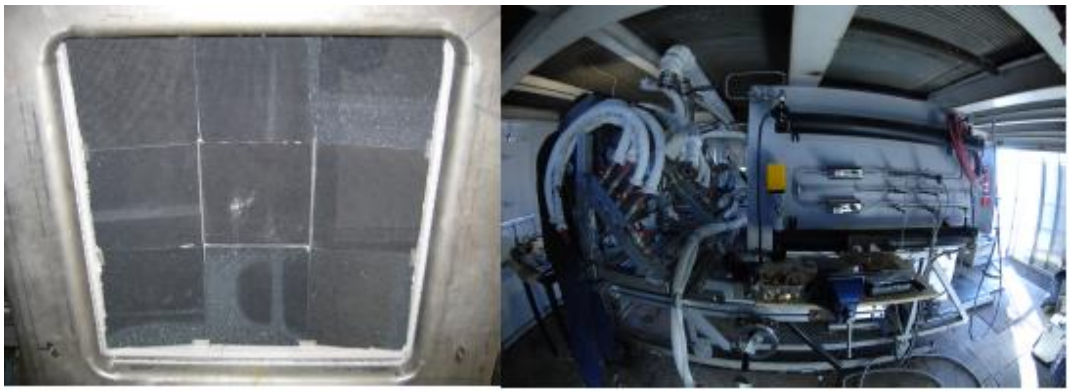
$3H_2 + CO_2$ => $CH_3OH + H_2$ (Methanol)

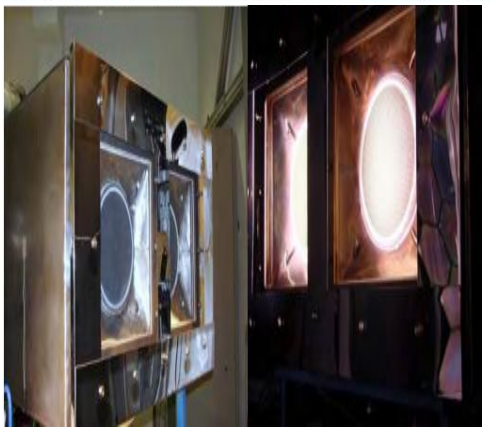
✓**Hydrogen and synthetic fuels can then be used in fuel cells or for combustion, but with much lower environmental impact than fossil fuels**

✓**Asynchronous production implies higher flexibility for line regulation and optimization of solar energy**

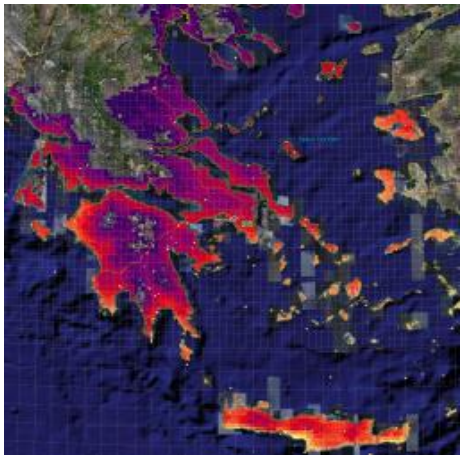
✓**Proven on experimental scale**

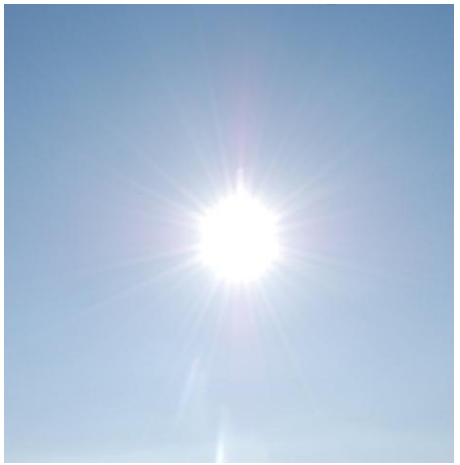
✓**Scaling up phase for commercialisation currently in Thessaloniki**





Potential for future combined applications





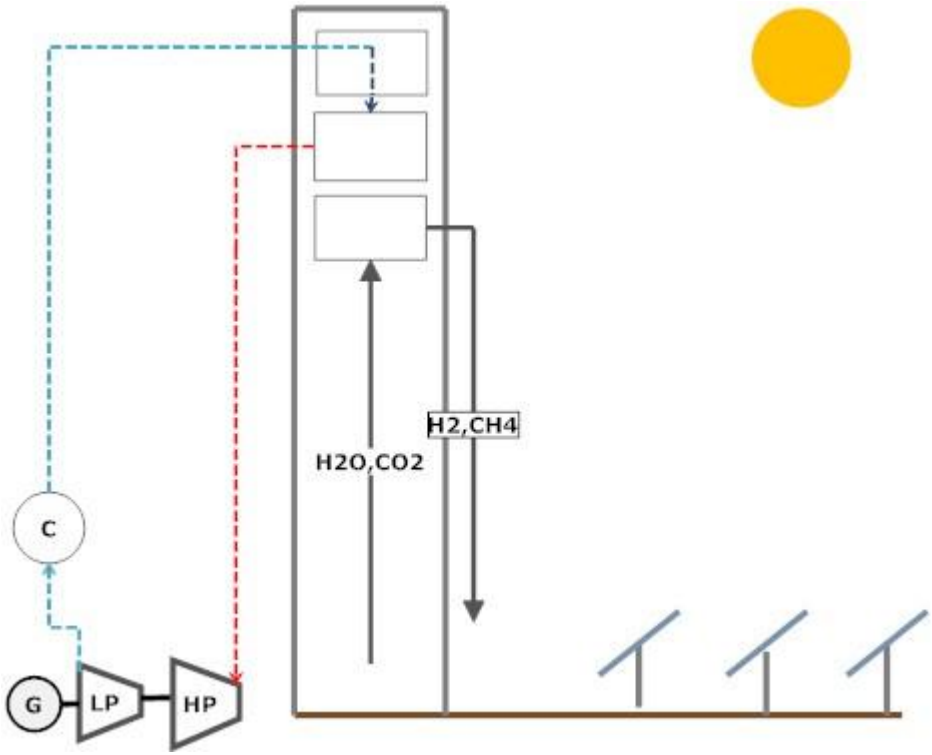
Example:

On a central direct steam generation tower CSP system, an auxiliary 'air' receiver could be added, which can reach 1000ºC, independently from the primary steam cycle

The solar field could be partly used for steam generation and partly for Hydrogen or Synfuel generation depending on prevalent weather and grid conditions

Hydrogen and/or Synfuel could be stored to provide non-intermittency and minimize or avoid the use of fossil fuel in a co-firing configuration

The combination of commercial technology with innovative concepts could lead to rise in efficiency and further drop in costs and carbon footprint



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