Waste biorefinery technologies for accelerating sustainable energy processes

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

Concentrated Solar Thermal Systems Integration into Thermochemical Processes: Examples and Opportunities

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The challenge

Depletion of fossil fuels

Greenhouse gases (mainly CO_2) intensifying environmental impact

Energy security issues

The proposed solution

Concentrated solar thermal power (CST or CSP) – what is it

*CSP technologies use mirrors or lenses to reflect and concentrate **sunlight** onto a receiver. The energy from the concentrated sunlight **heats** a high temperature fluid in the receiver*

Source: U.S. DOE

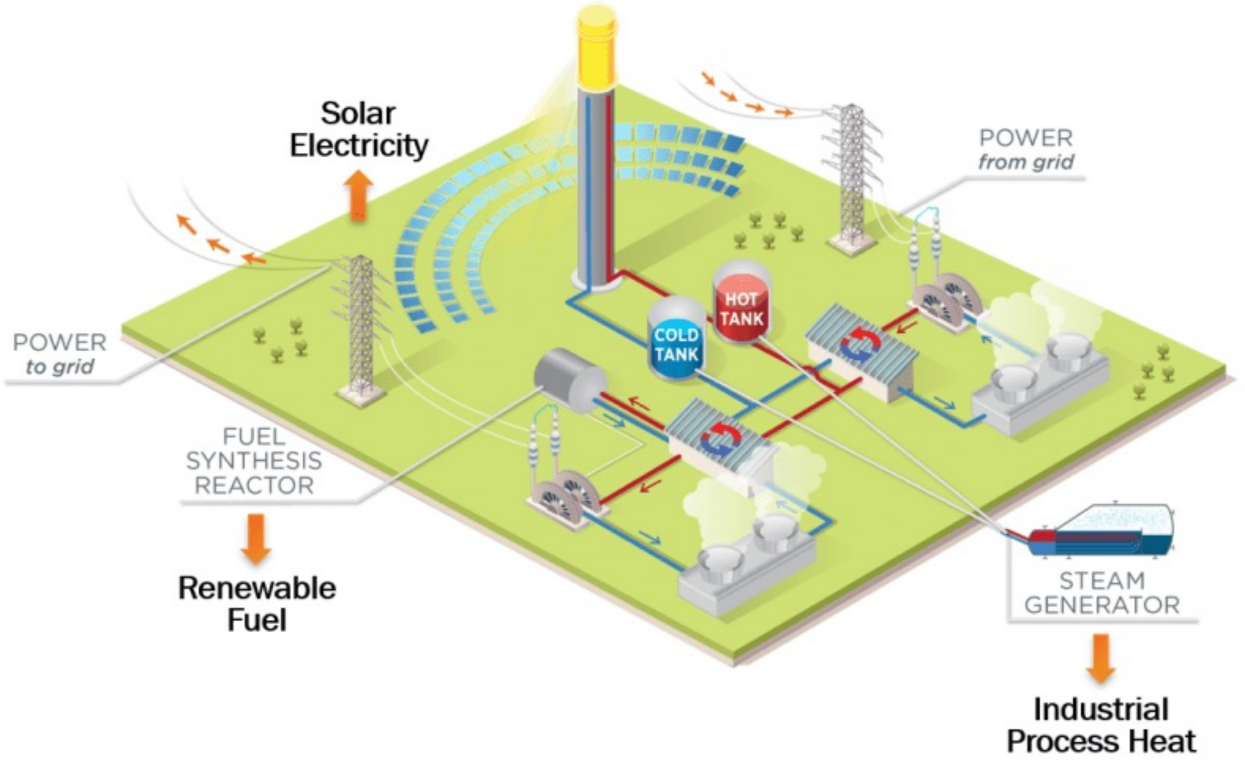
The proposed solution

Concentrated solar thermal power (CST or CSP) – what is it

*This **heat** - also known as **thermal energy** - can be used to spin a turbine or power an engine to generate electricity. It can also be used in a variety of industrial applications, like water desalination, enhanced oil recovery, food processing, chemical production, and mineral processing*

Source: U.S. DOE

A typical CSP plant



Source: U.S. DOE; https://www.energy.gov/eere/solar/concentrating-solar-thermal-power-basics

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The proposed solution

Concentrated solar thermal power (CST or CSP) - uses

- Electricity Generation
- Solar Heat for Industrial Processes (SHIP)
- District Heating
- Thermal Energy Storage
- Energy carriers* production

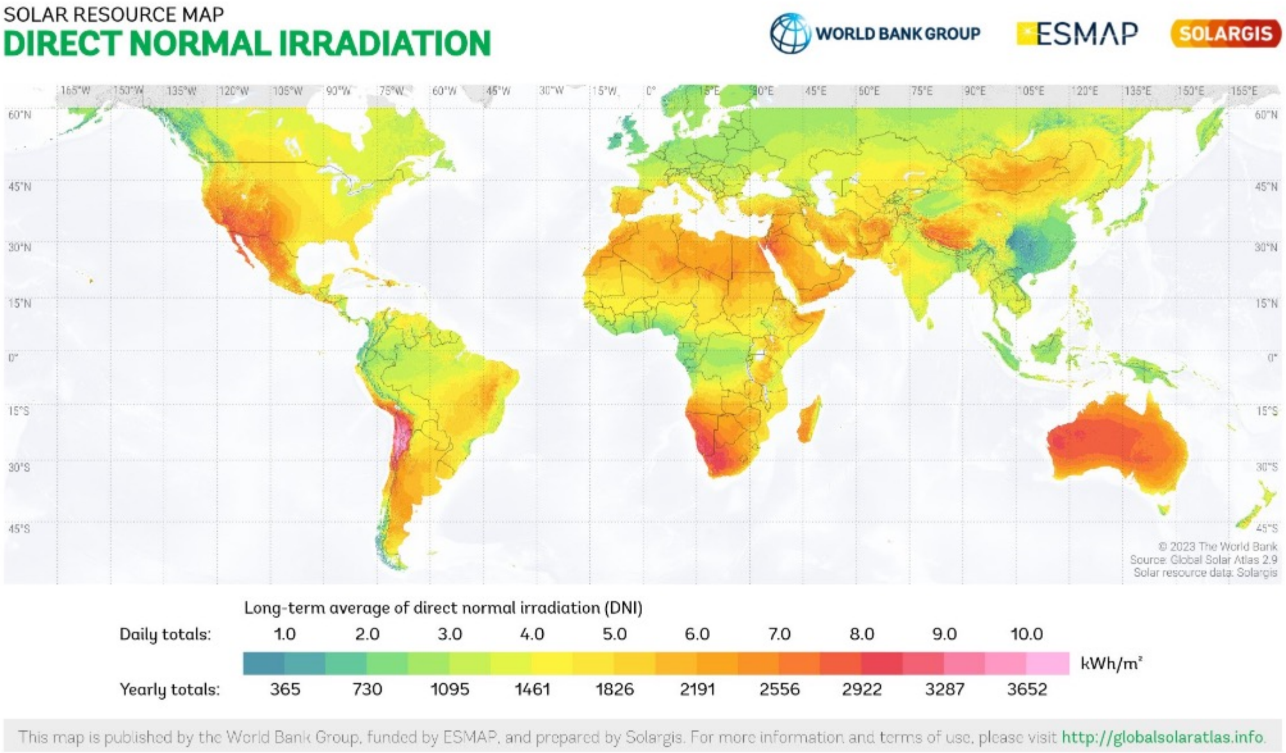
** Essentially any means of energy (incl. solar fuels, e.g., H_2) that can be stored, transported and used as a substitute for conventional fuels*

The proposed solution

Concentrated solar thermal power (CST or CSP) – challenges addressed

- ➢ Mitigates climate change
- ➢ Diversifies the energy mix
- ➢ Addresses intermittency in RE
- ➢ Provides dispatchable power
- ➢ **Leads to sustainable & resilient energy future**

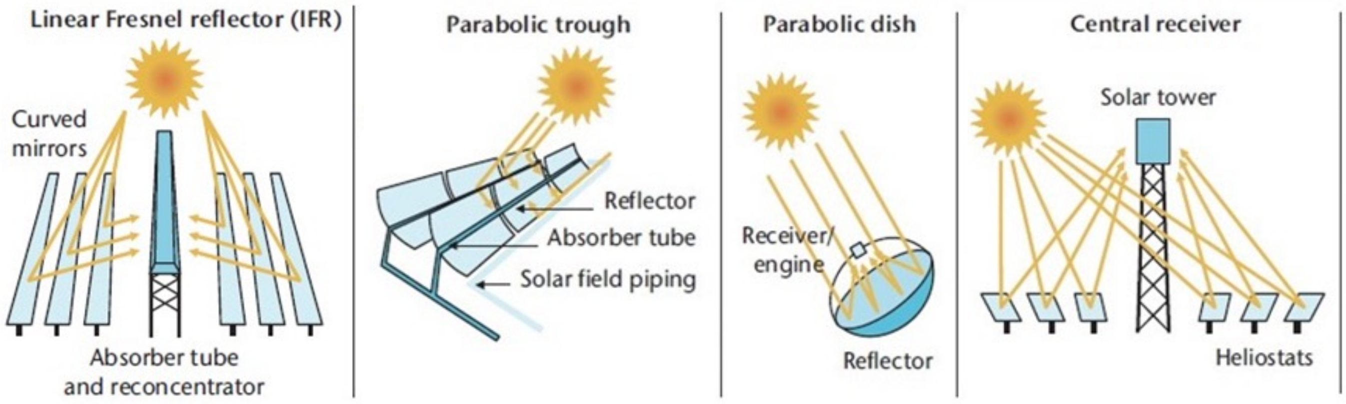
DNI World map



Source: World Bank Group

In-principle suitable areas typical DNI > 1500 kWh/m^2

CST system types



Source: U.S. DOE

50 – 300

250 – 550

800 – 900

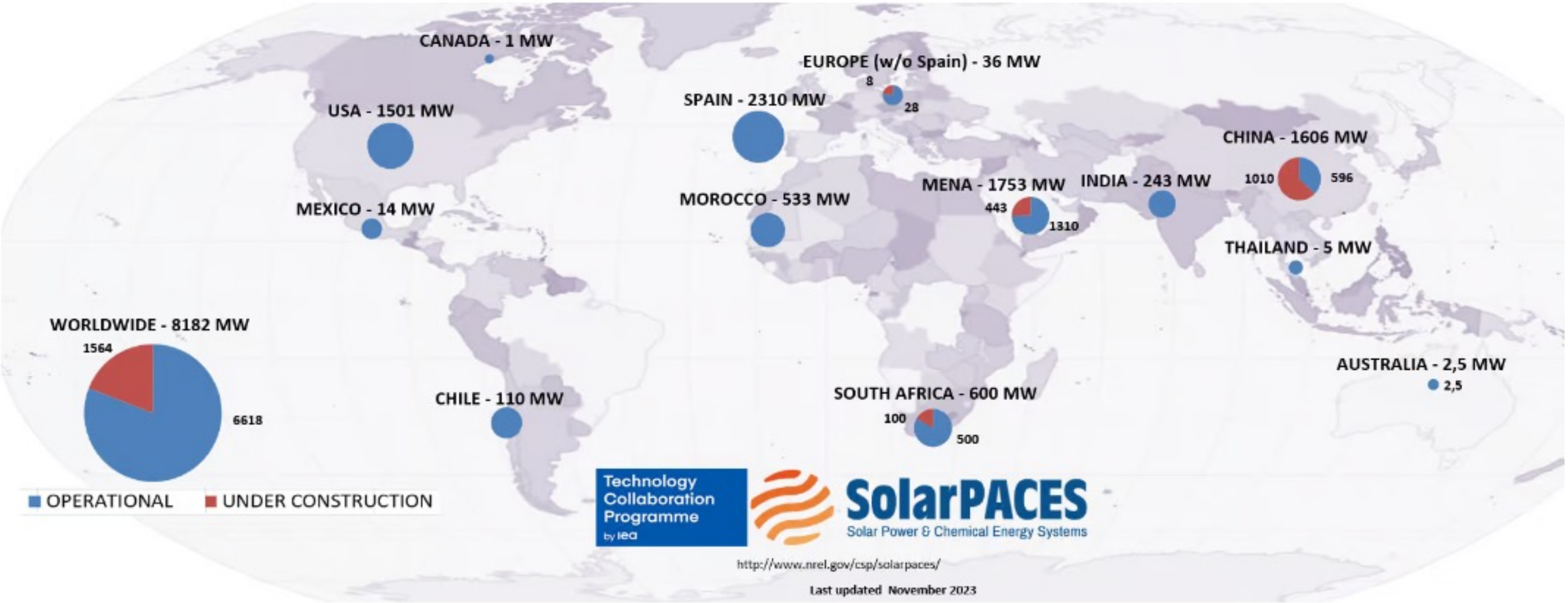
550 – 1000+

Operational Temperature (°C)

8.2 GW

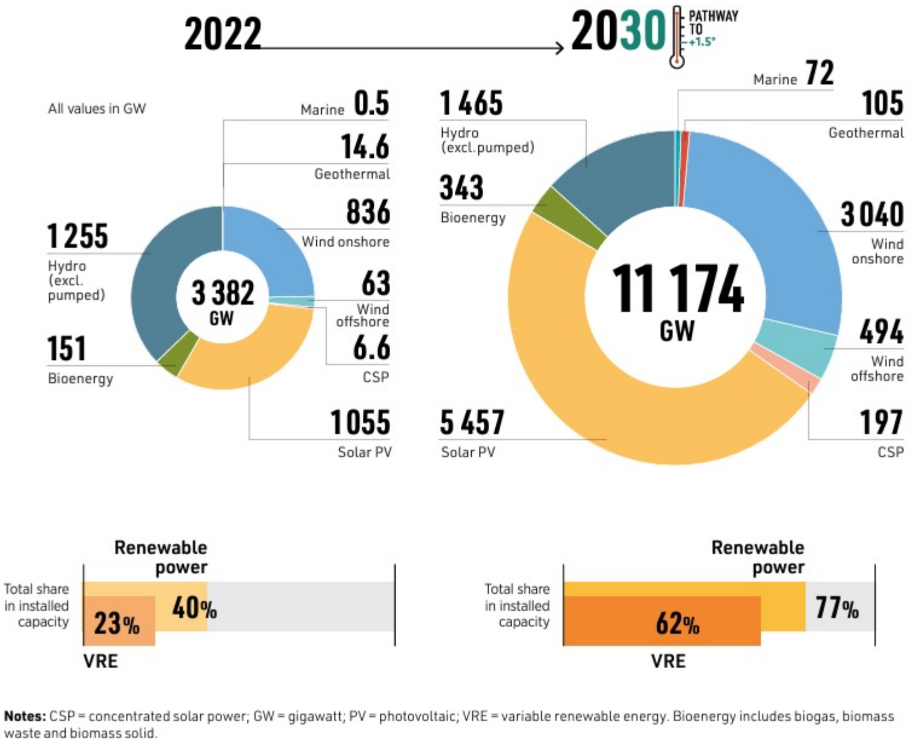
Total capacity of installed and under construction CSP plants

CSP projects around the World



Source: SolarPACES

CSP capacity projection



Source: IRENA report on COP28UAE

CSP capacity to raise from 6.6 GW (2022) up to **197 GW** by 2030

Examples of CST applications

Thermal Energy Storage

Elemental Sulphur Cycle

Hydrothermal Liquefaction of Residual Biomass

Examples of CST applications

WIRE

Thermal Energy Storage

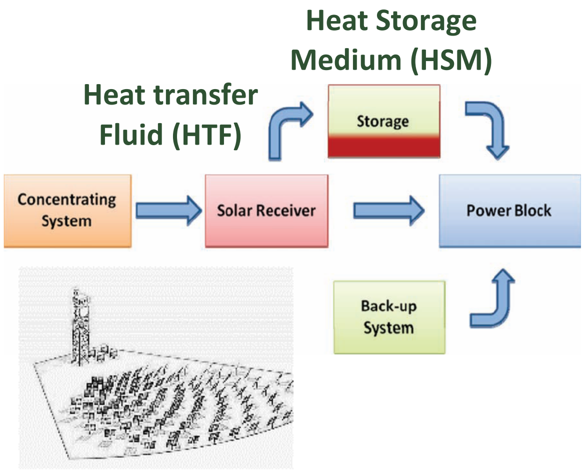
Elemental Sulphur Cycle

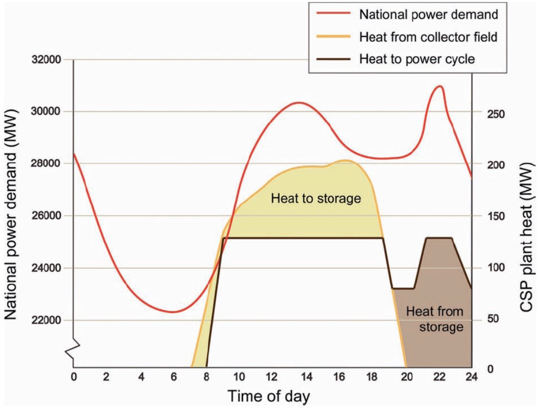
Hydrothermal Liquefaction of Residual Biomass

Thermal Energy Storage (TES) concept

CSP technologies main challenge: intermittence of solar energy → Energy storage

- ✓ Power block operation prolonged during off-sun conditions





Source: Denholm et al., Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart, NREL/TP-6A20-65023 Technical Report (2015)

- ❖ TES categories: *i) sensible heat; ii) latent heat;* ***iii) thermochemical heat***
- ❖ Exploitation of selected **reversible** chemical reactions
  - ✓ High energy density potential

Examples of CST applications

WIRE

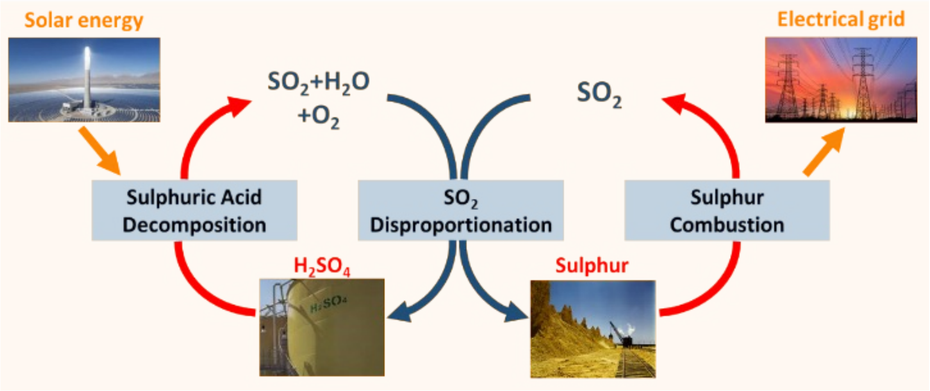
Thermal Energy Storage

Elemental Sulphur Cycle

Hydrothermal Liquefaction of Residual Biomass

Elemental Sulphur Cycle

		Reaction	Temperature (°C)	ΔH (kJ/mol)
1a	Sulphuric Acid Decomposition	$H_2SO_{4(aq)} \rightarrow SO_{3(g)} + H_2O_{(g)}$	450 – 500	560
1b		$SO_{3(g)} \rightarrow SO_{2(g)} + 0.5 \cdot O_{2(g)}$	700 – 900	
2	Disproportionation	$2 \cdot H_2O_{(l)} + 3 \cdot SO_{2(g)} \rightarrow 2 \cdot H_2SO_{4(aq)} + S_{(s)}$	50 – 200	-260
3	Sulphur Combustion	$S_{(l)} + O_{2(g)} \rightarrow SO_{2(g)}$	500 – 1500	-300



Technology	Energy Density (kJ/kg)
Hydrogen	141,886
Gasoline	47,357
Sulphur	**12,500**
Lithium Ion Battery	580
Molten Salt	282
Water Dam (100 m)	1

- Same step used for **H_2 production**: Sulphur-Iodine (SI) and Hybrid Sulphur (HyS) cycles

Elemental Sulphur Cycle

WIRE

Sulphur-based H_2 Production Reactions

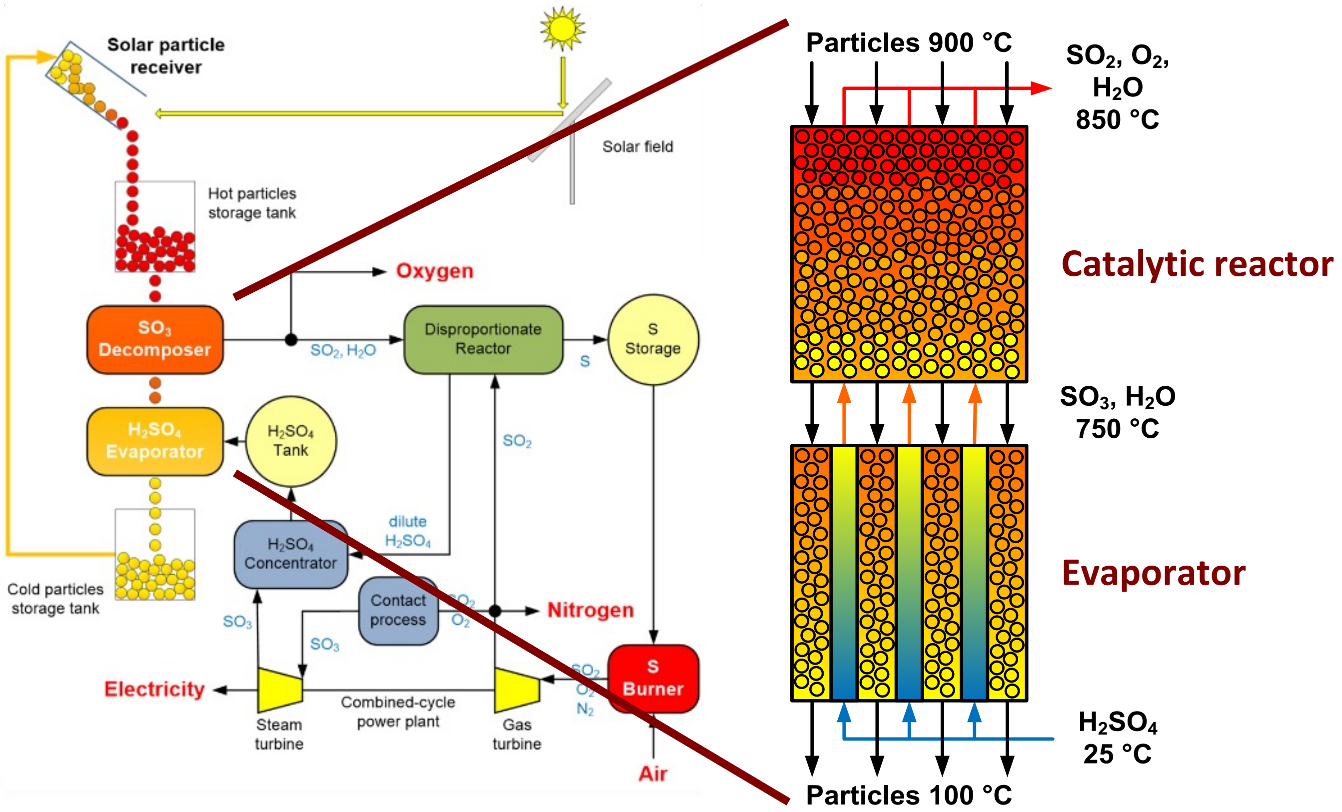
- Sulphur-Iodine Cycle

Reaction			Temperature (°C)
1a	Sulphuric Acid Decomposition	$H_2SO_{4(aq)} \rightarrow SO_{3(g)} + H_2O_{(g)}$	450 – 500
1b		$SO_{3(g)} \rightarrow SO_{2(g)} + 0.5 \cdot O_{2(g)}$	700 – 900
2	Bunsen reaction	$SO_{2(g)} + 2H_2O_{(g)} + I_{2(g)} \rightarrow H_2SO_{4(g)} + 2HI_{(g)}$	~120
3	Hydriodic acid decomposition reaction	$2HI_{(g)} \rightarrow H_{2(g)} + I_{2(g)}$	300 – 450

- Hybrid Sulphur Cycle

Reaction			Temperature (°C)
1a	Sulphuric Acid Decomposition	$H_2SO_{4(aq)} \rightarrow SO_{3(g)} + H_2O_{(g)}$	450 – 500
1b		$SO_{3(g)} \rightarrow SO_{2(g)} + 0.5 \cdot O_{2(g)}$	700 – 900
2	Electrolysis	$SO_{2(aq)} + 2H_2O_{(l)} \rightarrow H_2SO_{4(aq)} + H_{2(g)}$	80 – 120

Elemental Sulphur Cycle



Examples of CST applications

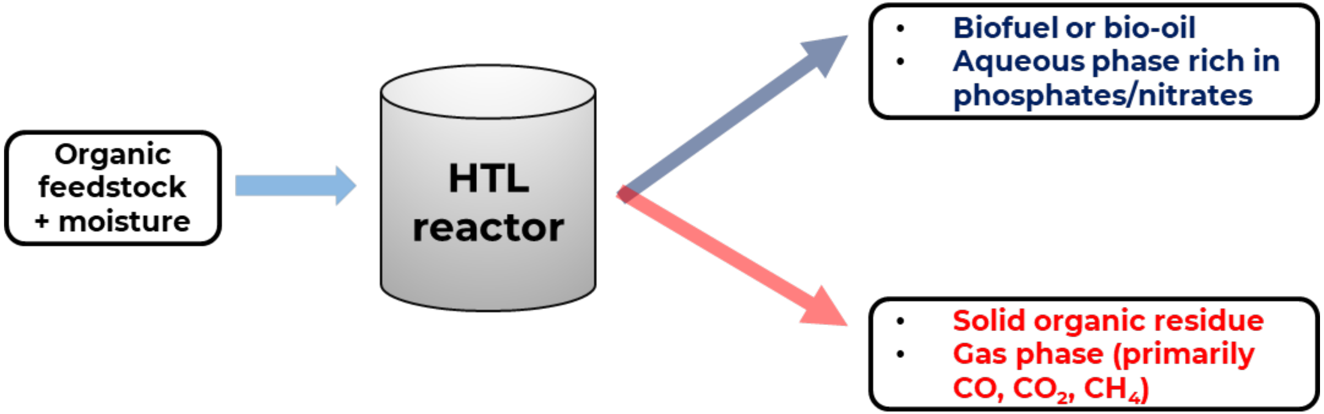
Thermal Energy Storage

Elemental Sulphur Cycle

Hydrothermal Liquefaction of Residual Biomass

Hydrothermal Liquefaction of residual biomass

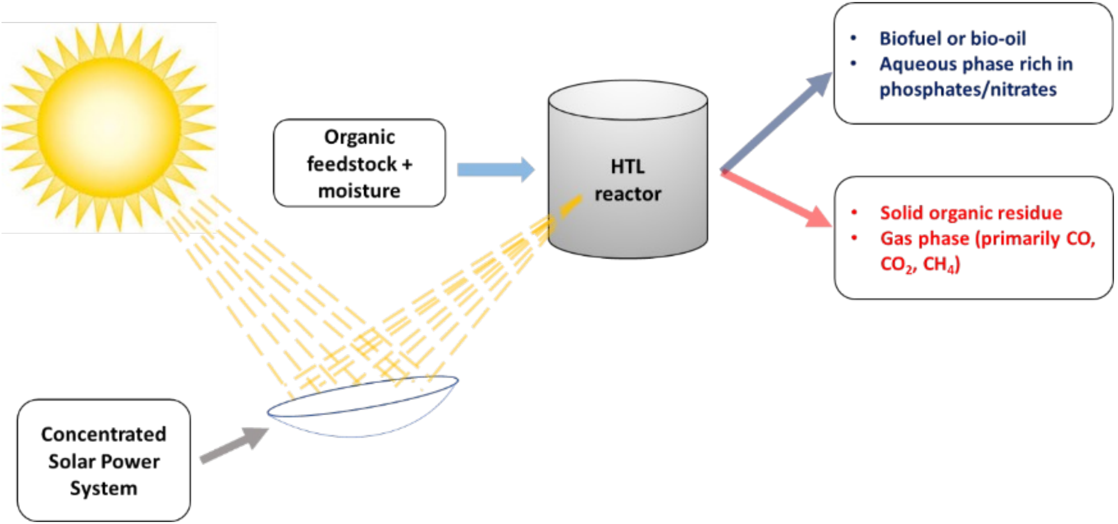
Conventional HTL



- ❖ Thermochemical conversion of organic waste into added value products
- ❖ Suitable technique for organic waste/byproducts with high moisture → ideal for agri-food/agricultural waste
- ❖ Treatment at 250 - 500°C & 50 - 250 bar
- ❖ Use of a reducing gas and (optionally) a catalyst
- ❖ Mostly water (moisture) used as solvent in its subcritical/supercritical condition

Hydrothermal Liquefaction of residual biomass

Solar-aided HTL



❖ Process thermal needs covered from a concentrated solar power system

❖ Linear Fresnel reflectors (50 - 300ºC) or Parabolic Trough collectors (250 - >400ºC)

❖ Ideal for operation at off-grid/remote areas

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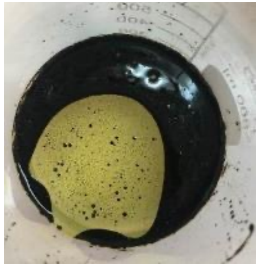
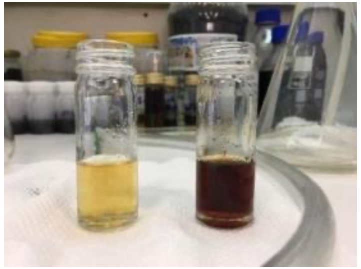
Indicative lab-scale results per feedstock

Feed	Maximum % yield to bio-oil	Solvent to separate oily from aqueous phase (Yes/No)
Plant oils	**84.3**	**No**
Polypropylene	53.9	No
Polymeric materials	39.2	Yes
Cow manure	37.8	Yes
Peach stones	16.4	Yes
Expired edible matter	10.2	Yes
Food waste	8.8	Yes



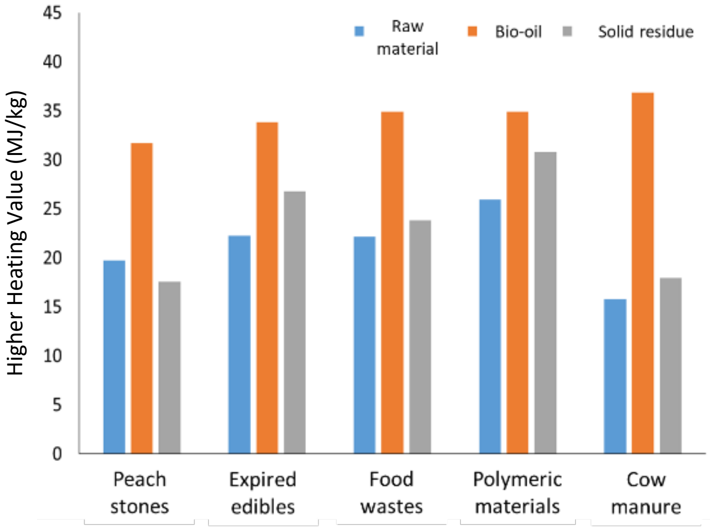
Aqueous phase + **Bio-oil**



Aqueous phase **Bio-oil**

Gaseous product for analysis

Higher Heating Value of products substantially higher (**energy upgrade process**)



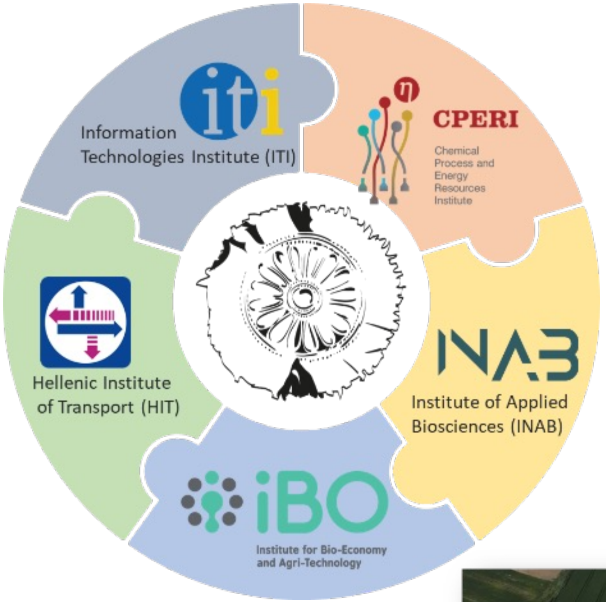
The Center for Research and Technology Hellas (CERTH)

- Founding year: **2000**
- **1500+** employees (260+ experienced researchers)
- Budget ~55 M€ in 2022:

  9% *state funding,*

  76% *European & National research projects,*

  15% *industrial contracts*
- **18** spin-offs



Horizon Europe

✓ **1st in Greece**

✓ **14th in Europe**

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CPERI
Chemical Process and Energy Resources Institute

Horizon Europe

- ✓ **1st in Greece**
- ✓ **14th in Europe**

The Chemical Process & Energy Resources Institute (CPERI) at a glance

Over 35 years of excellence, innovation, expansion and growth

1985
Foundation Year

3
Locations

324
Employees

12 M€/year
Competitive Grants

> 120/year
Publications

> 200 M€
Equipment

> 400
Collaborations

> 20,000
Citations

CPERI Brand Name:

Low Carbon Economy Technologies Institute

CPERI Research areas

Research areas

- **Clean Energy** (Deep decarbonization of energy-intensive industries, **Energy storage technologies**, **Development of novel zero/low-carbon fuels and chemicals**, Carbon capture storage and utilization, **Renewable energy and hydrogen technologies**)
- **Climate and Environment** (Clean transport/electrificatior of the transport system, Environmental technologies Water and waste-water management)
- **Sustainable development** (Just transition development plan, Circular economy, Polymers production and characterization)
- **Bioengineering/Biomedicine** (Development of biomaterials with application in the health sector, Advanced hybrid biotechnological applications, biosensors/biodevices, Biochemical process design for energy, materials and environmental applications)

ARTEMIS Lab at a glance

W I R E

2022	45	> 20 M€
Founding Year	Employees	Equipment
> 2 M€/year	> 100	> 9000
Competitive Grants	Collaborations	Citations

- Basic and applied research on **solar heat**, **novel hydrogen fuels**, as well as **innovative materials**
- Optimum integration of the **green transformation of industrial applications**
- Address the **relevant social challenges and priorities** of the National and European research and technology strategy

Core Scientific Objectives

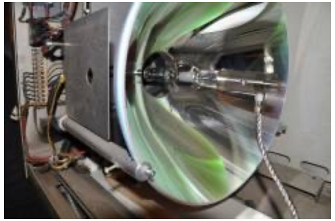
- Materials and subsystems for production of **energy carriers** from solar-thermal/thermochemical processes
- **Hydrogen** technologies
- **Combustion** processes and **emission control** technologies
- **Simulation** of physical, chemical, biological and biochemical processes
- **Aerosol technologies** and methods of **exposure/assessment** of the impact of particles' dispersion in biological systems

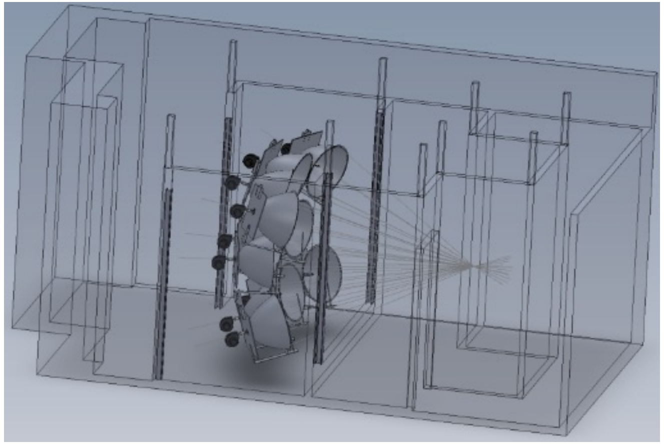
ARTEMIS Lab: Infrastructure

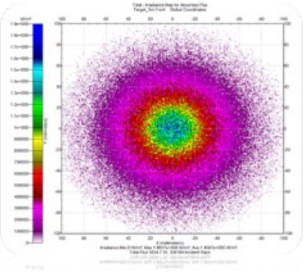
WIRE

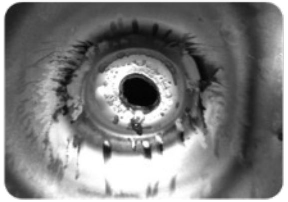
- Material synthesis and characterization units
- Battery lab
- Test rigs for the development and evaluation of membranes (ceramic, polymeric, hybrid)
- Gas analyzers (IR, mass spectrometers, gas chromatograph, sensors) & Portable analyzers
- Particulate emission measurements (number and mass basis) and size classification set-ups
- High pressure (1-350 atm) and temperature test rigs
- IR-furnaces & Split tube high temperature furnaces
- Foam burner lab-scale rig
- Biomass pyrolysis lab-scale unit
- Biomass gasification pilot plant
- Heavy duty and Light duty engine test cells
- 3 engine test cells
- **Solar simulator, Solar furnace & Parabolic Trough Collectors**
- Computational infrastructure
- Small Bio lab

Indoor high-flux solar simulator







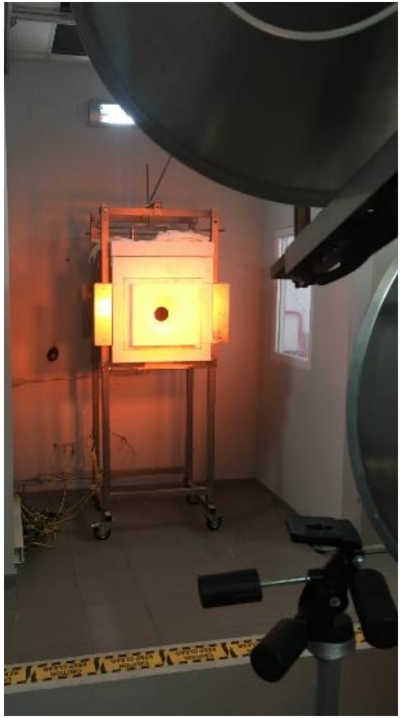


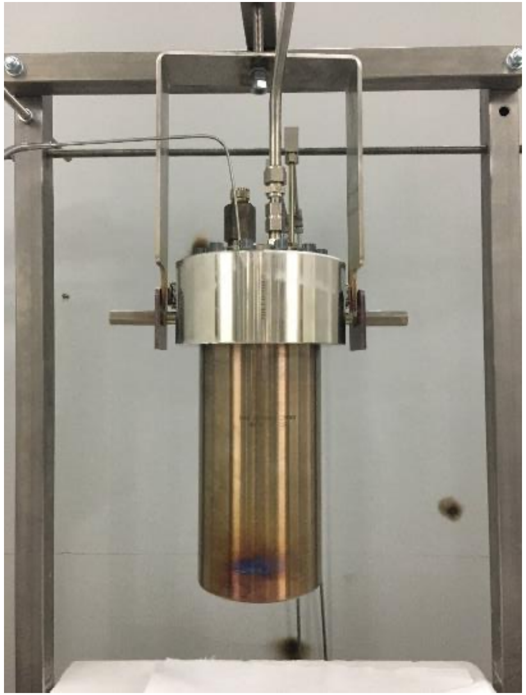
- Solar-like Concentrated Radiation
- Novel research for solar chemistry, solar fuels & solar receiver designs
- Accelerated aging of materials, material properties, thermal shocks

Indoor high-flux solar simulator

WIRE

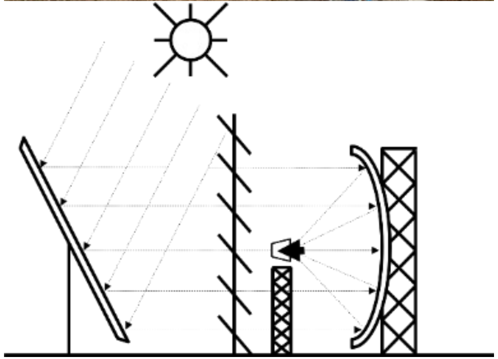
Lab-scale HTL reactor coupled with the solar simulator





❖ 8-10% bio-oil yield increase using the Solar Simulator (higher heating rates cf. electric heater)

Solar furnace



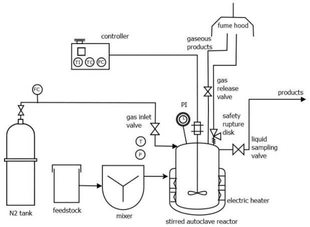
- Platform for testing solar chemistry related receiver-reactors & materials
- First of its kind in Greece; to be completed @end 2023
- Nominal power: 50 kW_{th}

Mobile solar HTL semi-pilot plant

- **Design** and **construction** of two modular 6 L tubular reactors
- **Parabolic troughs** as heating means; Dedicated **sun tracking system**
- A heat transfer fluid surrounds the reactor for improved heat conductivity
- **Successful proof of concept operation**; Experimental campaign underway

ARTEMIS HTL infrastructure developmental path

W I R E



Lab-scale

Electrically heated, stirred autoclave reactor

Solar lab-scale

Solar radiation simulation in a high-flux **solar simulator array**

Solar pilot-scale

Pilot-scale receiver-reactor employing **parabolic troughs**

Commercial scale

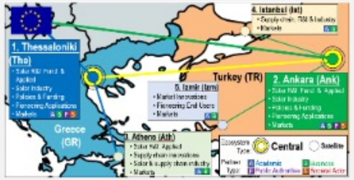
Future step: **Solar irradiated commercial scale** HTL reactor

ARTEMIS Current CST-related Research Projects

W I R E

SolarHub (2023-2026)

A Greek-Turkish Solar Energy Excellence Hub to Advance the European Green Deal



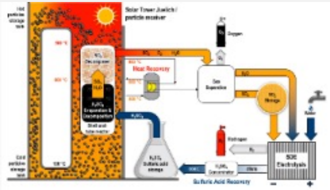
ODTU-GUNAM, **CERTH**, CRES, EGE, METU, ITU, DLR, GNDER, SHE, KALPV, BRITE, SAM, SLMPK, (…)

ARTEMIS Budget: 560.000 €

Strengthening connections between Greek and Turkish solar energy innovation ecosystems

HySelect (2023-2026)

Efficient water splitting via a flexible solar-powered Hybrid thermochemical-Sulphur dioxide depolarized Electrolysis Cycle



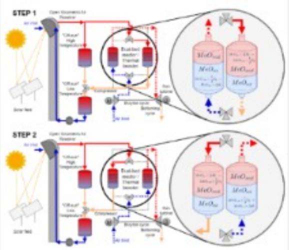
DLR, **CERTH**, AALTO, ENEA, FENR, GRILLO

ARTEMIS Budget: 500.000 €

H_2 production through hybrid Sulphur dioxide electrolysis cycle

ABraytCSPFuture (2022-2026)

Air-Brayton cycle Concentrated Solar Power Future plants via redox oxides-based structured thermochemical heat exchangers/thermal boosters



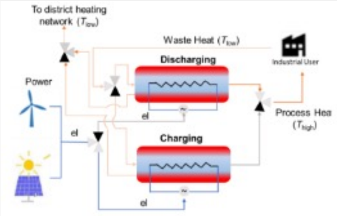
DLR, **CERTH**, UT, CENER, TEKNIKER, FHG, OPRA, KRAFTBLOCK, LANDSON, COBRA

ARTEMIS Budget: 400.000 €

Thermochemical energy storage by exploiting reversible redox reactions

HERCULES (2023-2027)

High-Temperature Thermochemical Heat Storage Powered by Renewable Electricity for Industrial Heating Applications



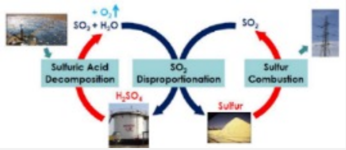
UT, DLR, **CERTH**, RISE, TATA, AWB, TMS, LET, COBRA, KB

ARTEMIS Budget: 780.000 €

High-temperature THS by renewable electricity for industrial heating

SULPHURREAL (2023-2026)

An Innovative Thermochemical Cycle Based on Solid Sulphur for Integrated Long-term Storage of Solar Thermal Energy



DLR, **CERTH**, ENEA, KIT, UP/DC, UD, RISE, EXOMATTER, SAINT-GOBAIN

ARTEMIS Budget: 350.000 €

Solar TES based on solid Sulphur

ARTEMIS

Dr. Nikolaos Tsongidis
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ARTEMIS Lab. | **A**dvanced **R**enewable **T**echnologies & **E**nvironmental **M**aterials in **I**ntegrated **S**ystems | CPERI | CERTH