“SOLAR CLINKER”

Dr. Davide Zampini

VP Global R&D
CEMEX

Net-Zero Cement Building a Sustainable Future Webinar

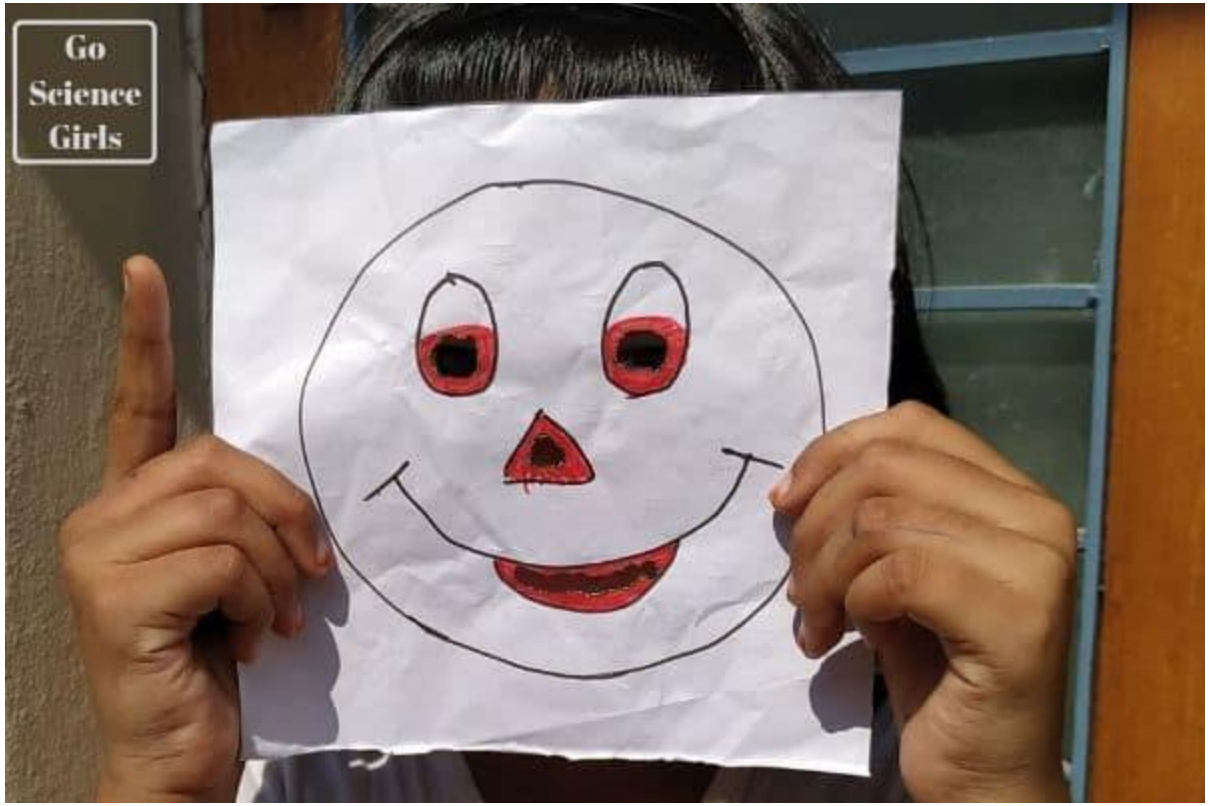
March 19, 2025

IMDEA
Mostoles, SPAIN

Concentrated Solar Thermal Power (CSTP)

The Technology

Concentrated Solar Thermal Power (CSTP)
"CHILD'S PLAY!"

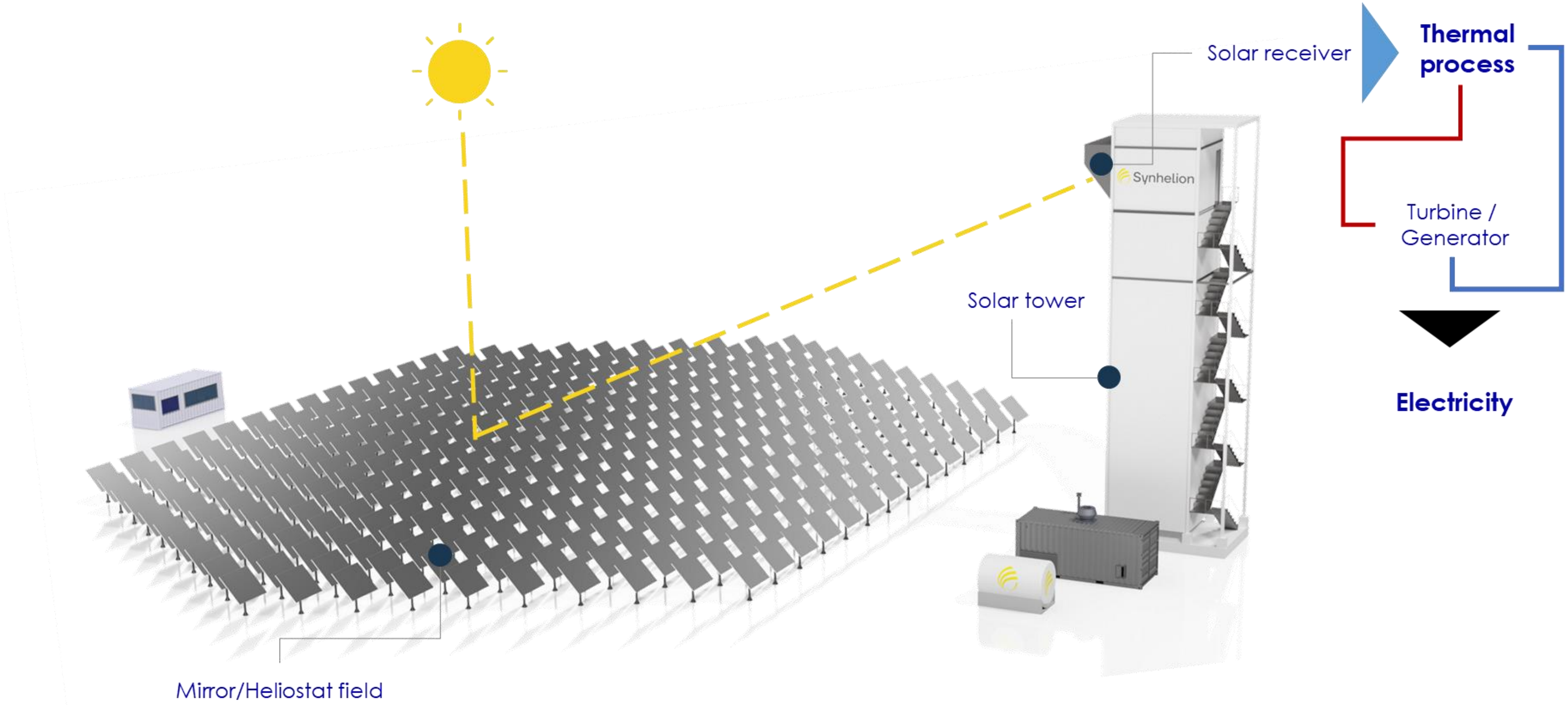


Source: https://gosciencegirls.com/

Go Science Girls
Empowering Girls in STEM

CEMEX

Solar Radiation-to-Power Generation
CONCENTRATED SOLAR THERMAL POWER (CSTP)



Concentrated Solar Thermal Power (CSTP)

March 2007, the **first commercial solar power plant – PS10 (Planta Solar 10)** – was put into operation in Sanlucar la Mayor near Andalusia, Spain. Although demonstration power plants with solar concentrators had already been built long before this date, the launch of **PS10 marked the beginning of the large-scale development of this sector of solar energy.**

Author: kallerna, CC BY-SA 4.0
https://aenert.com/news-events/industrial-tours/n/15-years-of-the-first-commercial-concentrating-solar-power-plant-ps10/

Concentrated Solar Thermal Power

State-of-the-Art

HTF state	*Receiver type*	*HTF type*	*Temperature range*	*Active institutions*
Gas	Tubular receiver	Air, CO_2	800 °C	DLR, Sandia
	Volumetric receiver	Air	1200 °C	DLR, ETHZ
	Absorbing gas receiver	H_2O, CO_2	1’600 °C	Synhelion solar fuels
Liquid	Tubular receiver/heat exchanger	Molten salts	800 °C	DLR, NREL
		Liquid metals	800 °C	CSIRO, IMDEA, PROMES-CNRS
Solid	Centrifugal/falling particle receiver	Ceramic particles	1000 °C	DLR, Sandia
	Co-located receiver/TES	Glass melt	1200 °C	ETHZ

400 °C 600 °C 800 °C 1000 °C 1’200 °C 1’400 °C 1’600 °C

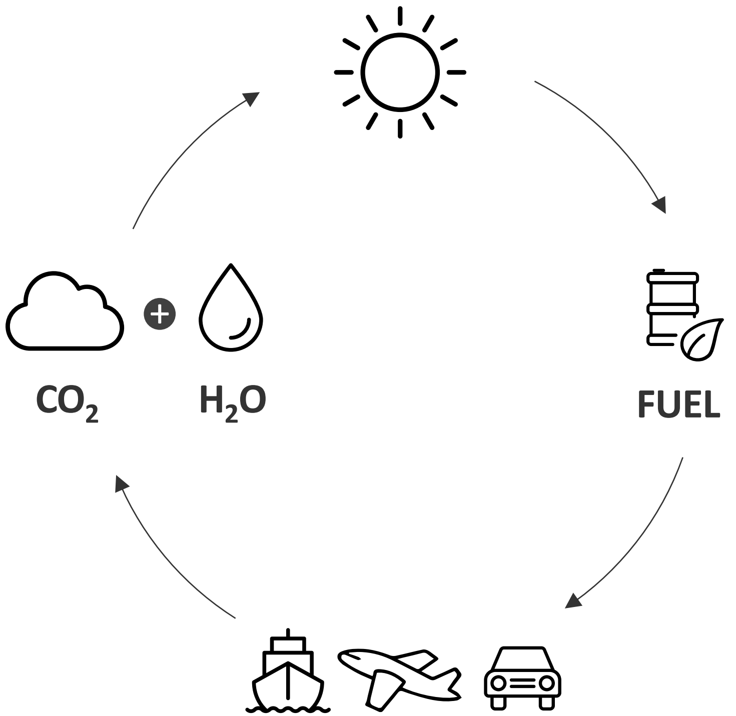
SOLPART project (solar-driven calcination) EU Funded 2016

Calcining

Clinkering

THE MISSION

We contribute to a net-zero transportation sector by replacing fossil fuels with carbon-neutral solar fuels.



THE TECHNOLOGY

We use solar heat for the production of synthetic fuels like kerosene, gasoline, or diesel.

ROADMAP

2024: 1st INDUSTRIAL PLANT
- Brainergy Park Jülich, DE
- 10'000 liters per year

2025: 1st COMMERCIAL PLANT
- Spain
- 1000 tons per year

2033: CAPACITY RAMP-UP
- 1 million tons per year

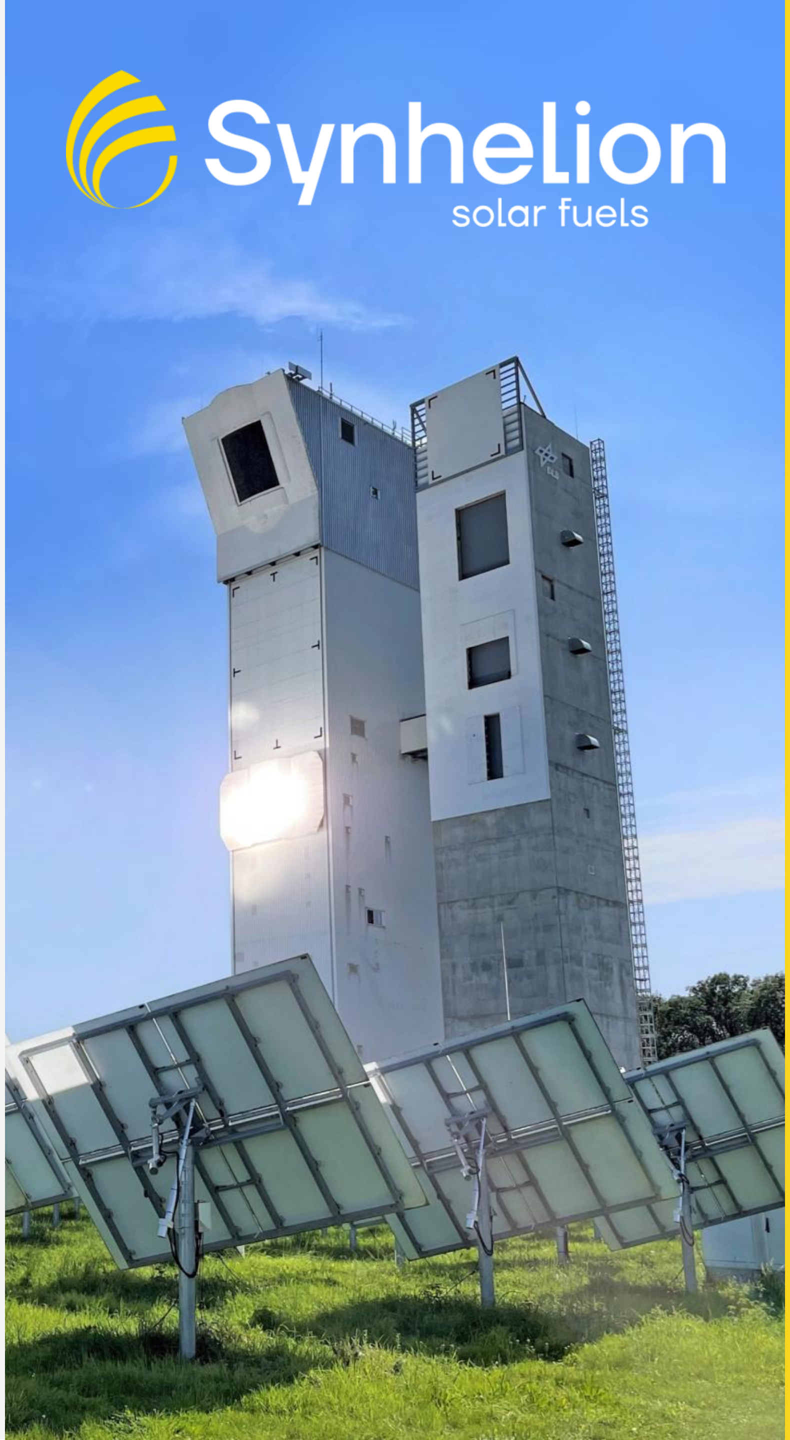
2040: TOWARD NET ZERO
- 40 million tons per year

BENEFITS

AFFORDABLE alternative to fossil fuels

COMPATIBLE with the global fuel infrastructure

SCALABLE to cover global fuel demand



TURNING SUNLIGHT INTO FUEL.

Synhelion

The People who are leading Synhelion

Dr. Gianluca Ambrosetti
CEO and Founder

- PhD in Physics/ Nanotechnology from EPFL Lausanne
- Recipient of the EPFL Prix Prof. René Wasserman 2011
- Held various positions in the concentrated solar power and photovoltaics industry
- Several patents and scientific publications

Dr. Philipp Furler
CEO and Founder

- PhD in Mechanical Engineering from ETH Zurich and an Executive MBA from the University of Strathclyde
- Over ten years of experience in high-temperature solar chemistry and reactor engineering
- Co-founded the ETH spin-off Sunredox, acquired by Synhelion in 2018

Dr. Philipp Good
CTO

- PhD in Mechanical Engineering from ETH Zurich
- Over ten years of experience in the design, modelling, engineering, and experimental testing of high-temperature solar receivers and the optical alignment, characterization, and operation of solar concentrators

Thomas Syfrig
CFO

- MBA from the University of St. Gallen
- CFA charterholder
- Over two decades of financial expertise in banking, corporate finance and as a CFO
- Studied and worked in Switzerland and abroad

Hans Hess
Chairman of the Board

- Master in Materials Science from ETH Zurich and an MBA from University of Southern California, LA
- Ex-chairman and board member of several companies and Swiss organizations
- Ex-CEO of Leica Geosystems AG, which he successfully listed at the Swiss Stock Exchange SIX

CEMEX

In 2020 **partnered with CEMEX** to **develop an innovative solar-driven technology** that aims to eliminate fossil fuels and the carbon footprint in the **clinker manufacturing process.**

TURNING SUNLIGHT INTO FUEL.

Synhelion Technology

Four Proprietary Innovations

1 **SOLAR RECEIVER – radically new technology for an energy-efficient and cost-effective production of high-temperature solar heat well beyond 1’000 °C.**

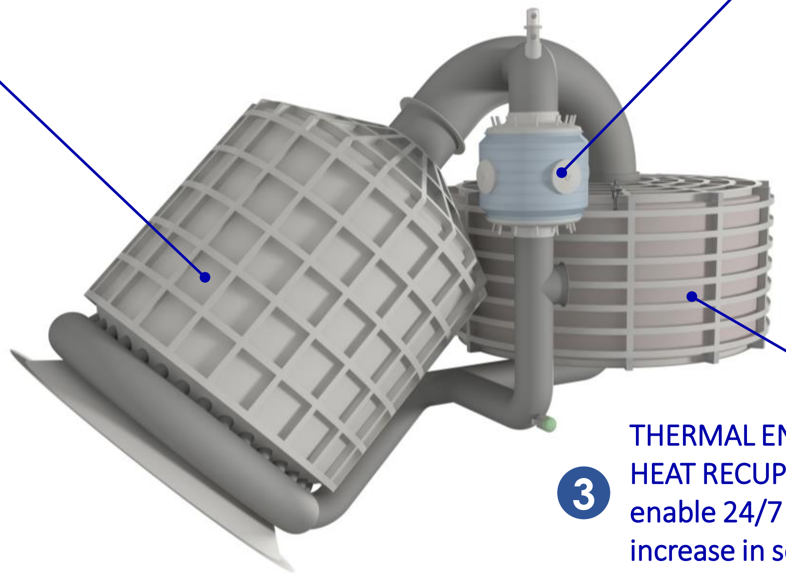
Since 2017:

- 4 patent filings (more in preparation)
- 1 publication

2 **THERMOCHEMICAL PROCESSES to produce solar fuels – formidable improvement of heat-to-fuel conversion efficiency.**

Since 2010:

- 2 patent filings
- 14 publications
- 2 PhD theses



3 **THERMAL ENERGY STORAGE (TES) AND HEAT RECUPERATION SYSTEMS – enable 24/7 operation and strong efficiency increase in some thermochemical processes.**

Since 2015:

- 4 patents
- 5 publications
- 1 PhD theses

4 **HELIOSTATS – intelligent and automated systems & solutions for the control of heliostats.**

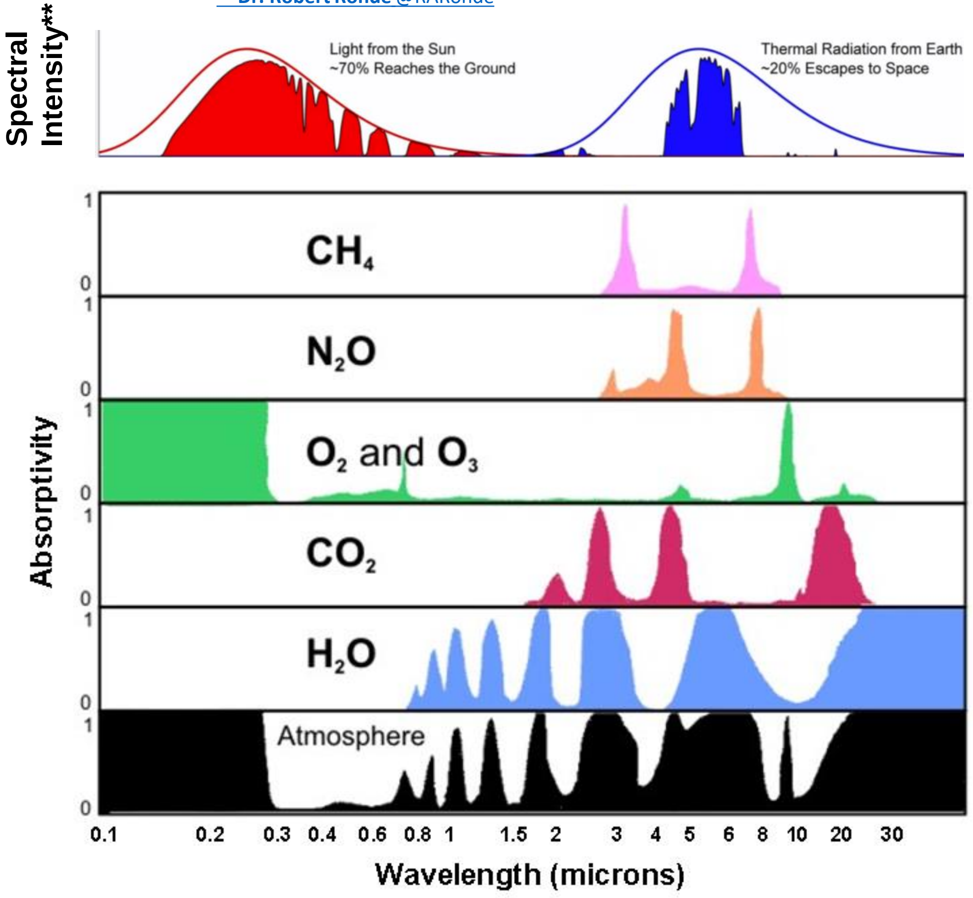
Acquistion of Heliokon experts in highly concentrating solar technology & state-of-the-art technologies for power generation in solar thermal power plants

The Greenhouse Effect

CO2 & H2O Best Gases to Heat – THE Fuel!

Radiation Transmitted by the Atmosphere**

**Dr. Robert Rohde @RARohde



The absorption spectra of various gases in the atmosphere, and of the atmosphere as a whole. Note that water vapor and carbon dioxide both readily absorb radiation at several infrared wavelengths (near 1 micron and greater on the graphic).

Credit: David Babb

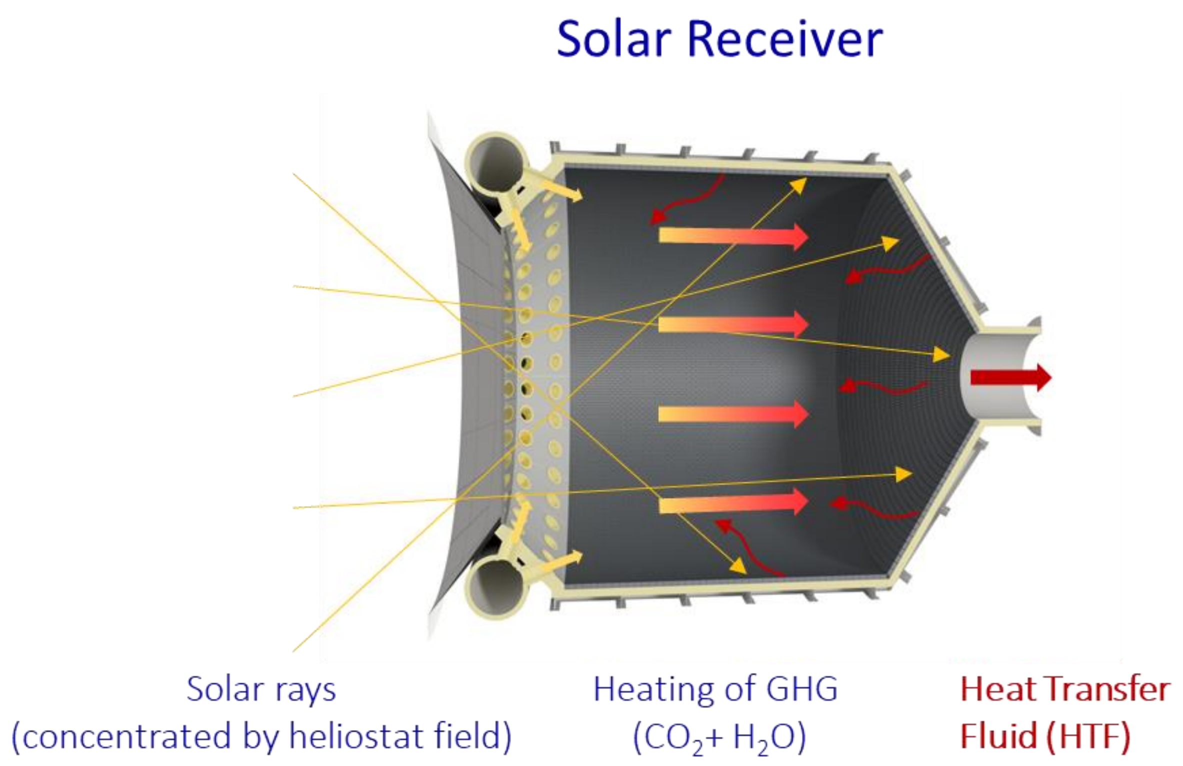
Atmosphere Gas Composition [vol%]*	
N_2	78.084
O_2	20.946
Ar	0.934
CO_2	**0.040**
Ne	0.00182
He	0.00052
CH_4	**0.00017**
Kr	0.00012
H_2	0.00005
N_2O	**0.00005**
H_2O	**1.000**

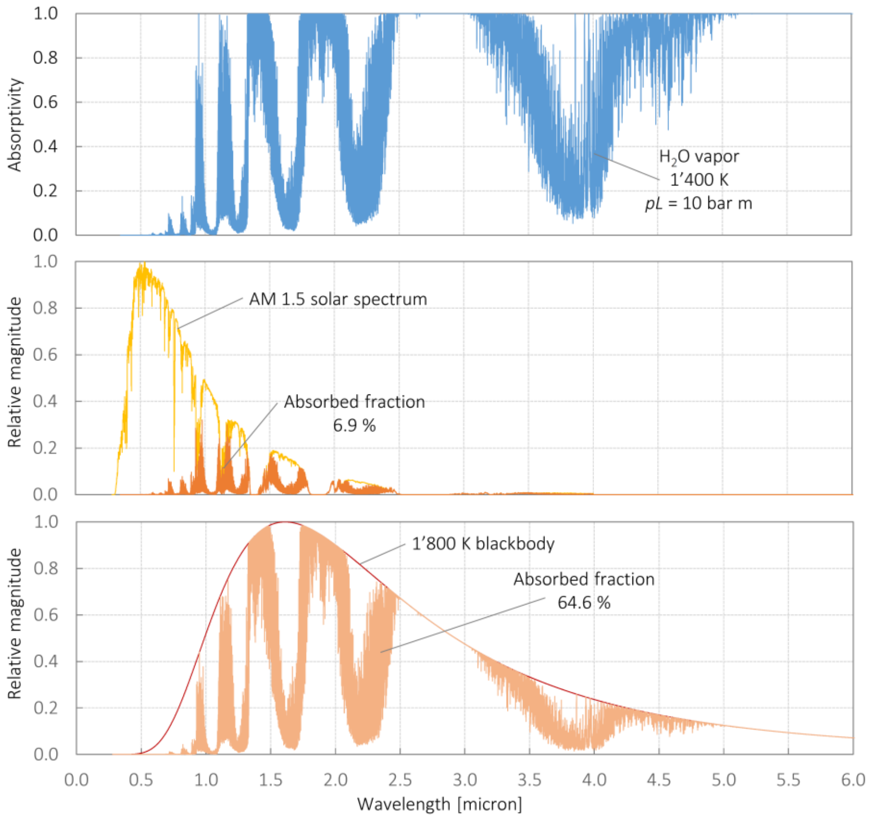
* Numbers do not add up to exactly 100% due to roundoff and uncertainty. Water is highly variable. Source: NASA

SYNHELION Technology

The Solar Receiver

The absorbing (greenhouse) gas is heated by the thermal radiation of the receiver walls and acts as heat transfer fluid (HTF).





- Heat transfer fluid (HTF): water vapor (H_2O) or mixtures of H_2O and carbon dioxide (CO_2)
- Delivers clean solar process heat at up to 1’500°C with receiver efficiency > 80% at moderate solar concentration (~1’000 kW/m²)

G. Ambrosetti and P. Good, Solar Energy 183, 521–531, 2019.

250 kW Receiver Prototype & Testing reaching 1500 ⁰C

(Germany, March 2020)

https://synhelion.com/

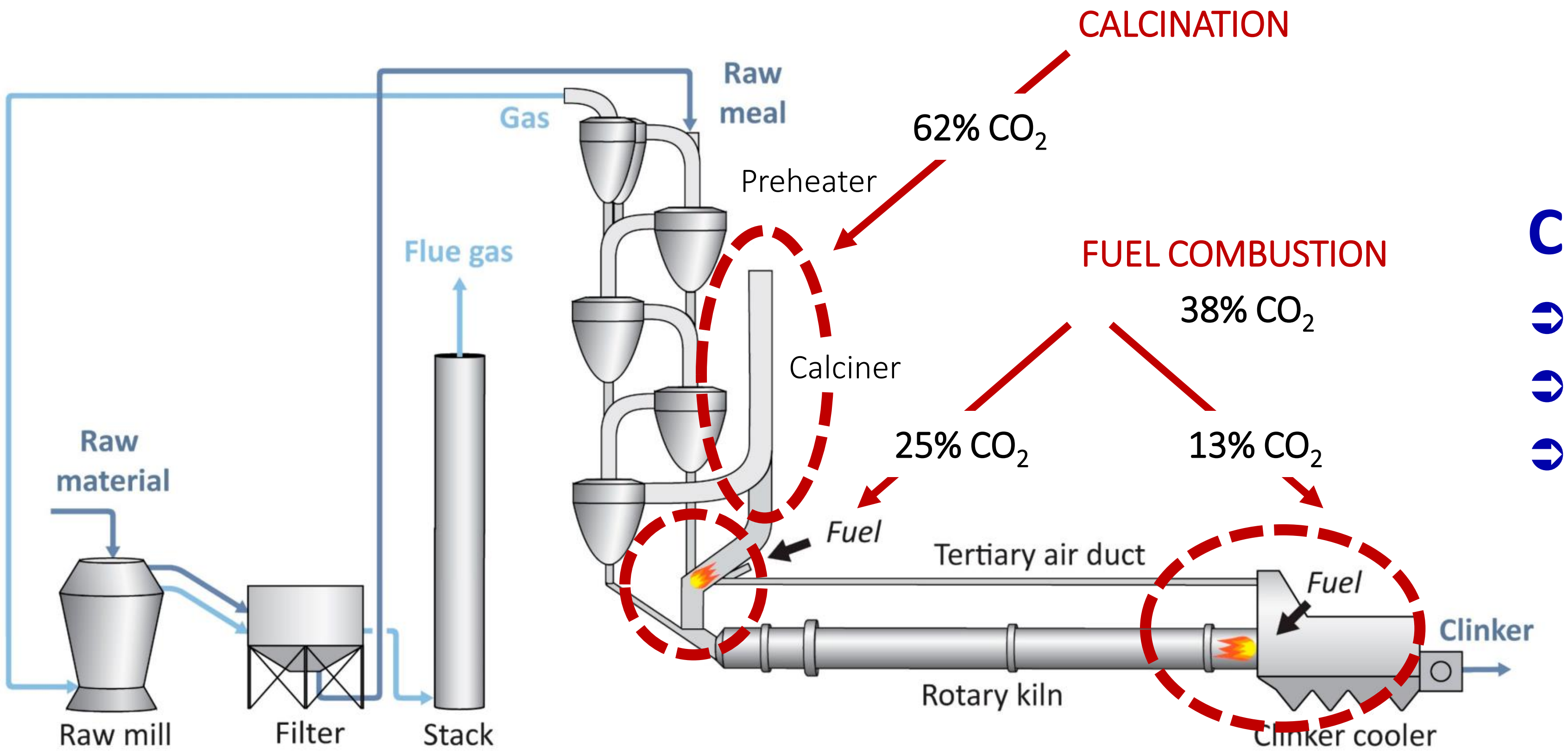
Concentrated Solar Thermal-Radiation Power (CSTP)

Applied to the Production of Clinker

- Feasibility Study
- Elaboration of the Concept

Clinkering Manufacturing Process

Emissions & Opportunities to Manage It



Cement Manufacture Diagram - Pires, J.. (2019). Carbon Capture and Storage.

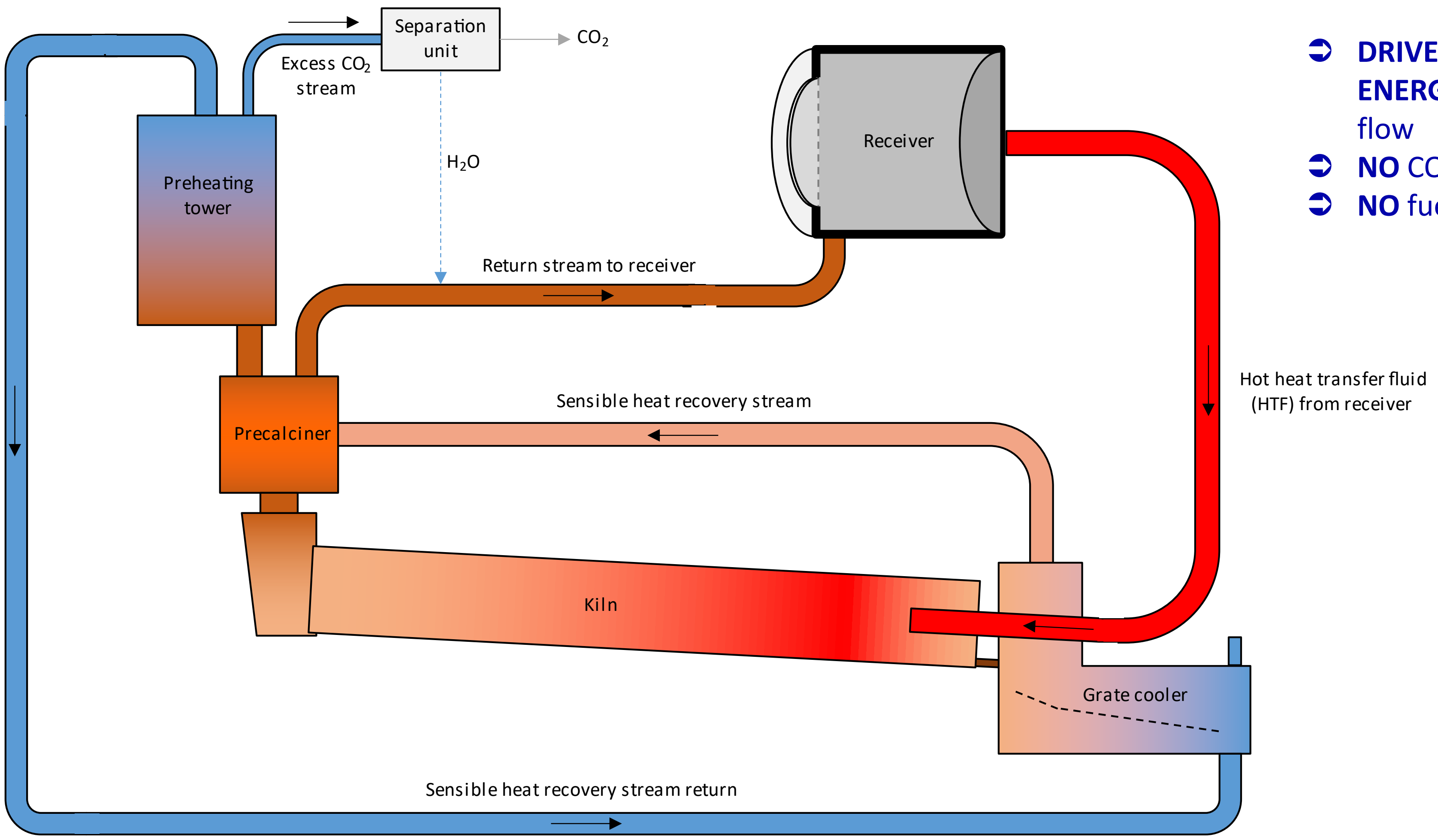
CHALLENGES

- CO_2 Reduction
- CO_2 Concentration & Capture
- CO_2 Reutilization

CEMEX

Solar-Driven Pyro-Processing Clinker

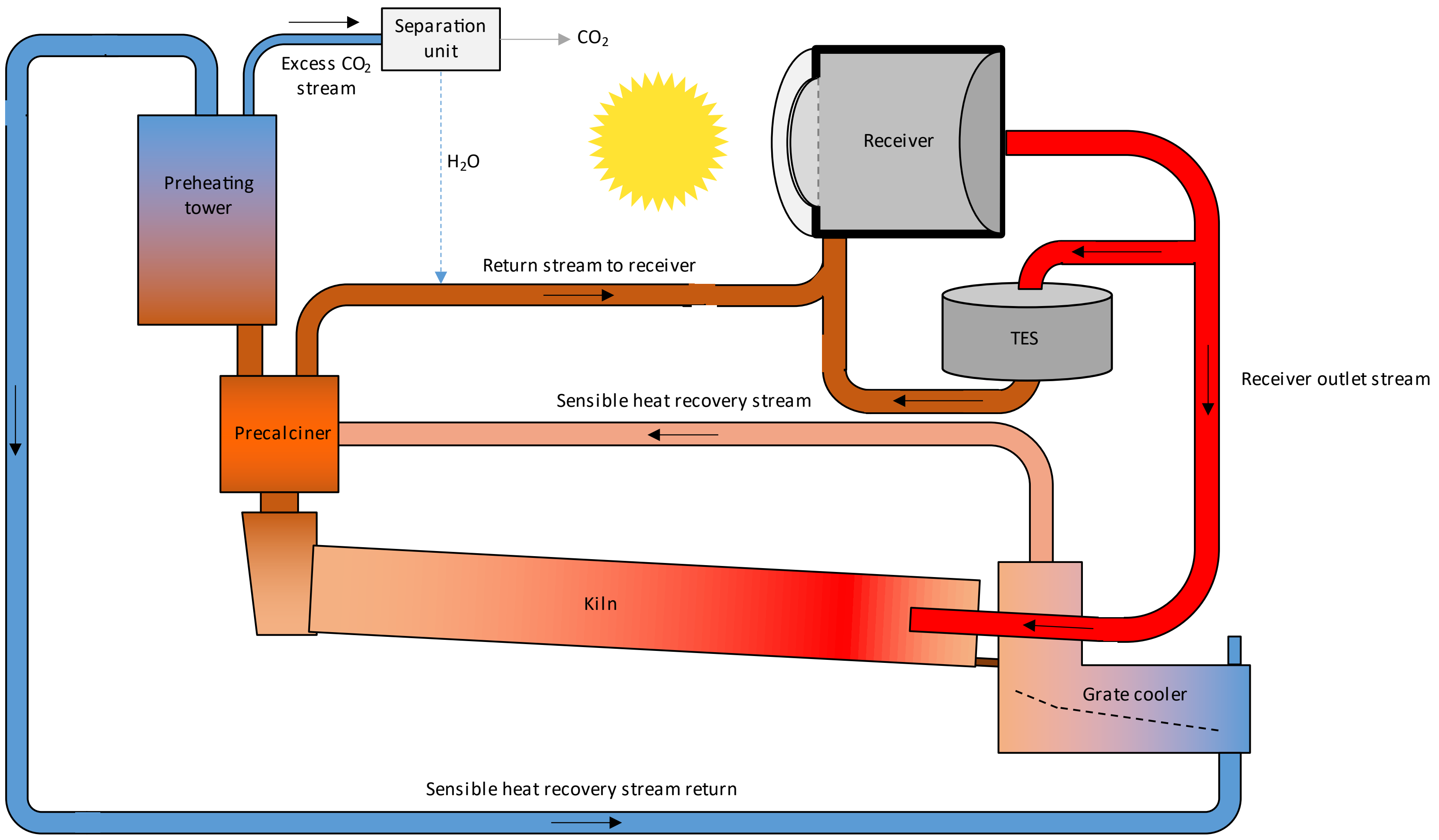
THE "Sketch"



- **DRIVE FULL PROCESS WITH SOLAR ENERGY** in line with conventional process flow
- **NO** CO_2 emissions
- **NO** fuel costs

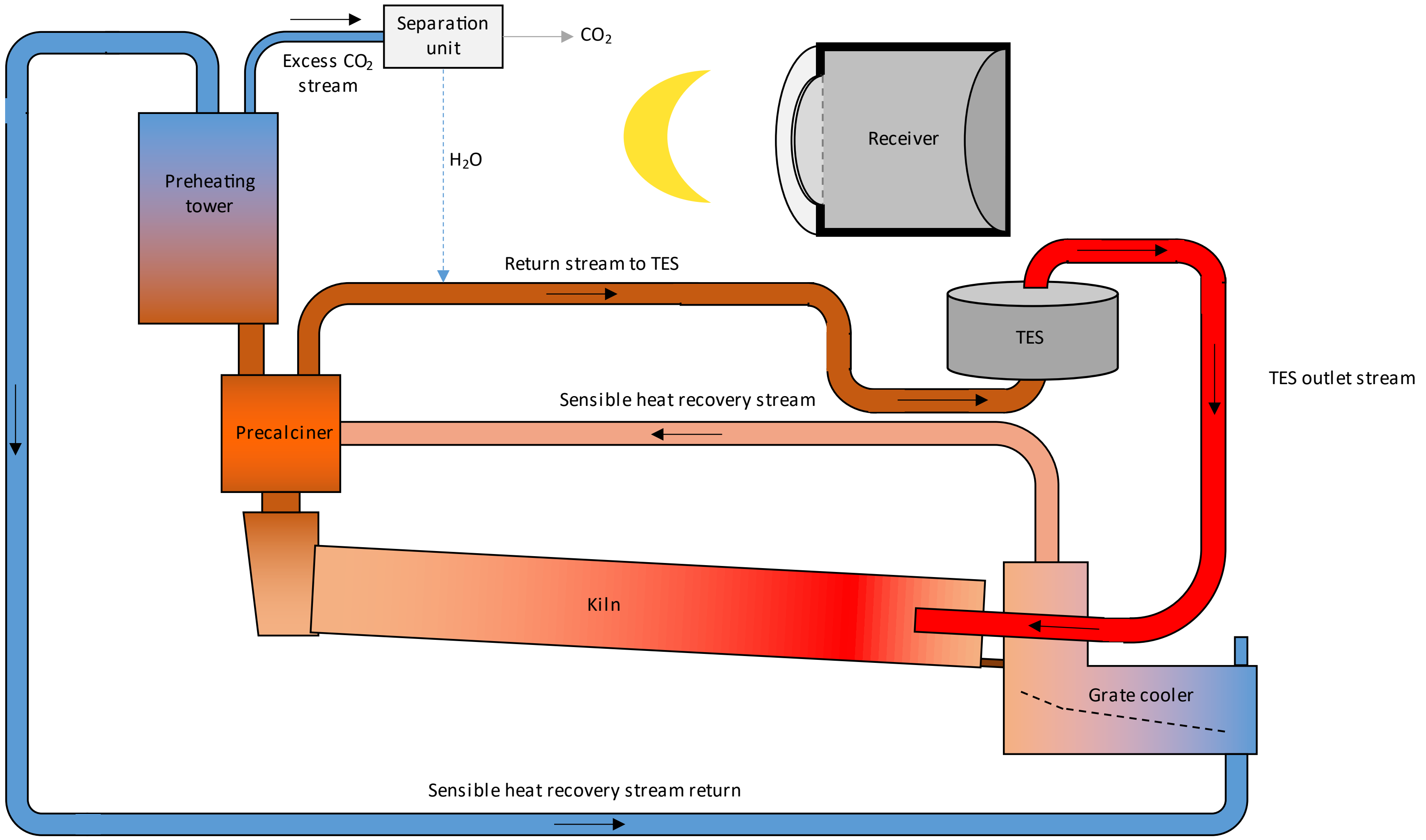
Solar-Driven Pyro-Processing Clinker – Daytime Operation

During the day the heat from the receiver is fed simultaneously to the process and to fill up the thermal energy storage (TES).



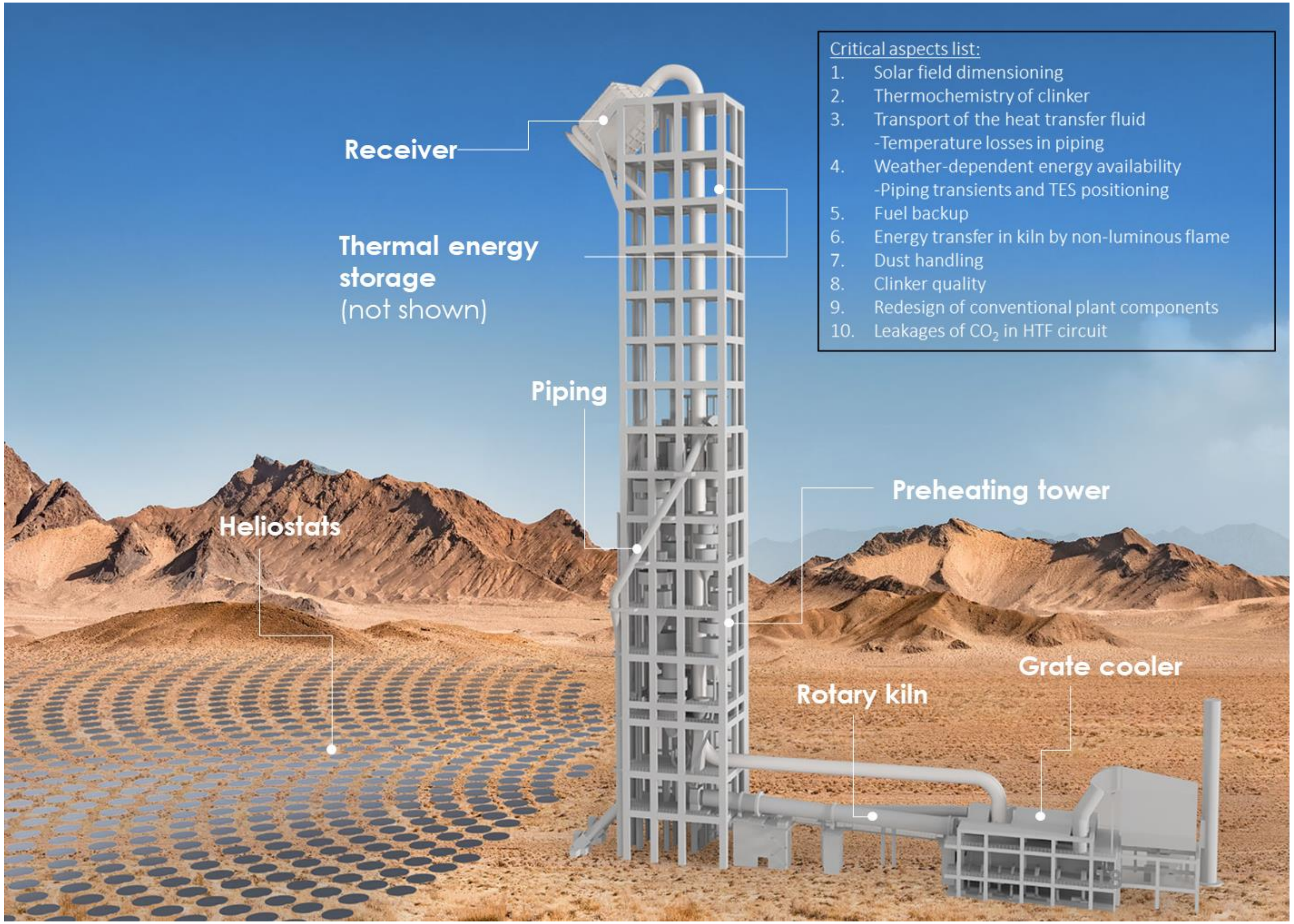
Solar-Driven Pyro-Processing Clinker – Nighttime Operation

During the night, the process is driven by the heat stored in the thermal energy storage (TES).



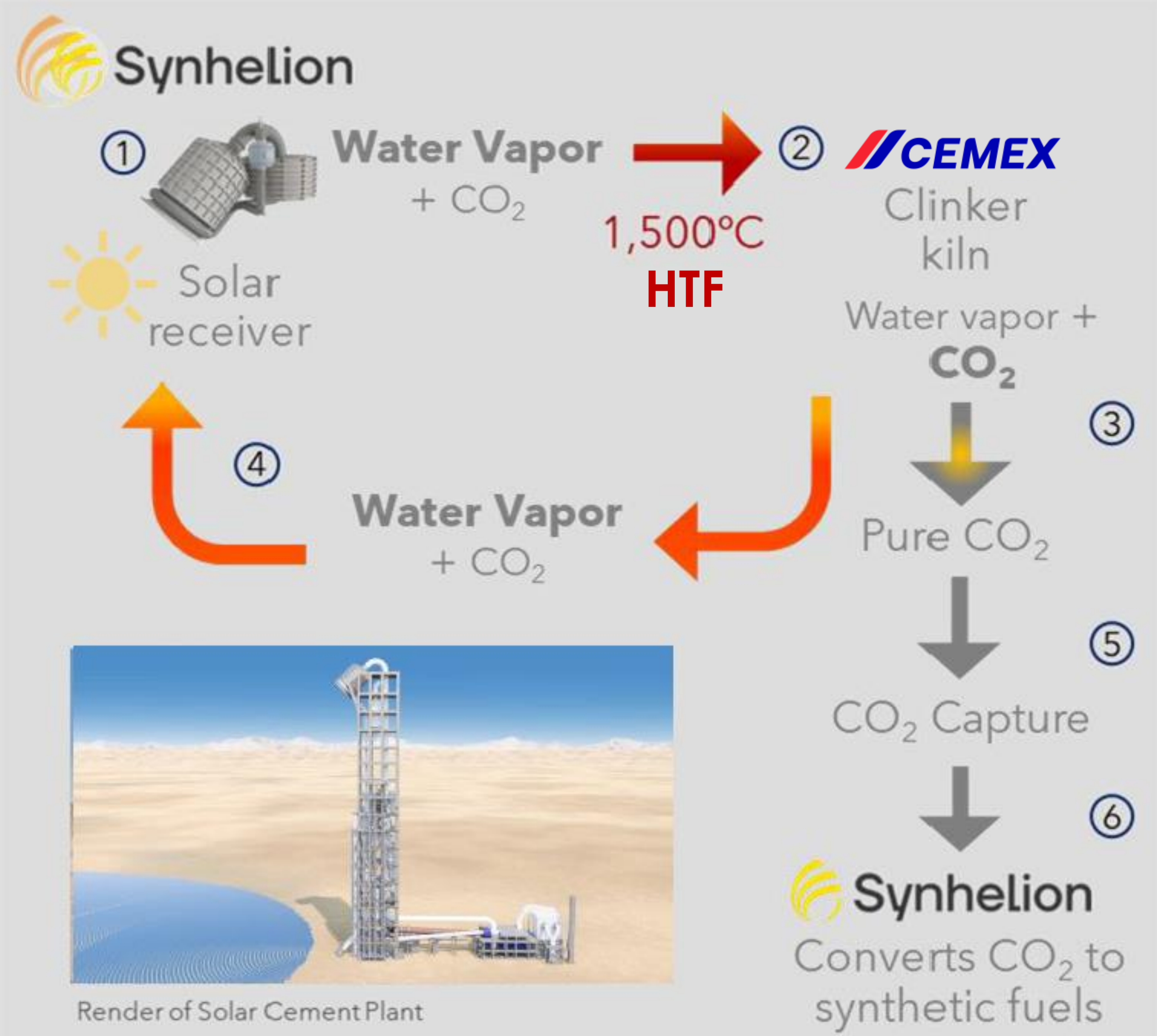
Solar-Driven Pyro-Processing Clinker – Feasibility Study Considerations

Highly Encouraging Outcomes – Technical & Economical



Application of Synhelion Innovations to Drive Clinker Manufacture

Exciting Outlook with Opportunities!



SOLAR PROCESS HEAT **REPLACES FOSSIL FUELS.** → **–90 %** FUEL COSTS

SIMPLE CO_2 CAPTURE AND **SEPARATION.** → **–60 %** CO_2 SEPARATION COST

ZERO CO_2 EMISSIONS INTO ATMOSPHERE. → **100 %** CO_2 CAPTURE

CSTP Applied to Clinker Production

Technology De-Risking - Pilots

IMDEA Energy – Overview

THE Laboratory

Concentrated Solar Thermal Testing Facility

1 Tower (16 m height)
169 (@ 3m^2) heliostats
250 kW high concentration field
P_{max} = 50 kW on circular aperture (diameter = 16 cm)

Created by the regional Government of 'Comunidad de Madrid' with the aim of **promoting energy-related R&D activities** that contribute to addressing global challenges in energy sustainability.

Committed to the effective **transfer of R&D results to the productive sector** and aims to join efforts, both with other research centers and universities, in order to promote excellence in research on energy issues.

148 employees

103 scientific publications

6,7 M€ external and R&D funding

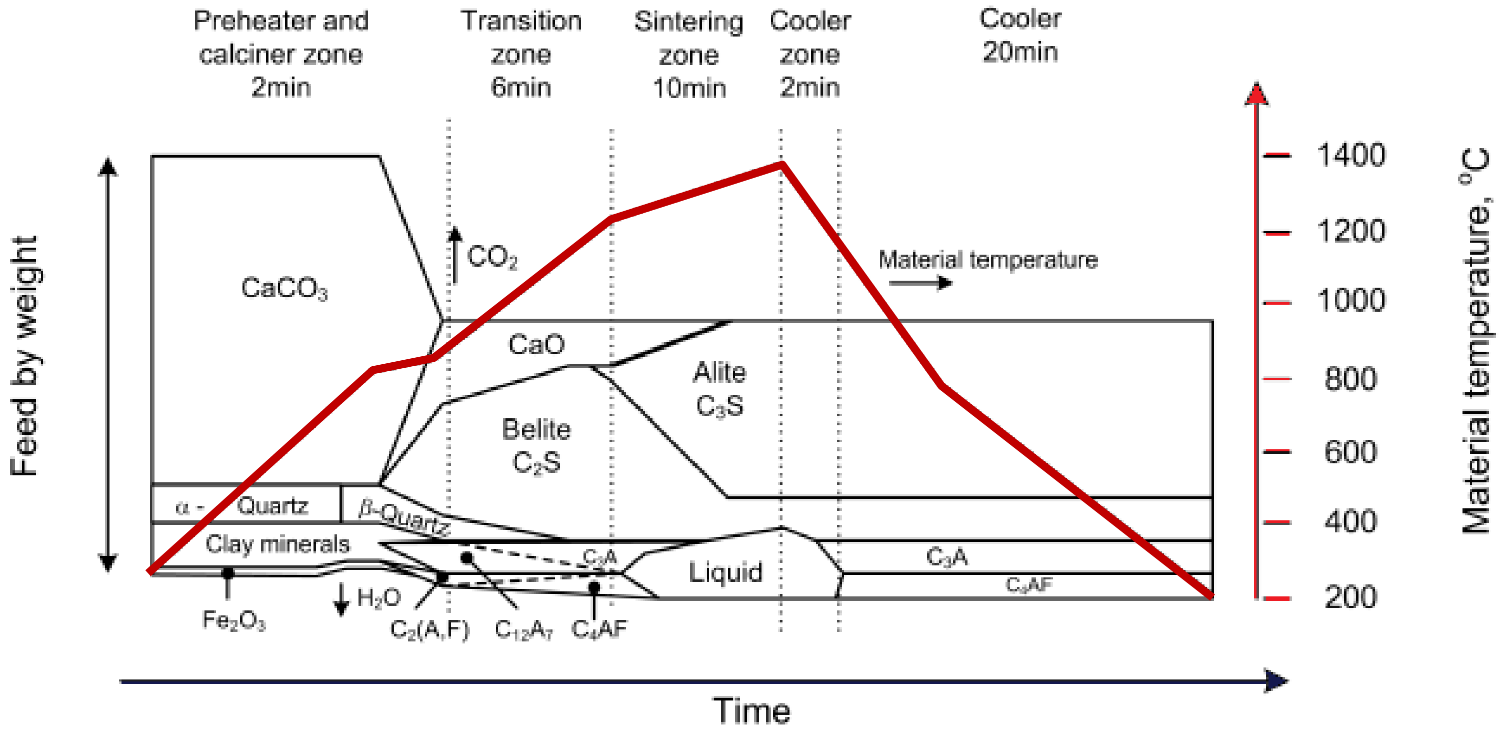
108 active R&D projects and contracts

46 personnel grants

5 European Research Council projects

Technological Validation - Chemistry

Impact of HTF (CO_2 + H_2O Mixtures) on Clinkerization & Calcination?



- Impact of the Heat Transfer Fluid (HTF) on the heating zones including residence time
- Heat exchange efficiency between material as a function of CO_2/ H_2O ratios
- Shifts of heating curves and phases formation

* Nørskov, L. K., Dam-Johansen, K., Glarborg, P., Jensen, P. A., & Larsen, M. B. (2012). Combustion of solid alternative fuels in the cement kiln burner. Kgs. Lyngby: Technical University of Denmark (DTU).

Technological Validation - Chemistry

Lab Trials: No Relevant Impact on Calcination & Clinkerization Chemistry

Calcination Process

Temperature	Atmosphere	% CO_2	% Calcination efficiency
950°C	Air	3.5	95%
	CO_2	34.5	0.9%
	CO_2/ H_2O	23	75%
1050°C	CO_2	8.3	93%

Findings: calcination with the HTF takes place at 100°C above the expected temperature – vapor pressure effects

Clinker Process

Temperature	Clinkerization	Free lime (%)	% Clinkerization Efficiency
1380°C	Air	1.46	98.5%
	CO_2	1.29	98.8%
	CO_2/ H_2O	1.61	98.4%

Findings: clinkering efficiency is not affected by the HTF

Clinker Chemistry

Mineral name	CO_2	Air
C3S	63.1	62.4
C2S	18.5	18.9
C3A	5.4	5.5
C4AF	12.1	12.1
Periclase	0.3	0.5
Lime	0.6	0.6

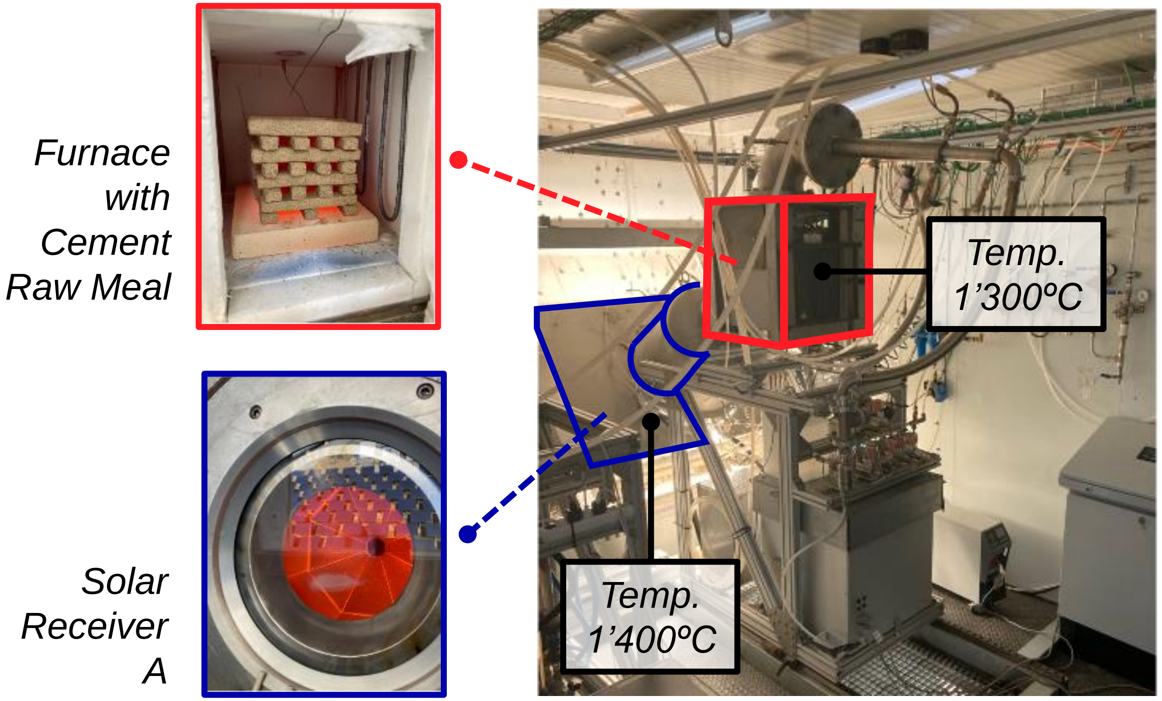
Findings: clinker is not affected using the HTF

CEMEX

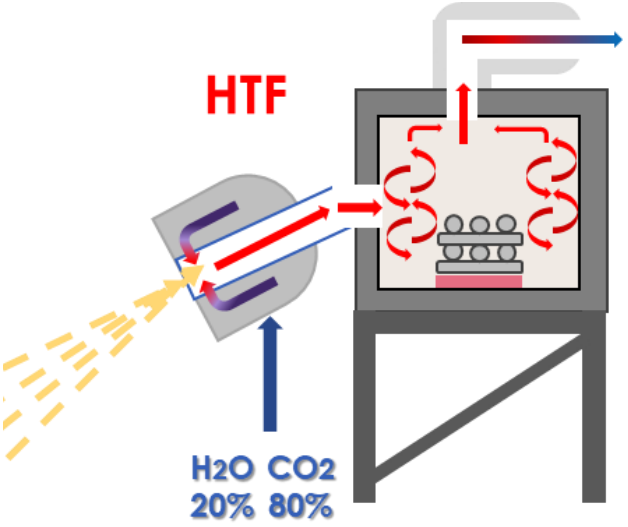
Solar Clinkerization – PILOT A

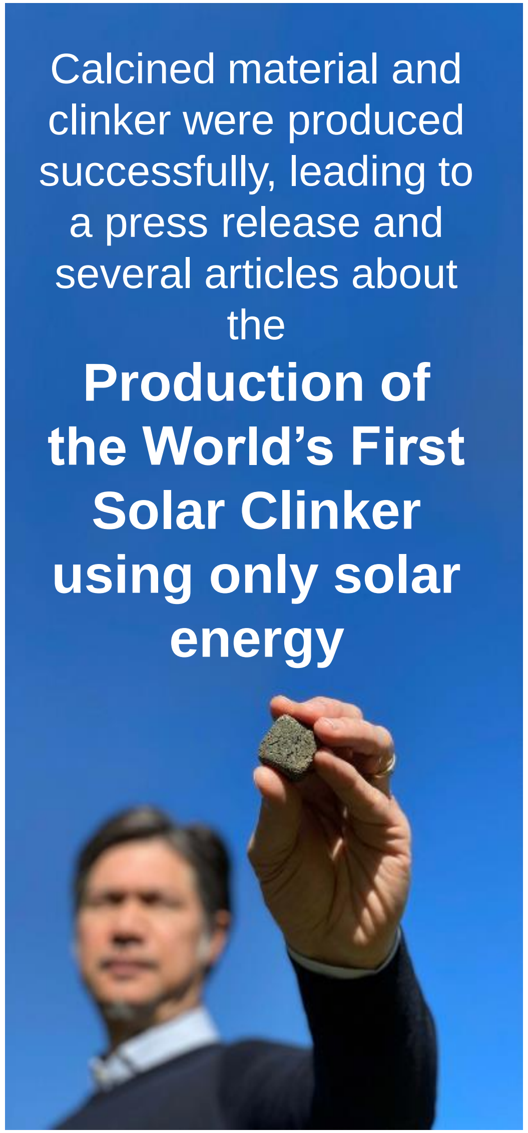
BATCH PRODUCTION SYSTEM [Q4 2022]

- Cement Raw Meal (CRM) was placed inside a modified Lab Furnace coupled to the solar receiver.
- The concentrated sunlight heated up mainly[1] CO_2 as the Heat Transfer Fluid (HTF) inside the Solar Receiver to 1’400°C.
  1) In Pilot A water vapor introduction system was limited.
- The CRM was brought to calcination and clinkerization by the solar-heated HTF.



Setup during heat-up





Press release media

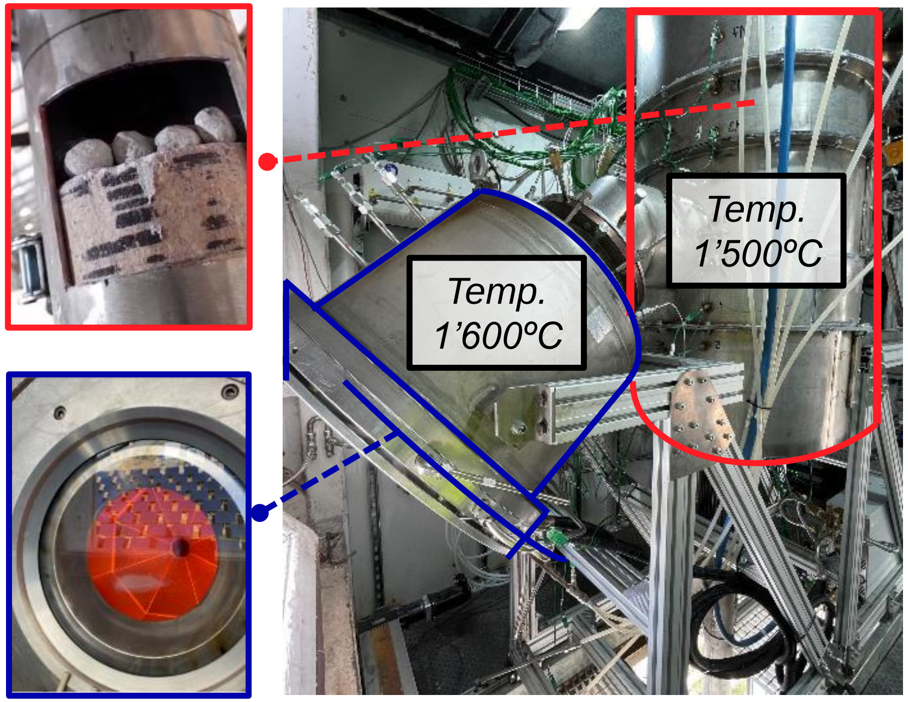
Solar Clinkeration – PILOT B
CONTINUOUS MOVING BED PRODUCTION [Summer 2023]

- Clinker Raw Meal (CRM) is loaded in pellets at the top of Continuous Moving Bed Furnace
- The concentrated sunlight heated up mixture of CO_2 and Water steam as the Heat Transfer Fluid (HTF) inside the Solar Receiver reaching temperatures of 1’600°C - a record.
- The HTF flows through the system upwards while a piston moves the CRM downwards to the hot region.

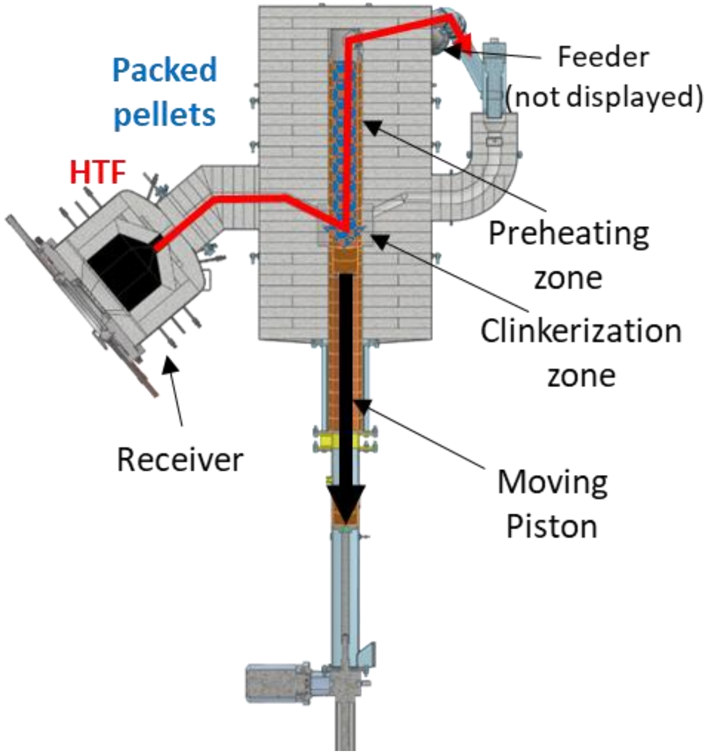
Continuous Moving Bed Furnace

Raw Meal Pellets on top of piston

Solar Receiver B ***Larger volume***



Vertical Moving Bed Architecture

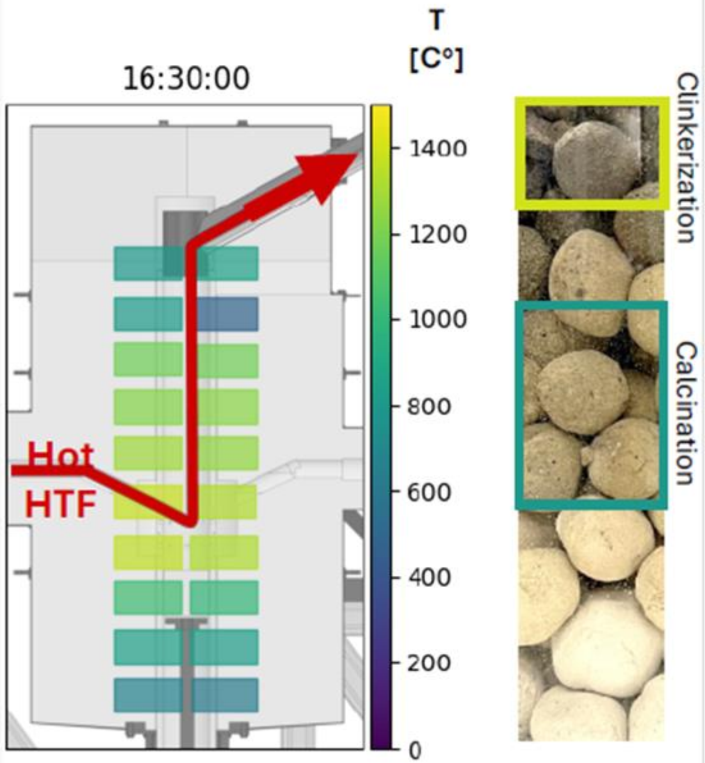


KEY OBJECTIVES

- ✓ Demonstration of **CONTINUOUS** production of solar clinker
- ✓ Exploring potentially scalable clinker production architectures
- ✓ Validation of clinker chemistry

Solar Clinkeration – PILOT B

CONTINUOUS MOVING BED PRODUCTION – Temperature Profiles Inside Kiln & Clinker Chemistry



SOLAR Clinker Composition

Clinker Composition *	Target	Obtained
C3S	> 55%	55-57%
C	< 2	1-2 %
C2S	≈ 15-20%	14-16%
C3A	≈ 6-8 %	6-7 %
C4AF	≈ 8-10 %	9-10%

*Notation:
C ≙ CaO
S ≙ SiO_2
A ≙ Al_2O_3
F ≙ Fe_2O

Achievements:

- Verified clinker chemistry with CO_2, H_2O and mixtures as reaction atmospheres
- Continuous movement of bed and feed of fresh material 3.5 Kg/ day
- Solar clinker production in potentially scalable architecture
- Clinker quality is within target

Roadmap to Adoption

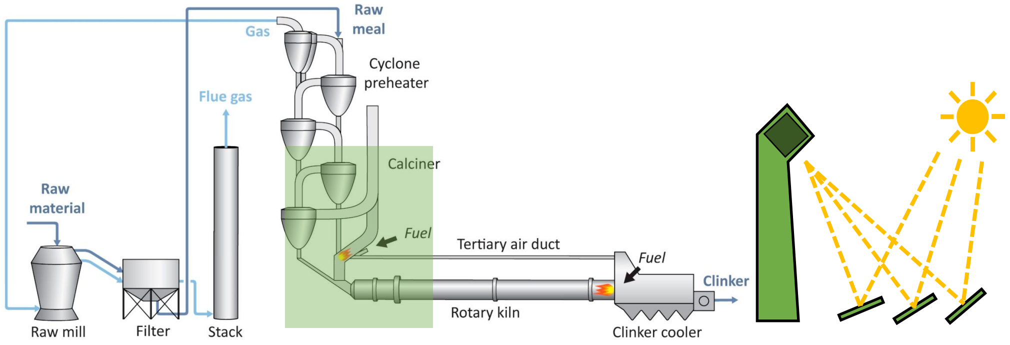
Progress – YTD / March 2025

STEP-WISE INTEGRATION APPROACH – DE-RISKING IS KEY!

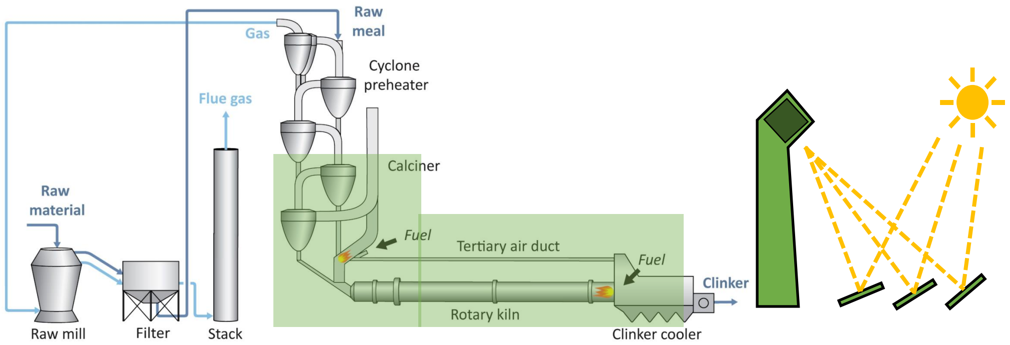
CONFIGURATION

INTERVENTION SCHEME

Solar Calcination →



Full Solar →



2019
Feasibility Study

2022
Pliot A – First Solar Clinker – Batch Production
50kW$_{th}$ Receiver

2023
Pliot B – Solar Clinker – Continuous Production
50kW$_{th}$ Receiver

SOLAR MEAD – DOE Grant Calcination Optimization

R&D & Engineering Activities

2026/ 27
Semi-Industrial Scale- Calcination & Clinkerization
1MW$_{th}$ Receiver

~2032
Industrial Scale
100-150 MW$_{th}$
~1 Mton/yr

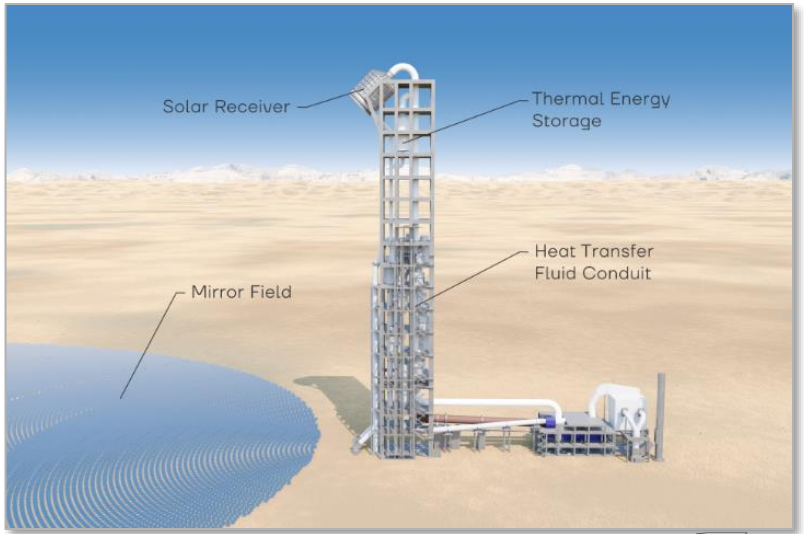
CEMEX

CEMEX's effort with Synhelion to test concentrated solar heating to drive full clinker pyro-processing

Technology able to achieve required temperatures and continuous operation…

HTF inside receiver heated to 1,500°C & transported to the ground to drive the clinker pyro-processing

Thermal energy storage allows for 24/7 solar operation during most of the year



…offering the lowest cost of any renewable energy source…

Renewable solar heat is the least expensive source of renewable energy and a unique opportunity to decarbonize thermal processes depending on fossil fuels combustion

… and a seamless way to capture a concentrated calcination CO2 stream…

Because of the composition of the HTF, separation of excess CO_2 from calcination in concentrated form is straightforward and cheap vs capture technologies

… but requires a sizable footprint (as all solar technologies)

Based on a reference plant with the capacity of 1Mtpa of clinker requiring 150 MW heat input, a field size of around 300'000 m2 of mirror surface would be needed, for an overall land plot surface requirement of around 0.9 km2

Concentrated Solar Thermal Power (CSTP)
“CHILD’S PLAY!”

Innovation @ CEMEX and Industry

Innovation at Cemex

well-positioned to build a sustainable future & industry

USING GREENER ENERGY

solar clinkerization & carbon capture

MANAGING ENERGY

energy storage

MINIMIZING FOSSIL FUELS CONSUMPTION

alternative fuels & hydrogen

LOWERING CLINKER FACTOR

clinker micronization

CREATING VALUE FROM CO2

carbon nanomaterials

OPTIMIZING CONSTRUCTION PROCESSES

3D concrete printing

REDUCING BUILDING'S CLIMATE IMPACT

bioclimatic construction

Innovation at Cemex

driving innovation on multiple fronts & schemes

actively supporting startups
to further develop their ideas & accelerate adoption

using our own resources and capabilities
to accelerate our decarbonization goals

collaborating with the rest of the industry, other industries and academia
to efficiently research solutions

Global Cement and Concrete Association

CONCRETE FUTURE

INNOVANDI
Global Cement & Concrete Research Network

INNOVANDI Research Roadmap

69 Actual Projects

Clinker production
3 Core Projects
18 Partner Projects

Blended systems including Calcined Clays
4 Core Projects
12 Partner Projects

Recycling / Recarbonation
2 Core Projects
5 Partner Projects

Carbon Capture Utilization and Storage (CCUS)
2 Core Projects
8 Partner Projects

Durability
1 Core Projects
9 Partner Projects

Admixture and others category
5 Partner Projects

12 ongoing/completed Core Projects

57 ongoing/completed Partner Projects

16 New Core Projects for next 8 years from 2024 (projection)

gcca Global Cement and Concrete Association

Innovation at Cemex

culture of innovation is deep-rooted at CEMEX

- 1989 – CemexNet satellite comm. system
- 1991 – Dynamic Synchronization of Operations (GPS)
- 1995 – Cemex Way
- 1997 – 1st Innovation Center (MEX)
- 1998 – CEMEX Patrimonio Hoy
- 1998 – Global Digital Program
- 2005 – Alternative Fuels *
- 2006 – Construyo Contigo (youth employment)
- 2006 – CEMEX ADMIXTURES
- 2007 – Centralized IP Management
- 2011 – Promptis: 1st Global Brand
- 2014 – Yo Construyo (affordable housing)
- 2014 – Clean Stoves
- 2016 – 7 EU Funded Projects (DESTINY, Leilac)
- 2017 – neogem: Aggregate Solutions
- 2017 – CEMEX GO

* Systematically / >50%

Digital Innovation · Product & Process Innovation · Social Innovation

Innovation at Cemex

a model that evolves – innovating on how we innovate

2017
CEMEX ventures

2017
CEMEX bim
1st CX BIM Plugin

2020
FUTURE IN ACTION

2021
SOLAR IMPULSE EFFICIENT SOLUTION LABEL
Vertua® Low carbon by design

2021
4 large-scale CCUS projects in progress

2022
CEMEX ventures | leaplab

2023
Vertua® LOWER CARBON®
Vertua® ENERGY EFFICIENCY®
Vertua® WATER CONSERVATION®
Vertua® RECYCLED MATERIALS®
Vertua® DESIGN OPTIMIZATION®

2023
Regenera
Committed to Circularity

Innovation at Cemex

facts & figures

intellectual property

+45 patent families

+55 trade secrets

+40 software products

innovation portfolio

smart_ innovation

+1000 ideas in the innovation pipeline

64% focused on CO2 mitigation

partnerships & collaborations

+50 partners developing industrial-scale net-zero CO2 solutions

innovation projects

+220 Projects in innovation portfolio

+20 projects under EU / DOE

CEMEX ventures

investment portfolio

23 invested startups

WtEnergy advanced solutions	HiiROC	Synhelion	carbon clean	carbon upcycling	neustark	Arqlite
solid waste into syn-gas	hydrogen production	solar-driven clinkerization	CO2 capture	CO2 into solid products	mineralization of CO2	gravel from recycled plastics

CEMEX

THANK YOU