SOCRATCES

Options for Scaling Up & Deploying Solar Calcination

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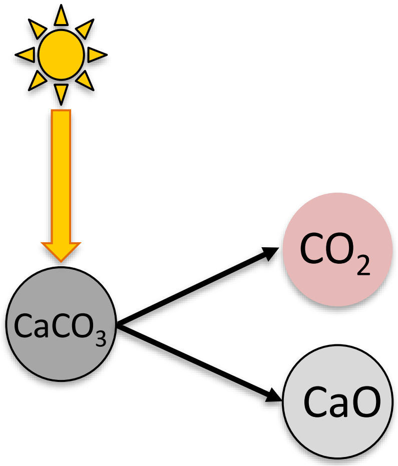
SOLAR CALCIUM-LOOPING INTEGRATION FOR THERMO-CHEMICAL ENERGY STORAGE

Presentation Overview

- ✓ Introduction to Solar Calcination
- ✓ Solar Calcination Technologies
- ✓ The Solar Calcination ‘Market’
  - ✓ Sectoral Size
  - ✓ Comparison of typical industrial plant size to CSP size
- ✓ Example: Cement
- ✓ Example: TCES
- ✓ Conclusions

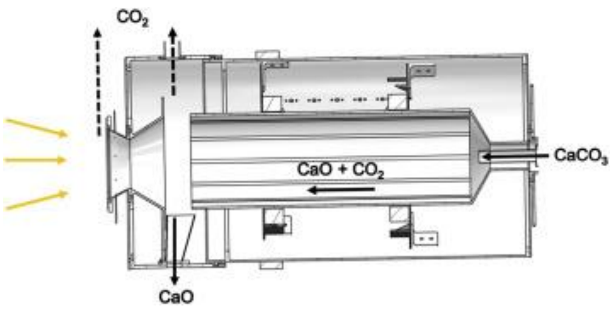
What is Solar Calcination?

- Calcination is the thermal decomposition of minerals
  - Inputs: typically carbonates
  - Outputs: typically oxide and a gas
- It is endothermic
  - requires a net addition of energy
- Often requires high temperatures
  - Limestone in pure CO_2 requires min ~900 °C
- This energy and temperature can be supplied from any appropriate source, including CSP



Solar Calcination Technologies: Solar Kiln

- Near-horizontal rotating cylinder (or cone)
- Solar energy is focused on the horizontal (via a secondary reflector?)
- Kiln walls re-radiate the heat to the minerals
- Moving parts within the reactor make sealing more difficult
- Residence time somewhat controllable by rotation speed and kiln angle



Solar kiln of the SOLPART project
doi: 10.1016/j.solener.2019.01.093

Solar Calcination Technologies: Fluidised Bed

- Vertical unit, with gas injected at the bottom to fluidise the minerals
- Solar energy is focused on the vertical via a secondary reflector
- No major moving parts within the reactor
- Residence time is controllable by flow rates in/out

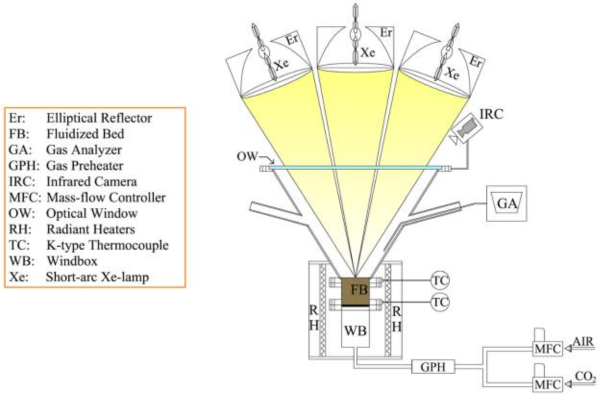


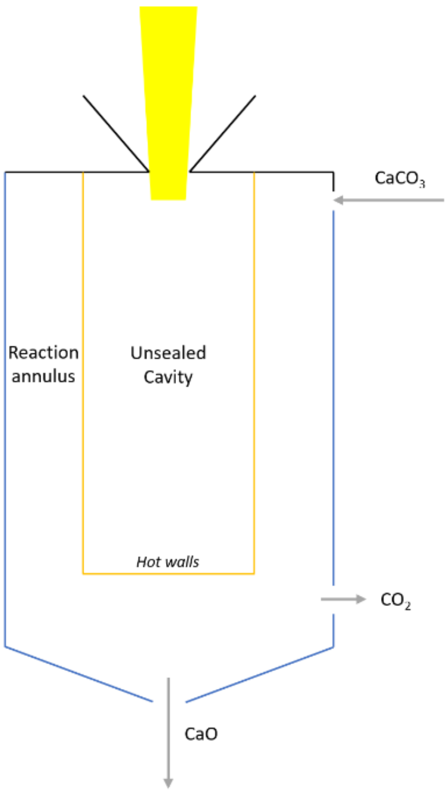
FIGURE 1. Outline of the experimental apparatus and its ancillary equipment.

Solar fluidised bed calciner of Tregambi et al
doi: 10.1063/1.4984456

Solar fluidised bed gasifier of Bellan et al
doi: 10.1016/j.cej.2018.10.111

Solar Calcination Technologies: (Indirect) Solar Flash Calciner

- Vertical unit, tangential gas injection with minerals to provide momentum & distribution
- Solar energy is focused on the vertical via a secondary reflector
- No major moving parts within the reactor
- Residence time is a function of calciner height and particle size



Solar calciner design of SOCRATCES

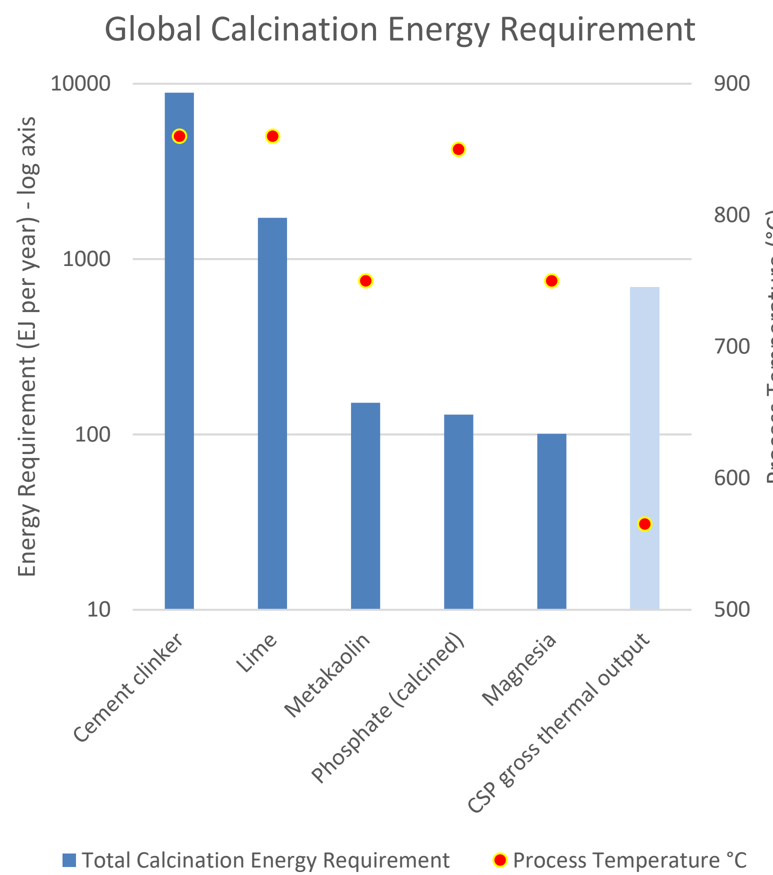
Size limitations for solar calciners

- Each design is limited in different ways:
  - Solar kiln becomes less efficient once above a given size
    - Moumin et al. suggest ca. 55 MW_{sol} as a maximum for that design
  - Solar Fluidised Bed heat input is dependent on a large bed cross-section
    - Trade-offs necessary to design an FBR which can capture the energy without excessive sintering & residence time
  - Solar Flash Calciner has a hot suspended cavity – susceptible to mechanical deformation
    - Limits on length, width and/or temperature to preserve the tube
- Solar field size can be limited by geography:
  - Moumin et al. suggest 130 MW_{sol} in Spain due to only Northerly fields being appropriate
- **However: Solar calcination is a 'hot' topic and solutions *will* be found and optimised**

Moumin et al: 10.1016/j.solener.2019.01.093

Markets for calcination technology

- **Cement:** calcination of limestone (in raw meal)
- **Lime:** calcination of limestone
- **Metakaolin:** partial thermal decomposition of kaolin
- **Phosphate** minerals for fertiliser manufacture
  - 10-15% require calcination
- **Magnesia:** calcination of magnesite
- **Thermochemical energy storage (TCES) for CSP:** variable minerals & chemistries
  - Ca. 5500 MW_e CSP capacity worldwide

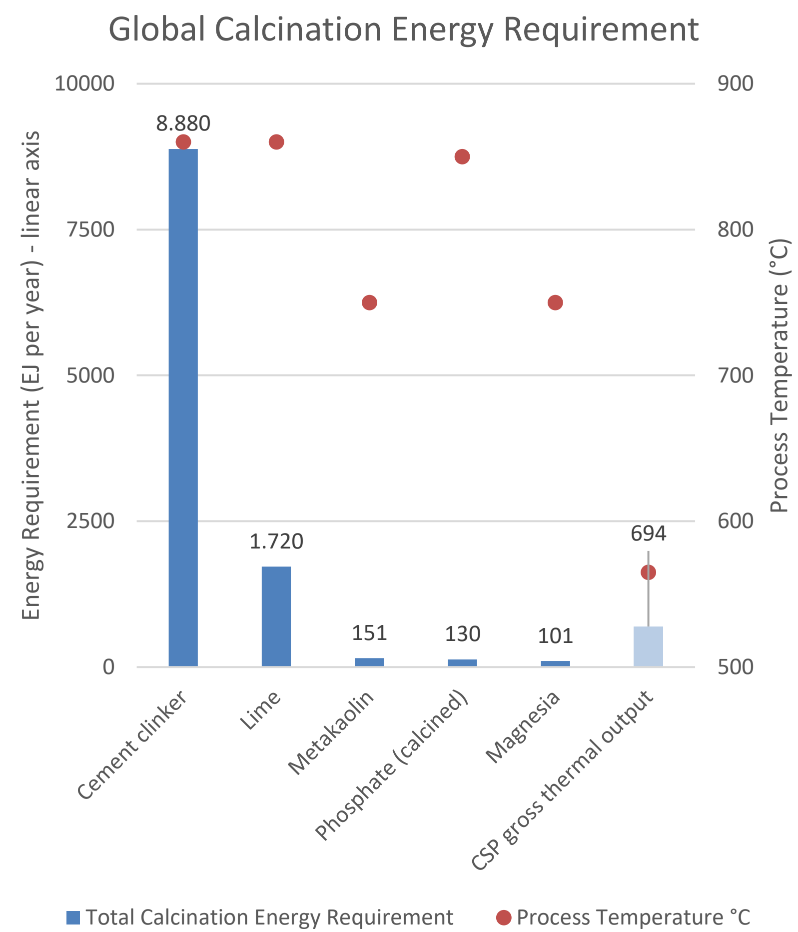


doi: 10.1002/wene.79

https://pubs.usgs.gov/periodicals/mcs2020/mcs2020.pdf

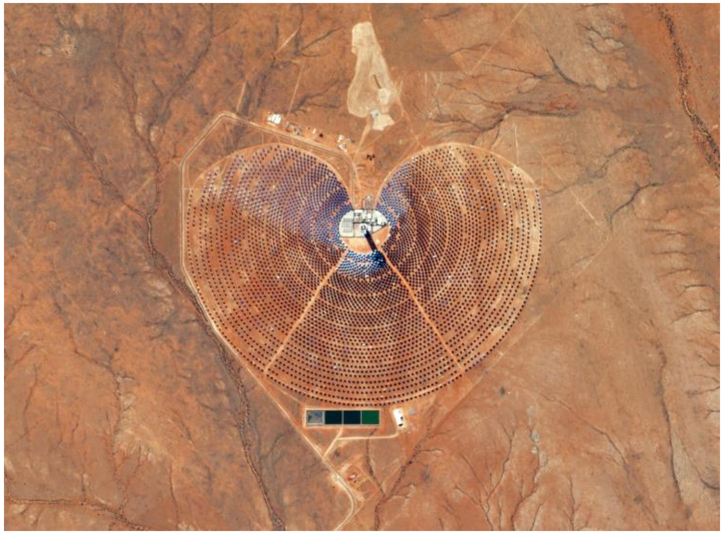
Markets for calcination technology

- Cement & lime calcination sectors dwarf existing CSP capacity
  - A huge, untapped market
- All these processes require temperatures in excess of typical CSP tower temperatures (up to 600 °C)
- **Key technical breakthroughs are required to tap into these markets**
  - **Existing approaches need further development with respect to scale and temperature control**



Comparison of industrial calciners vs. existing CSP installations

- Example CSP power tower: Khi Solar One, RSA
  - Cavity receiver type
  - 50 MW electric
    - 200 MW solar?
  - 41% capacity factor
  - 575 000 m^2 (58 Ha) heliostats
    - 350 W_{sol}/m^2
  - Assume 50% total efficiency from field to calciner
    - 175 W_{th}/m^2



Comparison of industrial calciners vs. existing CSP installations

- Typical cement plant:
  - 3000-9000 tpd clinker
  - 80-250 MWth of calcination
  - 24/7 operation
- Ca. 46 Ha of heliostats (0.8x KS1) required for a typical Western cement plant (3000 tpd)

- Typical lime plant:
  - 300 tpd lime
  - 14 MWth of calcination
  - 24/7 operation
- Ca. 8 Ha (0.14x KS1) required for a lime plant

Example: FYM Malaga

- FYM Malaga plant, part of HeidelbergCement
- 1.6 Mtpa cement → 5000 tpd clinker
- 139 MWth → 80 Ha = 0.8 km2
- Heliostats cover roughly the size of plant + quarry
- This does not account for the 40% capacity factor!
  - What do we do at night? Can't stop the kiln…
- Can we achieve 50% efficiency?
- Conclusion: converting [conventional] cement plants to CSP has significant challenges

Application focus: TCES

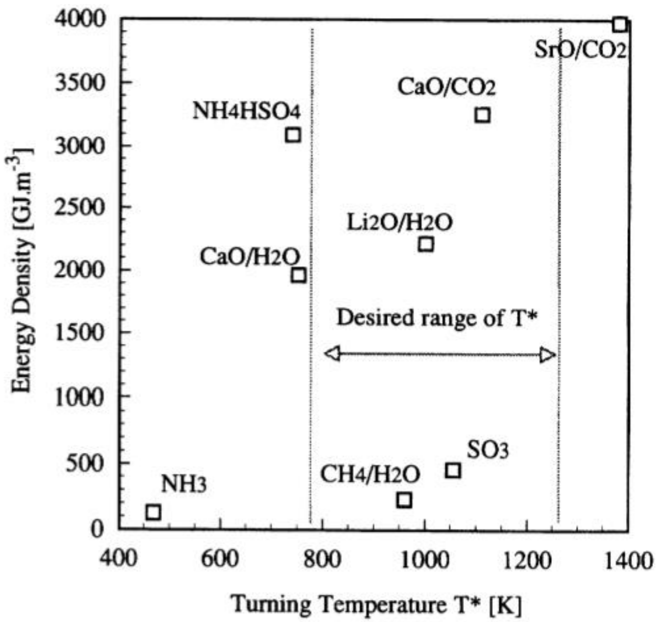
A key benefit of TCES for solar calcination is its flexibility

- Diurnal cycle
  - By its nature, TCES does not need to run 24/7, unlike e.g. cement
- Size
  - The TCES 'balance of plant' can scale from, say, 1-1000 MW_{th}
  - Ideal for location-specific applications where opportunities to expand are limited
- Chemistry
  - TCES can use different chemistries to meet requirements and capabilities regarding temperature and required efficiency

Application focus: TCES

Solar Flash Calcination can provide a route to commerciality

- Diurnal cycle: Fast turn-up and turn-down of the technology has been proven in other projects e.g. LEILAC
- Size: The tubes are easily modularised within a [solar] furnace
  - Slight change of geometry, ray-tracing etc but the same fundamental principles
  - Larger projects improve design & performance of solar flash calciners
- Chemistry: Compatible with any TCES chemistry up to ca. 900 °C process temperature
- Challenges remain around:
  - Reaching high temperatures, common with other calciner designs
  - Optimising design for scale-up and efficiency



doi: 10.1252/jcej.29.119

Conclusions

Not all calcination is made equal

- Markets for calcination vary by orders of magnitude, with cement being by far the largest
- Considerations other than temperature must be addressed:
  - Scale
  - 24/7 production
  - Retrofitting & new modes of operation
- Fitting meaningful levels of solar calcination into existing industrial processes is often a difficult task
- Tailored applications e.g. TCES offer clear 'quick wins'
  - The flexibility of the concept can facilitate successful deployment of TCES in the medium-term
- Experience developed in TCES can then be translated to other sectors, lowering deployment risks and therefore costs

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Thanks for your attention

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