Fraunhofer CHILE

Fraunhofer Chile Research - CSET

Renoval: A Novel Fresnel Solar Furnace for Aluminum Melting and Recycling

Pablo Castillo – September 24, 2025

SolarPACES
Concentrating Solar Power, Thermal, and Chemical Energy Systems
September 23-26, 2025
Almería, Spain
31st SolarPACES Conference

Fuente: Shutterstock

AGENDA

1 Design and Manufacturing

2 Experimental Operation

3 Thermal Model and Assessment

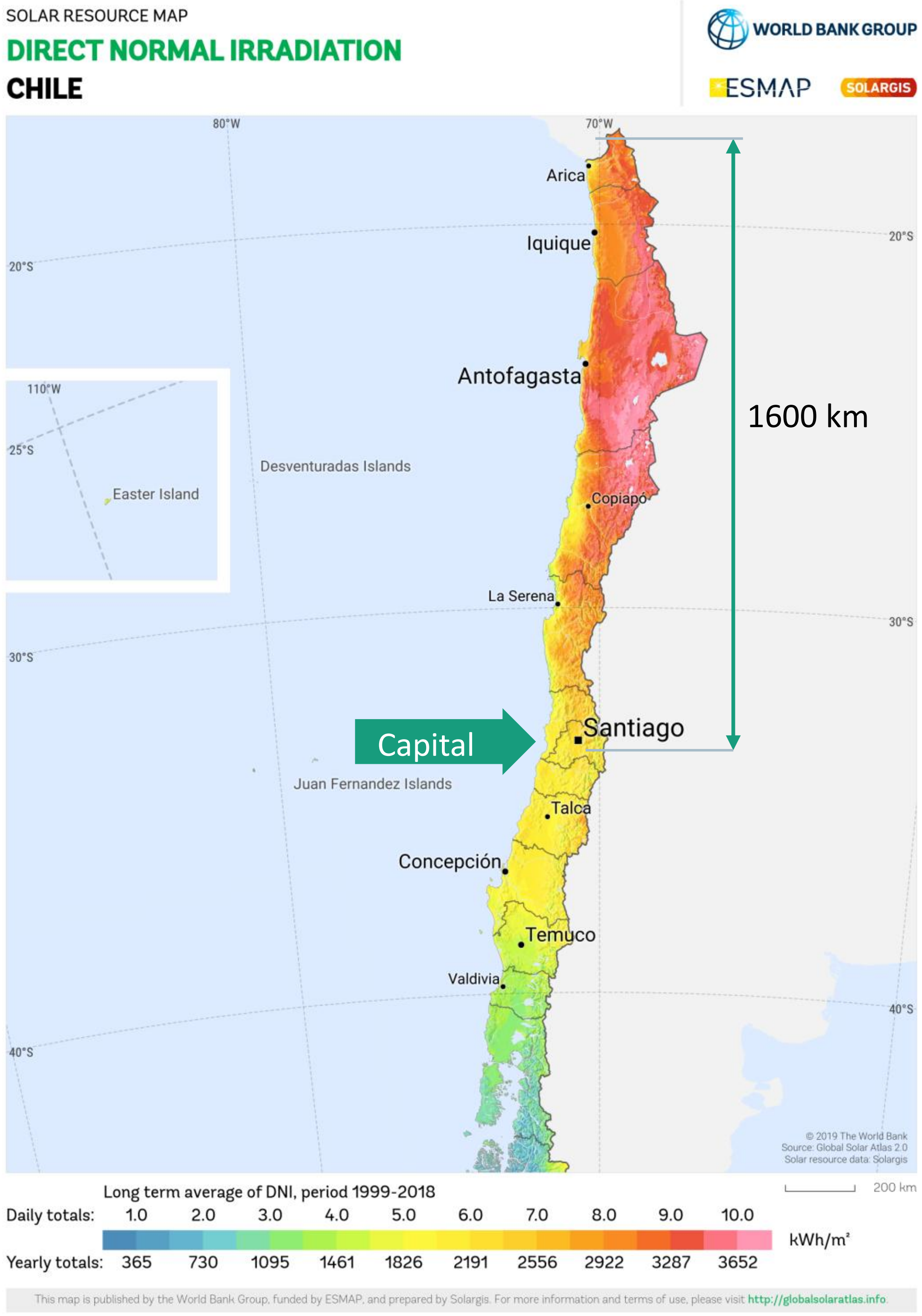
Design and Manufacturing

Design and Manufacturing

Our Country

Chile’s World-Class DNI Levels

- Northern Chile, particularly the region of Atacama Desert, records some of the highest Direct Normal Irradiation (DNI) in the world, exceeding **3,500 – 3,600 kWh/m² per year**.
- The extensive north and center regions provides vast (+1500 km) areas with consistent high DNI **(7–10 kWh/m² per day),** ideal for solar tech. deployment.
- Chile’s solar resource makes it a reference country for solar projects, attracting local and international investment and enabling solar technologies deployments (**PV: 11 GW, +680 installations**).



Design and Manufacturing
Inspiration

Stellenbosch's Flat Mirror Solar Dish

- Built with hundreds of small flat rectangular mirrors focusing onto a central receiver.
- Demonstrated temperatures above 1200 °C, enabling applications such as manganese ore processing [1].
- Served as our inspiration to design a concentrator with a simplified geometry that reduces the number of reflector elements required.
- There are recycling companies in Chile interested in clean process of aluminum. **Green Aluminum.**


Figure 1: Stellenbosch's Flat Mirror Solar Dish

[1]: L. Hockaday, F. Dinter, T. Harms, and Q. Reynolds, "The solar thermal treatment of manganese ore," *AIP Conf. Proc.*, vol. 2126, no. 1, p. 150003, 2019

Design and Manufacturing
Optical Design

Annular Fresnel Array Concept

- Revolution on a Fresnel array of mirrors.
- First prototype had 10 rings. Each ring has a width of approx. 10 cm.
- Aperture Area: 3.09 m^2
- Theoretical Receiver Area (20 cm disk): 0.0314 m^2

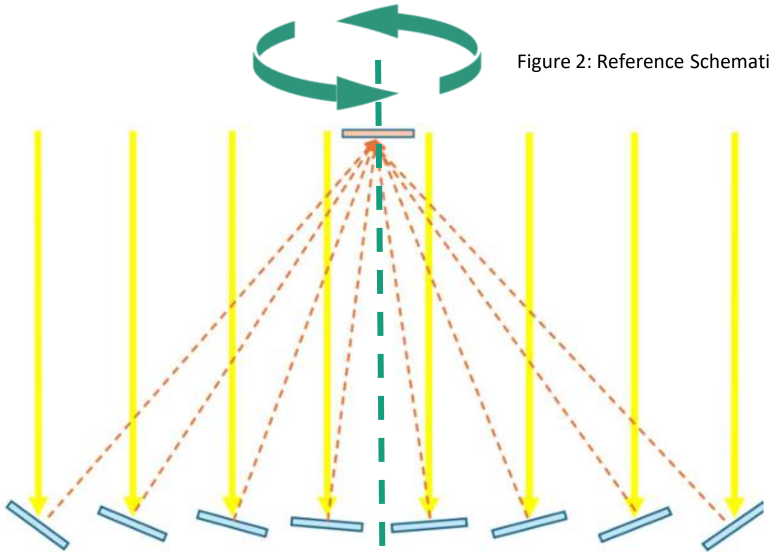


Figure 2: Reference Schematic.

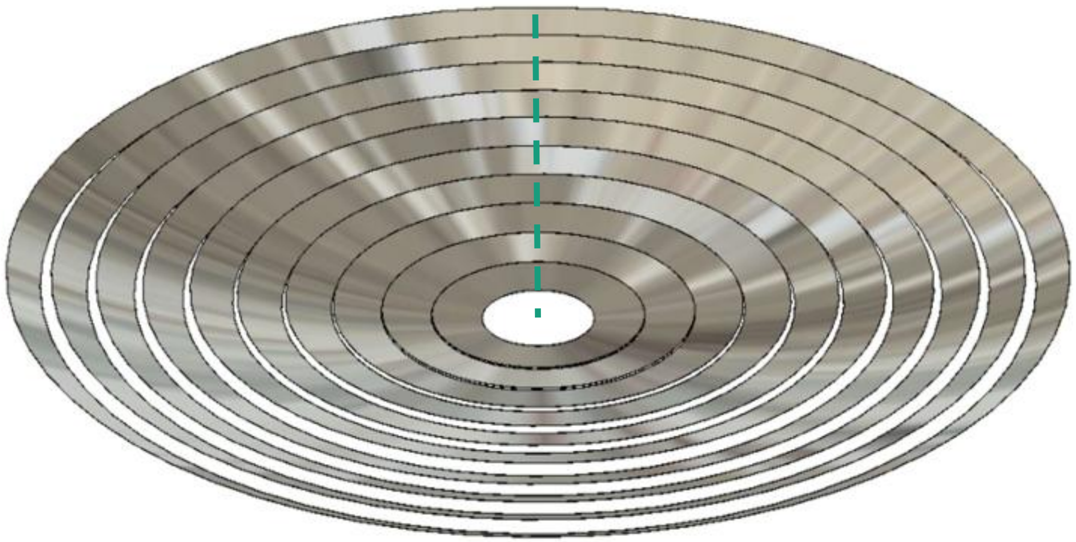


Figure 3: Initial CAD design of annular array

Design and Manufacturing

Optical Design

Raytracing Simulation

- First prototype had 10 rings.
- Aperture Area: 3.09 m^2
- Theoretical Receiver Area (20 cm disk): 0.0314 m^2
- Concentration factor: 98.4 suns.
- Simulation: Assuming a reference DNI of 1000 W/m^2, reflectivity 0.95, the receiver thermal power was 2774 W, achieving an optical efficiency of 0.89.

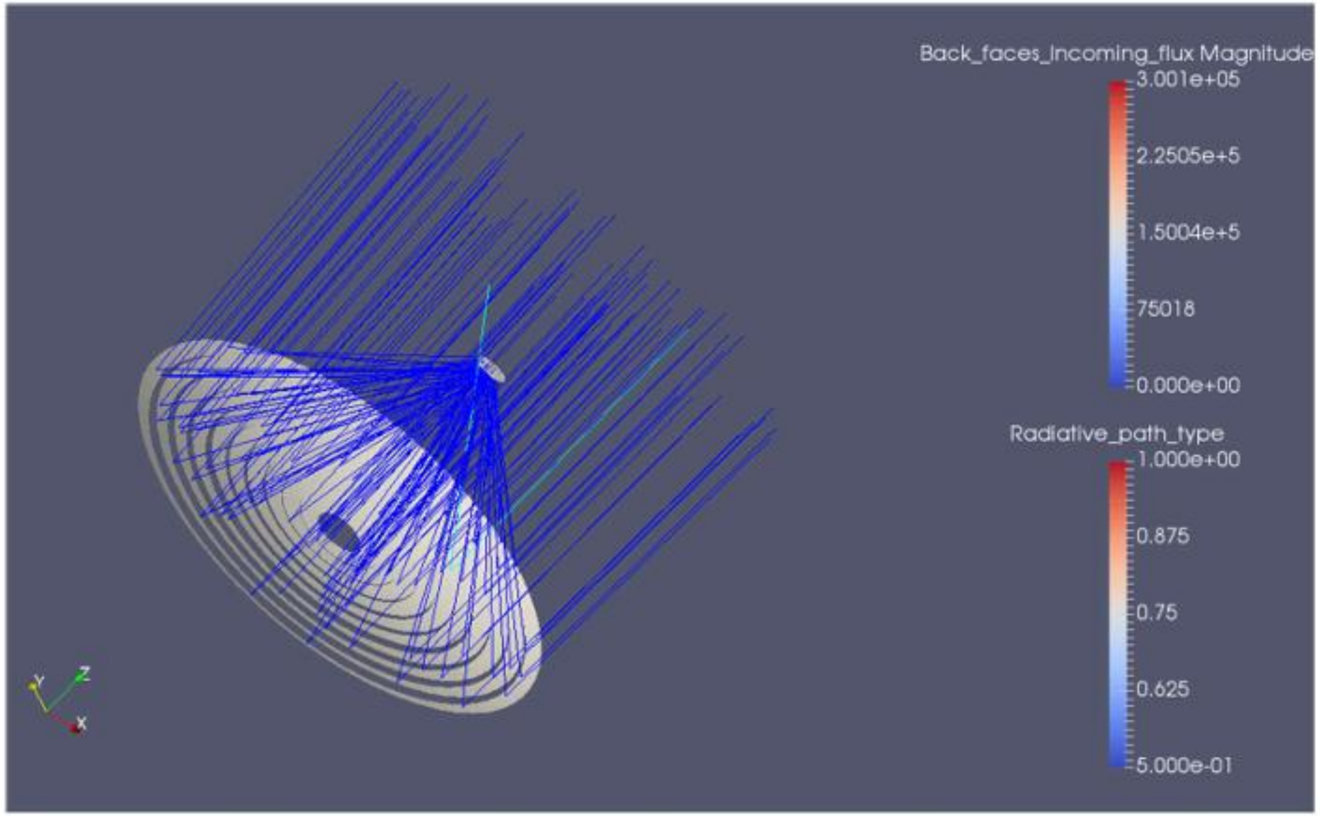


Figure 4: SOLSTICE raytracing simulation.

Design and Manufacturing
First Prototype

First Prototype Manufacturing.

- Reflector Material: Silver-plated acrylic sheet.
- Smaller rings divided in 3 sections. Bigger rings divided in 6 sections. 48 pieces in total.
- Manufactured by Laser cutting.
- **Initial Testing:** Autumn, DNI: ~800 W/m². Max Temperature: **544.74°C**
- **Internal Milestone:** Reach 750°C.
- Conclusion: Increase area -> more rings. Increase to **13** rings.

Figure 5: Installation on site

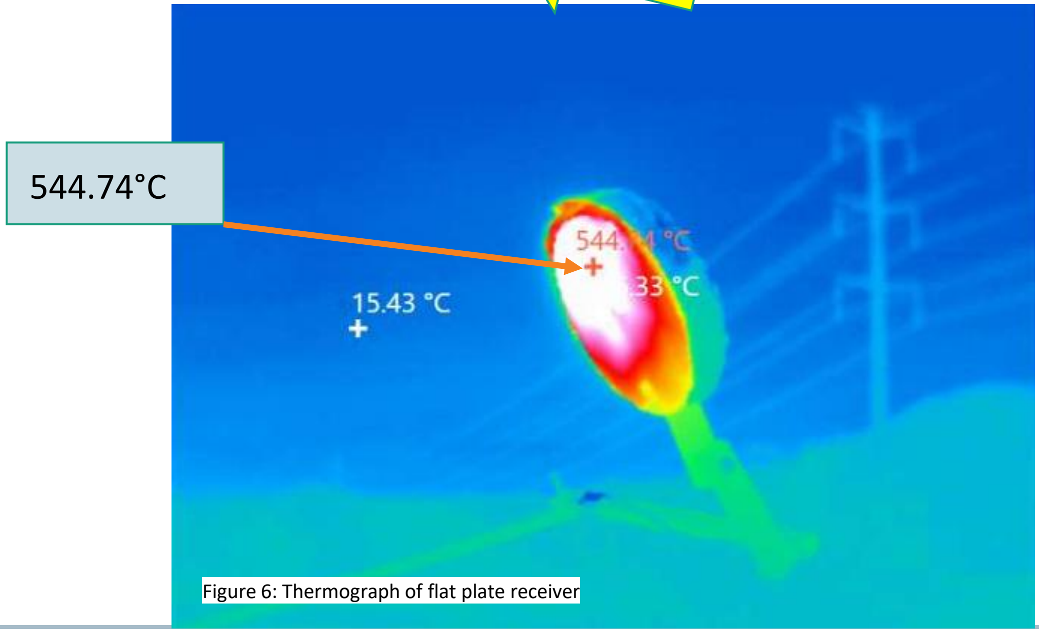


Figure 6: Thermograph of flat plate receiver

Design and Manufacturing

First Prototype

Second Prototype Manufacturing.

- 13 rings. Rings with 3, 6 and 12 sections. 111 acrylic pieces.
- Aperture area: 5.3 m²
- Concentration factor: 169 suns.
- Thermal Power: 3935 W at DNI 1000 W/m² for 20 cm disk (simulation).
- **Initial Testing**: Winter, DNI: ~850 W/m². Max Temperature ≈ **822°C**
- **Interal Milestone: 750°C. Reached.**
- **Next Step:** Receiver Design and Manufacturing.

Figure 7: Reflector with 13 rings..

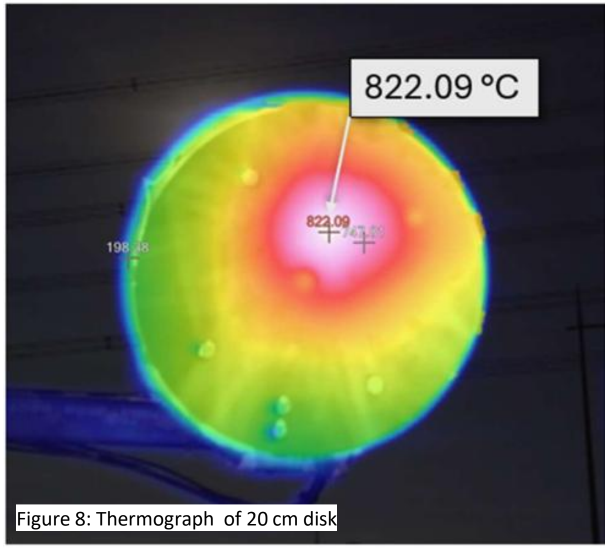


Figure 8: Thermograph of 20 cm disk

Design and Manufacturing

Receiver Design

We take inspiration from laboratory-grade furnace.

- High purity graphite crucible used in non-ferrous metal casting.
- Furnace body made of insulating firebricks.

Figure 9: Reference High purity graphite crucible.

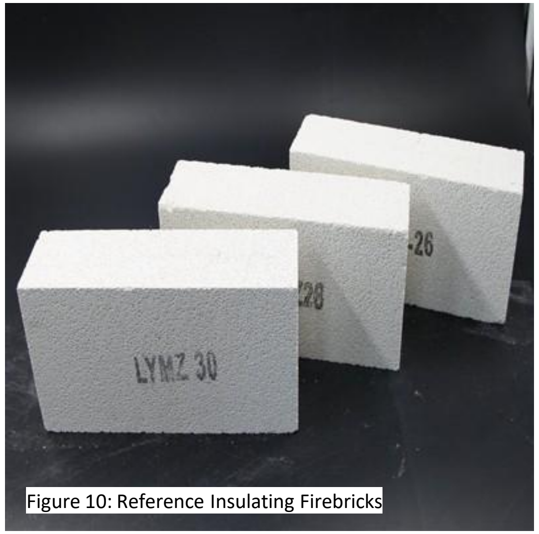


Figure 10: Reference Insulating Firebricks

Figure 11: Laboratory-grade electric furnace from UTSFM

Design and Manufacturing

Receiver Design

Custom-made furnace.

- Concentrated solar flux enter through the bottom of the furnace and is absorbed by the crucible.
- A transparent glass-ceramic window was used to reduce heat losses.
- Crucible diameter: 6 to 10 cm.
- Aluminum scrap is loaded from the top.

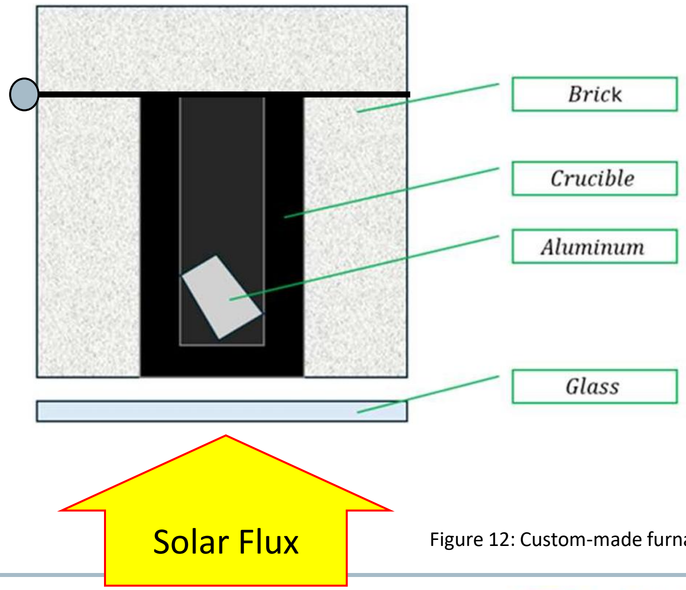


Figure 12: Custom-made furnace schematic

Figure 13: Pictures of custom-made furnaces

Design and Manufacturing

Receiver Design

Custom made Furnace.

- The furnace was mounted on the focal point.
- Three sizes of crucible were used -3, 5 and 6 kg nominal capacity *(rated as gold mass, a common crucible standard)*.
- Furnace mass ranged from 6-8 kg. Crucible mass from 0.5-1.0 kg.
- Crucible diameter was smaller than initial 20 cm receiver disk, which reduce the solar absorption area at the receiver.

Figure 15: Picture of furnace installed.

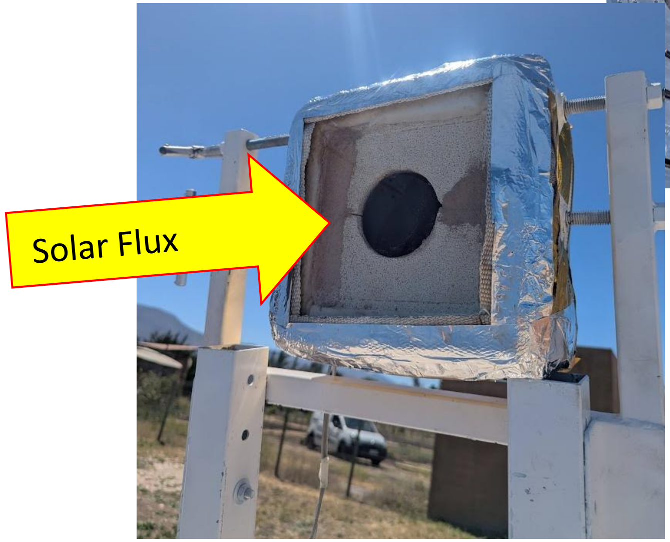


Figure 14: Picture of furnace installed.

System Overview

2nd Prototype Key Parameters

- Aperture area: 5.3 m^2
- Geometric concentration (75 mm crucible): 1200 suns
- Theoretical Optical Efficiency (75 mm crucible): 0.45
- Theoretical Useful Power (DNI = 1000 W/m^2): 2385 W
- Batch Capacity: up to 700 g of aluminum.
- Melt rate: *To be determined experimentally.*

Figure 16: Fresnel furnace prototype installed on site

Experimental Operation

Solar Melting Experiments
Aluminum Scrap Remelting

Procedure

- 1. Load the crucible with aluminum scrap .
- 2. Enable sun tracking until the charge reaches melting temperature.
- 3. Verify if aluminum is fully molten; if so, pour into the mold.

Easy, right? Not really.

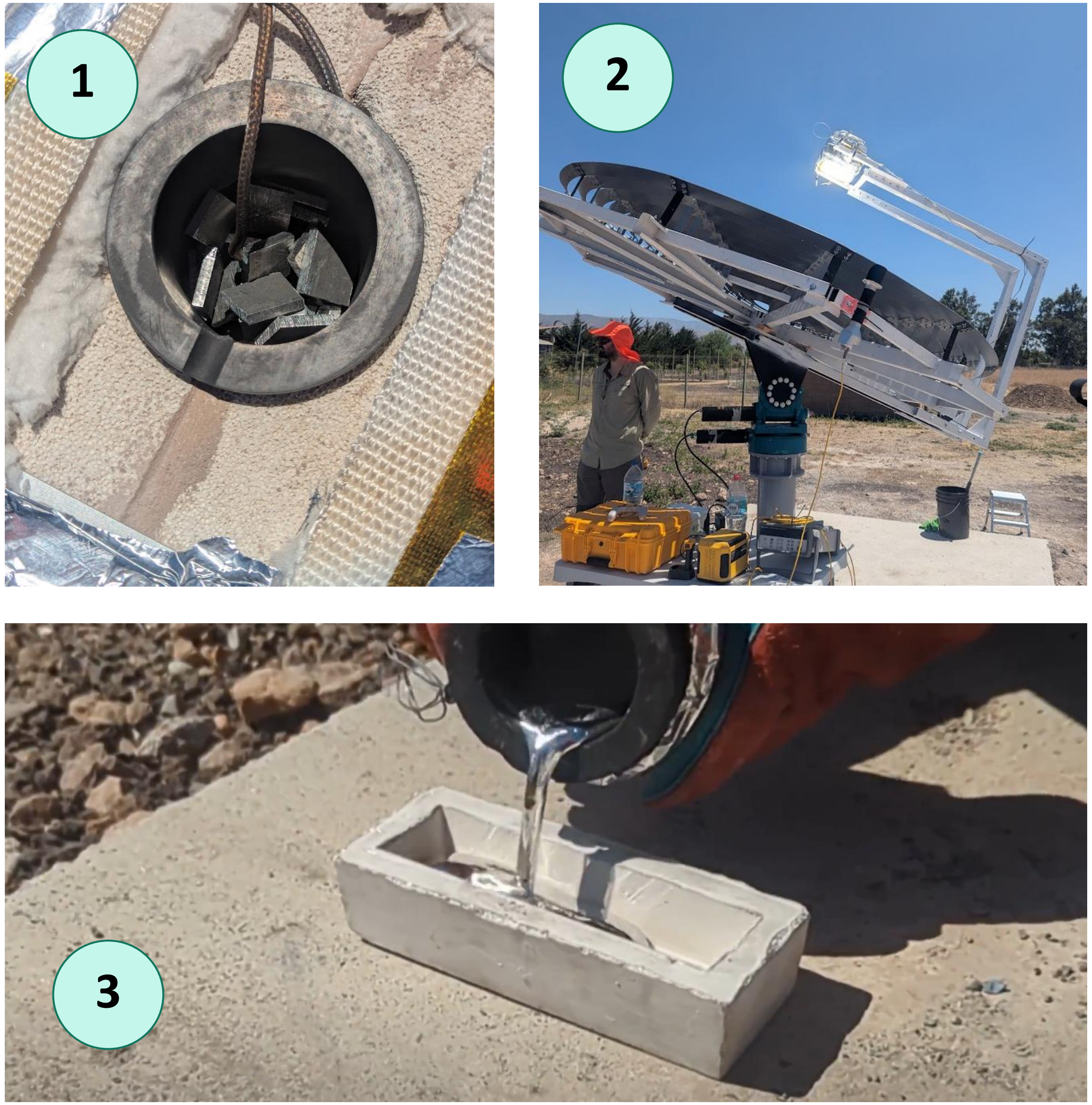


Figure 17: Pictures of the procedure developed.

Solar Melting Experiments

Aluminum Scrap Remelting

First Test

- Aluminum alloy: AA 7178.
- Initial charge: 120 g.
- Melted Mass: - g. (partial melt observed)
- Average DNI (during test): 1000 W/m²
- Duration: 84 min.
- Maximum measured temperature: 650°C

Pyrheliometer co-mounted with concentrator for DNI logging.

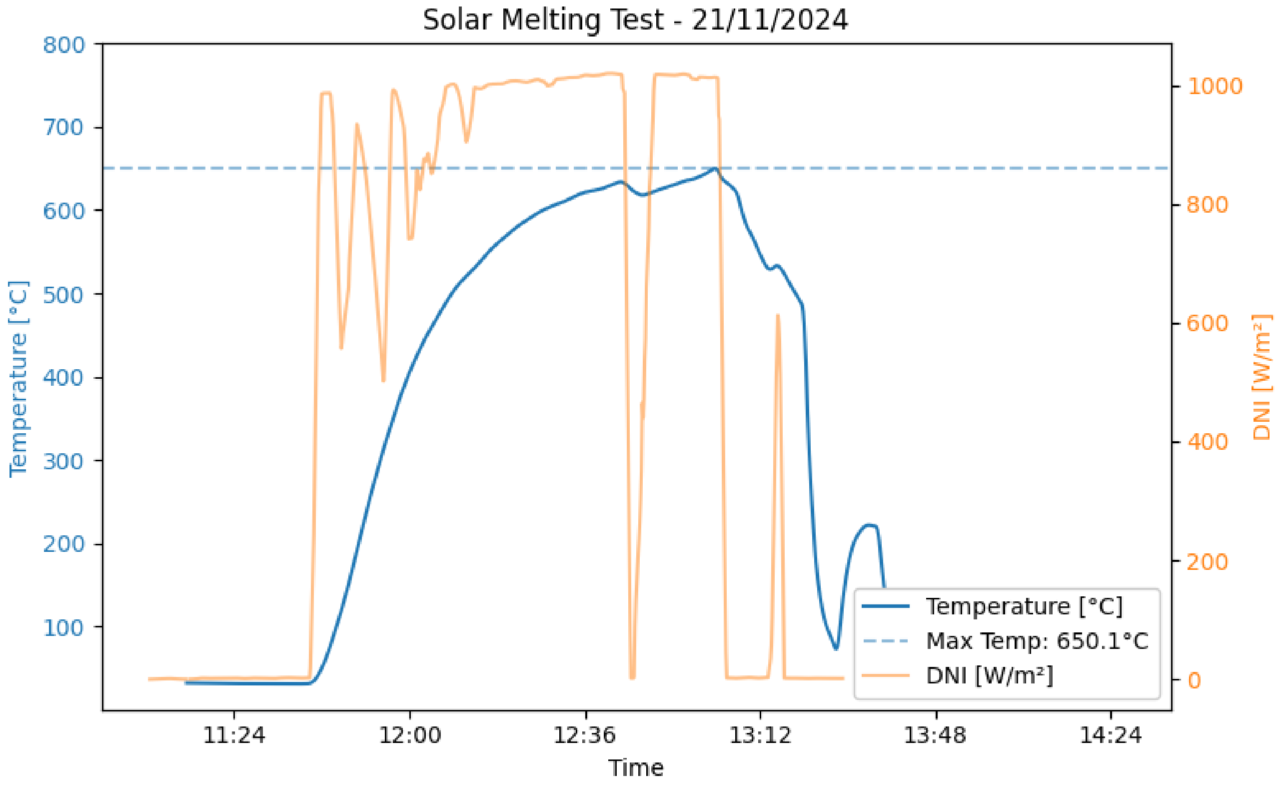


Figure 18: Solar melting test – 21/11/2024. Temperature and DNI over time.

Solar Melting Experiments

Aluminum Scrap Remelting

Analysis

Before

After

Figure 19: Batch Outcome: Crucible Load vs. Resulting Puck — Impurity Evidence

- Aluminum began the melting process, but due to surface impurities, the melting required more time (energy).

Solar Melting Experiments
Aluminum Scrap Remelting

2nd Test

Figure 20: Picture Resulting Puck — Impurity Evidence

Figure 21: Picture Solidified Sample — Impurity Evidence

Solar Melting Experiments

Aluminum Scrap Remelting

2nd Test

Figure 21: Picture Solidified Sample — Impurity Evidence

3rd Test

Figure 22:Feedstock — aluminum scrap (3rd test)

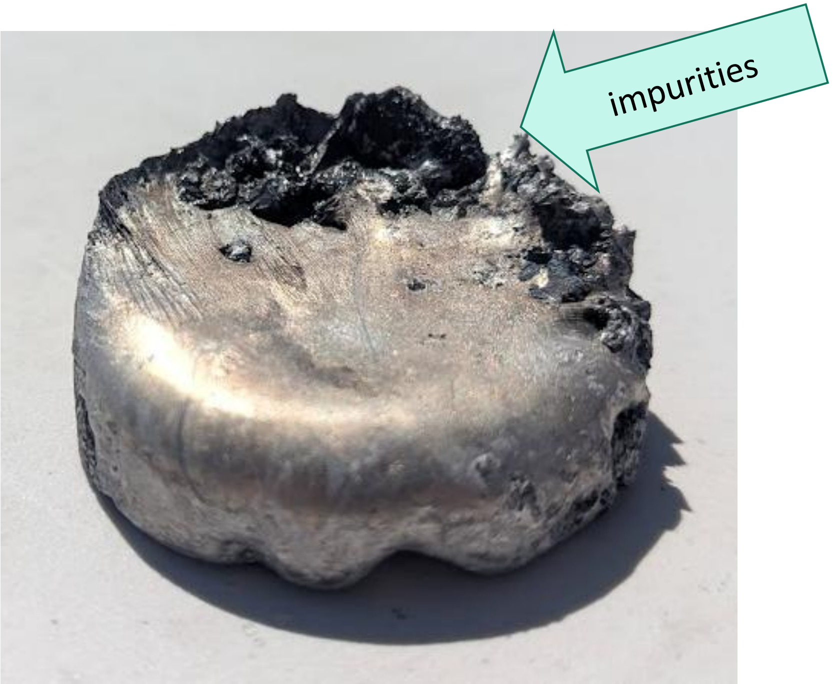


Figure 23:Cast puck — surface impurities

Solar Melting Experiments

Aluminum Scrap Remelting

2nd Test

Figure 21: Picture Solidified Sample — Impurity Evidence

3rd Test

Figure 23:Cast puck — surface impurities

4th Test

Figure 24: Cast puck — surface impurities

- We have perfected the remelting process but the casting was under developed.

Solar Melting Experiments
Aluminum Scrap Remelting

Successful casting!

5th Test


Figure 25: Pouring molten aluminum into the mold


Figure 26: Freshly cast aluminum sample (hand-held)


Figure 27: Freshly cast aluminum sample

Solar Melting Experiments
Aluminum Scrap Remelting

Really long tensile specimen

Figure 28: More pictures of remelting samples. Long tensile specimen.

Three casts in a row

Figure 29: More pictures of remelting samples. Three aluminum casts.

Fraunhofer-branded ingot

Figure 30: More pictures of remelting samples. Fraunhofer-branded ingot

- Having established a safe, reliable casting procedure, we focused on increasing the melting rate

Solar Melting Experiments

Aluminum Scrap Remelting

Test #21. Maximum Output Day.

- Alloy: AA 4032
- Average DNI (during test): ≈ 900 W/m² (early autumn)
- Total poured mass: 1770 g.
- Duration: 327 min (≈ 5.5 h)
- Average melting rate: 322 g/h
- Maximum measured temperature: 596.2 °C.
- Five successful castings.

Figure 31: Five casts' samples from 08/04/2025

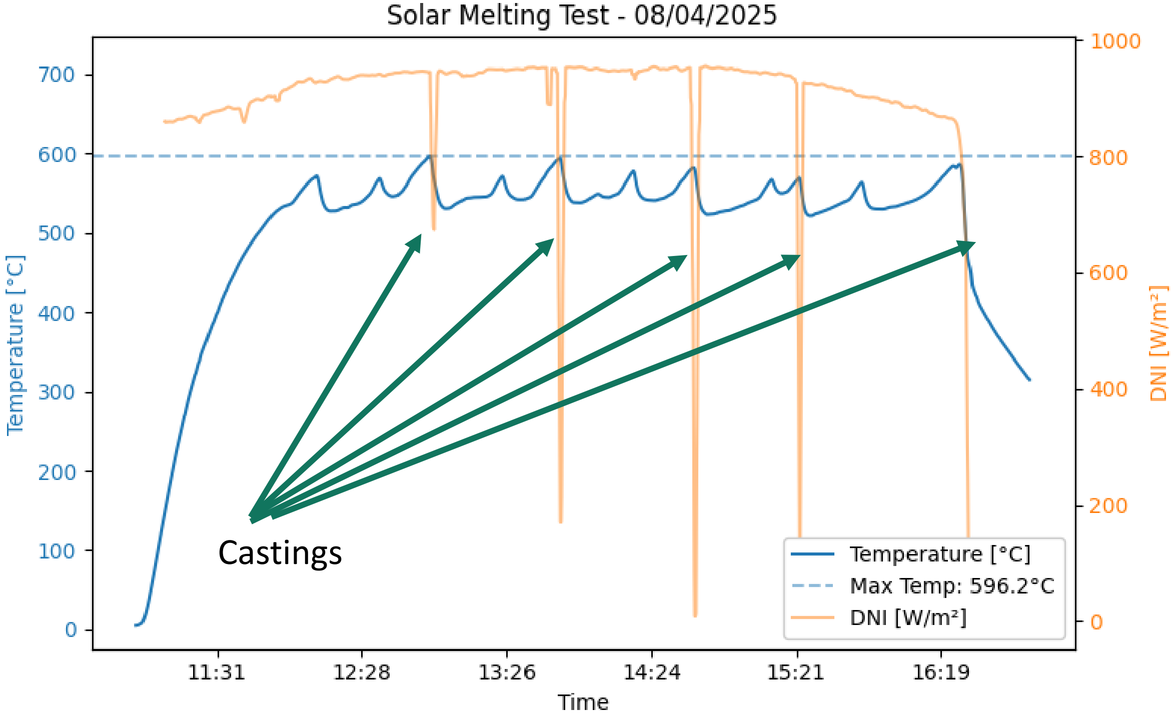


Figure 32: Solar melting test – 08/04/2025. Temperature and DNI over time.

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Figure 33: Five casts' samples from 08/04/2025

Over 15 kg of recycled aluminum was produced!

Figure 34: Close-up from a casting process

Thermal Model and Annual Assessment

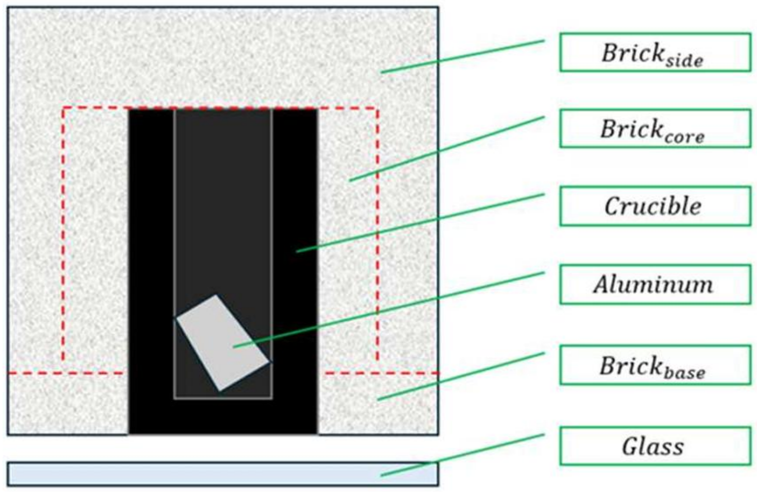
Thermal Model

Lumped-Resistance Thermal Model

Simplified lumped-resistance model

- Six bodies were considered: Aluminum, Graphite Crucible, Insulating firebricks (3 virtual bodies), Glass-ceramic window.
- Convection and radiation heat losses were included.
- Optical properties of glass-ceramic window were considered.
- Aluminum: Alloy 4032 alloy properties.
- Parameter tunning: fitted to the crucible–brick interface temperature to reproduce the receiver's thermal inertia.
- Validation: RMSE 17-20°C, mainly due difference between manual field operation and the automatic control assumed in simulation.

Figure 35: Receiver cross-section and lumped bodies used in the model



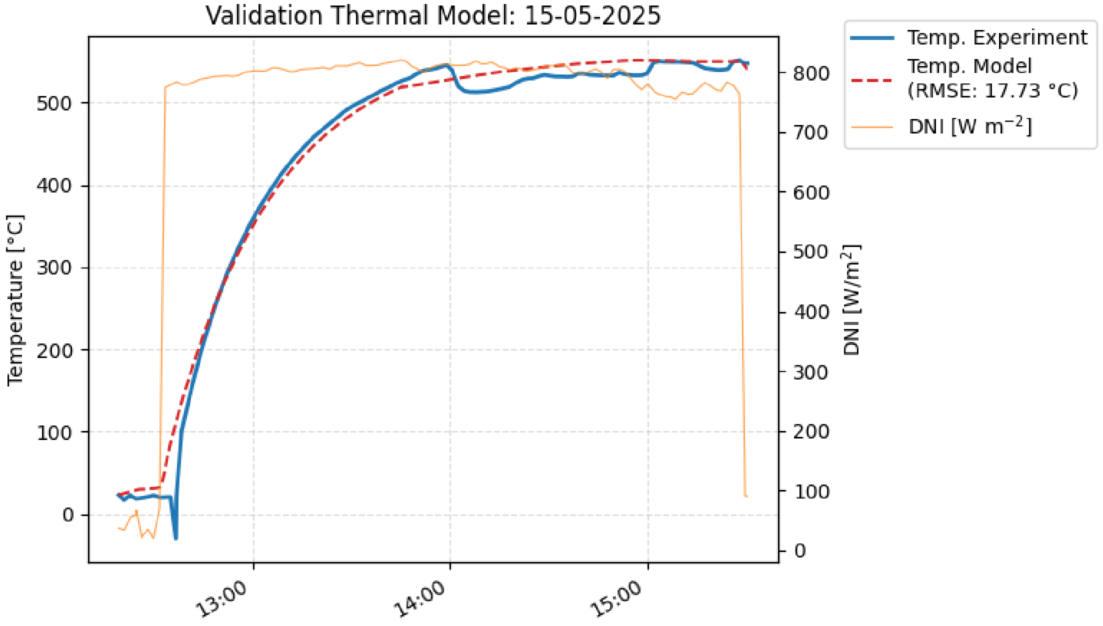


Figure 36: Model validation (15-05-2025): measured vs. simulated temperature at the crucible–brick interface

Annual technical assessment

Current Location and other cities

- Current installation location: Santiago, Chile.
- Daily average DNI: 7.58 kWh/m²/day
- Summer Conditions:
    - DNI up to 1,050 W/m²
    - Ambient Temperature up to 42°C.

- Additional assessment: several northern-Chile cities were assessed using TMY data from Explorador Solar[1], provided by Chile's Ministry of Energy.
- <u>Results: Annual Aluminum Output (model):</u>
    - **702 kg in Santiago.**
    - **1,237 kg in Calama.**

[1] A. Molina, M. Falvey, and R. Rondanelli, "A solar radiation database for Chile," *Scientific Reports*, vol. 7, Art. no. 14823, Nov. 2017

Conclusion

Experience and Learnings

- We successfully designed, built and operate a novel solar concentrator capable of melting and recycling aluminum.
- Although the process required extensive trial and error, in-house development and local manufacturing made iteration fast and effective.
- We established a prototype that will serve as a testbed for future reflector, receiver design and industrial heat-integration.

Developing locally turned budget into know-how, experience, and talent—shifting us from users to **creators**.

Figure 37: Fresnel annular reflector.

Thanks for your attention!

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Annex
Additional Pictures