Final report

1. Project details

Project title	New Silicone-based Lenses for Low Cost Concentrated Solar Heat
File no.	64018-0606
Name of the funding scheme	EUDP
Project managing company / institution	Heliac
CVR number (central business register)	35841911
Project partners	DTU, E.On, Inmold
Submission date	31 December 2021

2. Summary

The objective of the project has been to optimize lenses for Heliac's concentrated solar heat plants concerning the aspects of efficiency, safety and durability, and make a real-life-demonstration of this by installing them on Heliac's first major solar field at E.On in Lendemarke, Møn. The optimization has been done by changing two aspects of the original lens. First, the thermoplastic material has been replaced with a silicone-based material, where the UV-degradation is much lower, and the transparency is slightly higher. This required a new manufacturing method to be developed, where the thermoplastic film is used as casting film instead of as the lens itself. The second aspect that was changed was the ray-path of the focused light, in order to minimize the off-axis false focal spots. These have an intensity in the original lens that could set dry grass on fire, which is of course not optimal. The path has been altered to reduce the intensity of these false focal spots by 35-48%.

The new and optimized lens has been demonstrated by replacing the lenses on the Lendemarke plant with the new silicone lenses, and real-life durability of two years has been demonstrated without any visible degradation. For comparison, the original lenses were visibly degrading after less than one year. Furthermore, accelerated testing is in progress in Florida, but results from these have not yet been received.

The optical efficiency of the plant (at lens installation) was increased from around 53% to 60%, giving a significant increase in heat output, improving the commercial value by 13% (without counting the effect of less land use and the improved durability and safety).

The safer silicone lenses are now forming the technological basis of a new plant build for Norfors in Denmark and two more upcoming plants for industrial end-users in Spain, and as such the project has been a great commercial success.

3. Project objectives

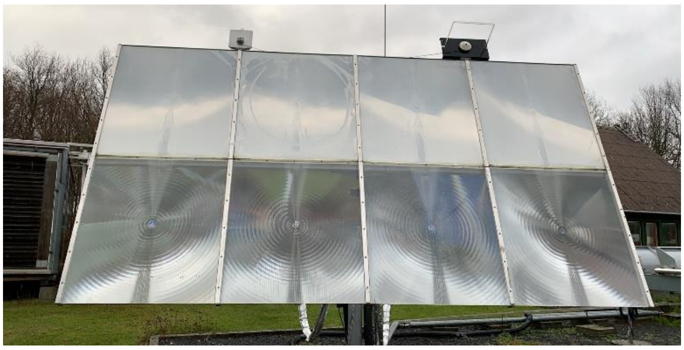
The objective of the project has been to optimize lenses for Heliac's concentrated solar heat plants with the aspects of efficiency, safety and durability, and make a real-life demonstration of this by installing them on Heliac's first major solar field at E.On in Lendemarke, Møn.

Principle of operation for the solar collector. A lens focuses the sunlight onto a receiver that heats a circulating liquid. The lens is kept perpendicular to the sun by 2D-solar tracking. However, under some conditions, such as high wind conditions, where the unit is placed horizontally, this will not be the situation. In these situations, the lenses may focus the incident sunlight onto other places than the receiver, e.g. onto the ground or the unit itself. This may damage the unit or set dry vegetation on the ground on fire.

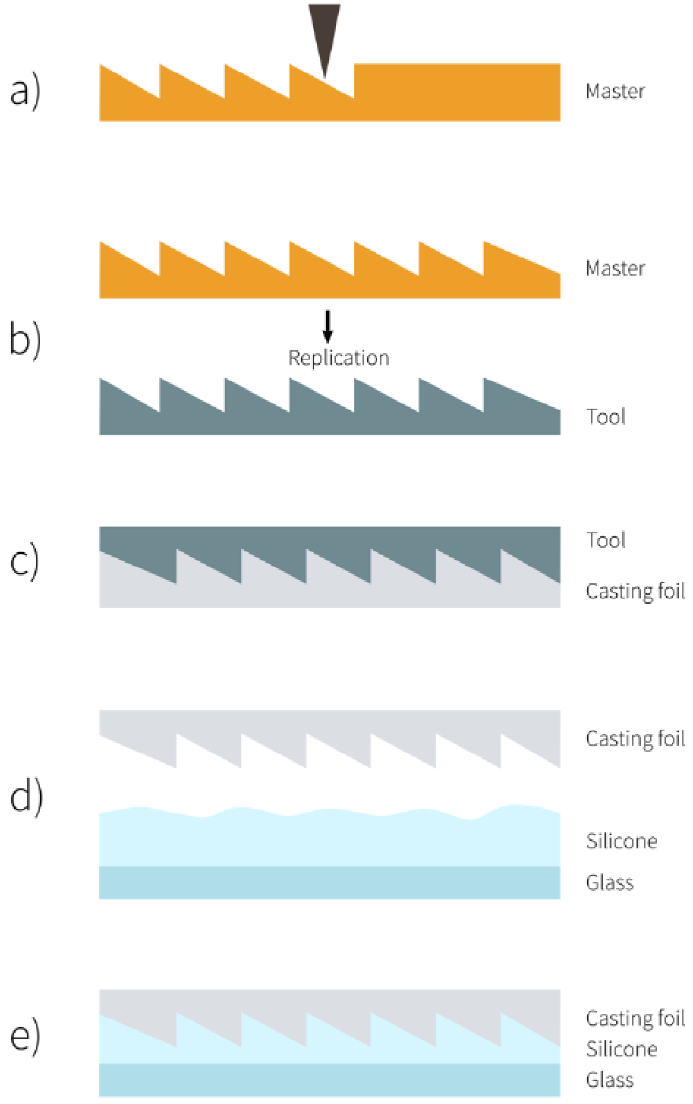
Lendemarke solar thermal plant.

The idea was to use an alternative material than the original Heliac lens. The original lens was a PET-PP thermoplastic film glued on a window glass, where the glass would be facing the sun and the film would be on the backside. By using normal 4-5 mm window glass (non-iron-free glass), the majority of the UV radiation would be absorbed and protect the thermoplastic film from degradation. This idea has been supported by dry-UV accelerated tests at Fraunhofer ISE, but turned out not to be representative for real-life conditions, as the lenses degraded 5-10 times faster in real life than predicted by accelerated tests.

The proposed material is a silicone resin used in the automotive sector with proven long-term durability and high optical transparency. The project objectives were to develop a method to form lenses in this material, to test the lenses and show increased efficiency and durability. The lens manufacturing method is shown schematically in the figures below, as well as lens degradation and fire hazard.



Left figure showing lens degradation, where upper lenses are degraded under real-life conditions for one year and the lower lenses are new non-degraded lenses. Right is shown the result of an off-axis focal point setting dry vegetation on the field on fire at Lendemarke). These problems were the ones set out to be solved in the project.



A master is made using CNC-milling (A). The master is replicated into a tool (B) that is used to make a casting foil (C). The casting foil is used to cast a liquid silicone resin on glass, which cures into the inverse surface geometry, resulting in a silicone-on-glass lens.

Furthermore, the original lenses (based on a standard Fresnel lens geometry) showed challenges with spots of focused light when the sun hit at non-perpendicular incidence (e.g. during horizontal positioning of the lenses in wind-mode). These spots could under certain conditions light dry grass on fire, posing a potential hazard, and increasing the need for costly and time-consuming field maintenance. This was proposed to be improved by a certain design of the lens geometry, reducing these false focal spots.

4. Project implementation

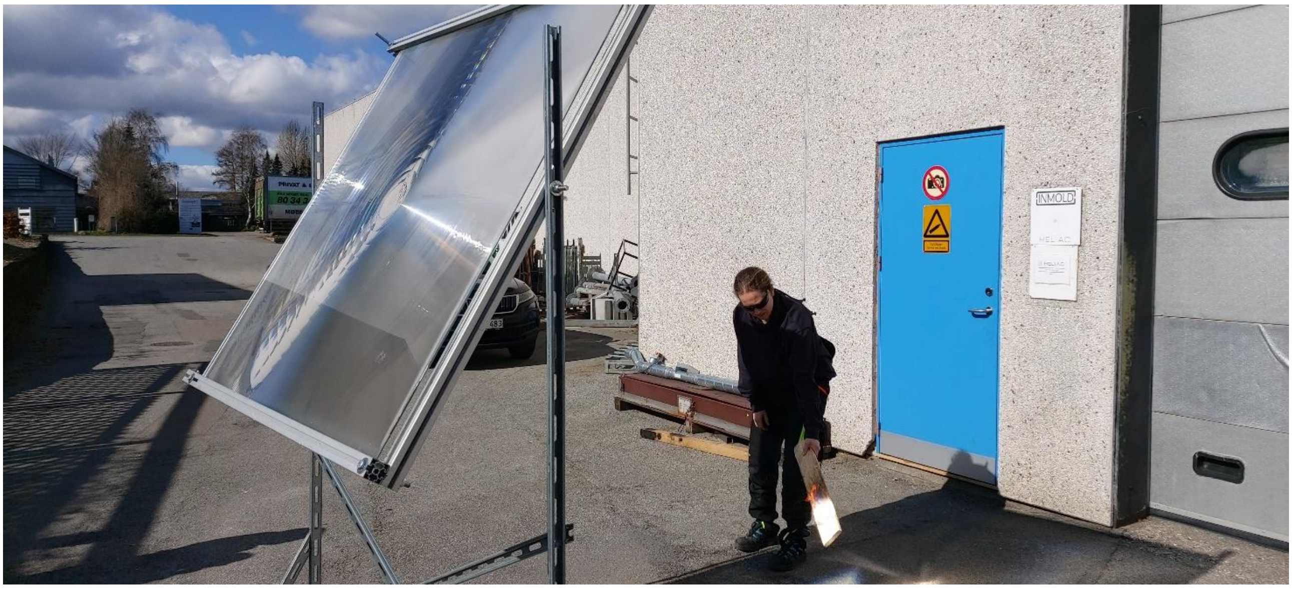
The project has been successfully executed according to the original plan. The new lens type and the manufacturing method of these have been developed with a large increase in durability (from <1 year to >>2 years, expected >10 years) and a significant increase in efficiency (from 53% to 60% optical efficiency).

Silicone lens development

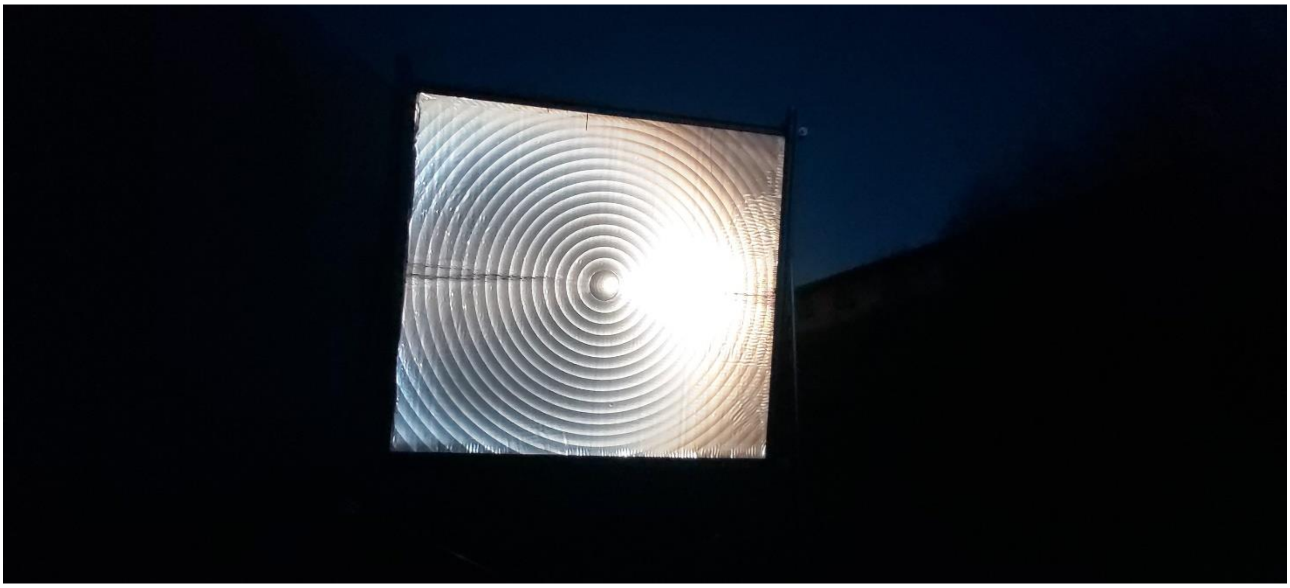
The first task was to find a suitable silicone material that was durable and processable. Eight different silicones were tested, where three were easily processable, and of these the two with the best durability data were chosen. These two were tested in full-size lens production, and the chosen type has been shown to have better processability and better economy than the other type.

The chosen type was then implemented in a full-scale production setup with automatic mixing and the mass-production of the lens was shown by manufacturing 1200 full-size lenses that were installed on the Lendemarke plant for real-life testing of efficiency and durability. The first prototype lenses were installed in December 2019 and the majority of the 1200 lenses were installed in April 2020. Two types of durability-related issues have been examined, UV-degradation (that the lenses become less transparent, coloured or milky) and delamination of the silicone layer from the glass substrate. So far, none of these issues have been observed. Also, one further point of concern has been examined, namely fouling of the lenses. One risk with using silicone instead of thermoplastic lenses was that the silicone is stickier, and dirt may therefore easier settle on these lenses. However, this has not been observed, and washing with a pure water spray has also been successfully tested, in case the plant would be situated in a dustier place than Denmark.

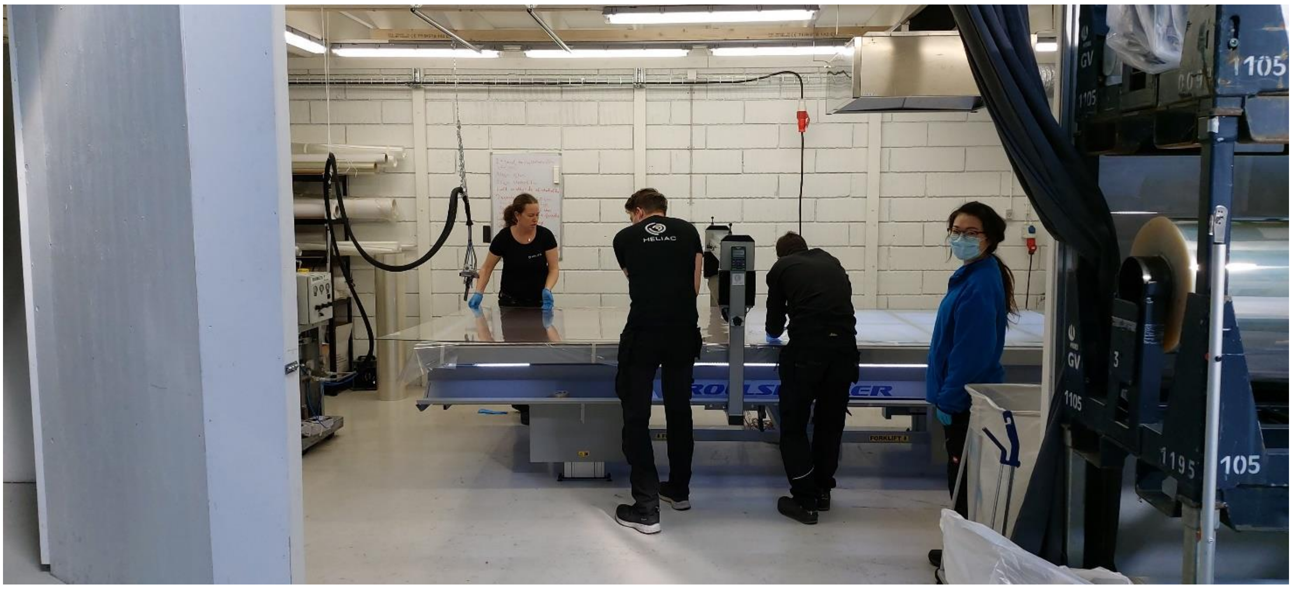
First manufactured silicone lens with the safer lens geometry.



Focal point testing of silicone lenses. The lens is placed in an adjustable holder and adjusted to be perpendicular to the sun. An object which is sensitive to concentrated sunlight (such as wood) is placed in the focal point to get a first impression of the solar distribution in the focal area. If the concentration is much higher in parts of the focal area, the wood will take colour faster.



Indirect focal point testing of the silicone lenses. The lens is mounted as shown above, but tracked towards the full moon, which has a similar size on the sky as the sun, but one million times less intensity. This allows for direct observation of the lens as seen from the focal area, which is otherwise impossible using normal optics or human vision. This enables characterization of the safety aspects of the lens, and allows for mapping of which areas of the lens that guides the light to different areas in the focal area.



Silicone lens mass production. Glass substrates are placed on a lamination table, silicone resin is dispensed on the glass and the casting film, and a roller is used to distribute the resin over the full glass substrate. After distribution, the resin cures and the lenses are ready for mounting.

Silicone lens installation on Lendemarke. The lenses are opaque due to the casting film still being on the lens to prevent uncontrolled focal points during installation.

Casting film removal after lens installation (left) and the solar field after installation of new lenses (right).

After the mounting of all the lenses and recalibration of the solar tracking, the solar field was operated and tested. This was compared to earlier data from the solar field from DTU.

5. Project results

The objectives of the project, to design a more effective and durable lens with lower intensity of the off-axis focal points were achieved, as described more detailed in Appendix 1. The lenses have been successfully tested in large scale at the Lendemarke solar plant, as well as being tested in accelerated tests in Florida.

The lens transmissivity was increased from 73.6% to 91.2-91.9%, depending on the silicone used. This has resulted in an increase in unit optical efficiency from 53% to 60%, as described in Appendix 2 and 3.

A more thorough report on the performance of the new lenses installed at Lendemarke has been submitted to Solar Energy, see Appendix 4.

Furthermore, the new process for making silicone lenses has been developed in a manner that will support mass production of these. Today, by manual production, a volume of 1 MWp can be made per month (4 people full-time). In the future, these processes are expected to be automated, so 20-50 MWp/month can be manufactured using the same manpower.

The improved performance of the field realized through the project has improved the project economy of the technology to a point where commercially feasible solar plants can be built. The first plant is being constructed at the DTU Science Park, where it will supply Norfors with district heating, as well as demonstrate that industrial process steam can be made with the technology. When this has been shown, two more plants will be built for industrial steam end-users in Spain.

6. Utilisation of project results

The project results are already being used by Heliac and are implemented in the main product, Fresnel solar collectors. These are already being sold to commercial end-users. Also, the project has improved the commercial viability of the Heliac concept to a point where it has been possible to attract significant private investments, as Heliac raised over 100 MDKK in equity in 2021. It is expected that two or three plants will be built in Spain in 2022, as well as the finalization of the Norfors plant. All these plants will use the developed technology.

The goal of the customers for the solar concentrators is to replace the use of fossil gas with solar heat. It therefore contributes to the green transition, and in most geographies, this can be done at a cost lower than the fossil alternative.

There are mirror-based competing technologies on the market, but so far these have not proved commercially viable. This has been due to a too high CAPEX, but also due to a quite high minimum size of installations. However, new types of products are being developed by different competitors such as Absolicon (Sweden), Solatom (France) or Heliogen (US) which may become competitive in the future. Therefore, it is important for Heliac to keep developing the product to achieve even higher efficiency and reduce the cost of the concept even further.

To increase the impact of the technology, heat storage needs to be integrated into the solution. This is work in progress, through the RockStore project, where the produced heat can be stored in rocks and used later.

7. Project conclusion and perspective

The project has been successfully completed, as a lens with superior efficiency and durability has been developed, as well as a method to reduce the strength of unwanted false focal points. The project has brought the technology to a commercial state. The technology will be improved further, both on the technical (efficiency, durability) parameters, as well as from an economic aspect (lower CAPEX and OPEX). Next steps will be to build more commercial plants and learn from these, integrate with heat storage to increase the fraction of solar heat usable by the end customers, and reduce the cost and increase efficiency further to be able to offer the most competitive solution to industrial heat customers using heat up to 180C.

8. Appendices

Appendix 1: Investigations of a Fresnel-lens solar collector, Adam R. Jensen, 2021

Appendix 2: Experimental Investigation of a Concentrated Solar Collector developed by Heliac, Adam R. Jensen, Janne Dragsted, Simon Furbo, 2018

Appendix 3: Test of Heliac 3rd Gen. Solar Collector, Adam, R. Jensen, 2020

Appendix 4: Thermal Performance Assessment of the World's First Fresnel Lens Solar Collector Field, Adam R. Jensen et al. 2021, submitted to Solar Energy