SolarPACES 2024, 30th International Conference on Concentrating Solar Power, Thermal, and Chemical Energy Systems

Emerging and Disruptive Concepts

https://doi.org/10.52825/solarpaces.v3i.2332

Published: 25 Nov. 2025

Fresnel Lenses for CSP

Large, Low-Cost Fresnel Lenses in Glass for CSP

Luigi Fornari[1,*] and Gianluigi Fornari[1]

[1]LenteSolare LLC, Texas, USA

*Correspondence: Luigi Fornari, lfornari@lentesolare.com

Abstract. The industrial revolution moved society organization from farming communities distributed on the land, self-sufficient in energy and food provided by the sun, to concentrated sources as oil and natural gas. Now there is a reversal of this trend due to the return to the use of solar energy. We produce electricity with PV panels, but we need also heat, and we do not have any way to do so in a distributed way. We propose a model of collecting, storing, and using the energy locally. The first step, collecting, we discuss in this paper. We propose the use of a large Fresnel lens in glass. To mold the lens in glass we use a modified groove design where the vertical step directs the light to the focal point through reflection by a mirror. The angle between facets is large enough to let the glass fill the grooves. We solve the problem of cost by producing the lens in a cylindrical configuration, extruding and calendaring the glass in a commercial plant for textured glass at a cost of $10/m². The basic unit size can be realized as an assembly of eight 4x8 feet glass panes, collecting what we expect to be 10kW per unit, at a cost of few hundred dollars per unit for the collecting optic. We will capitalize on the know-how on making the receivers for the Parabolic Reflector geometry. This proposal allows solar heating to be affordable by a homeowner, lowers CO_2 emissions.

Keywords: Fresnel Solar Field, Line Focus Systems, Point Focus Systems, CSP Technology, Distributed Energy Production

1. Introduction

Solar energy is of low density. It requires large collection surfaces. PV panel have allowed the production of electrical energy locally, therefore avoiding disruptions (political, due to “Black Hat” operatives, or natural causes [1]), but there is not an inexpensive offering on the market for the production of heat (at the present supplied by oil and natural gas, producing CO_2 during burning). We propose a solution based on Fresnel lenses.

2. The Fresnel Lens

Fresnel lenses have a long history [2]. They were first made in glass during the 1800s for lighthouse use. In the 1940s, with the advent of acrylic plastic, were made up to a couple of feet size for use in military and technical applications, where the cost was less important (Cryton Optics). When that market decreased in 1970s, there was a revival due to the application in overhead projectors (3M). Next big market flourished with the screens for projection television sets. It died with the advent of LCD displays. Starting in the 1980s, with the advent of pyroelectric detectors, arrays of thin Fresnel lenses in IR transmitting plastic have been used for motion detectors (Fresnel Technologies [3]). Today it is still a significant market, and the standard lenses are used for niche application. No other significant markets exist.

Use of Fresnel lenses for CSP applications was pursued in the 1970s. Large projection screen are possible in acrylic (see Stewart FilmScreen 9’x16’ [4]), but their cost, including the logistics of transportation, are too high to be competitive with other technologies. Various geometries were explored at the time (flat surface, cylindrical surfaces to optimize the collection during the day), but all in acrylic, since to produce anything in glass was impossible. The process of compression molding to produce the acrylic lenses was unfortunately too time consuming, and therefore expensive, to produce.

3. A Basic Overview

Both Count Buffon, and Augustine Fresnel realized that in a lens the deflection of the light rays was caused mainly at the interface between air and glass. They reasoned that if the extra glass thickness was removed, the optical properties would be still present. The result was what we call a “Fresnel Lens.” The procedure is illustrated in *Figure 1*.

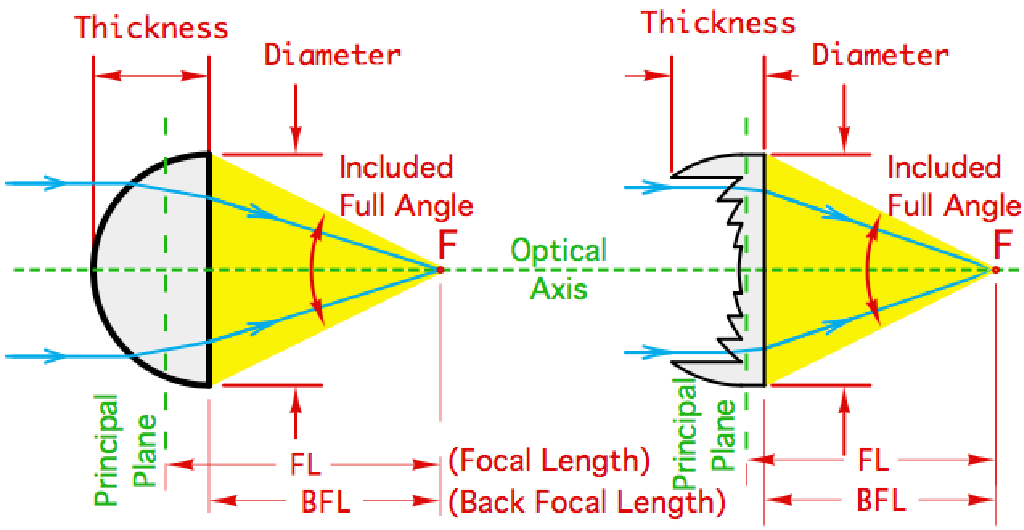

Figure 1. *Comparison between a standard lens and a Fresnel lens*

Figure 2. shows different ways of generating the Fresnel lens profile. Constant Width was the original way. Grooves are evenly spaced along the radius, and was used initially in making mols for plastic lenses because a tool plunging in the material of the mold would cut the grooves. The angle between the surface of the mold and the edge of the tool was changed at every groove. The grooves were thicker at the edge, and thinner at the center. With the advent of the single point diamond machining, it was possible: a) To make a rounded groove, similar to the actual surface of a standard lens, and b) To make the grooves all of the same thickness, obtaining a thinner lens, especially important for lenses for the infrared, where the materials are lossy. These are called “Constant Groove Depth” Fresnel lenses.

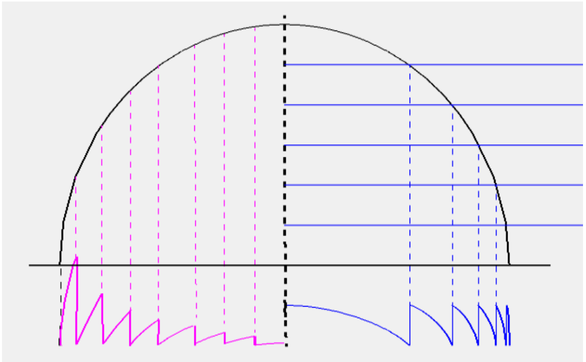

Figure 2. *Constant Width (red) & Constant Depth (blue) Design Comparison*

Designing the shape of the grooves the overall optical configuration needs to be kept in mind to optimize for the desired results (for example minimize spherical aberration, etc.) There are two basic configurations illustrated in *Figure 3.* “Grooves In” (GI), and “Grooves Out” (GO) corresponding to the conjugates of infinity and focal length on the flat side or grooved side of the lens to minimize the spherical aberration. There is also the “Finite Conjugates” case, where both sides have a finite conjugate (used in some optical applications).

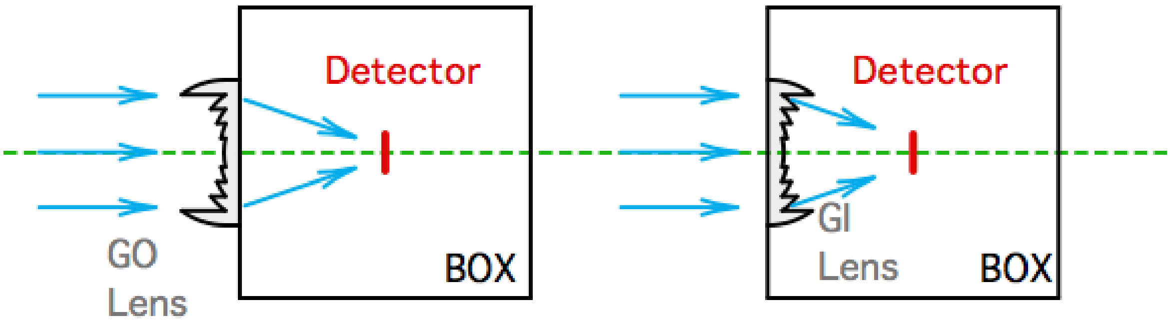

Figure 3. *Grooves Out and Grooves In collecting light on a target.*

The original lenses made by Fresnel for Lighthouses use were of the GO type, hand ground in glass for durability in the harsh marine weather. Many are still in use after more of a century of operation. The GO type allows for higher light intensity, while the GI type has a flatter focal plane. In collecting light, both types suffer from vignetting, as can be seen in *Figure 4.* for a GO groove. In the case of the GI groove, it is clear that the last groove will cause the light to undergo total reflection (if the groove tilt is greater than the total reflection angle), thus posing a limit on the maximum diameter of a GI lens.

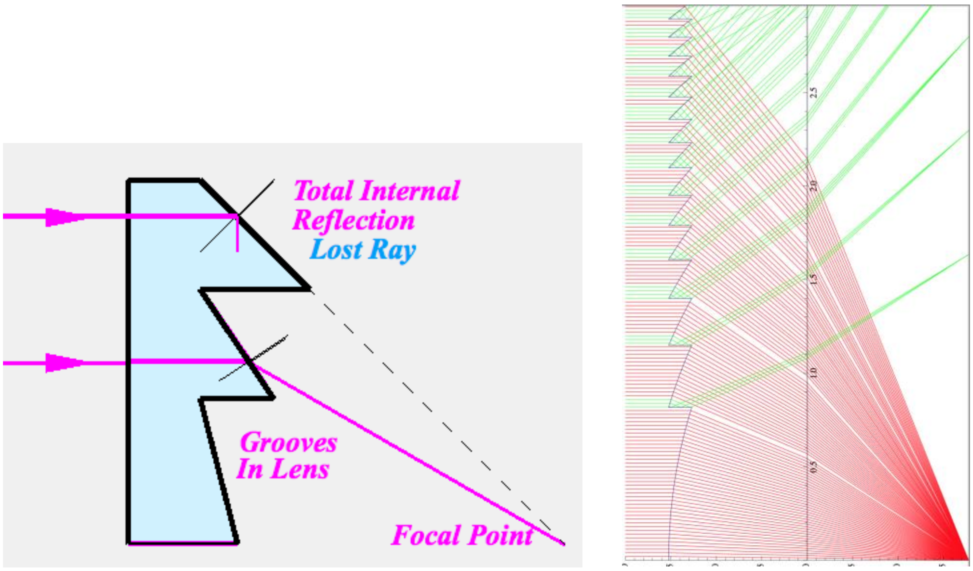

Figure 4,5. *Vignetting in GI (left) and GO (right) grooves (Vignetted rays are in green)*

The result is that the collected light depends on the f/# of the lens as in *Figure 5.*, and decreases dramatically past the f/1 mark (The specular reflection limits the transmittance to 92% in acrylic at large f/#.)

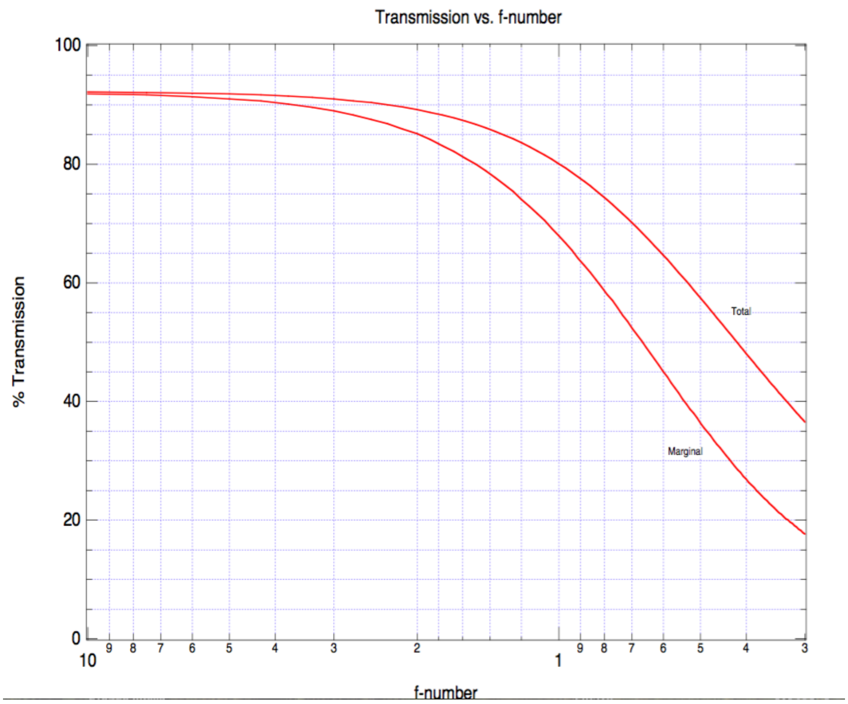

Figure 6. Transmittance of a GO lens. Notice the poor performance of the marginal grooves.

A first attempt to solve the problem was done by producing cylindrical lenses curved perpendicular to the axis [5]. This improved slightly the transmittance and lowered the tolerances in tracking. Attempt were made to use non-imaging optics [6],[7], but, as for the curved case, it proved to be too costly to manufacture. An attempt to lower manufacturing cost was done recently by extrusion coating, where a polymer melt is structured by a cooling roller and is applied to the back of flat glass sheet [8]. Lifetime is less than 5 years due to UV.

3.1 Groove Improvement in a Fresnel Lens

To solve the vignetting' problem we suggest a modification of the grooves as follows: We tilt the vertical groove so there is no vignetting, and we direct the light towards an adjacent focal point, or to the same point using a mirror [9]. *Figure 7,8.* compares the two types of grooves:

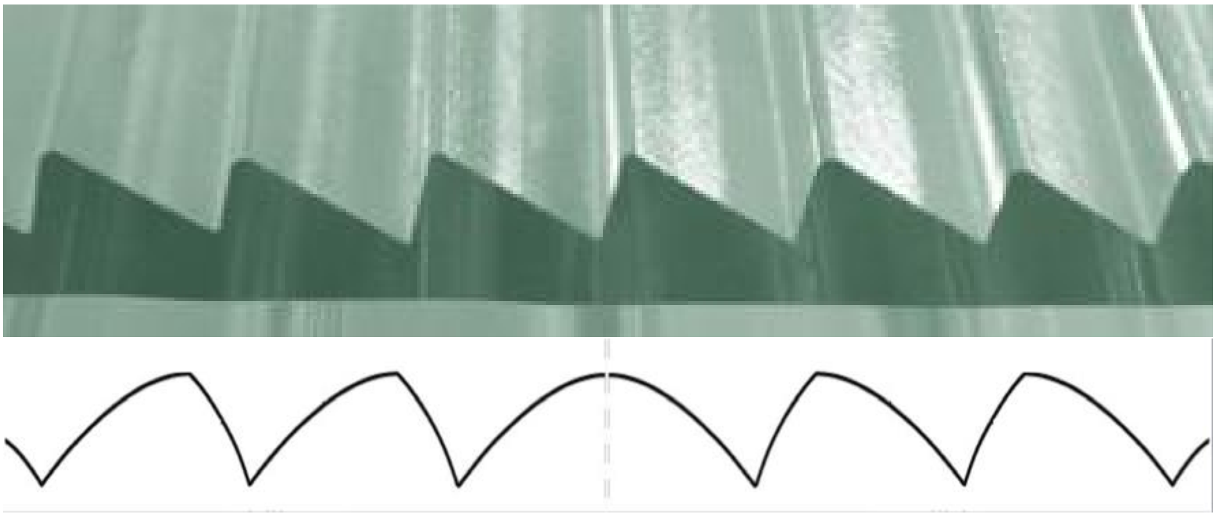

Figure 7,8. *Comparison between the old grooves (above) and the new ones (below).*

Figure 9. shows a picture of how the rays propagate in the new groove arrangement [9]:

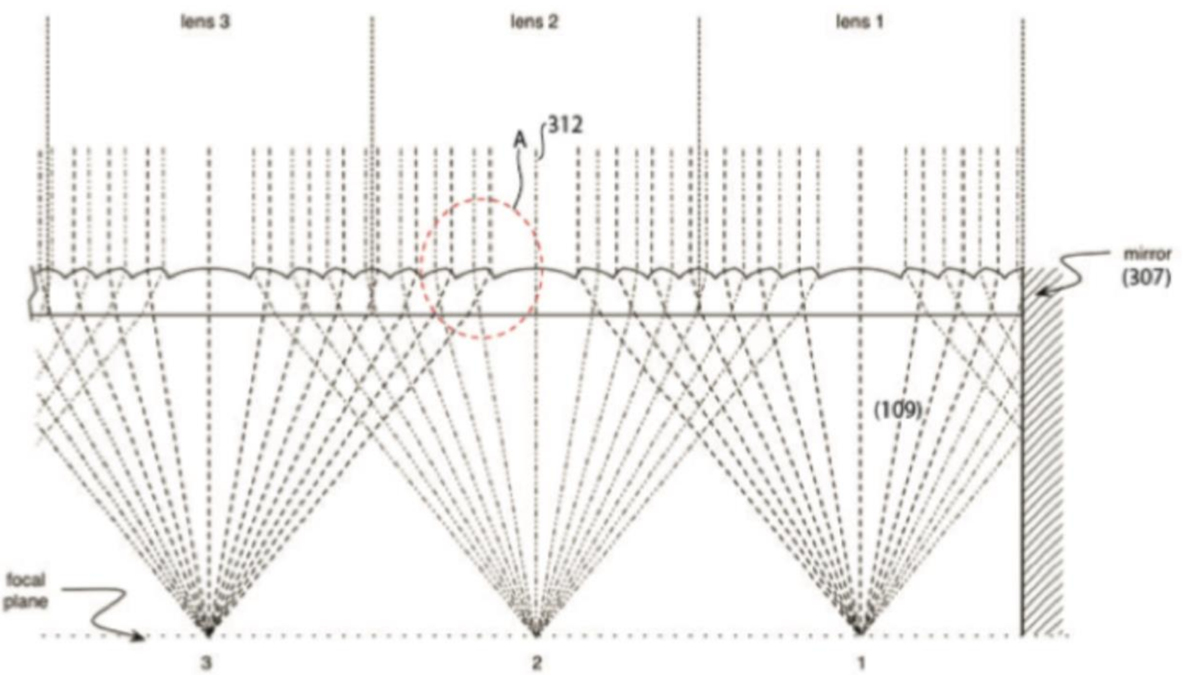

Figure 9. *Ray focusing in the new groove arrangement*

A sample design the grooves of a GI Fresnel lens follows: The on-axis ray intersects the lens at (x, z) = (0,0) = O, and the focal point is on it. Once the resolution is set (for example if the distance between the points is 10μm along the x direction), then next point is P_1= (10μm, z_1). Using Snell's law, we calculate the value of z_1 so that the ray incident on O-P_1 is directed to the focal point. Next point P_2 = (20μm, z_2) is calculated using the segment P_1-P_2 as above, and so on until the z value reaches the groove's depth; then next point z value is returned to zero. The following points are calculated as before to the outer edge of the lens.

Designing the grooves for the new profile can be done in exacly the same way as before, but in calculating the vertical step we change the focal point cohordinates to the next focus or to the same focus by using a mirror, as shown in *Figure 9.* above. The angles between the grooves can be easily calculated, as shown for example, in *Figure 10.* below.

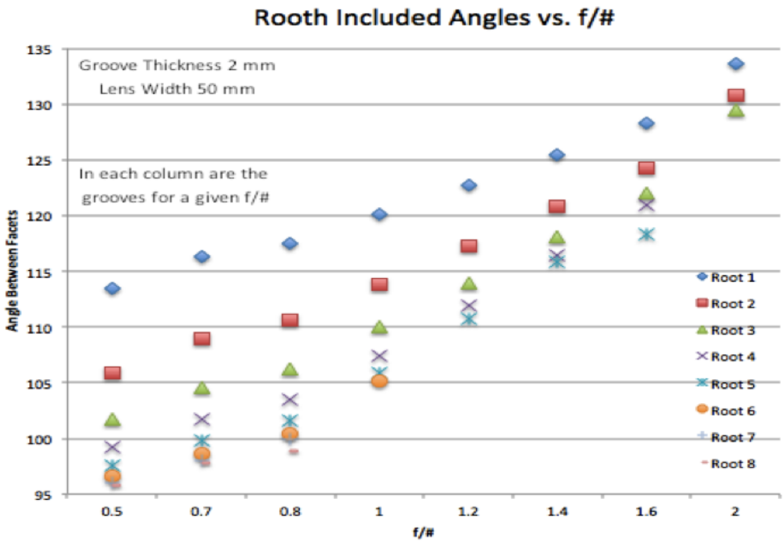

Figure 10. *Rooth Included Angles vs. f/#*

The above is a very simplistic view of the design process. In reality the incoming solar rays are distributed within a 0.5° angle, the focal region may not be a thin line, the ray bundle hits the lens at an angle that changes depending on the time of the day, of the year, and the latitude. Depending on the application, commercial ray tracing programs like Zemax®, etc. allow for the optimization of the lens according to whatever criteria are established.

3.2 The Glass

The new groove design allows for an improved Fresnel lens in many ways. Since the angles between facets of the grooves are large, glass can penetrate in the grooves, and a glass lens may be manufactured. A cylindrical lens (a lens with grooves along straight lines) can be manufactured by extruding and rolling the glass sheet in a commercial plant for textured glass at a cost of $10/m^2. Half lenses with center to edge sizes of 8 feet or more are easily manufactured, with a life of more than 30 year, as attested by lighthouse lenses.

A first question present itself: Such large lens will have a large number of grooves. The glass has a large surface tension. Will the grooves have rounded tips and roots? We can calculate the amount of light lost due to a given radius of such tips and roots. In *Figure 11.* is presented a calculation of the light lost as function of the radius of the tips and roots due to the glass' surface tension rounding.

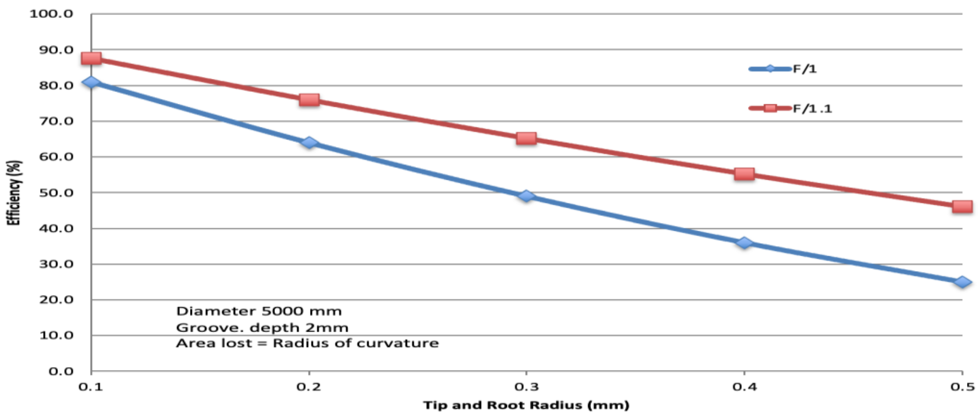

Figure 11. *Efficiency as function of tip and root radius.*

Problems may also arise during the molding process. After molding, will the grooves have the proper profile? The glass while cooling undergoes a phase transition that results in stresses and shrinkage that generates surface blemishes (for example depending on the thickness at that point). In the past this was a real obstacle. Today there are finite elements commercial programs that model the glass extrusion and calendaring, so we can model what happens during the glass cooling and profile deformation, and change the groove's profile to compensate for it, but it is still difficult to model the phase transition. Guided by the simulation a test lens can be made and correct the design by measuring the amount of light collected.

We plan to make a 300 mm half lens on a smaller glass extruder, and measure it. This because the plants that produce the textured glass cost hundreds of millions of dollars, and the tooling and the two days minimum run for a 4'x8' pane cost more than $200K. There are only a handful of them located all over the world, operated by multinational corporations. Only on that scale we can achieve the $10/m^2 glass pane cost that is our target (we have quotes that assure us that we can achieve such costs.)

An iterative approach will be used in producing such a lens. After a groove design that satisfies the geometry and the overall collection aims is obtained, such geometry and the extruder parameters are used to generate a simulation that characterizes the profile of the grooves after cooling. Such a profile may be passed to a commercial ray tracing program that will verify that the desired optical target is obtained. If not, the initial groove profile can be modified to take account of the deformations, and the design process is repeated until a satisfactory groove profile is obtained. Then the profile is used to make the mold for the small lens. Once the actual lens in glass is obtained, the grooves' profiles and the collected light can be measured, and compared with the desired ones. The process may be repeated until satisfactory results are obtained. Finally, on the basis of the knowledge acquired, a design for the large lens may be realized, and produced in an actual run. If again the results are not satisfactory, a new redesign would be needed and tested, and the whole process repeated until the desired specifications are obtained. Only one run of the large lens would be needed.

We are in the process of making the 600 mm diameter sample lens. We will list the measured energy at the focal point in the Data section (lentesolare.com/data) as soon as possible.

3.3 The Basic Unit

The preferred geometry will consist of a 4'x8'x1/4" glass pane with the profile of half of an f/1 GI cylindrical lens on one side with the grooves parallel to the 4' side, and the flat side towards the sun for ease of cleaning. The dimensions have been chosen to ease the logistic of transportation and handling. A full cylindrical lens can be obtained by joining two panes along the 4' side, where the grooves are wider (lens center). A basic unit 16'x16' (4.877x4.877 m) square will consist of four of the two panes set, side by side, as shown in *Figure 12.* below.

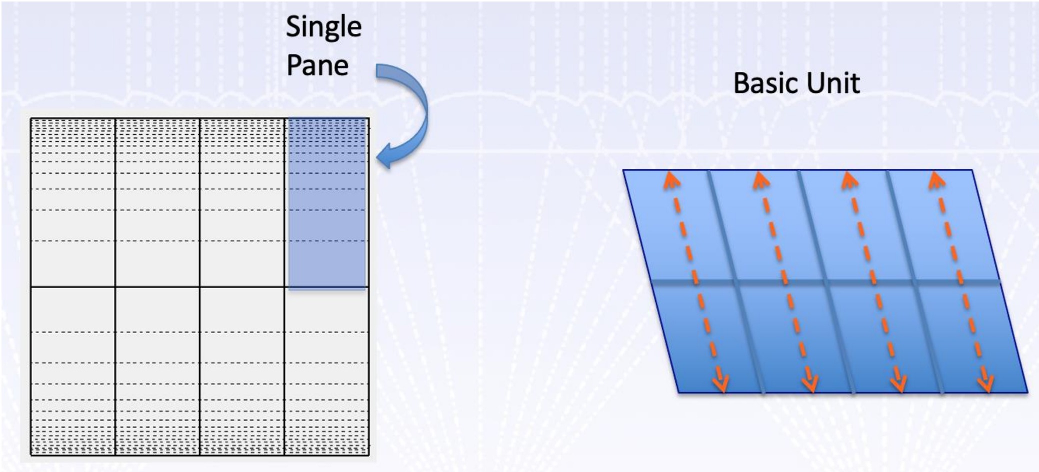

Figure 12. *Basic Unit 16'x16' (about 5m x 5m).*

The basic unit will have a surface area of 23.783 m^2, and will receive about 16.65 KW (at an insolation of 700W/m^2). We hope to collect on the receiver a minimum of 10KW per unit. The cost of the collector optics for one unit will be approximately $250 (= 25$m^2$ x 10$/$m^2$), (plus the ancillary cost of the frame, receiver, tracking and TES). Multiple units may be joined to each other side by side if more power is needed, benefitting from consolidation of the receiver, tracking etc. since one setup works for all.

We would like to place the flat side of the cylindrical lens towards the sun, and perpendicular to its rays at the middle of the day and the season. The apparent motion of the sun during the day causes the image to shift in the focal plane during its motion from East to West. Since a cylindrical lens focuses the sun's image as a line, during the day the line shifts on itself, and North-South depending on the sun altitude, so the tracking is needed only in the North-Sud direction during the day and the the year. See *Figure 13.* below. The position of the focal line in function of the sun altitude has not been simulated for this particular application, but is well known from the Grooves In lens characteristics.

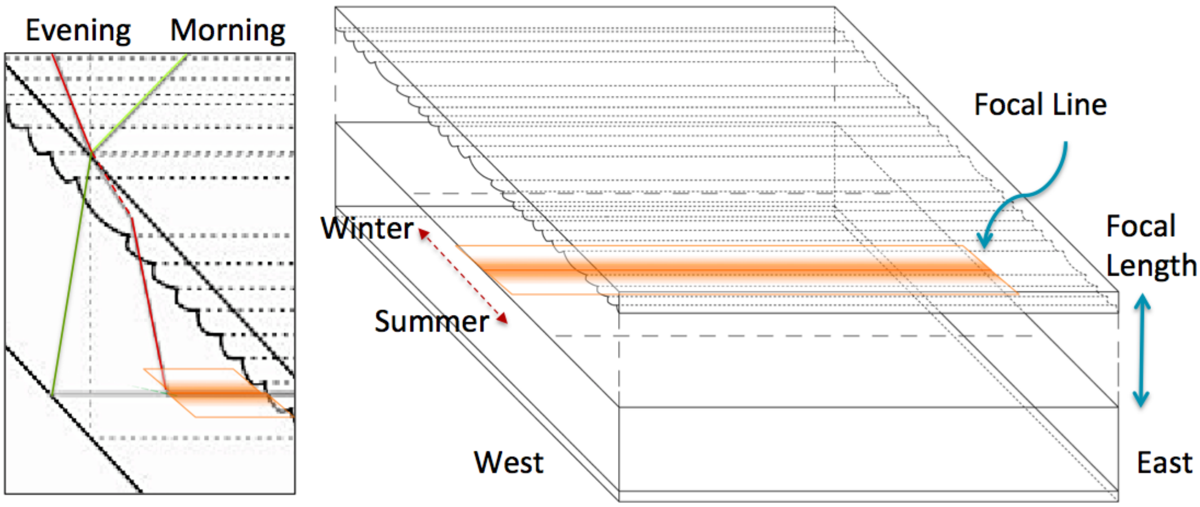

Figure 13. *Sun image motion during the day (left), and during the year (right).*

The receiver tracking can be easily accomplished using microprocessors and stepping motors. The simple motion also presents little mechanical problems even at high temperatures. The receiver may be extended to multiple units without extra hardware. The receiver is the same as the one developed for the cylindrical throughs in the last three decades. There is an extensive literature about the design of such receivers, and the fluids (HTFs) used to transport the heath. For the low temperatures required in the single-family, commercial, and light industrial market applications, water or steam are recommended for safety and environmental considerations.

Higher temperature can be reached by the use of two layers of cylindrical lenses with crossed groves. This results in a small focal area similar to a point focus, allowing for higher receiver temperature. High temperature fluids and still simple 2D tracking will be required.

To ensure operation around the clock, a thermal energy storage facility (TES) will be needed. This is the subject of an ongoing research, with many solutions available, depending on the details of the application. If a longer time range is desired, either a larger storage may be needed, or crossed Fresnel lenses can be used to reach higher temperatures. High temperature storage is already commercialized by Polar Night Energy [10], and can be extended through seasons (store in the summer for the winter).

Data availability statement

Data are available at lentesolare.com/data

Underlying and related material

At the present time there are no other material available. Further information, when available, will be in the website: www.lentesolare.com

Author contribution

The authors contributed equally to the paper.

Competing interests

The authors declare that they have no competing interests.

Funding

LenteSolare LLC

References:

[1] Matt Ribel, “Star, Destroyer,” Wired, issue 38.07/38.08, pp80—89, July-August, 2022
[2] *Chisholm, Hugh, ed. (1911), "Lighthouse" , Encyclopædia Britannica, vol. 16 (11th ed.), Cambridge University Press, pp. 627–651*
[3] Fresnel Technologies Inc., Fort Worth, Texas, 76110, www.fresneltech.com
[4] Stewart Filmscreen, 3919 Bach Buxton Rd., Amelia, OH 45102 U.S.A. caries 9’x16’ PMMA screens. www.stewartfilmscreen.com
[5] R.M. Cosby, “Solar Concentration by Curved-Base Fresnel Lenses”, NASA Report CR-2890, August 1977
[6] Welford & Winston, “High Collection Non-Imaging Optics”, Academic Press
[7] See Review in: “Solar Energy”, Volume 234, March 1st 2022, Pages 251-261
[8] Jensen et Al, “Thermal Performance Assessment of the World’s first Solar Thermal Fresnel Lens Collector Field”, Solar energy Volume 237, 1May 2022, Pages 447-455
[9] Luigi S. Fornari, Margaret Ree Fraelich, “Fresnel Lens Array with Novel Lens Element Profile”, United States Patent No: US9,097,841, August 4,2015

[10] Polar Night Energy, https://polarnightenergy.fi