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Linear Fresnel Solar Collectors for Heat Generation: An Overview of Existing Prototypes

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A B S T R A C T

A linear Fresnel collector (LFC) is categorized as a line focus collector, which is geometrically simple and converts beam radiation into heat energy. In this article, the introduction of concentrating solar power technology is first explained, covering the aspects of LFC technology and its historical development. The LFC operative projects globally are presented to show that the LFC technologies are technically and commercially proven to generate heat energy. The existing LFC prototypes are then illustrated using actual images and important results. Most prototypes obtained collector efficiencies ranging from 12% to 82%, and operating temperature difference spans from 5°C to 90°C. A broad range of improvements, including mirror arrangements, design of reflectors, absorber tube designs, cavity receivers, vacuum tubes, selective coatings, and secondary concentrators is reported. Along with detailed geometrical specifications, advancements are enlightened to demonstrate the progress and present state of LFC. This study provides a complete overview of the LFC prototypes and their progress, which offers practical support to future researchers.

1. Introduction

The utilization of fossil fuels to produce power is currently laden with problems, such as growing costs and the threat of a scarcity [1][2]. Moreover, using fossil fuels is the main cause of rising carbon dioxide concentrations, which change the natural equilibrium of the ecosystem by releasing chemicals or hazardous components into the atmosphere [3][4][5][6][7][8][9]. These factors make it necessary to employ green technology that generates green energy and protects fossil fuel

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reserves by utilizing sustainable fuels like solar energy [10][11].

Harnessing the endless potential of the sun, solar thermal technology offers a sustainable way to meet the growing demand for heat energy in the present and future [12]. In addition, they are the most economical renewable energy sources and can compete with fossil fuel power plants since they can store solar radiation during the day and use it again at night [13]. The four main classifications of concentrating technologies are, as seen in Figure 1, parabolic trough concentrator (PTC), linear Fresnel concentrator (LFC), solar power tower (SPT), and dish type collectors [14][15][16][17]. Line focus technologies such as PTC and LFC are categorized according to how radiation is directed towards a line focused receiver, whereas SPT and dish reflectors are referred to as point focus collectors since they reflect sunlight towards a point focused receiver [18][19][20].

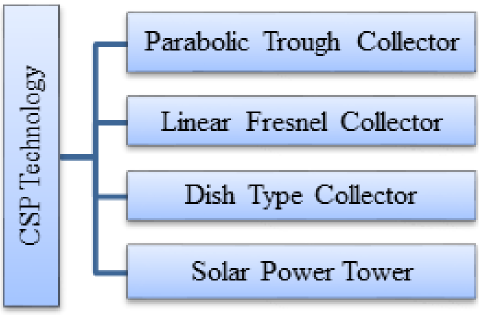

Figure 1. Classification of CSP Technology

1.1. Linear Fresnel concentrators

A Linear Fresnel concentrator is typically comprised of elevated inverted linear fixed receivers and flat reflectors [21][22][23][24][25][26][27][28][29][30]. The collector is composed of ground-mounted mirrors that revolve in conjunction with the sun's position to reflect and concentrate solar radiation directly over linear receivers, which are comprised of a long absorber tube coated selectively [21]. One of the benefits of utilizing a fixed receiver is that it eliminates the need for the flexible connections for the network of pipes, unlike receivers used in PTCs, which are thought to be the most difficult to maintain properly [25]. The ability of the fixed receiver to easily handle various types of heat transfer fluids (HTFs) like thermal oil, water, or molten salt increases the selection flexibility of HTFs [26]. Water can be used as the HTF because concentrated heat can convert it into dry steam at 250°C without the need for a heat exchanger in the receiver tube at 50 times atmospheric pressure. Because of this benefit, water is more frequently used in linear Fresnel technology than other fluids. The schematic of LFC technology is depicted in Figure 2.

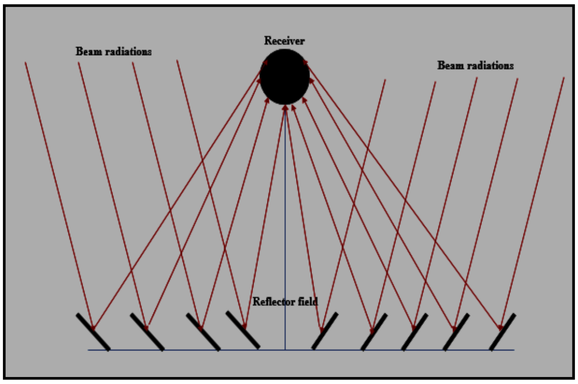

Figure 2. Schematic of a LFC

Its non-moving joints, stationary receiver, and flat reflectors make it comparable to parabolic trough technology in that it employs a line focus approach with cheaper capital expenditures [24]. Its lower optical efficiency, however, is caused by three things: (1) greater cosine losses due to neighbouring reflectors that shade solar radiation entering at lower sun positions and block reflected radiation; (2) the inability of reflectors on a horizontal plane to reach a model parabola; and (3) sheltering by the stationary receiver [25]. On the other hand, by developing the Compact LFC, an efficient collector that provides the capability for denser array packing [31], it deals with the prospect of capital savings and decreased area utilization [25]. Table 1 shows an overview of the characteristics of LFC.

The performance of a LFC system is greatly affected by various factors such as the optical efficiency of the mirrors, receiver design, the heat transfer in the receiver, and the performance of the HTF. The impact of advanced reflective materials on optical performance was studied by Yuan et al. [32]. It is found that optical efficiency using low-iron glass and silver-coated mirrors improved, especially in regions with high solar radiation. López Smeetz et al. [33] tilted small longitudes for rooftop-scale LFCs. Thermal performance was increased with a tilt of only a few degrees. The outcome proved that minor mechanical modifications can be helpful in situations with less-than-ideal solar geometry. Shojaei et al. [34] combined a field slope and a side mirror in short-length LFC installations that yielded thermal gain up to 6%. This research is best suited for uneven site layouts or space constraints. Wu et al. [35] compared three secondary-reflector geometries and found that a compound-parabolic secondary pushed the flux-uniformity index to 0.81, beating trapezoidal and segmented-parabolic options—especially at high incidence angles. Hasan et al. [36] added transverse ribs inside the absorber. Nusselt number gains of 115–175% were demonstrated in simulations, which doubled the heat transfer rate. John & Oyekale [37] replaced water-oil with an Al_2O_3–water nanofluid as HTF. Their 3-D model predicted wall-temperature drops and higher convective heat transfer without violating laminar turbulent limits. Grena et al. [38] studied a compressed air based optical-thermal model. Their model was evaluated against existing literature, demonstrated thermal efficiencies exceeding 0.90 at output temperatures of approximately 550°C. One noteworthy finding was that, in certain circumstances, the temperature differential inside the glass receiver for the LFC approached 100°C. Famiglietti & Lecuona [39] conducted a techno-economic analysis on LFC-powered solar air heater that delivers hot air (up to about 350°C) directly for industrial processes. They proposed that the LFC-driven air heating can be cost-competitive with natural gas. Thomas et al. [40] examined the LFCs for low-to-medium temperature rural polygeneration applications (heat, electricity, and desalination). Attention was drawn to the modularity and potential of LFCs in conjunction with thermal storage or inferior heat users.

Table 1. Characteristics of LFC [21] [22] [23] [24] [25] [26] [27] [28] [30] [31] [41] [42] [43] [44]

Aspects	Description
Principle of operation	Flat reflectors direct solar radiation on elevated fixed receiver
Type of focus	Line focus
Tracking system	Single axis
Application	Power plants, solar drying, cooling and process heat low temperature industrial requirements.
First demonstration	Lacédémone-Marseilles solar station, 1959
First commercial plant	14 MW_e LFC plant beside Stanwell power station, 2000
Peak solar conversion efficiency	18 % - 22%
Land required, m^2/MWh	4 - 6
Per unit cost for producing 100 MW_e	0.230 euro with buffer
Operating temperature	250°C–300°C (HTF: water)
Total capacity of operating plants	59.65 MW_e
Operating plants nations	Spain, France, Australia, U.S.

1.2. Historical development

The linear Fresnel reflector was first invented by Baum et al. in 1957. Giorgio Francia, an Italian mathematician, utilized this technology in 1961 by designing both single and two-axis tracking reflectors [45] [46] 47]. Subsequently, in the Lacédémone–Marseilles solar station, Francia designed and constructed the first LFC prototype after two years [46]. Following that, Francia tested the LFC prototype in 1964, producing 38 kg of steam per hour at 450°C and 100 atmospheric pressure [31] [48].

The American company FMC, which was founded in 1979 amid the oil crisis, developed linear Fresnel systems in the late 1970s with the goal of creating large-sized LFC power plants with a 10 MW_e and 100 MW_e output. A lack of money led to the project's abandonment after the initial parts of these plants were tested. Supporters of the technology asserted that the systems' effectiveness cost could have been lesser than that of the tower systems that were being developed concurrently at the time [31]. Israeli Paz Company erected an LFC at the Ben Gurion test center in 1991, as reported in [42]. The test's findings revealed extremely poor optical efficiency as a result of design flaws like blocking and shading.

An advanced LFC prototype known as the compact linear Fresnel collector (CLFC) was created in 1993 at the University of Sydney [37] [38]. As mentioned in [31] [49], it consists of two receiver towers to gather solar radiation reflected from interleaving mirrors. Considering that large-scale plants will have multiple fixed linear receivers, if the mirrors within the fixed collector are close enough, the beam radiation can be reflected to at least two absorbers. This results in considerably more compact packed arrays, which reduce blocking and shading effects and increase the optical efficiency [31].

As part of the Australian greenhouse renewable energy showcase program, Austa Energy, Stanwell Corporation, Solahart International, and Solsearch Pty. Ltd. jointly decided in 1999 to construct the first

CLFC plant at Stanwell Power Station in Queensland, Australia. This decision was made in response to increasing interest in reducing the reliance on coal for electricity generation. However, Austa's activities were abruptly cancelled, which cost them the development experience they needed to build the plant [49]. Stanwell Corporation partnered with the Universities of Sydney and New South Wales to develop a 14 MWe solar thermal power plant, which was integrated with a 1440 MWe coal-fired power plant to promote the advanced LFC technology [31].

In 2001, the Belgian business Solarmundo constructed a 2500 m² LFC prototype in Belgium [49] [50] [51]. While the overall concept of this LFC was not new, the business gained attention with their proposed LFC, which is supposed to be more economical than current solar thermal technology. According to [52] [53] [54], Solarmundo merged with the German Solar Power Group in 2004. Together, they built the massive Fresdemo pilot LFC system in Spain, which underwent testing until 2008. Numerous LFC plants have been erected since 2005 for industrial heat applications in a number of the United States regions [55].

Presently, a basic design has been advanced using an enhanced cavity receiver [41]. Linear Fresnel technology is advancing slowly in terms of optical performance, price of produced units, and land utilization, despite being theoretically steady and extremely efficient. It is now in the investigational stage, but if its optical efficiency is raised, parabolic trough technology may have direct competition. Across the globe, LFC technology has been utilized for the purpose of operating or constructing solar projects. However, the majority of these projects are either prototypes or demonstrations, with a small power output, designed to prove the technical and commercial viability of the technology. Additionally, these projects have the potential to be combined with energy storage systems or conventional fossil fuel sources. The operational projects of LFC worldwide are detailed in Table 2.

This study aims to present an in-depth review of the LFC prototypes by the following:

- Understand the features of LFC technology in addition to its historical evolution.
- Recognize the importance and worldwide reach of LFC technology to gain an understanding of its potential.
- Comprehensive descriptions of current LFC prototypes accompanied by actual pictures.
- Recent advancements and critical views of LFC projects.

The paper is described through the following primary sections: (1) technology introduction and (2) historical evolution. The remaining portion of the paper is organized in the following manner: Section 2 overviews the LFC prototypes with various developments and critical discussions, while Section 3 ends with a conclusion followed by future trends.

Table 2. LFC operative projects [31] [56] [57] [58] [59] [60] [61]

Name of Projects	Location	Capacity	Field area	Remarks
LFC plant next to Stanwell power station	Australia	14 MW	-	Solar-coal hybrid power plant
Puerto Errado- 1	Spain	14 MW	2100 m^2/kWh	With single-tank thermocline
Kimberlina	Bakersfield, CA, U.S.	5 MW	25,988 m²	The first Compact LFR plant of North America
Augustin Fresnel-1	Targassonne, Pyreneans, France	0.25 MW	1800 m^2/kWh	-
Liddell	New South Wales, Liddell, Australia	9 MW	18,490 m²	Solar-coal hybrid power plant
Puerto Errado-II Thermo solar	Murcia, Calasparra, Spain	30 MW	2095 m^2/kWh	Single-tank thermocline

2. Review of LFC Prototypes

Giovanni Francia was the first to apply the Fresnel reflector technology in actual line and point focus devices [46]. As seen in Figure 3, Giovanni Francia patented his concept for the first practical use in 1962 [62] . In Marseille, France, this design was put to the test for performance investigation. It had seven aluminium mirrors arranged in an east-west line, each measuring 8 m in length and 1 m in width. Every mirror revolved along its longitudinal axis, focusing solar energy onto a boiler situated corresponding to the mirrors at around six meters in height. The boiler measured 25 cm in width and just about 8 m in length. The plant produced steam at 450°C and 100 bar pressure with a capacity of 38 kg /hr [62].

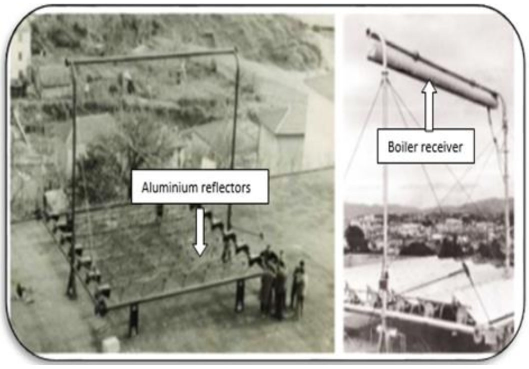

Figure 3. Francia LFC prototype [62]

A tubular absorber LFC with absorptive coatings was designed by Negi et al. [63] in 1989. The prototype consisted of long, thin, flat mirror components, each measuring 0.90 m in length and 0.025 m in width. These elements were attached to a sawtooth-shaped cross-section that was manufactured on a hardwood frame in accordance with the design specifications (Figure 4). A flat metal structure held the timber frame in place. The concentrator's aperture diameter was 1.0 m, and its length was 1.80 m. The components of the mirrors directed solar energy onto a tubular absorber positioned 0.40 meters from the concentrator's aperture throughout its length. Three copper tube absorbers of equal dimensions were designed and produced for the investigation. The first absorber was painted using standard black paint. Selective cobalt oxide coating was applied to the second absorber, and selective MAXORB foil-a thin, black-surfaced nickel foil was applied to the third.

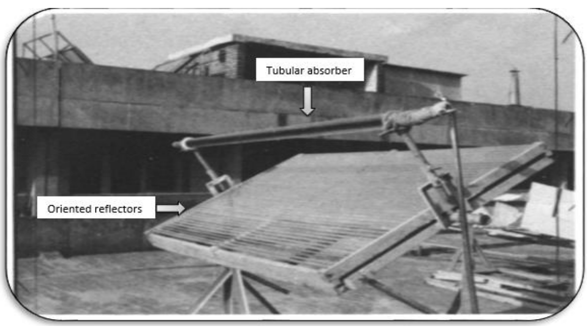

Figure 4. Tubular absorber LFC [63]

Every absorber was covered by a concentric glass cover with an outside diameter of 0.056 m. To support the glass tube and keep it apart from the absorber tube, ebonite spacers were employed. A revolving framework that could revolve around the concentrator's axis supported each concentrator-receiver system. The entire setup was fastened to an additional framework that allowed for daily adjustments for variations in the sun's declination.

The range of optical efficiency was 36% to 57%. Selective MAXORB foil—a thin, black-surfaced nickel foil—provided the best optical efficiency. On the other hand, when selectively coated absorbers were used instead of absorbers coated with regular black paint, the concentrator-receiver system's optical efficiency was significantly increased. The optical efficiency value attained with a regular black painted absorber was extremely low [63].

A Solar heat and power company developed a novel commercial prototype for a coal-fired steam power station using CLFC technology [64]. The CLFC was intended for large-scale commercial applications and used a multi-line tower as a component of a single collector. The main linear Fresnel technology used by Ausra, which changed its name to Areva Solar in 2010, was CLFC (see Figure 5).

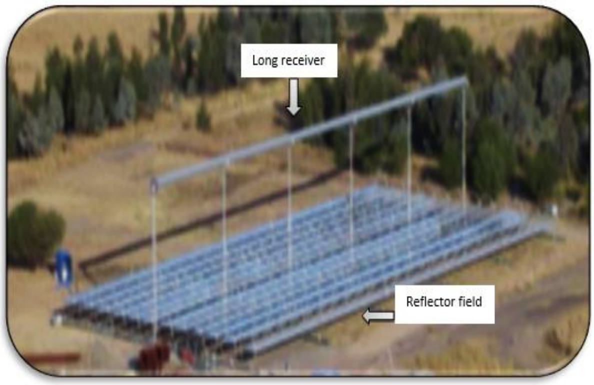

Figure 5. CLFC prototype by Solar Heat and Power Pty. Ltd [64]

This tracking axis field was north-south in the CLFC. It was made up of 135,000 m^2 of reflector and twenty absorber lines, each 300 m long. With twelve rows of reflectors positioned between the absorber lines, receiver towers were 31 m apart and 9.8 m high at the absorber plane. Each reflector module had five 1.83 x 2.44 m mirror panels and is 12.2 m long. The reflectors were carefully bent elastically to achieve a precise focus [64].

A prototype Fresnel collector was developed and set up in Belgium by a company called Solarmundo (see Figure 6(a)). Direct steam generation in horizontal tubes had been examined in this collector [65]. The Fresdemo prototype, a solar field using LFC technology, was installed at the Plataforma Solar de Almerfa [66]. The receiver, which was 50 cm wide, was located 8 m above the central mirror. The solar field consisted of 25 mirrors, each with a width of 60 cm. These mirrors were spaced 85 cm apart at their centerlines, as shown in Figure 6(b). The study utilized a one-tube receiver equipped with a secondary reflector. However, for the purpose of focusing on the optical process, the receiver was shown as flat and horizontal. Figure 7(a) illustrates the Freiburg LFC system prototype, which was installed in Bergamo, Italy, in August 2006. A 132 m² unit was intended to supply an NH_3/H_2O absorption chiller [67].

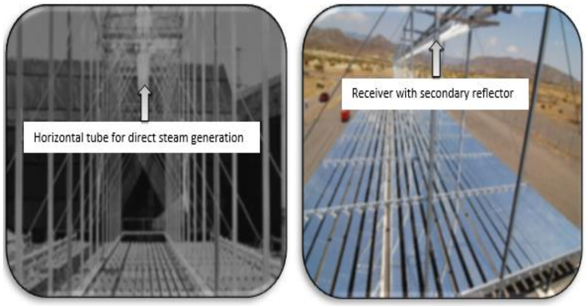

Figure 6. (a) LFC by Solarmundo, Belgium [65] (b) FRESDEMO LFC at Plataforma Solar de Almeria [66]

A massive LFC experimental setup was built above the engineering college of Seville, Spain. This configuration used steam with 174 kW of thermal energy to power an absorption chiller [68] [69]. The experiment's outcomes had been applied to potential future project improvements. The configuration is shown in Figure 7(b).

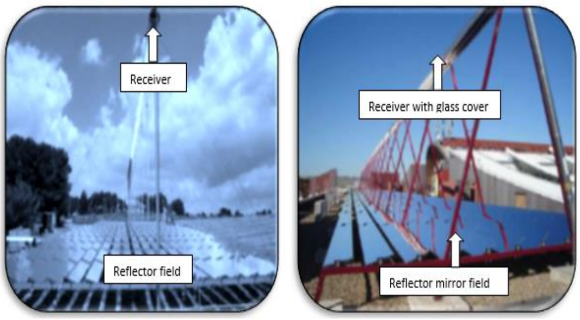

Figure 7. (a) LFC prototype in Sicily [67] (b) LFC for building cooling in Seville, Spain [68] [69]

Currently leading developers of high-temperature LFC are Areva Solar and Novatec [70][71]. For direct steam generation, both LFC designs were utilized. High-temperature steam was produced by a direct steam generation system and was directly sent to the turbine to generate energy. According to Figure 8 [71], Areva Solar (formerly known as Ausra) utilized their CLFC technology to construct the Kimberlina power station in California. Direct steam generation was also applied in the Kimberlina power station, which had produced steam at temperatures as high as 482°C [72]. Globally, Areva Solar had begun to establish large-scale plant construction projects [71].

Figure 8. Areva Solar's compact LFC, Kimberlina power station, California [71]

According to previous reports [70] [73], the solar field was able to achieve an output steam temperature ranging from 480°C to 520°C. Figure 9 displays the PE1 and PE2 LFC fields produced by Novatec Solar [74] [75]. Steam had been generated at temperatures reaching up to 520°C by the utilization of the latest SuperNova collector loop design. This design incorporated vacuum receiver tubes equipped with a secondary reflector.

SkyFuel had worked to create base-load storage-compatible, high-temperature molten salt LFCs utilizing its ReflecTech reflective film technology [72]. With funding from the DOE, SkyFuel began developing a linear Fresnel and advanced it to the prototype stage of collector engineering design. However, SkyFuel halted this work to concentrate on more immediate technological advancements. Molten salt was the proposed working fluid for the solar field and storage system, and above 500°C was the desired temperature for SkyFuel's LFC designs [72].

An LFC prototype was installed on an organization's rooftop in New Delhi, India (see Figure 10). This design can create steam at rates of 2.4 kg/hr and 6.3 kg/hr at 1.5 bar, respectively, with a total reflector field area of 5 m^2 and 13 m^2. Setup included a four-bar link mechanism tracking system that follows the sun all day long [76].

Figure 9. Novatec's PE1 and PE2 power stations [74] [75]

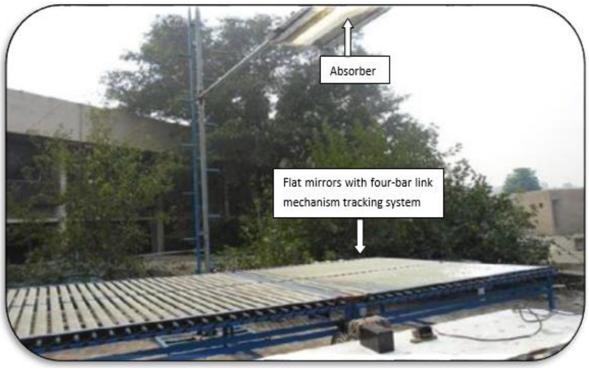

Figure 10. Setup installed in New Delhi, India [76]

Saad Dahlab University in Blinda, Algeria, had a small prototype, as depicted in Figure 11. In 2015, it was experimented for the evaluation of thermal performance with tap water serving as the working fluid. The outcomes indicated that the highest exit water temperature was 74°C and thermal efficiency was around 29% [77].

Figure 11. LFC Prototype at Blinda, Algeria [77]

An experimental setup was installed in Isparta, Turkey, for the thermal testing (see Figure 12). Water was used as the working fluid for the experiment, which was conducted in August, 2012. During the noon time, a peak efficiency of 34.1% was observed when water flow was allowed to reach 0.025 kg/sec [78]. The data centre of a telecommunications corporation had installed an operational industrial setup, as depicted in Figure 13 [79]. It was used to serve the requirement of cooling capacity of a chiller. The chiller was lithium bromide-water absorption based with a peak cooling capacity of 330 kW. When the return temperature was 165°C, it could handle water heating up to 180°C under 12 bar of pressure. It was possible to adjust the water flow rate and focus or defocus mirrors in accordance with the situation [79].

Figure 12. LFC Prototype at Isparta, Turkey [78]

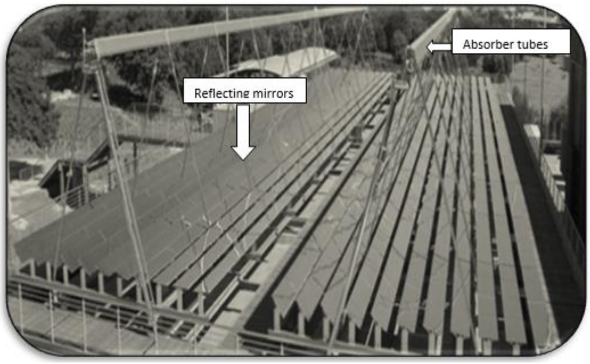

Figure 13. The roof-top installation in South Africa [79]

An experimental setup located in a mining site near Ayudin, Turkey, is seen in Figure 14. It was intended to lower LNG use during the ore drying process [80]. With a capacity of 1 MWth, the plant can generate 1.4 GWh of thermal energy annually. This system had the capacity to produce hot water up to 200°C [80].

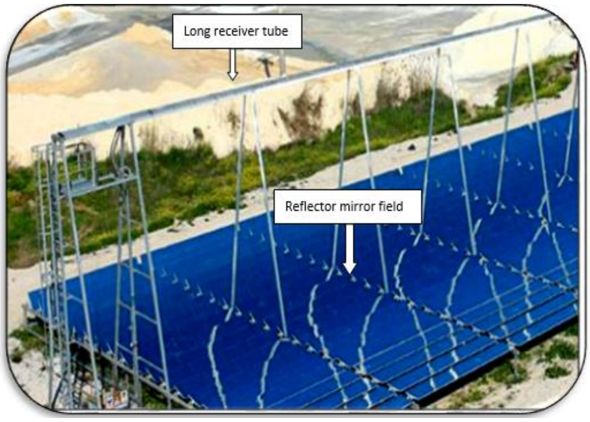

Figure 14. LFC at mining site of Turkey [80]

A linear Fresnel concentrator with variable width reflectors was designed and tested [81]. Figure 15 shows the experimental setup installed in Thanjavur, Tamil Nadu, India. There were 58 reflectors total, ranging in width from 0.03 m to 0.06 m. Each side of the absorber had 29 reflectors. Testing took place during the hottest months, March to June. The output temperature peaked in the middle of the day, with a 9°C temperature differential in the working fluid. The system achieved a peak thermal efficiency of 41.2% [81].

Figure 15. Experimental setup with varying width reflector [81]

Evangelos et al. [82] designed a LFC with a flat plate receiver (see Figure 16). Experimental and numerical analysis were conducted on the developed prototype. The testing findings demonstrated that this collector can run at a high efficiency for more than eight hours in the summer, producing roughly 8.5 kW during noon time. The collector performed worse throughout the other seasons, putting out 5.3 kW in the spring and 2.9 kW in the winter. The working fluid in the tests was water, and temperatures as low as 100°C were achieved. Additionally, this collector can operate at 250°C and produce satisfactory results when using thermal oil [81].

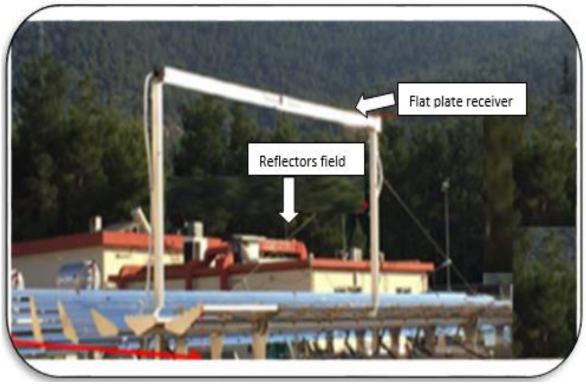

Figure 16. Experimental setup with flat absorber [82]

As shown in Figure 17, the Federal University had created a LFC for direct steam generation [83]. A multi-tubular trapezoidal cavity absorber was a novel component of the LFC. Six segmented tubes made of stainless steel, each with an outer diameter of 25.40 mm and an entire width of 152.40 mm, make up the absorber element. Every segmented tube was passed through once by the working fluid. Flexible hoses of stainless steel were used to link the tubes for accounting their thermal expansion. The optical peak efficiency varied from 52% to 47%. It was observed that the performance as a whole was significantly impacted by mirror cleaning. The fluid temperature range was up to 130°C [83].

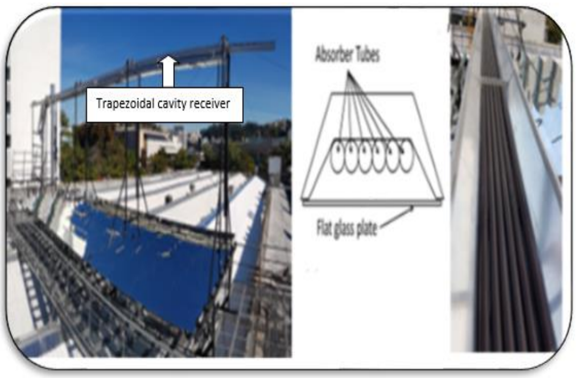

Figure 17. Multi-tubular trapezoidal cavity receiver LFC [83]

Lin et al. [84] tested a LFC with an enhanced V-shaped cavity receiver, as depicted in Figure 18. The experimental findings showed that the overall heat loss coefficient for the tested surface ranged from 6.25 W/m^2 K to 7.52 W/m^2 K. In addition, it was found that the system's ideal operating temperature was roughly 121°C and that it stagnated at about 260°C. The thermal efficiency declined from 45% to 37% as the average surface temperature improved from 90°C to 150°C [84].

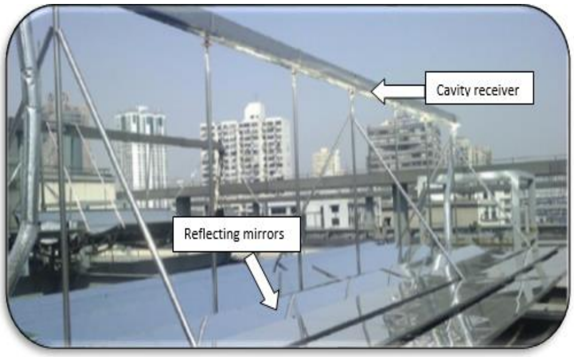

Figure 18. LFC with improved V-shaped cavity receiver [84]

A new type of elevation linear Fresnel reflector was researched by Nixon et al. [85]. In order to determine the heat loss, increase in working fluid temperature, thermal efficiency, and stagnation temperature, a number of tests were conducted at receiver temperatures ranging from 30°C to 100°C. Figure 19 displays a novel elevation LFC. It was discovered that there was less than a 5% discrepancy between the model projections and the measured fluid temperature gains. The observed values of the thermal efficiency and stagnation temperature differed by -39% to +31% and 22% to 38%, respectively, from the model predictions [85].

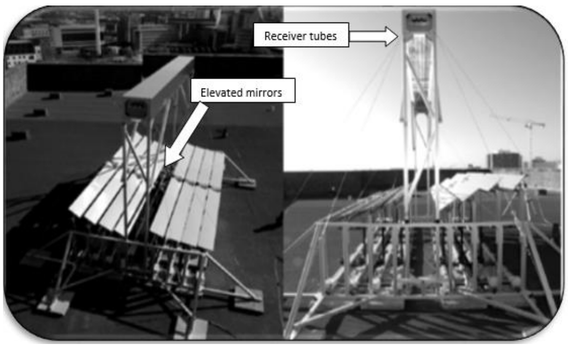

Figure 19. Novel elevation LFC [85]

Flat and parabolic reflectors were used in the study of the line focus solar collector by Kumar et al. [86]. Figure 20 shows a prototype LFC with mixed parabolic and flat reflectors. Only flat reflectors that lower tracking costs were given tracking. The prototype's thermal performance under various operating situations had been assessed. Around 55% of maximum thermal efficiency was attained, which was competitive with parabolic trough collector performance. The observed average temperature difference was 6.85°C, 1.14°C greater than that of the parabolic trough collector under examination [76].

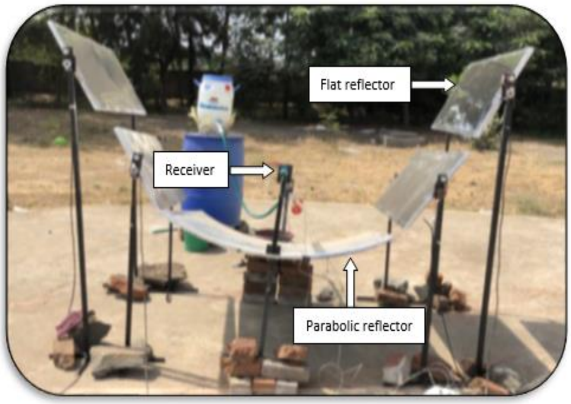

Figure 20. LFC with combined flat and parabolic reflectors [86]

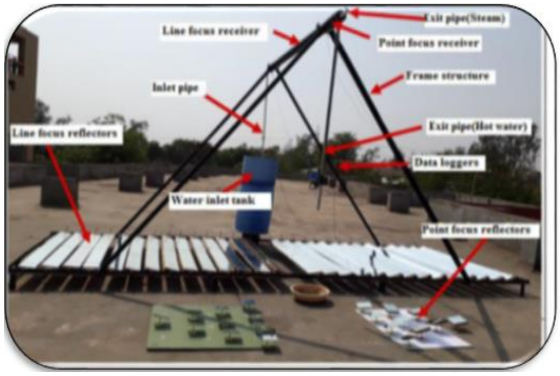

Figure 21. LFC based on combined focus technology [87]

The LFC and point focus collector were integrated to create a combined focus solar collector (see Figure 21) [87]. There is a series connection between the line and point focus receivers. The line focus receiver recorded a maximum exit temperature of 107°C during the experimentation period, while the point focus collector recorded a highest exit temperature of 121.6°C. The combined collector's maximum recorded temperature was 121.6°C. According to reports, the enhanced LFC's maximum power generation and efficiency were close to 1 kW and 20.82%, respectively [87]. Advancement and geometrical specifications including observations of reviewed prototypes are illustrated in Table 3.

Table 3. Highlights of reviewed prototypes

Details of Prototypes	Geometrical specifications	Receiver configuration	Collector orientation	Reflector types	Observations
Giovanni Francia LFC, Italy,1968 [46]	N =7, L= 8m, W = 1m, A = 64.78m^2, H = 6m, D = 0.25m	Aluminium reflectors	East-West	Flat mirrors	HTF: water m_f = 38kg/hr.
LFC at Centre of energy studies, IIT Delhi, India, 1989 [63]	L = 0.9 m, W = 0.025 m, H = 0.4 m, D = 0.038 m	Black painted Cu tube and elevated reflector field	North-South	Long narrow flat mirrors	ΔT = 11°C η = 36 % HTF: water m_f = 0.62 kg/sec
Hochdorf plant, Freiburg, Germany LFC, 2019 [88]	N =11, W = 0.5 m, A = 22 m^2, f = 4 m	Vaccum tube receiver, Secondary CPC reflector	-	-	Operating temp = 200°C η = 60% HTF: water
Seville, Spain LFC, 2011[68]	N =11, A = 352 m^2, H = 4 m, L= 64 m	Cavity receptor with secondary reflector and glass cover	East-West	Flat or slightly curved mirrors	Capacity: 174 kW HTF: water
LFC at IIT Delhi, India, 2013 [76]	N =100, L= 1 m, W = 0.05 m	Trapezoidal type receiver	North-South	Long narrow flat mirror strips	ΔT = 90°C HTF: water m_f = 0.0006 kg/sec
LFC at Shanghai Jiao Tong University, Shanghai, China , 2013 [84]	W= 0.3 m, D=12 mm, H=1.5 m	V-shaped cavity receiver	East-West	Slightly curved mirrors	CR = 6.2 η = 45 % HTF: synthetic oil
LFC at Isparta, Turkey, 2014 [78]	N= 10, L= 180 cm, W= 38 cm	Cu U-shaped tube receiver	-	Flat mirrors	ΔT = 23.1°C η = 34 % HTF: water m_f = 0.025 kg/sec
LFC, 2014 [89]	N = 80, L=1000 mm, W = 40 mm, D = 12.5 mm	Trapezoidal cavity absorber and elevated reflector fields	North-South	Flat mirrors	CR = 22.44 ΔT = 5°C η = 22 % HTF: water m_f = 0.025 kg/sec
Tele - communication Company, South Africa, 2016 [79]	No. of modules = 22 No. of rows per module = 11, A = 484 m^2	Evacuated tube receiver, compound parabolic secondary reflector	-	-	Operating temp = 180°C HTF: water
LFC at University of Blida, Algeria, 2016 [77]	N =11, W = 0.1 m, D = 0.02 m	Trapezoidal Cavity Cu black painted receiver	-	Reflective mirrors strips	CR = 3 ΔT = 62°C η = 26.07 % HTF: water m_f = 0.015 kg/sec

LFC at Aston University, Birmingham, UK, 2016 [85]	N = 8 H = 5m, W = 250 mm	Elevating linear Fresnel reflector	North-South	Flat mirrors	CR = 10 ɳ = 31 % HTF: water m_f = 0.41kg/sec
LFC at Seyne on sea, France., 2017[CNIM] [90]	H = 8.03m, N =14, D =7 cm	Receiver with secondary receiver	North-South	-	CR = 5 ΔT = 85°C ɳ = 35 % HTF: water
LFC at Athens-Greece, 2016 [82]	N = 36, W = 120 mm, H =3.5 m, Absorber width = 17 mm	Flat plate receiver	North-South	Flat plate mirrors	CR = 37 ΔT = 18°C ɳ = 24.6 % HTF: water m_f = 0.117 kg/sec
LFC prototype at Morocco, 2017 [91]	N = 11, L = 1 m, W = 0.4 m, H = 6m	Cylindrical tubes with secondary reflector	North- South	Flat mirrors	Power generation = 4 kW/m², ɳ = 82 %
LFC at Thanjavur, Tamilnadu, India, 2019 [81]	N = 58, Absorber width = 0.05 m, aperture diameter = 2 m	Trapezoidal cavity absorber	-	Varying width of reflectors	CR = 32.6 ΔT = 9°C ɳ = 41.2 % HTF: water m_f = 0.025 kg/sec
LFC at Barranquilla, Colombia, 2019 [92]	W = 0.12 m, N = 15, H = 2 m, D = 0.026 m	Trapezoidal Cavity Cu black painted	North-South	Flat mirrors	CR = 11.54 ΔT = 32°C ɳ = 30 % HTF: Thermic oil
LFC at Sahel, South Africa, 2020 [93]	-	Trapezoidal Cavity Cu selective coating	North-South	Flat mirrors	CR = 22 ɳ = 12.12 % HTF: Jatropha oil
LFC at Federal University of Santa Catarina, Brazil, 2021[83]	N = 10, W = 450 mm, H= 3.75 m, D = 25.4 mm	Stainless steel trapezoidal Cavity receiver	North-South	Parabolic shape mirrors	CR = 10 ΔT = 75°C HTF: Water
LFC at SRICT, Vataria, Ankleshwar, India, 2021[86]	N = 4, L = 1.2 m, W = 0.5 m, A = 0.96 m^2	Combined flat and parabolic reflector	East-West	Combination of flat and parabolic reflectors	CR = 8 ΔT = 6.85°C ɳ = 54.94 % HTF: Water m_f =0.033 kg/sec
LFC at SRICT, Vataria, Ankleshwar, India, 2023 [87]	N = 28, W = 0.15 m, H = 3 m, D = 10 mm	Combined focus technology	East-West	Flat mirrors	CR = 10 ΔT = 85°C ɳ = 21 % HTF: Water m_f =0.0004 kg/sec

2.1. Critical findings and Discussions

The review of current LFC prototypes provided substantial insights into their design evolution, performance criteria, and technological constraints. The findings of the study analysis are presented in Figure 22.

- LFC systems demonstrate a wide range of improvements, including mirror arrangements, types of reflectors, absorber tube designs (single versus multiple tubes), cavity receivers, vacuum tubes, selective coatings, and secondary concentrators (CPCs).
- Most prototypes achieved collector efficiencies ranging from 12% to 82%, depending on the operational temperature and working fluid utilized. Prototypes operating with pressurized water, thermal oils, and molten salts show that increasing the operating temperature improves the energy production. The simplicity and cost-effectiveness of flat mirror segments remain a fundamental advantage over alternate arrangements.
- LFCs are well-suited for medium-temperature applications (150–400°C), such as process heat in industries (food processing, textiles, chemicals) and preheating in power plants. Several pilot experiments confirm the feasibility of LFCs in hybrid solar-thermal systems or in cogeneration plants.
- Advanced prototypes incorporate automated single-axis tracking devices for improved sun tracking. However, maintaining precise tracking over time and limiting mechanical wear are constant difficulties.
- Receiver materials such as glass mirrors, stainless steel receivers, black painted Cu-tube and aluminium tube receivers, and selective coatings (e.g., black chrome, solar selective paint) are commonly used to receive the heat from the reflector field.
- The vital feature in favor of LFC technology is its low capital and maintenance cost compared to other CSP technologies. The combination of flat, commercially accessible mirrors and reduced mechanical tracking makes it ideal for decentralized and off-grid energy solutions.
- Environmental concerns, such as dust collection, wind loads, and thermal expansion, directly affect the operational reliability of LFC systems. Studies suggest that frequent cleaning schedules, proper row spacing, and protective enclosures for receiver tubes help prevent performance decreases. Local solar irradiance profiles and ambient conditions must be carefully studied during the design phase.

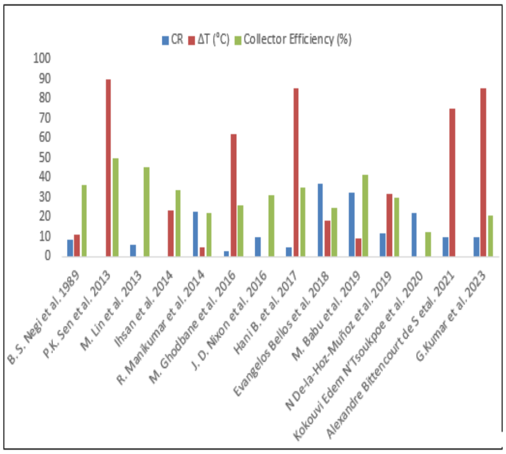

Figure 22. LFC Prototypes performance investigation

3. Conclusions

- Linear Fresnel collectors are basic line focus solar devices that produce heat at the expense of solar energy. LFC is advantageous to other CSP technologies in many ways.
  -The fixed receiver design of the LFC significantly reduces working fluid leaks and the related maintenance required.
  -Reduced wind load on the reflectors due to the low-profile geometric configuration of LFC lowers reflector assembly costs.
  -The concentration ratio gets easier to increase.
  -This technology is also the least land-intensive, which makes it the finest choice in situations where land is finite, like in urban areas.
- Linear Fresnel collectors are still in the research and development stage. It has the

lowest performance of any CSP technology available. It will put PTC technology in direct competition if and when its performance is improved.

- In this article, the characteristics of LFC are studied first, followed by the technology's historical development from its inception. The technology's potential is also demonstrated through worldwide operational projects. The majority of prototypes achieved operational temperature differences between 5°C and 90°C and collector efficiencies between 12% and 82%.
- Numerous efforts are made to raise LFC's performance. Tested prototypes with various novelties are thoroughly reviewed to oversee the efforts. Such a study also encourages researchers for future work in this field. A wide range of enhancements have been documented, including secondary concentrators, cavity receivers, vacuum tubes, reflector and absorber tube designs, mirror configurations, and selective coatings.

3.1. Future Trends

- The integration with thermal energy storage is required to study. However, integration systems are currently restricted and require further research to ensure continuous functioning.
- Materials and heat transfer fluid stability are in increasing demand as operating temperatures rise. Heat loss from the receiver is still a big concern, especially in hot weather.
- Durable, rigid, and affordable material is required for preventing heat stress, especially in harsh outdoor environments.
- It is always difficult to maintain accurate tracking of the system. Although they can increase initial costs, smart tracking systems that use real-time sun location algorithms and sensors can be utilized.
- Increasing the optical efficiency due to cosine loss, shading, and blocking effects continues to be a challenge.

Nomenclature

A	Aperture area (m^2)
CR	Concentration ratio
CSP	Concentrating solar power
CLFC	Compact linear Fresnel Collector
D	Diameter of receiver (m)
DSG	Direct steam generation
H	Height of receiver from ground (m)
HTF	Heat transfer fluids
L	Length of reflector (m)
LFC	Linear Fresnel concentrator
LNG	Liquefied natural gas
m_f	Mass flow rate of working fluid
N	Number of reflectors
PTC	Parabolic trough concentrator
SPT	Solar power tower
W	Width of reflector (m)
ΔT	Temperature difference of working fluid (°C)
Greek letters	
η	Collector efficiency (%)

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