5¢ / KWh Electricity from Concentrated Solar Power (CSP) – Finally a Reality

The Renewable Energy industry has been projecting lower cost per KWh of electricity from CSP for many decades. Although steady progress has been made in many areas, the current cost of CSP generated electricity is well above the projected levels. The current CSP designs, which have fundamentally been the same for last 20 years, seem to have reached a point of diminishing return. New and fundamentally different approaches are needed to continue the trend of lowering the cost of electricity from CSP. Stalix is currently engaged in the development of next generation of CSP technologies that will deliver a levelized cost of electricity (LCOE) below 5¢/KWh.

Background - Concentrating Solar Thermal (CST) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small receiver area. Heat Transfer Fluid (typically water or oil) passes through the receiver to obsorb the heat. The hot fluid is then transported to a heat engine to generate electricity.

Over the last few decades, various devices for collecting solar thermal radiation have been devised. Solar thermal power in the form of mechanical energy was first established near Cairo in 1914 for pumping water. It incorporated a water/steam operated parabolic trough array and a low pressure condensing steam engine. Solar electric trough development was activated by the U.S. Department of Energy in the mid 1970's. The first experimental system started operation in 1979. At the same time a private Research and Development company from Jerusalem, Israel, (LUZ) decided to design and implement commercial scale parabolic trough 'Solar Electric Generating Systems' (SEGS). This decision was strongly influenced by favorable power purchase agreements and tax credits offered in California.

Nine SEGS plants were built by LUZ between 1984 and 1989. These plants have a combined capacity of 354MWe. They are still operating on a commercial basis and together they represent by far the majority of operating solar thermal power station capacity in the world. During the early 1980s only small demonstration trough based solar thermal power systems were constructed in the USA, Japan, Spain and Australia. However, the recent rise in fossil fuel cost and concerns over global warming have increased interest in CSP. In the US, 14 States passed laws mandating a certain percentage of electricity be derived from renewable sources. Many utility companies view CSP as the best option for meeting this mandate. New CSP plants are now being built in Arizona, Nevada and California. The US Department of Energy estimates that by 2020 there may be as much as 20 Giga-Watts of CSP capacity world wide.

Parabolic trough technology is currently the most proven solar thermal electric technology. Large fields of parabolic trough collectors supply the thermal energy used to produce steam for a Rankine steam turbine generator cycle.

A different type of solar concentrator is the Linear Fresnel Reflector (LFR). This type of collector uses a series of long, narrow, shallow-curvature (or even flat) mirrors to focus light onto one or more linear receivers positioned above the mirrors. The concept of large reflectors being broken down into many Fresnel sub-elements to improve manageability was advanced by Baum et al. (1957), and in the 1960's, important development work was undertaken by the solar pioneer Giovanni Francia (Francia, 1968) of the University of Genoa, who developed both linear Fresnel reflector systems and Fresnel point focus systems, the latter of which directly led to a later point focus array at the Georgia Institute of Technology in the USA.

Francia's Linear Fresnel Reflector

These systems aim to offer lower overall costs by sharing a receiver between several mirrors, while still using the simple line-focus geometry with one axis of tracking. When suitable aiming strategies are used, mirrors aim at different receivers at different times of day. This can allow a denser packing of mirrors on available land area.

Many comapanies (Ausra, Solel, Novatech and others) are now designing and building variations of Francias' Linear Fresnel Reflectors. Recent prototypes of these types of systems have been built in Australia (Compact LFR) and Belgium (SolarMundo). Based on the Australian prototype, a 177MW plant is proposed near San Luis Obispo in California and will be built by Ausra. Although FLR systems offer some advantages, their performance is still below the parabolic trough relector types.

Picture Courtesy of Ausra

Stalix's Approach – Nearly all the parabolic solar plants in existence today have incorporated LUZ parabolic trough collector designs. Although minor variations of the parabolic trough have been introduced, the basic design remained relatively the same for the last 25 years. The approach used by Stalix is to first evaluate existing CSP systems, specifically trough and LFR, and to assess the benefits and shortcomings of each these systems. Next we need to compile a cost breakdown of the major system components and the recurrent operating cost of these types of power plants. The highest cost items will be targeted for improvements first. The next step is to use simulation models (existing and newly developed) that provide the basis for comparison of the various configurations and to be used for optimization of a new design. The final step is to come up with some new design concepts and to estimate their cost.

In the first step, our research revealed that although trough concentrator plants have been successfully demonstrated over the years, there is continued struggle to bring down the cost. Although the parabolic trough technology of today has significantly improved from the last SEGS plant built 20 years ago, substantial opportunities remain for further improvement. Many of the solutions offered by the industry focused on increasing the size of plants to take advantage of economies of scale, using integrated solar/fossil fuel Combined-Cycle System to reduce start-up cost, and lowering the cost for the steel structure, with a possible alternative of a lighter aluminum or composite structure. However, no one is proposing a different design. It is our opinion that the existing trough designs are dated and offer limited potential for continued reduction in the levelized cost of electricity.

Our research on the Compact Linear Fresnel Reflectors indicates that many companies are taking credit for a technology they did not invent. The claims for compactness due to alternating mirror configuration are over-hyped and provide marginal benefits. Also, no one is discussing how the reflectors will be cleaned in such compact configuration. Based on our analysis, FLR systems seem to work well when the sun is nearly vertical (noon ± 2 hours), but suffer rapid performance degradation outside this limited window. In fact, for a given area, FLR's solar collection efficiency averaged over a year period is only 5% above a simple tilted fixed plate pointed south, and is about 15% below that of a trough system. In addition, more reflectors add more complexity to the tracking system, and more axles, more bearings, and more motor mechanisms. This can add up to a significant cost and maintenance disadvantage. Another issue is that the receiver requires a secondary reflector pointing down.

The next step was to dissect the cost drivers in a CSP system. The table to the right shows a typical 100 MW parabolic trough CSP plant capital cost breakdown by percentages [Ref.1]. This table shows that the solar field accounts for nearly 59% of the total direct cost of a CSP solar plant. This high percentage is generally confirmed by other sources, which estimate the solar field cost between 50 to 60 % of a total CSP plant. Thermal energy storage accounted for nearly 15% of the total capital cost.

Item	**Percent**
Site work and infrastructure	0.6%
Solar field	58.7%
Heat transfer fluid system	2.5%
Thermal energy storage (6 hrs)	14.7%
Power block	9.9%
Balance of plant	5.7%
Contingencies	7.8%
Total Direct Cost	**100.0%**

In addition to the initial capital cost of a CSP plan, one must consider the recurring operation and maintenance cost. The table to the right shows the annual operating and maintenance cost breakdown, by percentages, for a typical CSP plant. Again in this case, the solar field annual parts and materials expenditure accounts for nearly 32% of the total operating cost. The operation and maintenance labor accounts for nearly 28% of the total operating cost of a CSP plant. The solar field annual parts and labor accounts for over 50% of the total annual operating cost of a CSP plant.

Item	**Percent**
Administration labor	9.0%
Operations and maintenance labor	27.6%
Service contracts & misc.	11.7%
Water treatment	4.5%
Spares and equipment	11.5%
Solar field part & materials	31.9%
Annual capital equipment	3.9%
Total Direct Cost	**100.0%**

Therefore, we can safely conclude that the major cost drivers of a CSP plant is the solar field. Our design and research work will focus on this area.

Although many sources were predicting low cost of electricity from CSP, the current estimates for levelized cost of energy (LCOE) of CSP plant range from $0.10 to $0.12 per KWh. [Ref. 2] estimates that the current CSP technology is capable of delivering LCOE between $0.065 and $0.085 per KW/h for a large scale trough system. [Ref. 4] is projecting the LCOE of a linear Fresnel system to be at $0.106 KWh.

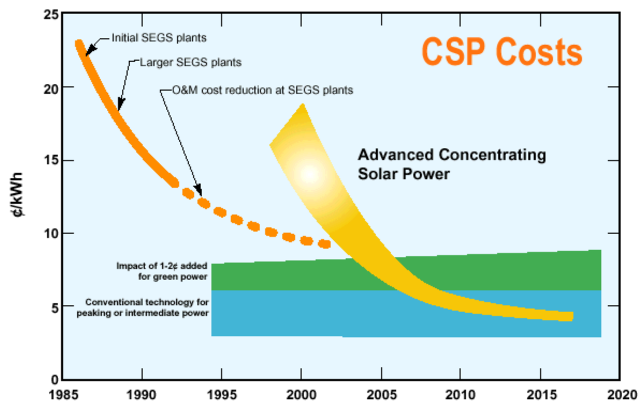
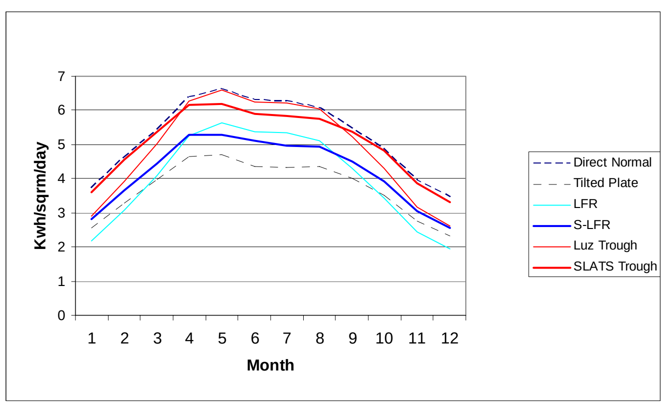


Chart Courtesy of Powerfromthesun.com

There are fundamentally 2 ways to lower the cost per KWh of electricity generated by a CSP plant. The first and most obvious is to reduce the initial cost of the solar field and the annual operating expenses. Stalix is addressing this by considering non-traditional designs options that focus on low cost materials, low complexity and low maintenance. The second way to lower electricity cost is to increase efficiency by maximizing solar energy capture. To demonstrate this, Stalix used a simulation to predict the solar capture efficiency per square area for different design options. The table to the right shows a comparison of the average amount of solar energy captured per day over a year period in Miami Florida (25 deg latitude) between 8 AM and 5 PM for different collector types. The isolation data for Miami was the average measured data over a 10-year period. The table shows that a typical Linear Fresnel Reflector performance is only slight better than a fixed tilted collector facing south, and much worse than a 1-axis parabolic trough collector. The shaded systems in the table (1-axis SLATS trough and the S-Linear Fresnel Array) represent 2 new design options being developed by Stalix. The SLATS trough offers at least 5% increase in efficiency over the traditional parabolic troughs and substantially lower cost. The S-Fresnel Array system offers marked improvement in efficiency when compared to the existing LFR.

Solar Collector System	KWh/day	Percent
Direct Normal (2-axis track)	5.26	100%
1-Axis SLATS Trough	5.06	96%
1-Axis Parabolic Trough	4.88	91%
S-Linear Fresnel Array	4.21	80%
Linear Fresnel Array	4.01	76%
Tilted Flat Plate Facing South	3.73	71%

The plot to the right shows the average amount of daily energy captured from the sun for each of the systems discussed above, assuming a location near Miami Florida. What is interesting to note from the figure is that the SLATS trough and the S-LFR not only provide higher average over a year period, but also provide a more uniform supply of energy over the 12 months. This is a key feature of our new designs. Typical parabolic trough and LFR seem to peak in the summer months, but fall substantially during the fall and winter months. It is our opinion that lower peaks in the



summer and higher levels throughout the rest of the year are more beneficial in CSP systems.

Stalix estimates that the new 1-axis SLATS trough system will cost about $\$184/m^2$ to construct. The new S-Linear Fresnel Array is estimated to cost about $\$180/m^2$. These estimates are for relatively small size projects and are expected to be lower for sizable projects (100MW or larger). According to Ref. 2 and Ref. 4, the estimated cost of the current LUZ trough collectors is about $\$441/m^2$, and of that of a Linear Fresnel Reflector is $\$234/m^2$. The Table to the right shows that Stalix designs will provide 23 to 47% cost reduction over existing solar fields, excluding the expect 12 to 14% reduction due to economies of scale when building large power plants.

Solar Collector System	**Cost/m²**
1-Axis Trough	$441
1-Axis SLATS Trough	$184
Linear Fresnel Array	$234
S-Linear Fresnel Array	$180

To address recurring operational and maintenance costs of the solar field, Stalix focused on the following areas:

1) Design simplicity and parts count reduction, which improves reliability.
2) Modularity and use of standard materials
3) High accessibility and ease of routine maintenance
4) Increased use of sensors for continued monitoring of the solar field
5) Automated reflector surface monitoring and washing

We estimate that the solar field operational and maintenance cost can be reduced by 25 to 50%.

Based on the expected efficiency increase (5%) of Stalix's trough design, the lower initial solar field cost (47% reduction), and the expected lower operating cost 25 to 50%), we believe that electricity from SCP plants can be generated at or below 0.05¢/KWh.

Technology - Stalix is developing new technologies that will change the way trough collectors are designed, manufactured and operated. In addition to providing substantial cost reduction over existing parabolic troughs, Stalix's single axis troughs will increase collector efficiency by at least by 5%. The simplicity of the design will reduce operational and maintenance cost. The entire systems can be built on site with low skilled labor and locally available raw materials. Stalix is also developing a unique Linear Fesnel Reflector system with improved solar collection efficiency and lower cost.

While there are many areas of research and development in CSP, Stalix technology focus has been in the following areas:

- Receiver — Leveraging existing highly reliable evacuated tube receiver designs with improved selective coatings, and ability to operate at higher temperatures
- Concentrator Structure — Reducing structural forces allowing use of lighter and lower cost materials that improve the tracking performance.
- Reflectors — Lower cost and higher performance reflectors that are more durable, with improved solar reflectivity, and that reduce mirror washing requirements.
- Balance of Collector Systems — Improved drives, controls, monitoring and collector interconnect.

Other areas we are looking at includes trade-offs for the thermal storage capacity, Direct Steam Generation to eliminate the heat exchanger, and the use of combined solar/fossil fuel plant.

Conclusion - The experience from the nine SEGS plants demonstrates the commercial viability of parabolic trough solar collector and power plant technologies. Given this experience, it is assumed that future CSP plant designs will continue to focus on trough collector technology and Rankine cycle steam power plants. However, it appears that the current LUZ parabolic design has reached a point of diminishing returns in terms of trying to reach lower LOCE. Most of the new solutions being provided today deal with making incremental cost reduction steps. If the LOCE of CSP systems is to move closer to (or even be lower) the cost electricity from fossil fuels, new designs and concepts must be considered. Stalix's technology offers new prospective and solutions to this challenge.

References:

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5. Graham L. Morrison & David R. Mills, "Solar Thermal Power Systems", The University of New South Wales, Sydney, Australia.

About Stalix

Headquartered in Orlando, Florida, Stalix is a technology development leader in many fields including Renewable Energy. The Company's foundation is based on 25 years of technology development and a proven record of transforming innovation into business opportunities. Applying our extensive expertise in many industries, we develop breakthrough innovations that make products more efficient and cost effective, thereby allowing our customers to compete successfully on the world market.