Project Proposal for a Compact Linear Fresnel Reflector Solar Thermal Plant in the Hunter Valley

*D.R.Mills, **G.L.Morrison, and ***P.Le Lièvre,

*School of Physics
University of Sydney
Sydney, NSW 2006
AUSTRALIA

**School of Mechanical & Manufacturing Engineering
The University of New South Wales
NSW 2052
AUSTRALIA

***Solar Heat and Power Pty. Ltd. (SHP)
Exchange Square, 10 Bridge St
Sydney, NSW 2000
AUSTRALIA

Telephone (SHP)): +61 (0) 412 862 939
E-mail: peter.lelievre@solarheatpower.com

Abstract

A proposal has been made to Macquarie Generation to mount a 25 MWe CLFR project in 2003/4 next to Liddell coal fired power station. The solar array will be a direct steam generation system preheating feed water going into the reheating circuit of the station. The design approach is to minimise costs by using existing generation infrastructure, and to maximise greenhouse gas savings by directly offsetting coal usage. This project offers a low risk, low cost transitional path for commercialising solar thermal energy. Electricity cost is estimated to be below $A0.065 per kWh, close to the price of wind generation. Subsequent stand-alone sites are also discussed.

Figure 1. Small segment of earlier 15m tower CLFR array. The tower height and spacing have been recently reduced to 7.5m. and 26m. respectively, with 10 reflectors between the towers. (Raytrace by P. Le Lievre)

1 BACKGROUND

Instead of tracking trough systems (Frier and Cable, 1999), one may use corresponding linear Fresnel systems. In these, long heliostats focus on absorber lines suspended from elevated towers. This was pioneered by Francia in the 1960's (1961,1968). Before the current Australian work, each field of reflectors was directed to a single tower. However, in 1995 it was shown that systems of high density could be set up in which a single field of reflectors used multiple receivers on different towers, with some proposals having reflectors which change their focal point from one receiver to another during the day. These are called the *Compact Linear Fresnel Reflector* systems, or *CLFR* systems, and have number of advantages that will be described in this paper.

2 CLFR DEVELOPMENT HISTORY

Development began on this Australian innovation at the University of Sydney in 1993. CLFR was patented in 1995. Dr. David Mills, the technology originator, eventually acquired the IP from the University of Sydney and supporting IP was then developed by Solsearch Pty. Ltd., a company owned by Dr. Mills and Prof. Graham Morrison, with support from groups including the NSW Sustainable Energy Research and Development Fund, Energy Australia, and a private investor.

Figure 2. Early Solahart CLFR tracking test rig

Interest subsequently arose in the CLFR within the Australian utility industry. Austa Energy and Stanwell Corporation agreed to jointly develop a 4MWe CLFR plant under the Australian Greenhouse Renewable Energy Showcase scheme in 1999. Unfortunately, Austa was abolished by the Queensland Government shortly after the project began and the six-member project management team was lost to the project. Without this direction, the project slowed to a halt and Stanwell has returned the IP to the inventors. Late last year Solahart was purchased by overseas interests and withdrew from the project as the new owners wanted to stick to core business (solar water heating). However, significant experimental work was carried out by both Universities of NSW and Sydney to prove the CLFR technology components and Solahart also assisted (Fig 2).

This year, new NSW legislation for reducing emissions by electricity retailers has stimulated high interest in renewable generation and the CLFR project was moved to NSW with Macquarie Generation playing a cooperative role. To facilitate the move to a new project site, a new company, Solar Heat and Power Pty Ltd., was formed as a specialist high technology commercialisation company with full IP rights and expertise in all aspects of CLFR. SHP is designed to be the ideal technology partner for an incumbent generator such as Macquarie Generation in that it offers the commercialisation, project management and engineering skills necessary in the integration of CLFR technology into existing power station operations. It will also cooperate with the Universities where additional research is required in the future.

This paper describes the proposal for the first plant, intended as a commercial beginning to an expansion of STE developments in NSW. SHP has been working with Macquarie Generation on a project proposal for a 25 MWe plant at Liddell power station. Space for at least three such projects is available in the area. Stage 1 of the project is a 5 MWe trial segment. Once this is commissioned it is hoped that Macquarie Generation will roll out a 20 MWe second stage following a critical performance evaluation. At the time of writing, SEDA RIP 8 funding is being sought as an underwriting instrument to proceed with Stage 1. Stage 1 is viewed as the bridge that will carry the CLFR technology in its transition from University to commercial use.

3 CLFR TECHNICAL FEATURES

Since SHP was formed, the reflector field has been redesigned completely for low cost outsourced production. The CLFR power plant project is a serious attempt to reduce all major costs in a solar thermal electrical system, and includes the following features that enhance the system cost/performance ratio:

- The array uses flat or elastically curved reflectors instead of costly sagged glass reflectors. The reflectors are of low cost 3mm mirrored glass, and are mounted close to the ground, minimising structural requirements. It is possible that common 3mm glass is more cost effective in this application than low iron glass.
- The heat transfer loop is separated from the reflector field and is fixed in space thus avoiding the high cost of flexible high-pressure lines or high pressure rotating joints as required in other technologies.
- The heat transfer fluid is water, and passive direct boiling heat transfer can be used to avoid parasitic pumping losses and the use of expensive flow controllers.
- An inverted cavity receiver has been designed using steel boiling tubes that are linked through a heat exchanger to an existing fossil fuel plant steam system. This is cheaper than the evacuated tubes.
- No secondary reflector is used in order to maintain high optical efficiency. This also avoids the use of hot reflectors.
- Low cost demineralised water is used as the heat transfer fluid and not expensive silicone oil.
- Only modest structures are required because reflectors are positioned close to the ground
- Maintenance will be low because of ease of reflector access for cleaning (Fig. 3).
- Excellent ground utilisation is achieved with at least 62% ground coverage.
- The reflector rows are 600 m long and 1.6 m wide, and composed of reflector space frame modules that are 10 m long. The long rows ensure that header length is kept to an absolute minimum (0.0046metres / m^2) and consequent losses.
- The towers are 7.5 m. high at the receiver aperture, reduced from previous designs to allow use of mass-produced tower components.

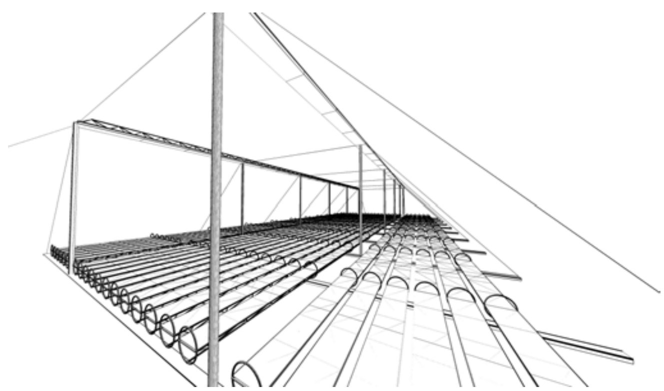


Figure 3. View showing ground level reflectors accessible for easy maintenance.

The CLFR uses simple but specially designed inverted cavity receiver containing a water/steam mixture that becomes drier as the mixture is pumped down and back through the receiver array, but still remains saturated. This design has particular advantages with direct boiling, because the boiling tubes always have a water interface inside where they are illuminated on the tube underside. This allows the system to operate freely under a wide variety of boiling regimes, including the one of stratified flow avoided by parabolic troughs. The steam is separated and flows through a heat exchanger where the thermal energy passes to the power plant system.

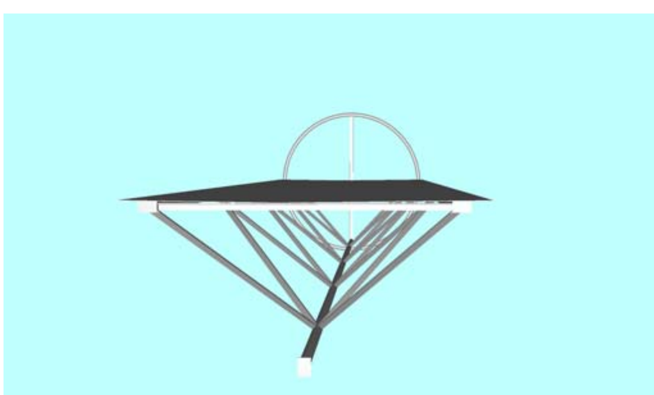


Figure 4. 10 m. space frame reflector module

This cavity receiver design was simulated to be more efficient than the evacuated tube receivers originally proposed (Mills and Morrison, 1999), having superior optical and net efficiency. The elevated absorber line is free to move at one end under thermal expansion. In the Hunter Valley projects, a coatings are being developed for higher temperature operations (320-370°C). The array always operates as a saturated steam system and therefore must operate below the triple point temperature.

The reflectors are slightly curved elastically to achieve a fine focus. The long focal length of a CLFR allows this to be done with elastic bending. The structure below the mirrors is a lightweight galvanised steel space frame (Fig 4). The mirror rows are driven by low voltage actuators at the centre of each row. The reflectors are made of low cost 3mm mirrored glass adhered to the space frame backing. These are likely to have a total solar reflectance of 0.83, which appears at the time of writing to be more cost-effective than 91% reflecting low iron glass. However, attempts will be made to obtain higher reflectance glass mirror at a lower cost.

4 APPLICATION IN THIS PROJECT - RETROFIT SUPPLY OF HEAT TO FOSSIL POWER PLANT

The solar array will be a direct steam generation system that will initially feed hot water via a heat exchanger directly into the Liddell Power Station steam cycle. Although this first trial 5MW CLFR plant will be used for preheating feed water going into the reheating circuit, subsequent CLFR plants will be able to be used for more efficient main boiler steam injection. The CLFR design steam delivery conditions for the Liddell project are 265°C and 5 MPa wet steam. The thermal energy will be use for preheating evaporator feed water, so that steam will not be produced on the plant side of the heat exchanger.

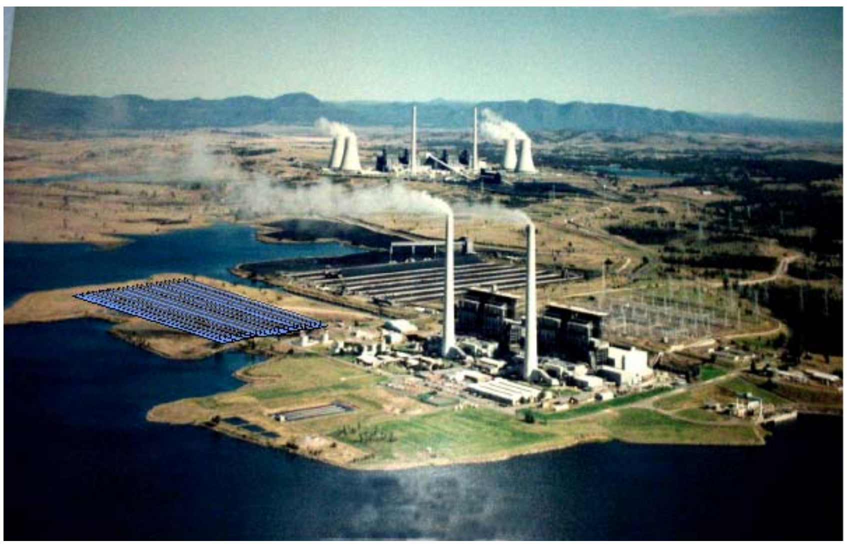


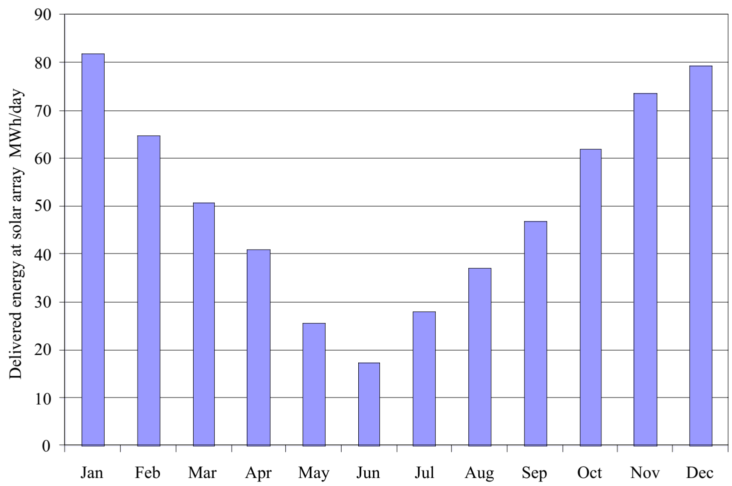
Figure 5. Liddell Power Station with an impression of the 25MWe CLFR array located at the proposed site adjacent to the plant.

Over the 20 year life of the plant, this saving will increase to 144,000 tonnes of carbon dioxide. The CLFR plant produces thermal energy in this application and so REC and State green credits would be calculated based on a conversion factor to electricity as supplied by Macgen. This conversion ratio would be reviewed and approved by SEDA.

The annual energy supplied by the plant has been modelled, and amounts to annualised power station output of 7300 MWh per year. Fig. 6 shows the monthly thermal output of the plant as predicted using satellite solar radiation data provided by the Bureau of Meteorology. The data were converted to simulated beam radiation and combined with an optical ray trace model of the array in the TRNSYS thermal simulation environment to produce the estimated performance. This figure does not include downtime for maintenance or other reasons. The CLFR is calculated to deliver tracked beam to electricity efficiency of 15% in summer with a 12% annual average. This figure is based on 30 % power conversion efficiency by Liddell power station, 10% line losses and simulated solar absorber efficiencies. Although these figures seem low, they reflect the relatively low solar radiation levels at a coastal site, and the array would collect a high 75% of the available beam if used with 91% reflector and 66% with inexpensive glass reflector.

O&M is low because cleaning can be done manually at ground level. This is less costly than an automatic cleaning system and also creates greater local employment opportunities in the Hunter. The entire array system is extremely simple and requires one laptop computer for operation.

The high density of reflector coverage provides around 100-125 MWe per km^2, depending upon mirror reflectance. As a comparison, an 80 MWe LS3 plant in California occupies about 1.35 km^2, about 60 MWe per km^2. The CLFR technology is therefore nearly twice as space efficient. This is a key benefit when seeking sites



close to existing coal fired power stations. The estimated potential of this site and additional sites close to Liddell and nearby Bayswater power station is 75MWe peak.

Figure 6. Predicted seasonal thermal output of solar array

The site is located far from residential areas and is unlikely to have any amenity or noise impacts. Further, the present industrial use of the site is in harmony with the intended construction and commissioning activities required for the project. There are no significant flora, fauna, water or soil impacts with only minimal land grading required for site adaptation to CLFR project use. All water required for the absorber lines will be provided from Liddell's existing demineralised water supply and all systems in the CLFR operation are 'closed loop' with no environmental emissions of any sort required. In the event of catastrophic failure the design contains no harmful materials, gases or fluids.

The prime construction materials for the 5 MWe stage are :

Steel	220	tonnes
Glass	27	tonnes
Concrete	320	cubic metres

The environmental costs of production of these materials are significant but are much lower than the lifetime and ancillary emission reductions afforded to the Liddell plant.

5 COSTS

In the Liddell project, the total commissioned array and heat exchanger cost is about *$A470 per peak electrical kilowatt* based upon quotes for components and estimates of labour. Breakdown for the costs are given in details but in summary:

Tower/Absorber Related	$698,540
Reflector field related	$901,547
HP plumbing	$462,000
Miscellaneous	$260,000

Key Indicators for the project are as follows:

5.1.1.1.1.1.1 Total Capital Cost $2,337,088
5.1.1.1.1.1.2 Capital Cost per peak KWe $467.42
5.1.1.1.1.1.3 Annual Plant Capacity Factor 0.17
5.1.1.1.1.1.4 Levelised Electricity cost per KWh (LEC) 6.28 cents

5 Yr Average Annual Gross Revenue per KWh	$97.90
Annual O&M per KWh	$4.27
Annual Net Revenue per KWh	$93.64

5.1.1.1.1.1.5 Payback Period 4.99 years

Because the financial plan is structured around a 5-year payback, the IRR is masked. If one uses revenues from the full 20-year plant life and assumes zero salvage then IRR is 19.5%. The LEC in subsequent projects depends upon discount rates and profit margins for each specific project.

6 FUTURE MARKET - STAND ALONE CLFR PLANTS FOR BASELOAD ENERGY SUPPLY

To address the even larger future stand alone generation market, the CLFR design will use higher temperature air stable selective coatings now under development. In NSW, the presence of both Federal and State green credits for greenhouse gas avoidance would direct preferential development of the system toward very high solar fraction operation. This is even more the case with the provisions in the newly enacted Spanish royal decree, which mandates 100% solar fraction. Three storage systems are currently available or close to production and all are aiming at a cost of around US$20 per kWh_{th} stored. These include mineral oil as used by early trough plants, molten salt (Pacheco et al., 2001), and modified cement storage (Tamme et al, 2002).

There are excellent sites within NSW for storage plants that reside at the end of the grid, and these sites have in excess of 9 hours of direct sun per day on an annual averaged basis. Discussions with TransGrid suggest that 300MW of base load solar could be installed at these sites without significant grid upgrade. The authors believe that the generation cost will comparable to advanced wind generation and much lower than expected photovoltaic generation costs. However, more valuable dispatchable power will be offered.

7 CONCLUSIONS

A proposal has been made to Macquarie Generation to mount a 25 MWe CLFR project in 2003/4 next to Liddell coal fired power station and concessionary grants for the project are being sought from SEDA. The solar array will be a direct steam generation system preheating feed water going into the reheating circuit of the station. The design approach is to minimise costs by using existing generation infrastructure, and to maximise greenhouse gas savings by directly offsetting coal usage. Such an approach offers a low risk, low cost transitional path for commercialising solar thermal energy. Electricity cost is estimated to be about $A0.07 per kWh, close to the price of advanced wind generation and well below long term estimated generation costs for trough, tower and PV systems. The land efficient design will allow approximately 75MWe peak of capacity to be installed in the Hunter Valley at this cost.

This array type is a transition to stand alone plant sited in inland NSW. Looking ahead to the solar electric economy of 2030, we have calculated that approximately 1000 km^2 of ground would be required to meet Australia's future electricity supply, which is about 1% of the combined ground area of two already identified high solar availability regions in NSW which are near the grid. There is therefore no resource issue. Far more important is the provision of adequate grid capacity to the new generation regions.

8 REFERENCES

Francia, G. 1961. Un nouveau collecteur de l'energie rayonnante solaire: theorie et verifications experimentales, United Nations Conference on New Sources of Energy, Rome, 1961, 554–588.

Francia, G. 1968. Pilot plants of solar steam generation systems, Solar Energy, 12, 51–64.

Frier, D. and Cable, R.G.(1999). An overview and operation optimisation of the Kramer Junction Solar Electric Generating System. ISES World Congress 1999, Vol. 1, pp. 241 – 246, Jerusalem.

Le Lievre and Jurachich (2002).EIA – Cost benefit analysis of a 200MW CLFR solar thermal power project at the Hunter Valley in New South Wales. Draft available from the third author.

Mills D.R and Morrison G.L.(1999). Compact linear Fresnel reflector solar thermal powerplants. Solar Energy. V68, pp 263 – 283.

Pacheco J.E., (2001). Development of a molten-salt thermocline thermal storage system for parabolic trough plants. Proc. Solar Forum 2001; Solar Energy: The Power to Choose. April 21-25, Washington, DC.

Tamme, R., Liang, D., Steinmann, W.D., and Zunft, S. (2002) Innovative thermal energy storage technology for parabolic trough concentrating solar power plants. . Eurosun 2002, the 4th Europe Solar Congress, Bologna, June.