Renewable Energy as the Basis of an Economy – A Workable Solution: The Liquid Solar Array (LSA)

The apparently serious consequences of climate changes caused by Greenhouse gasses are providing a strong incentive to establish global usage of renewable energy supplies such as solar power as an urgent priority.

This paper will outline the need, some existing prospects and describe a new economical solar technology, the Liquid Solar Array.

Background

There are some questions that we need to consider if we are to attempt to establish widespread usage of renewable energy:

- Can renewable energy be established as the basis of an economy?
- What is required to make this happen?
- Which energy technologies are likely to be effective soon as the energy supplies for a largely renewable economy?

To be widely used, any energy technology must be economically attractive in comparison to existing fossil and nuclear energy sources when all known costs are included for both. Otherwise there is an overwhelming pressure, especially in developing economies, to use whatever is the most economic in the short term, regardless of predictions of potential negative consequences.

This does not mean that the renewable energy sources need to be identical in nature to existing energy sources, as it is possible for industry and domestic users to adapt to some changes in price according to the availability of a given source (as we already do). To consider this issue properly, it is important not to prejudge the situation.

The hidden environmental costs of fossil and nuclear energy sources are clearly enormous but we won't try to evaluate these here as there is already an extensive amount written on this subject and the real costs are very hard to estimate in dollars. Let us simply say that these costs are likely to be so high for future generations that an alternative must be evolved very soon. Nevertheless this does not give us any moralistic excuse to try to legislate away the right to use fossil and nuclear fuels. Such an approach is likely to be futile, as many people will simply use them anyway in order to attain a comfortable and secure life.

This especially applies in the developing nations, which desperately need greater energy supplies to improve living standards. Note that this is not a matter of choice – the people of Africa and Asia require very large energy resources in the very short term.

In this discussion we will consider only the supply of electrical energy, as this is the first requirement for industry and it can ultimately be applied for transport and the majority of other needs.

What should be the Target?

To make clean energy available worldwide we must make it both fundamentally economically sound and attractive. This will remove the motivation to burn large quantities of fossil fuels. The true test of this is when developing economies choose to use renewable energy on a very large scale.

In the present circumstances this will only happen if the renewable energy can be supplied at costs comparable to the present costs of fossil fuelled power. The *primary objective must be* to match the cost of the cheapest and most widely used fossil electric power source: coal. Coal is also the single biggest source of pollution, especially carbon dioxide. This means a cost of under US$0.04 per kWhr which is a very ambitious target for renewables. The target really should be under three cents to allow for power storage costs. Many would say this is an impossible target, but this paper outlines a method that may well achieve this rapidly and perhaps do better.

This target does not necessarily mean that the renewable energy has to be as cheap as coal for 24 hours per day. People are adaptable and industry can make adjustments to suit time and place-varying power costs. Industry already does this, by using more power in off-peak periods when it can often buy power at a fraction of the peak period cost. Certain industries are also very happy to locate near to a source of substantial amounts of economical power such as a coalfield or a hydroelectric scheme.

The concept of time and place-varying power costs is very relevant to renewable resources, as they are not uniformly distributed in time or place. In places where we can achieve costs of $0.03-0.04 cents/kWhr, renewables could drive industrial production directly and cheaply at the times they are available. At other times stored power in the form of hydrogen can be used – at about three or four times the cost or we could use fossil fuels such as natural gas at those times. Note also that economic transmission of electric power is possible over 1000km or more. In the case of solar energy, availability is reasonably predictable in low cloud areas – the sun rises every day with great reliability.

Each of the renewables has good and bad resource locations, advantages and disadvantages and some degree of variability over time. For the present argument we will consider only wind, biomass and solar energy, as these are the most universally available.

Wind energy is currently the most economical but it has some severe limitations. The first is that good wind energy resources are not as widely available as we might like. The best resources seem to be at higher latitudes where wind is definitely the better option over solar. The second problem is that wind speeds are highly seasonal in most places. The most severe problem for wind energy is that the size and mass of the necessary turbines are very substantial so that the costs are relatively high. Although some further technology improvements might be made, it does not seem that there is any clear path to costs of production lower than coal fired power except in a few areas where average wind velocities are unusually high. Typical costs at the moment, when several gigawatts are being installed per year, are $1.30 per Watt corresponding to six cents per kWhr.

Energy from **biomass** is available in most areas in the form of wood and crop derived ethanol and bio-diesel. The primary advantage of biomass is that it becomes a stored fuel that can be transported and is available at any time. These work well, but take away large amounts of arable land that could be used for food production. To support a western-world living standard for all mankind using wind or biomass energy sources seems to be impractical on the basis of availability and of cost, although they can clearly provide a supplementary supply of energy.

Solar Power

Solar resources, on the other hand, are very widely available, effectively limitless and potentially cheap. Solar electricity production seems to have much better long-term prospects for the bulk of mankind. There are several promising solar technological pathways that should be able to match the costs of coal fired power given sufficient effort.

This does not mean that the present solar photovoltaic panels are economical. These are made of large sheets of highly refined silicon and are at present around US$5.30 per Watt or US$0.25 per kWhr, which is acceptable for certain remote area applications but completely unacceptable for supporting an industrial power system.

Given that solar power, in a good location, is available for six to seven hours per day average over the year, it is necessary for solar generators to cost no more than US$0.60 per Watt of capacity to achieve a cost of generation of US$0.03 per kWhr, the target we have set.

Such a target is not impossible, but requires better and smarter technologies than large quantities of sheet silicon. Let us consider what solar hardware needs to cost and what its efficiency needs to be to achieve US$0.60 per Watt. This is determined by a simple solar capacity cost formula, which is:

$$C = \frac{Q}{S \times E} = \frac{Q\left(\frac{\$}{M^2}\right)}{1000\left(\frac{W}{M^2}\right) \times E} = \frac{\$}{W}$$

Where ‘Q’ is the cost per square meter of the solar collector, E is its efficiency in converting sunlight into electricity, and S is the incident energy (1000 Watts, W) from sunlight onto a square meter (M^2). The formula is simply reflecting the fact that a given cost of power can be achieved either with a low efficiency system that has a very low cost per unit area or with a high efficiency system that has a higher cost per unit area.

If the overall efficiency is 0.15 (15%) and the target C is $0.60 per Watt, then $0.6 = Q/(1000 \times 0.15)$ so Q must be 0.6 x 150 = $90/$M^2$ for the whole system (or it can be $180/$M^2$ if 30% efficient). Conventional silicon flat plate systems are up to 15% efficient but cost around $525 per M^2 - far too high. This cost comes mainly from the quantity of pure silicon they use, which is not likely to become a lot cheaper as it is already in extremely high mass production (pure Silicon wafer is about US$350 per M^2). Hence they cannot reach the target at any achievable efficiency.

However, there are at least three solar technologies that do have a good chance of meeting this target, one of them very soon.

The three methods are **thin film** photovoltaics (PV), very **high efficiency concentrated** photovoltaics and water based PV concentrators such as the **LSA system**, which will be described below. Solar thermal concentrators combined with heat engines are another method that is very useful in the short term due to the ability to use natural gas as a backup, but these do not seem to have as good an economic potential as modern photovoltaics for the long term.

Thin film PV systems place a very thin coating of PV material onto a relatively cheap base and cover this with tough glass or plastic for weather protection. These systems, from Interphases and many others, are definitely showing promise but are probably seven to ten years away from reaching US$0.60/W in durable weather resistant form. There is no certainty that thin films will reach this target.

The high efficiency concentrator cells from Spectrolab, Emcore and others have been shown to work at 34% efficiency, but achieving system costs under the required $180/M² is a major challenge. Again, weather resistance is a big cost factor. Concentrators must follow the sun and be able to withstand winds of at least 150 km/hr without damage. In addition the PV cells used are much more complex and expensive than silicon.

The Liquid Solar Array (LSA) system

The Liquid Solar Array is a new type of PV concentrator that has all the right characteristics to reach the required cost target reliably and quickly. It uses relatively lightweight concentrators that operate in a pool of water that keeps them cool, clean and efficient while providing protection from high winds and hail. The LSA system uses existing off-the-shelf technologies in a new way to bring costs down dramatically. A patent is likely to be granted on the LSA system within a very short time. Australian Patent Application No. 200424336 is pending.

The LSA system is a way to make very low cost industrial scale power for daytime use in those regions with good sunlight resources and suitable bodies of water.

Basically the LSA method collects solar energy using sheets of durable plastic. It can be scaled up to any size and will work most economically within the band of ± 35 degrees latitude. Projections indicate electricity costs less than $0.03 per kWhr after a few years of production.

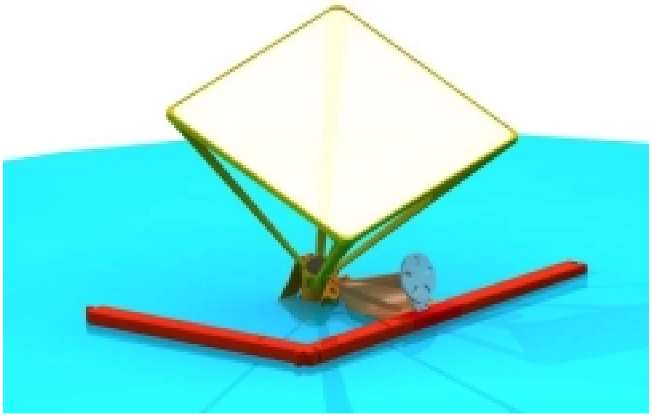
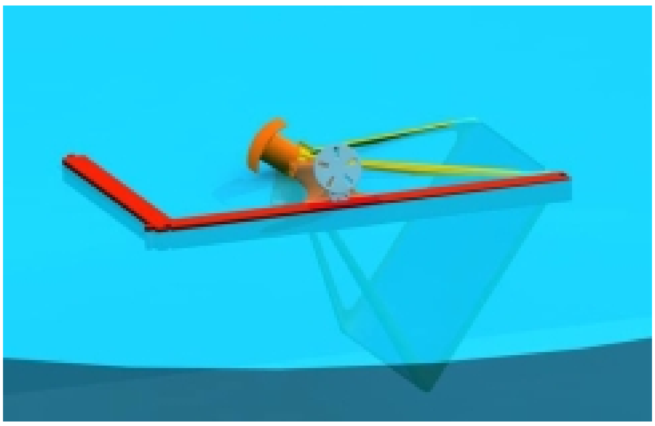


Figure 1 - The LSA System floating solar collector module – operating & protected.



How Does It Work?

- It is a synergy of sun and water.
- The LSA system is based on floating solar collectors made mostly of plastic. Each has a very small area of silicon photovoltaic cells at the water surface with a large plastic focussing lens rotating slowly above to track the sun. The water cools the silicon cells, and in bad weather the lens is protected by rotating it fully under the water to avoid damage in high winds. Thus the water becomes a structural component. (See Figure 1).
- Almost all the structure is low-mass plastic so costs per square metre are extremely low.
- The fundamental feature of the LSA system is that the energy is collected using a sheet of plastic rather than the large area of silicon and glass required in conventional photovoltaic systems.
- The large focussing lens can be as little as two millimetres thick but still survive winds over 150 km/hr, because of its unique method of weather protection (submergence).

- The lens is coated with a special self-cleaning surface, which allows clearing of any dust or salt deposited on the lens during operation by simply rotating the lens via its sun-tracking mechanism to dip it into the water.
- Because the system tracks the sun it produces more power from a given area than conventional flat PV systems, and this power is more uniform over the day.
- A proof-of-concept working model and a 3D CAD model have been built to demonstrate the practicality of the LSA system (See Figure 2).
- All the major components required are available off-the-shelf now, most at high mass production levels, so commercial sales could begin in one to three years, depending on the available capital.
- The LSA system is best suited to large-scale distributed electricity generation in sunny areas where suitable bodies of water are available (or can be constructed). This includes a multitude of coastal areas plus most reservoirs and lakes within 35 degrees of the equator.
- About two hectares (4 acres) of water are needed for each megawatt of electricity.
- The LSA is a new way to combine several existing technologies, which is likely to reduce the cost of raw solar electricity in the short term by a factor of four, from the present US$5/W to US$1.30/W, and in the longer term by a factor of eight (in the best locations) to under US$0.60/W. This corresponds to about three US cents per kWhr.
- The main cost in the LSA system is the set of plastic mouldings that make up each collector. For each square metre, about 13kg (30lb) of plastics are required (See figure 3).

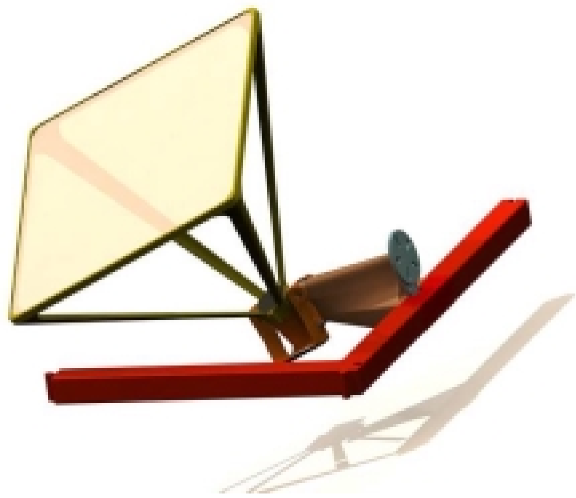


Figure 2 – The LSA CAD Model

- With technology improvements, such as the use of recently developed triple junction PV cells of 34% efficiency, the LSA method could eventually deliver even lower costs.

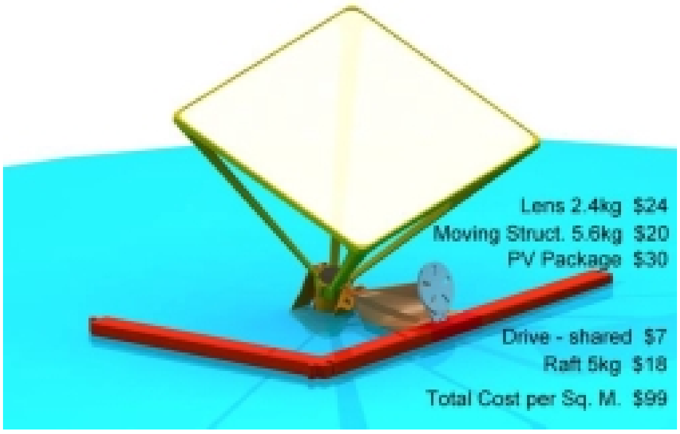


Figure 3 – Component Cost Estimates

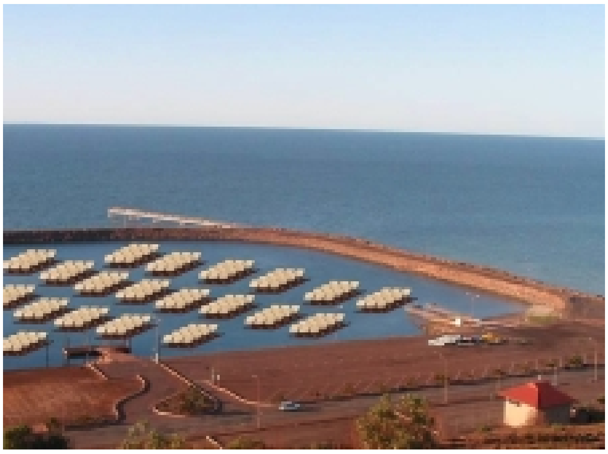


Figure 4 - The LSA System in Whyalla harbour – 130 kW

Figures 4 and 6 show artist's impressions of typical applications. Figure 7 shows a prototype in testing with a sensor operated tracking system.

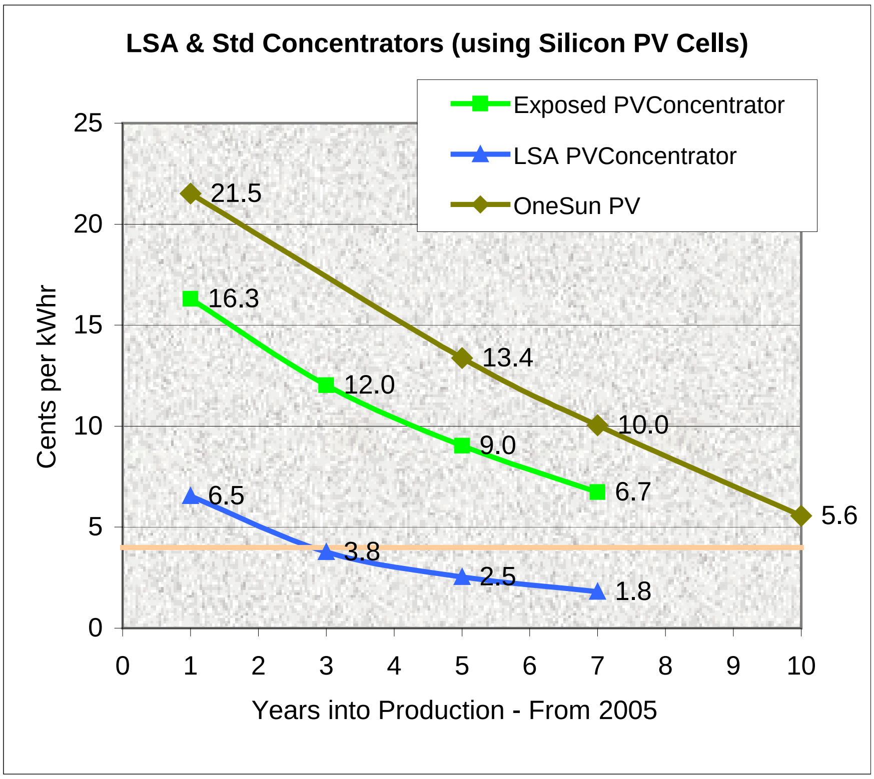


Figure 5 – Costs of LSA, Standard Concentrators and Conventional PV.

Figure 5 above shows how the costs of raw power from three different PV systems are likely to evolve. All cases use the same maths and have similar input conditions, such as the cost of the silicon cells at each point in time. These curves do not assume any major technological improvements, except for the final point in the "one-sun" case, which represents a possible result of developments in thin film PV technology. The blue curve of the LSA system is clearly in a much lower cost regime. Even if we allow for some error in estimation, these are very attractive figures.

Given that LSA power may well cost less than existing fossil fuel systems and **much less** than nuclear power, it opens the prospect for economically storing some of this energy in the form of hydrogen or other synthetic fuels for use at times of cloud cover or night time use. As an example, compressed hydrogen fuel for motor vehicles could likely be profitably sold at $3.80 per "gallon of gasoline equivalent" if the power cost were 3.5 cents per kWhr.

The LSA system should not be seen as a panacea for the world's energy problems. It is clearly limited to those areas that have sufficient water and solar resources, but in those areas it offers an economic way to make a rapid shift to a low emissions technology.

In the medium term, when only a small proportion of energy is provided by economical solar systems such as the LSA, it becomes attractive for industry to make use of the cheaper solar energy available through the day as much as possible, and use fossil fuelled energy at other times.

The cost of power from **stored** synthetic fuels will be higher than direct usage but a shift in our attitudes and systems of industrial manufacturing would allow us to accommodate the time dependent cost of power. We may need to re-learn how to "make hay while the sun shines".

When most power must be provided by renewable sources it simply means that power will be more expensive during the periods that stored power must be used. This gives an incentive to industry to use the most economical power, which is likely to be daytime solar power in most areas.

To make a transition to renewable energy is simply a matter of applied willpower.

Phil Connor
Sunengy Pty. Ltd.
Sydney.
www.sunengy.com

Figure 6 - The LSA System in a farm dam ~ 25 kW.

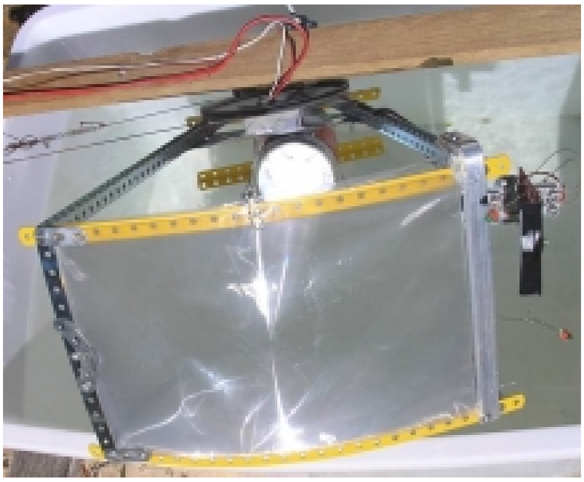


Figure 7 – Testing a prototype LSA