The Oil Drum: Europe

DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Solar Islands: A new concept for low-cost solar energy at very large scale

Posted by Francois Cellier on May 20, 2008 - 12:49pm in The Oil Drum: Europe
Topic: Alternative energy
Tags: alternative energy, concentrating solar power, energy supply, solar island, solar power [list all tags]

This is a guest post by Dr. Thomas Hinderling. Dr. Hinderling is the CEO of CSEM Centre Suisse d'Electronique et de Microtechnique SA. One of CSEM's most exciting projects concerns the design of a new class of large scale concentrating solar power systems, called Solar Islands [1]. This article introduces the solar island design to the readers of TOD [2].

Introduction – the Problem

During the next decades, the generation of sustainable energy will become one of the main challenges of our civilization. Worldwide energy demand is expected to grow from about 10 GTep (10^{10} Tep [Ton Equivalent Petrol], or $5*10^{19}$ Joule) in the beginning of the century to 15-20 GTep by 2050. Some scenarios predict even levels as high as 40 GTep. An analysis of future global petrochemical consumption needs (i.e. energy needs and/or raw material for chemical industry) implies that early petrol shortages might already appear in the mid of the century.

The need for large scale renewable energy sources is underlined by the global warming due to increasing CO_2 levels. CO_2 is an unavoidable by-product of the energy generation process using any kind of fossil fuel.

Or, in simple terms: Not only are we running out of petrol, but the combustion of petrol causes major environmental problems. However, worldwide deployment of renewable energy in very significant quantities constitutes a huge effort of political and financial nature; incredible amounts of invested energy infrastructures are involved. In view of this, the start of this evolution is becoming even more urgent, already today.

While these facts start to be more and more accepted, there is still no global solution for renewable energy sources available. Such a solution should provide usable energy in very large quantities and at competitive costs, i.e. competitive in regard to today's energy prices. Current solar solutions are either not sufficiently scalable (they are only of regional nature), or they are too costly. In most cases, their underlying business model is based on massive public subsidies (which clearly is impossible at large scale deployment), or on massively increased energy prices (at least five times as high as today [3]) which would simply disrupt the world economy.

Renewable Energy Sources

Among the many renewable energy sources, the potential of solar energy is at least one hundred times larger than any other renewable energy source (see figure 1).

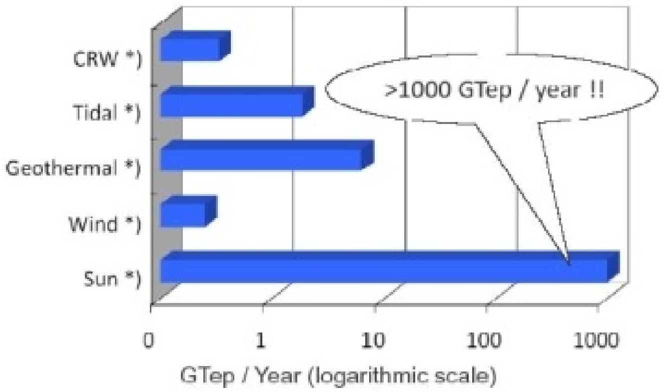


Fig 1: Yearly global energy for different energy sources (logarithmic horizontal scale, source: [Commissariat à l´Énergie Atomique, CEA, France])

Moreover, it can be shown that direct solar irradiation is the only source of energy that can satisfy the global long term energy demand – all other sources of energy are either too insignificant compared to the worldwide energy need (wind, CRW [combustible renewables and waste], tidal energy) or they are too costly (geothermal). Wind, CRW, tidal energy or geothermal energy can all be very interesting on a regional and local base, but they can by far not supply the necessary Gigateps of energy to satisfy the global demand. They have to be considered as auxiliary energy solutions.

Even nuclear fusion energy (should it become available soon, which is unlikely) cannot provide a global solution. Thousands of fusion plants would be needed in order to supply a significant amount of global energy; the ensuing technological and political complexity would be far too high.

Any solution for a future global energy supply must base on direct solar energy conversion at large quantities. Again, this does not mean that other forms of energy could not be interesting, but it means that a global solution can only be focusing on solar irradiation as the main supply of electric and combustible energy.

Classes of Solar Energy Converters

Today, there are four main classes of solar energy systems in operation or in development (aside from many other ideas in test):

1. **Photovoltaic panels:**

   Using the principles of photovoltaic conversion, solar light can directly be converted into electricity. This principle is extremely attractive, as the conversion into usable forms of energy is very simple; using little electronics, the output of solar PV panels can directly be fed into the electric grid. The problem with this solution is that the costs of such PV panels are still quite high, and the efficiency of the energy conversion is quite low (between 5 and 15%). Even though there is high hope that the costs will come down and that the efficiency will go up, PV solutions are based on semiconductor surface layers which are inherently expensive. It is doubtful that this technology will provide large scale solutions at sufficiently low costs. Another big and unsolved problem of photovoltaic solutions is the storage of the energy – a must for supply continuity over 24 hours a day. Future solar energy must be bulk energy, available according to daily fluctuating demands, not according to the position of the sun in the sky or the weather! Solar energy at large quantities implies the necessity for energy storage.

2. **Low temperature solar panels (collectors):**

   These panels use the direct irradiation of the sun to heat water. Temperatures of up to 100°C can be reached. This type of panel is highly efficient (heat is converted into heat). The heated water is relatively easily storable, even at large quantities. These panels are therefore ideal to generate a supply of warm water for domestic and industrial use. However, due to their low temperature, the conversion of the heat energy into other forms of energy (mechanical or electric energy) is very inefficient (see Annex 1).

3. **Thermo-solar high temperature panels and systems (100-350°C):**

   These systems, also called CSP systems (for "Concentrated Solar Power") collect heat energy from the sun (mainly visible and infrared irradiation), typically to generate saturated (but not super heated) vapor at high temperature (up to 350°C) and high pressure (up to 60 bars). The high temperatures are needed to increase the efficiency of the energy conversion from heat to usable electric energy. To get to these higher temperatures, the solar radiation needs to be concentrated, so that the surface-specific irradiation is corresponding not only to one sun, but to "many suns". Various examples of such concentrators have been developed, but there are two main types:

   - **Trough-shaped concentrators:** The sun is focused to a centrally disposed tube, in which a liquid circulates that can absorb heat. Heat absorbents are typically water or mineral oils.

Fig 2: Trough Concentrator

   - **Extra Flat Concentrators:** The same principle can be arranged in a lower cost arrangement, as in the following figures:

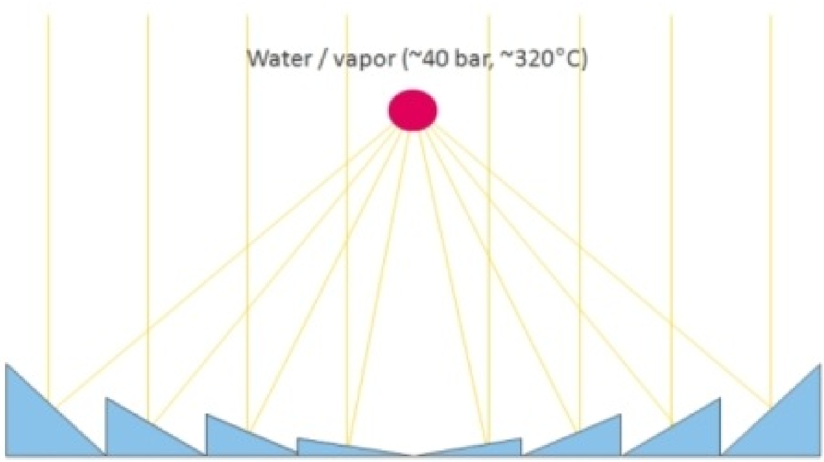


Fig 3a and 3b: EFC (Extra-Flat Concentrator)

4. **Thermo-solar very high temperature panels and systems (>1000°C):**

   There are many examples of very high temperature solar concentrators. The high temperature allows for a very efficient energy conversion, but current solutions are still by far too expensive. It is hard to understand that they ever could become cost competitive.

Cost Considerations

The costs of a solar solution for very high energy quantities need to be similar to today's energy costs, or at least not much higher, as this would have a very negative impact to the world economy.

To estimate the maximal costs that could be accepted in a competitive market environment, we have to start by considering the solar irradiation which is defining the potential revenues. Near the equator it is in the order of 1 kW (kilowatt) per square meter at noon and clear sky. This corresponds to an irradiated mean power of ~250 W (as a mean over 24 hours, i.e. day and night) , equivalent to an irradiated energy of 6 kWh (kilowatt-hours) per day and per square meter. The efficiency of the conversion from solar energy to usable energy (delivered at user's site) is around 10%. In an optimal case (365 days of sunshine, latitudes 0-20°), this mean solar power corresponds to a converted energy of 220 kWh per year and per square meter. At a price of crude oil of around 0.07 US$ per kWh (if converted to equivalent electric energy), this translates to revenues of ~14 US$ per square meter and year. Assuming that 10% of the costs per square meter are used for financing costs and amortization (amortization time of 20 years) and that 10% are used for operational costs, the investment becomes profitable if the costs per square meter are below 70 US$ per square meter (see detailed calculation below).

All current solar solutions are at least 5 times, most often rather 10 times more costly than that. Therefore, new ways and new solutions are needed to provide solar energy at truly competitive costs, so that it becomes a commercially interesting issue, not just an idealistic dream.

It is unlikely that PV panels would ever be available at costs below 200 US$ per square meter (see figure 4). This is mainly due to the fact that the material of the PV panels (semiconductor material) is process- and energy intensive. Also, the advantage of PV solutions at small and medium scale turns into a disadvantage at very large scale. The wiring, power conversion and cleaning would be difficult, and, most of all, the storage of energy is difficult, too.

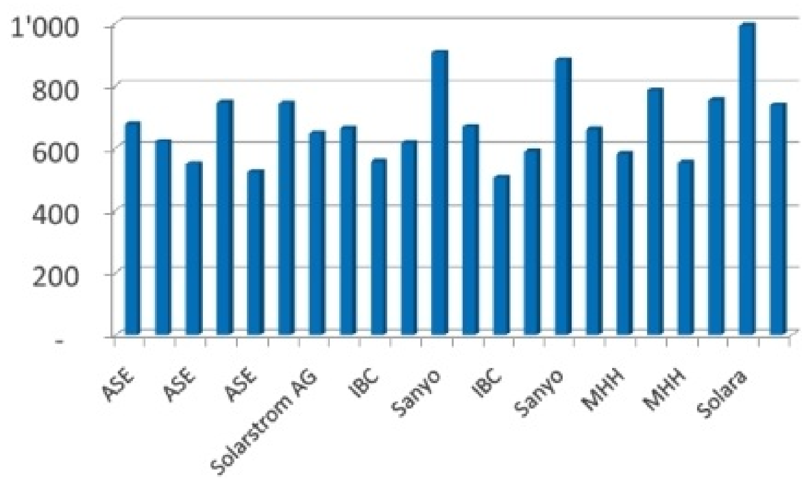


Fig 4: Photovoltaic module costs of various producers (US$ / square meter, without electronics!)

CSP systems are just the opposite: They are very expensive at small scale (the conversion of vapor to electricity is complex), but they are an excellent solution at very large scale. The reason is simply that at very large scale the active panel area becomes the main cost driver, while the auxiliary systems are much less important.

The conclusion is obvious: High temperature thermo solar panels (=CSP) are clearly the lowest-cost solution at very large scale, while PV systems are the best choice for small systems.

A New Solution

EFC (extra flat concentrators) panels, as described in figure 3, are already offering system solutions which are considerably less expensive than all other solutions. But they still suffer from two disadvantages which render them too costly. Firstly, as they need to follow the sun in its path across the sky, they have to make use of a precise and costly tracking mechanism. Secondly, they offer a large resistance to wind. They either have to be built very ruggedly (expensive), or they lose dramatically in efficiency (wind movement meaning de-focusing, therefore loss of efficiency). It does not seem to be possible at first glance to construct a panel which focuses horizontally, instead of vertically (i.e. turning left-right, instead of up-down), as the panels have to be linked to high pressure vapor lines that go from panel to panel:

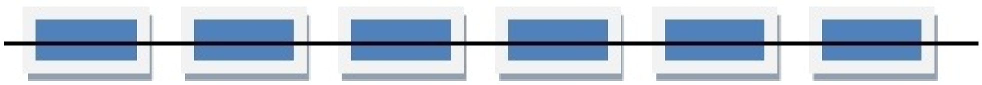


Fig 5: Schematics of a line of solar panels with connecting high pressure tube

As the figure shows, it is not possible to turn the panels in this line individually; they can only be turned as a whole. This is where the idea of Solar Islands comes in: If one could put all panels on a very large platform and then turn the platform as a whole, the panels could be fixed horizontally on the platform (offering almost no wind resistance) and be focused by turning the whole platform, thus providing a very cost-efficient solution.

Floating Platforms

Based on the ideas of the author, CSEM has designed a very simple way to provide such a solution, i.e. a very large platform which can be turned as a whole. As the weight per square-meter by the loading of the solar panels is extremely regular (for instance, one panel every 10 meters), we can make use of a very simple principle: A large low-cost surface sheet (typically a plastic sheet) is fixed to a frame in an airtight manner. An over-pressure is applied below the membrane, thus exerting a vertical force. The amount of the over-pressure can be adapted to the specific weight per square meter. In this way, very considerable weights can be easily lifted (without lateral forces!). One tenth of an atmosphere of overpressure exerts a force equivalent to 100 g per square centimeter. This corresponds to 1 ton per square meter already! Therefore, it is easily possible to exert a sufficiently high overpressure to lift the membrane with the panels fixed on top of it.

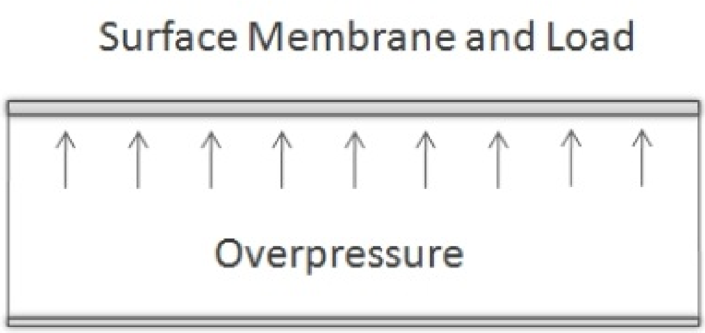


Fig 6: The principle of "floating". Note: No lateral forces are occurring!

In addition to that, there are ways to turn the platform as a whole to focus the panels to the sun. CSEM proposes to do this in two possible ways:

- **Solar Islands floating on water:**

  In this case, the easiest way to construct it is to design it as a spherical platform, which is formed by a swimming ring (typically made of pipeline tubing) over which the membrane is extended and which can be turned very accurately by means of hydrodynamic motors (spaced for instance every ten meters).

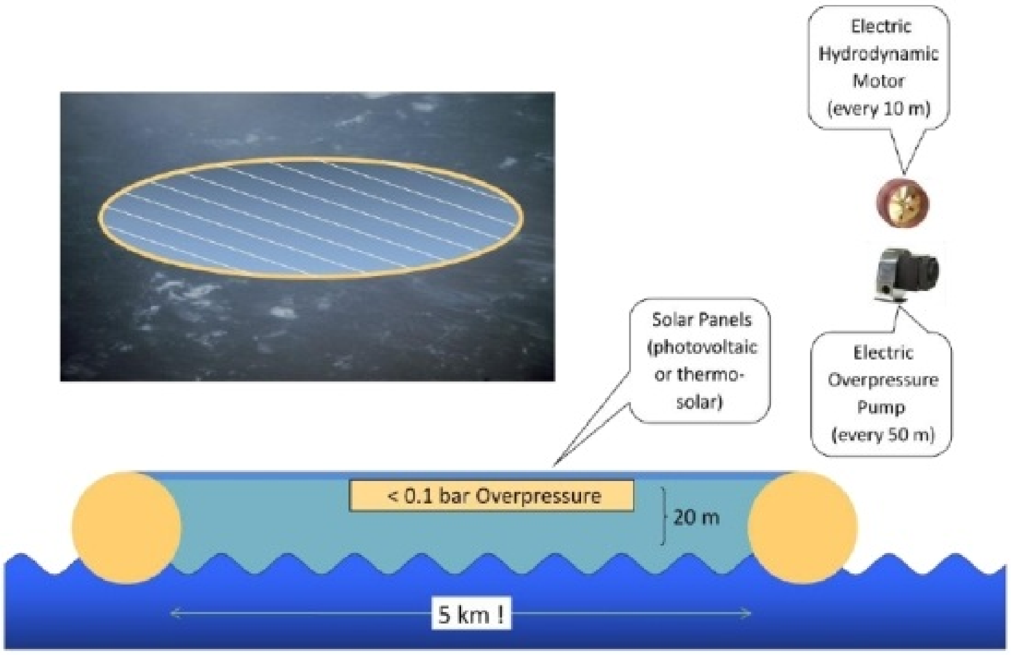


Fig 7: Principle of Solar Island

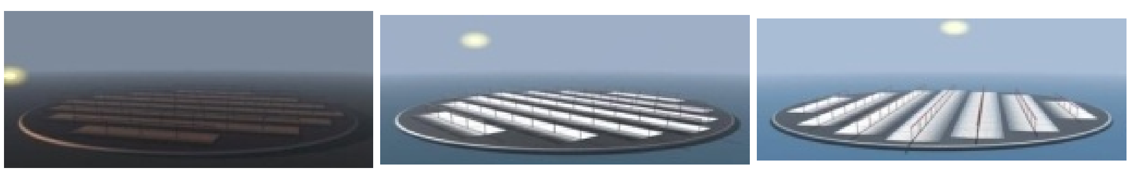


Fig 8: Turning with the sun

Fig 9: Focusing Principle

- **Solar Islands on Ground:**

  Using a special construction on land, one can use exactly the same principle as described above, as shown in figure 10.

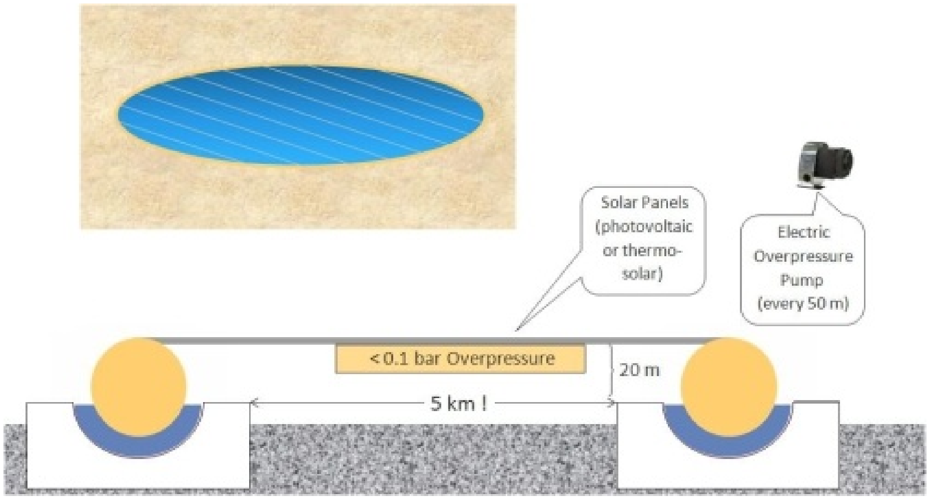


Fig 10: Solar Island on "terra firma"

In this case, a channel has to be built, filled with water or oil, in which the Solar Island can float just like on the sea. Please note that the length of the channel is proportional to the radius of the island, but the surface to the square of the radius. This means: The bigger the island, the less of a problem to build the channel – the costs become soon negligible in comparison to the total costs. The bigger the island, the more the costs are primarily defined by the costs of the solar panels.

Fig 11: Solar Islands – on high sea, near the coast or in the desert

This is why the concept of Solar Island clearly provides a lowest cost solution for solar energy, as the solar panels used are simply – glass! And the focusing mechanism is very simple.

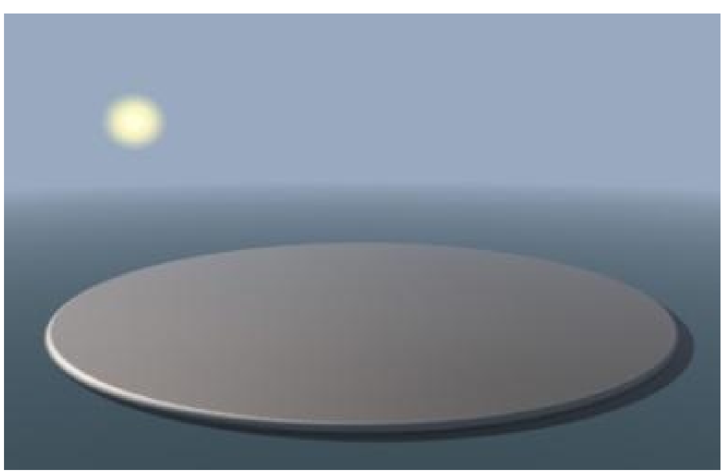


Fig 12: Computer simulation of large Solar Island

Combined Systems

The efficiency of the high temperature solar conversion into electricity is estimated to be around 10%, as mentioned in the paragraphs above. This is a very conservative value; actual experiences let us hope to achieve efficiencies nearer to 15% than to 10%. In addition to that, there is the clear and interesting possibility to combine the energy conversion to electricity with water desalination and/or district chilling. Depending on the local situation of the site of a solar island, as long as it is either on land or not far from a coast, the co-use of the electricity generation process can be used to increase the overall efficiency considerably. Values of up to 18% seem feasible. At such efficiency levels, solar islands would generate electric energy in a commercially competitive way already now.

Energy and Profitability Considerations

Efficiency can be estimated in several ways. We know that it will be somewhere between 10% and 20%, from solar energy to electricity. Let us, for the time being, assume an efficiency of 15%. As outlined above, in very sunny regions at latitudes between 20° north and 20° south, we get about 220 kWh converted energy per square meter and per year, at a mean power of about 250 W solar power per square meter (clear sky). An island with a radius of 1.5 km, covered at 90% with solar panels, having an active surface of 6.4 square kilometers, provides a maximal power of 0.96 GW (Giga Watt) and a mean power (24h/24h) of 192 MW, generating energy of 1.5 TWh per year (1.5 billion kWh per year). This is corresponding to the energy of a small sized nuclear power plant!

Calculation Sheet:

Radius	1.5	km
Surface	7'068'583	Square Meter
Conversion Efficiency	15%	
Active Surface Coefficient	90%	
Active Surface	6'400'000	Square Meter
Cost per Square Meter (Panel)	150	USD
Cost Overhead	20%	
Assumed Price per kWh (2008, no subsidies by Governments)	0.17	USD
Mean Solar Power Per Square Meter (clear sky)	200	W
Maximal Power Per Square Meter (perpendicular to sun)	1'000	W
Sunny Days per Year	330	
Mean Power	192	MW
Maximal Power	960	MW
Energy per Year	1'500'000'000	kWh
Income per Year and per Square Meter	40	USD
Income per Year	255'000'000	USD
Cost	1'152'000'000	USD
Operation and Maintenance Costs	115'200'000	USD
Amortization and Interest	92'160'000	USD
Profit	47'640'000	USD
ROCE (return on capital employed)	4.10%	

Break-even Price of kWh	0.15	USD

As this calculation shows, the business of Solar Islands starts to become profitable at an energy price of around 12 cents per kWh of electricity. The ROCE (return on capital employed) is already 5% at energy prices of 15 cents per kWh. Other important profitability parameters:

- Panel costs, estimated to be 100 US$ / m^2, will be quite possibly lower at high quantities
- Efficiency levels, estimated at 10%, will be quite possibly higher, for two reasons:
  - Maturity of technology will increase the performance
  - Co-generation of cold (for district cooling) and sweet water production is increasing the overall efficiency of the process

We do firmly believe that a mixture of these three areas for potential profitability increases will allow for a very interesting business in solar energy at very high volume.

Photovoltaic and Solar Island

A special construction of concentrators allows combining the principle of Solar Island with photovoltaic panels (figure 13).

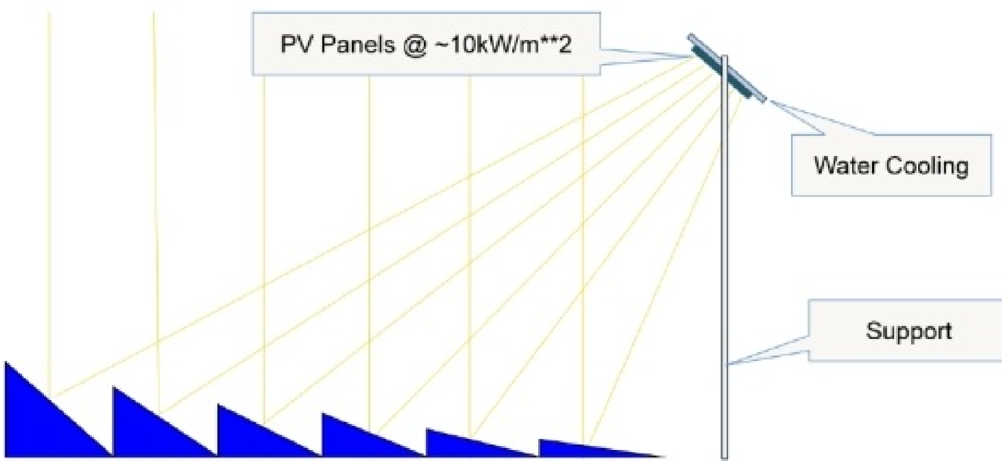


Fig 13: Photovoltaic panels combined with concentrating mirrors

As shown in this figure, the solar irradiation can be increased by up to a factor 10. This means that only 1/10th per sqm is photovoltaic material, 9/10th is of mirror material. Even at photovoltaic costs of up to 500 US$ per sqm, the mean cost per sqm is as low as 140 US$. This principle therefore not only allows for very cost-efficient PV solutions, but at the same time the fixation, cleaning and connection of the PV panels becomes much simpler. The concept of solar islands opens possibilities in CSP (concentrated solar power) and photovoltaic!

Cost Comparisons

The comparison of cost per kWh (i.e., not price – that is yet another issue!) is difficult to do. It has to base on a certain number of assumptions. Our estimations yield the following results (figure 14):

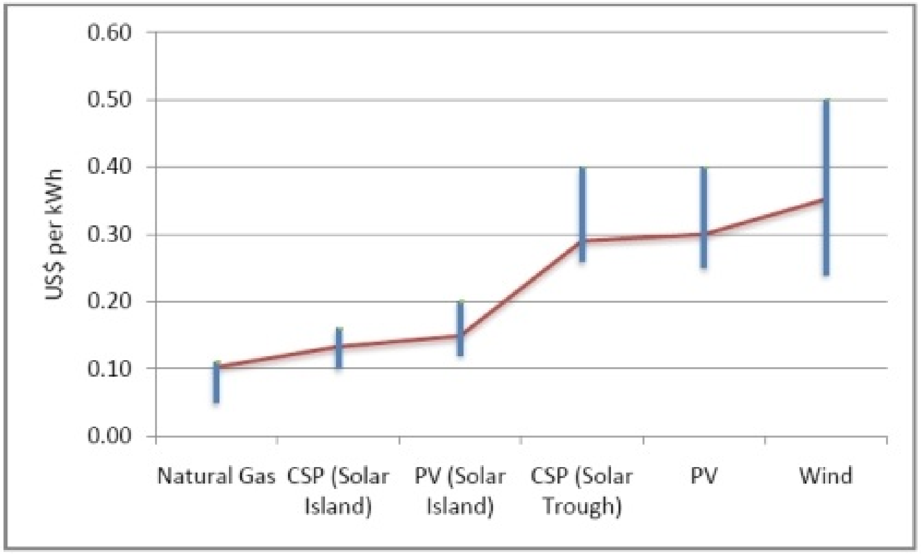


Fig 14: Cost comparison

The comparisons are made for latitudes of below 20^{0} - at more northern sites the costs per kWh goes up in line with the reduced solar radiation (see Annex 1). It is obvious that all solar-island-type solutions are extremely cost competitive.

Next Steps

Many countries and many institutions have shown their interest for the ideas of Solar Island. CSEM has founded a company named Nolaris Inc., so as to be able to follow up on this interest. Nolaris is currently in a start-up mode, but it already pursues potential contracts in Malta, Qatar, Chile and Tunisia.

The most concrete partner is the government of Ras al Khaimah, the northern-most Emirate in the United Arab Emirates (UAE). Ras al Khaimah decided to finance a prototype solar island in the desert of the UAE near Ras al Khaimah City. The construction of this prototype island (diameter 100m) has started; it should begin to operate by mid of 2008. It will prove the feasibility of the concept and give a clear idea about the achievable costs.

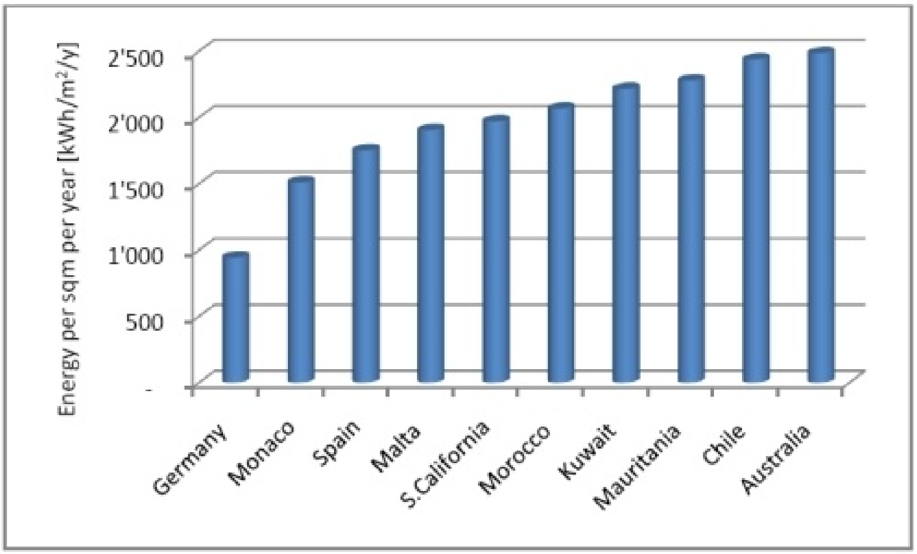
References

[1] Patents claimed and deposited - all ownership of intellectual property rights are with CSEM S.A. and Nolaris S.A..

[2] Disclaimer: This is a conceptual description, meant to clarify new ideas for solar technology, so that they can be discussed and analyzed. Please do not definitely rely on this data, as it is subject to detailed technical discussion and feasibility.

[3] Solar electric energy is today about three to four times more expensive than electric energy from nuclear power plants. Solar "storable" energy (like liquid hydrogen or other energy carriers) needs to be generated from solar electricity (at least, based on today's technologies). The comparison of crude oil and "solar" hydrogen is therefore even less in favor of solar energy. Yet it is this form of energy (not electric energy) which forms the bulk of the global consumption.

Annex 1: Solar Radiation Energy in Different Countries


Energy per sqm per year [kWh/m²/y]
2'500
2'000
1'500
1'000
500
-
Germany
Monaco
Spain
Malta
S.California
Morocco
Kuwait
Mauritania
Chile
Australia