A Technology Assessment of

PHOTOVOLTAIC CONCENTRATOR SYSTEMS (CPV) AND THEIR PROSPECTS

By Peter Stafford

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Declaration

The work contained in this dissertation entitled, ‘Technology Assessment of Photovoltaic Systems and Their Prospects.’ is the sole work of Peter Stafford and where other people have contributed they are suitably acknowledged.

Signed:……………………………………………………………………….

Date:………………..

ABSTRACT

This dissertation attempts to put some clarity and order into our understanding of the dynamic development of Concentrator Photovoltaic Systems (CPVs) in the world today. The photovoltaic industry is showing high growth and this is being driven by the demand for flat plate silicon modules (about 90 % of the market) and thin film modules (almost all of the remaining 10 percent). In the last two years we have seen a 'perfect storm' situation of favourable factors driving the development of CPV in line with the growth in the rest of the industry. The reasons behind this storm are multifactorial, including silicon supply shortages, increases in the power output of high efficiency cells, recognition that 'climate change' is a problem that needs remedying. Technology development programs have helped to solve problems that high concentration of sunlight cause, such as photovoltaic (PV) cell damage, tracking inaccuracy and lens degradation.
My method of adding clarity was to simply find out as much information as possible on CPV technologies and the businesses that are attempting to develop them and to then devise a method of rating their likelihood of success in this new market.

Information was very hard to come by with companies guarding their secrets well. After examining the data collected, trends such as lenses being preferred over mirrors in High Concentrator Photovoltaic (HCPV) systems became evident. HCPV conversion devices were more numerous in type and overall numbers deployed on the ground. This popularity over Low Concentrator Photovoltaic (LCPV) systems was by a factor of three with only two companies, Entech and Whitfield Solar, developing what I term a Medium Concentrator Photovoltaic System. (MCPV). Finally I rated ten firms as market leaders because of their potential to develop near MW and MW levels of power in 2008. Special mention is given to four firms who may be able to ramp up their production quickly. The industry has been changing rapidly during the short time of my research with firm acquisitions, mergers, technology sharing and buyouts common. An added bonus to my research is the collection of company contacts that may help interested parties keep abreast of this dynamic industry.

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ACKNOWLEDGMENTS

I would like to thank my loving wife and three children for supporting and understanding a sometimes tired and grumpy father.

There were also helpful individuals I encountered all over the world who chose to answer my questions, and interact with me, for what I guess may be a shared passion for renewable energy and perhaps something to do with the brotherhood of man.

I have had wonderful support both at work at the Metropolitan Fire Brigade in Melbourne and Murdoch University, where I've been very fortunate to have Professor Philip Jennings as my supervisor, who has been an intelligent and caring form of 'The Rock of Gibraltar'.

Finally, and under stress she was not responsible for, I'd like to thank Lisa Bryant of the MFB for providing the important format polish.

1. INTRODUCTION

As stated in my plan, I wished to become familiar with the Concentrator Photovoltaic (CPV) industry and its history, particularly a company called Solar Systems whose main office and workshop is located in Hawthorn, Melbourne, where I also reside.

I wanted to learn about the differences and similarities of rival CPV groups around the world. This includes learning about the different technologies of CPV systems and estimating their economic competitiveness (within CPV and in general) and thus gain an overview of where the industry may be heading, how fast and with whom in the lead. I desired to learn about conducting research using formal methods.

I wanted to make contacts in the industry and explore whether I want to work in it.

I set out to gain specific knowledge of the different CPV technologies and as much of their design, for example, operating the differences between high, medium and low CPV plant.

In summary, I wanted to know if the industry was succeeding, and who were the firms to emerge from the pack as the most likely to succeed.

Concentrator Photovoltaic Systems (CPV) have been a part of the PV scene almost from the start of PV technology. There were systems constructed in the mid 1970s firstly in the USA and then Europe that have made a small but significant contribution to the development of the PV industry. This history of CPV is nicely summarised by the European Renewable Energy Centres Agency (EUREC) at:

http://www.eurec.be/component/option,com_docman/task,doc_view/gid,5/Itemid,43/

At this site it states that there are three main reasons for the slow commercialisation of CPV technology compared to plat-plate PV. These are that CPV wasn't well suited to deployment in small industrial and roof-top applications and there are such a large variety of technical problems that have to be solved. In the longer term, this provides great scope for continued improvement. It is this improvement we need because in producing electricity using photovoltaic (PV) cells, the cost of electricity is still too high.

The price of the PV cells is usually the most expensive part of an installation. One way of reducing the cost is to concentrate the sun's energy using mirrors and/or lenses. This allows the PV cell size to be reduced, lowering system prices, decreasing costs by improving efficiencies and reducing material use. The concentrating PV industry can be divided into three categories, low, medium and high concentration. The area capturing the sun divided by the area of PV cells is termed the concentrating ratio (CR) and both low and high CR systems are being developed because both have their advantages and disadvantages, but MCPV systems are few. One author, (Maeda 2007), identified the three categories of CPV using the following criteria:

- **Low :** CR of 2 to 10 suns with Si cells and no tracking or single axis tracking.
- **Medium :** CR < 100 suns. Single axis tracking and direct sunlight.
- **High :** CR **>** 100 suns Si cells up to 100 suns and III-V cells for higher concentrations. Two axis precise tracking and direct sunlight.

In general the advantage of high CR cells, as already stated, is an increased efficiency and decreased area required to site the power system as well as lower material use per watt installed. There is a study on the NREL (National Renewable Energy Laboratory) (McConnell 1998) website that suggests it is 5 to 6 times less expensive to construct a 100 MW CPV plant compared with a polysilicon one (thin film or crystalline) producing the same wattage. It follows that to increase production of a solar technology, the higher the CR, the lower the cost of manufacturing per watt of output. This is because high efficiency cells and concentrating infrastructure are easier and cheaper to manufacture than the equivalent lower concentration system.

Mr Robert McConnell of the NREL in the United States (McConnell, 1998) states that it is the opinion of research and industry that with the advancement of III-V type cells, a price of US$3.00 a peak watt installed can be reached soon. Research papers state that they are confident US $1.00 a peak watt will be reached by 2020. (McConnell, 2005).

The 2006 CPV position paper from EUREC (Dr. A. Bett, 2006) stated categorically that a total system approach must be followed to maximise research efforts to decrease the cost of CPV and that automated industrial module assembly with high throughput would be essential as would quality assurance over a product life of at least 20 years. That is, the whole system including, for example, the BOS (Balance of system) components needs to be researched; not just cell efficiencies and material reduction.

The main disadvantages of the high CV systems are, being able to dissipate the heat produced, the ability of the cells to function efficiently under such heat, and the need for accurate and reliable tracking of the sun. Detractors of CPV also mention the technology’s inability to utilise the diffuse component of solar radiation, limiting CPV roll out perhaps in cloudy regions, more so than for thin film.

In sections 3.2 to 3.4 is a list of low, medium and high CPV systems that are being developed or have been developed is provided. At the end of the list is a section (3.5) on some promising new technologies, ‘hybrid solar thermal and CPV’ combined systems and some high efficiency CPV cell manufacturers.

There is a good introduction to CPV (with CR of 10 or greater) at the following site of the United States Department of Energy:

http://www1.eere.energy.gov/solar/solar_america/pdfs/41735.pdf

2. METHODS

2.1 Approach to the Project

The CPV industry at present is very immature and coupled with an increase in demand for energy, especially renewable energy; there are great opportunities for companies to develop new technologies. This provides me with an interesting topic, because of the variety and high number of CPV technologies being worked on. To bring some meaningful order in which to assess these pioneering companies I have adopted the following research plan:

1. Carry out web searches and literature searches on CPV companies
2. contact companies involved if necessary for further information
3. develop an assessment methodology
4. compile data on various models of CPV
5. make comparisons and assessments
6. draw conclusions about the state of this technology

2.2 Assessment Methodology

I intended to find the current, 2009 and 2014 Levelised Cost of Energy (LCOE) in $/kWh and manufacturing output and predicted output in MW's for all companies manufacturing or planning to manufacture CPV systems.The LCOE is the average cost of energy in real dollars over the lifetime of the system, including:

–Cost of components, design, permits, shipping, installation, profit

–Cost of ownership, such as O&M, insurance, taxes

–Financing, including taxes and permanent incentives

–Energy produced (kWh), including degradation

The LCOE is estimated using expected weather data and performance modelling.

In addition, I wanted to know how much capital the company has behind it and how much CPV it had installed and plans to install.

Information to assess the specifics of most systems was not available because of fears of IP theft and giving competitors an advantage, therefore I decided to use another method of assessing CPV products. This method was based on assessing the product in terms of the following criteria:

1. What type of photovoltaic cell does the module employ?
2. Does the system fit into the category of low, medium or high concentration?
3. What is the efficiency of the cells used?
4. Is the company well funded?
5. What niche market is available to this technology? That is, what is their target market?
6. Will it be a competitive, successful and suitable system on a domestic, commercial, or in a grid support situation as a power station or all or any combination of the above? (D-domestic roof, C-commercial roof, GS-grid support, PS-power station.)
7. Does it use lenses or mirrors or a combination to concentrate radiation?
8. What is the expense to build and operate this system?
9. Is the product available commercially yet? Is it mass produced? What quantity was made in the past few years?
10. What is the projected rate of manufacture?
11. How many people work for the company?
12. Is the company privately owned or a listed company on the stock exchange?
13. How experienced are relevant staff members?
14. How robust, reliable and long-lasting is the product? Have accelerated life trials taken place?

I planned to use a rating scale from one to ten for each criterion with ten being for outstanding success potential and a rating of one could be for an aspect of the firm or technology with very limited potential.

Unfortunately I judged that the accuracy and quantity of information returned to me did not justify such a rating comparison. Instead I instigated a more useful assessment on the information I had collected. This assessment method I produced is more general in outlook and probably more suited to the immaturity of this technology, although it still allowed statistical analysis and discovery of trends and interesting comparisons and interpretations of these statistics.

3. RESULTS

3.1 Literature Search for CPV Technology

To add to my knowledge in the area of Concentrator Photovoltaic technology, I read the recently released book titled 'Concentrator Photovoltaics' published by Springer (A.Luque and V. Andreev, 2007) as the latest text in their optical series. This led to me gaining a good background in the historical development of CPV, the technology and current research being undertaken. It provided literature references that allowed me to continue to improve my knowledge in CPV.

The USA's National Renewable Energy Laboratory research archives were equally as informative at the following website:

(http://www.nrel.gov/eis/publications_2003.html)

The Universities of New South Wales and the Australian National have also strong research history in PV technology. See the following two websites for research and general information in photovoltaics.

solar.**anu**.edu.au/level_1/links/others.php

www.ceem.**unsw**.edu.au/content/Pubs.cfm

NASA (SAO NASA ADS Solar Physics Abstract Service) also operates an abstract and full text papers retrieval service and I used the following site to access much of the scientific work on CPV that has been published to date. The website to access this immense resource is:

http://adsabs.harvard.edu/cgi-bin/nph-basic_connect?qsearch=concentrating+solar+photovoltaics&version=1

3.2 High Concentration PV Systems

3.2.1 Amonix

www.amonix.com

Amonix proudly boasts to be the leading CPV firm world wide and are producing their sixth generation system The company claim to have been in business since the late eighties. Its system is designed for large commercial and power plant scale use. As each unit weighs around 20 tonnes, they are not suitable to mount on rooftops.

Amonix has developed a HCPV system that concentrates the sun approximately 500 times using inexpensive flat plastic Fresnel lenses and a 26.5 % efficient silicon (Si) solar cell. They are located in Torrance, California. Amonix holds the world efficiency record of 26.5 % (for a commercial cell made from Silicon) through innovations including placing both electrodes on the same side of the cell allowing easier manufacturing through automated surface mounted robotic assembly and maximum capture of the sun's energy. The system uses tracking that provides 30 percent more radiation through their hydraulically driven tracking system. Amonix claim they offer the lowest levelized cost of electricity produced by any solar technology. They hope to decrease the cost of electricity produced by this system through high volume production as shown below in table 1.

Year	LCOE ($/kWh)	Manufacturing Capacity (MW)
2006	0.33	1
2009-10	0.14	60
2014-15	0.06	1000

Table 3.2.1 Production Data for Amonix

There is a very interesting paper (Slade *et al.*, 2007) available under ‘scientific papers’ on the Amonix website that compares the use of its silicon cell of 26.5 % efficiency with the use of the triple junction cells. Using modelling designed for comparison of thin film with multicrystalline modules in the flat plate industry, the Amonix employees found that high cost ($ per watt excluding cell cost) systems in large volumes best suited their lower cost but lower performing Silicon cell. This research led to the continued use of these silicon cells of 26.5 percent efficiency developed by Amonix.

An important point made in this paper (Slade *et al.,* 2007) was that their cell efficiency ceiling is 30 %, and so if the triple junction cells efficiency can improve to above 50 percent; the triple junction cells will have an advantage in both low and high cost situations.

Around 2005 Amonix signed an agreement with Guascor to service Europe. This joint venture has established a CPV plant in Talayuela (Caceres) of 950 kW capacity. Amonix is expanding to full commercialisation and has many employment and investment opportunities at present.

Amonix Incorporated.

3425 Fujita Street Torrance California 90505

P 3103258091

3.2.2 Arima EcoEnergy Technologies Corp

www.arimaeco.com

Arima is based in Taiwan and has developed a 476x GaAs triple junction HCPV system that is rolled out in 120 watt modules, with 8 modules forming a sub array on a tracker. Importantly, Arima has been selected as one of four new CPV companies to construct a demonstration 300 kW array at ISPHOC Institute in Spain, where it will be monitored. These four companies will join three already selected by ISFOC in the first round of tenders.

The seven companies demonstrating at ISFOC are:

SolFocus, Concentrix and ISOFOTON from the first group, and Arima Eco Concentracion Solar La Mancha, Sol3G and Emcore from the second round of bids.

Arima was the only company to fully answer my survey sent by hard mail and its responses are as follows:

1. What is the geometrical concentration ratio (GCR) of the system? **Ans:** GCR is 476 X
2. What is the efficiency of the cells you are to use? **Ans:** about 37% @ 500 X concentration
3. What is the capital backing of the company? **Ans:** about 3M US dollars
4. What market niche is the product aimed at? That is, is the market for the product, domestic roof, commercial or factory roof, grid support or power station and have you set up a sales network in Australia? **Ans:** We aimed at grid support and power station. We don't have a sales network in Australia yet, but we are glad to have cooperation companies in Australia.
5. What is the projected cost of power provided by the system? **Ans:** The projected cost under different conditions is described as follows:
   a) The hours of sun shine is 1500 hours/year.
      i) If your capital investment return is 8 years and the interest rate is 4%, then the cost will be 96.8 cents/kWh.
      ii) If your capital investment return is 20 years and the interest rate is 4%, then the cost will be 52.8 cents/kWh.
   b) The hours of sun shine is 2500 hours/year

i) If your capital investment return is 8 years and the interest rate is 4%, then the cost will be 58.08 cents/kWh.

ii) If your capital investment return is 20 years and the interest rate is 4%, then the cost will be 31.68 cents/kWh

6. Is the product manufactured yet? Is it mass produced? What quantity was made in the past few years? **Ans:** This product has been developed this year and it will be mass produced in spring 2008.
7. What is the projected rate of manufacture? **Ans:** 100kW/ month rate.
8. How many people work for the company? **Ans:** There are 37 crews in our company right now, and it is forecast to increase rapidly in near future.
9. Is the company privately owned or a listed company on the stock exchange? **Ans:** This Company is privately owned now, and we anticipate our company will go public in few years.
10. How experienced is the staff? **Ans:** The most experience staff has more than 5 years on CPV R&D.
11. How robust, reliable and long-lasting is the product? Have accelerated life trials taken place? **Ans:** We will do all the tests of IEC-62108 standard, and the product has been designed to meet the requirement of this standard.

E-mail: arimaeco.sales@arimaeco.com
Addr.: 2F., No.349, Sec. 2, Renhe Rdy, Dasi Township, Taoyuan County 33547, Taiwan (R.O.C.)

Mr. Bill Tzou (Sales manager)
Tel: 886-3-3909125 Ext. 7130
Fax: 886-3-3909131

3.2.3 Boeing Spectrolab (USA)-CPV Cells Only

www.spectrolab.com

Boeing is leading a 'Solar America' team that is aiming to produce 20 MW annually by 2010 at a cost of 15 cents / kWh and by 2015 to ramp the production up to 150 MW p.a. at half the price, 7 cents / kWh, see Table 1 below. It plans to achieve high power densities by concentrating the solar flux with lenses and mirrors that make use of record breaking triple junction cells. They also plan at least a two fold decrease in cost and increases in production targeted at a utility scale market.

It has an involvement with SolFocus (contract to buy 600,000 SolFocus modules) and also Pyron Solar and Lion Energy with whom they have signed an agreement to roll out CPV in Greece and the UAE and Middle East. The letter of intent was signed in mid 2007. It was also reported in mid- 2007 it was also reported that Delta Electronics had designed a CPV devise that converted solar radiation into electricity via Spectrolabs triple junction cells (TJCs) at 35 percent cell efficiency. See Pyron Solar, below, for more details.

Year	LCOE ($/kWh)	Manufacturing Capacity (MW)
2006	0.3181	1
2009-10	0.1494	20
2014-15	0.069	150

Table 1 Proposed production and cost of energy for Spectrolab systems

mailto:terrestrial@spectrolab.com
Spectrolab Incorporated
12,500 Gladstone Avenue, Sylmar, California, USA, 91342
Ph 818 365 4611

3.2.4 Concentration Solar La Mancha

www.cslamancha.com

CSLM (Concentration Solar La Mancha) has been selected as one of the two Spanish firms to present and trial at ISPHOC (Instituto de Sistemas Fotovoltaicos de Concentracion.) The CSLM system uses Triple junction cells (InGaP, InGaAs on Gallium substrate) under five hundred times concentration from patented refractive lenses. The exact concentration wasn't specified but there was mention of a patented semi- ventilation system that sounded interesting. CSLM is in partnership with a specialist tracking manufacturer and a construction company.

Poligono Industrial CalleD s/n
13200 Manzanares (Cludad Real) SPAIN
34 926 64 74 14
Info@cslamancha.com

3.2.5 Concentrix Solar (DE)

www.concentrixsolar.de

Concentrix is spin off from the Fraunhofer Institute for Solar Systems ISE and uses what it has named a 'flatcon' system. It concentrates the sun 500 times with a Fresnel lens onto triple junction cells produced by Azur. These triple layers of III-V semiconductors have a cell efficiency of 35 % and an efficiency of 25% in the 'Flatcon' module. The system employs dual axis tracking. Concentrix has a presence at ISFOC and is based in Freiburg, Germany.
At present there is a 5.6 kW demonstration plant in Freiburg in Germany and a 500 kW system is planned for the ISFOC project in Spain after Concentrix became one of the successful four initial tenderers. In February 2006,

GoodEnergies took a share in Concentrix. By mid 2008 an upgraded manufacturing capacity should reach 25 MW/yr.

Solar Info Centre
info@concentrix-solar.de
79072 Freiburg, Germany.
Ph. 49 761 2141080

3.2.6 Cool Earth Solar CES (USA)

http://www.coolearthsolar.com/

Cool Earth Solar is a group formed out of scientists concerned over the threat posed by climate change. These scientists gathered for a summit where they agreed to solve the global warming problem. Their concept to achieve this end is to concentrate solar radiation using plastic collectors tethered from poles, leaving the land underneath for other uses. Some details of the technology are available at:

http://www.coolearthsolar.com/CoolEarth%20Solar%20Power%202006%20Presentation.pdf

They estimate they will be able to achieve grid parity within three years. For phase one the predicted installed cost is $1.30 / watt for a 10 kW system and for phase two $0.47 / watt installed on a system of the same size. Phase two is scheduled for 2010. This system is designed to concentrate sunlight 250 times. Each two meter wide concentrating balloon is 400 times cheaper than polished aluminium, can be changed over in less than 15 minutes and is secured using a tensioned wire system to retain the farm of balloons from their harness to poles stuck in the ground. In June 2007, Cool Earth Solar merged with Radiant Energy who is a Renewable Energy development and owner company. CES also incorporated as a Delaware corporation.

7665 Hawthorne Avenue Livermore, California, 94550, USA.
Ph. 925 454-8506
info@coolearthsolar.com

3.2.7 Daido Steel Co Ltd

http://www.daido.co.jp/english/index.html

Daido Steel apparently has five systems installed. that use multi-junction Sharp cells and a system that concentrates the sun 550 times.

Daido Steel apparently constructed a 9 kW array as a demonstration of the technology in 2006. The company has been a part of a collaborative effort named the ‘Syracuse’ group, which includes Sharp, Daido Steel, and universities from England, Germany, Australia and Japan. The company has published research papers on CPV related technology. It’s hard to find any up to date information on this group.

Patrick Maeda (Maeda, 2007) states that it is working with Sharp and has a presence at the PARC research facility. Please see the information under ‘Sharp’.

Update: I have received a detailed response to my questionnaire from Mr Araki and he also took the time to forward to me a document describing the company’s research and development of a 400 and 550 concentration CPV module en titled “CPV Using 3J III-V Cells and Fresnel Lenses-Reliability, Applications and Perspectives”, by K. Araki and Associates. (K.Araki, 2005) He also states, see below, the company has worked on a 1340x CPV cell.

This is Mr Araki’s kind response to my letter:

Dear Peter,

I am happy to contribute to your study considering the importance of establishing a safety guideline of this technology. Unfortunately, there are several CPV systems designed by non-experienced or less-considered engineers and amateurs.

Answer:

1. What is the optical Concentration of the system? **Ans:** 550X and 1,340 X

These are geometrical concentration ratio (Aperture of optics / aperture of cells).

2. What is the efficiency of the cells you are to use? **Ans:** Typically, 32 - 35 % under concentration
3. What is the Capital backing of the company? **Ans:** See http://www.daido.co.jp/english/index.html.
4. What market niche is the product aimed at? That is, is the market for the product, domestic roof, commercial or factory roof, grid support or power station and have you set up a sales network in Australia? **Ans:** Domestic roof, commercial and factory roof Grid support. Sales network: **Ans:** Right now, NO
5. What is the projected cost of power provided by the system? **Ans:** Depends on construction and irradiation.
6. Is the product manufactured yet? Is it mass produced? What quantity was made in the past few years? **Ans:** It is not mass-produced. Total installation was about 10 kW.
7. What is the projected rate of manufacture? **Ans:** Not disclosed
8. How many people work for the company? **Ans:** See http://www.daido.co.jp/english/index.html

9. Is the company privately owned or a listed company on the stock exchange?

See http://www.daido.co.jp/english/index.html

10.How experienced is the staff? **Ans:** We are one of the pioneers in this field.

11.How robust, reliable and long-lasting is the product? Have accelerated life trials taken place? **Ans:** Designed lifetime: 20 years

The oldest system in the field has been working since 2003.

The following acceleration tests aside from the tests described in IEC62108 were done.

- High power UV concentration with spray cycle test
- Conventional UV degradation test typically done in automobile industries
- Dump heat test
- Temperature cycle test with and without bias injection
- freezing cycle test
- Pressure cooking test with and without bias
- Long-term water soak test
- Load cycle test typically done in automobile industries

Commenting on the fire risk, we are strongly encouraging all the CPV players in the world do off-axis endurance test described by IEC62108 (now sold by IEC). As far as I saw in the WEB pages, some unsophisticated CPV designs have potential risks in the fire by off-axis concentration. Attached is a paper from Daido Steel that shows

some example of off-axis endurance test with my own finger (presented at the 3rd International conference on solar concentrators in 2005).

Best regards,

Kenji Araki
Daido Steel

Daido Steel Co Ltd.
Kenji Araki
k-araki@ac.daido.co.jp

3.2.8 Emcore

www.emcore.com

Emcore constructed a 25 kW array in 2006 using 500 times concentration from lenses and reflectors, with two axis tracking and air cooling. Current annual production is greater than 50 MW.

Emcore is developing a 26.5 MW installation. Emcore states it is confident of reducing costs through system optimisation and cell efficiency increases.

From this website, Emcore predicts costs of thin film as US $ 2.00/watt, compared to flat plate US $3.50/watt and CPV $2.50/watt.

Emcore has been increasing its orders as I've been writing my notes and now has the following orders:

- A three year, 150 MW supply agreement spanning Greece, Italy and Spain.
- A 200 MW contract based in California, but needs a tax credit scheme to be continued after 2008 for it to proceed.
- It believes a few other orders totalling 38 MW should be placed in the near future.
- Green and Gold's order of 105 MW of chips has now increased from 24 to 39 million dollars due to the inclusion of concentrating receiver modules on top of the GaAs cell order.

- An ongoing 100 million dollar agreement with Isophoton to supply cells over five years.
- Someone in S.Korea has placed an order for 5.7 MW (to be extended to 14.3 MW) perhaps-rumoured to be involving DI Semicon who wish to enter the CPV market and have an order of 15 MW per year of Emcore CPV systems.

In December 2007: Emcore signed a MOU to supply 60 MW over the next three years in Ontario Canada for Pod Generating Group using Emcore's CPV technology. This project is due to start in mid 2008.

Fulfilling these orders has meant an increase in production from 75 MW per year from July 2006 to 150 MW in 2008 and the company has found that for each new 30 MW production, 5 – 7 million dollars of capital equipment is required.

Emcore has also bought ¼ to a 1/3 interest in Worldwater and Power Technologies to become a vertically integrated business in terrestrial CPV. The Emcore website claims this to be a first that it is both a triple junction solar cell manufacturer and a CPV systems provider.

Finally, Emcore was a successful tenderer for a second round place at ISFOC where it will install a 300 kW system.

On the 4/2/2008 it was reported in the 'Solar Daily' publication that Emcore were to supply 200 to 700 MW of CPV to California to act as peaking plant.

Emcore Solar Power Systems
10420 Research Road, SE
Albuquerque, NM 87123 USA
Tel: 505-332-5000 | Fax: 505-332-5038

Emcore Solar Power Design Centre
200 Ludlow Dr., Suite 3A

Ewing, NJ 08638

Tel: 609-671-6400 | Fax: 609-671-6414

3.2.9 Enfocus

http://www.enfocus.us/index.html

Enfocus is developing a CPV technology called Diamond Power, that will concentrate the sun 100 to 1000 times on a group of interconnected group of III-V, MJC (multi junction PV cells). This system is predicted to provide electricity at 40 to 100 percent greater power production than the equivalent area of flat plate silicon modules, at solar cell efficiency rates of greater or equal to 35 percent.. Enfocus modules will be stationary with dual axis tracking mechanisms inside the module, and will be able to be mounted as easily as flat plate modules. On the company website the company claims this technology will be cheaper and easier to produce and cheaper to scale up production when compared to standard silicon flat plate modules. With internal tracking, the normal maintenance problems with CPV of wind, hail, dust and moisture would be eliminated. The low profile of the module is a distinct advantage. On July 19th 2007 Enfocus received US $2.9 million incubator finance from the DOE through the EERE cost shared incubator projects fund. Enfocus' technology is rare in that its tracking is achieved inside the module and its design is aimed at rooftop installation.

1129 Robin Way, Sunnyvale, CA.

For further information contact Dr Jason Lu (CEO) via his email address:

Phone: 408 368-6123 | Jason.lu@enfocus.com, webmaster@enfocus.us

3.2.10 Entech

http://www.entechsolar.com/

Entech has been bought by ‘World Water and Power’, and is developing a 400 x CPV system using a colour mixing lens to concentrate the sun onto a Boeing Spectrolab cell. The company is combining 20x primary optical lens with 20x secondary optical lens to increase cost effectiveness of this terrestrial system. They are also developing a medium concentration (20x) CPV system. Refer to the medium concentration section for details. (3.3.1). Its two main products are the Solar Row which is 25 kW and the Solar Line which is 860 watts.

1077 Chisholm Trail
Keller, Texas 76248 USA
Phone: 817-379-0100
Fax: 817-379-0300
E-mail: marketing@entechsolar.com

3.2.11 Energies Nouvelle et Environnement (ENE)

ENE is apparently involved in a concentrator called an RXI type.

Both ENE of Brussells, Belguim, and the Ioffe Institute, St.Petersburg, are two partners in the CPV system produced by SolarTec AG of Germany. Other partners include STV Telekom of Moscow, Tongij University of Shanghi and SpectraTech of the USA. It’s been hard to find any more detailed information on this company. For information on this collaboration’s work, please refer to notes under SolarTec AG.in 3.2.23

Avenue Van der Meerschen 188, 1150 Woluwe-Saint-Pierre, Brussels.

3.2.12 Energy Innovations

www.energyinnovations.com

This is a start up company that had its genesis in the business incubator called Idealab of California, which is principally run by people successful in the IT revolution.

A distinguishing element of Energy Innovations technology is that it is attempting to design a very high CR system that will be suitable for rooftop use. Most CPV systems designed for rooftops are low concentration systems.

Energy Innovations' founder, Bill Gross, is rumoured to be manufacturing in China shipping 1 MW in 2007 perhaps using Emcore Cells. Thirteen MW of Emcore cells have been ordered, and speculation is that they are bound for Energy Innovations. The company is targeting the flat commercial rooftop market with a high concentration system in the order of 800 times, which can still be air cooled with aluminium fins attached to the rear of each cell. Its design is a little different and is referred to as a sunflower product and has a mounting system that allows for maintaining a low profile and tracking the azimuth and altitude. The system is not able to be mounted on a tilt and thus the residential market is unsuitable, but the sunflower can be mounted on the ground and so construction of solar farms is appropriate. The earlier design was using heliostats and the company has formed another branch called Esolar, (sister company) to utilise this technology in a solar thermal system. *Vice President, Steve Chadima (steve@energyinnoations.com) answered my survey saying the 'Sunflower' was 18 to 24 months away from sales outside California. The company is up to a year away from first sales and then because demand is so strong in California and so that it will be able to keep a close eye on the performance of their early product, it will initially keep sales close to home.*

130 W. Union Street, Pasadena, 91103, California, USA.
Ph. 626 585 6900
info@energyinnovations.com

3.2.13 Green Volts

www.greenvolts.com

GreenVolts is a small company in California that has secured contracts in California and Spain to produce its concentrator solar PV technology. This CSPV system, called the CarouSol, consists of a dinner plate size mirror, concentrating radiation onto a high efficiency PV cell made by Spectrolab. Each unit has 176 of these mirrors/cells on a rotating platform that sits low to the ground. Both the mirrors and the tracking platform increase the efficiency of the system by concentrating the sun's radiation 625 times. As with most CPV technologies, silicon use is reduced in comparison with normal flat-plate solar power generation. This technology has achieved a contract with P, G and E where it will construct a 5 MW plant designed to improve grid stability under peak use. This contract highlights a strength of all CSP systems, to have maximum electrical generation occurring at peak usage, which is during the hottest summer days when air conditioning units are utilised. As reported on the 2nd November 2007 by Renewable Access Daily, the CarouSol technology is on schedule for deployment in late 2008.

Green Volts believe that its technology is best suited as distributed supply, but closer to markets than competing technologies and at utility scale. In this report, 'series A' funding was said to have been achieved at $10 million.

Gunther energy blog, reported on GreenVolts claiming at an investment seminar, (Dow Jones VentureWire 'Alternative Energy Innovations' on the 24th October 2007 that the CarouSol has 2.5 times the power density at a lower cost than the SolFocus CPV system. This was claimed by CEO Mr Bob Cart. He also stated that the mounting system did not penetrate roofs and they were constructing a pilot manufacturing line of 12 MW which is scheduled for upgrade to 60 MW by 2010.

Green Volts, 50 First Street, #507, San Francisco, California, 94105, USA.

415 963 – 4030 | Info@greenvolts.com

3.2.14 Guascor Foton

www.guascorfoton.com

Guascor Foton concentrates the sun by 500 times using a refractive concentrator. It will have installed 950 kW by May 2008 and have 20 MW manufacturing capacity in the Basque region of Spain. It uses silicon (Si) cells in 225 kW dual axis tracking system. In this refraction point focus optics, direct concentration of up to 500 suns on 27 % efficient back contact Si cells is possible. The system efficiency is 18 %. This technology is licensed from Amonix,. which has 750 kW installed in the USA.

Guascor and Amonix are leading a Solar America initiative to reach a manufacturing capacity of 60 MW at 14 cents / kWh by 2010 using spectrolab cells, dropping to 6 cents / kWh in 2015 with 1,000 MW of production capacity.

Pol. Ind. Granada, Parc. 1,
48530 Ortuella (Bizkaia) Spain. Phone 34 94 635 37 10
info@foton.guascor.com

3.2.15 H2Go

www.h2go.org

H2Go is a company formed to develop the ‘hydrogen economy’ which is often touted as the solution to our energy problems. H2Go has decided to develop a CPV system as its source for cheap, relatively clean and abundant hydrogen. Interestingly it identified wind, solar and hydro resources around the world as very complementary. That is, where there is little wind, there is often a sunny climate and where there is less sun, there is often a good wind regime and water aplenty, etc.Therefore there would always be a market for all of these technologies. Seeing solar as having the best credentials to meet its needs the company decided to choose the type of technology in the solar field that it would pursue. It saw voltaic thermal as too unreliable and flat plate having problems of supply and inefficiency. Wind was further developed than solar and thus arguably had reached closer to its potential so the next big challenge to develop was solar and the best potential seen in the different solar technologies was CPV.

The update to H2Go is that they have ‘morphed’ or rebadged into SolFocus, one of the leading manufacturers of CPV’s. Please see heading ‘SolFocus’ in this high concentration listing.

18905 Ten Acres Road, Saratoga, California, 95070, USA.
Phone 408 872 1546.
info@h2go.org

3.2.16 InfoPyme Solar

InfoPyme Solar are the representative company of Pyron Solar in Spain and Portugal.

3.2.17 Isofoton

www.isofoton.com

Isofoton is developing a 20 % efficient compact module using non imaging optics with internal reflection and refraction to concentrate the sun 1,250 times onto triple junction cells. Isofoton also has products being tested at ISFOC for such things as optical efficiency, tracking accuracy, overall module design, total system integration, operation and maintenance. The use of refraction and then total internal reflection allow a thinner module than modules utilising Fresnel lenses.

Montalban, 9. 28014 Madrid, Spain.

Tel. 34914147800 | isofoton@isofoton.com; isofoton.m@isofoton.com

3.2.18 JX Crystals

www.jxcrystals.com

JX Crystals has both a High and Low CPV system in development.

Please see notes under heading 3.4.6 for details of the prototype HCPV system that JX Crystal have.

1105 12th Ave. N.W. Suite A2
Issaquah, WA 98027
Tel: 425 392 5237 | lfraas@jxcrystals.com - Dr. Lewis M. Fraas, President

3.2.19 Menova Energy

www.power-spar.com

Menova was an unsuccessful bidder for ISPHOC. I see it as predominantly a thermal concentration technology producer rather than a CPV producer, although it does, do both. The following is a press release from the Menova Energy Company:

Menova Energy Inc. Opens Production Plant for Assembly of Power-Spar® Solar Collector

Ottawa, ON - 26 July 2006. Menova Energy Inc.'s pilot production plant was commissioned in July 2006 and will be in full production by September 2006 producing the Power-Spar® PS-2 product.

The Power-Spar® PS-2 is a revolutionary high efficiency solar concentrator that co-generates heat and electricity on an industrial scale. A typical 12 meter panel can supply 8 kW thermal and 2.2 kW electrical. PS-2 panels are modular and can easily be added to existing buildings or ground mounted. The complete Power-Spar® PS-2 system can be incorporated in buildings to provide net-zero energy buildings.

.Contact: Dave H. Gerwing, M.Sc., P.Eng. President
dgerwing@menova.com | Ph. 613-599-6232 or 888-636-6821
1 Terence Matthews Cres.Suite 200
Ottawa, Ontario
Canada K2M 2G3
Email: info@power-spar.com

3.2.20 Pyron Solar

www.pyronsolar.com

Pyron Solar is the terrestrial CPV arm of the Boeing Corporation located in La Jolla California. In Spain and Portugal, Pyron is represented by InfoPyme Solar.

Its product has been designed with a short focal length lens and concentrates 800 times. A planar concentrator lens passes the sun's radiation through a tilted optical homogoniser to the Spectrolab triple junction cells. It has built a prototype of 7 meter diameter, 16 inches in depth which produces 6.5 kW. This unit costs an estimated US $18,000 ($2,000 rebate) which equates to $3/watt compared to $5 for the average solar product. This is a 40 %

decrease on normal solar cost. To remove heat from the cells, the entire system sits on water.

Pyron has an agreement with Spectrolab and Lion Energy to roll out CPV in Greece and the UAE and Middle East. The letter of intent was signed in mid 2007.

4060 Morena Boulevard, Suite J, San Diego, California, 92117, USA.
Tel: +1-858-270-0330 | Email: info@pyronsolar.com

3.2.21 Sharp Solar

Sharp produces 36 % efficient III-V Sharp cells and incorporates them into a system that concentrates 700 times using refractive optics with dual axis tracking. It has a 2.9 KW prototype in the Arizona Public Service PV test site in Tempe. The system is described as an ‘in frame Fresnel lens concentrator. Sharp is cooperating with Dado Steel on this Fresnel lens which is injection moulded into a domed shape and can be manufactured less expensively than other existing lenses.

It’s been hard getting information on Sharp CPV research and development. I’m not sure whether they’re continuing with CPV.

PO Box 6827, Blacktown, 2148,
1 Huntingwood Drive, Blacktown, NSW, 2148.

3.2.22 Solar Systems

http://solarsystems.com.au

Solar Systems Pty Ltd has developed power stations in the outback of Australia where it has 24 kW of mirror dish, 21% efficient Si cells and 33 kW with multi junction cells. The company has designed a 154 MW heliostat CPV system in which it has changed from mirrored dish technology to heliostat mirrors in a field focussing the sun on cells on a smallish tower. At present the company is looking at scaleable units of an approximate size of 2 MW. (G.Hering, 2007).I can confirm this report as the same was stated by the General Manager, Dave Holland, at a talk he gave in 2007 organised by the Australian Institute of Energy, which I attended.

On the 21st of November Solar Systems announced another funding agreement with the Federal Government. Each party will contribute 6 million dollars to fund the R&D and design of a commercial scale solar hydrogen plant. The total project will cost $60 million over seven years and will help solve the problem of intermittency with solar resourced power.

The latest news (December) is that the demonstration plant near Bendigo has been given planning approval. It will demonstrate Solar Systems CPV system based around heliostats and Spectrolab's high efficiency triple junction cells. Hayden Barwell, Project Officer Sales and Sustainability replied to my survey and undertook to be in touch after the 7/1/2008.

Hbarwell@solarsystems.com.au

322 Burwood Road, Hawthorn, Vic, 3122.
Tel: 8862 8100 | info@solarsystems.com.au

3.2.23 Solar*Tec AG (DE)

www.solartecag.de

Solar*TecAG is contributing to a consortium that is looking to build a CPV system with 700 times concentration of the sun and a solar cell of over 50 percent efficiency. The technology involves Fresnel lenses in the shape of a triangular prism in modules that are similar to flat plate size and shape.

The other partners involved in this enterprise are ENE of Belguim and the Ioffe Institute of St. Petersburg.

At present two plants produce a combined 5.2 MW in Germany and four plants were on line to be finished by the end of 2007, totalling a further 8.5 MW. In 2008, this firm is expecting to install 30 MW in Spain and 50 MW in Germany.

SolarTec AG is a large concern which is involved in the 3 main types of solar electricity and has offices in seven countries.

Lenbachplaz 2a, Bavarian Stock Exchange, 80333 Munich, Germany.
Phone 49 089 90 7749 97-49
info@solartecag.de

3.2.24 SolFocus

www.solfocus.com

SolFocus has evolved from H2Go. (See information under H2Go in section 3.2.15 above.)

Sol Focus is an interesting company in the start up phase. It has been chosen to display and test and has monitored systems at ISFOC in Castilla-La Mancha in Spain as have Concentrix, Isofuton and Guascor FutonSL.

The new system from Sol Focus has dual axis tracking, is passively cooled, allows 500 times the concentration of the sun, and is made up from a hexagon shaped two mirror unit. The system efficiency is in the order of 17.1 percent and the manufacturing is done in India by Mosur Baer. The company has bought out a Spanish tracking manufacturer in July 2007 increasing the world wide flavour of this start up.

Some of the positives of this CPV system include these points as listed on the Sol Focus Website:

- 26 % module efficiency
- Has monolithical optical design (minimizes critical joints and misalignments)
- Avoids covers, seals and hard to clean surfaces
- Reduces processing steps with glass pressed in one hit
- Fabricated with automated high volume throughput
- Has a wide acceptance angle of + or – 2 degrees
- Reduces total material usage
- It also packs flat to reduce transport costs

www.solfocus.com/technology_gen2.html

http://blogs.business2.com/greenwombat/solar_energy/index.html

On these websites, it is claimed that this technology produced by Sol Focus promises the lowest cost of solar power for the foreseeable future. The company plans to have a commercially available product in 2008.

There is an executive of 8, Board of 7 and Technical Advice panel of three. Sol Focus is filling 35 positions at present in late 2007 early 2008. In late 2007 it was reported by David Ehrlich in CleanTech (1/8/2007) that SolFocus' workforce had grown to sixty with their subsidiary company, Inspira, employing approximately ten.

The latest update is receipt of 52 million dollars in second round funding, half to be used in Spain on a European HQ and Indian production is to be increased.

I've arranged a face to face meeting with the CTO (Chief Technical Officer) Steve Horne, for January. steve_horne@solfocus.com

510 Logue Avenue, Mountain View, California, 94043, USA.
press@solfocus.com

3.2.25 Soliant Energy

www.soliant-energy.com

Located in Pasadena, Soliant (formerly Practical Instruments) has developed a rooftop heliotube reflective trough concentrating system with single axis tracking that magnifies the sun ten times. It can be mounted without penetrating the roof, has more even power output with the tracking and claims to use 88 % less photovoltaic material than traditional panels. In its submission for 'Solar America' funding, Soliant predicted these figures production and cost:

Year	LCOE	Manufacturing Capacity
2006	$0.147	1 MW
2009-10	$0.079	40 MW
2014-15	$0.056	600 MW

Table 2 Output performance and goals of Soliant Energy

The update on Soliant is that the company has increased the concentration of their module. I think this trough design is now redundant. Soliant has designed a very flat panel comprising square components that individually use dual axis tracking and the new 40 percent efficient triple junction cells. It is still targeting the rooftop market with a low profile module despite the high concentration of 500x. The module has bypass diodes, and is no maintenance and easily installed and passively cooled. If this technology is successful, the company will have a very valuable commodity as it is HCPV for the rooftop market.

133 N. San Gabriel Blvd., #205
Pasadena, CA 91107
(626) 396-9500

3.2.26 Sol3G

www.sol3g.com

Sol3G is Spain's dual axis Fresnel lens HCPV (high concentrating photovoltaic) company. The lens is a two component optical system resulting in a concentration ratio of 476 suns with high deviation tolerance.

Currently 4 kW is installed and 35 kWp is being installed in Europe and production is being increased to 5 MWp per year.

The Sol3G system (M40 module) uses triple junction cells manufactured using MOCVD (Metal Organic Chemical Vapour Deposition) of group III-V semiconductor material deposited on a substrate of Ge. Sol3G claims to have been the first producer of HCPV modules based on cells using triple junctions and has a module efficiency of 35 % and has secured 30 MW of cells for the next three years from Azur Space. This company is based in Barcelona. *Update on Sol3G is an acceptance of its tender to ISFOC to supply a 400kW system. Solucar has provided capital worth 25% of Sol3G's capital to allow the 5 MW expansion of manufacturing.*

Sol3G, S.L.,
Ronda Can Fatjo, 9 Edif. C, Ab
Parc Technologic del Valles
08290 Cerdanyola, SPAIN
info@sol3g.com

3.2.27 Sol 3y

This Spanish company is developing two installations both concentrating the sun 380 times. In 2007 it hopes to have installed 2.5 MW and by 2008 10 MW. The company projects a cost of $2.64 a watt for the 2008 plant.

The company's domain name has expired and I have my suspicions Sol3y is Sol3G! I can't get information to confirm.

3.3 Medium Concentration PV Systems

3.3.1 Entech

http://www.entechsolar.com/

Entech uses inexpensive Fresnel lenses to concentrate the sun twenty times. It operates out of Keller in Texas and has been involved in supply to the space industry for over 20 years. This concentrating system reduces the use of Silicon by 95 % and is still a Silicon based low concentration system. Entech is also working on developing a 400 x CPV system which you may read about in the high concentrator section above.

Entech's fourth-generation concentrator is the world's largest PV module, with an aperture area of 3 m^2 and a rated power output of 430 watts. This PV module uses a large acrylic plastic Fresnel lens to focus sunlight onto small silicon cells. Concentrating the sunlight to 20 times its normal intensity reduces the use of expensive silicon cell material by 95%, compared to conventional flat-plate PV modules. The solar cells are mounted to an extruded aluminium heat sink which keeps the cells about as cool as conventional 1-sun cells. The solar cell assemblies, electrically insulated and encapsulated for durability, use a unique patented optical device called a prism cover to boost performance. Aluminium housing supports and encloses the module. Each module is 0.9 m (3') wide, 3.7 m (12') long, and 0.9 m (3') high.

Entech's uniquely designed PV concentrator cell is a modified version of the crystalline silicon cell used in flat plate PV panels. The major difference is that the metallized grid on the concentrator cell's surface conducts over 20 times more electrical current. Consequently, the cell has a larger metallized conductive grid. Entech's optically clear prismatic cell cover is bonded to the cell to refract incoming light away from the grid onto the silicon.

Each module has 37 solar cells electrically connected together like the positive and negative connections of batteries, to provide 17 to 20 volts DC, depending on the temperature.

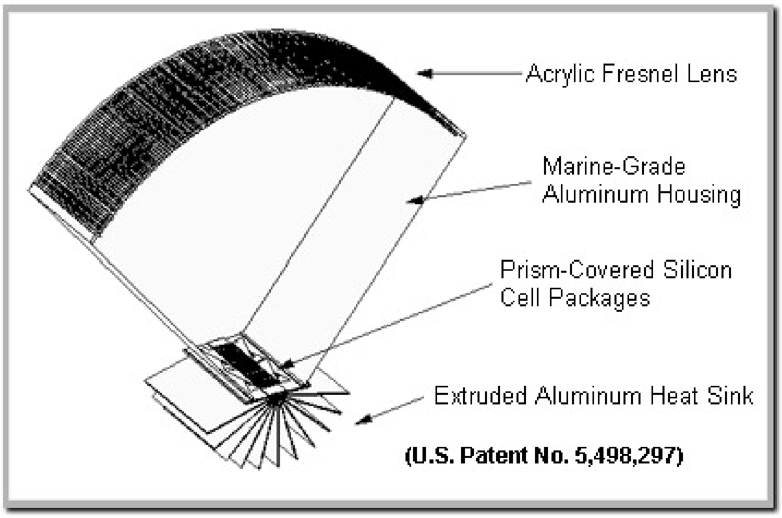

Figure 3.3.1 Module Cross Section

Support bearings are located at each end of the module housing so that it can roll from east to west. Modules are mounted in a supporting frame which tilts from north to south. The support structure is made from readily available structural steel materials. This simple durable structure enables the modules to move about the tilt axis up to 75°, and to roll east to west through 150°. All steel components are galvanized to ensure the 30-year design life of the system.

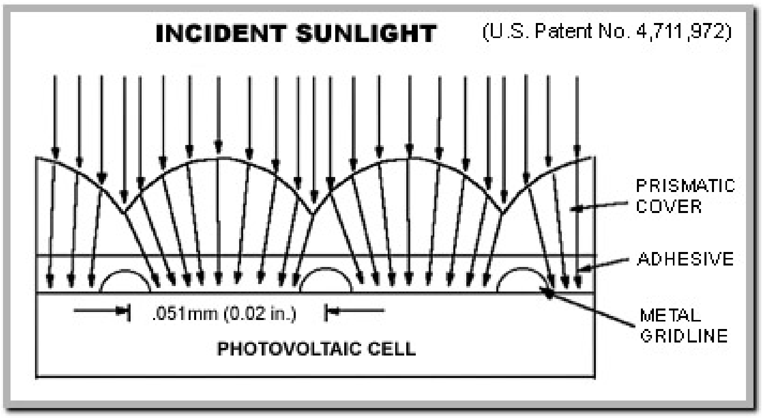

Figure 3.3.2 ENTECH's Prismatic Cell Cover

The combined roll and tilt motion enables the modules to stay aligned with the sun throughout the day. The two tracking drive actuators, one for the roll axis and one for the tilt axis, are common DC motor-driven linear actuators. The motors are controlled by a microprocessor unit with a built-in clock that computes the position of the sun based on the unit's geographic location, day of the year and time of day. In stow position the structure can withstand wind speeds up to 45 meters per second (100 mph) while being ready to start tracking the sun automatically when the wind abates.

Update: Entech has just (reported at Renewable Energy Access dot com) become a wholly owned subsidiary of World Water and Solar Technologies. A power plant of 50 MW in Spain is to be started immediately using 20 x Entech solar concentrator systems and a Spanish firm, M and G Promociones, has contracted Entech for 10 MW in 2008, 9 and 10 with 50 MW to be built in each of 2011 and 2012. World Water brings proprietary control devices to the partnership and Entech itsr patented 20x concentrator technology, allowing installations that dramatically decrease the need for solar cell material.

1077 Chisholm Trail
Keller, Texas 76248 USA
Phone: 817-379-0100 | Fax: 817-379-0300
E-mail: marketing@entechsolar.com

3.3.2 Whitfield Solar Ltd

http://www.whitfieldsolar.com/Technical_Specifications.htm

Whitfield Solar is a spin off from the University of Reading in the United Kingdom. Solar research has been undertaken there for the last 25 years and a concerted effort was made to produce a concentration system at low cost. Firstly 200 odd designs were trialled and four short-listed finally producing the 'Whitfield Low Cost Photovoltaic Concentrator.'

This PV system has two axis tracking PMMA Fresnel lens parquet concentrating 40 times. This system uses polysilicon and its main focus is on keeping the cost of manufacturing down.

Whitfield Solar Ltd.,
Webb's Court,
8 Holmes Road
Earley, Reading, Berks RG6 7BH, United Kingdom.
Tel: 44 (0) 1189264000 | office@whitfieldsolar.com (attn Dr Roger Bentley)

For engineering enquiries:
Mr Tom Bonner, Senior Design Engineer
For admin enquiries:
Miss Bridget Parslow, P.A and Office Manager

3.4 Low Concentration PV Systems

3.4.1 Arontis PVT

www.arontis.se

Arontis is in the early stages of research and development of a PV and Thermal system for rooftops where buildings require both power and heat. The project is initiated by the IEA. The concentration factor is eight, using an east west oriented trough concentrator, which has single axis tracking. As this is predominantly a hybrid system, I will not be placing it in the rating spreadsheet. The company's answers to my questions are as follows:

1. What is the optical concentration of the system? **Ans:**12x
2. What is the efficiency of the cells you are to use? **Ans:**16%
3. What is the Capital backing of the company? **Ans:** Seed financing
4. What market niche is the product aimed at? That is, is the market for the product, domestic roof, commercial or factory roof, grid support or power station and have you set up a sales network in Australia? **Ans:** Commercial or factory roof. No.
5. What is the projected cost of power provided by the system? **Ans:** Manufacturing cost €1,4/Wp
6. Is the product manufactured yet? Is it mass produced? What quantity was made in the past few years? **Ans:** Only demonstration units yet.
7. What is the projected rate of manufacture? **Ans:** Quick expansion!
8. How many people work for the company? **Ans:** 3 employees
9. Is the company privately owned or a listed company on the stock exchange?

   Ans: Privately owned
10. How experienced is the staff? **Ans:** Project active for five years, building on 20 years of Swedish research
11. How robust, reliable and long-lasting is the product? Have accelerated life trials taken place? **Ans:** No

Arontis Solar Concentrator AB
Ostanbacksgatan 16
SE-871 31 Harnosand, Sweden.
Phone: +46-611-2688 **|** info@arontis.se

3.4.2 BP Solar

BP Solar has a low concentration system consisting of a linear focus trough reflector with single axis passive tracking, thermohydraulic drive and integrated receiver. BP is hopeful of this technology becoming commercially viable by 2009. At present it is constructing three 25 kW demonstration plants with three 100 kW demonstration plants to be built in 2008. Contact Fritz Klotz for further information. A company called ZSW, located in Germany, was the original developer of this system.

Update: BP Solar owns the license for a technology called EUCLIDES which is a reflective parabolic trough concentrator (PTC) described above. It consists of a linear array tracking with a north-south axis and was designed and constructed during the 1990s largely at a place called Tenerife after a successful prototype deployment in Madrid. It utilised high concentration silicon cells developed by BP using the ‘Buried Grid Laser Groove’ technology developed by Martin Green and colleagues at the University of New South Wales, Australia. The system was classified as medium because of its’-30 times-’ level of concentration, and relied on passive heat loss.

BP Solar decided to shelve the technology because of reliability issues with the mirrors and modules although the project showed good potential and with a little more work, (Anton, Pachon and Sala, 2005: pp. 198-297) state the technology could be successfully deployed, particularly if higher efficiency solar cells were used; (In the order of 23 percent rather than the 18 percent efficient cells that were used). This prediction is based on the cost of 3.9 Euro per peak watt estimated using the Tenerife deployment.

www.zsw-bw.de | hans-dieter.mohring@zsw.bw.de

49 (0)711 78 70-27

NB/ I received an email letter from Nigel Morris, BP Solar's Australian Offer Development Manager stating that they are not pursuing CPV at the moment.

3.4.3 Day 4 Energy Inc.

www.day4energy.com

Day 4 Energy (Garrett and Hering, 2006) is a Canadian company based in British Columbia. They have a low concentration solar PV system achieving up to seven times concentration of the sun optically and utilise 'Q Cells' German manufactured high efficiency PV cells. Like all of this group's products, its low concentration solar system relies on a proprietary technology dealing with connections and contacting of crystalline PV cells. Day 4 Energy has developed a linear receiver and heat sink that it is now also supplying to other companies in the low concentration market.

Daniel Murray, the sales manager, answered the survey saying the Day 4 Energy CPV panels were not as yet available.

dmurray@day4energy.com

101/5898 Trapp Avenue, Burnaby, BC, V3N 5G4, Canada.
Tel. +1(604) 759 3294
info@day4energy.com

3.4.4 GE Energy

GE Energy is aiming to lower the cost of its low concentration PV systems by examining every aspect of the chain of production and installation and improving it where possible. It intends to work on many of the PV technologies and pursue the most promising. One such technology is bifacial cells in low concentration modules.

The company has attained and are chasing the following goals/predictions:

Year	LCOE ($/kWh)	Manufacturing Capacity (MW)
2006	0.19	20
2009-10	0.089	300
2014-15	0.0583	1500

Table 3.4.1 GE Energy's Production Goals

I've found it impossible to find any more information on GE. Emcore and GE owned a semiconductor business together but I'm not sure if they collaborated on CPV.

3.4.5 Green and Gold Energy

www.greenandgoldenergy.com.au

Green and Gold Energy of Adelaide in South Australia is developing concentrating solar PV products. Its latest invention is a device concentrating the sun to approximately five times using Fresnel lenses of moulded PMMA covered with toughened solar glass. Each unit, called a 'sun cube', has a rating of approximately 333 Watts, an internal inverter and dual axis tracker controlled by an internal microprocessor and is estimated to retail for A$1,500, including tax, although Greg Watson (the CEO) has revised his cost estimate recently. There has been lots of talk to date, but plenty of work still has to be done to answer criticism that 'the walk' may not back up 'the talk'. Watson hopes to gain Greenhouse Gas Office of Australia rebate status, build solar farms and adapt his product for sale in all markets, domestic, commercial and solar farms. He wants to make solar power available to all; renters, people who live in houses incapable of hosting an array, and people who can't afford a whole system.

G&G has undertaken to buy 105 MW of triple junction cells from Emcore and this order has increased to 39 from 24 million dollars due to G&G Energy wanting to buy some of Emcore's modules as well as Emcore's TJCells.

7 Provident Avenue, Glynde,

South Australia, 5070, Australia,
Phone: +61 8 8365 5844 | Fax: +61 8 8365 6241
Email: info@greenandgoldenergy.com.au

3.4.6 JX Crystals

www.jxcrystals.com

JX Crystals is a start up company that has begun to manufacture low concentration systems (3 x sun) replacing two thirds of the silicon that would be usually required with mirrors in the familiar flat plate like layout. This is seen as a first step toward manufacture of a high concentration and high efficiency CPV system based on its current research.

This research focuses on developing a high efficiency 500 sun product that uses Cassegrainian optics to split the solar spectrum into high and low energy bands. Dual Junction III-V GaInP/GaAs solar cells collect the high band energy at the focal point of a cold mirror reflector on the secondary optic, while JXC GaSb cells collect the low band energy transmitting through the cold mirror. Current development efforts are focused on design for low cost manufacturing and supply chain management.

1105 12th Ave. N.W. Suite A2
Issaquah, WA 98027
Tel: 425 392 5237 | lfraas@jxcrystals.com - Dr. Lewis M. Fraas, President

3.4.7 Mereg (DE)

www.mereg.de

Mereg is in the process of developing a very flexible technology of BIPV as a concentrator PV system that can produce power and/or hot water. The roof based system, named Ami Sol, is made of small tracking mirror leaves which concentrate and reflect light to a receiver on a mast or adjacent roof.

I received a reply to my email and the development of this Ami Sol system is being stopped by a lack of finance because of problems with getting insurance when there is no IEC norm available for CPV systems. The banks apparently will not lend to them without insurance and insurance isn't available unless the manufacturer complies to a standard. The Paul Scherrer Institute is helping to develop a solution to this impasse apparently.

This is a very promising design in its early stages of development. In September 2005 Mereg had 8 employees with 3 having 10 to 15 years experience.

Gewerbegebiet "Am Stadtforst"
Grüner Ring 15, 04509 Delitzsch
Tel.: +49-34202-3098-70, | info@mereg.de

3.4.8 NuEdison

www.nuedison.com

NuEdison is a company that has developed technology that concentrates sunlight optically and has a few prototype modules that can reduce the cost of PVs by decreasing the amount of silicon used to manufacturer a panel. It does this through optical concentration and total internal reflection which reduces the need for silicon 300 to 400 percent. One product is specifically designed for northern roof applications. The product is still being developed and has won the Cleantech $50,000 award for an innovative technology with great potential. NuEdison plans to sell the technology to existing manufacturers and also produce and sell its own panels displaying the low concentration technology.

NuEdison has been acquired by Silicon Valley Solar. Please refer to SV-Solar listing in section 3.4.11.

2NorthFirstStreet, San Jose, CA 95113

email:info@nuedison.com

3.4.9 Pacific SolarTech (Pacific ST)

www.pacificsolartech.com

Pacific ST, located in Fremont California, has produced a CPV module that uses a dome-shaped lens to concentrate tenfold the radiation onto a monocrystaline silicon cell, one tenth the size of the lens. There is no tracking required and this design reduces the amount of silicon used. The module works equally as well as a flat plate modules during sunny weather and not as well in diffuse conditions but has a cost advantage of up to 40 %. This company advises users to realign the modules 4 times during the year for better performance and that tracking can gain at least a 10 % improvement in power production.

44843 Freemont Blvd, Fremont, LA, 94539.
Tel. 510-979-0112

3.4.10 Prism Solar Technologies (PST)

www.prismsolar.com

PST located in Tucson Arizona and New York, has developed an imaging technology that results in passive solar concentrating that reduces the need for 85 % of the silicon required for a similar rating of a Si flat-plate module.

This bifacial technology the comany call a low cost ‘Holographic Planar Concentrator’, uses transparent holographical, optical qualities in its panels. Useful wavelengths are spectrally selected using holographic technology and focused on normal crystalline silicon solar cells to create electricity. Prism is partnered with Hitachi. As is stated on the Prism website (www.prismsolar.com), the concentration of the sun is achieved through using a hologram imaged onto a transparent medium that is sandwiched between two sheets of glass. Passive tracking allows better module performance without the cost and maintenance and reliability issues of physical tracking. This technology being planar is simply mounted as any flat plate solar collector would be. One other advantage designed into the panel is that it operates at lower temperatures, increasing its efficiency. This is an improvement on other attempts at bifacial modules that usually heat up, reducing cell efficiency. This is done by discarding the non-selected portions of the light spectrum. The company plans to be in production within the year 2008. Concentration of light with holographs has led to at least a 25 % increase in power output.

Prism was asked to present to the Industry Growth Forum by the NREL 2007 (National Renewable Energy Laboratory.) and also awarded the “Most Promising Technology” at the Cleantech awards.

Prism has undertaken a contract with an experienced module manufacturer from New York to continue to develop, manufacture and sell their CPV technology.

PST, PO Box 630 Stone Ridge, NY, 12484, USA.
Telephone 845 687 2406
info@prismsolar.com

3.4.11 Silicon Valley Solar (SVS)

www.sv-solar.com

SVSolar has bought out NuEdison and has in place a strong management team of six.

Silicon Valley Solar is a company with technology that uses total internal reflection to produce 2.2 sun concentrations on to monocrystalline cells.

SVS Sol-X2 products are high efficiency, low cost modules that have a unique internal concentrator. The modules have been designed to closely mimic a typical flat plate collector, although with ‘not so subtle differences.’ The ‘Sol – X2’ has similar output and dimensions of a normal panel, but uses half as much silicon which, is a real advantage with constrained silicon supply at present. The lack of tracking is also beneficial because it increases reliability and means the current installation methods need not be modified.

SVS is collaborating with GSS from East Germany and Conergy to bring their product to market.

On 11/12/06, it was reported that SVS signed a contract to supply PPM of Santa Clara California with 10 MW worth 35 million dollars.

It was reported on 18/6/07 that SVS secured series A funding of 10 million dollars.

SVS has contracted FrSol Solar Energy AG of Germany to supply high efficiency c-Si cells for the Sol-XTM modules.

On 18/9/07 SVS was named in the Going Green top 100.

SVS replied to my letter and is in pre-commercial stage and will not have an accurate costing until its pilot line produces modules scheduled for second half of 2008. Fabienne invited me to schedule a phone conference where he would give me more product information.

2985 Kifer Road, Santa Cara, CA, 95051.

Tel. 1.408.8447100 | 1650 804 2504

frodet@sv-solar.com

3.4.12 Solaria Corp

www.solaria.com

Solaria Corp is based in Freemont California and is working on a low concentration system that concentrates by a factor two to three with a non tracking array.

The following quote is taken from the news service of ‘Chemical and Engineering News’ and is written by Marc Reisch.

Q-Cells is committed to supplying Solaria with enough cells to generate 1.35 gigawatts of power over the next 10 years. Using its "cell multiplication technology," Solaria will double the output of cells it obtains by slicing them into thin strips and reassembling them to double the surface area they cover. This of course decreases the expensive silicon required for the same output, as is stated on the Solaria website. The technology includes packaging the cells under an optical concentrator to focus more sunlight on them. The Wall Street Journal describes the concentrators as plastic lenses. Solaria has received c series funding and it anticipates scaling up its existing pilot manufacturing line this year.

46420 Fremont Blvd, Fremont, LA, 94538.
Tel. 1-510-270-2500.
info@solaria.com

3.4.13 Soluca Energia

www.solucar.es | www.abengoa.es

Soluca Energia is a Spanish company that is developing a low concentration technology in Abengoa, Spain. This company has constructed a 1.2 MW plant. The technology uses twin tracking that concentrates the sun between 1.5 and 2.2 times.

Soluca has changed its name to Abengoa Solar and is a subsidiary of Abengoa which is a large multinational corporation and is focussing on CSP, after having constructed small demonstrations of LCPV and HCPV. In November 2007, Abengoa Solar (Soluca changed its name on the 26/10/2007) provided funds to Sol3G to allow expansion of Sol3G's manufacturing to 5 MW per annum.This funding equates to 25 % of Sol3G's capital.

Abengoa has research projects of low (5 to 10x), medium (30x) and high (1000x) concentrations in the field today in collaboration with other firms and Universities.

Avda, de la Buhaira, 2, 41018-Sevilla
Tel. 34 954 937111.

3.4.14 Stellaris

www.stellaris-corp.com

Stellaris started up approximately two years ago and concentrates light through little lenses on to a long, thin PV cell of CIGS, Silicon. It uses novel construction techniques and advanced optics to improve the efficiency of the power producing system. This allows it to save on the amount of PV material used. It's positioning its product for integration into buildings as it is transparent and attractive.

According to Stellaris' Chief Technical Officer, the company's 'ClearPower' technology employs passive concentrating optics and unique assembly techniques to decrease production costs by more than 40 percent while increasing the efficiency of energy generation by more than 20 percent. The technology captures and concentrates both direct and diffuse light via a translucent panel that can be used not only in conventional solar modules but also in windows, patio tiles, and skylights, combining architectural appeal with green energy production.

600 Suffolk Street, Lowell, MA, 01854.
PO Box 1745, Lowell, MA, 01854-1745.

3.5 CPV Technology: Including High Efficiency Cell Manufacturing and Hybrid Systems

3.5.1 Azur Space Solar Power (GMBH)

www.azurspace.com

Azur Space is a German firm with a history of providing solar cells for space travel. Another business has grown from powering space travel and that is

CPV solar cell production. Azur produces both silicon and triple junction III-V based solar cells for both space usage and terrestrial applications.

Theresienstr. 2 | 74072 Heilbronn | Germany

Tel. +49 7131 67 2603 | E-Mail info@azurspace.com

3.5.2 Cyrium Technologies

www.cyriumtechnologies.com

Cyrium has developed a new high efficiency solar cell for the CPV market with the use of quantum dot technology, which it has been working on for the last 10 years. In December 2007 it received another 5 million dollars funding and appointed a new CEO who is experienced in the terrestrial market as opposed to their previous CEO who was more experienced with space application. This new CEO is confident of shortly announcing another half a million dollars funding. The company will shortly be opening an operation in California's Silicon Valley to try to establish business with CPV firms.

1200 Montreal Road M50-IPF206
Ottawa, Ontario, Canada, K1A 0R6
Tel. (613) 482-3365 | info@cyriumtechnologies.com

3.5.3 Di.S.P. (Distributed Solar Power)

www.disp.co.il

http://newenergynews.blogspot.com/2007/11/israeli-solar-concept-funded.html

I haven't included CPV technology in the rating when the thermal energy derived from the system is greater than the electrical power generated.

Dr. Daniel Kaftori, co-Founder, Distributed Solar Power has developed a miniature HCPV parabolic dish producing power and heat. The developers talk of very low price energy potential but as yet no commercial work is mentioned. The technology was developed at Tel Aviv University.

Prof. Abraham Kribus (CTO)
Yozmot HaEmek Technological Incubator
P.O.Box: 73, Migdal Haemek, ISRAEL, 23100
Tel: 04-6544814/80 | Email: info@disp.co.il

I have a concern that this technology is rather involved. Tracking the sun requires lots of moving parts and thus maintenance. Adding to the complexity of this design is the solar thermal active cooling/heating, as well as the system needing many small units with lots of cable runs and pipes. It doesn’t surprise me that I can’t find a fully costed demonstration of this technology. I haven’t been able to contact Di.S.P as it is in the process of constructing its web site and its email address is not returning mail. The URL directly under the heading Di.S.P. contains the latest information I have on the research, development and deployment of this technology.

My guess is that Di.S.P is still a fair way from rolling out its technology, although the potential is there to take a market niche by providing cheaper green power and hot water in the one design.

3.5.4 Kyosemi Corporation

Kyosemi Corp has developed a technology that is worth mentioning as it is debatably concentrating and different to those covered thus far. Light can be reflected to the side and undersides of the spherical cells, concentrating radiation as well as increasing the surface area of the cell exposed to radiation. This effect is not unlike a bifacial cell set-up. The company manufactures solar cells of 1.0, to 1.5 millimetres in diameter in a spherical shape. These cells capture direct radiation from all directions as well as reflected and diffuse radiation and are reasonably shade tolerant because of the flexibility of cell connection. That is, parallel or series cell connections are possible in a module. Kyosemi is looking to advance to commercial production and claims that this technology has the potential for being integrated into buildings including glazing and for use in small and transportable applications. Like all LCPV systems, spherical solar cells reduce the amount of silicon used.

At this time, spherical cells seem to still be at the research stage for large power generation.

The technology has been bought by Spheral Solar Power Company of Canada which has begun to manufacturer many products utilising the spherical solar cells. Spheral is, along with Photowatt, part of Automation Tooling Systems (ATS), a listed company. Kyosemi has rebadged the technology as Sphelar Solar Cells.

The Prometheus Institute reports (P.Maycock, 2006) that the lifespan of a spherical cell might be limited to around three years at present, explaining its limited use to date. I haven’t authenticated this claim.

The saga continues with Photowatt losing over US100 million dollars last year on spherical cells as ATS’s needs dictated it enter in to an agreement with its competitor, CV21 (Clean Venture 21) of Kyoto, which has also enlisted help through a company called Fujipream of Japan. It is agreed that Photowatt will supply the cells with the right to buy back 50 percent of them after being laid onto a substrate which CV21 claims to have made more effective. It has done this by addressing some of the problems inherent in working with spheres, such as lost radiation through increased reflection from the curved surfaces of the spheres and increased self-shading when arranged in arrays. Another problem is the large gap between spheres and having only half of the sphere exposed to direct radiation. Using hexagon shaped reflectors around the spheres, a little similar to SolFocus' product, CV21 has improved this situation and in addition, has added an anti-reflective coating to the cells.

3.5.5 Menova Energy

www.power-spar.com

Menova was an unsuccessful bidder for ISPHOC. I see the company as more of a thermal concentration technology producer than a CPV producer, although it manufactures both.

The following is a press release from the Menova Energy Company:

"Menova Energy Inc. Opens Production Plant for Assembly of Power-Spar® Solar Collector

Ottawa, ON - 26 July 2006. Menova Energy Inc.'s pilot production plant was commissioned in July 2006 and will be in full production by September 2006 producing the Power-Spar® PS-2 product.

The Power-Spar® PS-2 is a revolutionary high efficiency solar concentrator that co-generates heat and electricity on an industrial scale. A typical 12 meter panel can supply 8 kW thermal and 2.2 kW electrical. PS-2 panels are modular and can easily be added to existing buildings or ground mounted. The complete Power-Spar® PS-2 system can be incorporated to provide net-zero energy buildings."

Menova Energy at 613-599-6232 or 888-636-6821.
Dave H. Gerwing, M.Sc., P.Eng. President
dgerwing@menova.com
1 Terence Matthews Cres, Suite 200, Ottawa, Ontario
Canada K2M 2G3
Email: info@power-spar.com

3.5.6 Photovolt

http://users.adelphia.net/~esch/papers.html

This is a potential cell type for use in CPV systems and the right to the technology is still to be bought and utilised.

Photovolt has developed a cell it has called a VMJ (vertical multi-junction) cell, which is an integrally bonded, series connected array of miniature silicon vertical junction unit cells, also called edge illumination cells. These cells have handled concentrations up to and above 1000 times the sun with no ill effects or performance loss. In a demonstration, no cell degradation has been observed with a cell operating since 2002. The developers believe that the key objectives of CPV systems, that being efficient production at high concentrations with low manufacturing costs, can be achieved by VMJ cells. Detailed papers on this promising CPV technology can be found on the website listed under the Photovolt heading, see above.

Bernard Sater undertook to answer the survey around the 10th January 2008.

Bernard Sater,
21282 Woodveiw Circuit, Strongsville, OH, 44149 USA
bslater@msn.com

3.5.7 Spire Bandwidth Semiconductor, LLC

www.spirecorp.com

Although not producing CPV systems, Spire is looking to capitalise on the increasing market for CPV high efficiency cells by producing GaAs PV cells.

25 Sagamore Park Drive
Hudson, NH 03051 (USA)
Phone 603-595-8900 | Email sales@bandwidthsemi.com

3.5.8 University of Delaware

www.ndel.edu

This year in July, a team from this University announced a new record of 42.8 percent for a cell based on a crystalline silicon platform. Even though this surpassed a record from a high concentrating cell, this cell concentrates the sun by 20 times, making it a low concentrating system cell. The University of Delaware News publication "UDaily" states that,

"The highly efficient VHESC cell uses a novel lateral optical concentrating system that splits solar light into three different energy bins of high, medium and low, and directs them onto cells of various light sensitive materials to cover the solar spectrum. The system delivers variable concentrations to the different solar cell elements. The concentrator is stationary with a wide acceptance angle optical system that captures large amounts of light and eliminates the need for complicated tracking devices."(UDaily, 2007)

Interestingly, 14 partners and research contributors helped achieve this record of efficiency, one being the Australian National University. Also of note is that three types of cells were used; one from industrial company, Elmore; one made by NREL; and one made by The University of Delaware.

University of Delaware
Newark, Delaware 19716, USA
(302) 831-2792

3.5.9 ZSW Germany

www.zsws-be.de

This company has a relative long involvement in LCPV and positions itself as a consultancy on CPV amongst other things. A recent system they designed was a MCPV system of 14 x, using mirrors and single axis passive tracking. It used silicon cells and was suitable for large ground mount or roof-top application.

Zentrum für Sonnenenergie- und Wasserstoff-Forschung
Industriestr. 6, 70565 Stuttgart
Telefon: +49 (0)711/7870-0 | Email: info@zsw-bw.de

3.6 Spreadsheet Data Presentation on Comparison of CPV Technologies

A spreadsheet showing the characteristics of the different CPV technologies is presented in Appendix B

3.6.1 Comparisons and Assessments

There are many ‘holes’ in the spread sheet where I would prefer that there were figures. Company secrecy is in common practice largely because the CPV business is highly competitive at the moment with many company start ups falling over, due to their inability to secure funding. Therefore every competitive advantage needs to be taken to secure the successful future of CPV business.

In this section I make comparisons of companies and the technologies of systems and designs. The total number of companies, systems and optical designs is not the same for the following reasons:

- Boeing, ENE, H2Go, InfoPyme Solar, Menova Energy, GE Energy, BP Solar, NuEdison and Arontis do not appear in the Table in Appendex B for reasons contained in the company notes in sections 3.2, 3.3, 3.4 and 3.5. Some companies are not strictly CPV systems and so do not appear in the table in Appendix B but have technologies very relevant to CPV and I felt they needed to be included in the discussion.
- Some companies have CPV technologies but are not currently pursuing their development.
- Some companies have more than one technology, for example Soliant Energy, and JX Crystals have worked on both LCPV and HCPV systems..
- Information was unavailable, for example I only know the CR of Enfocus' product is somewhere between 100 to 1,000 times.

Company Profiles

The industry is showing a rapid growth in research and development and this is borne out by the fact that out of 49 companies identified and surveyed only 11 of these companies have CPV systems in the field, excluding prototypes and small demonstrations. Nevertheless, meaningful trends and information on CPV can be gleaned by studying the data in the Ratings Table in Appendix

B. I deleted two columns relating to capital support and the price of power produced because information was hard to find on those topics.

System Types

There are three times more HCPV systems than LCPV ones available and only two systems that would be classed as Medium CPV (MCPV).The numbers in each category are:

HCPV-21

LCPV- 7

MCPV- 2

Optical Design

Out of the 31 concentrating technologies recorded, most were based on lenses. There were 20 lens systems (65 %); 8 systems used mirrors (26 %); 2 used a combination of both mirrors and lenses (6 %) and one used holographic technology (3 %). Please see table 3 below.

Note that there was a great variety in the design. Combinations and use of these reflecting and refracting devices and certainly other devices were incorporated as well. For example in the Entech medium concentrator system (20x), a prism was used in conjunction with a Fresnel lens.

Device	**No. of Systems Using Device**	**% of Total**
LENSES-	20	65 %
MIRRORS-	8	26 %
MIRRORS & LENSES-	2	6 %
HOLOGRAPHIC-	1	3 %

Table 3 Optical characteristics of CPV systems

It’s interesting to note that of the 21 HCPV systems, 15 (71 %), of them use exclusively lenses, while four use mirrors, and two use a mirror and lens combination.

Of the 7 LCPV systems, only 2 (33 %), use lenses, 3 use mirrors, one I’m not sure about (Day4Energy) and one uses holographic technology.

Thus, it is worth highlighting that lens use dominates in the HCPV field and mirror use is fractionally favoured in LCPV’s.

Concentration Ratios

The average level of concentration of all the devices I could find is 364x. The only company that has a system concentration close to this factor is Entech with its 400x. Entech is very successfully deploying commercial systems and has had much success with its medium concentration (x 20) system. It is curious that Entech’s two systems both occupy areas of concentration exclusively. I’m not sure whether this average is at all relevant, as the markets for the two levels of concentrators are being driven by different forces and exist separately in their own right.

The market for HCPV is being driven largely, but not exclusively, by multijunction cell development and the LCPV market because of the potential savings on expensive silicon.

Choice of Solar Cell

Standing out in the results table is the dominant use of TJCs and lack of silicon use in HCPV systems and the opposite in the LCPV systems. Actually, silicon is used exclusively in the LCPV group and only two HCPV devices use silicon. The cell types listed under ‘silicon’ cells are various, as efficiencies and prices vary and often with HCPV systems the higher efficiency cells (often called high performance silicon cells) are used and with LCPV systems, cheaper cells are often used.

Economics

It was hard getting information of the economics of CPV companies and the information I got was generally irrelevant. This is because the companies were forecasting optimistically to gain grants. Their prices are very speculative because of the immaturity of much of the development work and sometimes in the large corporations the CPV figures seemed to be engulfed by the business’ larger concerns.

Working within this high level of costing uncertainty, there are still some forecasts being made. The firm Sol3g believes it can produce its CPV system for $2.64 per watt, based on a production volume of 10 MW for 2008. .(Garrett and Herring, 2007) Boeing’s Pyron Solar, was reported to have produced its 800x system at a cost of US $3.00 per watt. CPV, as well as other low carbon energy sources, flat plate ‘solar thermal’ and other renewable energy technologies, will reduce in price quite quickly as carbon pollution is internalised and production volume increases. CPV will often be competing for market share with these other renewable technologies. The projected cost for most of these other technologies is more reliable because the industries are more mature, and historic costs are available. Often energy generation plants are compared using Levelised Cost of Electricity (LCOE), which I have already used in this paper. The LCOE is the money received for electricity produced throughout the lifetime of a plant that is sufficient for the plant to break even and cover the costs of building and running the plant. In the Switkowski report (Switkowski, 2006) it reports Australian levelised cost of electricity (LCOE) in Australian currency, from the following technologies to be:

- Nuclear - 4 – 6.5 cents / kWh
- Coal - 3 – 4 cents / kWh
- Gas - 3.8 – 5.5 cents / kWh
- Solar PV - 12 cents / kWh
- Solar Thermal- 8 cents / kWh
- Biomass - 8 cents / kWh
- High Capacity Wind - 5.2 cents / kWh
- Small Hydro - 5.2 cents / kWh

There has been criticism of these estimates and one critic, Ben McNeil of the University of New South Wales (UNSW), believes it is disingenuous to estimate the price of a first reactor in Australia at anything below 9 cents / kWh at the very best. He offers compelling arguments and evidence to support this view in his journal article titled, 'The Cost of Introducing Nuclear Power to Australia.' (McNeil, 2007)

The IEA (International Energy Agency) and the NEA (Nuclear Agency of Energy) reported the following LCOE in US Cents in 2005/6 with a 10 percent discount rate. (IEA and NEA, 2006)

- Nuclear - 3 – 5 cents / kWh
- Coal - 3.5 – 6 cents / kWh
- Gas - 4 – 6.3 cents / kWh
- Solar PV - 40 – 50 cents / kWh

- Solar Thermal - 20 cents / kWh
- Wind - 4.5 – 14 cents / kWh
- Hydro - 6.5 – 10 cents / kWh
- Oil - 83 – 92 cents / kWh
- Geothermal - 31.5 cents / kWh

There was only one power station studied and reported on for the oil and geothermal prices. The stations studied were located in Greece and the USA respectively.

To give some idea of the variation in estimates of the prices of electricity generated using relatively common means, I quote a study commissioned by the Royal Society of Engineers in the United Kingdom. See below for their results, which I have converted to US cents from the original pence.

- Nuclear - 4 cents / kWh
- Coal - 5.4 – 6.2 cents / kWh
- Gas - 4 – 6 cents / kWh
- Biomass - 6.8 cents / kWh
- Wind - 10.6 – 14.4 cents / kWh
- Marine - 13.2 cents / kWh

I have now included three studies above on current prices and price projections of different generating technologies. One study covers existing power plants and actual construction and operating figures from OEDC countries. One study is from Australia and contains predicted costs as well as actual operational figures and one study is from the UK to further diversify the data. Comparisons to the predicted LCOE from some CPV producing companies from sections 3.2.1 Amonix, 3.2.2 Arima EcoEnergy, 3.2.3 Boeing/Pyron Solar, 3.4.4 GE Energy, and 3.2.25 Soliant can now be made.

The average cost projections for these CPV producing companies in 2005/2006 were:

- 2006 – 24 cents / kWh
- 2009 – 11.5 cents / kWh
- 2014 **–** 6 cents / kWh

The average price in US cents per kWh for all the other technologies (in the three studies quoted directly above is 13.7 cents. So if predictions are accurate, CPV technology will approach the average cost of power in the OEDC in the next few years. This gives us the general idea that CPV technology is going to be a successful competitor in the energy generation business. How successful will depend on many factors, including some of the following:

Barriers to CPV –Technical

The barriers to CPV may be grouped in these categories below:

- **Immaturity of the Technology.** The longevity of lenses, concentrating materials and cells is not fully understood yet, and this uncertainty impacts on the confidence of investment and things like people being prepared to work in the industry. When the larger scale deployments, such as at ISFOC, have been collecting information on CPV over years, investment of capital and careers should follow, granted that the deployments are successful. The reliability of tracking in CPV systems is also not proven, and needs to be very accurate and reliable. The cost of construction and even the cost of maintenance is not known to any accurate degree at present. Even the quality of supplied equipment will have to be assessed. At present it is assumed that TJCs and high efficient silicon cells can be manufactured with a high degree of quality, in volume, as it is done for the space industry.

- **High Temperatures.** Working at such high levels of concentration, the high temperature is a technical issue in a number of ways. It is potentially very dangerous to both CPV components and people working near the arrays if mistakes are made, or systems go ‘off focus’. Many components need to be able withstand temperatures that melt steel, for prolonged exposure times. (Araki, 2005)

Barriers to CPV –Economic

- If conventional generation is cheaper such as coal with carbon capture and sequestration, or nuclear’s new breed of reactors such as the Thorium reactor, CPV will encounter a significant barrier.
- The emergence of a new technology could decrease CPV deployment.
- Other renewable energy sources may become cheaper than CPV, such as Concentrated Solar Power (CSP), geothermal, or any one of the PV flat plate technologies. Looking particularly promising at present are the thin film technologies.
- The high price of rare semiconductor material may be a substantial barrier in the future. It is feared that elements such as Indium, which is fairly rare, will continue to increase in price as demand increases.

Barriers to CPV –Political

- The successful deployment of CPV will at present probably rely on the continuation of subsidies, like generous feed-in tariffs.
- If the IPCC (Intergovernmental Panel on Climate Change) is unsuccessful in renegotiating the ‘post Kyoto agreement’, carbon

prices will dictate that most renewable energy technologies including CPV will struggle to compete in the short term.

System Efficiency

The highest system efficiency reported is 23 percent from the Concentrix system. With CPV being an immature technology, I estimate that continual increases in the efficiencies of systems will be achieved. Both the cells and systems have been evolving fast and it was reported on the 18/01/2008 in the Semiconductor Today publication, that an inverter tested at the Fraunhofer ISE in Germany achieved a maximum DC-AC conversion efficiency of 98.5 % using silicon carbide-based MOSFETs. Also, it was in the last few months of 2007 that the Delaware University team announced its world record of 42.8 % for a multi-junction cell conversion. Clearly the conversion of energy from the sun to electricity is set to be achieved more efficiently in the near future by CPV devises and I suggest this trend will continue. Multi-junction solar cells will be built with more junctions, soon four, and the research has mentioned that within a few years, six layers of cells could be used in CPV (Luque and Andreev, 2007)

Trends and Market Opportunities

HCPV seems to be deployed mainly in areas with desert like climates, near growing populations that have favourable tariffs for photovoltaic technologies. LCPV seem to be deploying mainly on commercial rooftops with the aim of some companies to also be able to compete with the flat plate for a share of the domestic rooftop market.

I anticipate a continued high growth in all CPV due to the increasing awareness of climate change, increase world energy use and increasing population, the imminent arrival of ‘peak oil’ (or at best, high oil prices) and the need for clean energy to drive the plug in hybrid vehicles that are predicted to be manufactured in large numbers after 2010.

Production Forecasts

Only ten firms out of the 33 surveyed have enough installed capacity at present to allow confident predictions of MW scale development next year. (See columns K and L on the CPV Ratings excel spreadsheet.) They are Concentrix and Sol Tech AG from Germany; Solar Systems from Australia; Sol3G, Guascor Foton and probably Abengoa Solar from Spain; Pyron Solar, GreenVolts, Emcore, Entech and Amonix from the USA and ArimaEco Solar from Taiwan. That is not to say that the other companies I’ve surveyed can not have MW scale development next year, but it’s unlikely given the fast rate at which their growth would have to occur. Exceptions to this list may be the big companies that have a long history of CPV prototypes and demonstrations in the field, but which have CPV commercialisation on hold. Sharp, Daido Steel and BP fit in this group. SolFocus and JX Crystals may also produce substantial amounts of panels in 2008 and 2009.

4. CONCLUSIONS

4.1 The State Of Concentrator Photovoltaic Systems

Future Directions: Antonio Luque is an elder statesman of the CPV research and development world community and he is largely responsible for setting up ISFOC (Instituto de Sistemas Fotovoltaicos de Concentracion) in Spain He has recently gone on the record as saying intermediate band cells could enable the next efficiency rise after 45 percent efficiency is reached in a CPV destined solar cell with a fourth cell added to a multijunction set up. Luque says there's potential to reach 63.2 percent in his design, theoretically. He thinks this is possible through the addition of the critical intermediate band middle, which he has failed so far to make using quantum dot material with GaAs, InAs and other more 'exotic material'.(Luque and Andreev, 2007) It is always hard to tell whether this sort of prediction is talking up the potential of increasing the efficiency of CPV high efficiency cells in the hope of receiving more funding and investment capital or an informed, reasonably objective opinion. My guess is that it is optimistic, but certainly not impossible. Even if these high efficiency cells are created, they then have to be mass manufactured economically.

Drivers

Irrespective of the speed and ultimate level of research success achieved, commercial contracts are being signed for deployment of CPV systems. The state of the CPV industry is one of health and rapid expansion due in principal to the rapid increase in efficiency of TJCs, the high price of silicon, the globe awakening to the threat of climate change, the great match for solar generation and peak demand and finally the increasing price of oil.

Market Leaders

SolFocus does seem to be a very clever design and the company claims confidently to lead the industry. Commercial vendor Concentrix has published a module efficiency of 23.5%, and commercial vendor SolFocus has published a module efficiency of over 22%. I feel that companies that increase their efficiencies to around this level should be successful, particularly if they have access to finance and knowledge to scale up their production.

I would expect, given the trends identified in my results and analysis, that HCPV systems will dominate CPV deployment. One distinct advantage, already demonstrated by Solar Systems of Australia, is the ease with which a HCPV system can upgrade its solar cell to one with increased conversion efficiency.

The firms listed under production forecasts, found in the last paragraph of ‘Comparisons and Assessments’, are the ones likely to successfully roll out multiple MW installations in the coming year.

Thermal Energy

I have not spent any time analysing the thermal use of energy from CPV systems. All the high concentration systems have the potential to increase their performance by utilising the heat extracted from cooling the PV cells. Even the low concentration systems have this additional bonus, albeit at a lower value. (G.Sala *et al*., 2003) and with more research and development in this area, I believe there will be quite a growth in this special subset of CPV, including rooftop combined heat and power systems.

Industry Outlook

In summary, concentrator devices decrease the amount of cell material needed. This is because the concentration mirrors and or lenses take up the same area as conventional flat plate, but they concentrate and focus the sunlight and allow less cell area to be used per energy generated. I believe the price of multijunction cells will tend to increase as their complexity of design increases along with their efficiency. This will provide even greater economic stimuli for the growth of CPV because reductions in the amount of cell material used will save more money as MJCells keep on increasing in price. Therefore there will be a greater return on increasing the level of concentration.

The future will see higher conversion efficiency in cells, modules and systems, greater concentration of solar flux, decreased costs through increased scale of production, and by 2020 the cost of CPV will be quite low compared to today.

One only has to look at the relatively large number of CPV focussed companies (more than thirty) that have been created in last few years to see that we are in the dawn of the commercialisation of this technology; This is a renewable technology industry, unlike fossil fuel extraction, on which the sun will not set for a long time.

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APPENDIX A

Sample of the Questionnaire used for this project

27/12/2007
71 Evansdale
Road Hawthorn
Victoria 3122.
AUSTRALIA.

To the Officer In Charge of Enquiries,
Dear Sir or Madam.

I am a firefighter and member of the 'Environmental Action Committee' for the Metropolitan Fire Brigade, in Melbourne. We would like to examine your CPV product as a possible source of power for our UPS and general power systems at our 50 plus buildings. Any information flowing from the following questions will certainly be appreciated and considered in future moves.

1. What is the optical Concentration of the system?
2. What is the efficiency of the cells you are to use?
3. What is the Capital backing of the company?
4. What market niche is the product aimed at? That is, is the market for the product, domestic roof, commercial or factory roof, grid support or power station and have you set up a sales network in Australia?
5. What is the projected cost of power provided by the system?
6. Is the product manufactured yet? Is it mass produced? What quantity was made in the past few years?
7. What is the projected rate of manufacture?
8. How many people work for the company?
9. Is the company privately owned or a listed company on the stock exchange?
10. How experienced is the staff?
11. How robust, reliable and long-lasting is the product? Have accelerated life trials taken place?

I am also completing a Masters' Degree in RE at Murdoch University, Western Australia and may use any information you provide to help me in my comparison of CPV technology on top of using such information to help me guide procurement in the MFB as outlined above. I am to finish my studies soon and may involve myself in the CPV industry in some capacity.

I appreciate that you must be very busy at this exciting time of CPV development and any information you may be able to provide will be greatly appreciated.

Wishing You Great Success,
Peter Stafford | Leading Firefighter 4084

APPENDIX B

List of Abbreviations

ACDC	Alternating Current Direct Current
AG	Public Company (Germany)
a-Si	Amorphous Silicon
ADS	Astrophysics Data System
ATS	Automated Tooling Systems
BIPV	Building Integrated Photovoltaic
BP	British Petroleum
CEO	Chief Executive Officer
CIGS	Copper, Indium, Gallium, Selenide
CPV	Concentrator Photovoltaic System
CR	Concentration Ratio
CSLM	Concentracion Solar La Mancha
c-Si	Crystalline Silicon
CSPV	Concentrator Solar Photovoltaic
DC	Direct Current
DE	German
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EUREC	European Renewable Energy Centres
GaAs	Gallium Arsenide
GaIP	Gallium Indium Phosphorus
GE	General Electric
GMBH	Company with Limited Liability
HCPV	High Concentration Photovoltaic
HQ	Head Quarters
IEA	International Energy Agency
IEC	International Electro technical Commission (Standards)
IP	Intellectual Property
ISFOC	Instituto de Systemas Fotovoltaicos de Concentracion
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelised Cost of Energy
LCPV	Low Concentration Photovoltaic
LLC	Limited Liability Company
MCPV	Medium Concentration Photovoltaic
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MOU	Memorandum of Understanding
MW	Mega Watt (1000 x Watts of power)
NASA	National Aeronautics and Space Agency
NREL	National Renewable Energy Laboratory
O and M	Operation and Maintenance
OEDC	Organisation for Economic Development and Cooperation
PMMA	Poly (methyl methacrylate) or poly (methyl 2 methylpropenoate)
PVT	Private
PV	Photovoltaic

R & D Research and Development

SAO	Smithsonian Astrophysical Observatory
Si cells	Silicon Cells
TJC	Triple Junction Cells
UAE	United Arab Emirates
UK	United Kingdom
USA	United States of America
UV	Ultra Violet (Radiation)
VHESC	Very High Efficiency Solar Cells
Wp	Peak Watts The power a pv module can produce when irradiated with 1000 Watts per square meter
WEB	Refers to the WWW (World Wide Web)
III – V	Refers to elements from groups 3 and 5 in the periodic table

APPENDIX C

CPV Rating Data

Company vs Business Rating Category	Cell type	Concentration Low or High (L or H) Medium (M)	Cell Efficiency	Market Niche	Fresnel Lenses(FL) or mirrors(M) or both(B)	Manufacture History	Projected Rate of Manufacture 2008	Workforce number	Private or public co?	Staff experience	Longevity of product	Module Efficiency %	Tracking O-none1-single axis,2-dual axis	System Efficiency %
				Power Station (PS),Grid Support (GS) Commercial C,Residential R										
Amonix	Si	H 500x	26.5	PS, C,	FL	750 kW	??	Hiring lots	Private	10	20 years		2	
ArimaEcoSolar	Ga/As TJ	H 476x	37 at 500x	PS, GS.	FL	R&D only	300 kW	37	Private	5	IEC 62108	~23	2	~19
Concentracion Solar La Mancha	IGaP,IGaA	H 500x	>30		FL						IEC 62108	23	2	
Concentrix Solar DE	TJC'sAzur	H 500x	35	PS, C, GS	FL	~13 kW	25 MW				IEC 62108	25	2	up to 23
Cool Earth Solar				PS	M	Prototype	hopeful		Private		short		1?	
Daido Steel	TJCells	H 550x	32-35	PS, GS,C,D	FL	10 kW		large	Public	Pioneers	20 years		2	20.5
Emcore	TJCells	H 500x	>30	PS	L & M	50 MW	>50 MW	>750	Public	Loads			2	
Entech x400	TJCells	H 400x	>35	PS, GS.	FL x 2	Development			Public	Loads			2	
Energy Innovations	TJCells	H 800x	>35	C, PS, R	FL x 2	Development	Finish Devt	~35	Private				2	
Enfocus	TJCells	H	35	C, D	FL	Prototype		V.Small	Private				internal 2	
Green and Gold Energy	TJCells	H 1100x	36 to 39	All	FL's	Prototype#		Recriuting	Private	Little	<1%/yr degredation		internal 2	
GreenVolts	TJCells	H 625x	>35	C, PS,	M	Development	5 MW		Private				2	
Guascor Foton	Si	H 500x	~25	PS	FL	950 kW	20 MW					27	2	18
Isofoton	TJCells	H 1000x	>35	PS	L & M							20	2	
JX Crystals	DJCells	H 500x	Research on 4JC 40%eff	PS	M	Prototype							2	
Pyron Solar	TJCells	H 800x	>35	PS	Lenses	6 MW	~50 MW		Public	Loads			2	
Sharp Solar	TJCells	H 700x	36		FL	2.9 kW			Public	Loads			2	
Solar Systems	TJCells	H 500x	>35	PS	M	~60 kW	~140 MW*	~50	Private	Some			2	
Solar Tec AG (DE)	TJCells	H 700x	~35	PS, GS,	FL		~80 MW	Large	Public	Loads			2	
SolFocus	TJCells	H 500x		PS, GS,C,	M x 2		500kW++	60+ see notes		New Staff		26	2	17.1
Sol3G	TJCells	H 476x	35		FL	39 kW	5 MW	17+ ?	75% Private			24	2	
Soliant Energy formerly PI	TJCells	H 500x	toward 40		FL								2	
Entech x20	Si	M 20x	20	PS, GS	FL+prism	Well established.		Large	Public		30 years		2	
Whitfield Solar Ltd	Si	M 40x		All	FL	Prototype		recruiting	Private				2	
Day 4 Energy(prod not avail)	Si (Qcells)	L 7x				Prototype			Public					
JX Crystals	Si	L 3x		All	M	400 kW+							1 or 2	
Pacific SolarTech	Si	L 10x		All	Domed L								None	
Prism Solar Technologies	Si	L ~7			Holograph	Prototype							None	
Silicon Valley Solar (SVS)	Si	L 2.2x		All	M	Prototype							None	
Solaria Corp	Si	L 2 to 3x			L	Prototype							None	
Soluca Energia (Abengoa Solar)	Si	L 1.5 to 2.2x		PS, GS	M	1.2 MW							2	12
Stellaris	see notes			C, R	L	Prototype		Small	Private				None	

* denotes firm contract to be completed by 2013
# have order for >100 MW Emcore TJC's.