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Instituto de Energía Solar

Becquerel Prize Ceremony 2013

Lecture

on

Concentrator Photovoltaic Technology: a short review

Gabriel Sala

Gratitudes

To the persons that have proposed for my **nomination**

To the **European Commission** for granting every year the Becquerel Prize and the **Committee** for appreciating so positively the work carried out by my **Group** at UPM.

The work of my team has highly contributed to earn this award. For this reason they deserve a big part of the Prize.

I want to highligh the special contribution of **Prof. Ignacio Antón** for sharing with me research and management in many projects.

Also to the **Direction** of the Institute of Solar Energy-UPM for easing our investigations while pursuing excellence along decades.

Thanks to all you for your presence.

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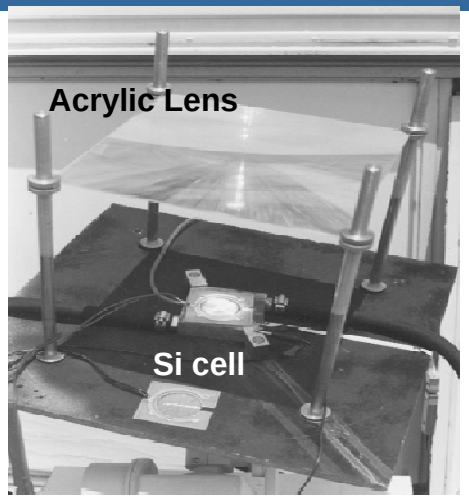
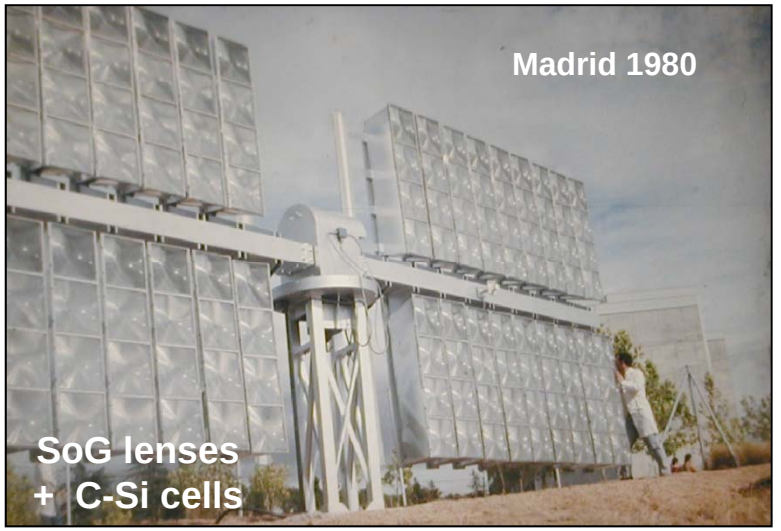
Introduction: few histories

In 70's the cost of Si cells and modules and the slow learning curve of PV suggested using concentrator optics for reducing the required area of solar cells



The first modern PV concentrator was the 1kW Sandia I, Albuquerque,NM

Soon in Spain, France and Italy it was imitated developing specific sub-system alternatives



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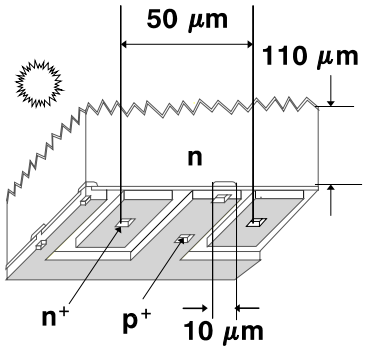
Early Concentrator cells and its Market

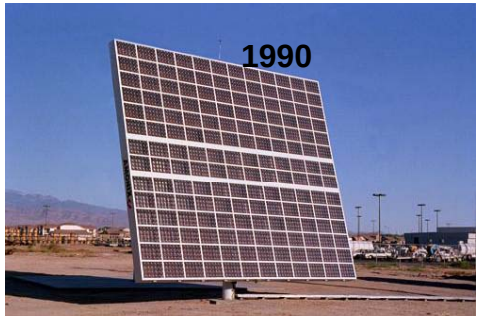
Soon was understood that using VERY HIGH EFFICIENCY cells was the only way for CPV suitability.

In 1986 Prof. Swanson and his team at Stanford U. developed the 28% efficient BPC cell operating at 150 suns.



But CPV business was unreal in 90's because multi-MW utility market did not exist yet.

However Vahan Garbusian, at Amonix, progressed developing successive prototype arrays based on the Sandia Labs technology and BPC cells at 300X.



18 years later, Spanish feed-in tariff Decrees and Si module shortage allowed the first CPV commercial deployment of 10 MW

AMONIX was ready for it and Guascor, an Spanish company deployed its technology

Acrylic Lens + BPC cells

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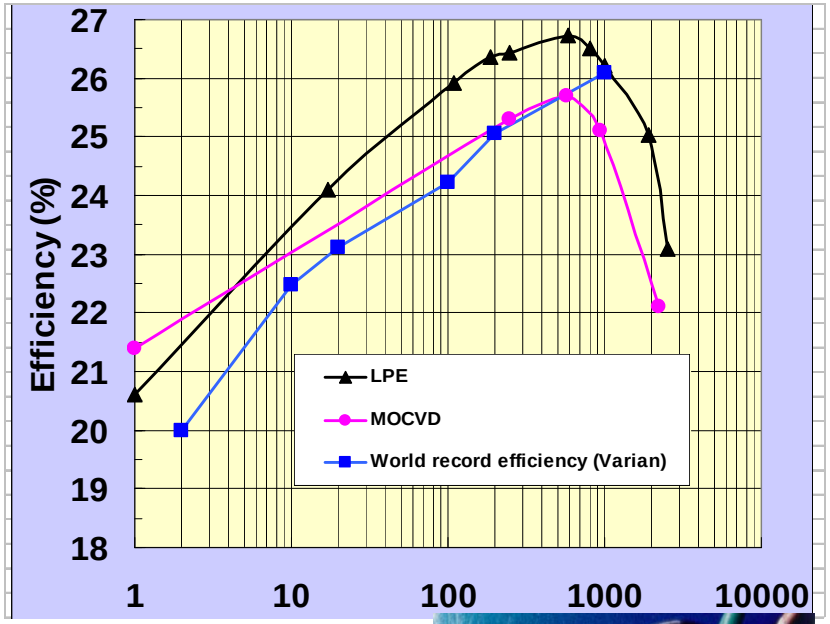
1990's steps preparing for the future of CPV

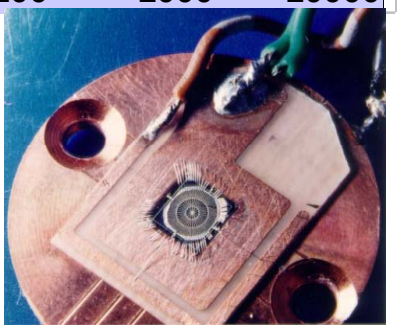
One significant experiment carried out with Concentrator GaAs cells along 90's showed that small cells can be operated beyond 1000 suns level, still at very reasonable temperature, low ohm loses and keeping high efficiency. (IES-UPM, IOFFE, Fraunhofer, NREL, ..)

However the cell efficiency was only 26.6 %....



The efficiency of single junction cells is ESSENTIALLY LOW because they cannot convert optimally the solar spectrum.

FULLSPECTRUM Project, subsidised by EC (2003), improved several cell technologies in this direction contributing to current competitive position of Europe in CPV.



AlGaAs/GaAs Cell
3mm Diameter

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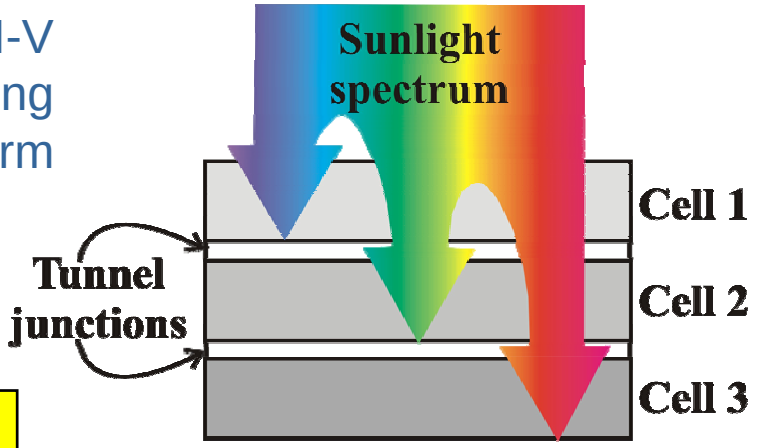
Multijunction cells

The monolithic Multijunction cells, made of III-V semiconductors, are currently those optimizing the PV use of the solar spectrum. They perform simultaneously as filters and PV converters.



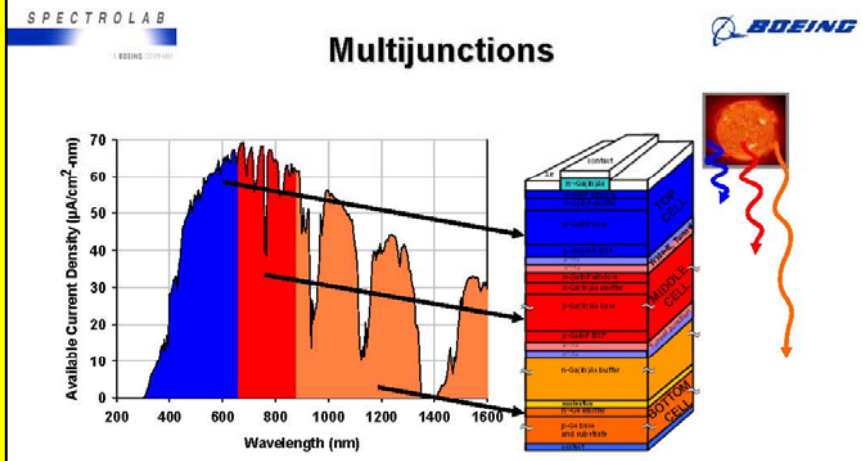
State of the art for MJ cells:

- 44.4 % (4J) Sharp (Japan), 44.0 Solar Junction (USA)

-Last week Europe took the lead: new record 44.7% efficiency by Fraunhofer, Soitec, LETI and Helmoltz

- 50 % will be reached soon.

- The 3J cell efficiencies at the production lines are at 40% range.



- Record efficiency of >40%: >1.3x that of single-junction silicon
- Cost is >100x that of single-junction silicon cells
- No current earth-bound applications outside of HCPV

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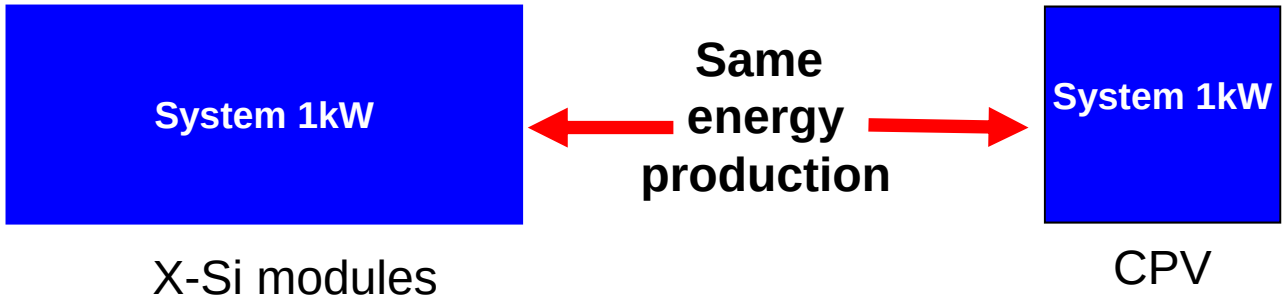
The New CPV concept

Multijunction cells are very expensive (100-200 times the silicon cells) but they can be used in terrestrial PV if are operated at Very High Concentration (300, 500, 1000X or more)

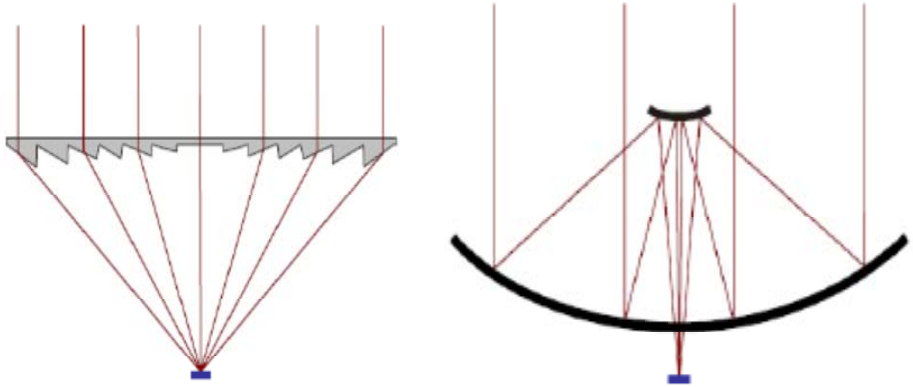
"CPV becomes the technology that will allow any sophisticated and highly efficient cell, no matter it is very expensive, being used in terrestrial applications in competition with PV and other sources.



It will allow reducing significantly the overall system area required for a given power: the reduction up to 50% or more will consequently reduce the energy cost (LCOE).

How making a CPV system?

The light must be concentrated with compact optics, i.e. with mirrors or lenses of short focal distance.

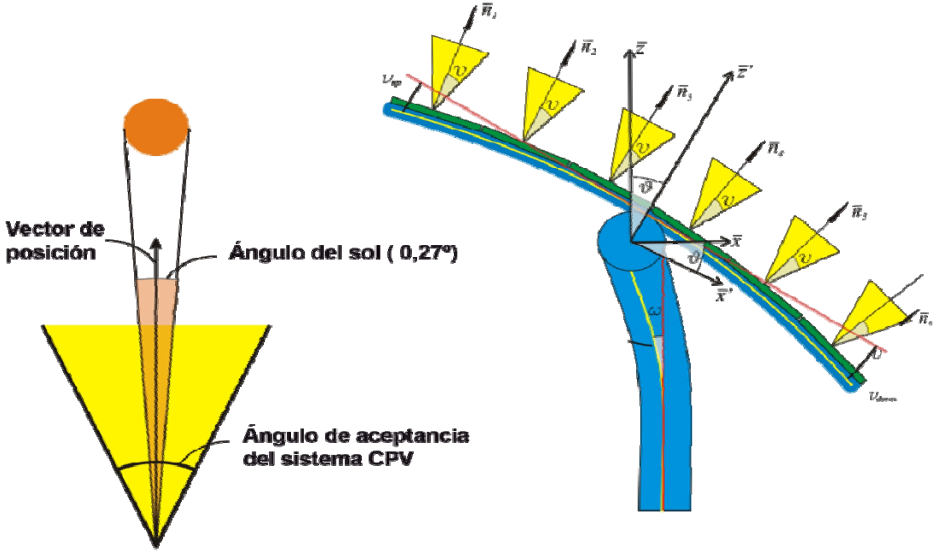


Mirrors are more compact, but lenses are simpler to use and are the most preferred by the industry.

Thermodynamics links the maximum concentration level with the angle of vision of the optical system.

$$C \times (\text{angle vision optics}) < n^2$$

For more than 5X we need a tracking system for pointing the optical collectors towards the sun disk.



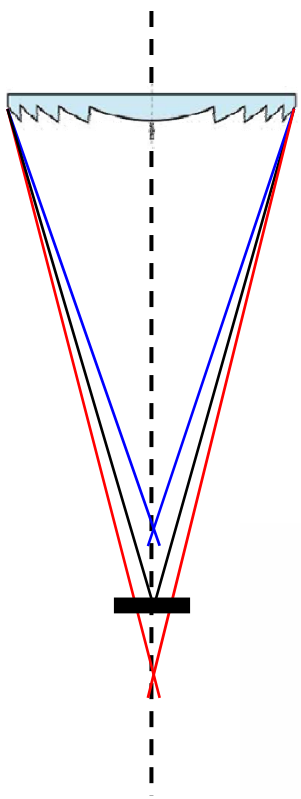
Courtesy: BSQ Solar

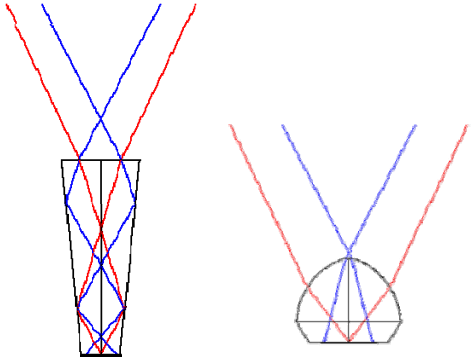
Limitations of optics

In addition to thermodynamic constraints the level of concentration of lenses is limited by the dispersion of light causing chromatic aberration (C.A.)

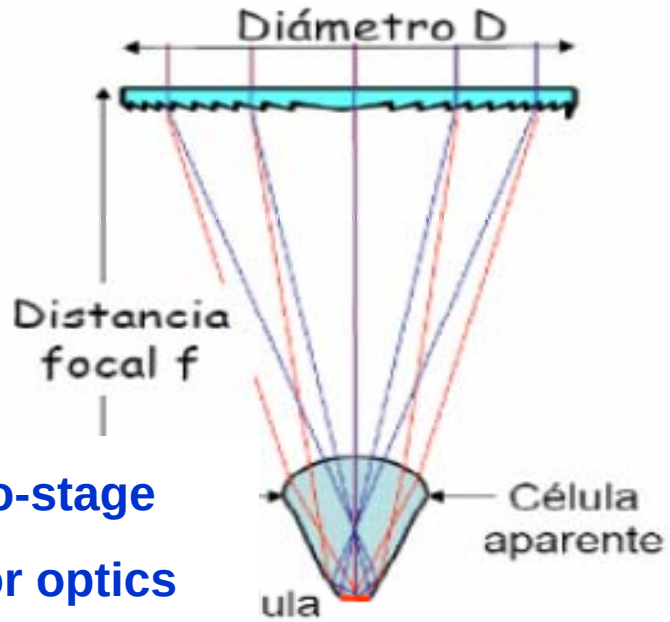
C.A. reduces the concentration level drastically: From 1200X for mono-chromatic light to 300X for the whole spectrum.

It is solved adding a Second Optical Element (SOE) which enhances the C level.





Dielectric SOE's



Classic two-stage concentrator optics (POE + SOE)

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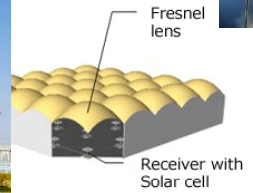
Two-stage optical technologies with MJ cells

Amonix, Solfocus, Daido Steel, Suncore, Semprius, Isofoton, Abengoa … use POE and SOE inside a metal backed module housing.

Many companies have reported over 32 % modules for concentration levels between 500 and 1200.

Semprius reported 35.5%, and Amonix recently reported a 35.9% record module, both tested at STC.

Amonix, Solfocus and Suncore have sold and deployed multi MW power plants, as shown in the pictures.



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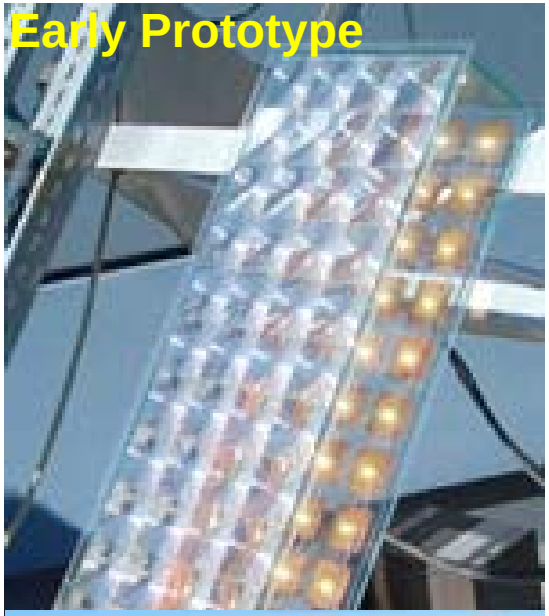
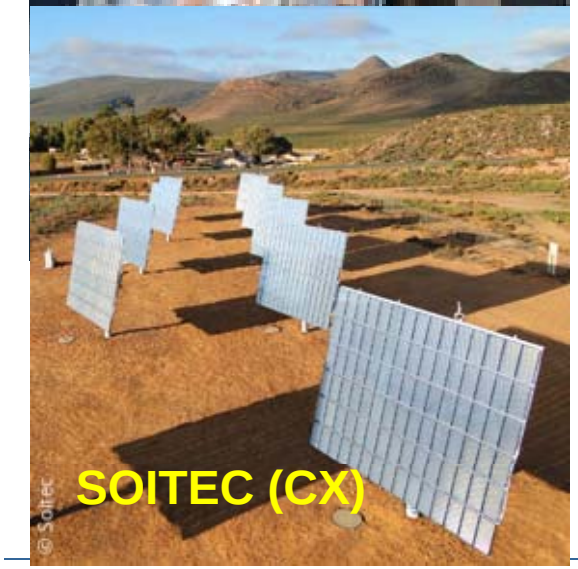
One stage optical technology with MJ cells: SOITEC (CX)





The mini receivers of SOITEC module are mounted on glass, imitating the successful flat PV module technology, which provides natural insulation and durability.

SOITEC commits for SIMPLICITY and RELIABILITY with one single optical stage module which allows only for a moderate concentration level. (320x)

SOITEC has installed in 18 countries and signed a 150 MW contract in USA and are building a 200MW facility in San Diego.

SOITEC seems going to dominate the sector in the short term.

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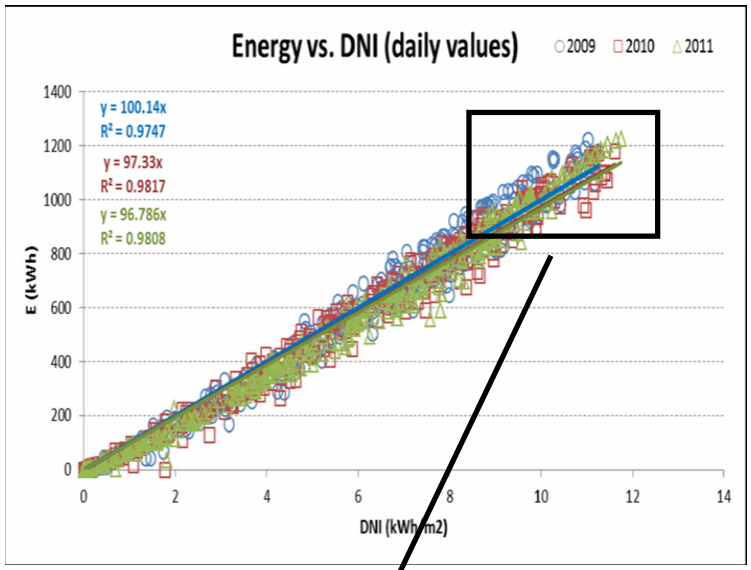
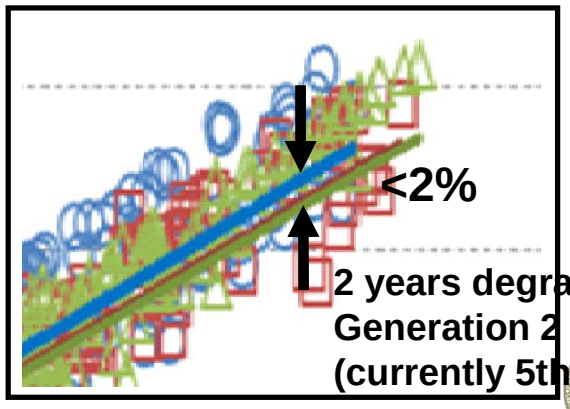
Energy Production and reliability.
Are the "complex" CPV systems productive and reliable?

ISFOC (Puertollano, Spain) has collected , along 5 years, system data of several large CPV systems (>300kW), made by 7 companies: SOITEC(CX), SOLFOCUS and ISOFOTON were the first operating.

The plot shows the performance a 100 kW CPV system, without any correction for spectrum, temperature, tracking, soiling, etc.;

We can see that <AC power to grid> varies LINEARLY vs. Available DNI Radiation, along three whole years. (2009-2011)





Looking closer to that plot we see an imperceptible degradation in early prototypes Gen 2-SOITEC in two years.

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Conclusions

Concentrator cells have reached 44.7 % in laboratory and 40% in manufacturing line. Modules 35% efficient at STC are reported.

The simplest CPV modules (1 stage) are becoming the most supported by Assurance Companies and most demanded in current market.

CPV systems require 50% less collecting area than conventional PV. CPV's allow dual land use (crops, cattle)

Reliability of CPV's is proven

CPV energy generation is predictable.

Market growth rate is comparable to the one of PV in the past. (Cumulated 1.2 GW is expected by 2016)

CPV requires the lowest CAPEX and procures intensive local economic growth.

European technology is probably going to lead global CPV progress next years.

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Thank You
for
Your Attention !

Pictures and graphics courtesy of Amonix, Soitec, Solfocus, Daido Steel, Suncore, BSQSolar, Fraunhofer ISE, J. Wiley, Elsevier, ISFOC, Spectrolab.

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