

For the last almost 40 years (since its foundation in 1979) the common goal at IES has been that photovoltaics (PVs) become one of the main energy source worldwide, able to contribute to its development thus making Spain a leading country on this technology.

Today, by the end of 2016, these objectives have been partly accomplished.

As an example, "Mexico concluded in March 2016 its [first Clean Energy Auction for energy, power and Clean Energy Certificates for purchase by CFE, Mexico's only utility](#). The results are stunning: ...11 PV projects have been awarded contracts worth 4 million megawatt-hours (DC) per year. That translates to 1,860 megawatts of capacity (using an average capacity factor of 33.6 percent)... Mexico defines clean energy quite broadly, so the auction was open to competition from wind, hydro, cogeneration, combined-cycle gas, and geothermal, as well as PV. Out of a total 5.38 million megawatt-hours of energy that was awarded, PV won 74 percent and wind won the remaining 26 percent, with no contracts won by any of the other technologies". The average electricity cost in this auction was 5.07 dollar cents per kWh.

"Solar power set another record-low price (May 2016) as renewable energy developers working in the United Arab Emirates shrugged off financial turmoil in the industry to promise projects costs that undercut even coal-fired generators. Developers bid as little as 2.99 cents per kWh to develop 800 megawatts of solar-power projects for the Dubai Electricity & Water Authority, the utility for the Persian Gulf emirate, announced on Sunday. That's 15 percent lower than the previous record set in Mexico last month", according to [Bloomberg New Energy Finance](#).

According to Bloomberg [New Energy Outlook 2016, Executive Summary], "Solar's precipitous cost decline sees it emerge as **the least-cost generation technology in most countries by 2030.**"

Perhaps it is to be clarified that "solar" means in general PVs. Concentrator Solar Power (CSP), that is, solar thermal, is much more expensive and less flexible than PVs even if some storage is provided with batteries to PVs to match the alleged storage advantage of CSP. [Lazard Levelized Cost of Energy Analysis—version 10.0, December 2016]

This seems to indicate that the first goal of our objectives has already been reached. Present reality and all serious forecast support this statement. However, there is a weakness in PVs which is still unsolved and calls for further research. It is the problem of electricity storage. One of the main goals of IES for the near future is the development of techniques of energy storage based on the very high latent heat of silicon and its recovery based on thermo-photovoltaics (TPVs).

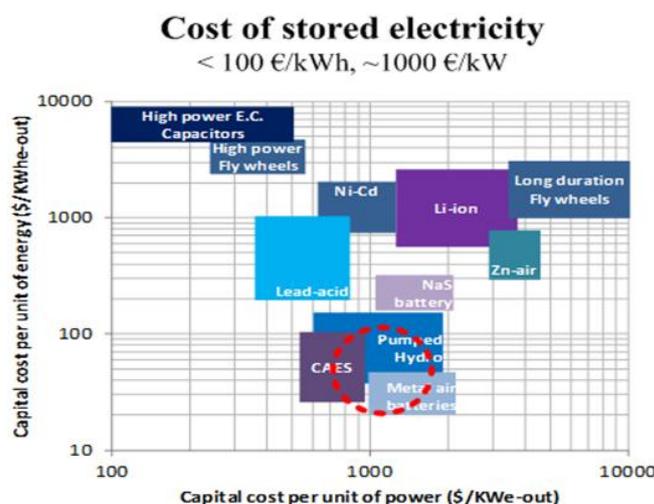


Fig. 1. The red dotted circle reflects the expected cost of this Molten Silicon/TPV storage method.

Concerning the goal of making of Spain a leading country in PVs, by the first decade of the XXI century, this goal was almost reached. By the beginning of the century Spain was the biggest producer of solar cells in Europe and Isofotón, an IES spin-off created in 1981 to manufacture the bifacial solar cell —its invention— was the seven biggest silicon cells producer. In 2008 Spain was the biggest PV world market, with 2.8 GWp installed in one year (based in a very favorable feed-in tariff of almost 50 cents of dollar). By this time Spain has almost half a hundred of companies working for PV, many of them exclusively.

### The Spanish PV industry

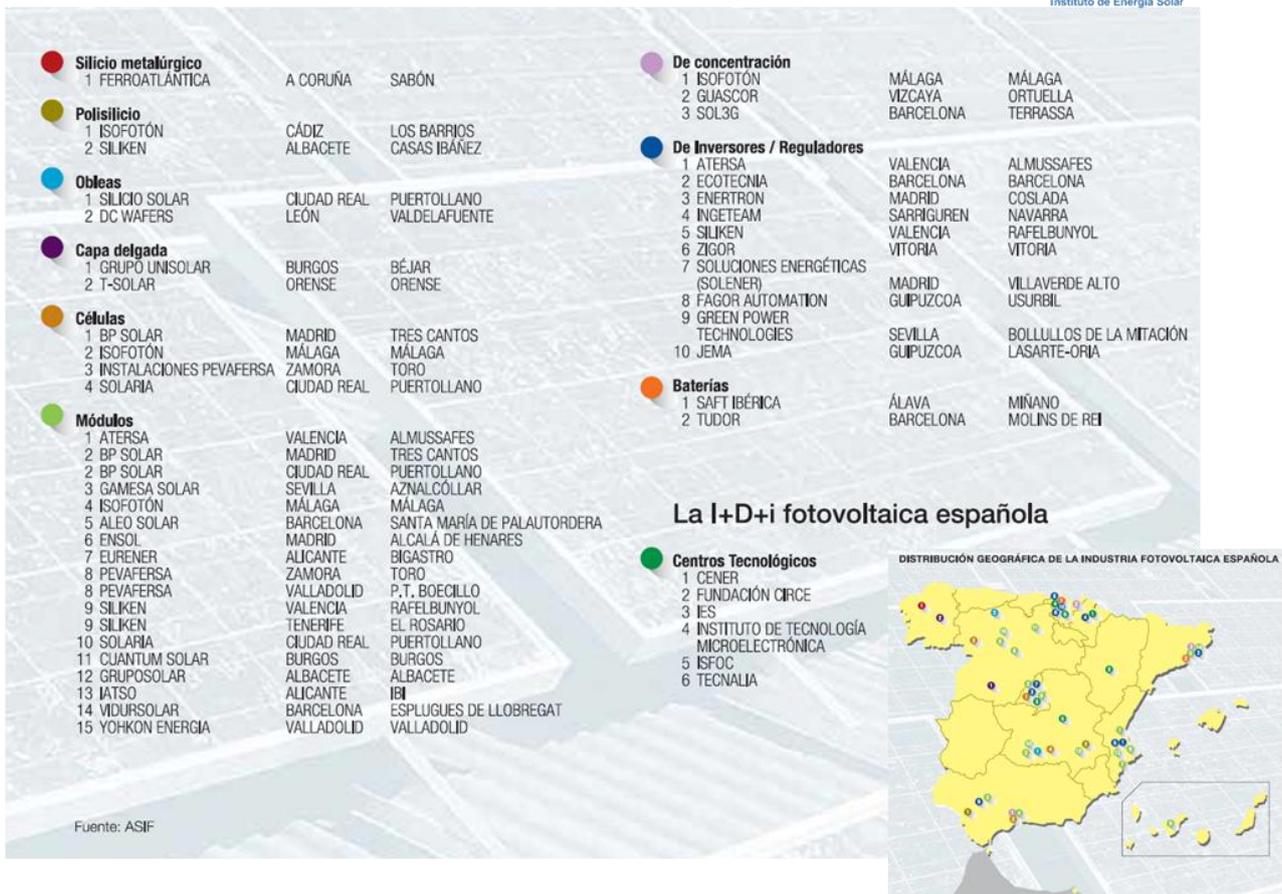


Fig. 2 Annual Report of the Association of the ASIF Spanish Photovoltaic Industry

However, the counterpart was that by 2010 PV was providing the 2% of the total Spanish electricity consumption at the price of 12% of the total electricity cost. When the economic crisis appeared, the subsidies were rapidly cut and most of the PV companies in Spain went to bankruptcy. This fate was also followed shortly after by most of the module manufacturers of the West, which were unable to compete with the low prices of the Chinese PV modules, which were the authentic artifices of the stunning cost reduction of the PV electricity, to date unchallenged. Nevertheless, some EPC companies (Engineering, Procurement and Construction) survived, both in Spain and in other leading countries and play an important role today in the World development of PVs.

The leading PV position of Spain started at the university, long time ago. By 1977 the UPM presented the concept of bifacial solar cell [1]—a cell converting into electricity the light received by its front and the back faces altogether. By 1979 the Solar Energy Institute (IES) was founded at the Technical University of Madrid (UPM). By 1980 the Back Surface Field Bifacial Solar Cell with efficiency of 15.7% under front

illumination and 13.6% under back illumination was developed [2] and shortly after the concept of albedo-collecting module—a module with bifacial cells able to respond to the albedo (or back) illumination (from a white painted surrounding) was presented [3]. These two achievements together led to the foundation in 1981 of Isofotón for the development of albedo-collecting modules, by this time the most efficient in the world when provided with a good enhanced albedo. By 1988 the IES developed thick emitter silicon solar cells with efficiency of 19%, by the time a European efficiency record. By 1994 the IES presented a back surface field bifacial solar cell with efficiency of 19.1% when illuminated on the back face and 18.1% when illuminated on the front face. Assuming an albedo of 50% the effective efficiency of these cells was of 28.2%, by far the most efficient silicon solar cell.

Silicon cell technology, which is the dominant technology today used, was complemented at IES by research in others cell technologies keeping in mind the importance that IES attributes to high efficiency [4]. In 2009 the IES produced a double junction solar cell with efficiency of 32.6% [5], the world record for this technology at that time.

In 1997 the IES proposed a new type of solar cell, the Intermediate Band Solar Cell, with an efficiency potential of 63% vs. the 41% of the existing solar cells [6]. Today (December 24, 2016) the paper where this concept was first described has received 1236 WOK (1833 Google Scholar) citations. Several other papers associated with this technology appear monthly in the WOK data basis as highly cited papers, that is, within the 1% of the most cited papers in their specialty. In July/august 2016 these papers are references [7] and [8]. Mention is also to be done to a new cell structure called the Heterojunction Bipolar Transistor solar cell that for increased efficiency, that may be of interest for certain applications. [9]

Additional reflect of the Spain's position, and the IES role of it is the coordination of important international research projects, like FULLSPECTRUM (SES6-CT-2003-502620), with 19 European research institutions in the period 2003-2008 and a EU grant of 8.3 million euro; the NGCPV (283798) project a joint EU-Japan project led coordinated by the IES in its EU part, with 7 European and 8 Japanese research institutes with a grant of 5+5 million euro from each side in the period 2012-2015. Also the xxx project with

The publication as editor of important strategic highly cited books such as the one in reference [10] (2370 Google Scholar citation by December 26, 2016, 2 editions) also stresses the IES and Spanish influence.

A direct consequence to the Spanish industrial success in PVs is that the IES has spun-off a set of companies some of which are still working successfully. LPI is a leader on consultancy for the optical design devoted to solar or other purposes, than brings to reality the theoretical developments of the non-imaging optics. InSpira specialized in high precision trackers for concentrator PVs (CPVs) was fruitfully sold to the USA's company SolFocus, in an operation widely publicized by the media.

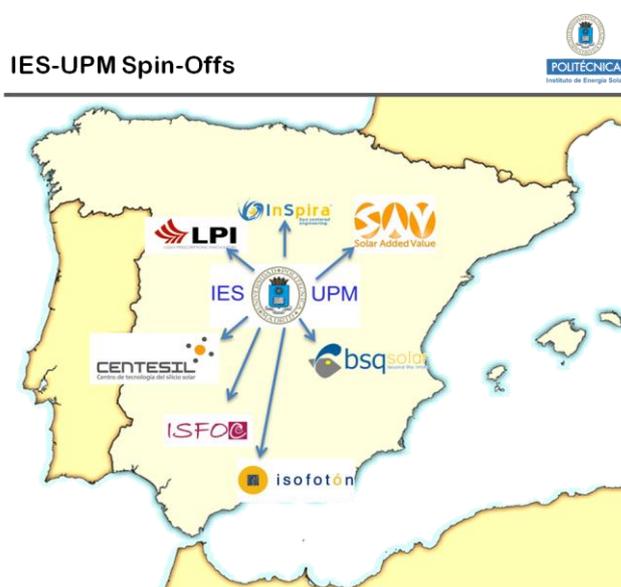




Fig. 3. Spain’s InSpira selling is announced widely

SAV has licensed and manufactured several pieces of equipment developed at IES for measuring the performance of concentrator PV (CPV) modules and by its improvement via analysis of the quality of the optics and the alignment results during the assembling. More than a dozen Helios© solar simulators with different additional fittings and software have been sold in four continents.

BSQ is the continuation of InSpira, once the compromises with SolFocus were extinguished and now they are manufacturing the whole CPV system, including tracker, optics, cells and assembly. BSQ has installations in eleven countries of four continents as well and uses one of the SAV CPV solar simulators. It holds presently 35 patents

Centesil, a pilot plant to test Siemens based silicon ultrapurification was a venture of Isofotón, the cell manufacturer, DC Wafers, a wafer manufacturer and Técnicas Reunidas, an engineering company together with the Complutense and Technical Universities of Madrid, is about to be concluded due to the bankruptcy of the two first companies. Now the unconcluded installations belong exclusively to the two universities.

ISFOC is a research company for the study and development of Concentration Photovoltaic Plants. I has about 3 MW of arrays installed from different companies, including Isofotón and SolFocus. It was at the origin of the incipient CPVs boom that attempted to challenge with very high efficiency multijunction cells the leading market position of ordinary silicon cells. About 100 million Euros were spent in this attempt between 2006-20013, that finally was almost fully swept out by the recent World crisis. The bankruptcy of most of the manufacturers has limited the action of ISFOC greatly. BSQ, with a smaller and more flexible structure is still resisting and is today one of the most important worldwide CPV manufacturers

Isofotón has already been described before.

During the preceding period, the IES has followed the following objectives:

- 1) Supporting the PV installations (with strong effort in big plant characterization)
- 2) Vertical Integration of PV technology (from metal silicon to solar module, with big effort in silicon ultra purification)
- 3) Improving the PV learning curve
  - a) Short term research and development (Multijunction Solar Cells, concentrator optics and CPV manufacturing tools)
  - b) Long term research (mainly Intermediate Band Solar Cells)

For the period from now on we propose the following changes

- 1) Supporting the PV installations (with strong effort in support of the Spanish bidders and development of the concepts of the smart grids and integration of PV in smart cities)
- 2) Improving the PV learning curve
  - a) Potential cost reduction in silicon (lower energy consumption of crystal growth or in ultrapurification)
  - b) Multijunction Solar Cells, concentrator optics and manufacturing tools
  - c) Novel concepts (Intermediate Band Solar Cell and Heterojunction Bipolar Transistor Cell)
- 3) Electricity storage
  - a) Molten Si storage
  - b) Thermo-photovoltaic Electricity Conversion

**Potential cost reduction in silicon.** Silicon is already largely domination but IES must preserve and augment its knowledge in cell engineering, electricity reduction in crystal growth and advantages in polysilicon purification, all this with goal of contacting with the cell manufacturers of today and offering solution that can help to further reduce the price. An additional and important goal is to have a bunch of specialists able to adapt any technology that could be offered in a reindustrialization process.

**Multijunction Solar Cells.** The low electricity costs offered by the PV operators are often suspected of being below production costs. If so, they are not sustainable. Research of CPV technologies, using the highest cell efficiencies ever dreamed, should not dismay of achieving the most competitive conditions in its field possible under the existing constraints.

**Novel Concepts.** For the same reasons above, the research on this topic must continue, taking into account that fundamental research is the reef where precious ideas may appear.

**Molten Si Storage.** The development of melting Si or alloys and keeping it hot until its energy is converted into electricity is a huge and important task.

**Thermo-photovoltaic Electricity Conversion.** The development of new cells for the molten Si-alloy temperature, possibly multijunction of using the Heterojunction Bipolar Transistor Cell. And the entire rig to return to the molten Si-alloy the heat under bandgap is also a huge task where steps must be given.

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