ABENGOA SOLAR

Solar Power for a Sustainable World

We Develop, Build, and Operate Solar Power Plants and Installations

Solutions to Global Climate Change

Photovoltaic Technology Plants

Photovoltaic
Technology Plants

The Issues…

Climate Change and Sustainable Development

We have all heard of acid rain, the Ozone layer and the Greenhouse Effect, but what exactly are they and how do they affect humans?

- Acid rain is caused by high concentrations of certain gases in the atmosphere. These high concentrations are the result of the emissions from the excessive burning of fossil fuel. Acid rain can cause fatal deterioration to field and forest regions.
- The ozone layer, considered the "protective shield" of life on Earth, regulates the amount of radiation that reaches Earth's surface. Because of the actions of humans, the ozone layer is deteriorating.
- The Greenhouse Effect produces rapid and alarming warming of the lower level atmosphere. It is caused by the presence of greenhouse gases (GHG) which trap heat that would otherwise escape into space.

The conjunction of these three phenomena will increase the number and intensity of catastrophic events, such as: floods, desertification, thaw, and ecosystem destruction. Additionally, the changes in climate patterns could create a food production crisis which would lead to a social crisis.

Perhaps the most significant cause of the increased greenhouse effect and global warming is the 30% increase in atmospheric carbon dioxide (a well known GHG) since 1750. Present carbon dioxide concentrations have not been seen in 20 million years. It is estimated that ¾ of the GHG emissions in the last 20

Figure 1: Solar Thermal Technology

"According to the World Health Organization (WHO), global warming killed 150,000 people in the year 2000 and this number could double in the next decade"
Source: WHO.

Figure 2: Photovoltaic Technology

years is due to the burning of fossil fuels for human consumption and transportation.

Today, one of society's primary concerns is moving from old development methods towards sustainable development. Sustainable development methods are intended to satisfy current needs without compromising future generations.

To ensure sustainable development, the corporate sector needs to work toward the objectives of Corporate Social Responsibility (CSR) and its stakeholders. In doing so, corporations would begin to manage their activities in a cleaner and more efficient manner.

The Kyoto Protocol, written in 1997, is an effort to work toward sustainable development. Although not signed by the USA, China or India, the Kyoto Protocol was signed by more than 55% of the countries worldwide. The goal of the Kyoto Protocol is to reduce the emissions levels of 6 major greenhouse gases in 1990 by 5.2% between the years 2008 and 2012. Only developed countries have been able to quantify their commitment to emissions reduction. Each developed country must distribute its emissions rights among its companies. If companies exceed their emissions rights they could be economically penalized. In the case that a company can not viably remain under its emissions rights, flexible mechanisms have been created to help them comply with regulations.

Within renewables, the potential of solar technologies has recently caused a large increase in its development. From a commercial point of view, working toward sustainable development has created a new market for energy companies which includes:

- New tax legislation, subversion and incentives for sustainable development being established in many countries.
- Flexible fostering mechanisms divided into: emissions trading, joint projects and clean development mechanisms that allow companies to receive emissions rights for investing in renewable energy (even if it is in another country).

Although the flexible fostering mechanisms that help companies comply with their emissions rights is good, it is undoubtedly better to avoid GHG pollution through the reduction or elimination of their emission. In order to do so we must use energy in a rational and efficient way and begin to integrate renewable energy technologies into our current systems.

Proposed Solution: Renewable Energy

Renewable energy technologies are those that provide energy from a source considered inexhaustible (i.e. the sun, wind, biomass, river water, etc.). The use of renewable energy technologies is an effective way to reduce emissions. Without initiatives to develop renewable energy technologies, today's total emissions would have increased by 30% above 1990 levels. Today, installed electricity capacity from renewable energy technology is 160 GW, which is 4% of the global installed electric capacity.

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Solar Power

Benefits of Solar Energy

The characteristics of solar energy make it well suited to supply peak electricity demands. In the developed world the summer peak demands have become overwhelming and the winter peak demands are primarily due to space heating. If we analyze the solar radiation curve during the summer, it coincides very closely with the peak power demand curve. This is very convenient because solar energy technologies can produce their maximum when the demand is at its maximum.

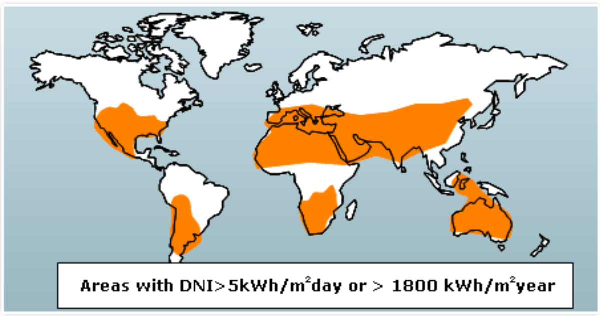
Although they produce the most power during peak daylight hours, solar technologies can also be used to provide electricity throughout the day. By storing heat from solar radiation in storage tanks and hybridizing with fossil fuels solar plants are able to provide clean and reliable electricity throughout the day.

Because they can provide base and peak demand electricity, solar technologies could become one of the foremost power sources worldwide.

The installation of solar plants is ideal in locations known as the "solar belt" (see picture). These locations in much of the world and receive high solar radiation.

Over the last century, the financial investment in solar technology development has coincided with oil shortages. Due to increasing power consumption worldwide, the life expectancy of fossil fuels is dramatically shrinking. Experts forecast a substantial increase in solar technology development due to increasing investment and an ever growing experience with the technology.

"If only 2% of the solar radiation from the world's deserts were used it would be enough to supply the worlds power demands."

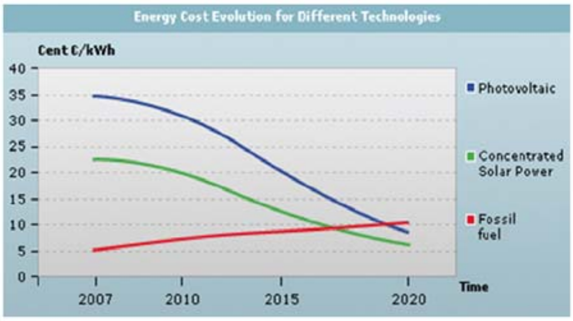


Source: Abengoa Solar

Figure 3: Irradiation map

Although energy from fossil fuels currently costs less than energy from renewables, concentrated solar power and photovoltaic technologies are predicted to cost less in the near future.

Future power costs from fossil fuels will tend to increase due to increased demand and economic sanctions imposed on CO_2 emissions.



Source: Abengoa Solar

Figure 4: Cost Trend for different technologies

Types of Solar Technology

As briefly mentioned above, there are two general branches within solar technology:

1.) Photovoltaic (PV) technology directly converts solar radiation into electricity through the use of semiconductors and the photovoltaic effect.
2.) Concentrated solar power (CSP) technology stores the energy from solar radiation in a working fluid in the form of heat. This heat can then be used to run a conventional power cycle.

Figure 5: Photovoltaic Technology

In both cases the electricity produced can be used locally or supplied to the grid at a specially set price.

Both PV and CSP technologies are highly matured technologies. Worldwide, conventional silicon PV has an installed capacity of 6 GW and CSP trough plants have been installed in the USA since the 1980s.

Abengoa Solar has become a pioneer in the solar market, developing and installing systems globally.

Figure 6: Photovoltaic Technology

Abengoa Solar

Abengoa Solar as part of Abengoa

Abengoa is an international company with the mission of applying innovative solutions for sustainable development in the infrastructure, environmental and power sectors.

Abengoa Solar offers deep know how, technology, and experience in building both CSP and PV plants. Internationally it has the backing of a large corporation that can offer financial support, an EPC company that builds our plants, and other companies with expertise in key areas like control systems and water management.

Global Expertise with Solar Support since the 1980's

With installations in several different countries and offices in Spain and the USA, Abengoa Solar has established a team of experts with vast solar knowledge and a globally respected reputation.
Abengoa Solar's industry leadership is based on a well established, but still growing, engineering team. More than 20 years of experience and collaboration with prominent research institutes (NREL, Ciemat, DLR, Fraunhofer ISE, and others) have allowed Abengoa Solar to build a wealth of solar energy knowledge and experience.

This wealth of knowledge and experience is devoted to all forms of solar energy technology. Research teams are focused on parabolic troughs, dish Stirling systems, thermal storage, solar hybridization and PV concentration. As evidence of the commitment to all of these technologies, demonstration facilities have been constructed to test and develop trough, dish Stirling, power tower, storage and PV technologies.

Source: Abengoa Solar

Figure 7: Abengoa Solar International Presence

Abengoa Solar Activities

Abengoa Solar provides solar thermal technology for all levels of use including: power plants for large-scale electric needs, customized industrial/commercial installations for thermal needs, and residential installations for thermal needs.

Abengoa Solar also provides PV technology for various levels of use, including: large-scale electricity generation from concentrated PV with two-axis tracking, smaller PV installations for independent projects, and integration of thin-film PV technology with buildings to achieve "off the grid" housing.

Abengoa Solar manufactures its own components for concentrated solar power installations (heliostats, structures and mirrors) as well as PV installations (solar trackers and concentrators). In doing so, Abengoa Solar becomes a technology vendor for its own plants and installations.

Examples of technological knowledge and experience are Abengoa Solar' plants and installations:

- **PS10** – The first commercially operating power tower in the world with PS20, which is under construction, becoming the second.
- **Solnova 1 and 3** – Of 80 MWs each that are the first of 5 parabolic trough installations.
- **Sevilla PV Plant** – The largest low-concentration plant in the world (1 MW).
- Construction of the first **hybrid plant** with an Integrated Solar Combined Cycle (ISCC) in Algeria.
- **Customized solar thermal** projects for industries in California, Arizona and Texas in the USA.

Photovoltaic

Figure 8: Low Concentration PV

Concentrated Solar Power

Figure 9: Trough Plants

Figure 10: PS10 Tower

Sevilla PV: The World Largest Double Concentration PV System

1. Photovoltaic Technology:Operating Principle

Photovoltaic cells use semiconductors to produce electricity. When solar radiation strikes the cell it is absorbed, and the absorbed energy excites electrons. A semiconductor must have at least two electric fields. When an excited electron leaves its electric field it must pass through an external circuit, producing electricity, to return to its original electric field. This is referred to as the photovoltaic effect.

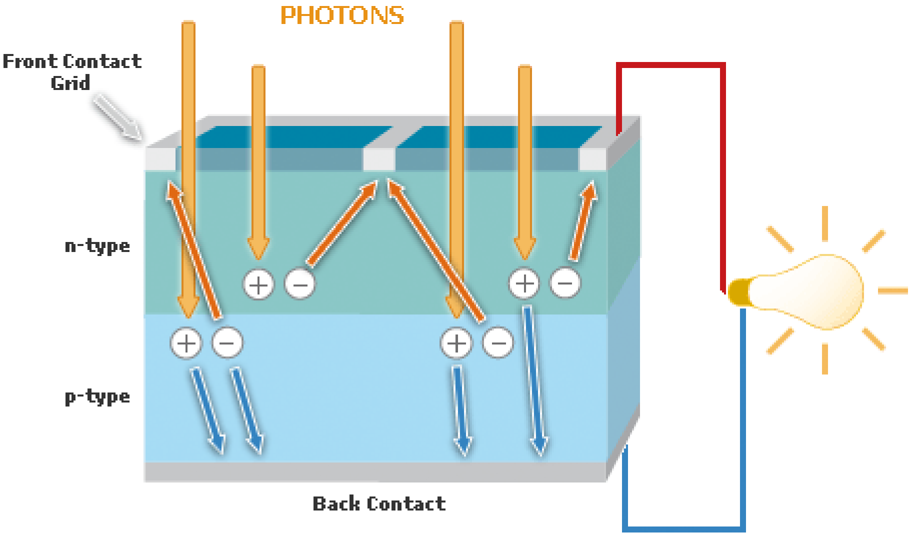


Figure 11 Photovoltaic Operating Principle

The following are the primary components of PV technology.

Optics: Different optical elements, such as mirrors and Fresnel lenses are used to concentrate solar radiation onto a point where a PV cell is located.

Photovoltaic Cell: The photovoltaic cell is the semiconductor used to produce the photovoltaic effect.

Inverter: Since the photovoltaic effect produces direct current (DC), an inverter must be used to change it to alternating current (AC).

The tracking system: Efficiently tracking the sun greatly improves the efficiency and electricity generation of PV systems.

2. Photovoltaic Cell Technology Types

There are two predominate PV systems on the market that each have their own pros and cons regarding application, efficiency and cost.

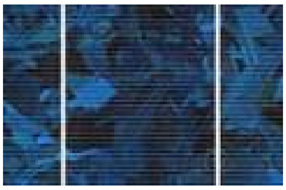
2.1 Crystalline Silicon (~200 µm)

A double layer antireflection coating is used to reduce reflection losses on the front surface of crystalline silicon wafers. The wafers are about 400 µm thick to ensure near complete absorption of all photons having energy greater than the band gap. At the bottom of the wafer, a SiO_2 layer is inserted between the wafer and the aluminum backing to achieve reflectance back toward the cell.

Single-Crystalline Si: The semiconductors of most PV cells are made from single-crystalline Si. This requires a highly purified silicon to be crystallized into ingots. The ingots are then sliced into thin wafers to make an individual PV cell.

Single

Polycrystalline Si: Polycrystalline Si cells are produced in a way very similar to single-crystalline cells. The primary difference is that silicon of less purity is used for polycrystalline cells. The result is a reduced cost and increased easy of production but a loss of efficiency.



Polycrystalline

Ribbon Si: Ribbon type PV cells are produced in a similar fashion to single- and polycrystalline silicon cells. The primary difference is that a ribbon is grown from molten silicon instead of an ingot. These cells often have a prismatic rainbow appearance due to their antireflective coating.

2.2 Thin film (~5 µm)

Thin film semiconductor technology may not be as efficient as traditional semiconductor technology, but its light weight and low cost make it an ideal solution for certain applications.

Amorphous Si

Unlike crystalline semiconductor which have a band gap of 1.1 eV, by manipulating the alloy of amorphous silicon semiconductors the band gap energy can be tuned between 1.1 eV and 1.75 eV. Additionally, because they have a much greater absorptance than crystalline silicon amorphous silicon semiconductors can be much thinner (less than 1 μm). Although amorphous Si cells can be manufactured at low temperatures (200-500 C) and at low costs a major drawback is their light induced degradation.

a-Si

Cadmium Telluride (TeCd)

Cadmium Telluride is another thin film technology that has been available longer and undergone more research than any other thin film technology.
Although there are diverse manufacturing techniques that can be used to produce the films, many of which are promising for large scale production, the cost and potential health concerns remain as drawbacks for this technology.

TeCd

Copper Indium Gallium Diselenide Solar Cells (CIS Cu In Se2) (CIGS Cu(In Ga) Se2)

Due to its relatively high efficiency and low material cost, this technology has emerged as one of the most promising thin films. By adjusting the ratio of In to Ga in CIGS cells the band gap can be tuned between 1.02 eV and 1.68 eV. The absorption elements of CIGS cells are incredibly high, allowing more than 99% of incoming radiation to be absorbed within the first μm of material. Although this technology has a relatively low material cost, the complicated and capital intensive manufacturing methods remain as significant drawbacks.

CIGS

Micro Si: Micro silicon cells are expected to surpass the efficiency and performance of amorphous silicon cells and become a competitor with other thin film technologies. The high efficiency and negligible degradation of Micro Si cells has been widely reported.

Titanium dioxide (TiO): Instead of the semiconducting materials used in most cells, TiD cells use a dye-impregnated layer of titanium dioxide to generate voltage. Because of their relatively low cost, TiO technology has the potential to significantly reduce the cost of solar cells.

2.3 Photovoltaic Concentration

Concentrating solar radiation allows for the highest efficiencies from PV cells. However, because it requires direct solar radiation it is only viable in certain locations.

Fresnel point focus (High concentration-GaAs) (GC~500): Fresnel point lenses concentrate direct solar radiation onto a focal point. Since Fresnel lens can provide concentration ratios of 500, the needed surface area of PV cell is greatly reduced. Since fewer PV cells are needed it is possible to use high quality, more expensive materials like Gallium Arsenide for the semiconductors.

Gallium Arsenide (GaAs) multi-junction semiconductors: Multi-junction semiconductors are a relatively new technology that offer significantly higher efficiencies than traditional, single-junction, semiconductors. Each electrical field junction within a semiconductor has only one band gap energy. Incoming solar radiation will either have less energy than the band gap (and therefore will not be used), more energy than the band gap (and therefore some energy will be wasted), or the exact energy as the band gap. By having multiple junctions, GaAs semiconductors are able to are able to utilize more energy from the incoming solar radiation.

Fresnel line focus (medium concentration-Si) (GC<500): Fresnel line lenses are flat cylindrical lenses that condense or diffuse light in a linear direction. This technology has lower concentration ratios than Fresnel point lenses, so high efficiency silicon semiconductors are used instead of expensive GaAs semiconductors.

Low Concentration (2-4 times): Low concentration technology uses mirrors instead of lenses to concentrate solar radiation. Since the solar radiation is much less condensed, conventional silicon semiconductors are often used because of their affordability.

Figure 13: Low concentration (2-4 times)

3. Low-Concentration Photovoltaic Technology: Operation and Main Advantages

Low concentration PV plants often use mirrors to concentrate solar radiation onto a PV cell. Abengoa Solar often uses GaAr or high efficiency Si in their low concentration PV installations.
The primary components of a low concentration PV installation are:

- **2-axis tracking heliostats**: Heliostats that track the sun on 2 axes are the structure upon which mirrors and PV cells are supported. 2-axis tracking PV yields 35% to 48% more energy production than fixed PV systems.
- **Concentrators:** Concentrators are used to direct solar radiation onto a PV cell. Often, mirrors manufactured with a silicone-covered metal. The orientation of mirrors on a concentrating PV module differ depending on their dimension, inclination angle and module design.
- **Photovoltaic cells**: PV cells are what convert solar radiation into electricity. Low concentration PV cells are often made from single-crystalline silicon semiconductors. This technology has an efficiency of roughly 12%.
- **Inverter:** Since the photovoltaic effect produces direct current (DC), an inverter must be used to change it to alternating current (AC).

Photovoltaic technology shows numerous advantages in relationship with other technologies, besides being a clean way to generate electricity which dramatically reduces emissions, and being potentially inexhaustible, it offers the possibility of installing modular and distributed energy which is especially appropriate for areas in which the electric network is not available or the installation too expensive.

The largest photovoltaic low-concentration plant in the world is Sevilla PV, developed by Abengoa Solar in Sanlúcar la Mayor, which shall be analyzed below.

4. Sevilla PV on the Solúcar Platform

The plant is located on the Solúcar Platform (Lat.: 37.2º).
Its construction started on June 28, 2004, and its commissioning date was May 1st, 2006.

The Sevilla PV existence brings social and environmental benefits to the area. The nearby City Councils obtain benefits from job creation (direct and indirect) and potential scientific tourism. For all its plants, its is policy of Abengoa Solar to educate the personnel of the are to foster part of the project with the purpose of adding value to the location.

Figure 41 shows the location of Sevilla PV, located beside PS10, the larger commercial tower of the world, also from Abengoa Solar.

Operation of the solar field is very simple. The photovoltaic modules produce direct current (DC). Inverters convert the direct current into alternating current (AC) in the solar field. Before the electricity is delivered to the grid, the voltage is boosted using a transformer.

Figure 14 Aerial view of Sevilla PV beside PS10

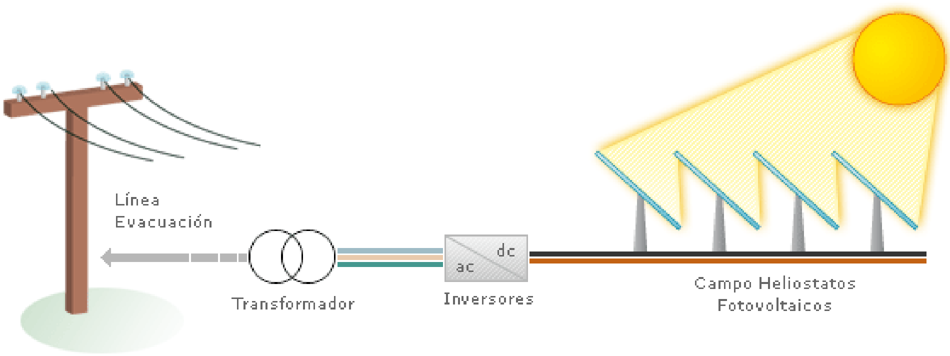


Figure 15: Sevilla PV Scheme

5. Sevilla PV Infrastructure

The Sevilla PV plant has 154 two-axles tracking PV units. These trackers were designed by our R&D company, Abengoa Solar NT.

The system allows, by means of calculated coordinates, the tracking of the two axles of the star through two engines:

- The elevation mechanism is composed of a trapezoidal-thread linear actuator
- The azimuth mechanism moves through a ring gear arrangement.

Each PV tracker has 36 PV modules and a collection surface area of 860 ft2 (80 m2). The entire plant covers 29.5 acres (12 hectares) and has a PV surface area of 63,500 ft2 (5913 m2).

Besides using Sevilla PV with commercial purposes, the plant was designed with a research purpose; therefore the plant was organized into three areas, each with a solar tracker prototype. Abengoa Solar obtains constant information from the behavior of the different types of modules.

- **Artesa**: 76 solar trackers used the polycrystalline Artesa A-133 with two-mirror rows per module (G.C =2.2x)
- **Iso-Photon**: 61 solar trackers with I-110 monocrystalline iso-photons and one-mirror row per module (G.C =1.5x)
- **Solartec**: 17 solar trackers with RADIX 72-116 monocrystalline Solartec modules and double concentration (G.C =2.2x)

Image 16 shows the solar trackers field distribution and some technical specifications of each of them.

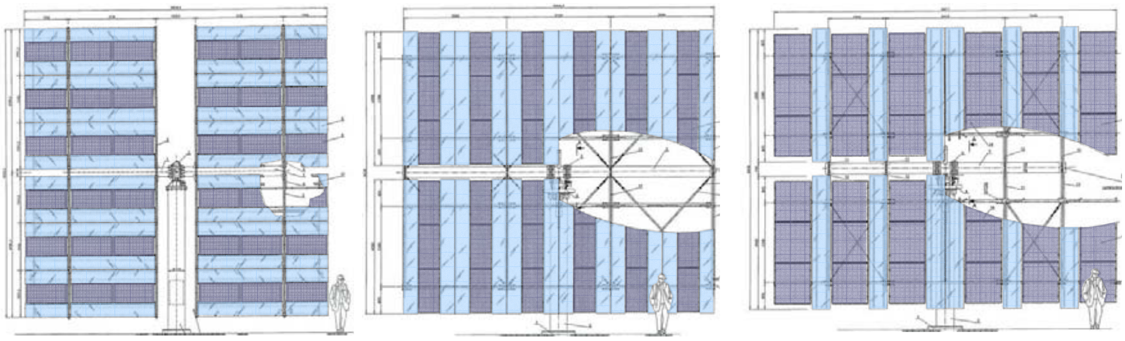


Figure 16: Trackers characteristics and field layout

Figure17: 2.2x Solar Tracker

Figure 18: 1.5x Solar Tracker

6. Sevilla PV Functioning and Operation

Despite being the first plant of its kind, the operation of Sevilla PV is not complicated. The only moving components are the solar tracking devices. None of the other components need special maintenance., besides the cleaning operations of the concentrators and photovoltaic modules with demineralized water when the plant's power descend 1%.

One of the main difficulties is tracker control. Under high-radiation solar conditions, high ambient temperature, and low wind speed, it is complicated to release the heat generated by the panels. Sevilla PV solar tracker has been manufactured and designed to withstand severe conditions with the purpose of assuring that the photovoltaic cell does not suffer any damages. The system goes out of focus when temperature is higher than 185ºF (85ºC). In fact, the photovoltaic module behavior improves 4.5% every 50ºF (10ºC) temperature reduction on the module.

Another issue that could appear is an excessive wind speed. Like in the case of PS10 heliostats, Sevilla solar trackers are located on a defense position when wind speed surpasses 22.5mile/h (36 km/h).

Despite of being the largest photovoltaic plant of its kind in the world, thanks to its design and R&D team, plant operation and maintenance does not show problematic issues, being reliable for commercial purposes.
Some interesting reference information about the plants is:

- With its installed power (1.2 MW) and considering the solar radiation conditions in its location, this plant is capable of generating 2.1 GWh of clean energy per year, which is enough to supply 525 homes, avoiding more than 800 tons of CO_2 per year.
- The total solar energy yield until the electric generation is around 12%, mainly due to the conversion power of the photovoltaic cells.

Figure 19: Sevilla PV Trackers

7. Future Developments on Photovoltaic Solar Energy

Abengoa Solar is committed to a great challenge for solar energy. Photovoltaic technology shows great potential thanks to the latest developments in this field, with and without concentration. Particularly, our company collaborates with leader institutions in the photovoltaic world, such as Fraunhofer ISE, NREL, Ciemat, among others. R&D department main performance areas are:

R&D in photovoltaic concentration with the purpose of cost reduction and efficiency improvement, both at optic as well as photovoltaic cell levels.

At the photovoltaic lab, of Abengoa Solar, we analyze the behavior of current technologies and develop new concepts.

8.- Conclusions

Solar energy technologies are one of the renewable with the most potential for growth in the near future. The technology has been proven to be feasible and reliable, which is often untrue about many other renewable sources. Solar energy technologies' promising future is can be forecast through the incredible technical advances and research that is currently being done. It is easily affirmed that solar energy technology is one of the best solutions for future energy production. It is clean, storable and will eventually be less expensive than fossil fuel..

ABENGOA SOLAR

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