Five reasons to choose mono-Si

Strategy and Planning Department, LONGi Silicon Materials Corp., Xi'an, China

ABSTRACT

One question to emerge in recent years is whether monocrystalline silicon (mono-Si) or multicrystalline silicon (mc-Si) will become the dominant mainstream technology in the future PV industry. However, despite all the arguments, the market share of mc-Si seems barely changed, while the market share of mono-Si has not increased significantly. The reasons why mono-Si has not made progress have been extensively mentioned in the literature and will therefore not be covered here; rather, the objective of this paper is to discuss several benefits of mono-Si.

Introduction

The advantages of monocrystalline silicon (mono-Si) will be examined in terms of five aspects:

I. Operating lifetime
II. Conversion efficiency
III. System cost
IV. Electricity generation ability
V. Return on investment

I. Operating lifetime

There is an obvious difference between monocrystalline silicon (mono-Si) and multicrystalline silicon (mc-Si) as regards crystalline structure. Mono-Si has a diamond lattice and an almost complete lattice structure, with all the lattice planes having the same orientation; these attributes make mono-Si more stable than mc-Si. The higher crystalline quality also makes mono-Si more reliable, which has been proved in long-term operation. In addition, mono-Si has a longer operating lifetime than mc-Si.

> "Mono-Si has a longer operating lifetime than mc-Si."

At one stage, PV power plants in Europe and test stations in China used only mono-Si modules. Some of these facilities have been operating for more than 25 years: for example, mono-Si modules installed in the 1980s are still in operation today. In contrast, because the development of mc-Si technology has mainly happened only in the past 10 years, more time is necessary to fully test and verify the lifetime of an mc-Si system.

II. Conversion efficiency

A common goal for the PV industry is to seek higher efficiencies because of the low energy density of solar radiation and the high cost of harvesting. Huge amounts of energy from the sun reach the earth every year; however, the solar radiation is very limited in terms of time and area coverage. Taking China as an example, it is estimated that the total solar energy received over its land area of 9.6m square kilometres is equal to the energy produced from 1700bn tonnes of standard coal, which equates to just 177kg of coal per square metre per year. Thus in obtaining the same amount of energy from the sun, the cost of harvesting in relation to the unit area of solar radiation must be calculated.

In the solar energy harvesting

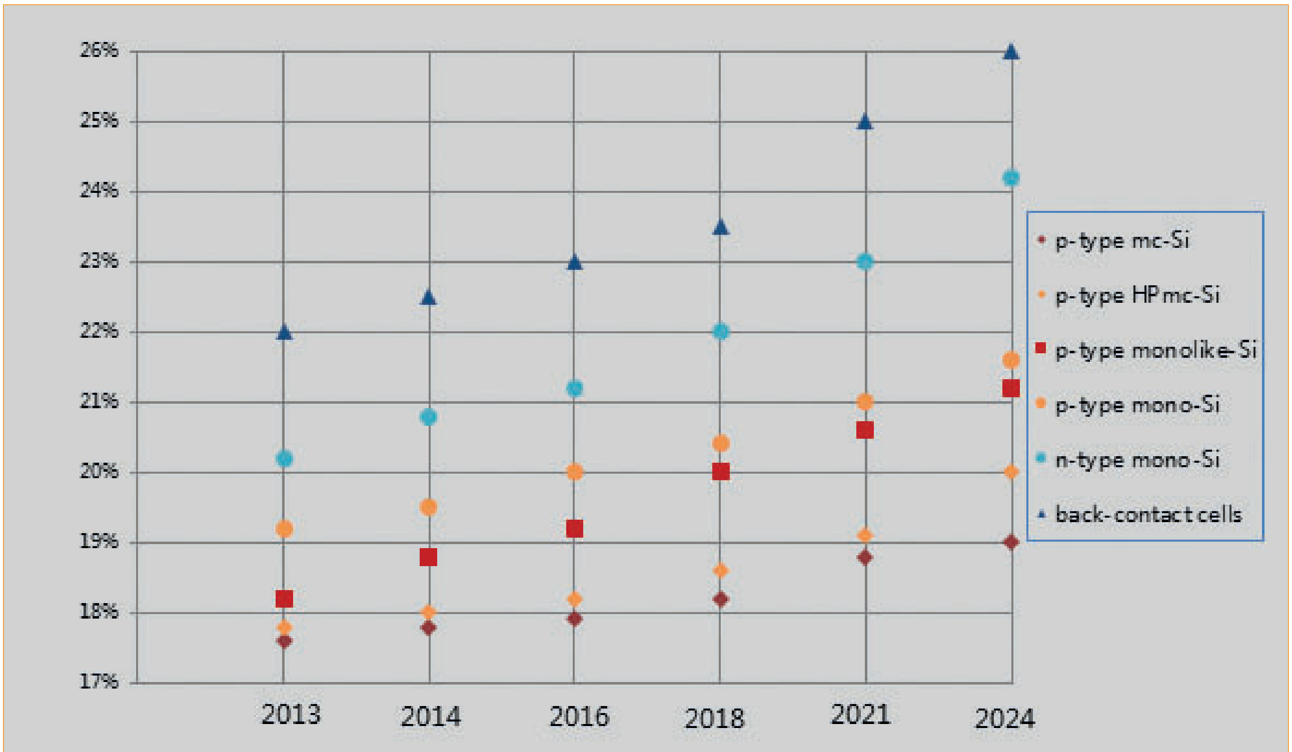


Figure 1. Module conversion efficiency trends for different types of crystalline silicon.

Source: SEMI PV Group Europe [1].

process, the conventional materials – such as glass, aluminium frames and mounting systems – have been developed over several decades and use mature technology. These materials represent a significant portion of the cost of the solar energy system, and it is difficult to reduce these costs through technological innovation. If calculations are made using an investment cost of US$1.2/W for a PV station in China, then of that amount, US$0.1 is attributable to the solar cell and the remainder to the other, conventional materials; in other words, the solar cell cost is less than 10% of the station cost. Therefore, if the efficiency of the cell doubles, the other costs (amounting to more than 90%) will fall by 50%, meaning that half the amount of glass, aluminium frame and other materials will be used. A 50% reduction in these materials means that, even if the cell processing cost increases by a factor of five, the same system cost can be sustained.

If the cost of the solar cell is not taken into account, and only the cost for the back plate and the stand is considered, then according to calculations of the cost of electricity generation in one square kilometre, solar energy does not make sense if its conversion efficiency is less than 15% (i.e. 15% is the efficiency threshold for the system to make money).

Furthermore, in China and elsewhere in the world, the space available to build PV power plants is very limited. In China, because of the differences in radiation conditions and resource distribution, the main PV stations in the east are distributed systems, whereas in the west they are mainly ground-based stations. There are strict requirements for distributed systems concerning the height of the building, the available roof area, the type of roofing material, the loading capacity of the roof and the lifetime of the roof; as a consequence, the effective rooftop area available for solar is becoming a scarce resource. The desert in the east is even more limited. On a similar note, opportunities for high-quality, ground-based solar plants in the west are gradually decreasing too; although there is a large area of desert and wasteland in the west, after considerations such as water and transformer stations are taken into account, the availability of desert sites for PV power plants is severely limited.

This all means that from the point of view of technical progress, it is a basic requirement for the PV industry to use the limited solar energy and space resources to generate more electricity. Higher conversion efficiencies are the way to go for the development of the PV industry.

Better conversion efficiencies and still plenty of room for improvement

Efficiency improvement is at the core of the development of the PV industry. Right now, mono-Si predominates over mc-Si in terms of conversion efficiency. The conversion efficiencies of n-type mono-Si – such as the heterojunction with intrinsic thin layer (HIT) solar cell from Panasonic and the interdigitated back-contact (IBC) solar cell from SunPower – on a mass-production scale can be close to 25%. The conversion efficiencies of p-type mono-Si cells – such as those offered by LGE and JA Solar – can reach 20% on a mass-production scale. In contrast, it is very difficult for mc-Si solar cells to achieve an efficiency of 19%.

Fig. 1 illustrates graphically the technology roadmap for the PV industry published by SEMI PV Group Europe [1]: the efficiency trends for the different types of crystalline silicon cells are shown. By 2024 the stable efficiency of p-type mc-Si solar cells is predicted to reach only 19%. In comparison, the efficiency of n-type mono-Si cells is expected to be 24.2% and the efficiency of p-type mono-Si cells will probably be 21.6%. As can be seen, there will be differences of 2.5–5.2% abs. in conversion efficiencies between mono-Si and mc-Si on a mass-production scale.

In recent years the passivated-emitter, rear-contact (PERC) cell technology has risen to prominence as a means of improving solar cell efficiency. All the big players in the PV market are currently speeding up the introduction of PERC technology: according to reports, Taiwanese Sunrise has introduced five PERC production lines for cells with a conversion efficiency of 20.7%, and Hanwha Q CELLS has introduced two production lines for cells with a conversion efficiency of 20.2%. Some mc-Si solar cell companies can demonstrate a conversion efficiency of 18.4–18.5% after introducing PERC technology in their cell designs.

From the status of its application by companies in China and overseas, PERC technology shows a better premium advantage and scope for development with the use of mono-Si solar cells. The technology yields a 1% boost in conversion efficiency for mono-Si solar cells, against only 0.5% for their mc-Si counterparts.

"PERC technology shows a better premium advantage and scope for development with the use of mono-Si solar cells."

III. System cost

For a long time, the Chinese market has paid too much attention to system cost, resulting in tough competition within the industry over cost and price. But over time, PV power plant investors have become more rational, while policy guidelines have sought to institute new requirements for a

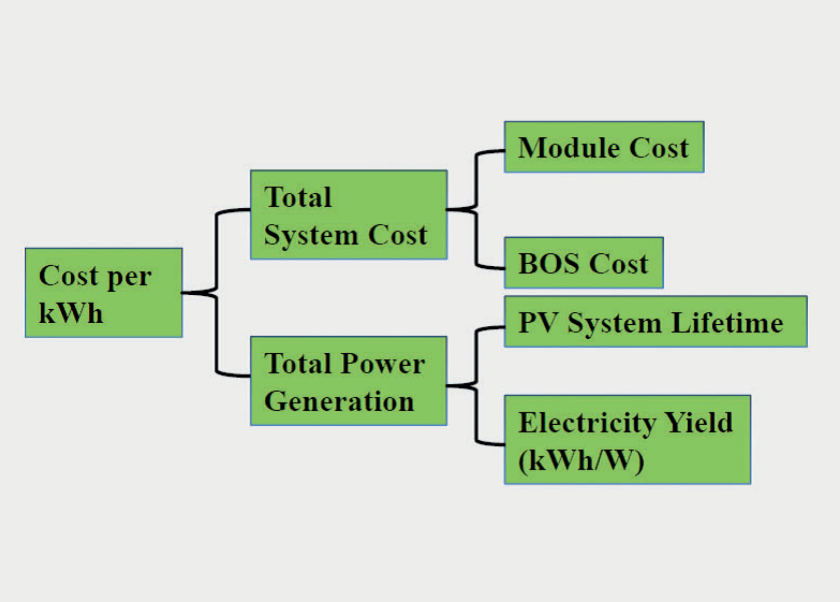


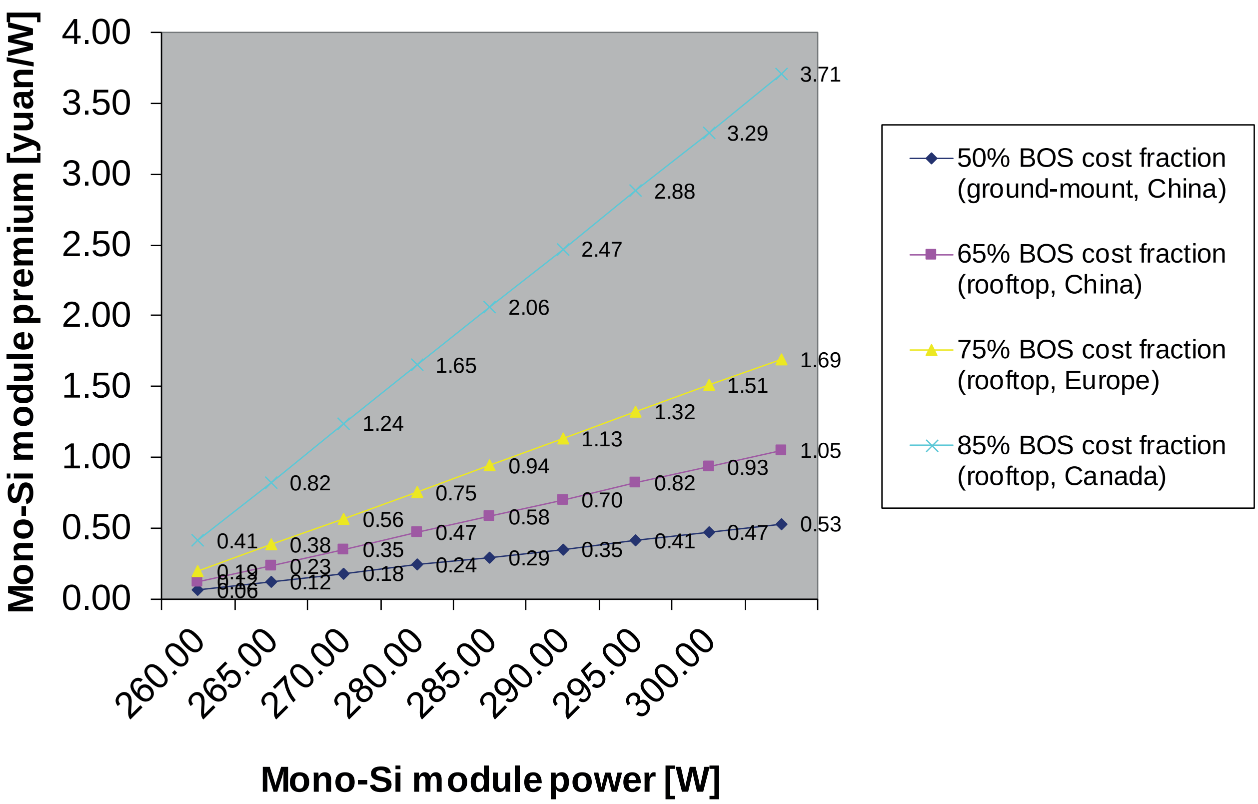
Figure 2. Schematic diagram for the key factors contributing to kWh cost.

healthy and orderly development of the PV industry. As a result, the market has gradually turned its cost focus from per watt to per kilowatt-hour (kWh), in order to benefit electricity generation the most.

The kWh cost is the total unit cost for the electricity injected into the grid. This cost mainly depends on two factors: the station system investment cost and the electricity generated. The system cost consists of module cost and the balance-of-system (BOS) cost, as shown in Fig. 2.

A system cost analysis for a station investment with mono-Si and mc-Si modules will be presented in this section. The current mainstream products are 265W mono-Si modules, which cost 4.3 yuan/watt, and 255W mc-Si modules, which cost 4 yuan/watt; the price difference for the modules is 0.3 yuan/watt.

On the BOS cost side (all other costs apart from the module and which include other equipment, installation labour, construction, and land cost), for an equivalent area the mono-Si modules have a higher power than mc-Si modules, and can thus generate more electricity. Public research and practice show that, for an electrical station with the same power capacity, the mono-Si system can save more BOS cost; and the higher the fraction of the BOS, the better the premium advantage for the mono-Si system. In a Chinese rooftop distributed system, the costs are the same for mono-Si and mc-Si systems. On the other hand, for Japan and Germany, where the BOS cost is higher, the system cost



Source: IHS Solar Solutions statistical data for system costs in various countries.

Figure 3. Cost premium offered by mono-Si for various system types and locations.

Ground-based station in Ningxia [yuan/W]				Rooftop station in Zhejiang [yuan/W}			
Project	Mono-Si	Mc-Si	Difference	Project	Mono-Si	Mc-Si	Difference
Module	4.40	4.10	0.30	Module	4.30	4.00	0.30
BOS	3.40	3.50	–0.10	BOS	2.90	3.10	–0.20
Total	7.80	7.60	0.2	Total	7.20	7.10	0.1

Table 1. Differences in system cost for PV stations in Ningxia and Zhejiang. (Note: mc-Si module = 250W; mono-Si module = 265W.)

for mono-Si is already lower than for mc-Si.

In Fig. 3 the premium of the mono-Si module has been calculated for different power levels (260–300W) with a baseline of 255W and for different BOS fractions (corresponding to different locations and station types). The assumptions for this calculation were:

- A standard power of 255W for the mc-Si module.
- A base module price of 4 yuan/W (tax included).
- No difference in electricity generation between the mono-Si and mc-Si modules.

Taking a ground-based PV station in Ningxia and a rooftop PV unit in Zhejiang as examples, Table 1 lists the differences in system costs. It is easy to see that mono-Si clearly has premium advantages over the mc-Si system in the distributed plant stations and in the region with a high BOS cost fraction.

IV. Electricity generation ability

For the analysis in section III it is assumed that there is no electricity generation difference for the mono-Si and mc-Si modules with the same power. However, because of the variations in crystal structures, mono-Si can generate more electricity. The main differences stem from the following:

1. Mono-Si demonstrates a better temperature effect

Operating temperature is an important parameter for a silicon PV module, impacting both energy conversion efficiency and electricity generation. Mainly owing to the negative temperature coefficient of mono-Si, the photoelectrical conversion efficiency decreases with a rise in the temperature of the solar cell. Every 1°C increase in operating temperature will cause a 0.4–0.5% reduction in module power, and the module will generate less electricity. In theory, the operating temperature of a mono-Si module will be lower than that of an mc-Si module, because of the mono-Si's simple crystalline structure, higher purity, lower inner resistance and higher conversion efficiency. Under the same conditions, a mono-Si module will generate more electricity than its mc-Si counterpart having the same power level.

	Spectral-radiation distribution fraction		
	Standard	AM1.5	Cloudy
Mono-Si response	90.06%	90.44%	89.54%
Mc-Si response	84.1%	84.76%	81.86%
Difference	5.96%	5.68%	7.68%

Table 2. Spectral responses of mono-Si and mc-Si under different lighting conditions.

2. Mono-Si modules degrade more slowly

In general, the degradation of PV modules includes the initial degradation and the long-term degradation. A module will experience a sharp degradation in the first month and then stabilize gradually after reaching a threshold value. Long-term light-soaking tests show that the module efficiency will experience a slight gradual recovery after the long-term radiation exposure. With the same initial degradation, the recovery of a mono-Si module is better than that of an mc-Si module.

At the same time, alternating changes in operating temperature will cause heat stress inside a solar module. The module will break at its weakest point when the heat stress is large enough, which will lead to a drop in module power.

Because of the differences in crystalline structure, theoretically there will be a difference in how well the mono-Si and mc-Si modules can withstand heat stress over time and adapt to changes in temperature and humidity. Mono-Si displays an obvious advantage over mc-Si in dealing with heat stress and adapting to variations in temperature and humidity. Station data for 2012–2013 from the same location in Zhongwei, Ningxia Province, demonstrate that the degradation of mono-Si is 0.34% less than that of mc-Si.

3. Mono-Si modules show better low-light response

To compare the different technologies, mono-Si and mc-Si distributed electrical stations were constructed at Longsheng Silicon Tech Corporation, Qingdao; apart from the type of silicon, all other conditions were the same. One-month operating data show that the mono-Si module can generate 6% more electricity than the mc-Si module with the same power rating. The better the illumination conditions, the greater the advantage of mono-Si over mc-Si. On a cloudy day, the mono-Si will generate 5% more electricity than the mc-Si; on a sunny day, the difference can be as much as 9%.

In fact, mono-Si shows a better spectral response to light on rainy or cloudy days. In his book, *Solar Cells: Operating principles, technology and system applications* [2], Professor Martin Green of the University of New South Wales reports the results of research on the spectral-response range and the capabilities of mono-Si and mc-Si under different radiation conditions. The results show that the mono-Si module has a better short-wavelength range response, which means that in cloudy conditions mono-Si will yield a better spectral response to light than mc-Si (Table 2).

The differences in electrical generation were analysed using the PV mechanism for mono-Si and mc-Si. It was also proved that mono-Si generates more electricity per watt than mc-Si in practical applications. Besides the Longsheng Silicon Tech Corporation project, studies from the Institute of Solar Energy Systems at Sun Yat-Sen University, the China Power Investment Corporation and other companies have also demonstrated that mono-Si generates more electricity than mc-Si.

- Both mono-Si and mc-Si systems were installed at the Institute of Solar Energy Systems at Sun Yat-Sen University to investigate the electricity generation of different technologies. The results between January and July of 2008 show the mono-Si systems generated 5.7% more electricity than their mc-Si counterparts.
- Operating results from companies such as the China Power Investment Corporation in Qinghai, Inner Mongolia and Ningxia demonstrate that the mono-Si systems generated

- 4.77 to 6.52% more electricity than the mc-Si systems.

- PV electricity stations in Hohhot, Inner Mongolia, consist of both mono-Si and mc-Si systems. Operating results show the mono-Si-based system generated 6% more electricity than the mc-Si one.

- Data from the two 30MW stations in Zhongwei, Ningxia, also show the mono-Si system generated 6.52% more electricity than the mc-Si system in the first quarter of 2014.

V. Return on investment

Whether from policy guidance or as a result of rational industry development, the market is paying more and more attention to the kWh cost. Against this background, the high-efficiency mono-Si system is a good way to lower the kWh cost and improve the return on investment. Perhaps some investors who choose mc-Si still think that mono-Si modules are more expensive. Some cost calculations will now be made for the rooftop electrical station with the following assumptions:

1. The roof area is 40m^2, with a possibility of installing 16 PV modules. Mono-Si modules of 270W and mc-Si modules of 255W are used. The total installation capacity of the rooftop station is 4320W for the mono-Si system and 4080W for the mc-Si system, which means a higher power for the mono-Si system with the same installation area.

2. Investment cost: the rooftop station is on a small scale, and it is assumed that all the other costs are the same for the mono-Si and mc-Si systems. Considering the current market prices – 4 yuan/watt for the 255W mc-Si module and 4.3 yuan/watt for the 270W mono-Si module – there is a 0.3 yuan price difference per watt between the mono-Si and mc-Si modules. The mono-Si system costs 18,576 yuan and the mc-Si system 16,320 yuan.

3. The effective number of sun hours in one year is 1200, which means 1.2kWh per watt.

4. A resident can receive an income of 1.2 yuan for every kWh generated. Of this, 1.0 yuan is the retail price and 0.2 yuan is derived from local government compensation.

Subject to the above conditions, the mono-Si rooftop station generates 5184kWh per year, whereas the mc-Si system generates 4896kWh per year; the mono-Si system therefore generates 288kWh more than the mc-Si system, with a corresponding increase in income of 345.6 yuan. The payback period for the mono-Si system on the extra 2256 yuan investment compared with the mc-Si system is 6.53 years, which is well within the 25-year lifetime of the rooftop system.

Considering the electricity generation advantage per watt for the mono-Si module compared with the mc-Si module, with the same power capacity the mono-Si station generates 5% more than the mc-Si station. The mono-Si station will therefore produce 5443kWh every year, which is 547kWh more than the mc-Si station, with a corresponding income increase of 656.4 yuan. The extra initial investment of 2256 yuan for the mono-Si can then be paid back in only 3.44 years.

> “Even with the higher initial investment cost, the high-efficiency mono-Si module has a lower cost per kWh.”

Even with the higher initial investment cost, accounted for within the 25 years’ lifetime, the high-efficiency mono-Si module therefore has a lower cost per kWh. Furthermore, as the difference in cost per watt for mono-Si and mc-Si will be smaller in the future, the high-efficiency mono-Si module system will have a greater investment benefit over the mc-Si system.

References

[1] SEMI PV Group Europe 2014, “International technology roadmap for photovoltaic (ITRVP): Results 2013”, 5th edn (March) [available online at http://www.itrpv.net/Reports/Downloads/].

[2] Green, M. 1998, *Solar Cells: Operating principles, technology and system applications*. Kensington N.S.W., Australia: UNSW.

Enquiries

Xi'an LONGi Silicon Materials Corp.
No. 388, Middle Aerospace Road
Chang'an District
Xi'an
China 710100

Tel: (+86) 29-8156 6686-8128
Website: www.longi-silicon.com

inter solar
connecting solar business

ees
electrical energy storage

inter solar award 2014 WINNER

ees electrical energy storage AWARD 2014 WINNER

Congratulations to the 2014 AWARD winners!

Photovoltaics
SMA Solar Technology AG
Steca Elektronik GmbH
TMEIC Corporation

Solar Projects in Europe
GOLDBECK Solar GmbH
IBC Solar AG
LTi REEnergy GmbH

Solar Projects in North America
First Solar
Solaire Generation Inc.
Princeton Power Systems

Solar Projects in India
Bosch Ltd.
Tata Power Solar Systems Ltd.
Trojan Battery

Champion of Change
Michael R. Peevey
President | California Public Utilities Commission (CPUC)

electrical energy storage (ees) AWARD
Ideal Power Inc.
International Power Supply
ViZn Energy Systems

The Intersolar AWARD and ees AWARD were presented to winners at celebratory award ceremonies during Intersolar Europe, Intersolar North America and Intersolar India.

Register now and submit your application by March 27, 2015!

www.intersolarglobal.com/award