in India as for as solar grade wafer development is concerned.

Early beginning

The programme for development of PV technology in India took off in the late 1970s. NPL (National Physical Laboratory) spearheaded such a programme followed closely by the launch of a major project known as 'NASPED (National Solar Photovoltaic Experimental Demonstration)'. This project was supported by the Government of India at CEL (Central Electronics Limited). Around the same time almost, some basic cell development work was in progress at SSPL (Solid State Physics Laboratory), IISc (Indian Institute of Sciences), IACS (Indian Association for the Cultivation of Science), IITs (Indian Institutes of Technology), BARC (Bhaba Atomic Research Centre) and importantly,

different universities. These efforts culminated in industrial production of crystalline silicon solar cells at CEL and BHEL (Bharat Heavy Electrical Ltd.) and were reinforced by the entry of private players during 1987–92. Silicon wafer was the element of concern right from the beginning as we can see in the accompanying description.

The raw material—silicon

Silicon happens to be the second most abundant element in the Earth's crust—27%. It does not occur as a native element due to the simple fact that SiO_2 in the form of Quartz, Quartzite, and other compounds is more stable. There are quite a few processing steps which are used to bring silicon from its native ore that is quartzite to the crystalline substrate form. It is this form basically that is put to use for the fabrication of solar cells or IC (Integrated Circuit) components. Importantly, metallurgical grade silicon which is about 99% pure is used as a starting material for the solar and IC applications. It is generally obtained via the carbon reduction of SiO_2 in an arc furnace as per the chemical reaction that is SiO_2 + C—CO_2 + Si. Incidentally, this grade of silicon is quite inexpensive ($1/kg), but the residual impurities (Fe, Al, and C) degrade the carrier lifetime to unacceptably low values. That is why it has to be purified to the desired extent which is more commonly known as the electronic grade silicon. Solar grade silicon lies somewhere between the metallurgical and electronic grade silicon and that is why it is slightly less costly. However, it is not capable of producing the best possible solar to electric conversion efficiencies.

Tracing the historical link

The history of development of poly silicon dates back to 1969. The erstwhile Mettur Chemical and Industrial Corporation (presently Chemicals and Plastics India Ltd.) together with the prestigious IISc, Bangalore entered into an agreement as early as in 1969 for developing chemical processes for silicon materials. Following which, the development of SiCl4 was taken up in 1978 and hydrogen in large quantity was available in-house as a by-product. The process of reduction of high purity $SiCl_4$ with hydrogen was pursued to produce high purity silicon. Accordingly, silicon produced turned out to be of a high purity having a resistivity of 300 Ohm-cm for n-type and 2000 Ohms-cm for p-type.

The commercial touch

Silicon wafer development for the solar cell industry was not an easy task by any measure. It took years of effort to achieve process specific maturity. Such efforts to develop polysilicon were somewhat scattered. For example, a pilot plant facility to make polysilicon material was established by the Chemplast Group. It was based on the technical know-how provided by the IISc. Then in late 1980s, MNRE (Ministry of New and Renewable Energy) supported a

major R&D project at Metkem Silicon (Chemplast Group Company) to design and set up a 10 TPA polysilicon reactor. Silicon wafer development is a highly energy intensive affair. However, the new reactor helped to bring down the energy consumption from a high of 450 kWh–250 kWh per kg. An allied benefit came in the form of upgradation of the production capacity to 40 TPA via an improvement of other reactors at Metkem. Subsequently, the silicon ingot and wafer production capacity was also enhanced by the company mainly to meet the domestic requirement of silicon wafers. So far so good, but it was not to be for long. The high price of electricity in the state of Tamil Nadu coupled with a few more factors in mid nineties forced the company to put an end to its polysilicon material production. Thus, the dream of building it into a huge material development facility turned sour. Between then and now, there have been many expressions of interest, but these have hardly matured for one reason or the other. Let us now take a quick look at our existing manufacturing facilities in this area.

Wafering capacity too little

Initial efforts to set up a polysilicon plant in the country were made in the eighties. Thereafter, no serious effort was made to realize such a plant, even though BARC developed the basic process to make polysilicon material. IIT, Kanpur also worked towards the development of silicon material from rice husk. Presently, there are mainly two companies in India namely Metkem Silicon and Maharishi Solar, which are engaged in the production of silicon crystals/ingots and wafers using imported polysilicon material. Metkem capacity is just enough to produce about 2 MW worth of solar cells. The combined capacity of these two companies is sufficient to produce about 4.5 MW equivalents of solar cells. This point to a huge gap in the demand and supply of silicon wafers and that is the prime reason for about 90% of the wafer requirement to be imported by the Indian PV industry.

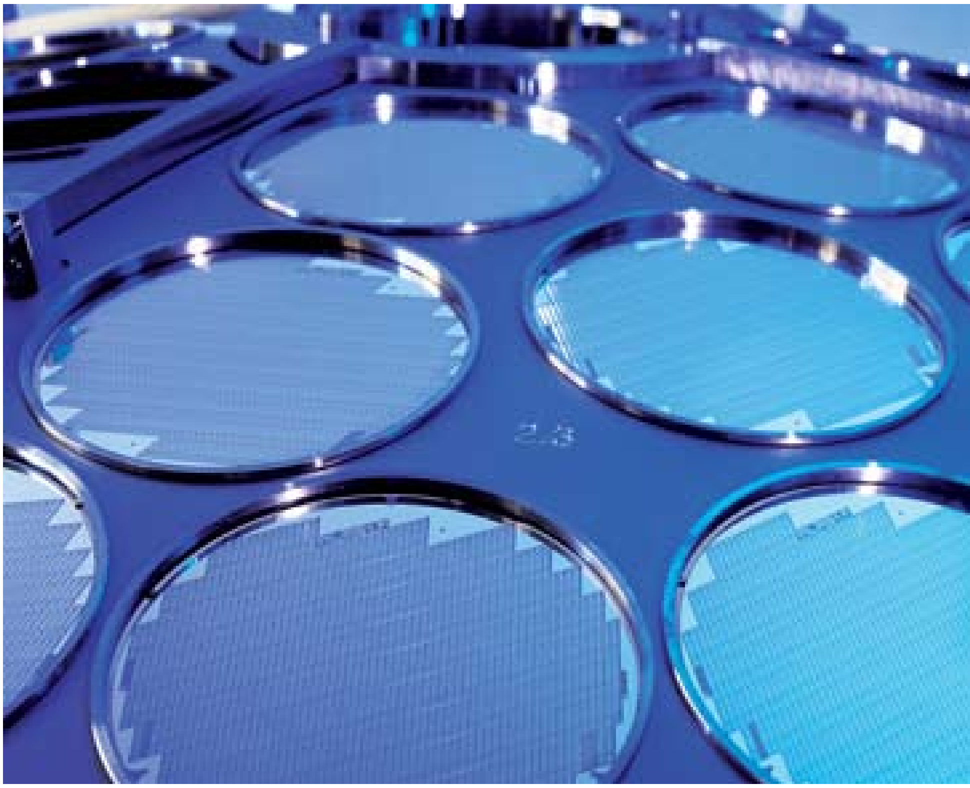
Maharishi Solar has set up a R&D plant (100 MT/annum) for solar grade polysilicon production at its facility in Srikalahasti in Andhra Pradesh. Further, it is working on an ambitious plan to establish a 3000 MT/annum plant for such a purpose. Metkem plant is equipped with state-of-the-art wafering machines and crystal pullers to produce mono crystals. These crystals varying in diameter between 4–8 inches with boron and phosphorus doping are being produced by the CZ technique. *Table 1* gives the key specifications of silicon wafers required for the manufacture of solar cells.

Table 1 Key specifications of silicon wafer required for manufacturing solar cells

S.No.	Parameter	Specifications
1.	Type	P type, boron doped
	Size	125 mm sq
	Dimensions	125 mm x 125 mm (±) 1 mm
	Thickness	325 micron (±) 25 mircon
2.	Resistivity range	0.5 ohm-cm to 3.0 ohm-cm
3.	Lifetime	> 10 microseconds
4.	Taper	In thickness of wafers <20 micron
5.	Bow	< 60 microns
6.	Both sides of the wafers	As cut and cleaned, free from slurry, cutting oil or grease and epoxy, and so on.
7.	Other physical requirements	To be completely free from any micro-crack, edge chipping, scratch, visually observable marks or mechanical damage.

Wafer volumes needed far in excess

As per available estimates, India's solar PV industry is registering an annual growth of about 25%. There



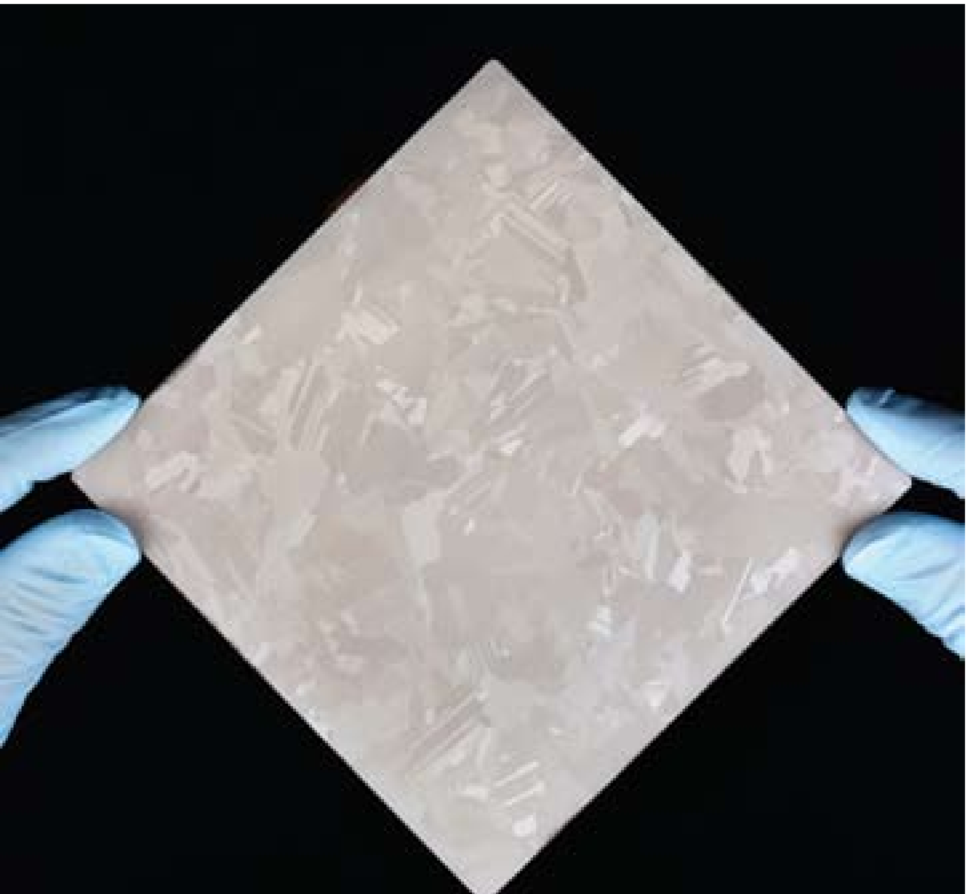


Photo courtesy: Scott

will be a likely demand of 1000 million wafers by 2012 with an accompanying requirement of polysilicon material to the tune of 2000–3000 TPA (tones per annum). It is an opportune moment to consider the setting up of a large capacity polysilicon plant in the country keeping both the growth pattern of the PV industry and the global shortages of wafers at times in view. Lately, the Government of India is considering a possibility to set up a 2500 TPA polysilicon facility using CZ growth of silicon single crystals with diameter of up to eight inches. Proposed outlay for the purpose is estimated at about Rs 12 000 million. After years of lull, there is also something to cheer about if, proposals to realize the following few silicon wafer manufacturing facilities come through for real.

- BHEL and BEL have announced plans to set up a 250 MW facility via an overseas collaboration. It is to process silicon wafers, solar cells, and modules and is a part of the national climate change policy initiative in the solar mission. The aim of this policy is to add 20 000 MW of solar power to the national grid by 2020. Both these companies have production facilities of 6 MW and 7 MW respectively.
- Solar semiconductor has signed a delivery agreement with Solar World AG for the production of multi-crystalline solar silicon wafers. The agreement is a multi-year contract for the delivery of wafers worth over $1.2 billion (Rs 5 160 crore). The tie-up would help solar semiconductor, which has manufacturing facilities in Hyderabad, to strengthen its position as a rapidly growing international manufacturer of high-quality solar PV modules.
- The Jyoti Poddar-controlled Environ Energy group plans to set up the country's first integrated polysilicon solar project at Haldia. The 5 500-crore project will be undertaken by Bhaskar Silicon Ltd, an SPV of the Singapore-based group. International technology giants such as Perseus of the US and Centrotherm may pick up participatory stakes in the project.
- RIL (Reliance Industries Ltd.) also plans to manufacture polysilicon, solar-grade wafers, and SPV modules with capacity of 1000 MW, at an investment of Rs 11 631 crore over a period of 10 years. While the solar project located at SEZ in Jamnagar, Gujarat, is expected to create over 11 000 jobs, the semiconductor wafer fab and ATMP units would employ another 4 000 people. RIL has sought a subsidy of Rs 3 394.50 crore for the semiconductor fab and Rs 2 326.20 crore for the solar project.
- Other companies that have applied to the government under the scheme are Videocon Industries (Rs 8 000 crore investment), Moser Baer PV Technologies (Rs 6 000 crore), Titan Energy System (Rs 5 880 crore), KSK Energy Ventures (Rs 3 211 crore), and Signet Solar (Rs 9 672 crore). Proposals received are for manufacture of items such as polysilicon, wafers, solar cells, SPV, and so on.

Cost reduction measures

Silicon material for PV use is still not cheap. It constitutes between 60%–70% cost of a solar cell even today. The trick of the trade is to keep the thickness of wafer as low as possible via a variety of technological innovations. In quantitative terms, it may mean achieving the following.

- reduce silicon consumption from an existing level of 13 to 14 t/MW to 10 t/MW by 2010 and 8 t/MW by the year 2020
- reduce silicon wafer thickness from the present level of 300 microns to 180 microns by 2010 and to 100 microns by 2020
- enhance efficiency of CZ based silicon cell to about 20%–22% and that of multi-crystalline silicon cell to 18%–20%
- enhance module efficiency to >20% and lifetime to >25 years

Choice of silicon material grade

Crystalline silicon is still regarded as the workhorse of PV industry worldwide. It currently accounts for close to 70% of the solar panel cost and it should ideally come down to 40%. There are varying perceptions about the material grade of silicon being used by the solar industry. A good majority seem to go in for silicon wafers of very high purity level, which may not be ideally needed. In early nineties, a few manufacturers were eager to experiment with the use of metallurgical grade silicon itself.

Today, nearly the same thought has returned to a few companies in India, including Moser Baer PV. It has made investments into a Slovenia based company to produce solar grade silicon, which would mean optimizing the quality. The distinct objective is to encourage a widespread use of PV technology across all the key sectors of our economy. Let us now turn our attention to the PV silicon material scenario at an international level.

Global outlook on PV silicon

Polysilicon is used in the manufacturing of common electronic devices such as telephones, wristwatches, stereos, and many more. Most of the polysilicon production is used in making such devices with only about 33% going to solar photovoltaic panels. This is part of the problem for the solar industry. The global, multiple market need for polysilicon has driven PV costs up in recent years and led to occasional material shortages. It is now projected that the polysilicon manufacturing sector exclusively for the PV use will catch up by 2011. This is partially due to the influx and growth of manufacturing companies, but also to the projected rise in thin-film solar cells. These are no doubt less efficient than polysilicon panels, but facilitate more building integrated products such as solar shingles. They also promise a large reduction in production costs themselves. CdTe (Cadmium Telluride) modules now being produced by First Solar looks like a definite reality, which may pose a good challenge to the crystalline silicon market in the time ahead.

However, as of now, things are good for the polysilicon manufacturers. Many have sold out their product even before they have produced. The existing manufacturers are expanding their production capacities and new entrants are lining up as is indicated in through the tabulated information. However, it is difficult to guess as to how long this state of affairs will actually last. The reality is that polysilicon manufacturers may have to adapt to the fact that demands not only increases, but also changes. Such has been a peculiar characteristic of the entire PV industry at a global level.

Polysilicon growth pattern

The last few years have witnessed a rapid growth of Solar PV cell market. Its immediate fallout has been a demand-supply imbalance in the polysilicon market. In fact, the high growth of solar cell production capacity in direct comparison to the volatile semiconductor market has made the solar market more attractive for the polysilicon producers. Incidentally, the production of solar grade polysilicon continues to be a highly capital intensive business. That apart, the lead time needed to add capacity has led to a short supply of the polysilicon material at times for the solar cell manufacturers. Let us now try to look at the immediate impact of such shortages on the worldwide markets.

At times, the prices for polysilicon have gone through the roof due to a sudden surge in the demand for this material. In fact, spot prices for polysilicon are much higher than the contract prices. In general, the silicon producers go in for 3–5 year supply contracts. This is evident from the fact that more than 90% of the PV supply chain is covered by the fixed supply contracts. Today, more than 90% of polysilicon is supplied by the following seven companies.

- Hemlock Semiconductor,USA
- Wacker-Chemie AG, Germany
- REC (Renewable Energy Corporation), Norway
- Tokuyama Corporation, Japan
- MEMC, USA
- Mitsubishi, Japan and USA
- Sumitomo-Titanium, Japan

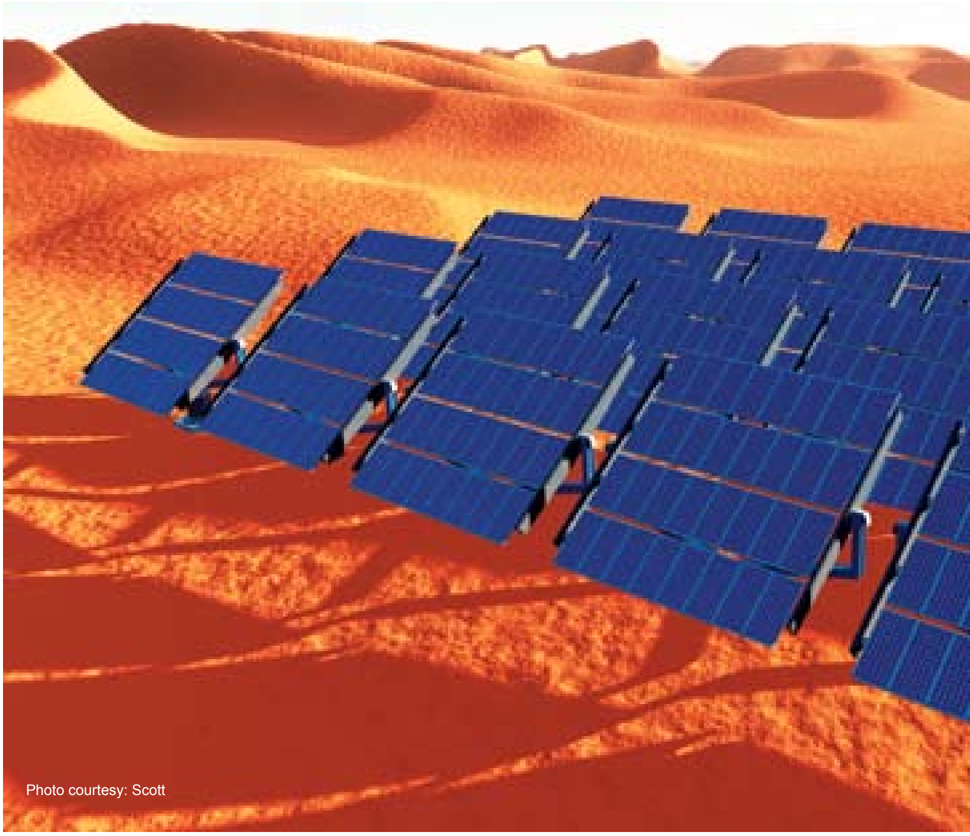


Photo courtesy: Scott

- The global capacity addition in polysilicon was only 6 800 MT between 2000–05 (from 24 200 MT in 2000 to 31 000 MT in 2005)
- The global silicon supply increased by about 30% in 2007
- In 2006, solar PV industry consumed about 45%–47% of the cumulative polysilicon supply for solar cell product, which increased to 54% in 2007
- The global silicon feedstock capacity meeting the solar PV and the semiconductor industry needs totaled to about 52 000 TPA by the end of 2007
- The price of polysilicon per kg in the year 2000 was a mere $9/kg, which increased to $75 in early 2006. Important to note here is that spot market prices touched an occasional high of about $100-200 per kg in 2006

The Hemlock Semiconductor Group has begun construction at its new plant in Clarksville, Tenn. It is projected that the facility will be complete by 2012. The new facility of the semiconductor features an investment of up to $1.2 billion, and it will create 500 full-time jobs. Initially, the new site will have the capacity to manufacture more than 10 000 MT of polysilicon, with an ability to expand production up to 36 000 MT. Most of the polysilicon produced at this facility will be consumed by firms in the solar industry.

New entrants to PV silicon

More than 15 companies have announced their plans to start the polysilicon material production. *Table 3* presents the targeted capacities by the year 2011.

All major polysilicon producers are currently embarking on an ambitious plan to expand their respective plant capacities. Expectedly, such a targeted increase may help to balance the demand-supply position of silicon material for the PV industry. It may

Table 2 The present and future capacity of polysilicon manufacturers

Company	Production base	Present capacity (MT)	Future capacity (by 2010) (MT)
Hemlock	Michigan	10 500	36 000
Wacker	Burghausen, Germany	10 000	22 000
REC	Montana and Washington	6 250	19 500
MEMC	Texas (USA) and Merano (Italy)	6 000	15 000
Tokuyama	Yamaguchi (Japan)	5 800	8 400
Mitsubishi	Albama (USA) and Yokkaichi (Japan)	3 100	3 500
Sumitomo	Japan	1 300	2 700
Others	China, Taiwan, and so on	9 050	79 050 (2011)

Table 3 The targetted capacities of polysilicon material production by 2011

Company	*Country of origin*	*Projected target for 2011 (MT)*
LDK Solar	China	15 000
M.Setek	Japan	13 500
DC Chemicals	USA	10 000
Elkem	Norway	10 000
Arise Technologies Corporation	Canada	10 000
Hoku	USA	8 000
Total China (other than LDK)	China	7 300
Solar Value	Germany	5 300
Isofoton	Spain	2 500
French Consortium	France	2 000
PV Crystalox	United Kingdom	1 800
Solar World	Germany/USA	1 500
Crystal Solar	Australia	1 200
Joint Solar Silicon (GmbH) and Co KG (JSSI)	Germany	850
JFE Steel	Japan	100
Total		79 050 MT

perhaps mean availability of silicon wafers at a lower price after 2010. In fact, the short supply of silicon together with its high prices has spurred the development/upgradation of a few alternative production technologies such as the following.

- FBR (Fluidized Bed Reactor)
- Upgraded metallurgical silicon
- Thin film technologies

Thinning the wafer to suit the cost

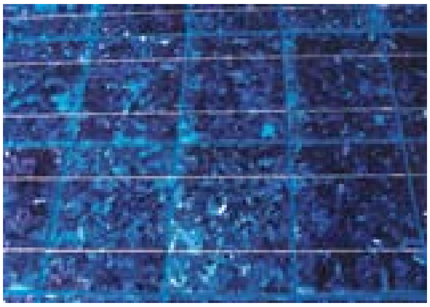
The present day approach is to process solar cells in bulk silicon wafers of about 180 micron thicknesses. As of now, majority of the PV fabrication facilities are not equipped to handle much thinner cells. However, research laboratories have successfully demonstrated that cells as thin as 50 microns with efficiencies >20% can be processed. With the help of advanced wafer handling (temporary carrier wafers), wafer-based processing may be extended down to 40 micron cells. There is a possibility that cell processing steps will gradually be integrated into module assembly lines.

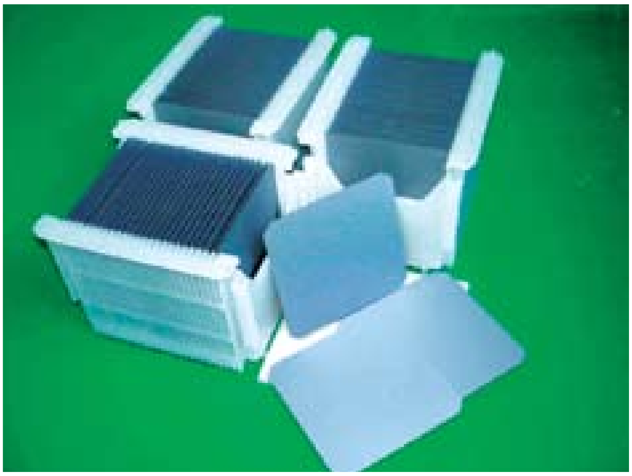
Surging forward

Today, about 90% of the PV market is controlled by the crystalline silicon solar cells. It is expected to be so for the next decade at least. Price erosion of about 30%–40% is expected within the next 3–5 years. So, availability of silicon wafer is an absolute must and that too at lower prices. The strong PV market growth of the past decade and the expected growth for the next decade have been enabled by the specific government measures. Notable amongst these is the feed-in-tariff system implemented in Germany, which has catalysed the market growth for wafers, cells, and modules beyond expectations. India is now waking up to the reality of setting up a mega capacity silicon production facility and may witness a huge boom with solar mission approval in place. There are vast coastlines in the country lined up with sand, but we also have to build elongated pathways of the Sun for all of us to stay illuminated all the time.

Photo courtesy: DOE/NREL

Photo courtesy: DOE/NREL





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Solar-wind hybrid technology for electrification in hilly regions of Haryana

SUMITA MISRA, Director, HAREDA

Background

Wind energy is one of the most viable renewable energy sources. Wind gets generated from an uneven heating of the Earth's surface by the Sun. Thus, it results in poles receiving less energy from the Sun than the equator. In the process, the dry land heats up and cool down more quickly than the sea. Such a differential heating drives a global atmospheric convection system reaching from the Earth's surface to the stratosphere, which acts as a virtual ceiling. Most of the energy stored in these wind movements can be found at high attitudes and sea coasts where wind of very high speed blows continuously. There is an estimated 72 TW (terawatt) of wind energy potential on the Earth that can be commercially viable.

Wind position in India

At 10 464 MW (megawatt), India presently ranks fifth in the world in wind power generation. The coastal region and some parts of Gujarat and Rajasthan witness very favourable wind regime, and therefore, the wind power development in these areas has been significant so far. For commercial exploitation of wind energy, wind velocity at a site should be more than six m/s and corresponding wind power density more than 200 W/sq m. In Northern India, such high wind velocities are found only on the high hilly regions where installation of large scale wind power projects is itself not feasible due to lack of infrastructure. Haryana has a very limited sub-mountainous region on the foot hills of the Shivalik Range in the northern part of the state and the Aravalli Range in the southern part. Due to their geographical location, wind velocity in these hilly areas is considerably low and therefore, commercial exploitation of the wind power is not viable.

Site survey

Wind monitoring carried out by HAREDA (Haryana Renewable Energy Development Agency) through CWET (Centre for Wind Energy Technology) during 1998–99, indicated that the wind velocity at Morni, Panchkula and Abheypur, Gurgaon at 25 m above ground level was 14.9–20.9 kmph and 12.5–17.12 kmph respectively for a considerably period of the year. Promoting wind energy in Haryana was a real challenge with technological barriers in such low wind speed areas. It was then mooted that Haryana should go for a small wind energy system which requires average wind

Solar and wind power at Morni Hills, Panchkula

velocity of 4 m/s. The idea to utilize the wind-solar power potential of the Morni Hills area adjoining Himachal Pradesh was conceived keeping in view the availability of good solar insolation levels (approx. 500 W/m²/day) supplemented by fairly good wind speed required for small wind hybrid projects.

Sun and wind normally complement each other with sun energy being available for the period when wind energy is comparatively low and vice-versa. Thus, the combination of sun and wind provides an ideal solution for a round the year source of energy. The idea was shared with an NGO (non-government organization), which readily offered to set up a wind-solar hybrid system as part of their social responsibility and outreach activities.

Village identification

HAREDA carried out surveys in various parts of Haryana and finally two villages—Chakli and Ramsar in Morni Hills in Panchkula district of North Haryana were selected for the project. These two villages were considered as the ideal locations because they both were situated on top of a hill with a favourable wind and solar insolation, compact size, and above all being in an environmentally fragile zone like Shivalik Hills. This was an added factor to look at green energy solutions to meet the energy demands of the local inhabitants. HAREDA then prepared a project proposal and sought financial assistance from MNRE (Ministry of New and Renewable Energy), Government of India.

Project Implementation—a challenge to reckon with

It was envisaged as a pilot-cum-demonstration project, and was to be the first wind-solar hybrid project in the entire North India. HAREDA then invited tenders for the project implementation. Ananda Solar Technologies, Gurgaon was selected on the basis of its competitive rates for the proposed 10 kW wind-solar hybrid system at a cost of Rs 3.43 million with five years AMC (annual maintenance contract). The Ministry provided Rs 2 million for the project and the balance cost of the system was borne by Ananda Solar Technologies, Gurgaon.

The installation of a hybrid system on top of the hill was an immensely challenging task, keeping in view the difficult terrain and weather conditions. The heavy equipment and the construction material were carried either manually or on ponies. Sometimes, incessant rains hampered the project work but, HAREDA was determined to install the system within the permissible period of three months. Finally, the project was completed within an allocated period of four months thus, adding further to its uniqueness.

People participating with a purpose

While developing the project, people's participation was a key consideration. It was ensured that interactive meetings were held with the Gram Panchayat who readily agreed to go for the project. The land was provided free of cost by the villagers.

Also, with the support of HAREDA's field staff, they formed a VEC (village energy committee) to look after the system. Following its successful commissioning, in September 2008, electricity connections were provided to 24 households, in these villages, with each having two light points and one ceiling fan. In addition, three street lights were also provided in each village to facilitate safe mobility during night time.

Performing as expected

The hybrid power plant has been generating 12 units of electricity/ day on an average. At times, when the wind velocity is high, the power generated touches about 30 units/day. The average per unit cost of power generation turns out to be Rs 15. The plant has generated about 2865 units of electricity in a year.

The villagers are contributing Rs 50 per month towards energy charges and are enjoying 24x7 availability of electricity. The power availability in these villages has increased from about 50%–100% and from 7–12 hours in the pre-project period to 24 hours in the post-project period. The VEC collects the charges and maintains the same in its account. As per the conditions agreed upon, the amount collected will be used for maintaining the system after the expiry of five year AMC period.

The carry over effect

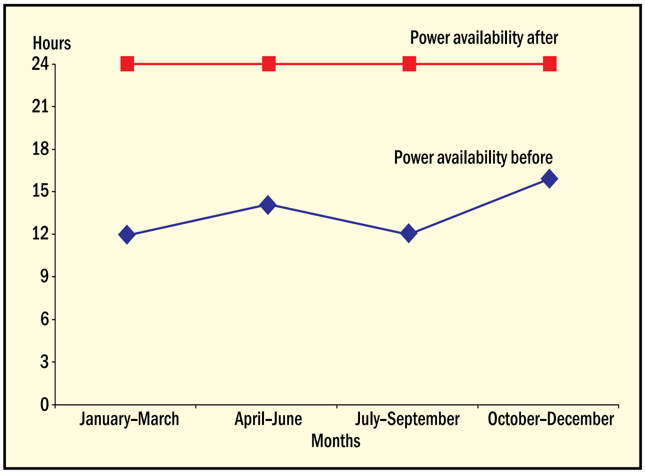
The beneficiaries are happy and seeing their increased comfort, the nearby villagers have also approached HAREDA for similar systems. Surinder Kumar, *Sarpanch* of the village is a proud person as the *Sarpanchs* of other villages want to know from him, as to how his village was transformed. Shyam Sunder, President, *Saur Pawan Urja Samiti* who maintains the system is also enthused about the hybrid system and advocates installation of similar systems all over the Morni Hills area where suitable wind velocity is available. According to the villagers, they now enjoy an un-interrupted supply of electricity for 24 hours a day. This allows the children to study for longer hours and provides additional working hours for the adults to better their lot.

Hybrid combination marching ahead

Encouraged by the success of the system, HAREDA proposes to install two similar systems during 2009–10 in collaboration with Shivalik Development Agency at Bhoj Balag and Panchayat Samiti Office, Morni. The Panchayats will contribute Rs 100 000 each for the system while the balance shall be met by the MNRE, HAREDA, and the Shivalik Development Agency.

The project has been a learning experience for HAREDA while successfully demonstrating solar-wind hybrid power generation technology on the ground. It also had a significant replication effect in terms of creating a 'demand' for renewable energy projects amongst the local inhabitants that too, in an ecologically sensitive zone like the Morni Hills.

On the basis of some valuable experience gained from this project, it can be concluded that wind-solar hybrid systems are an ideal solution for energizing remote hamlets in a decentralized manner. These systems are successful in locations having good sunshine and an above average wind velocity (4-5 m/s). The success of the systems also depends on the willingness of the local people to run and maintain the system. And the system is particularly useful for ecologically fragile areas.



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DEMONSTRATING NATURAL ENERGY FAR AND WIDE

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Background

'Seeing is believing' is not just an age old maxim. It holds true even now as far as maximizing the gains from a group of naturally owned technologies is concerned. Here an obvious reference is towards the RE (Renewable Energy) technologies like solar, biomass, hydro, and so on. Generally these have so far remained within the confines of rural areas mostly. Time is now ripe to deploy the same for a larger good in the urban areas too. Such a need is in fact dictated by several reasons like a growing gap between the demand and supply of power, increase in the per capita energy consumption and importantly, the much hyped climate change concerns. As of now, the technology promises of the above mentioned renewable sources have been firmly established alongwith their long-term endurance. However, on the cost front, solar energy technologies moreso solar PV (photovoltaic) are still craving for a low cost material/process alternative. Perhaps it would not be wrong to expect RE technologies making almost the same impact as the mobile telephony has managed to roll across the geographical boundaries and various economic strata.

Taking a cue it would instill fervour for use of RE technologies across all possible user segments within the urban areas. The gainful purpose is to look beyond the symbolic use geared at just the sample pieces of demonstration. It is not quite true with solar water heating system for example, which are finding an increasing acceptability now across key sectors of our economy. This article takes a quick look about the recently enunciated policy measures geared at an increased market deployment of a wide range of RE products and systems. The glaring point of difference is in terms of bringing within the RE fold a whole set of buildings/uses, which hitherto were considered out of bounds for one reason or the other.

Tracing the connection

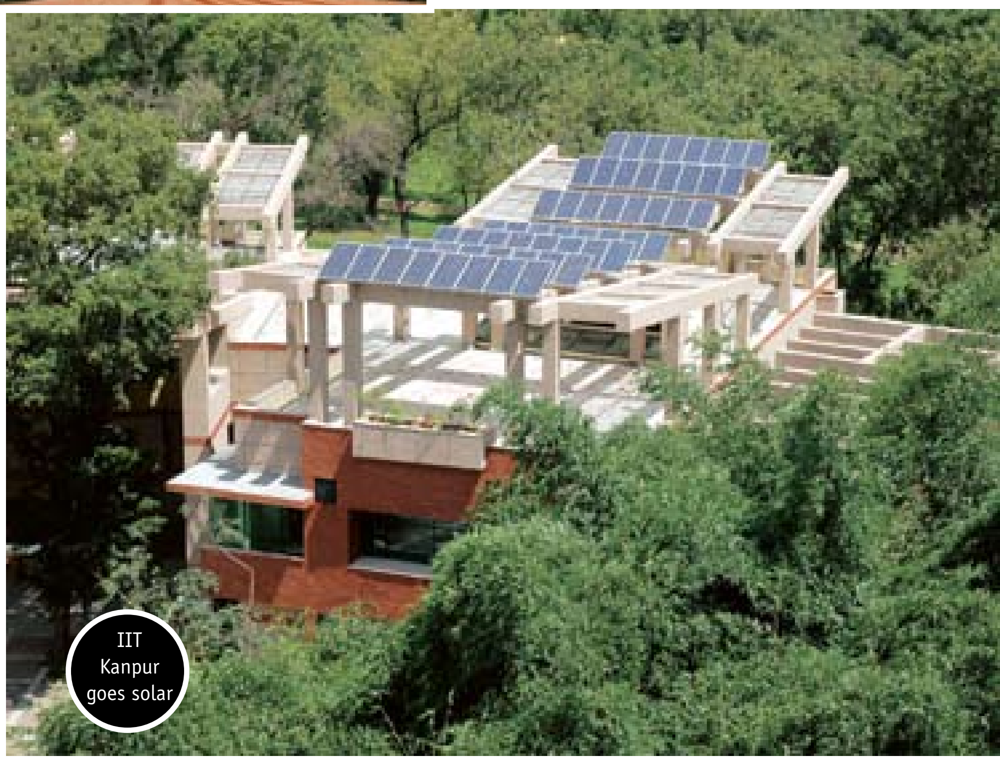
The mobile van as a replica of the RE demonstration models was enough to arouse the curiosity of an average man on the road for long. *Urjagrams* were considered as fine examples of how technologies like solar and biogas could mark a definite change in our limited availability of conventional energy supplies. An odd street lighting system or two in a grid-connected area stood out for its own reasons. Solar powered glow sign boards illuminated the nexus between the all mighty sun and the urban outlook. However, a bulk of urban needs remained under wraps at times deemed to be much beyond the affordable limits.

The beginning of a new demonstration

MNRE (Ministry of New and Renewable Energy) has recently announced a major scheme known as, 'Special Area Demonstration Project Scheme'. Significant objective of this scheme is to publicise the use of RE technology based systems in a wider frame of reference besides disseminating information on the technological developments specific to this fast emerging area. Several ministries/ departments of the government of India will be working in tandem to realize the maximum possible gains from a

Photo courtesy: DOE/NREL


Rashtrapati Bhawan goes solar


IIT Kanpur goes solar

variety of end-use considerations. The proposed outlay for the year 2009–2010 has been fixed at Rs 20 million. In fact, the striking points of difference between the old and new scheme may be seen along the following few points.

- demonstration of renewable energy systems/devices at places of national and inter national importance
- at centralized kitchens and at roadside eating joints and restaurants (where large flow of people and tourists takes place every day)

Coverage value and end use

The new scheme is a clear pointer towards the changes to set in especially within the government owned buildings/establishments. The private participation is also embodied mainly at such points where people can have a leisurely view of the renewable energy facilities. The end-use applications are projected to be as much need based as possible. Obviously enough, the larger purpose is to supplement the conventional energy use to the best possible extent. As demonstration value increases both in terms of system reliability and monetary savings, further replication could well be on the way in terms of expanded capacities as well. For the present, let us take a ready glance at the sectors chosen for this type of purposeful demonstration in the first instance. These range from the majestic Rashtrapati Bhawan on one hand to the zoological parks on the other end.

Table 1 mentions the end-uses that are intended to be met through a variety of renewable energy sources moreso solar energy technologies. Solar seems to edge past rest of the technologies for the following few reasons.

- fuel (movement free) availability—solar radiation
- clean and silent operation
- better aesthetic considerations
- quick system installation and commissioning
- easy maintenance

Table 1 End-use applications of renewable energy technology

Places/ Categories	Technologies (under consideration)	Day time applications	Night time applications	Central support	Annual maintenance contract
Rajghat Rashtrapati Bhawan Presidential Retreat Building (at Mashobara, Shimla and Rastrapati Nilayam, Bolarum Hyderabad) Parliament premises Raj Bhawans World Heritage Sites" (numbering around 27)	Solar PV/Solar Thermal/ Biogas plant based on kitchen waste	Indoor lighting Fans Ventilation Irrigation/Drinking water information kiosks ticketing counters Air conditioning Computers Water heating Cooking (both through biogas and solar thermal routes)	LED based flood lights Garden lights Outdoor lights	Up to Rs 100 lakhs per site will be provided for meeting full cost of procurement and installation of systems and devices	Charges payable for a period of five years
Places of tourist and religious interest /State Assembly premises, and so on.	Solar PV/Biogas (based on kitchen waste and cow dung)/ Biomass gasifier/ Solar Thermal	Indoor lighting Fans Ventilation Irrigation, information kiosks ticketing counters. Computers Water heating	LED based Flood lights Garden lights Out door lights	Central Financial assistance up to Rs 50 lakhs per site will be provided for meeting full cost of procurement and installation of systems and devices	Charges payable for a period of five years
Sites for places of national and religious importance other than those covered above (state govt. secretariats also included)	—	Indoor lighting fans, ventilation irrigation, information kiosks ticketing counters water heating	LED based flood lights garden lights Out door lights.	Central financial assistance up to Rs 25 lakhs per site will be provided for meeting full cost of procurement and installation of systems and devices	Charges payable for a period of five years
National parks, Zoological Gardens, Government Science Museums/Science cities, Collectorates	Solar PV/Solar thermal/Biogas (based on animal dung)	Emergency lighting computer irrigation and drinking water supply for cooking	Outdoor lighting garden lighting Solar lanterns	Up to 75% of the full cost of procurement and installation of systems for science museums, science cities, national parks and zoological gardens and up to 50% of the project cost limited to Rs. 5 lakhs. In case of premises of collectorates and district magistrates	Charges payable for a period of five years
Centralised Kitchens in Residential Schools, IITs, IIMs, Medical Colleges including hospitals, Military Establishments, Railway catering, Prisons, Industrial Establishments, Gurudwaras, Food preparation under Mid Day Meal Programme.	Solar Thermal/ Biomass gasifiers/ Biogas (based on kitchen waste)	Water heating, Cooking	—	Up to 50% of the cost of biomass based/solar cooking system, recovery and use of biogas from kitchen waste/ effluent treatment plant, solar hot water systems in case of government/ state / autonomous bodies / NGOs and up to 25% of the cost in case of private bodies.	—
Roadside eating joints, and restaurants	Solar Thermal/ biomass gasifiers/ biogas (based on kitchen waste)	Cooking, Water Heating	—	Up to 50% of the cost of biomass based/ solar cooking system, recovery and use of biogas from kitchen waste/ effluent treatment plant, solar hot water systems in case of government/ state / autonomous bodies / NGOs and up to 25% of the cost in case of private bodies.	

Parking on renewables

The special area demonstration scheme of the ministry envisages the development of two state level energy parks in each state. Care will be taken to locate these parks in an area, which registers huge footfalls of the common people. The concerned state nodal agency or a department will be assigned an overall responsibility to set up such parks. The parks will be set up in a sprawling campus of about 2.5–3.0 acres on the land arranged by the state agency. These parks will have a paid entry of the curious visitors and the agency in turn will take care of its O&M (operation and management) needs. It will have a flexibility of entering into annual maintenance contract for a period of five years. Locally available manpower will be trained for the purpose to keep various systems in the energy parks functional without fail.

Implementing for smooth gains

Special area demonstration scheme of MNRE is expected to evolve into a largely networked arrangement of various ministries like culture, tourism, environment and forests and departments like Archeological Survey of India, Central Public Works Department, State Public Works Departments, State nodal agencies for renewable energy, Social welfare and Prison reforms, Wildlife, Zoo authorities, and so on. Consultants belonging to various specialized skill areas will be empanelled for the purpose and will in turn offer consultancy support in accordance with the specific needs of individual projects. The cost to be incurred for this activity will be embodied in the total project cost. The beneficiary organization will be responsible towards the O&M needs of the systems and devices installed at the designated locations. The completion time for the projects undertaken in respect of category-I sites will range between 12–24 months.

Performance evaluation and monitoring

It is absolutely essential to undertake routine checks of installations that may finally come up under the ambit of this nation wide scheme. Perhaps the key to successful implementation of a scheme aimed at a large cross-section of both public and private groups rests on a fool proof mechanism of operation-cum-maintenance. Failing which, it may lose its charm sooner than later. This also calls for initiating a large scale drive aimed at capacity building measures. Field performance data needs to be collected on a regular basis and analysed in order to assess an overall suitability of the system design and component engineering. Take for example the use of solar PV panels at a busy intersection. These panels are quite prone to dust and smoke accumulation, which can reduce their power output. So, cleaning of the panels on a regular basis is an absolute must so as to ensure a desirable flow of energy from battery to load.

Caring more for visibility

At times a renewable energy based installation remains unnoticed for in an urban location. In a programme like this, far greater visibility of any installation should be ensured in a pronounced manner. The issue is more relevant in case of solar lighting installations (moreso indoor based) and a solar water heating system generally having a rooftop mounted collector. As such, there should be proper markings of the sum total system features.

Focused information material

More often than not, we come across information on technology and its mode of operation excepting some elaborately explained economic estimates of a system installation. It is now all the more desirable to prepare ready to estimate techno-economic estimates for a variety of end-use applications as suited to different geographical regions. It should explain in an easy to understand way the economic terminology and equally simple method of arriving at the simple payback periods

Case specific example-Tihar jail

The Tihar Jail spread over 400 acres is home to about 12 000 inmates. It is now

in the process of becoming green under the SAD (Special Area Demonstration) scheme of the MNRE (Ministry of New and Renewable Energy). As per the outline of the action plan worked for the purpose, following type of major energy uses will be promoted under a partnership mode.

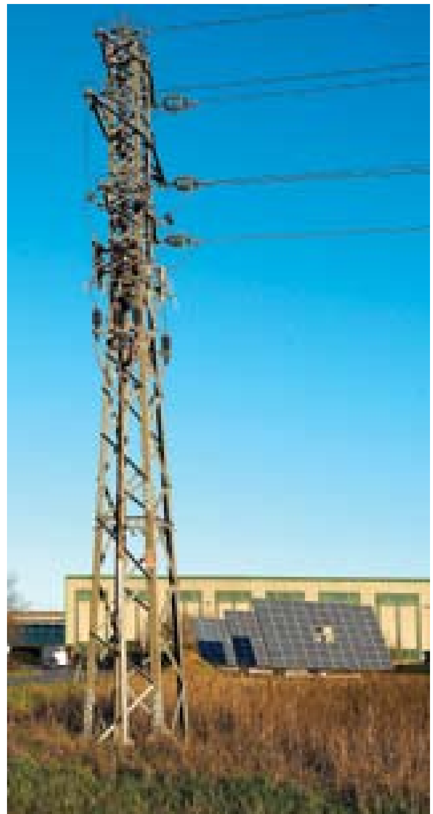
- four eco-friendly biogas be setup
- Solar energy use to be promoted for the most suited end uses. In fact, solar water heating systems are already at work here
- Biomass gasifier system will be installed to light up the jail complex besides operating its manufacturing units, kitchens and bakeries

Energy saving measures like the use of light emitting diode fixtures and pressurized natural gas ovens has already been taken up by the prison authorities and more are likely to follow. Key outcome of this 96.5 lakh worth collaborative project between MNRE and Tihar jail is expected to be along the following lines.

- 40% of the total energy requirements will be met by renewables
- It will be completed in three years
- Energy scheme will lead to a saving of Rs 66 million annually

The final demonstration

Initiatives like these will surely pave the way for an enhanced market penetration of various renewable energy technologies. The essence of the scheme hinges on the availability of appropriately designed systems, un-interrupted feedstock availability, smooth operation and maintenance network and importantly an overall urge to go beyond the symbolic call of going green. India has an enviable distinction of having undertaken one of the largest RE based and rural centric field demonstration programme in the past. One hopes that the SAD programme will help in understanding the urban and semi-urban acceptance of these systems from several important considerations.



THE EFFICIENCY RACE

BY SASCHA RENTZING

The slump in the photovoltaics sector also has a good side: manufacturers are paying more attention to technical innovations. Numerous examples were on display at Intersolar.

On second day of Intersolar, Martin Denz is already hoarse. 'We have got plenty of action,' says the Director of Hanover's module manufacturer and system provider Alfasolar in a scratchy voice. What has visitors flocking to the company's exhibition stand are its two new polycrystalline solar panels presented in Munich. The best performing of the panels converts light into electricity with 15.4% efficiency and delivers 326 W (watts) of power–7% more than its predecessor and significantly more than the average module.

The key to the high energy yield is the cells. The little powerhouses manufactured by Belgium's Photovoltech have 16.6% efficiency. To get maximum performance from the cells, Alfasolar packs them behind module glass textured with pyramid-shaped structures. The inside surface of the glass reflects light exiting the panel back at the cells, giving another chance to be absorbed to light not taken up by the silicon on the first go-round. Alfasolar wants to produce 17 MW (megawatts) of pyramid modules in 2009, five MW in its existing facility in Gällivare, Sweden, and twelve MW in its new 20 MW plant in Hanover. 'We believe that high efficiency and quality stands us in good stead with our customers.'

*This article has been reproduced from *New Energy* magazine

Efficiency over expansion

Technological advancements as a path to market success—manufacturers put far less emphasis on innovation at Intersolar 2008. With demand for solar exploding and businesses booming, the industry was completely focused on expanding mass production.

Companies with tales of massive expansion ruled the expo. Now, the crisis has clipped the high-fliers' wings. Even companies once spoiled by success increasingly pitched guarantees and performance, rather than GW (gigawatts) of production capacity. Consider Suntech, China's largest solar company, which has scuppered plans to double its capacity to two GW (new energy 6/2009) in the face of low demand. Now, the Chinese have shown their innovative side at Intersolar, introducing a new module which the company says delivers 7% more power than its next best performing panel (280 W).

At the heart of the new panels are 'Pluto cells' developed by Suntech and UNSW (University of New South Wales) in Sydney, Australia. The polycrystalline variant achieves 17.5% efficiency, while the monocrystalline panels top out at 19%; Suntech's normal polycrystalline cells get 15.2%, while its mono cells reach 17.2% efficiency. Pluto's secret is tiny pyramid-shaped pits in the light-collecting surface. Each pyramid's angled sides reflect light back onto the semiconductor, preventing it from escaping the cell. A silicon-oxide layer underneath the pyramids increases light particle absorption while simultaneously preventing charge carriers – negative electrons and positive electron holes – excited through absorption from canceling each other out on the surface of the cell, thereby being lost as a source of energy. This process, known as recombination, is particularly common on the cell's surface due to disruption of the crystal lattice. Furthermore, very thin electrical contacts reduce shading on the front side of the cells. While the new process steps add costs, higher efficiency more than offsets the additional expense, according to Jerry Stokes, President, Suntech Europe. The company expects the good cost-benefit ratio to create high demand for the new panels. Suntech will produce 50 MW of Pluto modules in 2009 and increase production over the next few years, Stokes has announced.

Back contact cells en vogue

Suntech faces stiff competition in the high-efficiency sector. Sunpower of the US has been offering 315-watt modules with 19.3% efficiency since July 2009. Only a select few panels have that kind of power. The backbone of the Suntech technology is 96 cells whose busbars and contacts are entirely on the back of the cell. Because there is no metallization to block incident light, efficiency climbs to more than 20%. But manufacturing the back-contact panels is difficult because the electron collecting layer (emitter) has to be connected to the negative contacts, which means that it also has to be on the rear of the cell. To prevent charge carriers from getting lost in the semiconductor on their long journey from the front side to the emitter, Sunpower has to use relatively expensive, highly pure monocrystalline silicon. Nonetheless, the company is a leader in cutting system costs, according to Photon Consulting. Sunpower has a per-watt manufacturing cost of $4.29 where the industry average is $5.46, giving Sunpower an edge on the competition. Thanks to falling system prices, utilities are increasingly investing in photovoltaics. Sunpower's modules and project expertise are in high demand in the US market. The American company has also created a stir in the building-integrated PV market. In Munich, the firm presented its new T5 Solar Roof tiles, which should go on sale in Europe in the third quarter of 2009. Bill Mulligan, Sun power's vice president of technology and development, said that the tiles will also be offered in a 315-watt version, making them the most powerful solar roof system in the industry.

In late 2009, Kyocera also plans to launch panels with back-contact cells. The Japanese firm, however, uses economical polycrystalline silicon rather than monocrystalline. Another process step is necessary when polycrystalline is used; Kyocera wraps the emitter layer through holes from the front to the back side of the cell. This construction ensures that charge carriers are captured quickly, rather than passing through the relatively impure semiconductor to get to the negative contacts on the back side. But, Kyacera says, the additional step pays off. The design increases cell and module efficiency by 1%–17.5% and 15.1% respectively, raising output by 7.1%.

Modules for cars

The back-contact cells were not the only Innovation Kyocera presented at Intersolar. The company also has a new panel, which Toyota plans to integrate into the roof of the new Prius hybrid car to operate the ventilation system while the car is parked. The panel

is based on standard polycrystalline cells but, unlike normal crystalline modules, is flexible because it has to follow the contour of the car's curved roof. Kyocera says that it set up a new production line in Japan with a special lamination machine just to make the panels. Market observers believe that the auto industry presents a great deal of income opportunity for photovoltaics and that more cooperation between PV companies and auto manufacturers is sure to come. So far, however, development of module designs specifically for cars is in its infancy.

On the cell level, however, the industry is closing in on the UNSW efficiency record of 24.7%. For instance, an alternative to back-contact cells is a technology known as heterojunction with intrinsic thin layer, or 'HIT cells' offered by Japan's Sanyo. The company combines crystalline with thin-film technology to boost power yield. Applying amorphous silicon to both sides of a monocrystalline slab reduces charge carrier losses on the surface of the cell—and that ratchets up efficiency. Sanyo recently increased the efficiency of its HIT cells to 20%. The company introduced a module at Intersolar that has an efficiency of 17.3% with an above-average output of 240 W.

On the heels of First Solar

Innovations in pure thin-film modules are also developing rapidly. CdTe (Cadmium-telluride panel manufacturer) First Solar, with its production capacity in excess of one GW and manufacturing costs of 0.93cents/W, continues to be the industry standard bearer. But the competition is catching up. Colorado State University spin-off Abound Solar has also been producing CdTe panels since April 2009 and wants to take the fast track to the industry's number one slot. While the company based in Fort Collins, Colorado, did not have a stand in Munich, its ambitious plans were much talked about. Abound Solar wants to produce at a dollar a watt this year in its new 65 MW line. Ahead of the exhibition, founder, President and CEO (Chief Executive Officer), Pascal Noronha, announced that the company is planning to produce at 0.90 cents/W in a 200 MW facility by 2010.

Berlin's Inventux also aims to produce at a cost of less than one euro. The company has been producing micromorphous silicon panels since late 2008. The technology is a refinement of common thin-film panels made of simple amorphous silicon. With the help of an additional absorber, micromorphous silicon vacuum-coated onto the amorphous layer, the manufacturer improved power yield by more than 8%. Inventux plans to achieve economies of scale with high-volume production and increased efficiency. 'In October, we want to overcome the 9% hurdle, and by 2010 we want to get to 10% efficiency,' says spokesman, Thorsten Ronge. Inventux wants to increase efficiency through process optimization while also profiting from the innovations of its supplier Oerlikon Solar, which provides the company's coating machines. In Munich Oerlikon, CEO, Jeannine Sargent, underscored the company's goal of seeing micromorphous panels manufactured on Oerlikon equipment at 0.70 cents/W.

There is also progress in CIS modules made of copper, indium, and gallium with selenide or sulfur. Increasing efficiency, lower cost. Various companies, above all Wurth Solar, are now producing this technology. Wurth, whose CIS panels can convert 12% of incident light into electricity, doubled its production capacity in 2008 to 30 MW Wurth's thin-film panels are achieving the efficiency levels that crystalline cells had just a few years ago.

Efficiency leaders

Solar modules can now achieve efficiencies only possible at the cell level just a few years ago. The best performing panel, Sunpower's 315 E, generates 315 W of power at 19.3% efficiency—a third more than the average module. Astoundingly, second place for efficiency goes to a polycrystalline panel—Chinese provider Yingli Solar gets 18.5% efficiency out of its YL240. Sanyo takes third place at 17.1% with its 'HIT module,' which combines thin-film and crystalline technology. China's Suntech Power, however, could soon take the Japanese company down a notch. Starting in the third quarter of this year, Suntech plans to offer a module made with its new Pluto cells that achieve up to 19% efficiency. The modules made from the new cell would then have 17%–18% efficiency.

Photo courtesy: DOE/NREL

SMART FINANCING IDEAS FOR SMALL SOLAR LIGHTING SYSTEMS

SONYA FERNANDES, Research Associate, TERI, <sonya@teri.res.in>

Background

Of the 1.6 billion people worldwide living without electricity, 706 million come from the countryside and rural hinterlands of the South Asian region Building a centralized power supply unit or extending the grid to these regions would either mean relying on the already strained power lines or setting up a new power plant involving subsequent capital cost, time, manpower, and resources.

Thus, these regions provide an ideal environment to serve as potential markets for testing and evaluating small/smart-grid or off-grid energy solutions. Realizing this business opportunity, several 'Renewable Distributed Energy Generation' solutions have emerged in such rural regions and villages in the last few years.

Most of the countries in South Asia are either under developed and paying the price of climate change, which is further impeding their growth or are being constantly refuted for prioritizing development and poverty alleviation over the climate change mitigation. Hence considering the resource availability, technology implementation space and potential, RE (renewable energy) seemed to be an answer to most of the energy development and climate change considerations, even though the issue of high technology and associated implementation cost continue to remain a major barrier.

Solution in sight

One of the few solutions to tackle high system cost emerges in the form of microfinance schemes for the implementation and maintenance of renewable energy technologies. For instance, solar lighting can be sighted as the simplest example of innovative where MFI (microfinance institutions) finance renewable energy distribution and production market. Thus, it helps to reach out to the grid deprived populace with a viable off-grid energy solution.

In many of the South Asian countries innovative microfinancing partnerships have emerged amongst the local rural banks, small microfinance institutions and renewable energy technology, and service providers. Credit institutions and people's banks have been formed locally to provide an easy access to credits. It has been observed that micro-credit in the renewable energy sector has shown some signs of success mostly by integrating an innovative financial scheme/model with an expensive technology like PV (photovoltaic) thereby improving its affordability and availability.

Moreover RETs are capable of operating quite efficiently in such places as these can operate at stand-alone bases with various other benefits, like generation flexibility, depending on the site specific requirements and various storage possibilities. Hence solutions like these play an important role in rural pockets, many of which are part of the industrial and agricultural supply chain hence highly energy dependent in order to sustain the livelihood of the inhabitants.

So is microfinance capable of driving small solar lighting technologies like solar lanterns in South Asia? Yes, it is possible with some support from non-government organizations, governments, financial institutions, and ESCOs (Energy Service Companies).

REEEP: an international funding organization

REEEP (Renewable Energy and Energy Efficiency Partnership), a global NGO and a partnership is one such organization aiming to catalyse the market for renewable energy and energy efficiency. It has a primary focus on emerging markets and developing countries.

Backed by the national governments, financial and business professionals, and NGOs, REEEP is uniquely placed amongst international initiatives in accelerating the integration of REES (Renewable Energy and Energy Efficient Systems) into national and global energy policy and the energy mix of the country. Its emphasis on energy efficiency improves a nation's energy security, reduces carbon and greenhouse gas emission, ensures socio-economic benefits by increasing the energy security, and reduces energy poverty of a country. REEEP's regional secretariats provide a ready access to the best practices in policy and finance so as to promote renewable energy and energy efficiency. The International Secretariat engages political, financial, and business support to reduce the risk inherent in implementing new policy and financing initiatives.

The REEEP South Asia Secretariat hosted by AEI (Asian Energy Institute) covers India, Pakistan, Bangladesh, Bhutan, Pakistan, Nepal, Srilanka, and Maldives. The Secretariat endeavours to pave the way for future regional activities built around renewable energy and energy efficiency. It aims to provide a regional focus and leadership for an increased use of renewable energy and energy conservation; promote dissemination of information about the potential contribution of renewable energy sources and efficient technologies in meeting the expected growth in energy demand, particularly in this region. At present, the South Asia secretariat is credited with more than 25 completed and 14 ongoing projects on renewable energy and energy efficiency. One of the major global priorities is to support pro-poor financing mechanisms in the region. These projects are also beginning to deliver new business models, policy recommendations, risk mitigation instruments, and regulatory measures.

Case study

SELCO—a shining example

A RE microfinance project is being funded by REEEP and implemented by SELCO (Solar Electric Light Company). SELCO India was started in 1995 as

an experiment to build a sustainable linkage between energy services and income generating activities and thereby to build a strong service network in rural areas for solar and other energy services.

The main objective of this project is to create a replicable innovative financial mechanism for renewable energy. It will be financed in coordination with regional banks and microfinance institutions in Karnataka and Gujarat. These are expected to influence the existing policy on financing energy services in these regions. The project has so far developed 12 clean energy activities with five different financial and/or microfinance institutions in renewable financing. Each of these case studies reinforces the belief that energy service delivery through financial innovation and micro energy enterprises in tandem with desired technical quality can compete with conventional energy services. SELCO India has used REEEP funds to remove financial barriers, and test finance and product innovation measures at the grassroot level.

Sun-weaving the dreams for real

According to the REEEP-SELCO booklet on 'Access to Sustainable Energy Services via Innovative Financing', one of the case studies of an innovative financing model is 'Margin money financing to handloom weavers co-operative for procuring solar lights for improving quality of sari production'. The project was implemented in Chitradurga in South East Karnataka. Here a small handloom weaver community continues to keep this dwindling traditional occupation alive. In order to delicately weave a simple silk sari, the weavers purchase raw silk reels and then weave one silk sari per week using traditional manual handloom units working for about 12 hours per day. A weaver typically earns about Rs 200–300 per day (approx $6–$7 per day) excluding their labour and other related costs.

Due to erratic power supply the area experiences severe power cuts, which results in delayed deliveries of saris and hence an economic loss. SELCO in partnership with the local bank and with the support of the 'Handloom Weavers Cooperative Society' studied the weaver's cash flow, lighting requirement and accordingly agreed to disburse loans to the interested weavers (total of eight weavers) to purchase solar lanterns. However, as per the bank's terms and conditions, the end users were expected to pay a down payment equivalent to 15% of the total loan amount. The weavers were unable to pay this large amount as one time payment although they were prepared to pay in monthly instalments. Support from REEEP was used to leverage financing by providing partial margin money on behalf of the end users. Within a week, the solar lighting systems were installed in all the eight households.

Motivated by the partial ease in their hardships from the unrestricted light supply, the weavers are now regularly paying the monthly installments and actively spreading the word about its benefits, thereby encouraging other community members to purchase the solar lights.

The case studies have demonstrated how funding can help remove financial barriers besides test finance and product innovation at the grassroots level. In the process, it has refuted many general assumptions about the affordability of renewable energy services, more so solar PV (photovoltaic) targetted at the rural poor.

SEWA-showcasing the resolve

Most microfinancing projects function successfully with the support of local banks and networks. For instance, the SELCO project might not be as successful without the partnership of local banks like the SEWA (Self Employed Women's Association) Bank and the Syndicate Bank so as to diffuse sustainable-energy services to the poor women in the region. What we need at this stage are networks like FWWB (Federation of Worlds Women's Banking) to promote the innovative financing mechanisms in India, and thus influence the policy-makers like NABARD (National Bank for Agriculture and Rural Development) to create separate portfolios of renewable energy.

SEWA Bank has been pioneering microfinance programmes since 1973. SEWA in Gujarat, India formed a bank–Mahila SEWA Cooperative Bank–to access certain financial services easily. Almost 4000 women contributed their share capital to form the bank. Today, there are more than 30 000 active clients in the SEWA bank.

Missing government support

Though many such examples and case studies can be provided, there has not been substantial interest from the government to encourage the expansion/replication of such projects in several other rural areas. However, the micro-credit mechanisms in South Asia have still managed to survive and succeed mostly when implemented at a small scale in partnership with local financial institutions, banks, associations, and so on. However, the participating institutions are compelled to keep it small and choose their customers very carefully so as to ensure a higher success rate. Otherwise, the high lending risks and operational cost could surface with a bigger financially deprived market.

Also, the need for building capacity and manpower at a large rate seems less cost effective than ensuring selective capacity and skill building of locals most likely to reside for an extended period in the region.

Microfinancing: the way forward

In the South Asian region – especially in countries like India, Bangladesh, Srilanka, and so on – it has been observed that the uptake and hence the mechanism of implementation of such projects varies with the demography, entrepreneurial inclination of the locals, the gender ratio and interest.

Without government initiatives and interventions, microfinance in renewable energy may continue to grow but at a reasonably slower pace. On the other hand without major policy and regulatory interventions many existing microfinancing schemes/models may continue to innovate and flourish, unhindered outside the government radar.

Presently, globally there are about 10 000 MFIs with about 150 million customers mainly women growing at a rate of 20%–30%. Many of these MFIs lack expertize and face challenges in serving the poor. Putting in place a monitoring mechanism so as to assess the financial outflow, lending procedure, and so on is important to isolate and encourage MFIs amongst the 10 000 existing ones that provide financially viable and sustainable solutions to the poor. Though exercising regulation on MFI can be a deterrent to their growth and profitability, moderate government intervention regarding interest rate may be necessary. This could also assist the quantification of this business sector in terms of assigning accurate figures to its present growth and potential.

GREEN SCHOOLS

A FIRST PERSON ACCOUNT OF EXPERIENCE WITH SCHOOL CHILDREN

SOLID SOLAR (GAUTAM POLYMERS GROUP)

Background

Gautam Polymers Group has an envious distinction of being India's largest manufacturer of solar lights. This keeps us busy with our business schedules round the year. Our position also brings with it lot of activities on the CSR (Corporate Social Responsibility) front. To begin with, our past CSR activities generally revolved around helping out in times of calamities like Tsunami, Aila, Bihar floods, and so on. But this year, we decided to undertake '*Suryodaya*' Programme, under which we handpicked the four most environmentally conscious schools in Delhi – The Shriram School, Vasant Valley School, Sanskriti School, and Modern School. We did the following activities with these schools.

- Hold an interactive talk with the students on solar energy
- Provide a 'Handbook on Solar Energy' to the school containing the list of activities that can be done around the year to spread awareness on solar energy
- Give a demo exhibit in the form of solar light and/or posters in the institution where *Suryodaya* Programme is held

GREEN SCHOOLS IN ACTION

Schooling with a green purpose

Today, schools not only dwell into the prescribed academic syllabus, but also motivate the students to think about the emerging topical issues of national and international significance. So, when we went to these schools, we were impressed with their focus on environmental issues and children's inquisitive minds and their questions about solar energy. Some of the questions raised by the fifth and seventh grade students are as follows.

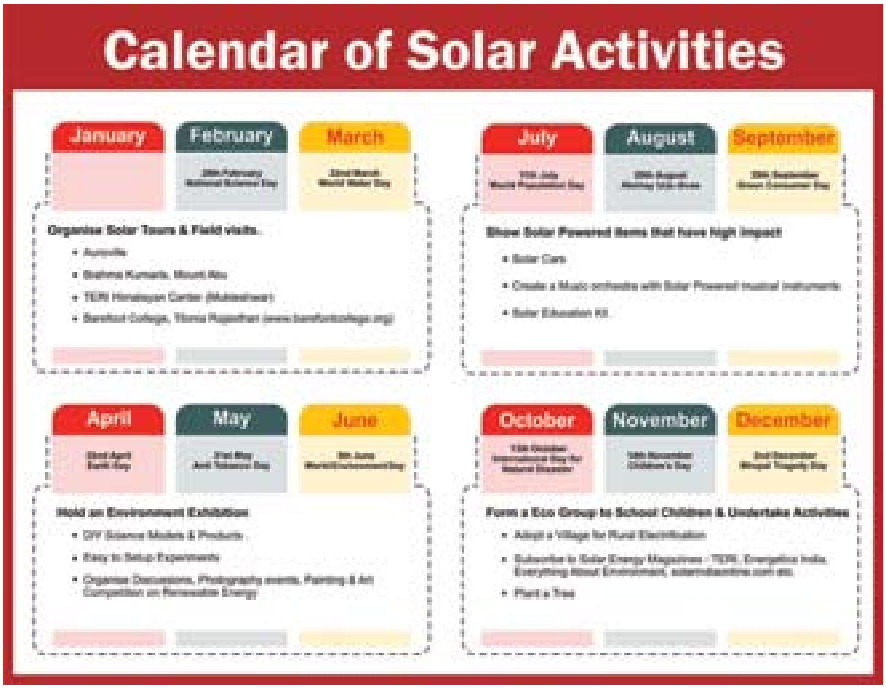
- Why only silicon is used for solar panels, why not any other material?
- If, making a solar panel is so expensive, can silicon be mixed in paints to make solar powered walls?
- Where can I get a solar backpack?

It was fun to see the spark in their eyes and if, there was anything competing with solar energy, it was their energy and enthusiasm that made the atmosphere electric. These questions reflect their passion for creating a sustainable future with the help of solar energy.

A very positive and encouraging thing was that all the above schools had dedicated teachers—'Environmental Coordinators'. These teachers were focused on making the school more environmental friendly and involving the students in various green activities.

Torch bearers of 'green' change

Vasant Valley for example, had conducted a solar music orchestra with solar powered guitars and drums. They also displayed a solar car for the school children. In Sanskriti School, the students had gone on a field trip to Barefoot College, Tilonia in Rajasthan, where the women of the village assemble solar lights on their own and also provide service for the same. They got exposed to the Tilonia Campus which is completely solar powered. Solar energy is used to run computers, cook food, and so on. Modern School had a 'green fair' where environment friendly things were on display and the students went for a Clean Yamuna Drive. In Shriram School, they had done work in rural electrification/



solarization of villages and were in the process of adopting five more villages.

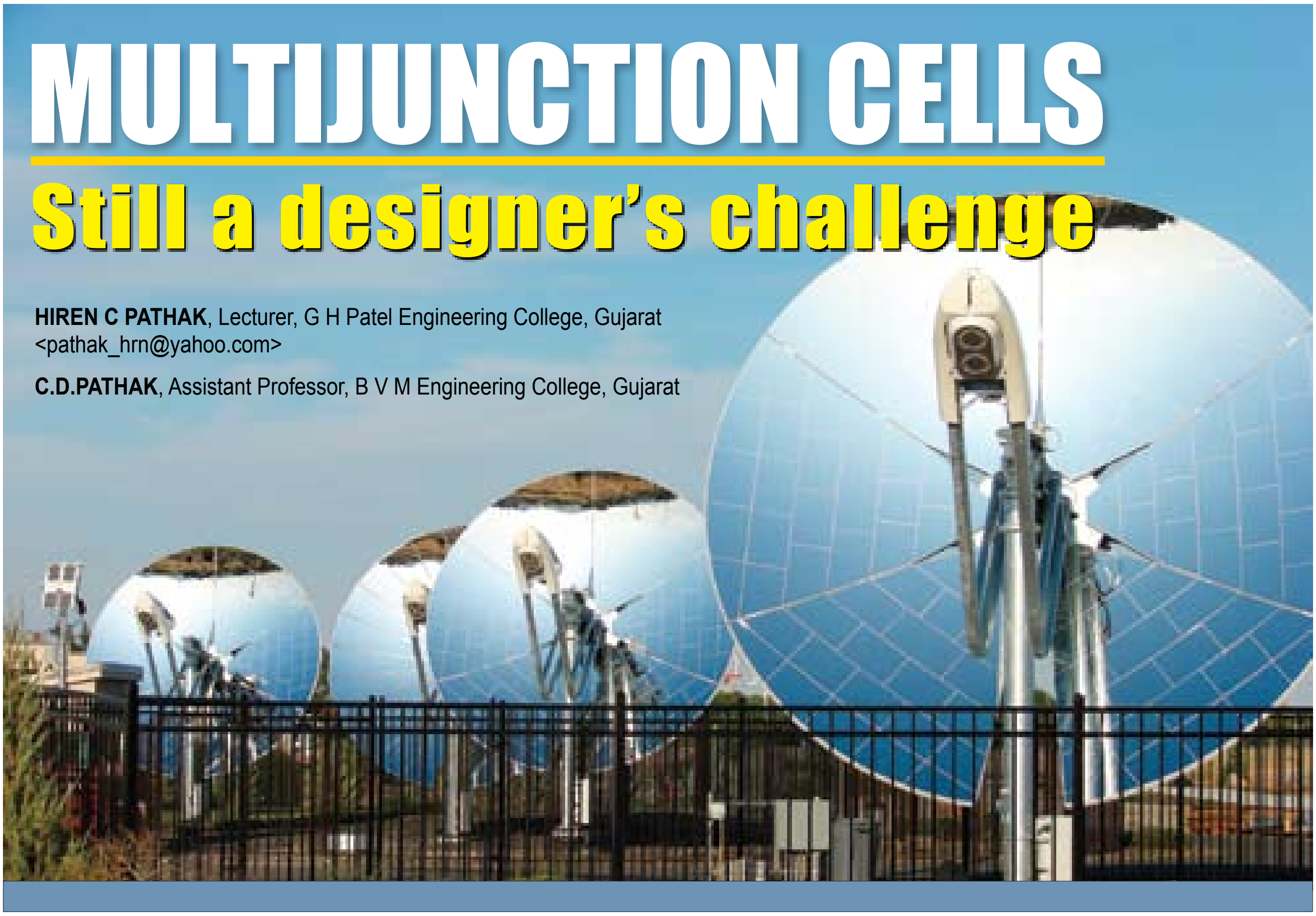
All these schools had a green brigade—an eco group of students who lead in all kinds of activities from the front. But the environmental activities were not confined to the environmental teacher or eco group alone, it had sparked the imagination of all the students and spread across the entire school community. This reflected in the level of awareness among the pupils. I am sure they will be early adopters of this technology.

Timing the sun

For ensuring that our CSR activity carves out a bigger role for itself, we have developed a solar calendar that lists the various activities. These can then be undertaken by various schools, colleges, and non-governmental organizations around the year for spreading awareness.

Kudos to the schools and their underlying philosophy of using the green-energy technology.

To conduct a *Suryodaya* Programme in your institution, kindly email us at *shubhra@gautampolymers.com* with a brief description of the environmental activities undertaken by you.



MULTIJUNCTION CELLS

Still a designer's challenge

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Introduction

Simply put multijunction solar cell comprises of two or more materials. These are optimally efficient over a limited spectral range. The underlying rationale is to obtain higher solar to electric conversion efficiency. These cells constitute of multiple thin-films produced using MBE (molecular beam epitaxy) and/or metal organic vapour phase epitaxy. Thus, each type of semiconductor will have characteristic bandgap energy. This causes it to absorb light most efficiently at a certain colour or more precisely to absorb electromagnetic radiation over a portion of the spectrum. In brief, within a multijunction structure, there are several layers. Each layer captures a part of sunlight passing through the cell. These layers allow the cell to capture more of the solar spectrum and convert it into electricity.

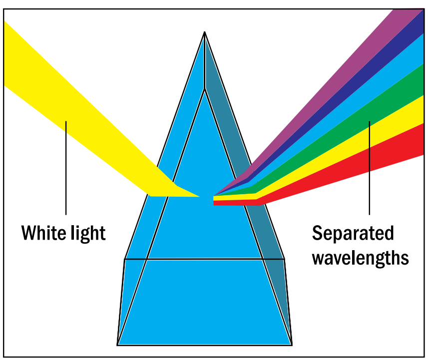

Figure 1 Refraction of light through a prism

Band gap selection

Consider the spectrum of sunlight split and distributed over a variety of semiconductor materials by using a prism *(Figure 1)*. In that case, a different semiconductor material could be selected *(Figure 2a)* that would best match each portion of the spectrum. Although such an arrangement is reasonable in theory, mechanically maintaining such a design would be problematic.

A more viable solution is to stack, or grow; multiple layers of semiconductors with decreasing bandgaps *(Figure 2b*). Top layers are designed to absorb higher-energy photons while transmitting lower-energy photons that are absorbed by lower layers of the cell. In theory, a number of these layers can be so arranged. This strategy is a key characteristic feature of the multijunction solar cells.

Alloys of Group III and Group V elements, as well as other related compounds, lend themselves

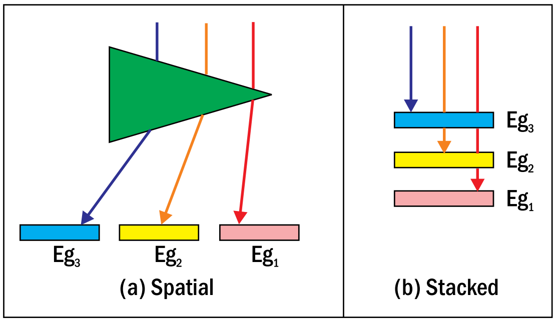

Figure 2 a and b Alternate configurations for multijunction spectral splitting

well to the design of multijunction cells. InP (Indium phosphide), GaSb (gallium antimony), and the more commonly used GaAs are examples of such III–V materials. By carefully adjusting the compositions, a range of bandgap energies can be achieved. Such selections are usually made in conjunction with lattice-constant constraints (discussed below). For example Ga0.5In0.5P (also known as $GaInP_2$) was selected for NREL's (National Renewable Energy Laboratory) record-setting triple-junction cell to produce a material with band gap energy of 1.85 eV and a lattice constant of 5.65 angstroms.

If, a lower-band gap material was desired, less gallium and more indium would be used in the compound, up to the point at which no gallium is included, and the resulting InP would have a band gap of about 1.3 eV. Note, however, that such an adjustment in band gap necessarily changes the lattice constant, as well.

Cell optimization

Band gap and lattice matching are central to the multijunction solar cell designs. But to maximize the efficiency of multijunction devices, other characteristics are equally desirable. Foremost of these for a monolithic (grown all in one piece), series-connected, two-terminal multijunction device is that in which each of the sub cells should have matched currents. That is, they should absorb photons at the same overall rate, thus producing the same current.

(a) Current matching

By the very nature of its series connection, the output current of the multijunction solar cell is limited to the smallest of the currents produced by any of the individual junctions. For this reason, it is desirable to design each junction so as to produce the same amount of photocurrent.

The current produced by a semiconductor junction depends on a number of factors, but most notably, the number of incident photons exceeding the semiconductor's band gap and the material's absorptivity. If, the photons that exceed the band gap of the material are in abundance, then cell layers need a minimal thickness to collect the desired current. Likewise, if, the absorption power of a material is relatively high, the photons must pass through less of the material before being absorbed.

In practice, for the GaInP/GaAs/Ge cell, this situation implies a relatively thick Ge layer because of its lower absorptivity. Further, there are design distinctions between terrestrial versions and space versions of the cell to account for the differing number of UV and near-IR photons for these two different environments.

(b) Power production

One may note that as additional cell layers are added, the level of total current necessarily decreases. This phenomenon occurs because a fixed number of photons are distributed over increasing number of cell layers, which decreases the amount available for electron promotion in any one cell layer. The tradeoff, however, is that the electrons promoted are, overall, more energetic and have a greater electric potential. As additional cell layers are added in series, the voltage each layer produces must be summed up with the others. Therefore, the total voltage of a multijunction solar cell is greater than that of a single-junction solar cell.

Maximizing total power – the product of total current and total voltage – is the photovoltaic designer's ultimate goal. Multijunction designs, as compared to single-junction designs, have reduced current. But this loss is more than compensated for by increases in voltages, so overall power (the product of current and voltage) is greater.

In addition, because resistive losses in circuits are proportional to the square of the current, these losses can be significantly reduced if, current can be minimized. Resistive losses are an especially important consideration in concentrator systems, in which currents produced are proportional to the levels of solar concentration. Again multijunction designs are advantageous in that they inherently reduce current while increasing voltage.

Present research identifies and qualifies a 1-eV band gap semiconductor material. Such a material could either be used as a substitute for the Ge (E = 0.67 eV) layer presently used in the triple-junction design, or as an additional layer in that design. In either case, the output voltage of the resulting cell would be increased and the current will be further reduced.

Concentration systems

Concentrators are a vital component of terrestrial multijunction solar

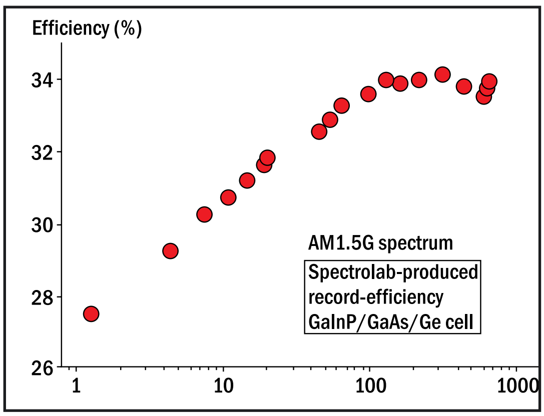

Figure 3 Efficiency under concentration for Spectrolab's GaInP/GaAs/Ge solar cell


Figure 4 A 5-kilowatt point-focus Sterling engine concentrator system. (Cummins Power Generation, Inc. /PIX01730)


Figure 5 5200-sun, point-focus concentrator for a solar furnace. (Sandia National Laboratories/PIX01728)


Figure 6 300-kilowatt linear concentrators. (Tom Lances - Austin American Statesman/PIX00014)

cell systems. By dramatically increasing the total power produced by a given solar cell 100–1200 fold, the increased cost of that cell is more readily justified. In addition, high solar concentrations actually work to improve the performance of the multijunction solar cells *(Figure 3)* indicates for the GaInP/GaAs/Ge cell).

Concentrator systems are varied and generally scalable. For example, the point-focus system shown in *Figure 4* is a smaller system appropriate for a home. *Figure 5* depicts a 5200-sun concentrator appropriate for large-scale energy production. *Figure 6* depicts a linear concentrator system in Austin, Texas. All these systems represent one that might be used in conjunction with multijunction solar cells.

NREL, United States of America is presently funding Amonix, a manufacturer of high-concentration PV systems, and Spectrolab to improve their close-packed array designs specifically for the multijunction solar cells.

Till date concentrator systems have been both costly and complicated. Optics and support structure related cost increases further with the increase in the concentrations. However, such systems still hold promise as a viable clean energy alternative with further development and economies of scale likely to reduce costs.

Triple-Junction GaInP/GaAs/Ge Solar Cell

The GaInP, GaAs, and Ge layers of NREL's record-setting triple-junction solar cell *(Figure 7)* were selected because of their collective ability to match band gap energies with the solar spectrum *(Figure 8)*. GaInP, with band gap energy of 1.85 eV, absorbs the photons in the ultraviolet and visible part of the solar spectrum. GaAs (E = 1.42 eV) absorbs near-infrared light, and Ge absorbs all the lower photon energies in the infrared that are above 0.67 eV.

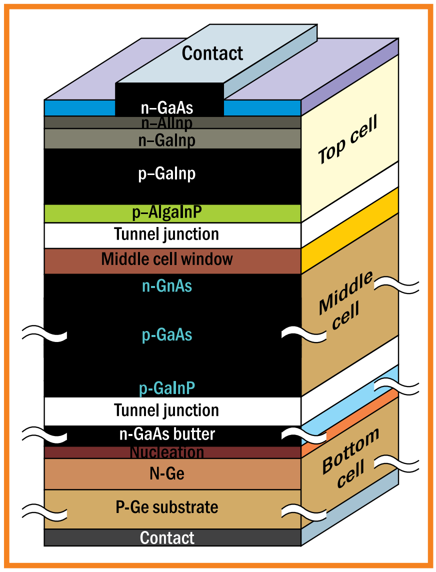

Figure 7 GaInP /GaAs /Ge triple-junction solar cell

In addition, these three semiconductors were selected because they are lattice matched with one another. An alternative to GaInP, with similar lattice constant and band gap energy, is Al0.37 Ga0.63As. However, high sensitivity to oxygen and water contamination makes Al0.37Ga0.63As an undesirable choice.

Each layer's thickness was selected to best match currents with the other two cells. Two versions of such a current-matched solar cell exist—one to best match the greater amounts of high-energy photons in space, and one with a thicker top cell for terrestrial applications.

The GaInP/GaAs/Ge solar cell is monolithically grown, which means that each of the twenty semiconductor layers were grown in situ. The alternative – a physical stacking of independently grown layers – has been accomplished by others with comparable efficiencies. But the bulkiness, additional expense, and heat-sinking challenges make mechanically stacked multijunction cells a less-desirable alternative.

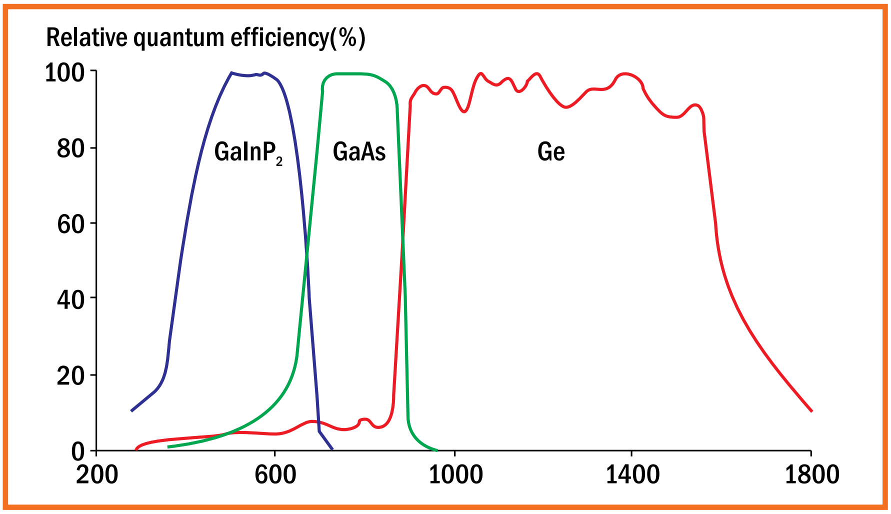

Figure 8 Quantum efficiency of each layer of the GaInP/GaAs/Ge triple-junction solar cell

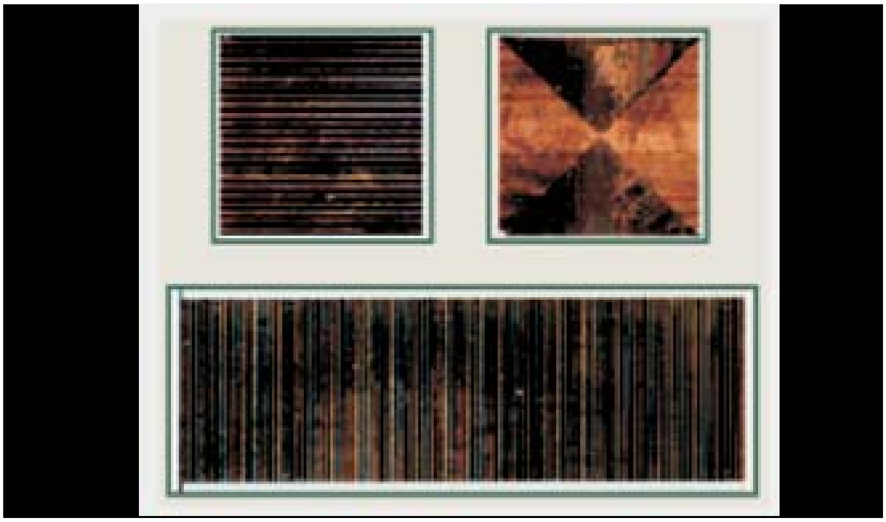

Figure 9 Spectrolab's production version of the GaInP/GaAs/Ge solar cel

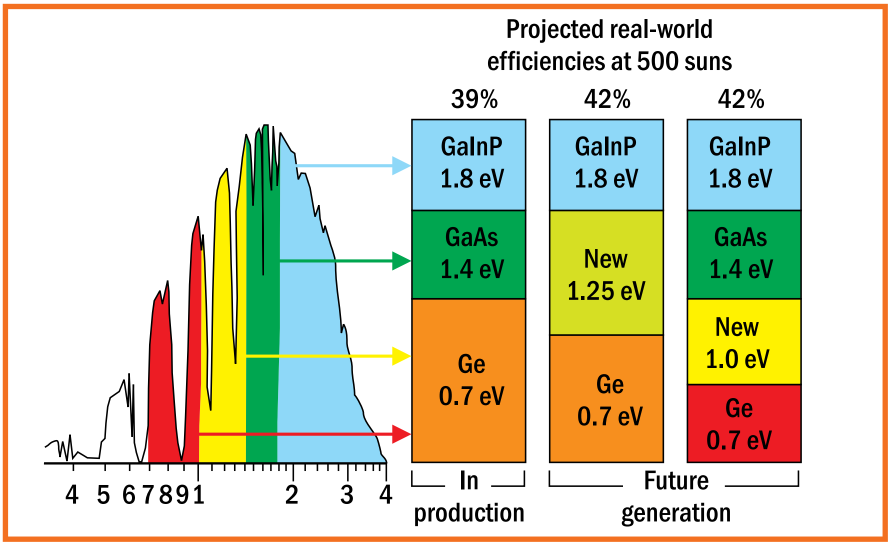

Figure 10 Projected real-world 500-sun concentrator efficiencies of multijunction designs

The result is a cell that achieves an efficiency of 34% under high concentration. NREL licensed this design to Spectrolab, Inc. and to EMCORE, the two manufacturers of space solar cells in the United States. The design is now being developed for terrestrial concentrator systems.

Spectrolab's production version of NREL's record-breaking GaInP/ GaAs/Ge triple-junction *Figure 9* Spectrolab's production version of the GaInP/GaAs/Ge solar cell solar cell is shown in *Figure 9*.

Current research and the future of multijunction cells

The Ge layer of the GaInP/GaAs/Ge triple-junction cell absorbs a larger proportion of solar spectrum photons than is ideal for current matching of the three layers. By replacing the GaAs layer with a 1.25-eV band gap material, this second layer could collect a larger current, while reducing the number of photons transmitted to the germanium layer. The top GaInP layer would be thickened to increase its current production. And overall, the multijunction device would generate a higher matched current, and thus, more power.

The next generation of multijunction solar cells may have four layers. The most direct path to such an achievement is to develop a 1.0-eV band gap material that is lattice matched with the GaInP, GaAs, and Ge of the present triple-junction solar cell. The theoretical results of such efforts are summarized in *Figure 10*.

The economic viability and competitiveness of multijunction solar cell systems will continue to improve over the period of time. Process technologies, particularly techniques with commercial scalability, can be expected to progress, as will designers' understanding of materials behaviour. Material costs are expected to decline as demand grows for solar cell technologies. The final goal is a multijunction solar cell with an efficiency exceeding 40%, and energy costs from such a device below 30% per watt at 300–500 suns.

Taking forward India's solar mission

The future of solar photovoltaic development in India seems to be very bright. The Jawaharlal Nehru National Solar Mission is a major initiative of the Government of India to address India's energy security challenge and promote sustainable growth. In an interview with *Dr Suneel Deambi and Arani Sinha, Dr EVR Sastry, former Advisor of the Solar Energy Centre at MNRE*, shares his views and vision about India's solar energy and other renewable energy sectors.

From 1993–95, Dr EVR Sastry, was the Advisor of the Solar Energy Centre at the MNRE. He has been involved with the development of photovoltaic technology in the country since its early stages and has contributed immensely towards its growth. Dr Sastry was member of numerous national and international committees. He was a member of the UN Committee on New and Renewable Sources of Energy and was elected as its Chairman in 1996. Presently, Dr Sastry works in the capacity of a Senior Adviser at the Centre for Energy Technology, Osmania University, Hyderabad.