The SOLAR QUARTERLY

The Complete Solar Magazine

Volume 2 • Issue 2 • January 2010

Rs 200

LIGHTING UP CAMBODIA
The solar way

MEETING EHS CONCERNS IN SPV

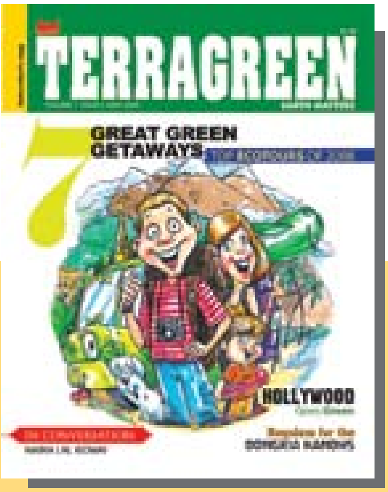
SOLECKSHAW
Status and vision

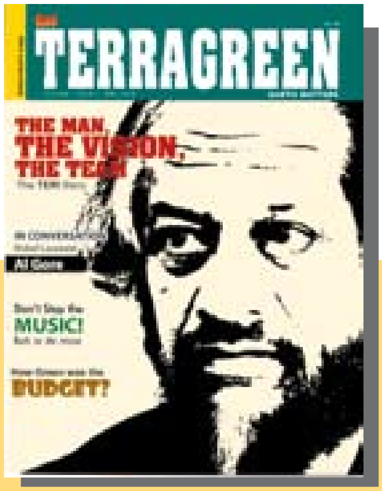
SOLAR-WIND HYBRID TECHNOLOGY
for electrification in hilly regions of Haryana

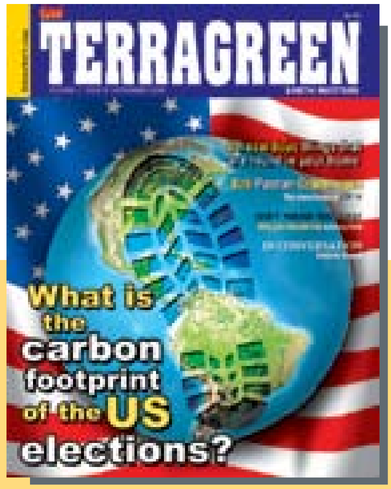
teri

TERRAGREEN

Earth matters







TERI's flagship monthly magazine – *TerraGreen* – is dedicated to disseminating information on issues of environment, energy, and sustainable development. Launched in 2004, *TerraGreen* has made an indelible impression on the minds of readers both in India and across the world. Today, it enjoys a readership of over 25000 and a subscriber base of close to 7000. Not only does *TerraGreen* focus on issues of crucial importance, it presents in-depth analysis of major environmental developments from around the world in crisp and simple language. Aimed at the common man the magazine stays away from all jargon and provides necessary knowledge and information. The rather vast coverage of issues makes the magazine one of its kind in the market—a gap it has filled with great panache.

New subscription rates for TerraGreen

Term (Yrs)	No. of Issues	Cover Price		You Pay		You Save		% Saving
		Rs	US$	Rs	US$	Rs	US$	
1	12	480	120	400	102	80	18	17%
2	24	960	240	750	192	210	48	22%
3	36	1440	360	1000	252	440	108	30%

Overseas subscriptions are accepted only in US Dollars.

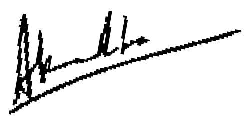
Mail to **TERI**
Attn: TERI Press
Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003, India
Tel.: +91 11 2468 2100, +91 11 4150 4900 • Fax: +91 11 2468 2144, +91 11 2468 2145
E-mail: teripress@teri.res.in
To advertise, contact: Binita Singh, e-mail binitas@teri.res.in

Buy online at http://bookstore.terriin.org

Let us usher in the New Year with a strong commitment to establish India as the world leader in solar energy. The Jawaharlal Nehru National Solar Mission aims at creating policy conditions and an environment for solar energy to penetrate into the country at both centralized and decentralized level. One of the most promising aspects of the National Solar Mission is its recognition of opportunities within and the relevance of the off-grid and decentralized sector. Within this sector, lighting is considered as one of the most critical applications that solar energy should target. Electrification, particularly lighting, as the first and a crucial step towards socio-economic betterment of rural communities, offers a large untapped market for solar entrepreneurship. There have been a few noteworthy initiatives in solar lighting in the recent past, and this sector is expected to grow in near future. However, the challenge would be to bring in the advantages of the latest technological and scientific developments in lighting, energy storage, and related areas in a cost-effective and reliable manner to the rural communities. The other dimension of this challenge would be the financing and distribution channels which would not only require innovative thinking and approaches, but also strategic alliances with other initiatives. The solar-cum-social entrepreneurship is likely to be more visible and expand further this year, possibly even beyond the national boundaries.

The National Solar Mission will facilitate other niche markets for the decentralized solar energy. *The Solar Quarterly* will bring its own analysis of these opportunities in the forthcoming issues.

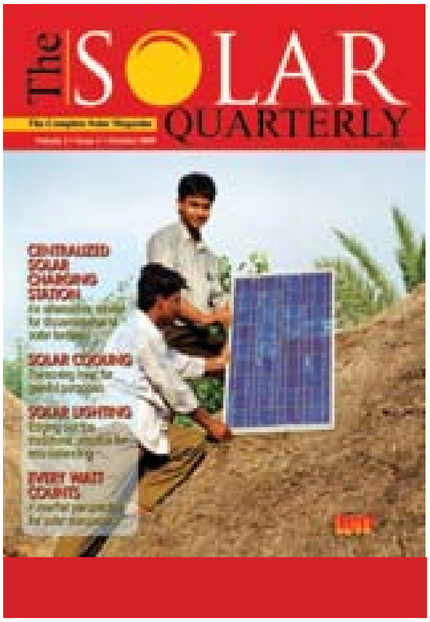
Wish you all a very happy New Year!



Akanksha Chaurey
Director, TERI

Owned, printed, and published by Dr R K Pachauri from The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003, Tel. +91 (11) 2468 2100 or 2468 2111, E-mail teripress@teri.res.in, Fax +91 (11) 2468 2144 or 2468 2145, Web www.teriin.org/pub, and printed by him at Batra Art Press, A-41, Naraina Industrial Area, Phase-II, New Delhi – 110028.

Letters to editor



I have received the last two issues of *The Solar Quarterly* magazine. I have found the articles quite informative and interesting. TERI (The Energy and Resources Institute) is doing a great job in disseminating the technology details and latest developments in the field of Renewable Energy through this magazine. This magazine has filled the vacuum and lack of information sharing in the field of renewable energy.

Sumita Misra,
Director-HAREDA

I am a regular reader of *The Solar Quarterly* magazine. I really liked the new section titled 'from the archives'. It gives a feeling of yesteryear and is a very informative section. I also like the way the article has been presented in this section.
Keep up the good work

Rakesh Sharma
New Delhi

The Solar Quarterly magazine is doing a wonderful job by disseminating information in the field of solar energy. The October issue was very interesting and informative. I particularly like S Jayachandra Naidu's article titled 'Operational Features of a Grid-Connected Photovoltaic System'. I think the editorial team should include more articles based on the Mtech thesis of researchers and professionals. It not only gives them a boost, but also helps us to know about the current and on going researches in this field.

Neha Kapur
Kolkata

I am a regular subscriber of *The Solar Quarterly* magazine. In last one year, the magazine has really evolved. Not only have the pages increased, because of which we have the opportunity to read more informative articles, but the contennt of the magazine has also improved. The USP of this magazine is that within the solar energy field, it includes various kinds of articles. This gives the readers a wide range of information.
All the best for your future issues.

Rakesk Kumar
Ludhiana

I am a regular subscriber of *The Solar Quarterly* magazine. As far as the content of the magazine is concerned, the editorial team is doing a great job. However, I fully agree with one of the letters that appeared in the last issue, that the number and size of the pictures need to reduce in the magazine. Hope the editorial team will work in this direction.

Suneet Rao
Patna

This is my first letter to *The Solar Quarterly*, although I have been reading it for quite some time now. I must say that the magazine is extremely informative for researchers, professors, students, and all those who want to know about the power and possibilities of solar energy technologies. The October 2009 issue of the magazine, too, was brilliant. The article on centralized solar charging station was very interesting. We must explore ways and means to reach out to the far-flung regions of India by all means and this seems to be a great alterative. The article on solar cooling was again very educating. From the very basic, it covered all the technical aspects of the process. Similarly, the other articles are also very good. However, the photograph on the cover was very different from the usual TSQ ones. It failed to grab my attention, which of course was taken care of by the articles. Kudos to the TSQ team and the authors!

Neharika Singh
Delhi

Thank you very much for your encouragement. The editorial team of *The Solar Quarterly* will make every effort to make this magazine highly informative and useful to all our readers. We welcome your suggestions and valuable comments to make further improvement in terms of content and presentation.

Editor
The Solar Quarterly

Contents

VOLUME 2 • ISSUE 2 • January 2010

4 NEWS

- Italy's solar power capacity rises to 700 MW
- Solar power 50% cheaper by year end
- India: 20 Gigawatt Solar by 2022
- NREL and Schott developing new solar receiver tube coating
- First Solar Sells 21-MW California Project to NRG
- Mitsubishi Electric supplies solar panels to 3MW roof top installation
- Thin-film market share doubling in four years
- DOW(TM) POWERHOUSE(TM) Solar Shingle Named a Best Invention of 2009 by TIME Magazine
- China to subsidize 294 solar power plants
- Andhra Pradesh to develop a new kind of Solar City

8 FEATURE

- Lighting up Cambodia: the solar way **8**
- Meeting EHS concerns in SPV **14**
- Soleckshaw: status and vision **22**
- Electrifying the sun soaked sand **30**
- Solar-wind hybrid technology for electrification in hilly regions of Haryana **38**
- Demonstrating natural energy far and wide **42**
- The efficiency race **47**
- Smart financing ideas for small solar lighting systems **50**
- Green Schools: a first person account of experience with school children **54**
- Multijunction cells: still a designer's challenge **56**

60 INTERVIEW

- Taking forward India's solar mission **60**
  Dr EVR Sastry, former Advisor of the Solar Energy Centre at MNRE

- Taking renewable to the masses **64**
  Shailendra Shukla, Director, CREDA

68 FROM THE ARCHIVES

- Decentralized V Grid Electricity for Rural India

74 CURRENT RESEARCH AND DEVELOPMENT

76 TECHNICAL CORNER

80 UNIVERSITY FOCUS

- Renewable Energy Research at the University of Oslo

85 EXPERT SPEAK

86 LEARNING PACKAGES

- Solar Passive Design by Ecotect

90 PRODUCT UPDATE

- Freeplay–LaBL Lantern

91 BOOK REVIEW

92 WEB UPDATE

93 BOOK ALERT

94 EVENTS CALENDAR

95 INDUSTRY REGISTRY

96 RE STATISTICS

Italy's solar power capacity rises to 700 MW

According to GSE (government sponsored enterprizes), the state-run energy management agency, Italy's total capacity of the PV (photovoltaic) installations that turn sunlight into power has risen to 700.7 MW from 650 MW a month ago. The number of PV installations on stream in Italy, a major solar power market in Europe, rose to 56 285 from about 53 000, GSE said in an update on the sector. Italy may well reach a total PV installed capacity of 800 MW by the end of this year and hit 1 200 MW by the summer of 2010, Gert Gremes, Chairman of Italy's PV association GIFI (Gruppo Imprese Fotovoltaiche Italiane) told Reuters. PV installations mushroomed in Italy from about 22 MW in early 2007 after the government launched a new incentive plan that was among the most generous in Europe. The government intends to cut incentives to ease the budget burden.

Source: solarplaza.com

Solar power 50% cheaper by year end

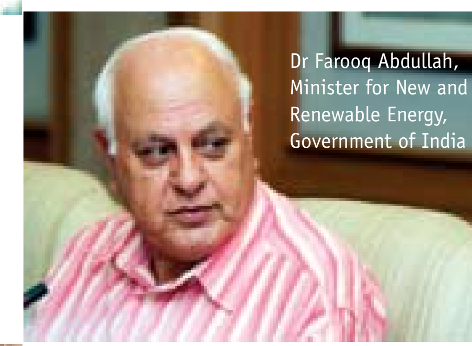
By the end of 2009, there will have been a 50% drop in the levelized cost – the lifetime cost per kWh before subsidies – of solar power, and a 10% reduction in the levelized cost of other sources of renewable energy sectors compared to the end of 2008, according to new analysis by the New Energy Finance. 'So far this year, the steady decline in the cost of equipment in sectors like solar and wind has been largely offset by the increasing costs of financing,' said Michael Liebreich, Chairman and Chief Executive Officer of New Energy Finance. 'By the end of this year, however, as capital markets loosen up and equipment prices continue their decline, we will see the levelized costs decline, finishing the year 10% below the end of last year across the board and far more than that in solar.' PV module prices across the board have continued their downward trend, although the rate of decline has tapered. Thin-film remains the low-cost leader in solar with projects as cheap as $3/W, making thin-film projects 25% less expensive than crystalline silicon systems on a levelized basis.


Michael Liebreich, Chairman and Chief Executive Officer of New Energy Finance

Source: solarplaza.com

India: 20 gigawatt solar by the year 2022

Dr Farooq Abdullah, Union Minister for New and Renewable Energy, in a statement in the Parliament on 23 November 2009 said that 'the government has approved a new policy on development of solar energy in the country by launching of the Jawaharlal Nehru National Solar Mission.' This was an official statement by the MNRE (Ministry of New and Renewable Energy). This is a historic and transformational initiative of the UPA (United Progressive Alliance) Government, and I am proud to have the privilege of being assigned the task of overseeing its implementation. The Solar Mission is very much in line with Pandit Nehru's vision of modern India, which has made India, a leading nuclear and space power. Solar energy provides a long term sustainable solution. The Solar Mission recommends the implementation in three stages leading up to an installed capacity of 20 000 MW by the end of the 13th Five-year Plan in 2022. It is envisaged that as a result of rapid scale up as well as technological developments, the price of solar power will attain parity with grid power at the end of the Mission, enabling accelerated and large-scale


Dr Farooq Abdullah, Minister for New and Renewable Energy, Government of India

expansion thereafter. During this time, we expect many new ideas to emerge and technologies to become more efficient. Quite obviously, in order to set the stage for achieving this ambitious target, what we do in the next 3–4 years will be critical. Therefore, the cabinet has approved the setting up of 1 100 MW of grid solar power and 200 MW capacity of off-grid solar applications utilizing both solar thermal and photovoltaic technologies in the first phase of the Mission.

Source: Solarplaza.com

NREL and Schott developing a new type of solar receiver tube coating

NREL (National Renewable Energy Laboratory) has selected Schott Solar Inc. as a partner to develop improved absorber coating for CSP (concentrating solar power) receivers. The project will be partially funded by NREL's TCDF (Technology Commercialization and Deployment Fund). NREL and Schott signed CRADA (Cooperative Research and Development Agreement) to collaborate on this project. The new absorptive coating would be applied to the inner steel tube of parabolic trough receivers, which sit at the focal point of parabolic mirrors in utility-scale solar power plants.

NREL originally solicited potential partners through the posting of a Federal Business Opportunity. Schott Solar was selected from the more than ten respondents to the business opportunity notice. 'The nation must include concentrating solar power at a utility scale as part of its portfolio of technologies to meet our clean energy goals,' said Dan Arvizu, Director, NREL. 'This partnership with Schott Solar reflects NREL's mission to accelerate cost-competitive clean energy innovations into the marketplace.' The project will be partially funded by NREL's TCDF (Technology Commercialization and Deployment Fund). The Energy Efficiency and Renewable Energy office in The Department of Energy created the TCDF programme to accelerate the commercialization of laboratory technologies.

Source: Renewableenergyworld.com

First Solar Sells 21 MW California Project to NRG

First Solar Inc. announced the sale of the 21 MW solar energy project, it has developed and constructed in Blythe, California, to NRG Energy Inc. Located in Riverside County about 200 miles east of Los Angeles, the Blythe project is California's first and largest utility-scale PV (photovoltaic) solar generation facility, and among the largest in North America. First Solar will provide operations and maintenance services at Blythe under a long-term contract with NRG. Construction began in September and is expected to be completed by year-end. Electricity from the plant will be sold to Southern California Edison under a 20-year power purchase agreement.

'First Solar is very pleased that the first of our utility-scale solar projects in California will be coming on line with a leading power producer like NRG,' said Bruce Sohn, president of First Solar. 'This clean, affordable, and sustainable energy will help California meet the goals of its Renewable Portfolio Standard.' Using First Solar's thin-film PV panels, the project is expected to generate more than 45 000 MW-hours of electricity per year. The construction of this project created 175 jobs. First Solar will provide operations and maintenance services at Blythe under a long-term contract with

NRG. Financial terms of the agreement were not disclosed.

Source: Renewableenergyworld.com

Mitsubishi Electric supplies solar panels to 3 MW roof top installation

Mitsubishi Electric has completed a 2 906 kW PV installation for Coop's new CNNA-Prato logistic centre in Prato, Italy. Of the 15 710 lead-free solder PV modules used for the 2 906 kW system, 15 650 modules (2 895 kW) have been installed on the warehouse roof, covering a surface area of 21 000 sq m, equivalent to five soccer fields. The system will reduce dependence on non-renewable energy, and is expected to generate 3.2 million kWh per year, which will not only completely meet the energy needs of the new logistic centre, but will also generate an estimated amount of 500 000 kWh excess electricity that will be transferred to the national distribution network.

The 2 895 kW installation on the warehouse roof has become the largest rooftop PV system on a single building in Italy. The warehouse roof was specially designed for PV installations, given that rooftop installations in Italy receive a higher feed-in-tariff rate than those on the ground, and effectively use space. In addition to the 2 895 kW rooftop system, an 11 kW system of 60 PV modules has been installed on the parking lot grounds.

Separately, in January 2010, Mitsubishi Electric will launch its new product lineup of high-output lead-free solder PV modules with outputs of up to 235 W. By utilizing these products and also expanding its product lineup in the future, Mitsubishi Electric intends to further strengthen its overseas PV business.

Source: Solarbuzz.com

Thin-film market share doubling in four years

With prices plummeting and production soaring, thin-film solar PV (photovoltaic) cells are poised to snatch business from leading c-SI (crystalline silicon) solar PV in the next few years, taking nearly a third of the market by 2013, according to a report from iSuppli. The success of First Solar – tops in the world with >1GW of solar power production, with production costs ($0.90) half those of c-Si module producers – has paved the way for the entire thin-film sector to take off, notes Greg Sheppard, Chief Research Officer, iSuppli. Average thin-film panel prices are expected to drop nearly 18% in 2010 to $1.40; c-Si panels will drop about 20% to $2.00, and will continue to close the gap as the sector uses its deeper pockets to spend more on tech R&D and manufacturing improvements, the firm says. Thin-film panels deposit layers only a few µm thick on a substrate, vs. thickness of hundreds of µm for polysilicon solar wafers.

That is part of the tradeoff—the manufacturing cost of thin-film is very less, but conversion efficiency is lower than silicon PV, and requires more (and costs 15%–40% more) for space-limited rooftop installations. Thin-film, though, is working on closing that gap, from about 10% now to lab results in the mid-teens, thanks to stacked (tandem and triple) junctions that can absorb more light spectrum with different materials. New variants of deposition processes (inkjet printing) help materials to deposit quickly than the variants of chemical-vapour deposition/screen printing.

Source: iSuppli

DOW(TM) POWERHOUSE(TM) Solar Shingle named the best invention of 2009 by TIME Magazine

The Dow Chemical Company's (NYSE: DOW) DOW(TM) POWERHOUSE(TM) Solar Shingle, the revolutionary flexible photovoltaic solar cell packaged in the form of a roofing shingle that can be easily integrated with standard asphalt shingle materials, has been named as one of 'The 50 Best Inventions of 2009' by TIME magazine. 'The introduction of the DOW(TM) POWERHOUSE(TM) Solar Shingle exemplifies Dow's commitment to deliver innovative solutions to the world's most critical challenges,' said Jane Palmieri, Managing Director, Dow Solar Solutions.

'This groundbreaking technology will make affordable renewable energy a reality now and for future generations. Dow is proud to be recognized by TIME magazine—a strong testimonial to the power of our chemistry and science to deliver sustainable solutions.' The DOW(TM) POWERHOUSE(TM) Solar Shingle integrates low-cost, thin-film CIGS

PV cells into a proprietary roofing shingle design, which represents a multi-functional solar energy generating roofing product. The innovative product design reduces installation costs because conventional roofing shingles and solar generating shingles are installed simultaneously by roofing contractors—no specialized skills or knowledge of solar array installations are required.

Additionally, Dow and Caltech (California Institute of Technology) recently announced the signing of a multi-year research collaboration that is strategic to both organizations' interests in solar energy. The arrangement is aimed at developing the next generation of ultra low cost, high-efficiency photovoltaic materials and will accelerate the speed to market for these next generation materials. Based on the Earth's abundant elements, these new PV materials should further reduce the cost of Dow's building integrated photovoltaic line, including the DOW(TM) POWERHOUSE(TM) Solar Shingle. 'Products like the DOW(TM) POWERHOUSE(TM) Solar Shingle demonstrate what the innovation engine of the new Dow can do,' said David Parrillo, Senior R&D Director for Dow Solar Solutions. 'Dow's innovation pipeline is robust and will allow us to continue to develop new building related PV materials and solutions. The collaboration with Caltech is projected to keep affordability and accessibility at the forefront of Dow's solar PV product lines and is another example of how Dow's leadership and innovation will further unlock the power of the Sun for the masses.' The DOW(TM) POWERHOUSE(TM) Solar Shingle systems are expected to be available in limited quantities by mid-2010 and projected to be more widely available in 2011, putting the power of solar electricity generation directly and conveniently in the hands of homeowners.

Source: dowsolar.com

China to subsidize 294 solar power plants

China has chosen 294 solar power projects, which will produce a total generation capacity of 642 MW, for its first pilot programme wherein it will subsidize at least half of the investment cost. Reuters reports that the expected total cost will be about 20 billion Yuan and should be in production within the next 2–3 years as stated by the Chinese Ministry of Finance. 232 projects will have a capacity of 290 MW and be constructed by industrial and commercial firms with the output consumed by them. 27 PV projects, with a capacity of 46 MW, are to be built in regions that currently have no power supply and will be able to generate enough power for 300 000 residents in the regions. The final 35 projects will total 306 MW and will be utility-scale plants with the power output being fed into grid networks.

The Ministry said it would subsidize 50% of the investment for the solar projects as well as relevant power transmission and distribution systems that connect the grid networks. They also arranged specific price and quality requirements for parts and components for the qualified projects. Reuters concluded that China will be raising its 2020 solar power generation target to 10 GW and with incentives, over 2 GW in new solar capacity could be installed by 2011.

Source: reuters.com

Andhra Pradesh to develop a new kind of solar city

In an effort to develop Andhra Pradesh as the solar hub of the country, Chief Minister, K Rosaiah, announced that Kadiri in Anantapur district will be developed as a cluster of solar farms and named it as 'Solar City'. This development comes on back of the Fab City—the other major initiative of the AP government to promote green energy. Speaking at the inaugural session of Solar India 2009, a three day event at Hyderabad Rosaiah said, 'Andhra Pradesh will be the future capital of solar energy in India. The National Solar Mission will drive down the costs and the state would soon announce a special policy for solar complementing the national policy for development of solar in the state.' He gave allotment letters for solar city to four companies including Sunbrone Inc, AES Solar (both from USA), Lanco Solar, and Titan Energy (two from India). These companies propose to set up 2000 MW of solar based power generation facilities in the solar city. This would envisage an investment of Rs 300 billion considering the average cost per MW being Rs 150 million. Allotment letter was also given to Moser Baer for development of manufacturing unit at Fab City.

Source : Solar India Online

LIGHTING UP CAMBODIA – THE SOLAR WAY

DEBAJIT PALIT, Fellow, TERI, <debajitp@teri.res.in>
VARUN GAUR, Research Associate, TERI, <varung@teri.res.in>

Facing the challenge

Cambodia is a tropical South East Asian country located in the lower Mekong region. The physical landscape is dominated by lowland plains around the Mekong River and the Tonle Sap Lake, the largest lake in South East Asia. Years of conflict in the country resulted in irreversible damage, devastation, and degradation of its developmental capacities. Incidentally, the country with a population of approximately 14 million, finds itself classified as LDC (Least Developed Country). In the last few years, it has geared up to the challenge of reconstruction, sustained economic development and importantly, integration with the global community. A priority goal of the Royal Government of Cambodia is its commitment to reduce poverty throughout the kingdom. The underlying strategy to accomplish this objective is the development of sustainable and affordable energy supplies for all its constituents.

The Working Group on Solar Lanterns, led by TERI (The Energy and Resources Institute) under the E4All (Energy for All) Partnership Programme of ADB (Asian Development Bank) recently conducted a scoping study in Cambodia to understand the existing electrification and lighting scenario especially off-grid lighting in the country. The wholesome purpose is also to identify the solar based off-grid lighting opportunities, which has

the potential for scaling up within Cambodia and the South East Asian region. This article is based on the results of the scoping study. The article also highlights the scope of LaBL (Lighting a Billion Lives) campaign as a vehicle to improve access to lighting in the rural and peri-urban areas of Cambodia. The LaBL campaign launched in February 2008 by TERI aims to bring light into the lives of one billion rural people by displacing kerosene lamps and paraffin candles with solar lighting devices.

Batteries-charging more for power

Cambodia's power supply facilities despite having significantly improved since the war years with support from international aid and foreign-funded private sector projects, covers only about 20% of its total population. Of this, approximately 13% is served by EdC (Electricite du Cambodge), which is the national electricity supplying company. It essentially covers the capital city Phon Penh and other provincial towns and cities. Apart from EdC, about 3% of the population is served by REEs (Rural Electricity Entrepreneurs), licensed by the government, and 4.0% by non licensed REEs. The REEs set up mini-grids with typically one or two small, old diesel generators, and distribute electricity to

Battery charging stations – lighting up the rural Cambodia

Box 1

Between 50% and 75% of Cambodia's rural areas get access to electricity by batteries. The communities buy the batteries and get them recharged by a local entrepreneur in the village. Each battery charging station uses old diesel gensets and on average charge 50–80 batteries a day, with an average charging time of 5–7 hours. The pollution generated by the genset is high and battery disposal is erratic. Each of such battery charging stations cater to 2–3 villages.

The type of batteries is shallow cycle lead acid, which is normally designed and used for vehicles. The sizes of batteries are 40 Ah, 70 Ah, 100 Ah, and 4.5 Ah. Batteries are used to supply electricity for home lighting and to run television, video, and so on. In general, 40 Ah battery is used for home lighting, 70 Ah for lighting and running television, and 100 Ah for running TV and VCD/DVD sets in addition to lights. Small size batteries are often used for a head lamp to catch frogs, birds, insects, and so on. The price for recharge varies from 1000 Rials (0.25 US$) for a 40 Ah battery to 2000 Rials (0.5 US$) for a battery of 100 Ah. The batteries are usually recharged at an interval of 2–3 days depending on the usage pattern. The batteries are imported from China, Thailand, and Vietnam by distributors and sold across the country.

the local households. The electricity is supplied for limited time (often in the evening) through small networks (low-voltage distribution lines). It is generally used to run 2 CFL lights and a television. It is reported that there are about 600–1000 REEs meeting different power services for an estimated 60 000 rural households. A major part of the population either do not see light after the Sun set or are dependent on the kerosene lamps or use rechargeable car batteries for lighting and entertainment purposes. Tens of thousands of people in the countryside bring their 40–100 Ah capacity batteries to a BCS (battery charging station) once or twice a week. They have also learnt the effective utilization of the battery and threat in the event of its complete discharge. (*Box1*).

Small is not always beautiful

At the heart of the problem is Cambodia's lack of a national power grid, which puts the prerogative to supply power in the hands of dozens of small, private power producers operating in a loosely regulated system. The country currently has 24 isolated systems with no interconnection between the load centres. All are fully reliant on diesel power plants except for the two hydro power stations.

As per the report on the power sector of the Kingdom of Cambodia for the year 2007, the total installed capacity in Cambodia is about 314 MW. In addition, almost 104 MW of power is also imported across the border from Thailand and Vietnam through privately-owned medium voltage transmission lines and government owned lines. With increase in the number of manufacturing units and more households being connected to the electricity grid, energy demand is expected to grow at the rate of 3.7% per year between now and 2030, according to a report recently released by the ADB and APEC (Asia-Pacific Economic Cooperation). This will further aggravate the already energy deficit scenario, if adequate generation capacity is not added to the current installed capacity.

Further, the electricity prices in Cambodia are highest in the region and perhaps in global comparison too (*Figure 1*). The tariff is about 10–20 cents/kWh in EdC's grid and 30–90 cents/kWh in rural areas served by the REEs. This can be partly attributed to the large use of aging small generators, reliance on fully imported diesel fuel, and huge losses in low quality medium voltage distribution systems. Those who use batteries for lighting and other applications pay the most, at about 95–100 cents/kWh.

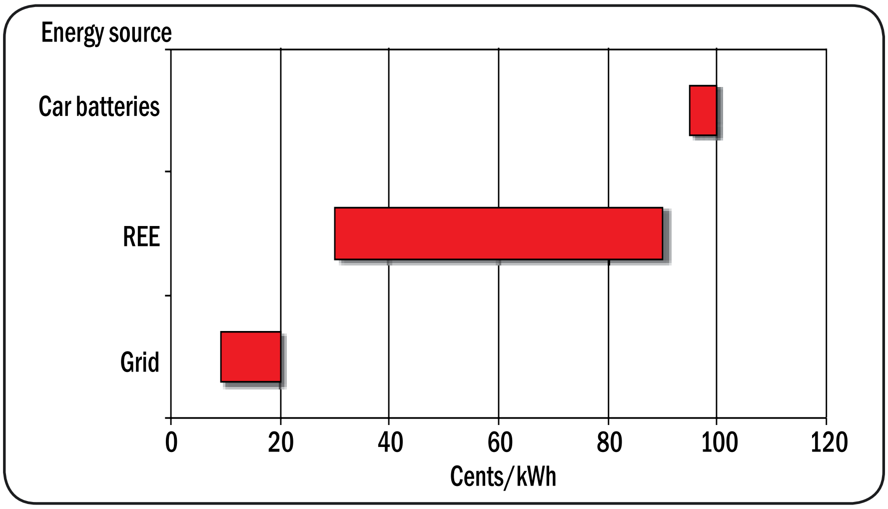


Figure 1 Cost of electricity from various sources
Source: Master Plan Study on Rural Electrification by renewable energy in the Kingdom of Cambodia, 2006

Solar energy-gearing up for the challenge

TERI study identified that the market for solar PV is very relevant for Cambodia, because of the use of huge number of decentralized off-grid applications especially the BCS. With high solar radiation in most parts of the country, there is a huge potential of solar as an alternative energy source. A PRESSEA (Promotion of Renewable Energy Sources in Southeast Asia) study shares that the country has an excellent potential for solar PV power generation with an average sunshine duration of 6–8 hours per day and solar radiation levels averaging at 5 kWh/m^2/day. Solar radiation increases gradually from the North West of the country with an average low of about 4.11 kWh/m^2 to the South West of the country with an average high of 5.23 kWh/m^2 .

The country has some experience of using solar technology albeit on a limited scale. The local use of PV systems was initiated almost a decade back with a few installations donated by UNICEF, the Red Cross, FONDEM (La Fondation Énergies Pour Le Monde), and NEDO (New Energy and Industrial Technology Development Organization). Although most of the applications were for health and rehabilitation centres, yet SHS (solar home systems) and lighting systems were also installed as demonstration units. Currently, the total installed capacity of PV installations in Cambodia is little more than 1 MW with almost 90% of the installations deployed for telecommunication use. Adaptive research has also been undertaken by MIME (Ministry of Industry, Mines, and Energy) to reduce the high cost of PV systems, and creating the necessary infrastructure to repair and maintain these systems in the long run. MIME developed a 12 V, 10 A charge controller with automatic high- and low-voltage cut-off options. These charge controllers also included an LED (light emitting diodes) to indicate the charging status of a battery. The charge controller technology developed under the programme was transfered to MIME/DET (MIME's Department of Energy Technique), which manufactured the charge controllers and installed the same in various demonstration projects funded by the government. Use of these charge controllers helped to reduce the price of PV systems, and it also ensured availability of spare parts and after-sales service. However, the initiative was not institutionalized, and thus was limited to the demonstration value only.

Some of the major solar PV companies currently operating in Cambodia are Khmer Solar Ltd, Metrofield Engineering Company Ltd, KCB Group, Kamworks Ltd, and Comin Khmere Co Ltd. Khemer Solar shared that the current cost of PV modules in the country is about 4–5 USD/Wp. These modules are generally imported from Thailand, China, and Japan. The suppliers reveal that most of the SHS systems are installed in the residential sector with 80 Wp capacity modules. An 80 Wp SHS, which consists of 80 Wp solar module, 80 Ah battersy along with 5 CFL and 1 point for TV/Fan generally costs about 700 USD. Whereas, a 40 Wp SHS costs about 400 USD.

Solar energy programmes-inside out

Rural electrification fund

The government is implementing REF (Rural Electrification Fund) project which is part of RE&T (Rural Electrification and Transmission) project, funded by the World Bank. Under the project, REF has been providing grant assistance of USD 100 per SHS to selected solar companies for the installation of 12 000 SHS (with a minimum installed module capacity of 40 Wp) in rural areas of the country. The purpose of providing the grant assistance was to encourage these companies to reduce their per unit capital cost of SHS so that the price of SHS becomes affordable to rural households and to facilitate an access to electricity where the electricity network has not yet reached. However, as only 1 300 SHS's out of the targeted 12 000 systems were put up, the SHS programme has recently been revised. The REF will now bulk purchase the SHS and undertake the installation of SHS at the rural households through approved suppliers. The beneficiary households will make down payment of 20% of the cost of the SHS and the balance repaid in instalments within a time period of up to five years. REF will pay a service charge to local service companies for maintenance of the SHS and collection of the instalment payment. The intended objective of the REF grant is to reduce the capital investment cost leading to a lower retail cost of power in the rural areas.

LED lanterns projects – a new trend for lighting

Although, majority of the Cambodian people satisfy their lighting needs via use of diesel based mini-grids or batteries, yet, lately, there have been a few lighting initiatives based on the use of LEDs. However, these initiatives are currently at pilot stage only and need further intervention for scaling up. A pilot project on commercialization of LED lanterns in rural areas of Cambodia under WB-ESMAP (World Bank-Energy Sector Management Assistance Programme) project was implemented by RDI (Resource Development International), a non governmental organization working in the rural development sector. The objective of the pilot project was to test and promote innovative business models so as to provide portable LED lanterns to all the social segments in the rural areas of Cambodia. The pilot trials were conducted in four selected districts within Kandal province of Cambodia. RDI imported 2000 LED lanterns (1.5 W LED), 600 solar panels (2.5 Wp), and 1000 batteries connectors (Lead Acid Battery DC Charger) from a company based in China for the pilot project. Chheang Penghorn, Project Manager of RDI mentioned that various payment schemes have been developed under the project with an aim to allow all classes of people to have an access to the technology, and thus give an opportunity to the villagers to choose both the duration and amount of payment as per their financial capacities. These schemes allowed the buyers to purchase the lanterns by paying off the amount in instalments or through the rent to own scheme within appropriate time frame and payment terms in accordance with the purchasing power of end users. Following which, the project took off well with about 1373 LED lanterns sold within seven months through various innovative business schemes with prices ranging from $30–$35 per lantern. However, the RDI initiative is reported to have received a setback due to the poor quality of lanterns used in the project and the lack of after sales service for the lanterns.

Renting out the charge

In yet another project, Eco-Biz, a part of GERES Cambodia, (Groupe Energies Renouvelables, Environnement et Solidarites), is implementing a lantern rental project called the Rural Home Lighting Project. 'By providing an alternative lighting solution at the same cost of operating a kerosene lamp, Eco Biz is confident to provide a safer, cheaper, long lasting, and better quality lights using renewable energy that will translate into a healthier environment', says Ruben Mahendran, Chief Executive Officer, Eco-Biz. Eco-Biz presently operates the project in Kandal and Kampong Chhnang Provinces. Kandal Province has three communes with four villages renting 300 lanterns. The second province, Kampong Chhnang, has two communes with five villages renting about 200 lanterns. A typical package usually consists of 30-50 LED lanterns, two 100 or 50 Ah car batteries, battery

charger, some spare lantern batteries, and lanterns. All the materials are sourced by GERES from its technology partners and then provided to the VO (village operator), who manages the lantern charging and renting business in the village. The cost of a typical package with 50 lanterns is $1375. The lanterns are rented out through the VO who swaps the discharged battery in the lantern with a fully recharged battery for use every fifth day and in lieu collects a rental (7–8 US cents/night/lantern) from the battery user. The VO keeps one-third of his collection as his income and the balance is sent back to Eco-Biz so as to cover the cost on hardware, repairs, replacement, and administration. The project besides providing safe and better quality lighting to the villagers also provides an income generating opportunity for the VO, who manages the battery-powered lantern charging station in the villages.

How the system works

The Rural Home Lighting Project, by GERES has been successful in terms of proving the acceptance of lantern technology and the rental model for its effective dissemination in rural Cambodia. However, it is still dependent on the diesel based BCS to charge its batteries. The VO needs to travel to a distant BCS every alternate day to get the car batteries charged, which are further used for charging the lantern batteries. Further, as batteries of different capacities are charged together for a fixed interval of time from the same source in a BCS, this results in an inefficient charging. Thus, high capacity batteries such as 100 Ah which are being used in the project do not get properly charged, thus reducing the life of the battery.

LaBL: the distant outreach

TERI's flagship programme – LaBL – has successfully demonstrated in India how solar lanterns have impacted the community; be it for lighting or for livelihood generation at the household and village level. The solar lantern, a portable lighting device that uses CFL or LEDs, has its own rechargeable battery that can be charged every day using an 8–10 W panel or in a centralized solar PV charging station. This is an ideal device to light up the Cambodian homes that currently are either dependent on the kerosene lamps or batteries charged from the diesel generators. The impact of the LaBL programme is not simply the provision of lighting in a physical sense, but it is actually an instrument by which lives can be transformed and aspirations generated on a plane that clearly enhances human welfare substantially.

The LaBL model has a high potential in Cambodia for providing the basic lighting services. Quite clearly, lighting is not synonymous with electrification, and which by no means can be equated with energization that includes energy for cooking, irrigation, micro enterprises amongst others. However, it still is one of the primary amenities required by a household to step onto the socio-economic cultural developmental ladder. The LaBL campaign can build on and strengthen the existing delivery and service model of GERES or involve the entrepreneurs to solarize the existing BCS to charge batteries and also rent lanterns to various communities.

Integrating solar PV with the current model of GERES, leaving the existing lanterns untouched could

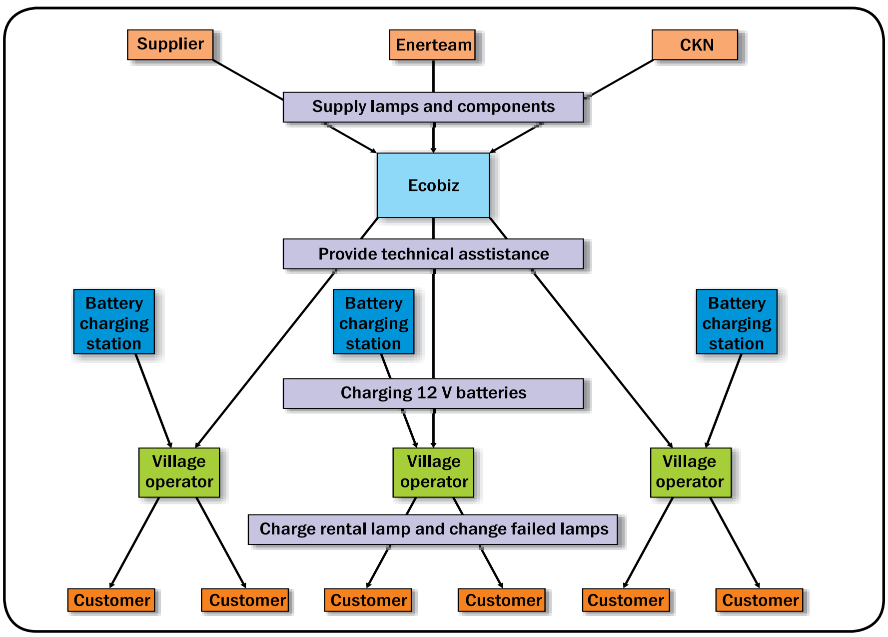


Figure 2 Service delivery model of Eco-Biz model

be adopted for quick impact. The fee-for-service model is well established and also familiar to most rural and peri-urban communities in Cambodia. This would also purge the reliance on diesel based BCS and would make the execution of such project clean and self reliant. Installing an adequately sized solar PV in the premises of VO, would help in the efficient charging of the batteries, making sure that the rural households are serviced properly by the VO. This would also eliminate VO's burden of taking the batteries to distant BCS and paying a tariff for getting them charged.

LaBL: the BCS connection

LaBL campaign can also build on the experience of the BCS, where households purchase new or recycled car batteries and charge them at the nearest BCS running on diesel generating set. Instead of diesel based charging, solar energy can be utilized for charging of the batteries. Additionally, LaBL can facilitate support to an entrepreneur to procure lanterns for renting to the rural households at an affordable price. The lantern charging stations can also promote sale of lanterns (both with and without solar panels) to individual households. Those purchasing lanterns without panels will have to come to the charging stations for recharging the lanterns. In addition to providing solar charging services for the lanterns, these stations can also be upgraded to SMU (solar multi utility) platforms to provide a variety of services such as charging for mobile telephones, battery-operated devices, and so on. The SMU can act as one stop solar energy service provider to the whole community. Other locally available renewable resources such as biomass and wind, which are also available in the country, can be harnessed to augment the capacity of such charging stations.

Solar PV modules are available in Cambodia and there are also institutions such as CKN (Centre Kram Ngoy) which can provide technical support for success of this initiative. CKN is a Cambodia based French NGO providing technical expertise to REEs and BCS. They also conduct training courses on electrical and electronics equipment and services. The technology for solar charging equipments, which is currently not indigenously manufactured, can be transferred to CKN through 'LaBL-PAT (LaBL Partners in Technology)' Forum under South–South Cooperation for assembling such systems locally for use in the solar based BCS. Such a measure could strengthen the capacities of CKN in giving an effective after sales service support to the end users. The LaBL-PAT, will also be able to facilitate linkages between international solar lighting (storage, electronics, and solar) industry and local system integrators so as to strengthen the local capabilities in designing, developing and delivering highly-efficient, reliable and cost-effective solar lighting products and services. The resultant outcome could well be an improved electricity access from a clean source like solar. On the government side, MIME can build on the LaBL experience and develop a systematic approach to assist the entrepreneurs in procuring equipment centrally following standard operating procedures so as to ensure quality control. The objective is to reduce the cost of solar equipment substantially thereby ensuring the viability of such charging stations. The joint effort of LaBL and MIME will in the medium to long run assist in creating the necessary service industry and trained human resources, which later on can be utilized by the solar industry to further strengthen the sector.

Solar charging stations: looking out for a gainful purpose

One of the drawbacks of solar energy devices is their high capital cost. The need of the hour is to create innovative financing schemes for setting up solar charging stations. Cambodia has an active microfinance market and these institutions are already financing diesel based BCS and micro-grids. However, the prevalent financing terms such as short term loan (two years tenure), high interest rate (average 2.5% monthly), and the collateral requirement need to be made more flexible and entrepreneur friendly for financing of solar products and solar charging stations. Though the government has recently reduced the import duties and taxes on solar devices from an average 40% to less than 10%, still more needs to be done. The government may provide further fiscal incentives such as low-interest loans, zero excise duty, total exemption from VAT, depreciation allowance, and so on for stimulating investment by an entrepreneur for solar charging stations. A 'Green Fund' for soft financing of renewable energy project in general and solar projects in particular may also be initiated by the government via pooling of resources from the bilateral and multilateral organizations. Expectedly, it may go a long way in an active promotion of solar energy programme in the country.

Going along with the billions

Thus, the LaBL campaign can complement the government's efforts in improving access to energy especially lighting in Cambodia. Such an effort will not only cater to the lighting needs of the rural poor but also help to create rural employment opportunities in the country in terms of rural charging stations and maintenance network. Thus, it may contribute to an overall socio-economic development of this tropical country trying to catch the developmental pace of its neighbours. What is certainly needed is a focused strategy in tandem with a concerted approach by all stakeholders in extending LaBL to Cambodia so as to improve the lighting access of the marginalized communities.

Meeting EHS concerns in SPV

DR SUNEEL DEAMBI, Consultant, TERI
<sdeambi@airtelmail.in>

Background

'Small is beautiful' does not mean saying it in customary terms. Take a look at a solar module—it generates a fair amount of curiosity as well as a feel good factor. Perhaps of all the RE (renewable energy) technologies, SPV (solar photovoltaic) modules offer the best possible aesthetic consideration. The modern day technology even offers the cell colour of your choice for use as novel as BIPV (Building Integrated Photovoltaics). Added to this attribute is the silent operation underlying the process of solar cell based electricity generation. But, is there anything that should be of immediate concern while dealing with a whole lot of materials, processes, equipment associated with solar cell/ module manufacturing? Well, to put it in perspective, PV technologies offer distinct environmental advantages for generating electricity in direct comparison to the conventional technologies. The operation of PV systems does not involve any noise, toxic gas emissions or GHG (greenhouse gas) emissions. It is beyond doubt that PV power generation irrespective of the nature of technology used (crystalline or thin film) is a zero emissions process. First, let us take a look at the realm of the available PV technologies as under.

Sunshine technologies making headway

The first practical PV cells were developed as early as in 1954 at the famous Bell Laboratories. These were made of silicon and were used primarily by the space industry for satellite power supplies four years later in 1958. Two very positive attributes in terms of the material properties and abundance of silicon made it quite a desirable choice for the solar cell production. On the other hand, the thin-film amorphous silicon technology was put to use in 1976. Development of thin film silicon cells began in the late 1970s. Silicon concentrator cells were initially used in the space, but are now being deployed for the terrestrial applications too. Thin film cells such as CdTe (cadmium telluride) were commercially produced in 2001. However, the PV market continues to be dominated by the crystalline silicon cells. Another relatively new cell type currently in the R&D (research and development) stage is the nano-crystalline dye sensitized cell. It basically uses ruthenium based organic dyes, while as a second type of dye-sensitised cell uses a porous layer of titanium dioxide covered with a layer of dye molecule. These are different cell technologies, which we will look at in terms of the EHS (environment, health and safety) needs in this specific article.

Material content in solar cells

Various metals are currently being used in the solar cell and module production. The material intake varies in accordance with the type of cell technology used. *Table 1* shows the amount of metals in use to produce different types of solar cells.

Use of chemicals

A variety of chemicals and materials find use in the production of SPV

Table 1 Quantity of metal in various types of PV cells

Cell type	*Material requirements*	*Quantity g/m^2*
Amorphous silicon/Ge	Sn	3.3
	Ge	0.22
	Si	0.54
	Al	2.7
CdTe	Sn	0.66
	Cd	4.9
	Te	4.7
	Mo	10.0
CIGS	Zn	9.1
	Cu	1.8
	In	2.9
	Ga	0.53
	Se	4.8
	Cd	0.19
	Mo	10.0

devices. The amounts and types of such chemicals used will vary in accordance with the type of cell being produced. *Table 2* gives a general list of the chemicals and materials used in the production of silicon and thin-film solar cells. Incidentally, the amount of semi-conducting materials by themselves turns out to be small. This is because only a limited quantity is required to produce ultra thin layers of a PV cell. To put it in perspective, an annual production volume of 2000 tonnes of solar panels is capable of producing about 10 MW (mega watt) of useful electricity. To attain this figure, just about 20 tonnes of semiconductor material is needed. You may be wondering as to what constitutes the major share then. Well, the rest is generally glass. Like for example, the amount of cadmium in a CdTe module is 5 g/m^2 and it is estimated at 0.04 g/cm^2 in a CIS module. A wide range of acids or corrosive liquids are used in fairly large quantities during the PV production process. These mainly include sulphuric acid, hydrochloric acid, nitric acid, and hydrogen fluoride. In practice, these chemicals are primarily used for the cleaning of wafers or to remove the impurities from the raw semiconductor materials. In addition, solvents including tricholoroethane and acetone are also used in large quantities during the various cleaning steps as a part of the main production process. Similarly, etching compounds such as sodium hydroxide also finds use in relatively large quantities. In general, the amount of a given chemical used will vary depending on the following factors.

- type of cell being produced
- amount of material processing required
- amount of wafer cleaning needed

Further, the wastes produced by the SPV industry are akin to those from the conventional semiconductor industry. This despite the fact that quantities used are generally small. *Table 3* presents the use of chemicals in relation to the cell technology.

It is interesting to know the role of various chemicals during different stages of PV production. *Table 3* highlights the role of each of the material used.

Potential hazards with PV technologies

The fabrication of a solar cell/module relies on a variety of materials, chemicals and processes. Each of these materials is accompanied by its specific advantages and possibly a few disadvantages too. Such disadvantages could be broadly grouped under a special category, which is commonly known as the EHS. In fact, this is more or less true with any energy source or product. However, with regard to SPV energy source, the use of toxic and flammable substances in PV industry is usually in smaller quantities compared to many other industries. The production of semiconductor solar

Table 2 Chemicals and materials used in manufacturing process of various PV cells

Crystalline silicon cells	*Polycrystalline silicon cells*	*Amorphous silicon*	*Cu2/ CdS cells*	*CdTe/ Cds*	*CIS*	*CIGS*	*GaAs*
Aluminium	Aluminium	Acetone	Ammonium chloride	Cadmium chloride	Cadmium	Cadmium	Arsenic
Ammonia	Ammonia	Aluminium	Ammonium fluoborate	Cadmium	Copper	Copper	Arsenic
Ammonium fluoride	Arsine	Chloro-silanes	Cadmium sulphide	Molybednum	Hydride gas	Gallium	Gallium
Hydrochloric acid	Boron trichloride	Diborane	Chromate coating	Nickel	Hydrogen sulphide	Indium	Hydrochloric acid
Hydrofluoric acid	Copper catalyst	Germanium	Copper	Sulphur	Hydrogen selenide	Molybednum	Methane
Hydrogen fluoride	Diborane	Germanium tetrafluoride	Cuprous chloride	Tellurium	Indium	Selenium	Phosphine
Isopropyl alcohol	Ethyl acetate	Hydrochloric acid	Gold	Thiourea	Molybdenum	Zinc	Trichloroethylene
Nitric acid	Ethyl vinyl acetate	Hydrofluoric acid	Hydrochloric acid	Tin	Selenium		Triethyl gallium
Nitrogen	Hydrochloric acid	Hydrogen	Hydrogen sulphide		Zinc		Trimethyl Gallium
Oxygen	Hydrogen	Isopropanol	Methanol				
Phosphorus	Hydrogen fluoride	Nitrogen	Nickel				
Phosphorus oxychloride	Hydrogen peroxide	Phosphine	Nitrogen				
Silane	Ion amine catalyst	Phosphoric acid	Polyvinyl butrol				
Silicon	Isopropyl alchohol	Silane	Silicon monoxide				
Silver	Nitric acid	Silicon tetrafluoride	Sodium chloride				
Sodium hydroxide	Nitrogen	Silicon	Tantalum pentoxide				
Sulphuric acid	Phosphine	Sodium hydroxide	Zinc				
Tin	Phosphorus trichloride silicon	Tin	Zinc fluoborate				
	Silicon dioxide						
	Silane						
	Silicon trioxide						
	Silicon tetrachloride						
	Silver						
	Sodium hydroxide						
	Stannic chloride						
	Sulphuric acid						
	Tantalum pentoxide						
	Titanium						
	Titanium dioxide						
	Trichlorosilane						

Table 3 Role of various chemicals at different stages

Material	*Process stage*	*Material*	*Process stage*
Phosphorus oxychloride	X-Si dopant	Hydrogen sulphide	CIS sputtering
Choloro-Silanes	X-Si and a-Si deposition	Indium deposition	CIS deposition
Arsine	CVD (Chemical vapour deposition) of GaAs	Lead	Soldering
Arsenic compounds	GaAs	Nitric acid	Wafer cleaning
Cadmium compounds	CdTe and CdS deposition, $CdCl_2$ treatment	Phosphine	a-Si dopant
Carbon tetrachloride	Etchant	Selenium compounds	CIS Deposition
Copper	CIS deposition	Sodium hydroxide	Wafer cleaning
Diborane	a-Si dopant	Silane	a-Si deposition
Hydrogen	a-Si deposition	Silicon tetrafluoride	a-Si deposition
Hydrogen fluoride	Etchant	Tellurium compounds	CIS Deposition
Hydrogen selenide	CIS sputtering		

Table 4 Potential hazards associated with various cell technologies

Module type	*Types of potential hazards*
Crystalline (Xi) silicon	HF acid burns
	SiH fires/explosions
Amorphous (a) silicon	SiH_4 fires/explosions
CdTe	Cd Toxicity, module disposal
CIS	H_2Se toxicity, module disposal
GaAs	AsH_3 toxicity, H_2 flammability, module disposal

Table 5 Various hazards related to chemicals used in PV module manufacturing

Chemicals	*Effects*
Arsenic	Poison
Arsine	Highly Toxic Gas
Cadmium	Poison
Diborane	Flammable gas
Diethyl silane	Flammable liquid
Diethyl zinc	Pyrophoric liquid
Dimethyl zinc	Spontaneously combustible
Hydrochloric acid	Corrosive material
Hydrofluoric acid	Corrosive Material
Hydrogen	Flammable gas
Hydrogen selenide	Highly toxic gas
Hydrogen sulphide	Flammable gas
Indium	Not regulated
Methane	Flammable gas
Molybdenum hexafluoride	Toxic and corrosive gas
Oxygen	Gaseous oxidizer
Phosphine	Highly toxic and Pyrophoric gas
Phosphorus	Oxychloride corrosive material
Selenium	Poison
Silane	Pyrophoric gas
Silicon tetrafluoride	Toxic and corrosive gas
Tellurium	Not regulated
Tertiary butyl arsine	Pyrophoric and highly toxic liquid
Tertiary butyl phosphine	Pyrophoric liquid
Tetramethyl tin	Pyrophoric and highly toxic liquid
Trimethyl indium	Pyrophoric solid
Trimethyl aluminium	Pyrophoric liquid
Trimethyl gallium	Pyrophoric liquid
Tungsten hexafluoride	Toxic and corrosive gas

cells is a specialized piece of work, during which health may be affected due to the use of different classes of chemicals and physical hazards. Such hazards are at variance with different thin-film technologies and deposition processes. *Table 4* lists the hazards associated with the commonly known cell technologies.

Classification of chemicals

A number of chemicals as mentioned in *Table 2* are used during various stages of PV device production. There are few chemicals which are definitely more toxic than the other. *Table 5* gives a hazard classification of chemicals in use within the PV industry.

Knowing the impacts first hand

Crystalline silicon cells continue to dominate the PV marketplace virtually unchallenged by the competing technologies. It is likely to remain so for the next 5–10 years as per the available market projections. The primary concerns for human health vis-à-vis silicon based cells arise due to the use of toxic gases and solvents during the manufacturing

Bell Laboratories, USA

process. It is important to mention here that arsine and phosphine gases are used in the production of silicon solar cell. However, there is just a minimal risk to the mankind due to the completed and installed silicon based cells. These two materials are also used in the manufacturing of gallium arsenide solar cells. There is a perceptible shift towards the use of thin film technologies, moreso CdTe, if, companies like the First Solar have their way in making solar truly affordable. Also, copper indium di-selenide will be a favourite thin-film material application in the near future. These two materials had a market share of less than 1% up to 2001.

Cadmium is of potential concern with the development of thin-film technologies and the cadmium compounds are used in CdTe, CIS, and CIGS. The point is, do the finished solar modules pose any type of immediate risk to the humans? There is no potential threat about release of chemicals as these are present in the weather proof sealed modules. Such releases may take place only in case of any unforeseen circumstances like fires and so on. Generally, leaching of metals from the installed modules is mostly possible during the stages of module production itself.

Specific concerns

Crystalline silicon

Potential chemical burns and inhalation of fumes can occur from HF (hydrofluoric acid), HNO_3 (Nitric acid), and NaOH (alkalis). These are generally used for crystalline silicon based wafer cleaning, removal of dopant oxides, and so on. Dopant gases and vapours like $POCl_3$, B_2H_3 may also prove to be hazardous, if, inhaled. $POCl_3$ is a liquid, but it generates toxic P_2O_5 and Cl_2 gaseous effluents

inside a deposition chamber. That is why, inhalation hazards are brought under check with properly designed ventilation systems in the process stations. Other occupational hazards concern the flammability of SiH_4 (silane) and its byproducts used in the silicon nitride deposition. As far as public health issues are concerned with the use of X-Si technology, these simply are absent. The environmental issues are related to the generation of liquid and solid wastes during the important stages of wafer slicing, cleaning, and etching and also at the processing and assembly stages of solar cells. To rectify such a situation, the crystalline silicon cell industry has already put in place result oriented programmes of waste minimization. Such efforts include recycling the stainless steel cutting wires, recovering the SiC in the slurry, and in-house neutralization of acid and alkali solutions to name just a few.

Thin-film technologies

Most commonly used thin film-technologies are amorphous silicon, cadmium telluride, copper indium diselenide and gallium arsenide. These typically use about one-hundredth of the PV material used on crystalline silicon cells. Key safety hazard of this type of technology is SiH_4, which is quite pyrophoric. By definition, pyrophoric materials are often water reactive and will ignite when these come in contact with water or humid air. Besides silane, hydrogen is also used in a-Si manufacturing. It happens to be both flammable and explosive. To counter such a threat, majority of PV manufacturers make use of sophisticated gas-handling systems with sufficient safety features to reduce the fallout of fire and explosion. Toxic doping gases (AsH_3, PH_3, and GeH_4) are used in very small quantities so as not to pose any major hazards to public health or the environment at large. However, all possible care is needed to avoid the leakages of these gases in the environment.

Case study of EHS aspects in cadmium telluride modules

CdTe is a leading cell material today, stimulated largely by the innovative efforts of First Solar, USA. The main life cycle stages in PV CdTe are as follows.

- Mining
- Production of CdTe
- Manufacture of CdTe modules
- Utilization of CdTe modules
- Safe disposal of spent CdTe modules

Cadmium is a by product of zinc, copper, and lead. The main resource of cadmium in CdS is ZnS (sphalerite) ore. The zinc cadmium ratio happens to be 350:1. It is interesting to draw a comparison between Cd used in the batteries as against Cd used in the solar cell production. *Table 6* presents an easy comparison of the same.

CdTe is much more stable than Cadmium and $Cd(OH)_2$ used in the batteries. Cadmium is encapsulated between glass sheets. Also, a C-size nickel cadmium battery uses about 10g of cadmium as against 7 g of cadmium in a 1 sq m CdTe module. Thus, seven batteries use 70 gm of cadmium, which as per the available estimates is equal to 1 kWp CdTe PV array. Interestingly, cadmium in CdTe produces 2 500 more electricity than the nickel cadmium batteries.

Table 6 Comparison between Cd used in batteries and Cd used in solar cell production

Compound	$T_{melting}$ (°C)	$T_{boiling}$ (°C)	Solubility (g/100cc)	Toxic/Carcinogen
Cd	321	765	Insoluble	Yes
Cd (OH)2	300		2.6e-04	Yes
CdTe	1041		insoluble	?

EHS in CdTe PV manufacturing

The occupational risks are mainly manifested in terms of inhalation risks and ingestion risks. CdTe modules under actual utilization involve zero emissions under normal conditions. However, there is a concern about cumulative emissions from a large number of smaller PV installations. Accidental emissions during fire could amount to 0.01 g/GWh. It is unlikely that encapsulated CdTe will vapourize in the residential fires. Now as far as decommissioning of end-of-life CdTe modules is taken up, there is some concern about disposal in the municipal landfills. However, it can be safely said that cadmium used in the PV application is much safer than other current uses involving cadmium.

Technology

CdTe technology may surpass many an expectations in terms of attaining the desired grid parity. Several attempts were made in the past to develop this technology, but it goes to the credit of First Solar that today CdTe is a commercial reality. Today, it is the leading PV technology in terms of carbon footprint and energy payback time. It has now attained the lowest manufacturing cost per Watt of all PV technologies. It has been assessed that there are negligible risks involved both during the normal operation, breakage of panels, and importantly in the case of accidental fires. This clearly means that CdTe panels can be put up in large numbers without feeling any major concern for the human health and environment. It is equally important to mention here that First Solar has implemented such policies, practices, and management systems to ensure the health and safety of the workers. Likewise, it has formulated policies, practices, and management systems which are essentially geared at protection of the environment that is at its manufacturing and recycling works. This is as far as the company perspective on the production, use and, safety practices are concerned. It has very recently been substantiated by a thorough review carried out by a designated authority. Following

section takes a look at the most important outcome of such a review.

First Solar-first to get reviewed

First Solar and EDF-Energies sought an independent and complete evaluation of its products from the authority of the French Minister of Ecology, Energy, Sustainable Development, and so on. Significant objective of this review was to assess the following few elements in particular.

- Manufacturing
- Product use
- End-of life recycling
- Disposal of the systems

The review was designed to assess these parameters with an active involvement of five experts from France's CNRS (Centre National de la Recherche Scientifique), the University of Utrecht, France's INERIS (Institut National de l'Environment Industriel et des Risques), France's CEA (Commissariat à l'Énergie Atomique), and the European Commission JRC (Joint Research Centre). This review was headed by Dr Daniel Lincot of CNRS. Pertinent to mention here is that the panelists are specialists in the following few areas.

- Life cycle analysis
- EHS and legislation
- CdTe materials research and PV

To begin with, the expert panel glanced through the available third-party literature on CdTe, CdTe, PV and importantly the documents obtained from the First Solar. It was followed up by an on-

the-spot assessment of the First Solar's manufacturing and recycling facilities in Germany. Meetings were conducted with the key plant staff and company management. This allowed in-depth analysis of key technical EHS aspects of the manufacturing, waste management, and recycling processes in place at First Solar. It is quite important to mention here that a similar peer review in 2005 had been organized by the European Commission's JRC and moderated by the German Federal Ministry of Environment. The expert panel reviewed the findings of that review as well as updates and changes that have occurred since that review. Following few are the key conclusions drawn by the review team on a closer scrutiny of all encompassing aspects related to First Solar only.

- No cadmium emissions—to air, to water, or to soil occur during the normal operation of CdTe modules. Cadmium emissions are negligible during accidental fires or broken panels. So, it means no immediate threat to human safety and environment
- Carbon footprint of CdTe PV systems is the lowest among currently available PV technologies. In fact, it compares well with nuclear and wind technologies
- EPT (Energy payback time) of the CdTe PV systems is less than one year, which is the shortest among all currently available PV technologies
- Atmospheric life cycle emissions of cadmium from CdTe PV are very low; liquid waste emissions are well below regulations for waste water effluents

- Low cadmium emissions, small carbon footprint, and short energy payback time are primarily related to the company's state-of-the-art technology
- No major concerns were identified during this review regarding EHS aspects of the company's manufacturing and recycling activities.
- The company has successfully obtained ISO 14001 certification of its environmental management systems for its plants in Germany and the USA
- First Solar has implemented several important EHS management programmes, which also includes specific cadmium management programmes
- The company has a manufacturing facility at Frankfurt (Oder). Data from this facility on workplace and health monitoring, as well as on emissions to the environment, presented during the review demonstrate the following.
    - Emissions are low compared to legal, recommended, and internal limit values.
    - In many cases these happen to be more than one order of magnitude lower than the limit value
- The company undertakes frequent checks concerning the exposure of its employees to cadmium compounds in terms of both workplace air quality monitoring and medical monitoring. There has been no trace of cadmium exposure amongst the company employees during its decade old monitoring programme.

The future concerns

EHS aspects are no longer shrouded in mystery now. In fact, PV industry is fast waking up to address such concerns in all possible ways. However, it is equally important to maintain EHS standards for all such units, whose range of products catches the fascination of the masses. The glaring examples are those of cadmium use in the nickel-cadmium batteries or use of mercury in the Compact fluorescent lamps. These items have a quick disposal period too as against the solar modules needing replacement after a long period. It is equally important to develop requisite awareness within the smaller R&D setups experimenting with a variety of concern prone chemicals and gases. SPV technology is now on the brink of a major upward shift and any misgivings about it need to be overcome moreso in case of a fast forward technology based on cadmium telluride.

SOLECKSHAW
Status and vision

RAJESH KUMAR*, Scientist, Department of Scientific and Industrial Research and PhD Student at IIT Delhi <rajesh@csir.res.in>

Background

India's solar mission envisages the promotion of solar energy to harness and distribute environment-friendly power, available with high scalability, for sustainable economic growth by empowering national energy security. The innovation is expected on a business model to make solar energy affordable and attain the desired grid parity in a limited span of time. The business plan, in respect to long-term available energy with low operation and maintenance cost, is to mechanize integrated plan and activities and incorporate the development under flagship programmes like Bharat Nirman and NREGA (National Rural Employment Guarantee Act). The issues like research, design, development, and manufacturing of product and process concerning the renewable energy are market-driven, and hence the demand for these technologies is the need of the hour for an immediate integration through a flagship programmes.

Soleckshaw-riding high

The pedicab has been named Soleckshaw—SOL stands for solar, E for Electric and CKSHAW for Rickshaw. It is a rickshaw—three wheeled vehicle driven by BLDC (brushless direct current) and PMDC (permanent magnet direct current), powered by a specially designed lead-acid battery. It is charged by solar energy. The research work is based on an advanced technology of mechanical propulsion, gear mechanism, advance motor, Li-ion battery and harnessing of renewable energy from available energy resources like solar, hydro, wind, and biomass.

'Soleckshaw', the project has been targetted for renewable energy equivalent to 1500 MW, major stack from SPV (solar photovoltaic), for eight million rickshaw pullers across

*The Author, Rajesh Kumar, is Scientist with DSIR and Ph.D student at IIT Delhi. He is associated with the Soleckshaw project and responsible for commercialization inclusive financial intervention for societal impact. He acknowledges CSIR and CMERI particularly Prof Samir K Brahmachari, Director General, CSIR for his genesis and continuous encouragement and Prof Gautam Biswas, Director, CMERI, who encouraged the development of a different variant of Soleckshaw. It is basically to provide a sustainable vehicle to different segment of people so as to fulfil the need of transport system. This article is the result of the experience gained during various stages of development of Soleckshaw accompanied by its technological transfer in the public domain.

the country. In the second phase, the market will be open for export and an additional coverage of converting three million polluting auto rickshaws. The second phase will further enhance the renewable energy demand by 500 MW. Presently, the rickshaw business volume is Rs 1.6 billion crore daily and annually the turnover will cross Rs 584 billion based on an average daily income of Rs 200 by the rickshaw puller. The turnover figure is significant enough for government intervention through technology and social promotion which may increase income of the rickshaw pullers with reduced human drudgery. Soleckshaw project aims to reduce drudgery by the use of motorized vehicles, and also increase income of the soleckshaw drivers by using environment-friendly solar energy.

Revealing the connection

Soleckshaw is a pedal driven, motorized vehicle targetted to reduce the drudgery of the driver. The Soleckshaw motor runs on DC power from lead-acid batteries, which are charged by SPV panels.

Soleckshaw—the technical model

Technologically advanced and cost effective single crystalline silicon cells are used for the PV. The CSIR's (Council of Scientific and Industrial Research) vision of using advanced material and technology for SPV, based on technologies like polycrystalline silicon, microcrystalline silicon, cadmium telluride, and copper indium selenide/sulfide is under consideration. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and PV arrays has advanced dramatically in the last decade. There are the two provisions for charging different models of Soleckshaw.

- Solar charging station—pre-installed solar panel stations where a number of Soleckshaws can be charged at any given point of time.
- Solar panel mounted on vehicle – the panels are mounted on the vehicle and the battery is charged by sunlight even while moving on the road.

System perspective

CEL (Central Electronics Limited) designed PV array is a collection of PV modules, which are made of multiple interconnected solar cells. The cells convert solar energy into DC via the PV effect. The power that one module can produce is seldom enough to meet requirements of Soleckshaw, so the modules are linked together to form an array. The array provides DC voltage, which is directly supplied to the batteries for charging. The modules in a PV array are connected in series to obtain the desired voltage of 36 V; the individual strings are then connected in parallel to allow the system to produce more current. A brief technical specification of a solar cell is given in *Table 1*.

Table 1 Brief technical specification of solar cells

Material	*Single Crystalline Silicon*
Size	125 mm × 125 mm (Pseudo Square)
Surface	Textured
Voc	600 mV
Im	4.0 Amp
Vm	480 mV
Pm	1.92 Watts
Fill Factor	70 %

Solar module for Soleckshaw roof

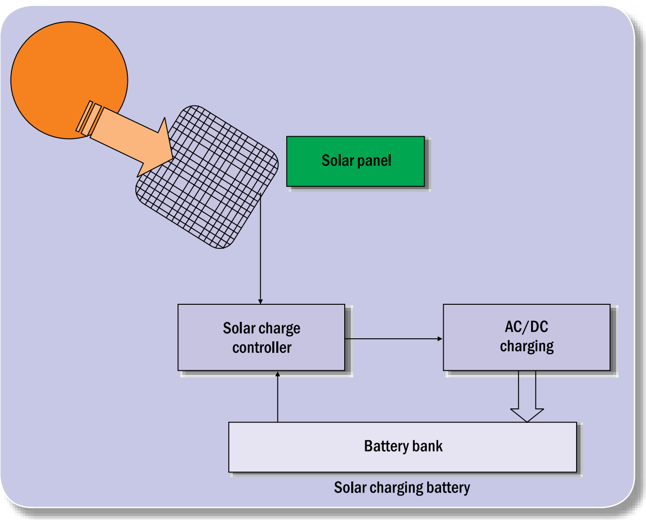
CEL's SPV module is designed for Soleckshaw using mono-crystalline silicon solar cells. These are high quality and high performance modules suitable for power generation. These specially designed modules have excellent durability to withstand extreme temperature and weather conditions of the high altitudes, deserts, and coastal regions. The array comprises of three solar modules of 50 W powers and is connected in series to get charging voltage of 36 V. The solar module has been designed to meet the specifications as given in *Table 2*.

For an individual unit of Soleckshaw, the panel is mounted on the vehicle and it charges the battery as per the following specifications.

a.	SPV array	: 150 Wp
b.	Charge controller (36V, 5A) (with current limiters)	: 1 No.
c.	Battery 36V, 32 Ah with box (VRLA) standby	: 1 set mounted on the vehicle (3 batteries of 12V)

Table 2 Solar cell designed to meet the following specifications

Physical parameters	*Electrical parameters*	*Environment rating*
• Number of cells 36 • Physical dimension (mm) (L x W x T) 845 x 550 x 35 • Weight (kg) 5.2	• Maximum power rating Pmax. (Wp)* 50.0 • Minimum power rating Pmin (Wp)* 47.0 • Rated current IMPP (A) 2.95 • Rated voltage VMPP (V) 17.0 • Short circuit current Isc (A) 3.30 • Open circuit voltage Voc (V) 21.4	• NOCT ** (°C) 45 ±2 • Maximum permitted module temperature (°C) -40 to + 85 • Maximum permissible system voltage (V) 600 • Relative Humidity at 85°C (%) 85 • Under standard test conditions: Air mass AM 1.5 Irradiance 1000 W/m² Cell temperature 25 °C • Nominal operating cell temperature at : Wind Speed 1 m/s Irradiance 800 W/m² Ambient Temperature 20°C



Solar charging battery

Solar module for Soleckshaw in a standby cluster

CMERI (Central Mechanical Engineering Research Institute) has designed and developed an efficient battery operated pedicabs with a 240 W brushless motor operating on 36 Volts, 32 Ah batteries. It is proposed that each pedicabs is provided with two sets of batteries so that one can be utilized in the vehicle, whereas the other standby set can be put on charging at the central charging station. The pedicabs puller will bring back the discharged battery for charging to the central charging station and will receive one set of the charged batteries. The charging station is equipped with a facility to charge the batteries simultaneously-via-solar panels.

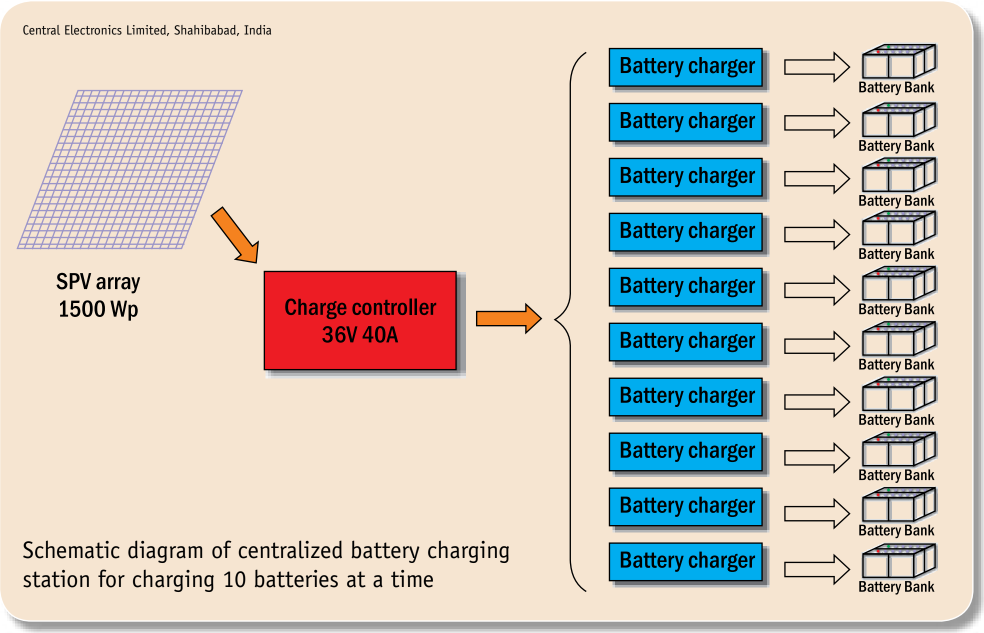
The integrated SPV modules for a cluster of 10 set of batteries has been designed for Soleckshaw using mono-crystalline silicon solar cells. These specially designed modules offering the best quality and performance have an excellent durability. The PV system comprises of 10 arrays parallel to 3 solar modules of 50 W power, connected in series to get charging voltage of 36 V for charging 10 battery sets.

Brief specifications of the proposed system for the cluster of 10 Soleckshaw are shown as follows.

a.	*SPV Array*	*:*	*1.50 KWp*
b.	*Charge controller (36V, 40A) (with current limiters in 10 ports)*	*:*	*1 No.*
c.	*Battery 36V, 32 AH with box (VRLA) standby*	*:*	*10 sets*
d.	*Structures, wires, cables, and other items*	*:*	*Lump sum*

SPV controllers and charger for Soleckshaw

Soleckshaw charge controller has been designed by CEL, so as to increase the battery life of a PV system. The controller is designed to charge the battery on different modes that is bulk, absorption and float to prevent the overcharging of the battery. The controller plays an important role in case of sealed batteries, where one cannot replace the water that is lost during the process of overcharging. To avoid the complexity of design, CEL and CMERI have been working on the model, where solar panel mounted on Soleckshaw and the charging source is very small in comparison to large battery. If, a PV module produces 1.5% of the battery ampacity or less, then



Schematic diagram of centralized battery charging station for charging 10 batteries at a time

no charge controller is needed. A PV controller also prevents reverse current flow at night. Reverse current flow is the tiny amount of electricity that can flow backwards through PV modules at night, discharging the battery, but the loss of power is insignificant.

Charging novelty: three stage battery charging

Bulk

During this stage, the batteries are charged at the bulk voltage setting and maximum current output of the DC source. When battery voltage reaches the bulk voltage setting, the controller goes to the next stage. During the bulk charging process, the status LED may blink before pausing. The more number of times it blinks consecutively, closer the battery voltage is to the bulk voltage setting.

Absorption

During this stage, the voltage of the battery is held at the bulk voltage setting until an internal timer has accumulated one hour. Current gradually declines as the battery capacity is reached. During the absorption stage, the status LED blinks five times, then pauses and repeats.

Float

During this stage, the voltage of the battery is held at the float voltage setting. Full current can be provided to the loads connected to the battery during the float stage from the PV array. When the charge controller reaches the float stage, the status of LED will be solid green. The charge controller has all necessary protection features such as overload and short circuit protection with automatic and manual reset and reverse flow protection.

Innovation in Soleckshaw technology

Soleckshaw on BLDC Motor

The present device is driven by a BLDC hub motor. The BLDC hub motor has been mounted at the centre of

BLDC Motors for Electric Vehicle-Solleckshaw

the front wheel directly replacing the hub of the wheel. The motor power is imparted in the front wheel and manually driven on the rear wheel. In the invented pedicab an override mechanism is provided on the rear axle to provide speed adjustments to rear wheels, whenever required. On the other hand, in prior works, rear wheels impart different speeds through automotive differential. In this pedicab, the lead acid batteries are charged offline and online from solar charging station.

Use of BLDC motor has eliminated torque enhancing devices and additional mounting structures, which are required for the PMDC Motor. By separating motor and mechanical drive on two different axles, one can eliminate many mechanical transmission devices like clutch, spring loaded frictional plate, and couplings. Finally, use of motor power or the manual effort or the combination of both the drives, as and when required, constitute the non-obvious inventive steps.

Differential mechanism for the rear wheel

Soleckshaw depends on a unique patented 'differential' on the rear axle. This 'differential' provides a unique arrangement of transmission of pedal power to the two wheels. This concept lets the wheel on the inner side of the curve take an override with regard to the inner wheel. This ensures that the power is always delivered to the wheel on either side at the rear. In comparison, the conventional rickshaws on one side have a free hub and only one hub transmits the power.

Achievements

Technological development

The Soleckshaw technology has been designed and developed at CMERI, Durgapur and its Phase I Mark I model has been tested for commercialization.

The Mark I Soleckshaw has the following unique features.

- Locomotion mainly by pedalling assisted by an electric motor run on solar power
- BLDC (brushless direct current) hub motor mounted on front wheel for easy maintenance
- Suitable arrangement for adjustment of chain tension
- The entire rear axle system is mounted on a separate structure to ensure better alignment of both the axles
- Brakes introduced on all three wheels
- Special differential mechanism introduced on rear axle.
- Provides better stability during driving
- Micro controller for better control and drive

Indian patent

CMERI, Durgapur, has filed two applications for the registration of patent in India for two innovative design features incorporated in Soleckshaw

- Solar powered motor assisted pedal driven pedicab
- A pedicab with novel speed override mechanism

Test and trial run centre

The trial run centre has been established to test the vehicle on road and also for sharing the technology with the people for feedback, who will actually use this. These centres have successfully completed one year and received value added inputs for technology improvement and for Soleckshaw commercialization through an innovative business model. The product is well accepted by the rickshaw puller community and CSIR has got lot of queries for the purchase of this vehicle. The trial centres were established with centralized charging station for 10 batteries at a time and operated from the following.

- CMERI, Durgapur
- Metro station, Chandni Chowk, Delhi
- Sector 17, Chandigarh

Technology transfer

CMERI, Durgapur, has now successfully transferred this technology to the Indian companies. The Soleckshaw technology has a manifold societal impact for people, representing the bottom of the pyramid of the life style, and hence the two companies from the small scale sector and one company from the large scale sector have been identified for technology transfer on non-exclusive right. The technology transfer document has been shared by CMERI after signing a Memorandum of Understanding for the encouragement of assembly of Soleckshaw vehicle with the locally available components. The three companies sharing the soleckshaw technology are the following.

- IMMPL (Innovative Modular Machine Pvt. Ltd), Faridabad
- Dean Systems, Kolkata
- HBL Power System Ltd., Hyderabad

To promote these technology incubator and success of the first phase of Soleckshaw commercialization, CMERI has shown resistance for more technology transfer, for a limited time.

CMERI has also received expression of interest in Soleckshaw technology from major players working on e-bikes and rickshaw segment. Some of them are listed here.

- Kinetic Engineering
- Lohia Auto Industries
- Monto Motors Ltd.
- CRD and Suvana Urja Windpower Pvt. Ltd.
- Ecowater
- Acme Cold Chain Supply

CMERI may consider more technology transfer during phase II of Soleckshaw commercialization.

Manufacturing initiatives

Innovative Modular Machine Pvt. Ltd and Dean Systems have started manufacturing and sale of this product. IMMPL had supplied Soleckshaws in various cities like Chandigarh, Jaipur, and Ahemdabad and procured orders for more than 200 Soleckshaws. Dean System manufactured Soleckshaws are running in Kolkata and Durgapur. HBL Power System Ltd, has successfully incubated the Soleckshaw technology from CMERI and manufactured two prototypes at their own campus.

International fascination

Soleckshaw vehicle has attracted the people from across the globe. CSIR and CMERI have received expression of interest for technology transfer and also purchase of vehicle, from many countries. The people from the US, UK, and South Africa have shown interest to run soleckshaw as tourist vehicle, while in Bangladesh company wants to deploy soleckshaw as a mode of city transport. Various Russian laboratories have shown interest for research work on Soleckshaw technology, specific to battery and motor. CMERI is in the process of exporting two Soleckshaws to the Russian R&D laboratories.

Participating in a movement

DSIR (Department of Scientific and Industrial Research) extends project mode support for research and development on the technology to deploy Soleckshaw for different applications across the country, under its innovative plan scheme TePP (Technopreneur Promotion Programme). The programme extends financial and technical support for R&D on Soleckshaw, by innovator and entrepreneur in the private sector.

MNRE (Ministry of New and Renewable Energy) promotes the product as it is an effective utilization of renewable energy sources. CMERI designed Soleckshaw uses the solar power for running of motor and plan is underway to promote the use of wind and biomass in the second phase of design modification. CSIR plans to submit a proposal to MNRE to obtain subsidy to promote Soleckshaw in phase I for a batch of 25 000 Soleckshaws in 25 cities. The subsidy is expected to popularize the technology and to share the accompanying risks of technology adoption.

ISB (Indian School of Business), Hyderabad, is working on a business plan for Soleckshaw manufacturers, operators/charging stations, and drivers. Two teams each comprising of four students, from different MNCs, are now working on business plan, as part of their PG programme at ISB, with expert guidance from the faculty.

CDC (Consultancy Development Centre) has been working on the web design for Soleckshaw and the excellent web design has been reviewed and is awaiting a formal public launch soon. CSIR has been working in an open domain innovative environment to seek expert advice and support from TERI, IVCF, and TEXAS in their respective areas of expertise. TERI has come up with an innovative business tool to promote Soleckshaw in tandem with an integrated movement with e-bike and LaBL.

Technology demonstration

- Two Soleckshaws exhibited at the Indian Science Congress held at NEHU, Shillong during 3–7 January 2009
- AECTP (Advanced Executive CDM Training Programme): presented case study on Soleckshaw
- Carbon Bazar 2009: live display presentation
- POA-CDM conference: presented a case study
- British High Commission-Deloitte: IITD project work case study proposed.
- Live demonstration at Vigyan Bhawan at CSIR foundation Day

CSIR vision

- Convert conventional rickshaws into Soleckshaw by 2020.
- Setup soleckshaw technology dissemination centre at state capitals
- Increase the income of Soleckshaw puller by at least Rs 75 via an intervention of science and technology
- Business model to transfer ownership to Soleckshaw puller in less than 15 months.
- Formal sector intervention for extension of insurance, banking, and medical facilities to this sector.
- To make Soleckshaw cost effective at a target cost of Rs 16 000 by 2011
- Every village with road connectivity will have Soleckshaw as a community vehicle to serve persons who are either old aged, ill or physically disabled.
- CSIR in coordination with state government plans to set up Model Centre for technology dissemination at all the state capitals by March 2010
- Soleckshaw availability in kit form by 2011.
- The Mark II model with updated technologies, two gears, and regenerative energy from brakes and shocker, and also incorporating user feedback will be made road worthy by 2010
- Soleckshaw dedicated micro-controller, which provides cost-effective solution for better operation, control, and display
- Soleckshaw to run on Li-Ion battery or any other batteries with advance and cost- effective technologies
- Soleckshaw batteries to be possibly charged with solar, wind, and biomass or a combination thereof
- Soleckshaw as a green transport vehicle for the Commonwealth Games 2010
- Soleckshaw variant for postman and community activities like garbage collection and ferrying of school children, by 2010
- Soleckshaw road show in Delhi by 2010 and later on in other cities.

Electrifying the sun soaked sand

DR SUNEEL DEAMBI, Consultant, TERI
<sdeambi@airtelmail.in>

The development of silicon wafers from ordinary sand, which are then readied into the electronic chips including the solar PV (photovoltaic), is a classic example of how two natural resources – the Sun and sand – can be used together. These cells become capable of converting the incident solar energy into electricity for a variety of end use applications; be it lighting, water pumping, battery charging, and so on. Before, we delve into the aspect of solar silicon, let us take a quick detour of the electronic chips. These chips too are made of ordinary sand that is silicon and are changing the way people live, work, and play. The modern era is replete with such chips; be it powering the internet, automating the factories, adding value to mobile telephony, and for that matter enriching the home entertainment. In short, silicon is at the core of an ever expanding and increasingly connected digital world. The process for making the chips is called fabrication and the factories where they are made are better known as fabs. Solar wafers, cells, and modules are lately foraying into the fabs under the ambit of specially announced schemes like the Special Incentive Package of MICT (Ministry of Information Technology and Communications).

Tracing a common connection between chips and solar cells

Silicon happens to be a starting material for developing silicon wafers, which are used for the high value chip production and solar cells. The principal ingredient is of course the sand that is silicon, which is widely regarded as a natural semiconductor. After oxygen, it happens to be the second most abundant element on earth. It is used for its sheer ability to oxidize with ease thus, forming S_iO_2 (silicon dioxide). In order to make wafers, silicon is chemically processed thus, bringing its purity level to 99.9999%. Following which, the purified silicon is melted and grown into long, cylindrical ingots. These ingots are then sliced into thin wafers, which are now commercially available in different sizes like 125 mm (5-inch), 200 mm (8-inch), and 300 mm (12-inch). While the first size suits the solar industry more, other two sizes befit the electronic industry. The distinguishing factor between the two is mainly in terms of the purity level

of the silicon used. For many years, solar industry has relied upon the use of off-specification material from the electronic industry. However, with an increasing recognition to rising solar to electric efficiencies, use of electronic grade silicon is gaining some acceptance within the solar industry too. Let us now look at the efforts made