7th International Conference on
"Lighting Engineering", LUX Jr. 2005,
Doernfeld-Ilm, Germany,
23 – 25 September 2005.

Decentralized Low-Cost Solar Photovoltaic Energy for Lighting and Other Applications for Rural Households

Prof. (Mrs.) VIJAYA AGARWAL
Selection Grade Assistant Professor (Electrical Engineering)
Department of Agricultural Structures & Environmental Engineering
College of Agricultural Engineering
Jawaharlal Nehru Agricultural University
Krishi Nagar (G – 83), Adhartal P.O., Jabalpur 482 004 INDIA
Email : vijaya.agarwal @ rediffmail . com Phone: + 91 - (0761) - 248 1820

&

Univ. – Prof. Dr. Ing. J. H. AGARWAL
Former Director Instrumentation - JNAU & Project Coordinator
UND - GOI - Microprocessor Application Engineering Program
Krishi Nagar (G – 83), Adhartal P.O., Jabalpur 482 004 INDIA
Email: jhagarwal @ sancharnet . in Phone: + 91 - (0761) - 248 0400

ABSTRACT : Present situation demands harnessing solar energy for the benefit of rural masses for lighting and other household applications by installing decentralized solar photovoltaic systems in stand-alone mode. Concepts of photovoltaics and a few case studies are presented to illustrate how a logical and philosophical approach to scientific and technological problems can help to meet societal needs.

1.0 PREAMBLE

For one third of our planet earth, nightfall means darkness. For the almost two billion people without electricity, the night is still lit only by fire, if at all. Burning wood or kerosene lanterns produces gasses, pollutes the air, and demands time and money spent getting fuel that poor people can ill-afford. According to the World Energy Council, the world's oldest energy technology, the cooking fire, still remains the most widespread fuel-using technology today. A reliance on traditional fuels and technologies keeps a large fraction of humanity, in particular women, in poverty, ill-health, and deprivation.

A study by W. Nordhaus (1997) has analyzed the real price of light : how much it costs in the way of resources and labour to produce a fixed amount of artificial illumination? It has been found that the real price of light has fallen by a thousand fold over the past two centuries. A middle-class urban household in 1800 would have spent perhaps 4 percent of its income on illumination: candles, lamps, oil, and matches. A middle-class urban household today spends less than 1 percent of its income on illumination, and consumes more than a hundred times as much artificial illumination as did its predecessor of two centuries ago. Yet we do not speak of the 'illumination revolution'. The productivity of illumination-producing technology has increased enormously, but its usage for lighting rural homes has been limited.

2.0 SUN – A RENEWABLE SOURCE OF ENERGY

Sun is a prime source of energy for inhabitants of the earth. The amount of solar energy that hits the surface of the earth every minute is greater than the total amount of energy that the world's human population consumes in a year. Every second the sun radiates 13 million times the annual energy consumption of the United States of America.

3.0 SOLAR TO ELECTRIC CONVERSION

Photovoltaic science is the science of converting energy produced from the sun into electricity. Edmond Becquerel discovered the concept known as the photovoltaic effect in 1839. Photovoltaic cells are semiconductor devices that convert light directly into electricity. They are usually made of silicon with traces of other elements [1].

3.1 Operation of Photovoltaic Cells

In a typical photovoltaic cell (Fig. 1), the bulk of the material is silicon, doped with a small quantity of boron to give it a positive or p-type character. A thin layer on the front of the cell is doped with phosphorous to give it a negative or n-type character. The interface between these two layers contains an electric field and is called a junction. Light consists of particles called photons. When light hits the solar cell, some of the photons are absorbed in the region of the junction, freeing electrons in the silicon crystal. If the photons have enough energy, the electrons will be able to overcome the electric field at the junction and are free to move through the silicon and into an external circuit. As they flow through the external circuit they give up their energy as useful work such as lighting lamps, turning motors.

3.2 Photovoltaic Cell Types

Three cell types are common, according to the type of silicon crystal used – mono-crystalline, poly-crystalline and amorphous. Their efficiencies under laboratory and field use are given in Table 1.

3.3 Photovoltaic Cells – Recent Development

The Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany, has produced thin crystalline photovoltaic cells with a thickness of 37 micro metres and an efficiency of 20.2%. In comparison, the currently available cells are comparatively thick and less efficient, about 300 micro metres (0.3 mm) thick and 16% efficiency.

3.4 Effect of Weather

PV solar modules are less efficient in low sun and cloudy conditions. They do generate electricity in cloudy weather although their output is diminished. Typically, a PV module is reduced to 5-20% of its full sun output when it operates under cloudy conditions. PV cells generate electricity from light, not heat and work better in cold weather situations.

3.5 Benefits of Photovoltaics

The photovoltaic process is completely solid-state and self-contained. There are no moving parts and no materials are consumed or emitted. It is silent, produces no emissions. Silicon used in photovoltaic devices is non-toxic. Although

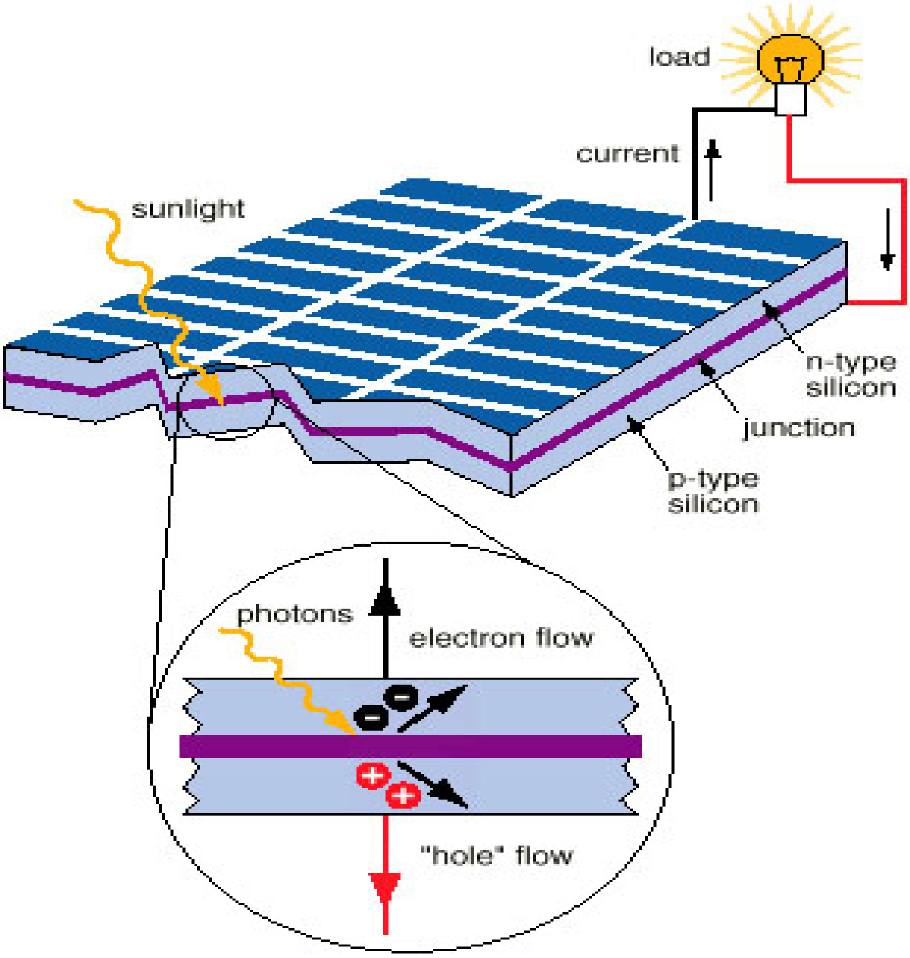

Fig. 1 : Operation of a photovoltaic cell

Cell type	Efficiency under Lab use (%)	Efficiency under field use (%)
Mono-crystalline Silicon	approx. 24	14 to 17
Poly-crystalline Silicon	approx. 18	3 to 15
Amorphous Silicon	approx. 13	5 to 7

Table 1 : Efficiencies of Photovoltaic cell types

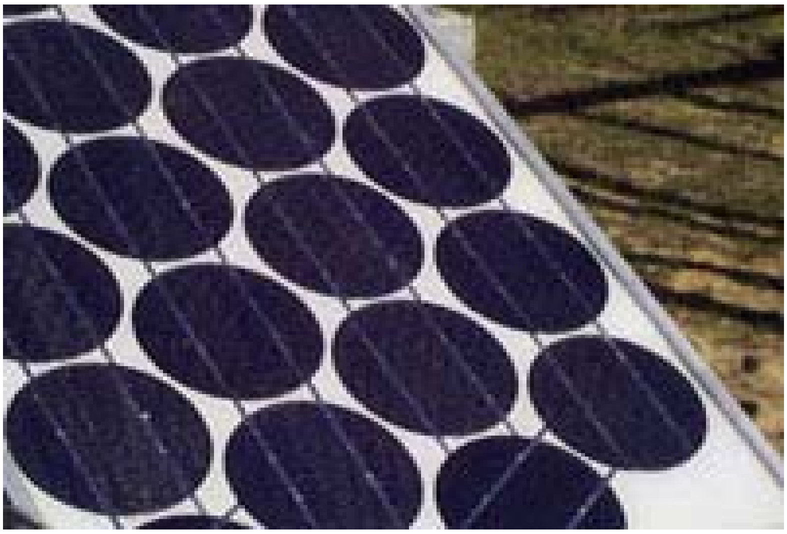

Photo 1 : Solar cells wired into a photovoltaic module

production of photovoltaic cells requires advanced technology, they are very simple to use [2].

PV cells are wired in different configurations to form PV modules and arrays (Photo 1). Once installed, PV modules and arrays require no maintenance other than an occasional cleaning of their surface.

Photovoltaic is one of the most benign methods of power generation known. Its benefits are many:

- Clean and green energy source
- Quiet operation and long life
- Reliable and minimal maintenance
- Modular and expandable
- Cost competitive with other energy sources.

A few photovoltaic installations are shown in Photo 2, 3, 4, and 5. From the power generated by solar arrays, stored in batteries, and converted to 230 AC

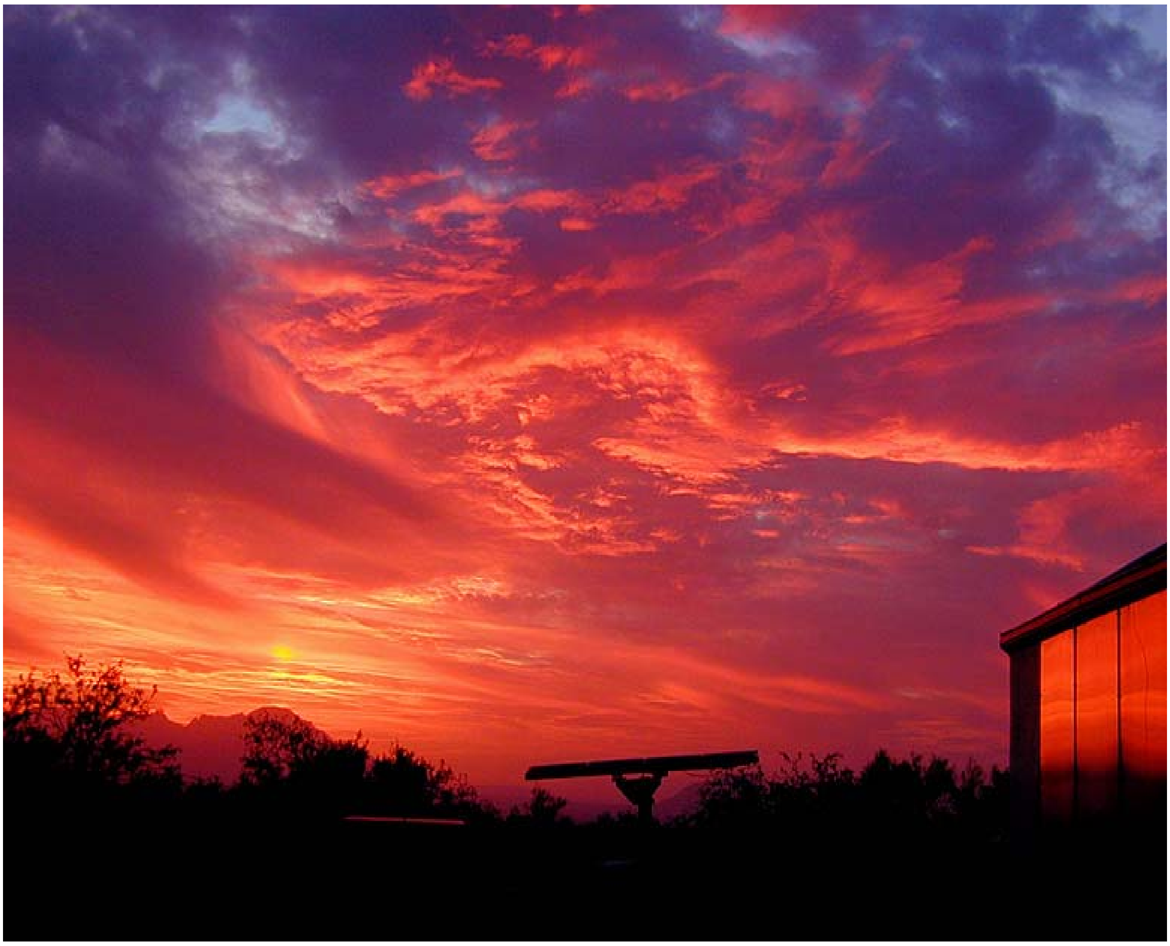

Photo 2 : Photovoltaic Panel for harvesting solar energy

Photo 3 : Photovoltaic Panels mounted in field

Photo 4 : Adjustable Photovoltaic Panels

Photo 5 : Photovoltaic Array

household current with an inverter, one can run many (though *not* all at a time in case of small photovoltaic installations) appliances [3] such as:

- Lights
- Radio receiver
- TV and VCR
- Refrigerator
- Microwave oven
- PC
- 1/2 horse power pump for water
- other appliances.

3.6 12–Volt Direct Current System

Since appliances, motors, and electronic devices run more efficiently on direct current when compared with their AC counterparts, a 12 V DC system is installed for the appliances which run with DC current. Fig. 2 shows a typical system consisting of one 40-watt solar panel and a large capacity storage battery to provide direct DC power. The system supplies power for three of the five DC pumps and a DC exhaust fan for a greenhouse. The pumps only use 10 watts each, but each pump is capable of moving three gallons of water a minute. The fan only uses 16 watts, less than half the wattage necessary to run an AC fan of the same size.

4.0 LOW-COST LIGHTING FOR RURAL HOUSES

Some attempts to provide lighting for rural houses in remote villages in Nepal, Sri Lanka, Bolovian Andes, etc. are ongoing [4]. Fig. 3 shows a rural house lit by using solar photovoltaics. A solar panel generates electric power that gets stored in sealed rechargeable batteries through a charge controller. The DC power thus stored is converted to AC by means of an inverter. The AC power is distributed through a low cost local grid network to groups of houses and street lamps. Each group has a distribution box containing a fuse and provides 50 watts of power per household (Fig. 4). The system is installed in village of Pokunutenna, situated bordering Uda Walawe National Park, in Sri Lanka.

4.0 LOW-COST LIGHTING FOR RURAL HOUSES

Some attempts to provide lighting for rural houses in remote villages in Nepal, Sri Lanka, Bolovian Andes, etc. are ongoing [4]. Fig. 3 shows a rural house lit by using solar photovoltaics. A solar panel generates electric power that gets stored in sealed rechargeable batteries through a charge controller. The DC power thus stored

is converted to AC by means of an inverter. The AC power is distributed through a low cost local grid network to groups of houses and street lamps. Each group has a distribution box containing a fuse and provides 50 watts of power per household (Fig. 4). The system is installed in village of Pokunutenna, situated bordering Uda Walawe National Park, in Sri Lanka.

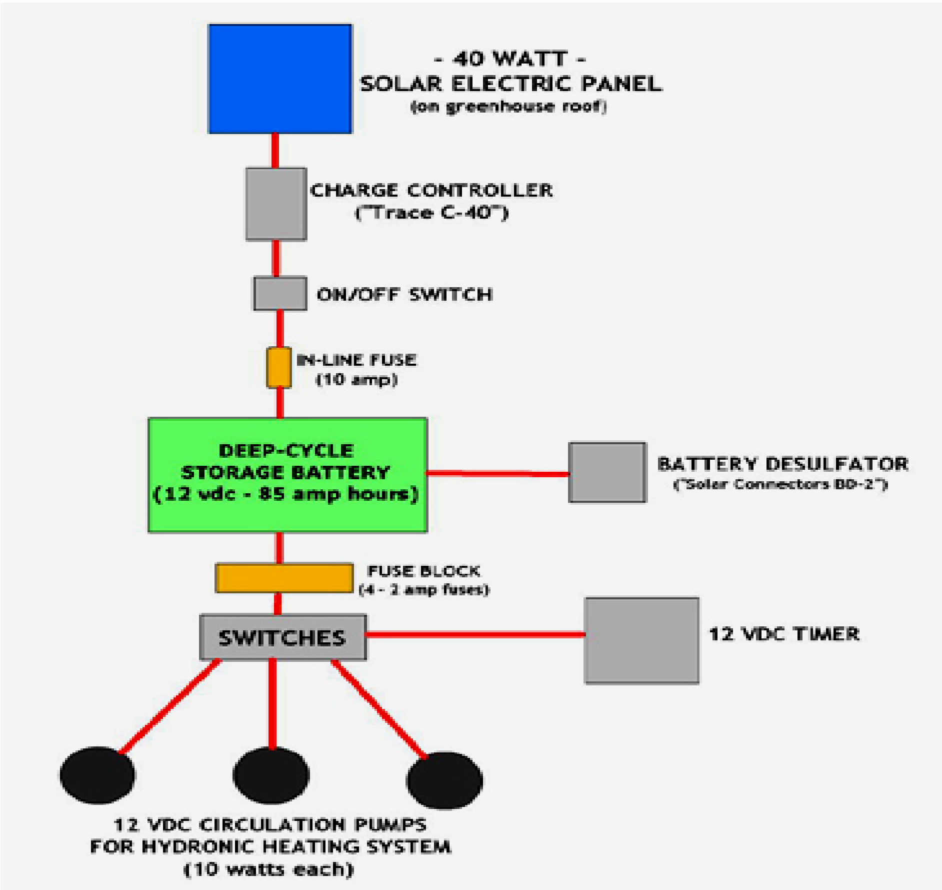

Fig. 2 : 12 V Direct Current System

4.1 Solid-State Lighting Technology

Under 'Light Up The World Organization' in cooperation with the University of Calgary, Canada, low cost lighting is provided by using White Light Emitting Diodes (WLEDs) [5]. LUTW founded in 1997 by Dr. Dave Irvine-Halliday is a humanitarian initiative whose chief goal is to assist poor villagers in the developing world obtain a useful, safe, reliable, environmentally friendly, and low-priced solid-state lighting based home lighting. In the village of Endagalayaya,

Fig. 3 : Photovoltaics for Lighting a rural house

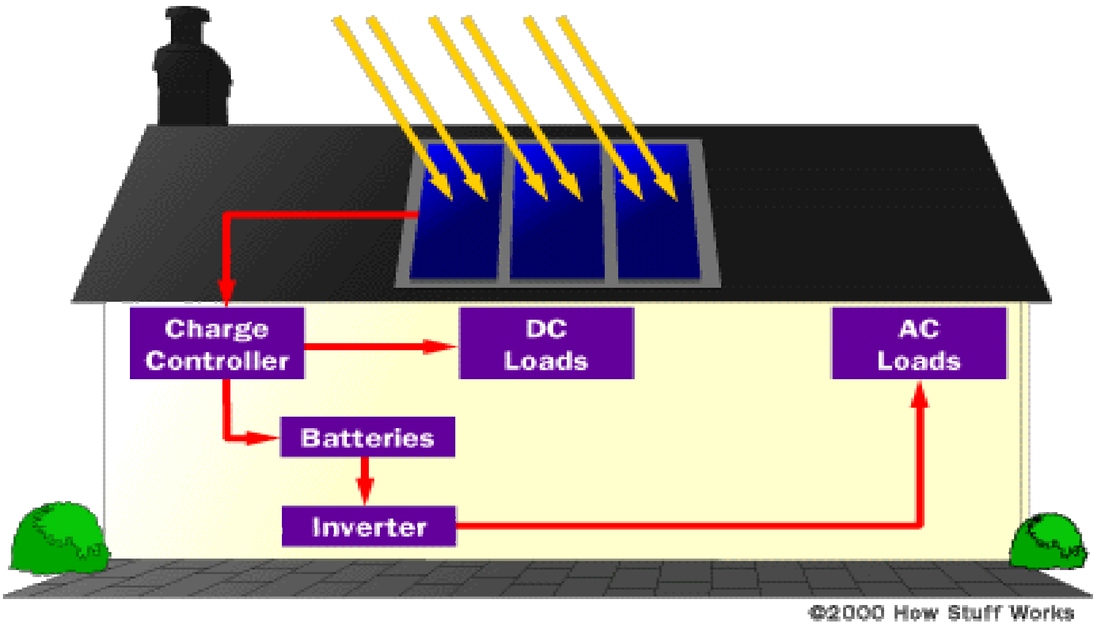

Fig. 4 : Schematic of a PV system with battery storage

adjacent to Pokunutenna, each household is provided with two 1-watt WLED and a compact 7.2 Ah sealed lead-acid battery. WLEDs use 5% of the energy of a conventional incandescent bulb.

Single WLED provides luminosity greater than that of a traditional kerosene lamp. Two 40-watt solar panel charging stations placed strategically in the village charge the individual household batteries. Initial trials have shown that this can be a good interim measure of providing a replacement to the kerosene lamps, until a more complete system of rural electrification is planned for lighting and other applications. Two more villages in central Sri Lanka, comprising of nearly 100 homes have been provided similar WLED-based lighting systems. Also, similar lighting is provided to light up homes and schools in remote, rural villages in Bolivian Andes [6].

4.2 Benefits of Solid-State Lighting

Since WLEDs use less than a single Watt, a hundred homes can be lit with the energy it would take to illuminate one 100-watt incandescent bulb. They are also cheap, and increasingly easy to manufacture in the developing world. Ultra-long life (100,000 hours) over forty years at 6 hours per night usage drastically reduces the maintenance requirements. Best yet, the efficiency of WLEDs has so far followed Moore's law, doubling roughly every 18 months. Based on pilot projects in India, Sri Lanka and Nepal, there is every reason to hope that these tiny diodes will soon be used in billions of rural homes around the world.

The solid-state lighting could: (1) decrease the global electricity used for lighting by 50%, (2) decrease the total global consumption of electricity by 10%, and (3) reduce global carbon emissions by 200 million tons/year [7].

The solid-state lighting technology can reorient development strategies toward the creation of enterprise, increased employment, enhanced income, gender equity, and protection of the physical environment.

5.0 CONCLUDING REMARKS

Jim Rohn, a motivational philosopher, advocates a simple but powerful concept -- the ant philosophy [8]. Ants never quit looking for where they are supposed to go. If they are heading somewhere and one stops them, they look for another way; they will climb over or climb under or climb around. Situation now demands a similar philosophy and approach, so that rural masses are not deprived of energy for their households. There are several alternatives and technology options available. While centralized grid-connected energy systems may not be cost effective in foreseeable future for lighting and other applications in remotely located rural households, decentralized community generating systems based on renewable energy sources like photovoltaics, wind, biomass offer a viable and low cost solution. Photovoltaic installations combined with technological options like solid-state devices for illumination purposes [9] can be a sustainable alternative means of providing a solution independent of the grid-connected systems. Recently announced direct methanol fuel cell (DMFC) can output 100 milliwatts of power for 20 hours with a 2 cc charge of methanol [10]. The DMFC has a potential for its usage in stand alone systems [11].

The Final Political Declaration [12] at the International Conference on Renewable Energies, held at Bonn, Germany, 1 - 4 June 2004, acknowledges that renewable energies (solar, wind, hydro, geothermal, biomass and biofuels) combined with enhanced energy efficiency can significantly contribute to sustainable development, to providing access to energy, especially for the poor; to mitigating greenhouse gas emissions, reducing harmful air pollutants, thereby creating new economic opportunities and enhancing energy security through cooperation and collaboration.

6.0 REFERENCES

[1] Markvart, T. (ed) (1995). Solar Electricity, John Wiley & Sons Ltd, Chichester.

[2] Zweibel, K. (1990). Harnessing Solar Power: The Photovoltaics Challenge, Plenum Press, New York.

[3] Foley, G. (1995). Photovoltaic Applications in Rural Areas of the Developing World, World Bank.

[4] Seneviratne, L. and G. Rossel (2004). Lighting Up a Village, *Refocus*, Jan./Feb. 2004, pp. 26-28.

[5] Anon. (2002). Benefits of Lumileds Solid-State Lighting Solutions vs. Conventional Lighting, *Application Note # AB 17*, October 14, 2002. (http://www.lumileds.com/pdfs/AB17.PDF).

[6] Fairley, P. (2004). Lighting up the Andes, IEEE Spectrum, Vol. 41, No. 12 (International Edition), December 2004, pp. 32-37.

[7] Anon. (2004). White Light Emitting Diodes (WLEDs), *RESPO Vision*, Vol. 27, June 2004, pp. 5-6 & 13.

[8] Rohn, Jim (2004). The Ant Philosophy, *Jim Rohn's E-magazine*, Issue # 221, 27 Jan. 2004 (http://www.jimrohn.com/ezineArchives/2004/221.asp).

[9] Mukherjee, P.K. (2004). LEDs will usher in a New Illumination Era, *Dream 2047 – Monthly Newsletter of Vigyan Prasar, New Delhi*, Vol. 6, May 2004, pp. 22-23.

[10] Anon. (2004). Toshiba announces world's smallest Direct Methanol Fuel Cell with energy output of 100 milliwatts, *PR Newswire*, June 24, 2004.

[11] Anon. (2004). Toshiba reveals thumb-sized 100 mWe DMFC prototype, *Fuel Cells Bulletin (Elsevier)*, Vol. 2004, Issue 8, August 2004, pp. 2-3.

[12] Anon. (2004). The Final Political Declaration : International Conference on Renewable Energies, Bonn / Germany, June 1-4, 2004. (http://www.renewables2004.de/pdf/Political_declaration_final.pdf).

ABOUT THE AUTHORS

VIJAYA AGARWAL. Presently with the Department of Agricultural Structures & Environmental Engineering, Electrical Engineering Division, at Jawaharlal Nehru Agricultural University, Jabalpur/India; she holds a Postgraduate Degree in Electronics and

Telecommunication Engineering. Her areas of interest are: Applications of Electrical, Electronics and Computer Engineering in Agriculture, Rural Electrification and Energy Efficient Systems. She has more than 40 publications and conference papers to her credit. She has chaired sessions and delivered key-note / invited lectures in several National and International Conferences.

Prof. Vijaya Agarwal has been the President of the Engineering Sciences Section, Indian Science Congress during 1993-94. She was a Member of the National Executive Committee and the National Council of the Indian Science Congress for three terms. As a Member of *Akhil Bhartiya Darshan Parishad* (Indian Philosophical Society), she is pursuing philosophical and logical approach to scientific and technological needs of the society. She is actively associated with the Indian Women Scientists' Association.

J. H. AGARWAL. Former University Professor and Director (Instrumentation), Jawaharlal Nehru Agricultural University, Jabalpur/India, Dr. Agarwal is associated with several Ministries / Departments of Government of India as Expert Member on technical committees and is active in professional societies like Institution of Electronics and Telecommunication Engineers (IETE), Indian Science Congress (ISC), Computer Society of India (CSI).

He is a pioneer in the field of applications of Electronics, Microprocessors, Computers and Information Technology in Agriculture. In 1970s, associated as an Expert with the Electronics Commission of India and the Scientific Advisory Committee to the Cabinet, Government of India, he introduced the applications of Electronics and allied Technologies in Agriculture in India. Thereafter, he has been guiding a large number of programmes under the ICAR, CSIR, DST, DOE, and several Universities. During 1985 to 1995, Dr. Agarwal headed a prestigious project of UNDP and Government of India on "Applications of Microprocessors and Computers in Agriculture".

He has been a Member of National Executive Committee of CSI and served as the Chairman of CSI Division III on Scientific Applications of Computers and Information Technology. He was on the National Council of Institution of Electronics and Telecommunication Engineers and was the Vice President of IETE, and Member on the Governing Council of DOEACC Society of Ministry of Communications and Information Technology, Government of India.

■