1 Photovoltaic capacity-building: Brazil

GENERAL INFORMATION

- **Implementing institution:**
  Laboratory of Photovoltaic Research (LPR)

- **Head**
  Ivan Chambouleyron

- **Details of institution**
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- **Implementation period**
  Established in 1979; ongoing.

◆ **Costs**

Total funding of about US$5 million.

Most funds from Brazilian funding agencies: *Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Financiadora de Estudos e Projetos (FINEP), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP)* and *Fundação Coordinação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).*

Private sector: US$1 million, mainly from *Fundação CESP*, Brazil.

International sources: US$100,000: European Union (EU), Organization of American States (OAS) and *Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (CYTED).*

SUMMARY

The Laboratory of Photovoltaic Research (LPR) was established at the State University of Campinas (UNICAMP) in 1979. Within a few years, the laboratory had established itself as a pioneer in solar power research and development, both within Brazil and throughout Latin America. While LPR focused its research on developing several new technologies for solar cells, modules and semi-conductors, it was also training young Brazilian and Latin American scientists in laboratory work and offering graduate and postgraduate courses in solar energy conversion, materials science and electronic device physics.

The main outputs of the laboratory are:

- highly trained Brazilian and Latin American scientists;
- significant contributions to state-of-the-art photovoltaic (PV) materials and devices; and
- increased understanding of the socio-economic aspects relating to the use of solar energy in developing countries.

In its first two decades of operation, LPR has awarded 50 M.Sc. and Ph.D. degrees. It has also generated a great deal of important research work: a total of 300 papers and technical communications on solar energy, PV conversion, materials science and device physics has been published in journals and/or presented at international conferences. Other works on the socio-economic aspects of solar energy have been equally successful on the international stage.

LPR is regarded as one of the top institutions of the developing world in terms of capacity-building and scientific output, and it has a prestigious international standing among the scientific community in both developed and developing countries. Its staff members have received national and international awards and have served on the committees of most international conferences on solar energy conversion in Asia, Europe, Latin America and the United States. LPR staff members are also on the editorial boards of important specialist journals, such as *Solar and Wind Energy*, *Renewable Energy*, *Solar Energy Materials* and *The Brazilian Journal of Physics*.

International partnerships are important to the work of LPR, which has collaborated with other laboratories in Argentina, France, Germany, Italy, Mexico and the United States. Among its achievements are promoting the study of solar energy conversion in the Latin American region (having trained students from Argentina, Bolivia, Brazil, Chile, Colombia, Peru, Uruguay and Venezuela) and helping to develop national awareness of the value of renewable energy for sustainable development (which is now included as an essential element of government energy planning).

Background and justification

In recent decades, it has become clear to national and international organizations involved in energy, the environment and development that action should be taken to stimulate the dissemination and use of new, renewable sources of energy in developing countries. Research and development (R&D) laboratories have been set up and technologies adapted with the ultimate goal of increasing the supply of energy and improving food production, health care and the environment, especially in the developing world.

Brazil imported most of the oil that it needed for its industrial development until the oil crisis of 1973, when the resulting price increases for liquid fuels triggered an energy policy that looked to new, renewable sources of energy. Research groups all over the country started to search for ways to answer this challenge, including a programme aimed at the industrial production of biofuel from sugar cane. In 1975, the Energy Group was established at UNICAMP with members from the university physics, chemistry and biology departments as well as its schools of mechanical, electrical and chemical engineering. The Group started to research various aspects of renewable energy, including architectural designs, hydrogen as an energy source, biomass conversion and solar thermal-energy conversion.

The main thrust of the solar energy research of the Energy Group was to develop the technology for generating low-temperature heat from solar radiation for use in coffee and soybean drying. At the time, Brazil had no activities or specialists in photovoltaic (PV) materials, and Ivan Chambouleyron was working on solar cell R&D in Mexico City. He visited UNICAMP in 1978 as part of a United Nations Environment Programme (UNEP) mission to study Latin American capabilities in the field of renewable energy resources and, following an invitation from the Energy Group, started a PV research programme in Brazil one year later.

The development and dissemination of new technologies depend on having qualified people to carry out and lead R&D efforts and to communicate their results within countries, regions and the international community. Recognizing that many developing countries lack such human resources, LPR made the training of specialized personnel one of its top priorities. With 12,000 undergraduate and about 50 graduate students, UNICAMP is now one of leading research centres in Latin America, accounting for 15 per cent of all the research carried out in Brazil. Its reputation for training highly qualified professionals has attracted a substantial number of scientific and technological industries to the area, which is also home to several other high-tech R&D institutions.

Description

In addition to the training of PV scientists, other areas of excellence of LPR include its research work into amorphous semiconductors, semiconductor materials and devices, and technology for solar cell fabrication, characterization and PV applications.

Chambouleyron's first action when setting up LPR was to contact the local electricity utility company, the Energy Company of São Paulo (CESP), to ask for funds. CESP liked his proposal and endowed the research programme with an initial US$400,000. Next, a laboratory was supplied with basic equipment (most of which was imported). Two technicians were trained in vacuum, cryogenic and semiconductor technologies.

The novelty and social implications of renewable energies encouraged numerous students to volunteer for work in the newly established facilities. Although the laboratory still lacked some experimental equipment, it was able to carry out research and establish collaboration with existing groups at UNICAMP and other institutions.

Within two years, LPR was producing silicon solar cells, and, a year later, it had developed small-area amorphous silicon solar cells. Although much of this early work duplicated research that had already been carried out in developed countries, these innovations were completely new to Brazil and Latin America and gave the laboratory instant political credibility. In addition, the experience gained from these first research initiatives was a useful foundation for the future, more original work of LPR.

A second source of funding for LPR was *Financiadora de Estudos e Projetos*

(FINEP), a federal agency interested in the development of solar-grade silicon cell technology. The programme was quite successful in this area and attracted the attention of a local solar-cell industry, Heliodinamica SA, with which LPR maintained informal but productive links for five years. However, because it takes a long time for PV conversion programmes to achieve tangible results, it is difficult to find donors that are willing or able to support such efforts for long and seemingly fruitless periods. The financial support of CESP and FINEP, for example, continued for only the first few years of the existence of the laboratory. Fortunately, by the time that CESP and FINEP withdrew their support, LPR was already well established and able to obtain funding from other sources. The momentum acquired during the first few years, in fact, was enough to keep research going at an ever-increasing speed.

The following are some of the most significant technical outputs of LPR:

- It reproduced the manufacturing technology for single-crystal silicon solar cells with 12-per cent conversion efficiency. Later, high-efficiency concepts were investigated, leading to an improved conversion efficiency of 17 per cent.
- It carried out R&D, which resulted in surface barrier tin oxide/silicon oxide/crystalline silicon solar cells of 4 square centimetres and with 14-per cent conversion efficiency.
- It developed technology for solar-grade polycrystalline solar cells with 5-per cent conversion efficiency in small areas (0.5 square centimetres). The solar-grade silicon base material is of 99.99 per cent purity and was grown out of metallurgical solution at UNICAMP.
- It designed and built a deposition system for hydrogenated amorphous silicon p-i-n junction structures with a conversion efficiency of 7 per cent in small areas (0.5 square centimetres).
- As part of its solar-cell computer modelling activities, it developed and published new views on the conversion efficiency of stacked tandem solar cells.

In addition, LPR has generated nearly 50 Ph.D. and M.Sc. theses over the past 20 years, organized several national and international events on photovoltaics, and published or presented more than 300 scientific research works in publications or at conferences and other events.

Patenting and commercialization

Patenting and commercialization were not among the main objectives of LPR. However, two pieces of software have been registered for patents.

Partnerships

Much of the success of the LPR training and research work is the result of its vast number of collaborations with numerous higher-education, research and other institutions in Brazil and the rest of the world. At home, it has worked with the public universities of Pernambuco, Rio de Janeiro, Rio Grande do Sul and São Paulo, and the private institutions CESP, Heliodinamica SA, Prologica SA, Texas Instruments (Brazil) and the Catholic University of Rio de Janeiro. Internationally, it has worked with:

- Argentina: INTEC Engineering, and universities in Buenos Aires and Santa Fe;
- Colombia: *Universidad del Univalle* (Cali), and the *Universidad Nacional de Colombia* (Bogota);
- France: *Centre National de la Recherche Scientifique (CNRS)*, Grenoble laboratories and the University of Paris VI;
- Germany: Max Planck Institute (Stuttgart), Paul Drude Institute (Berlin) and the Walter Schottky Institute (University of Munich);
- Italy: the University of Rome (La Sapienza) and the University of Trento;
- Mexico: National Independent University of Mexico and National Polytechnic Institute;
- United States: Harvard University, Princeton University and the University of Utah;
- United Nations agencies: United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO) and the United Nations University (UNU);
- other international agencies: the International Centre for Theoretical Physics and the Third World Academy of Sciences (Trieste, Italy), the Inter-American Development Bank, the International Programme in the Physical Sciences (Uppsala, Sweden), the Latin American Energy Organization (OLADE, Ecuador), the Organization of American States (OAS), etc.

Replicability

The experiences of LPR in PV research and training are of national and international relevance. Thanks, at least in part, to the efforts of the laboratory, other similar laboratories have been established in Brazil and elsewhere in Latin America. While these laboratories have met with varying degrees of success (depending on their specific environments and situations), they have all contributed to increasing public awareness of the benefits of using new and renewable sources of energy. It is now clear that the existence of laboratories such as LPR is necessary for the launching of serious renewable energy programmes in any country.

LESSONS LEARNED

One of the problems that has continued to challenge the work of LPR is the lack of trained, motivated human resources throughout Latin America. The reasons for this lack include: a tendency among some research institutions to switch rapidly to new, fashionable subjects before significant results have been obtained in other areas; a failure to establish clearly defined research objectives that can be realized with the available resources; a belief that the use of sophisticated, modern equipment will lead automatically to important scientific or technical results; and misconceptions about the value of research on the part of officials at financing agencies.

Another significant factor in developing countries is the practice of sending young scientists to laboratories in developed countries for advanced training. This has advantages: students have access to more sophisticated equipment than they would have in their home countries; they can collaborate on research with more experienced scientists; and they come into contact with a wider range of colleagues from different parts of the world.

However, this practice also has several drawbacks: the training students receive abroad may not be appropriate for the needs of their home countries; they may find that the research work done at home is undervalued because it is less advanced and less cutting-edge; and they may join the brain drain, finding work in other — usually developed — countries, where salaries are higher and facilities are more up to date. LPR helps to mitigate this problem by providing top-quality, prestigious research and training facilities in Latin America while being geared to the Latin American context and needs. The work of the laboratory is also relevant to — and highly thought of in — the rest of the world, including developed countries.

The initial stages of the project demonstrated that a general understanding of the benefits of renewable energy can lead to changes in national legislation. Therefore, throughout the remainder of the project, the importance of raising and maintaining public awareness of the technologies was emphasized.

IMPACT

It takes a long time for new ideas, concepts and technologies to have an impact on policies, but Brazilian policy-makers are already well aware of the potential of solar energy. Today, several programmes are generating PV power in isolated communities, and solar electricity is on official agendas. Numerous institutions offer courses in solar energy, and journals are dedicated to the spread of solar technologies.

When LPR started its first projects in 1979, Brazil had no experience of solar energy, so all of these new developments have taken just over 20 years to evolve. Recent data indicate that the solar systems installed in Brazil are generating peaks of more than five megawatts of power for rural homes, water pumps and street lighting. Solar electricity is improving the lives of thousands of families across the country.

The successes of the laboratory have been acknowledged at several international events, including: the International Workshop on Mass Production of Photovoltaics: Commercialization and Policy Options, held in São Paulo (Brazil) in September 1991; the Workshop on Crystalline and Amorphous Silicon and Its Alloys, hosted by LPR in May 1992; the Workshop on Thin Films for Photovoltaic Applications, organized by LPR in February 1994; and the Twentieth International Conference on Amorphous and Micro-crystalline Semi-conductors, to be held in São Paulo State (Brazil) in 2003, with Professor Chambouleyron as Chair and Professor Alvarez as Vice-Chair.

Future plans

The future plans of LPR include:

- providing cutting-edge leadership as an international centre in basic research into PV materials and devices;
- providing regional leadership in applied research, development and training in solar electricity generation technologies;
- serving as a regional resource of technical expertise in PV demonstration projects and implementation problems;
- serving as a regional centre for renewable energy policy research, studying the social and cultural factors relating to the use of solar energy;
- continuing to promote a strong scientific exchange with other countries in the region by offering advanced laboratory training to scientists and technicians, and specialized courses on PV conversion;
- developing special research projects that are of particular interest to the region.

Publications

The following are some examples of the publications that have been generated by this project:

Chambouleyron, I. (1984). Multiple-gap amorphous solar cells reconsidered. *Solar Cells*, 12(4): 393-400.

_______ (1986). A Third World view of the photovoltaic market. *Solar Energy*, 36(5): 381-386.

_______ (1990). Photovoltaic power generation: social, economic and environmental aspects. *Energy and Environment into the 1990s*, Volume 1. Pergamon Press. 205 pp.

_______ (2000). The development of science and technology in Latin America. *Chemistry and Industry*, 1(11).

Chambouleyron, I. and Comedi, D. (2001). Amorphous silicon and germanium. In K.H.J. Buschow, R.W. Cahn, M.C. Flemings, B. Ilschner, E.J. Kramer and S. Mahajan, eds. *Encyclopedia of materials: science and technology*, Volume 1, pp. 289-299. Elsevier Science, Oxford, United Kingdom.

Chambouleyron, I., Ventura, S., Birgin, E.G. and Martinez, J.M. (2002). Optical constants and thickness determination of very thin amorphous semiconductor films. *Journal of Applied Physics*, 92: 3093-3102.

Marques, F.C., Urdanivia, J. and Chambouleyron, I. (1998). A simple technology to improve crystalline solar cell efficiency. *Solar Energy Materials and Solar Cells*, 52(3-4): 285-292.

Santos, P.V., Graeff, C.F. de O. and Chambou-leyron, I. (1991). Light-induced meta-stability in a-Ge:H. *Journal of Non-Crystal Solids*, 128(3): 243-254.