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OVERVIEW OF PHOTOVOLTAIC SOLAR CELL R&D CAPABILITY IN CANADA ED. 4 (2009-2012)

Canada

OVERVIEW OF PHOTOVOLTAIC SOLAR CELL R&D CAPABILITY IN CANADA ED. 4 (2009-2012)

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EXECUTIVE SUMMARY

This report is the fourth of a series of reviews of the R&D capability in Canadian universities in the field of photovoltaic solar cells carried out by Natural Resources Canada (NRCan), CanmetENERGY, located at Varennes, Quebec. The objective of these reviews, which began in 2004, is to highlight the activities done in this area in Canada, monitor the R,D&D investments and disseminate the information gathered in order to facilitate the creation of partnerships amongst the researchers, government, and industry.

Worldwide demand for environmentally clean and sustainable energy continues to spur renewable energy development programs, including PV solar to electrical energy conversion. During the period under review (FY09/10 through to FY11/12) Canadian photovoltaic R&D capability was for the most part funded by NSERC at a level of about $4 million per annum and was involved in a broad range of basic research (organic solar cells, dye sensitized solar cells, thin silicon devices, etc.). PV R&D is performed in about 20 Canadian universities, mostly in Ontario and Quebec, within various science (chemistry, physics, materials science) and engineering (physics, chemical, electrical, computer, information technology, etc.) departments. According to this review, the fraction of the university groups working in collaboration with a national or international manufacturing partner continues to increase. Also, Canadian university capability to support research, development and implementation of photovoltaic solar cells in Canada is ample and diverse; and, as evidenced by the kind of research and the volume and quality of publications, the research is forefront and world-class.

In addition to NSERC funded R&D in Canadian universities, the National Research Council of Canada is also involved in photovoltaic R&D through the NRC National Institute for Nanotechnology (NINT) in collaboration with the University of Alberta, and through project SUNRISE in collaboration with the University of Ottawa and a number of industrial partners. Also, Sustainable Development Technology Canada is funding several PV development & demonstration projects in cooperation with universities and Canadian industry.

The establishment by NSERC of the Photovoltaics Innovation Network at McMaster was a major boost to university R&D on photovoltaic devices, and eventually photovoltaic technology development in Canada. The new Network has improved the level of collaboration amongst researchers, as well as with industry, and is making significant R&D breakthroughs.

BACKGROUND

Natural Resources Canada (NRCan), CanmetENERGY, located at Varennes, Quebec, manages the Integration of Renewable and Distributed Energy Resources Program, which includes Solar Photovoltaic Energy. Since 2004, CanmetENERGY monitors the activities of Canadian universities in the field of photovoltaic solar cell R&D. This report is the fourth of a series of reviews [1, 2, 3] of the R&D capability in Canadian universities in the field of photovoltaic solar cells. The objective of these reviews is to highlight the activities done in this area in Canada, monitor the R, D&D investments and disseminate the information gathered in order to facilitate the creation of partnerships amongst the researchers, government, and industry.

According to the 2013 IEA Photovoltaic Power Systems Program report [4], in 2012 photovoltaic (PV) technology for generating electricity amounted to a total installed capacity of about 96.5 GW [4]. Some 28 GW were installed in 2012, about the same capacity as in 2011. In Canada, the domestic market has

been growing on average at about 26% per year since 1993 and about 48% since 2000. It amounted to a total installed grid-connected capacity of 766 MW in 2012 compared to 497 MW in 2010 [5]. The Province of Ontario's feed-in tariff (FIT) program, launched in 2006 and expanded in 2009, has been a major stimulus. In 2012, it contributed 88 MW of grid-connected applications for residential and building-integrated applications, and 181 MW for large, ground-mounted, utility-scale systems. Under the FIT program, PV systems can enter into a 20-year contract to receive a fixed price of up to $0.549 CAD/kWh for the generated electricity.

Today, the main drawback of PV is still its relatively high price compared to electricity generated from conventional fossil fuels, nuclear, or hydroelectric power generation, partly because of solar cell production costs. However, PV module prices are coming down at a rate of about 30% per annum due to investments in technology improvements, plant automation and large manufacturing capacities. There is presently an expectation that the cost-reduction trend will continue further with continued research, development and demonstration (R, D&D). This high potential in market growth is spurring worldwide investments in PV R, D&D, making it one of the highest recipients of renewable energy technology investments. Public funding for PV R, D&D in IEA Photovoltaic Power System (PVPS) member countries amounted to $610 M ($US) in 2011 [4]. In Canada, public funding of PV R, D&D in 2012 amounted to $15 M [5]. Some of the leading countries in terms of R, D&D funding include the US ($223 M), Japan ($102 M), Korea ($94 M), and Germany ($78 M). Global investments in technology development and manufacturing will be required in order to bring down further the costs of PV.

In Canada, the Natural Science and Engineering Research Council of Canada (NSERC) and other provincial R&D programs targeting sustainable energy development are the main funding sources for material and solar cell research in about 20 institutions, mainly universities, included in this report (refer to Table 1-3).

CANADIAN UNIVERSITY CAPABILITY IN PHOTOVOLTAIC SOLAR CELL R&D

This document is an update of previous reviews [1,2,3], the latest carried out in 2009 [3], and focuses on R&D capability of Canadian universities in the field of photovoltaic solar cell research for the period covering April 2009 to March 2012. This update is based on information provided by researchers and the main R&D funding agencies, as well as information available from public sources through the internet. Research, carried out at Canadian universities, is summarized in Table 1 and discussed in more detail in Appendix 1.

According to the Natural Sciences and Engineering Research Council (NSERC) data [6], outlined in Table 1, Canadian university research underlying photovoltaics is carried out in about 50 university laboratories located mostly in Ontario (25) and Quebec (17), and to a lesser extent in Alberta and British Columbia. The research is multidisciplinary and covers a rather broad spectrum of forefront R&D. It is mostly performed in departments of Chemistry and Chemical Engineering (21), Electrical and Computer Engineering (13), Physics (7), Materials Science, and Mechanical Engineering. According to information provided by lead university scientists, more than about 400-450 full-time equivalent researchers (professors, postdoctoral fellows, research associates, graduate students, and technologists) are presently involved in PV solar cell R&D in Canadian universities.

A key R&D highlight during this reporting period was the development of the most efficient colloidal quantum dot solar cell as of 2011 by the Sargent group at the University of Toronto and other partners [10]. The team was able to make solar cells from quantum dots with a conversion efficiency up to 6%, a record result certified by Newport which is an external laboratory accredited by the US National Renewable Energy Laboratory.

Table 1. Researcher / Institution / Department / PV Research Area*

(*According to NSERC grant titles for FY09/10, FY10/11, FY11 /12) [6]

Researcher	University	Department	PV Research Area*
Adronov, Alex	McMaster University, ON	Chemistry	Covalent and supramolecular polymer chemistry of carbon nanotubes; Development of nanostructured photovoltaic devices
Aimez, Vincent	Université de Sherbrooke, QC	Electrical Engineering and Information Technology	Innovative photonic devices realization using heterogeneous integration and quantum well dot intermixing; nanointegration for sustainable photonics solutions; solar cell development for integration to solar cogeneration plants working at high temperature.
Arès, Richard	Université de Sherbrooke, QC	Mechanical Engineering	Semiconductors using nanostructures for record increases in solar-cell efficiency; chemical beam epitaxy for photovoltaics and GaN-based electronics; effects of bulk and surface defects in germanium on the performance of multijunction solar cells
Barati, Mansoor	University of Toronto, ON	Chemistry	Low cost production of solar grade silicon from metallurgical grade silicon
Baumgartner, Thomas	University of Calgary, AB	Chemistry	Organophosphorus pi-conjugated materials for organic electronics
Beatty, John Thomas	University of British Columbia, BC	Microbiology and Immunology	Engineering of photosynthesis proteins and attachment to electrodes for conversion of solar light to electrical power
Bender, Timothy	University of Toronto, ON	Chemical Engineering and Applied Chemistry	Subphthalocyanines to achieve broad spectral absorption and produce a photocurrent in an organic solar cell
Berlinguette, Curtis	University of British Columbia, BC	Chemistry	Solar energy conservation materials
Brett, Michael	NRC-NINT / University of Alberta, AB	Electrical and Computer Engineering	Nanostructured device architectures
Buriak, Jillian	NRC-NINT / University of Alberta, AB	Chemistry	Development of low cost, high energy output photovoltaic systems through applied nano-science; practical approaches towards building nanoscale architechtures; nanoscale graphitic coatings for photovoltaic and battery applications

Côté, Michel	Université de Montréal, QC	Physics	Electronic structure of polymers for photovoltaic applications and strongly correlated electron systems
Demopoulos, George	McGill University, QC	Mining and Materials Engineering	Nanocrystalline titania-based dye-sensitized solar cells; engineering nanostructured titania thin film electrodes for highly efficient solar energy conversion and storage systems
Ding, Zhifeng	University of Western Ontario, ON	Chemistry	Low cost CIGS photovoltaic devices on flexible polymer films; new strategy on CIGS solar cells; enhancing efficiency of photovoltaic cells by optimizations of their thin films
ElKhakani, MyAli	Institut National de la Recherche Scientifique, QC	Physics	Novel solar cells based on the nanohybrids of multiple-exciton-generation quantum dots and high-mobility single-wall-carbon nanotubes
Gao, Jun	Queens University, ON	Physics	Polymer p-i-n junction for photonic device applications
Gaspari, Franco	University of Ontario Institute of Technology, ON	Faculty of Science	Staebler-Wronski effect in tritiated amorphous silicon
Hall, Trevor	University of Ottawa, ON	Centre for Research in Photonics	Semiconductors using nanostructures for record increases in solar-cell efficiency
Hanan, Garry	Université de Montréal, QC	Chemistry	New coordination complexes for solar energy conversion
Hill, Ian	Dalhousie University, NS	Physics	Materials and devices for photovoltaic energy conversion
Hinzer, Karin	University of Ottawa, ON	Information Technology and Engineering	Green optoelectronics: solar cells and lasers using nanostructured materials; 4CPV: Materials and processes for quad-junction concentrated photovoltaic (CPV) solar cells with conversion efficiencies in the 45%-50% range, grown by chemical beam epitaxy
Hotchandani, Surat	Université du Québec à Trois-Rivières, QC	Chemistry	Dye-sensitized nanocrystalline solar cells and gold nanoparticles
Huang, He	University of Toronto, ON	Electrical and Computer Engineering	Investigations of novel quantum materials for advanced solar cells; multiple exciton generation in quantum dot photovoltaics
Kitai, Adrian	McMaster University, ON	Materials Science and Engineering Physics	Growth of semiconductor materials for flexible displays and solar cells
Kleiman, Rafael	McMaster University, ON	Engineering Physics	NSERC Photovoltaic innovation network
Koivisto, Bryan	Ryerson University, ON	Chemistry and Biology	Towards More Efficient Photovoltaic Materials: Study Photoinduced Electron and Energy Transfer
Kherani, Nazir	University of	Electrical and	Advanced silicon photovoltaic devices;

	Toronto, ON	Computer Engineering and Materials Science	Characterization of Optical Losses and Potential Performance Enhancement Strategies in Solar Photovoltaic Module
LaPierre, Raymond	McMaster University, ON	Engineering Physics	Nanowire photovoltaics
Leclerc, Mario	Université Laval, QC	Chemistry	Polymeric/inorganic semiconductor nano-composite materials for low cost photovoltaic applications; ANR All-polymer solar cells
Li, Yuning	University of Waterloo, ON	Chemical Engineering	Development of polymer solar cell fibres; functional donor polymer semiconductors for hybrid solar cells; study of deposition conditions of metal oxides
Lu, ZhengHong	University of Toronto, ON	Material Science and Engineering	Polymeric/inorganic semiconductor nano-composite materials for low cost photovoltaic applications
Ma, Dongling	Institut National de la Recherche Scientifique, QC	Centre Énergie, Matériaux et Télécommunication	Synthesis, characterization and application of highly functional nanoparticles
Madden, John	University of British Columbia, BC	Electrical and Computer Eng	Photosynthetic protein-based solar cells
Marsan, Benoît	Université du Québec à Montréal, QC	Chemistry	New electrode materials for the oxygen evolution/reduction reactions; solar cells based on novel solvent-free gel elctrolytes
Mighri, Frej	Laval University, QC	Chemistry	Polymer nanocomposites for photovoltaic cells
Mi, Zetian	McGill University, QC	Physics	Full-solar-spectrum InGaN tandem solar cells on Si; green hydrogen: solar-powered photochemical water splitting on InGaN nanowire arrays
Morin, JeanFrancois	Laval University, QC	Chemistry	Polymeric/inorganic semiconductor nano-composite materials for low cost photovoltaic applications
Nunzi, JeanMichel	Queens University, ON	Chemistry	Light rectification for solar energy conversion
O'Leary, Stephen	University of British Columbia, B.C.	Engineering	Defect detection in photovoltaic solar cells using infrared imaging; semiconductor devices for new solar cell applications; Hybrid solar cells for future renewable energy applications; Real-time feedback for the deposition of amorphous silicon based photovoltaic solar cells
Pearce, Joshua	Queens University, ON	Mechanical Engineering	Effects of nanostructure and defect states in solar photovoltaic materials
Perepichka, Dmitrii	McGill University, QC	Chemistry	Fluorescent plastic waveguides for photovoltaic energy conversion
Sargent, Edward	University of Toronto, ON	Electrical and Computer Engineering	Atomic Layer Deposition for Advanced Photovoltaics and Optoelectronics.
Sazonov, Andrei	University of	Electrical and	Development of high efficiency flexible

	Waterloo, ON	Computer Engineering	photovoltaic modules
Scholes, Gregory	University of Toronto, ON	Chemistry	Polymeric/inorganic semiconductor nano-composite materials for low cost photovoltaic applications; photophysical studies of light harvesting in photosynthetic organisms and conjugated polymers
Seferos, Dwight	University of Toronto, ON	Chemistry	Optoelectronic polymer-, nano- and macroscale materials
Semenikhin, Oleg	University of Western Ontario, ON	Chemistry	Conducting Polymer Based Materials for Solar Energy Conversion; nanoscale characterization of novel hybrid organic thin film photovoltaic materials for solar energy harvesting
Shankar, Karthik	NRC-NINT / University of Alberta, AB	Electrical and Computer Engineering	One-dimensional hybrid nanostructure arrays from pi-conjugated organic small molecules and inorganic semiconductors for use in excitonic devices
Shih, Ishiang	McGill University, QC	Electrical and Computer Engineering	Novel III-V and I-III-VI based solar cells with enhanced energy conversion efficiency
Sivoththaman, Siva	University of Waterloo, ON	Electrical and Computer Engineering	Development and practical implementation of spectral engineering and nanotechnology concepts for high efficiency photovoltaic devices
Skene, William	Université de Montréal, QC	Chemistry	New self-assembled polyazomethines for photovoltaic devices
Thomas, Michael	University of Alberta, AB	Electrical and Computer Engineering	Nanostructured organic solar cells
Wartak, Marek	Wilfrid Laurier University, ON	Physics and Computer Science	Dynamical processes in quantum dots based solar cells

Canadian university R&D funded by NSERC [7] for the period FY05/06 to FY11/12 is shown in Figure 1. NSERC funding for the last five years was at about $4 M per annum, about twice the funding for the FY05/06-FY06/07 period - largely as a result of increased emphasis on renewable energy development.

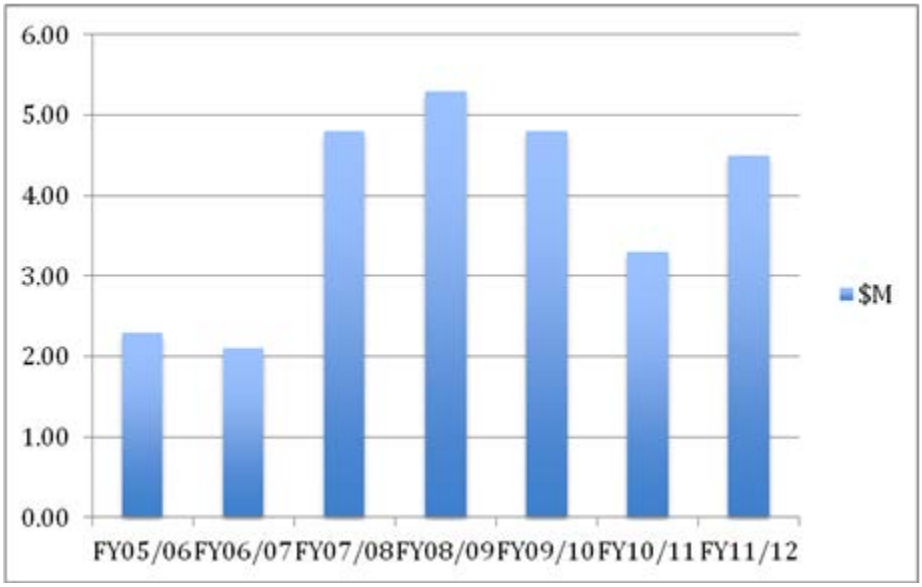

Figure 1. NSERC funding ($M) for PV during FY05/06 to FY11/12

In addition to NSERC funding of university research, the Canadian Foundation for Innovation continues to support relevant infrastructure at Canadian universities, as shown in Table 2 [7].

Table 2. CFI-funded infrastructure projects relevant to PV solar cells R&D

Project Title	Institution	Amount	Year
Laboratory for Advanced Photovoltaic Research	McMaster University	$4,346,418	2009
Laboratory for the Fabrication & Testing of FRET and Plasmon-Enhanced Nanostructured Photovoltaic Devices	University of Alberta	$80,000	2010
Laboratory for the Development of Optoelectronic Polymers and Nanomaterials	University of Toronto	$400,000	2010
Facility for Nanostructures, Surfaces, and Sensor Interfaces	Carleton University	$761,054	2011
Infrastructure for Research into the Creation of High Efficiency Organic Photovoltaic Cells	University of Saskatchewan	$126,614	2011
Multidisciplinary Test Platform for 1000x Concentrated Photovoltaic (CPV) Performance and New Technology	Université de Sherbrooke	$120,000	2011

ESTABLISHMENT OF A CANADIAN PHOTOVOLTAICS INNOVATION NETWORK

A major development for the period under review has been the establishment of the NSERC Photovoltaic Innovation Network, in May 2008, to promote PV innovation by linking university researchers amongst them, as well as with industry. CFI endowed the Network with a 4.3 M$ grant to establish the Laboratory for Advanced Photovoltaic Research at McMaster and NSERC approved a proposal for $5 million in funding, for the period 2010-2015. More than 100 researchers from across Canada are currently participating under the network's umbrella, examining new technologies that can achieve higher efficiency, lower cost solar cells than conventional silicon.

According to the Centre's mid-term report [9], several collaborations with a number of government and industrial partners are in place, including: ATS Automation Tooling Systems, Cleanfield Energy, CanmetENERGY, The Ontario branch of *Institut National d'Optique*, Unicel Architectural Corporation, Newport Corporation, Prised Solar and *Institut de Recherche d'Hydro-Québec*. In-kind contributions from various partners total $685,488.00 to date.

Research is being performed primarily under the following categories:

1. **Organic PV**
   - Improving Organic Solar Cell Efficiency Using Low Band Gap Polymers and Tandem Devices
   - Highly Efficient Low-Cost Polymeric Solar Cells
2. **Inorganic PV**
   - Third Generation Spectral Engineering for Increased Solar Cell Efficiencies
   - Advanced Thin Silicon High Efficiency Device Integrations
   - Novel III-V and I-III-VI Based Multi-Junction Solar Cells
3. **Hybrid PV**
   - Metal Oxide/Organic Hybrid Solar Cells
   - Polymer/Nanostructured Silicon Heterojunction Solar Cells
   - Novel High Efficiency Materials for Dye Sensitized Solar Cells
4. **Nano-Structured PV Solar Cells**
   - Optimization of Nanoscale Interfaces in Organic PV Active Layers
   - Copper Indium Gallium Selenide (CIGS) Nanowires for Photovoltaic Applications
   - Nanowire Photovoltaics
   - Novel Homojunction Thin-film Photovoltaic Devices Based on Nanostructured Cu(In,Al)S2 Materials Synthesized Using an Innovative Colloidal Method
5. **Organic and Bifacial Silicon-Based Semi-Transparent PV**
   - Cell Design for Window and Skylight Applications
   - Photovoltaics and the Transition to a Carbon-Neutral Energy System in Canada

Some of the key R&D highlights of the Photovoltaic Innovation Network, as of 2011, included:

- Fabrication of the most air stable organic solar cell, with an overall energy conversion efficiency of 7.1%.
- Fabrication of ultra-thin single crystal silicon solar cells, allowing for double sided processing and incorporating simple light trapping methods, having an energy conversion efficiency of 9.9%.
- Development of a method for creating regular arrays of shallower inverted pyramids for enhanced light trapping, currently being integrated into the 10 μm thick free standing silicon cells to increase efficiency, potentially as high as 20%.

- Demonstrated hybrid organic/ DSSC solar cells, using Zn0.9Ca0.1O, having a 50% increase in the open circuit voltage, and a doubling of efficiency compared to similar devices using pure ZnO.
- Developed solar cells based on III-V semiconductor nanowires using growth via molecular beam epitaxy, metal-organic chemical vapour deposition and a wide range of III-V compounds, including arsenides, phosphides and nitrides.

OTHER PHOTOVOLTAIC RESEARCH AND DEVELOPMENT SUPPORT IN CANADA

Other federal and provincial sources of funding for PV R&D were collected and are listed in Table 3. For the period under review, Sustainable Development Technology Canada funded one solar cell R&D project on Low Cost Printable Organic Solar cells with a Canadian consortium group composed of St-Jean Photochemicals, Konarka Technologies Inc., NRC - Institute for Microstructural Sciences and Université Laval, Department of Chemistry [8].

Table 3. Other Canadian Sources of PV R, D&D Funding

Source of Funds	Research Area	Funds
Sustainable Development Technology Canada	Low Cost Printable Organic Solar Cells	$1,673,424 total for 2008-2012
Federal Network of Excellence fund to the Canadian Institute for Photonic Innovations	Concentrated Photovoltaics Array Optimization	$36,500 for 2011
	Novel Fabrication Technology for High Efficiency Solar Cells	$52,000 for 2009-10
	High-Power, Outdoor Photovoltaic Test System for Characterization of a Lunar Rover Solar Power Subsystem	$24,295 for 2012
	Lunar Rover Photovoltaic Array Prototype Incorporating Flexible Multi-junction Solar Cells	$33,300 for 2011-12
Fonds de recherche du Québec	Hétérostructures novatrices à base de boîtes et de fils quantiques: Croissance sélective sur nanomasques, caractérisation et dispositifs	$50,000/year for 2010-2012
	Piles solaires tout plastique	$21,250 for 2010 $21,250 for 2011 $17,500 for 2012
	La compréhension et la dynamique de cellules solaires organiques	$14,000 for 2012
	Nouvelles cellules photovoltaïques à pigments photosensibles à partir de tétrakis-arboxyphényl)métalloporphyrines et ses versions pi-étendues (team grant)	$46,000/year, 2012-2015
	Upconverting materials for PV conversion	$55,000/Year for 2011-2014
Gouvernement du Québec	Matériaux Imprimables pour Piles Solaires Efficaces Contrat du MDEIE	$275,000/year for 2011 and 2012
Hydro-Québec	Novel Homojunction Thin-film Photovoltaic	$20,000/year, 2012-

	Devices Based on Nanostructured Cu(In,Al)S_2 Materials Synthesized Using an Innovative and Colloidal Method	2015
Ontario Research Fund	High Efficiency Silicon Photovoltaics	$100,000/year since 2007 (5 years).
	Advancing Photovoltaics for Economic Concentrator Systems	$3,257,965 for 2010-2014
	High Efficiency, Low Cost, Solar Cells.	$3,000,000 for 2010-2015
Ontario Centres of Excellence	Systems Integration of Flexible Multi-Junction Solar Cells	$25,000 for 2011-12
	Concentrator Module Optics: Optics Improvement	$25,000 for 2011-12
	High Fidelity Photovoltaic System for Lunar Vehicle	$13,500 for 2010
Ontario Power Authority	Efficient, Low-cost Solar Cells: Prototype Engineering to Enable Customer Validation and Investor Diligence	$100,000 for 2011/12
Canada School of Energy and Environment	A new concept for organic bulk-heterojunction solar cells: Charge transport in liquid crystals	$100,000 for 2010
	A Novel Approach Toward Efficient Acceptor Materials for Organic Photovoltaics	$25,000 for 2012

The National Research Council of Canada is also involved in photovoltaic R&D through the NRC National Institute for Nanotechnology (NINT) in collaboration with the University of Alberta, and through project SUNRISE in collaboration with the University of Ottawa, Université de Sherbrooke, Cyrium Technologies Inc., and OPEL International Inc. One of NINT's goals is to demonstrate, by 2015, organic photovoltaic materials with 10% energy conversion efficiency lasting 20,000 hours. Project SUNRISE (Semiconductors Using Nanostructures for Record Increases in Solar-Cell Efficiency) aims to develop concentrated photovoltaic (CPV) systems that employ special "triple junction" solar cell chips made using multiple semiconductor layers of different materials and conductivity to collect and convert the full solar energy spectrum, and sophisticated optics to focus 500 times more sunlight onto their surfaces.

CONCLUSIONS

A survey of photovoltaic R&D capability in Canadian universities, for the FY09/10 through FY11/12 period, shows about 50 research laboratories, mostly in Ontario and Quebec, in various science (chemistry, physics, materials science) and engineering (physics, chemical, electrical, computer, information technology, etc.) are involved. Relative to previous reviews by CanmetENERGY, the funding and overall effort appear to have stabilized to the levels observed during the 2007-2009 review period. However, thanks to the contribution from the PV Innovation Network, the level of collaboration amongst university researchers and with industry has improved substantially. The university R&D is funded for the most part by NSERC at about $4 M annually. The Canadian Foundation for Innovation has also provided supplementary funds for infrastructure development at Canadian universities at about $2 M annually. Canadian university capability to support research and development of photovoltaic solar cell in Canada is significant and at the forefront of global PV science and technology research, as evidenced by the kind of research, and the volume and quality of publications produced.

The recent establishment of the Photovoltaics Innovation Network is a major boost to university R&D on solar cells and photovoltaic energy development in Canada. The Network has raised the training capability of highly qualified researchers in this field and has improved the level of collaboration amongst researchers, as well as with industry. It is already making significant breakthroughs in photovoltaic R&D.

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