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Challenges of green jobs in Quebec's photovoltaic industry

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Special Projects

Studies and Research Projects

REPORT **R-871**

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ABSTRACT

The photovoltaic (PV) industry, which provides solar power with a small environmental footprint, is a booming business that generated some 220,000 green jobs around the world in 2010, with close to 2,000,000 projected by 2020. Yet it also has to deal with potential occupational health and safety risks throughout the life cycle of PV systems. The overall objective of this study was to profile the Quebec PV industry and more specifically, to (1) review the literature; (2) identify the chemicals to which workers are exposed and document the potential risks; (3) determine which manufacturing and operational processes are potentially hazardous to health and safety; (4) identify Quebec PV companies; (5) estimate the number of jobs created, directly and indirectly; (6) define needs for future research in occupational health and safety.

Our method consisted in reviewing the scientific and grey literature databases, identifying Quebec companies in the PV industry and developing, validating and administering a survey questionnaire to those companies for the purposes of drawing up a profile of the industry in Quebec.

Our findings highlighted the exposure of workers in the PV-component manufacturing and recycling industry to many potentially toxic chemicals and potentially hazardous materials with corrosive and explosive properties, including cadmium, arsenic, silane and indium. Workers in the operations sector, especially those installing photovoltaic systems, are exposed to safety hazards, such as falling from heights, electric shock and electrocution, lacerations and other injuries, as well as fire.

The 2012 survey found 163 Quebec companies active in the PV industry: 4 in mining/extraction and manufacturing and 159 in installation and distribution of PV systems and components. Close to half of the companies that responded had been active in the PV industry for more than five years and reported no workplace accidents. The survey data allowed us to estimate the number of workers in the PV industry at about 1,300. Although the future of the PV industry will largely depend on government energy policies and incentives, as well as on the strength of the overall economy, the number of workers should continue to grow.

This study is a Quebec first. It is an important contribution to the advancement of both scientific and organizational knowledge concerning the impact of the production and implementation of photovoltaic energy systems on occupational health and safety. Given the industry's potential for growth, and thus the increasing number of workers that will be affected, many issues and avenues for research raised here deserve further study.

CONTENTS

TABLES

FIGURES

Figure 4. All work performed during installation of PV systems in 12 months of 2012 and percentage of companies doing it....................29

1. INTRODUCTION

1.1 General Background

Throughout its life cycle, the photovoltaic (PV) industry, like the renewable energy industry, generates, directly and indirectly, a range of occupational activities in the various phases of production (mining/extraction, manufacturing of feedstock, production of solar cells, assembly of components and panels), marketing (design, transportation and installation), operations (servicing and maintenance), removal, waste recovery and, finally, recycling of both solar panels and batteries (IREC, 2008; CSE, 2009; PV Employment, 2009).

There are several generations of PV cells on the market now, including the one based on first-generation crystalline silicon, which holds over 50% of the market. The second- and third-generation cells with thin films, especially those using nanotechnology, are also gaining market share and involve the use of materials like cadmium telluride, cadmium sulphide, copper indium selenide and copper indium gallium selenide (EPIA/Greenpeace, 2011; Rahman, 2011).

As PV systems are associated with the production of energy with a small environmental footprint, jobs in the industry are classified as "green" according to the definition of the United Nations Environment Program (UNEP, 2008). The industry employed more than 220,000 people worldwide in 2010 and it is estimated that it will account for over 800,000 jobs in 2015 and close to 2,000,000 in 2020 (EPIA/Greenpeace, 2008, 2011).

1.2 Quebec Photovoltaic Industry

In Quebec, the PV industry is an emerging player on the energy landscape. The Quebec government has adopted measures view to support the industry in its latest energy strategy, *Using Energy to Build the Québec of Tomorrow: Québec Energy Strategy 2006–2015* (MRNF, 2006). In addition, both the favourable local environment, thanks to a satisfactory amount of sunshine, and future applications in construction should ensure significant growth in PV energy in Quebec (Funk, 2010; Bastien & Athienitis, 2011).

Several companies have invested in the industry and employ a number of workers, mainly in

– two silica mines devoted solely to PV energy;[1]
– a huge solar-grade silicon manufacturing plant (Marketwired, 2008);
– a unit for manufacturing and recycling pure materials (tellurium, cadmium, selenium) and derived salts (mainly cadmium telluride and cadmium sulphide), essentially in the form of nanoparticles intended for the development of cells with thin films (5N Plus, 2013);
– some 300 small firms that design, install, maintain and service solar panels, according to the business directory;

1. Information from correspondence with the Ministère des Ressources naturelles et de la Faune [Ministry of Natural Resources and Wildlife], November 1, 2011.

– two plants that, as part of their marginal operations, recover and recycle acid-lead batteries, but are not devoted primarily to photovoltaic energy (Exide Technologies, 2013; Newalta, 2013).

1.3 Occupational Health and Safety Issues

Although the PV industry's ambition is to generate "clean" power, it faces potential risks to workers' health and safety during all phases of production, operations and system end of life (DHHS/NIOSH, 2011).

Health and safety concerns have attracted a great deal of attention in both Europe (Heijungs et al., 2004) and the United States (SVTC, 2009). The inclusion in August 2012 of photovoltaic panels in the European Waste Electrical and Electronic Equipment (WEEE) Directive also illustrates the awareness of the toxic potential of waste from PV systems, now classified as electronic waste (Eur-lex Europa, 2012). Furthermore, since 2003, legal frameworks have been introduced to address these concerns through the implementation of the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive, which was strengthened in 2006 by the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). REACH took effect in Europe on June 1, 2007, to increase protection of human health and the environment without affecting innovation in the European chemical industry (Eur-lex Europa, 2006; Barboni & Giovanni, 2009). Canadian Solar Inc. received REACH certification in March 2011 (Canadian Solar, 2011). The company is one of the biggest solar panel manufacturers in the world.

National and international organizations have also offered many comments and recommendations on the need for studies to chart the development of the PV industry by carefully analysing both the occupational health and safety (OHS) issues and existing standards, along with the emergence of potential health and safety hazards related to manufacturing, recovering and recycling materials and processes (Apollo Alliance/Green for All, 2008; UNEP, 2008; DHHS/NIOSH, 2011; Ellwood et al., 2011).

The potential OHS hazards differ according to the generation of solar cells and the various stages of their life cycle: production, marketing and operations, and system end of life.

1.4 Objectives

The general objective of this study was to draw up a profile of the PV industry in Quebec and determine the key points in the area of occupational health and safety by anticipating the potential risks associated with exposure to potentially toxic substances, manufacturing processes and operational safety issues.

To be more specific, this study set out to do the following:

1) Review the literature
2) Identify the chemicals to which workers are exposed and document the potential risks
3) Determine which manufacturing and operational processes are potentially hazardous
4) Identify Quebec PV companies
5) Estimate the number of jobs created, directly and indirectly
6) Define needs for future research in occupational health and safety

2. METHOD

The method involved reviewing the literature, identifying Quebec companies in the PV industry and estimating the number of workers based on a survey of those companies.

2.1 Review of the Literature

To identify the chemicals to which workers in the PV industry are potentially exposed, as well as unsafe manufacturing and operational processes, we conducted a systematic review of the literature based on bibliographic data published in international journals and scientific databases and the grey literature made available through government, institutional, professional association and private company Web sites. The potential occupational health and safety risks were determined for each generation of solar cells and the various phases of the life cycle: production (both the crystalline silicon industry and the industry involving thin films using chiefly indium, selenium and cadmium telluride), marketing and operations (installation, servicing and maintenance of solar panels) and the end-of-life phase of solar power systems (removal of PV systems and recycling of components).

2.1.1 Scientific Literature

We systematically searched bibliographic databases, covering mainly the years 2000 to 2012: Current Contents, Embase, Référence SST (INRS-Bibliographie, CISILO, NIOSHTIC, OSHLINE), IRIS EPA, Toxline and SciFinder Scholar. As the concerns specific to workers in the field of photovoltaic energy have only been investigated in a sustained manner in the past 10 years, we concentrated on the literature published during that period.

Many French and English keywords were used in a variety of combinations: photovoltaic, panels, workers, manufacturing, installation, exposure, chemical hazards, physical hazards, crystalline silicon, cadmium,* tellurium,* selenium,* arsenic,* gallium,* indium,* germanium,*[2] nanoparticles, strong acid, strong base, electronic waste, recycling.

2.1.2 Other Data Sources

We also visited many government and institutional Web sites: US Environmental Protection Agency (US EPA), World Health Organization (WHO), International Agency for Research on Cancer (IARC), Agency for Toxic Substances and Disease Registry (ATSDR), United Nations Environment Program (UNEP), International Electrotechnical Commission (IEC), National Health Service (NHS), Centers for Disease Control (CDC), Health Canada (HC), Environment Canada (EC), Natural Resources Canada (NCR), Canadian Centre for Occupational Health and Safety (CCOHS), Office of Environmental Health Hazard Assessment (OEHHA), National Institute for Occupational Safety and Health (NIOSH), National Photovoltaic Environmental Research Center (Brookhaven National Laboratory), Council of the European Union (CEU-REACH), European Agency for Safety and Health at Work (EU-OSHA), Institut national de l'environnement industriel et des risques [French national institute for industrial environment and risks] (INERIS), Commission de la santé et de la sécurité du travail du Québec [Quebec

2. The asterisk after a chemical indicates that the study concerned the substance itself as well as its derivatives used in the PV industry (e.g., cadmium sulphide for cadmium, cadmium telluride for cadmium and tellurium, gallium arsenide for arsenic and gallium).

workers' compensation board] (CSST), Institut bruxellois pour la gestion de l'environnement [Brussels environmental management institute] (IBGE) and Agence de l'environnement et de la maîtrise de l'énergie [French environment and energy management agency] (ADEME).

The Web sites of PV industry associations, including the Organisme professionnel de prévention du bâtiment et des travaux publics [Professional Organization for Prevention in Construction and Public Works], Oregon Solar Energy Industries Association and Hespul, were also reviewed to gather more information on PV markets, as well as on the associated OHS hazards. We also visited Web sites of private companies in the PV industry in particular and renewable energy in general, including 5N Plus, Green Rhino Energy and Soluxtec, to learn more about mining/extraction, manufacturing and operational processes.

2.2 Identification of Quebec PV Companies

To identify Quebec companies in the PV industry and create an accurate, up-to-date directory containing the company name, address, phone number and contact person, we investigated many Web sites, including those of the Centre de recherche industrielles du Québec [Quebec industrial research centre], Association québécoise des énergies renouvelables [Quebec Association for the Production of Renewable Energy], Enviro-accès and the Canadian Solar Industries Association.

We also consulted the Répertoire québécois des énergies renouvelables (Énergie Solaire Québec, 2011–2012) and corresponded extensively with the Ministère des Ressources naturelles [Quebec Ministry of Natural Resources] (MRN), Ministère du Développement économique, de l'Innovation et de l'Exportation [Quebec Ministry of the Economy, Innovation and Exports] (MDEIE), Industry Canada, Human Resources and Skills Development Canada (HRSDC), Natural Resources Canada's CanmetENERGY and the Corporation des maîtres électriciens du Québec [Corporation of Master Electricians of Quebec] (CMEQ).

2.3 Survey of Quebec Companies

After visiting the various Web sites that might potentially supply data on the subject, the IRSST's Groupe connaissance et surveillance statistiques [Statistical Knowledge and Monitoring Group], which specializes in survey methods, concluded that the only way to obtain reliable data on the number of workers in the PV industry was to survey all the companies.

The survey was conducted by means of questionnaires sent to every Quebec company in the PV industry. The survey was innovative, as no study of this type had ever been done, and it enabled us to profile and provide a general assessment of the Quebec PV industry.

2.3.1 Development of Questionnaires

Initially, just one survey questionnaire was designed but, for reasons of clarity, it was decided that two questionnaires were needed, specifically targeting different types of companies:

– Mining/extraction or manufacturing for the PV industry (Appendix A)

– Installing PV systems (Appendix B)

The two questionnaires, which concerned 2012 only, had three parts on several topics, and totalled 14 or 22 questions, depending on the company's primary market:

a) The first part, descriptive and common to both questionnaires, had 5 general questions.
b) The second part, also descriptive, sought more specific information about the company's various activities in the PV industry. The content and the number of the questions depended on the type of the company: the questionnaire for mining/extraction/manufacturing companies had 5 questions, while the one for installation companies had 13.
c) The third part concentrated on occupational health and safety, with an emphasis on the number of workers and job categories, as well as the number and types of workplace accidents in the company's PV division. The content of the questions, 4 on each questionnaire, was significantly different with regard to job categories and the range of chemicals associated with the company's main activity.

Each questionnaire was assigned an ID number to ensure data privacy. Table 1 sums up the main topics of the two questionnaires and their specific subobjectives by company type.

Table 1 – Topics and subobjectives covered by two survey questionnaires used for two types of PV companies

Topics	Subobjectives – Miners and manufacturers	Subobjectives – PV system installers
General information	Find out company history and how long it has been working in PV industry	Same
Specific information	Find out specific characteristics of production market (mining/extracting raw materials or producing feedstock, recycling, etc.) Find out types of activities specific to market (handling, welding, using furnace, etc.)	Find out specific characteristics of installation market (types of PV systems installed and methods of installation, servicing and maintenance, recycling, etc.) Find out types of preparatory and other work done during installation of PV systems (mounting racks at heights, removing construction cladding, connecting to grid, etc.) Obtain information about pickup and recycling of PV systems
OHS component	Find out number of workers in each job category (truck drivers, engineers, technicians, etc.) Identify or confirm chemicals associated with company's PV business (materials handled, used and/or generated) Report and describe workplace accidents (number of victims, associated tasks, types of injuries, etc.) related to handling chemicals or performing related duties	Find out number of workers in each job category (electricians, crane operators, civil engineers, etc.) Report and describe workplace accidents (number of victims and type of accidents) related to activity (installing panels, doing electrical connection work , etc.) Find out if company determines whether there is asbestos in building components before installing panels

2.3.2 Validation of Questionnaires

The questionnaires were validated in three steps involving OHS professionals, the IRSST's Groupe connaissance et surveillance statistiques [Statistical Knowledge and Monitoring Group] and the Université de Montréal’s health research ethics committee (CERES). See appendixes A and B for the validated questionnaires.

Step 1. Occupational health and safety professionals
As mentioned above, a single questionnaire was initially developed for the survey of PV companies. The framework, the selection of questions, their sequence, the choice of terms and of potentially toxic and/or hazardous chemicals used in the PV industry were then fine-tuned in light of the recommendations of two industrial hygienists and an occupational safety expert.

Step 2. Groupe connaissance et surveillance statistiques [Statistical Knowledge and Monitoring Group]
To refine the job categories and improve the OHS component with respect to types of accidents and injuries, we consulted two professionals from the IRSST’s Groupe connaissance et surveillance statistiques [Statistical Knowledge and Monitoring Group]. In discussing the issues with them, the idea of using two different questionnaires for companies with different lines of business came up. Problems were anticipated with a single survey questionnaire, given the specific characteristics of production versus installation companies. Furthermore, the section on potentially toxic and/or hazardous chemicals applied mainly to production companies. As a result, two questionnaires were designed.

Step 3. Université de Montréal’s health research ethics committee
The Université de Montréal’s health research ethics committee (CERES) required a few changes to the covering letter inviting companies to respond to the questionnaires before it would grant an ethical certificate. We had to specify that the final research report would be systematically sent to participating companies and that personal (company) data would be kept confidential. Neither questionnaire required amendment.

The ethics committee also asked us to write a detailed script for the telephone call making first contact with companies, which had to state that the group of researchers undertook to maintain the confidentiality of all personal data. The script was subsequently approved. Its purpose was to establish contact with companies before the questionnaires were sent out, in order to boost the response rate.

2.3.3 Selection Criteria for Active Companies and Data Collection

As mentioned in Section 2.2, we drew up a list of companies working in the PV industry. For those installing PV systems, only companies in the construction industry that had data on health and safety hazards were selected. Quebec companies that specialize in installing PV systems on recreational vehicles were thus excluded.

Preliminary telephone contact was established and if the company met the selection criteria, it was informed of the study objectives; the telephone script was followed to the letter. This first call also confirmed the postal or mailing address and the name of the contact person to whom to send the questionnaire.

The specific questionnaire for each participating company’s primary market was then sent, along with a personalized covering letter and a prepaid reply envelope.

Fifteen to twenty-five days later, a second telephone call was made to check whether the questionnaires had been filled in and returned. Some companies asked to have the questionnaire sent again as an electronic file. A third follow-up call was sometimes required.

3. FINDINGS

3.1 Summary of Knowledge

3.1.1 Typology of PV Industry Jobs

Over the course of the PV life cycle, there are main types of jobs connected with the industry:

– Direct jobs, including researchers, designers, manufacturers, sales people, distributors, installers, maintenance technicians, service technicians and PV panel recyclers

– Indirect jobs, including miners/extractors of raw materials; manufacturers of connectors, wiring, glass, plastic, miscellaneous polymers, mirrors and lenses; suppliers of industrial metals (aluminum, copper, zinc, etc.), architects, financial advisors and investors, etc. (IREC, 2008; CSE, 2009; PV Employment, 2009; IRENA, 2011).

The PV industry generally includes traditional trades, especially for mining and metallurgy, along with other high-tech occupations in manufacturing cells and inverters and assembling modules. Only PV installers need extremely thorough training and a special qualification or licence for the type of work to be done and the many critical safety tasks, in Europe (OPPBTP, 2011), the United States (NABCEP, 2011), Canada as a whole (CSA, 2012) and Quebec (Régie du bâtiment du Québec, 2013). Table 2 sums up the main skills and jobs in the PV industry around the world, excluding administrative departments and the distribution network for electric and electronic PV components.

Table 2 – Skills and trades associated with PV industry

Skills	Trades
Mining/extraction of raw materials, including quartz, zinc, lead and copper	Civil or mining engineer, geologist, geological/mineral technician, blaster, machine operator, etc.
Materials processing	Metallurgical or process engineer, metallurgical technician and labourer, production technician, industrial mechanic, etc.
Manufacture of PV modules	Chemical engineer and physicist, production technician, technician in high-tech and conventional methods for assembling cells/modules/panels and inverters, furnace operator, electrician, glazier, mechanic, quality control technician, etc.
Manufacture of balance of system (BOS) components (solar batteries, inverters, cables, aluminum frames, etc.)	High-tech technician for inverter assembly and testing, manufacturing engineers to design processes, manufacturing engineer, metalwork technician, etc.
Installation of PV systems	Civil engineer, general construction electrical and electronics worker, electrician, welder, crane operator, heavy equipment operator, roofer, carpenter, labourer, plumber, etc.
Servicing and maintenance of PV systems	Service and maintenance operator.

Information from IREC, 2008; CSE, 2009; PV Employment, 2009; CanmetENERGY, 2011; Hamilton, 2011; IRENA, 2011

3.1.2 OHS Hazards in Photovoltaic Industry

Although most jobs in the PV industry are not new, the technological processes involve new working conditions and the probable emergence of new occupational health and safety hazards (ILO, 2011). Our review of the literature revealed that these hazards are likely to occur in the three main phases of the PV industry life cycle: production, operation and system end of life.

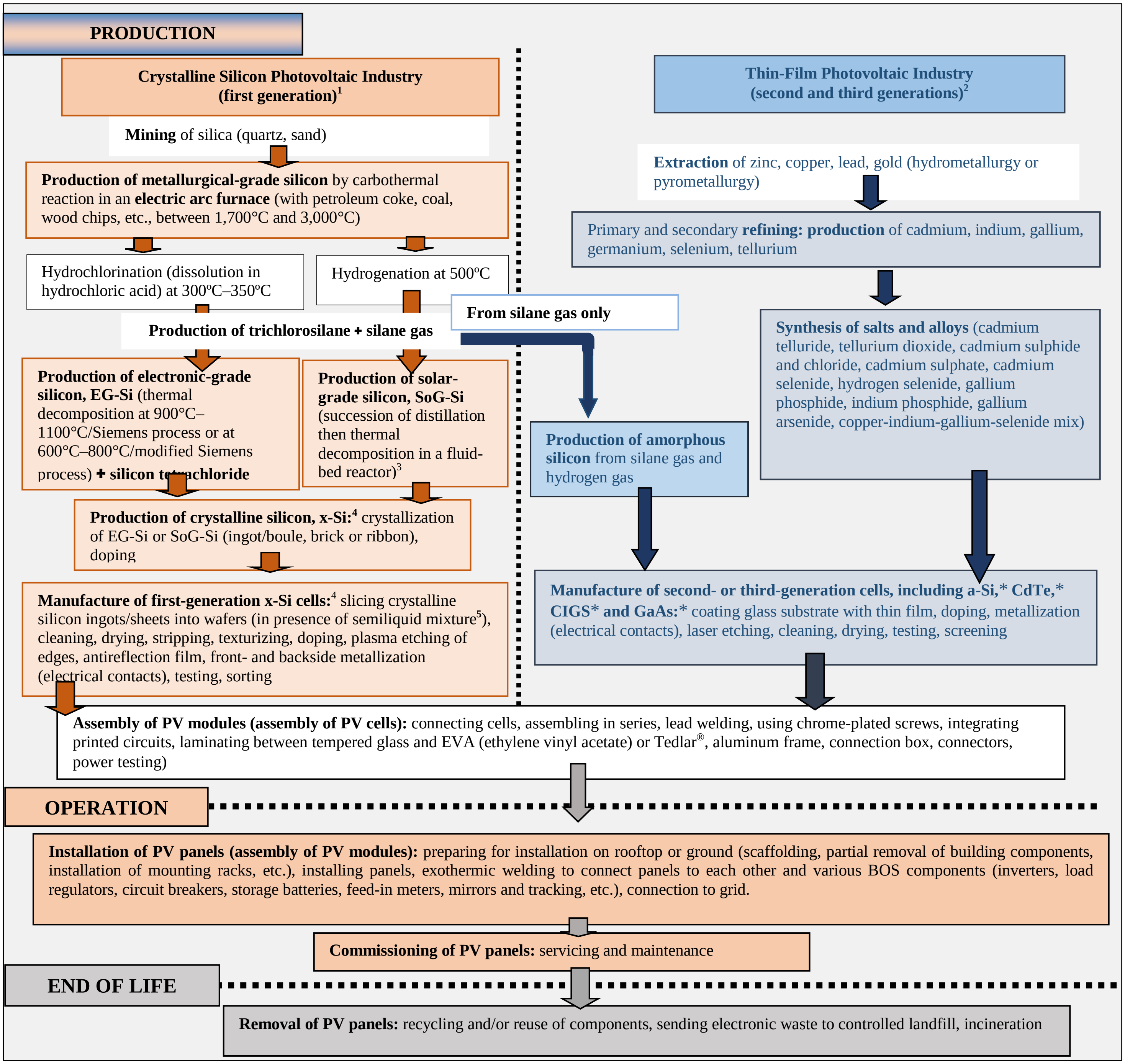
Each of these phases can be subdivided into several stages. The PV module production stages, especially the manufacturing of PV cells, differ depending on the generation of solar cell technology. First-generation crystalline silicon technology uses different manufacturing processes from second- and third-generation thin-film technology. The operational phase, common to all PV generations, consists in installing rooftop or ground-mounted panels and connecting them to other components, such as inverters (which convert direct current to alternating current) and solar batteries (to store energy in the case of standalone PV systems), so that they work as a system. The end-of-life phase consists in removing PV panels, recycling and/or reusing them and/or sending components to the landfill.

Figure 1 shows the main steps in the phases of the PV industry life cycle for crystalline silicon technology and thin-film technology. The information given in Figure 1 was taken from the following sources: Fthenakis, 2004; Miquel, 2009; SVTC, 2009; IBGE, 2010a; Gerbinet, 2011; CanmetENERGY, 2012; Green Rhino Energy, 2012; Billard et al., 2012; CMHC, 2014; 5N Plus, 2013.

Review of health component

Many potentially toxic chemicals are used, generated or handled by workers in the PV industry, who are thus exposed to possible chemical hazards. Their potential exposure may occur chiefly as a result of inhaling the chemicals in the form of dust, smoke and/or fumes, although ingestion, and skin and eye contact are also possible (Fthenakis & Moskowitz, 2000; EPRI, 2003; SVTC, 2009).

The chemical hazards associated with the production of PV modules differ depending on the generation of PV cells, because of the different manufacturing processes. Some materials are common to this phase, including adjuvants (dopants to enhance conductivity, coatings, additives for wiring and connectors, or flame retardants) and cleaning agents. Most of these substances are also covered by the US EPA’s Risk Management Program’s Rule (USEPA-RMP Rule) (Fthenakis et al., 2006).



1. Description of most common process for obtaining crystalline silicon chemically (it can also be done metallurgically).
2. The third generation is essentially gallium arsenide–based multijunction PV cells.
3. The production of solar-grade silicon by the silane route is the chemical method most used after the Siemens process.
4. x-Si represents crystalline silicon, in the form of thick monocrystalline or polycrystalline coatings or thin ribbons.
5. The semiliquid mix is a mixture of abrasive components (alumina, silicon carbide, gallium carbide, caustic soda, caustic potash, etc.).
*a-Si: Amorphous silicon; CdTe: Cadmium telluride; CIS/CIGS: Copper indium selenide/copper indium gallium selenide; GaAs: Gallium arsenide.

Figure 1. Main stages of life cycles in crystalline silicon and thin-film PV industries

Chemical hazards are also associated with the manufacturing and recycling of components used with PV panels, such as inverters, solar batteries and aluminum frames. PV module recycling workers may also be endangered by their potential exposure to substances deemed to be carcinogens contained in both support structures and PV cells, including lead, arsenic, cadmium and hexavalent chromium.

The handling of potentially toxic substances is only a partial indication of health hazards, which vary depending on their toxicological properties and their concentration in the environmental medium in question. The intensity, frequency and length of workers' exposure are basic parameters, as are ventilation, toxic-fume exhaust and detection systems, and personal protective measures (Fthenakis & Moskovitz, 2000; Fthenakis, 2003a, 2003b).

The chemical hazard associated with the installation of PV modules in PV panels lies essentially in the possible presence of asbestos, a known Group 1 carcinogen (IARC, 2012a) (Table 3), in some residential, commercial, agricultural or industrial buildings. In most installations, the panels are actually integrated into the building, which means ungluing the existing roofing (tiles, corrugated sheets and other roofing and cladding panels) during installation and the potential release of asbestos fibres in suspension in the air. According to Beillevaire and Moussus (2011) and the OPPBTP (2011), the asbestos risk during the installation of PV panels can be aggravated in the following cases:

- Lack of study of possibility of preparatory work and asbestos removal
- Incompatibility between asbestos removal and activities at PV panel installation site
- Inadequate training and personal and collective protection for workers
- Lack of removal plan, disposal companies or proper clean-up measures

Table 3 lists the main potentially toxic chemicals associated with the PV industry (carcinogenic and not carcinogenic), the type of PV technology concerned, their application and the source of workers' potential exposure. It should be noted, however, that, generally speaking, the information provided in this health component is essentially qualitative. The literature does not contain many field studies that quantify the exposure of PV industry workers. One of them that does (Chen, 2007) concerns the exposure to indium phosphide (InP), a Group 2A carcinogen (IARC, 2006a), of workers in the Taiwanese semiconductor industry. It should be kept in mind that 20% of InP production goes toward the manufacture of multijunction GaAs PV cells (IARC, 2006a). Chen's study found blood and urine indium levels higher than in unexposed administrative staff. There is also a correlation between the concentrations to which the workers are exposed and those in their body fluids. These findings reveal the reality of potential exposure to InP in the PV industry, especially, as Chen says, in the case of inadequate or defective protection systems.

Table 3 – Main potentially toxic chemicals related to PV industry, by type of toxic potential, type of technology, application and source of potential exposure

Chemical	Carcinogenic potential: IARC[a] classification and *organs/tissues affected*	Noncarcinogenic toxic potential: Organs/tissues affected and examples of pathologies	PV technol-ogy	Application	Source of potential exposure (stages in life cycle)
Hydrofluoric acid (hydrogen fluoride)		Skin (irritation); eyes (conjunctivitis, keratitis); lungs (chronic bronchopathy, pharyngitis) (INRS, 2011a)	CS[b]	Etchant and cleaning agent	Manufacture of x-Si* cells
Alumina		Lungs (fibrosis) (Krewski et al., 2007)	CS	Crusher and abrasive agent	– Production of silica powder by crushing quartz and/or silica in alumina ball mill – Manufacture of x-Si* cells (slicing x-Si ingots/boules*)
Aluminum	Aluminum production is classified Group 1[c] (IARC, 2012b) *Lungs*	Lungs (fibrosis) (Krewski et al., 2007)	CS/TF[d]	– Backside metallization technique (x-Si* and a-Si*) – Feedstock for certain multijunction GaAs PV cells* – Feedstock for aluminum PV panel frames – Welding material (mixed using copper oxide)	– Manufacture and recycling of x-Si* and a-Si* modules (electrical contacts), as well as some types of GaAs* panels – Manufacture and recycling of aluminum frames – Installation of PV panels: Exothermic welding to ensure electrical bonding
Asbestos	Group 1 *Lungs, mesothelial surfaces of lungs, larynx, pharynx, ovaries* (IARC, 2012a)	Lungs (WHO, 1998)	CS/TF	Building materials (roofing, cladding, etc.)	Installation of partly or totally building-integrated photovoltaic modules (partial or total removal of asbestos building components)
Silver		Skin (silver poisoning) (EPA IRIS record)[e]	CS	Frontside silver screen printing of x-Si* cells (electrical contacts)	Manufacture and recycling of x-Si* modules
Arsenic and gallium arsenide	Group 1 *Lungs, skin, bladder* (IARC, 2012c)	Skin (dermatitis and sores), blood (anemia), nerves (sensorimotor neuritis) (INRS, 2006a)	CS/TF	Feedstock for GaAs cells* and lead-acid batteries	Manufacture and recycling of GaAs* modules and lead-acid batteries
Arsine (arsenic trihydride)		Blood (hemolytic anemia in rats and hamsters) (INRS, 2000)	CS/TF	Dopant gas	Manufacture of PV cells

Chemical	Carcinogenic potential: IARC[a] classification and *organs/tissues affected*	Noncarcinogenic toxic potential: Organs/tissues affected and examples of pathologies	PV technol-ogy	Application	Source of potential exposure (stages in life cycle)
Cadmium	Group 1 *Lungs, prostate* (IARC, 2012d)	Lungs (emphysema), bones (osteomalacia), kidneys (proximal tubulopathy) (INRS, 1997)	TF	Feedstock for CdTe,* CIS*,[f] and CIGS*,[f] cells	– Refining of zinc, copper or lead – Manufacture and recycling of CdTe* and CIS*/CIGS* modules
Active chlorine		Skin (chloracne), lungs (chronic bronchitis), CNS* (headaches, vertigo) (INRS, 2008a)	CS	Oxidant	Manufacture of x-Si* cells (slurry component)
Hexavalent chromium [Chromium (VI)]	Group 1[c] *Lungs* (IARC, 2012e)	Respiratory tract (irritation, ulceration), skin (allergic dermatitis, ulcers) (Assem et al., 2007)	CS/TF	Feedstock for chrome-plated parts (screws, frames, coatings)	Manufacture and recycling of PV panels
Volatile organic compounds (toluene, benzene, methanol, isopropyl alcohol, acetone, dichloromethane, trichloroethylene, etc.)	Benzene: Group 1 *Blood* (IARC, 2012g) Dichloromethane: Group 2B[g] *Pancreas*[h] (IARC, 1999a) Trichloroethylene: Group 1[i] *Kidneys*[j]		CS/TF	Production byproducts	– Refining of zinc and copper by electrowinning – Manufacture of PV cells (cleaning, washing and drying)
Copper		Lungs (irritation, dry cough), kidneys (proximal tubulopathy in rats), liver (enlargement) (ATSDR, 2004)	TF	– Feedstock – Welding materials (copper oxide powder)	– Manufacture of CdTe* cells (production of tellurium); manufacture and recycling of CIS*/CIGS* modules – Installation of PV panels: Exothermic welding to ensure electrical bonding
Tin		Lungs (stannosis),blood (anemia), digestive system (gastrointestinal distension) (ATSDR, 2005)	CS/TF	– Feedstock – Thin-film deposition agent	– Manufacture of monocrystalline silicon cells – Manufacture and recycling of thin-film modules
Exothermic welding fumes	Fumes from exothermic welding not explicitly mentioned among carcinogenic hazards of welding fumes in general	Lungs (pneumoconiosis, asthma, bronchitis), skin (allergic dermatitis), other (metal fume fever) (INRS, 2012)	CS/TF	Welding byproduct	Installation of PV panels: Exothermic welding to ensure electrical bonding

Chemical	**Carcinogenic potential: IARC[a] classification and *organs/tissues affected***	**Noncarcinogenic toxic potential: Organs/tissues affected and examples of pathologies**	**PV technol-ogy**	**Application**	**Source of potential exposure (stages in life cycle)**
Gases (carbon monoxide, carbon dioxide, sulphur dioxide)		CNS* (headaches, vertigo), digestive system (stomach ache), lungs (chronic bronchitis) (INRS 2005, 2006b, 2009a)	CS	Production byproducts	Manufacture of metallurgical-grade silicon
Germane (germanium tetrahydride)		Blood (hemolytic anemia) (US EPA, 2007)	TF	Dopant gas for a-Si* PV cells	Manufacture of a-Si* cells
Indium		Lungs (pulmonary fibrosis, pulmonary alveolar proteinosis) (Cummings et al., 2012)	TF	Feedstock	Manufacture and recycling of CIS,* CIGS* and GaAs* panels
Phosphorus oxychloride (phosphoryl chloride)		Lungs (shortness of breath, dry cough), CNS* (vertigo, anorexia)—very little data on chronic toxicity (INRS, 2003)	CS	Dopant gas	Manufacture of x-Si* cells
Phosphine		CNS* (coma, convulsion), lungs (acute edema); heart (necrosis) (INRS, 2008b)	CS/TF	Dopant gas	Manufacture of PV cells
Indium phosphide (InP)	Group 2A[k] *Lungs (in rats and mice)* (IARC, 2006a)	Lungs (interstitial fibrosis in mice), reproductive system (deterioration in spermatogenesis and testicular damage in male hamsters) (ECHA, 2010)	TF	Feedstock for multijunction[e] GaAs PV cells*	Manufacture and recycling of GaAs* panels
Lead	Group 2A *Stomach* (IARC, 2006b)	Blood (anemia), digestive system (Burton's line, lead colic, cytolytic hepatitis, acute pancreatitis), CNS (encephalopathy, pseudo-radial paralysis), kidneys (tubulointerstitial nephropathy) (INRS, 2006c)	CS/TF	– Feedstock for lead-acid solar batteries and integrated circuits for PV modules* – Feedstock for protective glass – Welding of PV cells*	– Manufacture of protective tempered glass – Manufacture and recycling of PV modules and solar batteries

Chemical	**Carcinogenic potential: IARC[a] classification and *organs/tissues affected***	**Noncarcinogenic toxic potential: Organs/tissues affected and examples of pathologies**	**PV technol-ogy**	**Application**	**Source of potential exposure (stages in life cycle)**
Polybrominated diphenyl ethers (PBDEs)	Group 2B[g] *Liver (in rats)* (IARC, 1987a)	CNS* (irreversible brain damage in rats and mice), endocrine system (disruption, decline in T4 thyroid hormones in rats) (Buckenmeier et al., 2010)	CS/TF	– Feedstock for printed circuits for PV modules* and inverters – Flame retardant for PV panels* and inverters	Manufacture and recycling of PV modules and inverters
Selenium and derivatives (hydrogen selenide and selenium dioxide)		Oral cavity (metallic taste, garlic breath), skin (jaundice), skin appendages (brittle nails, hair loss) (INRS, 2011b)	TF	Feedstock or deposition agent (hydrogen selenide)	Manufacture and recycling of CIS*/CIGS* panels
Crystalline silica	Group 1[c] *Lungs* (IARC, 2012f)	Lungs (silicosis) (Sellamuthu et al., 2011)	CS/TF	Feedstock (x-Si* and a-Si*)	– Silica mining (quartz mine) – Manufacture of metallurgical-grade silicon: silica fumes – Manufacture of x-Si* cells: slicing of x-Si* sheets (emission of fine silica dust or kerf)[g] – Recycling of x-Si* panels
Organic solvents (acetone, isopropanol, dichloromethane, trichloroethylene, isopropyl alcohol, benzene, ethanol, dichloromethane, ethyl acetate, trichloroethylene, etc.)	Benzene: Group 1[c] *Blood* (IARC, 2012g) Dichloromethane: Group 2B[g] *Pancreas*[h] (IARC, 1999a) Trichloroethylene: Group 1[i] *Kidneys*[j]	CNS* (vertigo, headaches, sleepiness), skin (dermatitis), kidneys (failure), liver (cirrhosis), blood (hematotoxicity), eyes (visual disorder) (SPP, 2002)	CS/TF	– Cleaning agents – Extractant for refining zinc and copper by electrowinning – Binding agents for metal paste for front- and backside of PV cells	– Production of pure metals and metalloids (cadmium, indium, gallium, selenium, etc.) – Manufacture of PV cells (electrical contacts)
Hydrogen sulphide		CNS* (headaches, memory disorder), eyes (corneal edema), lungs [reactive airways dysfunction syndrome (RADS)], digestive system (nausea, diarrhea) (INRS, 2009b)	TF	Feedstock for CIS*/CIGS* cells	Manufacture of CIS*/CIGS* cells

Chemical	Carcinogenic potential: IARC[a] classification and *organs/tissues affected*	Noncarcinogenic toxic potential: Organs/tissues affected and examples of pathologies	PV technol-ogy	Application	Source of potential exposure (stages in life cycle)
Tellurium		Oral cavity (garlic breath), CNS (headaches, vertigo), lungs (edema) (RTK, 2009; Berriault & Lightfoot, 2011)	TF	Feedstock for CdTe,* CIS*/CIGS* cells	Manufacture and recycling of CdTe* and CIS*/CIGS* panels
Carbon tetrachloride (tetrachlorometh-ane)	Group 2B[g] *Liver (in mice and rats), breast (in rats)*[l] (IARC, 1999b)	CNS* (neurological damage), liver (cirrhosis), lungs (acute edema) (INRS, 2009c)	CS	Etchant	Manufacture of x-Si* cells
Thiourea	Group B2[m] *Thyroid and liver in rats and mice* (EPA, Toxnet record)[n] Group 3[o] (IARC, 2001)	Skin (contact allergy), thyroid (hypothyroidism), blood (leukopenia and agranulocytosis) (Toxnet record)[n]	TF	Feedstock	Manufacture of CdTe* and CIS*/CIGS* cells
Boron trifluoride		CNS* (headaches), digestive system (nausea, vomiting), kidney and liver damage (in animals) (EPA, 2008)	CS/TF	Dopant gas	Manufacture of PV cells

(a) IARC: International Agency for Research on Cancer. **(b) C**S: PV technology using first-generation crystalline silicon. **(c)** Group 1: Carcinogenic to humans. **(d)** TF: Second- and third-generation thin-film PV technology. **(e)** EPA IRIS record (US Environmental Protection Agency's Integrated Risk Information System), *Silver*. Retrieved from http://www.epa.gov/iris/subst/0099.htm. **(f)** The manufacturing of CIS/CIGS cells requires cadmium telluride as a buffer layer and cadmium sulphide as a deposition agent. **(g)** Group 2B: Possibly carcinogenic to humans. **(h)** Epidemiological studies: Increase in pancreatic cancer without a dose-response relationship (INRS, 2010). **(i)** Trichloroethylene was considered to be a Group 2A carcinogen until the publication of Guha et al. (2012), which proved that it is carcinogenic to humans (IARC monograph in preparation). **(j)** A meta-analysis reports a significant risk of kidney cancer, although the epidemiological evidence is limited to an association between exposure to trichloroethylene and non-Hodgkin's lymphoma or liver cancer (Guha et al., 2012). **(k)** Group 2A: Probably carcinogenic to humans. **(l)** Gaps in studies of carcinogenicity (Health Canada, 2011). **(m)** Group B2: Probable human carcinogen(US Environmental Protection Agency). **(n)** Toxnet record, *Thiourea*. Retrieved from http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+1401. **(o)** Group 3: Not classifiable as to its carcinogenicity to humans.
*****a-Si: Amorphous silicon; x-Si: Crystalline silicon; CdTe: Cadmium telluride; CIS: Copper indium selenide; CIGS: Copper indium gallium selenide; CNS: Central nervous system; GaAs: Gallium arsenide.

The toxicological properties and especially the chronic toxicity of certain substances are still being studied. That is the case, for example, of tellurium, gallium, indium, germane (germanium tetrahydride) and germanium, CIS and CIGS solutions, as well as cadmium telluride (CdTe), although animal experiments have shown less acute toxicity for CdTe than Cd (Zayed & Phillipe, 2009).

The emergence of nanoparticle photovoltaic technology adds a new problem in terms of chemical hazards in the PV industry. The markets for cadmium telluride, cadmium selenide or indium arsenide quantum dots or nanocrystals (Ma et al., 2009; Freitas et al., 2010), nanotubes and fullerenes (Manzetti & Anderson, 2012), and silicon nanowires (Tian et al., 2007) are growing rapidly thanks to their performance and increasingly competitive production costs (Razykov et al., 2011). Although the health risks of nanoparticles are not yet fully known, a few experimental studies on cultured human cells have revealed greater cytotoxicity with CdTe quantum dots in relation to aqueous cadmium solutions due to a critical size allowing them to penetrate and accumulate in nuclear inclusions that may then cause serious damage (Su et al., 2010). The high toxicity of carbon nanotubes and fullerenes has also been attributed to their heavy cell penetration levels and their ability to form aggregates and then interact with various biochemical cell components, which may give them their genotoxic and mutagenic potential (Manzetti & Anderson, 2012).

Review of safety component

There are two types of OHS hazards in the PV industry:

- Chemical hazards associated with potentially hazardous substances concentrated essentially in the PV cell production phase
- Physical hazards, chiefly in the PV system operational phase (installation, service/maintenance, removal)

Chemical hazards in PV cell production phase

The production of PV cells requires many chemicals with asphyxiant (argon, helium, hexafluoroethane, etc.), irritant [ammonia, diborane(6), selenium, etc.] and/or corrosive (strong acids and bases, silane tetrachloride) properties, which are thus potential hazards to workers in case of inhalation, ingestion, or accidental skin or eye contact. Some of these chemicals, such as silane, hydrogen and methane gases, are flammable, even explosive.

Although the PV industry is considered fairly safe during the production phase (Fthenakis et al., 2006), very few studies have been done examining the hazards associated with the handling of chemicals. The risk of explosion is still the chief safety concern. The USEPA-RMPs reported six nonfatal accidents in the United States between 1994 and 1999 (Fthenakis et al., 2008), while fatal silane gas explosions were reported in Taiwan in 2005 (Chen et al., 2006) and in India in 2007 (Biello, 2010).

Table 4 lists the main chemical hazards for workers during PV cell production, by type of PV technology, application and properties. The information given in the table was taken from Fthenakis & Moskowitz, 2000; Jha et al., 2001; EPRI, 2003; Fthenakis, 2003a, 2003b; Fthenakis et al., 2006; Miquel, 2009; SVTC, 2009; Oregon, 2013.

Physical hazards

PV systems are installed in several ways:

- In buildings, chiefly high up, either on a sloped roof (on mounting racks, as solar tiles or integrated into the building), on a flat roof (on a terrace), on a wall (cladding), on a balcony railing, as sun shading, a car park shade structure or canopy
- On the ground, on mounting racks in urban or agricultural areas (ABB SACE, 2010; INERIS/CSTB, 2010)
- On the ground, on mounting racks at generating stations or industrial-scale solar farms, in rural or desert-like areas (EPIA/Greenpeace, 2011)

High-up installations, on sloped or flat roofs, are preferred, because they offer a lot of room and optimize capture of sunlight. The placement and the connection of panels to each other and to various other PV system components is a complex and often difficult job, because it requires preparatory work (especially inspecting and repairing the roof, as necessary, partial or total removal of the roofing or cladding if the panels are integrated into the building), the set-up of a construction site to perform this work using a crane, winch, material hoist, etc., to raise and move the PV panels, and the serial connection of the panels with delicate exothermic welding, connection to the solar batteries and inverter, as well as connection to the grid (ABB SACE, 2010; IBGE, 2010a; OPPBTP, 2011).

The physical hazards are a unique combination specific to PV, because they are associated with risks of falls, cuts and scrapes, ergonomic hazards related to the handling of heavy, cumbersome solar panels and the risk of electric shock during installation, servicing and maintenance of PV systems (cleaning, inspecting connections, testing inverters), as well as the removal of PV panels for repair, replacement or at the end of their lives (OSEIA, 2006; OPPBTP, 2011; INRS, 2013).

Table 4 – Potentially hazardous chemicals related to photovoltaic industry, by type of technology and application

Potentially hazardous chemical	PV technology	Main application	A‡	C‡	F‡	I‡	E‡
Hydrochloric acid	CS[a]/TF[b]	Manufacture of EG-Si,* etchant and cleaning agent for x-Si, a-Si and GaAs cells		■	■	■	
Hydrofluoric acid	CS	Etchant and cleaning agent for x-Si* cells		■	■	■	
Ammonia[c]	CS/TF	Antireflection film for PV modules				■	■
Argon	TF	Thin-film deposition agent	■				
Strong bases (caustic soda, caustic potash)	CS/TF	– Leaching agents for production of zinc and recovery of cadmium – Cleaning agent for PV cells		■		■	
Active chlorine	CS	Component of slurry for slicing x-Si* ingots/boules/sheets		■		■	
Nitrogen (N2)	CS/TF	PV cell dopant	■				■
Diborane	TF	Dopant for a-Si* cells			■	■	
Selenium dioxide	TF	Byproducts and intermediate products of manufacturing CIS*/CIGS* cells				■	
Gallium	TF	Feedstock for GaAs* cells				■	
Helium gas	TF	Thin-film deposition agent	■				
Hexafluoroethane (C_2F_6)	CS	Etchant for x-Si* cells	■				
Hydrogen gas	CS/TF	Manufacture of x-Si* and a-Si* cells			■		■
Methane gas	TF	Manufacture of a-Si* and GaAs* cells	■		■		■
Phosphorus oxychloride (phosphoryl chloride)	CS/TF	Dopant for x-Si* cells				■	
Phosphine gas	CS/TF	PV cell dopant			■	■	■
Selenium	TF	Feedstock for CIS*/CIGS* cells				■	
Hydrogen selenide	TF	Deposition agent for CIS*/CIGS* cells			■	■	
Silane gas	CS/TF	Feedstock for x-Si* and a-Si* cells				■	■
Hydrogen sulphide	TF	Feedstock for CIS*/CIGS* cells			■	■	■
Tellurium	TF	Feedstock for CdTe* and CIS*/CIGS* cells				■	■
Silicon tetrachloride (tetrachlorosilane)[c]	CS/TF	Intermediate product and/or byproduct of manufacturing x-Si* cells and silane gas used to manufacture a-Si* cells		■		■	
Trichlorosilane	CS/TF	Intermediate product of manufacturing x-Si* cells and silane gas used to manufacture of a-Si* cells			■	■	
Nitrogen trifluoride (NF 3)	CS	Reactive cleaning agent and x-Si* etchant	■				
Boron trifluoride	CS/TF	PV cell dopant		■		■	

(a) CS: PV technology using first-generation crystalline silicon. **(b)** TF: Second- and third-generation thin-film PV technology. **(c)** Reacts violently with water to produce hydrochloric acid and can cause serious tissue damage (Kapias et al., 2001). **(‡)** A: Asphyxiant; C: Corrosive; F: Flammable; I: Irritant; E: Explosive. ***a**-Si: Amorphous silicon; EG-Si: Electronic-grade silicon; x-Si: Crystalline silicon; CIS: Copper indium selenide; CIGS: Copper indium gallium selenide; GaAs: Gallium arsenide; CdTe: Cadmium telluride.

The electrical hazards associated with the installation of PV systems are also complex, owing to their specific characteristics and sheer number (OSEIA, 2006; IBGE, 2010a, 2010b; INRS, 2013; Photovoltaique.info, 2012). The various people involved (civil engineer, electrician, labourer, welder, etc.) are exposed to

- two sources of electricity, and thus potential hazards: PV panels and the public grid itself;
- two types of current:
    - direct current (DC) in the circuit to PV panels, cabling to inverters, as well as cutoff, disconnect and protective devices;
    - alternating current (AC) in the circuit created by the inverter, converting DC to AC, the wiring and structures connecting to the solar batteries or the grid, as well as cutoff, disconnect and protective devices;
- an electrical hazard exclusive to DC:
    - due to the absence of a switch to cut off current from PV panels when they are in full sunlight;
    - producing persistent electric arcs, which are difficult to interrupt in case of poor contact, with a chance of fire.

Very few studies have looked at the occupational injuries of PV workers, although the safety aspect of solar panel installation is often underscored (OSHA, 2013). There are no specific statistics on falls during installation and servicing of PV panels, but there have been fatal falls reported in France (OPPBTP, 2011) and the United States (California Department of Public Health, 2010). This hazard is associated with a new type of work at heights for trades traditionally practised on the ground, like electricians and welders (OPPBTP, 2011).

A 2012 study on the hazards of LEED-certified (Leadership Award in Energy and Environmental Design) sustainable construction projects found a 24% increase in the number of falls in relation to conventional buildings (Fortunato et al., 2012). Others hazards were identified, including falling objects and accidents associated with general working conditions on construction sites, such as the movements of heavy equipment (INRS, 2013). Of course, such accidents are not specifically related to PV energy, but they are associated with it, as sustainable buildings often incorporate it. Table 5 lists the main physical hazards associated with the installation of PV panels, by activity, with examples of aggravating factors. The information given in the table was taken from OSEIA, 2006; Conergy, 2007; Erico, 2007; IBGE, 2010b; INERIS/CSTB, 2010, 2011; Soluxtec, 2010; OPPBTP, 2011; Richez et al., 2011; Photovoltaique.info, 2012; INRS, 2013.

Table 5 – Main physical hazards associated with operational phase of PV panels (installation/removal, service/maintenance)

Hazard	Causes	Examples of aggravating factors
Falling from height; slipping; falling object; loss of balance; collapse of panels under installer's weight	– Working at heights and/or on slopes – Moving around on surfaces with uneven resistance (panels, roofing, framing, cladding, etc.) – Big, heavy equipment: gripping tools (suction cups, hooks, etc.), harnesses, lanyards, backpacks, etc. – Scaffolding – Defective harness and lanyards	Weather: dew, rain, freezing rain, snow, strong winds (increased risks of falling at 30 km/h and higher) Slope: Risk of falling increases from 15º. Poor quality and inappropriate materials (standardized or not), inadequate inspection of personal and collective protective measures, scaffolding safety, and qualifications and experience in specific PV panel installation skills (especially working at heights, using fall arresters, habit of wearing harness and using heavy equipment). Poor coordination between workers on site. Lack of safe storage place for equipment.
Electric shock (could be fatal or cause fall), lightning strike, electrical burn	DC arcing Miscellaneous electrical work on DC and AC circuits, including serial connection of PV panels, connecting to solar batteries and/or connecting to grid) Servicing and maintenance of PV systems (especially inverters)	Working near high-voltage power lines.—Working in contact with bare overhead power lines.—Lack of regulatory signage for live wires. Insufficient experience and training of all workers/professionals, whether electricians or not. Poor quality PV connectors (inverters, cables, junction boxes, disconnect switches, etc.).—Defective electrical installation: overheating of electric circuits, defects, improper assembly, incompatible connectors, faulty connections, overvoltages, opening of junction boxes, etc.—Installation of PV modules of various configurations.—Disconnect switch closed during work. Unfavourable weather: high heat, lightning strike. Electric arc due to high-intensity current. Design flaw, falling objects, etc., because increased fire hazard from PV panels.—Artificial concentration of sunlight on PV modules.—Ageing of safety sheathing by heat generated by panels (approx. 70°C). Use of wet tools.—Unsafe movement on modules.—Stacked modules.—Wearing metallic jewellery.
Collision, shock	Movements of heavy equipment: elevator frame, telescopic cherry-picker, winch with accessories, forklift, etc.	Inadequate, irregular heavy equipment maintenance. Limited number or lack of signs.—Obstacles to equipment movement.—Poor coordination between workers on site. Lack of safe off-site parking for machinery.
Ergonomic hazard (overexertion)	All activities involving installation, service/maintenance and removal of PV panels (handling, carrying and moving heavy loads, limited movement on small surface areas, etc.)	Improper work method, leading to overexertion over medium and long term.
Injury, laceration	Handling related to installation of PV panels (PV modules with sharp edges)	Handling of PV modules without protective gloves. Handling of damaged PV modules; module breakage. Wearing short-sleeved work clothes.
Thermal burn	Heat generated by connected PV panels Exothermic welding to ensure electrical bonding between PV panels	Walking on PV panels without protective shoes. High heat.

Hazard	Causes	Examples of aggravating factors
Fire	DC arcing	Noncompliance with electric code for buildings.
	Overloaded electric circuits	Defective electrical installation: overheating of electric circuits.—Defects, improper assembly, incompatible connectors.—Faulty connections, overvoltages, opening of junction boxes, etc.—Wet tools.—Walking on modules.—Stacked modules.—Explosive hazard related to site activity.—High heat.

3.2 Results of Survey of Quebec PV Companies

A total of 163 Quebec companies involved in the PV industry were found: 4 in mining/extraction and manufacturing and 159 in installation and distribution of PV systems and components. Of these companies

- 46 could not be contacted by telephone or e-mail.
- 47 did not install PV systems. Although most of them were classified as solar panel installers, they only distributed PV system components. Some of these companies specialized exclusively in recreational vehicles or renewable energy consulting and/or operations. Some also contracted out all installation work to electrical contractors and did not wish to respond to the survey.
- 3 had not installed any PV systems in the 12 months of 2012.
- 1 was listed under two different names.
- 4 had gone out of business.
- 1 had not yet begun operating.

So the survey questionnaire was sent to only 61 Quebec PV companies. When a second telephone call was made to confirm that the questionnaires had been received,

- 3 companies withdrew, because they specialized in recreational vehicles and had neglected to say so during the first call;
- 1 was no longer active in PV.

Of those 61 companies, 34, or about 60%, completed and returned the questionnaire, although one questionnaire had to be discounted as the answers showed that the company installed PV systems exclusively on recreational vehicles. We therefore analysed the responses to 33 completed questionnaires concerning company activities in 2012.

3.2.1 General information

Number of years in PV industry

Close to half of the companies have been working in the PV industry for five years or more. Generally speaking, most companies (88%) have been in the field for at least two years (see Figure 2). This shows that the industry is already well established in Quebec.

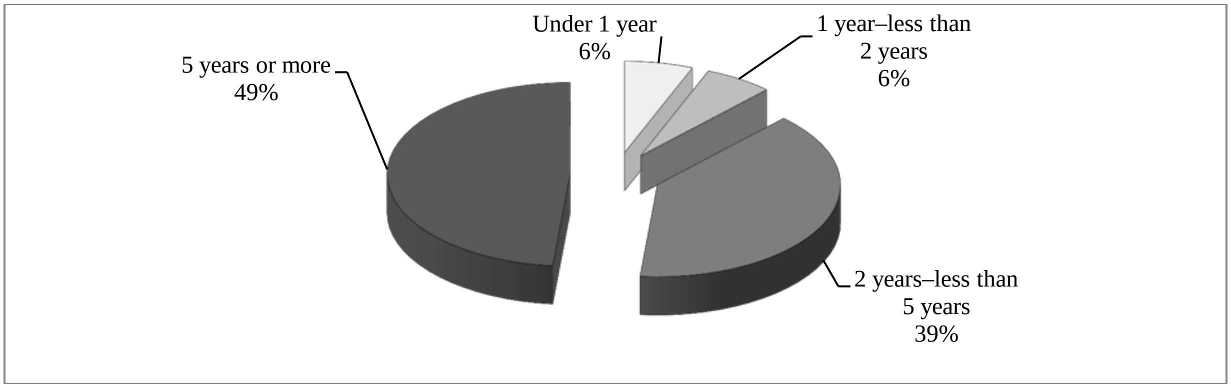


Figure 2. Years of activity in photovoltaic industry

Hours devoted to PV

Companies are not active solely in PV. Fewer than 10% specialize almost exclusively in PV, in other words, devoting 90% or more of their time each week to it, on average. Nevertheless, close to half of them (49%) spend more than 30% of their time on PV. The results also show that the more recent the company's activity, the more time it spends on PV, which indicates a growing tendency to do more PV work as new companies are established.

3.2.2 Specific information

Company active in mining/extraction and manufacturing for PV industry

One Quebec company specializes in making cadmium telluride for use in solar technology and recycling metal waste. It also engages in other production activities, such as white room work and the use of resistance furnaces.

PV system installation companies

There are 32 Quebec companies that install PV systems in residential, institutional, industrial, commercial and agricultural buildings.

Type of PV systems installed

Most Quebec companies (87%) install standalone PV systems, while 13% install only systems connected to the grid (Figure 3). No company had installed any solar farms (large number of ground-mounted panels connected to the grid) and none knew whether they would do so within the next five years.

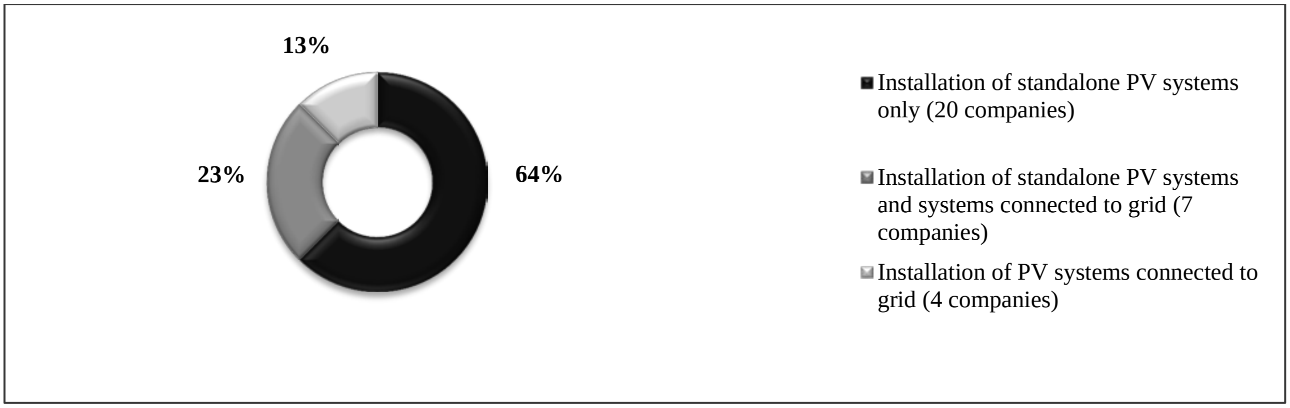


Figure 3. Types of PV systems installed by Quebec companies in 12 months of 2012

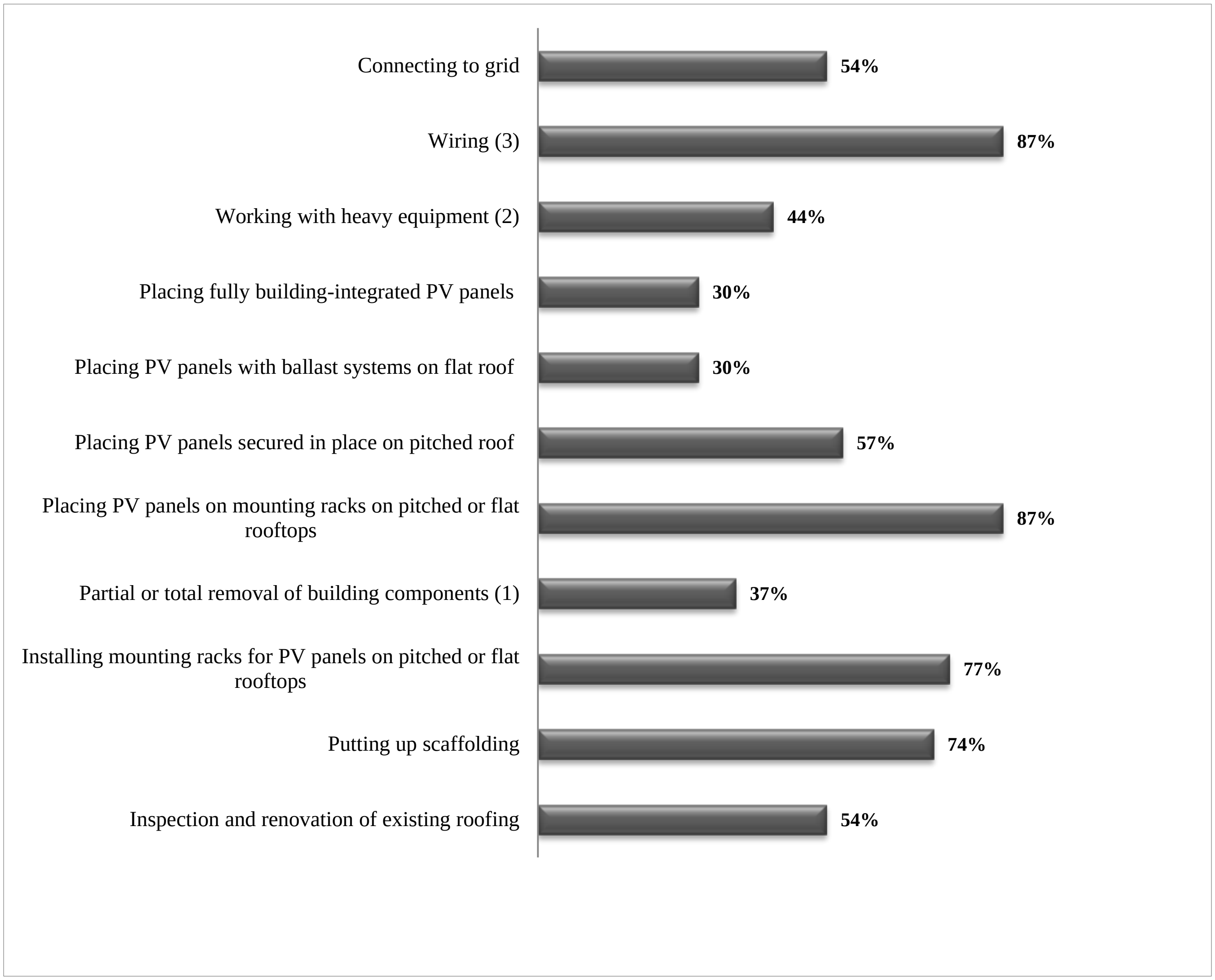
Close to 70% of companies that installed hybrid PV systems combined them with diesel generators as a backup energy source. Ninety percent of the PV panels installed were made of first-generation solar-grade silicon. Just one company installed second-generation panels made of cadmium telluride, copper indium selenide (CIS) and copper indium gallium selenide (CIGS).

In terms of work practices and handling conditions:

- Most companies that responded (91%) worked at heights on rooftops, while 9% only installed ground-mounted PV panels in urban or agricultural areas, outside of solar farms.
- 22% of companies installed fully building-integrated PV panels.
- The residential market (including isolated cottages) is the most served, with 97% of companies doing such installations, while 12% cater to the industrial market.

Work specific to PV system installation companies

The installation of PV systems on rooftops (pitched or flat) or on the ground requires a great deal of related work: preparatory work (inspecting and repairing the roof, as necessary, putting up scaffolding, installing mounting racks on rooftops, removing building components), serial installation of PV modules (on mounting racks secured in place, with ballast systems), working with heavy equipment (cranes, winches, construction lifts) to move modules and various materials, as well as miscellaneous electrical wiring (serial connection of PV modules and connection to inverters and solar batteries) and connection to the grid. Whether they do it themselves or contract it out, the vast majority of companies put up scaffolding (74%), erect mounting racks (77%) and install PV panels on pitched or flat rooftops (87%), as well as do electrical wiring (87%), secure PV panels to pitched roofs (57%), inspect and repair existing roofing (54%) and connect the system to the grid (54%). Figure 4 lists all the work done during installation of PV systems and the percentage of companies that reported doing it themselves or contracting it out.



(1) Roofing, siding and façades, railings, parapets, shade structures, etc.
(2) Cranes, winches, cherry-pickers, elevator frames, etc.
(3) Serial connection of panels and connection to inverters and batteries.

Figure 4. All work performed during installation of PV systems in 12 months of 2012 and percentage of companies doing it

The servicing and maintenance of PV systems and the collection of components at the end of their lives (PV panels, solar batteries and inverters) are also major activities of respondents in the PV industry (Figure 5).

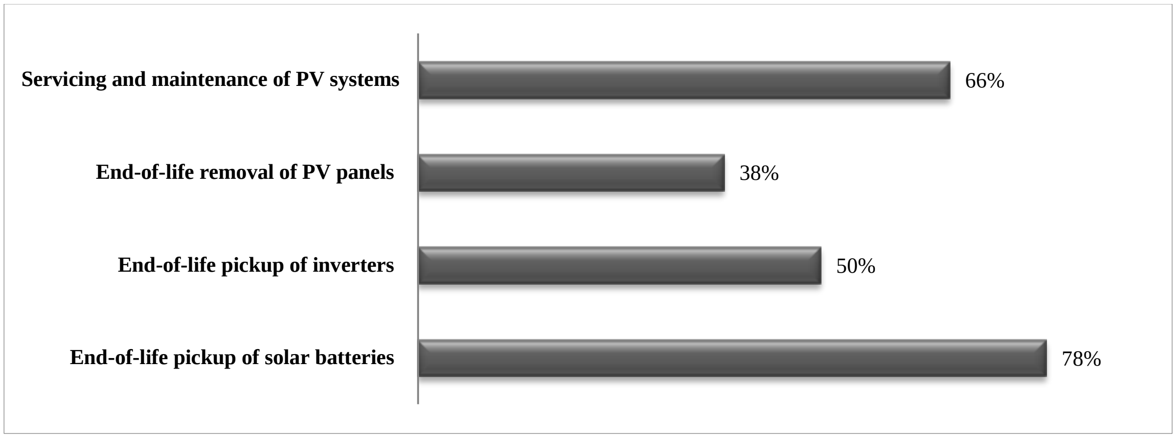


Figure 5. Other work performed during operation and at end of life of PV systems and percentage of companies doing it

3.2.3 Occupational Health and Safety Component

The direct and indirect jobs provided by Quebec PV companies are diverse and match the profiles found in the review of the literature. The results revealed that a total of 261 workers were involved at companies that responded to the survey in 2012. The details on job categories are shown in Table 6.

Table 6 – Number of workers in Quebec PV companies in 2012 that responded to survey

Worker classification	Number	Worker classification	Number
Architect	7	Process engineer	3
Carpenter-joiner	10	Mechanical engineer	2
Warehouse clerk	2	Stock keeper	1
Construction site equipment operator	6	Labourer/Material handler	23
Foreperson/Supervisor	8	Mechanic (including industrial mechanic)	7
Roofer	4	Administrative and management staff	29
Electrician	43	Cleaning staff	2
Roofing contractor	3	Shipping/receiving clerk	2
Geologist	1	Welder	5
Crane operator	3	Production technician	52
Chemical engineer	3	Salesperson	4

Worker classification	Number	Worker classification	Number
Civil engineer	10	Maintenance and service technician	8
Electrical engineer	13	Technician (other)	5
Metallurgical engineer	5	**TOTAL**	**261**

Table 7 lists the potentially toxic and/or hazardous chemicals that are handled, used and/or generated by the respondent companies, especially in mining/extraction and manufacturing. No workplace injuries related to the companies' PV business were reported.

Table 7 – Materials handled, used or generated by PV companies during mining/extraction and manufacturing

Materials	Handled	Used	Generated
Cadmium	✓	✓	
Volatile organic compounds ***(acetone, benzene, etc.)***	✓	✓	
Copper	✓	✓	
Gallium	✓		
Gases ***(carbon monoxide, sulphur dioxide, etc.)***	✓	✓	✓
Indium	✓		
Oxidants ***(chlorine, oxygen, etc.)***	✓	✓	
Metallic dust	✓	✓	✓
Epoxy resin, sealants	✓	✓	
Selenium	✓	✓	✓
Organic solvents	✓	✓	
Corrosives (***strong acids/bases***)	✓	✓	
Tellurium	✓	✓	✓
Cadmium telluride	✓	✓	✓
Metal vapour ***(furnace, electric welding)***			✓
Zinc	✓	✓	

4. DISCUSSION

4.1 Prospects of Quebec Photovoltaic Industry

As mentioned earlier, the survey revealed that a total of 261 workers were involved at companies that responded to the survey in 2012. This number is not representative of the entire Quebec PV industry, however, for two main reasons:

- Only 33 of the 57 companies that agreed to take part in the survey completed the questionnaire.
- Only 21 of the 33 companies that completed the questionnaire indicated their mean number of workers.

By simple extrapolation of the data supplied by those 21 companies, if all the others involved in installation or distribution had responded (163)**,** the total number of workers would be about 2,025. This is an underestimate of the actual number of workers, however, for the following reasons:

- The study does not include all the independent electrical contractors to whom some of the companies contacted that did not wish to take part in the survey provide work installing the PV systems they sell and distribute components for. It is hard to quantify the number of companies that contract out all of their installation work, because not all of them mention it. It would be extremely long and tedious to seek out all the independent electrical contractors in Quebec who do that kind of work.
- Most of the companies that responded contract out most of their PV panel installation work, including the partial or total removal of building components (83%), connecting to the grid (87%) and operating heavy equipment (64%). The workers performing those specific duties on a PV system installation project were not counted.
- The survey also does not cover workers at recycling centres, at the end of the PV technology chain, where solar batteries and inverters are sent at the end of their lives, because such centres are not exclusive to the PV industry.

The survey of Quebec PV companies indicates that the development of the industry is perceived favourably, as 91% of the companies feel that it will continue to grow over the next five years. Nevertheless, five new companies were founded in the past year, while four ceased operations. These closings resulted chiefly from a move to Ontario, where the PV industry is booming thanks to incentive programs like the Renewable Energy Standard Offer Program (RESOP), the Feed-in Tariff (FIT) program and the microFIT program (CanmetENERGY, 2012).

In Quebec, there have been a number of initiatives to encourage the installation of PV systems, both standalone and connected to the grid. PAIESO, the Quebec government's incentive program that provides financial support for solar thermal and PV installations not connected to the grid, was created March 27, 2012, and ended March 31, 2013. The program, with an overall budget of $7 million from the Green Fund, aimed to reduce greenhouse gas emissions by 3,500 t per year (MRNF, 2011), although it was reserved for the municipal, institutional, commercial, industrial and agricultural sectors. About 75% of total project costs were covered, up to $300,000. Projects accepted by the end of December 2012 would enable installation of 206.7 kW and if, at the end of the program, the entire budget was spent, there would be 802 kW of PV modules across Quebec.[3]

In terms of installations connected to the grid, the enthusiasm in Europe and North America for customer-generators (generating electricity from a renewable energy source and feeding it into the grid) led Hydro-Québec in 2008 to establish a net metering rate option for residential, agricultural and some industrial customers (Gagnon, 2008). There were 41 PV installations connected to the grid by February 2013, and Hydro-Québec anticipated 60 potential customers for that year in its customer-generator program (ESQ, 2013).

As far as the solar-grade silicon manufacturing industry is concerned, advances may be seen, as international league players may set up shop in Quebec and give it a boost.

At the same time, according to information gathered from people working in mines, the mining of high-grade silica for photovoltaic use could also see profitable growth in Quebec.

Although the future of the PV industry will largely depend on government energy policies and incentives, as well as on the strength of the overall economy, the prospects of the PV industry in Quebec point to a significant increase in the number of workers, not just in mining/extraction, but in manufacturing feedstock and installing PV systems, both standalone and connected to the grid.

4.2 Methodological Problems

The step that involved producing a list of PV companies was no mean feat, as there was no official, much less exhaustive, directory. So it had to be established by gathering scraps of information from various sources that were few and far between, and mainly from associations. The only sources that identified mining/extraction and manufacturing companies were Natural Resources Canada’s CanmetENERGY and an official we corresponded with at the Ministère des Ressources naturelles [Quebec Ministry of Natural Resources]. Énergie Solaire Québec’s membership directory was extremely useful, even though it is unfortunately far from complete. Visits to Web sites of trade associations or not-for-profit organizations (Enviroaccess.ca, panneauxsolaires.ca, Écohabitation.com) were necessary and fairly fruitful. The directory on the Canadian Solar Industries Association (CanSIA) Web site lists more companies in Ontario than Quebec, while the Association québécoise de la production d’énergie renouvelable [Quebec Association for the Production of Renewable Energy] could supply no information on companies in the PV industry.

We also searched the Canada 411 online directory extensively, using the keyword “solar,” not “photovoltaic.” A few PV companies contacted for the study also provided contact information for other players in the field.

3. Information obtained by e-mail correspondence with Quebec’s Agence de l’efficacité énergétique [Energy Efficiency Agency] run by the Ministère des Ressources naturelles [Ministry of Natural Resources], December 17, 2012.

This led us to the preliminary identification of 163 companies classified as being in the solar PV industry. Nevertheless, at this stage, the task was far from completed, because we had to determine which of these companies actually installed PV systems in buildings. As some companies specialize in the distribution of PV components and/or installation of PV systems on recreational vehicles, and others could not be reached despite several phone calls or e-mails and or had gone out of business, in the end we had a list of just 57 companies (see Section 3.2).

4.3 Priority Training Needs

Considering the prospective growth of the PV industry in Quebec, training for installers is extremely important, because it is still in the embryonic stage at present. Electricians are unfamiliar with the DC generated by PV panels. Teachers in the field of electricity don't know much about solar PV systems, either.

There are three major arguments in favour of prioritizing specific ongoing training and better certification in the field:

1) The reality of the major AC and DC electrical hazards associated with handling PV components while doing various types of connections and wiring

2) The PV installers' growing awareness of the gaps in their knowledge of PV power and their clear desire for training to protect themselves and prevent the hazards of a defective installation

3) The expected growth in the number of PV panel installers, given the forecasts of growth of the respondent companies and the miscellaneous incentive programs

4.4 Priority Research Needs

The literature searched revealed the existence of potential OHS hazards in the PV industry. The survey results confirmed that these are real hazards in Quebec companies and helped identify various sources:

- Manufacturing processes that could expose workers to potentially toxic substances (silica, cadmium, selenium, volatile organic compounds, gases, organic solvents, etc.)
- Operational processes that pose safety problems (working at heights for installation, servicing, maintenance and removal of PV systems, wiring PV panels, connecting to solar batteries and/or to the grid).

Studies should therefore focus on anticipating, preventing or at the very least limiting exposure to potential risk factors.

Health component
Priority research areas would be as follows:

- Characterization of PV industry workers' exposure throughout the life cycle to various potentially toxic substances, whether carcinogenic or not. Workers at PV component recycling centres should be included, because, over time, the volume of PV system components at the end of their lives will gradually increase province-wide

- Characterization of PV system installers’ exposure to asbestos, given its possible presence in building components being partially or totally removed during preparatory work
- Assessment of the significance of multiple exposures to potential carcinogens that might take place essentially in feedstock manufacturing and the recycling of PV components, as a prerequisite to the identification of priority avenues of research into potential carcinogenic hazards
- Identification of work processes and the organization of work that might affect exposure to various potentially toxic substances
- Documentation of company work practices, processes and methods with a view to measuring ambient levels of exposure to potentially toxic substances
- Documentation of company protective measure and biological and workplace monitoring methods
- Assessment of toxicological properties, especially the chronic toxicity of certain substances known to be highly toxic
- Characterization and control of workers’ exposure in the manufacturing of various PV nanoparticles

Safety component

Most of the main studies concerned with safety focus on the installation of PV systems:

- Documentation of organizational work practices for the installation of PV systems, especially at heights, in order to identify specific situations that might influence the exposure of workers to various physical hazards and accidents, including site preparation
- Documentation of organizational safety practices, with a view to protecting workers better and making various stakeholders more aware of the risk factors
- Developing and implementing communication, public awareness and information strategies for all companies, including those in installation, all electrical contractors, consulting engineers that specialize in green buildings, architectural firms and distributors/sellers of PV components

5. CONCLUSION

In this study, we have reviewed the literature on photovoltaic energy, identified the chemicals to which workers in the field are exposed, documented the potential hazards, identified manufacturing and operational safety issues, compiled a directory of Quebec companies in the PV industry, estimated the number of direct and indirect jobs sustained by the industry and determined needs for occupational health and safety training and research.

This study is a Quebec first. It is an important contribution to the advancement of both scientific and organizational knowledge concerning the impact of the production and implementation of photovoltaic energy systems on occupational health and safety. Given the industry's potential for growth, and thus the increasing number of workers that will be affected, many issues and avenues for research raised here deserve further study.

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APPENDIX A – SURVEY QUESTIONNAIRE FOR MINING/EXTRACTION AND MANUFACTURING COMPANIES

Profile of Quebec Photovoltaic Industry
Mining/Extraction and Manufacturing Component

Date: Day ☐☐ Month ☐☐ Year ☐☐☐☐

Questionnaire No. ☐

Note: In this questionnaire, **PV** stands for ***photovoltaic.***

PART A
First, we'd like some general information about your company.

QUESTION 1. How old is your company?

- ◯ Less than 1 year
- ◯ 1 year–less than 2 years
- ◯ 2 years–less than 5 years
- ◯ 5 years or more

QUESTION 2. How long has your company been active in the PV industry?

- ◯ Less than 1 year
- ◯ 1 year–less than 2 years
- ◯ 2 years–less than 5 years
- ◯ 5 years or more

QUESTION 3. In the past 12 months, what is the average number of working hours **per week** your company has spent on PV? ________________________

QUESTION 4. What **percentage** of total company activity does this average number of hours represent?

- ◯ Less than 10%
- ◯ 10%–less than 30%
- ◯ 30%–less than 50%
- ◯ 50%–less than 70%
- ◯ 70%–less than 90%
- ◯ 90% or more

QUESTION 5. How do you see your company's PV division developing over the next five years?

- ◯ Growth
- ◯ Decline
- ◯ Stability
- ◯ Don't know

PART B

Now we'd like some specific information about your company's work in the PV sector.

QUESTION 6. Please check the fields in which your company is active.

Mining/extraction of raw materials ◯ Yes ◯ No

If so, please specify.

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....

Production of feedstock ◯ **Yes** ◯ **No**

If so, please specify.

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Manufacture of PV cells ◯ Yes ◯ No

If so, please specify.

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Assembly of PV modules ◯ Yes ◯ No
If so, please specify.

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....

QUESTION 7. Does your company have a **recycling** department?

◯ Yes ◯ No

If so, which components are recycled?

◯ PV panel waste

◯ Metal waste

◯ Waste from various manufacturing processes

◯ **Other**, please specify

....

....

....

QUESTION 8. **If you recycle PV panels**, which types?

◯ Crystalline silicon ◯ Amorphous silicon ◯ Cadmium telluride

◯ CIS (copper indium selenide) ◯ CIGS (copper indium gallium selenide)

◯ **Other,** please specify. ....

....

QUESTION 9. Which of these activities is your company involved in?

- ◯ Underground work
- ◯ White room work
- ◯ Work using heavy machinery (e.g., construction and mining equipment)
- ◯ Welding
- ◯ Use of furnace

QUESTION 10. If you checked "use of furnace" for Question 9, please specify the types.

- ◯ Arc furnace
- ◯ Smelting furnace
- ◯ Oxycombustion furnace
- ◯ **Other**, please specify. ....
  ....
  ....

PART C
The following questions are about occupational health and safety at your company.

QUESTION 11. In the past 12 months, how many workers did your company have in each occupational category? Fill in the table below to show the number in each category.

Truck driver		Mechanic	
Warehouse clerk		Miner	
Construction site equipment operator		Machine operator	
Foreperson/Supervisor		Furnace operator	
Janitor		Crane operator	
Cook		Administrative and management staff	
Blaster		Mine maintenance and support staff	
Electrician		Cleaning staff	
Driller		Shipping/receiving clerk	
Security guard		Welder	
Geologist		Mechanical engineering technologist/technician	
Geochemist		Industrial engineering technician/technologist	
Geophysicist		Metallurgical engineering technician/technologist	
Nurse		Quality control technician/technologist	
Chemical engineer		Geological/mineral technologist/technician	
Civil engineer		Industrial maintenance technician/technologist	
Electrical engineer		Technician/Technologist, other:	
Metallurgical engineer		Technician/Technologist, other:	
Metal manufacturing engineer		**Other occupational classifications, please specify**.	
Mechanical engineer			
Process engineer			
Stock keeper			
Labourer/Material handler			

QUESTION 12. Which of the following materials has your company handled, used and/or generated within the past 12 months? Check all that apply. If you check ***Other***, please specify.

Material	Handled	Used	Generated
Alumina			
Asbestos			
Wood			
Cadmium			
Coal			
Glue			
Volatile organic compounds ***(acetone, benzene, etc.)***			
Copper			
Gallium			
Gas ***(carbon monoxide, sulphur dioxide, etc.)***			
Germanium			
Indium			
Oxidants ***(chlorine, oxygen, etc.)***			
Oil			
Lead			
Silica dust			
Metallic dust			
Wood dust			
Epoxy resin, sealants			
Selenium			
Silica			
Organic solvents			
Corrosives (***strong acids/bases***)			
Tellurium			
Cadmium telluride			
Metal vapour (***furnace, electric welding***)			
Zinc			
Other, please specify.			

QUESTION 13. Within the past 12 months, have there been any workplace accidents in your company's PV division?

○ Yes ○ No

If not, **you have completed the questionnaire. Thank you for your cooperation.**

If so, please fill in the table below to indicate the **number of workers** involved in each type of injury, by task.

	Effect		
Task	**Recovery without after-effects**	**After-effects***	**Death**
Heavy equipment operation			
Handling production machinery			
Handling chemicals			
Use of furnace			
Other			

*Refers to any permanent physical damage (e.g., ***loss of finger, loss of eye***) and/or neurological damage (e.g., ***trouble sleeping, unsteady gait***) and/or psychological problem (e.g., ***depressive disorder, pain condition***).

QUESTION 14. Fill in the table to indicate the **number of nonfatal injuries** of each type in the past 12 months. If a worker suffered **several injuries** in the **same workplace accident**, **count only the one that caused the longest absence.**

Type of injury	Number
Superficial injury	
Electrical burn	
Thermal burn	
Sprain/strain	
Broken bone	
Backache	
Open wound	
Other, please specify.	

Thank you for responding to this questionnaire

APPENDIX B – SURVEY QUESTIONNAIRE FOR COMPANIES IN THE PHOTOVOLTAIC INDUSTRY

Profile of Quebec Photovoltaic Industry
Installation Component

Date: Day ☐☐ Month ☐☐ Year ☐☐☐☐

Questionnaire No. ☐

Note: In this questionnaire, **PV** stands for ***photovoltaic.***

PART A
First, we'd like some general information about your company.

QUESTION 1. How old is your company?

- ○ Less than 1 year
- ○ 1 year–less than 2 years
- ○ 2 years–less than 5 years
- ○ 5 years or more

QUESTION 2. How long has your company been active in the PV industry?

- ○ Less than 1 year
- ○ 1 year–less than 2 years
- ○ 2 years–less than 5 years
- ○ 5 years or more

QUESTION 3. In the past 12 months, what is the average number of working hours **per week** your company has spent on PV? __________________________

QUESTION 4. What **percentage** of total company activity does this average number of hours represent?

- ○ Less than 10%
- ○ 10%–less than 30%
- ○ 30%–less than 50%
- ○ 50%–less than 70%
- ○ 70%–less than 90%
- ○ 90% or more

QUESTION 5. How do you see your company's PV division developing over the next five years?

- ○ Growth
- ○ Decline
- ○ Stability
- ○ Don't know

PART B
As your company installs PV systems, we would like to obtain some specific information about this activity.

QUESTION 6. Please indicate the types of systems you have installed within the past 12 months, the types of installations (***building-integrated PV panels, partially integrated and/or not integrated***) as well as the sector. Check all that apply.

	Standalone PV systems			PV systems connected to grid		
Sector	**Building-integrated** PV panels	**Partially building-integrated** PV panels (on racks or secured in place)	**Not building-integrated** PV panels (ground-mounted racks)	**Building-integrated** PV panels	**Partially building-integrated** PV panels (on racks or secured in place)	**Not building-integrated** PV panels (ground-mounted racks)
Residential						
Institutional						
Industrial						
Commercial						
Agricultural						
Other, please specify						

QUESTION 7. If you work with standalone PV systems, have you installed any **hybrid** PV systems within the past 12 months? (If you don't work with these systems, go to Question 8.)

- Yes
- No

If so, please indicate the other energy sources in the hybrid PV systems you have installed within the past 12 months.

- Diesel generator
- Wind turbine
- **Other**, specify

QUESTION 8. If you work with ground-mounted PV systems, have you installed any solar trackers within the past 12 months? (If you don't work with these systems, go to Question 9.)

- Yes
- No

If not, do you plan to start installing them within the next five years?

- Yes
- No
- Don't know

QUESTION 9. Have you installed any centralized PV systems (**solar farms**) within the past 12 months?

- Yes
- No

If not, do you plan to start installing them within the next five years?

- Yes
- No
- Don't know

QUESTION 10. What are the PV panels you have installed within the past 12 months made of? Check all that apply.

- Crystalline silicon
- Amorphous silicon
- Cadmium telluride
- CIS (copper indium selenide)
- CIGS (copper indium gallium selenide)
- **Other,** please specify. ....
- Don't know

QUESTION 11. Do you service or maintain the PV systems you have installed within the past 12 months?

○ Yes ○ No

QUESTION 12. When you installed PV systems in the past 12 months, which of the following work did **you do** and which did you **contract out**? Check all that apply.

Work	You	Contracted out
Preparatory work of inspecting or repairing existing roof before installing PV panels on pitched or flat rooftops		
Preparatory work of putting up scaffolding		
Preparatory work of installing mounting racks for PV panels on pitched or flat rooftops		
Preparatory work of installing racks for ground-mounted PV panels		
Preparatory work of partially or totally removing building components (***roofing, siding and façades, railings, parapets, shade structures, etc***.)		
Installing PV panels on mounting racks on pitched or flat rooftops		
Installing PV panels directly on **pitched roof without mounting racks**		
Installing PV panels with **ballast systems** directly on **flat roof without support**		
Installing PV roofing for **building-integrated** PV systems		
Work using **heavy equipment** (***crane, winch, cherry-picker, construction lift, etc.***) to raise/lift PV panels		
Wiring PV panels (serial connection and connection to inverter)		
Connecting to grid		

QUESTION 13. Do you **remove PV panels** at the end of their lives?

- Yes
- No

If not, go to Question **15**.

If so, have you **removed any PV panels** at the end of their lives within the past 12 months?

- Yes
- No

QUESTION 14. If you **removed any PV panels** at the end of their lives within the past 12 months, how did you dispose of them?

- Recycling centre
- Waste storage centre
- Landfill
- Other

QUESTION 15. Do you **recover inverters** at the end of their lives?

- Yes
- No

If not, go to Question **17**.

If so, have you recovered any **inverters** at the end of their lives within the past 12 months?

- Yes
- No

QUESTION 16. If you **recovered any inverters** at the end of their lives within the past 12 months, how did you dispose of them?

- Recycling centre
- Waste storage centre
- Landfill
- Other

QUESTION 17. Do you **recover solar batteries** at the end of their lives?

◯ Yes ◯ No

If not, go to Question **19**.

If so, have you recovered any **solar batteries** at the end of their lives within the past 12 months?

◯ Yes ◯ No

QUESTION 18. If you **recovered any solar batteries** at the end of their lives within the past 12 months, how did you dispose of them?

◯ Recycling centre ◯ Waste storage centre

◯ Landfill

◯ Other

PART C
The following questions deal with the health and safety of workers who helped install PV systems for your company within the past 12 months, regardless of whether or not they were your employees.

QUESTION 19. Within the past 12 months, **how many workers have** helped install PV systems for your company, whether or not they were your employees? Fill in the table below to indicate the number in each category.

Architect	
Carpenter-joiner	
Heavy-equipment operator	
Job site foreperson	
Roofer	
Electrician	
Roofing contractor	
Roofing-systems manufacturer	
Crane operator	
Civil engineer	
Electrical engineer	
Labourer	
Painter	
Welder	
Maintenance and service technician	
Other, please specify.	

QUESTION 20. Within the past 12 months, have there been any workplace accidents related to your company's **PV system installation**?

◯ Yes ◯ No

If not, go to Question **22.**

If so, please fill in the table below to indicate the **number of workers** involved in each type of accident, by task.

Type of accident	**Effects**	**Preparatory work** for installing PV panels	**Installing** PV panels	**Wiring** PV panels, including connecting to grid	**Servicing** and **maintenance** of PV systems
Electric shock	Recovery without after-effects	–	–	–	–
	After-effects*	–	–	–	–
	Death	–	–	–	–
Struck by an object	Recovery without after-effects	–	–	–	–
	After-effects*	–	–	–	–
	Death	–	–	–	–
Falling from height	Recovery without after-effects	–	–	–	–
	After-effects*	–	–	–	–
	Death	–	–	–	–
Overexertion	Recovery without after-effects	–	–	–	–
	After-effects*	–	–	–	–
	Death	–	–	–	–
Other	Recovery without after-effects	–	–	–	–
	After-effects*	–	–	–	–
	Death	–	–	–	–

*Refers to any permanent physical damage (e.g., ***loss of finger, loss of eye***) and/or neurological damage (e.g., ***trouble sleeping, unsteady gait***) and/or psychological problem (e.g., ***depressive disorder, pain condition***).

QUESTION 21. Fill in the table to indicate the **number of nonfatal injuries** of each type in the past 12 months. If a worker suffered **several injuries** in the **same workplace accident**, **count only the one that caused the longest absence.**

Type of injury	Number
Superficial injury	
Electrical burn	
Thermal burn	
Sprain/strain	
Broken bone	
Backache	
Open wound	

Other, please specify.

Question 22. If you have installed building-integrated PV systems within the past 12 months, did you determine whether there was **asbestos** in the building components you removed, whether partially or totally?

- ◯ Yes
- ◯ No
- ◯ I haven't done this type of installation within the past 12 months

Thank you for responding to this questionnaire