Renewable Energy Training Resources—Survey and Assessment

Energía, Tecnología y Educación SC (EnTE SC)
In association with Marbek Resource Consultants Ltd. and New Mexico State University

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Commission for Environmental Cooperation

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Publication Details

Publication type: *Background paper*
Publication date: *June 2010*
Original language: *English*
Review and quality assurance procedures:
Final Party review: September 2009
QA08.13

Disponible en français – Disponible en español

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Foreword

This report describes the results of a scoping process to identify, document and analyze renewable energy training capacities in North America for those parties involved in the design, procurement, installation, inspection, and operation and maintenance of both small and large wind, photovoltaic, and solar water heating systems.

The report is divided into four parts. Chapter 1 presents the results of the scoping process in terms of a number of parameters and some important findings. Chapter 2 answers a number of questions regarding difficulties, challenges, opportunities for improvement and recommendations, with a trinational perspective. Chapter 3 presents a technology assessment of the three technologies included in this study: photovoltaics, wind, and solar thermal. Chapter 4 describes knowledge requirements and institutional contexts for professionals involved in activities related to photovoltaic, wind, and solar thermal technology.

All of the courses that were part of this scoping process can be found on the CEC website at: http://www2.cec.org/energycourses.

Acknowledgements

Drafting of this paper was coordinated by Odón de Buen, from ENTE SC, who also drafted the section on solar thermal. The section on photovoltaics was prepared by Mark Pasini, of Marbek Consultants. The section on wind was prepared by Martin Gómez, of New Mexico State University. They also collaborated in the search for training capacities in each of their countries and in a general revision of the paper and the directory. Paola González integrated the databases; Eduardo Lang designed and assembled the directory; while Sergio Segura was in charge of the final assembly of the report and the directory.

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Executive Summary

Reflecting the growing importance of the renewable energy (RE) market in North America, there is a surge of interest and participation in renewable energy courses and practitioner training programs being offered by high schools, universities, community colleges, trade unions, and local and national nongovernmental organizations.

The scoping process identified 235 different RE training courses in the three countries. Data available for each of the courses were highly variable and in some cases it was only possible to identify an organization and some general themes.

- 83% of the courses are located in the US, 14% in Canada and only 3% in Mexico.
- A significant fraction of the courses (47%) is specifically oriented to photovoltaic technology, while a quarter is for RE, in general.
- Close to 40% of the courses identified did not disclose the duration of the training process in their literature. Of those that stated a duration, for 45% it was established in hours (from 2 to 20), for 25% in years (from 1 to 10), for 17% in days, for 8% in weeks and for 5% in months.
- Most of the courses (65%) are given either at colleges or universities. A significant fraction (20%) is offered by private companies involved in the relevant technologies. Close to 10% are offered by associations related to renewable energy or to trade unions.
- While more than 60% of the courses do not define the requirements for admission, they tend to require some level of practical experience (in those aimed at technicians and installers), or basic math, science and English knowledge (in those established as part of the requirements for obtaining an engineering degree in Canada and the US).
- About half of the courses mention some kind of certification.

However, as more programs are being offered by a variety of educational providers, there are a number of issues that have to be addressed in order to make the courses useful for the renewable energy job market, in particular, and for regional renewable energy promotion strategies, in general.

The most significant difficulties and challenges for the effective expansion of installation and maintenance support through the existing training and educational programs in a region include the following:

- The market is not yet sufficiently established to give a clear signal to academic institutions and potential students that this is a viable field for employment. For many institutions, this means that investing the resources to establish themselves as providers of training in the field of renewable energy may be too risky.
- There is growing concern that lack of availability of skilled labor may create a bottleneck in the expansion of the industry, if rapid growth continues without a focused recruitment strategy in place.

- A significant number of the courses offered in the region by institutions not directly related to the RE industry (mainly manufacturers and installers) have a very general character and do not necessarily respond to the specific needs of the market.

- The lack of qualified trainers represents both a present and future barrier to the development of training capacity, particularly if the industry is to grow faster than in recent years.

A number of areas present opportunities for industry, governments and learning institutions to undertake certain actions to effect improvements. These actions are:

  - establish and/or strengthen RE policy to increase confidence in the industry and thus investments in training capacity;
  - build on existing capacity and best practices;
  - implement new courses or add to existing ones;
  - mandate RE certification in contracts and programs;
  - strengthen accreditation;
  - strengthen online training capacity.

Actions specific to a trinational collaborative mechanism would be to:

  - make information on training capacity easily available;
  - promote and share common certification and accreditation; and
  - promote training of Mexican technicians and engineers.

In regard to potential financial mechanisms to facilitate training opportunities in renewable energy for students and experts from the three countries, recommendations include:

  - use existing governmental, trinational arrangements; and
  - promote industry arrangements.

It should be noted that the study does not quantify potential demand nor the capacity of the RE training courses in the region, and further analyses are recommended.

Also, the report gives the locations of the courses offered but does not match them with the locations of the RE employment opportunities, nor the with the policies established by states (in Mexico and the US) or provinces (in Canada), an issue which may merit some analysis.

Introduction

An envisioned era of renewable energy has now the potential to become a reality. From wind to solar and even biomass, renewable energy has become a viable option for energy supply in the world and around North America.

The 2007 report of the Renewable Energy Policy Network for the 21st Century (REN21) initiative indicates that in that year renewable energy accounted for 5 percent of global power capacity and 3.4 percent of global power generation [1].

Excluding large hydropower (which itself represents 15 percent of global power generation), renewable electricity generation capacity reached an estimated 240 gigawatts (GW) worldwide in 2007, an increase of 50 percent over 2004.

The fastest growing energy technology in the world is grid-connected solar photovoltaic systems (PV), with 50% annual increases in cumulative installed capacity in both 2006 and 2007, resulting in a total installed capacity of approximately 7.7 GW at the end of 2007. This translates into 1.5 million homes worldwide with rooftop solar PV feeding into the grid [1].

Wind energy is currently the fastest growing alternative energy source in the country. The Energy Information Administration (EIA) of the US Department of Energy estimates that net generation in 2007 was 32.1 billion kilowatt-hours (kWh), a 21% increase from one year earlier and a near five-fold increase since the start of the decade [2].

Rooftop solar heat collectors provide hot water to nearly 50 million households worldwide, and to space heating in a growing number of homes. Existing solar hot water/heating capacity increased by 19 percent in 2006, to reach 105 gigawatts-thermal (GWth) globally [1].

In terms of their global market shares, wind and solar energy have been growing at a rate of 49% and 29% per year, respectively [3].

In a short time, these technologies have gone from relatively small and almost handcrafted equipment to a billion-dollar industry.

An estimated $71 billion was invested in new renewable power and heating capacity worldwide in 2007, of which 47 percent was for wind power and 30 percent was for solar PV [1].

Investment in renewable energy is booming, surging from $10 billion in 1998 to at least $66 billion in 2007, equivalent to 18 per cent of all energy investment. It is expected to reach $343 billion in 2020 and to almost double again by 2030 to $630 billion [4].

However, these developments have taken place as a result of solid and consistent public policies that have to stay in place for several years in order to produce the desired results.

Markets have thrived and transformation advanced most where there has been strong and consistent political support [4].

An unstable policy environment and the lack of long-term incentives have hurt the investment climate for these (RE) technologies, preventing them from realizing even greater growth. With sufficiently generous and stable federal tax incentives and credit subsidies, significant new private-sector investment would flow naturally and quickly into these three renewable energy arenas [5].

Fortunately, several government initiatives in the three countries of North America have renewable energy elements that will significantly drive the RE market in the region.

In the US, Congress passed and the President has signed the American Recovery and Reinvestment Act of 2009 into law. This is a massive $800-billion spending bill that will drive new national strategies in renewable energy, smart grids, transmission, advanced vehicles, energy efficiency, and many other aspects of energy, environment, climate and sustainability. The tax and appropriations provisions include the following [6]:

Tax incentives: The bill provides an extension of the Production Tax Credit (PTC) for electricity derived from wind facilities, through 31 December 2012, as well as for RE facilities, through 31 December 2013; provides RE project developers of technologies eligible for the PTC the option of instead utilizing the 30% Investment Tax Credit (ITC) that previously only applied to solar and other clean technology projects; repeals subsidized energy Financing Limitation on ITC, even if the property is financed with industrial development bonds or other subsidized energy financing; and allows project developers to apply for a grant from the Treasury Department in lieu of the ITC.

Direct spending: The bill provides US$16.8 billion in direct spending for renewable energy and energy efficiency programs over the next ten years.

Bond and loan programs: The bill provides US$1.6 billion of new clean energy renewable bonds to finance RE facilities, and provides US$6 billion for a temporary loan guarantee program for renewable energy power generation and transmission projects.

In Mexico, the government has recently presented, for public comments, its Special Climate Change Program (PECC), which includes a number of activities and goals related to renewable energy, in particular the following:

Residential sector: In new housing built with support from the federal government, the goal is to have 375,000 new dwellings by 2012 incorporating RE features, notably solar water heating systems.

Hotels: The federal government will promote the use of RE in hotels.

The Government of Canada is investing $2 billion in ecoEnergy Initiatives to help Canadians use energy more efficiently, boost renewable energy supplies, and develop cleaner energy technologies. The suite of initiatives includes the following:

The ecoEnergy Renewable Initiative is an investment of more than $1.5 billion to boost Canada's renewable energy supplied through two programs.

- The ecoEnergy for Renewable Power program will boost Canada’s supply of clean electricity by 4000 megawatts (MW) by offering a production-based incentive.
- The ecoEnergy for Renewable Heat program offers incentives to encourage the use of clean renewable technologies for water heating and space heating and cooling in homes and buildings.

The ecoEnergy Efficiency Initiative earmarks approximately $300 million to promote smarter energy use. It includes the ecoEnergy Retrofit Program, which supports energy-efficiency improvements and selected renewable energy technologies, such as solar hot water and ground-source heat pumps, in homes, small buildings and industries.

The ecoEnergy Technology Initiative represents a $230-million investment in energy science and technology, through the funding of research, development and demonstration of clean energy technologies.

In Ontario, Canada, the Green Energy and Green Economy Act, 2009 (GEA) takes a two-pronged approach to creating a green economy that includes introducing more renewables into the province. The Act also includes measures that will foster a new green economy for Ontario by giving organizations and local communities such as First Nations and Métis communities more opportunities to develop distributed renewable energy generation projects. Among the measures are the following [7]:

Feed-in tariff (FIT). The Feed-in Tariff Program created under the Act established a comprehensive, guaranteed pricing structure for RE production, which is expected to generate more investment in renewable energy by affording investors greater confidence in the profitability of projects and increasing their access to funding.

Streamlining of processes for new projects. The Act streamlines the approvals process for renewable energy projects and provides service guarantees for them. It also establishes a “right to connect” to the electricity grid for renewable energy projects and “one-window” assistance and support to project developers, in order to facilitate project approvals.

Incentives for homeowners. Homeowners will have access to incentives to develop small-scale renewables, including low- or no-interest loans to finance the capital cost of renewable energy–generating installations, such as solar panels.

As a result, the expansion of the use of renewable energy will have a significant positive impact on employment:

Across a broad range of scenarios, the renewable energy sector generates more jobs per megawatt of power installed, per unit of energy produced, and per dollar of investment, than the fossil fuel–based energy sector [8].

On average, for every billion dollars invested, our green recovery scenarios create 30,100 jobs and save the economy $450 million per year in energy costs [9].

The renewable energy industry employs a wide range of professionals with a great variety of knowledge and skills. The range includes those involved in research of materials, parts, systems, and resource assessment; and in manufacturing, design, installation, sales, and operation and maintenance of the systems and their components.

The industry also requires an array of skills associated with general aspects of a business enterprise, such as sales, financing, data processing and human resources management.

Some additional facts show the impact of renewable energy development on employment:

- More than 2.3 million green jobs have been created in recent years in the renewable energy sector [4].
- The wind power industry employs some 300,000 people, the solar PV sector an estimated 170,000, and the solar thermal industry more than 600,000, a large proportion of these in China [4].
- According to the American Solar Energy Society (ASES), the renewable energy industry represented more than 504,000 jobs in 2007 alone. Assuming this growth continues at a similar pace, this industry could generate up to $560 billion in revenue and create more than 7 million jobs in the United States by the year 2030 [10].
- Wind is the leading and fastest-growing source of alternative energy, with over 300,000 jobs worldwide. In the case of the United States and according to the American Wind Energy Association (AWEA), at the time of compiling this report the industry employs some 50,000 people, and added 10,000 new jobs in 2007 [11]. In Canada, it is estimated that the wind energy sector could require a domestic labor force equivalent to more than 13,000 jobs by 2012 [3].
- Making and installing solar power systems already accounts for some 770,000 jobs globally. Opportunities to work in this field are available worldwide, and currently over 3,400 companies in the solar energy sector employ 25,000 to 35,000 workers in the

United States. The US Solar Energy Industries Association (SEIA) predicts an increase to over 110,000 jobs by 2016 [11].

Therefore, there is an increasing need to meet the demand of skilled human resources in the region, since a lack in availability of this kind of labor may cause a bottleneck for the North American renewable-energy industry if rapid growth continues and a focused recruitment and training strategy is not in place.

Skills gaps and shortages have emerged as a binding constraint on the greening of economies in industrial and developing countries alike [4].

While much of the attention focuses on technology, experience demonstrates that the weakest link in the production chain will determine the level of performance that can be attained [4].

Responding to this demand, in North America there is a surge of interest and participation in renewable energy courses and practitioner training programs offered by institutions that range from high schools to universities and from community colleges to the building trades.

However, as more programs are being offered by a variety of educational providers, a number of questions arise: How do potential students know that they will be taught the skills and knowledge they will need to do a good job? Do the facilities include the right equipment and hardware for training? Are there procedures that ensure safety and safe practices? Are the programs managed in a fiscally responsible way? Are the teachers qualified? [12].

This report intends to contribute, through its scoping and general description of what is available, to the development of the training capacities in North America.

1. Scoping of Established Training Capacities

This report focuses on the capacities across North America for training people to work in the design, procurement, installation, inspection, and operation and maintenance of both small and large photovoltaic (PV) and wind electricity-generating systems and solar water heating (SWH) systems.

1.1 The scoping process

To identify the extent of training capacities across North America for renewable energy (RE) jobs, the team working on the project performed a very detailed Web search, utilizing their knowledge of the RE field and of the main actors in the region.

The scope of the search involved a wide range of training options, from short courses to university-level courses and degrees.

For each of the courses identified, a set of data was collected:

- Where (Canada, Mexico or the United States)
- Subject (PV, SWH, wind and/or renewable energy in general)
- Type of course (onsite or online)
- Duration (from hours to years)
- Type of participant for whom course is structured
- Knowledge requirements for entrance
- Cost
- Certification offered, or none
- Name of institution
- Location
- General description
- Contact person
- Website

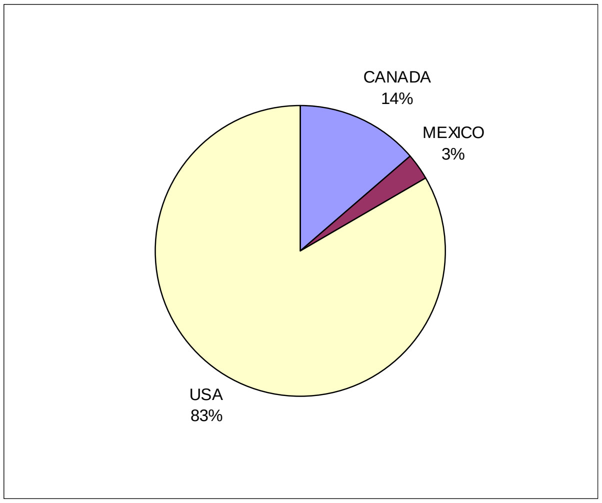
A database was assembled to collect and organize the data. This database was integrated into a directory and a website.

1.2 General results of the scoping process

The scoping process identified 235 different courses in the three countries. Data available for each of the courses were quite variable, and in some cases only the identity of the hosting organization and some general topics were provided.

- **By country and state or province**. By country, the US predominates, with 83% of the courses, while 14% are in Canada and only 3% in Mexico (Fig. 1).

Figure 1. RE training courses, by country



In Canada, more than 50% of the RE training courses that were identified are located in Ontario (Table 1).

Table 1. RE training courses, by province, Canada

PROVINCE	Number of courses
Ontario	14
Alberta	4
British Columbia	4
Quebec	4
New Brunswick	3
Nova Scotia	1
Prince Edward Island	1
NATIONAL	1
TOTAL	**32**

In Mexico, the identified RE training is only offered in three states (Table 2).

Table 2. RE training courses, by state, Mexico

STATE	Number of courses
DF	1
Michoacán	1
Morelos	2
Puebla	2
TOTAL	**6**

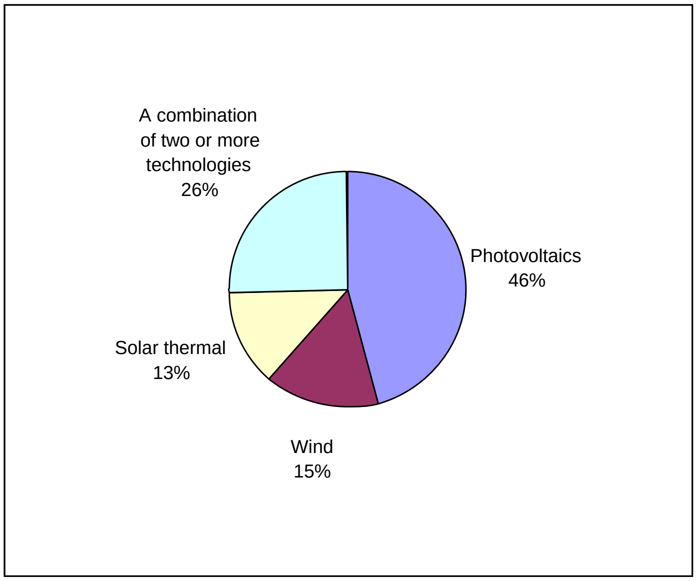
In the US, there were RE training courses identified for 38 states: 29 by private companies (with national scope), 7 by distance-learning organizations, and one by a national organization (Table 3). By state, California dominates in identified RE training courses, with 27, followed by New York (12), Wisconsin (11) and New Mexico (10).

Table 3. RE training courses, by state, US

STATE	Number of courses
California	27
New York	12
Wisconsin	11
New Mexico	10
Massachusetts	8
Minnesota	7
Arizona	6
Ohio	6
Oregon	6
Texas	6
Colorado	5
Florida	5
Michigan	5
Iowa	4
Maine	4
Maryland	4
Nevada	3
North Carolina	3
Washington	3
Idaho, Illinois, Kansas, Oklahoma, and Pennsylvania, each	2
Connecticut, Delaware, Georgia, Hawaii, Indiana, Louisiana, Missouri, Nebraska, New Hampshire, North Dakota, Puerto Rico, Tennessee, Utah and Virginia, each	1
Private company	29
Distance education	7
National organization	1
TOTAL	**196**

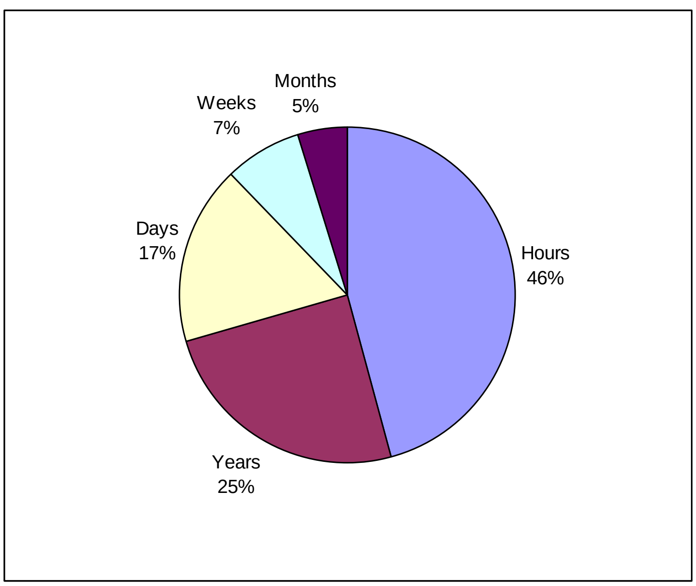
- **By subject**. A significant fraction (46%) in the three countries comprised courses specifically oriented to photovoltaic technology, while 15% focused on wind, 13% on solar thermal, and one-quarter covered RE in general (Fig. 2).

Figure 2. RE training courses, by subject



- **By duration**. Nearly 40% the courses identified in the three countries did not disclose the duration of the training process in their literature. Of those that did, for 45% the duration was in hours (from 2 to 20), for 25% in years (from 1 to 10), for 17% in days, for 8% in weeks and for 5% in months (Fig. 3).

Figure 3. RE training courses, by duration



- **By type of institution**. Most of the courses in the three countries are given by either colleges or universities (65%). A significant fraction are offered by private companies involved in the technologies (20%). Close to 10% are offered by associations related to renewable energy or to trade unions (Fig. 4).
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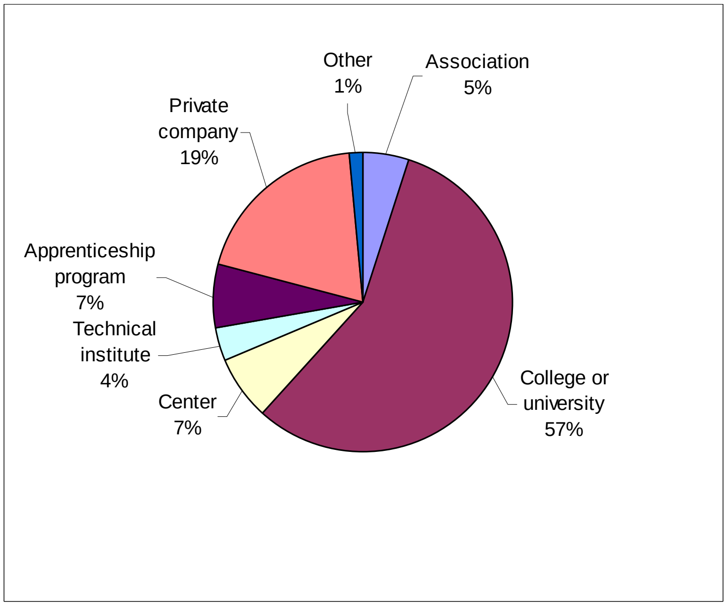
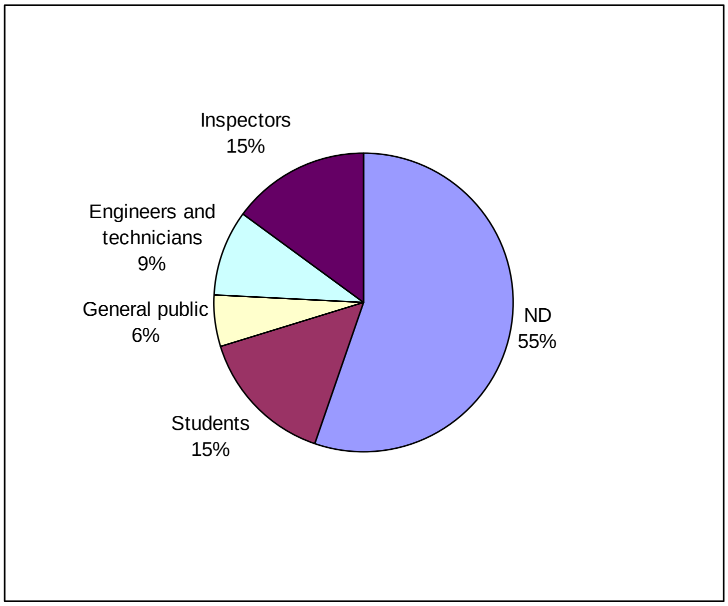
Figure 4. RE training courses, by type of institution



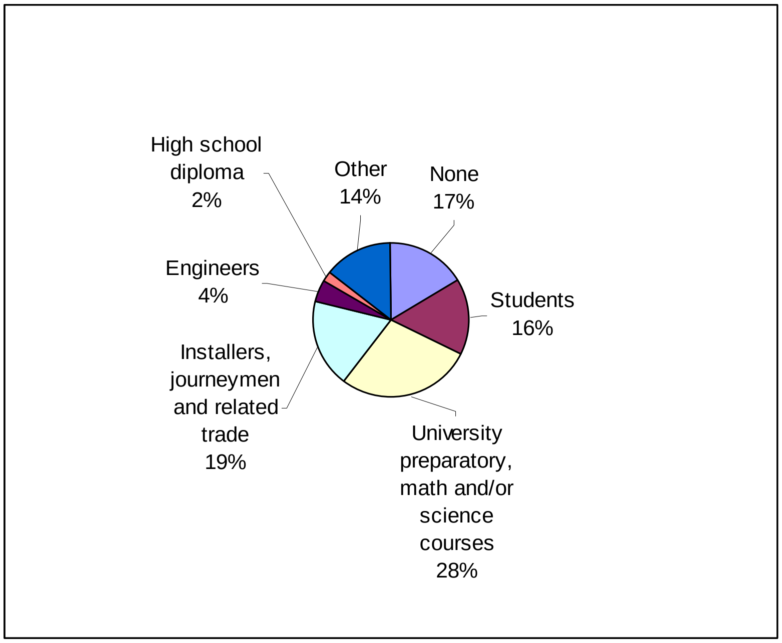
By type of participant for whom the course is structured. Courses in the three countries are directed towards a wide range of participants, from the general public to professionals with an engineering degree (Fig. 5).

Figure 5. RE training courses, by type of participant targeted



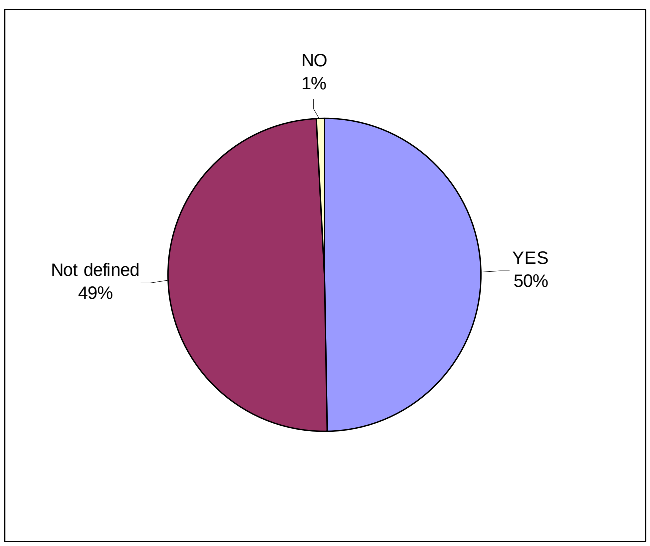
- **Knowledge requirements**. While more than 60% of the courses in the three countries do not define the requirements (which was interpreted to mean that these courses are oriented toward the "general public"), they tend to require some level of practical experience (for those courses directed toward technicians and installers), or basic math and science knowledge (for those established as part of the curriculum of an engineering degree program) (Fig. 6).

Figure 6. RE training courses, by knowledge requirements



- **Certification**. About half of the courses in the three countries refer to some kind of certification (Fig. 7).

Figure 7. RE training courses, with and without certification



1.3 Other important findings

In the process of the research for the project, beyond the search for what is offered in the market, other findings related to the purpose of the project were made.

1.3.1 Level of education

According to the study *Situational Analysis of the Canadian Renewable Energy Sector with a Focus on Human Resource Issues*, by The Delphi Group, the average level of education of people working either in PV systems design or in installation and manufacturing is trade certificates and engineering degrees [3].

The same study indicates that firms specializing in service and maintenance of large wind farms seek journeypersons with several years of related experience, as well as less experienced, recent trade school graduates. For more experienced labor they look for electricians with experience in power generation and transmission. For less-experienced labor they look for trades people with electrical and mechanical certificates [3].

1.3.2 On-the-job training

One very important aspect that was not evident through the search is the fact that many parties in the wind and solar industries offer their own on-the-job training.

According to a study developed by The Delphi Group, most firms provide training either internally or on the job in order to develop the required skills [3].

- In the solar thermal field, the main reason firms have to do their own training appears to be that there is a definite lack of training available at both the collegiate and university levels.

- In the case of PV, most firms hire technical trade school (electrical or mechanical) or engineering graduates with fundamental skills and then train them in more-PV-specific areas.

- In the case of training specifically for wind, the major players in the service industry, such as GE and Vestas, offer their own structured, internal training for servicing their equipment.

- Also, some firms focused on design and installation activities send staff on solar certification courses, while some manufacturers send staff for other forms of training, such as software and design.

In addition, particularly for large wind installations, the Center for American Progress reports that some utilities already have excellent training programs and relationships with their workforces and that many trade unions offer highly effective apprenticeship programs that provide clear pathways for skill development and credentialing [13].

1.3.3 Certification

Certification is an important issue for the solar and wind industries in North America.

In the US, some states (Arizona, California, Connecticut, Florida, Hawaii, Michigan, Nevada, Oregon, Utah and Wisconsin) and Puerto Rico have adopted contractor licensing requirements for solar water heating, active and passive solar space heating, solar industrial process heat, solar-thermal electricity, and PV. These requirements are designed to ensure that contractors have the necessary experience and knowledge to install systems properly [14].

Certification of a profession refers to a generally voluntary process in which the certifying organization formally grants recognition to those who meet certain predetermined standards or qualifications. It usually includes an examination of some kind to assess the candidates' qualifications. Over a thousand certification programs exist in the US, offering professional qualifications in fields ranging from crane operation to energy efficiency, from financial planning to automobile technical servicing [15].

Voluntary certification programs accomplish three important goals [15]:

1. They provide a measure of protection to the public by giving them a credential for judging the competency of practitioners.
2. They provide practitioners with a way to distinguish themselves from their competition.
3. By potentially improving quality, they improve the public perception of the given occupation, helping increase the industry's prominence and reputation.

1.3.4 The North American Board of Certified Energy Practitioners

The North American Board of Certified Energy Practitioners (NABCEP) is a key player in the region as it offers certifications and certificate programs to renewable energy professionals throughout North America [15].

NABCEP is a volunteer board of renewable energy stakeholder representatives that includes representatives of the solar industry, NABCEP certificate–holders, renewable energy organizations, state policy makers, educational institutions, and the trades. NABCEP's mission—to support, and work with, the renewable energy and energy efficiency industries, professionals, and stakeholders—is intended to develop and implement quality credentialing and certification programs for practitioners [15].

NABCEP began its work by creating a certification program for solar electric installers—referred to as the NABCEP™ Solar PV Installer Certification. As of October 2008, 587 individuals have passed NABCEP's PV Installer Certification exam. There are 85 NABCEP-certified solar-thermal installers [15].

Presently, under NABCEP, the new Small Wind Task Analysis group (comprised of small-wind educators, installers, and other experienced wind energy leaders) is working on establishing the material to be covered in the NABCEP Small Wind Certification examination, which may be ready by March 2010 [16].

1.3.5 Labor competence standard for solar water heating systems installers in Mexico

In Mexico, a newly formalized installers´ labor competence standard for solar water heating systems will help certify the quality of installers in the housing industry [17].

1.3.6 Accreditation

The Interstate Renewable Energy Council (IREC) is implementing the Institute for Sustainable Power Quality (ISPQ) framework of standards and metrics, in order to provide a means to compare content, quality, and resources across a broad range of training programs covering renewable energy, energy efficiency and distributed generation technologies. This international framework ensures the legitimacy of what's being taught and by whom [18].

IREC is a non-profit organization that supports market-oriented services targeting education, coordination, procurement, the adoption and implementation of uniform guidelines and standards, workforce development, and consumer protection. IREC's members include state energy offices, city energy offices, other municipal and state agencies, national laboratories, solar and renewables organizations and companies, and individual members. In addition, IREC works with many partners, including the federal government, national environmental and municipal organizations, regulatory commissions, state-appointed consumer representatives, energy service providers, utility groups, universities and research institutes [19].

1.3.7 Criteria for training programs

The Interstate Renewable Energy Council (IREC) has done work on quality assessment to ensure that practitioner training courses are designed to provide instruction that leads to defined workplace knowledge and skills and that appropriately address issues of safety and codes.

Working with the Institute for Sustainable Power (ISP), the Partnership for Environmental Technology Education (PETE), and other educational and credentialing experts, IREC has developed six criteria recommended for practitioner training [12]:

1. Practitioner training courses should provide educational, training, and skill development experiences that lead to defined workplace knowledge, skills, and abilities.
2. Training should appropriately address issues of safety, codes, and core competencies of an industry-approved task or job analysis.
3. Training should be taught in an environment with appropriate facilities, tools, and safe practices.
4. Training should offer a formal and planned learning structure where the learner receives some sort of feedback and the learner's progress is monitored.
5. Training should be taught under the administration of a legally registered entity.
6. Training should be offered by an entity that has proven administrative and managerial quality and has received third-party verification through conventional accreditation; government or trade approval; or the ISPQ accreditation or similar quality assessment.

1.3.8 Green jobs

A search for "green jobs" identified two important initiatives that should also be taken into account: (a) The Green Jobs Act of 2007 and (b) green jobs Internet search systems.

- **The Green Jobs Act of 2007**. As specified under the Energy Independence and Security Act, the US Department of Energy (DOE) was to establish an energy efficiency and renewable energy worker training program by 16 June 2008 [20]. Also, US DOE would award National Energy Training Partnerships Grants on a competitive basis to eligible entities, enabling them to carry out training that would lead to economic self-sufficiency, and to develop a skilled workforce in energy efficiency and renewable energy [21].

- **Greenjobs**. The Greenjobs website is an example of an Internet-based resource that provides renewable energy employment services and information. Greenjobs was launched in 2004 and focuses specifically on all aspects of employment in renewable energy worldwide, ranging from simple job listings to full recruitment services, as well as to provide an analysis of employment in the various RE industries [22].

1.3.9 AWEA Education Working Group

One important reference is the initiative by the Education Working Group of the American Wind Association (AWEA). This initiative provides a forum for wind industry members and individuals from the educational community. In particular, the Working Group promotes job and career training programs for community and technical colleges, academic and career development programs at undergraduate and graduate institutions, and scholarship opportunities through the AWEA Educational Scholarship Program [23].

2. Difficulties, Challenges, Opportunities for Improvement, and Recommendations, from a Trinational Perspective

This section examines three basic questions:

- What are the current difficulties and challenges for the effective expansion of installation and maintenance support through existing training and educational programs?
- What are the opportunities for improvement?
- What may be the role of a trinational collaborative mechanism?

a. What are the current difficulties and challenges for the effective expansion of installation and maintenance support through existing training and *educational programs*?

Reflecting the growing importance of the renewable energy market in North America, there is a surge of interest and participation in renewable energy courses and practitioner training programs being offered, as has already been shown above, by high schools, universities, community colleges, trade unions, and local and national nongovernmental organizations.

However, as more programs are being offered by a variety of educational providers, there are a number of issues that have to be addressed in order to make these programs useful for the renewable energy job market, in particular, and for regional renewable energy promotion strategies in general.

i. Market is not sufficiently established to support broader development of training programs

One of the more important issues, particularly for Mexico and Canada, is that the market has not yet established itself sufficiently to give a clear signal to academic institutions and potential students that this is a viable field in which to find work in [3]. For many institutions, this means investing the resources necessary to become established as providers of training in the field of renewable energy may not be a risk worth taking. That may also be reflected in the fact that most of what are offered are short courses that only give general elements of the technology but not the skills and knowledge necessary for the market.

ii. Fast growth of the RE industry

In Canada, there is growing concern that the lack of availability of skilled labor may cause a bottleneck for the industry if the latter continues to grow as rapidly as it has and a focused recruitment strategy is not in place [3].

iii. Lack of training available for solar thermal at both the college and university levels

According to the study done by The Delphi Group, for the Canadian Ministry of Industry, people with experience in solar design and systems are difficult to find; there do not appear to be any training programs for site identification, wind farm design, or project planning available at present; and there are very few PV-related training programs, likely because few people have viewed PV as a viable career option until recently [3].

iv. Disconnection between what is offered and the actual needs of the industry

In Canada (and probably in the whole region), there appears to be a disconnection between material in the courses offered outside the industry and the industry's actual needs. According to the study done by The Delphi Group, respondents to their queries in the wind industry generally did not appear to be actively seeking graduates from existing programs and remarked that the qualifications of new graduates could be improved by the addition of a few wind turbine system–related courses or credits to existing trade school programs and engineering degrees [3].

v. Lack of resources (qualified trainers) to adequately roll out training programs is expected

Also identified as a present and future barrier to the development of training capacities in particular but also of the renewable energy industry in general is the lack of qualified trainers, particularly if the industry is to grow faster than in the present.

vi. Uncertainties about policy developments

One of the main barriers to broader development of training programs is the fact that policies may not have enough levels of certainty to give an adequate signal to those who invest in creating RE-specific training capacities. This is particularly important in the Mexican context.

vii. Lack of codes and/or standards in Mexico

Lack of codes and/or standards in Mexico may affect the training, as there is no specific reference to be used in the process.

b. What are the opportunities for improvement?

To ensure that these workforce development efforts are successful, there are several important labor provisions that can be applied to federally supported contracting as we build a national grid. Clear criteria are extremely helpful in ensuring the integrity of the labor market, the contractors that bid on this work, and the quality of the jobs they create [13].

i. Establish and/or strengthen policy to give certainty to investments in training capacity

As one of the main barriers is the fact that the market is not established enough to support broader development of training programs, policies should be put in place that would give security to those who invest in creating this capacity. In many ways, such as incentives, tax breaks, grants, and mandatory obligations for levels of renewable energy in the grid, some of these policies are already well in place in some specific regions in both the United States and Canada. However, they should be melded into a common policy for the North American region.

ii. Build on existing capacities and best practices

The focus should initially be on recruitment into existing training programs and on following best practices. Once the market starts to grow significantly, new capacities based on the existing programs and practices could follow.

iii. Implement new courses or add to existing ones

In the case of areas where lack of capacity has been identified (such as courses or credits related to wind turbine systems and solar water heating) new courses should be designed and implemented and added to, for example, standard plumbing trade courses or HVAC training. This would suffice to cover near-term installation training requirements [3].

iv. Mandate RE certification in contracts

One clear policy, already in effect in some US states, that should be universally implemented is a requirement for installers working on publicly funded and/or supported projects to be certified. This would also help avoid negative perception in the marketplace resulting from bad installations and ensure that public investments create lasting public value, quality economic development, and good wages and benefits.

v. Strengthen accreditation

Together with mandated certification, accreditation of the institutions offering the training should be strengthened and expanded, in order to secure consistency and quality in the delivery of the training. Such accreditation could be modeled on the process used by existing best-practice institutions, such as that which the Interstate Renewable Energy Council (IREC) is implementing through the Institute for Sustainable Power Quality (ISPQ) [18].

vi. Get buy-in from RE industry

Any training programs developed must have input from industry stakeholders to be useful and successful. So getting buy-in from RE industry in the development and/or expansion of these programs, in terms of curriculum design and access to appropriate equipment for training, is key. One alternative that has been suggested is the creation of public/private workforce training partnerships with community-based organizations [3].

vii. Strengthen online training capacities

Online capacities, particularly in Spanish, could be very useful in jump-starting the Mexican RE training market.

c. What may be the role of a trinational collaborative mechanism?

i. Make information on training capacities easily available

A common, Web-based information system that integrates training-related data on regional institutions and capabilities could help match demand for training with the available supply, but could also foster collaboration among those institutions.

ii. Promote and share common certification and accreditation

Following best practices and through established capacities, common, regional certification and accreditation systems could be promoted to secure quality at least cost for the region.

iii. Promote training of Mexican technicians and engineers

As Mexico is evidently the country with the least development in training capacities and will probably have the fastest growth in the future, particular emphasis should be put on generating regional capacity for its technical personnel.

This could be done in different contexts, from collaboration among utilities, unions and universities, to specific programs.

d. What are the potential financial mechanisms (e.g., private sector, governments, philanthropic foundations, and international organizations) to facilitate training opportunities in renewable energy for students and experts from the three countries?

i. Use existing governmental, trinational arrangements

Both the Commission for Environmental Cooperation and the North American Energy Working Group are organizations that could be used to explore, facilitate and establish trinational arrangements that could be financed by the three countries through a common fund.

ii. Promote industry arrangements

As skilled personnel is a key issue in the sustainable growth of the RE industry, and some companies have or may have projects in all three countries, the creation of a trinational, public/private workforce to promote training partnerships with community-based organizations could be explored.

3. Technology Assessment

3.1 Solar Photovoltaic Systems

Photovoltaic (PV) systems produce electrical energy by using solar energy to promote the flow of electrons and thus produce direct current (DC) electricity. PV has been a market-ready technology for many years and is considered a relatively mature renewable energy (RE) technology, with many examples in small projects throughout North America. Since PV produces electricity, the highest grade of energy, it can therefore be used directly to power various types of equipment or be converted to various grades of heat. It can also be metered and sold back to the utility.

PV is flexible in terms of application and installation, not only because of the high grade of energy produced but also because building integration is possible (both on the roof and the facade). This makes PV a popular choice for smaller-scale electricity-generating RE systems.

3.1.1 Components

A PV system is composed of photovoltaic panels, which generate the DC electricity; electrical distribution and protection equipment, to distribute the electricity; as well as several other optional components for ensuring power conversion and power quality, providing energy storage, and providing a mounting structure, which vary according to application.

The main elements of PV systems are the following:

- **PV panel.** The PV panel is the central piece of a PV system, as it converts sunlight into direct current (DC) electricity. Commercial PV panels are typically composed of a silicon-based photovoltaic material, but several other materials are also available and recent research into conductive plastic materials shows promise, in terms of efficiency and low cost.

- **Inverter.** The inverter is responsible for converting the DC electricity from the panel into alternating current (AC) electricity, which is the common form of electricity supplied by the electrical grid and used by equipment in buildings and homes. Inverters for grid-tie applications can also provide islanding protection (prevents feeding of electricity into the grid in the case of grid failure) and power-quality measures to ensure that electricity fed into the grid is of corresponding voltage, current, and phase.

- **Electrical distribution and protection.** Electrical distribution and protection equipment is used for distributing electricity from the PV panels to the other system components. Protection devices include disconnects, fuses and breakers, which provide over-current protection and disconnect points for system maintenance.

- **Meter.** PV systems that feed electricity into the utility grid will either connect to the existing electrical meter, a separate feed-in meter, or a bi-directional meter, to allow tracking and measurement of the electricity produced by the PV system.

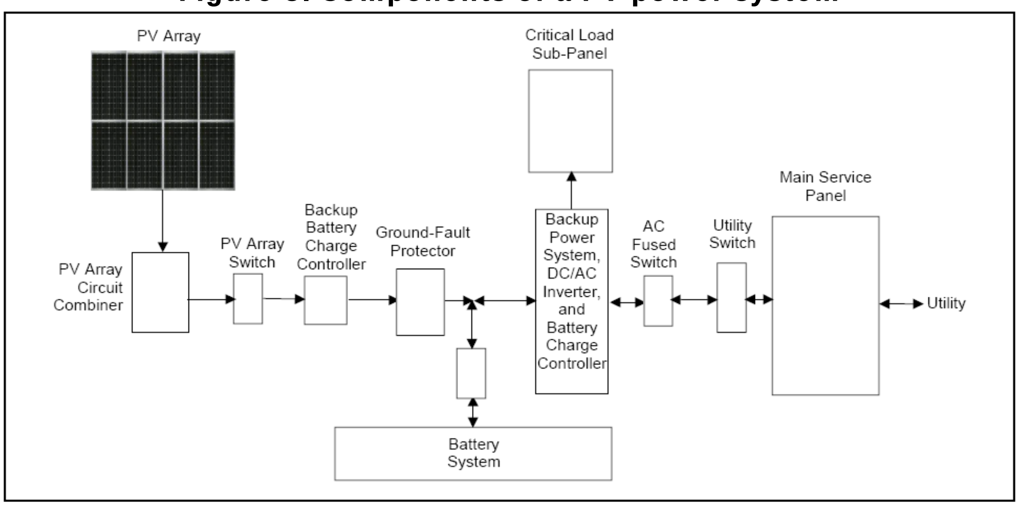
- **Storage.** PV systems that are not connected to the electricity grid will typically use batteries to store the electrical energy and to ensure the electricity needs of the intended end-use can be met and any excess electricity stored. Battery storage systems should therefore be appropriately sized not only to provide the desired number of days of autonomy during insufficient solar radiation but also to provide sufficient current to meet the needs of the intended end-use(s). Battery storage systems also require the use of a charge controller, to ensure that the batteries are being charged at the proper voltage and current. Several battery technologies exist, including lead-acid batteries, which are the most popular in commercial systems, and emerging technologies include vanadium redox batteries (VRB) and flywheels, and production of hydrogen gas for use in a fuel cell. [24]

- **Mounting structure.** PV panels, regardless of the application, require a structure on which to be mounted. In the case of building-integrated systems, the panels are typically mounted directly on the existing roof or wall structure, using brackets. In these cases the angle at which the panels are mounted will be dictated by the angle of the roof or wall structure. Non-building-integrated mounting options are also possible, which typically involve a racking system on which the panels are mounted. The racking system itself can be located on the roof of the building, or on land. Racking systems allows the flexibility of choosing a more-specific mounting angle to maximize the capture of incident solar radiation, and can also incorporate more-advanced options such as time of day and seasonal tracking of the movement of the sun to maximize electricity production even further.

3.1.2 How the main components are integrated

There are two general types of electrical designs for PV power systems for households: systems that interact with the utility power grid and have no battery backup capability; and systems that use battery storage and interact with the grid or are off-grid altogether (Fig. 8).

Figure 8. Components of a PV power system



Source: A Guide to Photovoltaic (PV) System Design and Installation, [25]

3.1.3 Particular issues related to design, installation and operation and maintenance

Design

Three main considerations to keep in mind when designing a PV system include: maximizing the incident solar radiation, meeting the electricity requirements for the intended application, and determining backup requirements and alternatives.

- ***Maximizing solar radiation.*** Since PV systems convert sunlight into electrical energy, they should be oriented in a manner that maximizes the amount of solar radiation that strikes the panels throughout the day and year. The first factor to consider is shading. Attention must be paid to ensure that the location of the panels is adequately free from obstructions that may shade the panels at various times of the day and year. When choosing the appropriate mounting angle, a common rule of thumb is to mount the panels at an angle that is similar to the latitude of the location. Several strategies may alter this technique, including: dealing with restrictions due to building integration (i.e., a panel likely needs to be mounted at an angle that is close to the angle of the surface to which it is being mounted); maximizing energy production to coincide with time-of-use electricity rates; and minimizing snow collection by increasing the angle.

- ***System sizing and protection.*** When sizing the components of a PV system, the electricity load of the intended application must be kept in mind. For non-grid-tie (or stand-alone) systems, the system is designed to meet the desired fraction of energy needs (known as the solar fraction). For a grid-tie system, the size is typically dictated by factors other than meeting a desired fraction of the electricity load of a project (e.g., drivers can include economics and social criteria such as a renewable energy target or greenhouse gas emissions reductions). When determining the size for an off-grid system, there are several factors to consider, including the number of hours of sunlight, the size of the battery bank, and the electricity demand characteristics of the load (this is discussed further in the “Backup” section below). Another factor to consider is the method used to connect the PV panels. Panels can be connected either in series or in parallel, with the choice affecting voltage and current and therefore losses in the distribution of the electricity.

- ***Backup.*** To determine the size of the battery backup, two main factors must be considered. The size of the battery bank should take into account the electricity needs of the load as well as the number of days of backup power the battery bank should provide. In addition, the capacity of the battery bank is inversely proportional to the rate at which it is discharged. This means that the slower the discharge rate, the greater the capacity of the battery bank.

- ***Code requirements*****.** When designing the system, the electrical code requirements of the jurisdiction in which the system is installed must also be followed. Important considerations include sizing the wires and protection devices to accommodate the appropriate temperature and current; having disconnects at various points to allow for maintenance of components such as inverters and batteries; and ensuring the system is property grounded.

Installation

There are a number of issues that require specialized attention during the installation of photovoltaic systems. In fact, installation is very particular to the specific house layout and the roofing type [25].

- **Location.** A photovoltaic system installer must be able to recognize location-specific problems, needs and solutions. These have to do with solar radiation availability (no shadows), mounting (in regard to available space, suitable surface conditions, and adequate support points and surfaces), and general working space (in regard to safety).

- **Mounting and maneuvering.** As a good part of the mounting occurs on the higher points of an installation, avoiding safety hazards and property damage makes maneuvering knowledge and skills indispensable.

- **Assembly.** Assembling a photovoltaic system requires general electric-trade skills but also some skills specific to this type of system.

- **Testing, troubleshooting, operation, and maintenance.** A photovoltaic system requires a series of tests to make sure it works in accordance with the original design and to identify any malfunctions.

An experienced crew can install a 2-kW non-battery PV system in two to four person-days. Systems with battery backup are more labor-intensive than non-battery systems because of the additional wiring required for the critical load subpanel. A battery system can add 50–100% to the time required for the installation [25].

Since PV systems generate electricity, they require certified electricians or their equivalent (according to the jurisdiction) for their installation. However, PV systems may require other trades people as well, such as roofers, when the panels are installed on the structure of a building. Installers should understand the importance of complying with the design specifications of the system, in order to ensure that the expected performance is met as closely as possible.

Operation and maintenance

Operation and maintenance requirements for PV systems are generally straightforward. To monitor electricity production, various options are available, from simple recording devices built into inverters or sold separately, to more elaborate programs that allow Web-based monitoring and tracking of a PV system's performance.

Maintenance is also generally straightforward, and includes ensuring battery terminals and connections are corrosion-free for standalone systems; any building penetrations remain sealed; all electrical connections are tight and connection boxes are sealed; and PV panels are clean and in good working condition. One method of ascertaining that the panels are working properly is to check that the system voltage remains at or near the original design value.

3.2 Wind Systems

Wind energy is a renewable energy that has reached a technological maturity; it is already a clean, mainstream source of electric power, a major source of economic growth, and is the world's fastest growing renewable energy technology.

Energy available in the wind is basically the kinetic energy of large masses of air moving over the Earth's surface. The blades of a wind turbine transform this kinetic energy into mechanical or electric forms, depending on the final user's needs. Mechanical energy is most commonly used for pumping water in rural or remote locations, while electric wind turbines generate electricity for homes and businesses, as well as for large-scale electrical generation utilities.

There are two basic designs of wind turbines: vertical-axis (the most famous being the Darrieus and Savonius designs) and horizontal-axis, which are fan-type machines. Horizontal-axis wind turbines are the most common today, and represent the major portion of all the generating-size turbines in the global market.

Wind energy turbines also can be classified according to their aerodynamics. Hence, the aerodynamic interaction of the blades with the wind can be by drag or lift or a combination of both.

Wind-energy systems come in many sizes but, generally speaking, can be classified according to the size of the rotor as large, medium or small generators. Large generators (megawatt-sized wind turbines) are usually part of wind farms and directly connected to the power grid, and medium and small wind turbines are usually used individually for some specific and local applications.

Megawatt-sized wind turbines. These are generally installed at wind farms. A wind farm is a group of wind turbines in the same location, used for production of electric power. A large wind farm may consist of a few dozen wind turbines or hundreds, and can cover an extended area of hundreds of square miles. A wind farm may be located offshore to take advantage of strong winds blowing over the surface of an ocean or lake. Wind turbines of 100-kilowatt (kW) capacity and larger are considered utility-scale generation wind turbines.

- ***Small and medium-size wind turbines***. The general convention is that medium-size wind turbines are those with rated capacities of up to 100 kilowatts. Although their energy contributions are smaller in absolute terms, they are a big help to many people living in rural communities; they are also beginning to appear in the interconnected electricity market and in some other off-grid applications all around the world.

3.2.1 Components

A wind energy installation involves a significant number of components. Those directly related to the turbine subsystems generally include the following:

- ***Rotor***. The rotor assembly comprises a hub and the blades, whose function is to convert the energy of the flowing air into rotational shaft energy. A typical utility-scale wind turbine has three high-tech blades made of laminated materials that must have high strength-to-weight ratios, such as composites, balsa wood, carbon fiber, and fiberglass, and often also include some material to protect against lightning strikes. The lift turbine type of blade is shaped like an airfoil, just like an airplane's wing, to maximize the power extraction from the wind. Each blade is bolted onto the hub of the rotor, with a pitch mechanism interposed to allow the blade to rotate on its axis so it can take advantage of different wind speeds.

- ***Nacelle***. The nacelle is the container holding the drive train. The drive train usually includes a gearbox, which is driven by the rotor through a shaft and whose main function is to increase the revolutions per minute to a speed suitable for the electrical generator. As a safety mechanism, the shaft usually has two independent braking systems. The gearbox must be strong enough to handle the frequent changes in torque caused by changes in the wind speed. The turbine has a yaw drive system to keep the rotor facing into the wind.

- ***Tower***. A high tower is used, in order to capture the maximum energy from the wind. It usually stands 30 meters or more above ground, so that the wind turbine can take advantage of faster and less turbulent currents. The nacelle and generator are mounted on top of this tower, which is typically made of several tubular steel sections joined by bolts and coated with paints and sealants. Installing such a tall tower, the nacelle and the rotor requires a crane of extraordinary height and capacity.

- ***Control system***. Operation of the wind turbine is regulated through electronic equipment that includes a computerized control module that responds to the input from a number of sensors. The sensors read important variables such as wind speed and direction, rotor speed, blades' pitch, turbine's vibration, lubricant's temperature, amount of electrical power generation, and other variables. A safety system is in place that can override the controller in an emergency. To control the power output and condition it to match the voltage, current and phase in the receiving grid, the generator is equipped with a remote control and monitoring system.

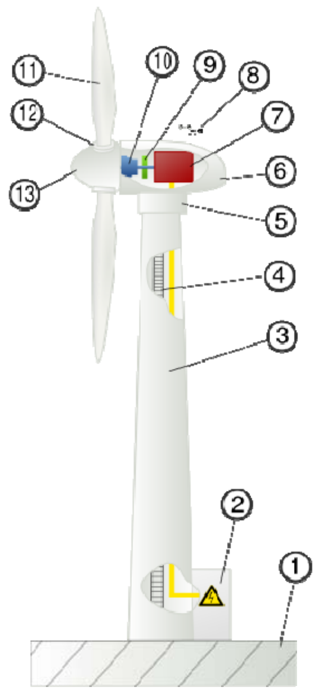
- ***Foundation***. The tower is usually fitted to a foundation by means of a base flange and screwed rods cast into concrete or bolted to an embedded tower stub. The foundation of tubular towers is engineered from a choice of slab, multi-pile and mono-pile constructions, determined by the condition of the ground where the turbine is being mounted. In addition to the installation of each of the turbines, there is other construction work that has to be carried out at the site, including: laying of electrical cable; electrical connection of the wind turbines to the power grid; access roads; ground support equipment; and building and installation of an electrical substation.

Small wind energy systems generally are simpler than the megawatt-sized turbines. Usually they comprise a rotor, a tail, a generator or alternator mounted on a frame, a tower, wiring, controllers, inverters and, if required, batteries. These small wind turbines usually generate direct current electricity, necessitating use of an inverter to convert the direct current electricity from the batteries to the alternating current electricity that household appliances run on.

3.2.2 How the main components are integrated

Wind turbines convert the energy in the flowing air to rotational shaft energy, which drives a power generator. Since the amount of power a turbine can produce is determined primarily by the size of its blades, this parameter defines its "swept area," or the quantity of wind intercepted by the turbine. The blades are mounted at the top of a high tower connected to a drive train, usually with a gearbox, that transfers the rotational energy from the blades to a generator which converts that energy into electricity. The shaft, drive train and generator are covered by a protective enclosure called the nacelle. Also inside the nacelle are electronic and electrical equipment, including controls, electrical cables, ground support equipment, and interconnection equipment. All this equipment controls the turbine, ensures maximum productivity, and transmits the generated electricity (Fig. 9).

Figure 9. Components of a wind energy system

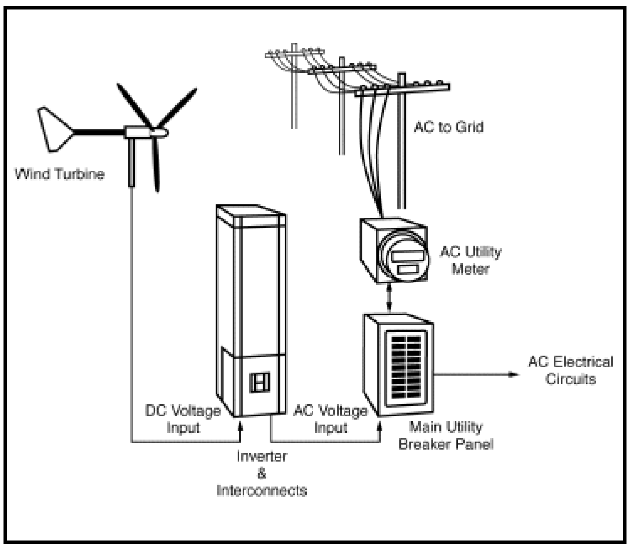


Foundation (1)
Connection to electric grid (2)
Tower (3)
Access ladder to the top (4)
Wind orientation (yaw) control (5)
Nacelle (6)
Generator (7)
Anemometer and wind vane (8)
Brake system (9)
Gearbox (10)
Rotor blade (11)
Blade pitch control (12)
Rotor hub (13)

Source: Wikipedia [26].

Small wind energy systems are mainly used for self-supply of electricity at homes or for water pumping systems and they can either be tied to the grid or be stand-alone systems, which also include some kind of energy storage system (Fig. 10).

Figure 10. Small grid-tied wind energy system diagram



Source: Ontario's Ministry of Agriculture, Food and Rural Affairs, Canada [27].

3.2.3 Particular issues related to design, installation, operation and maintenance

The design and installation requirements for a wind turbine system depend significantly on the size. While small systems can be installed by a homeowner, large systems involve complex operations.

Design

The main considerations to keep in mind when designing a wind system include the following.

- **Resource evaluation.** Evaluating the wind resource is a key element in the design of a wind system, since the availability of wind is critical to the technical and economic feasibility of the project, and the knowledge of the hourly and seasonal variations of intensity and direction of the wind (together with other secondary factors such as relative humidity) are fundamental to the definition of the most adequate wind technology.

- **Site selection and layout.** Selecting the site for a large system or establishing which location is appropriate for a small system is a very important issue. For instance, a site on the top of the windy side of a hill will be preferable because the wind turbine will have more access to prevailing winds than in a gully or on the sheltered side of a hill on the same property. In addition, existing obstacles such as trees, houses, and sheds should be considered, as well as possible future obstructions such as new buildings, or trees that have not reached their full height. Also, the turbine needs to be sited upwind of buildings and trees, and it needs to be 10 meters above anything within 100 meters.

- **Turbine selection.** Modern wind turbines are designed to work for some 120,000 hours of operation throughout their estimated design life-cycle of 20 years. Because wind speeds increase with height, the higher the tower, the more power the wind system can produce, so relatively small investments in increased tower height can yield very high rates of return in power production. The tower also raises the turbine above the air turbulence that can exist close to the ground because of obstructions such as hills, buildings, and trees.

- **Foundations.** The appropriate type of anchor or foundation is determined by the kind of soil where the turbine is being erected. Small wind turbines do not usually need foundations.

- **Code and safety requirements.** Installation of a wind turbine is subject to electrical codes. These code requirements emphasize proper wiring and installation parameters and the use of components that have been certified for fire and electrical safety by approved testing laboratories.

Installation

The issues related to the installation of wind systems depend on the size of the systems.

- **Megawatt-sized turbines**. Installing a big wind turbine is a complex endeavor. First, transportation of turbine components has to be well planned and organized, given the size, weight, and length of the components; innovative transportation and logistics and onsite manufacturing and assembly solutions are necessary. Also, and in addition to the maneuvers related to onsite assembly of the turbine itself, construction may include building a road network, building the turbines' foundations, laying electrical cable, and installing an electrical substation.

- **Small wind turbines**. The installation of small wind energy systems is quite different from that of mega-sized ones. For instance, a wind turbine of less than three meters in diameter can be installed by the homeowner or someone with basic construction skills. The use of lightweight, tilt-up masts and towers for small turbines has made the installation much easier than ever before. However, the risk is proportional to the wind turbine size being installed, since components are heavier for the bigger turbines, and in some cases special equipment could be required. For a medium-size wind turbine, the better option is to leave the installation to a professional and experienced contractor, since it requires specialized equipment for the lifting process.

Operation and maintenance

Maintenance of wind systems is an important factor in achieving their operational goals. Maintenance costs for wind turbines are typically less than those for conventional forms of electricity generation. Wind turbine maintenance is usually scheduled twice a year, resulting in about 12 to 18 hours of downtime for each turbine during the maintenance procedure. Generally, only a few turbines in a facility are down at one time for maintenance activities. The only time the whole facility is shut down is for substation maintenance, which usually lasts for only about 12 hours and occurs twice a year, during low-production periods.

Wind energy applications are among the most demanding applications for gearboxes and generators, due to variable loads that are extremely difficult to predict. Thus, the two items that most commonly require maintenance are precisely those components. Furthermore, they are two of the parts most exposed to friction and wear, and sometimes a large crane will be needed to repair them.

Blades usually do not require any kind of special maintenance. The only required, scheduled maintenance is for cleaning them or performing a visual inspection of their integrity.

Similarly to big turbines, small wind turbines also require some annual maintenance. The main components of the wind turbine should be checked for corrosion; both bolts and electrical connections must be checked, and they must be tightened, as necessary. After some years, the blades or bearings may need to be replaced. The binding on the leading edge of the blades must also be checked for wear, and replaced, if necessary.

3.3 Solar water heaters

Solar water heaters (SWH) are systems that heat water with direct and indirect solar energy. A SWH system uses a solar collector to heat a working fluid that transfers the sun's heat to a water-storage tank.

These systems may be used for direct or indirect water heating in a wide variety of applications in homes, business, industry and/or agriculture:

- domestic hot water, swimming pools, radiant heating, space heating or cooling;

- process hot water in multi-unit houses and apartment buildings and in commercial and institutional applications, such as schools, health centers, hospitals, office, buildings, restaurants and hotels;

- small commercial and industrial applications such as car washes, laundries and fish farms;

- large industrial loads and district heating networks.

SWH systems can be classified, based on the way the heat collected circulates in the system, as active or passive:

- ***Active.*** Active SWH systems have circulating pumps and controls and fall into two general categories:

    - **Direct circulation, or open loop**. Pumps circulate water through the collectors and into the end-use installation. They work well in climates where it rarely freezes.

    - **Indirect circulation, or closed loop**. Pumps circulate a non-freezing, heat-transfer fluid through the collectors and into a heat exchanger that heats the water that flows into the installation. They are commonly used in climates prone to freezing temperatures.

- ***Passive.*** Passive SWH systems work on natural convection, which causes warming liquid to circulate in a vertical closed-loop circuit without the need of a conventional pump. There are two basic types of passive systems:

    - **Thermosyphon**. Water flows through the system when warm water rises and cooler water sinks. The collector must be installed below the storage tank so that warm water will rise into the tank. These systems are reliable, but contractors must pay careful attention to the roof design because of the heavy storage tank. They are usually more expensive than integral collector-storage passive systems.

    - **Integral collector-storage**. In this type of system the hot water storage system is the collector. Cold water flows progressively through the collector where it is heated by the sun. Water is drawn from the top, where it is hottest, and cooled replacement water flows into the bottom. This system is simple because pumps and controllers are not required. These work best in areas where temperatures rarely fall below freezing and where the household's hot-water needs are greatest during daytime and evening.

3.3.1 Components

The main components of a SWH system are: collectors, storage tanks, circulation systems and back-up systems.

- **Collectors.** The solar collector is the main piece of a SWH system, as it collects solar energy and transmits it to the working fluid to heat it up. Using either domestic or solar electricity, fluid is circulated through the tubing to transport the heat from the absorber medium to an insulated water tank, sometimes directly, or otherwise through a heat exchanger or to some other device for using the heated fluid. The collector can be a simple glass-topped, insulated box, with a flat solar absorber made of sheet metal attached under copper pipes and painted black, or with a set of metal tubes surrounded by an evacuated (near-vacuum) glass cylinder. There are four main kinds of solar thermal collectors in common use: formed plastic collectors, flat-plate collectors, integral collector-storage, and evacuated tube collectors.

- **Formed plastic collectors.** These collectors (made of material such as polypropylene, EPDM or PET plastics) consist of tubes or formed panels through which water is circulated and heated by the sun's radiation.

- **Flat-plate collector.** A flat plate collector consists of a thin absorber sheet (of aluminum, steel or copper, to which a black or selective coating is applied), backed by a grid or coil of fluid tubing and placed in an insulated casing with a glass or polycarbonate cover. They are generally contained in weatherproof boxes under one or more glass or plastic (polymer) covers.

- **Integral collector-storage systems.** Also known as ICS or batch systems, they feature one or more black tanks or tubes in an insulated, glazed box. Cold water first passes through the solar collector, which preheats the water. The water then continues on to the conventional backup water heater, providing a reliable source of hot water. They should be installed only in mild-freeze climates because the outdoor pipes could freeze in severe, cold weather.

- **Evacuated tube collectors.** These feature parallel rows of transparent glass tubes. Each tube contains a glass outer tube and metal absorber tube attached to a fin. Sunlight passing through an outer glass tube heats the absorber tube contained within it. The glass-metal evacuated tubes are typically sealed at the manifold end, and the absorber is actually sealed in the vacuum.

The most commonly used solar collector is the insulated flat plate collector. In extremely hot climates, flat-plate collectors will generally be a more cost-effective solution than evacuated tubes. Less expensive panels, like polypropylene panels, are used for swimming pools. Evacuated tube collectors perform better than flat plate collectors in cold climates because they rely only on the light they receive and not on the outside temperature.

- **Storage tanks.** Except in the case of integrated collector storage solar collectors, most SWH systems require a well-insulated storage tank. Tanks are pressurized or unpressurized, and the type used depends on the overall system design. They are usually made of stainless steel, fiberglass, or high-temperature plastic. Concrete and wood (hot tub) tanks are also options. Tanks also have limits for temperature and pressure, and must meet local building, plumbing, and mechanical codes; insulation is necessary to prevent excessive heat loss; and protective coating or sealing is necessary to avoid corrosion or leaks. Specialty or custom tanks may be needed in systems with very large storage requirements.

- **Backup system.** SWH systems almost always require a backup system for cloudy days and times of increased demand. Conventional storage water heaters usually provide backup and may already be part of the solar system package. In one-tank systems, the back-up heater is combined with the solar storage in one tank.

- **Circulation systems.** A SWH system includes a pump, valves, strainers, and thermal expansion tank.

  - **Pump.** In an active system, the pump is required to transfer the fluid from the solar collector to the hot water storage tank. In a thermosyphon system, where circulation is natural, a pump is mot required.

- o **Working fluid.** The working fluid for the absorber may be the hot water from the tank, or a fluid containing anti-freeze, that is pumped in a separate loop which delivers heat to the tank through a heat exchanger (commonly a coil of copper tubing within the tank).

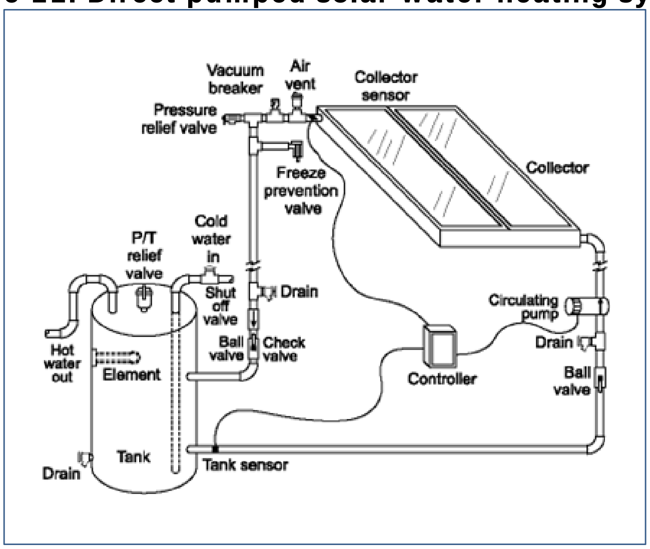
- o **Controls.** Active systems need controls to move the heat that is available from the solar collectors. They can also include features that are related to safety, such as overheating protection; seasonal systems freeze protection or prevention against restart of a large system after a stagnation period; display or transfer of error messages or alarms; remote display panels; and remote or local data-logging.

- **Housing and support.** Also important are the components used in housing and support, which are generally custom-made for each individual installation.

3.3.2 How the main components are integrated

The elements of a SWH system are connected either by pipes or electric wires, and their integration will depend on the size, the purpose, the patterns of demand, and the climate of the location (Fig. 11).

Figure 11. Direct pumped solar water heating system



Source: Karnitz, A. *Solar Water Heating System*. [28]

3.3.3 Particular issues related to design, installation, operation and maintenance

Design

The annual performance of a solar water heating system with a storage tank is dependent on system characteristics, solar radiation available, ambient air temperature, and heating-load characteristics. When properly designed, solar water heaters can work when the outside temperature is well below freezing and they are also protected from overheating on hot, sunny days.

The most important element of the design is the sizing of the collector and the tank, as it determines the cost-effectiveness of the investment. So, in order to have the right design, load calculations made using specialized software are recommended.

Also, while there is nothing daunting about the basics of solar installation, any new renewable system must be properly integrated with existing building services to deliver its full potential. This means the system designer and installer must have an in-depth knowledge of how conventional services work and how the renewable system can be designed to work in partnership with condensing boilers, for example [29].

Finally, the system must comply with local solar, plumbing and electrical codes.

Installation

There are a number of issues that require specialized attention during installation.

- **Location.** A SWH system installer must be able to recognize location-specific problems, needs and solutions. These have to do with solar radiation availability (no shadows), mounting (in regard to available space, suitable surface conditions, and adequate support points and surfaces), and general working space (in regard to safety).

- **Mounting and maneuvering.** As a good part of the mounting occurs on the higher points of an installation, maneuvering knowledge and skills are indispensable to avoiding safety hazards and property damage.

- **Assembly.** Assembling a SWH system requires general plumbing and electric trade skills but also some skills specific to the type of system. For example, in order to use a standard electric water heater in a solar system, the installer has to modify some of the plumbing, since a conventional tank does not have a collector feed and return port.

- **Testing, troubleshooting, operation and maintenance.** A SWH system requires a series of tests to make sure it works in accordance with the original design and to identify any malfunctions (leaks, adequate valve and control operation). Also, although little maintenance is necessary, these tests should be done every few years nonetheless.

Operation and maintenance

Solar energy systems require periodic inspections and routine maintenance to keep them operating efficiently. Also, from time to time, components may need repair or replacement.

Inspections of solar systems should cover the following issues/components: collector shading; collector glazing and seals; plumbing, ductwork, and wiring connections; piping, ducting, and wiring insulation; roof penetrations; support structures; pumps; heat transfer fluids; and storage systems [30].

4. Knowledge Requirements and Institutional Contexts

The renewable energy industry involves a wide range of professionals with a great variety of practices and skills. At the business end of the process are those professionals involved in research of materials, parts, and systems, and in resource assessment; and at the manufacturing end are those involved in design, installation, sales, and operation and maintenance of the systems and their components. The industry also requires a wide range of skills associated with general aspects of a business enterprise, such as sales, financing, data processing and human resources management.

In particular, this report focuses on those who prospect, design, procure, install, inspect, operate and maintain, and sell photovoltaic, small and large wind, and solar water heating systems.

4.1 Photovoltaic systems

The PV industry consists of the various market players involved in the research and design, manufacturing, installation, and sale of PV systems and components. More specifically, the types of employment for these systems can be classified in the following categories [3]:

- PV research and production
- System design and procurement
- Installers, inspectors, maintenance personnel, and technical sales specialists

4.1.1 PV research and production

This type of employment typically involves research and development (R&D) of PV panels and of the balance-of-system components. R&D of PV panels can involve research into the semiconductor materials themselves or the design aspects of the panel. R&D of system components will be concentrated primarily in the areas of inverters, charge controllers, and mounting systems. Electrical distribution and protection components are typically not designed exclusively for use with PV systems and therefore not considered to be directly related the PV industry.

- ***PV research***. Employment in this area typically requires a university education in technical areas such as physics and engineering, with emphasis on knowledge of materials, semiconductors, power electronics, and mechanical design, and on other related engineering and scientific skills. Positions are often filled by electrical, mechanical, chemical, materials, system design, and process engineers.

- ***Production technicians and technologists*.** This category of employment usually involves research and development (R&D) of PV panels and balance-of-system (BOS) components, or the post-sales or post-installation support of PV equipment. R&D people are typically also involved in the actual fabrication process for the various PV panel and BOS components and the assembly of the panels and components themselves. Employment in this category can sometimes require a college degree or certificate with a specialization in a particular part of the manufacturing process. However, for some general assembly positions no specific educational requirements exist.

Employment in the R&D area will typically be found within companies that manufacture PV panels and BOS components. Other employees in this category generally work for PV equipment distribution companies that offer installation services or for companies that simply install PV systems.

4.1.2 Systems design and procurement

System designers are involved in designing the integration of the various components of a PV system. Design at this level requires knowledge of the various system components, their design constraints and specifications, and their interaction. System designers can be electrical engineers or technologists, since the work involves the design of the various components of an electrical distribution network, from the electricity generator (panels) to the intended end use; however, no formal education or certification is required. A theoretical knowledge of electrical systems, AC and DC electricity, and the various components of a PV system are essential. System designers should also be familiar with the various electrical code requirements of the relevant jurisdiction.

System designers will typically be employed by distributors of PV systems or by private firms (usually engineering firms, to be able to issue technical drawings) that provide design services for PV system (and sometimes other renewable energy technologies).

4.1.3 Installers, inspectors and maintenance personnel

There are five general categories of professionals that are involved routinely in fieldwork.

- ***System installers***. PV system installers can posses similar knowledge to system designers; however, their skills should be more in the area of hands-on and working knowledge rather than theoretical. Also, as with designers, installers do not require formal certification. They will typically be trades people trained as electricians, since most of the work, except for installation of the panels and mounting system onto roofing or walls for building-integrated systems, involves electrical components and connections. To be qualified to install a PV system, installers must be trained to work with DC and AC electricity, and be familiar with inverters, charge controllers, batteries, measurement and display devices, and generators. Installers must also be familiar with the various electrical code requirements of the relevant jurisdiction.

- ***Maintenance personnel*****.** Those involved in post-sales or post-installation will usually provide technical support for PV equipment as well as for entire systems. The requirements for PV maintenance personnel are the same as for PV system installers, but they should also have troubleshooting capabilities.

- ***Technical sales specialists***. Technical sales specialists are typically technologists or engineers with some sales training. Technical sales specialists require a detailed knowledge of the equipment they are selling, which generally consists of PV panels, inverters, charge controllers, batteries, and the other BOS components. These technologists and technicians should be trained to work with electricity and should be very familiar with the various components of the PV system in order to be able to both troubleshoot issues and replace faulty equipment. Even though a company may not deal with the entire system, knowledge of the components, function, and purpose at a system level is typically required in order to properly assist customers with the selection of the proper materials and sometimes to create an initial high-level design.

- ***Human resources and administration staff*****.** Human resources and administration staff generally do not require specific training related to PV systems; however, some general knowledge on the subject is always helpful since that may mean less on-the-job training. General knowledge of PV systems and components is useful for various tasks, including routing calls and questions to the appropriate personnel, screening the qualifications for job applicants, maintaining the appropriate inventory of parts, and producing contractual agreements.

- ***Inspectors.*** Similarly, inspectors do not necessarily require a particular certification, but they should have an intimate knowledge of codes and standards to ensure that installations are compliant. Inspectors can therefore come from a variety of educational backgrounds; however, a technical degree is typically needed to understand the equipment and be able to identify alternative methods of achieving compliance.

Employment for installers is generally concentrated among PV system distribution companies that offer installation services or companies that simply install PV systems.

Inspectors, on the other hand, will generally be employed by municipalities or by third-party companies that provide services to municipalities.

Technical sales specialists will generally find employment in companies that sell PV system components, from panels to storage to power quality and protection equipment.

All types of employers require human resource and administration staff.

4.2 Wind systems

Wind energy is a multidisciplinary field that encompasses diverse kinds of engineering and skills. In addition, the international nature of the wind industry means that individuals with additional language skills are especially valued.

While many of the jobs do not require wind energy degrees or skills, there are some others that do require special training. In most of these cases, the requirement is any traditional college or university degree and then some kind of specialization in the wind energy field.

- ***Resource assessment and forecasting.*** The wind resource assessment specialist designs, prepares, installs and operates systems that gather data related to wind speed and direction (at different height levels), temperature, and humidity, to forecast the energy output from the wind, which is then used to define layouts and types of turbines. This specialist uses specialized software and prepares reports containing the most important results of this monitoring.

- ***Environmental impact assessment.*** This type of assessment is part of the permitting process of a wind farm. The environmental impact assessment specialist must have knowledge related to a number of subjects: wildlife (particularly avian and bat species), noise, landscape disturbance, shadow flicker, telecommunications interference, archeological issues, and those related to safety. The job of this specialist is to determine the actual impacts of installing wind turbines in a specific site in order to avoid or minimize them, and to fill the necessary reports. These positions usually require only a bachelor degree, and in some cases a technician diploma is sufficient.

- ***Design (engineering and procurement).*** The wind energy designer is a specialist responsible for the selection of the best turbine design and the best layout of the farm to be constructed, in order to take advantage of all wind characteristics of the candidate site and maximize the energy production. The procurement and engineering professional leads the efforts to source and manage delivery of major capital equipment, especially the main components of wind energy turbines. This includes: supporting long-term business plans by identifying key manufacturers; conducting total-cost-of-ownership evaluations; managing large and complicated supply agreements; and ensuring timely delivery of equipment to the project site locations. This type of position requires a higher college degree in an engineering field.

- ***Installation.*** In this case, wind energy installers can be divided into two different groups. The mega-sized wind turbine installers are those who construct and erect the towers that will support these huge wind turbines. Hence, these positions should be occupied by skilled personnel with expertise or education in the building field, since these activities involve civil engineering techniques as well as the operation of specialized equipment and heavy machinery, such as cranes, loaders, compacters, etc. The positions for constructing wind energy farms are diverse, and the grade of education required depends on the activity involved. On the other hand, for installations of small wind turbines, some basic handy skills are required, as well as a good knowledge of electric connections and installations.

- ***Operation and maintenance***. The wind energy operation and maintenance positions require some level of specialization, since these personnel are responsible for ensuring that optimal performance of the wind farm is achieved, as well as for keeping the wind turbines running smoothly. The operators are trained to detect and avoid potential problems and to maximize the energy output. They are also qualified to solve any possible emergencies during wind farm operation. The maintenance positions are also filled by highly specialized technicians, who must have in-depth knowledge of wind turbines in order to perform the scheduled maintenance activities. Usually, the wind energy technicians are trained through associated degrees courses, offered by community colleges, or by the project developers themselves.

- ***Technical sales specialists***. Wind energy systems sales specialists must have sufficient tools to demonstrate the product convincingly to potential buyers and developers, and in particular have technical knowledge of wind turbine specifications and capabilities and auxiliary equipment. For this, some technical college education is recommended, or some practical background in the wind energy field. In most cases, a wind energy seller is trained by the manufacturer, in order to allow the seller to know the whole product at a level of almost the smallest detail.

The wind energy forecasters and resource assessment specialists are commonly employed by the consulting firms which are focused on developing feasibility analyses of candidate sites for developing large wind energy projects. These specialists are also employed by national laboratories, universities, and local governments who want to know the available wind energy resource for specific sites or regions.

The designers also may be hired by consulting firms. The same may be true for the developers, whose job involves determining the best layout for maximizing the wind energy output from the local wind energy resource.

Installers are usually skilled and handy specialists who are often employed by large companies or contractors specializing in the construction field. For small wind energy systems, installers are often employed by small businesses in the renewable energy field or are sometimes just self-employed. Wind energy maintenance specialists and operators are usually hired by developers.

4.3 Solar water heating systems

In particular, the SWH requires specific expertise in three categories:

- System design and procurement
- Installers, inspectors and maintenance personnel
- Technical sales specialists

4.3.1 System design and procurement

System designers integrate the various components of a SWH system and must have technical knowledge of these various components, their design constraints and specifications, and their interaction. They also have to ensure that a system design adheres to the appropriate standards. System designers may be mechanical engineers or technologists, since the work involves design that uses various components of a plumbing system, along with some electrical and electronics parts. A theoretical knowledge of hydraulic and thermal systems is essential.

4.3.2 Installers, inspectors and maintenance personnel

There are three general categories of professionals who are involved routinely in fieldwork.

- **System installers**. A qualified SWH system installer can be defined as a person who has skills and knowledge related to the construction and operation of solar thermal equipment and installations and has received safety training on the hazards involved. This category includes the installer, the foreman, the supervisor, and/or the site manager.

- **Inspectors.** Similarly, inspectors do not necessarily require a particular certification, but they should have an intimate knowledge of codes and standards to ensure installations are compliant. Inspectors can therefore come from a variety of educational backgrounds; however, a technical degree is typically needed in order to understand the equipment and be able to identify alternative methods of achieving compliance.

- **Maintenance personnel.** Those involved in post-sales or post-installation will usually provide technical support for SWH equipment as well as for entire systems. The requirements for SWH maintenance personnel are the same as for their installers, but these personnel should also have troubleshooting capabilities.

4.3.3 Technical Sales Specialists

- Technical sales specialists are typically technologists or engineers with some sales training. Technical sales specialists require a detailed knowledge of the equipment they are selling and how the different components are integrated.

System designers will typically be employed by distributors of SWH systems or private firms that provide SWH system design services.

Employment for installers is generally concentrated in SWH system distribution companies that offer installation services or in companies that simply install SWH systems. Self-employment is also an option.

Inspectors, on the other hand, will generally be employed by municipalities or housing developers or third-party companies that provide services to both municipalities and developers.

Technical sales specialists will generally find employment in companies that sell SWH systems.

All these types of employers have need as well of human resource and administration staffs.

References

1. REN21, *Renewables 2007 Global Status Report*. 2008.
2. Global Insight, *Current and Potential Green Jobs in the US Economy*. 2008: Lexington, MA. p. 41.
3. The Delphi Group, *Situational Analysis of the Canadian Renewable Energy Sector with a Focus on Human Resource Issues*. 2007. p. 120.
4. UNEP, *Green Jobs: Towards Decent Work in a Sustainable, Low-carbon World. Policy Messages and Main Findings for Decision Makers*. 2008. United Nations Environment Programme: Nairobi, Kenya. p. 36.
5. Pollin, R., et al., *Green Recovery. A Program to Create Good Jobs and Start Building a Low-Carbon Economy*. 2008. Center for American Progress. p. 42.
6. ACORE, *Overview. Renewable Energy Provisions. American Recovery and Reinvestment Act of 2009*. 2009.
7. ONTARIO 39TH LEGISLATURE, *Green Energy Act, 2009*. 2009. Legislative Assembly of Ontario.
8. Kammen, D.M., K. Kapadia, and M. Fripp, *Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate?* 2004. University of California, Berkeley.
9. Trevor Houser, S. Mohan, and R. Heilmayr, *A Green Global Recovery? Assessing US Economic Stimulus and the Prospects for International Coordination*. 2009. p. 21.
10. Roger H. Bezdec, *Renewable Energy, Efficiency Creates Jobs for U.S. and Colorado.* American Solar Energy Assoc (ases.org). 2009 (March 2009).
11. Kamenetz, A. *Ten Best Green Jobs for the Next Decade* 2009. Fast Company [January 13, 2009] http://www.fastcompany.com/articles/2009/01/best-green-jobs.html.
12. Weissman, J.M. and K. Laflin, *TRENDS IN PRACTITIONER TRAINING FOR THE RENEWABLE ENERGY TRADES*, in *35th ASES Annual Conference*. 2006: Denver, Colorado. p. 5.
13. Hendricks, B., *Wired for Progress. Building a National Clean-Energy Smart Grid*, Center for American Progress, Editor. 2009. p. 66.
14. DSIRE. *Contractor Licensing Requirements for Renewable Energy*. 2009 [Available from: http://dsireusa.org/library/includes/type.cfm?Type=License&Back=regtab&CurrentPageID=7&EE=1&RE=1&Search=TableType.
15. NABCEP. *North American Board of Certified Energy Practitioners* 2009 [cited March 8th, 2009]; Available from: http://www.nabcep.org/.
16. NABCEP. *Small Wind Certification Comes to NABCEP*. 2009 [cited March 8th, 2009]; Available from: http://www.nabcep.org/news/small-wind-certification-comes-to-nabcep.
17. CONOCER, *Norma Técnica de Competencia Laboral para Instalación del sistema de calentamiento solar de agua*, CONOCER, Editor. 2009, *Diario Oficial de la Federación*. p. 13.
18. IREC. *Renewable Energy Training Catalog*. 2009 [cited March 8th, 2009; Available from: http://www.irecusa.org/trainingCatalog/.
19. IREC. *What is IREC?* 2009 [cited March 10th, 2009].
20. 110th Congress. *ENERGY INDEPENDENCE AND SECURITY ACT OF 2007*. Public Law 110-140 2007 [cited March 9th, 2009]; Available from: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_public_laws&docid=f:publ140.110.
21. EEI, *Title X – Green Jobs*, E.E. Institute, Editor. 2008, Edison Electric Institute. p. 3.

22. Green Jobs. *About Greenjobs*. 2009 [cited March, 8th 2009]; Available from: http://www.greenjobs.com/Public/Info/about_us.aspx.
23. Association, A.W.E. *AWEA Education Working Group* 2009 [cited March 8th, 2009]; Available from: http://www.awea.org/education/workinggroup/goals.html.
24. World, R.e. *Photovoltaic systems*. [cited 2008 December]; Available from: http://www.renewableenergyworld.com/rea/tech/solarpv.
25. CEC, *A GUIDE TO PHOTOVOLTAIC (PV) SYSTEM DESIGN AND INSTALLATION*, California Energy Commission: Sacramento, California.
26. Wikipedia. *Wind power*. 2009 [cited 2009 March]; Available from: http://en.wikipedia.org/wiki/Wind_power.
27. Clarke, S. *Electricity Generation Using Small Wind Turbines At Your Home Or Farm*. 2009 [cited 2009 March]; Available from: http://www.omafra.gov.on.ca/english/engineer/facts/03-047.htm.
28. Karnitz, A. *Solar Water Heating System*. Requirements for Engineering 115 2002 [cited 2008 December]; Available from: http://www.humboldt.edu/~ccat/solarheating/hotwaterheating/andySP2002/swh.html.
29. Jakeway, P. *Exploiting the opportunities for solar hot water*. MBS 2007 August 2007 [Available from: http://www.modbs.co.uk/news/fullstory.php/aid/3680/Exploiting_the_opportunities__for_solar_hot_water.html.
30. DOE. *Solar Water Heating System Maintenance and Repair*. 2009 [cited 2009 February 6th 2009]; Available from: http://apps1.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12950.