Review Article

Renewable Energy and Occupational Health and Safety Research Directions: A White Paper from the Energy Summit, Denver Colorado, April 11–13, 2011

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Renewable energy production may offer advantages to human health by way of less pollution and fewer climate-change associated ill-health effects. Limited data suggests that renewable energy will also offer benefits to workers in the form of reduced occupational injury, illness and deaths. However, studies of worker safety and health in the industry are limited. The Mountain and Plains Education and Research Center (MAP ERC) Energy Summit held in April 2011 explored issues concerning worker health and safety in the renewable energy industry. The limited information on hazards of working in the renewable energy industry emphasizes the need for further research. Two basic approaches to guiding both prevention and future research should include: (1) applying lessons learned from other fields of occupational safety and health, particularly the extractive energy industry; and (2) utilizing knowledge of occupational hazards of specific materials and processes used in the renewable energy industry. Am. J. Ind. Med. 56:1359–1370, 2013. *© 2013 Wiley Periodicals, Inc.*

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INTRODUCTION

Renewable energies, defined as "fuel sources that restore themselves over short periods of time and do not diminish" [U.S. Environmental Protection Agency, 2011] are expanding as a share of total United States energy consumption. According to the U.S. Department of Energy, renewable technologies including wind, solar, biomass, biofuels, and hydropower currently provide more than 10% of total U.S. energy generation [U.S. Department of Energy, 2010].

Wind and solar energy production have experienced a recent rapid increase owing to a reduction in technology costs along with marked increases in capital investment. From 2000 to 2009, installed electric capacity for wind and solar energy increased at a compounded annual growth rate of 33.7% and 39.3%, respectively [U.S. Department of Energy, 2010]. Biofuel development, with continued strong U.S. government subsidy support, has also experienced rapid growth. Between 2000 and 2009, corn ethanol production increased approximately sixfold, and biodiesel production increased 100-fold [U.S. Department of Energy, 2010]. Hydropower, which currently accounts for the largest share of U.S. renewable energy and nearly 7% of total U.S. electrical energy generation, has experienced stagnant growth in the recent past, but is now being reconsidered for expansion and development at several sites, given pressing national energy needs [Smith, 2011].

Given that more than half of all new U.S. electrical capacity installations each year are from a renewable source [U.S. Department of Energy, 2010], there is an accompanying major shift underway in energy industry employment. Currently, best estimates suggest there are approximately 15,000 individuals employed in the solar-photovoltaic and solar-thermal industries [U.S. Energy Information Administration, 2011], 75,000 in the wind energy industry [American Wind Energy Association, 2010], and at least 200,000 in the hydropower industry [National Hydropower Association, 2011]. Not only is renewable energy production believed to offer significant advantages to human health relative to standard fossil fuel energy production by way of less pollution and climate-change associated ill-health effects, but the limited data currently available suggests that renewable energy will also offer benefits to workers in the form of reduced occupational injury, illness, and death [Sumner and Layde, 2009].

Nonetheless, significant research and policy considerations are needed to assure improved occupational health and safety (OHS) in the energy industry. With the pending transition from an extractive fossil fuel economy to a renewable energy economy, there is an opportunity to reconfigure the approach to promoting OSH for an industry that has been among the most dangerous [CDCC, 2008].

The Mountain and Plains Education and Research Center (MAP ERC), one of 18 Education and Research Centers funded by the Centers for Disease Control/National Institute for Occupational Safety and Health (CDC/NIOSH), provides occupational health and safety education and conducts research for Colorado, New Mexico, Arizona, Montana, Wyoming, North Dakota, and South Dakota. In April 2011, the MAP ERC held the first annual Energy Summit in Denver, Colorado to explore issues concerning worker health and safety in the renewable energy industry. The conference aim was to share lessons learned, identify gaps in OSH research and policy, and articulate a general framework for assuring optimal occupational health and safety practices in the renewable energy industries. Leading researchers in the field of occupational health and safety in the energy industries were invited to present papers at the conference. Following the conference a working group of these researchers was convened. Each energy sector author reviewed the papers presented at the conference, conducted a literature search, and drafted a summary for inclusion in this overview. The paper represents a consensus of the papers presented at the conference and each energy sector author. A limitation is that the paper may not represent all views in the research community and not all aspects of each sector were presented, that is, nuclear energy industry power plants.

There are many potential types of renewable energy concepts and technologies being considered; the Energy Summit focused on the major areas of wind, solar, biomass/biofuels, and hydropower, given their importance and/or potential for growth in the renewable energy market. Wind, solar and hydropower are primarily used for electrical energy production whereas biomass converted into biofuels can take the place of conventional fuels like gasoline, diesel, and jet fuel.

EXTRACTIVE INDUSTRIES: LESSONS LEARNED

Extractive industries for the production of fossil fuels (coal, oil, and gas) and uranium have been at the center of United States energy policies for decades. The abundance of domestic fossil fuel and uranium reserves enabled unprecedented technological and economic growth since the industrial revolution; but this growth has come with human and environmental costs. These costs, though well known, are not often considered as part of the U.S. energy policy. Lessons learned from the extractive industries in terms of worker health and safety are applicable to the newer technologies of renewable energy industries.

Coal has been the center of the U.S. energy industry, first for heat and now as a major source of electricity production. Currently, coal accounts for one-third of U.S. energy production and just over half of the electricity produced [National Academies Press, 2010], with substantial and politically important geographic variation in terms of air pollution and air quality as well as in workforce and economic impact. Historically, improvements in coal mine health and safety have arisen in response to major disasters in the industry, including recent disasters at Upper Big Branch and Sago mines in West Virginia and Crandall Canyon mine in Utah. Since 1900, there has been a steady decline in work-related mortality in coal miners [CDCC, 1999] following regulatory interventions in response to disasters along with increased mechanization and the shift from underground to surface operations.

Compared to fatalities, chronic health effects due to coal mining have not shown the same sustained decline. The prevalence of coal workers pneumoconiosis (CWP) declined from 20%, 25%, and 35% in the early 1970s in active coal miners with 20–24, 25–29, and over 30 years of underground mining respectively to approximately 3%, 3%, and 7% in the late 1990s. However, the prevalence of CWP in those groups of coal miners increased to 6%, 8%, and nearly 10% in the mid-2000s, suggesting problems with adequacy of the current coal mine dust permissible exposure limit (PEL) of 2 mg/m^3 in protecting the lungs of US coal miners and/or problems with its enforcement [CDCC, 2007].

The uranium industry has a similar legacy of poor ventilation in underground mines and mills, resulting in hazardous exposures to respirable silica, radon and yellow cake that placed miners and millers at risk for progressive fibrotic lung disease as well as lung cancer and other malignancies [Archer et al., 1976, 1998]. Much of the U.S. production of uranium was linked to the nuclear defense industry and the Cold War, but regulatory changes and oversight of mining operations did not become common until the 1980s. Historically, uranium mining in the western U.S. had significant health impacts on vulnerable populations in tribal communities and among Native American workers [Amandus and Costello, 1991; Carta et al., 1994; Darby et al., 1995; Mapel et al., 1997]. Current expansion of uranium extraction by in situ leaching techniques along with stricter regulatory oversight has eliminated some of the previous hazards of underground mining, though environmental and health effects of these newer techniques are unknown.

The oil and gas industry remains a cornerstone of U.S. energy policy. Production of natural gas used for fuel, heat and electricity has increased and, in 2008, 30% of natural gas was used to produce electricity [National Academies Press, 2010]. Newer technologies, such as hydraulic fracturing or ‘‘fracking,’’ have expanded production into previously unattainable or prohibitively costly reserves of natural gas and oil. Within the last 10 years, the rapid expansion of the industry has led to an increase in fatality rates and reported injuries [CDCC, 2008]. Fatalities in the oil and gas industry accounted for almost two-thirds of the fatal work injuries in the mining sector in 2007 [National Academies Press, 2010]. The health consequences of exposure to a variety of toxic substances associated with fracking (including respirable silica, lead, volatile organic compounds and irritant chemicals) are well known, though exposure prevention strategies in the industry are in their infancy.

Extractive industries have had a long history of boom and bust cycles, often with hidden or unacknowledged costs to workers and communities. Society must acknowledge all of these costs so that the risks to worker health and safety as well as environmental and social costs are addressed in concert with the expansion of the renewable energy industries.

RENEWABLE ENERGY

Hydroelectric Power

The use of hydroelectric power, the production of electrical power through the use of gravitational force of falling or flowing water, began in the late 1800s. It is inarguably a low-carbon output renewable energy source. However, multiple hazards may attend the development, construction, and operation of these facilities.

The heyday of American hydroelectric dam construction occurred in the 1920s and 1930s, a convergence of rural electrification efforts and New Deal funding. From the time of its completion in 1942, Grand Coulee Dam on the Columbia River in Washington was the world's highest-yield hydroelectric facility, until being surpassed by two projects: the Simon Bolivar (Guri) in 1978 in Venezuela and Itaipu in 1984 in Brazil. All have been eclipsed by the massive Three Gorges Dam in China, the first phase of which was completed in 2008. There are prospects for other large hydroelectric projects in China, the Russian Federation, on the Congo River in central Africa, and in Canada [Wikipedia, 2011].

While hydroelectric dam projects are relatively mature in the lower 48 states [U.S. Energy Information Administration, 2009], major new hydroelectric sites are being considered in Alaska, foremost among these are the Susitna and Chakhachamna projects on the Susitna River drainage [Alaska Energy Authority, 2010]. The U.S. hydropower industry currently accounts for approximately 200,000 jobs and with expansion of the industry by 2050 could account for 230,000–700,000 jobs (both direct and indirect) [National Hydropower Association, 2011].

While surveying and planning for such large earthworks have inherent hazards, the most significant occupational risks occur during the construction phase. For instance, during 3-year construction of the Grand Coulee

Dam there were 77 work-related fatalities [Saul, 2005]. Hydroelectric dam construction involves massive excavation and earthmoving, materials handling operations with fill and concrete operations, and the immense steelworks necessary for spillways as well as concrete reinforcement. Occupational hazards include injuries from vehicle and heavy equipment operations, falls, and crush injuries, exposure hazards from cutting, welding, and brazing from metal and flux fumes, silica dust, and noise and severe ocular hazards.

Once these facilities are operational, there are many potential acute injury hazards. These range from electric shock, explosions, machinery entanglement, and drowning. There are chemical and metal exposure hazards including those inherent to the huge batteries deployed in some of the facilities (such as nickel–cadmium and vanadium), chlorine used in water processing, and the polychlorinated biphenyls formerly used in electrical transformers and other components. Unanticipated exposures related to geography may occur. In Canada, hydroelectric plant workers exposed to the remains of caddis flies present in a hydroelectric plant developed a positive response to caddis fly antigen and developed occupational allergies and occupational asthma [Kraut et al., 1994; Miedinger et al., 2012]. After sufficient time for the oxidation (rusting) of iron or steel contents, confined spaces in such structures can become oxygen depleted, posing a hazard for rapid suffocation. Less well-characterized hazards include those from the strong electric fields from massive generators and during proximate transmission of the resulting electricity [International Labor Organization, 1998].

Given the long history of development of hydroelectric projects, the hazards and injury risks during the construction phase have been well characterized and safety plans, if followed, should reduce or eliminate occupational injuries and fatalities. However, such safety plans do not often take into account the long term health effects of exposures such as PCBs, metals, and strong electrical fields, and further work is needed to better characterize and eliminate these hazards.

BIOMASS ENERGY

Biomass energy is derived from the combustion of renewable organic materials. ‘‘Traditional’’ biomass energy is generated with the direct combustion of wood and manure, while ‘‘modern’’ sources include liquid, gaseous, and solid biomass based fuels and are referred to as biofuels [Bringezu et al., 2009]. Biomass currently makes up 50% of the United States renewable energy supply, and is predominantly supplied by wood or wood derived fuels, followed by biofuels [U.S. Energy Information Administration, 2008]. The U.S. Energy Independence and Security Act, 2007 Renewable Fuel Standard (RFS), has set targets to significantly increase biofuel production by 2022 by increasing the number of bio-refineries and by the expansion of new and emerging biofuel production technologies. According to the Renewable Fuels Association [Renewable Fuel Association, 2011], in 2011 there were 204 bioethanol plants in the U.S., with 70,400 workers involved in the production of ethanol and the delivery of goods and services to ethanol producers. It is estimated that the advanced biofuel industry could employ up to 29,000 people in 2012 and 94,000 by 2016 [Bio-Economic Research Associates, 2009].

Lifecycle and economic assessments for biofuel production have received a great deal of attention [Marchetti and Errazu, 2008; Debolt et al., 2009; Kiwjaroun et al., 2009; Luo et al., 2009; Monti et al., 2009; Reinhard and Zah, 2009; Riviere and Marlair, 2009; Yee et al., 2009; Zah et al., 2009; Berndes et al., 2010; Gmunder et al., 2010; Guinee et al., 2010; Hecht and Miller, 2010; Hytonen and Stuart, 2010; Morais et al., 2010; Talens Peiro et al., 2010; Tsoutsos et al., 2010; de Vries et al., 2010; Campbell et al., 2011; Cherubini and Stromman, 2011; Esteban et al., 2011; Gottschalk and Nowack, 2011; Khoo et al., 2011; Kou and Zhao, 2011; Malca and Freire, 2011; Sanz Requena et al., 2011; Reno et al., 2012]. In contrast, occupational health and safety (OHS) assessment in biofuel production often appears to be an afterthought, usually attracting a single paragraph or two in papers predominantly focused on economic and environmental impacts. Only a handful of journal articles, conference papers or government reports specifically discuss OHS issues [Mittelbach et al., 2007; Harper et al., 2008; Madsen et al., 2009; Marlair et al., 2009; Riviere and Marlair, 2009; Powell, 2010; Law et al., 2011] even though there have been a number of occupational fatalities within the biofuel industry [Occupational Safety and Health Administration, 2011a].

Biofuel industry jobs include scientists working in research and development on engineering algae for biofuel production, agricultural workers involved in the production and harvesting of biomass feedstocks from field and forest, production engineers and technicians processing biomass, and transport workers delivering the fuel. The risks for fatal and non-fatal injuries among agricultural workers are well known. In addition, biofuel production workers may face exposure to hazardous materials such as acids, bases, and gasoline, as well as fire, explosion and electrical hazards [Occupational Safety and Health Administration, 2011a]. Potential biofuel industry exposures include both familiar and novel health hazards. Familiar hazards can be defined as those with well characterized risks or having current occupational exposure guidelines. Many of the recent injuries and fatalities have been due to well-known hazards with improper use of safety systems [Harper et al., 2008; Occupational Safety and Health

Administration, 2011a]. For the novel and less well characterized hazards, including bioaerosols and nanomaterials, there is limited acute and chronic health risk data and no occupational exposure guidelines.

A wide variety of microorganisms are utilized in the biofuels industry, with potential worker exposure to bioaerosols. For example, inhaled endotoxins can trigger immune responses leading to a range of respiratory system responses [Sigsgaard et al., 2005]. Endotoxin exposure has been described in the mass manufacture of bioproteins (single cell bacteria) used for animal feed supplements. In that industry, workers reported symptoms of fever, fatigue, chest tightness and skin dryness [Sikkeland et al., 2008], and had elevated levels of inflammatory cytokines [Sikkeland et al., 2008, 2009] and changes in lung function [Skogstad et al., 2005]. There is limited data on bioaerosol exposure from biofuel production. Respirable dust from biofuel plants has been reported to elicit strong inflammatory responses in experimentally exposed mice, and high endotoxin concentrations have been measured during use of straw and woodchip biomass feedstock [Madsen et al., 2004; Madsen, 2006; Madsen et al., 2009].

The spectrum of reported biological effects and health conditions associated with bioaerosol exposure include airway inflammation [Allermann and Poulsen, 2000; Wouters et al., 2002; Heldal et al., 2003; de Meer et al., 2007], altered lung function [Eduard et al., 1993; Post et al., 1998; Mandryk et al., 1999; Mandryk et al., 2000; Fishwick et al., 2001; Heldal et al., 2003; Douwes et al., 2006; Reynolds et al., 2006; Bünger et al., 2007; Pahwa et al., 2009], Organic Dust Toxic Syndrome [Carvalheiro et al., 1994; Boehmer et al., 2009], increased permeability of the lung-blood barrier [Daneshzadeh Tabrizi et al., 2010], immunological reactions [Góra et al., 2004; Gripenback et al., 2005; Muller et al., 2006; Reynolds et al., 2006; Burch et al., 2009; Daneshzadeh Tabrizi et al., 2010; Poole et al., 2010], and increased prevalence of asthma, cough, gastrointestinal illness and/or eye and nasal irritation [Douwes et al., 2001; Eduard et al., 2001; Rusca et al., 2008; Jacobsen et al., 2009].

Engineered nanomaterials are defined as those with structural components between 1 and 100 nanometers that provide unique properties not evident in the parent material [Centers for Disease Control-National Institute for Occupational Safety and Health, 2011a]. Engineered nanomaterial research has developed rapidly over the last decade, but the potential occupational health risks associated with manufacturing, processing and handling of nanomaterials are not well characterized [Koukoulaki, 2010; Lee et al., 2010]. Manufactured nanomaterials and nanosized catalysts have been explored in the trans-esterification reactions for both bioethanol and biodiesel. Some nanoparticles can penetrate biological barriers to access biological system inaccessible by larger particles, a concern because the manipulation of the nanomaterial properties may also alter their toxicity [Institute of Occupational Medicine, 2011]. Carbon nanotubes have been reported to have asbestos-like pathogenicity in the abdominal cavity of mice [Poland et al., 2008], and may increase risk for mesothelioma due to their potential for retention in the pleural membrane [Safe Work Australia, 2010; Murphy et al., 2011]. The paucity of data on the adverse chronic health effects from use of engineered nanomaterials indicates a need for full risk assessment as these products are used in biofuel production.

The paucity of OHS data for biofuel production is of concern as the technology is evolving rapidly. A comprehensive risk assessment of biofuel production would need to involve an assessment of biomass feedstock production including observation of known hazards within agricultural, forestry and the waste treatment and recycling industries [Mahar et al., 1999; Allermann and Poulsen, 2000; Douwes et al., 2003; Bünger et al., 2007; Greskevitch et al., 2008; Burch et al., 2009; Schenker et al., 2009], as well as goods transportation [Purdy, 1993; Jones et al., 2005; Verma and Verter, 2007; Salmoni et al., 2008; Centers for Disease Control-National Institute for Occupational Safety and Health, 2011b] and petroleum refineries [Jewett, 1934; World Health Organization, 1998]. It would be prudent to proactively introduce exposure controls in occupational environments in conjunction with further characterization of potential health risks in exposure research laboratories.

SOLAR ENERGY: PHOTOVOLTAICS

Photovoltaic (PV) devices convert sunlight directly to electricity using semiconductor and related materials, similar to those used in the computer and flat-panel display industries. Although PV remains small in the portfolio of electricity-producing renewable energy technologies, the industry has averaged 50% growth in module production from 2000 to 2009 and over a 100% growth in 2010 due to rapid expansion, primarily in China [Solar Industries Energy Association, 2011a]. According to the Solar Energy Industries Association (SEIA), the U.S. solar industry employs almost 100,000 workers across all fifty states [Solar Industries Energy Association, 2011b], and is projected to support over half a million American jobs by 2016. With continued rapid growth rates, PV will contribute significantly to world electricity production, with a number of accompanying occupational safety and health concerns.

PV modules are primarily deployed as flat panels in arrays, either in large fields or rooftops. These conversion technologies are primarily crystalline silicon (c Si) wafers (~200 μm thick), but the use of thin-film materials (<10 μm thick) is growing rapidly. Thin-film PV-conversion materials include cadmium-telluride (CdTe)), hydrogenated amorphous silicon (Si:H), and Copper–Indium–Gallium–Selenide (CIGS), in decreasing order of module production. There is increasing interest in a technology known as concentrating PV (CPV) that uses high performing and high cost cells based on gallium arsenide (GaAs).

Occupational health and safety challenges are likely to be variable across a wide spectrum of PV work tasks and settings. PV industry jobs include scientists and engineers improving materials and device performance; those who develop pilot manufacturing facilities; miners and millers of the mineral components; workers in factories manufacturing modules, power electronics and related products and equipment; those who plan and develop sites; those who install panels and integrate them into an electrical grid; and transportation jobs across the value chain.

While PV produces electricity without using any fuel, moving parts, or water, there are specific hazards associated with PV manufacturing and deployment [Fthenakis, 2003]. In the silicon-based conversion technologies, manufacturing hazards include the use of acids (e.g., HF, NH03) and caustic solutions (e.g., NaOH), as well as hazardous production material (HPM) gases such as phosphine, diborane, ammonia, and the pyrophoric gas, silane. The technology is similar to computer chip manufacturing for c Si and flat-panel displays, and there are a numerous codes and standards available to address the hazards present in silicon-based PV manufacturing.

In the cadmium–telluride (CdTe)-based conversion technologies, the primary manufacturing hazard is the use of heavy metals in both solid and liquid sources. Exposure to Cd-containing materials can occur in both the deposition of the various layers within the PV cell and the removal of Cd-containing materials. While the toxicity of Cd (acute pneumonitis, chronic lung and renal disease, lung and prostate cancer) is well known [Agency for Toxic Substances and Disease Registry, 2011], little is known about the toxicity of alloys of Cd, such as CdTe, other than it has a much lower water solubility than Cd and is an area for further research.

The manufacturing of CIGS poses a potential risk of exposure to heavy metals (copper, indium, gallium, selenium) with varying degrees of toxicity. While the elemental toxicity of the materials is well known, the toxicity of the alloys is less well characterized and is an area for further study. Most of the CIGS industry does not use hydrogen selenide (H_2Se), a highly toxic HPM gas, to introduce selenium (Se) into the CIGS layer, but the practice does exist. Other hazard risks include the reaction of Se in the deposition chambers with water vapor during cleaning operations, and the formation of H_2Se during maintenance. With inhalation exposure, H_2Se is a mucous membrane irritant, and can cause nausea, vomiting, dizziness, and pneumonitis as well as frostbite with skin contact [Centers for Disease Control-National Institute for Occupational Safety and Health, 2011c].

In the GaAs-based conversion technologies used in CPV, the primary manufacturing hazard is the use of HPMs, specifically highly toxic gases and liquid sources (e.g., arsine causing massive red blood cell hemolysis leading to global cellular hypoxia; phosphine causing convulsions, cardiac dysrhythmias, and shock). While the codes and standards for these technologies have been developed in radiation-hard computer chip manufacturing, the potential acute risk of these materials to workers is significant.

There are common hazards across the PV industry. Materials such as metals and transparent conducting oxides (TCOs) are used by all the technologies. TCO, indium-tin-oxide (ITO), has been linked to pulmonary alveolar proteinosis in manufacturing workers and is the focus of on-going studies by NIOSH [Cummings et al., 2010]. Early indications are that the toxicity of ITO is greater than that of its core elements.

The installation of photovoltaic panels combines three occupations that have high morbidity and mortality—roofing, carpentry and electrical work. Solar energy equipment can generate electrical energy and may be connected to electrical circuits. Workers installing or servicing solar panels may be electrocuted from the unexpected release of stored energy. In addition, the risk for falls is high among installers. Falls are the leading cause of construction fatalities and account for one-third of the on-the-job injury deaths in the construction industry [The Center for Construction Research and Training, 2008]. The specific hazards that contribute to falls and other injuries in solar industry include pitched roofs, working too close to the roof's edge, lack of fall protection, proximity to overhead power lines and unguarded skylights. There are many methods to implement safety procedures and practices for lockout/tagout and fall protection to prevent serious injury and death, and companies that install panels need to have safety plans that involves specific training and oversight for compliance. Less obvious hazards include burns associated with deploying concentrating optics in direct sunlight.

The industry has been proactive in the area of recycling PV system components at their end of life or after failure or damage. There is a need to protect workers in the recycling industry who may be at risk from exposure to metals and other hazardous components.

WIND POWER

Wind power can be used to generate electricity by harnessing the power of the wind to drive blades to rotate around either a horizontal or vertical axis that is connected to a gear box and a generator. The American Wind Energy Association (AWEA) reports that the U.S. wind industry installed over 1,000 megawatts of wind power in the second quarter of 2011, bringing the U.S. cumulative capacity to 42,432 megawatts, and that U.S. wind power capacity is 20% of the world's wind power. This rapid growth is supported by approximately 400 raw material suppliers and manufacturers of various components of wind energy including nacelles (the box-like component that sits atop the tower, connected to the rotor and containing components such as the gearbox, generator, and main frame), blades, and towers, as well as the installers and maintainers of wind farms.

Wind energy employed approximately 75,000 U.S. workers in 2010 [American Wind Energy Association, 2011], and the Bureau of Labor Statistics anticipates that employment will continue to grow. Most current wind energy jobs are in the manufacturing sector. Wind energy components are manufactured throughout the U.S. or are imported from international equipment manufacturers or suppliers. Other wind energy jobs are in construction, operation, and maintenance. Job growth in operations and maintenance is expected as new wind farms are brought on-line and older wind farms are upgraded to include newer and more efficient technology.

Specific occupations include research and development scientists; machinists, assemblers, and welders to manufacture components; engineers to design components, select and permit sites and manage wind farm installations; construction workers including those skilled in concrete and steel foundations; transportation workers; and operations and maintenance technicians [Hamilton and Liming, 2010].

To understand the hazards associated with erecting wind towers, installing blades and turbines, and maintaining the equipment, the size and height of these units must be considered. The specifications of a 1.5 MW turbine manufactured by General Electric include a blade length of 116 feet, operating at a maximum tip speed of 183 miles per hour at a tower height of 328 feet. The turbine housing, or nacelle, weighs over 56 tons, the blade assembly weighs over 36 tons, and the whole tower assembly totals over 163 tons [General Electric Company, 2011].

The Caithness Windfarm Information Forum 2011 compiled and analyzed all reported wind turbine related accidents from the 1970s through June 2011 [Caithness Windfarm, 2011]. Their research documented 83 fatalities, 58 of which were wind industry workers or small turbine owner/operators. The remaining 25 fatalities were among the public, including fire fighters and transport workers not directly dependent on the wind industry. The report described 208 incidents of blade failure, resulting in pieces of the blade or even the entire blade thrown from the turbine; 159 fires, two of which burned wind industry workers; 116 incidents of structural failure; 31 incidents of ice throw, some of which resulted in human injury; and 74 reported accidents related to transport of turbine sections [Caithness Windfarm, 2011].

The Occupational Safety and Health Administration (OSHA) describes wind energy hazards that include: falls both during erection and maintenance compounded by high winds; confined spaces; fires; unexpected energizing or startup of machinery and equipment, or the release of hazardous energy during service or maintenance activities; limited availability of medical and first aid; working around cranes, derricks, and hoists; arc flash, including arc flash burn and blast hazards, electric shock, and thermal burn hazards that can cause injury and death; and manufacturing-related hazards, including machine-related hazards associated with moving parts, electrical hazards, and machine guarding, and health hazards from operations such as buffing and resurfacing that may expose workers to harmful gases, vapors, and dusts [Occupational Safety and Health Administration, 2011b]. OSHA notes that these hazards are not unique, and there are OSHA standards that cover them.

As traditional jobs evolve to meet new challenges, workers may be faced with known risks that had not previously affected their specific occupation. These changes may also present employers with the opportunity to eliminate hazards through planning, organization, and engineering—a concept known at NIOSH as Prevention through Design (PtD) [Centers for Disease Control-National Institute for Occupational Safety and Health, 2010]. This concept addresses occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment. As wind energy components are designed, and the process for constructing, operating and maintaining the systems are engineered, occupational health and safety hazards should be identified and eliminated, if possible, and the risks associated with the remaining hazards should be minimized through effective use of engineering controls.

SUMMARY

Reliance on renewable energy in the United States has increased dramatically in recent years. Studies of worker safety in renewable energy industries are limited, and most of what we know is based on studies from Europe [Markandya and Wilkinson, 2007]. Investigations into the long-term occupational health effects of the emerging renewable energy methods of biomass, solar, and wind are virtually non-existent. The lack of information on the hazards of working in the renewable energy industry emphasizes the need for occupational health and safety research in this field but also raises the question of how to focus and prioritize such research.

The MAP ERC 2011 Energy Summit brought together thought leaders and researchers to frame the dialogue on occupational safety and health research and prevention in the renewable energy industry. Summit participants emphasized the importance of applying lessons learned from the extractive energy industry and applying current knowledge of hazardous materials and processes used in the renewable energy industry to frame future research and policy directions.

The discussions identified several areas of concern. Exposures with potential chronic health effects, particularly for diseases of longer latency, are more challenging to identify and study, and may require monitoring of exposure levels, long term clinical follow-up of exposed individuals, and well-designed systems for epidemiologic surveillance. It is unclear if the renewable energy industries are being proactive in establishing medical or exposure monitoring systems for early identification of work-related risks.

Another area of concern was the challenge posed by numerous small facilities involved in the renewable industries compared to fewer larger ones. Larger facilities make implementation of expensive engineering controls to reduce the risk of occupational injury and illness more cost-effective. Additionally, larger industries generally are better able to bear the costs of comprehensive industrial hygiene monitoring and epidemiologic surveillance.

The following sections summarize the known and potential occupational hazards of materials and processes used in each of the major emerging renewable energy industries along with recommendations for research directions.

Biomass

Biomass operations range from large, industrial bioethanol plants to small fermentation devices on family farms. Current and potential hazards range from the well-recognized hazards of wood combustion to the seldom studied hazards of genetically modified microorganisms used in biofuel production. Unlike solar and wind, biomass requires production of the ‘‘fuel,’’ generally by production agriculture, one of the most hazardous occupations in industrialized countries.

For biomass, basic research is needed on the toxicity and immunogenicity of emerging biomass hazards including bioaerosols, nanotechnology, genetically modified microorganisms, and other agents used in the rapidly evolving biomass technologies. This basic research should be complemented by prospective cohort studies of workers in the field including monitoring of exposure levels and long-term follow-up of exposed individuals. Because so little is known of the hazards in production of biomass and generating energy from it, prudent exposure controls will be needed for the foreseeable future.

Solar Energy

Photovoltaic technologies use a number of potentially hazardous materials including rare earth and heavy metals. While photovoltaics share many materials and technologies with microprocessor production, PV manufacturing does not typically utilize the emission controls used in ‘‘clean room’’ microprocessor production. Accordingly, extrapolation of health and safety data from microprocessors to photovoltaics is not supportable without detailed exposure monitoring. Installation of PV panels involves the hazards of roofing, carpentry, and electrical work by numerous small contractors in worksites that are seldom ideal.

Research needs include basic studies on the toxicity of rare earth elements and newer semi-conductors. These studies should include toxicological research at a range of exposure levels. In addition, prospective cohort studies of workers in manufacturing and installation of photovoltaics should be undertaken with particular attention to exposure levels and long-term health effects. As for solar energy, because relatively little is known of the long-term danger of exposure to many of the materials used in photovoltaics, prudent exposure controls in combination with worker medical surveillance will be needed for the foreseeable future.

Wind

Wind power manufacturing and generation does not involve occupational exposure to as many emerging hazardous materials as biomass (i.e., nanomaterials) or less common materials as photovoltaics (i.e., rare earth and heavy metals). The occupational hazards of wind power include those of heavy equipment manufacturing and construction of large elevated structures. A significant hazard in the wind industry is the risk of falls or other injury during maintenance in windy conditions at a considerable height on wind turbine towers that may not have been designed with worker safety in mind.

Because the processes and materials used in wind power are more familiar than many of those used in biomass and photovoltaics, there is little need for basic research in this field. Cohort studies of workers in wind power manufacturing, construction, and maintenance should be undertaken to identify any unanticipated hazards and to better quantify known or anticipated hazards.

In the worldview of economists, both occupational and environmental hazards are *externalities* of energy production, hidden costs not fully included or internalized in the market price of fuel, thus distorting true costs. Historically, occupational health effects from higher exposures in industrial settings often presaged future adverse effects on the general population from lower-dose environmental exposures. Using workers as ‘‘canaries in the coal mine’’ to detect adverse exposure circumstances is not an ideal approach to environmental risk management. With this understanding, opportunities to anticipate and prevent future exposure risks in the renewable energy industry should not be squandered.

In summary, new materials and processes used in renewable energy, particularly biomass and photovoltaics, requires basic research on cellular and specific end-organ effects. Prospective cohort studies with careful exposure measurement and clinical monitoring should be implemented. With the need to identify chronic as well as acute effects, these studies will need to be long-term. The relative paucity of our knowledge of worker health and safety risks in the field calls for particular care in limiting exposures. Only with worker health and safety as part of the equation will we know the true cost of renewable energy and how to factor that into U.S. energy policy.

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